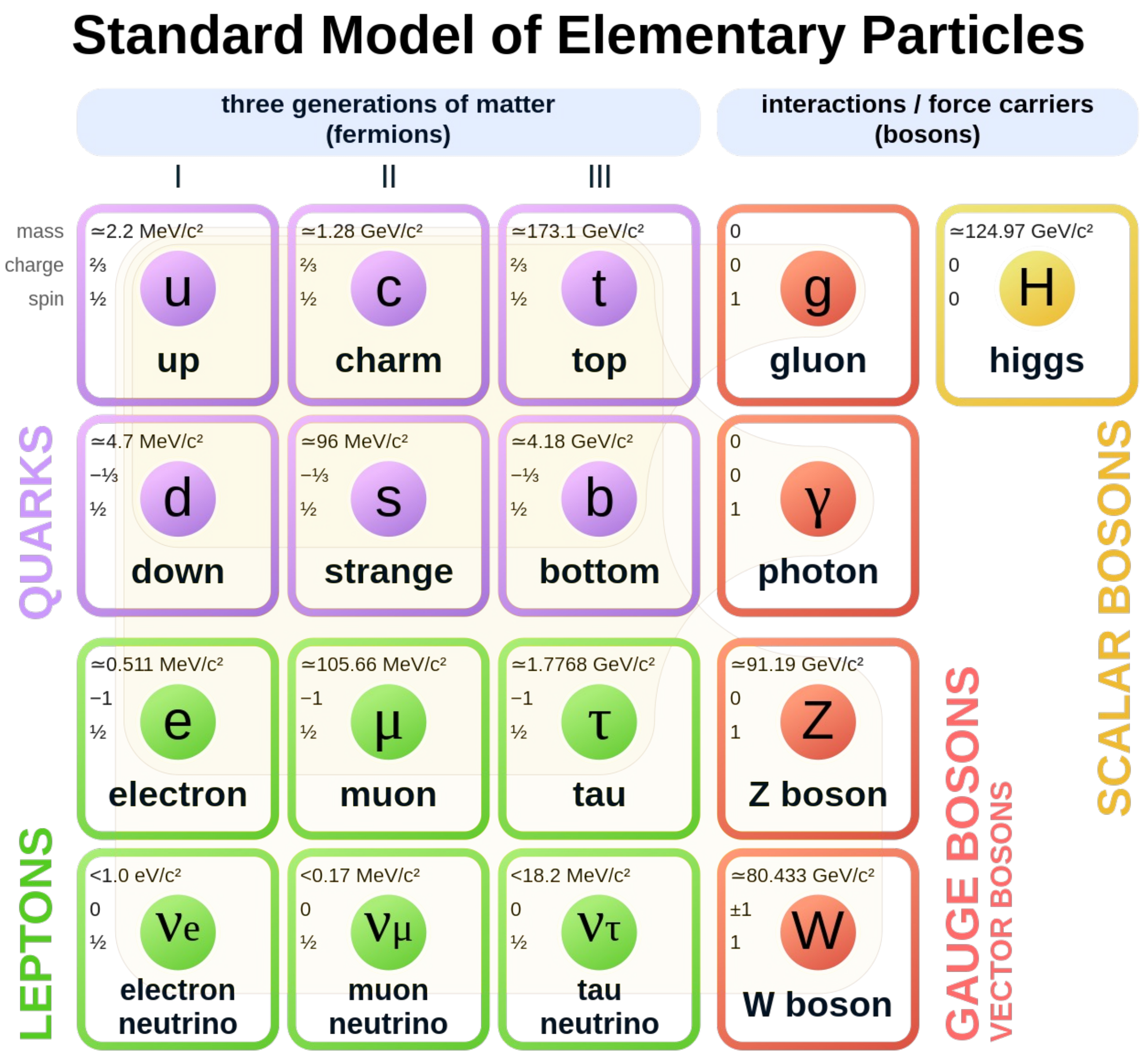
Intro to Particle Physics

CANDID Summer Program 2023

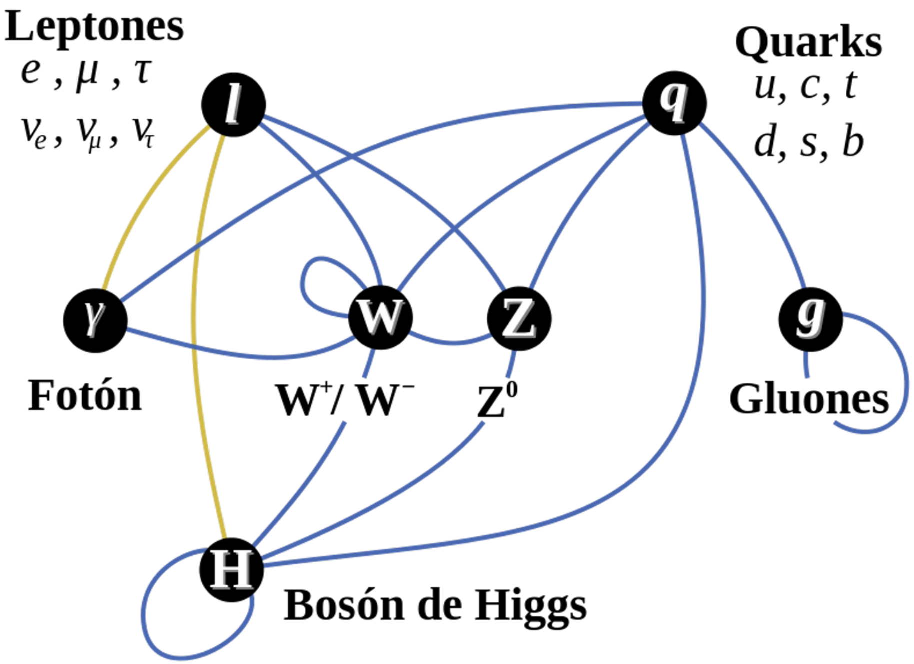
Andrea Delgado

High-Energy Physics (HEP)

