Event Generators

XI SERC School on Experimental High-Energy Physics

NISER Bhubaneswar, November 07-27, 2017

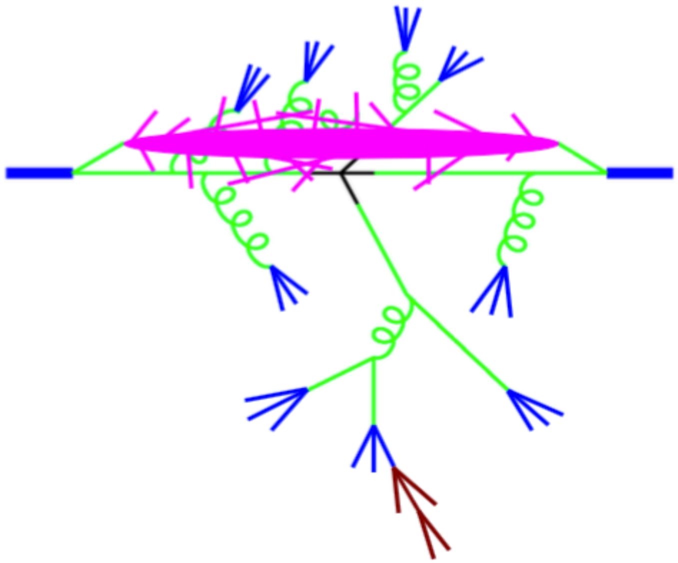
Event Generators Session

Introduction

Typical high energy event (p+p collision) and possible processes:

1. Hard process
2. Parton shower
3. Hadronization
4. Underlying event
5. Unstable particle decays

M. H. Seymour and M. Marx, arXiv:1304.6677 [hep-ph]



If we could create a model that rightly incorporates most physics processes and rightly predicts the physics results…

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Helps Increase the physics understanding of the high energy collisions and data results obtained

Event Generators – In General

- ✓ Computer programs to generate physics events, as realistic as could be using a wide range of physics processes.
- ✓ Use Monte Carlo techniques to select all relevant variables according to the desired probability distributions and to ensure randomness in final events.
- ✓ Give access to various physics observables
- ✓ Different from theoretical calculations which mostly is restricted to one particular physics observable
- ✓ The output of event generators could be used to check the behavior of detectors – how particles traverse the detector and what physics processes they undergo -- simulated in programs such as GEANT.

Need of Event Generators

- ✓ Interpret the observed phenomena in data in terms of a more fundamental underlying theory; Give physics predictions for experimental data analysis.
- ✓ To generate distributions that look sufficiently close to data to allow for detector calibration etc.; planning a new detector.
- ✓ Estimate detector acceptance/efficiency corrections to be applied on raw data to extract "true" physics signal.
- ✓ Device analysis strategies to be used on real data e.g. signal-to-background conditions for rare signals.

Real Experiment vs. Event Generators

Real Experiment

Collisions happening in machine

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Events/tracks detected by detectors – written on tape through data acquisition system (DAQ)

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Events/tracks reconstructed - electric signals translated into tracks,energy deposition inferring momenta and particle species' Information

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Physics analysis

Information is only available at final stage (reconstruction level)

Event Generator

Based on possible Physics processes, generate events

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Physics analysis – comparison/predictions..

- Output can also be put through same detector configuration & event reconstruction chain and Physics Analysis chain (Here we know what the "right answer" is) – Information is available at both initial (generation) and (final (reconstruction) level

A powerful tool to gain a detailed and realistic understanding of Physics

Early Evolution of Event Generators

The need for event generators was apparent in early 50's when the final state multiplicity became large. Y. Pang, BNL-65351, CONF-97123, 1997/2

- ✓ 1950: To locate and identify various hadronic resonances, a Monte-Carlo code was used to generate appropriate background corresponding to a uniform phase space distribution.
- ✓ 1960: As colliding energy increases, the spectra deviate from the uniform distribution and extra parameters were required to simulate the leading particle behavior and to limit transverse momenta.
- ✓ 1970: Hadronic string phenomenology alternative to phase-space parameterization was used.
- ✓ 1980: Focus got shifted to jet production from particle distribution

Since then many new versions, modifications, and models focusing on different physics aspects of the high energy collisions have appeared

High Energy Event Generators' Category

- ✓ *Experimental High Energy Physics (EHEP)* field is studied broadly in two areas : **Particle Physics (elementary collisions)** and **Heavy-ion Physics (heavy-nuclei collisions)**

- ✓ Since heavy-ion collisions in principle represent many elementary collisions, almost all event generators for relativistic heavy-ion collisions contain parts borrowed from event generators in particle physics.

