

Origin of mass

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Bedangadas Mohanty
National Institute of
Science Education and
Research, Odisha, India



Buxi Jagabandhu
Memorial Lecture
BJB College,
Bhubaneswar

24th January 2024



My tributes to Shri Buxi Jagabandhu Bidyadhar Bhramarabara Ray Mohapatra

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- Born around 1773 in Rorunga, near Puri. His ancestors were the commander in chief or Bakshi of the Khordha army.
- Led the Paika Rebellion in 1817 to revolt the land revenue policy of the British.
- Freedom fighter of India.

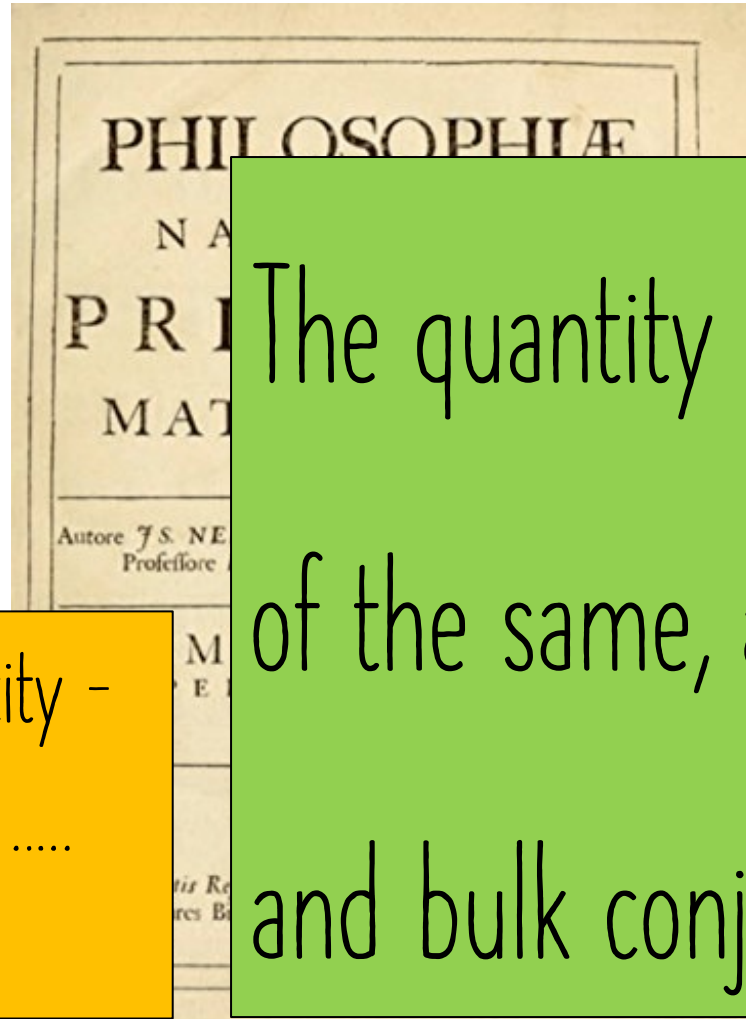
Fortunate to be asked to give a talk on a memorial lecture named after him and in a college (1957) named after him.

What is mass

According to Newton



Mass is a fundamental quantity -
Same in earth, moon, jupiter
Weight is different



MATHEMATICAL PRINCIPLES

The quantity of matter is the measure
of the same, arising from its density
and bulk conjointly.

Elephant versus Ant

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Which has
more mass
and why ?



Mass = Sum of mass of all building blocks ?

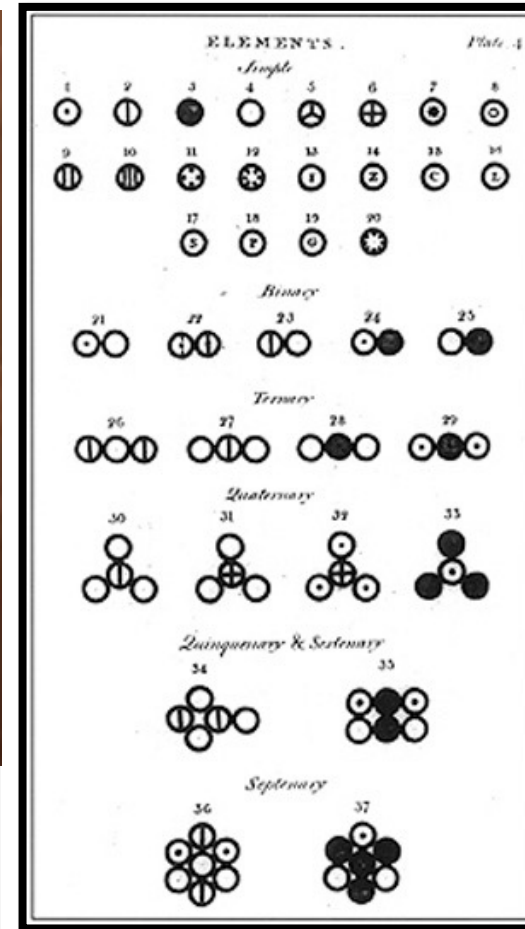
What are our
building blocks

Building blocks – Atoms ?

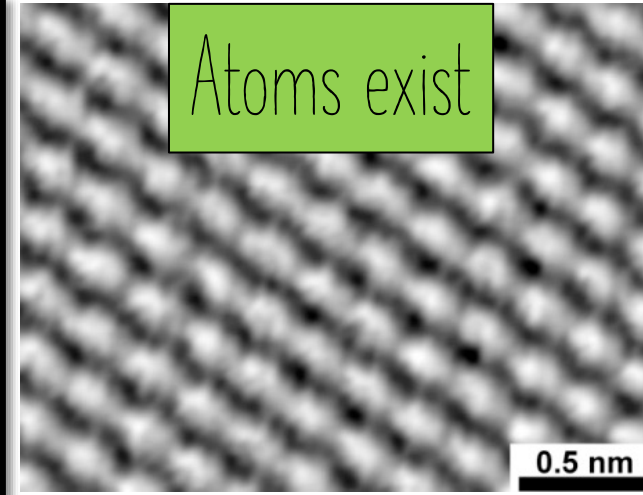
John Dalton



Greek ἄτομος/átomos, α-τέμνω, which means uncuttable, something that cannot be divided further.