- Seeks to understand matter and its interactions at the **fundamental** level.
- The **standard model (SM)** is currently the best description that we have about the subatomic world.
- Within the SM context, the interaction between the fundamental blocks of matter - the **leptons** and **quarks** - are mediated by the four **fundamental forces**.



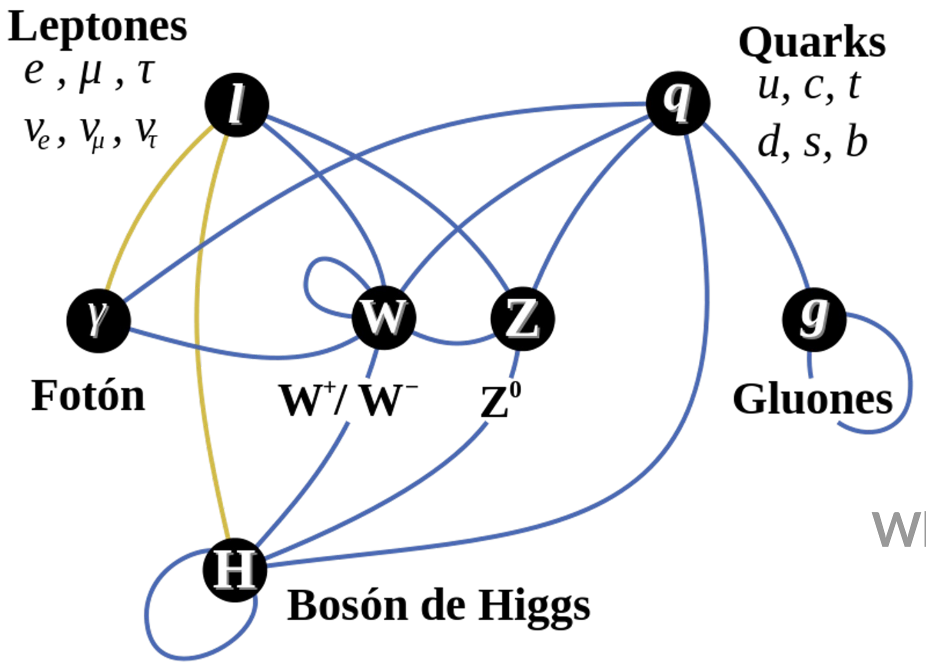
Not so easy?



Leptones
e , μ , τ
νe , νμ , ντ
l
Quarks
u, c, t
d, s, b
q
γ
W
Z
g
Fotón
W+/ W−
Z0
Gluones
H
Bosón de Higgs

The standard model has been an extremely successful theory, but…

Why do neutrinos have mass?



Why are there three generations of matter?

