Book of Abstracts

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Plenary talks

Science and Status of the Electron Ion Collider

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Topic(s): Detector development, future facilities and experiments

Abstract: Despite many decades of study of experimental and theoretical investigations in Quantum Chromodynamics (QCD), certain fundamental and profound questions remain unanswered. For example, while we know the nature of interactions between quarks and gluons at distances smaller than the size of the proton, don't know exactly how and why they are confined within the radius of the proton. While we know the quarks carry about 1% of the mass of the proton, and gluons are massless, how does the proton mass emerge from their interactions? How do the spin-1/2 quarks and spin-1 gluons give rise to the spin 1/2 of the proton? We don't know. Lastly, the quark and gluon distributions change in nuclei. Exact nature of it is ill-understood. Those interactions at very high energy are expected in QCD to give rise to intense gluon fields, and produce a unique form of ultra dense gluonic matter, known as Color Glass Condensate. If it exists, what are its properties? Is it universal? These and such profound questions in QCD can only be addressed by an electron ion collider (EIC), capable of providing high-energy electron-ion collisions and polarized electron-light ion collisions. The EIC is now being constructed at Brookhaven National Laboratory (BNL). I will summarize the science of EIC and present opportunities for collaboration.

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Recent results from the LHC heavy-ion programme

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Ultra-relativistic heavy-ion collisions enable the study of the quark-gluon plasma (QGP), a state of strongly-interacting matter characterised by the deconfinement of the colour charge that forms at high temperature and energy density. The characterisation of the QGP is the main goal of the LHC heavy-ion programme, which used lead-lead collisions at centre-of- mass energies of 2.76 and 5.02 TeV, per nucleon-nucleon collisions, in Runs 1 and 2, respectively. In addition to bringing to a strong progress towards this goal, the LHC also opened a new research direction, with the unexpected observation that high-density QCD effects gradually emerge also in proton-proton and proton-nucleus collisions when the multiplicity of charged particles increases. I will illustrate these points with a selection of recent results from the four large LHC experiments, ALICE, ATLAS, CMS and LHCb, and I will discuss the prospects for the future data-taking campaigns with upgraded detectors.

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MARS: From the Higgs Boson to molecular radiology

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Topic(s): Detector development, future facilities and experiments

Abstract: Photon counting and silicon-based detectors were developed in the early 1980s for high energy physics research. Soon after, demonstration of the technology for measuring x-ray photons were achieved. This led to the development of hybrid pixel detectors that specifically targeted medical applications. Since then, several research groups around the world have focused on answering today's medical imaging problems using the latest hybrid pixel detector technology.

This talk begins with a review of the history of hybrid detector technology for medical applications, followed by examples of how it is being used to answer questions in orthopedic, cardiovascular, and oncology research. Furthermore, it outlines the pathway for the technology reaching routine clinical practice.

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Circuit Complexity and (some of) its application

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Topic(s): Formal theory

Abstract: Motivated by recent interesting holographic results, several attempts have been made to study complexity (rather " Circuit Complexity") for quantum field theories using Nielsen's geometric method. Since then, it has found many interesting applications. In this talk, we discuss some of its applications to probe various physical properties of the underlying system and study its implications.

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2020: Highlights from ATLAS and CMS

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Topic(s): Standard model physics

Abstract: In this talk I'll highlight a few recent exciting results from the ATLAS and CMS Collaborations at the LHC, straddling the whole spectrum of the LHC physics programs, from precision measurements to searches for new physics, including flavor physics and have ion physics highlights. With the large LHC Run 2 data samples being fully analyzed, ATLAS and CMS reached unprecedented precision in many of these topics and conducted unique searches, which probe completely new territory in a number of new physics models.

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Future collider projects - the European perspective

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Topic(s): Detector development, future facilities and experiments

Abstract: Progress in understanding the fundamental structure of matter and its interactions, the realm of particle physics, requires adequate accelerator infrastructure. It is thus natural that the community looks into the future, beyond the high-luminosity Large Hadron Collider upgrade at CERN which will remain the focus of research for another two decades or so. I will concentrate on future projects and new concepts that were central to the recently completed update of the European Strategy for particle physics, both form the science and the technology point of view.

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Recent developments in silicon and diamond detectors - future of silicon trackers at CERN's LHC and beyond

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Topic(s): Detector development, future facilities and experiments

Abstract: CERN's Large Hadron Collider (LHC) is the world's largest particle accelerator and is used by a world-wide community for studies in particle physics. Experiments at the High Luminosity-LHC (HL-LHC) will record and analyse high-energy proton-proton collisions to study the fundamental structure of matter and its interactions. While detector upgrades are on their way for their installation during the "Phase-2" upgrade of LHC, further R&D is being pursued in view of future needs at HL-LHC and colliders beyond LHC.

The upgrade of tracking detectors, timing detectors and beam monitors for the High-Luminosity Large Hadron Collider and future envisaged colliders at CERN requires the development of novel radiation hard and very high resolution solid state detector technologies to cope with the ever increasing demands for accuracy, time resolution, hit-rate capability and radiation hardness. The presentation will start with an overview of currently planned R&D on novel detector technologies. It will give an overview of recent R&D results on silicon detectors at CERN's HL-LHC and future colliders emphasising technological challenges and developments being pursued in the context of the Experimental Physics Department strategy R&D programme.

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Latest results from heavy-ion collisions at RHIC

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: 2020 marks 20 years of very successful RHIC running. During that time the RHIC collaborations have made many important discoveries about the Quark-Gluon Plasma, a state of matter where quarks and gluons become deconfined. Although the Quark-Gluon Plasma only exists for a fraction of a second, we have demonstrated that it has an initial temperature 4 trillion degrees Celsius, flows like a near-perfect liquid and has a vorticity that's greater than super-cell tornado cores and Jupiter's Great Red Spot by many orders of magnitude.

In this talk I will report on the latest insights into the properties of this extraordinary state of matter, and our plans for future studies.

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Measurements of Neutron Stars and the Dense Matter EOS

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Topic(s): Particle astrophysics and cosmology

Abstract: Neutron stars are a window into the properties of dense nuclear matter. The first observed binary neutron star merger GW170817, pulse-profile X-ray observations of PSR J0030+0415 by NICER, and new theoretical many-body studies of neutron matter powerfully constrain the properties of neutron stars and the equation of state of dense matter. Inferring these constraints has been enabled by the use of parameterized equations of state, which probe the uncertain regions of dense matter and have revealed several semi-universal relations connecting global neutron star properties.

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Xenon TPCs for rare searches

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Topic(s): Detector development, future facilities and experiments

Abstract: The wunderkind of particle physics instrumentation was invented by Dave Nygren and collaborators almost half a century ago. At fifty, however, Time Projection Chambers are younger than ever. In this talk I will review their application to the field of rare searches, in particular the search for neutrinoless double beta decays and the search for WIMP particles, a favourite but elusive candidate to Dark Matter.

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Theoretical status of neutrino physics

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Topic(s): Neutrino physics

Abstract: This talk will summarize some of the leading theoretical ideas for generating small but nonzero neutrino masses. The scale of new physics could lie anywhere between the GUT scale of 10^{15} GeV and sub-electron volt. Expectations on neutrino mixing pattern arising from SO(10) grand unified theories will be discussed. If the seesaw mechanism is realized at the TeV scale, it may be directly confronted with collider tests, including lepton number violating processes, which will be discussed. Radiative mechanisms of neutrino mass generation and their experimental tests will be discussed. Implications of low scale mass generation schemes to non-standard neutrino interactions (NSI) will be outlined.

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The first image of a black hole

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Topic(s): Particle astrophysics and cosmology

Abstract: I will briefly discuss how the first image of a black hole was obtained by the EHT collaboration. In particular, I will describe the theoretical aspects that have allowed us to model the dynamics of the plasma accreting onto the black hole and how such dynamics was used to generate synthetic black-hole images. I will also illustrate how the comparison between the theoretical images and the observations has allowed us to deduce the presence of a black hole in M87 and to extract information about its properties. Finally, I will describe the lessons we have learned about strong-field gravity and alternatives to black holes.

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Indirect Dark Matter Searches: Status and challenges

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Topic(s): Particle astrophysics and cosmology

Abstract: I will start by reviewing what we know about the existence and nature of dark matter (DM), putting the strategies used for its identification in a broader context. I will briefly present the results of ongoing indirect DM searches, comparing their reach in terms of tests of the WIMP paradigm. Then, I will discuss the common challenges that this approach has to tackle with and in particular why the debate often revolves about 'interpretation of excesses'. Finally, I will present a couple of research directions for the 'road ahead', i.e. the next decade of indirect DM research, within and beyond the WIMP scenario.

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The Square Kilometre Array: a physics machine for the 21st Century

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Topic(s): Detector development, future facilities and experiments

Abstract: A partnership of 15 nations, including India, has designed and is poised to start construction of the world's largest astronomical observatory, the Square Kilometre Array. The global organisation will construct two huge radio telescopes, one in South Africa and the second in Australia. They are designed to enable an enormous range of fundamental science, from exploring the origins of our universe, the nature of gravity, magnetism across the cosmos to the study of bio-molecules, the precursors to life itself. I will describe the challenges of constructing such a huge infrastructure in remote areas of the world and how we plan to process the enormous volumes of data generated by these physics machines.

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Future Prospects in Neutrino Physics

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Topic(s): Neutrino physics

Abstract: Neutrino physics has entered the precision era. Spectacular results collected from experiments over the last few decades have opened up the possibility for designing next-generation neutrino experiments meant to unravel the final missing pieces of the neutrino puzzle. Answers to these puzzle could lead to far-reaching consequences, from deciphering the true theory of Nature to understanding the reason for our own existence. In this talk I will focus on future prospects in neutrino physics - what are the new experiments coming up on the horizon and what are we expecting to learn from their results. In particular, I will be discussing how precision measurements of neutrino properties will help us constrain BSM theory. In particular, I will focus on the measurement of the neutrino mass ordering, the octant of the mixing angle theta23, and the measurement of the CP violating phase - an essential ingredient in the theory of leptogenesis.

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Recent theoretical developments on QCD matter at finite temperature and density

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: QCD matter at finite temperature and density is a subject that has witnessed very impressive theoretical developments in the recent years. In this review I will discuss some new insights on the microscopic degrees of freedom of the QCD medium near the chiral crossover transition, arising from theoretical studies, primarily from lattice QCD. Latest high precision lattice data on the fluctuations and correlations between conserved charges like the baryon number, strangeness, electric charge can help us to understand and distinguish between different models of interacting hadrons. Furthermore, the latest updates on some aspects of the QCD phase diagram at finite baryon density, for e.g., the latest constraints on the location of the critical end-point and the curvature of the critical line will be discussed. In the later part of this review I will discuss about the insights on the thermal nature of the medium created in heavy ion collision experiments that have come from the theoretical analysis of the particle yields, and to what extent the lattice data on correlations and fluctuations of conserved charges can give us any information about the fireball at freezeout.

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The next-generation Event Horizon Telescope: new approaches to black hole imaging.

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Topic(s): Detector development, future facilities and experiments

Abstract: Until recently, no one had ever seen what a black hole actually looked like. Einstein's theories and more modern simulations predicted that a distant observer should see a ring of light encircling the black hole, which forms when radiation emitted by infalling hot gas is lensed by the extreme gravity near the event horizon. The Event Horizon Telescope (EHT) is a global array of radio dishes, linked together by a network of atomic clocks to form an Earth-sized virtual telescope that can resolve the nearest supermassive black holes where this ring feature may be measured. On April 10th, 2019, the EHT project reported success: we have imaged the supermassive black hole at the center of the galaxy M87 (Virgo A), and have seen the predicted strong gravitational lensing that confirms the theory of General Relativity at the event horizon. A new effort to design and build the next-generation EHT (ngEHT) will enable real-time black hole video, further transforming M87 and SgrA* (the supermassive black hole at the Galactic Center) into extreme laboratories for further tests of gravity and black hole physics. This talk will cover how the EHT results were accomplished and describe future directions towards black hole cinema.

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Mini-review talks

The Belle II experiment and first physics results

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Topic(s): Standard model physics

Abstract:

The Belle II experiment has recently started operations at the SuperKEKB e^+e^- collider, located at the KEK laboratory in Tsukuba (Japan). The unprecedented luminosity that it plans to collect in the next decade (50 ab^{-1}) will allow Belle II to greatly exceed the precision achieved by the first generation of B-factory experiments (BaBar and Belle), on the physics of B mesons, charmed particles, τ leptons, and exotic states.

After summarizing the challenges and the innovative solutions for accelerator and detector, the physics program of the experiment will be broadly presented, with particular emphasis to the areas on which some intriguing anomalies are now appearing. In many of these cases, the input from Belle II will be crucial to confirm or disprove these hints of physics beyond the standard model.

In the last part of the presentation, an overview of the physics results obtained with the early datasets will be given. Among these, some searches for Dark Sector particles are already capable of probing new ground, despite the relatively small integrated luminosity collected so far.

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In-medium properties of Heavy Quarkonia

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract:

We discuss the in-medium properties of the heavy quarkonium states. The medium modifications of the masses of the heavy quarkonia (charmonium and bottomonium states) and the partial decay widths of charmonium (bottomonium) state to $D\bar{D}$ ($B\bar{B}$) are investigated. The medium effects studied are due to the density, temperature, isospin asymmetry, strangeness fraction, as well as, due to the presence of a magnetic field in the hadronic medium. The partial decay widths of the heavy quarkonium states to the open heavy flavour meson pairs, are calculated using a field theoretical model for composite hadrons with quark constituents, as well as, using a light quark pair model, namely the $^3P_0$ model. The medium modifications of the decay widths arise due to the mass modifications of the heavy quarkonia as well as the open heavy flavour (charm and bottom) mesons, calculated using a chiral effective model. The mass modifications of the charmonium and bottomonium states arise due to medium modification of a scalar dilaton field in the effective hadronic model, which simulates the gluon condensates of QCD. On the other hand, the in-medium masses of the D, $\bar{D}$, B and $\bar{B}$ mesons are obtained from their interactions with the baryons and scalar mesons in the hadronic medium within the chiral effective model. In the presence of a magnetic field, there are contributions from the Landau energy levels for the charged baryons, as well as, from the mixing of the pseudoscalar and vector heavy quarkonia. The effect of isospin asymmetry is observed to be dominant for high densities, leading to appreciable difference in the decay channels of the charmonium to D^+D^- and $D^0\bar{D}^0$, and, of the bottomonium states to neutral and charged $B\bar{B}$ pairs. These isospin effects should show up in the asymmetric heavy ion collisions in Compressed baryonic matter (CBM) experiments planned at the future facility at FAIR. The mixing of the pesuodoscalar and longitudinal vector charmonium states (J/ψ-η_c, ψ'-η'_c mixings) is observed to lead to substantial modifications to the masses of these charmonium states (hence to the in-medium decay widths) in the presence of strong magnetic fields. This should have observable consequences on the yield of the hidden and open charm states at RHIC and LHC, where the produced magnetic fields are huge.

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Probing Ultralight Primordial Black Holes as a Dark Matter Candidate

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Topic(s): Particle astrophysics and cosmology

Abstract:

Dark matter (DM) is omnipresent in the universe. Despite its abundance, the microscopic identity of DM remains unknown, as it has evaded all direct and indirect probes thus far. Primordial black holes (PBHs), possibly formed via gravitational collapse of large overdensities in the early universe, are one of the earliest proposed and well-motivated DM candidates. Recent studies indicate that PBHs can make up a large or even entire fraction of the DM density for a wide range of masses. In this talk, I will briefly review the observational constraints on PBH as DM, concentrating on the ultra-light mass window. Ultralight PBHs emit particles through Hawking radiation and they can be probed via observations of such evaporated particles in various space as well as ground based detectors. I will also outline how next-generation MeV telescopes can set a stringent exclusion on ultralight PBH DM into a completely unexplored mass window by probing low energy photons.

Jets and jet substructure

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Topic(s): Standard model physics; Beyond standard model physics; Relativistic heavy-ion physics and QCD

Abstract: I will briefly review salient ideas behind jet finding strategies at colliders and extracting substructure information from them [1, 2]. The latter, over the past many years, have enabled us to extract crucial information in particle collisions and in characterising potentially interesting events [3, 4]. Jet substructure techniques, sometimes in tandem with newer approaches, remain at the forefront of the search for beyond Standard model phenomena today [5–7]. I will present a terse selection of topics related to recent progress and avenues where they have found applications.

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Soft theorem and classical radiation

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Topic(s): Formal theory

Abstract: In this talk I shall describe recent progress on extracting information on the classical electromagnetic and gravitational radiation using soft theorems.

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The experimental Overview : SUSY

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Topic(s): Beyond standard model physics

Abstract: The standard model (SM) of particle physics accurately describes the overwhelming majority of observed particle physics phenomena. Nevertheless, several open questions are not addressed by the SM, such as the hierarchy problem, the need for fine tuning to reconcile the large difference between the electroweak and the Planck scales in the presence of a fundamental scalar . Moreover, there is a lack of an SM candidate particle that could constitute the dark matter in cosmological and astrophysical observations. Supersymmetry (SUSY) is a well motivated extension of the SM that provides a solution to both of these problems, through the introduction of a symmetry between bosons and fermions.

The physics program of the CMS/ATLAS experiment at the CERN LHC is designed to explore the TeV energy scale and to search for new particles and phenomena beyond the standard model (SM), for example, those predicted by supersymmetry (SUSY). In this talk, I will present the latest results from both CMS and ATLAS experiment using data from proton-proton collisions at $\sqrt{s} = 13$ TeV collected with both the detectors, corresponding to an integrated luminosity of 137 fb^{-1}.

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Status of precision electroweak measurements

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Topic(s): Standard model physics

Abstract: Studies of electroweak observable continue to gain new grounds with excellent precision at the LHC. Highlights of some of the specific measurements ranging from mass of W-boson to single boson kinematics to multiboson productions will be discussed in this talk.

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Custom IC development for HEP applications

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Topic(s): Detector development, future facilities and experiments

Abstract: Tracking particle trajectories in the India-based Neutrino observatory(INO) requires time-to-digital converters(TDC). The large number of detector outputs merits development of custom ICs for TDCs. The design of a low power, compact multi-channel single-shot time-to-digital converter (TDC) capable of handling multiple hits per channel is presented. The system has 17 hit channels and 1 trigger channel and is designed to meet the requirements of the iron calorimeter detector(ICAL) in the INO. The TDC core consists of a delay chain stabilized by a delay-locked loop (DLL) and synchronous counters. The digital backend is programmable to allow for multiple configurations during the operation. Tradeoffs in the choice of clock frequency are discussed. The 0.13 μm chip occupies an active area of 3.72 mm^2 and consumes 3.4 mW per channel. Besides the specifics of the TDC chip, the presentation will also discuss the economics of IC development and opportunities for doing the same for science applications in India.

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Recent measurements of (anti-)Nuclei production in high energy collisions

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The measurement of light nuclei and anti-nuclei production in high energy collisions has been of great interest. It is known that the Universe started with a Big-Bang with nearly equal abundance of matter and antimatter. This symmetry got lost in the evolution of the universe with no visible amounts of antimatter being present now. The data from high energy experiments suggest equal abundance of matter and antimatter in the central rapidity region. Thus, the study of(anti-)nuclei production in these collisions can shed light on their production mechanism as well as can be related to the early evolution of the Universe after Big-Bang.

In this talk, the recent measurements of (anti-) nuclei from different experiments covering various observables such as spectra, yields, ratios, flow coefficients etc. will be presented. With the high statistics of data collected by these experiments it became possible to measure the lifetime of hypertriton precisely, to constrain the hyperon-nucleon interaction, measure mass difference of particle and anti-particle will be discussed. The comparison of experimental results with different model expectations will be also presented.

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Recent RHIC and LHC measurement on jets and heavy-flavors

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: At extreme temperature and nuclear density, the nuclear matter transits to the hot-dense QCD matter, where color degree freedom plays a significant role, is known as the Quark-Gluon Plasma (QGP). In heavy-ion collisions, jets and heavy-flavors are hard-produced probes created at the very early stages of collisions. They provide unique access to study the properties of QGP and its evolution. High precision data at the Large Hadron Collider and Relativistic Heavy-Ion Collider enable experimentalists to study the QGP properties using these hard probes. In this mini-review, I plan to give a brief overview of various jet-quenching observables and our current understanding of parton propagation and medium-induced energy loss in the QGP medium. Additionally, results from heavy-flavor measurements to study the heavy-flavor hadron production and its dynamics in the QGP medium will be discussed.

MPGD based Tracking and PID Detectors

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Topic(s): Detector development, future facilities and experiments

Abstract: Tracking and Particle Identification Detectors (PID) are vital systems for most experiments in high-energy and nuclear physics. While tracking is used to determine the charge and momentum of traversing particles, PID provides velocity determination which in conjunction with tracking yields the mass of the particle. Gaseous and semiconductor detectors are the two main types of detector technologies; other, more exotic technologies include fiber and transition radiation devices. In this mini-review, I will focus on Micro-Pattern Gaseous Detectors (MPGD's), namely gaseous electron multipliers (GEM's), MicroMegas (MMG's) and micro-Resistive Well (μ-RWELL) and their applications as PID and tracking devices. Also, I will briefly discuss technological considerations for MPGD's in past experiments and at the upcoming Electron-Ion Collider at RHIC.

Latest results on correlations and fluctuations (including collectivity)

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: In this talk I would like to provide a brief overview on the recent measurements of correlations and fluctuations in relativistic heavy ion collisions. Since this is a wide area I will focus on three specific topics: Criticality, Chirality and Collectivity. Finding conclusive experimental signatures of the phenomena related to these three topics have become major scientific goals of the heavy-ion physics program. These phenomena manifest largely over the spectrum of particles that is soft and therefore bulk correlations provide the best approach to explore them. Apart from several experimental artifacts, data-model comparison suffer from several major challenges in such explorations – highly non-perturbative nature of particle production and complex dynamics of heavy ion collisions often complicate the interpretations of the observation. This leads to many outstanding questions and provides the necessary impetus to pursue decisive and precision measurements. For example, it is natural to ask: do we see evidence of the QCD critical point or a crossover transition in the measurements of net-proton number fluctuations? Do we see evidence of chirality-genesis and local parity violation in strong interactions in the measurements of charge separation across reaction plane? Do the collective behavior of densely packed gluons inside nuclei manifest in the azimuthal angular correlation measurements in small collision systems ? How does the collectivity developed at the partonic level survive the process of hadronization – can precision measurements of flow provide some clue in this direction ? In the context of some of these questions I will mostly discuss a few selected results from the Solenoidal Tracker At RHIC (STAR) experiment at the Relativistic Heavy Ion Collider (RHIC) but will briefly outline the results from the Large Hadron Collider (LHC). I will also try to say a few words on how the remaining few years of heavy ion runs at RHIC with its upgrades and analysis of already collected data provide unique prospects towards a better understanding of the aforementioned topics.

The Conformal Bootstrap: An Overview

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Topic(s): Formal theory

Abstract: Conformal field theories (CFTs) are of wide importance across theoretical physics including as the UV fixed points in theories of high energy physics as well as being the starting point of the AdS/CFT correspondence. In this mini-review talk, I shall give a bird's eye view of recent developments in the so-called conformal bootstrap. This is a non perturbative approach to extract the data that defines a CFT viz. the anomalous dimensions Δ_i of primary operators as well the three point function coefficients C_{ijk}. I will focus more on progress on analytic tools that have been developed for this problem in the last few years.

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Neutrino astrophysics in mulit-messenger era

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Topic(s): Particle astrophysics and cosmology

Abstract: High Energy Astrophysics has been one of the integral part of particle physics and astrophysics since the discovery of cosmic rays (CRs, the highest energy CRs observed are ultra high energy CRs, UHECRs $> 10^{18}$ eV) from space and X-rays from astrophysical objects. With more significant discoveries it has been confirmed that high energy astrophysics have imprints even in other wavelengths, radio (1.4 GHz), optical and gamma-rays (>keV). The first discovery of Gravitational Waves (GWs) from neutron star- neutron star (NS-NS) mergers as a transient in other electro-magnetic (EM) wavelengths, as well as the recent multi-messenger observation of 290 TeV neutrino event from one of the highest energy astrophysical environment, blazars, could only become possible, because of the combined observations at different wavelengths with correlation in time and space.

Accelerated high energy cosmic rays from blazars, a class of AGN with their relativistic jets pointed towards us, are likely candidates for the TeV-PeV neutrino events detected by IceCube neutrino telescope at the South Pole [1, 2]. On 2017 September 22 IceCube detected neutrino track event (IceCube-170922A) with energy > 290 TeV, which was coincident in direction and time with a high gamma-ray state from a blazar TXS 0506+056. Subsequently a multi-wavelength campaign was followed involving telescopes across the globe [3, 4]. Further analysis of 9.5 years of data from the direction of TXS 0506+056 suggest excess of neutrino events above atmospheric background between September 2014 and March 2015 [5]. Recent correlation studies suggests blazar GB6 J1040+0617 (BL Lac) as possible origin of IceCube-141209A neutrino event [6] but with low confidence and consistent with background origin. Two sources 1H 0323+342 a narrow line Seyfert 1 (NLSY1) galaxy and PKS 1502+036 a flat-spectrum radio quasar (FSRQ) galaxy showed gamma ray flares during neutrino detection with p-value of chance coincidence 8% and 4% respectively [7].

Motivated with this We studied the spatial correlation of muon track events from the northern hemisphere and the variable sources of fourth Fermi Large Area Telescope catalogue (4FGL). Two blazars 4FGL J2255.2+2411 and 4FGL J0224.9+1843 have been identified within 50% CL uncertainty of two muon track events. We have carried out time dependent modeling of the multi-wavelength data from these two blazars, and the neutrino events including leptonic energy losses and proton-proton interactions in their jets to determine whether they could be the origin of the neutrino events. In our lepto-hadronic model the estimated jet luminosities are $L_j = 1.08 \times 10^{49}$ erg/sec and 2.6×10^{48} erg/sec during the neutrino phase for 4FGL J2255.2+2411 and 4FGL J0224.9+1843 respectively, which are nearly ten times higher than their Eddington luminosities.

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Fundamental physics with CMB: LCDM anomalies, new particles, and primordial black holes

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Topic(s): Particle astrophysics and cosmology

Abstract: Cosmological anomalies or inconsistencies between the predictions of standard cosmological model (LCDM) and observations indicate new physics beyond the simplest LCDM model. Hubble tension is the most significant anomaly at present, but increasing precision of cosmological observations may uncover more anomalies in future, such as deviation of the CMB spectrum from a perfect blackbody. I will show how we can learn about fundamental physics such as presence of new particles, new interactions, or non-trivial deviation from single field inflation from the observations of the CMB: the anisotropies as well as deviations of the CMB from a blackbody spectrum and present some new results on current (Hubble tension) and future anomalies.

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Implications of recent Flavour anomalies on New Physics

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Topic(s): Beyond standard model physics

Abstract: In recent times, several hints of lepton flavour universality violation have been observed in semileptonic B decays at the level of $(2-4)\sigma$, both in the rare flavour changing neutral current (NC) transitions $b \to s\ell\ell$ and charged current (CC) transitions $b \to c\ell\bar{\nu}_\ell$. These tantalizing signals point towards the possible existence of New Physics beyond the Standard Model. Numerous studies have been performed to understand these anomalies in various new physics models as well as in model-independent approach. Since the new physics scales involved in the CC and NC sectors are significantly different from each other, explanation of these intriguing set of discrepancies in a coherent manner using a single framework is rather challenging, We will discuss few such scenarios which could successfully illustrate all these anomalies in a lucid manner.

Latest results on light flavour hadron production at LHC and RHIC

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The ultimate goal of heavy-ion collisions is to study the properties of the deconfined and chirally restored medium known as the Quark-Gluon Plasma. Light flavour hadrons allow investigation of the bulk properties of the created medium. The shape of the transverse momentum distributions of identified hadrons at low and intermidiate transverse momentum, and their evolution with the collision centrality allow constraints to be placed on the collective expansion properties of the fireball. At higher transverse momenta, the study of identified particles provides insight into the mechanism of parton energy loss in the hot and dense medium. The particle densities at mid-rapidity allow for the study of the hadrochemistry of the event and comparison with the statistical hadronization model provide a crucial understanding about the hadronization and freeze-out temperatures. On the other hand, results in pp collisions are usually used as a baseline for the measurements in heavy-ion collisions. However, recent observations of intriguing similarities among small (pp, d–Au, p–Pb) and heavy-ion (Xe–Xe, Au–Au, U–U and Pb–Pb) collision systems suggest the presence of collective phenomena in pp, d–Au and p-Pb collisions, whose origin and detailed phenomenology is a very active ground of discussion in the heavy-ion community. In this respect, the study of identified particle production as a function of the collision energy and multiplicity is a key investigation tool.
The ALICE and STAR collaborations have studied the production of a comprehensive set of light-flavour particles, both in small collision systems and in heavy-ion collisions at LHC and RHIC energies, respectively. These include unique measurements over a broad momentum range of the production of π, K, p, strange and multi-strange hadrons, short-lived hadronic resonances and light-(anti-)nuclei. In this talk we will present the latest results on the production of light-flavour charged particles as a function of transverse momentum, charged particle multiplicity, participant nucleon numbers, and collision energy and will discuss the interpretation of the results.

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Dark matter theory: mini review

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Topic(s): Particle astrophysics and cosmology

Abstract: In this mini review on dark matter theory, I will first discuss why dark matter is inevitable from cosmological perspective and will briefly present thermal (mainly WIMP) and non-thermal (mainly axion like particle) production mechanism of dark matter. After that I will describe what is the status of dark matter searches from and which models are still viable. Finally I will give a overview of near future cosmological and gravity wave smoking gun signal which may help us to pin down the dark matter fundamental nature if we are lucky!

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Cosmology and high-redshift universe with the redshifted 21 cm line

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Topic(s): Particle astrophysics and cosmology

Abstract: The redshifted 21 cm line of neutral hydrogen is one of the most useful probes of the early universe. Several experiments are ongoing and are being planned to detect the signal from high redshifts. Detection of the signal will help in understanding the first stars in the Universe, the formation and evolution of galaxies and also constraining cosmological parameters. In this talk, we will discuss some of the most interesting problems in cosmology and high-redshift universe that can be studied using the 21 cm line, highlighting the contribution of the Indian community along the way.

Long Baseline Accelerator Neutrino Experiments

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Topic(s): Neutrino physics

Abstract: In this talk, I review the status of long baseline accelerator neutrino experiments. I briefly discuss the results obtained by the past experiments, MINOS and MINOS-plus. Then I discuss the various issues of degeneracies faced by the current experiments T2K and NOvA. Finally, I will discuss how the future experiments, especially HyperKamionade and DUNE, plan to overcome the present difficulties.

Relativistic Magneto-hydrodynamics in heavy ion collisions

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The relativistic systems close to the local thermal equilibrium are described by the equations of relativistic hydrodynamics; in other words, this implies that any fluctuation of the conserved quantities is carried away by hydrodynamic waves and the energy-momentum of the system are exactly conserved. When the system coupled with U(1) gauge fields, long-range correlations mediated by those fields are possible. The appropriate framework to describe such a system is relativistic Magneto-hydrodynamics (RMHD). The existence of ultra-intense transient magnetic fields in heavy-ion collisions (HIC) is conjectured to give rise to Chiral Magnetic Effect (CME). In CME, a charged current is generated along the magnetic fields induced by chirality imbalance in systems such as the hot and dense quark-gluon plasma (QGP) created in HIC. The CME is a consequence of chiral anomaly in a quantum field theory. The detection of CME and other related phenomena such as chiral magnetic wave, chiral separation effect etc., from the experimental data, requires comparison with results from dynamical models such as viscous RMHD. Recently much progress has been made towards the development of a causal relativistic Magneto-hydrodynamics and its application in HIC. In this talk, we will present the current status of the RMHD and its application in heavy-ion collisions. We will also discuss some open problems and future directions.

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Charm physics at the B-factories

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Topic(s): Standard model physics; Beyond standard model physics

Abstract: The "charm sector" is special and provides unique opportunities for the search of physics beyond the Standard Model. Belle has played crucial role in shaping the charm sector. I will try to summarize the recent development in the charm physics and also give a flavor of what to expect in the future from the Belle II experiment.

Cryogenic Detectors and Sensors for High Energy Physics

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Topic(s): Detector development, future facilities and experiments

Abstract: Cryogenic detectors and sensors have played a crucial role in particle and astroparticle physics experiments, where we desire an excellent energy resolution for high-precision measurements. From tonne scale to $\sim \mu$g detectors — where a formal distinction between source, sensor, and detector is very subtle — low temperature detectors have found attractive application in fundamental research. Its widespread use in the search for extremely rare events like neutrinoless double beta decay, dark-matter searches, neutrino mass measurement, coherent elastic scattering of neutrinos off nuclei, and x-ray spectroscopy, has resulted in a remarkable enhancement of sensitivity and precision. The high energy physics community is also constantly pushing to leverage the tools of quantum sensing, that sometimes rely heavily on cryogenic infrastructure, to reduce the readout noise to an unprecedented low level. In this talk, I will review the physics principles of cryogenic detectors, their merits, and performance limits for some applications mentioned above.

Parallel talks

Beyond standard model and standard model physics (Parallel talks)

M_{T2} as a probe of CP phase in $h \to \tau\tau$ at the LHC

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Topic(s): Beyond standard model physics

Abstract: Our Universe is matter-antimatter asymmetric and to explain it the CP violation is required. However, the Standard Model of particle physics does not provide an adequate amount of CP violation. Ergo, Many extensions of the SM modify the couplings of the SM Higgs to the gauge bosons and fermions to have additional source of CP violation. Recently, the CMS collaboration has constrained the CP phase [1–3], using the observables proposed earlier, with large uncertainty. Given the importance of the issue, a lab frame observable would be extremely important to give a complementary probe of the CP phase. We propose to utilize the transverse mass variable M_{T2} and it's descendant M_{2Cons} [4] for constraining the CP admixture of the tau lepton Yukawa coupling at the LHC. We have considered the tau lepton pair produced from the Higgs boson with each tau decays to a charged pion and a neutrino, $\tau^{\pm} \to \pi^{\pm}\nu_{\tau}$. Recently, for this channel, the LHC has employed the impact parameter method to measure the CP mixing angle of tau lepton Yukawa coupling with large uncertainty. The observables we propose here can be measured in the lab frame without the impact parameter measurement and, in turn, give a complementary probe of the CP admixture of tau lepton Yukawa. The CP mixing angle, with our method, can be constrained up to 17° (7°) with 300 (3000) fb^{-1} of integrated luminosity at the 14 LHC.

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Aspects of Charged Higgs Boson in the 2HDM Doppelganger

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Topic(s): Beyond standard model physics

Abstract:

We describe a model with an extended electroweak gauge symmetry $SU(2) \otimes SU(2) \otimes U(1)$ with EWSB facilitated by two scalar doublets Φ_1, Φ_2 and a non-linear sigma field Σ. We demonstrate that, at low-energy the scalar spectrum of our model mimics a typical 2HDM setup. The presence of additional gauge degrees of freedom allows us to identify novel channels and, as a consequence, demarcate both the scenarios in the future LHC experiments. We illustrate this point focusing on the charged Higgs boson phenomenology.

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Model independent analysis of $B \to K_1 \ell^+ \ell^-$ decay processes

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Topic(s): Beyond standard model physics

Abstract: In recent times, several discrepancies at the level of $(2-3)\sigma$ have been observed in the flavour changing neutral current (FCNC) mediated transitions $b \to s\ell^+\ell^-$decays, which may be considered as the smoking-gun signal of New Physics (NP). These intriguing hints of NP have attracted a lot of attention in recent times and many attempts are made to look for the possible NP signature in other related processes, which are mediated through the same quark-level transitions. In this work, we perform a comprehensive analysis of the FCNC decay of B meson to axial vector mesons $K_1(1270)$ and $K_1(1400)$, which are mixtures of the $^3P_1$ and $^1P_1$ states K_{1A} and K_{1B}, in a model independent framework. Using the $B \to K_1$ form factors evaluated in the lattice QCD approach, we investigate the rare exclusive semileptonic decays $B \to K_1(1270)\ell^+\ell^-$ and $B \to K_1(1400)\ell^+\ell^-$ ($\ell \equiv e, \mu, \tau$). Considering all the possible relevant operators for $b \to s\ell^+\ell^-$ transitions, we study their effects on various observables such as branching fractions, forward-backward asymmetries, of these processes. We also study the lepton polarization asymmetries, which show relatively strong dependency on the mixing angle θ_{K_1}, in the various region of dileptonic invariant mass and hence, they can be used for its determination. These results will not only enhance the theoretical understanding about the mixing angle but also serve as a good tool for probing New Physics.

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Next to soft corrections to Differential rapidity distributions at the hadronic colliders

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Topic(s): Standard model physics

Abstract: We present a formalism that sums up both soft plus virtual (SV) and next to SV (NSV) contributions to all orders in perturbative QCD for the rapidity distribution of any colorless particle produced in hadron colliders. Using this formalism one can also study variety of inclusive hadronic reactions such as Drell-Yan[1] or Deep inelastic scattering[2] to understand the structure of subleading logarithms and their resummation. We exploited the factorization properties and Sudakov K+G equations of the soft and virtual parts of the cross section. Using the state-of-the-art multiloop and multileg results, we determine the entire soft distribution function for the rapidity distribution up to third order in QCD and predict certain fourth order NSV terms for Drell-Yan and Higgs productions. Using the integral representation of our all order z space result, we show how the NSV contributions can be resummed in two-dimensional Mellin space.

References

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Jet substructure techniques to search for SUSY with gravitino LSP

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Topic(s): Beyond standard model physics

Abstract: In this talk, I will discuss the search strategy for compressed supersymmetry at multi-TeV scale, in the presence of a light gravitino dark matter. This scenario can get sizable uplift while looking into the associated fat-jets with missing transverse momenta as a signature of the boson produced in the decay process of much heavier next-to-lightest sparticle. Here, we focus on the hadronic decay of the ensuing Higgs and/or Z boson giving rise to at least two fat-jets and $\not{E}_T$ in the final state. This channel provides the best discovery prospects with most of the benchmarks discoverable within an integrated luminosity of $\mathcal{L} = 200$ fb^{-1} [1]. We will also discuss some kinematic observables which can distinguish between compressed and uncompressed spectra having similar event yields.

References

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Measurement of CP violating weak phase in mesonic pseudoscalar to vector-vector decay

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Topic(s): Standard model physics

Abstract: The measurement CP violating weak phase is achieved using 2017 and 2018 proton-proton collision data collected by CMS experiment at centre of mass energy 13 TeV [**1**]. This talk will discuss the recent result and its combination with the Run-I result, providing particular emphasis to the adopted methodology and discussing in detail the multidimensional fit and the DNN based event tagging.

References

[1] CMS Collaboration et al. , CMS public results, *Measurement of the CP violating phase* ϕ_s *in the* $B_s \to J/\psi\phi(1020 \to \mu^+\mu^-K^+K^-$ *channel in proton-proton collisions at* $\sqrt{s} = 13$ *TeV.*, CMS-PAS-BPH-20-001 (2020).

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Measurement of cross section of $pp \rightarrow t\bar{t} + \gamma$ process in lepton+jets events at $\sqrt{S} = 13TeV$ in LHC Run 2

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Topic(s): Standard model physics

Abstract: Top quark is the heaviest known elementary particle and plays a special role in the dynamics of fundamental interactions. As the top quarks are predominantly produced through strong interactions a photon can originate in the final state involving an additional electroweak vertex. Therefore, studying the top-antitop pair ($t\bar{t}$) production in association with a photon can lead to a thorough scrutiny of the Standard Model predictions.Any deviation in the measured cross section of this process can lead to BSM physics. This measurement is performed in events with a well isolated, high $p\bar{T}$ lepton (electron and muon), at least four jets from the hadronization of quarks and an isolated photon. The analysis makes use of simultaneous likelihood fits in several control regions to distinguish $t\bar{t} + \gamma$ signal from background. The Furthermore, due to the presence of the additional electroweak vertex the charge-asymmetry in $t\bar{t} + \gamma$ events can get enhanced and such a scenario can also be explored using $t\bar{t} + \gamma$ events during LHC Run 2.

Higgs self-coupling at the HL-LHC and HE-LHC

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Topic(s): Standard model physics; Beyond standard model physics

Abstract:

We study the prospects of observing the non-resonant Higgs pair production in the Standard Model (SM) at the high luminosity run of the 14 TeV LHC (HL-LHC), upon combining multiple final states chosen on the basis of their yield and cleanliness, namely, $b\bar{b}\gamma\gamma, b\bar{b}\tau^+\tau^-, b\bar{b}WW^*, WW^*\gamma\gamma$ and $4W$ channels by employing multivariate analyses using the Boosted Decision Tree (BDT) algorithm to optimise the discrimination between signal and backgrounds and find it performing better than simple cut-based analyses. We also explore the implications of varying λ_{hhh} for the most sensitive search channel for the double Higgs production, namely, $b\bar{b}\gamma\gamma$. The number of signal events originating from SM di-Higgs production in each final state is small and for this reason measurement of differential distributions may not be possible. In order to extract the Higgs quartic coupling, we have to rely on the total number of events in each final state and these channels can be contaminated by various new physics scenarios. Furthermore, we consider various physics beyond the standard model scenarios to quantify the effects of contamination while trying to measure the SM di-Higgs signals in detail. In particular, we study generic resonant heavy Higgs decays to a pair of SM-like Higgs bosons or to a pair of top quarks, heavy pseudoscalar decaying to an SM-like Higgs and a Z-boson, charged Higgs production in association with a top and a bottom quark and also various well-motivated supersymmetric channels. We set limits on the cross-sections for the aforementioned new physics scenarios, above which these can be seen as excesses over the SM background and affect the measurement of Higgs quartic coupling. We also discuss the correlations among various channels which can be useful to identify the new physics model. [1]

Upon continuation of the previous work, here, we analyse the prospects of observing the non-resonant Higgs production in the Standard Model at the proposed high energy upgrade of the LHC, namely, the HE-LHC ($\sqrt{s}$ = 27 TeV and 15 ab^{-1} of integrated luminosity). Various di-Higgs final states are considered based on their cleanliness and production rates, namely, $b\bar{b}\gamma\gamma$, $b\bar{b}\tau^+\tau^-$, $b\bar{b}WW^*$, $WW^*\gamma\gamma$, $b\bar{b}ZZ^*$ and $b\bar{b}\mu^+\mu^-$ channels. The signal-background discrimination is performed through multivariate analyses using the Boosted Decision Tree Decorrelated (BDTD) algorithm in the TMVA framework, the XGBoost toolkit and Deep Neural Network (DNN). The variation in the kinematics of Higgs pair production as a function of the self-coupling of the Higgs boson, λ_{hhh}, is also studied. The ramifications of varying λ_{hhh} on the $b\bar{b}\gamma\gamma$, $b\bar{b}\tau^+\tau^-$ and $b\bar{b}WW^*$ search analyses optimized for the SM hypothesis is also explored. [2]

References

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Probing BSM Physics with multileptons at CMS

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Topic(s): Beyond standard model physics

Abstract: The standard model (SM) is a successful milestone in our current understanding of the universe. But it does not accommodate phenomena such as dark matter, neutrino masses or the baryon asymmetry in our universe. We search for exotic physics beyond the SM in the multilepton final state; it serves as an excellent probe given the clean signature in the detector and relatively small backgrounds from known SM processes.

In PRL 119, 221802 (2017) [1] and JHEP 03 (2020) 051 [2], we searched for new heavy particles that couple to leptons and to a Higgs boson doublet. These searches could provide evidence of the type-III seesaw mechanism which explains the smallness of neutrino masses. The results placed constraints on the type-III seesaw fermions. We also searched for a doublet of vector-like leptons (VLL) in PRD 100, 052003 (2019) [3] by adding channels with hadronically decaying tau leptons. VLLs arise in a wide variety of models ranging from supersymmetry to extra dimensions. This search excluded VLLs coupling to the third generation in the mass range of 120–790 GeV. In addition, we also searched for new CP-even or CP-odd light scalar bosons [3] which are an ubiquitous feature of many beyond SM theories such as extended Higgs sectors, SUSY and dark sector. The light scalars or pseudoscalars may create a localized excess in the dilepton mass spectra, allowing a first direct search. We placed constraints on the masses of the new scalars under various branching ratio assumptions.

Currently, we are adding new tau-enriched final states, as well as many multivariate techniques to increase the sensitivity of the multilepton searches to new BSM phenomena.

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$D^0 \to K^0_{\mathrm{L}}\pi^+\pi^-$ amplitude model and a study of K^0_{L} reconstruction at BESIII

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Topic(s): Standard model physics

Abstract: The strong-phase difference $\Delta\delta_D$, between D^0 and $\overline{D}^0$ decays to a common final state, is a crucial input in the measurement of the weak phase γ/ϕ_3 of the CKM $(b-d)$ unitarity triangle extracted from $B^- \to DK^-$. Here D represents a D^0 or $\bar{D}^0$ decaying to the same final state. With the largest quantum-correlated dataset of $D^0\overline{D}^0$ pairs produced at $\psi(3770)$ resonance, corresponding to an integrated luminosity of 2.93 fb^{-1}, BESIII has the opportunity to facilitate the minimum systematic uncertainty on γ coming from D strong-phase. Model-independent, as well as model-dependent studies, are required to best constraint the strong-phase difference parameters. This paper reviews the strong-phase measurements reported by BESIII and presents preliminary results on $D^0 \to K^0_{\mathrm{S/L}}\pi^+\pi^-$ amplitude models with the BESIII $D^0\overline{D}^0$ dataset.

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Light Singlino Dark Matter at the LHC

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Topic(s): Beyond standard model physics

Abstract: Light (∼few GeV) dark matter (DM) particle is still very much allowed even in the presence of stringent constraints on DM particle masses from the direct detection experiments. In the Next-to Minimal Supersymmetric Standard Model (NMSSM), the lightest neutralino can be a promising candidate for dark matter (DM) with mass of few GeV and yet allowed by the relevant constraints, if it is singlino-like. The DM annihilation takes place via singlet-like light Higgs bosons which are natural in this model and also required to satisfy the relic density and direct detection bounds for DM. These light Higgs bosons and the singlino-like DM candidate can be indirectly produced at the LHC through production of SM Higgs boson and its subsequent decays. In this talk, I shall discuss how this DM candidate and the light Higgs bosons can be probed at the LHC with a reasonable signal significance ($\sim 5\sigma$), at the center of mass energy $\sqrt{s} = 14$ TeV and integrated luminosity options L =300 fb^{-1} and 3000 fb^{-1}. I shall also talk about how the allowed region of NMSSM parameter space can provide a light singlino-like DM solution.

Two loop QCD amplitudes for di-pseudo scalar production in gluon fusion

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Topic(s): Beyond standard model physics

Abstract: We compute the radiative corrections to the four-point amplitude g+g $\rightarrow$ A+A in massless Quantum Chromodynamics (QCD) up to order a_s^4 in perturbation theory. We used the effective field theory that describes the coupling of pseudo-scalars to gluons and quarks directly, in the large top quark mass limit. Due to the CP odd nature of the pseudo-scalar Higgs boson, the computation involves careful treatment of chiral quantities in dimensional regularisation. The ultraviolet finite results are shown to be consistent with the universal infrared structure of QCD amplitudes. The infrared finite part of these amplitudes constitutes the important component of any next to next to leading order corrections to observables involving pair of pseudo-scalars at the Large Hadron Collider. (JHEP02(2020)121)

Exploring the Structural Features of Quark Mass Matrices in the Flavor Basis

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Topic(s): Beyond standard model physics

Abstract: Understanding fermion masses and mixings is one of the most important problems of present day High Energy Physics. In this context, both in the quark sector as well as in the leptonic sector, there has been a continuous progress both on the experimental front as well as on the phenomenological front throwing good deal of light on the physics beyond the Standard Model. In the absence of any viable theory of Flavor Physics, emphasis is mostly on developing phenomenological models of fermion mass matrices which are in agreement with the ever improving data [1, 2].

In the case of quark sector with three generations, the mass matrices are characterized by complex 3×3 matrices in the up and down sectors, together leading to 36 free parameters. However, in the standard model including some of its extensions, without loss of generality, it can be shown that the general mass matrices can be reduced to hermitian mass matrices with 18 independent parameters [2]. The mass matrices are related to the mixing matrix, referred to as CKM matrix [3–5] characterized by three angles and one CP violating phase, with six quark masses leading to ten observables.

Weak Basis Transformations and texture specific mass matrices have been used to develop viable phenomenological interpretations of the mass matrices [2]. Briefly, weak basis transformations allows one to chose a basis in the Standard Model wherein one can have specific form(s) of the mass matrices in the up and down sectors. In particular, without loss of generality, we can have mass matrices to be diagonal in either up or down sector with the other being completely general hermitian matrix. The purpose of the present work is to explore in detail the structural features of the mass matrices in the flavour basis. Some very interesting results regarding the phase factors as well as the parametric ranges of the elements of the mass matrices have been found. In particular, the constraints of the angles of the unitarity triangle allows us to find a very simplified phase structure of the mass matrices which is compatible with the CP violation in the CKM paradigm.

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Search for a b* decaying to tW

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Topic(s): Beyond standard model physics

Abstract: A search for a heavy resonance decaying to a top quark and a W boson in the fully hadronic final state is presented. The analysis is performed using proton-proton collisions at a center-of-mass energy of 13 TeV. The search uses data corresponding to an integrated luminosity of 137 fb^{-1}recorded by the CMS experiment at the LHC. The analysis is focused on heavy resonances, where the decay products of each top quark or W boson are expected to be reconstructed as a single, large radius jet with a distinct substructure. An excited quark, b^{*}, is used as a benchmark model when setting limits on the cross section for a heavy resonance decaying to a top quark and a W boson. The hypotheses of b^{*} quarks with left-handed, right-handed, and vector-like chirality are excluded at 95% confidence level for masses below $2.61, 2.83$, and 3.04 TeV, respectively.

LHC signals of triplet scalars as dark matter portal: cut-based approach and improvement with gradient boosting and neural networks

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Topic(s): Beyond standard model physics

Abstract:

The recent data on direct search for dark matter (DM), especially those from the Xenon1T observation, rather strongly constrain scenarios where the 125 GeV Higgs acts as dark matter portal. The coupling of, say, a scalar SU(2) singlet DM to the Higgs boson of the standard model (SM) is restricted by such constraints to be $\lesssim 10^{-3}$. Ensuring the DM annihilation rate required for consistency with the observed relic density becomes a big challenge in such a case.

The restriction is considerably relaxed for an extended electroweak symmetry breaking sector. In that case one can have regions in the parameter space where the DM candidate has rather feeble interaction with h, the SM-like scalar, but sufficient coupling with the heavier neutral scalar H so as to be consistent with both direct search results and the relic density. it is also possible to have cancellation between the h and H-mediated scattering amplitudes. The allowed regions in 2HDM satisfying such requirements and the corresponding signals at the Large Hadron Collider (LHC) have been studied in detail.

Here we present the results of a similar investigation in the context of scalar triplet extension of the SM. We consider a scenario where an SU(2) triplet scalar acts as the portal for a scalar(singlet) dark matter particle. We identify regions of the parameter space, where such a triplet coexists with the usual Higgs doublet consistently with all theoretical as well as neutrino, accelerator and dark matter constraints, and the triplet-dominated neutral state has substantial invisible branching fraction. LHC signals are investigated for such regions, in the final state *same-sign dilepton* $+ \geq$ *2 jets* $+ \not{E}_T$ as it also has a rich collider phenomenology, largely due to the presence of a doubly charged scalar that decays either to same-sign dileptons or same-sign W pairs. Straightforward detectability at the high-luminosity run is predicted for some benchmark points in a cut-based analysis, there are other benchmarks where one has to resort to gradient boosting/neural network techniques in order to achieve appreciable signal significance.

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Gravitational Wave Signatures from First-order Phase transitions in an Extended Inert Doublet Dark Matter Model

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Topic(s): Beyond standard model physics; Particle astrophysics and cosmology

Abstract: We consider a particle dark matter model by extending the Standard Model (SM) of particle physics by an extra Higgs doublet and a real singlet scalar. A discrete $\mathcal{Z}_2$ symmetry is imposed in the model where under this symmetry the added Higgs doublet is $\mathcal{Z}_2$ odd while the SM and other added singlet scalar are $\mathcal{Z}_2$ even. The extra Higgs doublet does not acquire any vacuum expectation value (VEV) while the added singlet scalar acquires a non zero VEV and it mixes with the SM Higgs. Due to these facts, the added Higgs doublet is attributed to be an inert doublet and it does not have any direct coupling with fermion. Here the lightest of the two neutral scalars of the inert doublet acts as a viable candidate of dark matter. We constrain the model parameters by using vacuum stability [1], perturbativity, Large Electron-Positron Collider (LEP) [2] and Large Hadron Collider (LHC) bounds [3, 4], future generation collider bounds like High Luminosity LHC (HL-LHC), International Linear Collider (ILC) and China Electron Positron Collider (CEPC) or TLEP [5], PLANCK bound on the DM relic density [6] and the limits given by spin independent direct detection experiments such as XENON-1T [7], PandaX-II [8], LUX [9] and DarkSide-50 [10]. Then we consider a finite temperature effective potential [11] to explore the first-order phase transition (FOPT) within the framework of the model. We also discuss the possible production mechanisms of gravitational waves (GWs) from the strong FOPT [12, 13]. Finally, we calculate the intensities and frequencies of such GWs and investigate its detection possibilities at the future space-based detectors such as eLISA [14], ALIA [15], BBO [14], DECIGO [14], U-DECIGO [16] and ground-based detector aLIGO [14].

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Collider signatures of multi-charged fermions at the LHC in the framework of a radiative seesaw model

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Topic(s): Beyond standard model physics

Abstract: The tiny neutrino masses and non-zero mixings have been one of the key experimental findings to motivate for exploration beyond the framework of the Standard Model. We have explored a collider tastable model with TeV mass scale BSM particles to explain the generation of neutrino masses and mixings via radiative seesaw mechanism in the symmetery group of the SM itself. Non-requirement of any additional ad-hoc symmetry to forbid tree-level contributions makes its collider phenomenology quite interesting. The particle spectrum of the model have multi-charged fermions/scalars at the TeV scale to realize the Weinberg operator at 1-loop level. The model parameters have been constrained from the neutrino oscillation data as well as from the upper bound on the absolute neutrino mass scale. We have explored the production, decay and resulting collider signatures of these TeV scale fermions at the Large Hadron Collider (LHC). For production cross-section, the Drell-Yan and photoproduction, both taken into account. Depeneding upon the decay profile, we put bounds from the ATLAS searches.

Resummed transverse momentum distribution of pseudo-scalar Higgs boson at $\mathrm{NNLO_A} + \mathrm{NNLL}$

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Topic(s): Beyond standard model physics; Relativistic heavy-ion physics and QCD

Abstract: The Standard Model of particle physics has been very successful in explaining properties of the fundamental particles and the interactions among them, nevertheless, it has several shortcomings which can be addressed if we go beyond the standard model. Most of the extensions contain a pseudo-scalar Higgs boson along with the Standard Model Higgs boson. One of the important goal at the LHC Run-II is to search for such particles which require precise theoretical predictions for both inclusive as well as for exclusive observables [1–4] . In this paper we have studied the transverse momentum (p_T) distribution [5–7] of pseudo-scalar Higgs production through gluon fusion. The small p_T region which provides the bulk of the cross section is not accessible to fixed order perturbation theory due to the presence of large logarithms in the series. In the small p_T region the cross-section diverges due to presence of the large logs coming from incomplete cancellation of UV and IR singularities. We have resummed the logarithms upto next-to-next-to-leading logarithmic accuracy and matched with fixed order next-to-next-to leading order to obtain a prediction at low values of p_T [8–10] . Our works also shows a significant reduction in theoretical uncertainties due to the unphysical scales. We have calculated the Hard coefficients at next-to-next-to-leading order level from the virtual amplitude and used this result to study resummation. We have presented the p_T distribution valid for the whole p_T region and provide a detailed phenomenological study for both 13 TeV and 14 TeV LHC for different choices of masses, scales and PDFs. Our study will be useful for the study of properties of pseudo-scalar Higgs at LHC in near future.

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SUSY search with atleast one photon, p_T^{miss} and jets at CMS for full Run2

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Topic(s): Beyond standard model physics

Abstract:

A search for supersymmetry with at least one photon, jets, and large p_T^{miss} in the final state, produced in proton-proton collisions at 13 TeV center of mass-energy with 137.1 fb^{-1} of data collected in 2016-2018 with the CMS detector at the CERN LHC. This search is motivated by Gauge Mediated SUSY breaking in which LSP is the gravitino and bino-like neutralinos are expected to be the NLSP but generally there are arbitrary mixtures of bino-wino, bino-higgsino, and wino-higgsino which will result in the mixed branching fractions of Z, H, and photons in the final states.

This analysis is focussed on strong production but also includes the search region sensitive to the production of processes via electroweak interactions. In this search, N_{jets} and soft dropped mass of AK8 jets are important variables for defining the electroweak production search region because of the presence of boosted fat jet corresponding to the W/Z/H and lesser hadronic activity for the processes, via electroweak interactions, with given final states. Optimization studies have been performed, and good sensitivity has been observed. This analysis makes use of data-driven background estimations. In this talk, I would like to give an overview of the search of supersymmetry which is sensitive to both strong and electroweak productions, with at least one photon, jets, and large p_T^{miss} in the final state using full Run-2 data collected by the CMS experiment at LHC.

Search for dark matter with a Leptoquark and Missing transverse energy in the final state by using proton-proton collision data of CMS detector at LHC at 13 TeV

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Topic(s): Beyond standard model physics

Abstract: Leptoquarks are new bosons predicted by numerous extention of standard model (SM), having both lepton and baryon number. In the final state for this particular dark matter(DM) search, the selected events should have at least one high transverse momentum P_T muon, one high P_T jet and large missing transverse momentum(MET). A new paradigm "coannihilation codex", where dark matter particle will either annihilate or produce in conjuction with a coannihiltion partner "X" , is used for the this analysis. A pair of scalar leptoquarks are produced, where one decays to a high P_T muon and a jet, and the other decays to dark matter and some undetected SM particles called "X". The peak in the invariant mass distribution of the leptoquark, where it decays to highest P_T muon and jet, will give the signature of darkmatter. The results will be presented using Run2 proton-proton collision data of the cms detector at LHC. [1]

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Rediscovery of "wrong sign" $D^0 \longrightarrow K^+\pi^-\pi^0$ decay with Belle II

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Topic(s): Beyond standard model physics

Abstract: In the standard model, mixing and CP violation in the charm sector are expected to be very small and thus they constitute a sensitive probe for potential new physics contributions.

The "wrong-sign" $D^0 \rightarrow K^+\pi^-\pi^0$ decay is the best channel to study charm mixing, as this can be produced through two interfering processes: a direct doubly Cabibbo-suppressed decay of the D^0 meson, or through D^0-$\bar{D}^0$ mixing followed by a Cabibbo-favored decay of the $\bar{D}^0$ meson. In this analysis, our aim is to "rediscover" the "wrong-sign" $D^0 \rightarrow K^+\pi^-\pi^0$ decay and measure its signal yield in early Belle II data, where Belle II is the upgraded experimental facility at SuperKEKB, KEK, Japan.

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Recent measurement on $B \to \mu^+\mu^-$ properties by using CMS data

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Topic(s): Beyond standard model physics

Abstract: Rare decays of beauty mesons are an ideal place to search the effect of New Physics(NP) contributions by measuring decay rates and properties precisely. The decay of B_s and B_d mesons in two muons are highly suppressed in the SM because of helicity and CKM suppression and effects of NP could be observed. The CMS results concerning the $B_s^0 \to \mu^+\mu^-$ BF and its effective lifetime and the search for the decay $B^0 \to \mu^+\mu^-$ will be presented. This analysis exploits the data collected by the CMS experiment in 2011, 2012 and 2016, with center-of-mass energies of 7 TeV, 8 TeV, and 13 TeV, corresponding to an integrated luminosity of 5 fb^{-1}, 20 fb^{-1} and 36 fb^{-1}, respectively[1].

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LHC bounds on $R_{D^{(*)}}$ motivated Leptoquark models

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Topic(s): Beyond standard model physics

Abstract: Most of the popular explanations of the observed anomalies in the semileptonic B-meson decays involve TeV scale Leptoquarks (LQs). Among the various possible LQ models, two particular LQs – $S_1(3,1,1/3)$ and $U_1(3,1,2/3)$ seem to be most promising. Here, we use current LHC data to constrain the $S_1(3,1,1/3)$ and $U_1(3,1,2/3)$ parameter spaces relevant for the $R_{D^{(*)}}$ and $R_{K^{(*)}}$ observables. We recast the latest ATLAS $\tau\tau$ and $\tau\nu$ resonance search data to obtain new exclusion limits. For this purpose, we consider both resonant (pair and single productions) and nonresonant (t-channel LQ exchange) productions of these LQs at the LHC. For the limits, the most dominant contribution comes from the (destructive) interference of the nonresonant production with Standard Model backgrounds. The combined contribution from the pair and inclusive single production processes [1] is less prominent but nonnegligible. The limits we get are independent and competitive to other known bounds. For both the models, we set limits on $R_{D^{(*)}}$ motivated couplings [2] [3].

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Measurement of boosted top quark in CMS

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Topic(s): Standard model physics

Abstract: The precise measurement of top quark provides a crucial input for consistency tests of the standard model. LHC is the first particle accelerator that provides sufficiently high energy to produce large numbers of boosted top quarks. The current amount of data at LHC as well as our extensive knowledge in identifying top quark decay products in boosted kinematic phase space give us a strong motivation to perform boosted top quark related measurements such as its production cross section, extraction of its mass value and its various properties. The boosted top quark measurement is also relevant in near future of LHC where abundance of its production will be enhanced. In this talk we present the latest measurements of boosted top quark in CMS.

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Probing lepton-number and baryon-number violating tau decays at Belle

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Topic(s): Beyond standard model physics

Abstract:

Lepton flavor, lepton number and baryon number are conserved in the standard model, being accidental global symmetries of the theory. However, there is no reason to expect them to always be conserved in all possible particle interactions. In fact, lepton flavor violation has already been observed in neutrino oscillation [1, 2]. The Belle experiment at the KEKB asymmetric-energy e^+e^- collider provides an ideal platform to probe lepton and baryon number violation in decays of τ lepton. We report recent results on such studies performed at Belle [3] and their prospects at Belle II which has started data taking recently.

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Search for dark matter produced in association with a Higgs boson decaying to a pair of bottom quarks

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Topic(s): Beyond standard model physics

Abstract: A search for dark matter using the events characterized by large missing transverse energy accompanied by a Higgs boson decaying into a pair of bottom quarks is presented. The analysis is performed in two categories based on the lorentz boost of the Higgs boson, namely, resolved and merged category. The results are presented using data collected at CMS detector in 2017 and 2018 corresponding to a total luminosity of 101.3 fb^{-1} and interpreted in terms of limits on parameters in the type-2 two Higgs doublet model (2HDM) extended by an additional light pseudoscalar boson a (2HDM+a)[1].

References

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aQGC studies for WZ in the pp collisions using EFT framework at the LHC

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Topic(s): Standard model physics; Beyond standard model physics

Abstract:

At Hadron Colliders, Vector Boson Scattering (VBS) can be idealized as an interaction of gauge bosons radiated from initial state quarks yielding a final state with two bosons and two jets (VVjj) where V can be W or Z bosons. These VBS processes are widely recognized as being the most sensitive to the effects of new physics, which can be described using the Effective Field Theory(EFT) approach. In this paper, we will discuss the implications and correct usage of the dimension-eight operators of the EFT framework in the study of VBS in the pp $\rightarrow$ WZjj channel. As a final state, two jets and three leptons in proton-proton collisions (pp $\rightarrow$ W Z + 2jets $\rightarrow$ j j $l\ \nu\ l'\ l'$ + 2jets where l', l = e, μ) are observed at the LHC, and the data used, is collected by the CMS detector at $\sqrt{s}$ = 13 TeV during Run II from the year 2016-2018 with an integrated luminosity of 137 fb^{-1}. Results for the searches of the anomalous quartic gauge couplings(aQGC)[1] in the electroweak WZ data sample for the full Run II will be presented.

References

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Analysis of semileptonic decays of some $b-$baryons within the SM and beyond

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Topic(s): Standard model physics

Abstract: The observation of flavor anomalies in semileptonic B meson decays importantly hints physics beyond Standard model. The excess in the measurement of branching fractions of $\overline{B} \to D(D^*)\tau^-\overline{\nu}_\tau$ and $B_c \to J/\psi\tau^-\overline{\nu}_\tau$ [**1**]-[**2**] from the standard model expectation motivates the study of similar decays mediated by $b \to cl\nu_l$ transitions at the quark level. In this work, we analyse some b-baryon decay modes $\Xi_b \to \Xi_c\tau^-\overline{\nu}_\tau$, $\Sigma_b \to \Sigma_c\tau^-\overline{\nu}_\tau$, $\Omega_b \to \Omega_c\tau^-\overline{\nu}_\tau$ mediated by $b \to c\tau\nu_\tau$ transitions. We consider a general effective Hamiltonian which includes both Standard Model and new physics contributions and constrain the new physics couplings using the experimental measurements of R_{D^*},$R_{J/\psi}$ and $BR(B_c^+ \to \tau^+\nu_\tau)$ [**3**]-[**5**]. We study the effects of the new physics parameters on several observables such as the differential branching fraction, forward-backward asymmetry of the charged lepton, longitudinal polarization of the daughter baryon and the charged lepton and also the convexity parameter. Predictions for these observables within the standard model and in various new physics scenarios are presented here.

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Search for compressed mass spectrum SUSY via electroweak VBF in single lepton final states using LHC Run II data collected with CMS detector at $\sqrt(s)$=13 TeV

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Topic(s): Beyond standard model physics

Abstract: A search for supersymmetric electroweakino ($\widetilde{\chi}1^{\pm}$, $\widetilde{\chi}2^{0}$) produced in the vector boson fusion topology in proton-proton collisions at $\sqrt(s)$=13 TeV using the full Run II data collected by the Compact Muon Solenoid (CMS) detector at the Large Hadron Collider (LHC) is presented. The benchmark model for this search is the R-parity conserving MSSM, focusing on compressed mass spectrum scenarios. The experimental signatures of the signal process involve two jets, large missing transverse energy and one lepton. The dominant standard model background processes are estimated using data-driven techniques. In this talk, the results on the background estimation using various control regions and their validation will be presented.

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Effective Field Theory approach to lepto-philic self conjugate dark matter

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Topic(s): Beyond standard model physics

Abstract: We study the self conjugate dark matter (DM) particles interacting primarily with the standard model leptons in an effective field theoretical frame work. We consider SM gauge invariant effective contact interactions between the Majorana fermion, real scalar and a real vector DM with leptons by evaluating the Wilson coefficients appropriate for interaction terms upto dimension-8 and obtain constraints on the parameters of the theory from the observed relic density, indirect detection observations and from the DM-electron scattering cross-sections in the direct detection experiments. Low energy LEP data has been used to study sensitivity in the pair production of such low mass $\leq$ 80 GeV DM particles. Pair production of DM particles of mass $\geq$ 50 GeV in association with mono-photons at the proposed ILC has rich potential to probe such effective operators.

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New physics in $b \to s\ell\ell$ decays with complex Wilson coefficients

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Topic(s): Beyond standard model physics

Abstract: We perform a data-driven analysis of new physics (NP) effects in exclusive $b \to s\ell^+\ell^-$ decays in a model-independent effective theory approach with dimension six operators considering scalar, pseudo-scalar, vector and axial-vector operators with the corresponding Wilson coefficients (WC) taken to be complex. The analysis has been done with the most recent data while comparing the outcome with that from the relatively old data-set. We find that a left-handed quark current with vector muon coupling is the only one-operator ($\mathcal{O}_9$) scenario that can explain the data in both the cases with real and complex WC with a large non-zero imaginary contribution. We simultaneously apply model selection tools like cross-validation and information-theoretic approach like Akaike Information Criterion (AIC) to find out the operator or sets of operators that can best explain the available data in this channel. It is observed that the $\mathcal{O}_9$ with complex WC is the only one-operator scenario which survives the test. However, there are a few two and three-operator scenarios (with real or complex WCs) which survive the test, and the operator $\mathcal{O}_9$ is common among them.

Charged lepton flavour violating decays as signatures of A_4 symmetry

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Topic(s): Neutrino physics; Beyond standard model physics

Abstract: We study the charged lepton flavour violation in a popular neutrino mass model with A_4 discrete symmetry. This symmetry requires the presence of multiple Higgs doublets in the model and it also dictates the flavour violating Yukawa couplings of the additional neutral scalars of the model. Such couplings lead to the decays of the neutral mesons, the top quark and the τ lepton into charged leptons of different flavours at tree level. The A_4 symmetry of the model leads to certain characteristic signatures in these decays. We discuss these signatures and predict the rates for the most favourable charged lepton flavour violating modes.

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EFT validity issues in aQGC analysis of same sign WW Vector Boson Scattering processes

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Topic(s): Standard model physics; Beyond standard model physics

Abstract: Vector Boson Scattering (VBS) processes are regarded as the best laboratory to study the VVVV quartic couplings, where V= W,Z. Such studies are carried in the framework of Effective Field Theories (EFT). However, the EFT formalism is often not used in a fully consistent way. To search for anomalous QGC, analysis of the same sign WW electroweak vector boson scattering process is presented. The measurements are performed in the fully leptonic decay modes in proton-proton collisions at $\sqrt{s}$= 13 TeV at the LHC. The data is collected with the CMS detector during 2016-18 and corresponding to an integrated luminosity of $137 fb^{-1}$. "Clipping" technique is the most theory-motivated way to do data analysis in the EFT language. Results are presented both with and without "clipping" technique implementation. Also limitations of the EFT approach to describe New Physics effects are discussed.

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Estimation of low-energy constants for bottom mesons in heavy meson chiral perturbation theory

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Topic(s): Standard model physics

Abstract: Using the masses of lowest lying S- and P- wave of bottom mesons ($s_l^P = \frac{1}{2}^-$ and $\frac{1}{2}^+$ doublet), we have estimated the low-energy constants (LEC) of heavy meson chiral perturbation theory. The states are analyzed by considering effective fields of $s_l^P = \frac{1}{2}^-$ doublet ($J^P = 0^-, 1^-$) for$l = 0$ and $s_l^P = \frac{1}{2}^+$ doublet ($J^P = 0^+, 1^+$) for $l = 1$. We have computed the LEC's for strong decays of bottom mesons for tree level and one-loop corrections through light pseudoscalar mesons. Calculations of these constants are done by taking g and g' couplings vanish for these bottom states kinematically. We have also used h = 0.56. Four of the LEC's were computed previously. We have estimated other LEC's by putting a range on some of them.

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Searches for non-resonant and resonant Higgs boson pair-production, decaying into bb$\gamma\gamma$ final state, in the pp-collisions at $\sqrt{s} = 13$ TeV, using CMS Run2 data

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Topic(s): Beyond standard model physics

Abstract: The searches for non-resonant and resonant Higgs pair production in bb$\gamma\gamma$ final state[1] are presented. The analyses are performed using the proton-proton collision dataset recorded by the CMS detector at a center-of-mass energy of 13 TeV in 2016, 2017, and 2018 corresponding to the total 137 fb^{-1} integrated luminosity.
For the gluon-gluon fusion non-resonant di-Higgs case, analysis strategy and developments are presented in detail which mainly includes the study of optimal b-tagger for the analysis, improvement in the resolution of Higgs-mass with bb final state, and optimization study to remove ttH contamination. These are useful for resonant analysis as well and directly used for resonant studies.
For resonant analysis, using a model-independent approach two Beyond the Standard Model(BSM) scenarios [[2], [3]] are explored up to resonance mass 1 TeV. A 95% confidence level upper limits on the Higgs pair-production cross-section are studied as a function of the resonance mass. Preliminary results from both the BSM scenarios are presented assuming 1 fb signal cross-section.

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Rare charm decays at Belle II

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Topic(s): Standard model physics

Abstract: Belle II detector, situated at the SuperKEKB e^+e^- accelerator (plan to have $8 \times 10^{35} cm^{-2}s^{-1}$ instantaneous luminosity), will collect 50 times larger data than the Belle detector. This will allow one to do more precise measurements and tests of the Standard Model (SM). Flavor Changing Neutral Current (FCNC) processes are forbidden at the tree level in the SM. However, there are several new physics (NP) models that can enhance the branching fractions of the FCNC. $D^0 \to \gamma\gamma$ is one such decay mode sensitive to the NP searches. We will talk about the prospectus of the charm rare decays at Belle II (focusing on the $D^0 \to \gamma\gamma$ decay mode). Further, we will also demonstrate the capability of the Belle II detector in reconstructing the charm mesons from the neutral candidates (K_S^0 and π^0). The data/MC study of the neutral candidates uses the most recently collected data by the Belle II detector.

Study of Flavour Constraints on Dark Matter Models.

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Topic(s): Beyond standard model physics

Abstract: There has been a great effort by the particle physics community to succesfully extend the Standard Model (SM) in order to accomodate the unexplained mysteries of the Universe, including the dark matter problem. On the experiment side, huge amount of data has been collected and the SM is now known to unprecedented accuracy. Recently however, deviations from SM expectancy have been observed in some lepton flavour violating observables in semileptonic B-decays which give a strong hint of physics beyond the SM. The existence of dark matter requires the presence of one or more extra degrees of freedom beyond the SM of particle physics which may be constrained from the precise flavour data. In our recent works [1, 2], we show the combined new physics parameter space which not only satisfies the correct dark matter relic abundance, but also takes into account constraints from other low energy observables such as lepton flavour violating (LFV) decays and flavour anomalies. We also discuss interesting collider signatures in order to validate our model in ongoing and future collider experiments. In [1], we construct two toy models that can additionally generate small neutrino masses as well as address the anomalous results in the $K_L \to \pi^0 \nu\bar{\nu}$ decay observed in the KOTO experiment at J-PARC.

References

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Search for Lepton Flavour Violation in B decays

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Topic(s): Beyond standard model physics

Abstract:

The flavor changing neutral current B decays are forbidden at tree-level in the Standard Model and can only proceed via suppressed loop level diagrams. In the recent years, some deviation in the experimental measurements of Lepton Flavour Universality in B decays (i.e. $b \to s\ell\ell$ and $b \to c\ell\nu$) with the SM prediction and some theoretical models hint that there are lepton flavor violating interactions. Therefore observation of the Lepton Flavour Violation (LFV) in B decays would be a clear signal of physics beyond the Standard Model.

The Belle II experiment is a substantial upgrade of the Belle experiment at KEK, Japan and operates at the SuperKEKB energy-asymmetric e^+e^- collider. It has started recording collision data from spring 2019. The LFV in B decays have been studied in Belle ($B \to K\ell\ell'$ and $B \to K^*\ell\ell'$) and will be one of the important topics in Belle II. In this talk, we will present studies of $B_s \to \ell\tau; (\ell = \mu, e)$ at Belle.

Role of polarization in probing chiral structure of heavy gauge bosons at an e^+e^- collider

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Topic(s): Beyond standard model physics

Abstract: We study the top pair production at the proposed high luminosity e^+e^- linear collider with initial beam polarization. This is done to probe the chiral structure of the heavy gauge bosons couplings in the context of warped extra-dimensional models. The polarization of the top will be sensitive to the chiral nature of its coupling to the new resonance, therefore the top decay channels will be an effective tool in isolating the new physics effects through the study of the different polarization observables. We study in detail the angular distribution of the decay particle of the top (antitop) quark and construct various asymmetries to discriminate between the multiple resonances in the various extra-dimensional models. We finally conclude that the top polarization may serve as a window to the chiral structure of the new physics couplings.

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Study for vector bosons production in association with heavy-flavor jets in proton-proton collisions

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Topic(s): Standard model physics

Abstract: The kinematic properties of vector bosons decaying into two same leptonic flavour and heavy-flavor jets that originate from heavy flavor quarks have been studied using proton-proton collisions at Large Hadron Collider(LHC) with the CMS experiment at different centre of mass energies. Vector boson + heavy flavor-jets are originated in p-p collision from gluon-gluon, quark-quark and quark-anti-quark interactions. This study is important to test pQCD theory by comparing experimental cross section with theoretical predictions and to distinguish signal from the background in many SM processes and BSM searches. The kinematic properties have been compared with the prediction from several Monte Carlo event generators using different parton shower simulations.

Precise measurement of the top quark mass with single top events at CMS at $\sqrt{s} = 13$ TeV

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Topic(s): Standard model physics

Abstract: The t channel process provides a unique phase space with lower color reconnection probability as compared to the $t\bar{t}$ process. We report a precision measurement of the top quark and antiquark mass in the t channel, which is the most dominant production process for single top quarks at the LHC. The final state comprises a single top along with a light quark giving rise to at least two jets, (one of which arises from hadronization of b-quark), an isolated high-momentum lepton (electron or muon), and large missing transverse momentum due to an escaping neutrino from the W decay, in the final state. The study is based on proton-proton collision data, equivalent to $35.9\,\mathrm{fb}^{-1}$ integrated luminosity, recorded at $\sqrt{s} = 13$ TeV by the CMS experiment during 2016. Dominant standard model backgrounds are studied in different regions depending on the number of b quark and light-flavor jets in the final state. A multivariate technique relying on boosted decision trees is employed to separate the signal from backgrounds. The top-quark mass is reconstructed using kinematic information of the W boson and the b quark. We obtain the top quark mass by fitting its reconstructed mass distribution using an appropriate combination of parametric shapes.For the first time, a sub-GeV precision is achieved in the mass measured with single top quark events.

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Determination of CKM angle ϕ_3 at Belle and Belle II

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Topic(s): Standard model physics

Abstract: A more precise determination of the CP-violating parameter ϕ_3 (also called γ) is the most promising path to a better understanding of the Standard Model (SM) description of CP violation. Any deviation of the measurement from the prediction from other flavour measurements would indicate contributions from non-standard model physics. We present the measurement of the angle ϕ_3 using a model-independent Dalitz plot analysis of $B^{\pm} \to DK^{\pm}, D \to K_S^0\pi^+\pi^-$ decays, which currently provides the best sensitivity. The method uses, as input, measurements of the strong phase of the $D \to K_S^0\pi^+\pi^-$ amplitude from the BESIII collaboration. This is the first measurement which is using the combined data-set, of the order of 1 ab^{-1}, of Belle and Belle II. We report the measurement of the observables $x_{\pm}^{DK}$ and $y_{\pm}^{DK}$ which are essential for the ϕ_3 extraction. With the ultimate Belle II data sample of 50 ab^{-1}, a determination of ϕ_3 with a precision of 1° or better is foreseen.

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Exploring the Possibility of Right Angled Unitarity Triangle

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Topic(s): Standard model physics

Abstract: The unitarity of Cabibbo-Kobayashi-Maskawa (CKM) matrix [1] implies six unitarity triangles, four of these triangles are highly skewed, one of these involves the CKM matrix elements based on 't' quark, hence not directly observable. Therefore, the most important of these is the 'db' triangle or the usually talked about unitarity triangle (UT). This triangle has played a vital role in establishing the CKM paradigm as well as in understanding the CP Violation (CPV) observed in the B-decays.

At present, the angle β of the UT has been measured almost accurately as $(22.2 \pm 0.7)^o$[2] whereas the angle γ is measured to be $(73.5^{+4.2}_{-5.1})^o$ PDG[3]. The angle γ can easily be shown to be equal to the CP violating phase (δ) of the CKM matrix [4]. For the case of angle α, various groups like CKMfitter [5] and UTfit [6] quote the value $(91.6^{+1.7}_{-1.1})^o$ and $(90.9 \pm 2.0)^o$ respectively, while the world averages are $(84.5^{+5.9}_{-5.2})^o$ [3] and $(84.9^{+5.1}_{-4.5})^o$ [2], whereas for the case of $B \to \rho\rho$ decays, least affected by penguin contamination, PDG quotes a value $(90.9^{+5.6}_{-5.5})^o$.

It is clear from the above discussion that the values of the angle α of the unitarity triangle is inclusive of 90^o, suggesting the possibility of the UT being right angled. There are several theoretical motivations for assuming right angled UT which have implications for fermion mass matrices and quark-lepton complimentarity [7, 8]. The purpose of the present work is to examine the implications of the possibility of the UT being right angled on the phenomenology of the CKM paradigm. In this connection, we have explored those issues which are responsive to the assumption of right angled UT. In particular, we would like to examine the implications on the issues like tension between V_{ub} obtained from inclusive decays and exclusive decays, as well as on the parameters like ϵ_K, $\frac{\Delta m_d}{\Delta m_s}$, etc.

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Domain wall and CP violation in left right supersymmetry and its implications for leptogenesis and electron EDM

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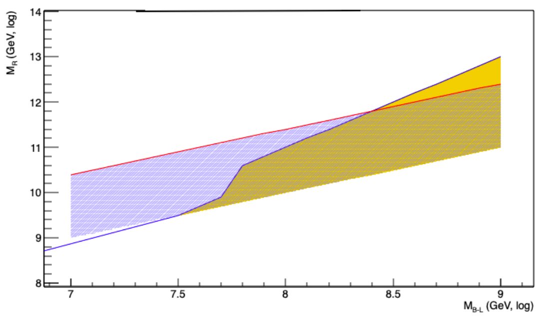
Topic(s): Beyond standard model physics; Particle astrophysics and cosmology

Abstract:

The left right symmetric supersymmetric model (LRSUSY) of Aulakh, Melfo, Rašin and Senjanović [1] based on the gauge group $SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ is an elegant model with low scale supersymmetry which spontaneously breaks parity at a high scale while preserving R-parity. Breaking of the discrete left right symmetry at high scale gives rise to two domains with a domain wall between them. Cline, Yajnik, Nayak and Rabikumar [2] described the possibility of having a spatially varying CP violating phase inside the wall arising from the triplet Higgs fields in the non-supersymmetric version of the model. Sarkar, Abhishek and Yajnik [3] exhibited the possibility of obtaining a spatially varying CP violating phase inside the wall from the bidoublet Higgs fields of LRSUSY; however they did not provide any explicit expression for the phase nor give any estimates about its spatial variation. Existence of such a phase may provide one way of successful leptogenesis and baryogenesis in the early universe.

In this work, we obtain explicit analytic expressions for a spatially varying CP violating phase inside the wall arising from the bidoublet Higgs fields of LRSUSY. From these expressions, we then calculate the amount of lepton and baryon asymmetry resulting from this phase in the early universe. This phase also gives a large contribution to the electric dipole moment (EDM) of the electron, which we calculate next.

The current experimental limits on baryon asymmetry divided by entropy density (10^{-10}, [4]) and electron EDM (10^{-29} e cm, [5]) thus constrain the parameters of LRSUSY. In particular, we see that the scale M_{B-L} of $U(1)_{B-L}$ symmetry breaking has to be larger than $10^{7.5}$ GeV. Moreover the scale M_R of $SU(2)_R$ symmetry breaking has to satisfy $M_R < 10^3 M_{B-L}$ for $M_{B-L} < 10^9$ GeV. These are the most stringent constraints on the parameter space of LRSUSY by far.



The region in the (M_{B-L}, M_R)-plane allowed by the experimental bounds on baryon asymmetry (blue) and electron EDM (green). The intersection shows the region consistent with both the experimental results.

