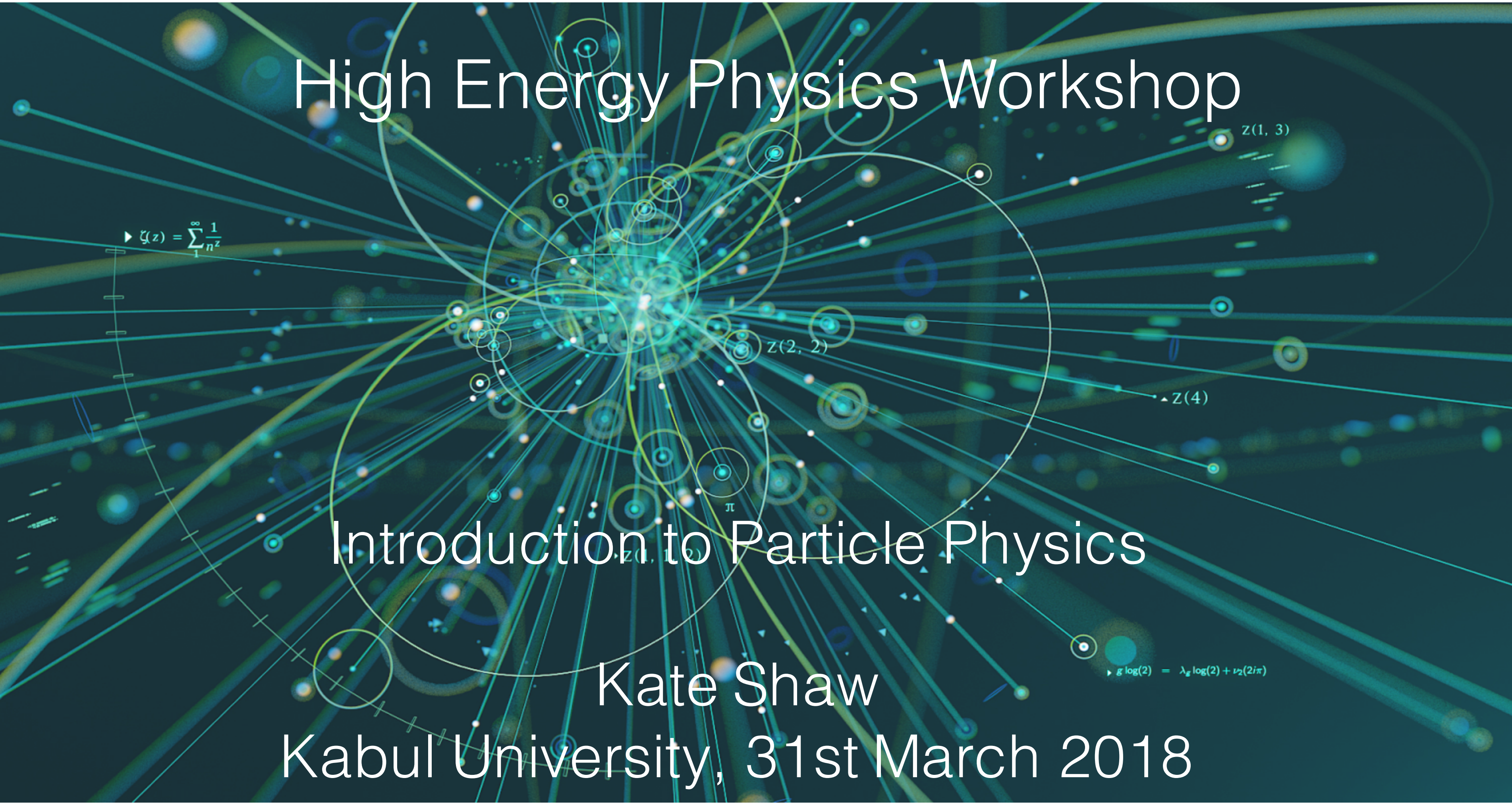
ICTP PHYSICS WITHOUT FRONTIERS AFGHANISTAN



High Energy Physics Workshop

Introduction to Particle Physics

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Kabul University, 31st March 2018

Institute for Advanced Studies in Basic Sciences
Gava Zang, Zanjan, Iran

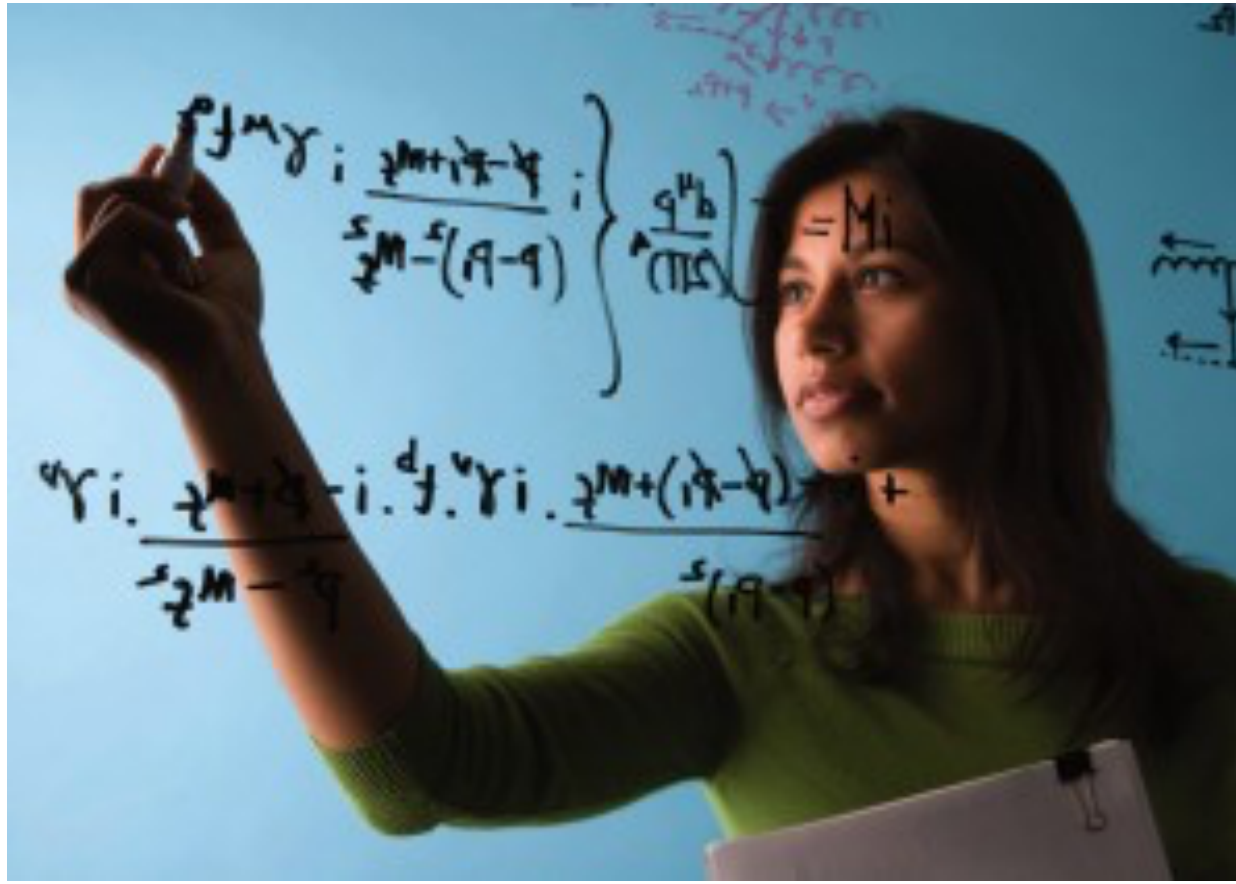
The Abdus Salam International Centre for Theoretical Physics

Kabul University
Ministry of Higher Education
Islamic Republic of Afghanistan

The Standard Model of Particle Physics

What are the fundamental particles that make up the universe?