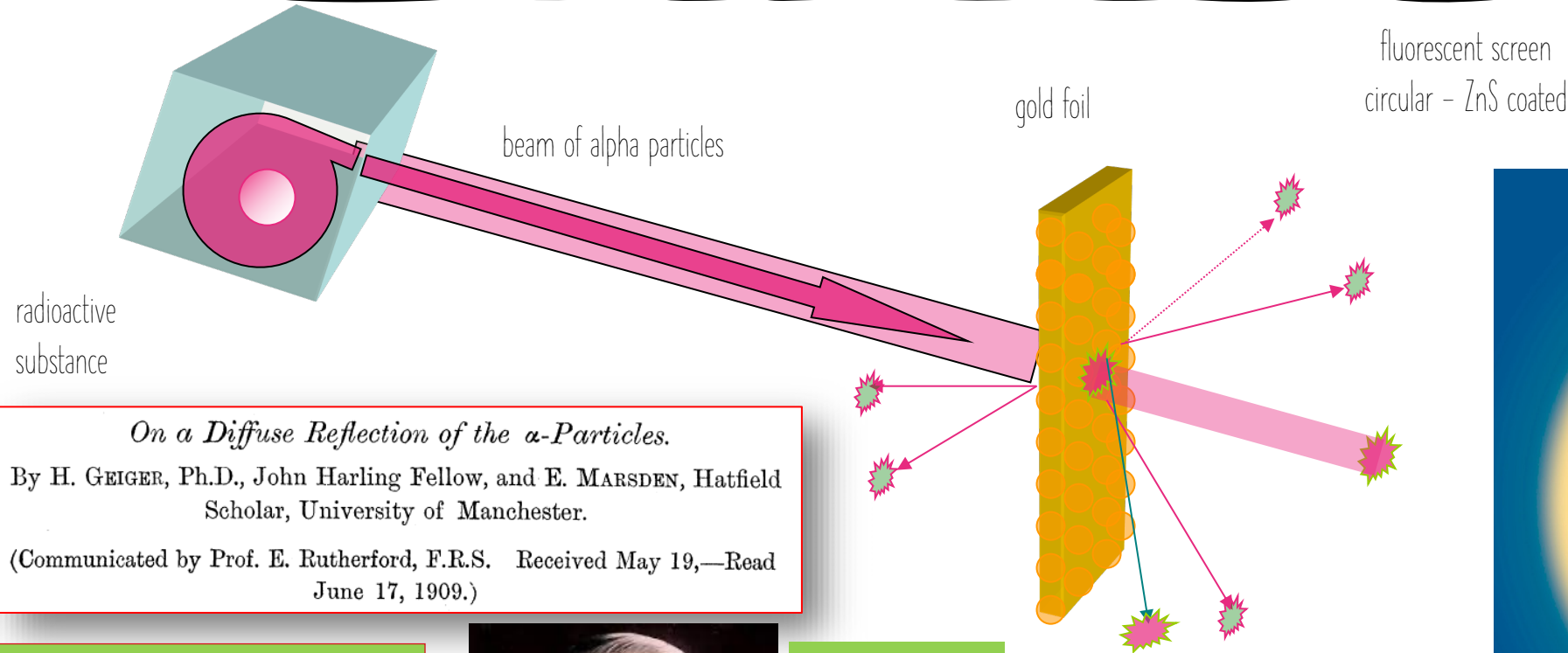


Atoms exist



Building blocks – proton, neutron, electron

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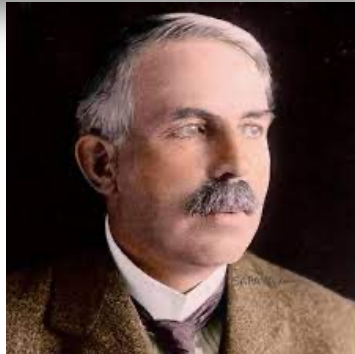


On a Diffuse Reflection of the α -Particles.

By H. GEIGER, Ph.D., John Harling Fellow, and E. MARSDEN, Hatfield Scholar, University of Manchester.

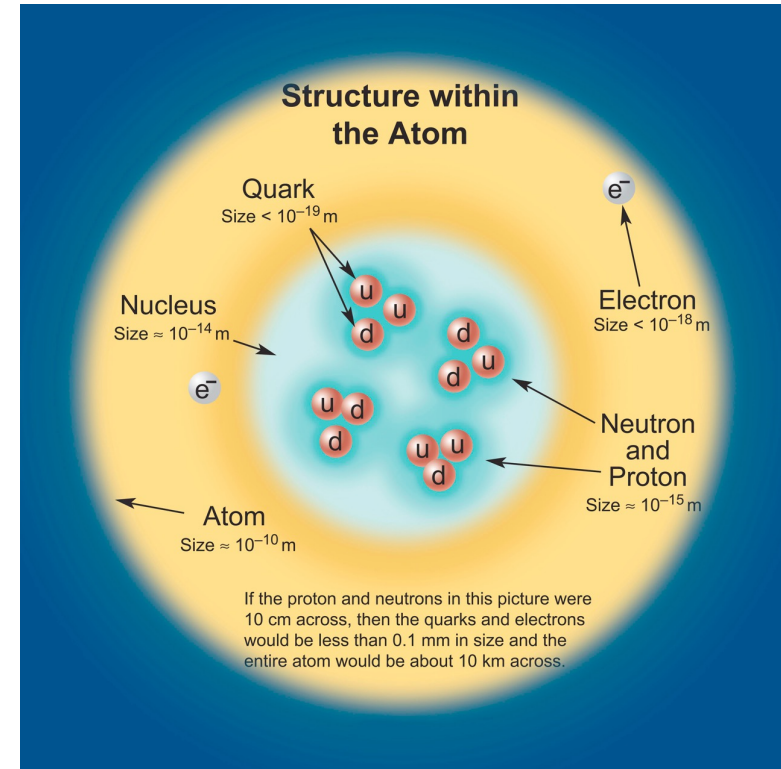
(Communicated by Prof. E. Rutherford, F.R.S. Received May 19,—Read June 17, 1909.)