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On next to soft corrections to Inclusive cross sections at the colliders

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Topic(s): Standard model physics

Abstract: We present a framework that resums threshold enhanced large logarithms to all orders in perturbation theory for the production of a pair of leptons in Drell-Yan process and of Higgs boson in gluon fusion as well as in bottom quark annihilation [1]. In addition, we apply this to Deep Inelastic Scattering (DIS) and hadron production in Semi-Inclusive Annihilation (SIA) of electron positron colliders [2]. These logarithms include the distributions $((1-z)^{-1}\log^i(1-z))_+$ resulting from soft plus virtual (SV) and the logarithms $\log^i(1-z)$ from next to SV contributions. We use collinear factorisation and renormalisation group invariance to achieve this. We find that the resummed result is a solution to Sudakov type differential equation and hence it can predict soft plus virtual contributions as well as next to SV contributions to all orders in strong coupling constant to the partonic coefficient function in terms of infrared anomalous dimensions and process independent functions. The z space resummed result is shown to have integral representation which allows us to resum the large logarithms of the form $\log^i(N)$ retaining $1/N$ corrections resulting from next to SV terms. We show that in N space, tower of logarithms $a_s^n/N^\alpha \log^{2n-\alpha}(N), a_s^n/N^\alpha \log^{2n-1-\alpha}(N)\cdots$ etc for $\alpha = 0, 1$ are summed to all orders in a_s.

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Recent measurements of Higgs boson properties in the diphoton decay channel with the CMS detector

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Topic(s): Standard model physics

Abstract: The Higgs boson within the Standard Model (SM) has been discovered by the ATLAS and CMS experiments in 2012. However analyzing a larger volume of LHC dataset collected by the CMS detector from 2016 to 2018 at a higher center of mass energy ($\sqrt{s} = 13$ TeV) is expected to shed more light on the Higgs boson properties and would improve the related measurement sensitivity. A comprehensive analysis on the $H \to \gamma\gamma$ signature (including all possible production modes) using the full Run 2 dataset of $137 fb^{-1}$, recorded by the CMS experiment would be presented here. The present analysis improves the sensitivity by categorizing the events based on different Higgs production mechanisms: Gluon-Gluon fusion (GGH), Vector Boson Fusion (VBF), Vector Boson associated production (VH) and top quark associated production (ttH, tH). Combining all channels, the total Higgs boson signal strength is measured to be $1.02^{+0.11}_{-0.09}$ with respect to the corresponding SM predictions. Also the measurements of other properties like standard model signal strength modifiers, production cross sections, and its couplings to other Standard Model particles will also be presented.

Search for dark matter produced in association with bottom quarks at 13 TeV with CMS detector

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Topic(s): Beyond standard model physics

Abstract: We present a search for dark matter particle in the events containing large missing transverse energy accompanied by b-quarks. The data collected by the Compact Muon Solenoid detector at the Large Hadron Collider in the years 2016, 2017 and 2018 in proton-proton collisions at center-of-mass energy of 13 TeV which correspond to $\sim$150fb^{-1} integrated luminosity has been analyzed in the present study. The interpretation has been carried out in terms of dark matter production to constrain the parameter space of two Higgs doublet model with an additional light pseudo-scalar (2HDM+a)[1]. Further, the analysis also has been interpreted in terms of simplified dark matter model[2] as well.

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Angular analysis of the decay $B^+ \to K^{*+}\mu^+\mu^-$ in proton-proton collisions at $\sqrt{s} = 8$ TeV

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Topic(s): Standard model physics

Abstract: The angular distributions of the decay $B^+ \to K^{*+}\mu^+\mu^-$ are studied using an integrated luminosity of 20 fb^{-1} of data collected with CMS detector at $\sqrt{s} = 8$ TeV. The forward-backward asymmetry of the muons, A_{FB}, and the longitudinal polarization of $K^*(892)$, F_L, are determined as a function of the square of dimuon invariant mass (q^2). In the full dimuon invariant mass squared range (1-19 GeV^2), the results are: $A_{FB} = 0.17^{+0.10}_{-0.06}$(stat) ± 0.08(syst) and $F_L = 0.71^{+0.11}_{-0.09}$(stat) ± 0.06(syst). These are the first results from this exclusive decay mode. I will be presenting these results in the meeting.

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Revisiting the Stückelberg mechanism

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Topic(s): Beyond standard model physics

Abstract: The Stückelberg mechanism will be discussed, in which an extra scalar gives mass to the photon without breaking the $U(1)$ gauge symmetry. It will then be shown that the gauge fixing becomes automatic in a symmetry-broken model if there is a Stückelberg scalar in addition to a Higgs scalar. We will then construct an extension of the Standard $SU(2)\times U(1)$ electroweak model with mass generation from a Stückelberg scalar and show that such a model may be phenomenologically viable.

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Search for the New Physics in bottomonium decays in Belle and Belle II

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Topic(s): Beyond standard model physics

Abstract:

Despite the tremendous success of the Standard Model (SM) of Particle Physics, there are several unexplained phenomena such as neutrino masses and mixing, mass hierarchy problem, etc. The conservation of lepton flavor is one of the accidental symmetries of the SM. Charged lepton flavour violating processes are forbidden in the SM but some new physics models such as leptoquark model, etc. predict such processes that could be observed in a particle collider experiment.

Bottomonium system is a good place to study such processes. Belle experiment, at KEK, Japan is a assymmetric energy $e^- - e^+$ colliders which is collected the data at the energy of $\Upsilon(4S)$, but it also collected some data at $\Upsilon(nS)$(n=1,2,3), so it is possible to study the decay of $\Upsilon(nS)$. Belle has the world's largest data sample available of $\Upsilon(2S)$. The Belle II experiment is an upgrade version of the Belle experiment which aims to collect 50 ab^{-1} of data. We will present the study of $\Upsilon(2S) \to l\tau$ at Belle. We also mention on the future prospect at Belle II

Unveiling Regions in multi-scale Feynman Integrals using Singularities and Power Geometry

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Abstract: With the increasing experimental accuracies at the colliders, the theoretical predictions for the quantum field theoretical observables need to more accurate. This implies that one needs to evaluate the higher order terms in the perturbation theory. The terms in the perturbation series are represented by the Feynman diagrams. Higher order corrections can be obtained by evaluating the multi-loop, multi-scale Feynman diagrams. It is a difficult task to obtain the analytical expression for the multi-scale Feynman diagrams due to the presence of multiple scales. It is helpful to consider systematic approximation for the evaluation of the Feynman diagrams when exact calculations are very difficult or not available. In 1997, Beneke and Smirnov[1] discovered a systematic way, named as "The Method of Regions", to evaluate the multi-scale Feynman diagram by utilizing the hierarchies between the scales. For multi-scale, multi-loop Feynman diagrams it is a challenging task to identify the exact regions which are needed for the asymptotic expansion of the given Feynman diagrams. There had been developments for the identification of the regions[2, 3]. We present a new alternative framework "ASPIRE"[4] to unveiling the regions associated with given Feynman diagrams by looking at the singularities of the Feynman diagrams. In this talk, we discuss the important considerations to identify the regions and the systematic way to obtain the asymptotic analysis of given multi-scale, multi-loop Feynman diagrams considered in the Lee-Pomeransky representation[5].

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A new distribution for the charged particle multiplicities in DIS at HERA and hadron-hadron collisions at the LHC.

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Topic(s): Standard model physics

Abstract: Charged particle multiplicities produced in the lepton proton collisions at $\sqrt{s}$ = 300 GeV [1] recorded using the H1 detector at the HERA accelerator and those from the proton proton collisions at $\sqrt{s}$ =7 TeV [2] at the LHCb detector at the LHC have been analyzed using Shifted Gompertz distribution. The normalized moments and factorial moments are calculated from the proposed new statistical probability distribution and have been compared to those calculated from the data. The study of the charged particle multiplicities is important to understand the underlying dynamics of hadronisation and charged particle production mechanisms. There are various statistical models which are used to study charged particle mutliplicities, the one most commonly and successfully used being the Negative Binomial distribution [3]. The new distribution used in this paper, the Shifted Gompertz distribution, has been used to successfully describe the charged particle multiplicities in the e^+e^- spectra at the ISR energies as well as to the $pp(\overline{p})$ spectra at the highest LHC (Tevatron) energies [4] [5] [6].

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Probing Doubly and Singly Charged Higgs at pp Collider HE-LHC

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Topic(s): Beyond standard model physics; Neutrino physics; Detector development, future facilities and experiments

Abstract: We analyse the signal sensitivity of multi-lepton final states at collider that can arise from doubly and singly charged Higgs decay in a type-II seesaw framework [1–6]. We assume triplet vev to be very small and degenerate masses for both the charged Higgs states. The leptonic branching ratio of doubly and singly charged Higgs states have a large dependency on the neutrino oscillation parameters, lightest neutrino mass scale, as well as neutrino mass hierarchy. We explore this as well as the relation between the leptonic branching ratios of the singly and doubly charged Higgs states in detail. We evaluate the effect of the uncertainties in the neutrino oscillation parameters [7] on the production cross-section of multi-lepton signal. Finally, we present a detailed analysis of multi-lepton final states for a future hadron collider HE-LHC [8, 9], that can operate with center of mass energy $\sqrt{s} = 27$ TeV.

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A study of the $B^0 \to K_S^0 \pi^0$ decay at Belle II

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Topic(s): Standard model physics

Abstract: The decay $B^0 \to K_S^0 \pi^0$ proceeds via $b \to s$ quantum loop diagrams [**1**]. Such flavour changing neutral current transitions are highly suppressed in the standard model and provide an important route to indirectly search for new physics. In particular, the expected large yield of charmless $B^0 \to K_S^0 \pi^0$ decay at the Belle II experiment will allow us to precisely measure the time-dependent CP violation asymmetry towards testing an isospin relation. We present preliminary results based on the data recorded by Belle II at the $\Upsilon(4S)$ resonance.

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Search for new physics with delayed jets in CMS

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Topic(s): Beyond standard model physics

Abstract: The existence of long lived particles are predicted by many beyond standard model theories, such as Split Supersymmetry, SUSY with gauge-mediated supersymmetry breaking (GMSB) , "stealth SUSY" and "Hidden Valley" models. The decay of these long lived particles can give rise to delayed jets which can be identified using the timing capabilities of the CMS Electromagnetic Calorimeter (ECAL). The search result will be presented for such long lived particles using the full Run 2 data collected by the CMS detector[1].

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Recent results of lepton flavor universality in B decays at Belle

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Topic(s): Beyond standard model physics

Abstract: Recent anomalies of lepton flavor universality violation (LFUV) in B decays could be a hint of new physics. The $b \to s\ell\ell$ ($\ell = e$ or μ) decays are flavor changing neutral currents and are good probe to test LFU. We report measurements of LFUV observables R_K [**1**] and R_{K^*} [**2**], the branching fraction of $B \to K^{(*)}\mu^+\mu^-$ to $B \to K^{(*)}e^+e^-$, at Belle. We also measure differential branching fraction ($d\mathcal{B}/dq^2$) and CP-averaged isospin asymmetries (A_I) in $B \to K\ell\ell$ decays [**1**]. The LFU test in charged current can be probed with $b \to c\tau\nu_\tau$ decays. Here, we present the R_D and R_{D^*} results, the ratio of $B \to D^{(*)}\tau\nu_\tau$ to $B \to D^{(*)}\ell\nu_\ell$ using semileptonic tag [**3**]. The analyses are based on the full data set recorded by the Belle detector at the $\Upsilon(4S)$ resonance containing 772 million $B\bar{B}$ pairs from e^+e^- collisions produced by the KEKB collider.

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Naturally freezing-in dark leptons

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Abstract: We consider a flavored dark matter in the Minimal Flavor Violation paradigm and show that a naturally feebly interacting dark matter can be arrived at with a minimal addtion of a flavored multiplet. We conduct a phenomenological study of an effective theory of lepton flavor and discuss the infrared (IR) and ultraviolet (UV) production mechanisms. We also discuss the plasmon production for light dark matter and find that this channel is sub-dominant for a UV-production, leading to larger couplings that can be probed in present/future experiments.

Study of the $B_0 \to \gamma\gamma$ decay at Belle II

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Topic(s): Standard model physics

Abstract: In the recent years, several measurements of B-decays with flavor changing neutral currents, i.e. $b \to d$ transitions hint at deviations from the Standard Model (SM) predictions. The $B_0 \to \gamma\gamma$ decays are forbidden at tree-level in the SM and can only proceed via suppressed loop level diagrams. Rare decays of B mesons are an ideal probe to search for phenomena beyond the SM, since contributions from new particles can affect the decays on the same level as SM particles. The Belle II experiment is a substantial upgrade of the Belle detector and operates at the SuperKEKB energy-asymmetric e^+e^- collider [1]. Early physics goals of the Belle II physics program are to rediscover these rare decays. This decay mode is yet to be observed with an expected branching fraction of 3.1×10^{-8} [2] in the SM. The best previous experimental upper limit on the branching fraction of this mode is 3.3×10^{-7} at 90% confidence level (CL) set by BaBar [4] using 426 fb^{-1} of data. We expect to make the first observation of this decay by considering the SM expectation or to put the most stringent limit on its branching fraction so far.

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Interference Effect in LNV and LNC Meson Decays for Left Right Symmetric Model

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Topic(s): Beyond standard model physics

Abstract: We study the effect of interference on the lepton number violating (LNV) and lepton number conserving (LNC) three-body meson decays $M_1^+ \to \ell_i^+ \ell_j^\pm \pi^\mp$, that arise in a TeV scale Left Right Symmetric model (LRSM) [**1**] with nearly degenerate right handed (RH) neutrinos. LRSM contains three RH neutrinos and a RH gauge boson. The RH neutrinos of masses in the MeV-few GeV range can give resonant enhancement in the semi-leptonic LNV and LNC meson decays. In the case, where only one RH neutrino contributes to these decays, the predicted branching ratio of semi-leptonic LNV and LNC meson decays $M_1^+ \to \ell_i^+ \ell_j^+ \pi^-$ and $M_1^+ \to \ell_i^+ \ell_j^- \pi^+$ are the same [**2**]. However, we find, that with at least two RH neutrinos contributing to the process, the LNV and LNC decay rates can differ. Depending on the neutrino mixing angles and CP violating phases, the branching ratios for the decay channels $M_1^+ \to \ell_i^+ \ell_j^+ \pi^-$ or $M_1^+ \to \ell_i^+ \ell_j^- \pi^+$ can be either enhanced or suppressed.[**3**, **4**, **5**, **6**]

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Rediscovery of $B^+ \to K^+\ell^+\ell^-$ at Belle II

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Topic(s): Standard model physics

Abstract: Rare decays of B meson provides an excellent probe to indirectly search for physics beyond the standard model (SM). For example, decays mediated by the flavor-changing neutral current transition $b \to s/d\ell^+\ell^-$ are very much suppressed in the SM as they are not allowed at tree level and can only proceed via higher-order loop diagrams. In recent times, $B \to K\ell^+\ell^-$ decays (mediated by $b \to s\ell^+\ell^-$ transition) have raised a lot of interest in the study of the lepton-family-universality ratio R_K, which is the ratio of the branching fraction of the muon to electron decay channel. The LHCb experiment at CERN has found a tantalising difference between its R_K measurement and SM prediction at the level of 2.5 standard deviation. Belle II, which provides a complementary experimental setup, has been successfully recording e^+e^- collision data since last year and aims to collect 50 ab^{-1} data with an instantaneous luminosity of 8×10^{35} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$. In these early days of the experiment, the rediscovery of rare decays like $B \to K\ell^+\ell^-$ would be a sign that we are moving along the right direction with proper calibration and detector performance. We shall share the story of how we rediscovered $B \to K\ell^+\ell^-$ at Belle II, and provide a quantitative comparison of the quality of Belle II data from the yield of the decay.

Measurement of Higgs self-coupling from non-resonant Higgs pair production and decay to $b\bar{b}\gamma\gamma$ final state in the CMS experiment

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Topic(s): Standard model physics

Abstract: The trilninear self coupling of Higgs can directly be accessed in proton-proton collision by inclusive Higgs pair (HH) production at the LHC. A search for the non-resonant HH production via gluon-gluon fusion (GGF) and as well as Vector Boson Fusion (VBF) processes has been performed in the most sensitive $b\bar{b}\gamma\gamma$ final state. LHC Run-2 proton-proton collision data at center of mass energy of $\sqrt{s}$=13 TeV, collected by CMS experiment has been used. Further, VBF HH process uniquely provides direct access to the coupling involving two Higgs and two Vector Bosons (HHVV). This talk will describe the highlights of analysis strategy and emphasize on the results of the inclusive cross section for HH production as well as various coupling parameters.

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Multiparton webs beyond three loops

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Topic(s): Standard model physics; Formal theory

Abstract: In perturbative QCD studies of IR singularities that appear in scattering amplitudes have a long history and lead us to remarkable all order insights into the organization of the perturbative expansions. Starting from amplitude, constructing an IR safe observable will lead us into the cancellation of these singularities after adding the real and virtual diagrams for a process. However these singularities leave their signatures in certain kind of logs which we need to resum to get all order finite result [1]. A detailed knowledge of infrared singularities is also important for collider phenomenology at finite orders: indeed, the cancellation of singularities between squared matrix elements with different numbers of external particles is difficult to implement at higher orders for complicated collider observables, which must be evaluated numerically.
In the eikonal limit, multiparton scattering amplitude factorizes into a process independent soft function, a jet function and a process dependent IR finite hard function. The soft function and the jet function are controlled by their respective anomalous dimensions. A one loop result for soft anomalous dimension was calculated in [2]. In 2009 E. Gardi and L. Magnea came up with their famous dipole formula which shows that the soft anomalous dimension depends only on sum over color dipoles for a multiparton scattering process [3]. The dipole formula needs correction beyond two loops.
An alternate diagrammatic way of looking at the soft function is through webs. Webs is a set of diagrams that is closed under permutation of gluon attachments on each leg for a multileg scattering process. In the soft anomalous dimension the color and kinematics of the diagrams in a web mix among themselves through a mixing matrix. We studied the classification of webs to higher perturbative orders, proposing a set of tools to generate them recursively. We have introduced the concept of Cwebs or correlator webs which is a set of skeleton diagrams built out of the connected gluon correlator, instead of individual Feynman diagrams [4]. We computed mixing matrices for all the 4-loops webs which can connect 4 and 5 legs using replica trick algorithm developed in [5] and found the general color structures at 4-loops which will be instrumental in the calculation of soft anomalous dimension at 4-loops.

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Search for lepton flavor violation in bottomonium decays

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Topic(s): Beyond standard model physics

Abstract: Conservation of lepton number is an accidental symmetry in the standard model (SM). The present experimental results provide the bounds on the lepton family number violation[1]. Experiments suggest each of the three lepton generations have their own conserved lepton number. However, neutrino flavor oscillation is observed, which can be explained by mixing between flavor and mass eigenstates of neutrinos. This may suggest that charge lepton flavor violation (CLFV) is already present but is expected to be suppressed in the SM [2]. However, several new physics models (such as SUSY, leptoquark) inspired by grand unified theory (GUT), enhances the decay rates of the CLFV transitions [3,4]. The observation of CLFV will be a smoking gun for the new physics[5]. We report on bottomonium decays using the unique world's largest and cleanest data collected at the $\Upsilon(2S)$ resonance by the Belle detector at the KEKB asymmetric e^+e^- collider.

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Indirectly probing new physics in charmless decays of $B \to \phi\phi K$

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Topic(s): Beyond standard model physics

Abstract: We present precise measurements of the branching fraction and CP-violation asymmetry in the B meson system, specifically in the charmless decays $B \to \phi\phi K$, $\phi \to K^+K^-$. The study is based on the full $\Upsilon(4S)$ data sample of 772×10^6 $B\overline{B}$ events collected by the Belle detector at the KEKB asymmetric-energy e^+e^- collider. These decays are mediated by the $b \to s$ flavor-changing neutral current transition, which could exhibit large CP violation due to interference of potential new-physics (NP) amplitudes appearing in the quantum loop with the $b \to c$ tree-level transition of $B \to \eta_c K$, $\eta_c \to \phi\phi$. Therefore, an observation of direct CP violation in $B \to \phi\phi K$ decays would be a clear sign of physics beyond the standard model. In addition to being an NP probe, the decays are sensitive to possible production of glueball candidates that later decay as $\xi \to \phi\phi$ [**1**]. Our results [**2**] obtained with nine times larger statistics and refined analysis techniques significantly improve upon, and supersede, the Belle's earlier result [**3**].

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Flavor anomalies and radiative neutrino mass with vector leptoquark

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Topic(s): Beyond standard model physics

Abstract: Driven by the recent experimental hints of lepton-flavor-universality violation in the bottom-quark sector [1], we consider a simple extension of the Standard Model with an additional vector leptoquark $V_{\rm LQ}(\mathbf{3}, \mathbf{1}, 2/3)$ [2] and a scalar diquark $S_{\rm DQ}(\mathbf{6}, \mathbf{1}, 4/3)$ under the SM gauge group $SU(3)_c \times SU(2)_L \times U(1)_Y$, in order to simultaneously explain the $b \to s\ell^+\ell^-$ (with $\ell = e, \mu$) and $b \to cl^-\bar{\nu}_l$ (with $l = e, \mu, \tau$) flavor anomalies, as well as to generate small neutrino masses through a two-loop radiative mechanism [3]. We perform a global fit to all the relevant and up-to-date $b \to s\ell^+\ell^-$ and $b \to cl^-\bar{\nu}_l$ data under the assumption that the leptoquark couples predominantly to second and third-generation SM fermions. We then look over the implications of the allowed parameter space on lepton-flavor-violating B and τ decay modes, such as $B_s \to l_i^+ l_j^-$, $B \to K^{(*)} l_i^+ l_j^-$, $B_s \to \phi l_i^+ l_j^-$, $\Upsilon(nS) \to \mu\tau$ and $\tau \to \mu\gamma$, $\tau \to \mu\phi(\eta^{(\prime)})$, respectively. Furthermore, we provide complementary constraints on leptoquark and diquark couplings from high-energy collider and other low-energy experiments to test this model.

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Investigating the parton shower model in PYTHIA8 with pp collision data at $\sqrt{s} = 13$ TeV

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Topic(s): Standard model physics

Abstract: Event-Shape Variables (ESVs) [1] are functions of the four-momenta of particles in hadronic final states and are theoretically robust. They are sensitive to both perturbative and non-perturbative aspects of QCD and help us understand the flow of energy in an event. Recently the CMS Collaboration have published measurement [2] of four ESVs - complement of transverse thrust ($\tau_{\perp}$), total jet mass (ρ_{Tot}), total transverse jet mass ($\rho^{\mathrm{T}}_{\mathrm{Tot}}$) and total jet broadening ($\mathrm{B_T}$) with multi-jets event using proton-proton collision data collected by the CMS at 13TeV. This study[2] shows disagreement with PYTHIA8 [3] (Monash tune[4]) and data for $\mathrm{B_T}$ and ρ_{Tot}, with an overestimate of the multijet nature of the events. This indicates that the flow of energy in the transverse plane (probed by $\tau_{\perp}$ and $\rho^{\mathrm{T}}_{\mathrm{Tot}}$) is better modelled by PYTHIA8 while the overall three-dimensional modelling is not adequate.

We have studied [5] the parton shower(PS) and hadronization model of PYTHIA8 in details for future tuning of the parameter set of PYTHIA8. Here we study PYTHIA8 extensively to figure out the dependence of the ESVs on strong coupling (α_S) used in initial-state (ISR) and final-state (FSR) radiations and maximum shower evolution scale. Finally, we have used RIVET and PROFESSOR [6] framework to estimate some optimum value for α_S corresponding to these shower kernels so that PYTHIA8 describe the data better. The optimized set of parameters is also tested against inclusive cross-section measurements at the CMS[7] and ATLAS [8].

With these optimized parameters, i.e. strong coupling and maximum shower evolution scale, PYTHIA8 shows significant improvement in agreement with data for both ρ_{Tot} and $\mathrm{B_T}$ over the entire range of energy scale of the events. PYTHIA8 with the optimized parameters also shows better agreement with inclusive jet cross-section measurements by CMS and ATLAS experiments. This study suggests that the models of ISR and FSR in PYTHIA8 can be improved to better represent various QCD measurement in high energy collisions.

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SUSY search with jets and large MET final state at CMS

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Topic(s): Beyond standard model physics

Abstract: A search for supersymmetry is performed in the final states containing multiple jets and missing transverse momentum produced in proton-proton collisions using 137 fb^{-1} data collected in 2016-2018 with the CMS detector at the LHC. The analysis is performed in a four-dimensional search region defined in terms of the number of jets, the number of tagged bottom quark jets, the scalar sum of jet transverse momenta, and the magnitude of the vector sum of jet transverse momenta. The standard model (SM) backgrounds estimated using data driven methods compared to the observed data in the search region. The observations are consistent with the SM background predictions and no evidence for supersymmetry is obtained. The results are interpreted in the context of simplified models of pair production of gluino and squarks. [**1**].

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Dark Matter, Muon Anomalous Magnetic Moment and the XENON1T Excess

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Topic(s): Beyond standard model physics

Abstract: The observation of an excess in the electronic recoil events at the XENON1T detector [1] has elicited much activity, especially in the context of Dark Matter. Here, a very economic scenario with only scalar fields beyond the Standard Model is invoked to explain the muon anomalous magnetic moment, the requisite relic abundance of dark matter as well as the XENON1T excess through the inelastic down-scattering of the dark scalar. Constraints from CMB observations, beam-dump experiments and collider experiments have been considered and a viable parameter space is found to exist. What makes this scenario particularly interesting is that a large part of the favoured parameter space would be testable in the near future both in terrestrial experiments as well as CMBR observations. [2]

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Improving bounds on invisible branching ratio of the Higgs with deep-learning

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Topic(s): Standard model physics; Beyond standard model physics

Abstract: Vector boson fusion, originally proposed as an alternative channel for finding heavy Higgs, has now established itself as a crucial production channel to probe different properties of Higgs or for new physics. We use image based deep-learning architectures to extract the non-identical radiation pattern arising due to difference in the exhange of color charge between the incoming beams between dominant backgrounds and the signal, trying to supersede tradional methods like central-jet veto. We investigate among different neural network architectures considering both low-level and high-level input variables as a detailed comparative analysis. We closely follow a recent experimental study of CMS search [1] on invisible Higgs with 36 fb^{-1} data, and find that sophisticated deep-learning techniques have the impressive capability to improve the bound on invisible branching ratio by a factor of three [2], utilising the same amount of data. Without relying on any exclusive event reconstruction, this novel technique can provide the most stringent bounds on the invisible branching ratio of the SM-like Higgs boson. Such an outcome has the ability to constraint many different BSM models severely.

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Cosmology and astroparticle physics (Parallel talks)

Leptogenesis at tree level in NMSSM extended by a singlet right-handed neutrino superfield

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Topic(s): Standard model physics

Abstract: In this work, we explore soft leptogenesis in the NMSSM framework extended by a right-handed neutrino superfield. We calculate the CP asymmetry, ϵ, and find it to be non-zero at tree-level without using thermal effects for the final state particles. This is in contrast to soft leptogenesis in the MSSM extended by a right-handed neutrino superfield where thermal effects are essential. The difference arises due to the presence of a 3-body decay of the sneutrino in the NMSSM that violates lepton number at tree-level. Apart from this, we also find that $\epsilon \neq 0$ if the additional singlet scalar has a complex vacuum expectation value while all the other NMSSM parameters including the soft SUSY breaking ones relevant for CP asymmetry remain real. We estimate the order of magnitudes of these parameters to produce sufficient baryon asymmetry of the Universe.

UV Completion & PQ Phase Transitions with Gravitational Waves

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Topic(s): Standard model physics

Abstract:

Attempts to solve naturalness by having the weak scale as the only breaking of classical scale invariance have to deal with two severe difficulties: gravity and the absence of Landau poles. With various softened gravity theories to resolve the first problem, the second problem calls for many new particles such that 4-dimensional Quantum Field Theories satisfy Total Asymptotic Freedom (TAF): the theory holds up to infinite energy, where all coupling constants flow to zero [1, 2].

Specifically we discuss a fundamental field theory of the QCD axion: all couplings flow to zero in the infinite-energy limit realizing the totally asymptotically free (TAF) scenario. Some observable quantities (such as the masses of new quarks and scalars) are predicted at low energies by the TAF requirement in terms of gauge couplings and a vector-boson mass. The axion sector is charged under an SU(2) gauge group and a dark photon appears at low energies. This model can be TAF and feature an absolutely stable vacuum at the same time [3].

Next the dynamics of the Peccei-Quinn (PQ) phase transition for the QCD axions; particularly we will see the region of the parameter space where the Peccei-Quinn (PQ) symmetry is broken quantum mechanically through the Coleman-Weinberg mechanism. This conformal symmetry-breaking results in an even more predictive framework: the axion sector features only two independent parameters (the PQ symmetry breaking scale and the QCD gauge coupling). In particular, we show that the PQ phase transition is strongly first order and can produce gravitational waves within the reach of future detectors. The predictivity of the model leads to specific characteristics of the phase transition (like its duration and the nucleation temperature) and the gravitational wave (GW) spectrum. The models predict a frequency peak in the range 100-1000 Hz with an amplitude that is already within the sensitivity of LIGO & advanced LIGO and can be thoroughly tested with other future GW interferometers [4–7].

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Helical magnetic fields from Riemann coupling

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Topic(s): Particle astrophysics and cosmology

Abstract: We study the inflationary generation of helical magnetic fields from the Riemann coupling with the electromagnetic field. Most models in the literature introduce non-minimal coupling to the electromagnetic fields with a scalar field, hence, breaking the conformal invariance. In this work, we show that non-minimal coupling to the Riemann tensor generates sufficient primordial helical magnetic fields at all observable scales. We explicitly show that one of the helical states decay while the other helical mode increases, leading to a net non-zero helicity. Our model has three key features: (i) the helical power-spectrum has a slight red-tilt for slow-roll inflation consistent with bounds from observations and free from backreaction problem, (ii) the energy density of the helical fields generated is at least one order of magnitude larger than the scalar-field coupled models, and (iii) unlike the scalar field coupled models, the generated helical fields are insensitive to the reheating dynamics.

Hunting for dark matter in the galactic centre with INO

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Topic(s): Neutrino physics; Particle astrophysics and cosmology

Abstract: Annihilation of Weakly Interacting Massive Particles (WIMPs) in the galactic centre (GC) region can give rise to neutrino fluxes, which can leave detectable signatures at the proposed 50-kt Iron Calorimeter (ICAL) detector to be built at the upcoming India-Based Neutrino Observatory (INO). We study prospects of detecting such events at ICAL[1, 2]. The neutrino fluxes from WIMP annihilation in the GC is proportional to velocity averaged annihilation cross-section $\langle\sigma_A v\rangle$ and the line-of-sight integral over the DM density profile J_Ψ factor[3], the latter being a function of the angular separation (Ψ) of reconstructed muon track at ICAL with the GC. The atmospheric neutrinos in GeV range constitute the major background which we suppress by exploiting the difference in directional dependence of the signal and background neutrinos. We accept muon events in a cone of half angle Ψ, the axis of the cone being in the direction of GC. We consider WIMP masses between (5-100) GeV and several annihilation channels. The expected 90 % C.L. sensitivity limits for a 30 GeV WIMP, assuming NFW[4] DM profile, neutrino spectra from [5] and assuming 100% branching ratio for each channel are: $\langle\sigma_A v\rangle \leq 1.19 \times 10^{-22}$ cm^{3}s^{-1} for the $\mu^+\mu^-$ channel and $\langle\sigma_A v\rangle \leq 6.35 \times 10^{-23}$cm^{3}s^{-1} for the $\nu\,\bar{\nu}$ channel.

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Common origin of Dark Matter and Low Scale Leptogenesis from Three Body Decay at Tree Level

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Topic(s): Particle astrophysics and cosmology

Abstract:

We study the possibility of realising tree level leptogenesis from three body decay, dark matter and neutrino mass in a minimal framework. We propose a first of its kind model to implement the idea of leptogenesis from three body decay where CP asymmetry arises from interference of multiple tree level diagrams. The standard model is extended by three heavy singlet fermions, one scalar singlet and one scalar doublet with appropriate discrete charges. Two of these singlet fermions not only play non-trivial roles in generating light neutrino mass at radiative level in scotogenic fashion, but also act as mediators in three body decay of the third singlet fermion leading to desired CP asymmetry through interference of tree level diagrams. With just one additional field compared to the minimal scotogenic model, we show that successful leptogenesis can occur at a scale as low as approximately 500 GeV which is much lower than the leptogenesis scale found for minimal scotogenic model. Also, the realisation of this tree level three body decay leptogenesis naturally leads to a two component scalar singlet-doublet dark matter scenario offering a rich phenomenology. Apart from having interesting interplay of different couplings involved in processes related to both leptogenesis and dark matter, the model can also be tested at different experiments due to the existence of its particle spectrum at TeV scale.

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Dirac Neutrino Portal Dark Matter

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Topic(s): Beyond standard model physics, Particle astrophysics and cosmology, Neutrino Physics

Abstract: We propose a Dirac neutrino portal dark matter scenario by minimally extending the particle content of the standard model with three right-handed neutrinos and a vector-like fermion as a dark matter candidate. The stability of the DM is ensured from the extra Z_4 symmetry imposed over the standard model gauge symmetry. The sub-eV light neutrino mass arises through the induced vev of the scalar doublet after the electroweak symmetry breaking. We have shown that the thermalization of right-handed neutrinos can significantly constrain the interaction strength of the right-handed neutrinos (RHNs) with the SM particles. In this model, DM can only be produced through the interaction with right-handed neutrinos and a singet scalar. The presence of this neutrino portal plays a crucial role in the production of DM and we have also studied the correlation between the two sectors. We have studied both thermal as well as non-thermal dark matter and its connection with the Dirac nature of the neutrinos. The model can mostly be constrained by the cosmological upper limit on effective relativistic degrees of freedom ΔN_{eff} which gets enhanced due to the thermalization of the right-handed neutrinos by virtue of their sizeable interactions. The currently allowed parameter space can be probed or even excluded by future experiments such as CMB-S4. The possible ways to avoid this exclusion are also discussed.

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Constraints on Axion like particles-Lepton coupling from Big Bang Nucleosynthesis

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Topic(s): Particle astrophysics and cosmology

Abstract: The BBN occurred when the temperature of the Universe was between 10 keV $<$ T $<$ 1 MeV, and therefore axions-like particles (ALPs) with mass less than a MeV can affect the physics in this era. The axions, due to their coupling with leptons, can be produced via $l^{\pm}\gamma \rightarrow l^{\pm}a$ and $l^{+}l^{-} \rightarrow \gamma a$ processes and have non-negligible abundance during Big Bang Nucleosynthesis (BBN), contributing to effective number of relativistic degrees of freedom ($\Delta \mathrm{N}_{\mathrm{eff}}$). In this talk, I will discuss the implications of the coupling between Axion-Like-Particles (ALPs) and Leptons to cosmology, in particular, the BBN. We will see that the BBN, through the constraint on the $\Delta \mathrm{N}_{\mathrm{eff}}$, provides the most stringent bound on the ALP-electron interaction strength for the mass of axion between 20 keV and 1 MeV. For other values of the mass, the BBN bound complements the stellar-evolution and laboratory bounds.

Latest results of cosmic ray energy spectrum and composition measurements from GRAPES-3 experiment

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Topic(s): Particle astrophysics and cosmology

Abstract: The open questions in cosmic ray physics like their astrophysical origin, acceleration, and propagation in the interstellar medium can be understood by precise measurements of the nuclear composition, and energy spectrum of the primary cosmic rays at the 'knee' and the region beyond it. The GRAPES-3 experiment located at Ooty in India is designed with a densely packed array of 400 plastic scintillator detectors and a large area muon detector [**1-3**]. It measures cosmic rays from several TeV to over 10 PeV that provide a substantial overlap with direct experiments as well as it covers the knee region. The muon multiplicity distribution measured by the large area tracking muon detector associated with the array provides precise measurement of the average nuclear composition of primary cosmic rays. Recently, we have attempted to measure the energy spectrum and composition from sub-TeV to over 10 PeV. The details of this study will be discussed.

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Investigation of muon puzzle with GRAPES-3 experiment

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Topic(s): Particle astrophysics and cosmology

Abstract: The muon excess in cosmic ray data compared to the expectations from Monte Carlo simulations observed by cosmic rays as well as by accelerator experiments such as ALEPH and DELPHI at CERN have remained a puzzle over the past one and half decade [**1-3**]. A hypothesis to understand this issue is the production of blobs of quark-gluon matter with large orbital momentum in nucleus-nucleus interactions [**1**]. While a theoretical investigation is needed, it is necessary to obtain as much as data possible beyond any ambiguity from various experiments, sensitive in different energy ranges of cosmic ray spectrum. The GRAPES-3 experiment located at Ooty, India is sensitive to the observation of cosmic rays over a wide range of energies from 10^{13} eV to 10^{16} eV. The large area muon detector of GRAPES-3 provides a sensitive measurement of muon content in the cosmic ray showers. An investigation of muon puzzle based on the GRAPES-3 data as a function of energy and zenith angle with the results from the Monte Carlo simulation of cosmic ray showers with CORSIKA will be discussed.

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A detailed investigation of thunderstorm events recorded in GRAPES-3 experiment

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Topic(s): Particle astrophysics and cosmology

Abstract: The large area tracking muon telescope of the GRAPES-3 experiment reported the measurement of 1.3 GV electric potential developed in one of the massive thunderclouds recorded on 1 December 2014 by using muon imaging technique [**1**]. The record-breaking Giga-Volt potential is ten times larger than the earlier reported direct measurements by balloon and rocket soundings, which proves ∼90 years old prediction by C.T.R. Wilson. However, the GRAPES-3 measurements rely on precise estimation of change in angular muon flux caused by the energy change due to acceleration of muons during its propagation through charged layers of thunderclouds. The electric potential is estimated by detailed modeling of change in muon flux as a function of applied potential using CORSIKA and in-house Monte Carlo simulation tools. A detailed summary on simulation methods and investigation of 184 thunderstorms recorded by the GRAPES-3 during the period from April 2011 to December 2014 will be discussed.

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Cosmological perturbations in the interacting dark sector: Mapping fields and fluids

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Topic(s): Particle astrophysics and cosmology

Abstract: There is no unique way to describe the dark energy-dark matter interaction, as we have little information about the nature and dynamics of the dark sector. Hence, in many of the phenomenological dark matter fluid interaction models in the literature, the interaction strength Q_ν in the dark sector is introduced by hand. Demanding that the interaction strength Q_ν in the dark sector must have a field theory description, we obtain a unique form of interaction strength. We show the equivalence between the fields and fluids for the $f(R, \chi)$ model where f is an arbitrary, smooth function of R and classical scalar field χ, which represents dark matter. Up to first order in perturbations, we show that the one-to-one mapping between the *classical* field theory description and the phenomenological fluid description of interacting dark energy and dark matter exists *only* for this unique form of interaction. We then classify the interacting dark energy models considered in the literature into two categories based on the field-theoretic description. We introduce a novel autonomous system for the general interacting dark sector. We show that the dark-energy dominated epoch occurs earlier than the non-interacting systems for a specific scalar field potential and a range of coupling strengths.

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Gravitational wave echoes from strange stars for various equations of state

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Topic(s): Particle astrophysics and cosmology

Abstract: The tentative Gravitational Wave Echo (GWE) at a frequency of about $72\,Hz$ has been recently claimed at 4.2σ significance level in the GW170817 event [1]. GWEs can be used as a tool to study the characteristics of ultra-compact stellar objects. Considering the final ultra-compact, post- merger object as a strange star, the GWE frequency can be calculated. However, GWEs are observed for only those compact stellar structures whose compactness lies in between 0.33 and 0.44. Alternatively, GWE can be obtained for those compact stars which feature a photon sphere and compactness not crossing the Buchdahl's limit radius $R_B = 9/4M$. A photon sphere is a surface located at $R = 3M$, R being the radius and M is the total mass of the ultra-compact object. Recently using the simplest MIT Bag model Equation of State (EoS) it has been reported that strange stars can produce GWEs with frequencies of tens of kilohertz [2]. In view of this, for a comparative study, we have calculated the respective echo frequencies associated with strange stars by considering three models of strange star EoSs, viz., MIT bag model, linear and polytropic EoSs [3]. We found that, not being too stiff the polytropic EoS can not emit GWE, whereas the MIT Bag model and the linear EoSs can emit GWEs at a frequency range of about tens of kilohertz. Also, GWE frequency increases with the increase in values of bag constant B and decreases with the increasing values of linear constant b. So a model-dependent nature of GWE frequencies is observed.

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Neutrino emissivity of dense quark matter in presence of magnetic field

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Topic(s): Particle astrophysics and cosmology

Abstract:

The study of the properties of strongly interacting matter in presence of magnetic field have been the subject of intensive research of contemporary interest [1, 2]. One of the phenomenologically important quantity to study concerns the effect of magnetic field on the dominant neutrino emission processes in neutron stars [3–6]. Recently, it has been proposed for non-central heavy ion collisions, depending on the collision energies and impact parameters, the intensity of the magnetic field due to presence of charged particles can be achieved of the order ~ 0.02 GeV^2 at RHIC and ~ 0.3 GeV^2 at LHC, respectively [7, 8].

We study the effect of magnetic field on the emissions of neutrinos and antineutrinos involving the direct URCA processes from a normal, degenerate quark phase in the core of a compact star. It is known that when a new star is born following a supernova explosion, large amount of neutrinos and antineutrinos are emitted immediately from the core involving the direct or the modified URCA processes, resulting in colder core and a hotter crust, thus a temperature gradient is set up. Then the thermal energy gradually flows inward by heat conduction which alternatively might be viewed as the propagation of the cooling waves from the center towards the surface leading to thermalization. One of the subjects of contemporary research in astrophysics has been the estimation of emissive power of neutron star due to such asymmetric neutrino emission [9–11].

In this work we derive the expressions for the neutrino emissivity in presence of weak and strong magnetic fields. The processes we have considered here are the quark direct URCA and its inverse reactions. In our model, when the field strength is below some critical value $B^{(c)}$, such that it is not strong enough to force the electrons to occupy the lowest Landau ground state i.e., quantization effects are negligible. This conditions is for weak field case and we take field strength is upto ~ 0.1 MeV^2 which is smaller than $B^{(c)}$. It has been observed that in presence of weak magnetic field the emissivity slightly suppresses than the non-magnetized case. Furthermore, we have shown when the applied magnetic field strength is more ($\sim 10^4$ MeV^2) than that of quantum critical value, emissivity enhances very rapidly compared to the non-magnetized stars. This suppression or enhancement in the emissivity is expected to influence the cooling of the compact stars.

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Singlet-Doublet Majorana Dark Matter and Neutrino Mass in a minimal Type-I Seesaw Scenario

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Topic(s): Particle astrophysics and cosmology

Abstract: Astrophysical observations like galaxy rotation curves, gravitational lensing, Cosmic Microwave Background (CMB) acoustic fluctuations etc. provide compelling evidences towards the existence of Dark Matter (DM)[1, 2]. In fact, satellite borne experiments like WMAP and PLANCK [3, 4], which measure anisotropies in CMB, established that DM constitutes almost 85% of the total matter content and 26.8% of the total energy budget of the universe. Even after this tantalising hint, we have no answer to the question what DM actually is. Since no Standard Model (SM) particle resembles the properties that a DM particle is expected to have, it is believed that DM is essentially one or more particles beyond the Standard Model (BSM) content. Another equally important puzzle in particle physics is the tiny neutrino mass which has been established by the solar and atmospheric neutrino oscillation experiments.

In a bid to simultaneous explanation of DM and tiny yet non-zero neutrino mass, we propose a minimal extension of the SM by a vector-like fermion doublet and three right handed (RH) singlet neutrinos. The DM arises as a mixture of the neutral component of the fermion doublet and one of the RH neutrinos, both assumed to be odd under an additional $\mathcal{Z}_2$ symmetry. As a result, the DM emerges to be a dominantly Majorana particle and escapes from spin-independent Z-mediated direct search constraints to mark a significant difference from singlet-doublet Dirac DM [5–10]. The other two $\mathcal{Z}_2$ even heavy RH neutrinos give rise masses and mixing of light neutrinos via Type-I Seesaw mechanism. The particle content automatically allows us to extend the model by a gauged $U(1)_{B-L}$ symmetry, which is anomaly free and brings an additional portal between DM and SM particles. Relic density and direct search allowed parameter space for both the cases are investigated through detailed numerical scan, while collider search strategies are also indicated.

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Non-thermal Hot Dark Matter from Inflaton/ Moduli Decay

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Topic(s): Particle astrophysics and cosmology

Abstract: At the end of inflation, it is natural for the early universe to enter an epoch of matter domination due to oscillations of the inflaton about its minimum or vacuum misalignment of moduli fields. Such epochs end with the decay of the associated cold particles leading to an era of matter to radiation transition. Production of non-thermal sterile dark matter particles produced during this transition is considered. Such particles have a characteristic energy distribution - that associated with decays taking place in a matter dominated universe evolving to radiation domination. In case of hot dark matter, the effects on the Cosmic Microwave Background (CMB) and Large Scale Structure (LSS), explicitly taking into account their non-thermal momentum distribution, is being studied. Our results for CMB angular power and linear matter power spectra reveals interesting features - such as an order of magnitude higher values of hot dark matter mass being consistent with the present data. We observe that this is related to the fact that $\Delta N_{\rm eff}$ and the hot DM energy density can be independent of each other unlike the case of thermal or non-resonantly produced sterile hot DM.

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Effect of dark matter in compact realistic neutron stars matter

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Topic(s): Particle astrophysics and cosmology

Abstract:

We study the effects of a dark matter (DM) core on the maximum mass of a neutron star (NS), on in the mass-radius relation based on the relativistic chiral sigma model. We consider the fermionic dark matter inside the neutron star. The dark matter couples to nucleons through Higgs field via effective Yukawa coupling [1]. The neutron star matter is consists of leptons, nucleons and hyperons and ineteraction between them through mean filed field approximation in the chiral sigma model [2]. The core of the neutron star matter is composed with dark matter.

If the dark matter composition is increased then the neutron star gets more compact and hence the size and mass reduce significantly. For example, if there is no dark matter and with dark matter Fermi momenta 0.04 and 0.06 GeV, the maximum masses and radii of neutron star are 2, 1.8 and 1.7 times solar mass and 10, 9.5 and 8.5 km, respectively. The particles ratios, momentum inertia, red-shifts and keplerian rotational frequency will be discussed in the presentation along with LIGO/ virgo upper limit on Lambda.

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Testing statistical isotropy in cosmic microwave background polarization maps

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Topic(s): Particle astrophysics and cosmology

Abstract: The standard cosmological model is based on the postulate that the Universe is homogeneous and isotropic on large distance scales. However, there exist many observations which suggest that this postulate is violated. We review our symmetry-based power tensor methodology [**samal2008**, **samal2009**, **aluri2011**] to test for possible violation of isotropy in the Cosmic Microwave Background data. The angular orientation of each mode is probed by a unique orthonormal frame $e^{\alpha}_{k}(l)$ and rotationally invariant eigenvalues $\Lambda^{\alpha}(l)$. These are obtained by diagonalizing the power tensor A, defined by $A_{ij} = \frac{1}{l(l+1)} \sum_{m.m'} a^{*}_{lm} (J_i J_j)_{mm'} a_{lm'}$, where where J_i are the rotation generator (agnular momentum operator) in representation l. The corresponding eigenvalues contain information about the power associated with each eigenvector. The sum of the three eigenvalues equals the total power, C_l.The orientation of these three orthogonal vectors, as well as the power associated with each vector, contains information about possible violation of statistical isotropy. This information is encoded in two entropy measures, the power-entropy and alignment-entropy.

We apply our symmetry based Power tensor technique to test conformity of PLANCK Polarization maps with statistical isotropy [**rath2018**]. On a wide range of angular scales ($l = 40150$), our preliminary analysis detects many statistically anisotropic multipoles in foreground cleaned full sky PLANCK polarization maps viz., COMMANDER and NILC. We also study the effect of residual foregrounds that may still be present in the Galactic plane using both common UPB77 polarization mask, as well as the individual component separation method specific polarization masks. However, some of the statistically anisotropic modes still persist, albeit significantly in NILC map. We further probed the data for any coherent alignments across multipoles in several bins from the chosen multipole range.

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Investigation of K/π ratio with accelerator and cosmic ray data

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Topic(s): Particle astrophysics and cosmology

Abstract: Cosmic rays (CRs) are high energy charged particles that continuously bombard the earth from space. They cover an extraordinary energy range from 10^8 eV to 10^{20} eV, which is unlikely to be achieved in the near future by man-made accelerators. One of the outstanding problems of CR physics is the muon problem and one of the proposed solutions is the formation of a thermally equilibrated Quark Gluon system as a result of CR interactions in the atmosphere [**1**]. Accelerator experiments like LHC and RHIC have provided clear indication of formation of Quark Gluon Plasma (QGP) at energies, which are far smaller than those achieved by CRs. This motivates us to look into the possibility of QGP formation in CR interactions.

Strangeness is a widely sought after indicator of QGP formation because of the high probability to form strange quarks in a QGP state [**2**]. We look at K/π ratio as an indicator for strangeness enhancement and compare cosmic data with the collider data. CORSIKA is a well known Monte Carlo simulation code used to study the development of Extensive Air Showers (EAS) [**3**]. We use CORSIKA to generate data on EAS and compare the K/π ratio with accelerator results.

Experimentally observed cosmic K/π values [**4**, **5**] are also compared with hadronic and symmetric & asymmetric nucleus-nucleus collisions [**6**, **7**]. Since CRs consist mostly of protons and the atmosphere is rich mainly in Nitrogen and Oxygen we can expect more proton-nucleus type collisions to occur and such a scenario agrees well with the experimental values.

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Simulation of cosmogenic neutron backgrounds for a dark matter search experiment at Jaduguda Underground Science Laboratory

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Topic(s): Particle astrophysics and cosmology; Beyond standard model physics

Abstract: Interaction rate of Dark Matter (DM) with detector material is so low that the detection of DM in a laboratory experiment has been one of the most challenging topics in physics. Interaction strength of DM with detector nuclei is in weak-scale. If we consider a cross-section of 7.2×10^{-6} pb, DM with a mass of 50 GeV/c^2 is expected to give only 11.1 interactions per kg-day in a Cs isotope and 10.3 per kg-day in a I isotope respectively [1]. On the other hand, the interaction rates from backgrounds could be very large. Because of this, the reduction and estimation of backgrounds is highly desirable in a DM search experiment; the sensitivity of a dark matter search largely depends on how well the backgrounds are known. Neutrons in DM search pose an irreducible background as they can easily mimic DM signals.

A dark matter search experiment is proposed to be set up at the Jaduguda Underground Science Laboratory (JUSL) in India. The laboratory will be located inside an existing mine with 555 m (1580 meter water equivalent) of vertical rock overburden. The experiment will be the first phase of Dark matter search at INO [2] (DINO). We present an estimate of cosmogenic neutron backgrounds produced from interation of cosmic muons with rock overburden or shielding at the JUSL site using a Geant4 [3] based simulation. Cosmic muons interacting with rock overburden or shielding materials produce neutrons via the following interactions: (1) interaction with nuclei producing nuclear disintegration, (2) muon capture by nucleus followed by neutron emission, (3) neutron production by hadrons from muon generated showers, and (4) neutron production by gammas from muon generated electromagnetic showers. Neutrons produced from these processes are simulated. The neutron flux estimated at JUSL compares well with experiments [4, 5] at similar underground depth.

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Importance of flavour effects in right handed neutrino induced gravitational leptogenesis

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Topic(s): Beyond standard model physics; Neutrino physics; Particle astrophysics and cosmology

Abstract: Inclusion of quantum effects of the right-handed (RH) neutrinos in the gravitational background within the Type-I seesaw mechanism can cause an asymmetric propagation of lepton and anti-leptons, which induces a curvature and Dirac neutrino Yukawa coupling dependent chemical potential and therefore a lepton asymmetry is generated in equilibrium [1]. Although at high-temperature lepton number violating scattering processes try to maintain a dynamically generated lepton asymmetry in equilibrium, with the decrease of temperature the interactions become weaker, and the asymmetry freezes out [2, 3]. The frozen out asymmetry can act as a pre-existing asymmetry before the standard thermal leptogenesis phase through RH neutrino decays. It is then possible to realize gravitational leptogenesis for a new RH mass spectrum which is not consistent with successful standard leptogenesis from decays. The main obstacle to this gravity-induced lepton asymmetry to successfully reproduce the observed baryon-to-photon ratio is the lepton number violating washout processes at $T_i \sim M_i$ [4, 5]. In a minimal seesaw model having two RH neutrinos [6–9], these washout processes are able to erase any pre-existing asymmetry. We show that when the flavour effects on the washout processes are taken into account [3, 10–15], the mechanism unveils the possibility of successful leptogenesis (gravitational) with a mass spectrum $M_2 \gg 10^9\text{GeV} \gg M_1$. We then briefly examine how, in general, the mechanism can be probed in low energy neutrino experiments [7, 16–18].

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I-Eccentricity-Q relation as the universal relation for rotating magnetized white dwarfs

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Topic(s): Particle astrophysics and cosmology

Abstract: The nature of matter at very high densities inside white dwarfs and neutron stars remains one of the most challenging and exciting fields of theoretical astrophysics. Probing the Equation of State (EoS) of matter inside compact stars through gravitational waves (GWs) have been possible today, thanks to the current and upcoming gravitational wave detectors such as the LIGO, Advanced LIGO, Advanced VIRGO, LISA, KAGRA, Einstein telescope etc. Binary neutron stars are one of the most promising GW sources [1, 2] for constraining the nuclear and quark EoSs . Neutron star binaries can be used to extract information about the EoS by detecting the GWs emitted in the late inspiral during which neutron stars are tidally deformed. Therefore, GWs emitted by neutron star binaries in the late inspiral must incorporate corrections induced by the neutron star internal structure, thereby providing information about the EoS [3, 4]. Unlike black holes, exterior gravitational fields of neutron stars are not determined by their mass, radius, spin angular momentum but also by their higher multipole moments. The extraction of the higher multipole moments from observations might be erroneous if EoS dependent description is neglected. There are numbers of studies carried out recently on slowly rotating neutron stars, quark stars and dark stars, which show the equation of state independent nature in the relations between certain multipole moments of these stars [5, 6]. Therefore, the use of the universality relationships in the subject of GW physics is limited by different conditions like rotation, magnetic field etc.

In the present work we consider the universal relationship of magnetized sub- and super-Chandrasekhar white dwarfs. Recently super-Chandrasekhar mass limit has been derived theoretically in presence of strong magnetic field to complement experimental observations [7, 8]. In the framework of Newtonian physics, we have studied the equilibrium configurations of such magetized white dwarfs by using the relativistic Thomas-Fermi equation of state for magnetized white-dwarfs comprising of four different compositions namely ^{4}He, ^{12}C, ^{16}O and ^{56}Fe. Hartle formalism, for slowly rotating stars, has been employed to obtain the equations of equilibrium. Various physical quantities of uniformly rotating and non-rotating white dwarfs have been calculated within this formalism. Consequently, the universality relationship between I, Q and rotational love number(λ), namely the I-Love-Q relationship, has been investigated for such magnetized white dwarfs. The relationship between I, eccentricity and Q i.e. I-eccentricity-Q relationship has also been derived. Further, we have found that irrespective of the composition, the I-eccentricity-Q relationship is more universal in comparison to I-Love-Q relationship.

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Parity in Planck full-mission CMB temperature maps

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Topic(s): Particle astrophysics and cosmology

Abstract: Isotropy of the universe via the Cosmological principle is one of the fundamental assumptions of modern cosmology. Hence Cosmic Microwave Background (CMB) sky is expected to preserve spatial symmetries. CMB ushered in the precision era in cosmology. Consequently it facilitated tests of this otherwise simplifying assumption of isotropy of cosmos. Multiple studies of CMB data in that direction indicated instances of isotropy violation. Here we search for evidence of a parity preference in the latest full-mission CMB temperature maps from ESA Planck probe. Specifically, we probe (a)symmetry in power between even and odd multipoles of CMB, that corresponds to a particular parity preference under inversion, in Planck 2015 angular power spectrum measurements. We also assess any specific preference for mirror parity (a)symmetry, by analysing the power contained in $l + m = even$ or odd mode combinations.

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Primordial black holes and particle dark matter from early matter domination

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Topic(s): Particle astrophysics and cosmology

Abstract: Primordial black holes (PBH) can be candidates for dark matter, however, the fraction of dark matter comprised of PBH is constrained with several astrophysical and cosmological observations. Theoretical possibility of having large density perturbations required to produce abundant PBH depends on both the primordial inflationary dynamics and details of post-inflationary history. On the other hand, theoretical models of particle dark matter are plenty, which can be constrained with observations at cosmic microwave background surveys, direct detection experiments etc. An early matter dominated epoch can originate in theories with metastable moduli fields, which can dominate post-inflationary energy density and decay to reheat the universe. In this work, we analyse the observational constraints on a multicomponent dark matter comprised of i) PBH, which are produced during such a moduli dominated early matter era and ii) particle dark matter produced during moduli decay.

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Investigation of Ultra Long Short GRBs (ulSGRBs)

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Topic(s): Particle astrophysics and cosmology

Abstract: Gamma-ray bursts (GRBs) are the most luminous(with $E_{\gamma,\mathrm{iso}} \sim 10^{48} - 10^{54}$ erg), short time (lasting from few seconds to few hours) explosions of the universe. These astrophysical objects produce electromagnetic radiations from optical to very high energy gamma rays (>GeV), even ultra high energy particles like cosmic rays, neutrinos are also expected to be produced in these sources. GRBs have been detected by Gamma-ray monitor detectors, BATSE, EGRET & Fermi GBM. GRBs are classified according to their durations of producing gamma-ray (T90). GRBs with T90 $<$ 2 s are called as short gamma ray burst (SGRBs) and with T90 $>$ 2 s are called long gamma ray bursts (LGRBs).

The aim of this project is to investigate possible presence of another class of GRBs, named ultra-long Short GRBs (ulSGRBs), the SGRBs with longer T90. The motivations is the detections of the first gravitations wave associated SGRBs [1], GW170817 / GRB 170817A as the a result of merger with T90 $\sim$ 2.73 s.

The presence of ulSGRBs can be established by searching for statistical significant populations around the time period of 1.5 s to 3.0 s in the durations of GRBs.

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Cosmic Inflation in Minimal $U(1)_{B-L}$ Model: Implications for (Non) Thermal Dark Matter and Leptogenesis

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Topic(s): Beyond standard model physics; Particle astrophysics and cosmology

Abstract: We have studied the possibility of realising cosmic inflation, dark matter (DM), baryon asymmetry of the universe (BAU) and light neutrino masses in non-supersymmetric minimal gauged $B-L$ extension of the standard model with three right handed neutrinos(RHN), which are required to cancel the triangle anomalies. The singlet scalar field responsible for spontaneous breaking of $B-L$ gauge symmetry and generating RHN masses, also plays the role of inflaton by virtue of its non-minimal coupling to gravity. While the lightest right handed neutrino is the DM candidate, being stabilised by an additional Z_2 symmetry, the other two RHNs can give rise to light neutrino masses with vanishing lightest neutrino mass, and also takes part in producing the required lepton asymmetry which gets converted into the observed baryon asymmetry via sphalerons.

Interestingly, by performing a detailed renormalisation group evolution (RGE) improved study of inflationary dynamics, we find that the stability of the inflaton potential and the strict limits on inflationary observables from Planck 2018 and BICEP 2 / Keck Array (BK15) data leads to thermal DM being overproduced due to insufficient annihilations through gauge and scalar portals. This happens due to strict upper limits obtained on gauge and other dimensionless couplings responsible for DM annihilation while assuming the non-minimal coupling to gravity to be of order unity. On the other hand, with very tiny gauge and Yukawa couplings, the non-thermal DM scenario is viable, with or without Z_2 symmetry, although in such a case the $B-L$ gauge sector remains decoupled from the inflationary dynamics, which merges with the usual case of quartic Higgs inflation with non minimal coupling to gravity.. We also show that the reheat temperature predicted by the model prefers non-thermal leptogenesis, which is very much sensitive to the details of inflation, while also being consistent with light neutrino data as well as non-thermal DM scenario.

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Cosmic muon momentum spectra at Madurai

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Abstract: A magnetised detector (mini-ICAL) with 10 layers of $2\,\mathrm{m}\times 2\,\mathrm{m}$ RPCs interspersed with 11 layers of 5.6cm thick soft-iron has been built to study the performance of INO electronics in magnetic field as well as to achieve confidence on other engineering aspects of the ICAL detector and magnet. This detector is operational at IICHEP, Madurai and is collecting data, triggered by muons produced in the cosmic ray showers at the top of the atmosphere due to the interactions of high energetic cosmic rays with the atmosphere. A magnetic field of $\sim 1.4\,\mathrm{T}$ is obtained in the iron by applying 900A of current through the copper coils. The trajectories of the charged particles are fitted to extract the momentum of the muons traversed through the detector. This paper will compare the measured momentum spectra with the Monte-Carlo prediction and the reconstructed spectra is unfolded to eliminate the detector's effects in order to obtain the true momentum spectra of cosmic muons at Madurai.

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A Gibbs ILC Algorithm to Estimate CMB Posterior over Large Angular Scales of the Sky

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Topic(s): Particle astrophysics and cosmology

Abstract: The discovery of Cosmic Microwave Background (CMB) radiation by the COBE satellite mission triggered an enormous amount of research in the field of CMB component separation and parameter estimation in modern Cosmology. Accurate measurement of CMB temperature and polarization anisotropies by subsequent satellite missions provide us with a wealth of knowledge regarding the geometry, composition and the origin of the Universe. The CMB observed by various satellite and balloon based observations contain copious amount of contaminations due to strong foreground emissions in the microwave region, by various astrophysical sources present within and outside our galaxy. Hence it is paramount to recover the underlying CMB signal without introducing any modifications to the signal while minimizing the foreground contaminations present in the observed CMB maps. The lack of complete understanding of the nature of foregrounds involved, makes the foreground removal techniques extremely complicated.

We formalize a new technique to investigate joint posterior density of CMB signal ($\mathbf{S}$) and its theoretical angular power spectrum ($\mathbf{C}_\ell$) given the observed data. To generate samples from the joint distribution we employ the internal-linear-combination (ILC) technique with prior information of Theoretical CMB covariance matrix [1] augmented by a Gibbs sampling technique [2]. We estimate the marginalized densities of $\mathbf{S}$ and $\mathbf{C}_\ell$ using the samples from full-posterior. We implement the method on low resolution CMB maps observed by WMAP and Planck satellite missions, assuming that the detector noise is negligible on large angular scales of the sky. Apart from the best-fit CMB cleaned map and its theoretical angular power spectrum along with their error estimates, using the samples of $\mathbf{C}_\ell$ from all Gibbs chains we estimate the likelihood function $P(\mathbf{C}_\ell|\mathbf{D})$ of any arbitrary $\mathbf{C}_\ell$ given observed CMB maps ($\mathbf{D}$) following Blackwell-Rao estimator. The likelihood function can be seamlessly integrated to the cosmological parameter estimation method. We validate the methodology by performing Monte Carlo simulations that includes realistic foreground models and noise levels consistent with WMAP and Planck observations [3]. Our method has a unique advantage that the posterior density is obtained without any need to explicitly model foreground components. Secondly, the power spectrum results with the error estimates can be directly used for cosmological parameter estimations. Finally, we found that our method is stable even in the presence of realistic levels of residual calibration uncertainties in the observed CMB maps [4]. I will discuss about all these in my talk.

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Dense matter equation of state in strong magnetic field model with density-dependent parameterization

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Topic(s): Particle astrophysics and cosmology

Abstract: The equation of state is one of the most crucial areas of research in regard to neutron star interior configuration. In order to match the observed properties of neutron stars such as maximum mass, cooling, glitch, etc., several configuration considerations have been made. Recent measurements of neutron star mass for several candidates reveals that the maximum possible mass for this class of compact objects is certainly higher than 2 $M_\odot$ [1–4]. Another class of neutron stars, *magnetars* are found to possess surface magnetic fields in the range of $10^{14} - 10^{15}$ G [5, 6]. Existence of stars with high mass brings the possibility of existence of exotic matter at the core region of the objects where matter density will be considerably high. One such possibility is the appearance of heavier baryons (Δ-resonances) [7–9] at high density inside compact objects.

With this possibility, we study the effect of strong magnetic field on the matter composed of nucleons hyperons and Δ isobars under strong magnetic fields within the framework of density-dependent covariant density functional theory model [10]. The functionals are constrained by the Λ, Ξ^- hypernuclei data from various terrestrial experiments. We find that the equation of state stiffens with the inclusion of magnetic fields of magnitudes $B \geq 10^{17}$ G which to some extent increases the maximum mass neutron star compared to non-magnetic case. The effect of magnetic field inclusion is mostly pronounced in case of nucleons and hyperons configuration. Typical oscillations of various matter properties viz. particle populations, Dirac effective mass etc. with density are observed due to the Landau level occupation.

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Detector development, future facilities and experiments, and societal applications (Parallel talks)

Charged hadron identification in Belle II silicon vertex detector

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Topic(s): Detector development, future facilities and experiments

Abstract: Charged hadron identification plays an important role in the physics program of the Belle II experiment at the SuperKEKB asymmetric- energy e^+e^- collider. We have developed a particle identification (PID) framework based on energy loss information in the silicon-strip vertex detector (SVD) for charged pions, kaons, and protons using $D^{*+} \to D^0[\to K^-\pi^+]\pi^+$ and $\Lambda \to p\pi^-$ decay samples. The study is based on 6.1 fb^{-1} data recorded near the Υ(4S) resonance by Belle II and the results are compared with that of a Monte Carlo sample. We have shown that the introduction of additional PID information from the SVD improves the overall PID performance in the low momentum region.

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Handling large data volumes of CMS High Granularity Calorimeter

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Topic(s): Detector development, future facilities and experiments

Abstract: Unprecedented fine transverse and longitudinal segmentations mark the most salient features of the CMS high granularity calorimeter (HGCAL) being built to replace the existing endcap calorimeters in view of the high luminosity LHC (HL-LHC). The HGCAL is a sampling calorimeter based on silicon and scintillator technologies, and is optimized for withstanding high instantaneous luminosity as well as integrated luminosity of 3000/fb over a span of ten years. With the much-increased number of pileup interactions in each event, HGCAL is expected to deliver O(10)Mbit events at an average event rate of 750 kHz. In this talk, we present a general overview of the HGCAL data acquisition system, the challenges foreseen in handling such large data rates, and explain how the input data transceiver links of FPGAs could be configured to optimize its available data transmission bandwidth without any saturation or running empty.

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Study of Radiation Damage in the CMS Hadron Calorimeter using Isolated Muons from 2018 Collision Data

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Topic(s): Detector development, future facilities and experiments

Abstract: Isolated muons from proton-proton collision data, collected by the CMS detector at the LHC, are used to study radiation damage of different towers of the hadron calorimeter of the CMS. All the channels of the barrel calorimeter and endcap calorimeter in 2018 are read using hybrid photo diodes and Silicon photo-multipliers respectively. The data indicate that the barrel towers at larger pseudorapidity ($|\eta|$) show larger degradation in performance at the end of the run period. For endcap towers, the high level of pileup at the highest $|\eta|$ makes it difficult to determine the peak position of the charge distribution and is difficult to make any measurement. To make a measurement in the forward region of the detector, low pile up data collected by the CMS detector in 2018 is analyzed. The peak positions of the most affected towers are estimated with much better precision in these data. It is observed that several low luminosity runs distributed over the year can monitor the level of radiation damage in these most affected towers.

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Heterogeneous Computing with GPUs for trigger decision in CMS experiment at the LHC

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Topic(s): Detector development, future facilities and experiments

Abstract:

Using current technology, the CMS experiment at the LHC can record only 10^3 events per second out of 10^9 events occurring when protons collide at the interaction point [1]. This huge rejection is achieved by diligent selection implemented in a 2-level trigger conditioning [2], Level 1 (L1) and High-Level Trigger (HLT). L1 trigger decision is made analyzing the back-end readout electronic information via custom-made hardware at the primary level. The HLT logic presently runs on a CPU farm and does a complete and fast reconstruction of the event. For the high luminosity LHC operation, the computing for trigger will be based on heterogeneous resources including substantial usage of GPUs to provide accelerations towards the trigger decision.For integration of GPUs to the existing computing ecosystem, a general framework for heterogeneous computing is being developed for the CMS experiment [3].

The GPU offloading, currently under development, has already helped to reduce the CPU usage by 30% in the complete HLT setup. It has enabled global track reconstruction in the innermost subsystem, the pixel tracker, to be performed more economically. Consequently some of the redundancies in the existing reconstruction scheme can be removed. We shall present some of the challenges and overheads in incorporating the GPU accelerators to an existing workflow. This opens up new possibilities in redesigning the existing Iterative tracking in CMS experiment much more efficiently.

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Performance of electrons and photons in run 2 and prospects for run 3 with the CMS detector

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Topic(s): Detector development, future facilities and experiments

Abstract: Electrons and photons are one of the most important signatures not only in precision physics but also in BSM searches. Many aspects of these searches depend on our ability to trigger, reconstruction and identify electrons, positrons, and photons with the CMS detector with excellent efficiency and high resolution. In this talk we present the full process of electron and photon reconstruction in CMS, starting from tracker hits and energy deposits in the electromagnetic calorimeter, the method to achieve the ultimate precision in Run 2 energy measurements, the trigger and identification strategies (based both on cut based approach and on multivariate analysis) to discriminate prompt electrons and photons from background, and the methods to estimate the associated systematic uncertainties. Finally, the performance on benchmark channels will be shown together with prospects for Run 3.

Evolution of LHC computing grid for Run-III and beyond with emphasis on TIFR CMS Tier-II and Indian contribution

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Topic(s): Detector development, future facilities and experiments

Abstract: World-wide LHC Computing Grid (WLCG) has seen continuous evolution since its inception in mid-2000. As the LHC prepares for Run3 and high luminosity operations, the need for agile computing resources have also increased many folds. The WLCG computing community has been preparing for these challenges and over the years, there have been important upgrades in almost all the aspects such as networking, submission infrastructure, storage technologies, Information system, to name a few. As a Tier-II WLCG site for CMS international experimental collaboration, TIFR has been part of these technological evolutions. Taking lead in many areas, TIFR has been contributing in development, testing and deployment in tandem with grid requirements. Here we will present the current status of TIFR Tier-II as well as highlight the key areas of the transformation of WLCG Grid where it has played an active role.

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Performance of CMS High Granularity Calorimeter prototype to positrons in beam test

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Topic(s): Detector development, future facilities and experiments

Abstract:

CMS is building a High Granularity sampling Calorimeter (HGCAL), which will replace the existing endcap calorimeters (electromagnetic and hadronic) as part of the CMS phase-II upgrade to prepare for the High-Luminosity phase of the LHC (HL-LHC), due to start around 2027. The HGCAL includes two compartments: the CE-E and CE-H for measurements of electromagnetic and hadronic showers respectively. The CE-E uses lead, copper and copper-tungsten as absorbers, with silicon sensors as active elements. The CE-H uses stainless steel as absorber and a mixture of silicon and scintillator as active elements, with silicon in the high-radiation regions and scintillator in the lower radiation regions. Beam tests of a 28 layer CE-E prototype and 39-layer CE-H scintillator prototype were performed at CERN's SPS in 2018 and exposed to muon, positron and pion beams. We present results of the CE-E prototype operation and performance with positrons, including energy and position resolution, as well as measurements of basic quantities such as longitudinal and transverse shower shapes. Comparisons are made to a detailed G4-based simulation.

Track-Based Muon System Alignment at CMS

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Topic(s): Detector development, future facilities and experiments

Abstract: The alignment of the CMS muon system is vital to maintaining reliable muon data. Misaligned muon detectors negatively impact the accuracy of recorded muon positions, which in turn affects momentum resolution and the sensitivity of the final physics analyses. To measure the misalignment of muon detectors, the recorded muon tracks are used in a multidimensional fit on the misalignment degrees of freedom. The performance of this track-based alignment algorithm is measured by using muons in Z boson decays and evaluating the alignment's accuracy in reconstructing the mass peak. Chamber alignment accuracies on the order of 100 m are achieved and alignment performance is presented using Run 2 data.

Magnetic field simulations and measurements on mini-ICAL

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Topic(s): Detector development, future facilities and experiments

Abstract:

The magnetic field B in the ICAL detector [1] (max 1.5 Tesla) is necessary for the electric charge identification and momentum reconstruction of muons resulting from ν_μ and anti-ν_μ interactions with iron [2]. One of the goals of the 85-ton mini-ICAL detector is to compare measurements of the magnetic field with 3-D finite element electromagnetic simulations and, if necessary, refine the latter.

The static 3-D simulation was done using MAGNET 7.4.3 software for 3 and 11 layered models of mini ICAL for various coil currents. The 11 layered model simulation uses the actual geometry, while the 3-layered simulation (with iron plates at layers 1, 6 and 11 only) can be performed in a much shorter time and also memory usage will be less therefore we can go for much finer mesh size for better analysis. In both cases layers 1, 6 and 11 have air gaps of about 3-4 mm between the 7 soft iron plate for inserting Hall probes. The other layers have an air gap of 2 mm. The simulations were carried out for coil currents of 600-900 Amps. A comparison of simulated B-field and its uniformity in iron layers for both the models shows agreement within about 5%. The simulation results from MAGNET 7.4.3 will be cross checked using COMSOL MultiPhysics 5 software. Earlier, simulation was done only for top layer (measurement layer) which has gaps of 3-4 mm [3] while, here using 3 and 11 layered models, simulation analysis of other layers (with gap 2 mm for non measurement layers) is also done.

The magnetic field measurements were done using 150 Hall sensors mounted on PCB strips which were inserted in the 3-4 mm gaps in layers 1, 6 and 11. It provided a real time measurement of the B-field. In addition, 5 sets of coils were wounded at suitable locations around the plates in the same layers and the magnetic flux during ramp up or ramp down of the coil current is measured. A comparison of this data vis-a-vis the simulation will be presented.

The sensitivity of the reconstructed muon momentum to the uncertainty in the magnetic field has also been estimated.

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A Simulation Study of Primary Ionization for Different Gas Mixtures using Gas Electron Multiplier

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Topic(s): Detector development, future facilities and experiments

Abstract: The detectors based on Gas Electron Multiplier (GEM) [1] have been widely used in various experiments of nuclear and particle physics. Their ability to detect the radiation has applications in medical field [2] also. The GEM detectors have been shown to possess excellent spatial and time resolution.

We present the simulation studies of a single GEM detector using the alpha and muon sources in different gas mixtures. The Geant4 [3] toolkit is used to estimate the properties of the primary ionization produced in the entire detector volume with Ar- and Ne-based gas mixtures [4]. The response of muon and alpha source in these gas mixtures is found to be different due to the different properties of these gas mixtures. Primary generation, as estimated by Geant4 and Heed [5] have been compared. A comparison of discharge probability while using these different sources and different gas mixtures will also be discussed. For this purpose, we will use a simple model to reflect the amplification within the GEM.

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Development of Front-end Electronics for an SiPM Based Cherenkov Telescope Camera

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Topic(s): Detector development, future facilities and experiments

Abstract: A prototype 64-pixel camera for a 4m class Imaging Atmospheric Cherenkov Telescope is in its final stage of development. The camera is based on 4x4 array of SiPMs as a pixel sensor and would be mounted on the focal plane of the telescope. A vertex element of the TACTIC array at Mt Abu will be used to test the prototype camera. Eventually, the camera would be expanded to 256 pixels.

Compared to a traditional choice of photo-multiplier, SiPM offers certain advantages like higher photon detection efficiency, operation at much lower bias voltage, no known aging effects and therefore posiibility of night observations under moonlit conditions etc. However using SiPM for this application is non-trivial due to on one hand, the factors arising from the charactristic nature of SiPM, operating conditions and set-up for this application. SiPM output pulse has a leading edge rise time of few nanoseconds, however the decay time of the pulse is quite large. It exhibit large terminal capacitance and we need to combine outputs from all 16 sub-pixels in a given pixel to form a pixel signal. The light of night sky background (NSB) contribute towards the noise that get integrated along with the signal. As the camera itself is mounted at focal plane, there are severe constraints on the space and power for the camera electronics. The complexity in the design of the signal conditioning electronics is further increased due to the pressing design objectives like a wide dynamic range of detection and the provision for in-situ calibartion of single photoelectron gain. Essentially then, one needs a wide bandwidth, low noise, low power preamplifier circuit that has to be accommodated within a few millimeters of pcb width available for each pixel.

The other design objective of the pixelated camera is to ensure the uniformity of the pixel gains within a tight tollerence band. A major contribution to a pixel gain comes from the gain of the SiPM itself which is governed by the applied bias voltage in excess of its breakdown voltage. Unfortunately the breakdown voltage changes with temperature and also the applied voltage changes with the a steady level of the current output from the pixel sensor. Both these factors result in the change of SiPM gain. Therefore, the bias supply should keep monitoring the temperature and load current periodically and apply corrections in applied bias voltage to maintain the pixel gain constant within the tolerence limit.

The paper describes the design features of the analog signal processing electronics and the SiPM bias supply to meet the requirements along with the performance evaluation.

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Characterisation of Hamamatsu SiPM for cosmic muon veto detector at IICHEP.

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Topic(s): Detector development, future facilities and experiments

Abstract:

The 50 kt Iron Calorimeter(ICAL) is proposed to be built at the India based Neutrino Observatory (INO). The main objective of ICAL is to study neutrino mass hierarchy. A prototype of ICAL detector i.e. mini-ICAL comprises of ∼85 ton magnet built using 11 layers of 5.6 cm thick iron plates and 10 layers of 2m × 2m glass Resistive Plate Chambers (RPCs), is currently operating at IICHEP Madurai. The plan is to cover the 4m × 4m × 1.1m mini-ICAL with a cosmic muon veto (CMV) detector and to estimate the efficiency of the detector to veto cosmic muons. This will establish proof of principle of the CMV detector for efficient rejection power of cosmic muons at the ICAL. The CMV detector will have three layers of extruded scintillators of size 4.4m × 5cm × 2cm on top and 4.4m × 5cm × 1cm on four sides of the mini-ICAL. The surface area of each layer on top is 4.4m × 4.4m and 4.4m × 2m for each of the four side layers. The photon signal will be collected through wavelength shifting fibers embedded in the extruded scintillators and readout will be taken on both sides using 2mm × 2mm Silicon PhotoMultipliers (SiPMs).

As a part of R&D for the veto system of mini-ICAL, SiPMs were characterized by various techniques available. At first, standalone SiPM characterization was done using SP5601 ultrafast LED driver with external trigger inside a small black box. Photoelectron peaks due to different number of electrons are clearly visible, which were then used to calculate the gain of the SiPM. Gain of the SiPM is calibrated with respect to the bias voltage and thus operating voltage of SiPM was calculated by optimising the gain and intrinsic noise rate. Correlated noise like afterpulse and crosstalk were also studied using noise triggers, where a few photoelectron peaks are observed [1, 2]. This can also be used to calculate the gain of SiPM from the spacing between different peaks. Finally, a radioactive source ^{22}Na was also used to cross check the gain. This paper will present the results of these characterization techniques of SiPM and summarise the results obtained using them.

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CMS L1 Trigger Upgrade Hardware

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Topic(s): Detector development, future facilities and experiments

Abstract: Starting 2027, the Large Hadron Collider machine will deliver proton-on-proton collisions with extremely high instantaneous luminosities, at the level of 5 to 7.5 *1034 /cm2/s. This HL-LHC avatar will boost the scientific capability, but will also pose major technical challenges, including trigger for the experiments. The trigger and data acquisition system of CMS experiment will continue to follow a two-level strategy while increasing the primary, hardware level maximum rate at level-1 to 750 kHz and the latency to 12.5 s. It will allow, for the first time, the inclusion of the tracker and high-granularity calorimeter information at Level-1. The custom-made hardware design for Level-1 trigger is based on the advanced telecommunications architecture to achieve interconnections and also using state-of-the-art FPGAs as well as serial optical links running at speeds up to 25 Gbps. Several types of prototype mezzanine electronic boards, incorporating system-on-chip, to be used in various subsystems of CMS experiment have been fabricated in Indian Industries. I will be presenting the functionality, challenges in fabrication of these boards and the testing methodology using in-house set up in the lab.

Fabrication, interfacing and performance of the High Voltage Bias Supply modules for ICAL RPCs

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Topic(s): Detector development, future facilities and experiments

Abstract: The Iron-CALorimeter detector of the India-based Neutrino Observatory is designed to use 28,800 single gap Resistive Plate Chambers (RPCs) of 2 m×2 m size as its active detector elements [1]. Each RPC requires a variable High Voltage (HV) bias supply of up to 12 kV for generation of the operating electric field in the RPC's gas medium. Considering the large number of supplies needed for the ICAL detector, an indigenously designed, programmable ± 6kV HV supply module, capable of providing 2 μA current per channel, has been developed [2]. A bias supply module will be mounted inside every RPC-Tray along with the RPC for local generation of HV, thus eliminating need for numerous high voltage cables and connectors, avoiding HV distribution problems as well as reducing overall cost of the detector. The control of the module and monitoring of its output voltages and currents are possible using its RS-232 and SPI interface buses. After initial prototyping and thorough testing of the module, a limited number of modules were fabricated and installed in the RPCs of the mini-ICAL detector, which is operational at IICHEP, Madurai.

The modules were interfaced using the SPI interface with the digital front-end (RPCDAQ) [3], which is part of the data acquisition electronics of the mini-ICAL detector. The RPCDAQ sends commands to the HV module to control and monitor the voltage, current and ramp rate. The RPCDAQ has an Ethernet link to the back-end servers and uses TCP/IP for control and data communication. A PyQt4 based software was developed to control and monitor the HV module remotely via the RPCDAQ. This software can control HV of multiple RPCs simultaneously. The software can also display and log the periodic monitoring data of the HV modules, like measured output voltage, current etc.

In this paper, we will discuss the fabrication, interfacing and performance of the HV bias supply in the mini-ICAL detector.

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The Micromegas detectors for ATLAS New Small Wheel upgrade

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Topic(s): Detector development, future facilities and experiments

Abstract: The upgrade of the Large Hadron Collider (LHC) to the High Luminosity LHC (HL-LHC) [1] is required to probe the physics beyond Standard Model. After the ongoing long shutdown (LS2) and eventually after LS3 in 2026, the accelerator luminosity will be increased up to 7 times as compared to designed luminosity value, thus reaching 7 X 10^{34} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$. To meet the requirements of HL-LHC era, the muon system of ATLAS detector needs to be upgraded. Therefore, the existing forward inner part of ATLAS muon spectrometer, the small wheel comprised of Cathode Strip Chambers (CSC), monitored Drift Tubes (MDT) chambers and Thin Gap Chambers (TGC) will be replaced by the New Small Wheel (NSW) [2]. The NSW will be constituted by MicroMegas gaseous detectors (from the MPGD family) and small-strip Thin Gap Chambers (sTGC). Micromegas detectors will be used mainly for tracking and sTGC detectors mainly for triggering purpose. But each type of detectors are able to participate to both systems. Micromegas are ionization-based gaseous detectors made up of parallel plates, having a thin amplification region separated from the conversion region via a thin metallic mesh. For each of the two NSW, 4 Micromegas detectors will be installed in each of the 16 sectors. Four types of Micromegas termed as SM1, SM2, LM1 and LM2 will be installed, each detector with an individual area between 2 and 3 m^2 . At CERN, integration of these detectors is in progress. In this talk, the construction of Micromegas detectors, the methodology to obtain the required and challenging results as well as obtained results will be presented. Specific measurement devices have been developed in the last few years to determine the mechanical metrology quality of Micromegas chambers, also presented here. The validation results using cosmic muons will also be shown.