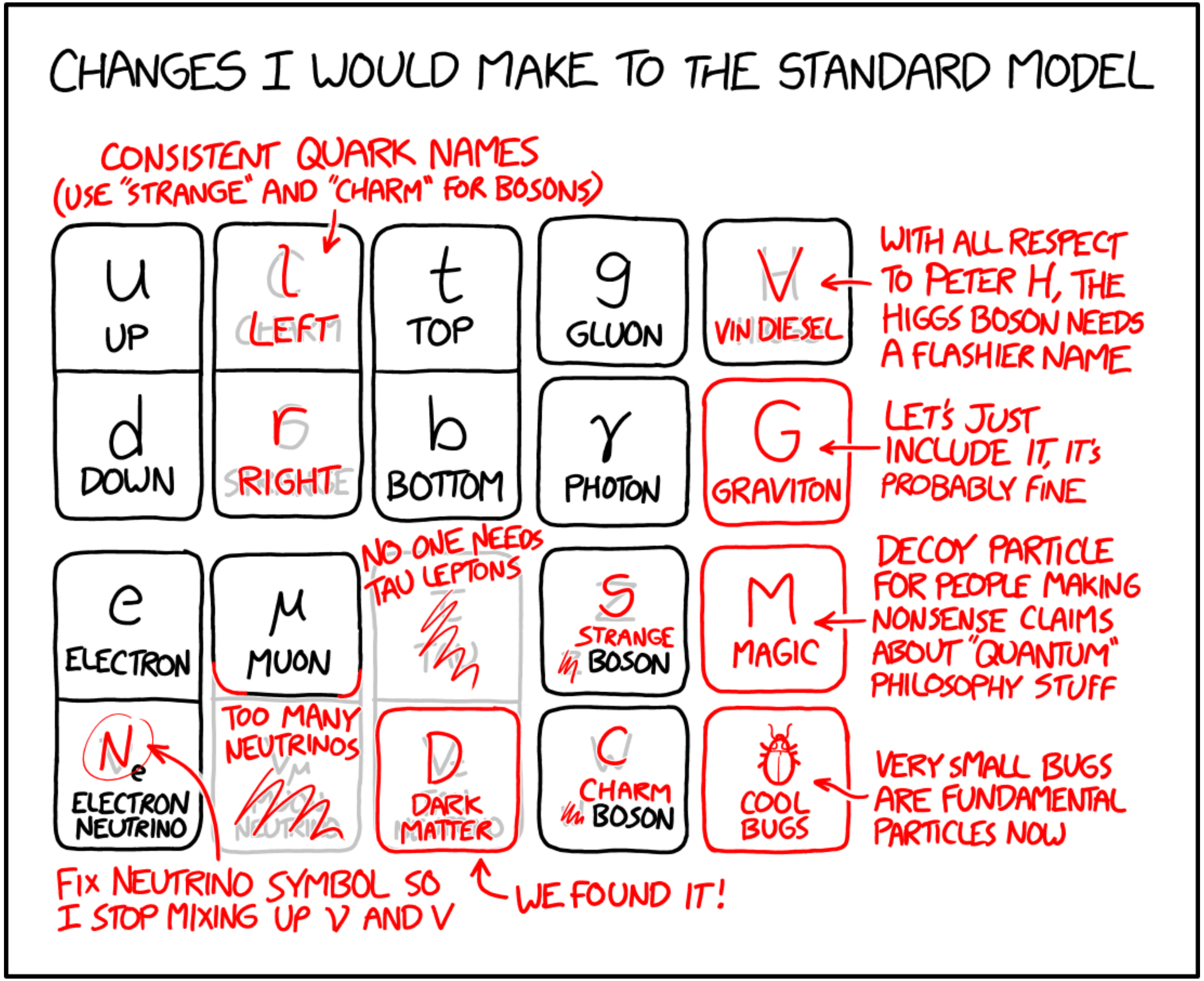
Is there a particle associated with gravity?

What is dark matter?

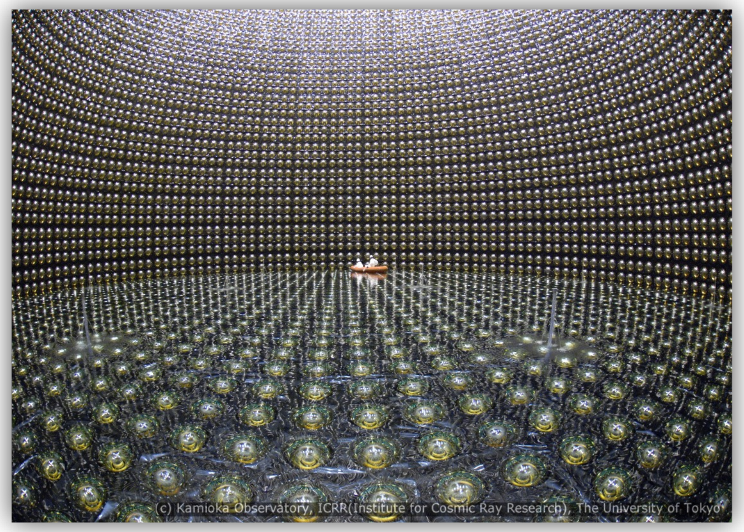
Why does the Higgs boson has a mass of 125 GeV?

… it is incomplete.

New ideas?

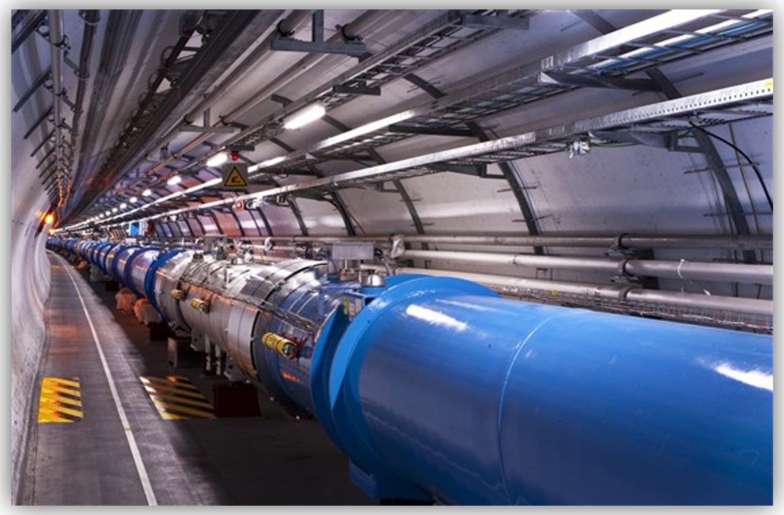

CHANGES I WOULD MAKE TO THE STANDARD MODEL
CONSISTENT QUARK NAMES (USE "STRANGE" AND "CHARM" FOR BOSONS)
u UP
l LEFT
t TOP
g GLUON
V VIN DIESEL
WITH ALL RESPECT TO PETER H, THE HIGGS BOSON NEEDS A FLASHIER NAME
d DOWN
r RIGHT
b BOTTOM
γ PHOTON
G GRAVITON
LET'S JUST INCLUDE IT, IT'S PROBABLY FINE
e ELECTRON
μ MUON
NO ONE NEEDS TAU LEPTONS
S STRANGE BOSON
M MAGIC
DECOY PARTICLE FOR PEOPLE MAKING NONSENSE CLAIMS ABOUT "QUANTUM" PHILOSOPHY STUFF
N ELECTRON NEUTRINO
TOO MANY NEUTRINOS
D DARK MATTER
C CHARM BOSON
COOL BUGS
VERY SMALL BUGS ARE FUNDAMENTAL PARTICLES NOW
FIX NEUTRINO SYMBOL SO I STOP MIXING UP ν AND v
WE FOUND IT!