Marsden was an undergraduate student

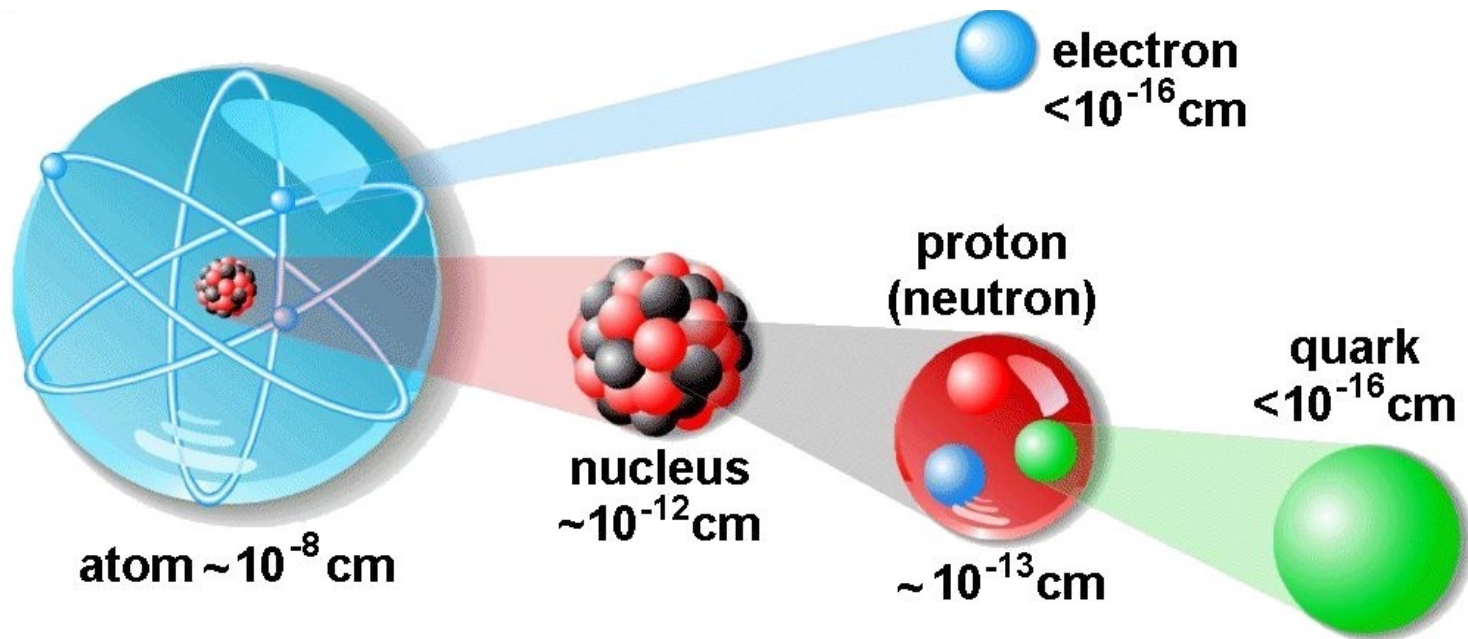


Rutherford

1908 Nobel Prize in Chemistry.
Albert Einstein called him a 'second Newton'



Building blocks: Quarks and electrons



Louis de Broglie

$$\lambda = h/p$$

$$f = E/h$$

1929 Nobel Prize
in physics for
his discovery of
the wave nature
of electrons

In 1952 the first Kalinga Prize was awarded to
him by UNESCO for popularization of science

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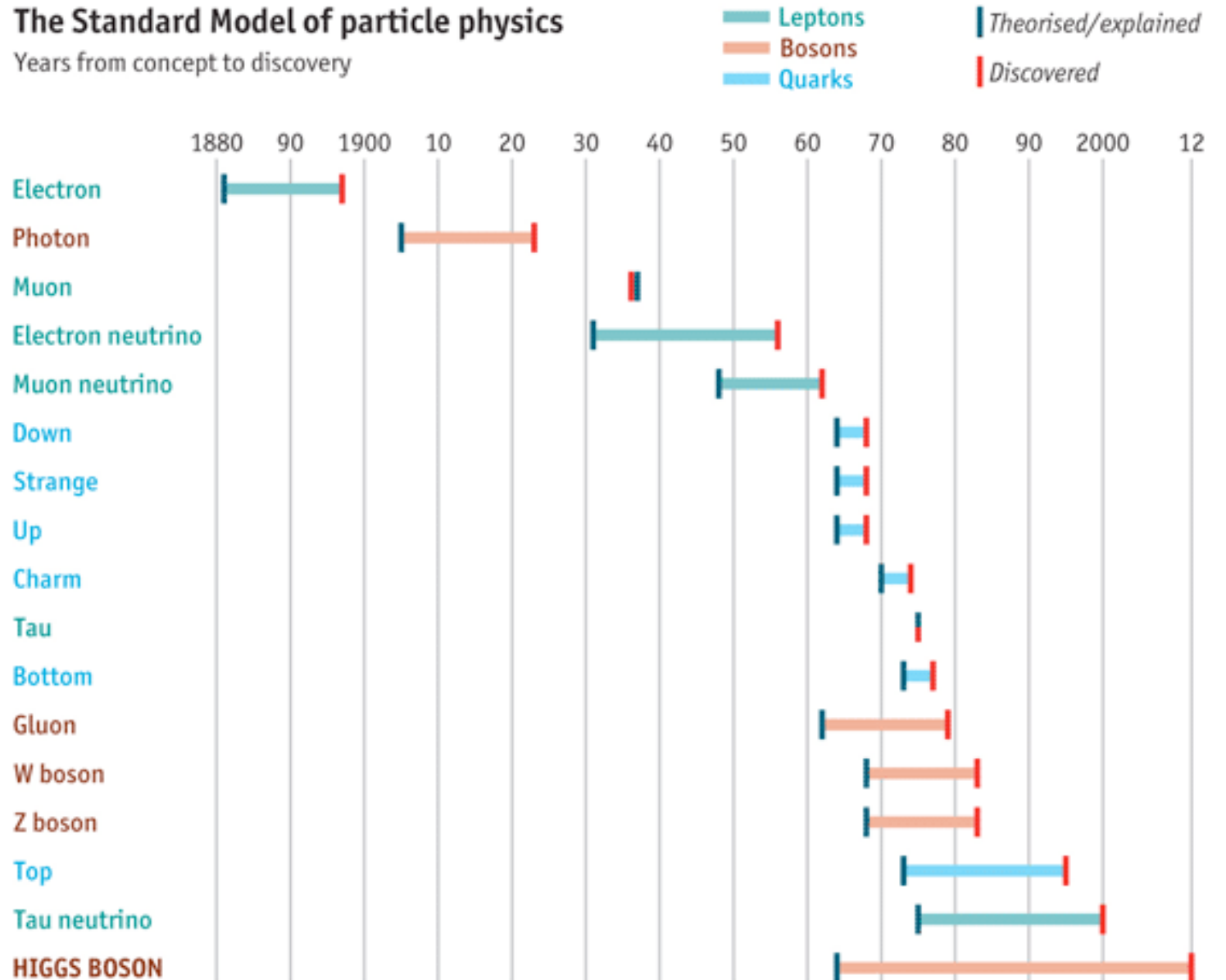
Fundamental building blocks of visible matter