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Backend Systems for mini-ICAL

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Abstract:

The India-based Neutrino Observatory (INO) is a multi-institutional mega science project supported by DAE and DST, with the aim of experimental neutrino physics besides other topics. The INO Collaboration proposes a large magnetized Iron Calorimeter (ICAL) comprising of about 50KT of magnetized iron and about 30000 RPC's as active elements. The mini-ICAL is a scaled down (1/600) prototype of the proposed ICAL, and it comprises of 20 RPC's with 85T of magnetized iron as absorber.

All the proposed design schemes of data acquisition for the ICAL have been implemented in the mini-ICAL located in the transit campus in Madurai. The mini-ICAL is currently in opertion and has been producing quality data from cosmic rays for past couple of years.

The "BackEnd Systems" refers to the set of servers and applications that receive, record, visualize and act upon various kinds of data that are pushed/pulled from the FrontEnd of the detector. "FrontEnd" refers to the set of all devices that generate data - these include the RPC's that generate physics data, devices/gauges that generate various time-series data and also various active devices that put out informational log lines.

The ICAL design proposal has the RPC's and the Backend systems connected up in the form of a LAN in which the RPC's and the servers at the backend are nodes of the LAN. Standard TCP/IP and UDP protocols have been employed. This scheme has been used and tested successfully in the operation of mini-ICAL.

The Backend systems comprises of entirely off-the-shelf hardware, and a mix of custom designed software and open source software. The operation of mini-ICAL upto now have demonstrated the success of both. Scaling up from the 10-RPC Phase-1 to the 20-RPC Phase-2 was trivially achieved because all systems are designed to be highly scalable. The scalability will be further demonstrated in the upcoming 320 RPC engineering module of ICAL.

The paper will describe in detail the overall networking scheme, the features of the software developed, the unification of various custom build applications under a single command and control center, operational interlocks, design features for various real-time and near-realtime visualization of detector performance metrics and the use of open source software, the data storage scheme.

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The single channel data acquisition (DAQ) module developed for dark matter search experiment using superheated liquid

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Topic(s): Detector development

Abstract: A single channel data acquisition (DAQ) module is developed for the dark matter (DM) search experiment using superheated liquid as target material of detector [1–3]. The DAQ module is tested with a piezoelectric sensor [4, 5]. During testing, the sensor was connected with a superheated emulsion detector (SED) which fabricated at the laboratory. This is a unique radiation detection technique using piezo sensors to detect production of acoustic emission by superheated liquid due to the bubble nucleation when the incoming energetic particle deposits energy in the active region of the detector [6, 7].

The DAQ unit consists of signal conditioning unit and a 32 bit ARM based Programmable System-On-Chip (PSOC) controller. The input signal from piezoelectric sensor is conditioned using a two stage amplifier with a total gain of 3000. A two stage band pass filter with cutoff frequencies from 150 Hz to 80 kHz filters out the noise due to low frequency mechanical vibrations as well as the high frequency EMI. Triggered data which are time-voltage pulses referred as signal are collected and transferred to a PC using serial line and a graphical user interface. This paper describes the basic design of the instrumentation for this experiment and the testing of the DAQ with the prototype of the actual experimental condition.

The initial test run is performed with SED, using R-134a ($C_2H_2F_4$, b. p. – 26.3 ^{0}C) as the superheated liquid and the detector is operated at room temperature (25 ^{0}C $\pm 1^0$C, approx). The gain has been adjusted to 2000 by watching the saturation of the amplitudes of the signals and the emitted power has also been evaluated for the background events which are in the range of about 5-890 Volt^2. A power-spectra (FFT) graph is constructed with the help of approximately 100 collected signals and the frequency lies in the range of about 150 Hz - 100 kHz. The above testing shows that the DAQ is working well for the prototype detector. The developed system will be used with the DM sensitive superheated detector at the underground laboratory.

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Improvement of time and position resolutions of RPC detectors using Time-over-Threshold information

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Topic(s): Detector development, future facilities and experiments

Abstract: The INO-ICAL is a proposed underground particle physics experiment to study the neutrino oscillation parameters. RPC detector has been chosen as the sensitive detector element for ICAL due to its position resolution, time resolution and large area coverage at a very low cost. Improving time and position resolution will enhance the sensitivity of the detector by offering excellent directionality and momentum resolution. A small prototype module called mini-ICAL is built to study the detector performance, engineering challenge in the construction of large scale magnet, magnetic field measurement system and test the ICAL electronics in presence of magnetic field. RPC signals are amplified using charge sensitive NINO front-end boards. The pulse width of the signals are recorded as it crosses the discriminator threshold (called Time over Threshold, ToT) along with strip hit and timing information. The acquired ToT information is used to correct the time information and position for multistrip signals. The paper will discuss the implementation of ToT correction and the resultant improvement in timing and position resolution.

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Mechanical design of Cosmic Muon Veto detector around Mini-ICAL

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Topic(s): Detector development, future facilities and experiments

Abstract: Ambitious 50kt magnetised Iron Calorimeter (ICAL) detector is proposed to be built by the India Based Neutrino observatory (INO) collaboration to study the properties of neutrino oscillations and make precision measurements. A scaled down prototype (1/600th size) of the ICAL magnet – called mini-ICAL, was set up and commissioned in the INO project's transit campus in Madurai to validate different engineering aspects, as well as refine the data acquisition and analysis techniques. Mini-ICAL detector comprises of 11 layers of soft Iron with a footprint of 4m x 4m and weighing about 85 tons. 10 layers of glass Resistive Plate Chambers (RPCs) – 20 in total, sandwiched between iron layers are the active detecting elements. As a feasibility study to improve the physics potential of the ICAL experiment, a Cosmic Muon Veto (CMV) detector was proposed to be built around the mini-ICAL magnet. It will be a three-layered extruded plastic scintillator wall covering all the four sides and top of mini-ICAL. Special care is taken in the design of the CMV detector scheme in order to provide flexibility and accessibility to the existing mini-ICAL detector which are required for its efficient operation. Optimal segmentation and mounting of extruded scintillator strips are ensured in order to achieve the best veto efficiencies by the CMV detector while achieving ease of construction and future maintenance. This paper will describe the overall scheme and architecture of the proposed of the CMV detector as well as structural and installation details of its various components.

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A Study of Avalanche and Streamer Simulation in GEM detector using hydrodynamic approach

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Topic(s): Detector development, future facilities and experiments

Abstract: The Gaseous Electron Multiplier(GEM)[1] detectors have been successfully operated in many high rate experiments such as LHCb[2] at CERN for their high rate handling capability and radiation hardness. These detectors have shown good gain, fast response, excellent spatial and time resolution in these harsh radiation environments. The gas amplification process in presence of high electric field plays a crucial role in the stable operation of the detector. It leads to growth of avalanches and streamers in the gas volume. The growth of avalanches are affected in the presence of space charges in the GEM foils. The streamers form in the gas volume due to uncontrolled avalanche of electrons. It depends on many factors such as applied voltage, hole geometry, gas pressure, field gradients, geometry and curvature of the electrodes, presence of humidity and dielectric surfaces.

We have developed a fast simulation framework of avalanche and streamer using hydrodynamic model of electron and ion transports. The simplified hydrodynamic model suggested by P. Fonte[3] for simulation of charges in GEM detectors has been improved and utilized in the present study. It studies the growth of charged fluids in the modelling volume with time. The present simulation framework is built using the COMSOL Multiphysics[4] platform. The simulation utilizes the primary ionization information from HEED [5] and electron transport parameters from MAGBOLTZ [6]. A two dimensional and two dimensional axissymmetric geometry of GEM are developed to perform the simulation. We will present the results of electric field, electron avalanche, streamer formation, gain, electron transmission, charge sharing and effect of hole asymmetry using the Argon + CO_2(70:30) gas mixture.

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Experimental and numerical studies of charging up in THGEMs

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Topic(s): Detector development, future facilities and experiments

Abstract: The time-dependent variation of avalanche-gain in micro pattern gaseous detectors, especially THGEMs, is one of the challenging problems in high-rate experiments. This has been attributed to the "charging up" and "charging down" processes of insulating materials present in the detectors[1]. These processes largely affect the gain stabilization and thus the optimum operating range. Experimental studies of stabilization of gain with time due to the aforementioned phenomena under various experimental conditions have been given in the presentation. Also, simulation studies of steady-state phenomena have been carried out using Garfield++ and stabilized gain under various electromagnetic configurations is presented[2].

Charging-up is a transient effect, occurring during the initial operation period of the detector; it does not affect its long-term operation. Gain stabilization is found to depend on the thickness of dielectric and ofcourse, on gas mixtures[3] and irradiation rate[1]. Experimentally, different sources have been used apart from different gas mixtures, to study the effect of irradiation rate on charging up and down of the dielectric. Moreover, the effect of dielectric thickness and presence of rim on steady-state gain have been simulated[4][5]. Finally, an attempt has been made to optimize the various electromagnetic parameters to have an optimum working range for THGEMs having steady-state gain. The experimental results are consistent with the studies done earlier and provide an insight into the transients of gain stabilization in THGEMs.

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Lepton identification using Belle II Silicon-strip vertex detector (SVD)

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Topic(s): Detector development, future facilities and experiments

Abstract: Belle II is a next generation flavor factory and a successor of Belle experiment situated in Tsukuba, Japan positioned at the collision point of SuperKEKB accelerator. Beams of electron and positron are collided at a center-of-mass energy of $\Upsilon(4S)$ resonance by the SuperKEKB accelerator, designed to work at a luminosity of $8 \times 10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ about 40 times higher than the luminosity achieved by it's predecessor, the KEKB accelerator. The primary aim of Belle II detector is to search for new physics in the flavor sector at the intensity frontier and improve the precision measurements of Standard Model parameters. Particle identification (PID) serves a crucial role in any flavor physics experiment. Combining the information from a range of sub-detectors we identify the final state particles and study the underlying physics processes happening inside the detector. In Belle II we use a likelihood based PID algorithm combining the information from various sub-detectors to identify a track as a lepton. The lepton identification algorithm relies heavily on the information provided by electromagnetic calorimeter for identifying electron and the K_{L} and muon detector for identifying the muon. The identification of leptons using current algorithm requires the tracks to have a minimum momentum threshold in order to reach these sub-detectors. The minimum momentum constraint results in a poor performance of the algorithm for low momentum tracks which fail to reach these sub-detectors. Using the specific ionisation information from Silicon-strip vertex detector (SVD) of the Belle II experiment, we have improved the lepton identification performance for such low momentum tracks. A study on the performance of the improved PID algorithm will be presented.

The upgrade of the CMS electromagnetic calorimeter: future prospects for precision timing and energy measurements at the High Luminosity LHC

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Topic(s): Detector development, future facilities and experiments

Abstract:

The Compact Muon Solenoid (CMS) electromagnetic calorimeter (ECAL) is made of about 75,000 scintillating lead tungstate crystals arranged in a barrel and two endcaps. The scintillation light is read out by avalanche photodiodes (APDs) in the barrel and vacuum phototriodes in the endcaps. The fast signal from the crystal scintillation, is amplified and sampled at 40 MHz by the on-detector electronics. This enables precise measurements of both the energy and timing of the electromagnetic shower.

The High Luminosity upgrade of the LHC (HL-LHC) at CERN will provide unprecedented instantaneous and integrated luminosities of around 5–7.5 x $10^{3}4$ cm$^{-}2$ s$^{-}1$ and 3000 fb$^{-}1$, respectively. An average of 140–200 collisions per bunch-crossing (pileup) is expected. This poses a major challenge to the CMS event reconstruction. The CMS detector is therefore undergoing an extensive Phase-2 upgrade program to prepare for these demanding/severe conditions. In the barrel region of the CMS ECAL, the lead tungstate crystals will continue to perform well. The APDs will also continue to be operational, with some increase in noise, which will be mitigated by reducing the temperature at which ECAL is operated. However, the entire readout and trigger electronics will need to be replaced to cope with the harsh conditions and increased trigger latency requirements at the HL-LHC. The upgraded detector will have a 25 times higher readout granularity and a sampling rate increase by a factor of 4. The upgraded ECAL will preserve the calorimeter energy resolution, and will significantly improve the time resolution for photons and electrons with energies above 10 GeV. The timing precision is used in important physics measurements and it is speculated that further improved time information could be exploited for pileup mitigation and for the photons assignment to the correct collision vertex. In this talk the status of the ongoing R&D activities for the ECAL upgrade will be presented.

Gain uniformity of a quad-GEM detector

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Topic(s): Detector development, future facilities and experiments

Abstract: Gas Electron Multiplier (GEM) technology [1] based detectors have been used in many experiments (such as PHENIX, ALICE [2, 3]) and will be used in many future experiments (e.g. CBM [4]). A quad-GEM detector consists of four GEM foils with an active area of 10×10 cm^2 [5]. A GEM foil is made up of a polymer (Kapton) foil of thickness 50 µm sandwiched between two copper foils of thickness 5 µm. The drift gap, three transfer gaps and the induction gap of the quad-GEM detector are fixed at 3 mm, 2 mm, 2 mm, 2 mm and 2 mm, respectively. A pre-mixed gas mixture of $Ar{:}CO_2$ in 70:30 volume ratio is used at a flow rate of 3 l/h. The signal is collected from the read-out anode plane consists of 120 number of 9×9 mm^2 copper pads arranged in a 2D array, placed after the fourth GEM foil.

The active area of the detector is irradiated with a Fe^{55} X-ray source and with a mini X-ray generator in a particular fashion, to measure the gain of the detector for a certain voltage between the cathode and the anode. The active area of the detector is divided into 11 rows and 11 columns. We scanned the detector row-wise and column-wise to cover the entire active area of the detector. The gain is calculated from the summed up signal [6, 7].

The present method of scanning the gain uniformity across the detector, explores the possibility of developing a proof of concept method for the fast measurement of gain uniformity and to locate the position of the non-uniform regions (or hot-spots) in the readout pads.

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Overview of the HL-LHC Upgrade for the CMS Level-1 Trigger

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Topic(s): Detector development, future facilities and experiments

Abstract: The High-Luminosity LHC will open an unprecedented window on the weak-scale nature of the universe, providing high-precision measurements of the standard model as well as searches for new physics beyond the standard model. Such precision measurements and searches require information-rich datasets with a statistical power that matches the high-luminosity provided by the Phase-2 upgrade of the LHC. Efficiently collecting those datasets will be a challenging task, given the harsh environment of 200 proton-proton interactions per LHC bunch crossing. For this purpose, CMS is designing an efficient data-processing hardware trigger (Level-1) that will include tracking information and high-granularity calorimeter information. The current conceptual system design is expected to take full advantage of advances in FPGA and link technologies over the coming years, providing a high-performance, low-latency computing platform for large throughput and sophisticated data correlation across diverse sources.

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Cosmic Muon Veto for the mini-ICAL detector at IICHEP, Madurai

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Topic(s): Detector development, future facilities and experiments

Abstract: A 51-kiloton magnetised Iron Calorimeter (ICAL) detector, using Resistive Plate Chambers (RPCs) as active detector elements, aims to study atmospheric neutrinos. It will be the flagship experiment at the India based Neutrino Observatory (INO) which will be housed in a cavern at the end of a 2 km tunnel in a mountain near Pottipuram (Tamil Nadu) [1]. A prototype - 1/600 of the weight of ICAL, called mini-ICAL was installed in the INO transit campus at Madurai, to gain experience in the construction of a large-scale electromagnet, to study the detector performance and to test the ICAL electronics in the presence of a fringe magnetic field. This 4 m × 4 m × 1.1 m detector, with 11-iron layers and 20 RPCs in the central region, is in operation for over 2 years and collecting cosmic muon data. A modest proof-of-principle cosmic muon veto detector of about 1 m × 1 m × 0.3 m dimensions was setup a few years ago, using scintillator paddles [2]. The measured cosmic muon veto efficiency of ∼99.98% and simulation studies of muon induced background events in the ICAL detector surrounded by an efficient veto detector [3] were promising. This led to the idea of constructing a bigger cosmic muon veto around the mini-ICAL detector.

The veto walls around four sides and top of the mini-ICAL will be built using three staggered (by 15mm) layers of extruded scintillator strips (donated by Fermilab) [4]. Strips of 4400-4700 mm in length, 50 mm wide and 10 or 20 mm thick will be used to construct the veto shield that aims at 99.99% efficiency to tag cosmic muons. Double clad WLS fibres ∼1.4 mm in diameter (from Kuraray) are inserted into two extruded fibre holes along the length of the strip and separated by 25 mm to collect the light signal. Hamamatsu SiPM's of 2 mm × 2 mm active area collect the light on both sides of the fibres. About 750 strips, about 7 km of fibre and 3000 SiPM's are going to be deployed. All the five veto walls/stations are designed to be movable from their designed positions, providing service access to the mini-ICAL inside.

Initially coincidence of ORed signals from two out of three layers from either side of a station will be used to generate a trigger signal from that station. Trigger signals from five stations are combined to form the final cosmic ray muon veto trigger signal. On veto trigger, the DAQ system will gather the charge produced by, arrival time and position of muon tracks in the scintillator strips. But the data collected is transferred to the backend only if the main trigger from the mini-ICAL detector is also received in time, or else the data is discarded. Extensive configuration, control and calibration of the detector elements are also planned.

Details of the design and construction of the detector including the electronics, trigger and DAQ systems planned will be briefly presented.

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Aspects of ladder assembly for the Silicon Tracking System of the CBM Experiment at FAIR

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Topic(s): Detector development, future facilities and experiments

Abstract: The Silicon Tracking System (STS) is the central detector for the charged-particle measurement and momentum determination in the future CBM experiment at FAIR. It comprises of about 900 low-mass detector modules, based on double-sided silicon micro-strip sensors distributed on 8 tracking stations. These stations are made from mechanical half units onto which carbon fiber detector ladders are mounted holding the modules. The positioning of modules assembled on the ladder is expected to be in the order of 100 μm [1]. In STS self-triggering read-out electronics is used which is capable of acquiring data at collision rate up to 10 MHz. To read-out, the double-sided microstrip sensors, STS XYTER, a dedicated ASIC is used. In this contribution, different aspects and techniques of assembling a ladder will be discussed. During the assembly of a ladder and module, various glues are used at different steps. These are required for gluing the ASICs to PCB, shielding layers and spacers, applying globtop layers on ASICs and LDOs [2] and glue the FEBs to the L-shaped fins and to test the thermal and mechanical properties of the glues is very important. Along with the assembly techniques, results from the thermal cycling tests will be presented.

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Performance of CMS High Granularity Calorimeter prototype to charged pions in beam test experiments

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Topic(s): Detector development, future facilities and experiments

Abstract: The High-luminosity phase of the LHC (HL-LHC) is planned to start around 2027 and last for at least 10 years, accumulating ten times more integrated luminosity by the end of its lifetime as compared to the LHC. The HL-LHC poses various challenges for the detectors, such as radiation damage and high pileup; especially in the forward region of the detectors. Parts of the current CMS detector will not be able to withstand such harsh conditions and will need to be upgraded or completely replaced. The CMS collaboration will replace the current endcap calorimeter system (Preshower, electromagnetic and hadronic calorimeters) covering the pseudorapidity range $\sim$ 1.5-3.0, with a radiation-tolerant detector with in-built pileup mitigation possibilities: the High Granularity Calorimeter (HGCAL) [1]. The HGCAL will offer unprecedented longitudinal and lateral readout and triggering granularity, which will facilitate efficient particle-flow reconstruction, particle identification and pileup rejection without losing physics performance.

A prototype of the electromagnetic and hadronic section of the HGCAL was built and tested in particle beams at CERN's Super Proton Synchrotron (SPS) in 2018. The prototype was exposed to beams of positrons and charged pions with energies ranging from 20 to 300 GeV in order to evaluate electromagnetic and hadronic shower performance as well as 200 GeV muons for calibration. We present the motivation, construction and calibration of the HGCAL prototype, as well as the measured physics performance for hadronic showers.

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Mitigation of anomalous missing transverse momentum measurements in CMS experiment at the LHC Run2

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Topic(s): Detector development, future facilities and experiments

Abstract: Proton-proton collision events with a signature of high missing transverse momentum are generally interpreted as containing high-momentum neutrinos, or possibly, other invisible particles expected in some of the scenarios of beyond the standard model physics. These could be production of dark matter candidate or the lightest stable particle in R-parity conserving Supersymmetry. Experimentally, detector noise or other issues can also lead to the measurement of anomalously high missing transverse momentum, thus mimicking an interesting physics signature. Various algorithms have been developed in CMS experiment at the LHC to identify and suppress such spurious events. The performance of these *filters* has been studied in events that contain at least one jet with high transverse momentum. This talk will highlight the experiemntal strategies and briefly present the results of this mitigation effort. The data were recorded by the CMS experiment during the LHC Run2.

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Slow pion Tracking Efficiency Studies at Belle II detector

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Topic(s): Detector development, future facilities and experiments

Abstract: Belle II is a second-generation high-luminosity B factory, operating at an asymmetric SuperKEKB accelerator (Tsukuba, Japan), which aims to collect 50 ab^{-1} data (40 times higher than Belle). Track finding efficiency is a vital input to various sources of systematic uncertainties in analyses involving charged particles. Especially, the track finding efficiency of slow pions emitted from D^* decays plays a key role in $R(D^*)$ measurements [**1**]. We aim to measure this efficiency in the low momentum regions and related systematic uncertainty using $B^0 \to D^{*-}\pi^+$ and $B^0 \to D^{*-}\rho^+$ decays at Belle II detector. Owing to its limited phase space, the pion from D^* decay is traditionally referred to as *slow* pion due to the small mass difference between the D^* and the D^0. Silicon Vertex Detector (SVD) is crucial to reconstruct such low-momentum tracks, having a transverse momentum down to 50 MeV. This makes the charged pion tracking efficiency to be an important benchmark for this sub-detector. We report herein a measurement of the track finding efficiency and related systematic uncertainty in the low-momentum region is performed using $B^0 \to D^{*-}\pi^+$ and $B^0 \to D^{*-}\rho^+$ decay modes, wherein the D^* further decays to $D^0\pi^+$ and ρ decays to $\pi^+\pi^0$.

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Simulation studies for electron gun based magnetic probe

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Topic(s): magnetic probe, electron gun, CCD, GEANT4, simulation

Abstract:

Accurate magnetic field measurements are fundamental to the construction, testing, and certification of magnetic systems. Often, in high accuracy systems, the measurement technique and its implementation may involve a considerable effort. One such example of this type of system is undulators for light sources. Advanced undulators require several magnetic measurements at different stages during its construction. Every magnet block, composed of several magnetic poles, must be measured individually and sorted based on the results of the magnetic moment.

The current sensing technologies for the magnetic field mapping, including Nuclear Magnetic Resonance [1], are accurate for the main field but have seen to be unsuitable for field gradient measurements. Another method is the Single Stretched Wire (SSW) [2], which is used for straight geometries and is not generally suited for local magnetic field measurements.

This paper proposes a novel technology that will provide a new level of magnetic measurement capability, along with overlapping range and field accuracy of several existing solutions. This will facilitate faster and simpler verification, construction, testing, and tuning complex magnetic systems such as undulators, wigglers, and magnets. The proposed magnetic probe is based on a very short micro Cathode Ray Tube (mCRT) integrated with an imaging sensor that can be based on gigital image pixelated sensor technology. In this novel idea, the CRT electron gun fires a low energy electron beam into the image sensor, which is mounted perpendicularly to the beam and located at the opposite end of the mCRT tube. Electrostatic deflecting plates continually manipulate the electric field and thus project a pattern onto the imaging sensor.

GEANT4 simulation tool [3] was used to model the components of the probe. The electron source is modeled as a gaussian source with a diameter of 100 μm. In this study, we used an OnSemi MT9M114 CCD sensor [4], which is comprised of a 250 μm thick silicon layer of dimensions 2.46 mm $\times$ 1.85 mm comprising of 1.29 million pixels each of size 1.9 μm $\times$ 1.9 μm.

Custom scoring for a single event for each event has been implemented to record the charge registered in each pixel. This would help us compute the detection efficiency of the CCD, which is defined as the number of pixels excited above the threshold for the number of primaries registered on the silicon sensor layer. Simulations were run by introducing accelerating plates for the electric field and different values of the magnetic field. The centroid deviation from the center of the sensor was used to calibrate the magnetic probe for unknown magnetic fields. The analysis of the difference in the centroid position would also help to figure out the minimum magnetic field that can be measured.

We present results from three different probe orientation and validate the simulation results with measurements.

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Sensitivity of Triple-GEM Detector for background radiation in CMS Experiment

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Topic(s): Detector development, future facilities and experiments

Abstract:

The collision experiments of modern era produce an extreme environment of radiation fields. It becomes quite challenging to operate the detectors in such an environment as the high radiation background complicates the particle identification. The Compact Muon Solenoid (CMS) is a general-purpose particle detector at the Large Hadron Collider (LHC) designed to study a wide range of particles produced in high energy collisions in LHC. The particles produced in collision interact with the beam pipe, shielding and the other detector supporting materials to produce neutrons along with gammas, electrons and positrons. These neutrons and their secondaries produced interact with the surrounding matter acting as a common background radiation field for CMS. The CMS is going to upgrade its forward region with Gas Electron Multiplier (GEM) detectors called as GE1/1. In this study, an estimation of the GE1/1 detector response to these background radiation is presented. The modeling of the flux of background radiation is done using FLUKA framework for the CMS forward region and response of the detector is modeled using the GEANT4 framework. A comparison of the modeled prediction is made with the GEM Slice Test data to validate the technique.

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The exploratory run at 555m deep underground with WIMP sensitive detector

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Topic(s): Future facilities and experiments; Beyond standard model physics

Abstract: Astronomical observations and accurate measurement of cosmic microwave background confirm the existence of dark matter (DM) but the particle nature and it's interaction are remain unknown [1, 2]. A most favorable candidate of DM named as weakly interacting massive particles (WIMPs) are predicted in many theories beyond the standard model that may responsible for the observed relic density [3, 4]. It might be detected directly through the direct detection of DM search experiments which aiming mainly to detect the signal induced by the WIMPs-nucleus elastic scattering. The world leading direct detection experiments are most sensitive in the 30-40 GeV/C^2 mass region. The null results from those experiments create recent interest among the experiments to explore the low mass WIMPs region [5]. The detector to be sensitive to low mass WIMPs requires low energy threshold and the low mass target.

Superheated liquid as target material and as the detector has been used since a long time in the WIMPs search experiment. The threshold energy of the detector can be controlled by operating at a suitable temperature and/or pressure combination [6]. WIMPs search detectors should be free from all kinds of background events or should work with all identified background events. Identification of background induced signals is the primary work in any DM search experiment. Study with $C_2H_2F_4$ (b.p. -26.3 ^{0}C) superheated liquid shows that it is sensitive to low mass WIMP operating at moderate temperature (room) for ^{12}C and ^{19}F nuclei as well as sensitive to mass below 1 GeV/C^2 operating at higher temperature due to presence of ^{1}H nucleus, the lowest mass possible [7].

The first run with $C_2H_2F_4$ superheated droplet detector operating at room temperature (24.3 $\pm$0.5^{0}C) has been performed at 555m deep underground at Jaduguda Underground Science Lab (JUSL), Jaduguda, Jharkhand during Sept, 2019. Superheated detector composed of droplets of superheated liquid of $C_2H_2F_4$ suspended in gel based matrix has been fabricated at SINP lab and carefully transferred to the JUSL for the measurement. Two types of acoustic sensors sensitive in the range of 2 Hz-30 kHz and few kHz-1 MHz were used in the experiments to explore both low and high frequency regions. The acoustic pulses generated during the phase transition were converted to electric signals through the sensors. Similar experiments were carried out at SINP lab with the same two sensors. The results shows that the background count rate at JUSL reduces by a factor of 4 in the low frequency and a factor of 2 at high frequency than that at SINP lab. R & D has been going on to fabricate and characterize the detector for the longer stability and larger mass. Future experiments are expected to be carried out in steps specially aiming for the low mass WIMPs with increased active mass and with a longer run time.

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Development of 256-pixel SiPM based Imaging Camera and Its Status

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Topic(s): Detector development, future facilities and experiments

Abstract: A 256-pixel imaging Camera based on SiPM is being developed for a 4m class cherenkov telescope and would be the first of its kind in India that uses SiPM as a pixel sensor in place of photomultipliers. A 4×4 array of SiPMs of size 13 mm × 13 mm would be used as a pixel sensor. It would be tested on the vertex element of the TACTIC telescopes at Mt Abu, Rajasthan. However, the design specifications for the camera are fixed considering the environmental conditions at the high altitude site of Hanle, Ladakh. The camera covers a field of view of 5° × 5° with a pixel resolution of 0.3° for the TACTIC telescope.

The challenges faced in the camera design are capturing the image of Cherenkov photons arriving at a time spread of few nanoseconds in the presence of a huge night sky background of random photons and dark counts due to large sensor size, sensitivity of sensor gain to temperature, requirement of in-situ single photoelectron gain calibration and pixel pulse profile recording on each event etc.

A modular design approach is adopted for the camera design considering quick development, easy maintenance and scalability. A Pixel Cluster Module (PCM) houses a cluster of 16 pixel sensors in 4×4 array, preamplifier cards and sensor bias cards. Sixteen such PCMs make up the front-end of the camera. Light Concentrator in front of each pixel sensor concentrates light coming from the telescope mirrors on to the pixel sensor. The bias cards control and monitor the bias parameters for all the 16 pixel sensors. The sensor gains are maintained constant independent of temperature variation by tuning their bias voltages in closed loop control. All the 16 PCMs in the camera are daisy chained for bias control and monitoring under Bias Server program running in Raspberry-Pi which in turn is connected over Ethernet to the Control room for supervisory commands and data transfer. Each channel in a preamplifier card processes, shapes and adds pulses from 16 elements in a pixel sensor called sub-pixels to form a pixel signal which is taken to the back-end electronics for further processing.

The back-end electronics crate houses 16 Cluster Digitizer Modules (CDM) for digitizing the pixel pulses and recording the pulse profiles. A CDM also generates pre-triggers based on the neighbouring pixels crossing a set threshold. These pre-triggers are processed in Control and Trigger Module (CTM) to generate a final trigger. On a final trigger, all the CDMs digitize pixel pulse profile sampled @ 1 Giga Samples Per Second (GSPS) and store the event data of camera in the segmented packets in parallel. These packets with common event marker are pushed to a Data Concentrator Module (DCM) over fast serial links. The DCM has 1 Gbps Ethernet links to the control room for event data transfer. The CTM does overall control and monitoring of Camera back-end under supervisory commands from the servers in the control room over an Ethernet link. The entire camera operation including commands, data transfer and monitoring is achieved under program control using high speed Ethernet links between the control room PCs and the camera.

A prototype 64-pixel version of the proposed camera is being developed. Various features of the camera will be presented along with the lab evaluation results of the prototype.

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Large-mass single-electron resolution detector for dark matter and coherent neutrino-nucleus elastic interaction searches

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Topic(s): Detector development, future facilities and experiments; Particle astrophysics and cosmology; Beyond standard model physics

Abstract: As more and more experiments are returning null results for dark matter searches in the traditional WIMP mass range, the search for low mass dark matter (< 1 GeV) candidates is gaining momentum [1]. The main requirement for low mass dark matter searches is sensitivity to very low(eV scale) nuclear recoils with good detector resolution. To reach low recoil energy measurements, phonon-mediated detectors [2] have taken advantage of the Neganov-Trofimov-Luke [3, 4] effect which increases the phonon amplification linearly with voltage up to a threshold voltage. This threshold voltage is limited by the leakage current of the detector. In terms of detector resolution, significant advancements have been made toward developing a single-electron resolution detector. However they have been limited to very small mass of ~ 1 g [5]. Scaling up the detector mass while maintaining the same single-electron resolution is required to improve the sensitivity reach for low mass dark matter searches. We present results from a prototype 100 g Si phonon-mediated detector with a new contact free interface architecture [6] between the Si substrate and the metal electrodes. This architecture helps delay the onset of leakage current and achieve single-electron resolution making it a good detector candidate for low mass dark matter searches. In addition, the linearity of the phonon signal has been observed up to 240 V, a large improvement over 70 V reported for previous such detectors. This detector is currently being used in a reactor based coherent elastic neutrino nucleus scattering (CEνNS) [7] experiment called MINER [8] which has similar detector needs. The technology presented here thus offers a solution for CEνNS measurements as well.

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Formal theory
(Parallel talks)

Crossing Symmetric Dispersion Relations in QFTs and CFT Mellin amplitudes

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Topic(s): Formal theory

Abstract: In quantum field theories, for 2-2 scattering, the usual fixed t dispersion relation exhibits only two channel symmetry. In this paper [1], we consider crossing symmetric dispersion relation, reviving certain old ideas in the 1970's [2]. Rather than the fixed t dispersion relation, this needs a dispersion relation in a different variable z which is related to the Mandelstam invariants s, t, u via a parametric cubic relation making the crossing symmetry in the complex z plane a geometric rotation by $2\pi/3$. Together with the parameter a in the cubic relation, we then consider fixed a dispersion relation which makes the 3 channel crossing symmetry in the s, t, u variables completely manifest. We derive non-perturbative sum rules from this dispersion relation and examine their validity. We apply this technique in Mellin space CFT correlator [3] which leads us to derive non-perturbative sum rules and we examine their validity

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Compactified Conformal Field Theories in Symplectic Manifolds

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Topic(s): Formal theory

Abstract: Exploring the concept of the extended Galilei group $\mathcal{G}$, representations for the symplectic field theory in the manifold of $\mathcal{G}$, written in the light-cone of a five-dimensional de Sitter space-time, has been derived associated with the method of the Wigner function. A Hilbert space is constructed endowed with a symplectic structure, and used as a representation space for the Lie algebra of $\mathcal{G}$. This representation gives rise to the spin-zero Schrödinger (Klein-Gordon-like) equation for the wave functions in phase-space, such that the dependent variables have the position and linear momentum contents. This is a particular example of a conformal theory, such that the wave functions are associated with the Wigner function through the Moyal product.

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Relative entropy in scattering and the S-matrix bootstrap

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Topic(s): Formal theory

Abstract: We consider entanglement measures in 2-2 scattering in quantum field theories, focusing on relative entropy which distinguishes two different density matrices. In χPT, relative entropy close to threshold has simple expressions in terms of ratios of scattering lengths. Definite sign properties are found for the relative entropy which are over and above the usual positivity of relative entropy in certain cases. We then turn to the recent numerical investigations of the S-matrix bootstrap in the context of pion scattering. By imposing these sign constraints and the ρ resonance, we find restrictions on the allowed S-matrices. By performing hypothesis testing using relative entropy, we isolate two sets of S-matrices living on the boundary which give scattering lengths comparable to experiments but one of which is far from the 1-loop χPT Adler zeros. We perform a preliminary analysis to constrain the allowed space further, using ideas involving positivity inside the extended Mandelstam region, and elastic unitarity.

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Analyticity of Off-shell Green's Functions in Superstring Field Theory

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Topic(s): Formal theory

Abstract: In [1] we have considered the off-shell momentum space Green's functions in closed superstring field theory. Earlier, in [2] the off-shell Green's functions — after explicitly removing contributions of massless states — had been shown to be analytic on a domain (LES domain) in complex external momenta variables. We have extended the LES domain further to a larger domain within the primitive domain (where the analyticity of off-shell Green's functions in local QFTs without massless states is a well-known result). The LES domain can be extended up to the union of certain convex tubes (i.e. primitive tubes) using Bochner's tube theorem and the fact that under complex Lorentz transformations the off-shell Green's functions retain their analyticity property. Up to the four-point function, we have obtained such tubes analytically, e.g. for the four-point function all the 32 possible primitive tubes are obtained. For the five-point function, out of 370 primitive tubes we are able to obtain 350 of them fully. For each of the remaining 20 tubes, it is difficult to show analytically that the application of Bochner's theorem yields the full tube. And this feature occurs for higher point functions as well.

Consequently, the analyticity properties of the infrared safe part of the S-matrix (for scattering involving a total of four or less number of external states) in superstring theory extend to all those of a standard local QFT.

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Effects of oscillating spacetime metric background on a complex scalar field and formation of topological vortices

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Topic(s): Formal theory

Abstract: In Bose-Einstein condensate of ultracold atoms, the generation of excitation and quantum turbulence (formation of tangled network of vortices) with oscillating trapping potential has been studied; ultimately, the condensate is destroyed completely. A similar kind of situation could arise in neutron star superfluidity during binary neutron star mergers. The spacetime oscillations of star metric during merger generate time dependent tidal deformations of neutron stars, which could couple to the condensate (a complex scalar field) and generate excitation in it. Motivated by this, we have studied the time evolution of a complex scalar field in the symmetry broken phase in presence of oscillating spacetime metric background. In our (2+1)-dimensional simulations, we have shown that the spacetime oscillations can excite an initial field configuration, which ultimately leads to the formation of topological vortices in the system. At late times, field configuration achieves a disordered state. A detailed study of momentum and frequency modes of the field reveals that these field excitation are driven by the phenomena of parametric resonance. For a suitable choice of parameters of the simulation, we have observed a persistent lattice structure of vortex-antivortex pairs. We also discuss the application of this study in the generation of field excitation in fuzzy dark matter near a strong gravitational wave source.

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Generalized uncertainty principle in resonant detectors of gravitational waves

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Topic(s): Formal theory

Abstract: With the direct detection of gravitational waves by advanced LIGO detector, a new "window" to quantum gravity phenomenology has been opened. At present, these detectors achieve the sensitivity to detect the length variation (δL), $\mathcal{O} \approx 10^{-17} - 10^{-21}$ meter. Recently a more stringent upperbound on the dimensionless parameter β_0, bearing the effect of generalized uncertainty principle has been given which corresponds to the intermediate length scale $l_{im} = \sqrt{\beta_0} l_{pl} \sim 10^{-23} m$. Hence the flavour of the generalized uncertainty principle can be realised by observing the response of the vibrations of phonon modes in such resonant detectors in the near future. In this paper, therefore, we calculate the resonant frequencies and transition rates induced by the incoming gravitational waves on these detectors in the generalized uncertainty principle framework. It is observed that the effects of the generalized uncertainty principle bears its signature in both the time independent and dependent part of the gravitational wave-harmonic oscillator Hamiltonian. Here we have discussed about the recent day sensitivity of these resonant detectors in short. We also make an upper bound estimate of the GUP parameter. In this paper, we have made an estimate of the GUP parameter β_0 which has led to an upper bound $\beta_0 < 10^{28}$. This is a much stronger bound than that obtained in recent literature, which is $\beta_0 < 10^{33}$.

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Cosmology of Bianchi type-I metric using renormalization group approach for quantum gravity

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Topic(s): Formal theory

Abstract: We study the anisotropic Bianchi type-I cosmological model at late times, taking into account quantum gravitational corrections in the formalism of the exact renormalization group flow of the effective average action for gravity. The cosmological evolution equations are derived by including the scale dependence of Newton's constant G and cosmological constant Λ. We have considered the solutions of the flow equations for G and Λ at next to leading order in the infrared cutoff scale. Using these scale dependent G and Λ in Einstein equations for the Bianchi-I model, we obtain the scale factors in different directions. It is shown that the scale factors eventually evolve into FLRW universe for known matter like radiation. However, for dust and stiff matter we find that the universe need not evolve to the FLRW cosmology in general, but can also show Kasner type behaviour.

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Formation of marginally trapped surface in gravitational collapse

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Topic(s): Formal theory

Abstract: In this article we show how spherically symmetric marginally trapped surfaces form during the gravitational collapse of dust and viscous fluids. By a combination of analytical and numerical techniques, we study the formation and time evolution of collapsing shells, spherically symmetric marginally trapped tubes, as well as the event horizon. It is found that the nature of these marginally trapped surfaces depend on the different density profiles of matter and it changes as we change the energy-momentum tensor. These studies reveal that depending on the mass function and the velocity profile, there can be situations where these marginally trapped surfaces becomes dynamical horizons, timelike tubes, or isolated horizons [1].

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Neutrino physics
(Parallel talks)

A new approach to probe neutrino non-standard interactions in atmospheric neutrino experiments

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Topic(s): Neutrino physics

Abstract: We propose a new approach to explore the neutral current non-standard neutrino interactions (NSI's) in atmospheric neutrino experiments using oscillation dip and valley [1]. We consider the flavor-changing NSI parameter $\varepsilon_{\mu\tau}$, which affects ν_μ to ν_τ transitions the most in these experiments. In the presence of non-zero $\varepsilon_{\mu\tau}$, we show that the oscillation dips in L/E distributions of the up/down event ratio of reconstructed μ^- and μ^+ get shifted in opposite directions. The charge identification capability of ICAL enables us to introduce a new variable Δd representing the difference of dip location in μ^- and μ^+. We demonstrate that Δd is sensitive to the magnitude as well as sign of $\varepsilon_{\mu\tau}$, and is independent of the value of Δm^2_{32}. We also show that the oscillation valley in the $(E, \cos\theta)$ plane bends in the presence of NSI, its curvature having opposite sign for μ^- and μ^+. We further propose, for the first time, the identification of NSI with the curvature of oscillation valley in the reconstructed $(E_\mu, \cos\theta_\mu)$ plane, feasible for detectors like ICAL having excellent muon energy and direction resolutions. We show how the measurement of contrast in the curvatures in μ^- and μ^+ can be used to estimate $\varepsilon_{\mu\tau}$. Incorporating the statistical errors using 100 independent sets of simulated data, we show that $|\varepsilon_{\mu\tau}|$ may be constrained in the range [-0.02, +0.02] at 90% C.L. with 500 kt·yr of ICAL data. Our method would provide a direct and robust measurement of $\varepsilon_{\mu\tau}$ in the multi-GeV energy range, complimentary to that of SuperK at low energies and IceCube at very high energies.

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nEXO studies on neutrinoless double beta of ^{136}Xe

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Topic(s): Neutrino physics

Abstract: The observation of hypothetical neutinoless double beta decay will verify lepton number violation and Majorana nature of neutrino. The characteristic experimental signature is a peak at Q-value of the decay. The experimental studies on $0\nu\beta\beta$ demands large mass of source with excellent energy resolution in a radio-pure atmosphere with large exposure time [1]. The proposed next generation experiments are tonne scale in mass with enhanced detector performance. The salient features of these global experiments with emphasis on next generation of Enriched Xenon Observatory (nEXO) will be presented.

The nEXO is a proposed single phase time projection chamber with 5 tonne of liquid xenon (enriched $\sim$ 90% in ^{136}Xe) to study neutinoless double beta decay in ^{136}Xe with ionization and scintillation read out. The target half-life sensitivity of nEXO is $\sim 10^{28}$ years [2, 3]. The nEXO design is rooted to that of it's predecessor, EXO -200 [4]. EXO-200 achieved 1.23% energy resolution at Q-value by exploring the anti-correlation between ionization and scintillation signal [4]. The avalanche photon detectors and wire chamber were respectively used for photon and charge detection.

The charge collection in nEXO is achieved at the top of the cylindrical time projection chamber, with the primary design calling for silica "tiles" [5] patterned with crossed metallic strips. The VUV sensitive silicon photo-multipliers [6] installed behind the field cage and all along the barrel of the time projection chamber facilitate the photon detection. The limited information available on reflective properties of materials (including SiPMs) in ultraviolet region complicates the optimization of light collection in nEXO. The angular resolved reflectivity and photon detection efficiency of Hamamatsu SiPMs in liquid xenon was observed to decrease with the increase of incident angle [7]. These improvements are aimed towards enhancing energy resolution to 1.0% at Q-value and effective event reconstruction.

The event reconstruction towards discriminating signals (single site) and background (multi-site) events, the detector's monolithic nature along with radioactive background control program (to measure, control, and mitigate sources of background due to radioactivity coming from primordial U/Th, radon, cosmogenic activation products, and surface contamination) help towards achieving the desired sensitivity and will further be discussed.

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Effect of second class currents in $\nu_l(\bar{\nu}_l) - N$ scattering

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Topic(s): Standard model physics; Neutrino physics

Abstract: An enhanced value of the axial dipole mass M_A has been discussed in the literature to explain the experimental data on the charged current quasielastic scattering of neutrinos on the nuclear targets by MiniBooNE, K2K, T2K, NOvA, MINOS, MINERvA, etc., collaborations [1]. Recently, we have shown that the higher cross section can be obtained by taking $M_A = 1.026$ GeV (which is the world average value) and the non-zero value of the second class currents [2]. In this work, we have extended our study to include the charged current quasielastic interactions induced by $\nu_\tau(\bar{\nu}_\tau)$.

The effect of the second class currents with and without time reversal (T) invariance has been studied in the quasielastic production of nucleons induced by neutrinos and antineutrinos:

$$\begin{array}{rcll} \nu_l(k) + n(p) & \longrightarrow & l^-(k') + p(p'); & \qquad l = \mu,\ \tau \\ \bar{\nu}_l(k) + p(p) & \longrightarrow & l^+(k') + n(p'), & \end{array}$$

where the quantities in the parenthesis represent the four momenta of the corresponding particles.

The polarization components of the final nucleons and leptons produced in the (anti)neutrino-nucleon interactions provide important information about the nucleon vector and axial vector form factors *viz.* the axial dipole mass, presence of the second class currents with and without T invariance and the pseudoscalar form factor independent of the total and differential cross sections [2, 3]. The longitudinal and perpendicular components of polarization lies in the plane while the transverse component of polarization lies out of the reaction plane and is forbidden if T invariance is assumed. The measurement of the transverse component of polarization also gives information about the second class currents which are forbidden by G and T invariance. Such a measurement will, thus, provide an opportunity to study the underlying physics of T violation in weak interactions. The weak vector and axial vector form factors are determined using the symmetries of the weak hadronic currents like T invariance and G invariance, while assuming the hypotheses of conserved vector current (CVC) and partially conserved axial vector current (PCAC). The weak vector form factors are determined in terms of the electromagnetic form factors of the nucleons, which in turn, are parameterized in terms of the Sachs' electric and magnetic form factors for which various parameterizations are available in the literature [2, 3]. For the axial vector and second class current (weak electric) form factors, dipole parameterizations have been used [2]. Using PCAC, the pseudoscalar form factor has been determined in terms of the axial vector form factor and Goldberger-Treiman relation; as well as using the modified PCAC relation.

The numerical results will be presented for the total scattering cross section (σ) as well as for the longitudinal, perpendicular and transverse components of the polarization of the outgoing nucleon and lepton, with and without T invariance. The results will also be discussed for the lepton mass effect on the total cross section as well as on the polarization observables.

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$\nu_\tau/\bar{\nu}_\tau -^{40} Ar$ DIS cross sections with perturbative and nonperturbative effects

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Topic(s): Neutrino physics

Abstract: Among the three Standard Model neutrinos viz. ν_e, ν_μ and ν_τ, we know least about ν_τ. It has been realized that to test the Standard Model predictions and check the validity of the Lepton Universality hypothesis, the interaction cross sections for all the three flavors of neutrinos should be known to high accuracy. Furthermore, ν_τ interaction studies are also required to better determine the third neutrino weak eigenstate to have precise understanding of neutrino oscillation parameters besides the intrinsic interest to better explore ν_τ physics. The scattering cross section for $\nu_\tau/\bar{\nu}_\tau - Nucleon(N)$ have large uncertainties as compared to $\nu_e/\bar{\nu}_e - N$ and $\nu_\mu/\bar{\nu}_\mu - N$ cross sections. Several theoretical studies for $\nu_\tau/\bar{\nu}_\tau - N$ deep inelastic scattering (DIS) calculations have been performed like the works of Kretzer and Reno [1], Jeong and Reno [2], Hagiwara et al. [3], Paschos and Yu [4] and it is observed that these studies have large variations in the cross sections among themselves. These nucleonic cross sections are also used as an input in the evaluation of $\nu_\tau/\bar{\nu}_\tau -$ nucleus(A) cross sections, where nuclear medium effects become important. Hence, it is strongly required to determine the $\nu_\tau/\bar{\nu}_\tau - N$ scattering cross sections with better precision and accuracy so that the translated uncertainties at the nuclear level would be reduced. Several experiments have been proposed such as SHiP, DsTau, DUNE and T2HK to study the $\nu_\tau/\bar{\nu}_\tau$ physics as one of their goals with medium and heavy nuclear targets like oxygen, argon and lead. While there is no theoretical study at all of the nuclear medium effects in $\nu_\tau/\bar{\nu}_\tau - A$ scattering in the DIS channel. Keeping this in mind, we have theoretically studied the $\nu_\tau/\bar{\nu}_\tau -^{40} Ar$ DIS process in the energy region relevant to DUNE experiment which is planned to be performed using LArTPC(Liquid Argon Time Projection Chamber). In this work, we have studied the modifications in the nuclear structure functions due to the presence of medium effects such as Fermi motion, binding energy and nucleon correlations by taking into account the QCD corrections such as perturbative evolution of parton densities at next-to-the leading order and nonperturbative effects of kinematic and dynamic higher twist corrections at the free nucleon level. The above mentioned nuclear effects are incorporated through the use of spectral function of the nucleon in the nuclear medium. The effect of mesonic contribution as well as shadowing and antishadowing corrections have also been included. Furthermore, we have discussed the effects of center of mass energy (W) cut, massive charm and the lepton mass on $\nu_\tau/\bar{\nu}_\tau -^{40} Ar$ scattering cross sections. We have also compared the present theoretical results with our earlier calculations for $\nu_\mu/\bar{\nu}_\mu$ induced DIS process [5] in order to understand the lepton mass effect as well as the contribution from nuclear structure functions viz. $F_{4A}(x, Q^2)$ and $F_{5A}(x, Q^2)$ which are negligible in the massless lepton limit. This study will be helpful for the understanding of ArgoNEUT and DUNE experimental results. Furthermore, our study for the less explored ν_τ induced DIS cross-sections will be important for the development of a better theoretical understanding of τ lepton production events rate and their contribution in the determination of neutrino oscillation parameters.

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Coherent pion production in Neutrino (antineutrino)-Nucleus interaction

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Topic(s): Neutrino physics

Abstract: We present a study for the coherent pion production in neutrino-nucleus scatteing in the resonance region using the formalism based on partially conserved axial current (PCAC) theorem which relates the neutrino-nucleus cross section to the pion-nucleus elastic cross section. The pion-nucleus elastic cross section is calculated using the Glauber model in terms of the pion-nucleon cross sections obtained by parametrizing the experimental data. In the coherent scattering process, the nucleus interacts as a whole with the neutrino and remains in the same quantum state as it was initially before the interaction. It happens when the four-momentum transfer |t| to the nucleus remains small. The characteristic signature of this scattering process is a sharp peak in the low |t| region. We calculate the differential and integrated cross sections for neutral and charged current coherent pion production in neutrino nucleus scattering for materials of different Z-value (used in different experiments) like Carbon, Hydrocarbon, Iron and Lead etc. The nuclear density function for materials of low Z-value like Carbon is taken as the harmonic oscillator type while for high Z-value is taken as two parameter Fermi form. The results of integrated cross-section (for different energies and nucleus) calculations are compared with the measured data of MINERvA, Aachen-Padova, Gargamelle, CHARM, SKAT, 15' BC, NOMAD, SciBooNE and MINOS.

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Simulation study of electron energy resolution and reconstruction with thinner iron plates by using plastic scintillators in ICAL

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Topic(s): Neutrino physics

Abstract:

The proposed Iron calorimeter (ICAL) is a 51 K ton detector at the India based Neutrino Observatory (INO) which is magnetized with magnetic field of 1.3 T and is placed inside a cavern to study atmospheric neutrino and anti neutrinos. In ICAL, 56 mm thick iron plates are used as the interaction material with a 40 mm gaps in which the active detectors, the RPCs, are placed. This makes ICAL sensitive to muons with energy in the range 1-15 GeV, that will be produced in charged current interactions of atmospheric muon neutrinos and anti neutrinos with iron.

It has been shown that sub-GeV electron neutrino (and anti-neutrino) charged current events are sensitive to the CP phase, δ_{CP} [2], independent of the neutrino mass hierarchy. In order to increase the sensitivity to electrons in such events, we present the study of electron energy resolution (in sub GeV range) with thinner iron plates of 18 mm and a reduced air gap of 12 mm for an active detector (such as plastic scintillator). Such a detector will also be able to study potential supernova events. As a prelude to this study, ICAL simulation is done with iron thickness 25 mm and gap 40 mm for electron neutrinos by varying the number of iron and RPC layers using Monte Carlo and NUANCE neutrino events generators.

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Impact of high energy beam tunes on the sensitivities to the standard unknowns at DUNE

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Abstract: Even though neutrino oscillations have been conclusively established, there are a few unanswered questions pertaining to leptonic Charge Parity violation (CPV), mass hierarchy (MH) and θ_{23} octant degeneracy. Addressing these questions is of paramount importance at the current and future neutrino experiments including the Deep Underground Neutrino Experiment (DUNE) which has a baseline of 1300 km. In the standard mode, DUNE is expected to run with a *low energy* (LE) tuned beam which peaks around the first oscillation maximum ($2 - 3$ GeV) (and then sharply falls off as we go to higher energies). However, the wide band nature of the beam available at long baseline neutrino facility (LBNF) allows for the flexibility in utilizing beam tunes that are well-suited at higher energies as well. In this work, we utilize a beam that provides high statistics at higher energies which is referred to as the *medium energy* (ME) beam. This opens up the possibility of exploring not only the usual oscillation channels but also the $\nu_\mu \to \nu_\tau$ oscillation channel which was otherwise not accessible. Our goal is to find an optimal combination of beam tune and runtime (with the total runtime held fixed) distributed in neutrino and antineutrino mode that leads to an improvement in the sensitivities of these parameters at DUNE. In our analysis, we incorporate all the three channels ($\nu_\mu \to \nu_e, \nu_\mu \to \nu_\mu, \nu_\mu \to \nu_\tau$) and develop an understanding of their relative contributions in sensitivities at the level of $\Delta\chi^2$. Finally, we obtain the preferred combination of runtime using both the beam tunes as well as neutrino and antineutrino mode that lead to enhanced sensitivity to the current unknowns in neutrino oscillation physics *i.e.*, CPV, MH and θ_{23} octant.

For details see arXiv:2009.05061.

Hierarchy Sensitivity with Combined Standard and Rock Muons in ICAL at India-based Neutrino Observatory

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Topic(s): Neutrino physics

Abstract:

The neutrino mass ordering [1] of the third mass eigen state vis a vis the first remains one of the undetermined parameters of neutrino physics. The proposed magnetized Iron CALorimeter detector (ICAL) at the India-based Neutrino Observatory (INO) [2] has a good sensitivity to this mass ordering which it achieves by its capacity to distinguish neutrino and anti-neutrino induced events through its charge identification capability. The charged current (CC) interactions of atmospheric muon neutrinos with the ICAL detector will produce muons [3] and hadrons [4]. The atmospheric muon neutrinos can also interact with the rock material surrounding the detector and produce muons and hadrons in corresponding CC interactions with the rock. While the hadrons get absorbed in the rock, some of these muons will reach the detector and get detected as well. These "rock muons" [5] lose energy due to traversing the rock and hence these "rock events" correspond to higher energy neutrinos than the "standard muons" [6] which are directly observed in the detector. Both arise from the same (atmopsheric) source and via the same interactions with matter, but probe different energy ranges of the oscillated neutrino spectrum. It is therefore interesting to combined these events and perform a study for the sensitivity of ICAL to the neutrino mass ordering. We show that the combined sensitivity exceeds the sum of the two sensitivities by comparing the $\Delta\chi^2$ for the two cases. We discuss their significance for INO.

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Fully constrained mass matrix: Can symmetries alone determine the flavon vacuum alignments?[1]

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Topic(s): Neutrino physics

Abstract: Using the irreducible triplet of S_4 group as an example, we show[1] that flavon alignments fully defined by the residual symmetries under S_4 form unique orbits. On the other hand, alignments obtained by extremizing flavon potentials may not always be unique; i.e., by carefully adjusting the parameters in the potential we may obtain almost any arbitrary vacuum alignment having no residual symmetries. We argue that constructing such arbitrary potentials goes against the spirit of using discrete symmetries to explain the flavor structure. Yet, to obtain phenomenologically viable models, we may have to resort to using a vacuum alignments having no apparent residual symmetry.

It is in this context that we introduce a new framework in which the flavor group is obtained as the direct product, $G_f = G_r \times G_x$ where the flavons transform under both G_r and G_x while the fermions transform only under G_r. By coupling together several flavons that transform under $G_r \times G_x$, we obtain an effective irreducible multiplet that transforms only under G_r. We define the alignments of the constituent flavons in terms of the residual symmetries under $G_r \times G_x$. As a result we uniquely obtain the alignment of the effective G_r multiplet as well, even though this multiplet may not possess any residual symmetry under G_r. We argue that models constructed in this framework can lead to interesting predictions in flavor physics, for example[2].

It was recently shown[3] that a fully constrained complex-symmetric mass matrix can be conveniently mapped into a sextet of $\Sigma(72 \times 3)$. With the help of such a sextet, we constructed a model resulting in trimaximal mixing[4] with $\delta_{CP} = \pm\frac{\pi}{2}$. We reconstruct this model in the $G_r \times G_x$-framework. Besides $\Sigma(72\times3)$, we introduce a flavor group X_{24} so that the vacuum alignment of the $\Sigma(72\times3)$-sextet is determined by the symmetries of $\Sigma(72 \times 3)$ as well as X_{24}. We note that a similar framework was studied in[5–7] to decouple different multiplets in flavor models. This can find application in models such as [8, 9] where the decoupling of different sectors is assumed.

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Discriminating Type-II, Inverse and Linear seesaw mechanisms within A_4 Flavour Symmetry

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Topic(s): Neutrino physics

Abstract: Though sufficient work has been done on neutrino masses and mixings and flavour structure of fermions, still there is not a clear-cut picture about the latter. In this work, we present a comparative study of three of the seesaw models, viz., type II [**1**], inverse [**2** , **3**] and linear seesaw models[**4**], to investigate about the rich phenomenological aspects such as their masses and mixings, viable flavour structure and effective neutrino mass in neutrinos double beta decay experiments. We have chosen to do so within with the framework of A_4 flavour symmetry and some other discrete symmetries [**5**], like Z_2, Z_4 etc. Taking into account the present experimental data for the known neutrino parameters from recent global fit data and results, we have evaluated the currently unknown neutrino parameters such as the lightest neutrino mass (m_1), CPV phase (Dirac and Majorana), and effective light neutrino mass in the neutrino less double beta decay, by considering different VEV alignments of the triplet scalar flavon fields in these models. Finally, we discuss and analyse our results of comparative study among the three seesaw mechanisms, commenting on the viability of the same, and also present the region of parameter spaces of m_1, CPV phases, octant of θ_{23} and of neutrino less double beta decay experiments, that can be tested in future experiments. The precision future measurements of these paarameters will verify or refute our models presented here, and one would be able to pinpoint also that which model out of the three - type II, inverse or linear seesaw is the best to describe the experimental results.

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Baryogenesis through leptogenesis in a S_4 flavon model with TM_1 mixing for neutrinos

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Topic(s): Neutrino physics; Particle astrophysics and cosmology

Abstract: We explore a flavon model[1] based on Standard Model with S_4 discrete symmetry group[2–4] adhering to Type-I seesaw mechanism. The model leads to TM_1 mixing pattern for light neutrinos through the incorporation of appropriate flavon fields. In this model neutrino oscillation[5] phenomenology is described using only four parameters. We carry out a chi-squared analysis to fit these parameters with the three mixing angles, the CP phase and the two mass-squared differences. The fact that the TM_1 mixing has two inbuilt constraints which are consistent with the data enables us to successfully carry out this fit. One of these constraints dictates near-maximal breaking of the CP symmetry, $-1 < \sin\delta < -0.9$. The specific texture of the seesaw mass matrix in the model results in the prediction of the light neutrino masses. We show that their values are consistent with the $\sum m_i$ and $m_{\beta\beta}$ bound. Furthermore, we show that the model under consideration is capable of producing adequate baryon asymmetry through leptogenesis. Lagrangian parameters already constrained by the 3σ limit of oscillation data[6] are used in the calculations of leptogenesis. It is well known that only high energy parameters contribute to the unflavoured leptogenesis whereas the asymmetry in the flavoured case can get non zero contribution from both high energy as well as low energy (Dirac and Majorana type) CP Phases. We have successfully generated baryon asymmetry within the experimentally observed range[7] through flavoured and unflavoured leptogenesis[8, 9] which suggests that the high energy parameters are contributing nontrivially to the asymmetry. The estimation of final baryon asymmetry has been carried out by solving the network of coupled Boltzmann equations as well as using appropriate analytical fits[10, 11]. Equivalence between these two methods has been shown clearly with corresponding numerical results. Results of the analytical fit differs from that of the numerical solution of Boltzmann equations at most by 10%. These nearly accurate analytical formulas are used thereafter to evaluate baryon asymmetry for the whole parameter space allowed by 3σ global fit[6] of oscillation data and to impose a constraint on the yet unbounded mass scale. Moreover we have explicitly pointed out the substantial contribution from the decay of next to lightest right handed neutrino (N_2 leptogenesis) towards final baryon asymmetry in the context of flavoured leptogenesis.

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Probing the second oscillation maximum at DUNE

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Topic(s): Neutrino physics

Abstract: After the successful experimental confirmation of the phenomenon of neutrino oscillation, the major goal of the neutrino experiments has mainly shifted to the search for leptonic CP-violation (CPV), determination of neutrino mass ordering and the precision measurement of the oscillation parameters. Leptonic CPV, if it can be established, can offer a crucial ingredient in explaining the puzzle of the baryon asymmetry [1] in the observed universe through an elegant mechanism called leptogenesis [2]. Determination of mass ordering and precision measurements will shed light on the plausible set of models for neutrino mass generation [3, 4]. All these require the investigation of neutrino oscillation over a wide range of the ratio (L/E) of neutrino propagation length L and neutrino beam energy E. This will help in gathering information over several oscillation maxima to search for the physics issues mentioned above [5]. Deep Underground Neutrino Experiment (DUNE) [6, 7] is a next generation long baseline experiment that is expected to see the second oscillation maximum (SOM) in addition to the first oscillation maximum (FOM). We discuss how at the SOM, the CP sensitivity can potentially become larger compared to that of FOM. We write a new $\Delta\chi^2$ code that estimates, for the first time in literature, the sensitivity of DUNE to probe the SOM in its projected data.

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Hadron energy estimation from atmospheric neutrino events

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Topic(s): Neutrino physics

Abstract: The ICAL at INO is designed to mainly observe the muons produced in the charged current interactions of atmospheric muon neutrinos and anti-neutrinos. The track of the muon is reconstructed using the hits they produce in the detector. From this track, the charge, the energy and the direction of the muon are estimated, which are used to do oscillation physics analysis. In a large fraction of events, a number of hadrons are also produced in addition to the muons. The charged hadrons also leave hits in the detector which can be utilized to estimate the hadron energy. In this work, we generate atmospheric neutrino events using two different neutrino event generators: NUANCE and GENIE. The generated events are passed through the Geant4 simulator of ICAL. In each case, we study the relation between hadron hits, defined to be the difference between the total number of hits and the muon track hits, and the hadron energy. We find that a non-negligible number of baryons are produced in atmospheric neutrino interactions. For $E_{had} < 5$ GeV, almost all the hadron energy is carried by these baryons. Finally, we formulate a procedure by which the hadron energy can be estimated from the number of hadron hits.

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The Mitchell Institute Neutrino Experiment at Reactor (MINER)

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Topic(s): Neutrino physics; Beyond standard model physics; Particle astrophysics and cosmology

Abstract:

The Mitchell Institute Neutrino Experiment at Reactor (MINER) at Texas A&M University, USA is a reactor based neutrino experiment which aims to measure coherent elastic neutrino-nucleus scattering (CEνNS) where a neutrino interacts with a nucleus as a whole creating a nuclear recoil [1, 2]. The main challenges for this experiment are (1) detectors capable of measuring low-recoil energies, and (2) mitigation of neutron, gamma and muon backgrounds. MINER addresses these challenges by deploying two types of novel silicon detectors which allows discrimination of signal from background on an event-by-event basis while providing baseline resolution of $\sim$ 1 e$^-$/h$^+$ pair [3, 4]. The gamma and neutron backgrounds are reduced by using active and passive shieldings while muons are rejected by an active muon veto [5]. The reactor has an added advantage of having a movable core allowing us to change the distance between the core and detector from 1 to 10 m which facilitates the measurement of short baseline neutrino oscillation [5]. In addition to measuring CEνNS, MINER will search for sterile neutrinos and axions [6, 7]. MINER is presently operational with a kg-scale payload at a distance of approximately 4.5 m from the reactor core. We will report the science goals, shielding design and detectors performance during test runs using the low threshold detectors and conclude with future plans for the experiment.

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Exploring the new physics phases in 3+1 scenario in neutrino oscillation experiments

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Topic(s): Neutrino physics; Beyond standard model physics

Abstract:

In accordance with the highly successful Standard Model(SM) of particle physics, with a nominal extension that includes massive neutrinos, 3-neutrino oscillation picture (the $3+0$ scenario) has been consolidated through numerous global analyses [1–3], analysing neutrino data from various sources such as atmosphere, sun, particle accelerator and nuclear reactors. However, there are a few short-baseline (SBL) anomalies [4–7] which indicate that there is a possibility of existence of a fourth type of neutrino (essentially, sterile) implying a $3+1$ scenario with mass squared difference ($\Delta m^2_{41} = m^2_4 - m^2_1 \sim \mathrm{eV}^2$). This sterile neutrino can have small mixing with the three active flavours. In this $3+1$ scenario, we will have 6 more oscillation parameters (one mass squared difference: Δm^2_{41} , three active-sterile mixing angles: θ_{14}, θ_{24}, θ_{34} and two more CP violating phases: δ_{24}, δ_{34}) in addition to the standard 3-neutrino oscillation parameters. Should sterile neutrino exist in nature and its presence is not taken into consideration properly in the analyses of neutrino data, these additional parameters, especially the CP phases can severely impact the results. This can, for instance, completely blur the interpretation of data as far as the search for leptonic CP violation is concerned in long baseline (LBL) neutrino experiments [8].

It is thus of utmost importance to estimate the capability of existing (T2K, NOνA) and future (DUNE, T2HK) LBL experiments to probe the CP phases. In the current work we have analyzed the capability of LBL experiments to reconstruct all the CP-phases ($\delta_{13}, \delta_{24}, \delta_{34}$). The correlations of the CP phases have been illustrated with each other and also with the three active-sterile mixing angles (θ_{14}, θ_{24} and θ_{34}). We have done this exercise initially in context of DUNE [9] experiment and then illustrated the improvement when combined with T2K, NOvA and T2HK. Here, we have considered the ν_τ appearance channel in addition to ν_e appearance channel and ν_μ disappearance channel which has enabled us to probe the parameter spaces associated to θ_{34} and δ_{34} with better sensitivities.

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Multi-Higgs doublet model under the framework of minimal extended seesaw

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Topic(s): Beyond standard model physics; Neutrino physics

Abstract: We study a model of neutrino and dark matter within the framework of minimal extended seesaw (MES) [1–3]. This framework is based upon A_4 flavor symmetry [4] along with the discrete Z_4 symmetry to stabilize the dark matter and construct desired mass matrices for neutrino mass. We use non-trivial Dirac mass matrix with broken $\mu - \tau$ symmetry to generate the leptonic mixing and consider a non-degenerate mass structure for right-handed neutrinos to verify the observed baryon asymmetry of the Universe [5] via the mechanism of thermal Leptogenesis [6]. We also discuss the neutrino-less double beta decay [7] process within the fermion sector to put bound on the absolute neutrino mass in presence of sterile neutrino. Scalar sector is also studied in great details for multi Higgs doublet scenario. In presence of two Higgs doublets, we also add another inert Higgs doublet [8] and the lightest component of this inert doublet behaves as a viable dark matter candidate. Stability of the dark matter is ensured by discrete Z_4 odd charge. A significant impact on the region of DM parameter space as well as in the fermionic sector are found in the presence of extra scalar particles. Influence of the Yukawa couplings on the fermion sector are observed and we are able to find bounds on Yukawa couplings from the baryon asymmetry of the Universe study. Within the scalar sector also, we successfully able to bring down the dark matter mass upto 42.2 GeV satisfying all theoretical as well as experimental bounds.

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Understanding the MiniBooNE and the muon $g-2$ anomalies with a light Z' and a second Higgs doublet

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Abstract: Two of the most widely studied extensions of the Standard Model (SM) are *a*) the addition of a new $U(1)$ symmetry to its existing gauge groups, and *b*) the expansion of its scalar sector to incorporate a second Higgs doublet. We show that when combined, they allow us to understand the electron-like event excess seen in the MiniBooNE (MB) experiment as well as account for the observed anomalous values of the muon magnetic moment. A light Z' associated with an additional $U(1)$ coupled to baryons and to the dark sector, with flavor non-universal couplings to leptons, in conjunction with a second Higgs doublet is capable of explaining the MB excess. The Z' obtains its mass from a dark singlet scalar, which mixes with the two Higgs doublets. Choosing benchmark parameter values, we show that $U(1)_{B-3L_\tau}$, which is anomaly-free, and $U(1)_B$, both provide (phenomenologically) equally good solutions to the excess. We also point out the other (anomaly-free) $U(1)$ choices that may be possible upon fuller exploration of the parameter space. We obtain very good matches to the energy and angular distributions for neutrinos and anti-neutrinos in MB. The extended Higgs sector has two light CP-even scalars, h' and H, and their masses and couplings are such that in principle, both contribute to help explain the MB excess as well as the present observed value of the muon $g-2$. We discuss the constraints on our model as well as future tests. Our work underlines the role that light scalars may play in understanding present-day low-energy anomalies. It also points to the possible existence of portals to the dark sector, *i.e.*, a light gauge boson field (Z') and a dark neutrino which mixes with the active neutrinos, as well as a dark sector light scalar which mixes with the extended Higgs sector.

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Enhanced violation of Leggett-Garg Inequality in three flavour neutrino oscillations via non-standard interactions

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Topic(s): Beyond standard model physics; Neutrino physics

Abstract: Neutrino oscillations occur due to non-zero masses and mixings and most importantly they are believed to maintain quantum coherence even over astrophysical length scales.It is thus natural to explore geometric aspects of the phases involved as well as think about quantification of the coherence properties of neutrinos via temporal correlations in the form of Leggett-Garg Inequalities (LGI).[1, 2] In this paper, we study the quantumness of three flavour neutrino oscillations by studying the extent of violation of LGI [3, 4] if non-standard interactions are taken into account. We report an enhancement in violation of LGI with respect to the standard scenario for certain choice of NSI parameters.

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Theory of Fast Flavor Conversion for Supernova neutrinos

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Topic(s): Neutrino physics

Abstract: We all know that in the dense anisotropic interior of the star, neutrino-neutrino forward-scattering [1, 2] can lead to fast collective neutrino oscillations [3–6] which has striking consequences on flavor dependent neutrino emission and can be crucial for the evolution of a supernova and its neutrino signal. The flavor evolution of such dense neutrino system is governed by a large number of coupled nonlinear partial differential equations [5, 6] which are almost always very difficult to solve. Although the triggering, initial linear growth and the condition for fast oscillations to occur are understood by a well known trick known as "Linear stability analysis" [7], this fails to answer an important question – what is the impact of fast flavor conversion on observable neutrino fluxes or the supernova explosion mechanism? This is a significantly harder problem that requires understanding the nature of the final state solution in the nonlinear regime. Interestingly, stellar explosion and the neutrino signal are sensitive to the processed flavor-dependent fluxes, but the required neutrino theory prediction is still lacking. My talk will address this crucial theoretical and phenomenological obstacle and present the first ever theory of fast flavor conversions that will explain how, when and to what extent do the flavor differences change. This talk will be based on our recent works [8, 9] where we do one of the first numerical as well as an analytical study of the coupled flavor evolution of a non-stationary and inhomogeneous dense neutrino system in the fully nonlinear regime considering one spatial dimension and a spectrum of velocity modes.To be more precise, I will talk about the following important theoretical concepts :

- How to simplify the set of coupled nonlinear P.D.E's into a *single decoupled linear diffusion-advection equation* in multipole space?
- How coarse-graining of the solution of this simplified equation results in irreversible decoherence like processes which can bring neutrinos of different flavors closer to each other and cause loss of information even with a time-reversible equation of motion to begin with?
- I will show how the epoch of *T2 relaxation* determines *when* such depolarization occurs, what determines it's rate and why polarization vectors at different spatial locations relatively dephase?
- Like Landau-Zener formula in case of MSW scenario, we finally gave a strategy and a formula for computing the extent of depolarization and the final neutrino fluxes.

This work solves a critical problem revealing the final state of fast conversions that has eluded the community for almost two decades and thus paves the way for supernova neutrino phenomenology.

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Evolution of Mass-Mixing Parameters in Matter with Neutrino Non-Standard Interactions

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Abstract: We explore the role of matter effect in the evolution of neutrino oscillation parameters in the presence of lepton-flavour-conserving and lepton-flavour-violating non-standard interactions (NSI's) of the neutrino. We derive simple approximate analytical expressions showing the evolution/running of the mass-mixing parameters in matter with energy and in presence of NSI's (considering both +ve and -ve NSI's). We observe that only the NSI's in 2-3 block ($\varepsilon_{\mu\mu}, \varepsilon_{\tau\tau}$, and $\varepsilon_{\mu\tau}$) affect the running of θ_{23}. Though all the NSI's influence the evolution of θ_{13}, $\varepsilon_{e\mu}$ and $\varepsilon_{e\tau}$ show stronger impact at the energies relevant for DUNE. We demonstrate the utility of our approach in addressing several important features related to neutrino oscillation such as: a) unraveling interesting degeneracies between θ_{23} and NSI parameters, b) estimating the resonance energy in presence of NSI's when θ_{13} in matter becomes maximal, c) figuring out the required baseline length and neutrino energies to have maximal matter effect in ν_μ to ν_e transition, and d) studying the impact of NSI's in 2-3 block on the ν_μ to ν_μ survival channel.

Relativistic heavy-ion physics & QCD (Parallel talks)

Temperature fluctuations and Tsallis statistics in Relativistic Heavy Ion collisions

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: We study temperature fluctuations in the initial stages of the relativistic heavy ion collision using A Multi-Phase Transport (AMPT) model [1, 2]. We use the non-extensive Tsallis statistics to find the entropic index in the partonic stages of the relativistic heavy ion collisions [3, 4]. We find that the temperature and the entropic index have a linear relationship in the partonic stages of the heavy ion collision. This is in agreement to the experimental observations in the hadronic phase. A detailed analysis of the dependence of the entropic index on the system parameters is done. We compare our results with recent experimental results and find that the general results of the experimental data are in agreement with our results. Our work indicates that anomalous transport models can be used to study the non-equilibrium statistics in the partonic phase of the relativistic heavy ion fluid.

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Open charm mesons in magnetized asymmetric strange hadronic matter

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The in-medium masses of open charm mesons such as $D(D^0, D^+)$, $\bar{D}(\bar{D^0}, D^-)$ as well as ${D_s}^+$ and ${D_s}^-$ are investigated in strongly magnetized isospin asymmetric strange hadronic matter. In Heavy Ion Collision experiments at Relativistic Heavy Ion Collider (RHIC) at BNL and at Large Hadron Collider (LHC) where strong magnetic fields are created, this study is necessary as they affect the experimental observables. The strength of these magnetic fields are estimated to be eB $\sim 2\mathrm{m}_\pi^2 \sim 6\times10^{18}$ Gauss in RHIC and eB $\sim 15\mathrm{m}_\pi^2 \sim 10^{19}$ Gauss in LHC [**1**] [**2**]. In this study we use a chiral $SU(3)_L \times SU(3)_R$ effective Lagrangian model based on non-linearization of chiral symmetry and the broken scale invariance of QCD through the dilaton field [**3-8**]. The non-strange scalar field σ, strange scalar field ζ, isovector scalar field δ are associated with the chiral condensates and the dilaton field χ is incorporated to simulate the gluon condensates within this chiral effective model. This effective Lagrangian is generalized to $SU(4)$ flavor to derive the interactions of the charmed mesons with the light hadronic sector.

In the presence of the magnetic field, the number density and scalar density of charged baryons have contributions from Landau energy levels [**3**]. We have incorporated the effects of strangeness fraction and anomalous magnetic moments of baryons in this study. The equations of motion of scalar fields are solved as a function of baryonic density at various magnetic fields and strangeness fractions. The mass modifications of open charm mesons arise due to their interactions with nucleons, hyperons, and the scalar fields (σ, ζ, δ) in presence of magnetic field. The interaction Lagrangian of these mesons in magnetized strange hadronic medium gives rise to equations of motion and their Fourier transforms lead to the dispersion relations. These relations are solved to obtain their in medium masses.

The in-medium mass of open charm mesons are observed to decrease with increase in baryonic density. The charged D^+ , D^-, ${D_s}^+$ and ${D_s}^-$ have additional positive mass shifts due to Landau quantization effects in the presence of magnetic field. The effects of strangeness fraction are observed to become more prominent at larger magnetic fields especially for $\bar{D}$ mesons as compared to the D mesons. Moreover the presence of hyperonic matter leads to a larger mass drop of D_s mesons compared to nuclear matter. In hyperonic medium, the mass degeneracy of the D_s mesons is observed to be broken, due to opposite signs of the Weinberg-Tomozawa interaction term. This mass degeneracy grows with increase in baryonic density and strangeness fraction of the medium. These in-medium effects should show in observables in the Compressed Baryonic Matter (CBM) experiment at FAIR at the future facility at GSI, where baryonic matter at high densities and moderate temperatures will be produced.

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NLL resummation of recoil-sensitive angularities using SCET

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Jet angularities are a class of event shapes that are designed to measure the energy-flow into angular regions of phase space between energetic jets. Angularity description relies on a free parameter b ($b > -1$) such that varying the exponent b changes the sensitivity of the observable to the substructure of the jet. When measured with respect to the standard thrust axis, this class of QCD observables is a generalization to the well known jet observables, thrust ($b = 1$) and jet broadening ($b = 0$) where the former is insensitive to the recoil of soft against collinear radiation while the latter being maximally sensitive to it. A unified SCET_I framework for thrust-axis angularities was worked out in [1, 2] which is applicable for angularity exponents close to the thrust limit (i.e. $b \gtrsim 1$), as this analysis does not account for recoil contributions. Similarly, jet broadening ($b = 0$) cross-section was also established in [3, 4] described within a SCET_II framework. In a recent publication [5], we formulated a universal framework based on SCET_II that can be utilized for the whole range of angularity exponents, thereby allowing to smoothly connect the special limits of broadening ($b = 0$) and thrust ($b = 1$), for the first time.

In this talk, I will first review the formalism developed in Ref. [5]. We find new kind of logarithmic structures appearing from the leading order SCET framework, which reproduce the well-known logs of 2 for jet broadening and die off for b values close to the thrust limit ($b \gtrsim 1$). These new logarithms provide large corrections and require resummation also in the intermediate τ_b region of the distribution. Resummation of large logarithmic contributions that plague the fixed order distributions is known to provide a better convergence of the perturbation theory and is essential for comparison of the theoretical results to experimental data. Taking the specific case of $b < 0$ angularities, I will address the resummation of these recoil-sensitive angularities at NLL accuracy and highlight the principal results of our findings.

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Correspondence between Israel-Stewart and first-order casual and stable hydrodynamics for the boost-invariant flow

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract:

The success of relativistic hydrodynamics as the main tool used for modeling heavy-ion collisions triggered broad interest in general aspects of this theory [**1**, **2**]. A relativistic generalization of the viscous hydrodynamics had been put forward by Landau and Eckart. However, the formalism by Landau and Eckart has been argued to be acausal in nature [**3**]. Phenomenological hydrodynamic models used to analyze the data are based on the Israel-Stewart (IS) version of this theory [**4**]. In most of the studied cases, the IS theory is stable and causal, which is essential for its practical applications. The IS approach treats the shear stress tensor ($\pi_{\mu\nu}$) and the bulk pressure (Π) as new hydrodynamic variables, in addition to temperature (T) and hydrodynamic flow u^μ (in a baryon free case).

Very recently, a completely new formalism of first-order causal and stable hydrodynamic (FOCS) approach has been proposed by F. S. Bemfica, et al. and P. Kovtun [**5**, **6**]. It treats T and u^μ as fundamental hydrodynamic variables. It also employs the opportunity of a more general choice of the hydrodynamic frame and introduces a new set of kinetic coefficients that play the role of ultraviolet regulators of the theory.

A natural question can be asked about possible relations between the IS and FOCS formulations. In general, no direct connection between these two theories exists, as IS theory leads to ten differential equations, while FOCS gives four second-order equations which are equivalent to only eight equations of the first order. Nevertheless, there may exist special cases where the two frameworks lead to the same dynamical equations. Such cases are interesting and useful as they allow us to "transfer" the knowledge gained in one theory to the other one. In particular, the information about causality and stability established for the FOCS approach can be used to analyze IS solutions, provided such connections exist.

We discuss an exact correspondence between Israel-Stewart theory and first-order causal and stable hydrodynamics for massless particles for the boost-invariant flow (Bjorken flow) with zero baryon density [**7**, **8**]. In this case, the general solution of the new first-order formulation can be determined analytically. Using this correspondence between the IS and FOCS theory the stability and causality properties of the IS theory will be discussed.

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ηB interactions in the strange baryonic matter

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract:

We employ the conjunction of chiral SU(3) model and chiral perturbation theory to study the ηB interactions in the strange baryonic matter. The in-medium scalar and vector densities of the baryons are calculated in the chiral model which are later used in the interaction Lagrangian of chiral perturbation theory, derived up to next to leading order. Along with the strangeness effect, we also include the effect of medium density,ρ_B, and temperature, T. The medium modified mass and optical potential of η meson is calculated from the ηB equations of motion. In this work, the effect of Sigma term, Σ_η, and scattering length, $a^{\eta N}$ is also studied. We observe decrement in the in-medium mass of η-meson as a function of density, which may leads to the formation of bound state between η meson and nuclei.

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Measurement of cumulants of net-charge and net-kaon distributions in Au+Au collisions at $\sqrt{s_{NN}} = 27$ GeV from the STAR experiment at RHIC

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Higher-order cumulants of conserved charges in high-energy heavy-ion collisions are excellent probes of phase structure in the QCD phase diagram, nature of quark-hadron phase transition, and freeze-out dynamics. The cumulants and their ratios are related to the correlation length of the system and susceptibilities. The susceptibilities are calculable in various QCD-based models and lattice QCD.

We present the cumulants of net-charge and net-kaon distributions from high statistics Au+Au collisions at $\sqrt{s_{NN}} = 27$ GeV recorded by the STAR detector at RHIC in 2018. Cumulants and ratios of cumulants measured at mid-rapidity will be presented as a function of collision centrality. The results will be compared with model calculations. Finally, the status and prospects of such measurements in the ongoing phase II of the STAR beam energy scan program at RHIC will be discussed.