Experimental High-Energy Physics



Super-Kamiokande
(Neutrino Observatory)
Japan, underneath mount Ikeno
First evidence of neutrino oscillation

Tevatron (Particle Accelerator)
Illinois, USA
Top quark discovery



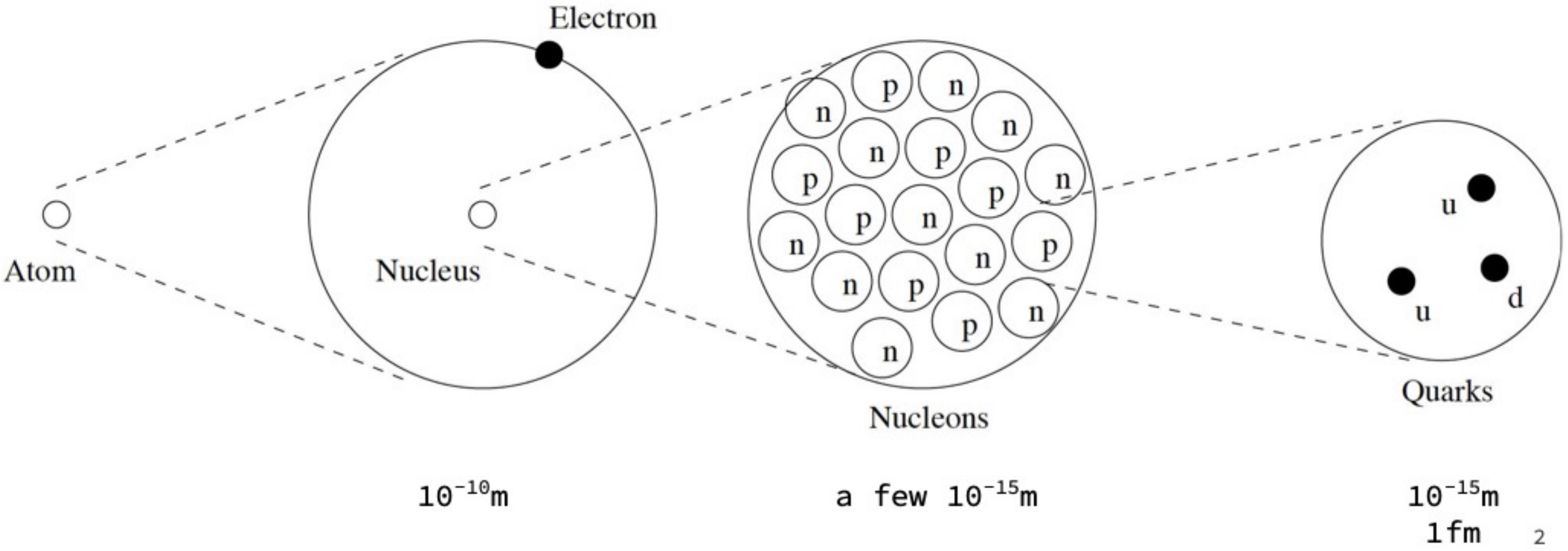
Large Hadron Collider
(Particle Accelerator)
Switzerland
Higgs boson discovery

History of Particle Physics

Griffiths has a nice historical overview of particle physics, what follows is a brief timeline of important events.