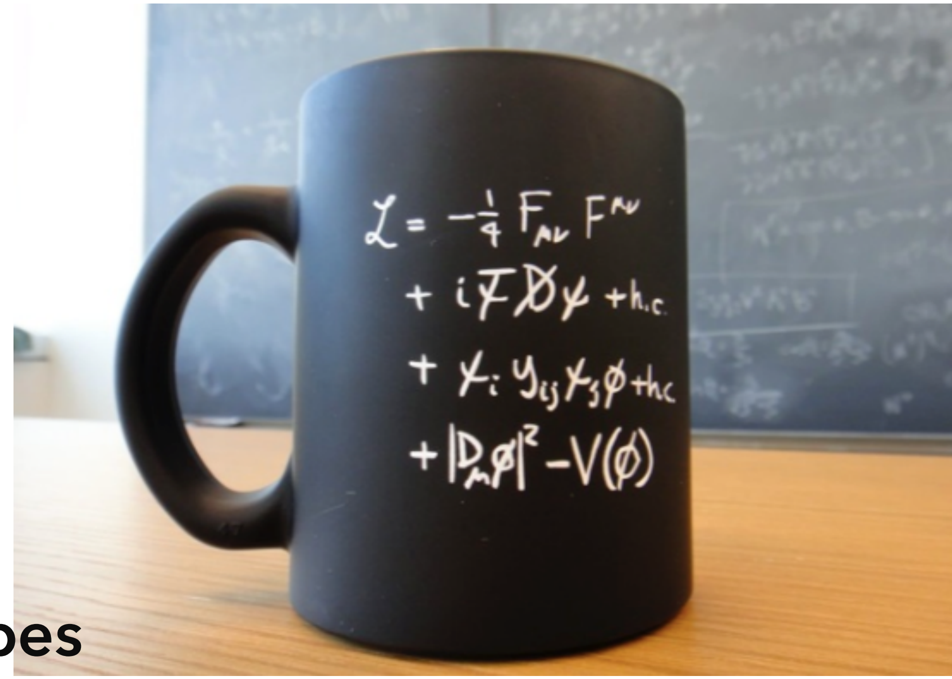
What theories predict how they will interact?



The Standard Model of Particle Physics

We do this using the Standard Model

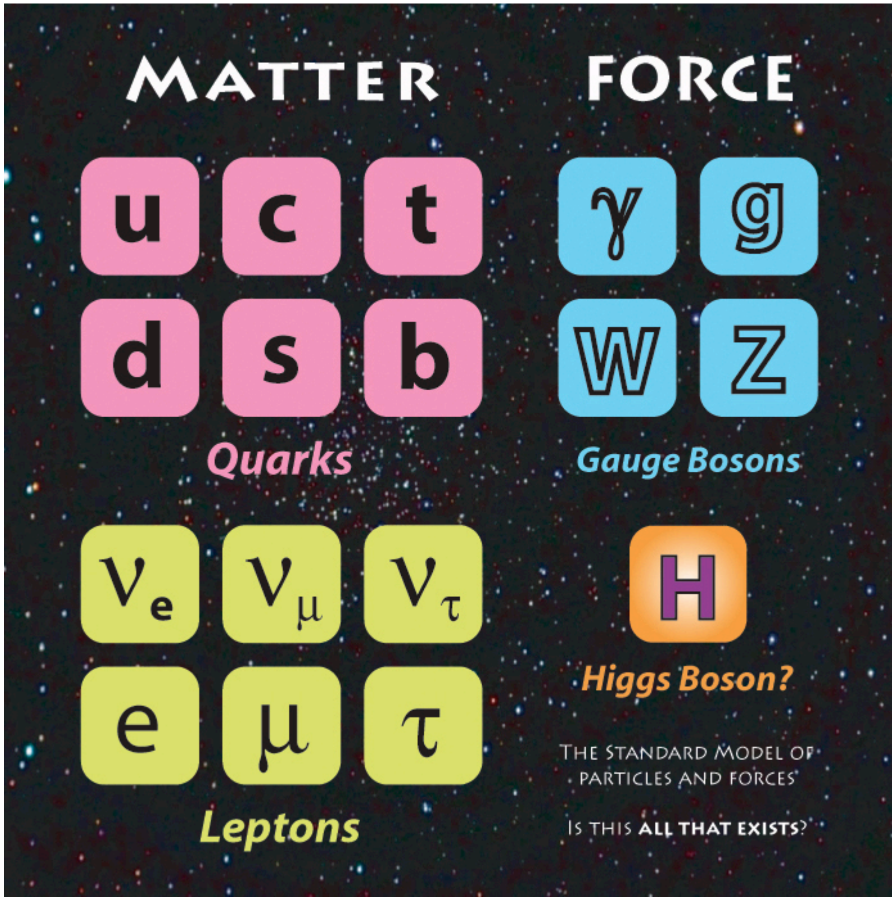
Fundamental particles of matter are described as *excitations of the quantum fields* that also govern their interactions.

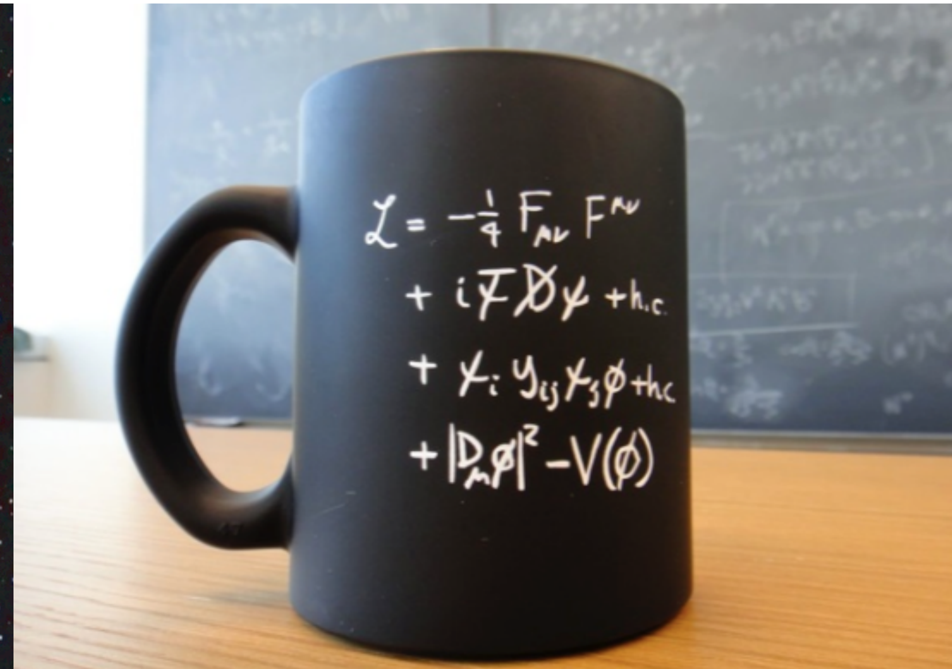


The Standard Model describes these fundamental particles and fields, and their dynamics.