We are made of electron, quarks and gluons

Origin of Mass

The Standard Model of particle physics

Years from concept to discovery



Source: *The Economist*

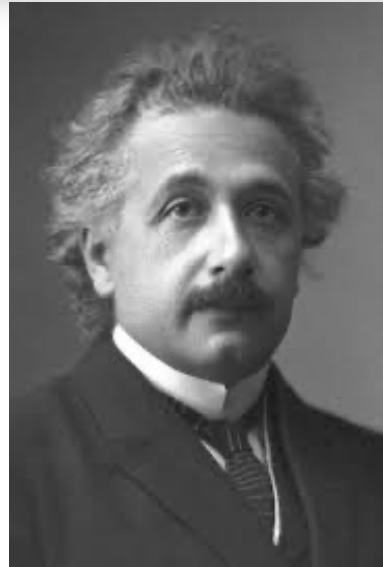
What will happen if electron mass is zero ?

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If equal to Zero

$$E = mc^2 = \frac{m_0 c}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Electron will move with speed of light



1921 Nobel Prize in Physics
"for his services to
theoretical physics, and
especially for his discovery
of the law of the
photoelectric effect"

No atoms
No Molecules
No Compounds
No Life
We won't exist

What happens if electron mass a bit higher or a bit lower ?

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Expression of Bohr radius

$$r_n = 4\pi\epsilon_0 \frac{n^2 h^2}{m z e^2}$$



Nobel Prize for 1922 for structure of atom



World will no longer be same

Role of mass in nature/physics

Newton:

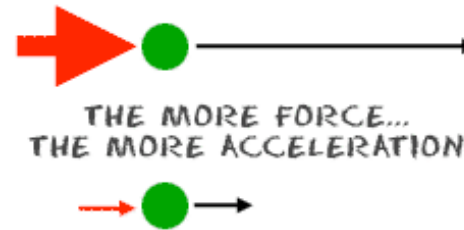
Weight proportional to Mass

Einstein:

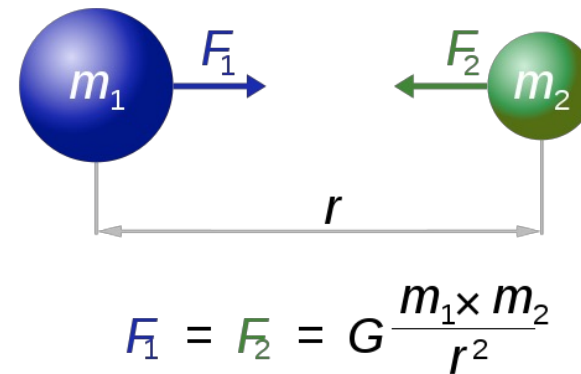
Energy related to Mass

Neither explained origin of Mass

$$\mathbf{F} = m\mathbf{a}$$



$$T = 2\pi\sqrt{\frac{m}{k}}$$



$$E_K = \frac{1}{2}mv^2$$

E_K = Kinetic Energy
 m = Mass
 v = velocity

Origin of mass ?

How did electron get its mass ?

Mass is
generated by
interactions

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Anderson-Brout-Englert-Guralnik-Hagen-
Higgs-Kibble - Boson



Idea documented in journals

BROKEN SYMMETRY AND THE MASS OF GAUGE VECTOR MESONS*

F. Englert and R. Brout

Faculté des Sciences, Université Libre de Bruxelles, Bruxelles, Belgium

(Received 26 June 1964)

VOLUME 13, NUMBER 16

PHYSICAL REVIEW LETTERS

19 OCTOBER 1964

BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs

Tait Institute of Mathematical Physics, University of Edinburgh, Edinburgh, Scotland

(Received 31 August 1964)

GLOBAL CONSERVATION LAWS AND MASSLESS PARTICLES*

G. S. Guralnik,[†] C. R. Hagen,[‡] and T. W. B. Kibble

Department of Physics, Imperial College, London, England

(Received 12 October 1964)

"When the time is ripe for certain things, these things appear in different places in the manner of violets coming to light in early spring." – Farkas Bolyai

Higgs field and mass

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"Light" means All Electromagnetic Waves

*Gamma Rays, Xrays,
Ultraviolet light
Visible Light
Infrared Light,
Microwaves, Radio
Waves*