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Far from equilibrium hydrodynamic attractor for an azimuthally symmetric system

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Hydrodynamics is an effective theory for the description of long-wavelength phenomena of fluids, that can be expressed as a small gradient expansion of fluid velocities relative to a thermal background [1]. Thus, hydrodynamics is expected to fail for systems which are far-from-equilibrium. The medium produced in *pp* collisions at LHC and RHIC energies is an example of such a system. However, recent experimental results of high energy *pp* collision have shown evidence of collectivity similar to those observed in heavy-ion collisions [2–6]. The unprecedented success of hydrodynamics to describe collectivity in heavy-ion collisions, as well as small systems, can be attributed to the fact that there exists a stable universal attractor which makes the dynamical equations to quickly converge and enter a hydrodynamic regime, at a time scale much smaller than the typical isotropization time scales [7–11]. In the present work, we go beyond the previous works which considered 1+1d longitudinal boost invariant systems, by considering a system undergoing Gubser flow which has a simultaneous transverse and longitudinal expansion.

To investigate the dynamics of such a system, the Boltzmann equation is solved in the relaxation time approximation using a hierarchy of angular moments of the distribution function [12]. The dynamics of transition is described by the presence of fixed points which describes the evolution of the system in various stages. We found that unlike 1+1d Bjorken flow which has late-time thermalization/hydrodynamization, Gubser flow is intrinsically a 3+1d expanding system with dynamics such that the system goes from early time free-streaming regime to intermediate thermalization/hydrodynamization and back to free-streaming in the late time regime. The attractor solution is found for various orders of moments as an interpolation between these fixed points.

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Spin dynamics in relaxation time approximation

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract:

In off-central ultra-relativistic heavy-ion collisions, the two colliding nuclei carry a large amount of orbital angular momentum $\boldsymbol{L}$. After the collision, a substantial portion of this orbital angular momentum $\boldsymbol{L}$ can be retained in the interaction zone which can further be transformed to the spin form $\boldsymbol{S}$ with the total angular momentum $\boldsymbol{J} = \boldsymbol{L} + \boldsymbol{S}$ being conserved. The latter can be revealed in the spin polarization of the produced particles. Indeed, the spin polarization of various particles (Λ, K^*, ϕ) produced in heavy-ion collisions has been recently measured by the STAR [1, 2], ALICE [3]. At present, hydrodynamic models used to describe the experimental data for the spin polarization of particles along both the longitudinal and the transverse directions make use of the thermal vorticity $\varpi_{\mu\nu} = -\frac{1}{2}(\partial_\mu \beta_\nu - \partial_\nu \beta_\mu)$, where β_μ is defined as the ratio of the fluid flow vector u_μ and the local temperature T. The use of thermal vorticity does not require any modifications of the existing hydrodynamic codes as spin effects are determined solely by the form of u^μ and T. This method seems to work well, however, there still remains a puzzle known as sign problem *i.e.* the sign of the quadrupole structure of the longitudinal component of the polarization three-vector as function of particles transverse momentum is opposite compared to that found in the experiment[4]. One of the reason for the disagreement between theory and experiments could be that the spin degree of freedom may not reach equilibrium in the fireball and thus the spin polarization tensor is not exactly equal to thermal vorticity. On general thermodynamic grounds [5] one expect the spin polarization effects to be govern by spin polarization tensor $\omega_{\mu\nu}$. This suggest for new hydrodynamic approach (known as hydrodynamics with spin), which allow the spin polarization tensor to be treated as an independent dynamical variable. Motivated by this intriguing fact, we formulate first the perfect-fluid relativistic hydrodynamics with spin by treating the spin degree of freedom at a classical level and compare it with the previous formulations obtained using the phase-space distribution functions for spin-1/2 particles and antiparticles in local equilibrium as well as using local equilibrium Wigner functions. Later, we extend formulation of the perfect-fluid hydrodynamics with spin to the case including dissipation. Our work is based on the analysis of classical kinetic equations for massive particles of spin-1/2, with the collision terms treated in the relaxation time approximation. This kinetic-theory framework allows us to determines the structure of viscous and diffusive terms and explicitly calculate a complete set of new kinetic coefficients that characterize dissipative spin dynamics.

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Simulation studies of $\mathrm{R}_2\,(\Delta\eta, \Delta\varphi)$ and $\mathrm{P}_2\,(\Delta\eta, \Delta\varphi)$ correlation functions in p–p collisions with the PYTHIA and HERWIG models

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Two- and multi- particle azimuthal correlation functions have confirmed the existence of anisotropic flow and quark scaling (approximate) of flow coefficients in A–A collisions at RHIC and LHC as well as reveals the presence of flow in smaller systems (e.g., p–A and high multiplicity p–p collisions). Measurements of two particle differential- number correlations, R_2, and transverse momentum correlations, P_2, have provided the collective nature of the azimuthal correlations observed in Pb–Pb collisions [**1-2**] . Centrality studies in A-A collisions show that near-side peak of both charge-independent (CI) and charge-dependent (CD) correlations is narrower for P_2 than in R_2 [**3**]. This correlator P_2 provides a more discriminating probe of the correlation structure of jets and their underlying events than the R_2. To understand, we performed this study in three p_T ranges $0.2 < p_\mathrm{T} \leq 2.0$ GeV/c, $2.0 < p_\mathrm{T} \leq 5.0$ GeV/c, and $5.0 < p_\mathrm{T} \leq 30.0$ GeV/c, using PYTHIA and HERWIG models for the charged hadrons in pp collisions at $\sqrt{s} = 2.76$ TeV for both CI and CD.

We presented a study of CI and CD two-particle differential- number correlation functions R_2 and transverse momentum correlation functions P_2 in p–p collisions at $\sqrt{s} = 2.76$ TeV with the PYTHIA and HERWIG models. Calculations were presented for unidentified hadrons as well as for $\pi^\pm$, $K^\pm$ and $p\bar{p}$ individual species in selected ranges of transverse momentum. PYTHIA and HERWIG both qualitatively reproduce the near-side peak and away-side ridge correlation features reported by experiments. At low p_T, both models produce narrower near-side peaks in P_2 correlations than in R_2 as reported by the ALICE collaboration in p–Pb and Pb–Pb collisions. This suggests that the narrower shape of the P_2 near-side peak is largely determined by the p_T dependent angular ordering of hadrons produced in jets [**4**]. Both PYTHIA and HERWIG predict widths that decrease with increasing p_T. Widths extracted for P_2 correlators are typically significantly narrower than those of the R_2 counterparts. We also showed that the models predict non-trivial dependence on the mass of identified particles arising in part from resonance decays.

We additionally find that the models produce large amplitude ridge structures at $\Delta\varphi = \pi$ in P_2 correlation functions while yielding relatively modest ridges in R_2. The amplitude of the ridge structure in P_2^{CI} is found to increase with the particle p_T range considered reaching rather large amplitude for particles in the $5.0 < p_\mathrm{T} \leq 30.0$ GeV/c range. An away-side ridge is also observed in P_2^{CD} correlation functions [**5**]. The magnitude of this ridge shall depend on jet-to-jet charge correlations. Measurements of P_2^{CD} correlation functions of high-p_T particles in p–p collisions might then be sensitive to the charge of the partons initiating the observed jets. Elucidation of this conjecture, however, requires further studies, with both PYTHIA and HERWIG, of the correlation functions obtained when jet production is restricted to gluon-gluon or quark-quark processes.

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Jet quenching parameter in a Polyakov loop plasma

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: We study the jet quenching parameter $\hat{q}$ for a quark like jet propagating in a thermal medium. The non-perturbative effects arising from the Polyakov loop are incorporated via single particle distribution function and resummed gluon propagator. The color dependent distribution functions of particles are given as [1–3]

$$f_a^0(E) = \frac{1}{e^{\beta(E-iQ_a)}+1}, \;\; \tilde{f}_a^0(E) = \frac{1}{e^{\beta(E+iQ_a)}+1},$$
$$f_{ab}^0(E) = \frac{1}{e^{\beta(E-i(Q_a-Q_b))}-1},$$

where single and double color indices are for quarks/anti-quarks and gluons. For SU(3) gauge group, $Q^a = 2\pi T(-q, 0, q)$ with $3l = 1 + \cos(2\pi q)$, where l is expectation value of the Polyakov loop. Furthermore, the color dependent resummed gluon propagator reads as [4, 5]

$$D\mu\nu; abcd(K) = P^L_{\mu\nu}\frac{k^2}{K^2}D^L_{abcd}(K) + P^T_{\mu\nu}D^T_{abcd}(K),$$

where $P^T_{\mu\nu} = g_{\mu i}\bigg(-g^{ij} - \frac{k^ik^j}{K^2}\bigg)g_{j\nu}$ and $P^L_{\mu\nu} = -g_{\mu\nu} + \frac{k_\mu k_\nu}{K^2} - P^T_{\mu\nu}$ are the longitudinal and the transverse projection operators and the color dependent longitudinal and the transverse gluon propagators are written as

$$D^L_{\mu\nu;abcd}(K) = \left(\frac{i}{K^2+F}\right)_{abcd},$$
$$D^T_{\mu\nu;abcd}(K) = \left(\frac{i}{K^2-G}\right)_{abcd},$$

where F and G are longitudinal and transverse component of gluon self energy. It is expected that near critical temperature the quenching parameter to show significant non-perturbative effects arising from Polyakov loop.

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Anisotropic pressure and quark number susceptibility of strongly magnetized QCD medium

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract:

Nowadays, it is well known that in non-central heavy ion collisions a magnetic field perpendicular to the reaction plane can be produced by the spectator particles. It is found in various studies that the produced magnetic field can reach very high value $eB \sim 10^{18}$ Gauss [1, 2]. The energy of fermion in presence of the background magnetic field gets quantized. It can be shown that considering only the lowest energy level *i.e.,* the lowest Landau level is sufficient to study the QCD matter in presence of strong magnetic field. In this work, we compute the hard thermal loop pressure of quark-gluon plasma in strong magnetic field approximation in one-loop order [3]. Magnetic field breaks the rotational symmetry of the system. As a result, the pressure of QGP becomes anisotropic and one finds two different pressures along the longitudinal (along the magnetic field direction) and transverse direction. Similarly, the second-order quark number susceptibility, which represents the fluctuation of the net quark number density, also becomes anisotropic [4]. We compute the second order QNS of deconfined QCD matter in strong field approximation considering same chemical potential for two quark flavors.

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Energy and Pseudorapidity Dependence of Multiplicity and Mean p_{T} Fluctuations in Ion-Ion Collisions at FAIR Energies

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Event-by-event fluctuations in multiplicity and mean transverse momentum, in ion-ion collisions at FAIR energies are examined in the frame work of Monte Carlo models, AMPT and URQMD. Two families of strongly intensive measure, $\Delta(A, B)$ and $\Sigma(A, B)$ are considered as measures of particle number and transverse momentum fluctuations. Pseudorapidity(η) dependence of these quantities are examined at beam energies $E_{Lab} = 10,\ 20,\ 30$ and 40 A GeV/c. Such a dependence of particle number fluctuations corresponds to changing the baryon chemical potential and the temperature at freeze-out stage. Centrality dependence of these measures are also looked into and the findings are compared with the available results from the SPS experimental data. It is observed that the multiplicity and mean p_{T} fluctuations exhibit significant dependence on the charges of emitted hadrons and on the width and/or position of the η windows. The study of short- and long-range multiplicity correlations in terms of $\Delta(A, B)$ and $\Sigma(A, B)$ indicates that $\Sigma(A, B)$, for the most central collisions, acquires a value ~ 1, irrespective of the beam energy and the position of η windows, which is in accord with those reported by NA61/SHINE collaboration for pp collisions at 20 and 158 GeV/c.

Latest results on hadronic resonance production with ALICE at the LHC

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Hadronic resonances, due to their short lifetimes, are useful to probe the properties of the hadronic phase in ultra-relativistic heavy-ion collisions. They are good candidates to investigate the interplay between re-scattering and regeneration effects on the particle production in the hadronic phase. In addition, having different masses, quantum numbers, and quark content, they carry a wealth of information about the processes which determine the shapes of particle momentum spectra, strangeness production, parton energy loss and the possible onset of collective effects in small systems.

In this contribution, we present the latest results on $\rho(770)^0$, $K^*(892)^{0,\pm}$, $f_0(980)$, $\phi(1020)$, $\Sigma(1385)^{\pm}$, $\Lambda(1520)$, $\Xi(1530)^0$ production at mid-rapidity in pp, p–Pb, Pb–Pb and Xe–Xe collisions at different LHC energies. Results include the system-size and the collision-energy evolution of transverse momentum spectra, integrated yields, mean transverse momenta and particle ratios. The results will be compared with model predictions and measurements at lower energies.

Multiplicity dependence study of thermodynamic and transport properties of the matter formed in ultra-relativistic collisions at LHC using Color String Percolation Model

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: For a better understanding of the matter formed in ultra-relativistic high energy collisions, Color String Percolation Model (CSPM) is a widely used and well tested model [**1**]. Using the transverse momentum spectra of the produced particles, in the framework of CSPM, we have estimated various thermodynamic and transport properties such as mean free path (λ), energy density (ϵ), speed of sound squared (c_s^2), bulk viscosity to entropy density ratio (ζ/s), shear viscosity to entropy density ratio (η/s), isothermal compressibility (κ_T) and bulk modulus (B) for the matter formed in high energy collisions [**2**, **3**]. In addition, to study the measure of fluidity of the system, η/s is an important observable. The elliptic flow measurements from the heavy-ion collisions at RHIC [**4**] give the η/s value close to the KSS bound, which suggests that QGP is almost a perfect fluid. Similarly, the study of isothermal compressibility can give us an idea about the degree of deviation of the system from being a perfect fluid. We also have looked for the possible heavy-ion like behaviour of high multiplicity *pp* collision systems, which would further contribute to the new direction to search for QGP droplets in high multiplicity *pp* collisions at TeV energies [**5**, **6**]. A final state multiplicity dependence of these observables taking various hadronic and nuclear collisions is a way forward in the direction of finding a threshold multiplicity for a phase transition or the change of dynamics of the system.

We have studied all the above-mentioned observables as a function of final state charged particle multiplicity ($\langle dN_{ch}/d\eta\rangle$), which is an event classifier in ALICE, for various collision systems such as Pb-Pb, Xe-Xe, *p*-Pb and *pp* at LHC energies. We observe a threshold of charged particle multiplicity ($\langle dN_{ch}/d\eta\rangle \simeq$ 10-20) regardless of the collision system, after which there is a change in the dynamics of the system [**7**, **8**]. This observation contributes to the fact that high multiplicity *pp* collisions may produce QGP droplets, which need a deeper exploration. We also conclude that the matter formed in ultra-relativistic collisions is the closest to a perfect fluid found in the nature.

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Criticality in hadron resonance gas model: Critical exponents and transport properties

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: We perform an analytic study of shear and bulk viscosity of hadronic matter near quark-hadron phase transition. We model hadronic matter using hadron resonance gas model with hagedorn density of states. The hadron resonance gas model with exponentially rising mass spectrum shows critical behavior near QCD transition temperature if the parameter characterizing degeneracy of hagedorn states is properly chosen. We calculate the critical behavior of viscosity coefficients within ambit of hadron resonance gas model.

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Directed flow of identified hadrons in Au+Au collisions with the STAR experiment at RHIC

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Rapidity-odd component of the directed flow (v_1) is considered to be sensitive to the early collision dynamics and the equation of state (EoS) of the QCD matter formed in heavy-ion collisions. Hydrodynamic models predict that the double sign change of v_1 slope at mid-rapidity ($\mathrm{d}v_1/\mathrm{dy}$) of net-baryon is a signature of first order phase transition [1]. The STAR experiment at RHIC [2] shows the collision energy dependence of $\mathrm{d}v_1/\mathrm{d}y$ of net-proton and net-Λ have a minimum at $\sqrt{s_{NN}} = 14.5$ GeV, implying the possible softening of EOS. We further explore such observations with new measurements. A comprehensive transverse momentum (p_T) dependent v_1 measurement of strange and non-strange light hadrons (π^+, π^-, K^+, K^-, p, $\overline{p}$, K^0_S, Λ, $\overline{\Lambda}$, ϕ) enables us to test the constituent quark number scaling and provides a better understanding of the coalescence mechanism of particle production. In this talk, new results of p_T and rapidity dependent v_1 for identified hadrons in Au+Au collisions at $\sqrt{s_{NN}} = 19.6$, 27, 54.4 and 200 GeV will be presented. These results will be compared to model calculations.

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Studying explicit $U(1)_A$ symmetry breaking in hot and magnetised two flavour non-local NJL model constrained using lattice results

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: We study the two flavour non-local Nambu–Jona-Lasinio (NJL) model in the presence of a magnetic field and explored the chiral crossover in presence of a non-local form of the ‘t Hooft determinant term [1]. Its coupling is governed by a dimensionless parameter c. This term is responsible for the explicit breaking of $U(1)_A$ symmetry. We have attempted a systematic analysis of the model parameters by fitting to self-consistent lattice QCD calculations [2, 3]. Three parameters of the model are fixed by $eB = 0$ results from published lattice QCD on the chiral condensate, the pion decay constant (F_π), and the pion mass. The difference of the u and d quark condensates in the presence of a magnetic field (eB) is quite sensitive to c and we fix c using published lattice QCD [4] results for this observable. We see no evidence that c depends on eB. The crossover temperature decreases with increasing eB only for condensate values at the lower end of the allowed values (as already seen in [5]) and F_π at the upper end of the allowed values. We further check our model predictions by calculating the topological susceptibility with the fitted c values and compare it with lattice results. Since the topological susceptibility is related to the extent of the $U(1)_A$ symmetry breaking, we find that it is sensitive to the value of c.

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Shear viscosities of a conformal fluid in the presence of strong external magnetic field

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The main goal of the relativistic nuclear collision experiments at Relativistic Heavy Ion Collider (RHIC) and Large Hadron Collider (LHC) is to create a colour deconfined state of hadronic matter called quark-gluon plasma (QGP). Intensive theoretical and experimental efforts are on to characterize the QGP. It has been shown that a transient but large magnetic field (B) will be created due to the Ampere's circuital law [1] in non-central collisions of heavy ions at RHIC and LHC energies. The magnitude of this magnetic field sets an energy scale which is much beyond the value of QCD scale, Λ_{QCD}. Therefore, the heavy-ion collision provides us an opportunity to investigate the strongly interacting matter under the influence of ultra-high magnetic field. Significant progress has been made theoretically and experimentally in this direction to investigate the effects of B on QGP. The detection of the effects of B on QGP is blurred by several uncertainties e.g. lifetime of the transient field in the evolving QGP, background of the experimental signal, distribution of axial charge etc. One of the outstanding issue in this field of research is to investigate the effects of B on various transport coefficients of QGP as the transport coefficients plays a crucial role on the evolving matter. Here, we investigated the effects of B on the shear viscous coefficient. In the presence magnetic field the shear viscous coefficients breaks up in to five components [2]. We take diagrammatic approach to evaluate these components in the presence of B by using Kubo relations [2] in the Ritus basis [3] within the scope of real time thermal field theory [4]. In the strong magnetic field, the lowest Landau level is the only level which is significant and higher Landau levels (hLL) are suppressed by a large energy gap $\sim \sqrt{|e|q_f B}$. Surprisingly we find all the components of the shear viscosity are zero. Therefore, a conformal fluid with non zero-shear viscosity (at $B = 0$) will become a super-fluid in the limiting case of $B \to \infty$ (where LLL is a good approximation). However, if the magnetic field is not very strong, then one has to go beyond the LLL which gives non-zero shear viscosity.

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QCD critical point, universality and small quark mass

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The universality of the QCD equation of state near the critical point is expressed by mapping QCD pressure onto the Gibbs free energy in the Ising model. The mapping parameters are, in general, not universal, i.e., determined by the unknown details of the microscopic physics, rather than by symmetries and universal long-distance dynamics. We point out that in the limit of small quark masses when the critical point is close to the tricritical point, the mapping parameters show certain universal dependence on the quark mass. Further, we discuss possible phenomenological consequences of these findings.

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Thermal and electric charge transport in a weakly magnetized hot QCD medium

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The experimental facilities at Relativistic Heavy Ion Collider and Large Hadron Collider have provided the opportunity to create and study the deconfined nuclear matter in extreme conditions. The quantitative analysis of the experimental observables of the relativistic heavy-ion collision experiments from the dissipative hydrodynamical simulation involves the dependence upon the transport parameters of the created hot nuclear matter. Intense magnetic fields are produced in the very initial stages of non-central asymmetric collisions and can affect the transport properties of the hot QCD medium. However, a proper theoretical model for the evolution of the magnetic field in the nuclear medium is yet to be known. The current analysis focuses on the thermal and electric charge transport in a weakly magnetized quark-gluon plasma [1]. An effective kinetic theory has been employed to quantify the dissipative effects while incorporating the mean-field contributions in the medium [2]. The particle dispersion is not directly affected by the field as the strength of the magnetic field is weak (magnetic field can be considered as a small perturbation), unlike the $1+1$ dimensional Landau level dynamics in the strong field limit. The electric current induced and the associated electrical conductivities in the response of the electric field in a weakly magnetized medium has been studied [3, 4]. The thermal dissipation in the medium is due to the temperature gradient over the spatial separations of fluid and can be described in terms of thermal conductivity. The Hall-type conductivity associated with thermal dissipation in the medium in the presence of a weak magnetic field has been explored. The relative significance of thermal transport and electric charge transport in a weakly magnetized quark-gluon plasma has been studied in terms of Wiedemann-Franz law. It is observed that the Wiedemann-Franz law violates in temperature regimes not very far from the transition temperature [5]. The analysis of the temperature behavior of thermal conductivity and electrical conductivity has further extended to the strong magnetic field limit [6]. Both the equation of state and magnetic field seen to have significant impacts on the thermal dissipation and electric charge transport in the medium.

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Study of Heavy flavor decay muons in p-p and Pb-Pb collisions at LHC energies using Angantyr model for heavy-ion collisions in PYTHIA8

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The heavy-quarks are produced at the very early stage of high energy nucleon-nucleon and heavy-ion collisions mainly through intial hard parton-parton scattering due to their heavy masses. After the production of heavy-quarks, they interact and pass through the medium of deconfined state of matter called Quark-Gluon Plasma (QGP) produced at extremely high temperature and/or energy density in ultra-relativistic heavy-ion collisions. During the propagation through the medium, they experience energy loss and contribute to the collective dynamics. Hence, the measurement of heavy quarks provides a test of purturbative QCD (pQCD) calculation for a wide range of transverse momentum (p_T). The study of heavy-flavor quark production in pp collisions serves as a baseline for the corresponding measurement in heavy-ion collisions. The modification in the transeverse momentum (p_T) spectra measured in heavy-ion collisions with referenece to that in pp collisions represents a very sensitive probe to study the properties of QGP.

In ALICE (A Large Ion Collider Experiment) at LHC (Large Hadron Collider), the production of heavy-flavor are being investigated mainly through their semi-leptonic decay channels. We shall present the results of heavy-flavor production decaying to muons using PYTHIA8. PYTHIA8 is a general purpose Monte Carlo event generator, widely used by the scientific community for the study of high energy phenomena mainly in pp collisions and very much succeded in simulating the dynamics of strong and electroweak process from high momentum transfer down to the scale about Λ_{QCD}. The extrapolation of high energy PYTHIA8 based on pp dynamics is implemented in heavy-ion collisions using Angantyr model and intended to build up the complete hadronic final states in nucleus-nucleus collisions. This Angantyr model has two eseential features such as diffractive excitation which is related to the fluctuations in the nucleon partonic sub-structure and multi-parton interactions. The study has been done for p-Pb and Pb-Pb collisions at LHC energy using Angantyr model very recently. In this work, we will be presenting the results for open heavy-flavor muon (HFM) production in pp and Pb-Pb collisions at LHC energies using this PYTHIA8 heavy-ion model. The results obtained in Pb-Pb with respect to that in pp can give an understanding of the non-collective background to the observable which are sensitive to the collective behaviour. In the study of PYTHIA8 heavy-ion model, one has to calculate the number of participating nucleons ($< N_{part} >$) and corresponding nucleon-nucleon binary collisions ($< N_{coll} >$) for a given centrality class using Glauber model. The Glauber model is based on the impact parameter space which directly interprets the probabilities of total cross-section.

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Constraining the Chiral Magnetic Effect with charge-dependent azimuthal correlations in ALICE

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: In a non-central heavy-ion collision, the spectator protons can create a very strong ($\sim 10^{18}$ Gauss) but short lived (lasting few fm$/c$) magnetic field $\vec{B}$. In its presence, the spins of (anti-)quarks tend to align along $\vec{B}$, leading to the development of a vector current in this direction and the creation of an electric dipole moment of QCD matter. The subsequent effect is the charge separation in the hadronic medium along the direction of $\vec{B}$ and perpendicular to the 2^{nd} order event plane (Ψ_2), a phenomenon called the Chiral Magnetic Effect (CME). However, the charge separation effect relative to the third harmonic symmetry plane Ψ_3 is expected to be negligible, as Ψ_3 and Ψ_2 are weakly correlated.

Here we present the results on two-particle correlations of different orders as well as various two-particle correlations with respect to the second-, third-, and fourth-order order symmetry planes for charged particles in Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ and 5.02 TeV. Assuming that the correlators with respect to third (and fourth-order) order symmetry planes are only sensitive to background phenomena, we attempt to estimate the signal contribution in the CME correlator with respect to Ψ_2. We also present the background estimate from a blast-wave inspired local charge conservation model.

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Measurements of inclusive photon production at forward rapidities using PMD in p-Pb collisions at $\sqrt{s_{NN}} = 8.16$ TeV with ALICE

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Relativistic heavy-ion collisions produce a Quark Gluon Plasma (QGP) [1] that hadronizes predominantly into pions, of which approximately one third are neutral pions that decay into photons. The measurement of photon multiplicity [2] therefore provides important information about bulk physics [3] from initial scatterings to final state QGP effects. The measurement of multiplicity in p-Pb collisions [4] is very important as it is an intermediate step going from hadronic to heavy-ion collisions. In this analysis the multiplicity of photons is measured by the Photon Multiplicity Detector (PMD) [5] which is a highly granular preshower gaseous detector used to measure the multiplicity and spatial distribution of photons generated from relativistic hadronic, hadron-nucleus and nucleus-nucleus collisions in an event by event basis.

We will present the multiplicity and pseudorapidity distributions of photons at forward rapidities ($2.3 < \eta < 3.9$) produced in p-Pb collisions at $\sqrt{s_{NN}} = 8.16$ TeV using the ALICE PMD data. The results will also be compared with theoretical MC models such as HIJING.

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Light neutral mesons measurement with the ALICE experiment at the LHC

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract:

Simultaneous measurement of light neutral mesons production in different collision systems at the LHC provides the possibility to explore a large variety of physics effects: In pp collisions, it can be used to validate pQCD predictions, constrain structure and fragmentation functions and act as a reference for p–Pb and Pb–Pb collisions; In p–Pb collisions, it is important to study cold nuclear effects; In Pb–Pb collisions, neutral mesons spectra measurement allows to study parton energy loss and particle suppression by the hot and dense medium called the quark-gluon plasma. In ALICE, neutral mesons have been reconstructed by invariant mass analysis of two decay photons using the calorimeters EMCal and PHOS, as well as the central tracking system with the photon conversion method. Results from different techniques are combined to provide precision measurements of π^0 and η mesons over a wide p_{T} range. The combined measurement allows to reach p_{T} down to 0.35 GeV/c and beyond 20 GeV/c. In this talk, we will present an overview of the recent experimental results on the light neutral mesons, π^0 and η, produced in pp, p–Pb and Pb–Pb collisions at different center-of-mass energies obtained with the ALICE experiment at the LHC.

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Azimuthal anisotropy measurement of ϕ mesons in Au+Au collisions at $\sqrt{s_{NN}} = 27$ and 54.4 GeV at STAR

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The hadronic interaction cross section for ϕ mesons is expected to be small. Hence, the study of azimuthal anisotropy of ϕ mesons allows one to access the collective properties of the medium at the early stage in heavy-ion collisions. The STAR experiment recently recorded high statistics data for Au+Au collisions at the new centre-of-mass energies ($\sqrt{s_{NN}}$) of 54.4 GeV (∼600 million events) and 27 GeV (∼350 million events). The newly installed Event Plane Detectors (EPDs) allow one to measure the azimuthal anisotropy of particles with high precision and less non-flow contributions using event planes with large gaps in rapidity.

In this talk, we will present the second-order azimuthal anisotropy (v_2) of ϕ mesons measured at midrapidity ($|y| < 1.0$) as a function of transverse momentum (p_T) and centrality at $\sqrt{s_{NN}}$=27 and 54.4 GeV. Measurement will be carried out using event planes from both Time Projection Chamber ($|\eta|<1.0$) and EPDs ($2.1<|\eta|<5.1$). A high precision test of the number of constituent quark scaling of ϕ meson v_2 (by including measurements for other hadrons) will be shown. The results will be compared to transport-based model calculations. Finally, the physics goals of such measurements at the other collision energies $\sqrt{s_{NN}} = 19.6$, 11.5, 9.2 and 7.7 GeV of the RHIC beam energy scan phase II will be discussed.

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A beyond mean field approach to Yang-Mills thermodynamics

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: We have proposed a formalism based on functional integration techniques for a model that describes Yang-Mills thermodynamics within a quasiparticle model framework using the background field method ([1]). In different Polyakov loop extended quasi-particle models like Polyakov-Nambu—Jona-Lasinio (PNJL) model , Polyakov-quark-meson (PQM) model gluon dynamics is approximated by the dynamics of the Polyakov loop. Near the transition region the gluonic potential is modeled up to the mean field level considering the symmetry properties of the system. However these Polyakov models treat gluons only as a constant background field and thus inadequate to describe specific gluonic interactions, particularly those which need the medium modified gluonic distribution function. A quasiparticle model for the pure gauge system with a background Polyakov field can be formulated starting from basic Yang-Mills theory ([2, 3]), and can successfully reproduce the ideal gas limits. However, the thermodynamic quantities, evaluated from this model, using saddle point approximation, happen to have unphysical behaviour for temperatures below the critical temperature (T_c). We claim that this unphysical behaviour below the critical point is an artifact of the mean field approximation, and one should look beyond the mean field to get the correct physical picture. The path integral based approach we described ensures the physical behaviour of all the thermodynamic quantities throughout the complete temperature range. We have constrained our functional integration to only the configurations that remain constant in space-time and integrated over all possible values of the Polyakov loop field variable. With appropriate parameterization of the gluon mass, our results are in very good agreement with the Lattice data for a pure gauge system. Under this new formalism, this model also provides a good understanding of the distribution of the Polyakov loop field for two different phases corresponding to confinement and deconfinement.
Thus, now we have a quasiparticle model description for SU(3) pure gauge system that gives physically consistent results for the complete temperature range. This model can be coupled to the existing quasiparticle models (NJL model, Quark-Meson model, etc) in order to have a better understanding of the medium formed in the heavy-ion collision experiments.

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Understanding long-range near-side ridge correlations in p−p collisions using rope hadronization at LHC energies

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract:

The observation of long range ridge-like structure in the near-side region of the two particle $\Delta\eta - \Delta\phi$ correlations as measured by CMS and ATLAS experiments at LHC in high multiplicity p−p collisions at $\sqrt{s}$ = 7 TeV and 13 TeV indicated towards the presence of collectivity in the small system which are similar to that observed in p−A(nucleon-nucleus) and A−A (nucleus-nucleus) collisions [1–3]. The particle production in high multiplicity events in hadronic collisions are highly influenced by non-perturbative QCD processes and the study of such events can provide information about the potential microscopic processes leading to such novel observations.

In this work, the two particle correlation between the charged particles in $\Delta\eta - \Delta\phi$ for p−p collisions at $\sqrt{s}$ = 7 TeV and 13 TeV is studied using Pythia 8 [4, 10] event generator within the framework of different final-state partonic color reconnection effects such as multi-partonic interactions (CR-0), QCD mode (CR-1) and the gluon-move scheme (CR-2) [6, 7] etc. as well as the microscopic rope hadronization model. The rope hadronization relies on the formation of ropes due to overlapping of strings in high multiplicity events followed by string shoving [8, 9]. A correlation peak near $(\Delta\eta, \Delta\phi) = (0, 0)$, originated primarily due to jet fragmentation and an away side ($\Delta\phi \sim \pi$) ridge-like structure extended up to higher values of $|\Delta\eta|$ containing the contributions from back-to-back jets are observed for both low and high multiplicity events for both the energies. Also, ridge-like structures at near side have also been observed for high-multiplicity events for both the energies when the mechanism of rope hadronization (with shoving) was enabled, which is qualitatively similar to the observed ridge in data.

The observed two-dimensional correlation functions were projected into one-dimensional distribution in $\Delta\phi$ for different $\Delta\eta$ ranges, namely the short range (when projected over $\Delta\eta < 1.0$, the jet region) and the long range ($\Delta\eta > 2.0$, the ridge region). In the long range region, along with the away-side peaks emanating from back-to-back jets for all the three multiplicity classes, non-zero associated yield peaks in the near side are also observed in the near-side for long-range region for high multiplicity events when the rope hadronisation is enabled. Both the near-side and away-side peaks are observed in the short range region which are originated from the jets and away-side ridge like structure, respectively. The strength of the correlation function is higher for CR-1 and CR-2 mode compared to CR-0 mode. The observed ridge-like structure in the near-side region is qualitatively similar to the ones observed in data which supports the idea that microscopic processes at partonic level can mimic collectivity like features without assuming the formation of a thermalised medium.

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Kasner space-time, second order hydrodynamics and gravity dual

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: We consider Kasner space-time describing anisotropic three dimensional expansion of RHIC and LHC fireball and study the generalization of Bjorken's one dimensional expansion by taking into account second order relativistic viscous hydrodynamics. Using time dependent AdS/CFT correspondence, we study the late time behaviour of the Bjorken flow. From the conditions of conformal invariance and energy-momentum conservation, we obtain the explicit expression for the energy density as a function of proper time in terms of Kasner parameters. The proper time dependence of the temperature and entropy have also been obtained in terms of Kasner parameters. We consider Eddington-Finkelstein type coordinates and discuss the gravity dual of the anisotropically expanding fluid in the late time regime.

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Search for the Chiral Magnetic Wave using the ALICE detector in Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract:

In heavy-ion collisions a strong magnetic field is created ($\sim 10^{15}$ T), mostly by the spectator protons. Its presence along with a non-zero electric and axial charge density leads to vector and axial currents called the Chiral Magnetic Effect (CME) and Chiral Separation Effect (CSE), respectively. Their coupling gives rise to a collective excitation in the quark-gluon plasma (QGP) called the Chiral Magnetic Wave (CMW). The CMW causes a separation of positive and negative charged particles leading to a charge-dependent elliptic flow, denoted as (v_2^+) and (v_2^-). As a result, the normalized difference of v_2 of positive and negative charges, (Δ $v_{2_{Norm}}$), exhibits a positive slope as a function of charge asymmetry A_{ch}. However, non-CMW mechanisms like Local Charge Conservation (LCC) can also describe the Δ v_2 dependence on A_{ch}. To probe this type of background one needs to do a similar kind of measurement with v_3 as we expect it not to be affected by the CMW.

Here we present ALICE measurement of v_2, Δ $v_{2_{Norm}}$, v_3 and Δ $v_{3_{Norm}}$ of charged hadrons as function of the charge asymmetry (A_{ch}) in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. The slope parameters from v_2 and v_3 are compared to estimate the background contribution in CMW phenomena at LHC energies.

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Causality and stability in relativistic non-resistive dissipative magnetohydrodynamics

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The applicability of the relativistic hydrodynamics framework ranges from very large scale astrophysical phenomena to the femtoscopic heavy-ion physics. The relativistic hydrodynamics is one of the most successful theory in describing the dynamics and bulk properties of the matter produced in heavy-ion collisions. The theory of relativistic hydrodynamics can be expressed as a gradient expansion of fluid velocities and thermodynamic quantities . The first order theory i.e. first-order in gradient a.k.a. Navier-Stokes equation which is acausal and unstable. But it is known that the second order theory is causal and stable in a restricted sense. Such a second-order theory has been derived by Israel and Stewart from the kinetic theory using extended Grad's method which is known as the Israel-Stewart (IS) theory [1]. The causality and stability of IS theory is discussed in details in Ref. [2] using the linear stability analysis around the hydrostatic state.

In non-central heavy-ion collisions an extremely strong transient magnetic field ($\sim 10^{18} - 10^{19}$ Gauss) is produced in the initial stages [3] mostly due to the spectator protons. The dynamics of the interaction of this large magnetic field and electrically conducting QGP fluid is governed by the relativistic magnetohydrodynamics (MHD) formulation.

Here we investigate the causality and the stability of the relativistic viscous magneto-hydrodynamics in the framework of the Israel-Stewart (IS) second-order theory, and also within a modified IS theory [4]. We compute the dispersion relation by perturbing the fluid variables around their equilibrium values. In the ideal magnetohydrodynamics limit, the linear dispersion relation yields the well-known propagating modes: the Alfvén and the magneto-sonic modes [5]. In the presence of bulk viscous pressure, the causality bound is found to be independent of the magnitude of the magnetic field. The same bound also remains true, when we take the full non-linear form of the equation using the method of characteristics. In the presence of shear viscous pressure, the causality bound is independent of the magnitude of the magnetic field for the two magneto-sonic modes. The causality bound for the shear-Alfvén modes, however, depends both on the magnitude and the direction of the propagation. For modified IS theory in the presence of shear viscosity, new non-hydrodynamic modes emerge but the asymptotic causality condition is the same as that of IS theory [6].

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In medium properties of axion within a Polyakov loop enhanced Nambu-Jona-Lasinio model

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: We estimate the axion properties i.e. its mass, topological susceptibility and the self-coupling within the framework of Polyakov loop enhanced Nambu-Jona-Lasinio (PNJL) model at finite temperature and quark chemical potential. PNJL model, where quarks couple simultaneously to the chiral condensate and to a background temporal quantum chromodynamics (QCD) gauge field, includes two important features of QCD phase transition, i.e. deconfinement and chiral symmetry restoration. The Polyakov loop in PNJL model plays an important role near the critical temperature. We have shown significant difference in the axion properties calculated in PNJL model compared to the same obtained using Nambu-Jona-Lasinio (NJL) model. We find that both the mass of the axion and its self-coupling are correlated with the chiral transition as well as the confinement-deconfinement transition. We have also estimated the axion properties at finite chemical potential. Across the QCD transition temperature and/or quark chemical potential axion mass and its self-coupling also changes significantly. Since the PNJL model includes both the fermionic sector and the gauge fields, it can give reliable estimates of the axion properties, i.e. it's mass and the self-coupling in a hot and dense QCD medium. We also compare our results with the lattice QCD results whenever available.

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Deciphering quark and gluon jet modifications in heavy-ion collisions with γ-tagged jets

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The relativistic collisions of heavy nuclei produce a dense de-confined medium of quarks and gluons - the quark-gluon plasma (QGP) [1]. The QGP formation is often characterized by the energy loss of high-momentum particles or jets, generally referred to as the "jet quenching" [2]. The jet-quenching effects are manifestly evident from the results of heavy-ion collisions at RHIC and LHC that show large suppression of inclusive yields of particles with large-transverse momentum against a proton-proton baseline. The QCD energy loss models predict the magnitude of jet energy loss depending on the flavour of the jet initiating parton. The radiative picture of jet energy loss asserts gluon jets to lose more energy than a quark jet. However, till date, no unambiguous evidence has been obtained to support such a claim. This is mainly because of the difficulty in discriminating a pure sample of quark or gluon initiated jet on a jet-by-jet basis. Nonetheless, this issue can be addressed by using a special class of jets which are recoiled against prompt photons. This so-called γ-tagged jets provide an enriched sample of quark jets that can be used to study modifications of jet sample with higher quark fraction (almost 80% at LHC kinematics).

We use a pQCD inspired model of jet energy loss - JEWEL [3] to sample γ+1jet events for Pb+Pb collision at 5.02 TeV and calculate fragmentation functions and radial momentum distributions. In this work we report a flavour dependence of jet energy loss by comparing modifications of above mentioned jet-shape observables in gamma-tagged jets against a sample of inclusive jets at same kinematics.

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A unified formalism to study *soft* as well as *hard* part of the transverse momentum spectra

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Among the important goals of heavy ion collision experiments is to the study the QCD matter produced under extreme condition of temperature and density called Quark Gluon Plasma (QGP). In QGP state the quarks and gluons are free to move over a nuclear volume rather than the nucleonic volume as is the case in hadrons. The temperature which is sufficient enough to support the formation of QGP droplet is known as the critical temperature T_c and at this point the phase transition from hadronic state to QGP takes place. Experiments such as LHC and RHIC are trying to explore QCD phase diagram to search for for T_c and the type of phase transition. We can utilize the transverse momentum p_T spectra of final state particles to extract the information of temperature which is required to study the Phase diagram.

Asymptotic freedom and the very nature of QCD coupling constant limits the applicability of perturbative QCD theories as the coupling strength is very strong in low p_T regime. To tackle this issues, we resort to the phenomenological approach which includes hydrodynamical models as well as statistical thermal models with later being the most accepted to explain low p_T part of the spectra. On the other hand, we have a power law form of the distribution function derived from well established perturbative QCD theory to explain the spectra in high p_T regime which is dominated by the particles produced in hard scattering processes.

We have developed a unified formalism [1] to explain both low as well as high p_T part of the spectra in a consistent manner. In this presentation, we will discuss this formalism in detail followed by the results obtained by fitting the transverse momentum spectra using the generalized method. We will also discuss the applicability of this formalism in extracting information related to elliptic flow coefficient.

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Observation of light-by-light scattering and search for axion-like particles with CMS experiment

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Light-by-light (LbyL) scattering ($\gamma\gamma \to \gamma\gamma$) is a fundamental quantum mechanical process which could not be observed until recently due to its tiny cross section. By using huge photon fluxes from lead-on-lead (PbPb) ultra-peripheral collisions (UPC), the process has now been observed by both ATLAS and CMS experiments [1–3]. LbyL process is also a sensitive channel to probe physics beyond the standard model where an intermediate pseodupsacalar, axion-like-particle (a) could be produced, ie, ($\gamma\gamma \to a \to \gamma\gamma$) . The diphoton invariant mass distribution of LbyL process is used to search for such a resonance production. A new exclusion limits on the mass of the pseudoscalar axion-like particles, in the range of 5–90 GeV has been set. This presentation will discuss highlights of the measurement of LbyL scattering by CMS experiment.

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Strangeness and rapidity dependent studies in small system with ALICE at the LHC

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Hadronic resonances are useful tool to understand the properties of hadronic matter created in relativistic heavy-ion collisions. Due to their short lifetime ($\sim 10^{-23}$ sec), resonances are ideal candidates to probe the dynamics of the hadronic phase formed in heavy-ion collisions. As the lifetime of phi (ϕ) meson is longer compared to the lifetime of the fireball, it is expected that its production will not be affected by hadronic phase effects, such as re-scattering and regeneration. The ϕ meson contains strange-antistrange quark pair ($s\bar{s}$), its production measurement can contribute to the study of strangeness production. Recent ALICE results show that although ϕ has zero net strangeness content, it behaves like a particle with open strangeness in small collision system. In asymmetric collisions, the produced particle yield are different in forward and backward rapidity direction. Rapidity asymmetry (Y_{Asym}) studies are sensitive to nuclear modification effects like shadowing, the Cronin enhancement, multiple scattering and energy loss.

We will report on measurement of ϕ meson production at mid rapidity in p-p, p–Pb, Pb–Pb and Xe-Xe collisions at different LHC energies. The results include the transverse momentum spectra (p_{T}) as well as the dN/dy, $<p_{\mathrm{T}}>$ and particle yield ratios. The rapidity dependent studies of ϕ and K^{*0} production in p–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV will be shown. The results include transverse momentum spectra (p_{T}), dN/dy, rapidity asymmetry (Y_{Asym}), $<p_{\mathrm{T}}>$ and particle yield. These results will also be compared with various model measurement (HiJING, EPOS, DPMJET, Pythia).

Feasibility studies of J/ψ measurement with CBM detector setup at FAIR SIS100 energies

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: J/ψ meson, the bound state of charm (c) and anti-charm ($\bar{c}$) quarks, is believed to be one of the most important diagnostic tools to probe the hot and dense matter produced in relativistic heavy-ion collisions. The suppression of J/ψ in high energy heavy-ion collisions has long been predicted to be a prominent signature for the phase transition from confined to de-confined matter [**1**]. Till date, no data exist on J/ψ production in heavy-ion collisions below top SPS energy, mostly due to the extremely low production cross-sections. The Facility for Anti-proton and Ion Research (FAIR) at Darmstadt, Germany enables us with the opportunity to measure J/ψ production in nuclear collisions with the unprecedented high interaction rates [**2**], thanks to the foreseen high intensity heavy-ion beams and the state-of-the-art detectors with high rate handling capability. At FAIR SIS100, heavy-ions will be accelerated up to beam kinetic energies 11 A GeV, whereas light ions up to 14 A GeV and protons up to 29 GeV [**3**]. One of the major physics goals of the Compressed Baryonic Matter (CBM) experiment at FAIR is the detection of the J/ψ mesons via their di-muon decay channel using the Muon Chamber (MuCh) detector sub-system [**5**]. In this contribution, we will discuss in detail, the Monte-Carlo (MC) based studies of the reconstruction of J/ψ mesons at FAIR energies, via their di-muon decay channel ($J/\psi \rightarrow \mu^+\mu^-$) and with the realistic detector setup as implemented in GEANT for 10 A GeV Au+Au collision and for 15 A GeV Ni+Ni collisions. Different methods of signal extraction and acceptance correction to the extracted spectra will also be reported.

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Structure of magnetic field quantization in viscosity expression for relativistic fluid

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Topic(s): Relativistic heavy-ion physics and QCD; Formal theory

Abstract: A strong magnetic field can be can be produced in non-central heavy ion collisions (HICs), occurred in RHIC and LHC experiments, whose magnitudes are expected around 10^{18}-10^{20} Gauss [1], which is quite larger than naturally observed strong field in astrophysical objects like neutron stars (10^{14} Gauss) and magnetars (10^{15} Gauss). So the quantum picture of Landau quantization might be very important ingredient for dissipative relativistic matter, produced in RHIC or LHC experiments. The 'strongly' interacting matter produced in HICs behave like a (nearly) perfect fluid by nature, as its shear viscosity to entropy density ratio (η/s) becomes very close to its lower bound or KSS bound. A huge number of microscopic calculations of viscosity for that relativistic matter are addressed during the last two decades, few of which [2–4] (and few references therein) are recently revisited for finite magnetic field picture. Due to magnetic field, five shear viscosity and two bulk viscosity components are expected [5, 6], which are mostly attempted to be estimated via kinetic theory approaches [2–4] but never have been attempted in Kubo approaches. A rich structure in viscosity component expressions can be found if someone goes for quantum field theoretical version, based on Kubo framework [7]. Present article has attempted to zoom in that rich quantum structure.

Two point function of viscous-stress tensor ($\pi^{\mu\nu}$) and dissipative pressure operators ($\hat{\mathcal{P}}$) in zero frequency limit basically provide us the shear (η) and bulk (ζ) viscosity through the following Kubo relations:

$$\eta = \frac{1}{20}\lim_{q_0,\vec{q}\to 0}\frac{1}{q_0}\int d^4x e^{iqx}\left\langle\left[\pi^{\mu\nu}(x),\pi_{\mu\nu}(0)\right]\right\rangle_\beta , \quad (1)$$

$$\zeta = \frac{1}{2}\lim_{q_0,\vec{q}\to 0}\frac{1}{q_0}\int d^4x e^{iqx}\left\langle\left[\hat{\mathcal{P}}(x),\hat{\mathcal{P}}(0)\right]\right\rangle_\beta . \quad (2)$$

The simplest possible Feynman diagram of these two point functions can be one-loop diagram with fermion-fermion or boson-boson prpagators for fermionic and bosonic medium respectively. Using appropriate projection operators, different components of shear viscosity $\eta_{0,1,2,3,4}$ and bulk viscosity $\zeta_{1,2}$ at finite temperature T and magnetic field B have been obtained. As far as our best of knowledge, we are first time calculating this rich T, B dependent functions of $\eta_{0,1,2,3,4}$ and $\zeta_{1,2}$ in Kubo formalism, which is completely different from the earlier kinetic theory based expressions [2–4] and numerical differences are observed in strong field zone, which reflect that our expressions carry a rich quantum structure of Landau quantization.

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Thermal dilepton production in collisional hot QCD medium in the presence of chromo-turbulent fields

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract:

We study the effects of collisional processes in the hot QCD medium to thermal dilepton production from $q\bar{q}$ annihilation in relativistic heavy-ion collisions [1]. The collisional corrections to the near-equilibrium momentum distribution functions have been determined from the ensemble-averaged diffusive Vlasov-Boltzmann equation by incorporating the collisional effects and turbulent chromo-fields in the QGP medium. This analysis has been done by employing a quasiparticle model for the hot QCD medium which incorporates the realistic EoS effects. The contributions from the $2 \rightarrow 2$ elastic scattering processes have been quantified for the thermal dilepton production rate. We have showed that the collisional corrections induce appreciable enhancement in the dilepton spectra. A comparative study between collisional and anomalous contributions to the dilepton production rates has also been explored.

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Calculating meson and baryon resonances from lattice QCD

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: In the recent years, lattice techniques have been extended to study properties of unstable QCD states at and close to physical pion mass lattice simulations. We present the Lüscher formalism through which we can compute infinite volume observables of QCD resonances from lattice energy spectrum. We show the results from a benchmark calculation of the lowest lying meson resonance, the $\rho(770)$ which appears in the P-wave of the $\pi\pi$ scattering. Additionally, this calculation is a precursor to the computation of the radiative decay width in pion photoproduction. Furthermore, we showcase the results from one of the first lattice calculations of the lowest lying baryon resonance, the $\Delta(1232)$ in the P-wave of the πN scattering.

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Quantum aspects of anisotropic conduction in Hadron Resonance Gas

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Hadron resonance gas (HRG) model is quite successful to map thermodynamics of latice quantum chromodynamics (LQCD) within the hadronic temperature range, so it is also used for estimation of other phenomenological quantities like transport coefficients. Based on the possibilities of high magnetic field [1], produced in heavy ion collisions experiments like RHIC or LHC, transport coefficients of HRG system in presence of magnetic field has been studied by Refs. [2,3,4] in recent times. In electrical conductivity, they have found differences between perpendicular ($\sigma_\perp$) and parallel ($\sigma_\parallel$) components, where the perpendicular component reduces with magnetic field but parallel component remain unaffected by magnetic field B. In quantum picture, this parallel component can be a B dependent function via Landau quantization of hadrons. Present article has been explored this quantum aspects. With respect to earlier results of classical based expressions, numerical values of quantum expression become different in high magnetic field (B) and low temperature (T) domain.

We have also gone through the microscopic calculation of relaxation time τ_c by connecting inversely with density, relative velocity and hard-sphere scattering cross section. In classical picture we don't get any scope of B dependence in τ_c, but in quantum picture, density can be gone through Landau quantization through which we can get B dependent τ_c. Anisotropic conduction will come due to appearence of another time scale τ_B of hadrons, which are basically inverse of synchrotron frequency and increses with increase of resonance masses. Collective T, B dependence of τ_c and τ_B ultimately provide a complex profile of $\sigma_{\parallel,\perp}$ and we will get a little new pattern of anisotropic conduction of HRG system due to considering its quantum aspects.

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Collisional energy loss of Heavy Quark in strong magnetic field

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: We study the effect of the magnetic field on the collisional energy loss of heavy quark (HQ) moving in a magnetized thermal partonic medium. This is investigated in the strong field approximation where the lowest Landau level (LLL) becomes relevant. We work in the limit, $g\sqrt{eB} \ll T \ll \sqrt{eB}$, which is relevant for heavy ion collisions. Similar approach has been taken with similar approximations to calculate the diffusion coefficients of heavy quark at rest in strong magnetic field [**Fukushima:2016prd**]. Effects of the magnetic field are incorporated through the resummed gluon propagator ,as discussed in Ref.[**Hattori:2018prd**], in which the dominant contribution arises from the quark loop. We also take the approximation, $\sqrt{eB} \ll M$, M being the HQ mass, so that the HQ is not Landau quantized. It turns out that there are only two types of scatterings that contribute to the energy loss of HQ; the Coulomb scattering of HQ with light quarks/anti-quarks and the t-channel Compton scattering. It is observed that for a given magnetic field, the dominant contribution to the collisional energy loss arises from Compton scattering process i.e., $Qg \to Qg$. On the other hand, of the two processes, the Coulomb scattering i.e., $Qq \to Qq$ is more sensitive to the magnetic field. The net collisional energy loss is seen to increase with increase in the magnetic field[**Surasree:2020JHEP**]. For a reasonable strength of the magnetic field, the field dependent contribution to the collisional energy loss is of the same order as to the case without magnetic field (as in Ref.[**Peshier:2008prd**]) which can be important for the jet quenching phenomena in the heavy ion collision experiments.

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Topological studies of charged particle production and search for jet quenching effects in small collision systems with ALICE

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Recent results for high multiplicity pp and p–Pb collision systems have revealed that they exhibit collective-like behaviors. These were formerly thought to be achievable only in heavy-ion collisions. To understand the origins of these unexpected phenomena, event shape observables like the relative transverse activity classifier (R_{T}) can be exploited as a powerful tool to disentangle soft and hard particle production. Jet quenching, originally proposed as a signature of QGP, can also give an insight on the origin of collective-like behaviors in small collision systems.

Here, results on the system size and R_{T} dependence of charged particle production in pp, p-Pb and Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV will be presented. The results include evolution of the transverse momentum (p_{T}) spectra, integrated yields and $\langle p_{\mathrm{T}} \rangle$ in different topological regions. These will be compared with event generators such as EPOS-LHC and PYTHIA8 (ANGANTYR). Finally, within the same approach, we present a search for jet quenching effects by studying the yield of charged particles in different topological regions associated with high transverse momentum triggered particles. These were measured in the ALICE detector in pp, p–Pb and Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV.

Recent bottomonium measurements in pp, p–Pb and Pb–Pb collisions at forward rapidity with ALICE at the LHC

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: In ultrarelativistic nucleus-nucleus collisions, a deconfined state of strongly interacting matter is thought to be produced, commonly known as the quark–gluon plasma (QGP). Quarkonia, bound states of a heavy quark and antiquark, are an important probe to study properties of the QGP. At the LHC, bottomonium ($\mathrm{b\bar{b}}$) is of particular interest to study the QGP complementary to the lighter charmonium ($\mathrm{c\bar{c}}$) system due to its heavier mass. In addition to the nucleus-nucleus collisions, the reference measurements in proton-proton and proton-nucleus collisions have been also carried out in order to better understand the bottom quark production and cold nuclear matter effects.

ALICE measures the bottomonium production in the dimuon decay channel at forward rapidity ($2.5 < y_{\mathrm{lab}} < 4.0$) with the muon spectrometer. In this contribution, the recent measurements of bottomonium nuclear modification factors and azimuthal anisotropies in Pb–Pb collisions will be presented. The bottomonium production in p–Pb and pp collisions will also be discussed.

Posters

Beyond standard model and standard model physics (Posters)

Revisiting Texture 4 zero Fritzsch like Quark Mass Matrices

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Topic(s): Beyond standard model physics

Abstract: Understanding fermion masses and mixings, an important aspect of Flavor Physics, is one of the key challenges in present day High Energy Physics. In the Standard Model (SM), fermion masses are characterized by fermion mass matrices which are related to the corresponding mixing matrices. Over the last couple of decades, noticeable progress has been made in measuring the fermion mixing parameters, in particular, quarks mixing parameters are now known to have reached a high level of precision [1, 2]. Also, a good deal of refinement in the ranges of quark masses has been made [3, 4]. Keeping in mind these 'precision measurements', it becomes important to formulate corresponding quark mass matrices.

To this end, following the 'bottom-up' approach, which involves examining the compatibility of phenomenological fermion mass matrices with the recent fermion mixing data, the concept of texture zero mass matrices has proven to be quite successful [5]. In absence of any compelling theory, in order to arrive at a set of mass matrices which are compatible with the latest data, one needs to go for a case by case analysis of texture zero mass matrices.

Recently, it has been shown [6, 7] that the minimal texture structure, i.e., texture 6 zero mass matrices as well as its immediate extension i.e., texture 5 zero mass matrices are ruled out in the era of precision measurements. This motivates us to carry out a similar analysis for the case of texture 4 zero quark mass matrices, as a next step. In particular, Fritzsch like texture 4 zero mass matrices, which have been shown to be playing an important role in understanding of quark masses and mixings [8–10] have been investigated in detail. Interestingly, our analysis reveals that this particular set of texture 4 zero quark mass matrices remain compatible with the present set of precision data.

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Measuring CP nature of tau-Higgs couplings at e^-p collider

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Topic(s): Beyond standard model physics

Abstract: We study the prospect of determining the CP violating phase in $\tau-$lepton Yukawa coupling at the e^-p Collider (LHeC) for electron and proton beam energy of 150 GeV and 7 TeV respectively. We have analyzed interesting CP odd observables utilizing the dominant channels with the semi-invisible hadronic decay of τ. Various asymmetries were constructed corresponding to the T odd observables to measure the CP violating phase and found very promising results.

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Recent Higgs boson measurements in the WW final state using CMS data

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Topic(s): Standard model physics

Abstract: The latest CMS results on the Higgs boson decays to a W boson pair are presented. The focus of the talk are the inclusive and differential cross section measurements performed using the full Run2 data collected by the CMS detector at LHC, as well as the constraints on the Higgs boson couplings to fermions and vector bosons arising from the simultaneous measurement of different production mechanisms.

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Theoretical predictions for a $H - H$ bound state in 2HDMs

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Topic(s): Beyond standard model physics

Abstract:

We investigate the possibility of a Higgs-Higgs bound state in the two Higgs doublet model. Specifically we look for the effect of dimension six operators, generated by new physics at a scale of a few TeV, on the self-couplings of the heavy CP even scalar field in the model. We have chosen the scale of new physics to be at 1 TeV. Following the pioneering work of Grinstein and Trott [1], we construct an effective field theory formalism to examine the physics of the Higgs sector. The magnitudes of the attractive and repulsive coupling strengths are compared to estimate the possibility of the formation of the $H - H$ bound state. Another way to check if a bound state is formed or not is from the formation and decay times of the bound state. The possibilities in various types of two Higgs doublet models have been discussed. The bound state energy has been evaluated and the allowed parameter space has been studied in the linear and non-linear realizations.

From the comparison of the coupling strengths [2–6], it was found that for obese Higgs the attractive coupling was stronger than the repulsive coupling thus facilitating the formation of the bound state. Moreover as m_H increased the possibility was high. Next we have considered the decay of the parent particle into various channels and the corresponding decay times were estimated [7]. Decay times were compared with the formation time of the bound state. If the formation time was smaller than the decay time, then bound state formation would take place readily. From this approach we concluded that for obese Higgs the bound states are likely to form in Type - I and lepton specific models but not in Type -II and flipped 2HDMs.

Non-relativistic Higgs effective theory has been approached to calculate the bound state energy of the heavier CP-even Higgs boson. The 4-point interaction leads to a chain of bubble diagrams for the $H - H$ scattering with both h and H appearing as the loop particles with equal probability. The pole in the resummed bubble chain is to be interpreted as the bound state energy of Higgsium [8]. We have calculated the bound state energy to be $E_b = m_H \left(\frac{16\pi}{\tilde{C}^H_{NR}}\right)^2$. In future we aim to evaluate the shifts in E_b by computing the complete amplitude of the infinite bubble chain diagram for $H - H$ scattering.

We have further studied the non-linear realization of the effective theory where the presence of Higgs doublets is not essential. In this scheme we again conclude that bound states of the heavier CP even Higgs boson can be formed for $m_h < m_H <$ 1 TeV for substantial region of the parameter space.

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Radial & Orbital Excited States of $\Sigma_b^{\pm}$ Baryon

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Topic(s): Standard model physics

Abstract:

Radially and orbitally excited masses of singly heavy beauty baryon $\Sigma_b^{\pm}$, containing two up and/or down quarks and one beauty(bottom) quark ($uub(\Sigma_b^{+})$ & $ddb(\Sigma_b^{-})$), has been calculated by using the hypercentral Constituent Quark Model(hCQM)[**Giannini**], a non-relativistic framework. The hCQM is based on the idea of Constituent Quarks (CQs) and it converts the three body interaction problem to one body interaction by using hypercentral co-ordinates[**Giannini**]. The hyper Coulomb plus screened potential[**Li**](an additional term which screens or softens the potential by third quark) is used as confining potential to elaborate hypercentral quark interaction between the constituent quarks inside the $\Sigma_b^{\pm}$ baryon. Our predicted masses of $1S$, $2S$ & $3S$ (radial) states and $1P$ & $2P$(excited) states of $\Sigma_b^{\pm}$ baryon has been presented in this work, compared with other references[**Ebert**, **Thakkar2017**].

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Dealing With CPT Violation In Mixing For Neutral Pseudoscalar Meson Decaying To Two Vectors

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Topic(s): Beyond standard model physics

Abstract: CPT invariance is believed to be a fundamental symmetry of nature. However, it has been seen earlier that though P and CP were assumed to be two exact symmetries, experiments involving weak interactions showed it otherwise [1, 2]. Therefore, testing the validity of CPT symmetry through experiments is of paramount importance. Apart from various astrophysical and neutrino based observations, neutral meson mixing is a promising area to search for this effect [3]. Several experiments in this direction have been performed by FOCUS [4], KTeV [5], BaBar [6], Belle [7], LHCb [8] and other collaborations so far considering the semi-leptonic and pseudoscalar decay modes of neutral mesons, but the measurements of CPT violation in these experiments are not precise enough to rule it out completely. Nonetheless, two vectors decay modes of neutral mesons have not been well-studied in this context. A general procedure has been studied to deal with CPT violation in mixing and extract it analytically. Actually, a large number of observables can be constructed in two vectors decay modes depending on the polarization of the final state. However, all of these observables are not independent to each other and hence different relations among observables emerge automatically based on the underlying theory which could help in keeping the error bars small. This method has also been used to explore some special cases like SM scenario [9], SM plus direct CP violation, and SM plus T and CPT violation in mixing [10].

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Analysis of $B_s \to (K^{(*)}, D_s^{(*)})\tau\bar{\nu}_\tau$ decay modes in scalar leptoquark model

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Topic(s): Beyond standard model physics

Abstract: We scrutinize the impact of various relevant scalar leptoquarks [1, 2] on the physical observables associated with the rare semileptonic decay processes of B_s meson involving $b \to (u,c)l\bar{\nu}_l$ quark level transitions. We constrain the new parameter space consistent with the experimental limit on $\mathrm{Br}(B_{u,c} \to \tau\nu_l)$, $\mathrm{Br}(B \to \pi\tau\bar{\nu}_\tau)$, $R_{D^{(*)}}, R_{J/\psi}$ and R_π^l observables. Using the allowed parameter space, we compute the branching ratios, forward-backward asymmetries, lepton and hardon polarization asymmetries of $B_s \to (K^{(*)}, D_s^{(*)})\tau\bar{\nu}_\tau$ decay modes [2, 3]. Forbye, we look at the possibility of existence of lepton non-universality in these processes.

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Soft-virtual rapidity distribution and threshold resummation for n-colorless particles to fourth order in QCD

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Topic(s): Standard model physics; Formal theory

Abstract: Exploration of the threshold behaviour of differential distributions has been an interesting topic over the years and several results are already available to very good accuracy for different processes. In this talk, I will discuss a framework to study the leading threshold contributions of differential rapidity distribution for the production of n-number of colorless particles in the hadronic collision within the realm of perturbative QCD. This has been achieved based on the collinear factorization of the differential cross section, the renormalisation group invariance, universality of perturbative infrared structure of the scattering amplitudes, and the process independence of the soft distribution. In this formalism, we present a general structure for the soft-virtual differential cross section for a generic $2 \to n$ scattering process up to next-to-next-to-next-to-next-to-leading order (N^{4}LO) and also the resummed predictions till next-to-next-to-next-to-leading logarithmic (N^{3}LL) level in QCD. We show that both the fixed order and resummed predictions of the differential cross section can be expressed in terms of a universal soft collinear operator along with the process specific form factor.

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New physics contributions to Wtb anomalous couplings.

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Topic(s): Beyond standard model physics

Abstract: We discuss the possibility of having a T-odd anomalous vertex t-b-W in the context of top-pair production and their consequent decays into a pair of dilepton and b-jets at the LHC [1–5]. An estimate of sensitivities to such T-odd interactions would also be discussed for the already existing 13 TeV LHC data and its projections for the proposed LHC runs at 14 TeV and beyond.

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A new mechanism for matter-antimatter asymmetry and connection with dark matter

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Topic(s): Beyond standard model physics; Particle astrophysics and cosmology

Abstract: We propose a new mechanism for generating matter-antimatter asymmetry via the interference of tree-level diagrams only, where the imaginary part of the Breit-Wigner propagator for an unstable mediator plays a crucial role. We first derive a general result that a nonzero CP-asymmetry can be generated via at least two sets of interfering tree-level diagrams involving either $2 \to 2$ or $1 \to n$ (with $n \geq 3$) processes. We illustrate this point in a simple TeV-scale extension of the Standard Model with an inert Higgs doublet and right-handed neutrinos, along with an electroweak-triplet scalar field, where small Majorana neutrino masses are generated via a combination of radiative type-I and tree-level type-II seesaw mechanisms. The imaginary part needed for the required CP-asymmetry comes from the trilinear coupling of the inert doublet with the triplet scalar, along with the width of the triplet scalar mediator. The real part of the neutral component of the inert doublet serves as a cold dark matter candidate. The evolutions of the dark matter relic density and the baryon asymmetry are intimately related in this scenario.

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Evidence for the Higgs Boson Interaction with Muons by CMS

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Topic(s): Standard model physics

Abstract: Evidence for Higgs boson decay to a pair of muons and a measurement of its properties are presented. This result combines searches in four exclusive categories targeting the production of the Higgs boson via gluon fusion, via vector boson fusion, in association with a vector boson, and in association with a top quark-antiquark pair. The analysis is performed using proton-proton collision data at $\sqrt{s}$ =13 TeV, corresponding to an integrated luminosity of 137 fb^{-1}, recorded by the CMS experiment at the CERN LHC. An excess of events compared to the expectation in the absence of a H to dimuon signal is observed in data with a significance of 3.0 standard deviations, where the expectation for the standard model (SM) Higgs boson with $m_H = 125.38$ GeV is 2.5. The combination of this result with that from data recorded at $\sqrt{s} =$ 7 and 8 TeV, corresponding to integrated luminosities of 5.1 and 19.7 fb^{-1}, respectively, improves both the expected and observed significances by 1%. This result constitutes the first evidence for the Higgs boson decay to fermions of the second generation and is the most precise measurement of the Higgs boson coupling to muons reported to date.

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Looking for leptoquarks with boosted tops and light charged leptons at the LHC

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Topic(s): Beyond standard model physics

Abstract: TeV scale Leptoquarks (LQs) are attracting a lot of attention in the current literature because of their possible roles in explaining the persistent anomalies in the B-meson decays. The LHC search strategies for LQs that couple dominantly to a top quark are different than for the ones that couple mostly to the light quarks. We consider the LHC phenomenology of LQs that can decay to a top quark and a charged lepton giving rise to a resonance system of a boosted top quark and a high-p_{T} lepton. In particular, we look at all possible LQ models (scalar and vector) within the Buchmuller-Ruckl-Wyler classifications with the desired decay and present some simple phenomenological Lagrangians that are suitable for bottom-up/experimental studies and cover the relevant parameter spaces. We study the pair and single production channels of LQs at the LHC. We find that the single production of top-philic LQs in association with a charged lepton could be significant for order one LQ-t-ℓ coupling(s) in certain scenarios. We employ a strategy of selecting events from both pair and single production processes with at least one hadronic-top and two high-p_{T} leptons. This can significantly enhance their discovery prospects at the LHC, especially in the high-mass region where the single productions become more prominent. We estimate that a scalar LQ upto 1.7 TeV can be discovered at the 14 TeV LHC with 3 ab^{-1} of integrated luminosity with a 100% branching ratio of the scalar LQ decaying to top and lepton [1]. In the case of a vector leptoquark, a scale of upto 2.55 TeV can be probed for 100% branching ratio in the top lepton mode at the 14 TeV LHC [2].

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Exploring the role of new physics in $b \to u\tau\bar{\nu}$ decays

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Topic(s): Beyond standard model physics

Abstract: The recent measurements on R_D, R_{D^*} and $R_{J/\psi}$ by three pioneering experiments, BaBar, Belle and LHCb, indicate that the notion of lepton flavour universality is violated in the weak charged-current processes, mediated through $b \to c\ell\bar{\nu}_\ell$ transitions. These intriguing results, which delineate a tension with their standard model predictions at the level of $(2-3)\sigma$have triggered many new physics propositions in recent times, and are generally attributed to the possible implication of new physics in $b \to c\tau\bar{\nu}$ transition. This, in turn, opens up another avenue, i.e., $b \to u\tau\bar{\nu}$ processes, to look for new physics. Since these processes are doubly Cabibbo suppressed, the impact of new physics could be significant enough, leading to sizeable effects in some of the observables. In this work, we investigate in detail the role of new physics in $B \to (\pi, \rho, \omega)\tau\bar{\nu}$ and $B_s \to (K, K^*)\tau\bar{\nu}$processes considering a model independent approach. In particular, we focus on the standard observables like branching fraction, lepton flavour non-universality parameter, forward-backward asymmetry and polarization asymmetries. We find significant deviations in some of these observables, which can be explored by the currently running experiments LHCb and Belle-II. We also briefly comment on the impact of scalar leptoquark$R_2(3, 2, 7/6)$ on these decay modes.

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Excited charmed meson decays to light pseudoscalar and light vector mesons using HQET

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Topic(s): Standard model physics

Abstract: Recent experimental advances in the charm sector renewed the interest in identification of newly observed states. Very recently, LHCb collaboration has reported the evidences of four charmed resonances $D_2^*(2460)$, $D_1^*(2680)$, $D_3^*(2760)$ and $D_2^*(3000)$ by analysing the Dalitz plot of $B^- \to D^+\pi^-\pi^-$ [1]. In 2013, LHCb observed two unnatural parity resonances $D_J(2580)^0$ and $D_J(2740)^0$ and two natural parity resonances $D_J^*(2650)^0$ and $D_J^*(2760)^0$ [2]. Proper J^P assignments are crucial as various experimental outcome is based on them. Within the heavy quark limit $m_Q \gg \Lambda_{QCD} \gg m_q$, the HQ symmetries allows to classify the heavy mesons into spin doublets [3]. Those doublets are represented by the effective superfields [4, 5]. Using the heavy quark effective field theory approach we discuss the strong decay analysis of the states $D_2(2740)$ and $D_3^*(2760)$ and identified them as $(2^-, 3^-)_{\frac{5}{2}}$; $n = 1, L = 2$ doublets. The allowed decay channels emitting the light charmed meson and light pseudoscalar meson (π, η, K) are studied. The total decay widths of these channels are then compared to experimental value in order to extract the effective coupling constant. From the present analysis the effective coupling constant G_Y is found to be 0.50. Similar analysis is carried out for $D_{s3}^*(2860)$ and we are able to assign it as the strange partner of $D_3^*(2760)$. The light vector mesons can be incorporated through the hidden local symmetry method [6] into the Lagrangian describing the heavy meson decays [7]. The decay widths of the allowed channels for transitions $D^* \to DV; (V = \rho, \omega, K^*)$ are also calculated to provide the ratios independent of coupling constants.

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Enhancing Scalar Productions with Leptoquarks at the LHC

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Topic(s): Beyond standard model physics

Abstract: The Standard Model (SM), when extended with a leptoquark (LQ) and right-handed neutrinos, can have interesting new implications for Higgs physics. We show that sterile neutrinos can induce a boost to the down-type quark Yukawa interactions through a diagonal coupling associated with the quarks and a scalar LQ of electromagnetic charge 1/3. The relative change is moderately larger in the case of the first two generations of quarks, as they have vanishingly small Yukawa couplings in the SM. The enhancement in the couplings would also lead to a non-negligible contribution from the quark fusion process to the production of the 125 GeV Higgs scalar in the SM, though the gluon fusion always dominates. However, this may not be true for a general scalar. As an example, we consider a scenario with a SM-gauge-singlet scalar ϕ where an $\mathcal{O}(1)$ coupling between ϕ and the LQ is allowed. The $\phi q\bar{q}$ Yukawa couplings can be generated radiatively only through a loop of LQ and sterile neutrinos. Here, the quark fusion process can have a significant cross section, especially for a light ϕ. It can even supersede the normally dominant gluon fusion process for a moderate to large value of the LQ mass. This model can be tested/constrained at the high luminosity run of the LHC through a potentially large branching fraction of the scalar to two jets.

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TeV scale trinification model in presence of color octet scalar

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Topic(s): Beyond standard model physics

Abstract:

We propose a non-susy E_6 GUT with intermediate D-parity violating trinification symmetry ($G_{333} = SU(3)_C \otimes SU(3)_L \otimes SU(3)_R$), where D-parity breaking [1] at the GUT scale M_U, is induced by dimension-5 gravitational correction (ϵ) to the gauge kinetic term [2, 3]. It is observed that, TeV scale trinification [4] can be achieved with admissible gauge unification, in presence of a color octet scalar belonging to 650_H along with the fundamental Higgs 27_H. The analytical expressions for gauge unification mass M_U as well as the GUT coupling constant α_G, for a given intermediate scale M_I, are shown to be independent of the gravitational parameter ϵ, whereas the electroweak mixing angle $\sin^2\theta_W$ does depend on it [5].The predicted value of M_U is compatible with the accessible limit of the proton lifetime in Hyper-Kamiokande collaborations [6, 7]. The presence of color octet scalar with mass of the order of few hundred GeV may suppress the production of the Higgs boson through gluon-fusion [8]. These scalars may be produced in pairs at the LHC, leading to multi-jet final states. With reference to cosmological issue, the model does not in principle possess the well-known domain-wall problem [9, 10], since the discrete D-parity is broken at the GUT scale.

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Exploring the Light Baryon Resonances

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Topic(s): Standard model physics

Abstract: Hadron Spectroscopy has been a promising tool towards revealing the quark dynamics within baryons and mesons, through excited state spectra as well as other properties such as magnetic moments, decay widths, etc. The realm of light and heavy hadrons has been exploited investigated through various theoretical and phenomenological models in addition to varied experiments world-wide [1]. The primary focus of the present study is on light flavoured baryons of basic octet and decuplet $3 \otimes 3 \otimes 3 = 10 \oplus 8 \oplus 8 \oplus 1$ through non-relativistic constituent quark model.

The potential term consists of a Coulomb-like term and a confining term which is taken to be linear. The hypercentral Constituent Quark Model (hCQM) has been employed such that the potential term depends only on the hyperradius x obtained through Jacobi coordinates for three body system [2, 3]. Also, spin-spin, spin-orbit and tensor terms along with correction terms are being added to the potential. The detailed study of N^* (isospin $I = \frac{1}{2}$)[4] and some Δ (isopsin $I = \frac{3}{2}$) [5] resonances have been attempted to explore the known and unknown excited state and their properties. The current assignment investigates another member of octet Ξ with $I = \frac{1}{2}, J = \frac{1}{2}$ with quark composition uss for Ξ^0 and dss for Ξ^-[6]. The radial excited state 2S and 3S with spin assignment $\frac{1}{2}$ and $\frac{3}{2}$ are obtained using the hCQM with linear potential term and compared with available data. The results shall be presented during the symposium accordingly.

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Search for the decay $B_s^0 \to J/\psi\pi^0$ at $\Upsilon(5S)$

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Topic(s): Standard model physics

Abstract: We search for the decay $B_s^0 \to J/\psi\pi^0$ using 121.4 fb^{-1} of data collected at $\Upsilon(5S)$ resonance state by the Belle detector at the KEKB asymmetric energy e^+e^- collider located at the High Energy Accelerator Research Organisation, KEK, in Japan. In the Standard Model, the decay is expected to be rare proceeding through the W-boson exchange and annihilation processes. The quantitative prediction of amplitudes for such transitions have resisted attempts and differ significantly between approaches. The QCD factorization (QCDF) [1],[2],[3] approach suffers large uncertainties due to the endpoint singularities whereas, the perturbative QCD (pQCD) does not differentiate among exchange and annihilation topologies [4]. Nevertheless, pQCD provides more precise predictions in the charmless decays [5],[6]. However, annihilation topologies with charm in the final state have not been studied in detail. The experimental investigation of the issue is very desirable since the decay mode has the potential for advancement of the field. The present experimental upper limit of 1.2×10^{-3} at 90% confidence level (CL) on the branching ratio of $B_s^0 \to J/\psi\pi^0$ was set by L3 collaboration in 1997 [7]. This analysis will be the first attempt to search for this decay using the available dataset from the Belle experiment with an expectation of reaching the SM sensitivity.

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Muon and electron $g-2$ anomaly with 2HDM and vector-like leptons

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Topic(s): Beyond standard model physics

Abstract: We explain the contributions of the beyond standard model (BSM) particles to observed discrepancies in the electron and muon anomalous magnetic dipole moments (MDM) in two Higgs doublet model (2HDM) along with a complex scalar singlet and a vector-like lepton (VLL) singlet field. We find the allowed parameter space constrained from electroweak precision measurements and Higgs decays.

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Mass spectra and decay properties of Charmonia

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Topic(s): Standard model physics

Abstract: Mass spectra and decay properties of Charmonia are computed in nonrelativistic quark-antiquark Cornell potential model with additional smearing interaction. We have employed the non-relativistic numerical solution of Schrödinger equation to compute mass spectra and decay properties. The spin hyperfine, spin-orbit and tensor components of the one gluon exchange interaction are computed perturbatively to compute the mass spectra of excited P, D and F-states. The predicted mass spectra and decay properties are compared with latest results of PDG data and different theoretical predictions.

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Semileptonic decays of D_s mesons

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Topic(s): Standard model physics

Abstract: Recently, BESIII have provided the most precise results on the semileptonic decays of charmed mesons to various channels. Based on this, we study the semileptonic decays of D_s mesons within the standard model framework of covariant confined quark model (CCQM). CCQM is the effective quantum field theoretical approach for hadronic interaction with the constituent quarks. The transition form factors are computed in the entire physical range of momentum transfer. The computed form factors are used for computation of semileptonic branching fractions. We also compare our findings with the experimental data and theoretical approaches. Recently [1–4], we have successfully computed semileptonic decays of D_s mesons to various pseudoscalar, vector and scalar mesons and found to be matching very well with the BESIII and other experimental data.

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Muon lifetime in Iron and muon spin rotation to measure magnetic field in miniICAL

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Topic(s): Standard model physics

Abstract: The mini-ICAL is a small prototype for the 51 kton iron calorimeter detector, which is proposed to be built in the INO cavern. It is approximately 600 times smaller than the proposed ICAL detector. It is made of 11 layers of iron of size $4\,\mathrm{m}\times4\,\mathrm{m}$, weighing approximately 85 tons. The detector is magnetized by passing about 900 amp DC current through two sets coil of 18-turn each through detector. Measurement of the magnetic field is done using search coils and Hall probes placed in between iron layers. Hall probes can not measure the magnetic fields inside iron, because they are placed in the gaps between the iron plates. This paper addresses the feasibility of measuring the magnetic field complementary to the Hall Probes and search coils using a technique called muon spin rotation. This method uses the fact that the atmospheric muons have partial longitudinal polarization($\geq (21\pm3)\%$)[1]. This partial polarization of cosmic-ray muons originate due to the shape of the parent pion energy spectrum. The pion decay into muon and corresponding neutrino. For pions at rest, to conserve momentum, the muon and the neutrino must have equal and opposite momentum. Muon spin will be opposite to that of neutrino spin, because pions have zero spin. Since neutrino has a negative helicity, the muon spin will also be similarly aligned. In a magnetic field the muon-spin undergoes Larmor precession. So muon will get a chance to precess till it decays. This implies that the life time spectra in both forward and backward detectors will be modified depending on the precession fre-quencies[2]. A net polarization is possible if the energy spectrum of pion is not flat. This polarized component in cosmic-muons will help to produce a asymmetry in the lifetime spectra in forward and backward detectors relative to an absorber where muon stops and decays. The lifetime of μ^- is different in different material due to the formation of muonic atom[3].

The details of determining the precession frequency and the local magnetic field, along with the study of muon lifetime for μ^+ and μ^- in iron will be presented in this paper.

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Study of $\Omega_c(3000)^0 \rightarrow \Xi_c^+ K^-$ decay using heavy hadron chiral perturbation theory (HHChPT)

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Topic(s): Standard model physics

Abstract:

Our attempt is to assign a possible spin-parity to the recently observed $\Omega_c(3000)^0$ baryon [1, 2]. The latest review article of Particle Data Group (PDG) reported its world-average mass 3000.41 MeV [3], which is close to the theoretical predictions of $1P$-wave states obtained in various potential models [4–7]. Here we want to analyze the decay $\Omega_c(3000)^0 \rightarrow \Xi_c^+ K^-$ into each possible quantum state of $1P$-wave. And, we try to compare the decay width of our calculation with the experimental value 4.5 ± 0.6 (stat) $\pm$ 0.3 (syst) MeV, measured with first statistical and second systematic uncertainties [2]. That can be used to confirm or reject the quantum number assignment of this newly observed $\Omega_c(3000)^0$ baryon. To calculate the strong decay of $\Omega_c(3000)^0$ baryon the heavy hadron chiral perturbation theory (HHChPT) is used, into which the spin-flavor symmetry of the heavy quark and the chiral symmetry of the light quarks are incorporated [8–10]. In addition, we will extend this scheme to analyze the strong decays of its ($\Omega_c(3000)^0$) experimentally observed sister states such as $\Omega_c(3050)^0$, $\Omega_c(3065)^0$, $\Omega_c(3090)^0$, and $\Omega_c(3120)^0$ [1, 2].

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Search for the rare decay $B_s \to \rho^0 \pi^0$ at $\Upsilon(5S)$ resonance using Belle detector

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Topic(s): Standard model physics

Abstract: The Belle experiment at KEK, Japan has at present one of the largest dataset accumulated at $\Upsilon(5S)$ resonance. This dataset produced at e^+e^- centre-of-mass (CM) energy of approximately 10.86 GeV corresponds to an integrated luminosity of 121.4 $(fb)^{-1}$ [**1**]. We plan to search for the rare decay $B_s \to \rho^0 \pi^0$ for the first time using the accumulated dataset.

The decay $B_s \to \rho^0 \pi^0$ is a neutral, charmless, charged current mediated, strangeness non-conserving decay and within the Standard Model (SM) propagates via W-exchange and W-annihilation Feynman diagrams. As the annihilation processes are highly suppressed within the SM they are mostly ignored in theoretical calculations. Nevertheless, as we are progressing towards an era where precision measurements will have greater role to play in discovering New Physics (NP), there contributions will have to be included and hence experimental measurements are necessary. Rough estimates of the branching fraction (BF) of these types of decays ranges between $10^{-6} - 10^{-8}$ depending on the type of models used. In perturbative QCD (pQCD) framework, the BF is predicted to be $(0.23 \pm 0.08) \times 10^{-6}$ [**2**]. Whereas, the QCD framework roughly estimates the BF at around $\sim 0.003 \times 10^{-6}$ [**3**]. However, no prediction from other approaches such as the flavor SU(3) symmetry exists yet. Moreover, phenomenological studies could not be performed on them because of lack of experimental data. As is evident, there exists a considerable disparity in the BF prediction between the two frameworks, an experimental search is always necessary to find a quantitative answer for such discrepancies which may be due to some NP contributions to the SM.