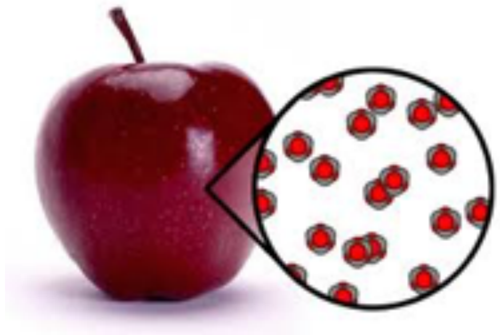
What do we mean by 'fundamental'?

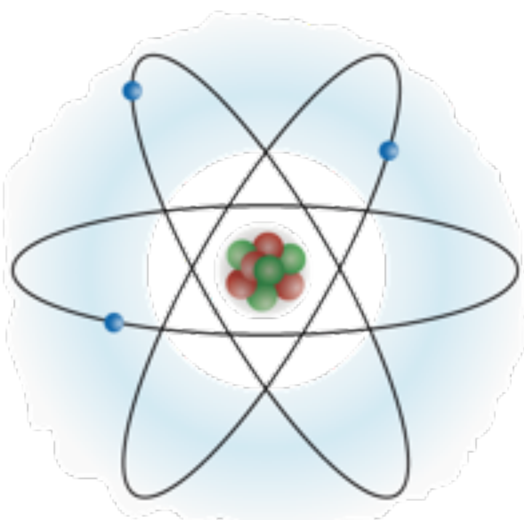
The Standard Model of Particle Physics

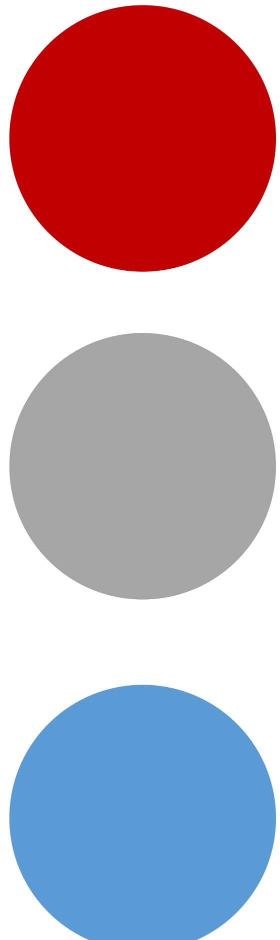




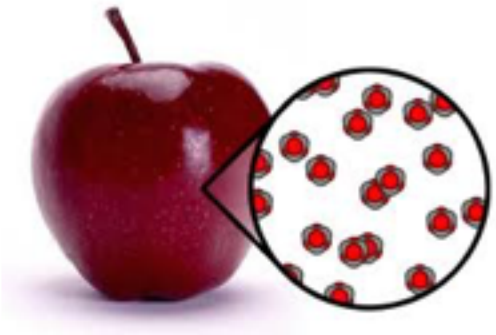
The Standard Model of Particle Physics

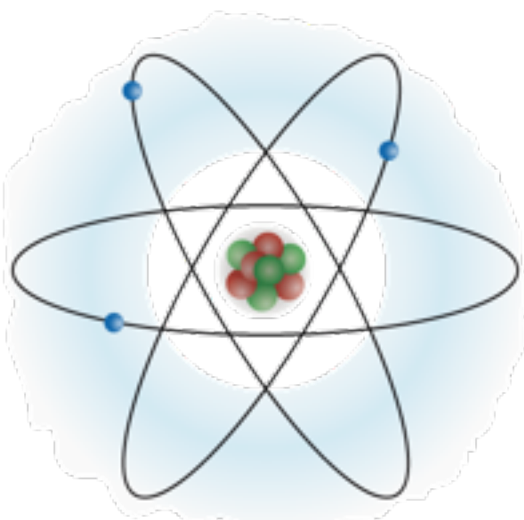




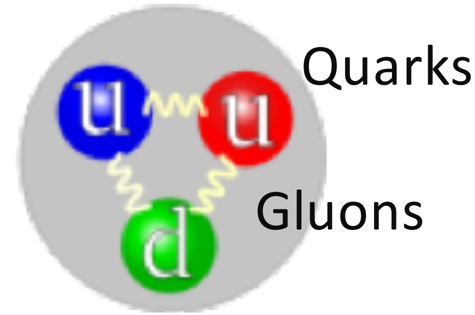


The Standard Model of Particle Physics

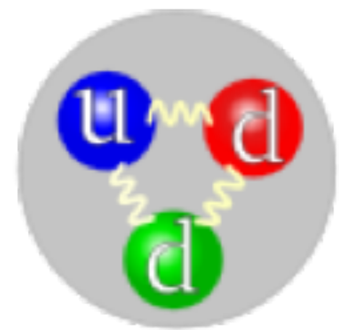




Proton

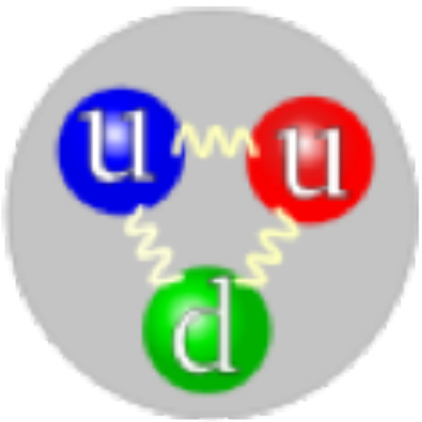


Neutron

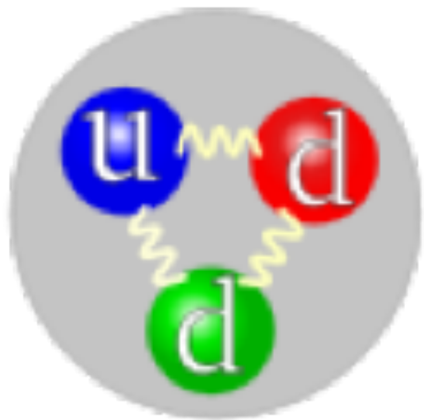


Electron

The Standard Model of Particle Physics



Proton
up (+2/3)
up (+2/3)
down (-1/3)