- ✓ There are some key differences between Event Generators used in these two fields

Differences: Elementary and heavy-ion Generators

Key differences between particle physics and heavy-ion event generators

Term	Particle Physics (Elementary)	Heavy-Ion Physics
Medium formation:	No medium	Medium is formed
Hadronization envionment:	simple	Complicated
Hadronic final state interaction:	Almost negligible	Very important
Background processes:	Can be simply defined	Not easily defined

Note: Recent LHC results on multiplicity dependence of pp collisions suggest effects like heavy-ion

Commonly Used Event Generators

Particle Physics (Elementary Collisions):

PYTHIA:
http://home.thep.lu.se/~torbjorn/pythia.html;
arXiv:0710.3820 [hep-ph]

PHOJET:
https://wiki.bnl.gov/eic/upload/Phoman5c-2.pdf

HERWIG: Hadron Emission Reactions With Interfering Gluons
http://projects.hepforge.org/herwig;
arXiv:0803.0883

Only a few event generators are listed here, there exist many more…

Commonly Used Event Generators

Heavy-Ion Collisions:

HIJING: Heavy-Ion Jet Interaction Generator
http://ntc0.lbl.gov/~xnwang/hijing/index.html;
X. N. Wang and M. Gyulassy, Phys.Rev.D 44, 3501 (1991)

AMPT: A Multi-Phase Transport Model
http://myweb.ecu.edu/linz/ampt/
Z. W. Lin et al. Phys.Rev.C72, 064901 (2005)

UrQMD: Ultra Relativistic Quantum Molecular Dynamics
https://urqmd.org/
S. A. Bass *et al.*, arXiv:nucl-th/9803035

Only a few event generators are listed here, there exist many more…

Open Standard Codes And Routines (OSCAR)

- ❑ There had been appearance of many event generators in the market

- ❑ People felt need for
  - Accessibility of source code and documentation
  - Systematic version controls
  - Standardized tests, and
  - Common interfaces

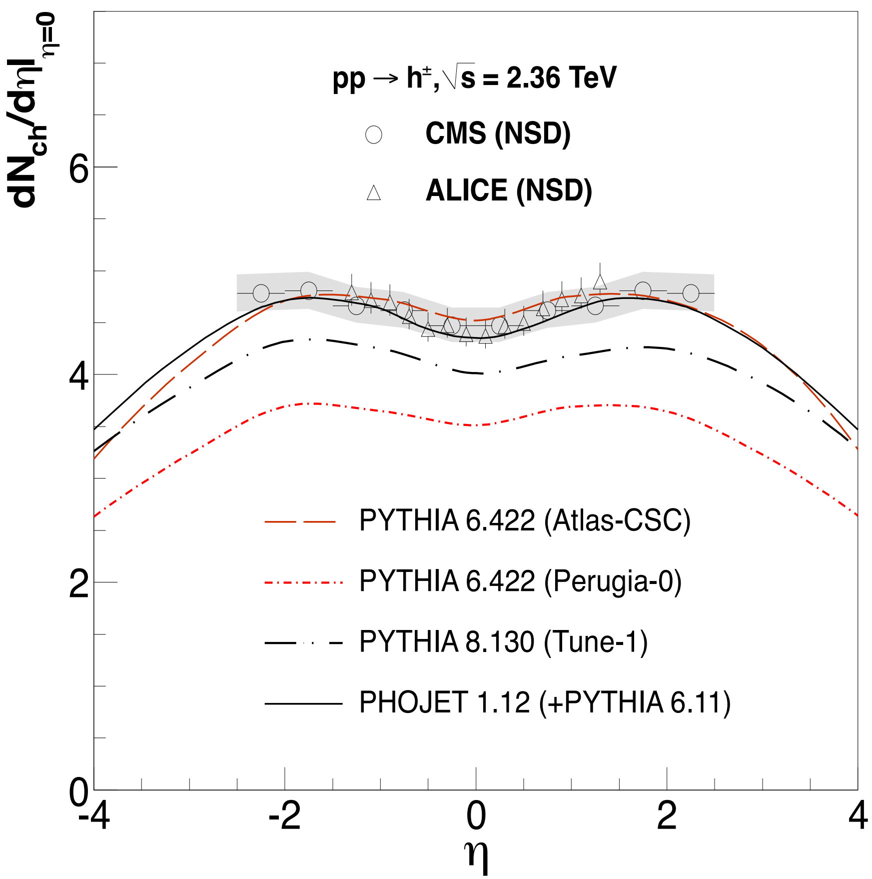
- ❑ *Open Standard Codes And Routines* for event generators was developed: https://karman.physics.purdue.edu/OSCAR-old/models/list.html

  - ✓ Set of minimum requirements for the accessibility of the source codes and documentation, and the reproducibility of the published results for event generators in OSCAR