To perform this analysis, we first simulate the decay in an event generator and reconstruct the decay process from its final state particles using conservation of four momentum. We apply selection criteria to remove all the uninterested events and suppress backgrounds which mimics the decay process. As the final state consists of a neutral pion, the continuum background has to be further suppressed using multivariate analysis technique such as a neural network. The modelling of the events of interest will be done using probability distribution functions (PDF) which will be eventually used to extract the signal in the final dataset.

We expect to reach the SM sensitivity of the decay with the present data sample and put the first limits on the BF for this rare decay.

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Standard Model Drell-Yan cross section at N^{3}LO$_{sv}$+N^{3}LL accuracy in QCD at LHC

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Abstract: In this article we present we present the resummed predictions for inclusive cross-section for Drell-Yan (DY) production as well as onshell Z,W$^\pm$ productions at next-to-next-to-next-to leading logarithmic (N^{3}LL) accuracy. We use the standard procedure to derive the N-dependent and N-independent coefficients in Mellin-N space and match the resummed results with next-to-next-to-next-to leading order soft-virtual (N^{3}LO$_{sv}$) corrections. In addition to the standard $\ln N$ exponentiation, we study the numerical impacts of exponentiating N-independent part of the soft function and the complete $\bar{g}_0$ that appears in the resummed predictions in N space. All the analytical pieces needed in these different approaches are extracted from the soft-virtual part of the inclusive cross section known to next-to-next-to-next-to leading order (N^{3}LO). We perform a detailed analysis on the scale and parton distribution function (PDF) variations and present predictions for 13 TeV LHC for the neutral Drell-Yan process as well as onshell charged and neutral vector boson productions.

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Observation of electroweak production of $W\gamma$ and $Z\gamma$ with two jets at the LHC

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Topic(s): Standard model physics

Abstract: Studies of electroweak gauge bosons produced in LHC play crucial role in establishing the validity of the Standard Model at high energies. Electroweak production of a W or Z boson in association with a photon, and two jets with high dijet invariant mass and large separation in pseudorapidity has been observed for the first time at the LHC by CMS collaboration. For this analysis proton-proton collision data at centre-of-mass energy of 13 TeV collected in 2016, corresponding to an integrated luminosity of about 36 fb^{-1}, has been used . In this talk we shall present the experimental measurement of cross section of the process and the derived constraints on anomalous quartic gauge couplings in the context of effective field theory. [1], [2]

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Quarkonium spectroscopy via linear plus inverse square Yukawa potential model

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Topic(s): Standard model physics

Abstract:

Numerous potential models are used to calculates the various properties of the given quarkonium system. The investigation of quarkonium systems is widely studied by using the solution of the second order differential equation. We proposed linear plus inverse square Yukawa potential model (LISYP) is combination of the two potential, the linear potential and inverse square Yukawa potential as

$$V(r) = Ar + B\frac{e^{-\alpha r}}{r^2} = B\alpha^4 r^2 + (A - B\alpha^3)r - \frac{B\alpha}{r} + B(1+\alpha^2) \tag{1}$$

Solution of the D- dimensional radial Schrödinger equation with LISYP model obtained via Nikiforov-Uvarov (NU) method [1–3] as

$$E^D_{n\ell} = \frac{6B^{'}}{\delta^2} + \frac{3A^{'}}{\delta} + B(1+\alpha^2) - \frac{\frac{2\mu}{\hbar^2}\left(\frac{8B^{'}}{\delta^3} + \frac{3A^{'}}{\delta^2} + B\alpha\right)^2}{\left(2n + 1 \pm \sqrt{1 + \frac{16\mu}{\hbar^2}\left(\frac{A^{'}}{\delta^3} + \frac{3B^{'}}{\delta^4} + C^{'}\right)}\right)^2} \tag{2}$$

$$A^{'} = A - B\alpha^3,\ B^{'} = B\alpha^4,\ C^{'} = \frac{\hbar^2}{2\mu}\left(\frac{(D-1)(D-3)}{4} + \ell(\ell + D - 2)\right)$$

where A, B, C, δ are constants and α is screening parameter. To determine charmonium masses in the D-dimensional space for $\hbar = 1$, following relations used.

$$M_c = 2m_c + E^D_{n\ell} \tag{3}$$

m_c and $m_{\bar{c}}$ is mass of the charm quark and anti charm quark respectively. The properties of charmonuim meson have been calculated. Calculated results are in good agreement with experimental data and other theoretical studies [4–7].

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Isgur-Wise function for the semileptonic decay of Λ_b baryon

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Topic(s): Standard model physics

Abstract: In this study, we present exclusive semileptonic decay of $\Lambda_b^0 \to \Lambda_c^+ \ \ell^- \ \bar{\nu}_\ell$. The chosen semileptonic transition is one of the prominent decay channels out of the various available channels of the Λ_b baryon reported by PDG [**1**]. This particular semileptonic transition has been studied using many theoretical approaches such as Covariant Confined Quark Model [2], QCD Sum Rules [3], quark Model [4], Relativistic Quark Model [5], Light Front Approach [6] etc. The experimental group like LHCb collaboration [7] and DELPHI collaboration [8] are also reported their measurement on the slope parameter ρ^2 of the Isgur-Wise function.

The Isgur-Wise function for $\Lambda_b^0 \to \Lambda_c^+ \ \ell^- \ \bar{\nu}_\ell$ is studied in the framework of the phenomenological quark model. The six-dimensional hyperradial *Schrödinger* equation is solved in the variational approach to get masses and wavefunctions of heavy baryons [9,10]. The matrix elements of weak decay are written in terms of the overlap integrals of the baryon wave function. In the heavy quark limit, the six form factors which define semileptonic transition of $\Lambda_b^0 \to \Lambda_c^+ \ \ell^- \ \bar{\nu}_\ell$ are related to a unique universal Isgur-Wise function ($\xi(\omega)$). The present result for the slope (ρ^2) at the zero recoil of the Isgur-Wise function is in good agreement with experimental measurement as well as theoretical models. The calculated decay width for $\Lambda_b^0 \to \Lambda_c^+ \ \ell^- \ \bar{\nu}_\ell$ agrees with experimental observation.

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Decoding the low mass puzzle of $D_{s0}^*(2317)$

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Topic(s): Standard model physics

Abstract:

Seventeen years after the discovery of $D_{s0}^*(2317)$ meson [1, 2], the puzzle of its low mass is still not understood [3]. The observed mass of $D_{s0}^*(2317)$ is below DK threshold, and is much smaller than the mass of the corresponding state $D_s(1^3P_0)$ calculated in the various theoretical studies based on normal (quenched) potential model [4–7]. Such a meson has to decay by violating the isospin quantum number, called isospin-breaking mode [8]. In 2003, the *BABAR* [1] and the CLEO [2] Collaborations have subsequently reported the invariant mass distribution of $D_s\pi^0$ narrow resonance state at 2.317 GeV with a branching fraction $100^{+0}_{-20}\%$ of the total decay rate [3]. Our effort is to analyze the strong decay of $D_{s0}^*(2317)$ meson into the isopin violating mode $D_s\pi^0$ in the framework of heavy quark effective theory (HQET) [9, 10]. Moreover, the ratio of the decay rates $\Gamma(D_s^*(2112)\gamma)/\Gamma(D_s\pi^0)$ is also obtained. And, it can be confronted with the experimental measurements where available [3]. The $D_{s0}^*(2317)$ is still categorized into conventional P-wave strange charm meson family by introducing the $D_s\pi^0$ channel contribution [3]. Such a low mass puzzle is strongly affected by the coupled channel effect [11, 12], by which the resonance state $D_{s0}^*(2317)$ can not coupled with nearby DK threshold. We foresee to understand the low mass problem that exists in other states $\Lambda(1405)^0$, $D_{s0}(2460)^{\pm}$, $\Lambda_c(2940)^+$, and $X(3872)$ [3].

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Fermion Mass Matrices with $S_3 \times Z_3$ Symmetry

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Topic(s): Beyond standard model physics

Abstract: Recently large amount of efforts have been put into to understand fermion mass matrices which are in agreements with ever improving flavour mixing data. In particular, one of the popular approach has been to use the discrete symmetries for formulating viable set of fermion mass matrices[1–3]. However, most of the efforts are directed in formulating neutrino mass matrices which are able to accommodate neutrino oscillation data [4–6]. There are not many attempts to formulate mass matrices for quarks as well as leptons together using the same discrete symmetry group.

The purpose of the present work is to formulate and investigate the implications of mass matrices for quarks as well as leptons using a particular discrete symmetry group. In this context, it should be noted that the smallest non-Abelian symmetry group is S_3 [7, 8], being group of six permutations of three objects. It can be geometrically represented by the different rotations that leave invariant an equilateral triangle. An S_3-invariant extension of the SM requires the extension of the scalar sector as well. Furthermore, the Higgs sector of the standard model already has too many parameters which need to be determined. To increase the predictiability of the fermion mass matrices, the number of free parameters should be reduced. This demand can be met by changing the basis of fermion mass matrices from the adapted symmetry basis to the flavor basis. To acheive this, one can add some Abelian discrete symmetry group Z_n[9, 10] which is a cyclic symmetry group with n number of elements. In particular, we have considered the group $S_3 \times Z_3$ [11, 12], which provides interesting structure of the mass matrices. The phenomenological implications have been investigated in details, both in the quark as well as lepton sector.

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Probing Resonant Leptogenesis from Inverse and Linear seesaw based Neutrino Models with A_4 Flavour Symmetry

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Topic(s): Beyond standard model physics

Abstract: In this work we discuss the feasibility of how an additional sterile singlet neutrino can generate the observed baryon asymmetry of the universe (BAU) at TeV scale by carefully considering neutrino models through inverse and linear seesaw mechanisms, using operators upto dimension-six, within the framework of A_4 discrete flavour symmetry and some other discrete symmetries [**1**], like Z_2, Z_4 etc. The resonant effect of the CP-violating asymmetries of heavy Majorana neutrino decays is enhanced with their quasi-generate mass spectrum by manifesting the inverse and linear seesaw mass matrices as conventional type I seesaw variants. For consistency with the observed BAU, we take the values of the model parameters obtained from our recent work with the same neutrino models for Inverse seesaw (ISS) [**2**, **3**] and Linear seesaw (LSS) [**4**] scenarios. We constrain our models by testing their compliance with the recent global fit values of the BAU, and present a comparative study among the two seesaw models.

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Probing new physics in $B_d \to \phi\eta^{(\prime)}$ decay modes

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Topic(s): Beyond standard model physics

Abstract: We inspect the exclusive hadronic decay mode $B_d \to \phi\eta$ [1], induced by quark level transition as $b \to d$ ($\Delta S = 0$), in vector like down quark model. As this decay mode insists flavor changing neutral current (FCNC) transition in standard model, thus it is highly suppressed followed by the predicted branching fraction $\sim 10^{-9}$ which reflects to scrutinize physics beyond the standard model. We constrain the new parameter space inferred from experimental limits on leptonic $B_d \to \ell\ell(\ell = e, \mu, \tau)$[2], and nonleptonic decay modes $B_d \to \eta'\pi^0$ and $B_u \to \rho^-\eta'$[2]. We then check the new physics contributions can have significant impact on the prominent observable so called branching fraction. If this mode could be measured in LHCb experiment and/or Belle II Collaboration with good precision, then it will provide a clear signal of new physics.

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Sensitivity study of $B^+ \to D_s^{(*)+}\eta$ and $B^+ \to D_s^{(*)+}K_S^0$ decays at Belle

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Topic(s): Standard model physics

Abstract: $B^+ \to D_s^{+(*)}\eta$ and $B^+ \to D_s^{+(*)}K_S^0$ are poorly measured decays in the world. These rare decay $B^+ \to D_s^{+(*)}\eta$ ($B^+ \to D_s^{+(*)}K_S^0$) proceeds via the suppressed transition $b \to u$ (annihilation process). We plan to improve the measurement by using the full $\Upsilon(4S)$ data sample collected by the Belle detector situated at the KEKB e^+e^- asymmetric collider. We will present the sensitivity study using the Monte Carlo simulations and techniques used to suppress the background.

Compact Stars under Cosmic Acceleration: The Anisotropic behavior and nature in f(T) gravity under Strong Energy Condition

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Topic(s): Beyond standard model physics

Abstract: Anisotropic behavior of different compact stars using modified f (T) gravity has been investigated where T is torsional scalar quantity [1]. The local impact of quintessence field upon the compact stars has been studied mainly on the Neutron stars with a wide range of mass distribution. Using anisotropic property and concept of Massachusetts Institute of Technology bag model, required equations of motion are acquired [2] under the strong energy condition. The metric, derived by Krori, K.D. and Barua J. [3] with Reissner-Nordstrom metric [4] are compared to find out the different unknown parameters of this work. Some important parameters like anisotropic stress, adiabatic constant, surface redshift, compactness factor, stability etc. are also analyzed to get a clear idea for the further study on these types of stars and to understand their nature.

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Double Higgs production as an exclusive probe for a sequential fourth generation

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Topic(s): Beyond standard model physics

Abstract: It has been shown that the data from the Large Hadron Collider (LHC) does not rule out a chiral sequential fourth generation of fermions that obtain their masses through an identical mechanism as the other three generations. However, this is possible only if the scalar sector of the Standard Model (SM) is suitably enhanced, like embedding it in a type-II two-Higgs doublet model. We have tried to show that double Higgs production (DHP) can unveil the existence of such a hidden fourth generation in a very efficient way. While the DHP cross-section in the SM is quite small, it is significantly enhanced with a fourth generation. We perform a detailed analysis of the dependence on the DHP cross-section on the model parameters, and show that either the DHP is seen is the early next run of the LHC, or the model can be ruled out.

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Dark matter and neutrino mass in the radiative seesaw model

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Topic(s): Beyond standard model physics

Abstract: We study the simplest viable dark matter model with an additional neutral real singlet scalar, including a vectorlike singlet and doublet fermions. We find a considerable enhancement in the allowed region of the scalar dark matter parameter spaces in the presence of these fermions. This model could also accommodate tiny neutrino masses and mixing at one loop-level through the radiative seesaw mechanism. Dilepton+$\not{E}_T$ signature arising from the new fermionic sector can observe at Large Hadron Collider (LHC), satisfying relic density, including other theoretical and experimental bounds. We perform such analysis for a benchmark point in the context of 14 TeV LHC experiments with a future integrated luminosity of 3000 fb^{-1}.

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Transition form factors for $B_s \to D_s^{(*)}$ channels

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Topic(s): Standard model physics

Abstract: We compute the weak transition form factors for the channels $B_s \to D_s^{(*)}$ within the framework of covariant confined quark model with built-in infra-red confinement. We also compare our findings with different other theoretical approaches. Further the transition form factors are utilised for computing the semileptonic branching fractions. We observed that our preliminary results are found to be consistent with the most recent LHCb data.

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Vacuum instability in singlet scalar, inert doublet and mixed scalar Dark matter models

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Topic(s): Beyond standard model physics; Particle astrophysics and cosmology

Abstract: The stability of EW vacuum is gaining considerable attention from researchers during recent times. We study the one-loop vacuum stability bounds of scalar extensions of Standard Model (SM) - a singlet scalar (SSM), an inert scalar doublet (IDM) and a mixed scalar dark matter model (MSM). The singlet scalar model faces a large number of experimental and theoretical constraints, most notably from the results of direct detection experiments like XENON1T [1–3]. The inert scalar doublet model on the other hand can be valid up to the Planck scale (M_{PL}) [4, 5]. For the mixed scalar DM model we consider mixing between the singlet and the CP-even component of inert doublet dark matter particles. The lightest neutral Higgs that comprises of the CP-even component of inert doublet and the singlet scalar is considered to be the DM candidate[6]. Depending on the mixing, the dark matter can be dominated by either - the inert doublet or singlet scalar. We briefly review the bounds on the aforementioned models in such scenarios and identify parameter spaces that can lead to the electroweak (EW) vacuum stability. We also consider the current limits from XENON1T experiment to study the constraints on the parameter space of the models, and match our theoretical results with the same.

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Dark Matter in an Inverse Seesaw Model with A_4 Flavor Symmetry

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Topic(s): Beyond standard model physics; Neutrino physics

Abstract: The composition of dark matter (DM) remains as one of the unsolved puzzles in high energy physics. Many models have been proposed that can successfully describe more than one beyond standard model (BSM) experimentally established phenomenon, in a unified theory. Very recently, an Inverse seesaw model (ISM) with discrete A_4 flavor symmetry [1–3], has been proposed, that contains an additional sterile (SU(2) singlet) neutrino, and triplet and singlet flavons, in addition to the SM particles, and the model can successfully explain the observed light neutrino oscillation parameters. Some additional discrete symmetries are also added to forbid the unwanted terms in the Lagrangain. In this work, we attempt to explain the DM of the Universe in above mentioned ISM framework, where the lightest of the sterile neutrinos can be a viable DM candidate. We constrain our formalism with the currently allowed global fit values of the DM parameters[4–6].

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Jet and missing transverse momentum reconstruction performance in CMS Run 2 data

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Topic(s): Standard model physics

Abstract: Jets are experimental signatures of hadronic activity in a collision event while missing transverse momenta may point to particles escaping detection or imperfect energy/momenta measurements. The high pileup condition during Run 2 of LHC poses a challenge to the reconstruction algorithms. This talk summarises the studies done for measuring the performance of reconstructing these derived objects using Run 2 CMS data.

Hierarchy problem and dimension-6 effective operators

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Topic(s): Beyond standard model physics

Abstract: Without any mechanism to protect its mass, the self-energy of the Higgs boson diverges quadratically, leading to the hierarchy or fine-tuning problem. One bottom-up solution is to postulate some yet-to-be-discovered symmetry which forces the sum of the quadratic divergences to be zero, or almost negligible; this is known as the Veltman Condition [1, 2]. Even if one assumes the existence of some new physics at a high scale, the fine-tuning problem is not eradicated, although it is less severe than what it would have been with a Planck scale momentum cut-off [3–6]. We study such divergences in an effective theory framework, and construct the Veltman Condition with dimension-6 operators [7]. We show that there are two classes of diagrams, the one-loop and the two-loop ones, that contribute to quadratic divergences, but the contribution of the latter is suppressed by a loop factor of $1/16\pi^2$. The Wilson coefficients of these higher-dimensional operators play an important role towards softening the fine-tuning problem. We find the parameter space for the Wilson coefficients that satisfies the extended Veltman Condition, and also discuss why one need not bother about the $d > 6$ operators [8, 9]. The parameter space is consistent with the theoretical and experimental bounds of the Wilson coefficients, and should act as a guide to the model builders [10–13].

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Triggering long-lived particles in HL-LHC and the challenges in the first stage of the trigger system

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Topic(s): Beyond standard model physics

Abstract: Triggering long-lived particles (LLPs) at the first stage of the trigger system is very crucial in LLP searches to ensure that we do not miss them at the very beginning. The future High Luminosity runs of the Large Hadron Collider will have increased number of pile-up events per bunch crossing. There will be major upgrades in hardware, firmware and software sides, like tracking at level-1 (L1). The L1 trigger menu will also be modified to cope with pile-up and maintain the sensitivity to physics processes. In our study we found that the usual level-1 triggers, mostly meant for triggering prompt particles, will not be very efficient for LLP searches in the 140 pile-up environment of HL-LHC, thus pointing to the need to include dedicated L1 triggers in the menu for LLPs. We consider the decay of the LLP into jets and develop dedicated jet triggers using the track information at L1 to select LLP events. We show in our work that these triggers give promising results in identifying LLP events with moderate trigger rates.

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A fresh look at proton decay in SUSY SU(5)

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Abstract: We show that assuming flavour violation in the first two generations of sfermions in the decoupling limit leads to interesting consequences for proton decay. Assuming the decoupling sfermions lie within 30 TeV, for the decay mode $p \to e^+\pi^0$, which has sensitivity beyond that of DUNE and Hyper K is brought within the reach of those experiments. The most of the decay modes which is $p \to K^+\bar{\nu}_e$ which essentially rules this model out for this range of masses, is now able to survive and further interestingly can be explored at DUNE and HyperK. Finally partial decoupling has interesting consequences for the mode $p \to K^+\bar{\nu}_\tau$.

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Diluting SUSY flavour problem on the Landscape

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Abstract: We consider an explicit effective field theory example based on the Bousso-Polchinski framework with a large number N of hidden sectors contributing to supersymmetry breaking. Each contribution comes from four form quantized fluxes, multiplied by random couplings. The soft terms in the observable sector in this case become random variables, with mean values and standard deviations which are computable. We show that this setup naturally leads to a solution of the flavor problem in low-energy supersymmetry if N is sufficiently large. We investigate the consequences for flavor violating processes at low-energy and for dark matter.

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Modified dark matter region with singlet scalar under *scotogenic* model

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Topic(s): Beyond standard model physics

Abstract: We study a simplest viable dark matter model with a real singlet scalar, vector-like singlet and doublet fermion [1] under the well established *scotogenic* model by E. Ma [2]. We find a considerably enhanced allowed region of the scalar dark matter parameter spaces. The decay of the lightest component of the fermion doublet ignite the lepton number violating process, which produces sufficient lepton asymmetry in the strong wash-out regime, lead to the successful execution as explanation of observed baryon asymmetry $Y_B = 8.75 \pm 0.023 \times 10^{-11}$[3]. This model could also accommodate the discrepancy of the muon anomalous magnetic moment that is observed as [4, 5]: $\delta a_\mu = a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = (2.74 \pm 0.73) \times 10^{-9}$ and $\delta a_e = a_e^{\text{exp}} - a_e^{\text{SM}} = -(8.8 \pm 3.6) \times 10^{-13}$. Hence, under this radiative model we cover tiny neutrino mass and mixing angles and dark matter. Dilepton+$\not{E}_T$ signature arising from the new fermionic sector can observe at Large Hadron Collider (LHC) [1, 6, 7]. We perform such analysis for a benchmark point in the context of 14 TeV LHC experiments with a future integrated luminosity of 3000 fb^{-1}. We are getting significant results from the collider searches for the discovery of dark matter in future 14 TeV run.

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Quarkonia spectroscopy in pNRQCD framework.

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Topic(s): Standard model physics

Abstract: We compute mass spectra and various decay properties of charmonium and bottomonium, adding $\frac{1}{m^2}$ relativistic correction in the framework of pNRQCD to the Cornell potential. The decay properties have been calculated using the same set of parameters used for calculating mass spectra. The computed mass spectra and decay properties[1–3] are compared with theoretical and experimental available data and is found to be in good agreement with experimental data.

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Recent CMS results on soft and small-x QCD physics

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Topic(s): Standard model physics

Abstract: Quantum chromodynamics (QCD), the theory of strong nuclear interactions, is undoubtedly a very rich and successful theory. There are interesting phenomena in nuclear interactions which have yet to be seen, phenomena that are ultimately related to the properties of color confinement and asymptotic freedom of the strong interactions. These effects can take place in special corners of phase space accessible at the Large Hadron Collider (LHC). More concretely, it is not clear whether a gluon-gluon recombination mechanism takes place at low values of the fraction of the nucleon momentum x carried by its partonic constituents. Said mechanism is believed to slow down the rapid growth of the nucleon's structure function at very small values of x.

On the other hand, we have to refine our understanding of the underlying dynamics in low momentum exchange processes in hadronic collisions. The description of these effects rely on phenomenological models, whose parameters are tuned based on fits to data. Dedicated measurements provide valuable inputs for Monte Carlo event generators, which are of great importance for precision measurements of Standard Model processes and searches for New Physics at the LHC.

Latest results of soft and small-x QCD measurements with the CMS experiment, such as minimum bias/underlying event physics, and studies on forward jet production is presented.

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Search for rare annihilation decay $B^0 \to J/\psi\gamma$ using 771 million $B\bar{B}$ events at Belle

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Topic(s): Standard model physics

Abstract: The physics potential of the rare annihilation decays $B^0 \to J/\psi\gamma$ in the framework of standard model and beyond using 771 million $B\bar{B}$ events collected at $\Upsilon(4S)$ resonance by Belle detector at the KEKB asymmetric energy e^+e^- collider are being investigated in this analysis. In a naive factorization approach [1], the expected branching fraction is 1.6×10^{-6} at 90% CL. If there is any enhancement in the decay rate of $B^0 \to J/\psi\gamma$, it will be due to charged right handed currents (V+A) in addition of (V-A), and this admixture will give a significant contribution to the new physics. In this analysis, only leptonic final state for the reconstruction of J/ψ is used. To estimate signal efficiency, 100,000 signal events are generated and detector response is simulated by using GEANT4. Photons are reconstructed from clusters in the electromagnetic calorimeter (ECL) and are required to have energies (in the lab frame) greater than 100 MeV. We veto candidate photons from $\pi^0 \to \gamma\gamma$ and $\eta \to \gamma\gamma$ by combining them with any other photon and then by rejecting both γs in the pair if the $\pi^0(\eta)$ likelihood is greater than 0.25 (0.25). The background from hadronic decays of B mesons is estimated using a large MC sample having size 100 times that of data and is dominated by $B^0 \to J/\psi\pi^0$, $B^0 \to J/\psi K_L$, $B^0 \to J/\psi K_S$ and $B^0 \to J/\psi\eta$ which are being modeled using different PDFs. The reconstruction efficiency is (33.9 ± 0.2) % from 3-dimensional fit of ΔE $(E_{reco.} - E_{beam})$, beam-constrained mass $M_{\rm bc} \equiv \sqrt{E^{*2}_{\rm beam} - p^{*2}_B}$, and helicity of J/ψ $(\cos(\theta))$. Further, it has been found that there is no threat from continuum background and no bias was found in the fitter as confirmed using ToyMC and GSIM studies. Concludingly, we have described the full event selection criteria for decay $B^0 \to J/\psi\gamma$ and using large data sample of Belle, we are expecting a first evidence or better upper limit on this analysis from the previous measurement on upper limit of $1.6 \times 10^{-6} (1.5 \times 10^{-6})$ by BaBar (LHCb) [2, 3].

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Search for top quark associated Higgs boson production using full Run-2 data in CMS

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Topic(s): Standard model physics

Abstract:

An overview of the search for top quark associated Higgs boson production ($t\bar{t}H$ and tH) using full Run-2 proton-proton collision data (137.1 fb^{-1}) collected by the CMS experiment at center-of-mass energy of 13 TeV will be presented. This will cover Higgs decays into final states involving pairs of b-quarks, photons as well as final states involving leptons (electrons, muons and taus). This search is important in providing a direct probe of the top-Higgs Yukawa coupling which might be influenced by beyond standard model physics. Comprehensive details about search strategies e.g. event categorization, background estimation and signal extraction will be provided. The overview will conclude with the latest CMS results[1, 2] on this search.

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Lepton Identification in Belle II

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Topic(s): Standard model physics

Abstract:

The Belle II experiment at the SuperKEKB energy-asymmetric e^+-e^- collider is an upgraded version of the Belle experiment which aims to record the 50 ab^{-1} of data. The designed luminosity for the SuperKEKB collider is $8.0 \times 10^{43} cm^2 s^{-1}$ which is 40 times larger than its predecessor. The powerful Particle Identification (PID) is the main aspect of any high energy physics experiment. Several physics analysis measurements involving flavor physics such as B decays can only be possible due to good PID. In Belle II, Particle Identification is done by the Time-Of-Propagation (TOP) counter in the central (barrel) region and the Aerogel Ring Imaging Cherenkov (ARICH) counter in the forward end cap region. With the available data set, we aim to report the Lepton mis-identification probabilities sampled from $D^{*+} \to [D^0 \to K^- \pi^+]\pi^+ decay$ in Belle II.

Study of energy deposition patterns in hadron calorimeter for prompt and displaced jets using convolutional neural network

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Topic(s): Beyond standard model physics

Abstract:

Many BSM scenarios motivate the existence of long lived particles (LLPs) which have moderately large lifetimes and decay after traveling macroscopic distance in the collider detectors ($\gtrsim \mathcal{O}(\text{cm})$). However since standard LHC searches were mostly designed for prompt particles, LLP searches need special attention.

Sophisticated machine learning techniques have promising potential in search for physics beyond Standard Model in Large Hadron Collider (LHC). Convolutional neural networks (CNN) can provide powerful tools for differentiating between patterns of calorimeter energy deposits by prompt particles of Standard Model and long-lived particles predicted in various models beyond the Standard Model.

We demonstrate the usefulness of CNN by using a couple of physics examples from well motivated BSM scenarios predicting long-lived particles giving rise to displaced jets. Our work [1] suggests that modern machine-learning techniques have potential to discriminate between energy deposition patterns of prompt and long-lived particles, and thus, they can be useful tools in such searches.

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Annihilation widths of J/ψ using Cornell potential

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Topic(s): Standard model physics

Abstract: We compute the mass spectra of charmonia using the framework of nonrelativistic potential model. For present computation we consider the Cornell potential for quark-antiquark interaction. Using the potential parameters, we compute selected weak decay properties such as decay constant and annihilation widths including dileptonic, $\gamma\gamma\gamma$, ggg, γgg decay widths. We further compare our findings with different theoretical approaches and available experimental data.

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Hybrid Seesaw model based on A_4 Symmetry and relic density of dark matter

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Topic(s): Beyond standard model physics; Neutrino physics

Abstract: The Standard Model(SM) of particle physics is an effective low energy theory explaining most of the dynamical phenomena emanating from interaction amongst fundamental particles. Despite its great success, SM is inadequate to explain (i) non-zero neutrino mass (ii) existence of dark matter and (iii) matter anti-matter asymmetry in the universe. The results from the study of galactic rotation curves [1], gravitational lensing [2] and cosmic microwave background (CMB) [3] has assured the existence of dark matter, in general. A cohesive approach may be required to understand the underlying mechanism explaining these theoretical unknowns. Out of various extensions of the SM, non-abelian symmetries within the framework of seesaw mechanisms, are widely discussed to explain small neutrino mass. In this work, we have adopted a hybrid approach to explain neutrino mass and relic density of dark matter. We implement inverse seesaw [4] in conjunction with type-II seesaw [5] mechanism in a model based on A_4 symmetry to realize observed pattern of neutrino masses and mixing. Non-abelian discrete A_4 symmetry spontaneously breaks into Z_2 subgroup and hence provide stable dark matter candidate [6, 7]. We have, also, imposed the Z_3 cyclic symmetry to avoid unwanted Yukawa couplings. We have observed that the correct choice of dark matter candidate mass, mediator particle mass and Yukawa coupling results in relic density of dark matter as observed in PLANCK 2018 [8]. For the dark matter candidate mass around 45 GeV-55 GeV, we obtain the mediator particle mass(right-handed neutrinos) ranging from 138 GeV to 155 GeV. Furthermore, Yukawa coupling is found to be in the range 0.99-1 in order to get observed relic abundance of dark matter.

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Kinematic fitting of Neutral Current events in the lepton proton Deep Inelastic Scattering.

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Topic(s): Standard model physics

Abstract: In this paper we present the technique to perform a kinematic fit to reconstruct the kinematic variables, in the neutral current events from the Deep Inelastic Scattering (DIS) [1][2] of electron on protons at the HERA energies, using Bayesian approach [3][4]. This technique uses the four directly measured quantities (energy and angles of electron and jets) in the final state as input. The output from the fit are the scaling variables x and y and energy of initial state radiation (E_γ) which otherwise goes undetected close to the beam pipe. The initial state radiation changes the incoming lepton energy which changes the center of mass energy available for the DIS process. A better resolution in the reconstruction of scaling variables has been achieved using a Kinematic fit.

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Properties of [cc][$\bar{c}\bar{c}$], in a non-relativistic quark model

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Topic(s): Standard model physics

Abstract:

In this particular report we aim to present our study the spectroscopy of a fully charmed tetraquark T_{4c} composed of [cc][$\bar{c}\bar{c}$], in the non-relativistic model [**1**]. We treat four body problem in to two body problem by making it color triplet and antitriplet diquark and antidiquark configuration respectively. To form a color singlet tetraquark the diquark and antidiquark need to be combined accordingly $|qq| - |\bar{q}\bar{q}|\rangle : \bar{3} \otimes 3 = 1 \otimes 8$ which makes the one-gluon exchange potential to attractive.

The Schrödinger equation have been solved numerically with a Cornell-inspired potential (a very well known and accepted model for charmonium) to study the spectroscopy of [cc][$\bar{c}\bar{c}$] state [**2**, **3**]. We have incorporated the contribution of the one gluon exchange, confinement along with spin-dependent interaction to understand the behavior of the fully charmed tetraquark T_{4c} with the inclusion of radial and orbital excitation.

To describe the splitting structure of charmonium ($c\bar{c}$) spectrum and the interaction between diquarks, spin-dependent terms i.e. spin-spin, spin-orbit and tensor have been used. We observed that in the diquark-antidiquark [cc][$\bar{c}\bar{c}$] system, despite of being heavy diquark mass, contribution from spin-dependent terms are significant and the diquarks have finite size if they are treated as c$\bar{c}$ system[**4**].

We have fixed the parameters in our model, which are obtained by recent experimental data on charmonium and obtained satisfactory description of the charmonium spectrum. The results obtained from our calculation shows that the lowest S-wave tetraquarks lie below the (anti)diquark threshold mass, and might dissociate spontaneously into low lying charmonium pairs, whereas the radial and orbital excitation would be mostly lie above the corresponding charmonium pair thresholds. Our results are in good agreement with recently experimentally observed states [**5**].

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Rediscovery of $D^0 \longrightarrow K_S^0 K_S^0$ with early Belle II data

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Topic(s): Beyond standard model physics

Abstract: The decay $D^0 \to K_S^0 K_S^0$ is a singly Cabibbo-suppressed transition that involves the interference between $c\overline{u} \to s\overline{s}$ and $c\overline{u} \to s\overline{s}$ amplitudes, mediated by the exchange of a W boson at the tree level, that can generate CP asymmetries at the 1% level, even if the Cabibbo-Kobayashi-Maskawa phase is the only source of CP. Moreover, the CP asymmetry is non vanishing only when $SU(3)_F$ is broken. Both these features make the $D^0 \to K_S^0 K_S^0$ mode quite important in the understanding of the origin of CP violation in charm decays. Current experimental measurements of the CP asymmetry in $D^0 \to K_S^0 K_S^0$ decays are still limited by the statistical precision, with the best measurement performed by Belle using integrated luminosity of 921 fb^{-1} : $A_{CP}(D^0 \to K_S^0 K_S^0) = (-0.02 \pm 1.53 \pm 0.02 \pm 0.17)\%$ [1], where the first uncertainty is statistical, the second systematic and the third due to the CP asymmetry of the reference $D^0 \to K_S^0 \pi^0$ mode. In this work, our goal is to "rediscover" the $D^0 \to K_S^0 K_S^0$ decay in early Belle II data, where Belle II is the upgraded experimental facility at SuperKEKB, KEK, Japan.

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LNV meson decays as a probe of Majorana neutrino

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Topic(s): Beyond standard model physics; Neutrino physics

Abstract: Rare meson decays work as an interesting probe of lepton number violation (LNV). The LNV meson decays such as $M_1^+ \to \ell_1^+ \ell_2^+ M_2^-$ and $M_1^+ \to M_2 \ell_1^+ \ell_2^+ M_3^-$ are sensitive to the low right-handed (RH) neutrino mass scale (in the few 100 MeV-few GeV range) [1, 2]. In this mass range, the processes, mediated via the RH neutrinos, are resonantly enhanced. The rare LNV meson decays are complementary to the collider searches which are sensitive to GeV - TeV mass scale of the RH neutrinos. We looked for three body meson and tau decays, mediated via theese RH neutrinos. Being free from any nuclear matrix uncertainty, these rare decays can be more accurately evaluated compared to $0\nu\beta\beta$. Albeit their small decay rates, they may be accessible at various ongoing and proposed beam dump and collider experiments. Few of them are NA62 (K^+), SHiP(D, D_s), MATHUSLA(B,D), FCC-ee(B), Belle-II(B) etc.

We also proposed to persue a study on the four body LNV meson decay $M_1^+ \to M_2 \ell_1^+ \ell_2^+ M_3^-$ for this model. Four body meson decays are suppressed compared to three body meson decays due to phase space suppression. However, if the transition M_1^+ to M_2 is Cabibbo favoured then the four body meson decays can have sizable rate. One such example is $B_c^+ \to B_s^0 \ell_1^+ \ell_2^+ \pi^-$ decay mode [3]. For the $c \to s$ decay, it will be a Cabibbo favoured transition. Hence, the mode $B_c^+ \to B_s^0 \ell_1^+ \ell_2^+ \pi^-$ is expected to have a significantly large branching fraction.

In evaluating these LNV meson decays we have also taken into account the effect of detector length. For small masses of RH neutrinos in the MeV range, the decay width of the RH neutrinos will be very small. Hence, the neutrinos will have displaced decays. The number of signal events within the detector crucially depend on the detector length [1]. We show that inclusion of parent meson velocity further increase the decay length. In view of this, it is preferable to consider large detector length for beam dump experiments to observe these meson decays.

All of the above discussions are valid when only one RH neutrino contributes. The branching ratios of the LNV meson decays change dramatically, if more than one RH neutrino state with almost degenerate masses contribute in these processes [4, 5]. The predictions for LNV and lepton number conserving (LNC) meson decay rates can then widely differ due to the interference amongst the contributions of different RH neutrinos. In this case the ratio of LNV and LNC decay rate can vary between 0 to 1.

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Mass Spectra and Flavor Changing Decays of B, B_S Mesons in a Relativistic Independent Quarks

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Topic(s): Standard model physics

Abstract: By studying the features of the mass spectra and the decay properties of the B and B_S mesons, we take a relativistic independent quark model. We have set up the square root potential of the Quark confinement with its parameters determined from a fit to the mass spectra of B and B_S mesons. The calculated results are listed on the S-wave are very consistent with experimental and other theoretical predictions [1]. We also estimated the pseudoscular decay constant (f_p), radiative decay widths, mesonic decay widths, leptonic decay widths and the mesonic decay branch ratio, BR ($B^+ \to \tau + \nu_\tau$), $B_S^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$. This is in line with the research data announced by CMS and LHCb Collaborations [2–5]. The magnitude of the pseudoscalar decay width of the B meson $f_B(1S) = 196.52$ MeV is closely related to the test results of UKQCD Collaboration, Fermilab [6–8]. The magnitude of the pseudoscalar decay width of the B meson $f_{B_S}(1S) = 226.15$ MeV is also consistent with recent lattice QCD and QCD sum rule [6, 9–18]. Results obtained using this independent quark model. It is experimental and agrees with Lattice and other theoretical models. The Cabibbo-flavored mesonic branching ratios of $B^0 \to D^-\pi^+(3.224\times10^{-3})$, $B^0 \to D^{*-}\pi^+(3.125\times10^{-3})$, and $B_S \to D_S^-\rho^+(3.621\times10^{-3})$ remain a unanimity with the PDG values [1]. Finally, our forecast results for the hybrid parameters X_q and χ_q of $B^0 - \bar{B}^0(X_d = 0.771, \chi_d = 0.1860)$ and $B_S - \bar{B}_S(X_S = 26.44, \chi_S = 0.4993)$ are very consistent with Particle Data Group Value [1].

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Inelastic Fermion Dark Matter Origin of XENON1T Excess with Muon $(g-2)$ and Light Neutrino Mass

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Topic(s): Beyond standard model physics; Particle astrophysics and cosmology

Abstract: Motivated by the recently reported excess in electron recoil events by the XENON1T collaboration over the background in the recoil energy E_r in a range 1-7 keV, peaked around 2.4 keV [1], we propose an inelastic fermion dark matter (DM) scenario [2-4] within the framework of a gauged $L_\mu - L_\tau$ extension of the standard model [5-7] which can also accommodate tiny neutrino masses as well as anomalous muon magnetic moment $(g-2)_\mu$. A Dirac fermion DM, naturally stabilised due to its chosen gauge charge, is split into two pseudo-Dirac mass eigenstates due to Majorana mass term induced by singlet scalar which also takes part in generating right handed neutrino masses responsible for type I seesaw origin of light neutrino masses. If the mass splitting between these two mass eigenstates is appropriately tuned, the heavier component can be long-lived and can comprise a significant fraction of total DM density in the present universe. Here we show that inelastic fermion DM can give rise to the required electron recoil events observed by XENON1T while at the same time being consistent with relic abundance, muon $(g-2)$ and light neutrino mass criteria. The inelastic down scattering of heavier DM component can give rise to the XENON1T excess for keV scale mass splitting with lighter DM component. We fit our model with XENON1T data and also find the final parameter space by using bounds from $(g-2)_\mu$ [8], DM relic [9], lifetime of heavier DM, inelastic DM-electron scattering rate, neutrino trident production rate [10] as well as other flavour physics [11,12], astrophysical and cosmological observations [13]. A tiny parameter space consistent with all these bounds and requirements will face further scrutiny in near future experiments operating at different frontiers.

While inelastic DM as an origin of XENON1T excess has already been pointed out in hidden sector DM models (where DM is a SM singlet but charged under hidden sector symmetry and hence interact with the SM particles via kinetic mixing), our framework provides a scenario where both DM and SM are charged under the additional gauge symmetry and hence DM-SM interaction happens without kinetic mixing. This is a crucial difference which not only leads to a better prospects of detection, specially in the context of several muonic probes , but also gives a different DM phenomenology in the context of early universe compared to hidden sector models.

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Connecting Low scale Seesaw for Neutrino Mass and Inelastic sub-GeV Dark Matter with Abelian Gauge Symmetry

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Topic(s): Beyond standard model physics; Particle astrophysics and cosmology

Abstract: We propose low scale seesaw scenarios for light neutrino masses within $U(1)_X$ gauge extension of the standard model that also predicts stable as well as long lived dark matter candidates. The new fields necessary for seesaw realisations as well as dark matter are charged under the $U(1)_X$ gauge symmetry in an anomaly free way. A singlet scalar field which effectively gives rise to lepton number violation and hence Majorana light neutrino masses either at tree or radiative level, also splits the dark matter field into two quasi-degenerate particles. While non-zero neutrino mass and non-zero dark matter mass splitting are related in this way, the phenomenology of sub-GeV scale inelastic dark matter can be very rich if the mass splitting is of keV scale. We show that for suitable parameter space, both the components with keV splitting can contribute total dark matter density in the present universe, while opening up the possibility of the heavier dark matter candidate to undergo down-scattering with electrons. We check the parameter space of the model for both fermion and scalar inelastic dark matter [1-3] which can give rise to the recent excess of electron recoil events reported by the XENON1T experiment [4] while being consistent with other phenomenological bounds [5-8]. We also discuss the general scenario where mass splitting between two dark matter components can be larger, effectively giving rise to a single component dark matter scenario.

We discuss three seesaw scenarios [9-10] i.e. inverse seesaw, a variant of type-II seesaw and a radiative seesaw mechanism which can be realised at low scales unlike the conventional seesaw mechanisms and connect the light neutrino mass origin with sub-GeV inelastic DM. Since all such seesaw models have similar DM phenomenology, we study the latter for a sub-GeV inelastic DM whose interactions with SM relies primarily on kinetic mixing of $U(1)_X$ gauge symmetry with $U(1)_Y$ of the SM. We calculate the relic abundance of DM and constrain the parameter space from all available bounds and the requirement of fitting XENON1T electron recoil excess.

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Distinguishing Beyond the Standard Model Scenarios at Colliders

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Topic(s): Beyond standard model physics

Abstract: Beyond the Standard Model (BSM) scenarios are motivated as solutions to the shortcomings of the Standard Model. Many such scenarios predict various resonances with different spins. However, the Large Hadron Collider (LHC) being a hadronic machine, the centre of mass(CM) frame of the colliding partons are not known, and hence, neither the angular distributions of the scattered states at the CM frame. We showed how longitudinal boost can be estimated from the final states, which then can be instrumental in measuring the spins of such BSM particles at LHC[**1**]. In similar context we also explored the electron-photon colliders in probing Leptoquark productions and zeros in the cross-section in their angular distributions. Different such leptoquark models can be distinguished using these angular distributions in a scattering involving a photon[**2**]. Later part of our studies are performed for electron-proton colliders for the final states involving a leptoquark and a photon.

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Standard parameter degeneracies in presence of non-standard interactions with DUNE and T2HKK

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Topic(s): Beyond standard model physics; Neutrino physics; Detector development, future facilities and experiments

Abstract: Current neutrino oscillation experiments have determined the values of various neutrino oscillation parameters with an unprecedented accuracy. The future long baseline experiments are, primarily, focused on the determination of unknowns like sign of Δm^2_{23}, octant of θ_{23}, CP phase δ and probing sub-dominant oscillation effects emanating from non-standard interactions(NSIs) [1, 2]. There are certain discrepancies in the measurement of these unknowns which arise due to the presence of standard parameter degeneracies [3–5] in neutrino oscillation experiments.

In the present work [6], we have investigated these standard parameter degeneracies in presence of NSIs with long baseline experiments, DUNE [7] and T2HKK [8]. We have simulated these experiments using GLoBES software [9, 10]. We study the sign-degeneracy or mass hierarchy degeneracy considering two cases(i) when all NSI parameters are non-zero and (ii) with one non-zero off-diagonal NSI parameter. We find that in the later case the sign-degeneracy can be resolved with DUNE and T2HKK experiments due to relatively small uncertainties arising from the NSI sector. DUNE shows stronger hierarchy sensitivity for $-180^o < \delta < 0^o$ in true NH than true IH case with maximum sensitivity at $\delta \approx -60^o(15\sigma C.L.)$, whereas for $0^o < \delta < 180^o$ the hierarchy sensitivity in true IH case is stronger and is maximum at $\delta \approx 40^o(11\sigma C.L.)$. T2HKK shows stronger hierarchy sensitivity in true NH case than true IH case for the region $-90^o < \delta < 90^o$ at $5\sigma C.L.$. Neutrino and antineutrino modes are examined to investigate the octant degeneracy. We find that to resolve this degeneracy, long baseline experiments with both neutrino and antineutrino modes are required. Furthermore, we have studied DUNE and T2HKK to examine CP phase degeneracy due to standard and non-standard CP phases. We find that DUNE and T2HKK, in conjunction, show higher sensitivity for discovery reach of CP violation effects in presence of matter NSIs.

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Mass spectrum and decay constants of heavy-light scalar and axial quarkonia

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Topic(s): Standard model physics

Abstract: There has a been a renewed interest in recent years in spectroscopy of heavy hadrons in charm and beauty sectors, which was primarily due to experimental facilities the world over such as BABAR, Belle, CLEO, DELPHI, BES etc.[**olive14**, **zyla20**], which have been providing accurate data on $c\bar{c}$, and $b\bar{b}$ hadrons with respect to their masses and decays.

A lot of investigation has been carried out on S-wave mesons such as pseudoscalar (0^{-+}), and vector (1^{--}) quarkonia, while comparatively lesser investigation has been carried out on P-wave quarkonia such as scalar (0^{++}), and axial (both 1^{++} and 1^{+-}). Further, new states are continuously being discovered at experimental facilities around the world. Some of the recently discovered P-wave conventional quarkonium states are: $h_b(1P), h_b(2P), \chi_{b1}(3P)$ and $\chi_{b2}(3P)$[**patrignani16**]. There are also a number of unconventional states named(X, Y, Z) that were discovered, that do not fit into conventional quarkonium states, and are believed to be strong candidates for non-conventional hadronic states. Amongst these states are $Z_c(3900)$ and $Z_c(4430)$, whose quantum number assignments have been confirmed to be 1^{+-} as per the Particle Data Group (PDG) 2020 tables[**zyla2020**]. Further there is a lack of knowledge of decay constants of axial meson states in general.

Thus, the present work involves calculation of mass spectrum and leptonic decay constants of ground and excited states of P-wave mesons in the framework of a QCD motivated Bethe-Salpeter equation (BSE). These are scalar 0^{++} and axial vector (both 1^{++},and 1^{+}) heavy-light ($c\bar{u}, c\bar{s}, b\bar{u}, b\bar{s}$, and $b\bar{c}$ quarkonia. We have made use of the exact treatment of the spin structure $(\gamma_\mu \bigotimes \gamma_\mu)$ in the interaction kernel. In this 4×4 BSE framework, the coupled Salpeter equations for $Q\bar{q}$ hadrons (that are more involved than the equal mass $(Q\overline{Q})$ mesons) are first shown to decouple for the confining part of interaction, under heavy-quark approximation, and analyically solved, and later the one-gluon-exchange interaction is perturbatively incorporated, leading to their mass spectral equations, and is an extension of the previous works[**eshete19**, **lmenew18**] on pseudoscalar and vector quarkonia. We have worked out the contribution of the one-gluon-exchange (OGE) interaction to the masses of all hadronic states. The analytic forms of 3D wave functions are obtained as a solutions of the mass spectral equations. We have obtained plots of these wave functions as a function of internal momentum, $\hat{q}$ of the hadron. These wave functions not only provide information about the long range non-perturbative physics, but also tell us the shortest distance to which they can penetrate in a hadron. These feature is also supported by the percentage contribution of OGE interaction to hadron mass. It is in this sense the computed wave functions are physically reasonable and can build a "bridge" between the long distance non-perturbative physics, and the short distance perturbative physics. The analytic forms of wave functions obtained from these equations are then used for calculation of leptonic decay constants of ground and excited states of 0^{++}, $1^{+-}$and 1^{+-} as a test of these wave functions and the over all framework.

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Vacuum Stability in Inert Higgs Doublet Model with Right-handed Neutrinos

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Topic(s): Beyond standard model physics

Abstract: The status of Standard Model vacuum stability with generic problems beyond Standard Models (BSM) will be scrutinised. We will see how addition of scalar from different SU(2) representations, i.e. Inert Higgs Doublet model (IDM) and Inert Higgs triplet model (ITM) enhance the stability of electroweak vacuum. Addition of fermions can decrease the stability and need additional scalar to get to the stability which would be clear while discussing the extension with Type-I Seesaw and IDM. Finally we also see for Type-III seesaw +IDM due to SU(2) triplet fermions, the impact on g_2 is visible and it increases with energy unlike SM or Type-I Seesaw and IDM. This constraints the fermion generation to only two for Planck scale stability. Dark matter and collider phenomenologies will also be discussed briefly.

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Performance of Lepton Identification at Belle II

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Topic(s): Standard model physics

Abstract: Belle II, the successor of Belle experiment, has been successfully collecting data since 2019 aiming to collect 50 ab^{-1} data at a peak luminosity of 8×10^{35} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$, which is 40 times higher than Belle. Identification of charged final-state particles is a key feature of any flavour physics experiments such as Belle/Belle II. These particles are identified based on the measurement input from different sub-detectors. In particular, electrons are identified mainly using the energy measurement by the Electromagnetic CaLorimeter (ECL) whereas the muon identification relies on the difference in longitudinal penetration depth and transverse scattering of the related track extrapolated to the KL and Muon detector (KLM). At low momentum ($0.4 < p < 0.8$ GeV/c) the electron-pion and muon-pion separations are rather poor. A new machine learning based approach has been developed exploiting a number of weak classifiers in order to improve the lepton identification performance. We shall discuss the development and performance of such advanced particle ID methods used within Belle II.

Impact of modular S_3 symmetry on neutrino mixing and leptogenesis with type III seesaw

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Topic(s): Beyond standard model physics

Abstract: Discrete symmetries are being preferred to explain the neutrino phenomenology, since these provide a specific flavor structure to the neutrino mass matrix. We chose the simplest discrete group S_3, where the usual scenario requires multiple number of scalar doublets, which leads to certain complications in explaining FCNCs and VEV alignments [1, 2]. Thus we explore the impact of modular S_3 symmetry on neutrino mixing and leptogenesis within the framework of type III seesaw. In the present context, the couplings transform non-trivially under the symmetry and replaces the requirement of multiple scalars [3, 4]. Since the scenario of type III seesaw is less frequented as compared to type I or type II, we explore a detailed analysis of neutrino mixing consistent with the 3σ observation. Numerical diagonalization of the flavored neutrino mass matrix provides an explanation of neutrino masses and mixing parameters in terms of the Yukawa couplings. Thus all the model parameters can be constrained from the neutrino oscillation data and the observed sum of active neutrino masses to obtain the correct ranges for the model predicted mixing angles and CP phase. Here, we can have nonzero values of reactor mixing angle and Dirac CP phase to satisfy the current experimental limit. Apart, we also discuss the scenario of resonant leptogenesis by generating the lepton asymmetry from the decay of lightest heavy fermion triplet to the final state lepton and Higgs [5, 6]. We solve the coupled Boltzmann equations to explain the evolution of lepton asymmetric number density to obtain an observed baryon asymmetry of order $Y_B \approx \mathcal{O}(10^{-11})$.

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A dark clue to seesaw and leptogenesis in singlet doublet scenario with (non)standard cosmology

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Topic(s): Beyond standard model physics

Abstract: We present an appealing alternative scenario of leptogenesis assisted by dark sector which leads to the baryon asymmetry of the Universe satisfying all theoretical and experimental constraints. We adopt the singlet doublet fermionic dark matter framework [1, 2] with the inclusion of copies of a singlet scalar field within this dark sector. A small Majorana mass term for the singlet fermion, in addition to the typical Dirac term, provide the more favourable dark matter of pseudo- Dirac type, capable of escaping direct search. Such a construction also offers a pivotal role in the radiative generation of active neutrino masses. In the presence of a (non)standard thermal history of the Universe, we perform the detailed dark matter phenomenology adopting the suitable benchmark scenarios [3], consistent with direct detection and neutrino oscillations data. Besides, we have demonstrated that the singlet scalars can go through CP-violating out of equilibrium decay, producing an ample amount of lepton asymmetry [4, 5]. Such an asymmetry then gets converted into the observed baryon asymmetry of the Universe through the non-perturbative sphaleron processes owing to the presence of the alternative cosmological background [6] considered here. Unconventional thermal history of the Universe can thus aspire to lend a critical role both in the context of dark matter as well as in realizing baryogenesis [7, 8].

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Soft-virtual cross section and threshold resummation for n-colourless particles to fourth order in QCD

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Topic(s): Standard model physics; Formal theory

Abstract:

We present the general form of a universal soft-collinear distribution operator to compute the soft-virtual cross-section to next-to-next-to-next-to-next-to-leading order ($\mathrm{N^4LO}$) in QCD for a process with any number of final state colourless particles in hadron colliders. By acting this universal operator on the pure virtual corrections, which need to be computed explicitly for a process, the soft-virtual cross-section can be obtained. The operator is constructed by exploiting the factorisation and renormalization group evolution of amplitudes in QCD, and the universality of soft gluon contributions. We also provide the hard coefficient to perform the threshold resummation to next-to-next-to-next-to-leading logarithmic ($\mathrm{N^3LL}$) accuracy. Furthermore, we present the approximate analytical results of the soft-virtual cross-sections at $\mathrm{N^4LO}$ and $\mathrm{N^3LL}$ for the Higgs boson production through gluon fusion and bottom quark annihilation, and also for the Drell-Yan production at the hadronic collider.

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Lepton flavour violating $B \to K^* l_1 l_2$ decays in Z' model

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Topic(s): Beyond standard model physics

Abstract: Inspired by the various LHCb results of lepton flavour violation on $b \to s$ transition we study the lepton flavour violating $B \to K^* l_1 l_2$ decays in terms of transversity amplitudes in non-universalZ' model. These lepton flavour violating (LFV) processes are extremely suppressed in the Standard Model (SM) because the expected levels at the SM lie far below current experimental sensitivities. In particular, the branching fractions of $B^0 \to \tau^\pm \mu^\pm$ and $B_s \to \tau^\pm \mu^\pm$ decays are obtained in SM of order 10^{-54} [1] whereas experimentally they are constrained at the order of 10^{-5} by BaBar and LHCb with 90% and 95% confidence level respectively [2, 3]. There are several theoretical models proposed to explain various popular anomalies of B meson sector. It can be said that the models that generate lepton flavour universality (LFU) violation also can generate LFV processes. Various lepton flavour violating decays, such as $\tau \to 3\mu, \mu \to 3e, l \to l' M$ (where l, l' are different leptons and M is meson) and radiative decays $\mu \to e\gamma$ etc are studied in different new physics (NP) models [4, 5] though there are no direct experimental evidence of these decays but their experimental bounds exist. In this work, we will study the differential branching fractions of LFV decays $B \to K^* l_1 l_2$ induced by the quark level transition $b \to s l_1 l_2$ in Z' model where l_1 and l_2 are charged leptons of different flavours. We constrain the NP couplings using several experimental upper limits. It is expected that the study of these decays might emboss the footprints of NP more aesthetically.

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Decay constant and magnetic transition calculations of B-meson using screened potential model.

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Topic(s): Standard model physics

Abstract: We compute the decay constant and magnetic transition widths of B-meson by utilizing the mass spectra and normalised reduced wave function obtained considering the screening effect[1–3] for distances greater than $\approx 1fm$ in quark anti-quark interaction. These decay properties are calculated using the same set of potential parameters used for mass spectra calculations. The computed results are compared with different theoretical approaches and available experimental data. Computed results are systematically smaller than experimental[4] and other approaches by $5-10\%$ because of screening effect.

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Quantum Mechanical Coherency Effects in Neutrino-Nucleus Elastic Scattering

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Topic(s): Standard model physics

Abstract: Neutrino-Nucleus Elastic Scattering (νA$_{el}$) is a well defined process in Standard Model of particle physics. It provides a unique laboratory to study the quantum mechanical coherency effects in electroweak interactions. We present an analytical formulation [1] to quantify these coherency effects (α). This parameter characterize the devation of the cross-section from the fully coherent region. This deviation from full coherency region can be used as a sensitive probe for the study of physics beyond Standard Model (BSM). We relate this parameter (α) to nuclear form factors and experimental cross-section ratios, and characterize how its energy dependence leads to complementary among measurements at various neutrino sources with different targets [2-4]. Latest results and prospects of observing νA$_{el}$ at the Kuo-Sheng Reactor Neutrino Laboratory with germanium detectors with $\mathcal{O}$(100 eV) threshold will also be presented.

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Possible interpretation of recently observed heavy baryons

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Topic(s): Standard model physics

Abstract:

The Particle data Group(PDG) has listed the ground and excited states of various hadrons in charm and bottom sector [1]. The many new heavy hadrons are observed by the experiments like LHCb and Belle in recent years. Specifically in the baryon sector, the singly heavy baryons such as, $\Lambda_c(2860)$, $\Xi_c(2970)$, $\Omega_c(3000)$, $\Omega_c(3050)$, $\Omega_c(3066)$, $\Omega_c(3090)$, $\Omega_c(3119)$, the singly bottom baryons such as, $\Lambda_b(6072)$, $\Lambda_c(6146)$, $\Lambda_c(6152)$, $\Sigma_b(6097)^{\pm}$, $\Xi_b(6227)$, $\Omega_b(6316)$, $\Omega_b(6330)$, $\Omega_b(6340)$, $\Omega_b(6350)$ and the doubly heavy baryon $\Xi_{cc}^{+}(3620)$ are observed [2-4]. The Baryonic states are determined with symmetry of their flavor, spin, and spatial wave functions by considering their multiplates in theoretical studies [5-7]. The observations of masses, widths and decay modes give the idea of the internal structure. With the use of Hypercentral Constituent Quark Model, we predicted their states and J^P values. Our study suggests that the above mentioned partices are 1D, 2S, four 1P, 1S, 2S, two 1D, 1P, 2S, four 1P and 1S states, respectively. They are experimentally confirmed with the similar predictions. We also determined their J^p values by considering all splittings. These new states are studied by many theoretical approaches and their predictions are also compared. The possibility of unknown states are also be disscussed with their J^P values.

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Electromagnetic production of $K\Lambda$ off the proton induced by photons

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Topic(s): Standard model physics

Abstract: In this work, we have studied the associated particle production of $K\Lambda$ from the free proton target induced by the photons, using an isobar model in which the resonance as well as non-resonant contributions have been considered [1]. In the resonance sector, the contribution from the various nucleon resonances *viz.* $S_{11}(1650)$, $P_{11}(1710)$, $P_{13}(1720)$, $P_{11}(1880)$, $S_{11}(1895)$ and $P_{13}(1900)$ in the s channel, the hyperon resonances ($\Lambda^*(1405)$ and $\Lambda^*(1800)$) in the u channel, and the kaon resonances (K^* and K_1) in the t channel, which are present in the PDG having spin $\leq \frac{3}{2}$ and mass $<$ 2 GeV with significant branching ratio in $K\Lambda$ decay mode have been considered. In the numerical calculations, the background part of the hadronic current constitute the t and u channel resonances along with the non-resonant contributions while the contribution from the nucleon resonances constitute the resonance part of the hadronic current. In the case of the nucleon resonances, the couplings γNR at the electromagnetic vertices are determined in terms of the helicity amplitudes and the $RK\Lambda$ couplings at the strong vertices are determined by the partial decay width of the resonances (R) decaying to $K\Lambda$ channel. In order to take into account the hadronic structure in the nucleon resonances, a form factor of the dipole form is used with a cut-off parameter Λ_R taken to be the same for all nucleon resonances considered in the s channel. In the case of t and u channel resonances, due to the lack of the experimental data available on the kaon and hyperon resonances, the strong and electromagnetic couplings of these resonances are not well determined phenomenologically and are, therefore, varied to fit the data available on the total cross section in the low energy region for the process $\gamma p \to K\Lambda$ from SAPHIR [2, 3] and CLAS [4, 5] experiments. In the case of t and u channel resonances, a dipole form factor is taken into account with the cut-off parameter Λ_B taken to be the same for all the background terms.

The non-resonant terms are obtained from a non-linear sigma model assuming the chiral SU(3) symmetry. The model also predicts a contact term and its coupling strength in a natural way along with the coupling strengths of the various Born terms. The strong couplings at the meson-nucleon-baryon vertices like $g_{Kp\Lambda}$, $g_{Kp\Sigma}$, etc., are determined in terms of the pion decay constant f_π and the vector and the axial vector couplings of the baryon octet expressed in terms of the symmetric and antisymmetric couplings D and F, determined from the electroweak phenomenology of nucleons and hyperons. In the non-resonant sector, the model is almost parameter free except a common cut-off parameter Λ_B, which is used to describe the hadronic form factors at the strong kaon-nucleon-hyperon ($KN\Lambda$) vertices. In the case of the contact term, the strong form factor is determined using the parameterization given by Davidson and Workman [6].

The numerical results will be presented for the total and differential scattering cross sections and will be compared with the available data from SAPHIR [2, 3] and CLAS [4, 5] experiments as well as with some of the recent theoretical models available in the literature.

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Cosmology and astroparticle physics (Posters)

Quantum Simulation Of Entangled Oscillating Neutrinos

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Topic(s): Neutrino physics

Abstract: Two and three flavor oscillating neutrinos are shown to exhibit the properties bipartite and tripartite quantum entanglement respectively [1]. The two and three flavour neutrinos are mapped to qubit states used in quantum information theory [2–5]. Such quantum bits of the neutrino state can be encoded on a IBMQ computer using quantum computing as a tool [6]. We construct a 3x3 PMNS (Pontecorvo-Maki-Nakagawa-Sakita) unitary gate by identifying the rotation matrix in two flavor neutrino oscillations as a U3 universal quantum gate. By preparing the time evolution operation gate we outline the simulation of neutrino oscillation on a quantum computer. We suggest the implications of the implementation of entanglement in the neutrino system on the IBM quantum processor.

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Relativistic Freeze-in with scalar dark matter and Heavy Neutrino

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Topic(s): Beyond standard model physics; Neutrino physics; Particle astrophysics and cosmology

Abstract: We consider relativistic freeze-in production of dark matter in models that contain one additional BSM scalar and right handed neutrino (RHN). We show that in addition to the Standard Model Higgs, the scattering and decay of the BSM scalar can also contribute substantially to the dark matter production. We consider two different scenarios, where the BSM scalar is in thermal equilibrium, and is in out of equilibrium. In evaluating the relic density, we consider the thermal mass correction of the scalars, as well as the temperature dependence of the SM Higgs and BSM Higgs mixing. We show that relic density can change significantly if thermal mass correction and Bose-Einstein, Fermi-Dirac statistics are used.

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A novel approach of thermal micro-behavior and intriguing microstructures for charged AdS black holes surrounded by quintessence with a cloud of strings background

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Topic(s): Particle astrophysics and cosmology

Abstract: In this paper, we present a study of Ruppeiner's thermodynamic geometry for charged AdS black holes with a cloud of strings and surrounded by quintessence with the motivation to probe the nature of interactions between black hole microstructures. With the help of the Ruppeiner thermodynamic geometry, entropy and Hawking temperature of the black hole, we propose a novel method for the relation between the interaction and thermal motion for charged AdS black holes surrounded by quintessence with a cloud of strings background. We use a dimensionless ratio to determine this and observed that there is always a transition between the interaction state and thermal motion state depending on the coupling constants associated with quintessence and the cloud of strings. We also determine the relation between the interaction and thermal motion for charged AdS black holes with quintessence only.

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Possibility of quantum Hall effect in compact star

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Topic(s): Particle astrophysics and cosmology; Formal theory

Abstract: Compact stars, like white dwarfs, neutron stars are a very interesting astro-physical objects, which provides the opportunity to study quantum effect of degenerate matter in a strong magnetic field. Present article is focused on microscopic calculation of electrical conductivity of those compact stars, which is a very important quantity, connected with different phenomena of compact star like magnetic field decay, internal heating, propagation of plasma waves, various instabilities etc. Our mathematical calculations starts from the microscopic description of current density in terms of deviation of distribution function, whose form is obtained with the help of relaxation time approximation (RTA) of relativistic Boltzmann transport equation (RBTE). The equilibrium distribution function of degenerate matter is considered as zero temperature form of Fermi-Dirac distribution function at finite chemical potential, representing the relativistic Fermi energy. During the transition from zero to non-zero magnetic field picture, the force term of RBTE will be mainly changed from electric field to electric and magnetic field based Lorentz force. At the end of this microscopic calculations, when one connect it to macroscopic Ohm's law, then the expression of electrical conductivity can be obtained in terms of relaxation time (τ_c), energy ($\omega = \sqrt{\vec{k}^2 + m^2}$), momentum ($\vec{k}$) of medium constituents and chemical potential (μ) of the medium. In presence of magnetic field, another time scale τ_B (inverse of synchrotron frequency), which is inverse of magnetic field, will be entered along with the relaxation time. We find an anisotropic factor, for which perpendicular and Hall conductivity remain lower than the isotropic values, obtained for zero magnetic field. At strong magnetic field picture, we have considered the quantum effect via Landau quantization. The final and simplified expressions of conductivity and resistivity tensors will receive the forms:

$$\begin{aligned}
\sigma_{xx} = \sigma_{yy} &= \sigma_F \frac{1}{1+(\tau_c/\tau_B)^2} & \rho_{xx} = \rho_{yy} &= \frac{1}{\sigma_F} \\
\sigma_{yx} = -\sigma_{xy} &= \sigma_F \frac{\tau_c/\tau_B}{1+(\tau_c/\tau_B)^2} & \rho_{xy} = -\rho_{yx} &= \frac{\tau_c}{\tau_B \sigma_F} \ .
\end{aligned} \tag{1}$$

Here, $\tau_B = \frac{\mu}{qB}$ for q charge particle in presence of magnetic field B and σ_F has classical (left) and quantum (right) forms:

$$\sigma_F = \frac{gq^2}{6\pi^2}\tau_c \frac{(\mu^2 - m^2)^{3/2}}{\mu} \qquad \sigma_F = gq^2 \sum_{l=0}^{l_{\max}} \alpha_l \frac{l(|q|B)^2}{2\pi^2} \frac{1}{\mu(\mu^2 - 2lqB - m^2)^{1/2}} \tau_c \ , \tag{2}$$

where g is degeneracy factor of compact star system and $l_{\max} = \frac{\mu^2 - m^2}{2qB}$ is maximum values of Landau level l. With the help of the expressions of σ_{xy}, ρ_{xy}, we obtain their quantized pattern in high magnetic limits, which expose a possibility of quantum Hall effect within a compact star due to strong magnetic field.

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A field theoretic approach to the energy momentum tensor for theories coupled with gravity

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Topic(s): Particle astrophysics and cosmology

Abstract: We provide a field-theoretic algorithm of obtaining energy-momentum-tensor (EMT) for gravitationally coupled scalar field theories. The method is equally applicable to both minimal and non-minimal coupling. The algorithm illuminates the connection between the EMT, obtained by functional variation of the metric, and local balance of energy and momentum.

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Signature of noncommutative structure of space in resonant detectors of gravitational wave

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Topic(s): Particle astrophysics and cosmology

Abstract: The present day gravitational wave (GW) detectors [1, 2] strive to detect the length variation $\delta L = hL$, which, owing to the smallness of the metric perturbation $\sim h$, is an extremely small length $\mathcal{O} \sim 10^{-18}$–$10^{-21}$ meter. The recently proposed noncommutative structure of space [3, 4] has a characteristic length-scale $\sqrt{\theta}$ which has an estimated upper-bound in similar length-scale range[5, 6]. We therefore propose that GW data can be used as an effective probe of noncommutative structure of space [7–12]. In this paper we demonstrate how spatial noncommutativity modifies the responding frequency of the resonant detectors of GW [13–15] and also the corresponding probabilities of GW induced transitions that the phonon modes of such resonant detectors undergo. We present the complete perturbative calculation involving both time-independent and time-dependent perturbations in the Hamiltonian.

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Investigation of the circular geodesics in a rotating charged black hole in presence of perfect fluid dark matter

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Topic(s): Particle astrophysics and cosmology

Abstract: Dark matter is one of the most mysterious substance present in our universe whose real nature is yet unknown. Many speculations are being made regarding it but none has worked. Every galaxy is supposed to have a supermassive central core whose mass can be accounted for by the most compact structure, the black hole. The direct evidence for the existence of black hole is provided by the shadow image of M87 [**1**]. Also there are large number of indirect evidences of dark matter in the large scale of universe. In our study we consider a black hole system surrounded by dark matter and for simplicity we consider the dark matter to be a perfect fluid [**2-5**].

Considering such a system, we give a charged black hole solution in perfect fluid dark matter ($PFDM$). The metric corresponding to the rotating avatar of the black hole solution is obtained by incorporating the Newman-Janis algorithm [**6**]. We then compute two type of circular geodesics, namely, the null geodesics and time-like geodesics for the mentioned spacetime geometry. For the case of time-like geodesics we consider massive particles characterized by charge with values $q = 0$ and $q \neq 0$. The effective potentials of the corresponding circular geodesics has also been studied briefly. We then continue the subsequent analysis by graphically representing the collective effects of the black hole parameters, namely, the charge of the black hole (Q), spin parameter (a) and the PFDM parameter (α) on the energy (E), angular momentum (L) and effective potential (V_{eff}) of the concerned particle [**7**].

Finally we discuss the Penrose process [**8**] by which energy (E) can be extracted from the black hole. In discussing so, we analyse the negative energy particles and energy gain (ΔE) from the black hole and how the different black hole and dark matter parameters influence them.

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Investigating cooling anomaly in globular stars via scalar-photon conversion.

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Topic(s): Particle astrophysics and cosmology

Abstract: The properties namely, accelerated expansion, the temperature distribution of cosmic microwave background radiation, the distribution of large scale structure and the relic abundance of the light elements lend support to a model known as Lambda Cold Dark Matter Model (ΛCDM) of the universe, that we live in. The closed flat structure of the universe, in this model is due to five percent baryonic and twenty five percent– illusive non-baryonic cold dark matter, having speculative origin. That include, supersymmetric origin (neutralino, gravitino etc), leptonic origin (sterile neutrino), higher-dimensional origin (scalar dilaton ϕ) and particles of extra-standard model of elementary-particle physics origin (pseudoscalar axion ϕ'). In this work we focus on particles of the last two type, those couple to photons with dimension five interaction term. Much like neutrino flavour oscillation, these particles are capable of oscillating into a photon and reverse – in an external magnetic field. In vacuum their probability of oscillation into photon and reverse are same; provided they couple to photon with universal strength and their masses are identical.

In this work we argue that, incorporation of the parity violating part of the photon polarization tensor (originating through the magnetized-medium induced effects, of a magnetized media), in the effective Lagrangian of these systems actually helps in optimizing this conversion. Once produced in the stellar environment, they stream out as free particles, thus cooling the system efficiently.

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Investigations of scalar-photon oscillations in astrophysical events.

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Topic(s): Particle astrophysics and cosmology

Abstract:

Higher dimensional unified theories like Kaluza Klein, String theory, modified (F(r)) gravity, predicts the existence of scalar fields like dilaton, moduli etc. These spin zero particles ($\phi(x)$), due to the smallness of the size of coupling constant and light mass, are supposed to be typical candidates of the Dark matter and Dark energy. They have interaction vertex with two photons. As a result in an external magnetic field, oscillation between scalars and photon turn out to be possible [1]. Here we report the dynamics of their oscillations in magnetized plasma through and their possible astrophysical consequences. We explore the possibilities of finding their signature, using polar cap model of pulsars [2].

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A study of shower properties after extended particle density measurements at GRAPES-3 experiment.

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Topic(s): Particle astrophysics and cosmology

Abstract: The GRAPES-3 extensive air shower (EAS) experiment located at Ooty in Southern India is equipped with 400 plastic scintillator detectors [**1**] spread over an area of $25000\,\mathrm{m}^2$ and a muon telescope of $560\,\mathrm{m}^2$ area built with 3712 proportional counters [**2**] with a primary objective to measure cosmic ray energy spectrum over the knee at ∼3 PeV. One fourth of the plastic scintillator detectors are equipped with two photo-multiplier tubes (PMTs) [**3**]. The particle densities from the EAS recorded by dual PMT detectors are more than 10,000 particles m^{-2} [**4**], whereas, single PMT measurements are limited below 300 particles m^{-2} due to saturation effects. Various attempts have been made to improve the performance of dual PMT detectors and therefore, significant improvements have been seen in the estimation of various shower parameters such as size, age and core location. The findings undertake that the new estimated shower parameters would provide rather more reliable measurements of the cosmic ray energy spectrum above PeV energies. The details of this study will be presented during the conference.

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Achieving Inflection-point Inflation & Dark Matter in Viable Particle Models

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Topic(s): Particle astrophysics and cosmology

Abstract: After the release of Planck 2018 data [1], one of the most interesting possibilities for inflation is the inflection-point scenario. In this case, Inflaton does not require non-minimal couplings to gravity/curvature. Instead the flatness of the potential is ensured by running of the quartic couplings through loop corrections induced by fermions & U(1) gauge fields [2] or scalar fields [3]. This characteristic behaviour gives one the opportunity to study inflation in various/several particle physics models. In this talk we describe a few such cases which can also be tested in future collider experiments. As an example, we consider the minimal gauged B-L extended Standard Model, where we identify the B-L Higgs field as the inflaton field, and study freeze-in fermionic Dark Matter. We discuss the detailed reheating dynamics and show that reheating occurs successfully even with very low inflaton mass. Finally we also study the formation of Primordial Blackholes and predict secondary tensor spectrum which could be detectable at Gravitational Waves (GW) detectors.

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Comparison of modified NKG functions for lateral electron distribution of EAS in GRAPES-3 experiment

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Topic(s): Particle astrophysics and cosmology

Abstract: The traditionally accepted lateral distribution function (LDF) of electron density for an extensive air shower (EAS) is the Nishimura-Kamata-Greisen (NKG) function [**1-3**], although there have been reports of poor reconstruction of EAS with NKG function [**4-6**]. Hence, several modified functions have been proposed for better reconstruction of EAS [**7**]. The GRAPES-3, an EAS experiment located in Ooty, India consisting 400 scintillator detectors [**8**] and a large area (560 m^2) tracking muon detector [**9**] uses NKG function for the reconstruction of EAS. Investigation of modified NKG functions with the reconstruction of GRAPES-3 EAS data in TeV-PeV energy range will be discussed.

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Spin Coefficients Approach for a Cylindrical Space-Time in Einstein-Cartan Theory

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Topic(s): Particle astrophysics and cosmology

Abstract: Symmetry plays an important role to understand the nature of the universe. Although general relativity (GR) and its modified theories are assumed to be highly nonlinear but in their solutions we have seen symmetries. Hence, the concept of symmetry will be helpful for describing the geometry of the space-time. Newman and Penrose [1] developed a new approach to general relativity (GR) called spin-coefficients approach which is also known as a Newman-Penrose (NP) formalism that presents a deeper insight into the symmetries of the space-time. An extension of NP formalism was put forwarded by Jogia and Griffith [2] to find a proper description of the symmetries of the space-time for the semi-classical aligned Weyssenhoff spin fluids, satisfying the Weyssenhoff condition [3] in the context of Einstein-Cartan theory (ECT) [4]. Although cylindrical symmetry in relativity turns out to be similar to spherical symmetry in many ways but quite different in others. The studies of theoretical analysis of gravitational fields, exact solutions of the field equations and now-a-days algebraic computation of solutions etc. using cylindrical structure are getting reasonable attention. Also in cylindrically symmetric space–time, the study of geodesics is comparatively easier than others. Prasanna [5] first studied the spin polarized static cylindrical symmetry space-time and obtained its interior and exterior solutions adopting Hehl approach [6, 7] in the context of ECT. Latter Tsoubelis [8] and Manna et al. [9] also studied the same considering Ray and Smalley [10] energy-momentum tensor. Here, we consider a cylindrical symmetric space-time with torsion and spin in the context of ECT. Adopting NPJG spin coefficients approach we setup the equations of gravitational field for a cylindrical symmetric metric. Also we obtain a solution for these equations and anlyse the contribution of spin torsion in the context of ECT.

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Evolution of the universe with a common scale factor and Black Holes

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Topic(s): Particle astrophysics and cosmology

Abstract: To give a proper explanation for recently observed accelerated expansion of the universe [1, 2], theoretical cosmology demands that the present universe should be dominated by an unknown form of energy having negative pressure, termed as dark energy [3, 4]. Again, for satisfying the early observational facts, starting from primordial nucleosynthesis [5] to formation of large scale structure [6], it is considered that the universe had passed through radiation-dominated and matter-dominated eras, before it reached the present state. Corresponding to the three different eras, three different types of scale factors are used in literature [7, 8]. But for the exact evolution of the universe, there must be a common scale factor [9].

In this work, we design a single scale factor for describing the whole evolution of the universe. Using this scale factor, we calculated different cosmological parameters like density of the universe, Hubble's parameter and deceleration parameter etc. and found that their values are in agreement with observations [10]. From our analysis, we also reached at the conclusion that the present universe is dominated with quintessence type dark energy. Again we study the black hole dynamics in this environment by considering both Hawking evaporation and accretion of energy matter from the surroundings. Our result predicts that in the present case black holes will live longer due to greater rate of accretion in comparison with standard model of cosmology [11], scalar-tensor theory [12] and modified theory of gravity [13]. Thus for the universe having common scale factor, more number of black holes are thought to be exist today than any other models, which strengthens the conjecture that the black holes are the proper candidates for dark matter [14].

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Estimating the Cosmological Parameters with Low redshift Long Gamma Ray Bursts

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Topic(s): Particle astrophysics and cosmology

Abstract:

Type Ia Supernovae (SNe Ia) have made an indispensable contribution in the development of modern cosmology. Alongside, Long Gamma Ray Bursts (LGRBs) have also shown the potential to play a crucial role in high redshift cosmology. Both SNe Ia and LGRBs together can be used to estimate the important cosmological parameters such as expansion rate of the Universe (H_0) and the density parameter (Ω_M). We use the 68 LGRBs in the redshift range $0.0335 < z < 1.46$ for which peak photon energy (E_{Pi}) and isotropic equivalent energy (E_{iso}) are available [1]. These are combined with 182 SNe Ia (hereafter GD07) from [2] to prepare a homogeneous sample which includes both low as well as high-z objects. The reason for using GD07 instead of the latest and bigger SNe data sets are (i) GD07 is free of systematic effects [3] and (ii) latest data sets will dominate over GRBs as the number of SNe in these sets is order of magnitude larger than the GRBs in our sample. First, we apply the maximum likelihood method to estimate the best fit values of cosmological parameters. We obtain $\Omega_M = 0.38$ and $H_0 = 62.5$ km s^{-1}Mpc^{-1}. Finally, Bayesian analysis is implemented to marginalize over the density parameter to obtain $H_0 = 63.0$ km s^{-1}Mpc^{-1}.

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Effect of vacuum energy on the evolution of primordial black holes in Brans-Dicke theory

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Topic(s): Particle astrophysics and cosmology

Abstract: The observations of distant supernovae of type Ia [1–3] indicate that the expansion of the present universe is accelerating one. This has led to the conclusion that nearly two-third of the critical energy density of the universe exists in dark energy component with a large negative pressure and unknown composition. The simplest candidate of dark energy is vacuum energy with equation of state parameter $\gamma = -1$. Again, the present observations [4, 5] predict that the vacuum energy should dominate from redshift $z_{q=0} \approx 0.75$.

In our work, we study the evolution of primordial Black Holes (PBHs) within the context of Brans-Dicke theory [6] by considering the present universe is no more matter dominated rather vacuum energy dominated. We here, integrate the vacuum energy accretion by PBHs with radiation and matter accretions in respective dominant periods. We also present the comparison of the results of the present study with the corresponding results of the previous work using standard model of cosmology [7]. Due to the time variation of Newton's gravitational constant G in Brans-Dicke theory, the scale factor a(t) takes a different form and it controls the PBH evolution in a distinct manner compared with General Theory of Relativity (GTR). Here we use the solutions of G(t) and a(t) for different phrases of universe obtained from recent works[8, 9].

From our analysis, it is found that the rate of accretion of radiation is slower whereas the rate of accretion of matter is larger in Brans-Dicke theory in comparison with GTR. Though in contrast to GTR , here accretion of vacuum energy is possible throughout the PBH evolution during vacuum dominated era respecting the limit on vacuum energy accretion efficiency f_{vac}, which should be less than 0.61 and the rate of vacuum energy accretion is much slower than corresponding GTR results. Thus the PBHs evaporate at a faster rate in Brans-Dicke theory than standard model of cosmology, if we consider the presence of vacuum energy in both the cases. We also found that the constraint on the initial mass fraction of PBH obtained from the gamma ray background limit becomes stronger in the presence of vacuum energy but this limit is 1.8 times weaker than the standard cosmology case.

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Cosmological implications of interacting dark energy model

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Topic(s): Particle astrophysics and cosmology

Abstract: Standard Model of Cosmology demands a decelerated expanding universe through out its evolution where as current observations [1] show that the present universe is expanding at an accelerating rate. For removal of this controversy, two general ways have been used in the field of theoretical cosmology. One way is by introducing a new type of energy having negative pressure called dark energy [2] and the other way is by modifying the theory of gravity [3]. Recent observational data [4] supports dark energy model by predicting that nearly 68.3% of present universe is filled with this dark energy. The unknown nature of dark energy evokes many of its forms like the cosmological constant or vacuum energy [5], phantom energy [6], quintessence [7] etc. But these considerations are not able to explain all features of the universe like for example the coincidence problem [8]: why the observed values of cold dark matter density and dark energy density are of same order of magnitude today, although they differently evolve during expansion of the universe. As a new alternative, different types of interacting dark energy models are discussed in literature [9, 10].