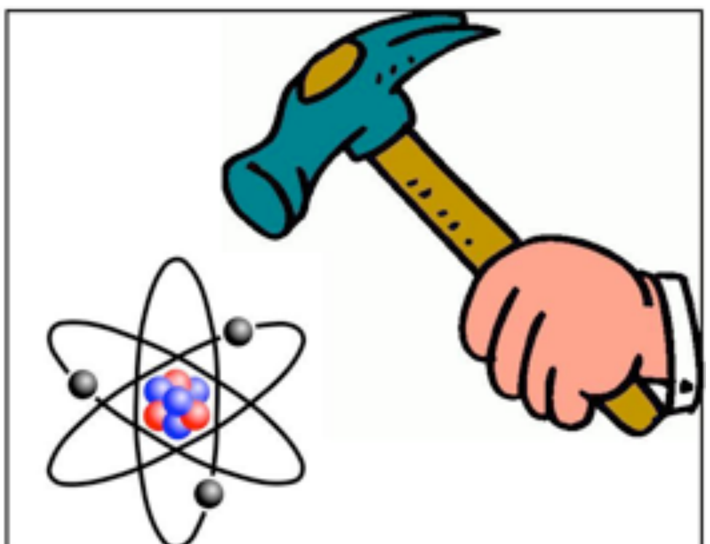
neutron
up (+2/3)
down (-1/3)
down (-1/3)

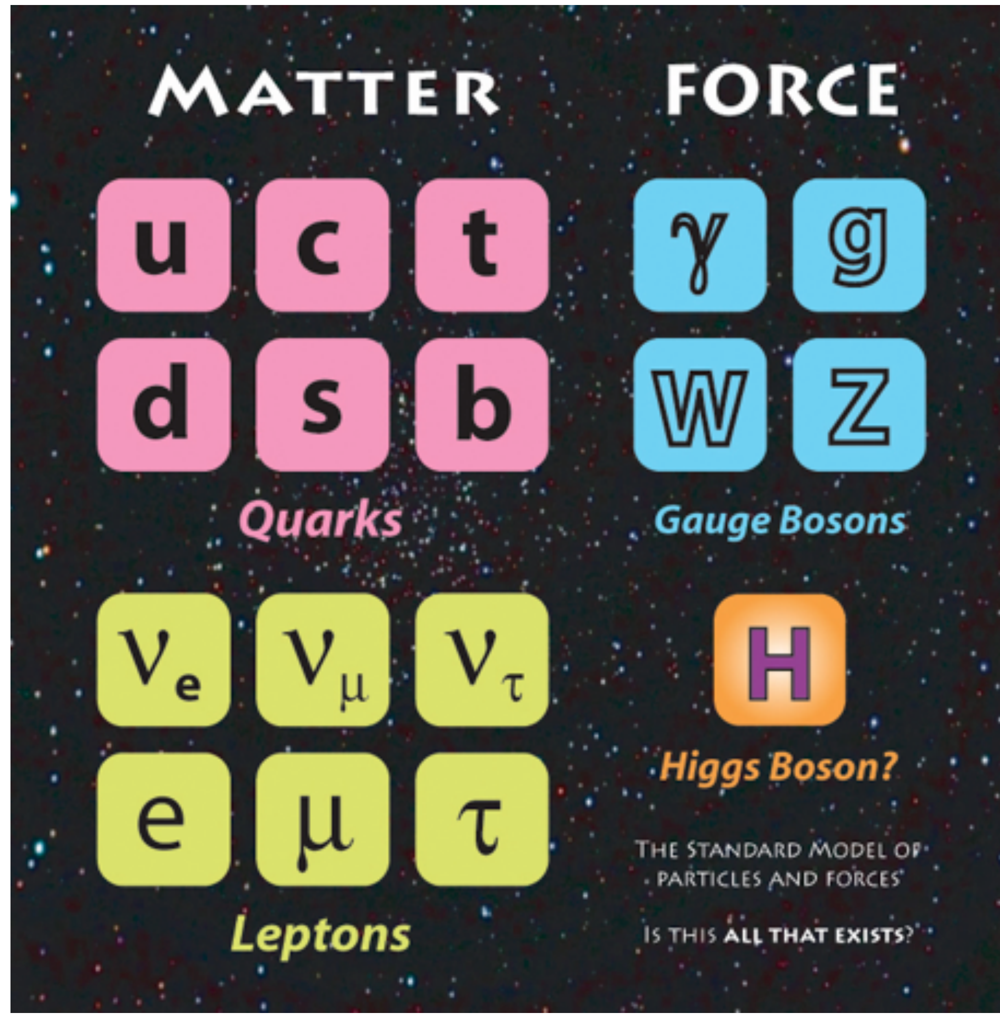
Gluons are the mediator of the strong force
Zero mass, zero charge,
Only interact between quarks

The Standard Model of Particle Physics

Fundamental Particles

- electron (e)
- up quark (u)
- down quark (d)
- gluon (g)