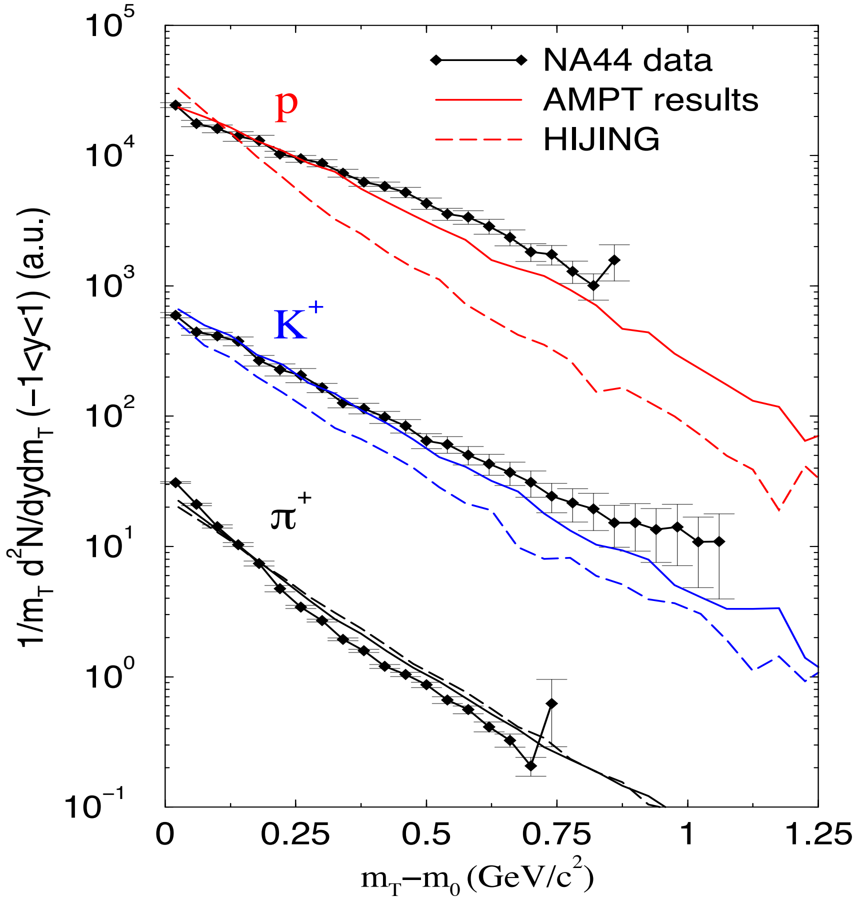
  - ✓ Series of Standard Tests for event generators in OSCAR

Good collective information is available but not being maintained….

Some Examples of Published Results



D. d'Enterria et al. Astropart. Phys. 35, 98 (2011)



Z. w. Lin et al. Nucl. Phys. A 698, 375 (2002)

Running of Event Generators

The Event Generators are used to run in two ways

A). Stand-alone: Run the model with desired parameters, get the output file and do the Physics analysis.

B). With Detector Response: Run the model with desired parameters, get the output file, pass this output to the other simulation program GEANT to get the detector response. The output will include the information of how the particle traverse the detector and underwent Physics processes (behavior in magnetic field, showers in calorimeter etc.)

In this tutorial:

- ✓ Run the stand-alone Event Generators covering particle physics and heavy-ion physics i.e. **PYTHIA, PHOJET, HIJING, and AMPT**
- ✓ Analyze the output file to perform different exercises

PID (Flavor) Codes

Quarks and leptons

1	d	11	e^-
2	u	12	ν_e
3	s	13	μ^-
4	c	14	ν_μ
5	b	15	τ^-
6	t	16	ν_τ

Gauge bosons

21	g
22	γ

Baryons

		1114	Δ^-
2112	n	2114	Δ^0
2212	p	2214	Δ^+
		2224	Δ^{++}
3112	Σ^-	3114	Σ^{*-}
3122	Λ^0		
3212	Σ^0	3214	Σ^{*0}
3222	Σ^+	3224	Σ^{*+}
3312	Ξ^-	3314	Ξ^{*-}
3322	Ξ^0	3324	Ξ^{*0}
		3334	Ω^-
4112	Σ_c^0	4114	Σ_c^{*0}
4122	Λ_c^+		
4212	Σ_c^+	4214	Σ_c^{*+}
4222	Σ_c^{++}	4224	Σ_c^{*++}

4132	Ξ_c^0		
4312	$\Xi_c'^0$	4314	Ξ_c^{*0}
4232	Ξ_c^+		
4322	$\Xi_c'^+$	4324	Ξ_c^{*+}
4332	Ω_c^0	4334	Ω_c^{*0}
5112	Σ_b^-	5114	Σ_b^{*-}
5122	Λ_b^0		
5212	Σ_b^0	5214	Σ_b^{*0}
5222	Σ_b^+	5224	Σ_b^{*+}

Diquarks

		1103	dd_1
2101	ud_0	2103	ud_1
		2203	uu_1
3101	sd_0	3103	sd_1
3201	su_0	3203	su_1
		3303	ss_1

Mesons

211	π^+	213	ρ^+
311	K^0	313	K^{*0}
321	K^+	323	K^{*+}
411	D^+	413	D^{*+}
421	D^0	423	D^{*0}
431	D_s^+	433	D_s^{*+}
511	B^0	513	B^{*0}
521	B^+	523	B^{*+}
531	B_s^0	533	B_s^{*0}
111	π^0	113	ρ^0
221	η	223	ω
331	η'	333	ϕ
441	η_c	443	J/ψ
551	η_b	553	Υ
661	η_t	663	Θ
130	K_L^0		
310	K_S^0		

Thank You