In our present work, we study the evolution of the universe by assuming an interacting dark energy model, where dark energy interacts with matter and grow at the expense of the latter. Basing on this model, first we calculated the dark energy density parameter and using that we have picturised the expansion of the universe. From our analysis, we found that presently observed accelerated expansion of the universe can be explained by interacting model, if the dark energy is quintessence type. Though equation of state parameter of dark energy γ_ϕ for quintessence varies between 0 and -1, our results predict that accelerated expansion is only possible for γ_ϕ less than -0.166. It is also found that in early time the universe was undergoing a decelerated phase of expansion and transition from deceleration to acceleration would occur in recent past. Further, our model predicts that in near future again expansion of the universe will undergo a second transition from the accelerated phase to a decelerated one and finally deceleration parameter will take a constant positive value 0.5 as in early universe indicating a constant rate of deceleration in far future like distant past.

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A modified set of Newman-Penrose quantities to study Polarization modes of Gravitational Waves

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Topic(s): Particle astrophysics and cosmology

Abstract: The Newman-Penrose formalism is helpful to find out the polarization contents of null Gravitational Waves (GWs) [1, 2]. But for the metric theories with massive polarization mode, the formalism fails [3]. In a recent study, a modified set of Newman-Penrose scalars and exact amplitudes of GW polarizations were introduced [4]. However, in metric $f(R)$ gravity, this new formalism can not predict the existence of breathing mode when the longitudinal mode vanishes. Recently, we show that, the pure massless transverse (but not traceless) breathing mode can exist in pure R^2 $f(R)$ gravity model as a third scalar polarization mode [5]. Therefore, we have further modified the Newman-Penrose scalars to predict the massless breathing modes explicitly in a metric theory [6]. This new set of Newman-Penrose scalars obtained in this study are applicable to any metric theories irrespective of the presence of massive modes or breathing modes.

Moreover, we introduced a toy model [6] and made a comparative study of it with two known $f(R)$ gravity models viz., power law model and Hu Sawicki model [7] to check its viability under solar system tests using a method introduced by Guo [8]. Then we have perturbed the field equations of these models to study the associated scalar fields and found out the GW solutions. Further, we have calculated modified Newman-Penrose scalars and polarization amplitudes associated with the models.

This study shows that the modified Newman-Penrose scalars introduced by us are capable of finding the polarization modes of GWs in a metric theory accurately. This new set of scalars can show that a theory with a massless scalar field can have a transverse breathing mode of polarization of GWs. Among the $f(R)$ gravity models considered here, we see that Hu Sawicki model and the toy model introduced by us can pass the solar system tests easily. These three models predict GWs with an additional massive scalar mode which is a mixed state of longitudinal and breathing modes. However, in pure R^2 model, which is a special case of power law model, the additional scalar mode is massless and a pure breathing mode.

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Search for multi-TeV γ-rays from Crab Nebula with GRAPES-3 experiment

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Topic(s): Particle astrophysics and cosmology

Abstract: Since γ-rays are not deflected by the interstellar magnetic fields, they can be traced back to their source. The detection of high energy γ-ray sources can play a very important role in understanding the origin of cosmic rays. The GRAPES-3 experiment at Ooty in India is designed to study cosmic rays (CRs) and γ-rays in the TeV-PeV energy range. It comprises an array of 400 scintillator detectors [**1**, **2**] and a large area (560 m^2) tracking muon detector [**3**]. To search for an exceedingly small flux of γ-rays expected from an astrophysical point source at multi-TeV energies against an overwhelming background of CR flux, a high rejection of CRs is a necessary requirement. We have studied the CR background using the muon component in the shower which is a distinguishing parameter between the CRs and gamma-ray induced showers. We have achieved a CR rejection efficiency of more than 95% above 50 TeV. The sensitivity for γ-ray search has been further enhanced with an excellent angular resolution achieved recently [4]. We will discuss the background study and our efforts to search for γ-ray signal from the standard TeV γ-ray source, Crab Nebula.

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Investigating the Effect of Accretion on a White Dwarf using Computer Simulations

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Topic(s): Particle astrophysics and cosmology

Abstract: Type Ia Supernovae (SNe Ia) are among the most important probes for distance measurement and hence to estimate the cosmological parameters. As per the current understanding SN Ia occurs when a White Dwarf (WD) in a binary system accretes matter from its companion and its mass reaches Chandrasekhar limit. The complex explosion mechanism of SNe Ia has not been fully understood; and, computer simulations are the only way to fill the gap between the observations and theoretical understanding. We perform numerical simulations to study various properties of WD during accretion, using the 1-d stellar evolution code MESA (Modules for Experiments in Stellar Astrophysics) [1, 2]. Helium is accreted onto a WD of mass 1 $M_{\odot}$ with slow accretion rates ranging from 1×10^{-10} to 10×10^{-10} $M_{\odot}yr^{-1}$. We calculate and plot the variation of surface gravity (g) and luminosity of the WD as a result of accretion process. Our results show that g increases initially, but towards the end of the run it drops sharply due to sudden expansion as a result of He ignition. Rapid variation in luminosity is also observed at this stage.

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Hawking-Page Transition in 2D Gravity

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Topic(s): Particle astrophysics and cosmology

Abstract: I will start by Dimensional reduction of a 5D action in which gravity is coupled with Abelian and Non-Abelian Fields leading to 2D Gravity (JT- Gravity) with non-trivial interactions. We find out two types of perturbative solution of Equation of motion for 2D action in Lightcone Gauge i.e.
1. Vacuum solution having AdS_2 in Infrared limit and $Lifshitz_2$ in the Ultaviolet limit.
2. Blackhole solution having $Lifshitz_2$ asymptotics.
Here I will discuss what causes the geometry to change in the asymptotics. After that I will demonstrate the key feature of this model i.e. Hawking-Page Transition which means there exist a critical temperature below which thermal radiation will dominate and once we cross this temperature globally stable blackhole will dominate.

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Energy reconstruction technique for very high energy muons with DUNE far detector.

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Topic(s): Neutrino physics

Abstract: DUNE (Deep Underground Neutrino Experiment) is a proposed long-baseline neutrino oscillation experiment located in the United States. The main physics objectives of DUNE are to characterize neutrino oscillations, search for nucleon decay, and observe supernova neutrino bursts. The DUNE far detector will be located 4850' underground at the Sanford Underground Research Facility in Lead, South Dakota. It will house the world's largest liquid argon time projection chamber. The DUNE Far Detector can be used to detect high-energy muons that arise from interactions of cosmogenic neutrinos and search for neutrinos originating in the decays of Weakly Interacting Massive Particles (WIMPs). Selecting upward-going muons reduces the background from cosmic-ray muons. The muon energy is estimated from the electromagnetic showers accompanying the muon, a technique that allows energy reconstruction up to a few hundreds of TeV.

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Status of Two Singlet Scalar Dark Matter

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Topic(s): Particle astrophysics and cosmology

Abstract:
A real singlet extension to the scalar sector of the Standard Model has been studied extensively to explain dark matter. However, it fails to explain the gamma-ray excess from the galactic center due to the overabundance in the desired mass range. Here we will consider the two singlet scalar extension of the Standard Model with a $Z_2 \times Z_2$ symmetry which satisfies the twin constraints of relic abundance and the gamma-ray excess. The parameter space has been constrained using latest bounds from direct detection experiments and the importance of scalar mixing in relaxing those constraints on the parameter space of the model is emphasized.

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Effective Interactions of Heavy Quark-philic Dark Matter

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Topic(s): Particle astrophysics and cosmology

Abstract:

We investigate the bottom and top quark philic dark matter interactions induced by the higher dimension operators under the domain of the effective field theory. The contribution of the cosmologically constrained coefficients of these operators from PLANCK data are found to be consistent with the observations from Direct and Indirect detection experiments. We have also constrained the allowed parameter region from the available Collider data.

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SPIN-SPIN INTERACTION BETWEEN GRAVITONS AND SUPERFLUID QUANTUM VACUUMS IN A BLACK HOLE

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Topic(s): Particle astrophysics and cosmology

Abstract: In this paper, spin-spin interaction between gravitons and superfluid quantum vacuums has been studied.The detection of gravitational waves in 2015 confirms the need for the quantization of General Relativity [1]. Recently, gravitational waves are quantized using Loop Quantum Gravity. The space is quantized as superfluid quantum vacuums [2, 3]. The variable density of vacuum gives rise to vacuum fluctuations which is the cause of gravity. According to General Relativity, the variable density of vacuum can be described by curvature in space. The vacuum energy density of the superfluid quantum vacuums on the surface of the black hole and within it is calculated in [2]. Here, we find out the magnitude of the energy of the superfluid quantum vacuums on the surface and any distance d from the surface of the black hole as well as inside the black hole. The spin-spin force between two massless particles having spin h_1 and h_2 is studied in [4]. In our work, we have studied about the spin-spin force between gravitons and superfluid quantum vacuums which can be determined considering, $h_1 = 2\hbar$ as spin angular momentum of the graviton and $h_2 = \frac{3}{2}\hbar, \frac{5}{2}\hbar, \frac{7}{2}\hbar$..... as the spin angular momenta of the superfluid quantum vacuums. We have also calculated the heat energy produced due to diffusion of gravitons with superfluid quantum vacuums using the relation change in momentum multiplied by velocity of gravitational waves as [5] $k_B T = (\Delta p)c = E_n$ .There can be emission of neutrinos from the black holedue to the diffusion of gravitons with superfluid quantum vacuums having mass around $m_v = 10^{-6} eV$ [6]. The energy of the superfluid quantum vacuums are found to be comparatively less or comparable to the mass of gravitons which is about $m_g = 10^{-23} - 10^{-34} eV$ [7, 8].

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Probing cosmic ray anisotropy using GRAPES-3 experiment

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Topic(s): Particle astrophysics and cosmology

Abstract: The deflection of cosmic rays (CRs) by the interstellar magnetic field results in isotropic flux on Earth. However, anisotropy in CR flux of the order of $10^{-3} - 10^{-4}$ has been observed [**1**, **2**]. This study of anisotropy can provide valuable insights into the propagation and acceleration of CRs. The GRAPES-3 experiment located at Ooty, India consists of an array of 400 plastic scintillator detectors that measures the particle densities and relative arrival times of extensive air showers induced by the primary CRs (PCRs) in the atmosphere [**3**]. This information collected is then reconstructed to obtain the energy and direction of PCRs [**4**, **5**]. The direction measured in zenith and azimuth angle are converted to celestial coordinates such as right ascension and declination to obtain the distribution of the PCR flux in the sky. The near-equatorial location of the GRAPES-3 experiment provides the opportunity to study anisotropy for a wide range of declinations covering the celestial equator in the TeV-PeV energy range. However, challenges remain in removing the detector and atmospheric effects that induce a few percent change in the PCR flux to probe anisotropy of magnitude less than 0.1%. The techniques developed to remove systematic effects along with the results of anisotropy search will be presented.

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Measurement of radon by GRAPES-3 plastic scintillator detectors

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Topic(s): Particle astrophysics and cosmology

Abstract: The GRAPES-3 experiment is a high-density extensive air shower (EAS) array located at Ooty in India designed for high precision measurements of cosmic ray energy spectrum and composition in the TeV–PeV energy range. The array consists of 400 plastic scintillation detectors of $1\,\mathrm{m}^2$ each spread over an area of $25000\,\mathrm{m}^2$ [**1**, **2**]. The presence of radon in the array surroundings can be inferred through the detection of its decay products [**3**]. Especially, during rainfall, a significant increase in the detector counting rates has been observed. The origin of this increase was established to be due to radon decay products through measurements with NaI(Tl) detectors which showed their presence in rainwater [**4**]. We propose here that the plastic scintillation detectors, an inexpensive alternative to inorganic crystal scintillator detectors such as NaI(Tl), can also effectively be used to identify aforementioned radon decay products. The details of this extensive study will be presented at the conference.

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Nonclassicallity of Two-mode Squeezed Coherent state and Coherent Squeezed state of the Oscillating Quantize Scalar field in the FRW Universe

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Topic(s): Particle astrophysics and cosmology

Abstract: We in our earlier series of papers have used the two-mode formalism of squeezed coherent state and coherent squeezed state to represent the massive scalar field in the FRW Universe using the semi-classical theory of gravity and successfully explained the phenomenon of particle production and the concept of preheating/reheating after inflation. Therefore, it turns necessary to examine whether the two-mode quantize state of the scalar field exhibit classical or non-classical nature in the cosmological context. We in our present article, have made use of the cosmological Q parameter (analogous to the Mandel's parameter) to examine the non-classical nature of the two-mode squeezed state after inflation during the oscillatory phase of the scalar field.

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Study of the neutrino mass, dark matter and baryogenesis within the framework of minimal extended seesaw

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Topic(s): Particle astrophysics and cosmology

Abstract: We study a model of neutrino and dark matter within the framework of a minimal extended seesaw. This framework is based on A_4 flavor symmetry along with the discrete Z_4 symmetry to stabilize the dark matter and construct desired mass matrices for neutrino mass. A non-degenerate mass structure for right-handed neutrinos is considered to verify the observed baryon asymmetry of the Universe via the mechanism of thermal Leptogenesis. The scalar sector is also studied in great detail for a multi-Higgs doublet scenario, considering the lightest Z_4-odd as a viable dark matter candidate. A significant impact on the region of DM parameter space, as well as in the fermionic sector, are found in the presence of extra scalar particles.

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Rotation curves of galaxies in Modified Gravity

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Topic(s): Particle astrophysics and cosmology

Abstract: We study the behaviour of the rotational velocities of neutral hydrogen gas clouds around the centres of galaxies within the framework of modified gravity theories [1, 2]. In general, the neutral hydrogen gas clouds [3] behave as test particles moving in stable circular orbits around the galactic centres. The behaviours of test particles are explained by postulating the existence of dark matter (DM) [4] through the galactic rotation curves [5]. We take into account the hybrid metric-Palatini gravity theory [6], which is a modification of the Einstein-Hilbert action with an $f(R)$ term in the Palatini variational approach. The tangential velocities of test particles are derived. The theoretical results obtained are compared with observations of few samples of both low surface brightness (LSB) and high surface brightness (HSB) galaxies. The theoretical and observational results fairly agree with each other, showing that modified gravity theories can explain the DM paradigm.

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Comparison of muon flux at Madurai obtained with different phenomenological models

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Topic(s): Particle astrophysics and cosmology

Abstract: A 12-layer RPC stack was built to study long-term performance of the Resistive Plate Chambers (RPCs) produced in Indian industry as well as indigenously built electronics for the ICAL. The performance of the detector was studied using cosmic muons events with various trigger conditions. The same muon data were also used to measure the integral intensity of vertical muons, zenith angle distribution and also the azimuthal dependent muon flux at the experiment site. For this study, the experimental data was recorded based on coincidence from four fixed layers within 100 ns time coincidence window. The estimated vertical muon flux was compared with a measured values at different locations on the earth and the azimuthal spectrum of cosmic muons is compared with the same obtained using different phenomenological models in CORSIKA simulation and HONDA predictions. The results of the muon flux at Madurai will be discussed and its comparison with predictions will be presented in the paper.

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Displacement relation for Non-thermal radiation of Hawking quanta from Black Holes

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Topic(s): Particle astrophysics and cosmology; Formal theory

Abstract: Study of quantum phenomena in gravitational field has been a long pursued field of research. In the absence of a fully renormalisable theory of Quantum Gravity, one can study the quantum effects in gravitational backgrounds, by coupling quantum matter fields with classical curved spacetime. An important landmark in this line of research is the discovery of emission of particles from Black Holes (BH) by S. W. Hawking [1]. Hawking radiation from a BH poses some deep "conflict of principles". Considering the foramtion of BH in a pure state and then its evaporation into thermal (mixed state) Hawking radiation, is in contrary to principle of unitary evolution and hence implies a loss of information [2]. This conundrum is famously known in the literature as "*Information Loss Paradox*".

However, the radiation spectrum is not strictly thermal if the back recation or, the self gravitation effect of the emitted particles is taken into account [3]. While some beleive that this non-thermal correction in Hawking radiation can solve the information paradaox problem [4, 5], others strongly opine [6, 7] that this resolution does not address the main problem of the paradox; rather, small corrections are not expected to solve this unitary crisis. However, an important result from [5] is that if we define entropy of the emitted particles in particular way, then the total entropy of the radiation at the end of complete BH evaporation is same as the initial BH entropy. This does not happen for thermally radiated Hawking quanta.

With that definition of entropy of emitted particles, we have derived that the probability of a BH (given mass M) to decay into n particles is given by $p_n = \Omega_n exp(-4\pi GM^2) = \frac{(4\pi GM^2)^{n-1}}{(n-1)!} exp(-4\pi GM^2)$, where, $\Omega_n = \frac{(4\pi GM^2)^{n-1}}{(n-1)!}$ denotes the number of ways in which BH can decay into n particles. From this probability, we can estimate the most probable number of particles (n_{max}) i.e, the number of particles for which the probability of BH decay (of a given mass) is maximum. It turns out that the n_{max} follows a nice displacement relation, $n_{max}T_{BH}^2 = \frac{1}{16\pi G}$, where $T_{BH} = \frac{1}{8\pi GM}$ is the BH themperature. We have also shown a relation of this relation with the Wien's displacement relation for blackbody radiation. Finally, we have also commented that the BH entropy can be represented as a sum of (i) entropy due to uncertainty in the decay mode and (ii) average entropy due to uncertainty in the microstates of a given mode.

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Dependence of Type Ia Supernovae Luminosity on The Host Galaxy Stellar Mass

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Topic(s): Particle astrophysics and cosmology

Abstract: Studies of Type Ia Supernovae (SNe Ia) have led to the discovery of dark energy [1, 2]; and, till date, SNe Ia have been playing a crucial role in modern Cosmology. Although, a distinct class of objects, however, recent observations indicate a larger diversity than expected [3]. It is important to understand the reliance of SN properties on the characteristics of its host galaxy. We wish to investigate the dependence of SN Ia absolute magnitude on the stellar mass of the host galaxy. The data sample for our study has been taken from [4] which contains 24 well observed nearby SNe Ia. These SNe have been calibrated through the Surface Brightness Fluctuations (SBF) method, a technique which can be used for very precise distance measurements [5]. Our results show a small but significant correlation between the SNe Ia brightness and the stellar mass of the host galaxy leading to the conclusion that massive galaxies favor brighter SNe Ia.

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Non-classical nature of single-mode squeezed thermal vacuum state in the oscillating FRW universe

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Topic(s): Particle astrophysics and cosmology

Abstract: We used squeezed thermal vacuum states to represent the massive inflaton field in the semi-classical gravity. Using formalism of squeezed thermal vacuum states we analyze particle production during the oscillatory region of massive inflaton [1], also studied particle production due to the thermal black hole [2] and analyzed the validity of semi-classical gravity[3]. Therefore, it is interesting to analyze the non-classical behavior of squeezed thermal vacuum states. In the present study, we analyze the non-classical nature of the squeezed thermal vacuum states using Mandel's Q parameter [4] in the context of cosmological background.

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Flow of Dark Energy on Black Holes vs Flow on Black Holes Sitting in Dark Energy : Comparative Studies

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Topic(s): Particle astrophysics and cosmology

Abstract: A rotating supermassive black hole surrounded by a quintessence dominated universe is chosen Ghosh. General relativity predicts that the geodesic equations around such an object will be highly nonlinear due to the compactified presence of time and space as coordinates. To study the matter infall towards such a steep gravitational well, we incorporate a pseudo-Newtonian potential prescribed by Sarkar and Biswas in the reference Sarkar. We observe some intermediate radial speed profiles which are neither parallel to distance axis like adiabatic fluid flows onto simple black holes, nor we observe them to be parallel to the radial inward speed axis like phantom energy flow onto a rotating black hole. These profiles justify very efficiently the density variations observed in different accretion cases. Surprisingly, this case shows the shear viscosity coefficient to entropy density ratio for the accretion flow violates the pre-prescribed lower limit given by string theory.

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Thermal chaos in extended phase space of AdS black holes in Einstein-Gauss-Bonnet gravity with quadratic nonlinear electrodynamics

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Topic(s): Particle astrophysics and cosmology

Abstract: We study the inception of chaos in Einstein Gauss-Bonnet gravity with quadratic Maxwell invariant term in AdS space by using Melnikov function under both, temporal and spatial perturbations . In temporal case, when a small time periodic perturbation at subcritical temperature, is applied upon the black hole when it is quenched in spinoidal region of phase space, chaos starts. It is controlled by the saturation limit of tuning parameter γ. By analyzing the simple zeros of appropriate Melnikov function exact analytic limit for γ was obtained. It depends on topological parameter k, Gauss bonnet coupling α and nonlinear correction parameter β. For spatial case small perturbation, periodic in space, was applied in subcritical region and it shows that chaos is always present for all possible topologies.

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Drop of Density in Viscous Dark Energy Accretion Flow Near a Supermassive Black Hole

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Topic(s): Particle astrophysics and cosmology

Abstract: In this paper we investigate the density profile of Dark Energy dominated accretion flow towards a supermassive Black hole or a compact object. We take the equation of state of Modified Chaplygin Gas as representative of Dark Energy to construct our model. We also incorporate viscosity by introducing Shakura-Sunyaev viscosity parameter. To avoid the complexity arise with General Relativistic equations we consider Pseudo-Newtonian potential, introduced by Mukhopadhyay2002. Here we show the variation of density near a supermassive Black Hole with respect to the radial distance from the central Black Hole. We construct a C-programming for solving the hydro-dynamical equations and use GNUPLOT for plotting.

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Light dark matter and rare B decays with missing energy

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Topic(s): Particle astrophysics and cosmology

Abstract: We investigate the phenomenology of light GeV scale fermionic dark matter in an $U(1)_{L_\mu - L_\tau}$ gauge extension of standard model. With a ($\overline{3}$,1,1/3) scalar leptoquark [1] and light Z' mediating dark to visible sector, we make compute relic density and WIMP-nucleon cross section. We also study some rare semileptonic decays of $B \to M(= K^{(*)}, \pi, \phi, \rho)+$ missing energy [2] decay modes both in the scalar leptoquark model and in the model independent approach.

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Variation of secondary cosmic gamma ray flux during lunar eclipse

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Topic(s): Particle astrophysics and cosmology

Abstract: Astronomical events such as Solar eclipses and Lunar eclipses provide the opportunity for studying the disturbance produced in the atmosphere and its effect on cosmic ray intensity. There are earlier reports on decrease in secondary cosmic gamma ray (SCGR) flux during solar eclipse and enhancement of the same during lunar eclipse [1-4]. We have measured the variation of SCGR flux during two lunar eclipses that took place in India in the year 2018, one on 31^{st} of January and the other on 27^{th} of July. Both the measurements have been carried out at the Detector laboratory of Bose Institute, Kolkata, India, using NaI (Th) scintillator detector. We observed variations in SCGR flux in the low energy regime during the night of both the eclipses. The influences of weather parameters, geomagnetic field and interplanetary parameters on SCGR flux have been considered. Detailed measurement techniques, experimental set up and results will be presented.

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Decay of density inhomogeneities in an expanding universe

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Topic(s): Particle astrophysics and cosmology

Abstract:

Density inhomogeneities can be generated very early in the universe. These inhomogeneities then decay by particle diffusion in an expanding universe. We study the decay of density inhomogeneities in the early universe using the diffusion equation in the FLRW metric. We do the calculations close to the electroweak phase transition. We incorporate the interaction cross section of the quarks with the neutrinos, electrons and muons and obtain the diffusion coefficient. The diffusion coefficient is temperature dependent. We find that the expansion of the universe causes the inhomogeneities to decay at a faster rate. We also find that the decay of the inhomogeneities is enhanced due to the presence of the neutrinos with the electrons and muons playing a much smaller role. We obtain the length scales of the inhomogeneities that may survive till the quark hadron epoch. We also look at later times closer to the quark hadron transition. During this period we include the interaction of the muons with the neutrons and protons till 100 MeV. We find the largest length scales of density inhomogeneities which can survive till the nucleosynthesis epoch in an expanding universe.

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Neutrino energy reconstruction using machine learning algorithms

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Topic(s): Neutrino physics

Abstract: Long-Baseline Neutrino Experiments aim to measure the fundamental neutrino oscillation parameters with high precision and explore physics beyond the standard model. The determination of the neutrino oscillation parameters [1] depends on the knowledge of the neutrino energy, that is reconstructed based on the particles in the final state that emerge out of the nucleus after the neutrino-nucleus interaction. This scattering becomes more complicated for the heavy nuclear targets [2] that are currently used by the upcoming neutrino experiments. Here, we attempt to check the viability of using machine learning techniques to improve the systematics due to mis-reconstrued neutrino energy and compare it with the traditional methods i.e. calorimetric and kinematic methods of neutrino energy reconstruction. In this work, Monte Carlo (MC) samples obtained from the neutrino event generators are used to train the machine learning algorithms.

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Impacts of power-law cosmology on metric f(R) gravity

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Topic(s): Particle astrophysics and cosmology

Abstract: Modified theories of gravity [1, 2] are introduced in cosmology as an alternative of dark energy [3, 4] to explain the presently observed accelerated expansion of the universe [5, 6]. Among different types of modified theories of gravity, the simplest one is f(R) gravity obeying metric formalism [7, 8]. In the present study, we use power-law cosmology [9, 10] to discuss the cosmological implication of metric f(R) gravity. Power-law cosmology implies the existence of power-law solutions corresponding to different phases of cosmic evolution. During our analysis, we consider that metric f(R) gravity satisfies the conditions provided by Starobinsky model [11]. The most important think about Starobinsky model is that it could explain the inflationary scenario of early universe.

We, here, assume that after inflation, the evolution of the universe was occurred through conventional cosmological eras of radiation-domination and matter-domination. In our analysis, first we have shown that how the density of the energy-matter filling the universe get changed due to modification of gravity. Then we determined the scale factor and consequently deceleration parameter for both the eras. From these calculations, we found that in radiation-dominated era, the evolution of the universe remains same as in the case of standard model of cosmology [12] and scalar-tensor theory [13]. Hence our integrated modified gravity model does not affect the early observational facts, starting from primordial nucleosynthesis [14] to providing the stage for formation of large scale structure [15]. But in matter dominated era, modified gravity plays its role by affecting the evolution of the universe. Assuming that present universe is matter-dominated, we are successful in explaining the observed accelerated expansion of the universe without requiring the dark energy.

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Present accelerated expansion of the universe and loop quantum cosmology

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Topic(s): Particle astrophysics and cosmology

Abstract: One of the long-standing problems in the standard Big Bang cosmology is the initial singularity, from which all matter and energy originated. Standard model of cosmology based on general theory of relativity offers no resolution to this problem. However, it is expected that quantum gravity may offer nice solution to this problem. Loop quantum gravity [1, 2], which is a non-perturbative and background independent approach to quantization of gravity, is one of the best motivated theories of quantum gravity. When loop quantum gravity is applied to cosmology to analyse our universe, it is called loop quantum cosmology (LQC) [3, 4]. The special focus of LQC is to remove the classical big bang singularity by quantum big bounce and provide sufficient explanation to solve the problems like avoidance of the big bang singularity, the big rip [5, 6] and several future singularities [7] etc.

Again, recently observed accelerated expansion of the universe has put a challenge for its theoretical understanding. As a possible explanation of this, it is considered that the most part of the present universe is filled with a form of energy that exerts a negative pressure, called dark energy [8]. Since dark energy and dark matter [9] comprise approximately 96 percentage of the total energy density of the universe with unknown character and origin, sometimes it is assumed that perhaps the dark energy and dark matter are coupled to each other so that they behave like a single dark fluid. Although this consideration sounds slightly phenomenological but this possibility cannot be ruled out by any observations. So, one can of course think of some interaction between these two fields. In fact, the standard cosmological laws can be retrieved at any time under the no interaction limit. Additionally, the dynamics of the universe in presence of any coupling between dark energy and dark matter becomes quite richer with many possibilities.

In our present work we used an interacting dark energy model and discuss the evolution of the universe within the context of LQC. Our work successfully explains the presently observed accelerated expansion of the universe by predicting that the present universe is phantom dominated. We also found that in the past the expansion of the universe was decelerated one and transition from deceleration to acceleration would occur at $t_{q=0} = 0.688t_0$, where t_0 is the present age of the universe. Again our calculation predicts that at transition time $t_{q=0}$, the universe would be dominated with quintessence type dark energy.

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Correlation of muons arrival times from two different cosmic showers

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Abstract: A 12-layer stack of 2 m×2 m Resistive Plate Chambers (RPCs) has been operational at IICHEP, Madurai for few years to study the long term performance of the RPCs produced by the Indian industries. The same data samples are also used to study the muons produced in the cosmic ray showers at the top of the atmosphere due to the interactions of high energetic cosmic rays with the atmosphere. The particles generated in different showers occasionally form random coincidence in the detector and recorded as a single event. Besides the timing there are many other distinct features to distinguish muons from the same cosmic shower from those produced in different cosmic showers. In this study, the number of events with random coincidences is estimated from the cosmic ray data and is compared with that obtained number using the coincidence time window for the trigger.

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Constraints on flavor dependent long range forces from planetary motion

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Topic(s): Particle astrophysics and cosmology

Abstract: The standard model particles can be gauged in an anomaly free way by three possible gauge symmetries namely $L_e - L_\mu, L_e - L_\tau$, and $L_\mu - L_\tau$. Of these, $L_e - L_\tau$ and $L_e - L_\tau$ forces can mediate between the Sun and the planets and change the perihelion precession of planetary orbits. It is well known that a deviation from the $1/r^2$ Newtonian force can give rise to a perihelion advancement in the planetary orbit, for instance, as in the well known case of Einstein's gravity which was tested from the observation of the perihelion advancement of the Mercury. We consider the long range Yukawa potential which arises between the Sun and the planets if the mass of the gauge boson is $\mathrm{M}_{Z'} \leq \mathcal{O}(10^{-19})$ eV. We derive the formula of perihelion advancement for Yukawa type fifth force due to the mediation of such $U(1)L_e - L_{\mu,\tau}$ gauge bosons. The perihelion advancement for Yukawa potential is proportional to the square of the semi major axis of the orbit for small $\mathrm{M}_{Z'}$, unlike GR, where it is largest for the nearest planet. However for higher values of $\mathrm{M}_{Z'}$, an exponential suppression of the perihelion advancement occurs. We take the observational limits for all planets for which the perihelion advancement is measured and we obtain the upper bound on the gauge boson coupling g for all the planets. The Mars gives the stronger bound on g for the mass range $\leq 10^{-19}$ eV and we obtain the exclusion plot. This mass range of gauge boson can be a possible candidate of fuzzy dark matter whose effect can therefore be observed in the precession measurement of the planetary orbits.

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Measurement of Cosmic-Ray Muon flux in the surface and underground laboratory using plastic scintillators and SiPM

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Topic(s): Particle astrophysics and cosmology; Detector development, future facilities and experiments

Abstract: The cosmic-ray muon flux has been measured at surface level and at a depth of 555 meter (1554 m w.e.) in the underground laboratory at Uranium Corporation of India Limited (UCIL), Jaduguda, Jharkhand, India.

Our experimental set up consists of total four plastic scintillators, out of which three of them are coupled to photo multiplier tubes (PMT) to generate a coincidence trigger for acquiring data. The fourth scintillator which has been coupled to a Silicon Photo multiplier (SiPM), is placed in between those three detector and it's signals are processed with respect to the coincidence trigger. In this scintillator, a light yield of 22 photoelectrons per muon has been observed both at the underground and surface laboratory. The measured time resolution was 1.3 ns at the surface. Conventional NIM electronics has been used for analog signal processing and trigger generation, while VME based DAQ is used for data acquisition. The muon rate measurement shows a reduction factor of $(1.67 \pm 0.11) \times 10^4$ at the underground lab which is consistent with measurents reported from other sites.[1–18]

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Addressing the High-f Problem in Pseudo - Nambu - Goldstone Boson Dark Energy Models with Dark Matter-Dark Energy Interaction

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Topic(s): Particle astrophysics and cosmology

Abstract: A popular dynamical dark energy model is a scalar field (ϕ) dark energy model with a slowly varying (very flat) potential. But in Ref. [1] the authors pointed out a serious problem for any slow rolling scalar field dark energy model. The problem is to prevent any additional terms to the field potential $V(\phi)$, which would spoil the flatness of the potential. In order to avoid this problem, the dark energy models are considered where the light mass of the scalar field ϕ is protected by a symmetry. Such scenario can be realised if a pseudo - Nambu - Goldston boson (pNGB) acts as a dynamical dark energy field [2, 3]. A pNGB could play the role of dark energy with the form of potential $V(\phi) = \mu^4 (1 + \cos(\phi/f))$, where f is the spontaneous symmetry breaking scale. In Refs. [2, 4, 5] the authors discussed that generally for dark energy with pNGB potential, f is greater or equal to the reduced Planck mass $M_{\rm pl}$ ($f \geqslant M_{\rm pl}$). But it is very difficult to interpret such high values of f since such values of f are not compatible with the valid domain of field theory. This problem is termed as high-f problem of pNGB dark energy model.

In our work [6] we consider a dark energy scenario driven by a scalar field ϕ with a pseudo - Nambu - Goldstone boson (pNGB) type potential $V(\phi) = \mu^4 (1 + \cos(\phi/f))$. We consider two cases namely the quintessence dark energy model with pNGB potential and another model namely the Slotheon dark energy model [7, 8] with pNGB potential. The latter is inspired by the theories of extra dimensions such as the DGP theory. We demonstrate that for this pNGB potential, high-f problem is better addressed when the interaction between dark matter and dark energy is taken into account. We also observe that Slotheon dark energy scenario works even better over quintessence in this respect.

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Detector development, future facilities and experiments, and societal applications (Posters)

Precision luminosity measurements using the CMS detector

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Topic(s): Detector development, future facilities and experiments

Abstract: Luminosity is a key parameter for most physics analyses at collider experiments, and a particularly challenging quantity to measure at the LHC. The measurement of the luminosity delivered to the CMS Experiment in proton-proton and lead-lead collisions during the Run 2 of the LHC operation is presented. The visible cross-sections of the luminosity detectors are determined under special beam conditions with Van der Meer (VdM) scans, where the two proton beams are separated transversely. From the rate measurement of a luminosity detector as function of the transverse beam separation, the absolute luminosity scale is inferred and used to determine the calibration constant. The leading sources of systematic uncertainty in the integrated luminosity which stem from the limited knowledge of beam conditions and detector-specific effects are discussed.

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CMS Drift Tube Chambers : Upgrade activities during LHC Long Shutdown II

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Topic(s): Detector development, future facilities and experiments

Abstract: To sustain and extend its discovery potential, the Large Hadron Collider (LHC) will undergo a major upgrade in the coming years, referred to as High Luminosity LHC (HL-LHC), aimed to increase its instantaneous and integrated luminosity respectively by a factor of five and ten beyond the original design value. After delivering an integrated luminosity of more than 160 fb^{-1} until the end of Run 2, at the beginning of 2019, LHC has been shutdown for two years (LS2) in order to get its accelerator-chain and detectors upgraded for the HL-LHC phase. During this LS2, the CMS experiment aims to upgrade its electronics and detector performance to improve the data taking and a precise reconstruction of all the particles in high pile-up conditions of HL-LHC. The Drift Tube (DT) chambers are one of the important parts of the CMS muon system responsible for identifying, measuring and triggering on muons by the precise measurement of their position. This talk briefly summarises the ongoing activities and plans related to the upgrade activities of the DT chambers.

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Effect of light guide on the pulse height distribution of scintillation detectors for cosmic ray

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Topic(s): Detector development, future facilities and experiments

Abstract: Several plastic scintillation detectors are fabricated using BC400 material to measure the cosmic ray flux in Kolkata (altitude $\sim$ 11 meters from sea level) [**1**]. A systematic study of the pulse height distribution for cosmic ray muons is also carried out using these detectors [**2**].

In this study, the coincidence technique is used to identify the muon and their energy deposition (pulse height) distribution from the individual detectors are investigated. All scintillation detectors are made of the same material and have the same thickness. The lengths of the perspex light guides are different. All detectors are operated at the same voltage and same discriminator thresholds are set. It is observed that because of the difference in the length of light guides, the pulse height varies for a particular event. The detailed method of measurement and experimental results will be presented.

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Phase 2 tracker in Fast Simulation

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Topic(s): Detector development, future facilities and experiments

Abstract: The CMS detector is one of the multipurpose detectors at the LHC. The continued success of the CMS experiment relies on effective upgrades in preparation for the HL-LHC phase. The present tracker of the CMS detector will be upgraded for HL-LHC and replaced by a new tracker which would be more radiation tolerant with increased forward acceptance, higher granularity, and higher data taking rates to maximize tracking performance in the high pile-up scenario at HL-LHC.

Fast simulation at CMS is an invaluable tool for physics analysis and is about a hundred times faster than the full GEANT4 based simulation. The tracker upgrade of the CMS detector also requires corresponding updates in the geometry and track reconstruction algorithms used in Fast simulation. In this presentation, I shall discuss the implementation of the phase 2 tracker geometry in fast simulation, and the modified algorithms to take advantage of the improved detector geometry.

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GEM foil characterization using a cheap and efficient way and attempt made to use it as an imaging detector

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Topic(s): Detector development, future facilities and experiments

Abstract:

The Gas Electron Multiplier (GEM) is a new age detector for nuclear and particle physics experiments where the flux is very high. This technology was first developed at the European Center for Nuclear Research (CERN). The GEM foil is constructed using 50 μm highly insulating foil (Kapton/Apical) coated with 5 μm layers of copper, on both sides, with a network of specifically shaped holes with a diameter of 60-80 μm on the surface of the metal and 40-60 μm holes in half of the foil′s thickness. The holes have a peculiar hourglass, double-cone shaped cross section. Thanks to that shape, and very fine thickness, when a small voltage (250-550)V is applied in between the top and the bottom layer of the foil, the electrical field in the holes achieves strength of up to (50-100) kV/cm, which creates an avalanche of multiplied electrons. CERN has been the sole supplier of the GEM foils until recently when few private companies started manufacturing GEM foils under the transfer of technology (TOT) from CERN. Techtra is one of the company in Europe which gained a right to use CERN developed technology in order to produce GEM foils. Due to microscopic structure of holes and dependence of the electric field inside it, it becomes essential to study the defect and uniformity of holes along with the electrical property of foils with ambient condition. In our work we have tested Techtra GEM foils and develop a cheap and efficient technique to study the GEM holes, along with changing property of foils with ambient condition. An attempt has been made to configure GEM detector for imaging using India(Micropack) made GEM foils and compared with Techtra.

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Investigation of UV radiation effect on etching parameters and activation energy of CR-39 plastic detector

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Abstract: This research paper deals with the investigation of UV radiation effect on etching parameters and activation energy of CR-39 plastic detector. Nine samples of dimension 1 cm x 1 cm were cut from CR-39 sheet of thickness 0.9 mm (C12H18O7, density 1.32 g/cm3) manufactured by HARZLAS TD-1, Japan. The first three samples (first set) were irradiated to alpha particles from 241Am source of 75 kBq intensity and then exposed in air with UV radiation using 30 watt deuterium lamp (wavelength = 160 nm) for 60 minutes (post-exposed). The second set containing three CR-39 samples was first exposed to UV radiation for 60 minutes and then irradiated to alpha particles under the same condition (pre-exposed). The third set containing three CR-39 detectors was irradiated to alpha particles only (un-exposed) under the same condition. Track diameters (D), Bulk etch rate (VB), Track etch rate (VT), Critical angle (C), Etching Efficiency (), Sensitivity (S) were determined using 6.25 N NaOH solution at different temperatures i.e. 60, 65, 70, 75 and 80C. The energy carried by UV radiation results in, hardening and chain scission of CR-39 plastic detector. Results show that VB and VT vary in all three cases and also all etching parameters vary accordingly. Bulk and track etch rates follow Arrhenius equations and slopes of graph reveal information about activation energy of bulk and track etch rates. Etching parameters and activation energies are found to be in agreement with available research literature. [1–4].

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G-APD characterization for the Imaging Camera

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Topic(s): Detector development, future facilities and experiments

Abstract: The Silicon Photomultiplier (SiPM) sensors are excellent solid state detectors with low light detection capibilites. The fast timing response and high photon detection efficiency (PDE) can be exploited in the detection of nanosecond flashes of Cherenkov light produced by atmospheric extensive air showers. The SiPM consists of a dense array of avalanche photodiodes (APD) operating in Geiger mode, each with its own quenching resistor for passive quenching of an avalanche. It is operated in reverse bias mode with the applied voltage little beyond the breakdown voltage of the APDs causing a high electric field across the APD junction. In response to an incident photon a photoelectron may be produced in the APD which can trigger a Geiger discharge under the influence of the high electric field giving a rise to a current pulse. The currents from each of these individual APDs combines to form a quasi-analog current pulse from which the number of detected photons can be estimated. The SiPM photo sensor exhibts features of similar to Photo Multiplier tube (PMT) and are best alternative for future applications. Traditionally, most of the Imaging Atmospheric Cherenkov Telescopes (IACT) have been using PMTs for light detection but for future telescopes SiPMs are seen nowdays as promising alternative to PMTs for all future telescopes. In fact the usefulness of the SiPMs for such an application is successfully demonstrated by FACT-the First G-APD Cherenkov telescope [1] and CTA dual mirror telescope [2].

Hamamatsu G-APD make SiPM arrays will be used as detectors in upcoming 256 pixel camera being developed for 4m class imaging atmospheric Cherenkov telescope. Each pixel sensor consists of 4x4 or 16 channel array of SiPM with area of 3x3 mm^2 per channel. Performance of these SiPM arrays has been studied for the detection of nanosecond flashes. The performance of SiPM array is evaluated by measuring various characteristics such as photo-electron spectrum under low light level condition, pulse shape, breakdown voltage, cross-talk, dark count rate, charge resolution, timing jitter, dependency of gain on bias as well as temperature. The primary effects of temperature change on the SiPM are a change in the breakdown voltage and the dark count rate which affect the gain of detector. Results from these studies will be presented.

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**Also at some institute.

Electron and Photon HLT studies in barrel for the Phase II upgrade of the CMS detector at the LHC

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Topic(s): Detector development, future facilities and experiments

Abstract: The Compact Muon Solenoid (CMS) detector is one of the two multi-purpose experiments at the Large Hadron Collider (LHC) and has a broad physics program. Many aspects of this program depend on our ability to trigger, reconstruction and identify events with final state electrons, positrons, and photons with the CMS detector with excellent efficiency and high resolution. In this talk we present the reconstruction and trigger development at the HLT level for the electron and photons in the barrel for the HL-LHC based on the shower-shape, isolation and identification variables. This study will also include the information related to the depth segmentation of the HCAL detector.

AuL mini-X-ray source facilitated with 2-axis movement setup at Institute of Physics, Bhubaneswar

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Topic(s): Detector development, future facilities and experiments

Abstract: Recently a mini-X-ray (AuL) source with 2-axis movement facility was installed at Institute of Physics, Bhubaneswar for various applications. Because of its small size, light weight, and handy nature, this mini-X-ray source will be very much useful to characterise large area X-ray Detector used in High-Energy Physics research, In-Situ X-ray fluorescence analysis of large samples, multi-elemental analysis of rocks or stone at the mining site, X-ray volume plasmon scattering study etc. The present miniature X-ray tube (AMPTEK Inc., USA) is fully computer controlled through USB system. This miniature X-ray source potential very from 10-50 kV and 10-200μA with a maximum power of 4W. The focal spot and the target thickness of this miniature transmission type X-ray tube are about 2mm and 1 $\pm$ 0.1 μm, respectively. The intensity of the AuL line, i.e.,$I_L = Bi(V_{appl} - V_L)^{1.5}$, where V_{appl} is the applied potential, B is the proportionality constant, i is the tube current and V_L is the L-excitation potential of the gold target. The target dependent proportionality constant used to calculate the exact number of photons emitted by the source. The typical photon flux of the gold mini-X-ray source is about 2.2 $\times 10^6$ cps/mm^2 (@ 30 cm on axis, at 50 KV and 1 μA) and can provide typical dose rate of 2.2 Sv/hr (@ 30 cm on axis, at 50 KV and 80μA) [1]. The thickness of the Be-window of the X-ray tube is about 125μm. A number of parameters such as L-shell fluorescence yield, focal spot size, window transmission %, actual power required to convert X-ray etc. are required to calculate the above proportionality constant (B). The mean L-shell fluorescence yield of the Au-target is about 0.338 $\pm$ 0.007 [2]. Applying various corrections the maximum AuL X-ray photon emitted per second by the X-ray source approximately in the order of 10^7 photons/sec. This intensity is quite ideal for a number of experiment purpose. In the present experiment we have taken a preliminary run set at an optimum voltage 20 KV and varying current viz.5μA, 10μA, 20μA, and 25μA. The optimum potential 20 KV is so selected to obtain all the AuL X-ray characteristics lines viz. AuL_α (9.713 KeV), AuL_β (11.442 KeV) and AuL_γ (13.382 KeV) clearly. The takeoff angle of the X-ray tube is about 27^0 and the geometry was so arranged to carry out experiments. The present experiment was carried out by placing the PVT scintillator detector ($20 \times 20 \times 2cm^3$) at a distance 50 mm perpendicular to the beam direction to record the number of photon emitted by the source. The solid angle formed by the detector with the source found out to be 5×10^{-3} sr and the number of photon received by the detector at maximum source power (4W) is about $4{\times}10^4$ photons/sec. In the presentation, we will be discussing the characteristics of the mini-X-ray source and its potential applications to characterise different materials.

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A Novel perception on the radiation safety concerns arising from radiographic examinations in the COVID19 wards along with strategic prevention and mitigation

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Topic(s): Societal application: Medical Physics

Abstract: Ever since its inception, Corona virus is causing havoc all over the world. COVID-19 caused by Corona virus is a respiratory disease, to evaluate the infection, at least one Chest radiograph per patient is necessary based on the patient condition. X-ray radiation is an ionizing electromagnetic radiation and has the potential to break molecular bonds and cause damages to the DNA of the exposed cell. This damaged DNA can cause cell mutation and may cause various health hazards including Cancer, genetic disorders etc. Even a very low exposure to X-ray can cause the damage [1]. Any unwanted exposure may lead to serious health consequences in the long term.

Thus, special radiation protection protocols set by various regulatory agencies all over the world are followed to utilize X-rays for human benefit keeping the exposure under permissible limit. In India Atomic Energy Regulatory Board (AERB) is the regulatory authority. Most of the COVID-19 wards are make shift rooms, so they may not have X-ray rooms built as per AERB guidelines [2]. To provide care to a large number of patients, higher numbers of beds are accommodated per ward. Sometimes patients may not be able to move from their respective bed to the X-ray room. In such cases bedside radiographs are taken. Now, during that bedside X-ray exposure, along with the patient, all the neighboring patients & staffs get unwanted radiation exposure. And the same process is repeated every time a bedside radiograph is taken. This may give a mass exposure for the entire COVID-19 ward.

The aim of this study is to assess the radiation dose around the X-ray facility in COVID-19 ward with special reference to bedside X-rays. In this study, the actual situation is simulated with a water phantom in place of a real patient. The radiation dose is measured at different locations around the X-ray patient couch during the exposure using a digital pocket dosimeter. The collected data is analyzed for probable deviations from radiation safety protocols and also possible radiation hazard [3]. A fitting solution of the above issues has been proposed in this study. Also, as the X-ray technicians/Radiographers are wearing PPE kit, hence they are unable to wear radiation protection gears. This may lead to a serious radiation exposure. In this study, an alternative method of radiation protection for such special cases has been suggested.

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Impact of multilayer insulation technique in the designing of a cryostat

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Topic(s): Detector development, future facilities and experiments

Abstract:

Multilayer insulation (MLI) is an important technique to reduce the radiation heat load in cryostats. For the continuous and reliable functioning of a cryostat, it is desired to have a minimum heat load (thermal radiation, solid conduction and gas conduction) to the inner wall of the cryostat, and the requirement of minimum heat load (radiation heat load in particular) can be well accomplished by using the multilayer insulation (MLI) technique [1]. The basic principle of MLI technique is to obtain the multiple radiation reflection by placing the reflective layers called radiation shields, in the vacuum space between the two walls (hot radiating surface and cold surface) of the cryostat. Generally, these reflective layers are made up of thin polyethylene or Mylar sheet, coated with highly reflecting material (Aluminium or Gold, but most commonly Aluminium is used due to low cost) on both the sides of the sheet, so called double−Aluminized reflective layer. Hence, there may be a chance of conduction due to adjacent reflective layers. Therefore, low conductivity materials or insulators called spacers are placed in between these reflective layers. As these reflective layers are interleaved with insulating spacers, they do not touch each other and reduce thermal conduction.

The current work is an attempt to address the question of what is the best MLI system (reflective layer and spacer material in MLI systems), which is usually asked before designing the cryostat in an experiment. In our analysis, we have selected perforated double−Aluminized Mylar (DAM) with Dacron, unperforated DAM with Silk−net and perforated DAM with Glass−tissue for their evaluation as the reflective layer as well as spacer materials in MLI technique and used Modified Lockheed equation for checking the performance which is given by the expression (1)

$$q_{\text{total}} = \frac{C_R\ \varepsilon\ (T_h^{4.67} - T_c^{4.67})}{N} + \frac{C_S\ \bar{N}^{2.63}(T_h - T_c)(T_h + T_c)}{2\ (N+1)} + \frac{C_G\ P\ (T_h^{0.52} - T_c^{0.52})}{N}\ , \tag{1}$$

where $\bar{N}$ and N represents the layer density and number of layers. The symbol C_S, C_R and C_G denotes solid conduction coefficient, radiation coefficient and gas conduction coefficient respectively. Here T_h and T_c are the temperatures (in K) of the outer (hot) wall and the inner (cold) wall of the cryostat, and P symbolizes the residual gas pressure [2]. With these ingredients we have observed that perforated DAM with Glass−tissue is the best among the three selected combinations by calculating the effect of layer density and number of layers on the heat load and evaluated optimal layer density and favorable thickness of insulating blanket for these selected materials in MLI technique.

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Track Reconstruction in Time Projection Chamber (TPC) of future CRS-External-target Experiment (CEE) at HIRFL, Lanzhou, China

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Topic(s): Detector development, future facilities and experiments

Abstract: One of the main aims of heavy-ion collisions experiments is to study the Quantum Chromo Dynamics (QCD) phase diagram which gives information about the phase transition and possible existence of critical point (CP) of the strongly interacting matter. The future heavy-ion collider experiments, CRS-External-target Experiment (CEE)[1] will use heavy-ion beams with energies of 0.3 GeV/u to 2.8 GeV/u provided by HIRFL, Lanzhou, China to probe the high-baryon density region of QCD phase diagram. In addition, CEE aims to study the equation of states of asymmetry nuclear matter, properties of cold nuclear matter, production of exotic particles carrying the medium effects and the possible occurrence of quarkoyanic matter phase. Time Projection chamber (TPC) is the main tracking device of CEE spectrometer. Momenta of produced charged particles can be extracted from curvatures of their trajectories. Due to high particle multiplicity of HICs, it is a huge challenge to reconstruct the tracks precisely and efficiently. We are developing a tracking algorithm for the CEE-TPC. The algorithm starts with a combinatorial search for track candidates (tracklets) based on the Cellular Automaton [2] track finding method and later Kalman Filter [3] is used for the evaluation of track parameters. In this talk, the tracking reconstruction performance, the track finding efficiency, resolution and treatment of hit positions will be presented and discussed.

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Single Particle Response from 2018 Low Luminosity Collision Data at $\sqrt{s} = 13$ TeV

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Topic(s): Detector development, future facilities and experiments

Abstract: The response of the CMS calorimeter[1] to hadrons was measured from the collision data in the past at $\sqrt{s} = 7$[2], 8[3], and 13 TeV using tracks isolated in the tracker as well as in the calorimeters. These measurements were compared with Monte Carlo tuned to the test beam data. These comparisons helped in testing and tuning the Monte Carlo program used within the CMS experiment. However, the earlier results were limited for particles of momenta below 20 GeV. In this paper, we study the effects due to containment, contamination, pile-up, trigger bias for the low luminosity data collected by the CMS during 2018[4]. The low luminosity data of 2018 provide an opportunity to increase the momentum range upto 40 GeV. For comparison, Monte Carlo events with single particles of the right composition are also looked into.

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Prototype TPC for the measurement of cosmic muon flux

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Topic(s): Detector development, future facilities and experiments

Abstract: The main source of error in atmospheric neutrino flux comes from the uncertainties in cosmic ray flux and nuclear interactions at very high energies. It is crucial to study the atmospheric neutrinos are produced before oscillation occurs. The major production of atmospheric neutrinos occur in the decay of charged pions, $\pi^+ \rightarrow \mu^+\nu_\mu$, $\pi^- \rightarrow \mu^-\bar{\nu}_\mu$ and subsequent decay of the muons, $\mu^+ \rightarrow e^+\nu_e\,\bar{\nu}_\mu$, $\mu^- \rightarrow e^-\bar{\nu}_e\,\nu_\mu$[1]. The earth's magnetic field produces a zenith and azimuth angle variation in muon flux at different locations on earth surface. This in turn modifies the corresponding neutrino fluxes[2]. Current studies show a discrepancy in the observed and calculated atmospheric muon fluxes. The main goal is to study the integrated muon flux in different directions at different latitude, altitudes and underground and that can be included in neutrino event generators to reduce the uncertainty of neutrino flux. For this the most suitable detector is a Time Projection Chamber (TPC)[3], which provides position resolution in millimeter range and better rate capability compared to atmospheric muon rate. Also the electronics required is minimal compared to other detectors and transportation easier. A prototype is built to learn the common issues that can occur while making a bigger one. The drift space for the prototype TPC is only 14 cm. The readout is via a pixelated pad in an MWPC placed at one end. The change in the amplification in various gas mixtures like P10 and Ar-CO_2 is studied. The TPC is triggered by cosmic muons passing through plastic scintillators placed above and below of the drift region. The anode wires in the MWPC are of 25 μm diameter and are placed 3 mm apart. The distance between anode and cathode planes is 6 mm. Field cage is made using cylindrical copper gaskets attached to many grooved G10 rods. The drift velocity, diffusion constants, townsend and attachment coefficient for different gas mixtures derived using MAGBOLTZ[4] will be discussed in the paper along with the preliminary test results obtained with this small TPC.

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Correlation of strip multiplicity with other parameters in a Resistive Plate Chamber

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Topic(s): Detector development, future facilities and experiments

Abstract: The Resistive Plate Chambers(RPC) are fast gaseous detectors with good position resolution and time resolution, but with a simple construction procedure. This makes them a good candidate for muon triggering and tracking systems. Nonetheless while trying to improve various parameters like time resolution, position resolution, efficiency, etc., the improvement in all parameters together is somewhat contrary in nature. Wide gap RPC's(6 mm-8 mm gas gap) has less gain variation, which can be easily operated in avalanche mode and good efficiency characteristics compared to 2 mm gas gap RPC's[1]. Stable operation of small gap RPC's is possible with the help of the electron quencher. But the occasional appearances of streamers deteriorate the position resolution very drastically[2]. The streamers are mostly accompanied by larger strip multiplicities. This paper tries to reconcile the correlation of strip multiplicites with other parameters of RPC's like gain, time resolution, position resolution, muon angle, etc. Also the drastic deterioration in position resolution with large strip multiplicities is studied to estimate the streamer fraction.

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Position measurement using timing at two ends of a strip in RPC

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Topic(s): Detector development, future facilities and experiments

Abstract: The purpose of this paper is to explore a technique in single gap Resistive Plate Chamber (RPC) where the position of the particle along a strip is extracted by measuring the timing difference from the two ends. This technique has been successfully tested in the case of multigap-RPCs with a sensitivity of 104 ps/cm and a resolution of 18 ps or 1.7 mm in [1]. It is expected that this method would work on single-gap RPCs also. This is because the timing-difference resolution does not depend on the intrinsic timing resolution of the device, as the signal will be induced to both the sides of a strip simultaneously. The intrinsic uncertainty due to fluctuation in avalanche formation will be common to both the ends and will be cancelled out. This paper will present the preliminary result on the timing performance with a single gap RPC.

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Summary of Legacy certification of combined 2016-2018 CMS data and status of Run3 preparation for the Data Quality Monitoring and Certification

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Topic(s): Detector development, future facilities and experiments

Abstract: At the Large Hadron Collider, the CMS detector reads out particle collision data from over 100 million electronic channels with the recording rate for physics events of up to 1 KHz. The data needs to be scrutinised to ensure that no hardware or software related issues may compromise its integrity. For physics analysis, the certification of CMS data is performed centrally, first, with the promptReco data, as data are processed, in each week while the data taking is in progress. Then, typically, when the data are reprocessed in the end of a year, data certification is performed again. Finally, in order to make 2016-2018 data as coherent as possible, Legacy ReReco data certification is carried out. Summary of the Legacy certification of combined 2016-2018 CMS data will be presented along with status of the CMS data quality monitoring and certification preparations for Run3.

Mechanical Design for SiPM based 64-pixel Camera Prototype

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Topic(s): Detector development, future facilities and experiments

Abstract: SiPM based 256 pixel Camera is being developed in TIFR for an Atmospheric Cherenkov Telescope keeping its specifications to operate at a very high altitude location. The Camera has an aperture of 5° × 5° with a pixel resolution 0.3°. The Camera is planned with a modular structure with 256 pixels organized into 16 modules of 16 pixels each in the front-end as well as in the back-end of the camera. A prototype is made with 64 pixels supported by a mechanical structure to study its performance. The front-end and back-end structures are mounted independently on a camera interface plate which is coupled to the base plate held at the focal plane of the telescope. A pixel cluster module (PCM) houses all the front-end electronics cards catering to a cluster of 16 pixels. The PCM housing is a single shell made of ABS plastic using 3D printing for master mould and vacuum casting process for the production. The PCM housing is designed for easy assemby of 8 electronics cards with a consideration to efficient heat dissipation, extreme temperatures at high altitude site and easy servicing. The Light Concentractor (LC) designed indegeneously focus the faint light onto each pixel sensor comprising of an array of SiPMs. An LC cluster assemby is made by gluing the 16 LCs on a machined Aluminium base. The assembly is fixed over pixel cluster of PCM front-end ensuring accurate one-to-one alignment between each LC and corresponding pixel sensor. Both the LC cluster assembly and PCM housing are the prototypes for the final Camera.

Four PCMs are assembled on a front-end structure which will be mounted on bottom surface of the camera interface plate. The Back-end is desinged using Crate structure to house back-end modules. The machanical structure for the crate is made with flexible vertical movement for cable harnessing and servicing. The whole back-end structure is mounted on top surface of interface plate. Both these structures are covered by the plates in all sides to protect from weather with proper air circulation to dissipate the heat generated by the camera electronics. The poster will describe the details of the mechanical components of the camera and their current status.

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Algorithm Development and Performance matrix Optimization for-CMS Phase 2 Calorimeter Trigger

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Topic(s): Detector development, future facilities and experiments

Abstract:

The Phase-2 upgrade of the trigger and DAQ system for CMS experiment will continue to operate with a two-level strategy while increasing the level-1 maximum rate to 750 kHz, from the current value of about 1 kHz. The total latency will be increased from 4.2 μs to 12.5 μs to allow for the first time, the inclusion of the tracker and high-granularity calorimeter information.The Phase-2 L1 trigger receives inputs from the calorimeters, the muon spectrometers and the track finder.The algorithm implementation in firmware greatly benefits from the introduction of High-Level-Synthesis software that could be used to design advanced machine learning trained variables or even iterative processes in the core of the trigger system. Our group is working towards the optimization and static timing analysis of the Calorimeter Trigger algorithms viz; Regional Calorimeter Trigger (RCT) and Global Calorimeter Trigger (GCT) The important features about the timing performance optimization in the RCT and GCT algorithms will be discussed including the challenges faced and the results achieved.

INO's RPC-DAQ module: Performance review and upgrade plans

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Topic(s): Detector development, future facilities and experiments

Abstract: The India-based Neutrino Observatory (INO) is planning to build a magnetised Iron-CALorimeter (ICAL) to study atmospheric neutrinos with precise measurements of their oscillation parameters [1]. ICAL detector will deploy about 28,800 single gap Resistive Plate Chambers (RPCs) of 2 m $\times$ 2 m area as active detector elements. Induced signals from the point of particle interaction in the RPC are picked up by 64 pick-up strips each on orthogonal X- and Y- planes. These signals are amplified and converted into differential logic signals using discriminators which are operated at set thresholds.

These logic signals are processed by the RPC-DAQ module [2] which is mounted in every RPC-Tray with the RPCs. RPC-DAQ module is essentially built around Altera's Cyclone IV FPGA, HPTDC and Ethernet controller chip Wiznet 5300. The pre-trigger signals generated from each of the RPC-DAQ modules, participate in forming a global ICAL event trigger. On receiving the global trigger, the RPC-DAQ module records mainly the event time, RPC strip-hit pattern along with relative precise time stamps of the hits. The strip signal rates in batches, are recorded as a background job periodically in order to monitor the health of the RPC detectors. The RPC-DAQ then packages this data and sends it over Ethernet to the back-end servers [3]. For the purpose of communication and data transfers between the RPC-DAQ and the back-end, the former is configured as a network element with a unique IP number. A Soft-core processor has been instantiated inside the FPGA for many data acquisition tasks and data interfaces.

The RPC-DAQ has been the workhorse of the prototype RPC detector stack at IICHEP, Madurai as well as the mini-ICAL detector which has been operational since about 2 years. In this paper we present, the performance metrics of the current version of the module and upgrade plans based on the experience gained after the deployment at site.

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Performance of cosmic veto scintillator and WLS fiber of CMV.

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Topic(s): Detector development, future facilities and experiments

Abstract:

The plan to build 50 kt Iron Calorimeter(ICAL), to study neutrino mass hierarchy is proposed at the India based Neutrino Observatory (INO). To gain experience about the detector and electronics involved, a small prototype of the ICAL detector i.e. mini-ICAL was built and is currently operational at IICHEP Madurai. Mini-ICAL consists of a ∼85 ton magnet built using 11 layers of 5.6 cm thick iron plates and 10 layers of 2m × 2m glass Resistive Plate Chambers (RPCs). The idea is to shield the 4m × 4m × 1.1m mini-ICAL with a cosmic muon veto (CMV) detector and to estimate the veto efficiency with a goal of ∼99.99%. This will establish proof of principle of the CMV detector for efficient rejection power of cosmic muons at the ICAL. The CMV detector for mini-ICAL will have three layers of extruded scintillators of size 4.4m × 5cm × 2cm on top and 4.4m × 5cm × 1cm four sides of the mini-ICAL. The surface area of each layer on top is 4.4m × 4.4m and 4.4m × 2m for each of the four side layers. Wavelength shifting (WLS) fibers are embedded into the holes throughout the length of extruded scintillators and readout is taken using Silicon PhotoMultipliers (SiPMs).

For the CMV detector of mini-ICAL, various components of CMV have been tested as a part of the research and development. Extruded scintillators with dimensions (60cm × 5cm × 2cm) and (60cm × 5cm × 1cm) with embedded WLS fibers are tested in a test set-up. Wavelength shifting (WLS) fiber are used to collect the scintillator signals and readout is taken on both sides of the fiber by SiPMs [1]. This setup is used to calculate the muon detection efficiency for different thresholds of signal. About 10 m long WLS fiber is also tested, where scintillator signals are produced at different lengths of the fiber to estimate the attenuation of the muon induced photon signal along the 4.4 m long extruded scintillator. This paper presents these test results of the extruded scintillators such as efficiency, position resolution, timing resolution as well as performance of the WLS fibers.

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Effect of dead or noisy channels in position resolution of an RPC.

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Topic(s): Detector development, future facilities and experiments

Abstract:

A magnetized Iron Calorimeter(ICAL) with a target 50 kt mass is proposed to be built at the India based Neutrino Observatory (INO) in TamilNadu. The physics goal of the ICAL detector is to study neutrinos (mainly neutrino mass hierarchy) by observing atmospheric neutrinos from cosmic showers. Meanwhile, a small prototype detector of ICAL has been built on the surface, i.e., mini-ICAL at IICHEP, Madurai. The mini-ICAL comprises of a ∼85 ton magnet built using 11 layers of 5.6 cm thick iron plates and 10 layers of 2m × 2m glass Resistive Plate Chambers (RPCs). The mini-ICAL detector has been collecting data for the past 2 years and various properties of cosmic muons have been studied using mini-ICAL data.

Each RPC has a total of 119 readout strips of width 3 cm, where 58 strips are at the bottom (X-plane) and 61 strips are on the top (Y-plane) in orthogonal directions to have three dimensional coordinates of the muon trajectory. During the data taking period, a few strips in an RPC go dead or become unusable due to various reasons like poor electrical connectivity as well as having noisy strips or strips with very large gain. Such strips or channels are found to affect the overall performance of RPC detector. This paper presents the effects of dead or noisy channels on the RPC performance especially on the position resolution, which is one of the main characteristics which affects the ICAL physics potential.

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Software scheme for an SiPM based Imaging Camera

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Topic(s): Detector development, future facilities and experiments

Abstract: A 256-pixel imaging camera based on SiPM is under development for a 4 m class Cherenkov telescope. The camera is placed at the focal plane of the telescope and its entire operation is manoeuvred with the help of a stack of firmware plus software programs. At the lowest level of the stack is the firmware associated with the camera components for local control with the flexibility achieved through the supervisory remote commands from the back-end software in the control room PCs. Beside the firmware, there are three pieces of servers hosted by the camera viz. Camera Bias Server (CBS), Camera Control and Monitoring Server (CCMS), and Data Concentrator Server (DCS). These programs communicate over a local network and in addition, talk to the back-end software programs over a single high speed optical down link.

Two microcontroller based bias boards takes care of overall operation and monitoring of camera front-end module called Pixel Cluster Module (PCM) which caters to a cluster of 16 pixels in the camera. The 32 Bias boards of all the 16 PCMs in the camera are daisy chained over customized SPI interface and controlled by CBS, the master program running in Raspberry Pi, a single board computer. CCMS runs in camera back-end module called Control & Trigger Module (CTM) and communicates with 16 Cluster Digitizer Modules (CDMs) for configuration, control and monitoring. CCMS program also talks to the back-end software in the control room over an Ethernet for commands and monitor data transfer. The CDMs in the camera back-end generate segmented event data packets that are pushed to another local back-end module called Data Concentrator Module (DCM). DCM hosts two servers which are connected to two TCP/IP clients in the control room for pooling these data packets and building the events.

At the uppermost level of the stack are the set of back-end software programs running in the control room PCs and include data Base Software(DBS), Bias Control and Monitoring Software (BCMS), Event Builder (EB) and the Main Console (MC). They communicate with the servers hosted by the camera for the overall operation, control, monitoring and event data acquiring. The GUI-based DBS maintains camera components data base, calibration constants and Run configurations. BCMS takes care of the biasing of 256 pixels and, overall control and monitoring of front-end electronics of Camera. The EB builds the events one by one by collating the segmented event data packets pooled. MC supervises overall operation of the camera especially the back-end section of the camera. The data base, event data and monitoring data are all stored in NAS storage system.

The Camera software is developed using C code running in processors like Atmel Microcontrollers and NIOS soft processors. The CBS running in the camera and also the back-end software hosted by control room PCs are developed using Qt. The communication between the software programs in the camera and those in the control room is based on client-server technology and make use of some standard protocols like TCP/IP, UDP etc.

The details of the software scheme and the progress made so far will be discussed in the paper.

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Evolution of the germanium detector technology in the dark matter and neutrino search

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Topic(s): Detector development, future facilities and experiments

Abstract:

To look at different modern sectors of physics like the study of, dark matter interaction, different properties of neutrino and other exotic particle interaction, detectors having a very low threshold of the order of eV (electron equivalent) is one of the prime need [1]. Germanium ionization detector is one of the apt technology with good resolution and the low threshold [1]. Various configuration of a highly pure germanium detector has been used to look at the above-mentioned properties [1–6]. Among them, the point contact and ultra low energy detector configurations have shown a very promising energy threshold near the desired range [2, 3]. Ultra low energy detectors also have a very good resolution but their low mass is a point of concern in scaling up the detector [1, 6]. Whereas coaxial configuration has a large mass but the resolution is not that much good [1, 4, 5]. All the advantages and the disadvantages of the highly pure germanium detector technology based on different configurations will be presented here.

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Update on Muon momentum reconstruction in mini-ICAL

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Topic(s): Detector development, future facilities and experiments

Abstract: Kalman filter based fitting algorithm is being used for reconstructing muon 4-vectors for INO-ICAL detector. The same algorithm is also being used for the prototype ICAL (mini-ICAL) with 10 layers of RPCs. Due to shorter track length and relatively wider strip-width of the RPC, the detector causes saturation in the momentum estimation at about 2 GeV. Therefore, other possible reconstruction techniques are explored to get a better estimation of muon momentum. The algorithm that gives the best estimation for mini-ICAL detector consists of three sections, namely finding the initial parameters (p,θ, ϕ) using effective circle fit, propagation of the trajectory using 4th order Runge-Kutta-Nyostrom numerical integration and estimating the physics parameters by minimising the χ^2 by varying initial parameters to the particle propagation. The performance of this algorithm and the estimated efficiency and momentum resolution will be discussed in the paper.

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Calorimeter Level-1 trigger upgrade for the CMS detector at the HL-LHC

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Topic(s): Detector development, future facilities and experiments

Abstract: Phase-II upgrade of the LHC and its detectors will reach an unprecedented performance in terms of instantaneous luminosity of $7.5 \times 10^{34} cm^{-2} s^{-1}$, which opens a new era of physics program which includes new physics searches, Higgs boson coupling measurements, and precision tests of the standard model. The Phase-II upgrade of the level-1 trigger system of the Compact Muon Solenoid (CMS) detector is designed not only to maintain the efficiency of the signal selection to the level of the Phase-I performance but also to enhance the selection of any possible new physics manifestations that could lead to unconventional signatures. [1].

In this talk I will describe the algorithm developments for the calorimeter trigger of the Phase-II upgrade of the level-1 trigger system. Calorimeter trigger will have two stages: Regional Calorimeter trigger (RCT) and Global Calorimeter trigger (GCT). RCT takes energy deposits as inputs from barrel electromagnetic calorimeter (ECAL) and barrel hadronic calorimeter (HCAL), cluster them, and sends to next level, i.e., GCT for further processing. GCT, takes information from barrel calorimeter (ECAL and HCAL) through RCT and also receives inputs from endcap calorimeters (HGCAL) and HF. The information is used to build triggerable physics objects - Egamma, Jets and Taus and send them to next level in the level-1 trigger chain.

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Beam Diagnostics : A case for Low Energy - Low Intensity Beams

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Topic(s): Detector development, future facilities and experiments

Abstract:

The diagnostic instruments play a very important role on a daily basis in an accelerator performance [1]. They are particularly paramount when new detectors/components are commissioned at the start-up or after a long shutdown. Besides that during the daily operation of the machine, these beam measurements inform the operator, if the machine is performing as per requirements or not and furthermore, these instruments will help him to find potential defects in the accelerator components. So the diagnostics tools are crucial. In one aspect they enable to control the particle beam and provide elaborate information concerning the stability and the quality of the particle beam delivered at the user-area. Beam instrumentation and diagnostics combines the principles of accelerator physics with mechanical, electronic, and software engineering to improve the diagnostic equipments for the observation of particle beams, with the needed tuning precision and thereby enhancing the performance of accelerators and their associated transfer lines.

Although non-perturbative devices are preferred, the destructive solutions are also often used for the transfer lines and first turn diagnostics. The measurements of beam profiles using non-destructive or minimally-invasive techniques, where the instruments can be operated in real time, are much needed apparatus for accelerators. Moreover, in the high energy accelerators, especially storage rings, the non-destructive beam measurements are highly desirable to minimise the effect on the beam quality. For high intensity machines like Large Hadron Collider (LHC) [2] they are absolutely crucial for the beam dynamic studies. A range of beam monitors are required for various stages of accelerator performance optimisation and its later operation. A number of different types of device exist for just such a purpose that come under the generic title Beam Position Monitor, or BPM. Thus the non-destructive measurements of beam position are essential for the effective running of any modern day accelerator.

However for the low energy machines, they are very crucial, since the low energy beams are very important for many existing and recently commissioned **national** accelerator projects. An increasing number of their applications encompass the varied aspects of experimental research and applied physics. Sometimes the low energy beams are required at low intensities, where a restricted number of particles may be a consequence of a small cross-section for the production of nuclear species of interest, along-with the injection/extraction losses, space charge limitations, or applied deceleration and collimation techniques. The resulting low intensities may not be easy to handle. Henceforth, the already not so easy task of effective beam diagnostics of the low energy beams becomes even more complicated, and specially the practical aspects of the beam uniformity and energy. So there is a need to develop a device that should be able to operate in two (low-energy and low-intensity) regimes as a non-destructive beam diagnostic component. The attributes of non-destructive diagnostic methodologies towards the implementation of such a device will be discussed and presented.

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Machine learning studies for Data Quality Monitoring (DQM) in the CMS Tracker

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Topic(s): Detector development, future facilities and experiments

Abstract: The CMS DQM group is in charge of data certification which, up to Run2, consisted of human based inspection of histograms representative of data quality from each of the sub-detectors on a run by run basis. Machine Learning (ML) techniques can help on the automatisation of this process and allow to fully exploit the whole set of information available in a single lumisection (LS, 23s of data taking), in order to consolidate the LS-by-LS granularity of the decisions..

This talk will discuss some ML methods and architectures which are being explored and their performances in certifying CMS tracker sub-detector data taken during years 2017 and 2018 as well as the future plans in automatising this intensive data certification process.

Validation tool to compare track properties between Data and MC production in CMS for Run-2

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Topic(s): Detector development, future facilities and experiments

Abstract:

It is important to check the agreement of reconstructed track properties between Data and Monte-Carlo using the CMS Tracker detector for different production campaigns. We have developed a validation tool within the CMS Data Quality Monitoring (DQM) framework for that purpose. We select different kinds of physics events with the help of suitable filters and study track parameters. The tool complements the official DQM application and provides prompt feedback on track reconstruction performance during data taking. We have performed the work for the 2016-2018 data taking period. We shall show a description of the tool along-with its various components. Some preliminary comparison of the most relevant physics observables used for accessing the improvements in the description of the CMS tracker simulation and calibrations will be presented.

Start to end beam dynamics studies of a 250 MeV RF electron linac for focused VHEE beam

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Topic(s): Societal applications

Abstract: In this paper, the start to end beam dynamics simulation results of a 250 MeV travelling wave RF electron linear accelerator for VHEE purposes is presented. The simulation output data find optimal design of the linac to provide desired beam for irradiation of deep-seated tumours. The tracking simulations in the linac include the self field effects in the injector section [1–4]. The bunch compressor is designed to reduce the bunch length with a careful choice of beam parameters and accelerator parameters such that the transverse emittance is not significantly increased. The linac consists of electron gun followed by an accelerating section. The accelerating section consists of TW cavities. Beam focusing is ensured by solenoids, quadrupoles. The bunch compressor is a 4-dipole chicane magnet to compress the bunch.

This beam dynamics study with ASTRA [5] and ELEGANT [6] explores the optimized beam parameters and predict the beam quality for the linac operation.

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Position and Time resolutions of large area RPC detector

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Topic(s): Detector development, future facilities and experiments

Abstract: As a part of its R&D, the ICAL collaboration has built a small prototype module called miniICAL to study the detector performance, engineering challenges in the construction of large scale magnet, magnetic field measurement system as well as test the ICAL electronics in presence of magnetic field. This modest detector was also used to measure the charge dependent muon flux, muon spin rotation and feasibility study of cosmic muon veto for shallow depth ICAL. The mini-ICAL consists of 11 layers of iron plates (dimension $4\,\mathrm{m}\times4\,\mathrm{m}\times0.056\,\mathrm{m}$) with an interlayer gap of 45 mm. The RPC (area $\sim2\,\mathrm{m}\times2\,\mathrm{m}$) detectors are inserted in between iron layers. The characterisation of RPC detectors and its electronics is an essential part of the experiment before looking for physics data and results. Detector efficiencies, position resolution, time resolution are the major parameters to characterise. All the above mentioned parameters will affect the physics potential of the experiment. The paper will discuss the position and time resolution obtained from the stack of RPCs used in miniICAL.

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Cosmic muons track reconstruction for Muon Tomography using ISMRAN scintillator matrix

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Topic(s): Detector development, future facilities and experiments

Abstract: Highly penetrating cosmic ray muons with mean energy of 3-4 GeV, continuously showers the earth surface at the rate of $\sim$ 10,000 $m^{-2}min^{-1}$. Due to their highly penetrating characteristics, they can be used as a probe to detect and image the high-Z material [1]. Multiple Scattering Muon tomography(MSMT) works on the basis of the deflection of muon when they pass through the materials. The more accurately the muon tracks are measured, the better is the material discrimination and identification capability and it also results in an improved reconstructed image. Various types of position-sensitive muon detectors employed for muon tomography applications include Gas Electron Multiplier (GEM) [2], Resistive Plate Chamber (RPC)[3] and Drift-Tube detectors [4]. In addition, plastic scintillator detectors are being explored for muon tomography applications, due to their ruggedness with a relatively low weight, high detection efficiency and ease of deployability [5].

The work presents the preliminary results of track resconstruction using the Indian Scintillator Matrix for Reactor Anti-Neutrinos (ISMRAN) [6], a plastic scintillator array, which is being constructed for the purpose of electron anti-neutrino ($\bar{\nu}_e$) detection for reactor monitoring applications. 81 scintillator detectors of ISMRAN matrix have been setup in 9 $\times$ 9 geometry. The data acquisition system based on waveform digitizers is used for pulse processing and event triggering. Characterization of plastic scintillator detectors is done with known radioactive sources by placing the sources at the different positions along the length of the scintillator bar, for energy, timing and position measurements.

To generate the muon track in 3D, the hit position in each layer of scintillators is estimated, using the parameterization function obtained from their characterization. Muon track in 3D is reconstructed by doing the linear fit in two different planes in two dimension keep one axis common in both. Using the fitted muon tracks the angular distribution of cosmic muons have been obtained. Measurements are planned for a configuration where scintillator matrix is split into two halves with a $\sim$ 1m vertical distance between them, for placing the materials to be discriminated.

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Closed loop gas system for INO's mini-ICAL detector and plan for its engineering module

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Topic(s): Detector development, future facilities and experiments

Abstract: Mini-ICAL is a pre-prototype detector which is operational in the transit campus of the INO Project in Madurai, mainly to study the engineering aspects of its ambitious ICAL detector. Mini-ICAL - a truly a scaled down version of ICAL, is a 10-layer, 85-ton magnetised detector built using20 RPCs of about 2m x 2m in area as its active elements. The RPCs are operated in the avalanche mode, requiring a mixture of R134a, Iso-butane and Sulphur Hexafluoride gases in fixed proportions. For the mini-ICAL detector, the gas volume amounts to about 130 litres. Due to environmental and cost considerations in respect of the ICAL detector, it is envisaged that the gas can be recycled through the RPC detectors, only by topping up small amount of fresh gas to offset for the leaks in the long gas lines and release of over pressure. Besides, the gas pressure heads both at the input and output ports of the RPC detectors must be maintained accurately. For ensuring safe working of the detector and for the operating personnel, the system must monitor gas leaks and generate alerts if the levels cross set limits. [1–3].

A closed loop gas system incorporating these requirements was designed and deployed for the mini-ICAL detector. The system is in successful operation for the past few years. In order to improve the performance of the system further, activation of a diaphragm pump, the addition of pneumatically operated valves and operation/safety interlocks based on differential pressure have been implemented in the system. Automation of various processes such as vacuum, gas filling, gas make-up, molecular sieves regeneration, open-loop mode of operation was also carried out [4–8].

Based on our experience gained so far, we begun to work on the design of scaled-up closed loop gas system meant for the engineering module (E-ICAL) of the INO project. The proposed E-ICAL with 8 m x 8 m x 2 m in size will have 20 layers, housing 320 RPCs in total. The total gas volume for the E-ICAL detector will be of 2055 litres which also needs to be recirculated by the gas system.

The requirements of the closed loop gas systems for the mini-ICAL as well as E-ICAL will be discussed. The design aspects as well as the performance of the mini-ICAL system will be reported. Overall plan for the design and safety aspects of the system for the E-ICAL will also be presented.

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Commissioning of Resistive Plate Chambers for the mini-ICAL detector at IICHEP, Madurai

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Topic(s): Detector development, future facilities and experiments

Abstract: The mini Iron Calorimeter (**mini**-ICAL) is a tiny, but exact replica of the ICAL detector planned by the INO Collaboration at Theni, Tamil Nadu. The **mini**-ICAL detector comprises of 11-layers of soft iron plates of 5.6 cm thickness, copper coil system for magnet, water cooling system, magnet power supply, closed loop gas system and so on. The detector **is sensitive to record the trajectories of charge particles - mainly cosmic ray muons**. During the first phase, we have tested and installed 10 Resistive Plate Chamber (RPC) modules The detector, electronics and data acquisition system used for the **mini**-ICAL are identical to what are planned to be used for the **engineering module of the ICAL detector (e-ICAL)** to be built at Madurai later as well as for the ICAL. In fact, one of the main purposes of building **mini**-ICAL is to understand the challenges and gain experience in building large scale the magnet, detector and electronics systems. During the second phase of installation, ten more RPCs were installed and commissioned - thus completing the construction of **mini**-ICAL. In this talk, various sub-systems of the **mini**-ICAL detector will be presented briefly. The challenges faced in the construction, testing and performance of the detector will also be discussed.

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Attenuation of electromagnetic radiation in Nuclear Track Detectors

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Topic(s): Detector development, future facilities and experiments

Abstract: Nuclear Track Detectors (NTDs) have often been the detectors of choice for detecting highly ionizing rare particles (strangelet, magnetic monopole) in cosmic rays [1, 2] and in accelerators [3, 4]. Some of the most important advantages of NTDs are their low cost, ease of use, and the existence of natural thresholds of detection [5]. In addition, being passive in the nature of action (as they do not require electrical power during their operation), NTDs are often the choice for setting up of detector arrays in remote locations [6]. Previous studies show that the responses of the NTDs (e.g., bulk etch-rate, sensitivity etc.) are affected both in open-air exposures and in accelerator experiments by electromagnetic radiation [7, 8]. To investigate this particular issue, we pursued a systematic study on the attenuation of electromagnetic radiation over a wide range of energies for three commercially available NTDs, namely - PET (Desmat, India), Makrofol® (Covestro AG, Germany) and CR-39® (TASL, England). For this purpose, NTDs are exposed to electromagnetic radiation across the spectrum - gamma ray, X-ray, UV-visible and infrared, and the attenuation is studied using NaI(Tl) detector, Gas Electron Multiplier (GEM) detector, UV-Vis spectrophotometer and FTIR spectrophotometer respectively. The values of some important parameters (e.g., optical depth, attenuation coefficient) of different NTDs at relevant region of electromagnetic spectrum have been determined. The details of the experimental techniques and the results are presented in this article.

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MET performance study in Gamma+Jet channel with 2018 p-p dataset in CMS

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Topic(s): Detector development, future facilities and experiments

Abstract: The missing transverse momentum (MET) is an important measurable quantity for many processes in SM physics and beyond, viz. leptonic decay of W or production of SUSY par- ticles in certain scenarios. In the experiment there can be other sources of momentum mismeasurement due to detector resolution and sensitivity. MET is also sensitive to the presence of pileup interactions, both in-time and out-of-time. The performance of the measurement of the missing transverse momentum in events containing a photon and jets collected by the CMS experiment in proton-proton collisions at $\sqrt{s} = 13$ TeV in 2018 will be presented.