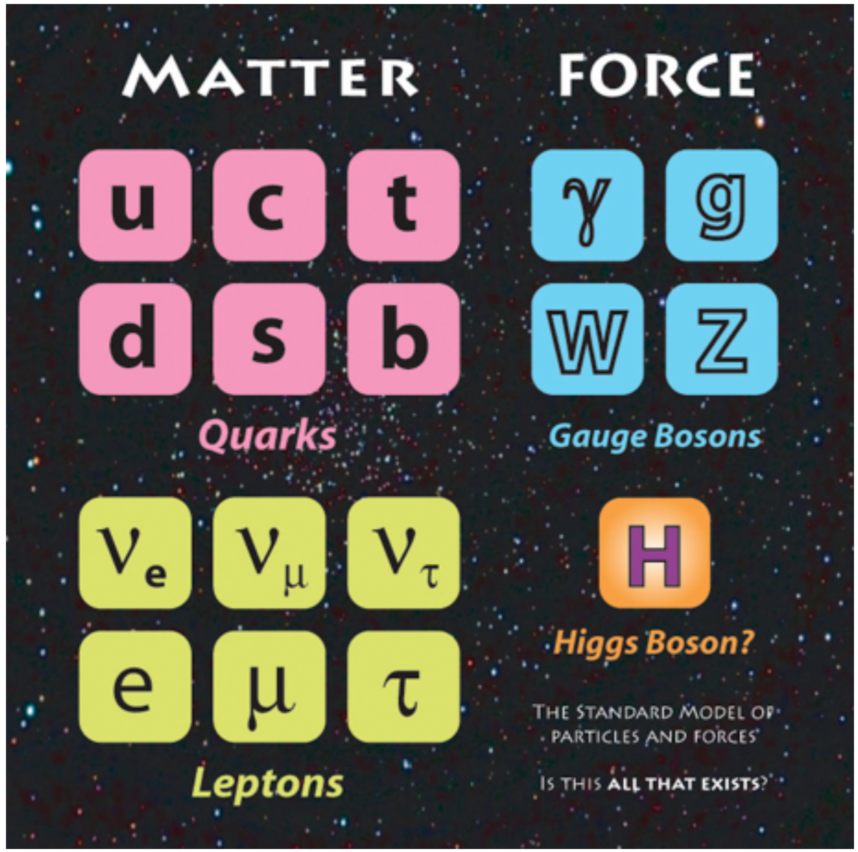




The Standard Model of Particle Physics

Quarks and Leptons are Fermions

Spin 1/2 particles

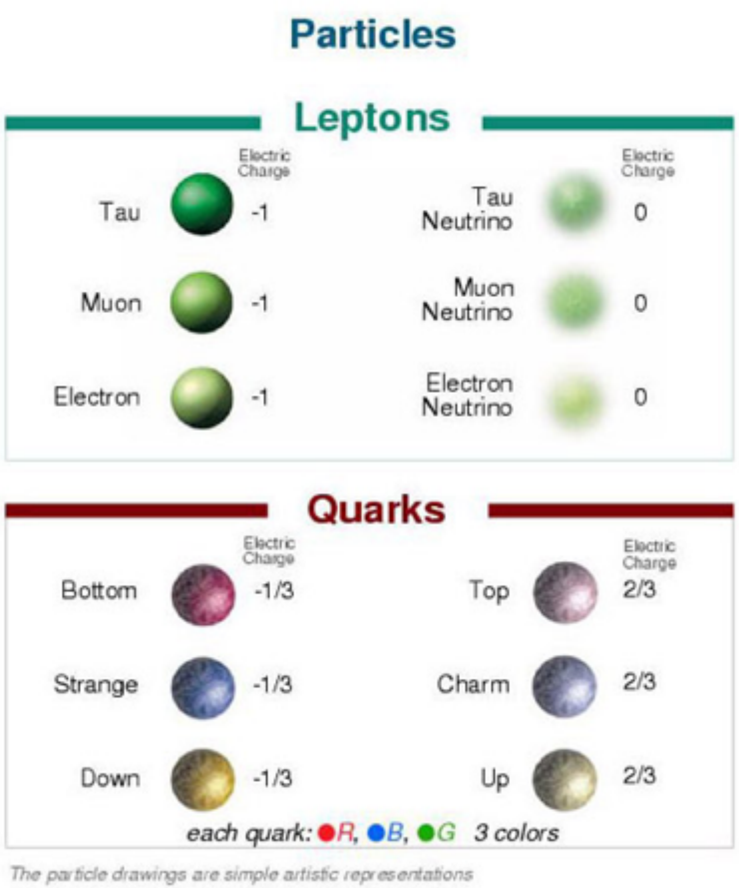


Gauge bosons are bosons

They mediate the forces

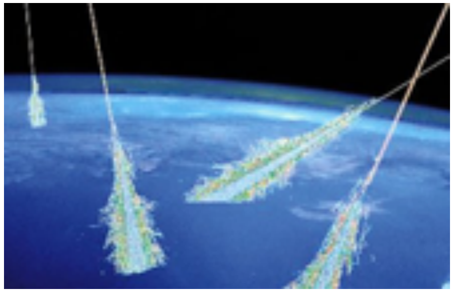
Spin integer particles

The Standard Model of Particle Physics



Electrons are stable!
Muon (μ) lifetime = 2 x 10-6s
Tau (τ) lifetime = 3 x 10-13s

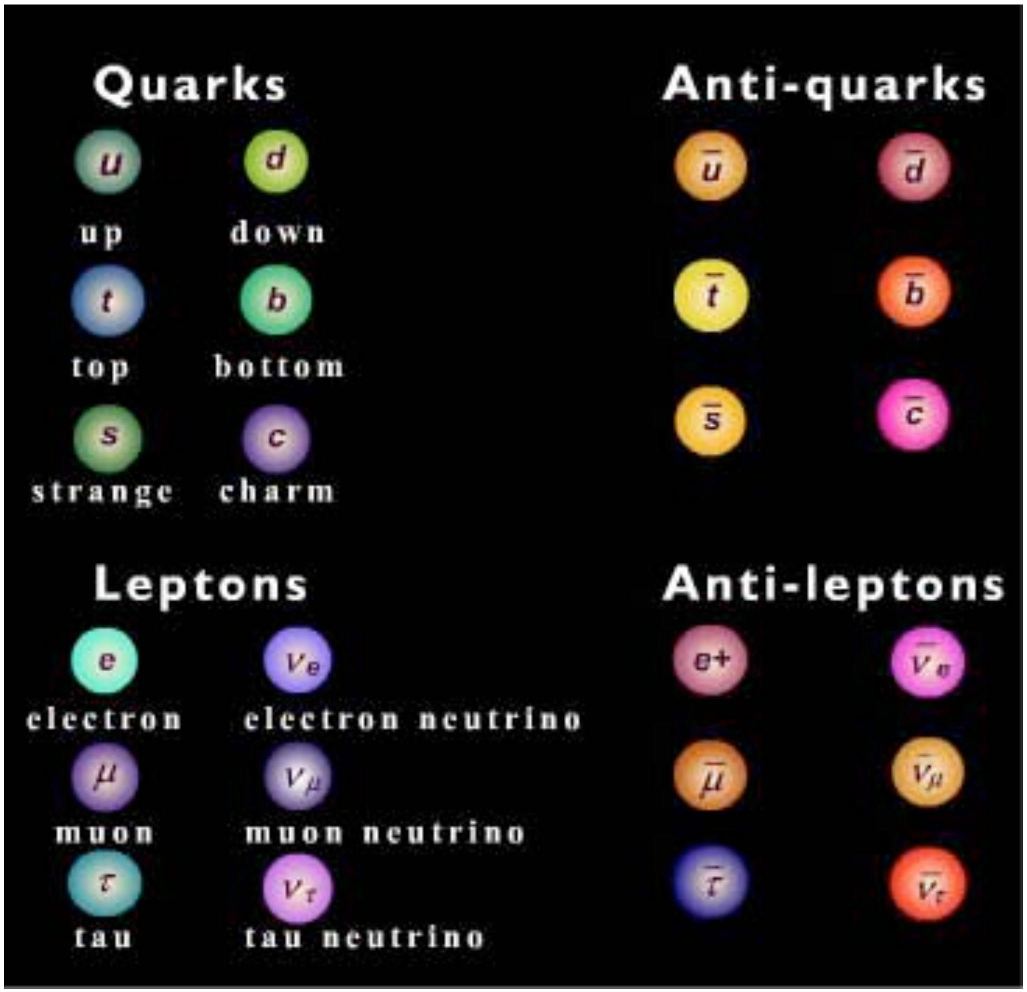
Neutrinos:
Almost massless
Zero charge



Muons can be detected from cosmic rays hitting the Earth's atmosphere

Quarks must exist in groups of two of three!
Have colour charge and electrical charge.