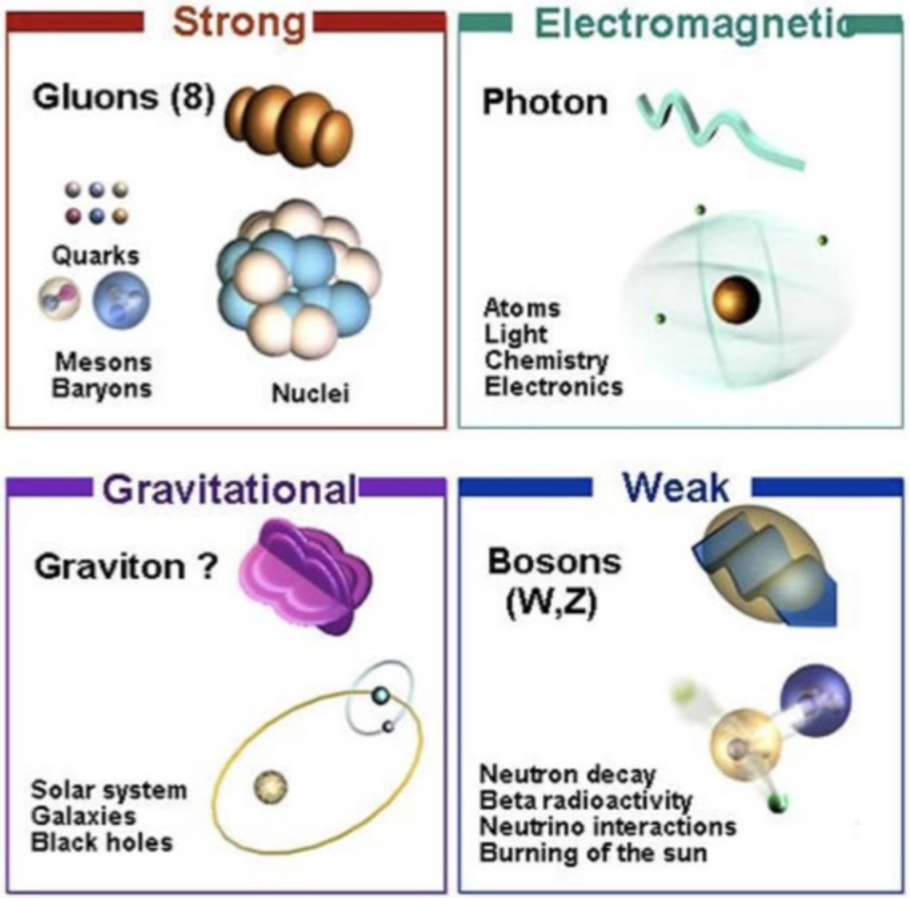
- **1896**: Becquerel discovers radiation from uranium.
- **1897:** Thomson discovers the electron.
- **1898:** The Curies propose the term "radioactivity" for material which emit rays. Discover polonium and radium.
- **1911:** Rutherford discovers that the atom mainly consists of empty space with a hard and heavy, positively charged nucleus.
- **1930:** Dirac combines relativity and quantum mechanics with Dirac's equation.
- **1931:** Pauli and Fermi propose the neutrino.
- **1932:** Anderson discovers the positron.
- **1935**: Yukawa proposed that neutrons and protons in nuclei are held together by a strong force.
- **1964:** Gell-Mann and Zweig postulate the existence of quarks.
- **1978:** Glashow, Weinberg, Salam formulate the SM.

Zooming into the sub-atomic world



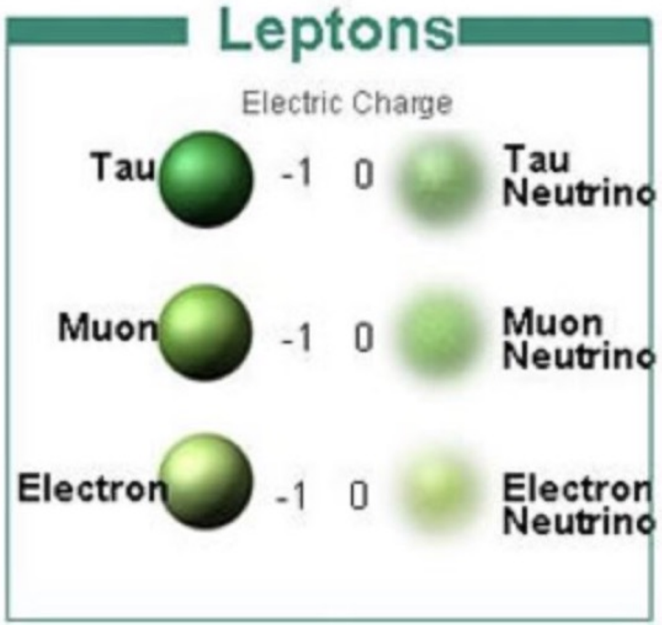
Force Particles

Force	Name	Symbol	Number	EM charge
Strong	Gluons	g	8	0
EM	Photon	γ	1	0
Weak	W and Z	$W^{\pm}$, Z^0	3	± 1, 0



Matter Particles

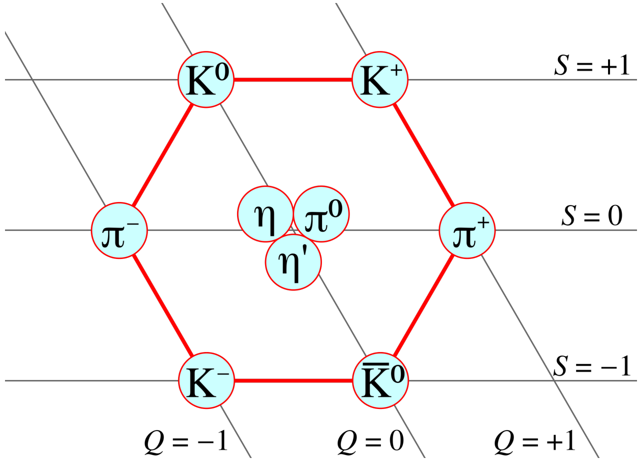
	Generation			Charge	Feels the force of		
	1^{st}	2^{nd}	3^{rd}	Units of e	Strong	EM	Weak
U-Type Quarks (×3 colours)	u	c	t	$+2/3$	Y	Y	Y
D-Type Quarks (×3 colours)	d	s	b	$-1/3$	Y	Y	Y
Charged Leptons	e	μ	τ	-1	N	Y	Y
Neutral Leptons (Neutrinos)	ν_e	ν_μ	ν_τ	0	N	N	Y