Higgs Field

Higgs Field
Exists Everywhere

May Be Zero **X**

May Not Be Zero

Higgs
Waves

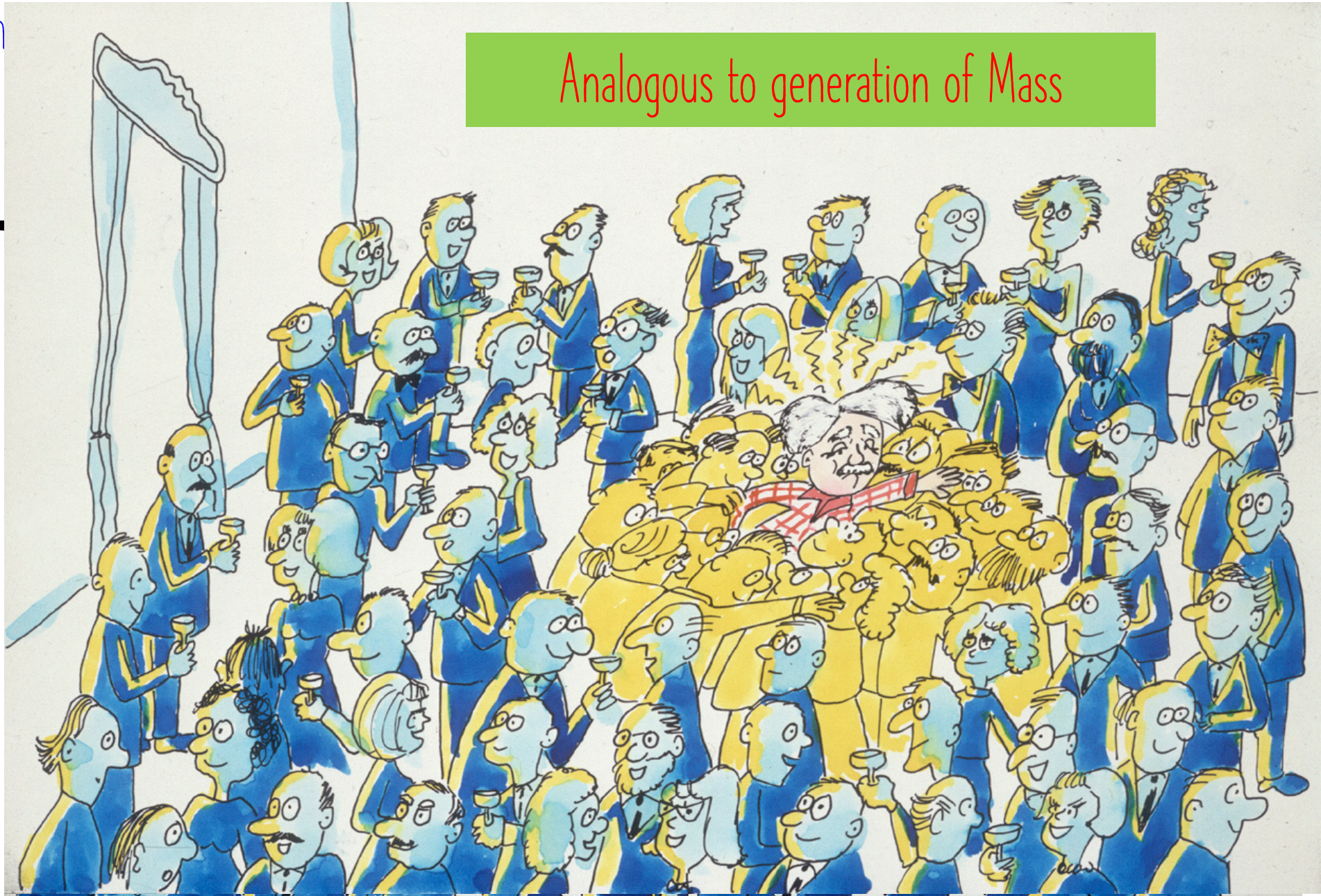
Higgs Particle

How mass is generated?

Cost to build LHC: \$4.75 billion

Professor David J Miller of the Physics and Astronomy Department at University College London– bottle of Veuve Cliquot 1985 by Mr Waldegrave (UK Minister)