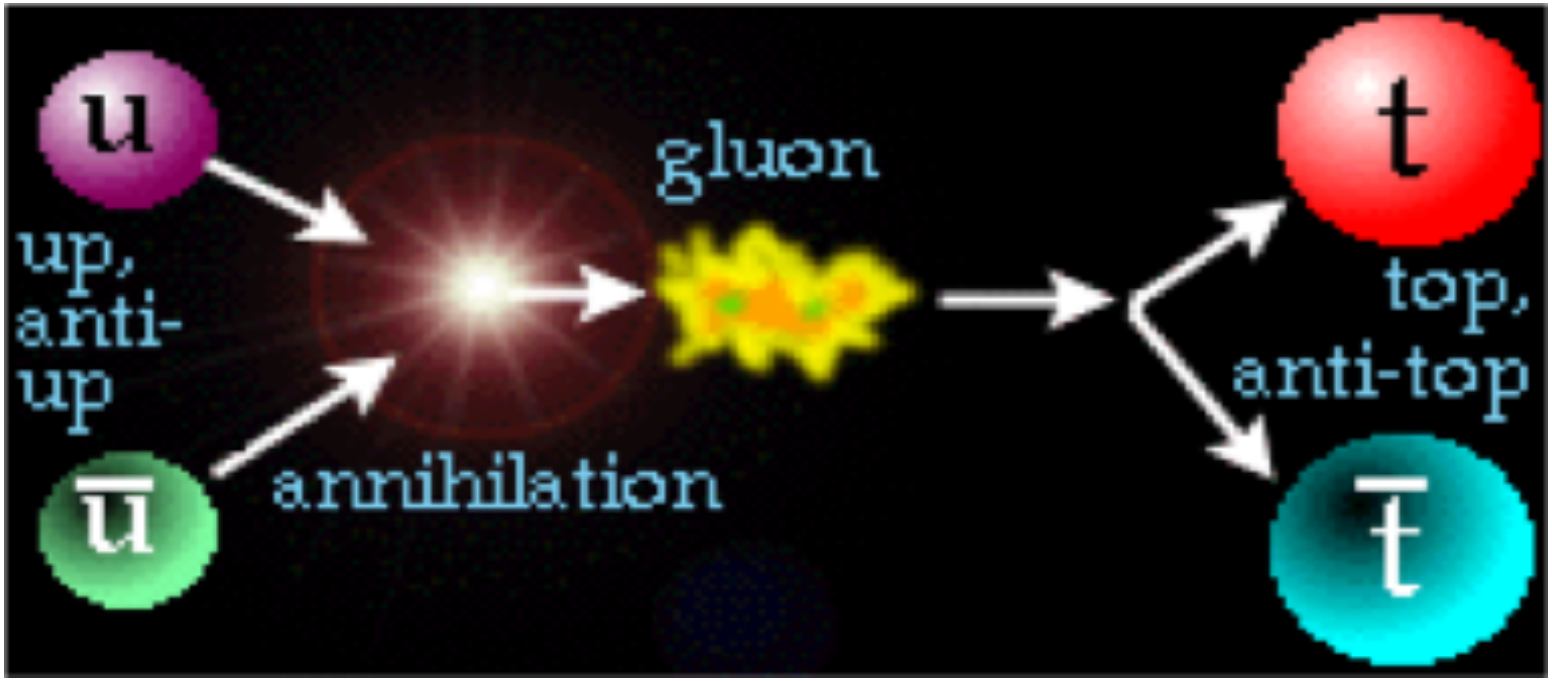
The Standard Model of Particle Physics



Anti-particles

Each particle has a partner with the same mass (and other properties) but OPPOSITE charge

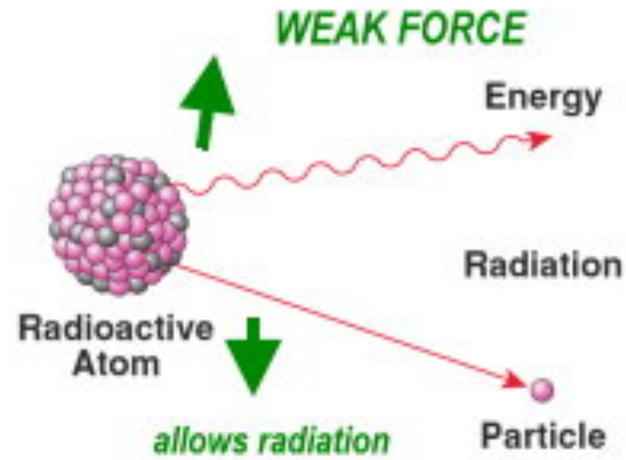
The Standard Model of Particle Physics

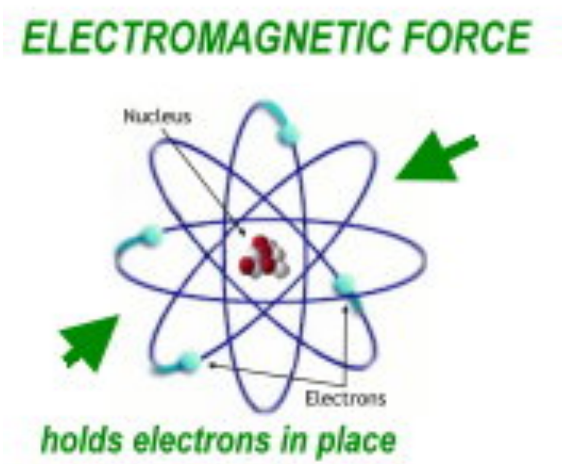


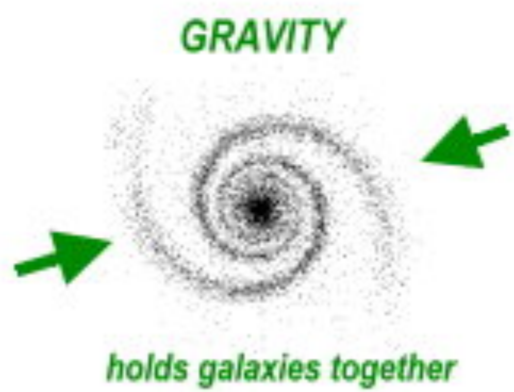
Annihilation of a particle and its antiparticle into a force mediator, a photon, gluon or W or Z