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Data Acquisition and Monitoring for SiPM based Imaging Camera

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Topic(s): Detector development, future facilities and experiments

Abstract: SiPM based 256-pixel camera for a 4m class Imaging Atmospheric Cherenkov Telescope (IACT) is being developed in house by TIFR. It is built with a modular design concept applied to its both the front-end and back-end sections. The tasks of biasing all the SiPMs and conditioning of SiPM signals to form 256 pixel signals are handled by the front-end electronics. Back-end electronics processes these pixel signals and generates event triggers. Pulse profiles of all the 256 pixel signals are recorded @ 1 GSPS on each event trigger.

There are three type of modules developed using Intel's MAX 10 FPGA which are housed in a crate, viz. 16 Cluster Digitizer Modules (CDMs), 1 Data Concentrator Module (DCM) and 1 Control & Trigger Module (CTM). Each CDM processes and digitizes the analog signals of 16 pixels brought in from the front-end section. Prior to digitization, it uses 2 signal paths (low-gain and high-gain) for each pixel to cover the required dynamic range of detection. The amplified signals are used to generate primitive triggers based on the criterion of neighbouring pixels crossing the set threshold. CTM generates a final trigger based on the primitive triggers received from the CDMs using a coincidence window of 10 ns. The readout scheme for the processed pixel signals makes use of analog sampler chip DRS4 developed by PSI, Switzerland. On receipt of a final trigger, samples in the DRS4 chips are frozen and only the samples of region of interest (ROI) are digitized at a slower speed and recorded. CDM packs the data of digitized samples of a group of 4 pixels in an independent data packet with unique group identity and a common global event marker. Each CDM pushes these packets asynchronously to a common Data Concentrator Module (DCM) in the crate over dedicated LVDS fast serial link. The DCM is designed to collect the event data packets from 16 CDMs and store them in a temporary local buffer. The received data packets are pooled by remote clients in the control room over dedicated 1 Gbps Ethernet links via optical 10 Gbps downlink in a network switch. The CTM connected to the Control room over Ethernet, controls overall operation of the camera and monitors the various signal rates to check the camera health. The CTM is connected to all the modules in the crate for command and data transfer using a customized common SPI interface.

The paper gives design details and overall performance results of the back-end electronics of the camera.

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A high-speed 16-channel Data Concentrator Module for SiPM based camera

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Topic(s): Detector development, future facilities and experiments

Abstract: The Imaging Atmospheric Cherenkov Telescope (IACT) camera comprises a large number of photo-sensors demanding a high throughput Data Acquisition (DAQ) system due to pulse profile recording at 1 GSPS. One such 256-pixel camera based on an array of SiPMs as a pixel sensor is under development by TIFR. A pixel signal readout scheme in the camera employs a 9 channel digitizer module developed in house with a sampling rate of 1 GSPS to record pulse profile of low gain and high gain version for each of 4 pixels. The size of the pulse profile data packets may be either fixed or variable as per a user set configuration. Upon receiving a final trigger, the data packet is generated by the digitizer with a unique identity and an event marker information and stored temporarily in a local FIFO buffer. The digitizer accepts next trigger only when all digitizers are ready.

Four such digitizers catering to a cluster of 16 pixels are housed in a Cluster Digitizer Module (CDM). All of the 16 CDMs in the camera are linked to a Data Concentrator Module (DCM) over 16 dedicated fast serial links running through the back panel of the crate that houses all the modules. We have adapted mesochronous system approach for connecting CDMs with a DCM over the dedicated LVDS links for the event data transfer. All these modules are synchronized with a common reference clock.

DCM is a custom-built module, one for the whole camera that does the job of collecting the data packets from 16 CDMs and push them to the control room server over two '1 Gbps' downlinks. It has two identical sections and each section is connected to a set of 8 CDMs to pool the 32-bit serialized data packets over 8 dedicated '45 Mbps' asynchronous serial links in parallel. The data collected over these serial lines are stored in respective local FIFO buffers. The maximum throughput is achieved in each section by using a commercial hardwired TCP/IP Offload Engine (ZestETM1 from Orange Tree Technology) with the 1 Gbps Ethernet downlink. The data packets from each of these buffers are written one at a time to TOE buffer in a round-robin fashion and the data are pooled by client requests in the control room server. All the circuit blocks including 32 bit deserializer, FIFO buffer, TOE interface and overall control logic are implemented in an FPGA (Intel's MAX10). The module is successfully tested. The design and performance study of the module will be presented in the poster.

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Automation of High Energy GEM Detector Experimental Setup with Wireless Communication

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Topic(s): Detector development, future facilities and experiments

Abstract:

The Gas Electron Multiplier (GEM) detector is a very popular detector in high energy particle physics experiment. The performance of this detector is sensitive to the environmental parameters like ambient temperature, atmospheric pressure, humidity, gas flow rate etc. These parameters are required to store continuously for various calculations. Also certain parameters like count rate and anode current need to be measured for characterisation of the detector for further experimental application[1].

The experimental setup of the GEM detector is kept away from the data acquisition setup, as the detector is exposed to high luminous radioactive radiations. The entire duration of experiment, it is essential to record ambient data to calculate compensation factor. All those information are recorded from the detector environment and communicated to the DAQ PC (Data Acquisition Computer). The system is designed with two parts, one records environmental temperature, atmospheric pressure, humidity and gas flow, other is a multichannel quad TTL counter and Keithley Pico Ammeter KE6485, these are controlled and communicated with the DAQ PC using wireless connectivity[2].

The DAQ PC is running with LabVIEW based software to read the data from the detector and environmental data logger is also stored in a file system. The LabVIEW based DAQ software is developed with two parts one to read the Environmental Data logger directly using Ethernet protocol and other instruments like multichannel quad TTL counter and Keithley Pico Ammeter KE6485 is connected through a wireless hub using serial protocol. The data stored from different instruments in the files is used for further analysis and characterisation of the GEM detector[3].

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Investigation of applicability of plastic scintillation detector for imaging

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Topic(s): Societal applications

Abstract: Plastic scintillation detectors are generally used in High Energy Physics (HEP) experiments for triggering and calorimetry [**1-2**]. They are also extensively used in the study of cosmic rays [**3-5**]. Due to the good timing properties and low fabrication cost, the plastic scintillator is a potential candidate for imaging [**6-7**]. In this work, the timing properties of the plastic scintillation detectors of different dimension have been measured using cosmic ray muons. The time resolutions of all the detectors are found to be less than 1 ns. The variation of the time resolution with the applied voltage to the Photo Multiplier Tube (PMT) is also studied.

Since the time resolution of these scintillation detectors is quite good, the applicability of the detectors for imaging is investigated. A Na^{22} source that emits two back to back gamma-rays is used for the proof of the principle of imaging. The details of the experimental setup, method of measurement, and results will be presented.

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Silicon vertex layout optimization for the proposed TauFV experiment

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Topic(s): Detector development, future facilities and experiments

Abstract: The TauFV experiment[1] is designed in order to test the phenomenon of lepton flavor violation. This is a fixed target experiment where high energy protons hit tungsten targets which leads to the production of D_s mesons which then decay to produce $\tau\nu_\tau$. The decay of this τ to three muons is a process which can be enhanced by beyond standard model lepton flavor violation. The experiment attempts to detect this $\tau \longrightarrow \mu\mu\mu$ process. The experiment is designed for the proposed Beam Dump Facility at CERN and would accumulate 4×10^{18} protons on target over five years.

The layout was designed considering five tungsten targets, stations placed with an inner radius of 2.5 cm and outer radius of 6 cm. The stations/sensors consist of square pixel of dimensions 55×55 μm building stations of square geometry around the beam axis. The layout is optimized considering each track to hit the stations for a minimum of four times and considering them to fall within 0.03 radians and 0.3 radians from the beam axis. An algorithm was designed to optimally build a layout keeping the farthest station at 120 cm from the first target. A simulation is used to study the occupancy, impact parameter resolution and vertexing capability of the silicon detector layout.

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Study on RPC Charge dispersion as a function of Surface Resistivity

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Topic(s): Detector development, future facilities and experiments

Abstract: Resistive Plate Chamber (RPC) is a parallel plate gaseous detector built using electrodes of high volume resistivity. Operation and performance of the RPCs crucially depends upon the conductive coating on the outer side of the electrodes. In this paper, we report our studies on the effect of the surface resistivity of electrode coating (i.e. graphite conductive coating) on the RPC characteristics and performance [1]. Our experimental study on surface resistivity of electrode coating has shown a remarkable influence on the basic RPC parameters like efficiency, strip rates, pulse shape, position resolution and space dispersion of the induced charge [2]. We fabricated three prototype RPCs of different surface resistivities namely 1 MΩ/sq, 100 kΩ/sq, 40 kΩ/sq and experimentally studied the effect on the RPC parameters. Tests were carried out with two different types of pickup panels - one made up of plastic honeycomb core of pitch 30 mm and the other made up of G10 based core material of pitch 6 mm [3]. Measurements performed with both types of pickup panels indicated that charge diffusion on either sides of main strip was found to be increased with the decrease in the surface resistivity from 1 MΩ/sq to 40 kΩ/sq [4]. Also the asymptotic efficiency (emax) for the Main strip was found to be more than 95% for all three RPCs [5]. The knee voltage was found to shift to lower values as the surface resistivity of the RPCs is increased.

Charge spread across the pickup strips was studied in detail when tests carried were repeated with G10 based pickup panel of strip pitch 6mm. Out of the 50 readout channels, we instrumented only 25 channels in our data acquisition setup. A double-Gaussian function was used to fit the dispersion of the induced charge of the RPC. It is shown that the Gaussian distribution with the narrower width is due to the spread of the avalanche charge in the gas gap of the RPC and that of larger width is due to diffusion of charge as it passes through the resistive coat film. As part of detailed optimization studies on Resistive Plate Chambers (RPCs), effects of integration time on the dispersion of the induced charge as well as position resolution of a prototype RPC was also studied [6]. Our studies showed that, much better position resolution of the order of (0.57±0.05) could be obtained in case of finer strips of pitch of 3mm.

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Investigations on link loss in mCBM Data

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Topic(s): Detector development, future facilities and experiments

Abstract: The CBM experiment [1] at FAIR [2] is designed to operate at very high interaction rates using a free running DAQ. Mini-CBM @ SIS18 is a miniature experiment for testing the free running DAQ of a heterogeneous detection system. CBM will record data in a triggerless mode, hence the particle detectors and associated electronics has to be robust, noise free and very fast. The data flow in the final experiment will be such that the Front End Boards (FEB) are connected via e-links to a Read out Board (ROB) and will digitize the analog signals coming from the detector. The ROB will aggregate the data streams and sends them via optical links towards the Data Processing Board (DPB). The DPB will process the data of multiple ROBs by a high performance FPGA. Methods to discriminate the detector electronics noise from raw data have been studied as reported in reference [3]. Apart from the noise issue, e-link break or e-link loss is another major issue in the mCBM that is encountered while online data taking. A link break can be triggered by a spark in the detector and such phenomenon must be rigorously studied before employing any detector in the final experiment. There may be other reasons of link break that is also important to investigate and find out its effects on the raw data. Several detector subsystems have faced this link break issue. We have developed a simple and fast method to find e-link breaks in mMUCH from the huge amount of collected data. mMUCH is comprised of 2 Gas Electron Multiplier (GEM) trapezoidal shaped modules in mCBM with around 2000 readout pads (channels) [4]. The regularity of such link breaks in a given experimental run and its effects on the mMUCH data is analysed. A later firmware upgrade is believed to mitigate the effect of the e-link break issue on the collected data. A brief summary of the work will be presented.

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Simulation and Designing of Time Projection Chamber (TPC) for the CEE Experiment

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Topic(s): Detector development, future facilities and experiments

Abstract: CSR External Target Experiment (CEE) is a future facility to be constructed at IMP, CAS, China. One of the main goals of the experiment is to search for the critical point in the QCD phase diagram in low energy regime ($\sim$ 1 GeV) [1, 2]. The time projection chamber (TPC) is the most critical detector in the CEE experiment, which will provide position, charge sign, momentum, and energy loss for charged particles.

In this talk, I will report the simulation and optimization of the CEE TPC. In a single collision event, as many as hundreds of created charged particles may go through the TPC, which is followed by gas ionization, electron drift and diffusion, avalanche in the GEM layers, and finally read-out pad and electronics responses. I will describe how we simulate these complicated processes and how we reconstruct the event using the simulated data. Finally, I will talk about how we plan to optimize the TPC design using the simulation software, in order to obtain the best performance in terms of two-track separation, tracking efficiency and momentum resolution.

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Development of a novel FPGA-based readout system for muon tomography

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Topic(s): Detector development, future facilities and experiments

Abstract: We plan to build a prototype muon tomography system for material identification utilizing multiple Coulomb scattering suffered by cosmic ray muons while passing through a matter [1, 2]. The resultant deflection from the original trajectory can be represented by a gaussian distribution dependent on several physical properties of the matter and also the muon momentum. Thus the measurement of the scattering angle by tracking the pre and post-interaction muon trajectories enables one to identify the material. The tracking of the muons can be accomplished with a series of position-sensitive detectors which facilitate the reconstruction of the trajectories from the position information obtained from each of them. We plan to use 6 Resistive Plate Chambers (RPCs) in two sets, each containing 3 of them, for tracking muons before and after their interaction. A multi-parameter data acquisition system has been developed in this context for collection of position information and subsequent track reconstruction. This work will report its performance by measuring the muon detection efficiency of an RPC with respect to a plastic scintillator and the position of the detected muon event.

In our test setup, a Bakelite-RPC of dimension 30cm x 30cm, filled with a gas mixture of 95% Freon and 5% Isobutane, equipped with two orthogonal panels of readout strips of width 1 cm and pitch 1.2 cm, has been operated. An 8-channel ultra-fast front-end preamplifier discriminator chip NINO [3] has been used to obtain Time-Over-Threshold (TOT) outputs corresponding to the current signals induced on the readout strips due to a muon event. For each readout plane, 3 NINO chips have been connected to acquire signals from 24 strips in total. Each NINO chip provides as outputs 8 pairs of LVDS (Low Voltage Differential Signalling) signals which are suitable for low-power, high-speed transmission with better noise immunity. For parallel post-processing and to take advantage of this LVDS scheme, we have used a FPGA development board with ALTERA MAX 10, which has dedicated pins for direct acquisition of LVDS analog signals. Moreover, using ALTERA MAX 10, which has a dedicated PLL (Phase Locked Loop)-controlled clock (500 MHz max frequency) for sampling of LVDS analog signals, we have achieved 2 ns resolution for signal acquisition. Because of the direct LVDS signal handling capability, it is not necessary to use any LVDS to TLL conversion devices and thereby, LVDS signal purity is maintained. The FPGA is programmed to transfer the acquired data to the computer using UART protocol. The RPC data for muon events as collected by the present readout scheme have been analysed to estimate the position information. The data have been used for determining the efficiency of the RPC in muon detection in comparison to plastic scintillator.

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Electronics and DAQ for a cosmic muon veto around mini-ICAL detector

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Topic(s): Detector development, future facilities and experiments

Abstract: A 10-layer, 85-ton magnetized mini-ICAL detector was built at the INO transit campus in Madurai, using 20 RPCs as active detector elements. A 3-layer Cosmic Muon Veto Detector (CMVD) is planned around the mini-ICAL on all the five open sides using extruded scintillator strips. The position and charge information recorded in the CMVD on mini-ICAL trigger is used to estimate the efficiency of identifying the Cosmic Muon events in the mini-ICAL in the offline analysis.
The scintillator strips of 50mm in width and readout with two, 1.4 mm dia fibres spaced at 25mm, are used. 2mm×2mm Hamamatsu SiPMs are used to read light from both ends of fibres to extract the charge and position information of interaction. The SiPM signals from both ends of the strips are processed separately for trigger redundancy and position sensitivity. The SiPM signals crossing the set charge threshold, would produce pre-trigger pulses. These pulses from one side of a layer are ORed to get a Layer Trigger, which in turn is used along with those from two other layers, to generate a local trigger. The SiPM signals are conditioned in the front-end electronics and, its charge and arrival time are recorded on local trigger. After validating the local trigger with that from the mini-ICAL, the charge and time information of the participating channels in a layer, along with the event marker are sent to the back-end servers over an Ethernet link. These data packets from three layers of all the five sides of CMVD are collated by comparing the event marker to build the events. Event data from the mini-ICAL and CMVD is used to estimate the VETO efficiency in offline analysis.
The gain of an SiPM is sensitive to temperature and a closed loop control of gain to a constant value is planned by sensing the temperature and suitably correcting its bias voltage. An in-situ gain calibration of the SiPMs is also planned by flashing pulsed light and recording the charge information to obtain the single photoelectron spectrum. Counting rates of SiPM signals as well as various stages of trigger signals are periodically recorded to monitor the stability and efficient functioning of CMVD.
Overall specifications and design of the CMVD DAQ system, choice of front-end components, trigger system architecture as well as other implementation plans will be presented in this paper.

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Measurent of Muon flux in the surface laboratory using plastic scintillators and SiPM

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Topic(s): Detector development, future facilities and experiments; Particle astrophysics and cosmology

Abstract: The measurement of cosmic muon flux has been carried out at surface level at Saha Institute of Nuclear Physics, Kolkata, India using experimental setup constructed at SINP.
The experimental set up consists of total 7 plastic scintillators, all coupled through WLS fibers to SiPM. For signal processing and trigger generation in top 3 and bottom 3 SiPM, digitizer unit from CAEN (DT5702) has been used, which can bais a maximum of 32 SiPMs, process the analog signals with data aquisition capability and the data can be stored event by event basis in root format while for middle SiPM VME based DAQ has been used for data acquisition. This set up is easily portable and will be very usefull for muon flux measurents at different attitudes in underground laboratory.[1–13]
The estimated muon flux value using this set up at surface level at SINP with 4-fold coincidence is $(7.978 \pm 0.128(stat)) \times 10^{-3} cm^{-2} sec^{-1} sr^{-1}$ which is consistent with other literature.[14]

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Studies on the pad-based readout system for RPC detector

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Topic(s): Detector development, future facilities and experiments

Abstract: Resistive Plate Chamber (RPC) is a parallel plate avalanche type particle detector which uses gas mixture as its active detection medium. While high resistive glass or bakelite plates are used as the detector electrodes, plastic core based and metal foil laminated pick-up panels with segmented strips are used to readout the induced signals. Large area RPCs of this design are chosen as active detector elements for the INO's ICAL detector. As a part of the ongoing R&D, pad-based instead of strip-based readout scheme is being studied to address better localization of particle hit positions, charge profile and noise rate statistics of the RPC based detectors [1]. An RPC gas gap of dimensions 260 mm $\times$ 260 mm is sandwiched between two readout panels namely the pad-based readout panel on the top and strip-based panel on the bottom side. Pad-based panel is a single layer G-10 PCB bearing the pad in 11 $\times$ 11 matrix, each of dimension 20 mm $\times$ 20 mm and separated by 2 mm gap. Strip-based readout panel has 11 channels, width of each copper strip being 20 mm and separated by 2 mm. The RPC is tested with cosmic ray muon triggers generated by a telescope, which is setup using three scintillator paddles. Width of the paddles is 20 mm, specifically designed to match with that of the strips and pads. HMC based preamplifiers are used to amplify the RPC signals, both from strips and pads. A VME based data acquisition system is configured to study the charge and timing characteristics for cosmic muons. Besides, the data acquisition is also setup to study the noise rate data of the strips and pads as well as the hit-pattern of the pads. The motivation of the study, the design of detector and telescope, the data acquisition system setup as well as the preliminary results will be discussed.

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Modelling and Tracking of Cosmic Ray Muons in a 3-D Scintillator Detector using Machine Learning

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Topic(s): Detector development, future facilities and experiments

Abstract: High-energy cosmic rays impinging onto the atmosphere of the earth initiate cascades of secondary particles which led to formation of extensive air showers (EAS). Mainly muons, electrons and photons arrive on ground and can be measured with particle detectors. In order to understand the origin of cosmic rays, one needs to study various components of primary cosmic rays including energy and arriving direction. This is possible by studying electron and muon components carefully using sensitive detectors. Muons are the most abundant charged particles arriving at sea level and the only ones to penetrate deeply underground. Because of the close relation between muon and neutrino production, it is the most important particle to keep track.

We have modelled a multi-layer 3-D Scintillator detector for EAS studies using GEANT4 simulation package where geometry has been prepared by providing various dimensional parameters. Finally, the EAS is simulated using CORSIKA (COsmic Ray SImulations for KAscade) with focus on muons originating from EAS. We propose a novel tracking algorithm based on Machine Learning approach of directed graph structure to incorporate domain knowledge to track cosmic ray muons in our 3-D scintillator detector. We shed some light on the performance, limitations and application of proposed algorithm in tracking applications with the possibility to generalize to other detectors.

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Development of Cosmic Muon Tracker for INO outreach activities

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Topic(s): Detector development, future facilities and experiments

Abstract: The INO project [1] plans to build a 50 kton magnetized iron calorimeter (ICAL) to study atmospheric neutrinos. Resistive Plate Chambers (RPCs) are chosen to be the active detectors in ICAL to track the muons generated in the neutrino interactions inside the iron absorber plates. To demonstrate the working of the ICAL detector to students and general public during INO outreach campaigns, a portable Cosmic Muon Tracker (CMT) was developed. The CMT comprises of a vertical stack of eight RPCs - each of 26cm $\times$ 26cm in area and are operated in the gas-sealed avalanche mode. Each RPC provides signals on eight pickup strips (3cm wide) on both X- and Y-planes. Typically, cosmic ray muons passing through the stack produce tracks in all the eight RPCs and induce signals in the pickup strips. Each RPC front-end amplifier and discriminator board receives these signals and sends processed signals to the FPGA based data acquisition module (RPC-DAQ)[2]. LEDs - one per strip, mounted on the front-end boards of X- and Y-planes of each RPC in the stack, display the tracks of these cosmic ray muons in real time. The RPC-DAQ also acquires muon data and sends it to the server for detailed data analysis. This detector module can also be used to study angular distribution of muons, effect of ambient parameters such as temperature, relative humidity and barometric pressure - which are also recorded - on the performance of the RPC detectors. The CMT played an important role in publicising INO project and its INO-ICAL experiment at various science popularisation and outreach events. CMT was one of the main attractions of the INO pavilion at the year-long Vigyan Samagam, which is India's first-ever, global Mega-Science exhibition. In this paper, the design, construction and salient features of this detector are presented. A few simple physics concepts which can be studied using the CMT will also be mentioned.

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Formal theory (Posters)

Rotating Holographic Superconductor

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Topic(s): Formal theory

Abstract: High-T_c superconductors were discovered by Bednorz and Müller in 1986. These are prototype of the so called strongly correlated systems in condensed matter physics. Such systems generically fall under strongly coupled field theories. However, due to strong coupling these systems are hard to tame using traditional field theoretic approaches. In the last decade, the gauge/gravity duality has emerged as a powerful tool to study such systems.The importance of the gauge/gravity correspondence in strongly coupled systems was realized in 2008 when Gubser showed that for an asymptotic AdS black hole, near to its horizon, $U(1)$ gauge symmetry spontaneously breaks giving rise to the phenomenon of superconductivity in the vicinity of the black hole horizon [**Gubser**]. Immediately using this result Hartnoll, Herzog, and Horowitz used the AdS/CFT correspondence to study holographic superconductors which mimics the properties of high-T_c superconductors [**Hartnoll**]. Since then various aspects of such holographic superconductors have been explored in various black hole space-time settings.

In this paper we have investigated, in the probe limit, s-wave holographic superconductors in rotating AdS_{3+1} spacetime using the matching method as well as the Stürm-Liouville eigenvalue approach. We have calculated the critical temperature using the matching technique in such a setting and our results are in agreement with previously reported results obtained using the Stürm-Liouville approach. We have then obtained the condensation operators using both analytical methods. The results obtained by both these techniques share the same features as found numerically [**Lin**]. We observe that the rotation parameter of the black hole affects the critical temperature and the condensation operator in a non-trivial way [**Srivastav**].

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Generalized entanglement temperature and entanglement Smarr relation: A holographic approach

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Topic(s): Formal theory

Abstract: We observe that in presence of excitation, a thermodynamic Smarr like relation corresponding to a generalized entanglement temperature (T_g) can be holographically obtained for the entanglement entropy of a subsystem. Such a relation emerges naturally by demanding that the generalized entanglement temperature produces the exact Hawking temperature as the leading term in the IR limit ($l \to \infty$). Remarkably, this relation has the same form as the Smarr relation in black hole thermodynamics. Furthermore, in the IR limit, T_g produces the Hawking temperature T_H along with some correction terms which bears the signature of short distance correlations along the entangling surface. The generalized entanglement temperature T_g also firmly captures the quantum mechanical to thermal crossover in the dual field theory at a critical value l_c of the subsystem size in the boundary which we graphically represent for $SAdS_{3+1}$ and $SAdS_{4+1}$ black holes. We observe that this critical value l_c where the crossover takes place decreases with increase in the dimension of the spacetime.

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Conformal bootstrap signatures of the tricritical Ising universality class

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Topic(s): Formal theory

Abstract: We study the tricritical Ising universality class using conformal bootstrap techniques. By studying bootstrap constraints originating from multiple correlators on the conformal field theory(CFT) data of multiple operator product expansions(OPEs), we are able to determine the scaling dimension of the spin field Δ_σ in various noninteger dimensions $2 \leq d \leq 3$. Here, Δ_σ is connected to the critical exponent η that governs the (tri)critical behavior of the two-point function via the relation $\eta = 2 - d + 2\Delta_\sigma$. Our results for Δ_σ match with the exactly known values in two and three dimensions and are a conjecture for noninteger dimensions. We also compare our CFT results for Δ_σ with ϵ-expansion results, available up to ϵ^3 order. Our techniques can be naturally extended to study higher-order multicritical points.

This poster is based on the paper- Chethan N. Gowdigere, Jagannath Santara and Sumedha. Conformal bootstrap signatures of the tricritical Ising universality class. Phys. Rev. D **101**, 116020(2020). arXiv: 1811.11442v1 [hep-th].

Extended Calogero-Wolfes type three-body potentials associated with exceptional orthogonal polynomials

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Topic(s): Formal theory

Abstract: A class of rationally extended Calogero-Wolfes type three-body potentials are constructed by introducing a new interaction terms with the well known Calogero-Wolfes type conventional potentials. These extended three-body potentials are exactly solvable and their eigenvalues are same as that of the corresponding conventional cases. The wavefunctions of these new three-body potentials are written in terms of X_1 exceptional orthogonal polynomials. These are further generalized to the X_m case by introducing a more general m-dependent ($m = 1, 2, 3...$) interaction term. In particular for $m = 0$, we get the corresponding three-body conventional Calogero-Wolfes models.

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Pentaquarks

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Topic(s): Formal theory

Abstract: Skyrme model is the low energy limit of QCD [1]. In this model, baryons emerge as the solitons of non- linear pion field. Physical properties of baryons like mass, magnetic moment etc. were calculated [2] in the model within 30% accuracy. Using this model, a new particle called exotic Z^+/Θ^+ baryon (spin $1/2$, isospin zero and strangeness $+1$) was predicted [3] with mass 1530 MeV and decay width of 15 MeV. These particles are also called pentaquarks because they consist of five quarks uudds- and are members of anti-decuplet. The existence of such particles was confirmed experimentally [4] with Mass 1540 MeV. Here, the mass of Z^+/Θ^+ exotic baryon is calculated analytically within the Skyrme model again by using the arc-tan ansatz for chiral angle. On quantization of the model, two moments of inertia obtained determine the splittings between octet and decuplet, and between octet and anti-decuplet respectively. Using these splittings, mass of anti-decuplet $M_{\overline{10}}$ obtained is about 1761 MeV and Skyrme parameter e to be 4.46. With symmetry breaking parameters [5], the mass splitting within the members of anti-decuplet is found to be 108 MeV. This implies the mass of exotic baryon Z^+/Θ^+ to be about 1545 MeV and its decay width about 20 MeV. which is an improvement over that of Diakonov et al [3].

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New orthogonal polynomials and exactly solvable potentials

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Topic(s): Formal theory

Abstract: The discovery of two new orthogonal polynomials also known as X_m exceptional Laguerre and Jacobi orthogonal polynomials motivate researchers to search a class of new exactly solvable (ES) potentials. Unlike the classical orthogonal polynomials, these exceptional orthogonal polynomials (EOPs) start with degree $m \geq 1$ and still form a complete orthonormal set with respect to a positive definite inner product defined over a compact interval. The newly searched ES potentials are the extension of the well known corresponding conventional potentials. The energy eigenvalues of these extended potentials are same as that of the corresponding conventional one but the eigenfunctions are completely different and reduced in the forms of X_m EOPs.

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Path-integral action of a particle with the generalized uncertainty principle and correspondence with noncommutativity

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Topic(s): Formal theory

Abstract: The existence of an observer independent minimum length scale can lead to the modification of the Heisenberg uncertainty principle to the generalized uncertainty principle. The possibility of the GUP has led to the investigation of various aspects in theoretical physics [**1-7**]. This in turn would be responsible for the modification of the Hamiltonian describing a nonrelativistic particle moving in the presence of an arbitrary potential. The literature contains an investigation of the free particle kernel in the presence of the GUP [**8**] but the analysis lacks in giving the transition amplitude in a path integral representation. In this work we carry out a path-integral formulation to compute the transition amplitude for this particle. The formalism yields the action of such a particle in an arbitrary potential. Interestingly, the action indicates that there is an upper bound to the velocity that a particle can have which depends on the generalized uncertainty principle parameter. We observe that there exists a curious connection between the transition amplitude of the free particle in the generalized uncertainty principle framework with the corresponding result in noncommutative space found from the path-integral formulation in [**9**]. From the harmonic oscillator result for the transition amplitude, we calculate the ground state energy of the harmonic oscillator. The result shows that the ground state energy of the harmonic oscillator in the framework of the Heisenberg uncertainty principle gets augmented by the presence of the generalized uncertainty principle and also depends on the mass of the particle. We also demonstrate that the result agrees with that obtained using the operatorial approach.

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Hybrid Hydrodynamic Attractor and the Quark-Gluon Plasma

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Topic(s): Formal theory

Abstract: Hydrodynamics is an effective theory for the long-distance, long-time properties of the many-body systems. One of the key assumptions of hydrodynamics is associated with the system's proximity to its local thermal equilibrium. However, recent experiments in ultra-relativistic heavy-ion collisions and cold atomic systems have revealed that hydrodynamics works even in far from equilibrium conditions. These observations call for a better theoretical understanding of the foundations of hydrodynamics.

The discovery of hydrodynamic attractors has opened the door to the theoretical understanding of hydrodynamics' applicability in far away from equilibrium conditions[1]. It has been influential in the study of the phenomenology of the quark-gluon plasma produced in heavy-ion collisions. However, in the latter case, we need to consider both weakly interacting and strongly interacting degrees of freedom.

In our work[2], we study how hydrodynamic attractors can also emerge in such a complex system involving the flow of hybrid degrees of freedom. To this end, we couple two viscous fluids, one strongly self-coupled and other weakly self-coupled via *democratic metric couplings*. In this framework, the interactions between the two sectors are encoded in their *effective metric backgrounds*, which are determined mutually by their energy-momentum tensors such that the total energy-momentum tensor is conserved in the physical metric background[3]. We study the non-equilibrium evolution of this *hybrid fluid model* in boost-invariant Bjorken flow[4] and find that a two-dimensional hydrodynamic attractor surface characterizes its phase space. One of our work's key findings is that at early times the energy distribution between the two sectors on the attractor evolves quite similar to the bottom-up thermalization scenario of heavy-ion collisions[5] while we also gain new insights into how initial conditions affect hydrodynamization of the hybrid system.

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Casimir Effect in non-commutative space-time

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Topic(s): Formal theory

Abstract:

We study the fluctuations of quantized fields in a non-commutative space-time, by analysing the modifications to the Casimir effect in kappa-Minkowski space-time. This is calculated by studying κ-deformed scalar theory in presence of two parallel plates, separated by a distance and represented by δ-function potentials. Using the relation between energy-momentum tensor and Green's function, we calculate the κ-deformed corrections to Casimir force, valid up to second order in the deformation parameter a. We show that the correction terms are attractive in nature and they scale as L^{-4} and L^{-6} respectively. We also obtain a bound on the deformation parameter as $a < 10^{-23}$ m using experimentally measured value of Casimir force.

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Maximal acceleration in non-commutative space-time

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Topic(s): Formal theory

Abstract: We show the existence of an upper bound on allowed acceleration of particles moving in the 4-dimensional κ-Minkowski space-time. This is derived by using a specific realisation of the coordinates of κ-Minkowski space-time in terms of commutative coordinates and their derivatives. We also obtain a bound on the acceleration by considering the line element in 8-dimensional phase space associated with κ-Minkowski space-time, where we used a different realisation. We further derive a bound using the uncertainity relations between κ-deformed coordinates and corresponding momentas. We discuss the implications of these results. All these results are valid up to first order in the deformation parameter.

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Neutrino physics (Posters)

The effect of Scalar Nonstandard Interactions at long baseline experiments

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Topic(s): Neutrino physics

Abstract: The Non Standard Interactions(NSI) [1, 2] has a notable impact on neutrino oscillation. Specially it has a significant effect on CP sensitivity and neutrino oscillations. Recent works [3, 4] on scalar NSI have shown great potential to probe it further. Unlike the vector NSI, scalar NSI appears as a correction to the mass matrix rather than acting as an extra matter potential term in the Hamiltonian. So the scalar NSI effect is no longer a matter potential. This also enables a direct possibility to study it's impact on the neutrino mass models. Also, as the scalar NSI affects the mass matrix in the Hamiltonian, it's matter effect is energy independent while the vector NSI matter effect scales linearly with neutrino energy.

In this work, we explore the effects of scalar NSI at various long baseline experiments like T2HK, DUNE [5–7] etc. As the effective mass matrix gets modified by the inclusion of scalar NSI term, various neutrino mixing parameters may directly get influenced by it. We probe the impact of the scalar NSI term of various mixing parameters and the corresponding possibility of probing the mass matrix. We also show the sensitivity of those experiments towards finding scalar NSI effects.

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Effect of sterile phases on parameter measurement capabilities of LBL experiments

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Topic(s): Neutrino physics

Abstract: In sterile neutrino (3+1) parameterisation, we observe that sterile phases (δ_{14}, δ_{24}) are always together in oscillation probability, even when the MSW effect is considered. We see that the difference between the sterile phases has a more dominating effect over event rates compared to small variations due to changes in individual values. In this work, we show the value of sterile phase difference($\delta_{14} - \delta_{24}$), least effects the parameter degeneracy resolution of δ_{13}, θ_{23} and sign measurement of Δm^2_{32} at long-baseline experiments. We find the value of sterile phase difference that will give a greater chance at sterile neutrino discovery.

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Study of long range force of $L_\mu - L_\tau$ symmetry at INO-ICAL

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Topic(s): Neutrino physics

Abstract: Flavor-dependent long range leptonic force mediated by an ultralight and neutral gauge boson Z' associated with $L_\mu - L_\tau$ symmetry constitute a minimal extension of the Standard Model. In the presence of such long range force, matter fermions in Sun can interact with terrestrial neutrinos via mixing between Z' and Standard Model Z boson and create potentials for neutrinos. This potential has opposite sign for neutrino and antineutrino. We study the effects of such leptonic flavor-dependent potential in terrestrial neutrino oscillation. For this, we use the upcoming atmospheric neutrino detector Iron Calorimeter (ICAL) at India-based Neutrino Observatory (INO). The 50 kt ICAL detector will be magnetized, thus, we will be able to distinguish neutrino from antineutrino in event-by-event basis at the detector. The ICAL detector will have excellent energy and angular resolutions for muon in multi-GeV energy range. Using the reconstructed haron energy and muon momentum in analysis, ICAL will be sensitive to the long range force of $L_\mu - L_\tau$ symmetry with an exposure of 500 kt·yr exposure if the effective gauge coupling $\alpha_{\mu\tau} > 2 \times 10^{-51}$. We show that the ICAL detector will play an important role in exploring such long range leptonic force in neutrino and antineutrino channels separately.

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Neutrino tomography of Earth using ICAL@INO

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Topic(s): Neutrino physics

Abstract: Iron Calorimeter (ICAL) detector at India-based Neutrino Observatory[1] (INO) aims to detect atmospheric neutrinos and antineutrinos in multi-GeV range of Energy. This experiment has potential to throw light on some unknown parameters in the neutrino sector. Atmospheric neutrinos passing long distances through Earth can be detected at ICAL with good resolution in energy and direction. Neutrinos experience coherent forward elastic scattering with electrons which modifies the neutrino oscillation pattern. This matter effect is dependent on the density of electrons inside the Earth. In this work, we explore the possibility of utilizing neutrino oscillations in presence of matter to extract information about the internal structure of Earth complementary to seismic studies[2]. The effect of the presence of various layers on neutrino oscillation is studied to determine the ranges of energy and direction where oscillation is affected most. Good directional resolution at ICAL enables us to identify the events passing through the core, mantle, and crust. The event distribution of reconstructed muons at ICAL is calculated for 10 years for neutrinos passing through various layers. Statistical analysis is performed to establish the presence of high-density core and rule out other alternate models of Earth. We also show the importance of the charge identification capability of ICAL in establishing the presence of various layers inside Earth.

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Combining JUNO with long baseline experiments for determination of neutrino mass hierarchy

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Topic(s): Beyond standard model physics; Neutrino physics

Abstract: This work is based on [1] and extended further to explore the prospects of determining the neutrino mass hierarchy in light of two accelerator-based long baseline (LBL) experiments T2K-II and NOνA-II, and a reactor-based medium baseline experiment JUNO. For the LBL experiments, the simulated oscillation data samples ν_μ disappearance and ν_e appearance in both neutrino(ν) and anti-neutrino($\bar{\nu}$) modes and for JUNO, disappearance of electron anti-neutrino ($\bar{\nu}_e$) are studied. T2K-II, a proposed run extension up to 2026 by T2K is expected to cover an exposure of 20×10^{21} POT [2] and NOνA-II or NOνA extended program will collect 72×10^{20} POT [3], equally divided in both ν and $\bar{\nu}$ modes. For JUNO, the scheduled run-time of 6 years has been considered [4]. It is shown that the combined analysis of the three experiments definitely determines the mass hierarchy for all the true values of δ_{CP} and independent of the θ_{23} octant with a confidence level of greater than 5σ. In the analysis, the best fit values of the oscillation parameters are taken from Ref. [5]. In Ref. [6], the authors address a similar objective and come to a quite similar conclusion even though a different sensitivity calculation method and assumption of the experimental setup are used.

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The Muon ID System of the SAND detector of the Deep Underground Neutrino Experiment

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Topic(s): Standard model physics

Abstract: The Deep Underground Neutrino Experiment (DUNE) is going to be a world-class neutrino observatory and nucleon decay detector designed to answer some of the most fundamental questions concerning the microscopic world, like why there is more matter than anti-matter? Is there a grand unified theory? It is also going to look farther into the outer space, studying supernovae, that can deepen our understanding of core-collapse. DUNE will consist of a far detector (FD) to be located about 1.5 km underground at the Sanford Underground Research Facility (SURF) in South Dakota, USA, at a distance of 1300 km from Fermilab, and a near detector (ND) system to be located at Fermilab. The far detector (FD) will be a very large, modular liquid argon time-projection chamber (LArTPC) with a 40 kt fiducial mass. It will be exposed to the world's most intense neutrino beam. A high-precision ND system, located 575 meters from the neutrino source on the Fermilab site, will be used to characterize the intensity and energy spectrum of this wide-band neutrino beam. The PRISM concept of DUNE ND system requires two sub-detectors, one staying on axis (**S**ystem for on **A**xis **N**eutrino **D**etection, the SAND) and the other moving across the beam. The former being always on the axis, is crucial for beam monitoring. The stability of the beam is checked by monitoring the rate, neutrino energy spectrum, and spatial distribution of the charged current (CC) interactions on a weekly basis corresponding to 3.78×10^{19} protons on target (p.o.t). Muon identification plays a significant role in selecting CC events. The KLOE barrel magnet has been re-purposed to design the SAND detector. There are two main components in the muon ID system: the KLOE electromagnetic calorimeter (ECAL) consisting of 24 barrel modules and 2 endcaps, with 4π coverage, and a scintillator tracker outside the magnet return yoke consisting of alternating layers of scintillator and iron. The purpose of these two components, is to distinguish muons from pions that behave very similarly in the detector. Here we discuss the design of the muon ID system and the techniques used in determining the performance. GENIE+GEANT4 and smearing based on hits are used. Energy deposition and cell topology are used to find discriminating variables to train a neural network. The pions that behave exactly like the muons in the ECAL are identified with the help of the external tracker, the thick iron layers of which help stop the hadrons. We summarize the overall performance of the muon ID system of the SAND detector of the DUNE ND system and its current status.

Flavor symmetric realization of TeV scale LRSM

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Topic(s): Beyond standard model physics; Neutrino physics

Abstract: In this work, we have realised TeV scale Left-Right symmetric model (LRSM),where type I and type II seesaw terms arises naturally using $A_4 \times Z_2$ discrete flavor symmetry. Within the model we have considered type I and type II dominant cases to study neutrino phenomenology.Neutrinoless double beta decay is studied in the model by considering various contributions coming from different particle of LRSM .We basically tried to find the leading order contributions to NDBD coming from typeI or type II seesaw along with the decay rate of the process in our work.

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Model independent and model dependent analysis of Dirac CP violating phase in type-I see-saw

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Topic(s): Beyond standard model physics; Neutrino physics

Abstract: We present both model independent and model dependent analysis of Leptonic CP violating phase (δ_{CP}) for type-I scenario. The model independent corrections to mixing matrices are parameterized in terms of complex rotations to satisfy the recent experimental data. Effect of these complex rotations are studied for Leptonic CP violating phase (δ_{CP}) and Jarkslog Invariant (J_{CP}). We have also analyzed the neutrino mass model with A_4 flavor symmetry. An additional flavon is used to produce realistic neutrino mixing in the model. The inclusion of the new field leads to the deviation from exact $\mu - \tau$ symmetric neutrino mixing pattern thereby producing a nonzero θ_{13} which is consistent with the recent experimental results. Neutrino phenomenology involving Leptonic CP violating phase (δ_{CP}) and Jarkslog Invariant (J_{CP}) are also studied within the model.

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Long baseline experiments sensitivities in presence of Light sterile neutrinos

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Topic(s): Neutrino physics

Abstract:

The experimental results from Liquid Scintillator Neutrino Detector (LSND) [1] and MiniBooNE [2] provides indirect hint for the existence of eV-scale sterile neutrino. As these sterile neutrinos can mix with the standard active neutrinos, they may affect the experimental sensitivities for the standard neutrino parameters. In this paper, we explore the effect of such active-sterile mixing on the determination of various neutrino and antineutrino oscillation parameters by the currently running long-baseline neutrino experiments such as T2K [3] and NOVA [4] experiments.

We present an estimated senstivities for the ν and $\bar{\nu}$ oscillations for long-baseline experiments using Charged-Current (CC) ν_μ and $\bar{\nu}_\mu$ independent interactions with the detector under standard three neutrino scheme as well as 3+1 neutrino scheme. We show the results assuming under different octants of θ_{23} and δ_{CP} combination. The observed ν_μ and $\bar{\nu}_\mu$ events spectrum folded with realistic detector resolutions and efficiencies are separately binned to the energy bins, and a χ^2 is minimized with respect to each bin to find out the oscillation parameters for ν_μ and $\bar{\nu}_\mu$ independently. We will also show the joint sesntitivity of T2K and NOVA detector for the present case.

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Study of CPT violation in long baseline neutrino oscillation experiments.

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Topic(s): Neutrino physics

Abstract: The upcoming long baseline neutrino oscillation experiments play a crucial role in shedding light on the CPT symmetry of the universe. If we assume fundamental CPT symmetry to be conserved both neutrino and antineutrino oscillations can be parametrised using same set of oscillation parameters. In this work, without assuming intrinsic CPT symmetry, we study the sensitivity of forthcoming LBL experiments to constrain the difference between neutrino oscillation parameters and antineutrino oscillation parameters.

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Imprints of Sterile Neutrino CP violation phases in DUNE and T2K

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Topic(s): Beyond standard model physics

Abstract: Sterile neutrinos are proposed as the additional neutrino flavors theorized to explain discrepancies in the certain neutrino experiments. The hints of sterile neutrinos come from the observations of a couple of experiments like LSND, MiniBooNE, MINOS, Daya Bay etc. which lead to a world-wide research programs, on the possible existence of sterile neutrinos. The existence of sterile neutrinos if confirmed in the ongoing and future experiments would definitely provide challenges for the Standard Model of particle physics. In these lines, we study in detail the impact of a light sterile neutrino and CP Violation in the interpretation of latest data available from the long baseline experiments DUNE and T2K. We study the behaviour of the standard 3ν flavor mixing parameters with respect to the changes caused due to the presence of light sterile neutrinos (i.e. considering 3+1 scheme). We also present the correlation between the standard CP phase (δ_{13}) and the additional CP phase (δ_{14}, and δ_{24}), and with the corresponding CP Violation re-phasing invariants.

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Neutrino masses and mixing angles in a model with six Higgs triplets and A_4 symmetry (arXiv:2003.09809)

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Abstract: We have considered a model , where masses and a mixing pattern for neutrinos are governed by six Higgs triplets and A_4 symmetry. In this model we have applied a certain diagonalization procedure through which we have shown that neutrino masses can have both normal or inverted hierarchy. We have also shown that current neutrino oscillation data can be explained in this model.

Neutrino oscillation parameter determination at INO-ICAL using track and non-track hit information from GEANT

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Topic(s): Neutrino physics

Abstract: We study the capability of INO-ICAL to determine the atmospheric neutrino oscillation parameters, using the full GEANT4 simulation of atmospheric neutrino events in the detector. In a previous study which used a similar tehcnique, done by other authors, only the track momentum and the track direction were used. In this study, we include the non-track hit information, produced by the hadrons in the event. We show that the inclusion of this additional variable leads to a 20% reduction in the uncertainities of both $|\Delta m^2_{31}|$ and $\sin^2\theta_{23}$.

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Neutrino Mixing by modifying the Yukawa coupling structure of constrained sequential dominance

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Topic(s): Neutrino physics

Abstract: In the constrained sequential dominance (CSD), tri-bimaximal mixing (TBM) pattern in the neutrino sector has been explained, by proposing a certain Yuakawa coupling structure for the right-handed neutrinos of the model. Since the current experimental data prefers deviation from the TBM pattern, we first propose a phenomenological model where we consider Yukawa couplings which are modified from that of CSD. Essentially, we add small complex parameters to the Yukawa couplings of CSD. Using these modified Yukawa couplings, we demonstrate that neutrino mixing angles can deviate from their TBM values. We also construct a model, based on a flavour symmetry, in order to justify the modified form of Yukawa couplings of our work.

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Breaking $\mu - \tau$ symmetry of tri-bimaximal mixing

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Topic(s): Neutrino physics; Beyond standard model physics

Abstract: One of the unresolved mysteries of the neutrino physics is the origin of the neutrino masses. If the three neutrino masses are distinct and non-zero, the mass and flavor eigenstates of neutrinos are not identical. The flavor eigenstates (ν_f) can be written as a linear combination of the mass eigenstates (ν_i). If the three neutrino masses (m_1, m_2 and m_3), three neutrino mixing angles (θ_{12}, θ_{23} and θ_{13}) and the three CP violating phases (α, β, and δ) are known, the neutrino mass matrix can be reconstructed as

$$M_\nu = U^* M_\nu^{\text{diag}} U^\dagger \tag{1}$$

where, $M_\nu^{\text{diag}} = \text{diag}\{m_1, m_2 e^{2\iota\alpha}, m_3 e^{2\iota\beta}\}$. The reconstruction of the neutrino mass matrix from the experimental observation of masses and mixing angles results into many possible structures like equalities, zeros, hybrids of zeros and equalities, zero trace, or some other patterns between the elements of neutrino mass matrix. The experimental measurements of a non-zero θ_{13} ruled out many such structures. One such structure corresponded to the Tri-BiMaximal (TBM) mixing [1] that predicts $\theta_{13} = 0$ and $\theta_{23} = \frac{\pi}{4}$. After the measurement of non-zero θ_{13}, the TBM scheme cannot be compatible with the neutrino data at the leading order. Yet, one can modify the mass matrix corresponding to the TBM mixing (M_{TBM}) by adding some correction terms that break the underlying symmetry of M_{TBM}. However, such modifications need not break the symmetry of M_{TBM} completely. We can modify M_{TBM} in such a manner that the resulting mixing matrix still has its first or second column identical to the TBM mixing matrix U_{TBM} [2, 3]. Such mixing schemes can be called Tri-Maximal (TM) mixing of first and second kind (TM_1 [4] and TM_2 [5]), respectively.

In the present work, we propose simple textures that can modify M_{TBM} to have non-zero θ_{13} and non-maximal θ_{23} while preserving its first or second eigen vector at their TBM values. We study the phenomenology of these textures and confront them with the experimental data [6]. Our textures are testable at the future neutrino experiments like NOνA and T2K that aim to measure the octant of θ_{23} and CP-violating phase δ. We also study the predictions of these textures for the Majorana phases (α and β) and the neutrino masses as measured in the beta decay, the neutrino-less double beta decay and the cosmological experiments.

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Probing quantum decoherence through ultrahigh energy neutrinos

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Topic(s): Beyond standard model physics; Neutrino physics; Particle astrophysics and cosmology

Abstract: It has been previously shown that strong limit on quantum decoherence can be obtained using high energy neutrinos coming from astrophysical sources [1]. Using the model of decoherence where only diagonal elements were considered, it was shown that strong limits can be put on decoherence using neutrinos produced from n-decay process in extragalactic astrophysical sources [2]. In this work, we extend this formalism using a generic model of decoherence and study the impact of additional parameters on the standard result.

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Role of higher-dimensional operators in Neutrino and Z' phenomenology in an anomaly-free U(1) extension

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Topic(s): Beyond standard model physics; Neutrino physics

Abstract: We consider an anomaly-free U(1) extension of the Standard Model with three right-handed neutrinos (RHNs) and two complex scalars. The anomaly constraints allow only certain combination of charges under the new gauge group and we choose such a combination which precludes all the tree-level mass terms for the neutrinos. Considering this setup, in turn, to be only a low-energy effective theory, we introduce higher-dimensional terms *a la* Froggatt-Nielsen to naturally generate tiny neutrino masses without invoking either ultrasmall Yukawa couplings or an almost inaccessible new (seesaw) scale. One of the RHNs turns out to be very light, thereby constituting the main decay mode for the Z' and hence relaxing the LHC dilepton resonance search constraints and at the same time having unsuppressed couplings with the quarks and leptons. The lightest RHN has a lifetime comparable to or bigger than the age of the Universe, and, hence, could account for a non-negligible fraction of the dark matter.

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Sensitivity to 1–2 oscillation parameters with GeV neutrinos and their effects on δ_{CP} measurement

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Topic(s): Neutrino physics

Abstract: Two of the current unknowns in neutrino oscillation physics is the value of leptonic CP violation phase δ_{CP} and neutrino mass hierarchy. This causes a δ_{CP} - hierarchy ambiguity in the measurement of these parameters which can be removed by probing oscillations in appropriate energy regions. It was shown in Ref. [1] that the hierarchy ambiguity on δ_{CP} measurement is removed at sub–GeV energies. It is also interesting to study the effects of 1–2 oscillation parameters on the measurement of δ_{CP} and what kind of sensitivity GeV neutrinos will provide for 1–2 oscillation parameters themselves. Whether the (in)sensitivity to 1–2 oscillation parameters by GeV neutrinos be used to constrain other phenomena can also be studied.

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Sterile dark matter and N_1 leptogenesis in a flavor symmetric ν2HDM framework

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Topic(s): Beyond standard model physics; Neutrino physics; Particle astrophysics and cosmology

Abstract: In this work, we have discussed sterile dark matter and leptogenesis in low scale seesaw. A sterile fermion singlet(ξ) is introduced in the ν2HDM framework, which is further realised with the help of discrete flavor symmetries $A_4 \times Z_4$. From the model, we obtain the mass of sterile fermion in keV range and that of the light active neutrinos within the Planck limit. Also the sterile-active mixing is found to be less than 10^{-6}, thereby obeying the cosmological bound for the sterile neutrino to become a probable dark matter candidate. We have also studied N_1 leptogenesis in this work for TeV scale right handed neutrino. Thus, this model can be considered to be sensitive to the future collider experiments as well.

The duality of background and exposure in the searches of neutrinoless double beta decay

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Topic(s): Neutrino physics; Beyond standard model physics

Abstract:

Neutrinoless double-β decay ($0\nu\beta\beta$) is an experimentally feasible avenue to probe the nature (Majorana or Dirac) and mass scales of neutrinos. There are already intense activities world-wide committed in the experimental searches of $0\nu\beta\beta$. The current work [1] would quantitatively explore the interplay between exposure and background levels in $0\nu\beta\beta$ experiments with respect to their target sensitivities at their design stage. Although the primary goal of current running and projected experiments is to probe the inverted mass hierarchy, current neutrino oscillation experiments reveal a preference of non-degenerate (ND) normal mass hierarchy (NH). Therefore the strategy of scaling the summit of $0\nu\beta\beta$ should also take this genuine possibility into account. The present work would explore the role of background suppression in alleviating the necessity of large exposure for future $0\nu\beta\beta$ experiments with sensitivity goals of approaching and covering ND-NH.

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Estimation of Extrinsic CP Violation in Long Base-Line Neutrino Experiments

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Topic(s): Neutrino physics

Abstract:

An immediate goal of Long Baseline neutrino oscillation experiments is to measure the CP violation phase δ_{CP}[1, 2]. However, the presence of matter complicates the determination of the CP violation phase as the interaction of neutrinos with asymmetric matter leads to an additional contribution known as extrinsic or fake CP violation and warrants the accounting of these fake effects while searching for CP violation in Long Baseline neutrino oscillation experiments[3–7].

In the present work, we estimate the magnitude of extrinsic CP violation in terms of CP asymmetry for various experimental scenarios assuming neutrinos traveling in the matter of constant density. We also investigate the dependence of CP asymmetry on the oscillation parameters like mixing angles, mass squared differences, as well as on the intrinsic CP violation phase.

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On Matter Effect and Associated Degeneracies in DUNE in the Precision Era

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Topic(s): Neutrino physics

Abstract: Matter effect plays a pivotal role in the upcoming Deep Underground Neutrino Experiment (DUNE) to address pressing fundamental issues such as leptonic CP violation, neutrino mass hierarchy, and precision measurements of the oscillation parameters in the precision era. In this paper, for the first time, we explore in detail the capability of DUNE to establish the matter oscillation as a function of $\delta_{\rm CP}$ and θ_{23} by excluding the vacuum oscillation. With the optimized neutrino beam design and using an exposure of 300 kt·MW·years, DUNE can confirm the presence of Earth's matter effect at 2σ C.L. irrespective of the choices of hierarchy, $\delta_{\rm CP}$, and θ_{23}. Moreover, DUNE can rule out the vacuum oscillation at 3σ (5σ) significance with a $\delta_{\rm CP}$ coverage of 64% (46%) for normal hierarchy and maximal θ_{23}, whereas for inverted hierarchy, the $\delta_{\rm CP}$ coverage is 82% (43%). The relative 1σ precision in the measurement of line-averaged constant Earth matter density ($\rho_{\rm avg}$) for maximal CP-violating choices of $\delta_{\rm CP}$ is around 10% to 15% depending on the choice of neutrino mass hierarchy. The same for CP-conserving values of $\delta_{\rm CP}$ is around 25% to 30%. We find that if $\delta_{\rm CP}$ turns out to be around $-90°$ or $90°$, the precision in measuring $\rho_{\rm avg}$ in DUNE is better than that one can achieve using the atmospheric data from Super-Kamiokande, combined data from Solar and KamLand, and from the full exposure of T2K and NOνA. We also identify new degeneracies in ($\rho_{\rm avg} - \delta_{\rm CP}$) and ($\rho_{\rm avg} - \sin^2\theta_{23}$) planes and notice that the uncertainty in $\delta_{\rm CP}$ affects the measurement of $\rho_{\rm avg}$ more than that of θ_{23}. A detailed understanding of these degeneracies are essential to correctly assess the outcome of DUNE.

Linear seesaw under A_4 modular symmetry with neutrino mixing and Leptogenesis.

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Topic(s): Neutrino physics; Beyond standard model physics

Abstract: The present work is inspired to execute the A_4 modular symmetry in linear seesaw framework by limiting the use of multiple flavon fields. Linear seesaw is acknowledged by extending the Standard Model particle spectrum with six heavy fermions and a singlet scalar. The non-trivial transformation of Yukawa coupling under the A_4 modular symmetry helps to explore the neutrino phenomenology with a specific flavor structure of the mass matrix. We discuss the neutrino mixing and obtain the reactor mixing angle and CP violating phase compatible with the observed 3σ region of current oscillation data. Apart, we also collectively investigate the nonzero CP asymmetry from the decay of lightest heavy fermions to explain the preferred phenomena of baryogenesis through leptogenesis.

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A_4 symmetry based realization of Hybrid textures in Neutrino mass matrix and Phenomenological implications

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Topic(s): Beyond standard model physics; Neutrino physics

Abstract: Hybrid texture in the effective low energy neutrino mass matrix imply simultaneous existence of one zero and one equality amongst the elements, to have predictions on unknown neutrino parameters [1–3]. In this work, we have realized three such hybrid textures using A_4 symmetry within type-I + II seesaw mechanism [4–10]. Standard model(SM) is extended with two right handed neutrinos (singlets under A_4), one A_4 triplet of Higgs doublets having vacuum expectation value(vev) alignment $v/\sqrt{3}(1,1,1)$ [11] and one scalar singlet field for type-I seesaw implementation. In addition, two scalar triplet Higgs fields (singlets under A_4) are added for type-II seesaw interplay. Within the current setup, the variation in charge assignments of fields lead to only three hybrid texture structures in effective Majorana neutrino mass matrix. Only one of the hybrid texture structure is found to be compatible with current experimental data. Phenomenological predictions of this hybrid texture are studied in detail, both analytically and numerically. In the charged lepton mass basis, hybrid texture give two complex constraining equations containing nine parameters viz., three lepton mixing angles(θ_{12}, θ_{23}, θ_{13}), three CP-violating phases (δ, α, β) and three neutrino mass eigenvalues (m_1, m_2, m_3). These equations can be solved for two complex mass ratios. Using the mass squared differences, absolute value of these ratios lead to two values of lightest neutrino mass. The consistency of the formalism induces a new parameter $R_\nu \equiv \frac{\Delta m^2_{21}}{|\Delta m^2_{32}|}$ which, further, constrains the allowed parameter space. The predictions of model include: normal hierarchical mass spectrum for neutrinos, higher octant for θ_{23} and nearly maximal Dirac CP violating phase δ. The distinguishing feature of model includes a lower bound on effective Majorana mass parameter $|M_{ee}|$ which is well within the sensitivity reach of future $0\nu\beta\beta$ decay experiments.

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Study on sterile neutrino dark matter phenomenology from texture zeros

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Topic(s): Neutrino physics

Abstract: Inverse seesaw $(2, 3)$ is well known for explaining neutrino phenomenology and dark matter simultaneously as the model accommodates a sterile neutrino in keV range. In this model, the standard model of particle physics is extended by the addition of two right handed neutrinos and three gauge singlets sterile fermions leading to some special textures of mass matrices. The importance of the model is the addition of two right handed neutrinos instead of three which implies that it depends on less parameters than the conventional inverse seesaw model. Again, implementing texture zeros in the structures of the mass matrices reduces the free parameters. We have studied the neutrino mass matrix M_ν favoring one zero texture in the framework of inverse seesaw $(2, 3)$. The effect of one zero texture of neutrino mass matrices on sterile neutrino dark matter phenomenology has been studied extensively. The zero textures highly constrain the model from the dark matter mass and mixing. The viability of each of the textures is verified by plotting the relic abundance, decay rates as well as the dark matter mixing with the active neutrinos and implementing cosmological limits on these plots.

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Impact of Systematics due to Multi-Nucleon Effects on the measurement of Neutrino Oscillation Parameters

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Topic(s): Neutrino physics

Abstract: Poor knowledge of neutrino scattering cross sections, and nuclear effects in them are one of the major sources of systematic uncertainties in neutrino beam oscillation experiments. The insufficiency in our present understanding of these effects inflicts the precision measurements of yet unknown neutrino oscillation parameters, and some other experimentally observed anomalies in neutrino sector. Another source of uncertainty is the energy dependence of neutrino oscillation probability which is a nontrivial function of the true incoming neutrino energy. This energy is reconstructed using different methods, which in turn is used in the analysis leading to the extraction of various neutrino oscillation parameters. The extraction of still unknown parameters like the leptonic CP violation phase demands the precision level in these measurements to be very high. The NUMI Off-Axis ν_e Appearance (NOνA), a long baseline neutrino oscillation experiment, is designed to measure $\nu_e(\bar{\nu}_e)$ appearance probability and $\nu_\mu(\bar{\nu}_\mu)$ disappearance probability at Fermilab's NUMI (Neutrinos at the Main Injector) beam. The NOνA target has graphite segments, and consists of two functionally equivalent detectors - the 300 tonne near detector (ND) is located at Fermilab, 1 km from the NUMI beam and the 14 kilo-tonne far detector (FD) at a distance of 810 km is sited 14 $mrad$ off-axis to produce a narrow-band beam around the oscillation maximum region ($\sim 2GeV$). The NOνA experiment investigates-neutrino mass hierarchy, CP violation phase in neutrino sector, and precise measurement of θ_{23} and Δm^2_{32}. Neutrinos in the beam have energy in range 0.5-3 GeV, where dominant interactions are - Quasi Elastic (QE), Resonance (RES), and Meson Exchange Currents (2p2h/MEC) interactions [1–5]. In this work, we use the kinematic method of reconstruction of the incoming neutrino energy, both at the near and far detectors of NOνA (USA) experiment, and investigate the role of multinucleon (MN) effects on the sensitivity measurement of various neutrino oscillation parameters. We use the values of various light neutrino oscillation parameters from their latest global fit values in our analysis [6].

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Fully constrained mass matrix: Can symmetries alone determine the flavon vacuum alignments?[1]

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Topic(s): Neutrino physics

Abstract: Using the irreducible triplet of S_4 group as an example, we show[1] that flavon alignments fully defined by the residual symmetries under S_4 form unique orbits. On the other hand, alignments obtained by extremizing flavon potentials may not always be unique; i.e., by carefully adjusting the parameters in the potential we may obtain almost any arbitrary vacuum alignment having no residual symmetries. We argue that constructing such arbitrary potentials goes against the spirit of using discrete symmetries to explain the flavor structure. Yet, to obtain phenomenologically viable models, we may have to resort to using a vacuum alignments having no apparent residual symmetry.

It is in this context that we introduce a new framework in which the flavor group is obtained as the direct product, $G_f = G_r \times G_x$ where the flavons transform under both G_r and G_x while the fermions transform only under G_r. By coupling together several flavons that transform under $G_r \times G_x$, we obtain an effective irreducible multiplet that transforms only under G_r. We define the alignments of the constituent flavons in terms of the residual symmetries under $G_r \times G_x$. As a result we uniquely obtain the alignment of the effective G_r multiplet as well, even though this multiplet may not possess any residual symmetry under G_r. We argue that models constructed in this framework can lead to interesting predictions in flavor physics, for example[2].

It was recently shown[3] that a fully constrained complex-symmetric mass matrix can be conveniently mapped into a sextet of $\Sigma(72 \times 3)$. With the help of such a sextet, we constructed a model resulting in trimaximal mixing[4] with $\delta_{CP} = \pm\frac{\pi}{2}$. We reconstruct this model in the $G_r \times G_x$-framework. Besides $\Sigma(72\times 3)$, we introduce a flavor group X_{24} so that the vacuum alignment of the $\Sigma(72\times 3)$-sextet is determined by the symmetries of $\Sigma(72 \times 3)$ as well as X_{24}. We note that a similar framework was studied in[5–7] to decouple different multiplets in flavor models. This can find application in models such as [8, 9] where the decoupling of different sectors is assumed.

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Systematics due to hadronic production in the final states for QE and RES channel with the DUNE setup

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Abstract: One of the uppermost priorities in neutrino oscillation experiments is the accurate measurement of neutrino oscillation parameters. For exact knowledge of these parameters depends on many elements amongst which accurate reconstruction of neutrino energy is of utmost importance. As we know any imprecise measurement of neutrino energy will result in inaccurate measurement of neutrino oscillation parameters. To achieve sufficient interaction rates, recent neutrino oscillation experiments use materials with high atomic number as nuclear targets such as Carbon, Argon etc. The use of these complex targets introduced nuclear effects in the experimental environment and need to be measured as they add to the systematic errors. Nuclear effects are largely present in the nuclear targets i.e. nuclear fermi motion effects, uncertainties from the binding energy, multinuclear correlation and final state interactions of produced hadrons in different interaction channels. Therefore if these nuclear effects are not included in the analysis, we finish up with an imprecise reconstruction of neutrino energy.

We present a simulation-based study using two neutrino event generators GENIE (Generates Events for Neutrino Interaction Experiments) [1] and NuWro [2]. Neutrino energy reconstruction can be done using two methods: (i) Kinematic method: uses the kinematic information of single outgoing lepton and (ii) Calorimetric Method [3] : Uses the information of all final state particles. In this work reconstruction of neutrino energy is done using the calorimetric method for both the process, QE and RES [4]. Argon (Ar) as a target will be used in the upcoming neutrino experiment like DUNE (Deep Underground Neutrino Experiment) [5], therefore this study will help in the estimation of the uncertainties in the oscillation probability measurement as a function of reconstructed neutrino energy due to nuclear effects. For quantifying this we use events from small target like Hydrogen (H) that has only one nucleon. The presented ratio of the oscillation probability (P(Ar)/P(H) as a function of reconstructed neutrino energy will measure the amount of uncertainty in the Ar target [6] due to nuclear effects for RES channel.

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Studies of fast neutron response with an array of plastic scintillator

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Topic(s): Neutrino physics

Abstract: We present a measurement of the fast neutron response in EJ-200 plastic scintillator at Purnima neutron generator facility(PNGF), BARC, Mumbai [1]. These measurements are useful in context of Indian Scintillator Matrix for Reactor Anti-Neutrino(ISMRAN) detector which will be used to measure reactor antineutrino through inverse beta decay(IBD) signal [2]. ISMRAN detector is close to the reactor core (13m) and above ground, high intensity of fast neutron is encountered inside the nuclear reactor hall. Therefore a good understanding of fast neutron response in EJ-200 plastic scintillator is an essential prerequisite for suppression of fast neutron background. This is accomplished through a series of measurements performed at the PNGF.

The detector setup at PNGF consists of 4 plastic scintillator bar in form of 2×2 array, each bar wrapped with Gadolinium oxide(Gd_2O_3;areal density:$4.8mg/cm^2$) coated aluminized mylar foils. Each plastic scintillator bar is 100 cm long with a cross-section $(10 \times 10)cm^2$. Photomultiplier tubes(PMT) of $3''$ are coupled at the both ends of each plastic scintillator bar. The whole setup is located 50 cm away from the target holder of the neutron generator. The data acquisition system based on waveform digitizers has been used for pulse processing and event triggering [3].

Sealed tube neutron generator at PNGF produced the monoenergetic neutrons via the fusion reactions deuterium-deuterium(D-D) at 2.5 MeV and deuterium-tritium(D-T) at 14 MeV. The monoenergetic neutrons along with AmBe neutron source were used to characterize the energy response. To obtain the true energy conversion the detector was calibrated for energy using compton edges of gamma ray from Na^{22}, Co^{60}, Cs^{137}. The monoenergetic neutron energy response function have been simulated using the GEANT4 toolkit version 4.10.05. The agreement between data and simulation indicates that the light response function reproduces the observed spectra very well. These experimental results will be used for determining the energy response of the plastic scintillator for fast neutron background measurements inside the nuclear reactor hall [4–9].

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Can Leptoquark be the solution for the tension in δ_{CP} measurement of NOvA and T2K?

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Topic(s): Neutrino physics

Abstract: The recent CP violating phase δ_{CP} measured by T2K and NOvA experiments is found to be different, indicating a possibility for the existence of new physics. Owing to the longer baseline in NOvA experiment, it is likely that neutral current non-standard interactions (NSIs) of neutrinos with the earth matter are causing such discrepancy [1, 2]. In this work, we consider the effect of vector leptoquark [3] which can induce the interaction between the propagating neutrinos and the nucleons in the earth, contributing to a large value of NSI parameter $\epsilon_{e\mu}$. We show how this further accounts for the discrepancy in δ_{CP} measurements of recent NOvA and T2K experiments.

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Probing Lorentz Invariance Violation with Atmospheric Neutrino at INO-ICAL

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Topic(s): Neutrino physics; Beyond standard model physics

Abstract:

In the unified field theories, e.g., String Theory and Quantum Gravity allow a tiny amount of spontaneous breaking of Lorentz Symmetry. These spontaneous Lorentz Violation at the Planck scale (10^{19} GeV) can manifest itself as a perturbative Lorentz Invariance Violation (LIV) at observable low energy limits with strengths of the order of $(1/m_p)$, where m_p is the Planck Mass scale. In the Standard Model Extension (SME) frame-work [1] neutrino oscillation offers a portal to probe these parameters in accessible range of energies. The atmospheric neutrino experiments [2, 3] with wide range of energies and baselines provide a unique opportunity to explore LIV effects efficiently. The Iron Calorimeter (ICAL) detector at India-based Neutrino Observatory (INO) can detect atmospheric neutrinos and anti-neutrinos separately in multi GeV range of energies. The physics of LIV is implemented at ICAL and a detailed analysis at the level of probability and events for both neutrinos and anti-neutrinos is done. We carry out full $\Delta\chi^2$ analysis with 500 kt·yr of exposure and put stringent constraint on relevant LIV parameters. We show the importance of charge identification capability of ICAL in constraining LIV parameters. The impact of the LIV physics on standard atmospheric oscillation parameters is also studied.

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Non-zero Reactor angle and Leptogenesis in A_4 based Magic Neutrino mass model

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Topic(s): Beyond standard model physics; Neutrino physics

Abstract: Standard model is accredited as the most successful low energy effective theory explaining the flavor dynamics and interactions of fundamental particles. Despite its success, there are many unresolved questions like neutrino mass generation, large mixing in leptonic sector as compared to quark sector, matter-antimatter asymmetry, to name a few, which need to be explained beyond the standard model. Various mixing patterns were proposed to explain the large mixing in lepton sector such as bi-maximal mixing, tribimaximal mixing (TBM), golden ratios etc [1–8]. TBM mixing matrix gives $\mu-\tau$ symmetric magic neutrino mass matrix (sum of elements of row/column is equal). In particular, TBM predicts mixing angles $\theta_{13}=0$ and $\theta_{23}=\pi/4$ which is inconsistent with current neutrino oscillations data. Also, it is established that CP violation in quark sector is not enough to explain matter-antimatter asymmetry. The leptonic sector can provide additional sources of CP violation which can explain the observed baryon asymmetry. In this work, we present $A_4 \times Z_3$ symmetric model with broken $\mu-\tau$ symmetry which retains magic symmetry in the framework of type-I +II seesaw. Z_3 cyclic symmetry constrains the Yukawa structure of the invariant Lagrangian. Standard model is extended with two right handed neutrino (singlets under A_4) and a A_4 triplet scalar field, δ(triplet under $SU(2)_L$). In effective theory layout, two A_4 triplets(ϕ_l, ϕ_ν) and two singlet of flavon fields(χ_1, χ_2) are employed for spontaneous symmetry breaking through flavon fields vacuum alignment. The breaking pattern emerging out from the model have been proposed in [9]. The Yukawa coupling signifying interaction of leptons doublets with scalar triplet Higgs field breaks $\mu-\tau$ and contribute to baryon asymmetry. The parameter space is constrained by employing magic symmetry and using neutrino oscillation data on masses and mixing. Furthermore, we have studied leptogenesis using the approximated solutions of Boltzmann equations for the case having large scalar triplet Higgs mass(M_Δ) in comparison to lightest right-handed neutrino mass (N_1). In accordance to Davidson-Ibarra bound on right-handed neutrino mass scale [10] and observed baryon asymmetry, inverted hierarchy is ruled out at 2.5σ C.L..

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NSI effects on quantum correlations in neutrino oscillations

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Topic(s): Neutrino physics; Beyond standard model physics

Abstract: The phenomena of neutrino oscillation provides the signature of physics beyond standard model(SM). Currently neutrino experiments are looking for the unknown quantities like sign of Δm^2_{31},leptonic CP violating phase (δ_{CP}), octant of θ_{23} [1],[2]. The estimation of these quantities may be masked by the presence of non standard interaction(NSI) [3],[4]. The effect of NSI is weakly constrained when neutrino is propagating through matter[5]. Such effects can be studied in long baseline (LBL) neutrino experiments. In our work we have calculated the effects of NSI in matter on quantum correlations(QC) in neutrino oscillation in the context of LBL experimental set-up. We found that QC's are sensitive to physics beyond SM.

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Relativistic heavy-ion physics & QCD (Posters)

Measurement of inclusive photon multiplicity at forward rapidity in p–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV with ALICE

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Global observables such as multiplicity and pseudorapidity distributions of the produced final state particles are some of the most fundamental measurements for the shedding light on the physics processes involved in the collisions [1]. Measurements of these observables in proton-lead (p–Pb) collisions provide an important baseline to understand lead-lead (Pb–Pb) results by disentangling hot nuclear matter effects from cold nuclear matter effects [2]. Moreover, multiplicity measurements are very important since they put constraints on various theoretical models describing the initial interactions, e.g., to what degree the nucleon/nuclei interact as dilute (partons) or dense (CGC-like) fields. The study of inclusive photon multiplicity aims to provide the complementary measurements to those in charged particles since the photon production is dominated by the decay of neutral mesons [3, 4].

We will present the multiplicity and pseudorapidity distributions of inclusive photons at forward rapidity ($2.3 < \eta < 3.9$) in p–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. The data samples have been collected using the Photon Multiplicity Detector (PMD) [5] of ALICE [6]. The dependence of photon production on centrality will be presented and compared with theoretical Monte Carlo predictions.

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Study of heavy quark transport coefficients within viscous QGP

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Heavy quarks (namely, charm and bottom) are created during an early stage of the heavy-ion collision via hard scattering. Due to their large masses, they do not get thermalized with the constituents of the quark-gluon plasma (QGP). Hence, they witness the entire evolution of QGP and can be used as a probe to study the strongly interacting matter. Heavy quark transport coefficients are sensitive to the interaction of the probes with the QGP medium. Hence, estimation of the drag and diffusion coefficients of heavy quark in the hot QCD medium is a field of high contemporary interest. The effects of gluon radiation by heavy quark on the transport coefficients e.g., drag and diffusion coefficients, have been studied [1] within the ambit of perturbative quantum chromodynamics (pQCD) and kinetic theory for a viscous QGP medium, utilizing a recently proposed effective modeling of the hot QCD medium based on the lattice QCD equation of state (EoS). The effective modeling of the QCD medium modifies the momentum distribution function of the QGP constituent particles, i.e. light quarks (u, d), anti-quarks ($\bar{u}$, $\bar{d}$) and gluons by introduction of a temperature-dependent effective fugacity parameter. Viscous corrections to heavy quark transport coefficients due to shear and bulk viscosities [2, 3] of the medium is incorporated at leading order in the thermal distribution function. We found that the soft gluon radiation has substantial effects on the transport coefficients of the heavy quark in the QGP medium, and the results may have a significant impact on the experimental observables like the nuclear suppression factor and elliptic flow.

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Study of degrees of freedom in dense QCD matter using Color String Percolation Model

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The Quantum Chromodynamics (QCD) phase diagram is closely related to the history of the universe and can be probed by heavy-ion collisions. Of particular interest in the heavy-ion collision experiments are the details of the deconfinement and chiral transitions which determine the QCD phase diagram. One of the main challenges of the field is to simultaneously determine the temperature and the energy density of the matter produced in a collision and hence the number of thermodynamic Degrees Of Freedom (DOF) [1]. The present work explores the initial stage of high energy collisions at LHC energies analyzing the published ALICE data [2, 3] on the transverse momentum (p_T) spectra of charged particles using the framework of the clustering of color sources [4] . Only the softer part of the spectra in the p_T range 0.15-1.0 GeV/c are considered . This approach has been successfully used to describe the initial stages in the soft region in high energy hadronic and nuclear collisions [4–9]. The determination of the DOF requires the measurement of the initial thermalized (maximum entropy) temperature and the initial energy density also at time $\sim$ 1 fm/c of the hot matter produced in high energy nucleus-nucleus collisions.

We present the extraction of the temperature by analyzing the charged particle transverse momentum spectra in lead-lead (Pb-Pb) and proton-proton (pp) collisions at LHC energies from the ALICE Collaboration using the Color String Percolation Model (CSPM). From the measured energy density ε and the temperature T the dimensionless quantity ε/T^4 is obtained to get the degrees of freedom (DOF), ε/T^4 = DOF $\pi^2/30$. We observe for the first time a two-step behavior in the increase of DOF, characteristic of deconfinement, above the hadronization temperature at temperature $\sim$ 210 MeV for both Pb-Pb and pp collisions and a sudden increase to the ideal gas value of $\sim$ 47 corresponding to three quark flavors in the case of Pb-Pb collisions.

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On the analytical study of Mellin moments of parton density functions

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract:

Parton density functions (PDFs) are important part of collider physics which is a necessary ingredient for high energy physics predictions. Study of PDFs open a new way to a better understanding of the partonic quark-gluon structure of the nucleon [**1**, **2**]. Mellin moment is an important tool in the study of structure functions. Mellin moments of PDFs are obtained as integrals of the distribution over Bjorken-x variable [**3**]. They are not only used for obtaining the solution of scale evolution equation of parton densities but also for the evaluation of scattering cross sections [**4**, **5**]. In the present work, we review and evaluate the evolution equations of moments of parton density functions and their applications in QCD analysis have also been studied.

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Charge dependent azimuthal correlations in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The chiral imbalance along with the magnetic field produced during heavy-ion collisions may cause a charge separation in the magnetic field direction, a phenomenon known as the chiral magnetic effect (CME). A new technique, the sliding dumbbell method (SDM), is designed to study the CME-like charge separation. Here, we slide a dumbbell of 90 degree size in steps of 1 degree to scan the whole azimuthal plane to maximize the positive charge fraction on one side and negative charge fraction on the other side of the dumbbell in each event. The obtained distribution of charge separation is then divided into 10 percentile bins for each collision centrality to gain more insight into CME-like events. Charge-independent and charge-dependent particle azimuthal correlations are measured for different charge separations as a function of centrality and will be presented for Pb-Pb data at $\sqrt{s_{NN}} = 2.76$ TeV. The background contribution to the measurement is estimated by reshuffling the charges.

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Relativistic non-resistive viscous magnetohydrodynamics from the kinetic theory: a relaxation time approach

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: In non-central relativistic heavy-ion collisions mostly the spectators nucleons act as a source of electromagnetic field and produce intense transient magnetic field. This magnetic field is even larger than the magnetic fields observed in astro-physical objects like on the surface of magnetars. The magnitude of the magnetic field in Au+Au collisions at top RHIC energies is known to be peaked around 10^{18} G. A super dense and hot matter called quark-gluon plasma (QGP) is also produced in heavy ion collision at RHIC. The properties and dynamics of the QGP is studied using the framework of relativistic hydrodynamics or the kinetic theory. It has been shown that the QGP behaves like a near perfect fluid with ($\frac{\eta}{s} \to 0$) where η is the shear viscosity and s is the entropy density of the fluid. However, the transport co-efficients like shear-viscosity, bulk viscosity are expected to get modified in the presence of an external electromagnetic field. Relativistic generalisation of the first order Navier-Stokes relations are known to be acausal. The solution to this is to go beyond the Navier-stokes limit and derive the causal second order theory such as one given by Israel-Stewart theory. There are many ways of deriving these equations but two popular methods are the Chapman-Enskog method and Grad's method of moments. We derive the second order relativistic viscous magnetohydrodynamics equation using the relativistic Boltzmann equation in the presence of electromagnetic field. The collision kernel in the Boltzmann equation is taken in the relaxation time approximation and expansion of the distribution function is done using chapman-Enskog method. We have limited our calculation to a non-resistive case that is electrical conductivity is assumed to be infinity. The evolution of viscous stresses are derived and shown to have a similar structure to that obtained by the Grad's moment method as can be seen in the reference [1] in the limit when the order of gradient expansion is comparable to the magnitude of qB, where q is the charge and B is the magnetic field. However without any assumption about the strength of the magnetic field additional transport co-efficients appear that couple magnetic field(B) with the viscous stresses. By taking the Navier-Stoke limit, ie. by only keeping those terms which are first order of gradient of velocities and other thermodynamic quantities like chemical potential, we retrieve the usual anisotropic transport co-efficients obtained in the reference [2].

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Two Loop Order Running Coupling Constant in Toy Model Using Imaginary Time Formalism

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: There are different quasi-particle models [1, 2] used to describe the state of the quark gluon plasma. All these models depend upon the corresponding running coupling constant. Most of them take a readily available coupling constant from QCD and evaluate their results.

These models consider quarks and gluons as quasi-particles with thermal mass dependent on several parameters like coupling constant, temperature, magnetic field, etc. Here we try to address the questions regarding non-thermal mass dependence from the basic field theory perspective and give particular care about the quartic theory (also known as the Toy model) in the context of thermal and non-thermal field theory.

We define Lagrangian density

$$\mathcal{L} = \frac{1}{2}\left(\partial_\mu\phi\partial^\mu\phi - m^2\phi^2\right) - \frac{\lambda}{4!}\phi^4 \tag{1}$$

and follow a systematic approach. Using imaginary time formalism [3–5] in thermal field theory, we derive an expression for running coupling constant in two loop order. We use the method [6] of expressing imaginary time formalism Feynman diagram as sum of combinations of non-thermal Feynman diagrams with coefficients that depend on temperature and mass.

We use diagrammatic subtraction method [7] to find re-normalization constants. Combining this result with the Callan Symanzik equation on thermal dependent proper vertex function, we observe that the coupling constant has implicit dependence on temperature. We derived coupling constant and thermal mass as functions of non-thermal mass and temperature.

By following the idea of self consistent quasi particle model put forwarded by VM Bannur [1, 2, 8], and substituting our result of thermal mass and coupling constant in it; we obtain the pressure and energy density for ϕ^4 theory in two loop order.

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(Multi-)Strange hadron production at RHIC and LHC energies using HYDJET++

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The production of strange and multi-strange hadrons is a complex physical process. Unlike light hadrons, in heavy ion collisions, (multi-)strange hadrons do not simply produce according to their statistical weights as described in grand canonical ensemble. An unified theoretical or simulation model which reproduce the multiplicity distribution of (multi-)strange hadrons alongwith multiplicity of non-strange hadrons is still lacking. We have used HYDJET++ model to study the transverse momentum (p_T) spectra and elliptic flow (v_2) of K, Λ, Ξ and Ω in $Au+Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV and $Pb+Pb$ collisions at $\sqrt{s_{NN}} = 2.76$ TeV. We have compared HYDJET++ results of these strange and multi-strange particles with the experimental data and also with AMPT and VISHNU model. We found that HYDJET++ results for p_T spectra and v_2 are in good agreement with the experimental data for various centrality classes at RHIC and LHC energies. Further, we have investigated the mass ordering of elliptic flow among π, K, p, Λ, Ξ and Ω. We found that HYDJET++ reproduces the mass ordering of elliptic flow at both RHIC and LHC energies.