Analogous to generation of Mass



Imagine a room
full of political
activists

The Prime
Minister
walks in

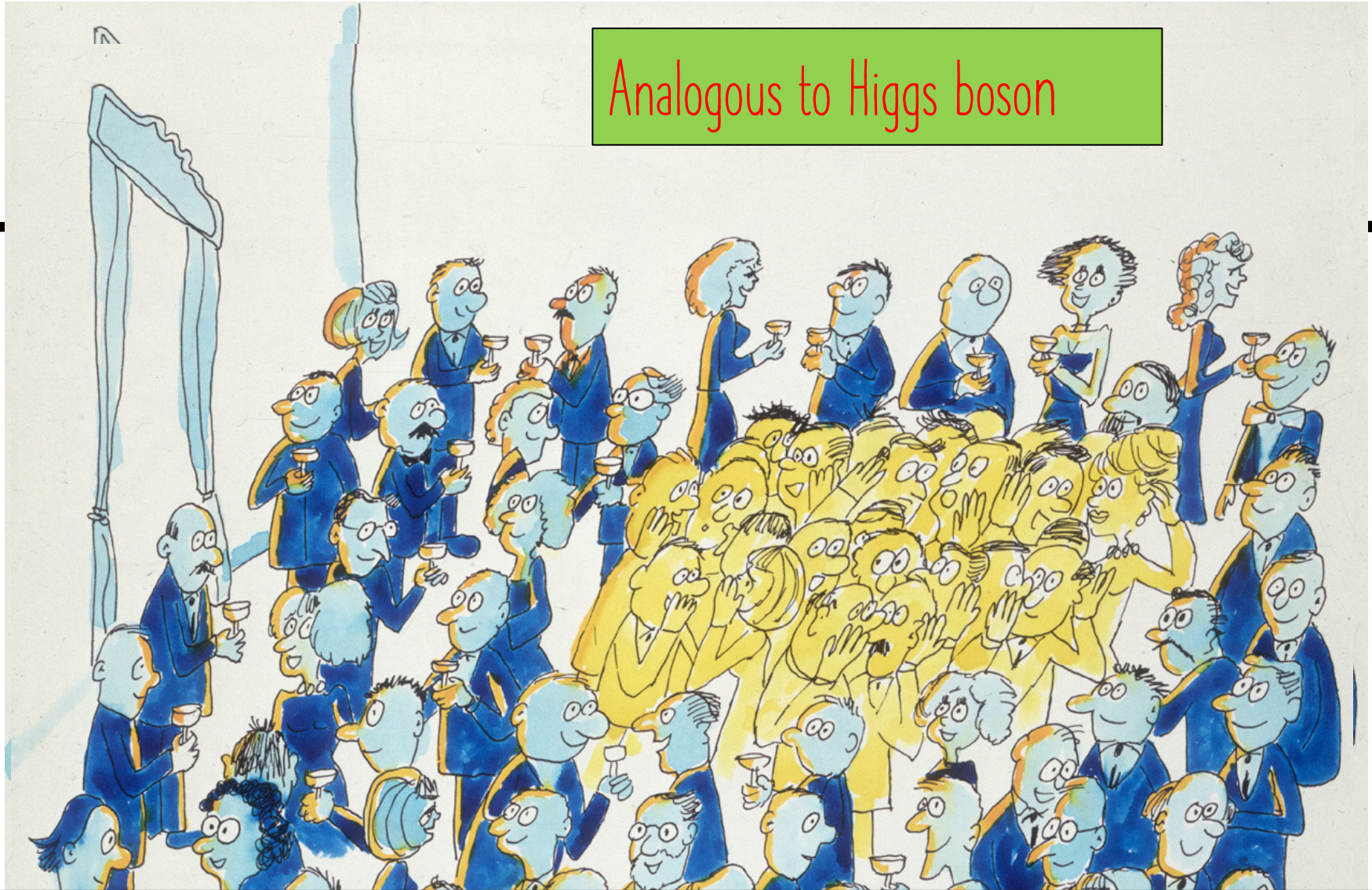
He is
surrounded
by a cluster
of people

Imagine the same room
again

An interesting
rumour is
introduced

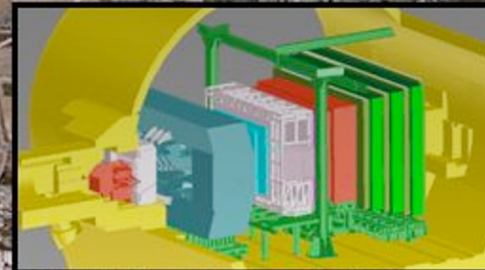
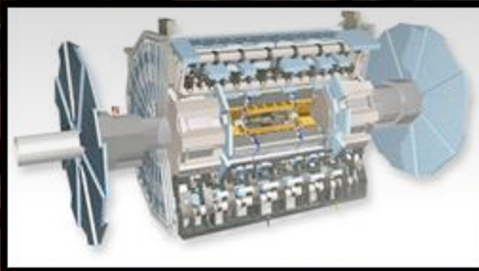
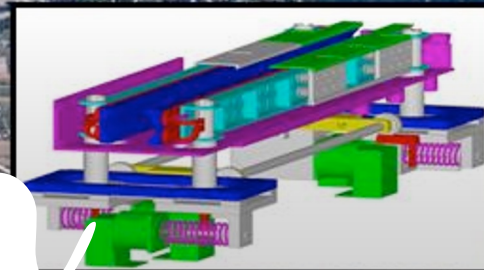
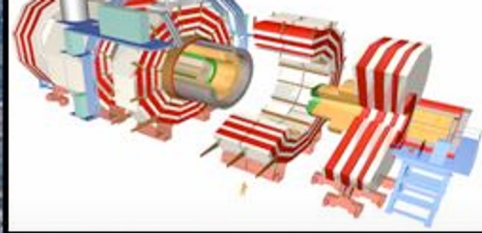
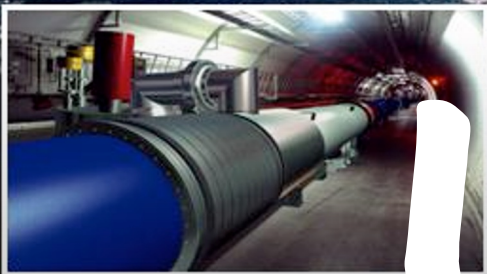
Soon we have a
cluster of people
discussing it

Analogous to Higgs boson



Discover Higgs Boson → Higgs field exists → electron gets mass by interaction with field

Large Hadron Collider



Large Hadron Collider

value	
energy	mass speed of light
$E = mc^2$	
J kg	299,792,458 m/s
units	

www.liugaila.it

- ✧ Largest particle accelerator: Circumference is 26.659 Km.
- ✧ Worlds Coldest place: 9300 magnets at -271.3°C (1.9 K) - Colder than outer space
- ✧ Worlds Loneliest place: Internal pressure 10^{-13} atm. 10 times less than the pressure on moon
- ✧ Fastest Race track: Trillions of protons race 11245 times a second with speed 99.99999991% speed of light
- ✧ Maximum energy 7 TeV (Tera electron volt)
- ✧ 600 Million collisions per second
- ✧ Produces matter with temperature more than 100,000 times the temperature of Sun
- ✧ Data recorded will fill around 100,000 dual layer DVDs every year



Hottest matter produced

LHC collisions

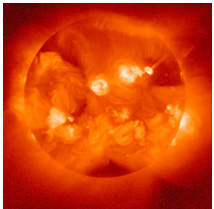
~ 120 MeV ~ 10¹² K



Neutron Star Thermonuclear Explosion
(Terrestrial Nuclear explosions)