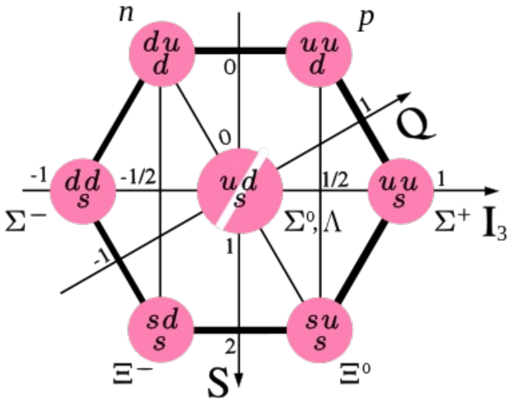
Anti-particle: same mass as ordinary matter but opposite charge and magnetic moment

Composite Particles: Hadrons

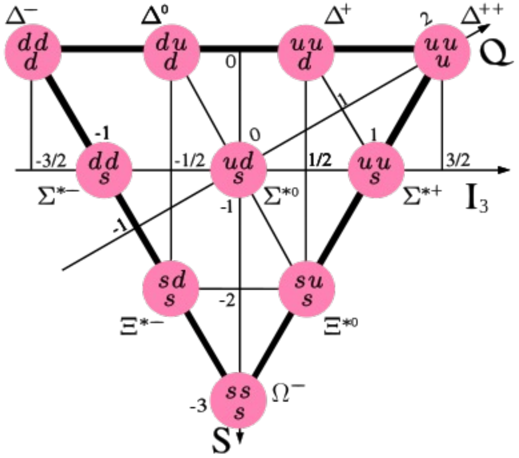
Mesons: quark-antiquark states - bosons



Baryons: 3 quark states - fermions

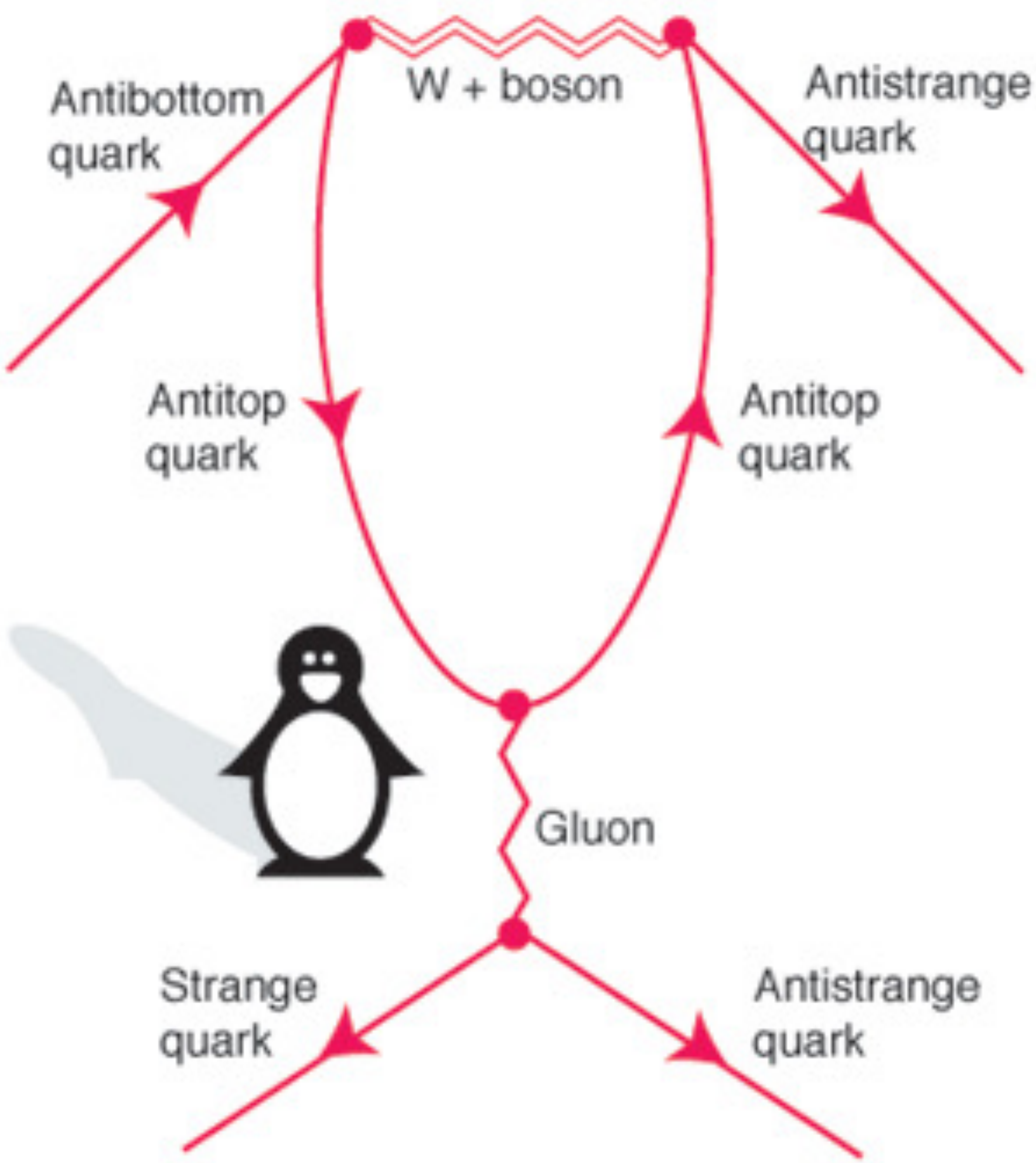


Spin 1/2



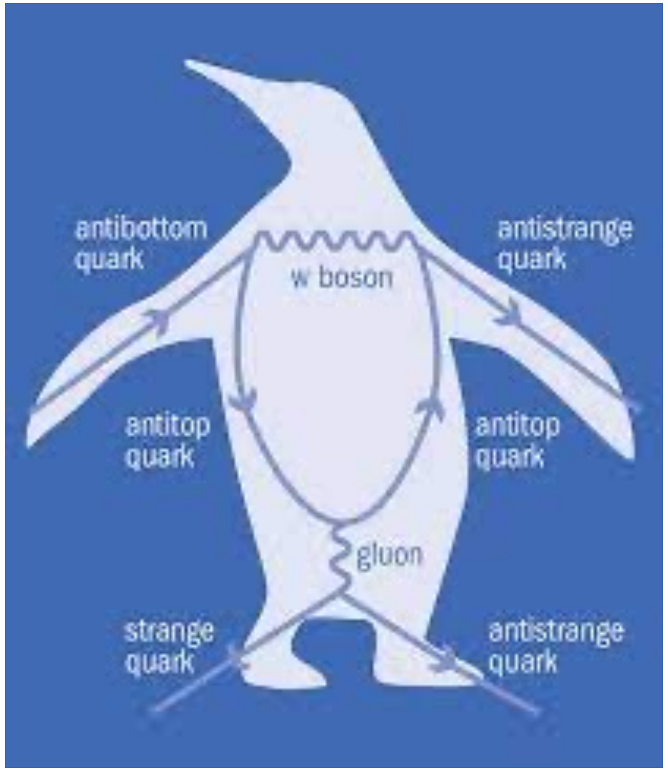
Spin 3/2

What is this?