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Forward Backward Momentum Correlations in Pb-Pb Collisions; HYDJET++ Model Study.

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Forward backward (FB) correlations between event mean transverse momenta (p_{T}) in Pb-Pb collisions at center of mass energies, $\sqrt{s_{\mathrm{NN}}} = 2.76$ and 5.02 TeV are studied using Monte Carlo (MC) generator, HYDJET++. This MC model simulates relativistic heavy-ion collisions as a superposition of the soft, hydro-type state and the hard state resulting from multi-parton fragmentation. The centrality of a collision event is determined by following the ALICE V0 detector psedorapidity(η) acceptance criteria.

FB correlation function, $b_{cor}^{p_{\mathrm{T}}p_{\mathrm{T}}}$ is constructed using the event averaged p_{T} values in two separated η windows placed symmetrically in the forward and backward regions of the η distribution. Event-by-event mean p_{T} values are used because intensive variables, if used, instead of multiplicity, the observed FB correlations would be robust against the volume fluctuations. Dependence of $b_{cor}^{p_{\mathrm{T}}p_{\mathrm{T}}}$ on the collision centrality and on the width and/or positions of η windows are examined and the findings are compared with those reported for 2.76 TeV Pb-Pb data from ALICE detector. Contributions to $b_{cor}^{p_{\mathrm{T}}p_{\mathrm{T}}}$ coming from hydrodynamics and jet parts are extracted using the model predictions. It is observed that the values of $b_{cor}^{p_{\mathrm{T}}p_{\mathrm{T}}}$ predicted by HYDJET++ for $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV for various centrality classes and different positions of η windows are smaller as compared to those reported from the real data but agree closely with the HIJING predictions.

Jet-shape modifications in JEWEL

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Heavy-ion collisions at relativistic energies produce a dense medium of de-confined quark and gluons, the quark-gluon plasma (QGP). During early stages of these collisions (time scale < 1 fm/c), large transverse momentum transfer processes (hard scattering) between quarks/gluons from the incoming nuclei produce energetic shower of secondary partons that eventually fragment into collimated spray of hadronic final states, known as jets [1]. In heavy-ion collision, because of jet-medium interactions, secondary shower partons are scattered to a large distance from the jet-axis resulting in degradation of overall jet energy and modifications of several intra-jet properties.

In this work, we report a study on the medium modifications of inclusive jet yields and set of jet-shape observables namely, the fragmentation functions and radial momentum distributions using a pQCD (perturbative quantum chromodynamics) inspired model of jet-medium interaction (including recoil-effect), JEWEL [2]. Our results for the nuclear modification factor (R_{AA}) for the inclusive jet yields are in good agreement with the experimental data for Pb+Pb collisions at LHC energies [3]. JEWEL is also able to qualitatively reproduce the modifications to fragmentation functions and radial momentum distributions in data, in particular, the enhancement of jet constituent at low and high transverse momenta, and away from the jet-axis respectively. We further extend this work to study the modifications of radial momentum distributions out-of the jet-cone which will be reported here as well.

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Bulk description and collectivity in HIC with the rapidity spectra

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Relativistic heavy-ion collision offers the high energy and/or matter density to set up the platform for the onset of a deconfined strongly interacting matter. The created fireball undergoes a fast spatio-temporal evolution, and the energy and matter density dilute, which is followed by hadronization. In the canonical picture, the freeze-out occurs when the mean free paths of the hadrons become longer than the system size. We detect these free-streaming hadrons in the detectors and reconstruct all the information of the created medium. There are two main aspects of discussing this medium properties, **(1)** a **bulk description**, which helps to project the thermodynamic properties of the various heavy-ion collision on the QCD phase diagram[1], and **(2)** a **space-time evolution** picture of the created medium, which is generally addressed in the framework of hydrodynamics[2]. Amongst the final observables, one necessary information is the energy and momentum of the detected particles, which is generally convoluted in the form of transverse momentum spectra of detected particles dN/dyp_Tdp_T. These spectra contain the information of kinetic freeze-out, as the elastic collision stops, and momentum distribution gets frozen at that boundary. Whereas, the momentum integrated rapidity spectra dN/dy of detected particles get fixed at the chemical freeze-out surface. The inelastic collisions stop at the chemical freeze-out, and yields of particles get frozen. The bulk description of the freeze-out is extracted from comparing the dN/dy with number density calculated from the thermal model like the Hadron Resonance Gas Model (HRG). Recently we have introduced a novel formalism to extract these freeze-out temperature and chemical potentials. Our formalism relies on the conserved charges of QCD, like net baryon, net electric charge, and strangeness [3]. This model is adequate to describe a centrality dependence of equilibration in heavy-ion collisions [4]. This framework has also addressed the light nuclei equilibration in Ref.[5]. In this presentation, I shall briefly discuss the recent developments in this direction. A hydrodynamical model is successful in providing a collective description of the spatio-temporal evolution. A boost-invariant Bjorken model is successful at higher energy LHC to describe the flat rapidity spectra[6], whereas the Landau non-boost-invariant description seems necessary to address the Gaussian rapidity spectra of lower and intermediate collision energy[7]. Recently we have found an analytical solution for the dissipative Landau hydrodynamics, with a non-conformal equation of state [8]. We have successfully extracted the value of the speed of sound c_s^2 for AGS and SPS energy range. This presentation will mainly discuss how these rapidity spectra form in a spatiotemporally evolving medium and how we can utilize these rapidity spectra to extract the bulk description of the medium.

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Characterizing high energy pp collisions at LHC using thermodynamic and transport properties

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Recently there has been a tremendous rise in the interest among physicists to study high multiplicity pp collisions at TeV energies. At first, pp collisions were taken as baseline for heavy-ion collisions to characterize the formation of Quark-Gluon Plasma (QGP). Production of a QGP medium was not expected in hadronic collisions. But recent studies indicate a new direction and now we expect that high multiplicity pp collisions may produce QGP droplets [**1**, **2**]. This motivates us to understand the detailed dynamics of the system produced in pp collisions. We have characterized the pp collisions by using various thermodynamic and transport properties such as mean free path (λ), isobaric expansivity (α), shear viscosity to entropy density ratio (η/s), isothermal compressibility (κ_T) and speed of sound squared (c_s^2) [**3**, **4**]. Mean free path of the system gives us an idea about the state of the system under consideration. Isobaric expansivity is another important thermodynamic property, which gives us information about the thermal expansion of the matter. η/s value can be used to study the measure of fluidity of a system. According to elliptic flow measurements from heavy ion collisions at RHIC [**5**], the medium formed in such collisions give η/s value closer to the KSS bound, which suggests that QGP is almost a perfect fluid. This increases our motivation to study the η/s value for high multiplicity pp collisions. Isothermal compressibility tells us how the volume of a system changes with the change in pressure at constant temperature. It can give us information about the degree of deviation of a real fluid from a perfect fluid, as for a perfect fluid the isothermal compressibility is zero. Similarly, the study of the speed of sound will give us a proper understanding of the equation of state (EOS) of the system.

To explain the dynamics of pp collision systems better, we have taken the help of a thermodynamically consistent Tsallis distribution function [**6**]. By considering a differential freeze-out scenario, we have fitted the Tsallis distribution function to the p_T spectra of identified particles for pp collisions at $\sqrt{s} = 7$ TeV [**7**] and extracted the fitting parameters T and q [**8**]. By using these parameters, we have estimated the above-mentioned thermodynamic and transport properties and studied them as a function of charged particle multiplicity, which is an event classifier in ALICE. We clearly observe a threshold for charged particle multiplicity ($dN_{ch}/d\eta \simeq$ 10-20), after which there is a change in the dynamics of the system [**9**].

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Dispersion of phase space perturbation in an expanding background.

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract:

Dispersion of non-hydrodynamic phase space perturbation in an expanding system has been investigated. The dispersion relation is obtained by using the Boltzmann equation to study the evolution of the perturbation in the expanding background governed by Bjorken's hydrodynamical model [**1**]. It is observed that expansion affects the propagation and dissipation of different modes considerably. Moreover, the direction of the expansion plays crucial role in deciding the dissipation of momentum dependent perturbation. Expansion also affects the dissipation of various modes with increasing dissipation rate with time. The propagation speed of various modes does not vary monotonically with momentum. Such variation may consequently convert the non-hydrodynamic modes to hydrodynamic modes due to longer time span in the medium. This conversion of the non-hydrodynamic modes to the hydrodynamic modes and the increase of dissipation with time in presence of expansion may lead to attractor behaviour [**2**]. It is also found that non-conformality of the background has less effect on the propagation speed. However, the deviation from conformality of the background is observed to reduce the dissipation.

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Intermittency Study on the Multiparticle production in ^{16}O-AgBr Collisions at 60 AGeV and 200 AGeV

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The investigations are performed on the multiplicity fluctuations of the charged secondaries produced in ^{16}O-AgBr collisions at $60A$ GeV and $200A$ GeV offered by the EMU-01 Collaboration at SPS CERN. We have performed a self similar analysis in three dimensional phase-space. The similar analyses has been performed to the simulated data sets generated by the AMPT, UrQMD and modified FRITIOF models. The experimental as well as simulated data sets have been linearly fitted well for orders $q = 2, 3, 4$ according to the following relation

$$\ln F_q = a + \phi_q \ln M$$

The results for $\ln F_q$ vs. $\ln M$ for orders $q = 2, 3, 4$ are shown. The exclusion of first point in the linear fits is attributed to reduce the influence of momentum conservation. Thesimulated data sets are found to agree well with the experimental results.

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Scaling characteristics of multiplicity fluctuations in Relativistic Heavy Ion Collisions

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: We investigate the presence of non-statistical fluctuations in the in case of ^{16}O - AgBr interactions at $60A$ and $200A$ GeV/c offered by the EMU-01 Collaboration at SPS CERN . The occurrence of power law behaviour of normalised factorial moments (NFMs) is investigated. The findings point towards the presence of non-statistical fluctuations in these interactions. We further look into the presence of the Ginzburg - Landau (G-L) type of phase transition in terms of the intermittency indices obtained from the linear fitting of the factorial moments. The results from the experiment are compared with the predictions of AMPT and UrQMD models. Both the models are found to corroborate with what has been found in the experiment.

Further, we present the analysis on Factorial Commulants which have been calculated from the factorial moments. The behaviour of the Commulants gives an idea of the presence of correlation at various levels.

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Search for the Chiral Magnetic Effect in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract:

Experimental searches for Chiral Magnetic Effect (CME) in heavy-ion collisions have been going for a decade, but there is no conclusive evidence for its existence. A new technique, Sliding Dumbbell Method (SDM), is used to search event-by-event back-to-back charge separation [1]. The charge separation distribution for each collision centrality is divided into 10 percentile bins to get samples where CME-like events are enriched. δ- and γ- correlators are obtained for 10 percentile bins for each collision centrality for data as well as background. The SDM is tested on Anomalous Viscous Fluid Dynamics (AVFD) having CME signal with Local Charge Conservation (LCC). The collision centrality dependence of fractional contribution of the CME (f_{CME}) in the observed $\Delta\gamma$- correlator will be presented.

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Finite size effect on mass and diffusion of Chiral partners

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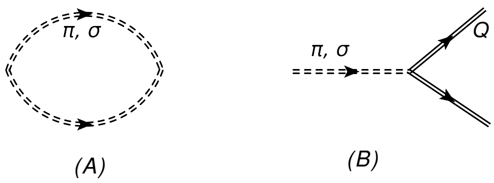
Topic(s): Relativistic heavy-ion physics and QCD

Abstract:

The π and σ mesons are chiral partners as they have the same quark composition and spin but opposite parity. One can use the Nambu-Jona-Lasino model to build a mass merging picture of chiral partners beyond the transition temperature when the chiral symmetry is restored. When one considers the interaction of NJL Lagrangian density with scalar and pseudo-scalar type condensate terms respectively, the real part of the self-energy diagram for dressed quark-anti-quark loop gives us the temperature-dependent masses of π and σ mesons, while the corresponding imaginary part gives us their dissociation or drag coefficients, whose interpreting diagram is shown by decay-type diagram (B).



These temperature-dependent masses ($m_{\pi,\sigma}$) and drag coefficients ($\gamma_{\pi,\sigma}$), can be related to the diffusion coefficients D and conductivity σ of scalar and pseudo-scalar condensates in the following manner relations:

$$\begin{aligned} \sigma &= D\chi_s \\ &= \frac{T}{m_{\pi,\sigma}\gamma_{\pi,\sigma}}\chi_s \ , \end{aligned} \tag{1}$$

where χ_s is the static susceptibility of π and σ mesons. In the zero-frequency limit of correlators of π and σ mesons, the Kubo framework allows one to get conductivity from the currents. The Feynman diagram, shown in diagram (A), representing π-π and σ-σ loops allows one to calculate the conductivity.

These estimations of different dissipation quantities like conductivity, drag and diffusion coefficients for chiral partners π and σ mesons get modified due to the finite size effect. It can be implemented by shifting zero momentum to a lower momentum cut off $P_{min} = \pi/R$, which is the expected quantum effect for R dimension system size. Finite size effect of quark and hadronic matter, explored in present work, can be connected with RHIC or LHC phenomenology (e.g. finite size effect on dilepton production, heavy mesons suppression), for which a systematic detail evolution picture has to be adopted. This investigation, whose details are documented in Ref. [1], will be presented at the conference.

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Transport coefficients of hadron resonance gas in presence of a magnetic field

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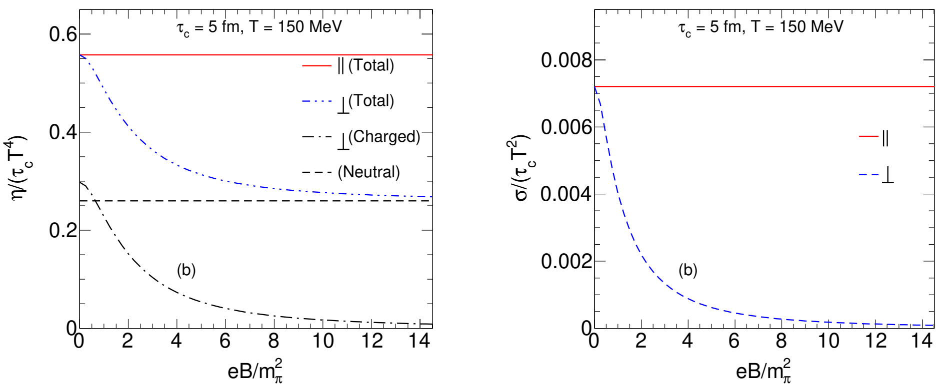
Topic(s): Relativistic heavy-ion physics and QCD; Formal theory

Abstract: A very high transient magnetic field (B) is produced in the heavy-ion collision experiments like RHIC and LHC along with a hot and dense quark-gluon plasma (QGP) which is also created in such collisions and exposed to that intense magnetic field. The magnetic field is expected to generate anisotropic transportation of energy-momentum in the QGP and subsequent hadronic phase. Mainly charged (q) particles with velocity $\vec{v}$ in the medium are directly influenced by the magnetic field and show the Hall-like flow due to the Lorentz force $q\vec{v} \times \vec{B}$. Using the relaxation time approximation (RTA) for collision kernel in the Boltzmann equation we calculate the transport coefficients (like shear viscosity η, electrical conductivity σ). In the magnetic field, these transport coefficients become anisotropic, the parallel components of which remain unaffected i.e. $\eta_{\parallel} = \eta$ and $\sigma_{\parallel} = \sigma$ but the perpendicular components are reduced by the following relations [1]:

$$\Big(\eta_\perp, \sigma_\perp\Big) = \frac{1}{1 + (\tau_c/\tau_B)^2}\Big(\eta, \sigma\Big) \,, \tag{1}$$

where $\tau_B = \omega/(qB)$ is inverse of cyclotron frequency for charge particle with energy ω. We note that these anisotropic coefficients becomes isotropic in absence of the magnetic field. In the present work we evaluated these transport coefficients for a hadron resonance gas (HRG) system, consisting of charged and neutral hadrons with different mass states (upto 2 GeV). The shear viscosity and the conductivity of these charged+neutral system of HRG are shown in figure given below. Unlike the electrical conductivity which is related only to the charged hadrons, the total shear viscosity has contribution from both charge and neutral hadrons, as shown in the figures. In summary, we conclude that the transport coefficients (transverse) values are reduced due to the magnetic field and mostly the charge hadrons are responsible for that reduction, the details of which can be found in [1].



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Causality of the relativistic third order hydrodynamics

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The hot and dense QCD medium created in relativistic heavy ion collisions behaves like a fluid system and successfully studied by tools of relativistic hydrodynamics. A theory of relativistic hydrodynamics should be causal so that the disturbance in the fluid medium propagates with finite velocities. Causality is the restriction imposed by special theory relativity which doesn't allow any information to travel faster than the speed of light. The earliest formulations of relativistic hydrodynamic equations for non-ideal fluids were covariant generalisations of the Navier-Stokes equations of Newtonian non-perfect fluids by Eckart [1] and Landau-Lifshitz [2]. These are first-order theories which involve parabolic differential equations and violate causality and face instability problem. The parabolic character is responsible for the thermodynamic fluxes to react instantaneously to the corresponding thermodynamic forces which leads to the infinite speed of propagation of disturbances.

The attempts to get rid of acausality and remove the instability of first-order hydrodynamics and to obtain a hyperbolic second-order theory led to the derivation of Israel-Stewart equations. In this generalised theory, dissipative fluxes such as heat flux, shear and bulk stresses are treated as independent variables and their evolution equations are hyperbolic in nature. The second-order theories allows the existence of a relaxation time for dissipative processes so the system doesn't returns to the equilibrium states instantaneously unlike Navier-Stokes theory, which restore causality. Hiscock and Lindblom later showed that the perturbations in the medium evolve causally in Israel-Stewart theory around equilibrium states [3].

Despite the success of Israel-Stewart theory in explaining a wide range of collective phenomena observed in heavy-ion collisions, it has resulted in unphysical effects such as reheating of the expanding medium [4] and negative longitudinal pressure [5]. This motivates the improvisation of the relativistic second-order theory by incorporating higher-order corrections. In Ref. [6] a new relativistic third-order evolution equation for the shear stress tensor from kinetic theory is derived. We will be presenting the analysis of the causality property of the third-order relativistic hydrodynamics and some interesting results about the dispersion relation and group velocity of modes of propagation of disturbances.

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Estimation of Isothermal Compressibility in the framework of Polyakov−Nambu−Jona-Lasinio model

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: From the famous pressure (P) vs volume (V) diagram for water-vapor phase transitions at different temperatures (T), one can find isothermal compressibility

$$\kappa = -\frac{1}{V}\left(\frac{\partial V}{\partial P}\right)_T \tag{1}$$

to change quantitatively from vapor to mixed to water phases, thus signifying associated transitions. However, this evolution can only be seen below the isothermal curve at critical temperature T_c, beyond which first order phase transition disappears. Such behavior has been explored in 1869 in Andrews plots of $P - V$ diagrams for CO_2 liquid-gas phase transition and later obtained for many more substances in different experiments. Here we attempt to visualize the Andrews-like plots for quark-hadron phase transition through the lens of the quantity - isothermal compressibility κ. Lattice quantum chromodynamics (LQCD) provides a robust technique to investigate the exotic matter in the non-perturbative domain. Among the alternative approaches of using effective QCD models to map the physics and associated phase transitions, Polyakov loop extended Nambu-Jona–Lasinio (PNJL) model is one of the successful frameworks, which has been adopted in present work. The order parameters in this framework are chiral condensates and Polyakov loop for chiral and confinement-deconfinement phase transitions respectively. Looking for different observables in order to extract associated Physics is always under concern. We thus explore here such a quantity. Also searching indirect impacts of these order parameters on κ might be very interesting.

κ from Eq.(1), can also be expressed in the form of Eq.(2) [1,2]. We have gone through the estimation of κ as a function of temperature T, quark chemical potential μ_q, after expressing in terms of different order derivatives of free energy using thermodynamic relations.

$$\kappa = \frac{1}{V}\frac{(\partial n_q/\partial \mu_q)}{(\partial P/\partial \mu_q)^2} = \frac{1}{V}\frac{\chi_q^{(2)}}{n_q^2}\ . \tag{2}$$

Here, n_q is the quark number density and $\chi_q^{(2)}$ represents the leading order quark number fluctuation. We have noticed a non-monotonic transition from high to low values of κ when we approach T-μ domain of quark phases from hadronic region, which might be crudely compared to the infinite to finite values of κ for water to vapor transition. κ, as it involves both first and second order derivatives of pressure, is expected to show some discontinuities in presence of phase transitions of corresponding orders all along the phase boundary. We have also explored the finite system size effect on κ. Its behavior under different experimental conditions might also help to explore some interesting features.

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Transverse momentum spectra of identified hadrons in Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV at RHIC

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract:

Quantum Chromodynamics (QCD), the theory of strong interactions, predicts that at sufficiently high-temperature and/or high-energy density normal nuclear matter converts into a deconfined state of quarks and gluons, known as Quark-Gluon Plasma (QGP). The Relativistic Heavy Ion Collider (RHIC) has recorded data from Au+Au collisions at $\sqrt{s_{NN}} = 7.7$ - 200 GeV to study the QCD phase diagram and the properties of QGP. In the year 2017, a high statistics dataset from Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV was recorded by the STAR experiment at RHIC to fill the energy gap between 39 and 62.4 GeV. The transverse momentum (p_T) spectra of identified hadrons are essential to study the bulk properties, such as integrated yield (dN/dy), average transverse momenta ($\langle p_T \rangle$), particle ratios, and freeze-out properties of the medium produced. The systematic study of these bulk properties may provide insight into the particle production mechanism and evolution of the system formed in heavy-ion collisions.

In this presentation, we will present the p_T-spectra of identified hadrons ($\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$) at mid-rapidity ($|y| < 0.1$) in Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV. The dN/dy, $\langle p_T \rangle$ and particle ratios will also be presented and compared with the previously published results at other beam energies.

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Role of magnetic screening mass on heavy quark diffusion

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Heavy quarks (HQs) are considered as one of the most efficient probe of Quark Gluon Plasma (QGP), created in heavy ion collision at RHIC and LHC [1] energies. HQs are produced predominantly in the early stage of the collisions due to energy threshold and survive the entire evolution of the QGP due to the low abundance of HQs (and anti-HQs) in QGP and thereby witnessing the evolution history of the QGP. The HQs share their momentum to the light quarks and gluons in the bath through interaction which are reflected in the transverse momentum spectrum of the heavy hadrons formed from HQs via hadronization. Therefore,the observed suppression of HQs momentum distribution can be used as an evidence for the creation of QGP. Hence, it is crucial to accurately estimate the diffusion of HQs by including as many physical processes as possible which affects the HQs distribution in the bath. In this context we attempt to include the screening of color magneto-static interaction in the evaluation of drag and diffusion coefficients which affects the momentum distribution of HQs.

The drag and diffusion coefficients of heavy quarks propagating through QGP have been estimated by shielding both the electric and magnetic type infra-red divergences. It is well known in quantum field theory that, the infrared divergences occur when massless gluons are exchanged in the t or u channel processes. Electric type screening mass in thermal perturbative quantum chromodynamics (pQCD) calculations have been used [2] earlier. Here, we make an attempt to estimate the impact of magnetic type screening mass on the heavy quark diffusion [3,4] in QGP. It is found that the effect of magnetic screening mass on the drag and diffusion coefficients is quite significant and its contribution should not be ignored in explaining the experimental data of heavy quark's momentum suppression. The details [5] will be presented in the symposium.

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Strange quark matter under strong magnetic fields

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Present study incorporates the effect of strong magnetic field in the framework of Polyakov Chiral SU(3) Quark Mean Field (PCQMF) model on the strange quark matter (SQM) which may occurs in a proto-quark and quark star. The case of each with and without trapped neutrinos matter at fixed entropy density is calculated and compared. Under the effect of β-equilibrium condition in PCQMF model, the study of SQM at finite density and temperature under the influence of magnetic field is also investigated. From obtained results it was anticipated that the constituent quark mass drop almost linearly from its vacuum mass in low baryon density region and then, show sharp decrement for higher baryon density. Moreover, the calculation of sound velocity square is also carried out in existing work. Sound velocity square measures the hardness and softness of SQM and is always found to be less than 1/3 at zero magnetic fields and without vector interaction. Author believes that the derived results can be beneficial for the study of heavy ion collision and better understandings on lattice QCD results.

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Study the characteristics of shower particles produced in peripheral collision

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract:

The study of heavy ion collision reveals various concepts of the nuclear physics [1, 2]. After the confirmation of the new phase of matter called Quark Gluon Plasma the study of hadron-nucleus and nucleus-nucleus gets more attention from the scientific community [3, 4]. The unique feature of the heavy ion collision is its dependence on the type of collisions [1–4]. The target fragmentation is an isolated process in the complex scheme of heavy ion collision [5]. The main focus of this article is to study the emission characteristics of the shower particles emitted in the peripheral collision in the interaction of ^{84}Kr with nuclear emulsion detector at 1 GeV per nucleon. The present study shows that the multiplicity distribution of shower particles is increasing with the increase in projectile mass. The results are also compared with the other observations [1] and found to be consistent.

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Characteristics of the target fragments at relativitic energy

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The physics analysis of heavy-ion collision at relativistic energy draw a conclusion on various concepts of the nuclear and particle physics, such as particle emission at high temperature and high density, interactivity mechanism of two different nuclei [1–3]. The study on hadron-nucleus (H-A) and nucleus-nucleus (A-A) become more thrilling and striking topic from the scientific community, after the authentication of the new phase of matter called Quark Gluon Plasma [4–6]. In the complex scheme of heavy ion collision the target fragmentation is a secret process [7]. The focus of this study is on the target fragmentation characteristics of the events emitted from the interactivity of ^{84}Kr with emulsion at 1 GeV per nucleon. This investigation reveals that the release of the different target fragments are have strong corelation with eachother. The outcome of this study are also compared with the other observations and found to be consistent.

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Study the characteristics of alpha projectile fragments emitted in peripheral collision

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The nuclear fragmentation is an unique phenamenon in the experimental study of nucleus-nucleus interaction at relativistic energy [1, 2]. The concept of participant spectator model is important to study the nuclear reaction mechanism and geometrical concept of two interacting nuclei [3–6]. The emission probability of events in heavy-ion collision is strongly depend on the type of collision [7–10]. The emission probability of alpha projectile fragments is decreases as we move from peripheral collision to central collision. In the present analysis we have focused on the characteristics of the alpha projectile fragments emitted in the interactivity of ^{84}Kr with nuclear emulsion at 1 GeV per nucleon.

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The fate of perturbation near the QCD critical point

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The fate of a perturbation (disturbance) imparted in the QGP fluid governed by the second order Israel-Stewart viscous hydrodynamics has been studied when it passed through the Critical End Point (CEP). The effects of CEP has been incorporated in the system through the Equation of State (EoS) [**1**]. The dispersion relation for the perturbation in freequency (ω) wave vector (k) space has been derived. An expression for the threshold wavelength (λ_{th}) has been derived such that waves with wavelength, $\lambda > \lambda_{th}$ can propagate in the QGP but waves with lower λ will dissipate. The sensitivity of λ_{th} on transport coefficients, temperature and baryonic chemical potential of the system have been investigated. Most interestingly, it is found that the value of λ_{th} at CEP diverges blocking waves of all wavelength [**2**] irrespective of the value of transport coefficients. The role of first and second order causal hydrodynamics have been demonstrated mathematically. The fluidity of the system has been obtained near the CEP in terms of λ_{th}. Near the CEP the correlation length (ξ) diverges, violating the hydrodynamic limit, $\xi << \lambda$[**3**, **4**, **5**] and the development of sound wave is prevented. The forbiddance of sound wave will lead to the vanishing of Mach cone (Mach angle, $\alpha = Sin^{-1}(c_s/v)$, v is the fluid velocity). Therefore, the vanishing of Mach angle will indicate the presence of critical point [**6**].
Various harmonics of the azimuthal distribution of produced particles in Relativistic Heavy Ion Collider Experiments are useful quantities to characterize the matter. For example the triangular flow helps in understanding the initial fluctuations and elliptic flow can be used to comprehend the equation of state of the system. The presence of critical point makes the viscous horizon scale, $R_v \sim 1/k_{th}$ to diverge. Since the highest order of surviving harmonic vary as, $n_v \sim 2\pi R/R_v$ [**7**], ideally the vanishing harmonics will indicate the presence of critical point. However, the experimentally measure quantities are superpositions of different temperatures and densities from the formation to the freeze-out stage, therefore, even if the system hits the critical point in the $T - \mu$ plane, the harmonics may not vanish, but will be suppressed.

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Power spectrum of density fluctuation near the QCD critical point

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The power spectrum of the density fluctuation near the QCD critical point has been derived using linear response theory within the scope of Israel-Stewart relativistic viscous hydrodynamics. The change in the spectral structure of the system as it moves toward Critical End Point (CEP) has been shown. The effects of the critical point have been introduced in the system through a realistic Equation of State (EoS)[**1**] and the scaling behaviour of various transport coefficients and thermodynamic response functions [**2**, **3**]. We have found that the Brillouin peaks (B peaks) and the Rayleigh peak (R peak) are distinctly visible when the system is away from the critical point but the peaks tend to merge as the system approach the CEP. The sensitivity of the structure of the power spectrum on wave vector (k) of the sound wave has been demonstrated. It has been shown that the Brillouin peaks get merged with the Rayleigh peak because of the absorption of sound waves in the vicinity of the critical point.
The R peak is originated from the entropy fluctuation at constant pressure and the B peaks are due to the pressure fluctuation at constant entropy. As the system approached the CEP, the B peaks merge with R peak, and the magnitude of the R peak gets amplified. Therefore, one can argue that when the system is near the CEP, the thermal fluctuation is very high, which prevents the system to relax and makes the system stay out of equilibrium for a long time due to critical slowing down [**4**].
For electromagnetically interacting system the effects of critical point has been investigated by measuring the intensity of the scattered light. For such system the phenomenon of critical opalescence at the CEP is considered as a signal of large density fluctuations [**5**]. The possibility of detecting the phenomenon of QCD opalescence by measuring the suppression of hadronic spectra in RHIC-E (R_{AA}) has been indicated in [**6**]. The R_{AA} can be used to estimate the opacity factor, $\mathcal{K}$ as: The R_{AA} can be used to estimate the opacity factor, $\mathcal{K}$ as:

$$\mathcal{K} = -\frac{ln(R_{AA})}{R_{HBT}}$$

where R_{HBT} is the Hanbury-Brown Twiss radius of the system. Various aspects of the power spectrum, specifically the role of sound wave will be discussed in the presentation.

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Systematic study of Tsallis Distribution at LHC energies

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The quark-gluon matter is created at a very high energy density in heavy-ion collisions at the Large Hadron Collider (LHC). The system expands, reaches chemical equilibrium and then finally freezes out after the initial very hot stage. Thermal models are part of the standard set of tools to analyze such high-energy collisions. Power law distributions have been widely applied in high energy physics to describe the transverse momentum spectra of secondary particles produced in nucleus - nucleus (nucleon - nucleon) collisions. A thermodynamically consistent model based on the Tsallis distribution[1, 2] has been investigated in pp and $Pb-Pb$ collisions at LHC energies elsewhere[3, 4, 5]. It is quite remarkable that the transverse momentum distributions measured up to 200 GeV/c in p_T can be described consistently over 14 orders of magnitude by a straightforward Tsallis distribution. The distribution has been used to determine the energy density, the pressure, the entropy density and the particle density at kinetic freeze-out stage using the transverse momentum distributions of charged hadrons measured by the LHC experiments. A more systematic study of the thermodynamically consistent form of the Tsallis distribution will be presented in this paper.

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Energy dependence of strangeness production in small collision systems with ALICE

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The ALICE experiment at the LHC is used to study particle production in high-energy pp, p-Pb and Pb-Pb collisions. Enhanced strangeness production in heavy-ion collisions is one of the proposed signatures of quark-gluon plasma (QGP) formation. An enhancement of strangeness production in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV compared to pp collisions analysing the Run 1 data (2009-2013), contributed to evidence that a QGP had been formed. However, a surprising result from Run 1 was that an enhancement could also be seen in high-multiplicity pp and p-Pb collisions at $\sqrt{s} = 7$ TeV and $\sqrt{s_{NN}} = 5.02$ TeV respectively, where QGP formation is not expected. A smooth increase of strange particles relative to non-strange ones with event multiplicity was observed in all three collision systems. The latest results from Run 2 (2015-2018) p-Pb collisions at higher energies will be presented. This will allow the energy dependence of this phenomenon to be investigated as well as a direct comparison between p-Pb and Pb-Pb results at high multiplicities.

Heavy Quark propagation in hot QCD medium at finite chemical potential

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The exploration of QCD phase diagram at finite baryon density and moderate temperature is expected to be traced with the upcoming experimental facilities such as Anti-proton and Ion Research (FAIR) and Nuclotron-based Ion Collider fAcility (NICA). The theoretical research needs the inclusion of finite chemical potential while studying the hot QCD medium produce there. Therefore, the aim is to investigate the polarization energy-loss of heavy quarks moving in the interacting collisional hot QCD medium having small but a finite quark chemical potential. To do so, we applied the effective kinetic theory along with the extended effective fugacity quasi-particle model [1–3]. To incorporate the collisions in the medium we employed the ÂăBhatnagar-Gross-Krook (BGK) collisional kernel. Finally, the change in the energy of charm and bottom quarks have been investigated at different values of momentum, collision frequency and chemical potential. It is found that bottom quark loses less energy than charm quark at a particular momentum, collisional frequency and chemical potential. Also, the energy-loss is observed to decrease with increasing chemical potential. The results are found to be consistent with the ones already available in the literature [4].

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The pseudorapidity and transverse momentum distributions of charged particles produced in simulated pp and Pb-Pb collisions at LHC energies.

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Topic(s): Standard model physics

Abstract: The results on the pseudorapiidty(η) and transverse momentum (p_t) distributions and their dependence on the multipliicty of the produced particles will be presented. An attempt is also being made two look for the presence of clusters of various sizes (2,3,4 and 5 particles) in η and p_t space. The pp data used in the present study has been generated using pythia and the PbPb da has been generated using HIJING.

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Transverse spherocity dependence of azimuthal anisotropy in heavy-ion collisions using AMPT

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Transverse spherocity has been studied successfully as a tool to separate jetty and isotropic events in small collision systems such as proton-proton collisions [**1**, **2**]. It has very unique capability to distinguish events based on their geometrical shapes [**3-5**]. In our work [**6**, **7**], we report the first implementation of transverse spherocity in heavy-ion collisions using a multi-phase transport model (AMPT) [**8**]. We have studied the $p_{\rm T}$-spectra, integrated yield (dN/dy) for identified particles and performed an extensive study of azimuthal anisotropy of charged particles produced in heavy-ion collisions as a function of transverse spherocity (S_0). We have followed a two-particle correlation method [**9**, **10**] to estimate the elliptic flow (v_2) in different centrality classes in Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV. This method enables us to suppress the non-flow effects, which are present in heavy-ion collisions and affect the elliptic flow significantly. By using proper pseudo-rapidity cuts while making the particle pairs, we could subtract substantial non-flow effects from our calculations. We have also performed a comparative study between AMPT and PYTHIA8 (Angantyr) [**11**, **12**] and found that the two-particle elliptic flow ($v_{2,2}$) is almost zero in the later one and it is almost free from residual non-flow effects. Also, transverse spherocity does not introduce any bias to the system as far as the elliptic flow is concerned, which is clear from the comparison between the two models. Our results show, transverse spherocity successfully differentiates heavy-ion collisions' event topology based on their geometrical shapes *i.e.* high and low values of spherocity (S_0). The high-S_0 events have nearly zero elliptic flow while the low-S_0 events contribute significantly to elliptic flow of spherocity-integrated events.

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Skewness and kurtosis of net baryon-number in Polyakov Chiral Quark Mean Field model

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract:

We analyze the baryon number fluctuations by studying variance, σ_B^2, skewness, S_B and kurtosis, K_B, at different valuess of baryon chemical potential and strangeness chemical potential.The chiral dynamics of non-perturbative quantum chromodynamics (QCD) is modeled by the Polyakov-loop extended Chiral Quark-Mean Field (PCQMF) model that includes the quark-meson and meson-meson interactions based on broken scale invariance and non-linear realization of chiral SU(3) symmetry at finite temperature and density. We focused on the properties of net-baryon-number fluctuations which are quantified by the nth-order susceptibilities,χ_B^n. The present investigation will help to explore QCD phase structure and location of critical end point.

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Feasibility study of ω reconstruction at FAIR SIS100 with CBM Muon Chamber (MuCh) detector set up

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The Compressed Baryonic Matter (CBM) experiment at the Facility for Antiproton and Ion Research(FAIR)[1] accelerator complex in Darmstadt Germany, is aiming at the study of the QCD phase diagram in the region of high net baryon densities. In the first phase of FAIR, the SIS-100 accelerator ring will provide accelerated beams up to an energy of 30 GeV for protons, 12A GeV for heavy ions and 15A GeV fo light ions. One of the important physics observables at SIS100 is the measurement of di-muons produced in high-energy heavy-ion collisions in the beam energy range from 4A to 12A GeV. We will report our latest simulation results on reconstruction of $\omega \to \mu^+\mu^-$ mesons in central Au+Au collisions at the beam energy 8A GeV. In this simulation, realistic configuration of the Muon Chamber (MuCh) detector system [2], optimized for the measurement of $\mu^+\mu^-$ pairs coming from the decay of low mass vector mesons(LMVM) has been considered. The reconstruction efficiency (ϵ_ω) and the signal-to-background ratio (S/B) has been calculated. The efficiency correction and the invariant mass spectra for ω mesons in different p_T bins has also been calculated and will be reported in detail.

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Heavy quark diffusion in QCD matter : Plasma vs Glasma

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Heavy quarks are considered as noble probes of the QCD matter produced in high energy heavy-ion collisions. In the pre-equilibrium stage of relativistic heavy-ion collisions, a strong quasi-classical gluon field emerges at about $\tau_0 = 0.08$ fm/c which evolves according to the classical Yang-Mills (CYM) equations. Recently, it has been shown [1, 2] that these gluon fields induce diffusion of charm quarks in momentum space investigated within Wong equations resulting in a tilt of their spectrum without a significant drag. As a consequence, it leads to a suppression of the nuclear suppression factor at low transverse momentum and enhancement at intermediate transverse momentum. We find that such a feature can be reproduced within a Langevin dynamics in a quark-gluon plasma (QGP) medium with only diffusion coefficients evaluated within pQCD framework. We observe that if we include the drag coefficients within the Fluctuation-Dissipation Theorem (FDT) in the Langevin dynamics up to temperature 2 GeV the impact of the drag coefficient is still significant [3]. These results are encouraging since they show that neglecting energy loss, we overestimate the effect of diffusion on nuclear suppression factor when the system approaches the initialization time of hydro. A purely diffusive motion of heavy quark within Langevin dynamics in QGP can be achieved at a temperature around 3 GeV or higher.

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Strange and multi-strange hadron production with relative transverse multiplicity activity classifier (R_{T}) in underlying event

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract:

Recently, the most important observations in high multiplicity pp collisions at LHC energies, such as, strangeness enhancement and collectivity show remarkable similarity with heavy-ion collisions, where a deconfined state of quarks and gluons is expected. Furthermore, the results from pp collisions are used as a baseline to understand the particle production in heavy-ion collisions, which is questionable at LHC energies. Hence, a more differential study is required to understand the dynamics of the small collision systems. This contribution measures the strange and multi-strange hadron production in proton-proton collisions using the relative Underlying Event (UE) transverse multiplicity activity classifier (R_{T}). This mostly focus on the particle production in the transverse region, which are dominated by soft QCD-processes. The PYTHIA8 Monte-Carlo (MC) generator is used along with different implementation of color reconnection and rope hadronization models to demonstrate the pp collisions at $\sqrt{s} = 13$ TeV. The relative production of the strange and multi-strange hadrons is discussed in low and high transverse activity regions, which is significant at higher R_{T} region. We observe an enhancement of the strange baryons as compared to mesons in the transverse region. In addition, the particle ratios as a function of R_{T} confirm the baryon enhancement in newColor Reconnection (newCR), whereas the Rope model confirms the baryon enhancement only with strange quark content. This study with R_{T}, provides qualitative evidence of increase in strange and multi-strange hadron production in the underlying event. An experimental confirmation of these results will provide more insight into the soft physics in the transverse region which will be useful to investigate various tunes based on hadronization and color reconnection schemes.

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Strange particle production in $p + p$ collisions at $\sqrt{s_{\mathrm{NN}}} = 7\ TeV$

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The p+p collisions are important to understand particle production mechanism in partonic collisions and are also used as baseline for heavy ion collisions. We present a systematic study of transverse momentum (p_T) spectra of strange particles such as (K_s^0) ,($K^* + \bar{K}^*$) , ϕ, ($\bar{\Omega} + \bar{\Omega}^+$), ($\Lambda + \bar{\Lambda}$) and ($\bar{\Xi} + \bar{\Xi}^+$) in different multiplicity classes (i.e. $\frac{dN}{d\eta}$) in $p+p$ collisions at $\sqrt{s} = 7\ TeV$ measured by ALICE Experiment [**1**]. We use Tsallis distribution which successfully describes the p_T spectra of particles in $p + p$ collisions using two parameters T and n, where the parameter T (Tsallis temperature) governs the soft bulk spectra (at low p_t region) and power n determines the initial production in partonic collisions (at high p_T region). Here we consider the p_T spectra of different hadrons by considering both differential and single freezeout scinarios. We parametrize all these measured hadron spectra using Tsallis distribution and study the variations of parameters n and T with avarage multiplicity densities. We observe that for most of the particles, the Tsallis parameter (T) increases with multiplicity densities and also increases with mass of particles in $p+p$ collisions. For particles with higher strangeness the T is seen to be higher, which indicates an early freeze-out of the multi-strange particles.

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Multiplicity and transverse spherocity dependent study of inclusive charged jet properties in pp collisions using PYTHIA

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Jets are collimated showers of particles produced from the fragmentation and hadronization of hard-scattered partons (quarks and gluons) in high energy collisions. Jets provide an important probe to characterize the strongly interacting matter, namely Quark-Gluon Plasma (QGP), created in heavy-ion collisions [1, 2]. Recent studies in small colliding systems have shown collective behaviour similar to the heavy-ion collisions where these effects can be understood through the formation of QGP [3, 4]. However, some other characteristic features of heavy-ion collisions have not been observed in small systems [5], indicating that the collective-like effects might have different origins. In order to understand the sources of these effects in small systems, soft and hard sectors of Quantum Chromodynamics (QCD) need to be properly disentangled. At high transverse momenta (p_T), particle production is well described by perturbative QCD (pQCD), while the production mechanism at low-p_T is not well understood yet. As a tool to disentangle the two domains, event shape observables might prove to be quite useful. One of the important event shape observables is the transverse spherocity which is widely used to categorize the data into samples of hard and soft processes corresponding to events with low and large numbers of multi-parton interactions, respectively [6, 7]. In this work, we will present the dependence of inclusive charged jet properties on event multiplicity and transverse spherocity in pp collisions at LHC energies using the MC event generator PYTHIA.

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Multiplicity distributions of shower particles and target fragments in $^{84}kr_{36}$ - emulsion collision at 1 A GeV

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Multiplicity distributions of shower particle and target fragments in $^{84}kr_{36}$ - Em collision at 1 A GeV with NIKFI BR-2 nuclear emulsion detector has been observed [1]. In this paper, attempt has been made to study the shower particle multiplicity distribution and its characteristics with respect to emitting particle in inelastic collision of $^{84}kr_{36}$ with nuclear emulsion at 1 GeV per nucleon. The target nucleon are emitted shortly after the passage of leading hadron and therefore, it is more motivating to study the multiplicity of target fragments such as black particle (b), gray particles (g), and shower particles (s) which are produced during the interactions. The present article focus on the shower particles of projectile^{84} Kr_{36}-emulsion at 1 A GeV which is then compare to ^{7}Li – emulsion at 7.1 A GeV [2-3]. Shower particle tracts (N_s) which are freshly created charged particles are then normalized with grain density g* less than 1.4. These particles having Velocity $\beta > 0.7$ are mostly fast pions with a small mixture of kaons and they released proton from the projectile in the condition having proton kinetic energy should be greater than 400 MeV [4].

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QGP vorticity and particle spin polarization

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Measurements made recently by the STAR collaboration show that the Lambda hyperons produced in relativistic heavy-ion collisions are subject to global spin polarization with respect to an axis coincident with the axis of rotation of the produced matter. Recently formulated formalism of relativistic hydrodynamics with spin, which is a generalization of the standard hydrodynamics, is a natural tool for describing the evolution of such systems. This approach is based on the conservation laws and the form of the energy-momentum tensor and spin tensor postulated by de Groot, van Leeuwen, and van Weert (GLW). We show how this formalism may be used to determine observables describing the polarization of particles measured in the experiment.

Centrality, transverse momentum and collision energy dependence of kinetic freeze-out parameters in relativistic heavy-ion collisions using Tsallis statistics

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract:

Heavy-ion collisions at relativistic energies produce matter at extreme conditions of temperatures and energy densities with a very short lifetime ($\sim$7-10 fm/c). The new form of matter, called the quark-gluon plasma (QGP) transforms rapidly to a system of hadron gas. The information about the initial condition of the collision system gets mostly lost by multi-partonic interactions throughout the dynamics of the collision. The final state information is nevertheless most useful for understanding the particle production mechanisms and the nature of the matter at extreme conditions. The transverse momentum (p_{T}) spectra of produced particles describe the production mechanism and are useful for the study of thermodynamic properties of the colliding system. A non-extensive Tsallis statistics [1, 2] has been shown to provide a better description of the nature of the non-exponential transverse momentum spectra.

In this work, we present the results of thermodynamic freeze-out parameters from the fits of transverse momentum (p_{T}) spectra of the identified charged particles ($\pi^{\pm}$) as well as all charged particles using the Tsallis fitting in heavy-ion collisions corresponding to eight different collision energies at RHIC and two collision energies at the LHC [3]. The dependencies of the parameters on the collision centrality, collision energy and fitting ranges in p_{T} are investigated. The fit parameter q measures the degree of deviation of the system from an equilibrium state and T is the kinetic freeze-out temperature. It is observed that, in general, q increases with the increase of collision energy and the variation with respect to centrality is collision energy dependent, whereas, T decreases with collision energy, and increases with collision centrality. A reversal of the centrality dependency has been observed for collision energies below 27 GeV. The Tsallis parameters are found to depend on the p_{T} range of the spectra which can be understood as different physics processes dominate at different p_{T} domains. The correlation between the Tsallis fit parameters have been understood by making profile plots of q and T where it is clearly observed that the Tsallis parameters q and T are anti-correlated and have visible centrality dependency. Results of the fits to the p_{T} spectra corresponding to particle production at RHIC and LHC energies will be presented.

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In-medium ϕ meson decay width in the asymmetric nuclear matter

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: We investigate the medium modified mass and decay width of the ϕ meson in the hot asymmetric nuclear matter using an effective ϕ $K\bar{K}$ Lagrangian approach. The ϕ meson self-energy is computed by the in-medium contributions of $K\bar{K}$ loop, which is calculated in chiral SU(3) model. We regularize the ϕ loop integral with a dipole form factor for the range of cut-off mass parameter, Λ_c=1-3 GeV. We anticipate that the in-medium mass of kaons and antikaons decrease with the increase in nucleonic density. Furthermore, we anticipate that the ϕ meson decay width increases with nucleonic density and depends upon the choice of cut-off parameter as the value of decay width increase more for low cut-off parameter and vice-versa. The present investigation will be helpful to study the experimental observations such as ϕ momentum dependence and dilepton spectra in dense matter at the CBM/PANDA experiments at FAIR.

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Effect of D^+ and D^- mass splitting on the decay width of higher charmonia

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract:

The in-medium decay width of higher charmonium states ($\psi(3686), \psi(3770)$) into D^+ D^- pair is studied by using the $^3P_0$ model. The medium modified mass of D^+ and D^- is evaluated from the unified approach of even-odd QCD sum rules and chiral SU(3) model. The light quark and gluon condensates have been calculated from the chiral model and further plugged into QCD sum rules calculations. The effect of medium density and isospin asymmetry on the decay width is also calculated in the present work. Further, we compared the results by using D^+ D^- mass calculated in the centroid approximation. We observe a substantial change in the decay width of ψ state concerning nuclear density and medium asymmetry. The results obtained here will shed light on the J/ψ suppression, which is treated as a QGP signature.

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Factorial Moments and detector efficiencies : A Toy Model Study

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Abstract: The transition from quarks to hadrons and thus the associated critical phenomenon of matter in heavy ion collisions is still not understood. Heavy ion collision experiments record the particles produced during various stages of hadronization and provide means to learn about the properties of the system and its dynamics. Scaling of the observables from these experiments can reveal a many of the properties of the system created, as it expands from quark-gluon plasma phase to hadronic phase. Studying multiplicity fluctuations, the processes of multiparticle production and underlying dynamics of heavy ion collisions can be characterized. One of such techniques is to study the scaling behaviour of the normalized factorial moments (F_q) of multiplicity fluctuations with the bin size resolution or the number of bins (M) in the phase space [**1**]. $F_q(M)$ is proportional to M^{ϕ_q} if there are self-similar fluctuations in the multiparticle distributions [**2**]. A power law scaling of the normalized factorial moments(NFM) with that of the second order normalized factorial moments (F_2) is observed in Ginzburg-Landau theory when studied for formalism with second order phase transition having scaling exponent (ν) ≈ 1.304 [**3-5**].

In heavy ion collisions, the produced particles pass through the material budget and get recorded as signal by the detectors. The signals so recorded depend on the efficiency of the detectors. These need to be corrected for any detector effects altering the real values, before any meaningful conclusions can be drawn from measures under study. Over the acceptance region of the detector, the efficiency in measuring the signal may be uniform or non-uniform depending on the factors such as detector geometry, tracking routines etc. Depending on the causes, leading to detector efficiencies not being ideal, observables from experiments are corrected using monte-carlo simulations. However to optimize the techniques and methodologies for such corrections, use of toy model is also in practice and is quite helpful. In this work a study is performed on the toy model events to see the dependence of the normalized factorial moments on the detector efficiencies of different nature. An efficiency correction methodology is tested for its efficacy to recover original signal. The methodology of efficiency correction and results from this study will be presented.

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Open charm studies as a function of charged-particle multiplicity in pp collisions at $\sqrt{s}$ =13 TeV with ALICE

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Charm and beauty are produced in initial hard scattering processes in heavy-ion collisions. Due to their small formation time (t ~0.1 fm/c) as compared to the formation time of the quark-gluon plasma (QGP) (t ~0.3 fm/c) at the LHC, they experience all the stages occuring during the evolution of the hot and dense medium produced in the relativistic heavy-ion collisions. Therefore, the measurement of open charm and beauty production allows probing QGP properties as they interact with the medium while traversing through it. Moreover, due to their large masses (m_c, m_b » Λ_{QCD}) their pp production cross-sections are calculable with perturbative QCD constituting an excellent test of pQCD calculations.

The study of D-meson yield in pp collisions as a function of charged-particle multiplicity helps to understand the processes involved in the production of charm quarks. Moreover, analyzing the charm production could help disentangling between hard and soft processes of particle production. Along with that, they also serve as a reference for the similar measurements in p–Pb and Pb–Pb collisions.

In this contribution, the prompt production of D mesons (D^0, D_s^+, D^+ and D^{*+}) and Λ_c^+ in their hadronic decay channels as a function of the event multiplicity at mid-rapidity ($|\eta| < 1$) in pp collisions at $\sqrt{s}$ = 13 TeV using minimum-bias and high-multiplicity triggered data collected by the ALICE experiment at the LHC will be presented. Also the measurement of the self-normalized yield of heavy-flavour hadron decay electrons at mid-rapidity ($|\eta| < 1$) as a function charged particle multiplicity will be shown.

Soft contribution to the damping rate of a hard photon in a weakly magnetized hot medium

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Abstract: We have studied photon damping rate in weakly magnetized QED plasma consisted of electrons and positrons. In thermomagnetic medium, photon has one longitudinal and two distinct transverse dispersive modes. In lowest order coupling constant, photons are damped by Compton scattering and pair creation process. We evaluate the damping rate of hard photon by calculating the imaginary part of the each transverse dispersive modes in a thermomagnetic QED medium. We note that one of the fermions in the loop of one-loop photon self-energy is considered as soft and the other one is hard. Considering the resummed fermion propagator in a weakly magnetized medium for the soft fermion and the Schwinger propagator for hard fermion, we calculate the soft contribution to the damping rate of hard photon. In weak field approximation the thermal and thermomagnetic contributions to damping rate get separated out for each transverse dispersive mode. The total damping rate for each dispersive mode in presence of magnetic field is found to be reduced than that of the thermal one. This formalism can easily be extended to QCD plasma.

Study of Net-charge fluctuation at SPS to LHC energies

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: According to Big-Bang theory, at the earliest of its expansion, universe existed as Quark Gluon Plasma (QGP) [1]. As it cooled down, the deconfinement-confinement phase transition occurred and hadrons were formed. The transformation of matter at high enough energies, from nucleons to constituent quarks and gluons has been very interesting and equally very challenging. Study about this kind of a stage can lead us to understand the early stages of universe formation.

The studies of Fluctuations of conserved quantities in event-by-event basis are considered as promising signatures of quark-gluon phase transition. Charge fluctuation, net-baryon number and net-strangeness fluctuations have been proposed to be the most direct observable to study properties of QGP [2].

The net-charge fluctuations of identified charge multiplicity distributions has been carried out on simulated data for all existing experimental data ($\sqrt{S_{NN}}$= 7 GeV to 5.02 TeV). We would like to present a comprehensive study of net-charge fluctuation as a function of impact parameter fluctuation and fluctuations coming from the finite number of charged particles within the detector acceptance in simulated data and compare our results with published data from SPS[3] to RHIC [4] energies including recent and exciting results at LHC[5].

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Evolution of chemical freeze-out scenario in pp collisions as a function of event topology and multiplicity using PYTHIA8

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract:

Recent results in high multiplicity pp collisions at Large Hadron Collider (LHC) energies show heavy-ion like features, with hints of strangeness enhancement and higher degree of collectivity in the system. These results could shed light on whether the results in small collision systems still can be used as a baseline study to understand the particle production in the heavy-ion collision or one may look for the possible formation of QGP droplets in pp collisions. Event topology together with multiplicity can help to understand the particle production in small systems by separating the events originated from the soft- and hard-QCD (pQCD) processes. In this study, we have classified the events using one of the event-topology observables known as transverse spherocity, which classifies the events as isotropic (soft-QCD) and jetty (hard-QCD) events [1]. Further, the study of identified particle yields in the thermal model such as THERMUS, can give important information about the chemical freeze-out conditions as a function of event-topology and multiplicity [2, 3]. In this study, the minimum-bias events are generated in pp collisions at $\sqrt{s}$ = 13 TeV using the PYTHIA8 Monte Carlo (MC) event generator. The event-topology and multiplicity dependence of chemical freeze-out temperature ($T_{\rm ch}$), freeze-out radius (R), and strangeness saturation factor (γ_s), which are the free parameters in THERMUS, are obtained by fitting the identified particle yields. THERMUS allows us to study these parameters by considering three ensembles namely canonical, strangeness canonical, and grand canonical. A clear multiplicity and event class dependence of $T_{\rm ch}$, R, and γ_s is observed. A final state multiplicity $N_{ch} \geq 30$ in the V0 detector acceptance in ALICE, appears to be a thermodynamic limit, where the freeze-out parameters become almost independent of ensemble types. This study plays an important role in understanding the particle production mechanism in high-multiplicity pp collisions at the Large Hadron Collider (LHC) energies in view of a finite hadronic phase lifetime in small systems. We believe this study to be very important and will guide to make similar analysis on experimental data, when become available.

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Event shape and multiplicity dependence of $K^*(892)^0$ meson production in pp collisions with ALICE at the LHC

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The lifetimes of short-lived hadronic resonances are comparable to the hadronic phase lifetime of the system produced in ultra-relativistic nucleon-nucleon or nuclear collisions. These resonances are sensitive to the hadronic phase effects such as re-scattering and regeneration processes which might affect the resonance yields and shape of the transverse momentum spectra. In addition, event shape observables like transverse spherocity are sensitive to the hard and soft processes and they represent a useful tool to separate the isotropic and jetty events in pp collisions. A double differential study of transverse spherocity and multiplicity allows us to understand the resonance production mechanism with event topology and system size respectively. Furthermore, the measurements in small systems are used as a reference for heavy-ion collisions and are helpful for the tuning of Quantum Chromodynamics (QCD) inspired event generators. In this contribution, we present recent results on $K^*(892)^0$ obtained by the ALICE experiment in pp collisions at several collision energies, event multiplicities and as a function of transverse spherocity. The results include the transverse momentum spectra, yields and their ratio to long-lived particles. The measurements will be compared with model predictions and measurements at lower energies.

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Relaxation time approximation for interacting particles

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Relaxation-time approximation (RTA) has been applied widely for deriving the kinetic coefficients in dissipative hydrodynamics from Boltzmann equation [1, 2]. However formulation of RTA uses a single thermalization timescale for all microscopic interactions (elastic or inelastic). This is acceptable as long as the kinetic equilibration is followed by the chemical equilibration and the timescale for inelastic processes is much less than elastic processes. However for comparable timescales, RTA will require modification to include the elastic and inelastic processes separately [3, 4]. We write a set of Boltzmann equations by modifying the RTA to accommodate particle species changing processes forming an interacting mixture as,

$$p^\mu \partial_\mu Q = -(u \cdot p) \left[\frac{\delta Q}{\tau_{\rm eq}} - \frac{1}{2\tau_{\rm tr}} \left(\frac{\delta G}{\sinh \alpha} - \frac{\delta Q + \delta \bar{Q}}{\sinh 2\alpha} \right) \right], \tag{1}$$

$$p^\mu \partial_\mu \bar{Q} = -(u \cdot p) \left[\frac{\delta \bar{Q}}{\tau_{\rm eq}} - \frac{1}{2\tau_{\rm tr}} \left(\frac{\delta G}{\sinh \alpha} - \frac{\delta Q + \delta \bar{Q}}{\sinh 2\alpha} \right) \right], \tag{2}$$

$$p^\mu \partial_\mu G = -(u \cdot p) \left[\frac{\delta G}{\tau_{\rm eq}} + \frac{r}{\tau_{\rm tr}} \left(\frac{\delta G}{\sinh \alpha} - \frac{\delta Q + \delta \bar{Q}}{\sinh 2\alpha} \right) \right], \tag{3}$$

where $Q, \bar{Q}, G$ corresponds to quark, anti-quark and gluon distributions respectively, $\alpha = \mu/T$; $r = g_q/g_g$ (see Ref. [4]). The R.H.S. of (1) vanish at local equilibrium, and the detailed balance condition as well as the conservation laws ensure only two independent relaxation time scales remain ($\tau_{\rm eq}$ and $\tau_{\rm tr}$) in such an interacting system. While the total transport coefficients are found to be independent of transition timescale ($\tau_{\rm tr}$), the individual components of the bulk viscosity and conductivity of the mixture depend on the transition time.

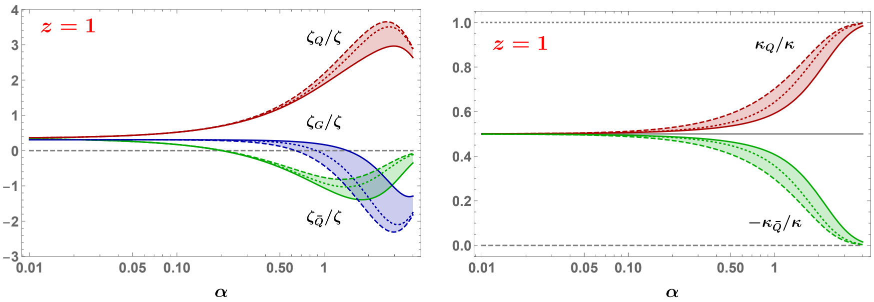

Figure 1: Components of (left panel) bulk viscosity and (right panel) baryon conductivity coefficients (re-scaled by total value) for $z = m/T = 1$; $\gamma = \tau_{\rm tr}/\tau_{\rm eq}$ varies from 0.1 (solid lines), through 1 (dotted lines) to 10 (dashed lines).

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Xe-Xe collision systems at $\sqrt{s_{NN}} = 5.44$ TeV under HYDJET++ framework

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: We present the study of Xe-Xe collisions at 5.44 TeV centre of mass energy by employing Monte Carlo HYDJET++ model. Here, we calculate the pseudorapidity distribution, transverse momentum spectra p_T, and the elliptic flow (v_2) of charged hadrons in two geometrical configurations: body-body and tip-tip type of Xe-Xe collisions. Results are obtained for seven classes of centrality. The results obtained for Xe-Xe collision systems for minimum bias at mid-rapidity match well with the ALICE/CMS experimental data. We observe that the pseudorapidity density depends on the geometry of the colliding system. Average transverse momentum $\langle p_T \rangle$ and average elliptic flow $\langle v_2 \rangle$ are found to be centrality dependent.

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Quantum Field theoretical structure of electrical conductivity of quark matter in presence of magnetic field

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Topic(s): Relativistic heavy-ion physics and QCD; Formal theory

Abstract: Nature provides us exotic matter like neutron stars in which high magnetic fields exist of the order $10^{12}-10^{13}$ Gauss, while that of magnetars feature even greater strength of $10^{15}-10^{16}$ Gauss. Similar (even larger) order of magnetic field strength can be produced in heavy ion collisions occurring in RHIC or LHC experiments [1]. The electrical conductivity is an important transport coefficient, which controls the decay time of the produced magnetic field in RHIC/LHC matter [1]. So its microscopic calculation to know a detail temperature and magnetic field dependent profile of electrical conductivity for relativistic matter might be a very important research topic, which is investigated in the present work. Due to magnetic field, the multi-component structure of conductivity is a well-known fact and studied for neutron stars [2], quark matter [3] and hadronic matter [4] in recent times, which are mostly based on kinetic theory approaches. However, a rich structure in conductivity expression can be found if someone goes for quantum field theoretical version, based on Kubo framework [5,6]. Present article has attempted to zoom in that rich quantum structure.

Owing to the thermal field theory version of Kubo relations, electrical conductivity tensor can be expressed as

$$\sigma^{\mu\nu}=\frac{1}{6}\lim_{q_0,\vec{q}\to 0}\frac{A^{\mu\nu}_{\sigma}(q_0,\vec{q})}{q_0}\ \text{, where } A^{\mu\nu}_{\sigma}(q_0,\vec{q})=\int d^4x e^{iqx}\Big\langle\Big[J^{\mu}(x),J^{\nu}(0)\Big]\Big\rangle_{\beta} \tag{1}$$

is the spectral function of current-current correlator $\Big\langle\Big[J(x),J(0)\Big]\Big\rangle_{\beta}$. By using the projectors, based on magnetic field vector b^{μ} and fluid velocity u^{μ}, [4]

$$P^{||}_{\mu\nu} = b_{\mu}b_{\nu} \tag{2}$$
$$P^{\perp}_{\mu\nu} = \Delta_{\mu\nu}-b_{\mu}b_{\nu}=g_{\mu\nu}-u_{\mu}u_{\nu}-b_{\mu}b_{\nu} \tag{3}$$
$$P^{\times}_{\mu\nu} = ib_{\mu\nu}=i\epsilon_{\mu\nu\alpha}b^{\alpha}\ , \tag{4}$$

we have estimated parallel ($\sigma_{||}$) and perpendicular ($\sigma_{\perp}$) components of electrical conductivity of relativisting matter, where a change in temperature and magnetic field dependent profile is noticed with respect to the earlier kinetic theory based estimations. This differences might be realized as rich quantum field theoretical structure of Landau quantization.

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Differential Analysis of Identified Particle Yields Fluctuations

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract:

A Monte Carlo (MC) study of event-by-event (ebe) fluctuations in heavy-ion collisions at LHC energies is carried out in terms of the fluctuation measure, ν_{dyn}. The MC model HIJING is used in two modes- HIJING default with jet quenching on and with off and with jet/minijet production switched off. The observable, ν_{dyn}, quantifies the magnitude of dynamical fluctuations in ebe measurements of particle yields. The study is undertaken because of the idea that the fluctuations of identified-hadrons in limited phase space would provide information about the QGP formation and QCD phase diagram.
Fluctuations in identified particle ratio in Pb–Pb collisions at $\sqrt{s}_{NN} = 2.76$ TeV as a function of collision centrality are investigated in terms of variable ν_{dyn} and the findings are compared with those reported for the real data. It is observed that the trend of variations of $\nu_{dyn}[\pi, k]$ and $\nu_{dyn}[p, k]$ increases with increasing collision centrality in the same fashion as that reported by the ALICE Collaboration. It is also observed that the results with jet quenching off are close to the experimental findings. Scaling properties of ν_{dyn} with charged-particle density $(dN_{ch}/d\eta)$ and strongly intensive observable Σ are also investigated. The results favour that HIJING is based on the concept of superposition of independent nucleon–nucleon collisions.

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Charged particle erraticity in the AMPT model at LHC energies

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Abstract: Fluctuations in the spatial patterns in heavy ion collisions can be effectively described by normalized factorial moments (F_q). In event-by-event study these factorial moments are obtained by taking average over the number of bins in an event and then averaging over event sample [**1-3**]. In averaging over event space, information on the variation of spatial patterns from event-to-event is lost and thus, is not represented by the normalized factorial moments. To fully account for all the fluctuations that a system exhibits in heavy ion collisions, Hwa and Cao [**4**, **5**] introduced moments of moment distribution, which takes into account the spatial fluctuations as well as the event space fluctuations. To gauge the degree of event-by-event fluctuations in spatial patterns, the double moments ($C_{p,q}$) have been proposed [**6**]. $C_{p,q}$ moments can be used as a tool to probe the multiparticle production dynamics more deeply than normalized factorial moments.

$C_{p,q}$ moments are the normalized p^{th} order moments in the event space of q^{th} order normalized factorial moments $F_q(M)$. The double moments measure fluctuations of the spatial patterns from event to event and quantify this in terms of an index named as erraticity index (μ_q). μ_q is a measure to address the event space and phase space fluctuations together and is independent of M and p. In a model tuned for fluctuations of critical nature, erraticity indices, μ_q for $q > 2$ are observed to be good measures to distinguish various criticality classes at LHC energies [**1**, **7**].

In this work observations and results on the study of event-to-event fluctuations in the spatial patterns, using $C_{p,q}(M)$ moments will be presented for the event samples generated using the string melting version of the A Multi Phase Transport (AMPT) Model [**8**] for Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. Analysis is done for the charged particles generated in the two dimensional (η, ϕ) phase space in the region $|\eta| \leq 0.8$, $0 \leq \phi \leq 2\pi$ in small p_T bins limited to $p_T \leq 1$ GeV/c. Double moments, $C_{p,q}(M)$ which give an economical way to represent the multiplicity fluctuations, are determind for q = 2 - 5 and p = 1.0, 1.25, 1.5, 2.0. These have been studied for their dependence on M. Scaling of $C_{p,q}(M)$ with M, termed as erraticity, has been studied and erraticity indices are obtained for q = 2, 3, 4 and 5. Whereas AMPT does not have phase transistion or fluctuations of critical nature [**2**], the results from present analysis will provide a baseline to compare the experimental results and hence to understand multiparticle production processes in heavy ion collisions.

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Distributions of Gluon in Momentum Space

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: In this paper, we present transverse-momentum-dependent distributions (TMDs) of the gluon in the spin-1 target using light-front dynamics. Specifically, we calculate unpolarized, longitudinally polarized gluon distributions with different polarization configurations of spin-1 hadron. We obtain TMDs using the overlap representation of light-front wave function.

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Modified Excluded Volume Hadron Resonance Gas Model with Lorentz Contraction

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Strongly interacting matter under extreme conditions is an active field of research for several decades. Such matter is expected to have been present microseconds after the Big Bang in color-charge deconfined quark-gluon plasma phase [1]. On the other hand, dense strongly interacting matter can be found inside neutron stars [2]. Such matter can also be created in Ultra-relativistic Heavy Ion Collision experiments. The theory of strongly interacting matter, Quantum Chromodynamics (QCD) is not presently exactly solvable. Lattice QCD uses first principle approach to successfully describe the physics of such matter at high temperatures. However, the Monte Carlo techniques of LQCD cannot be applied to a system with finite baryon chemical potential μ_B, as the fermion determinant becomes complex. However, the Taylor expansion of thermodynamic quantities around $\mu_B = 0$, for a given temperature T, can be used until μ_B is close to a phase boundary. For this reason, people build effective models to study properties of strongly interacting matter in nonperturbative domain.

Such a model which has been successfully applied to describe some aspects of hadronic state is Hadron Resonance Gas (HRG) model which treats the unstable resonance particles as stable particles to incorporate the long range attractive interactions among them [3]. Short range repulsive interactions among them are included by means of excluded volume corrections in Excluded Volume Hadron Resonance Gas (EVHRG) model [4]. In this work we discuss a modified version of Excluded Volume Hadron Resonance Gas model (MEVHRG) and also study the effect of Lorentz contraction of the excluded volume on scaled pressure and susceptibilities of conserved charges. The modified version of Excluded Volume Hadron Resonance Gas (EVHRG) model takes into account the effect of unequal radii of different hadron species. We take four different sets of hadronic radii and compare their results. We find that a larger variety of radii for hadrons enlarges the difference between the results of MEVHRG model and EVHRG model.

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On the Jet quenching parameter of quark gluon plasma in presence of magnetic field

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: We have explored on the estimated values of jet quenching parameter $\hat{q}$ in presence of magnetic field B. Reviewing the existed references on temperature (T) dependent values of $\hat{q}$ for $B = 0$, we have first attempted to calibrate our proposed quasi-particle model of quark gluon plasma (QGP), which can map thermodynamics of lattice quantum chromodynamics (LQCD) by adopting T-dependent degeneracy factors. Then we have extended our estimation to finite magnetic field case, where we have attempted to build a kinetic theory type framework of $\hat{q}$ for direct estimation from our finite B-extended model [1], which can map finite B thermodynamics of lattice quantum chromodynamics (LQCD) [2,3] by adopting a T, B-dependent degeneracy factors. Unlike to isotropic expression of $\hat{q}(T)$, we will get two un-equal components $\hat{q}_{\parallel}(T, B)$ and $\hat{q}_{\perp}(T, B)$, which are parallel and perpendicular to external magnetic field. We have explored the indirect estimation of $\hat{q}_{\parallel,\perp}(T, B)$ from inverse connection with viscosity to entropy density ratio $(\eta/s)_{\parallel,\perp}$. By normalizing with $B = 0$ case, we can get two simple massless expressions:

$$\frac{\hat{q}(T)}{\hat{q}_{\parallel}(T,B)} = \frac{1}{\left[16+\frac{7}{8}36\right]}\left[16+\frac{7}{8}\times 12\sum_{u,d,s}\frac{1}{1+(\tau_c/\tau_B)^2}\right] \quad (1)$$

$$\frac{\hat{q}(T)}{\hat{q}_{\perp}(T,B)} = \frac{1}{\left[16+\frac{7}{8}36\right]}\left[16+\frac{7}{8}\times 12\sum_{u,d,s}\frac{1}{1+4(\tau_c/\tau_B)^2}\right], \quad (2)$$

where, two time scale - τ_c (relaxation time) and τ_B (inverse of synchrotron frequency) are mainly creating the anisotrpic jet quenching within a massless QGP. Adopting our proposed T, B-dependent degeneracy factors, we have estimated average values of $\tau_{c,B}(T, B)$, for which we can get a non-perturbative estimation of $\hat{q}_{\parallel,\perp}(T, B)$. Estimations obtained from the guidance of holographic theory [4,5] will also be discussed. In addition, we will perform the quantum aspect of our framework via Landau quantization technique.

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Fractional energy loss of heavy quarks at RHIC and LHC energies

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract:

The main goal of the ultra-relativistic heavy-ion collision experiment is to study the properties of the strongly-interacting, hot and dense, de-confined state of nuclear matter, usually referred to as the Quark-Gluon Plasma (QGP). Heavy quarks, i.e. charm and beauty quarks, are excellent probes of the QGP as they are produced in the early stage of the collisions and witness the entire space-time evolution of the system. In particular, they allow to investigate the partonic energy loss in the medium. Heavy quarks lose their energy in QGP via collision and radiation processes [1, 2] and ultimately fragment to heavy mesons such as D and B mesons. The energy loss can be quantified via the measurement of the nuclear modification factor (R_{AA}) which is defined as the particle transverse momentum spectra in heavy-ion collisions with respect to the corresponding cross section in pp collisions scaled by the nuclear overlap function [3]. However, An alternate measurement of in-medium energy loss, recently discussed by PHENIX Collaboration [4]. They have estimated a fractional energy loss ($\Delta p_T/p_T$) of hadrons from the invariant yield measurements in pp and heavy-ion collisions.

In this work, we have pursued a similar formalism and estimated the fractional energy loss of heavy mesons at RHIC and LHC energies. Invariant yield of heavy mesons have been parameterised by Hagedorn function [5]. The fit parameters are utilised to estimate the fractional energy loss (Δm_T) of heavy mesons at different centre of mass energies. The variations of Δm_T vs m_T are found well described with a power law. We have also calculated transverse energy loss (ΔE_T) of a heavy quark inside QGP using different theoretical formalisms such as DGLV [6], XDZR [7] and AJMS [8]. It is found that ΔE_T vs E_T from these theoretical calculations show similar power law behaviour that support our empirical study using experimental data.

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Elucidating the implications of deep inelastic scattering in proton-proton collisions with Glauber-like model

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract:

Partonic medium formation in heavy-ion collisions is often chalked by values of the ratio of certain observables measured in such collisions with $p+p$ collisions as a reference. But recent studies of small systems formed in $p+p$ collisions at the LHC energies hint towards the possibility of production of medium with collective behaviour. Results from $p+p$ collisions has routinely been used as baseline to analyse and understand the production of QCD matter expected to be produced in nuclear collisions. Therefore, results from $p+p$ collisions required more careful investigation to understand whether QCD matter is produced in high multiplicity $p+p$ collisions. With this motivation, the Glauber model traditionally used to study the heavy ion collision dynamics at high energy is applied here to understand the dynamics of $p+p$ collisions. We have used anisotropic and inhomogeneous quark/gluon based proton density profile, a realistic picture obtained from the results of deep inelastic scattering, and found that this model explains the charged particle multiplicity distribution of $p+p$ collisions at LHC energies very well. Collision geometric properties like impact parameter and mean number of binary collisions ($\langle N_{coll}\rangle$), mean number of participants ($\langle N_{part}\rangle$) at different multiplicities are determined for $p+p$ collisions. We further used these collision geometric properties to estimate average charged-particle pseudorapidity density ($\langle dN_{ch}/d\eta\rangle$) and found it to be comparable with the experimental results. Knowing $\langle N_{coll}\rangle$, we have for the first time obtained nuclear modification-like factor (R_{HL}) in $p+p$ collisions. We also estimated eccentricity and elliptic flow as a function of charged particle multiplicity using the linear response to initial geometry and found a good agreement with experimental results.

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Investigating the markers of thermalisation in a small system using event topology and final state multiplicity at the LHC energies

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract:
High-multiplicity pp collisions at the Large Hadron Collider(LHC) energies has generated special importance with regard to understanding the underlying physics and particle production mechanisms. Recent results obtained at the LHC, such as long range angular correlation, strangeness enhancement etc. in high-multiplicity pp events are yet to decipher completely. Thermodynamical properties of the system formed in heavy ion and high multiplicity pp collisions are extracted by analysing transverse momentum (p_T) spectra. To ascertain the possibility of medium formation in the collisions of small systems like pp, thermodynamical treatment is necessary. With this motivation, in this work, we have investigated the multiplicity and collisions energy dependence of conformal symmetry breaking measure (CSBM), speed of sound (c_s) and scaled heat capacity (C_V) by cubic power of temperature and inertial mass using ALICE data for pp collisions at $\sqrt{s} = 7$ TeV. The non-availability of event topology dependent experimental data for pp collisions on the spectra of hadrons constrains us to use the PYTHIA8 simulated data to study the event shape and multiplicity dependence of above mentioned thermodynamical quantities. As for results obtained from experimental data, it has been contrasted with PYTHIA8 and it is found that PYTHIA8 (devoid of thermalisation) is inadequate to explain the features reflected in these quantities, thereby hinting towards the possibility of thermalisation in such small systems. Moreover, we found that the estimated observables show a clear dependence on final state multiplicity and event topology. Also a threshold in the particle production in the final state multiplicity emerges out from the present study, confirming some of the earlier findings in this direction.

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Magnetic field effect on the meson masses in the two flavor quark meson model

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: The two flavor Polyakov loop augmented quark meson model (PQM) with proper accounting of fermionic vacuum fluctuations is used to investigate the effect of magnetic field. In the two flavor PQM model pseudoscalar(π;η) and scalar(σ;a_0) mesons are the chiral partners. We have studied the thermal evolution of masses of chiral partners in external magnetic field (eB). The mass degeneration of chiral partners signalling $SU(2)_A$ symmetry restoration. At higher magnetic field $SU(2)_A$ symmetry restores at higher temperature.

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Estimation of Multiparton interactions in pp collisions at the LHC using machine learning

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract: Recently measured collective-like effects in small collision systems at the LHC [1–4] have drawn the attention of the heavy-ion physics community towards Multi-Parton Interactions (MPI) in pp collisions as a possible explanation of the origin of such effects. Here [5], we report the charged-particle production in events with a large number of MPI ($\mathrm{N_{mpi}}$) normalized to that obtained in minimum-bias pp collisions shows interesting features in PYTHIA 8.244 [6]. After the normalization to the corresponding $\langle \mathrm{N_{mpi}} \rangle$, the ratios as a function of p_{T} exhibit a bump at $p_{\mathrm{T}} \approx 3\,\mathrm{GeV}/c$; and for higher p_{T} ($> 8\,\mathrm{GeV}/c$), the ratios are found to be independent of $\mathrm{N_{mpi}}$. The size of the bump increases with increasing $\mathrm{N_{mpi}}$, the behavior at high p_{T} is expected from the "binary scaling" (parton-parton interactions), which holds given the absence of any parton-energy loss mechanism in PYTHIA. The bump at intermediate p_{T} is reminiscent of the Cronin effect observed in the nuclear modification factor in p–Pb collisions. In order to unveil these effects in data, we propose a strategy to construct an event classifier sensitive to MPI using Machine Learning-based regression. The study is conducted using TMVA [7] and the regression is performed with Boosted Decision Trees (BDT). Event properties like forward charged-particle multiplicity, transverse spherocity and the average transverse momentum (p_{T}) are used for training. The kinematic cuts are defined in accordance with the ALICE detector capabilities. For the validation of the method and to find possible model dependence, we also compare the results from PYTHIA 8.244 with HERWIG 7.1 [8]. In addition, we also report that if we apply the trained BDT on existing (INEL > 0) pp data by ALICE collaboration at the LHC [9], i.e. events with at least one primary charged-particle within $|\eta| < 1$, the average number of MPI in pp collisions at $\sqrt{s} = 5.02$ and $13\,\mathrm{TeV}$ are 3.76 ± 1.01 and 4.65 ± 1.01, respectively.

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Multiplicity dependence of Single Muon production in p+p collisions at $\sqrt{s} = 13$ TeV using PYTHIA8

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract:

The measurement of heavy-flavour production as a function of the charged-particle multiplicity produced in the small systems at LHC (Large Hadron Collider) energy regime encourages the study of these observales using theoretical models.This study involves an interplay between hard and soft mechanism in particle production both at parton level and at hadronization. The hard process can be understood in the framework of perturbative Quantum Chromodynamics (pQCD). The partonic interactions occur with low momentum transfer represents the soft process lies in the nonperturbative QCD system where multiple partonic interactions (MPI) play a significant role in the theoretical approach. The phenomenological models with free parameters adjusted (tuned) could estimate the theoretical description of these components of particle production reproducing the experimental data.

In ALICE (A Large Ion Collider Experiment), at LHC the study of production of quarkonia and heavy quarks (charm and beauty) versus charged-particle multiplicity study has been done in proton-proton (pp) and p-Pb collisions in wide rapidity range at different LHC energies. In this work, the open heavy-flavour decay muons (HFM) as a function of multiplicity will be presented using pQCD inspired event generator, PYTHIA8, in the p + p collisions $\sqrt{s} = 13$ TeV for the first time. The results will be compared to the available ALICE experimental measurements obtained in pp collisions.

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Multiplicity dependence of strange and multi-strange hadrons in p-p, p-Pb and Pb-Pb collisions at LHC energies using Tsallis -Weibull Formalism

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Topic(s): Relativistic heavy-ion physics and QCD

Abstract:

In the collisions at LHC, the hadrons are produced in non-perturbative domain in the process of hadronization. It has an inherent cascade branching fragmentation. Such dynamically evolving processes that are governed by sequential branching and fragmentation, is described by Weibull distribution [**1**, **2**]. Hence, the multiplicity distribution of charged particles is favourably described by Weibull distribution in hadron-hadron and leptonic collisions[**3**].. The q-Weibull distribution is given by the following equastion.

$$P_q(x; q, \lambda, k) = \frac{k}{\lambda}(\frac{x}{\lambda})^{k-1} e_q^{-(\frac{x}{\lambda})^k}$$

where,

$$e_q^{-(\frac{x}{\lambda})^k} = (1 - (1-q)(\frac{x}{\lambda})^k)^{(\frac{1}{1-q})}$$

The q-Weibull is obtained by incorporating Tsallis statistics to Weibull-distribution. The measurement of transverse momentum (p_T) distribution of strange hadrons (KS_0 and $\Lambda + \Lambda$) and multi-strange hadrons(Ξ and Ω) is done on p-p,p-Pb and Pb-Pb collisions at LHC energies for different multiplicity classes using Tsallis-Weibull (or q-Weibull) formalism for the 1st time. The q-Weibull function perfectly fits with the p_T distributions for all ranges of measured p_Ts. The extracted parameters from the fit, were examined for all the systems of collision. The λ parameter is associated with the collective expansion velocity, strength of mechanisms like multi-partonic interactions and color reconnections which mimic features of collectivity. The q parameter Is related to the degree of deviation from thermal equilibrium and the k parameter can be related to the dynamics of the system that is associated with the collision types and the charged particle density. It was observed that λ systematically increased with the collisions centrality in Pb-Pb and p-Pb collisions. The larger values of λ was observed to be seen in heavier particles hence implying a mass hierarchy. These features are consistent with the presence of radial flow in the medium formed and hence one can relate λ parameter to the collective velocity. The behaviour of the parameter is found to be similar for p-p collisions. q is almost a constant with respect to centrality for all collision systems studied.For all collision systems,the values of q deviated from one. The slightly higher value for Pb-Pb and p-Pb collisions indicates that the system from which the strange hadrons are emitted is not fully equilibrated. The k values vary slightly with centrality. The decreasing values of k while moving from high multiplicity region to lower ones for certain particles, can be associated with certain dynamical features of collision.This could indicate the presence of dynamical processes which are dominant in initial stages of collision.

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