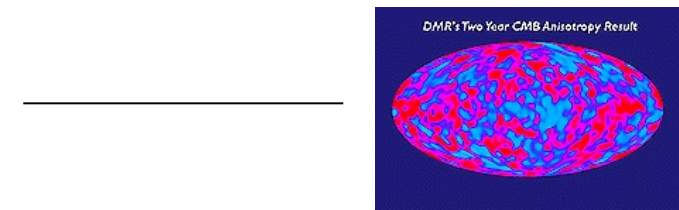


Solar Interior
Solar Surface



Solar Surface

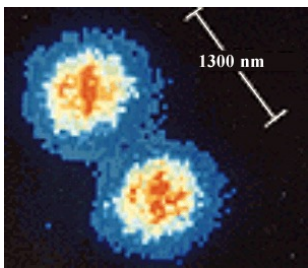
Room Temperature ~ 1/40 eV



Cosmic Microwave Background

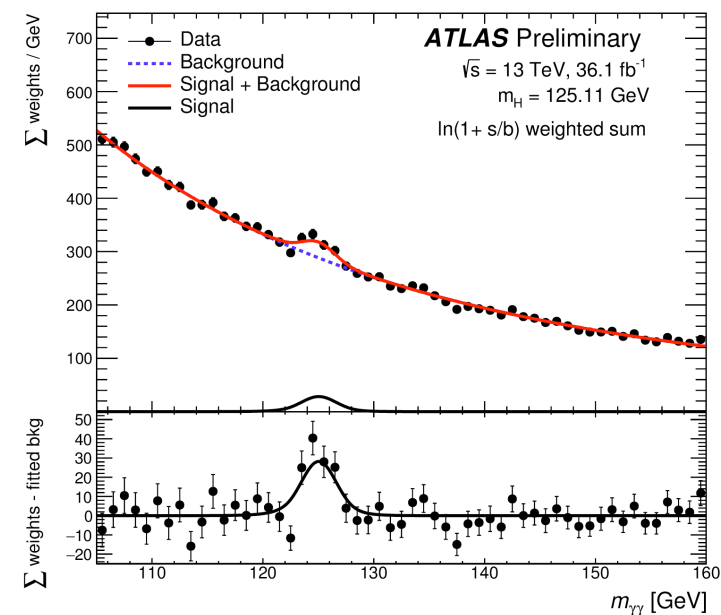
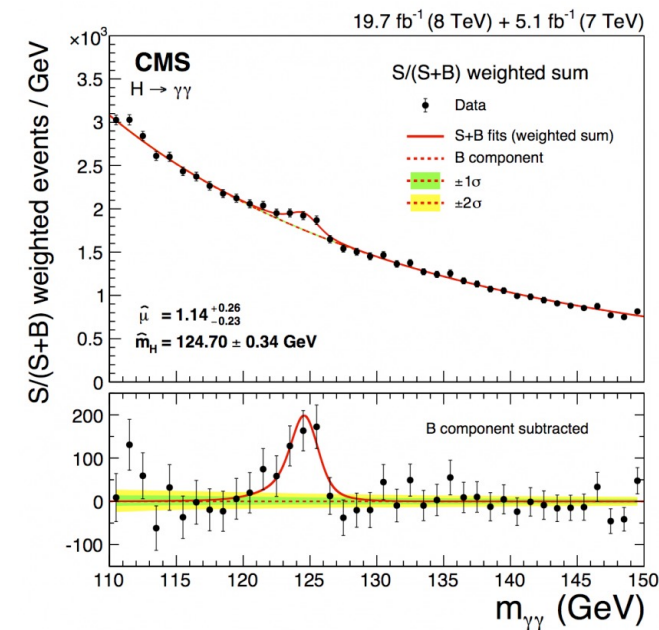
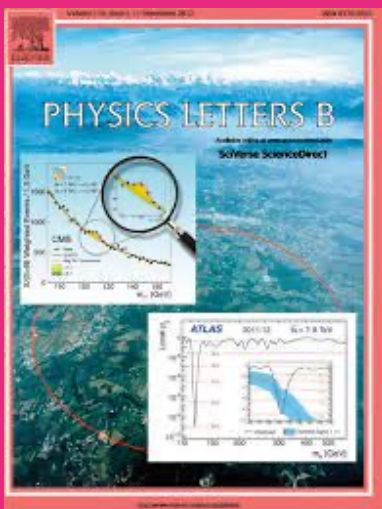
Rhodium metal spin cooling (2000)


(Low-T World Record!)



Trapped Ions

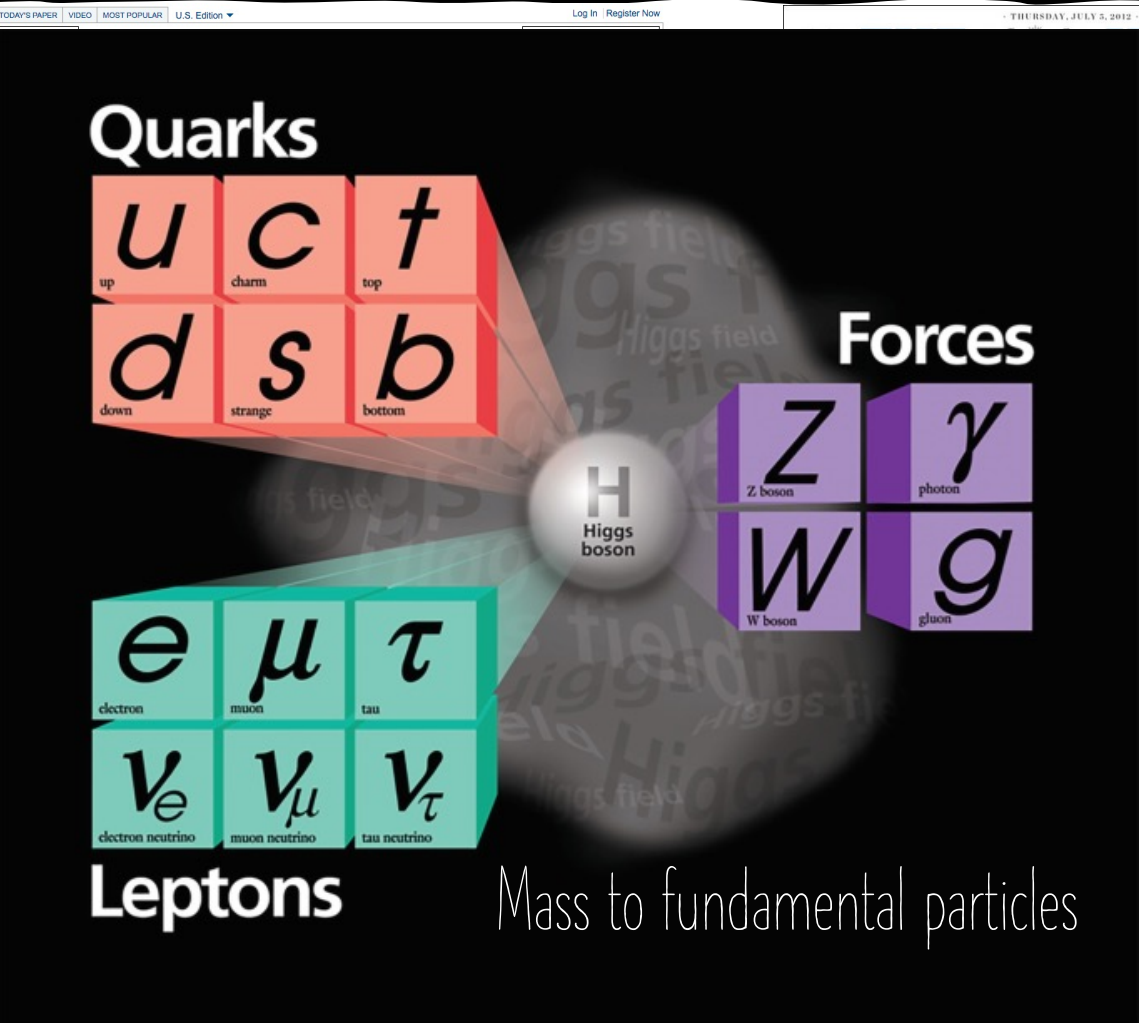
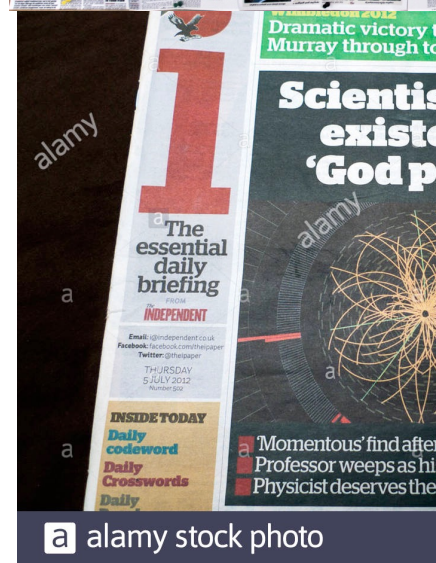
Higgs boson discovery – 4th July 2012