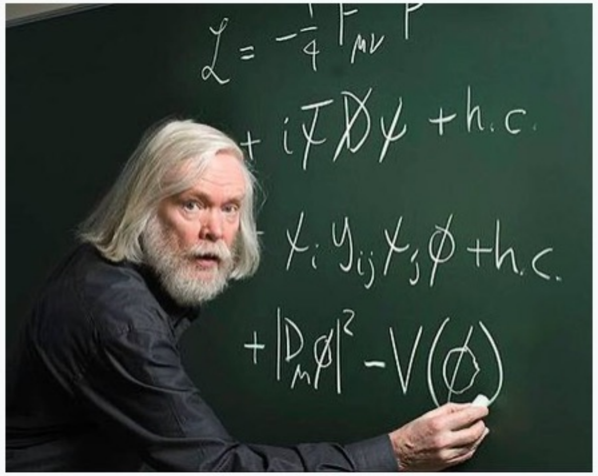


Oak Ridge National Laboratory

Penguin diagram



John Ellis
CBE FRS HonFInstP

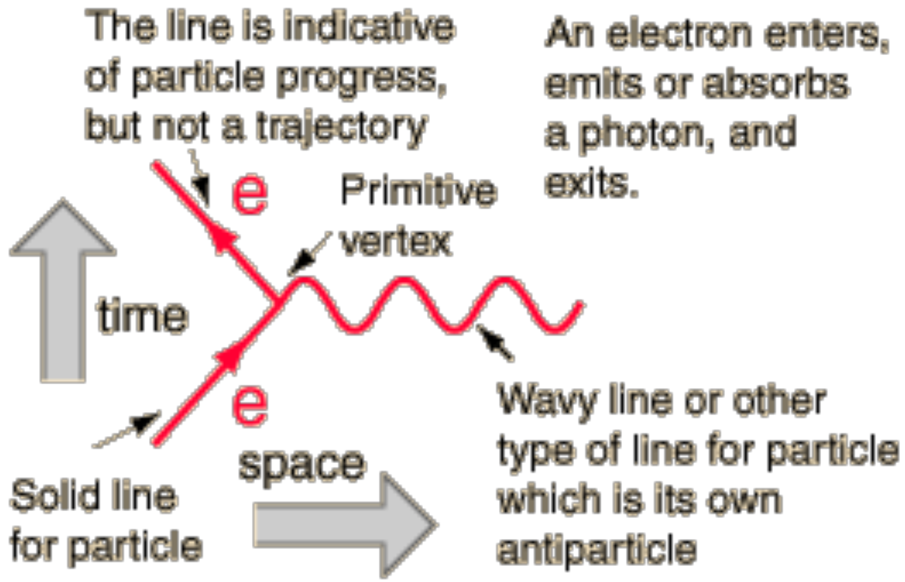


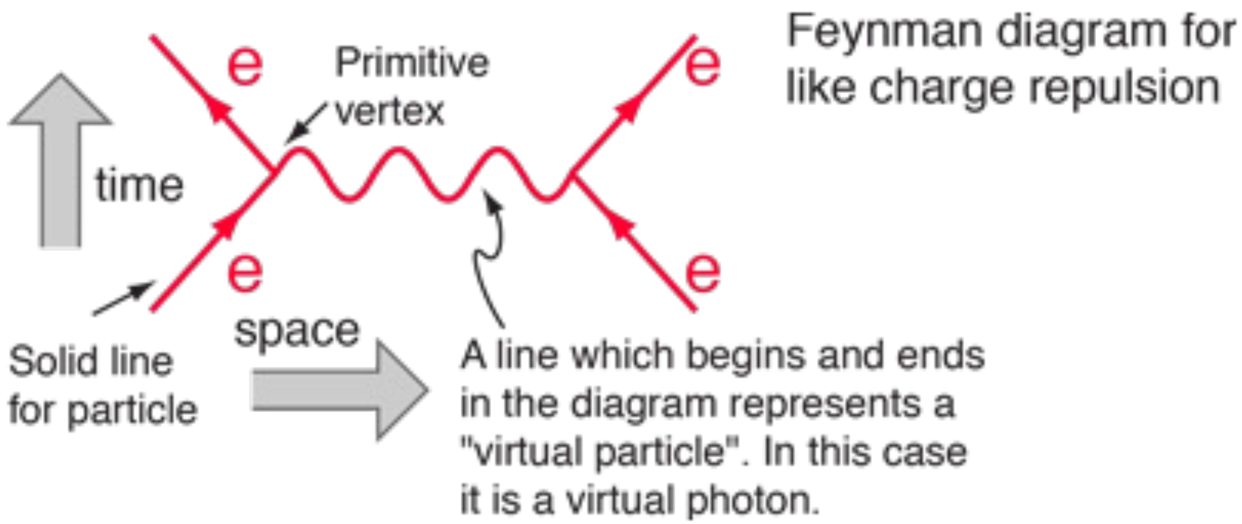
Born	1 July 1946 (age 76) Hampstead, London, England, UK
Nationality	British
Alma mater	King's College, Cambridge
Known for	Penguin diagram Coining the term "theory of everything"[1][2]
Awards	Mayhew Prize (1968) Maxwell Medal and Prize (1982) Paul Dirac Medal and Prize (2005)

Scientific career

Fields	Physics
Institutions	King's College London CERN

Feynman Diagrams





Relativistic Kinematics

At HEP experiments, we often deal with particles traveling close to the speed of light, so we define:

$$\beta = \frac{v}{c}, \qquad |\beta| < 1$$

$$\gamma = \frac{1}{\sqrt{1-\beta^2}}, \qquad \gamma \geq 1$$

Thus, the total energy of a particle with non-zero mass is