Pair Production into two new particles with opposite charge

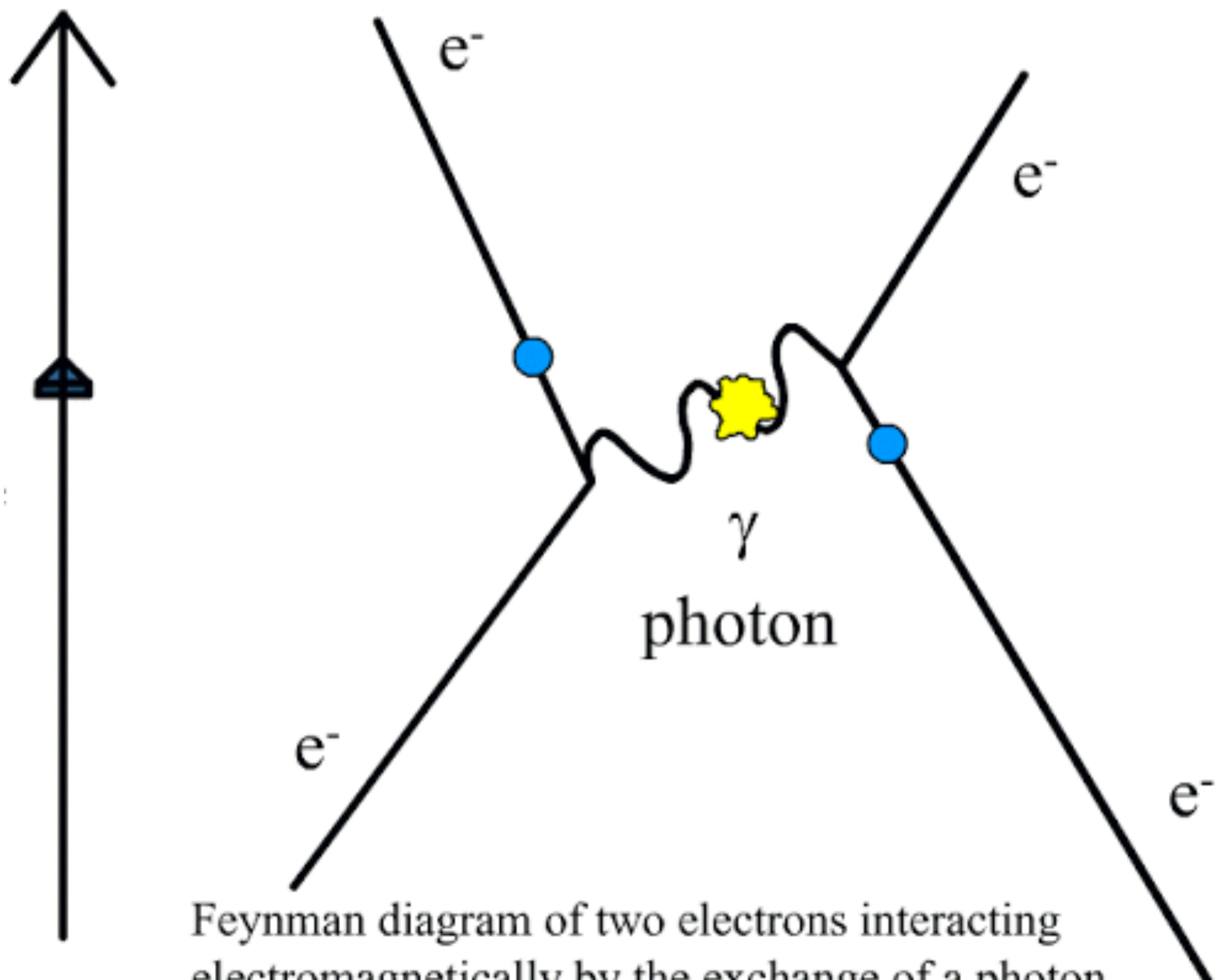
Fundamental Forces







Fundamental Forces

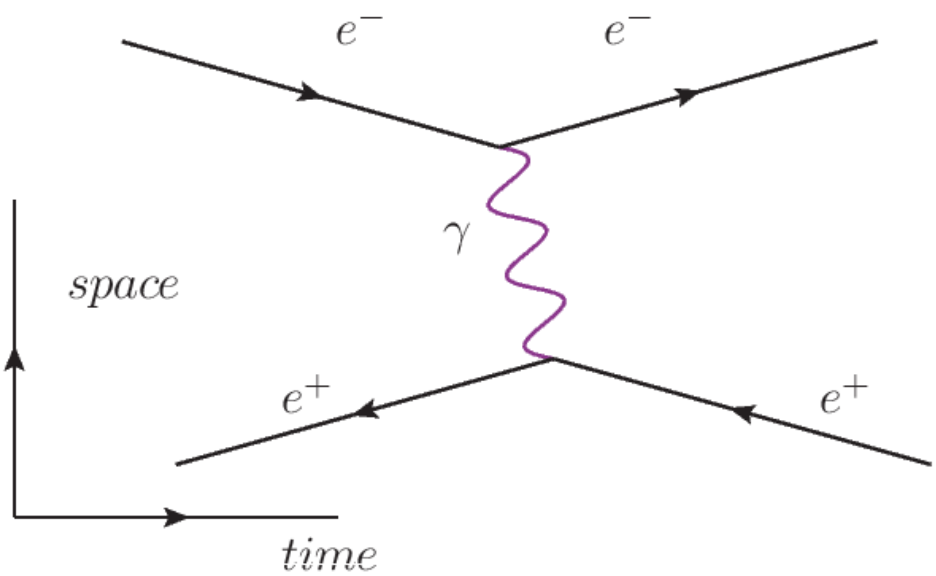


Feynman diagram of two electrons interacting electromagnetically by the exchange of a photon.

Fundamental Forces

Fundamental forces described using relativistic quantum field theories

Electromagnetism: **Quantum electrodynamics** describes how light and matter interact



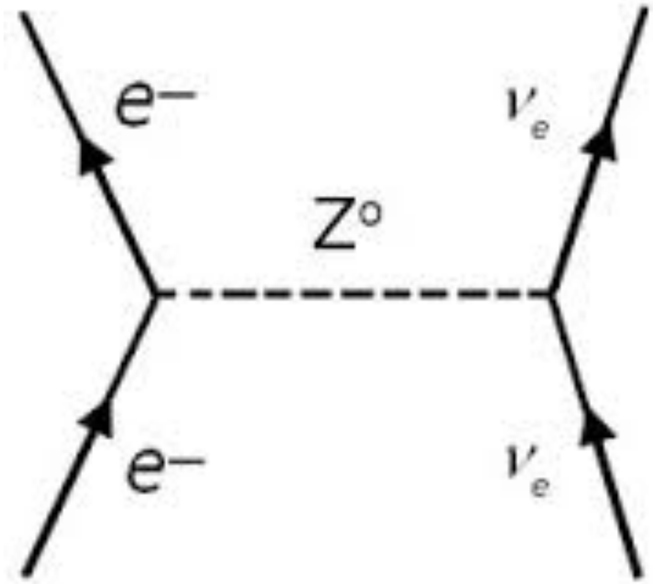
When electrically charged particles interact they exchange a photon