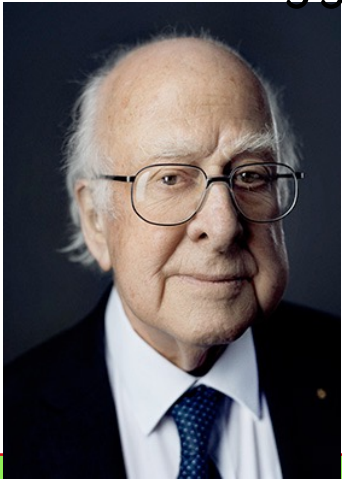
www.spaceandintelligence.com

Worldwide media attention



Nobel Prize in Physics 2013

Peter W. Higgs



2013: Origin of mass

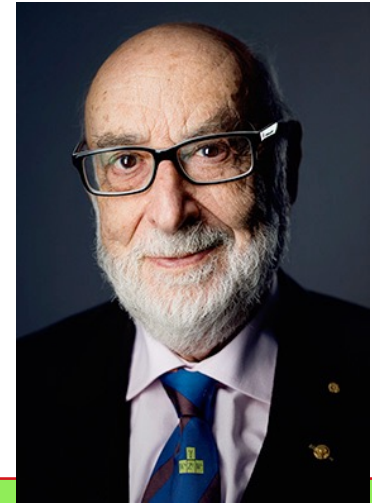


Front



Back

François Englert



"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"

The Standard Model

	Fermions			Bosons
Quarks	u up	c charm	t top	γ photon
	d down	s strange	b bottom	Z Z boson
Leptons	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson
	e electron	μ muon	τ tau	g gluon
				H Higgs* boson

Source: American
Association for the
Advancement of Science;
The Economist

*Confirmation just announced

Fundamental
constituents
of the visible
Universe

"I do not know what I may appear to the world; but myself I seem to have been only like a boy playing on the Sea shore and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me." – Attributed to Sir Isaac Newton (1642 - 1727)

BIG BANG



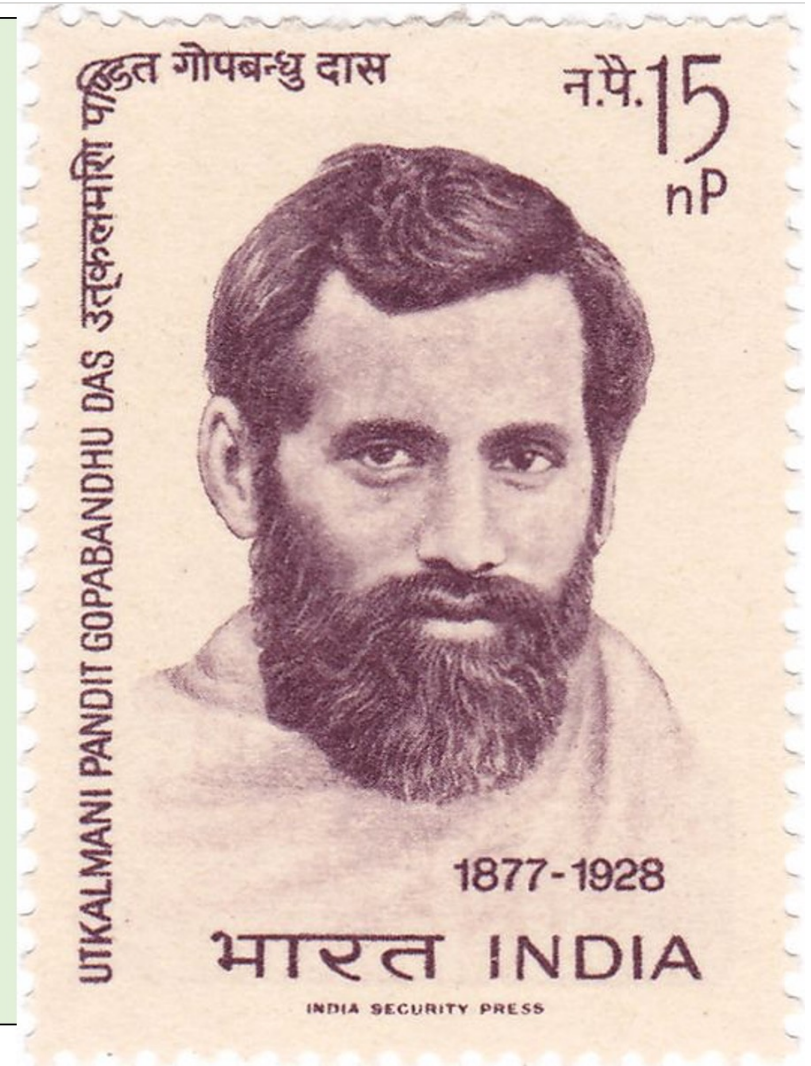
An artist's impression of the evolution of the universe, showing one key area of science for each project.

Few words for the students

Science
makes things
humbling



ମାନବ ଜୀବନ ନୁହଁଇ କେବଳ ବର୍ଷ ମାସ ଦିନ ଦଣ୍ଡ !
(Human life is not of years,
months, days and hours,)
କର୍ମେ ଜୀବି ନର କର୍ମ ଏକ ତାର ଜୀବନର ମାନଦଣ୍ଡ !!
(Man lives on his action, the only
measuring rod of life)
କାପୁରୁଷ ପରି ମରିବା ଜଗତେ, ନୁହେଁ ନର-ପଞ୍ଜରୁଷ
(It is not in the world to die like a
coward, but to be a man)
ପରହିତ ସାଧୁ ମରେ ଯେ ମହାରେ, ସେହି ଏକା
ସୁପୁରୁଷ।
(The one who dies doing good for
others, he alone is the good man)



Prof. C. V. Raman: 1930 Nobel Prize "for his work on the scattering of light and for the discovery of the effect named after him"

"Youth is the most glorious time of all. I have said elsewhere that most of the great discoveries in Science have been made by young people. It is not the experience or wisdom that old age brings, but the freshness of outlook, the indomitable desire to achieve, which is the characteristic of youth, that makes discoveries possible. It is this that makes life worthwhile. If only you realise this and realise that here I am, I am still young, let me see what I can do, that all discoveries become possible."

Thank you