$$E = \gamma m c^2$$

And momentum $p = \gamma$mv = γmcβ

Lorentz Transformations!

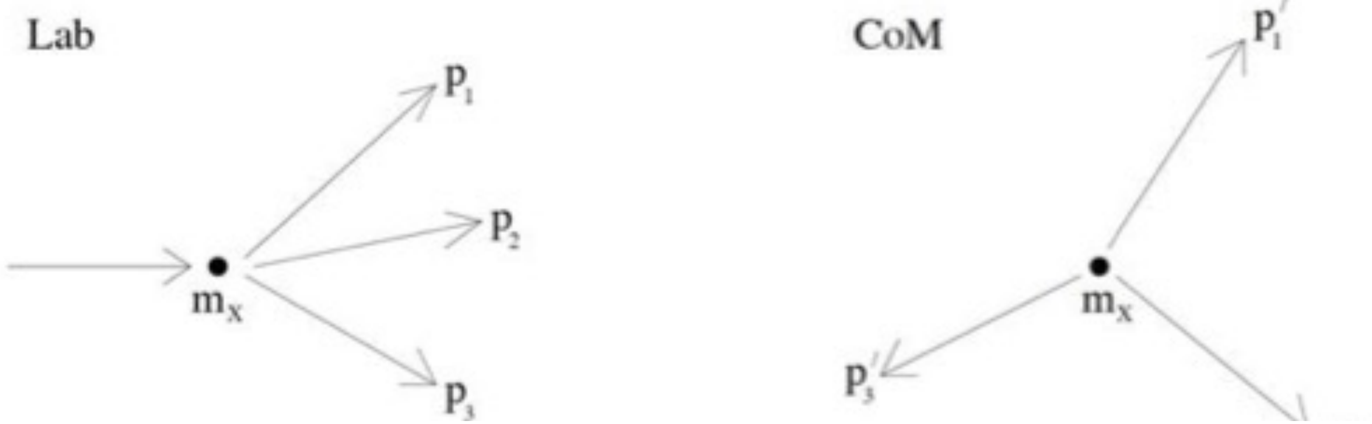
Multi-particle systems

- In collisions, or decays, more than one particle is involved. The total energy and momentum of the system, are always conserved. We call "frame independent" the condition that:

$$m_T{}^2 c^4 = E_T{}^2 - p_T{}^2 c^2$$

And we usually consider two cases:

The particle mx can be identified from its decay products, since mx = mT!



References

- Halzen & Martin “Quarks & Leptons: an Introductiry Course in Modern Particle Physics” Although somewhat out of date (1984), many lectures are still taught out of this book, theoretical oriented.
- Grifiths “Introduction to Elementary Particle Physics” An easy to read reference, nice historical overview, less robust in terms of content.