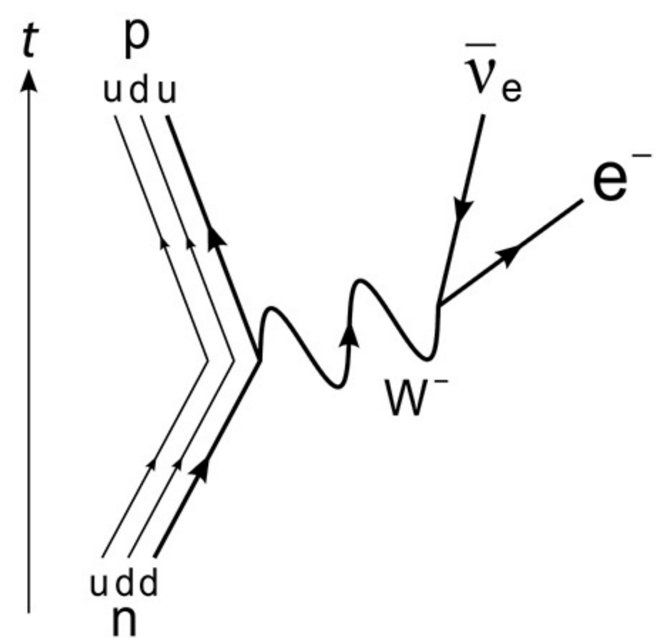
Extremely successful theory! e.g. measurements of the fine structure constant show agreement to within ten parts in a billion (10^{-8})

Fundamental Forces

Fundamental forces described using relativistic quantum field theories

A unified theory with electromagnetism was obtained in 1968 – the electroweak theory
W and Z predicted and discovered at CERN 1983

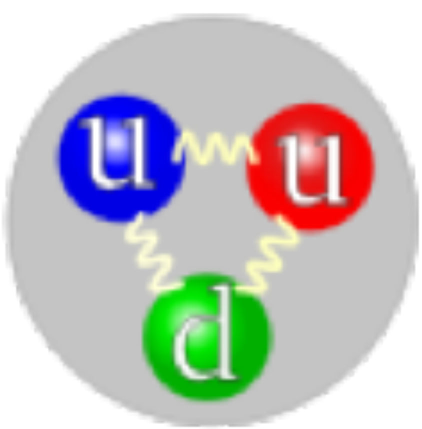


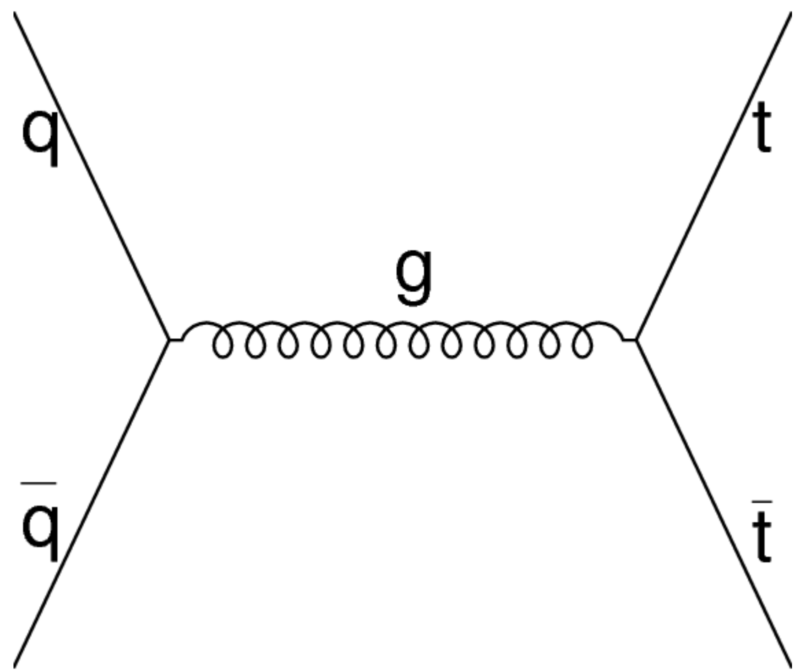


Fundamental Forces

Fundamental forces described using relativistic quantum field theories

Finally the Strong Force – a very much more complicated force – was described in Quantum Chromodynamics





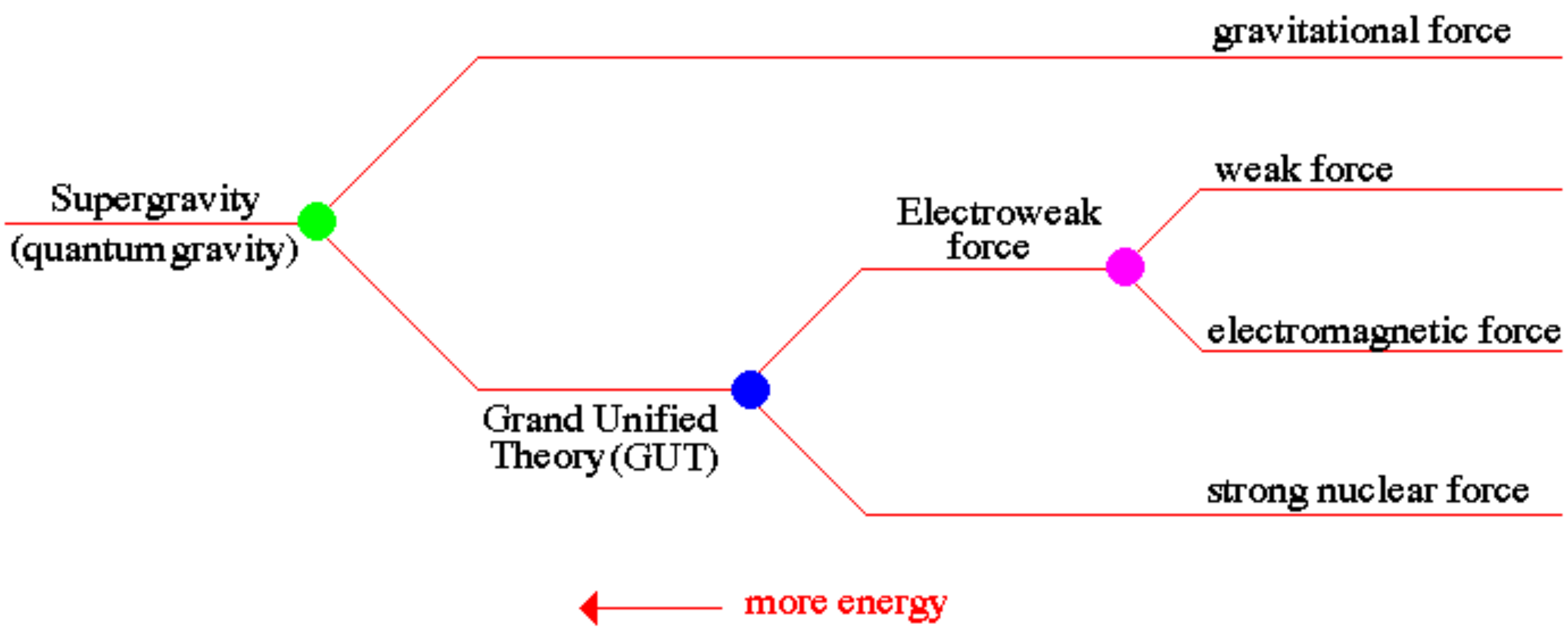
Fundamental Forces

name	relative strength	carrier name	symbol	range (fm)	mass (MeV/c^2)
strong force	1	gluon	g	2	0?
electromagnetic force	10^{-3}	photon	γ^0	∞	0
weak force	10^{-16}	intermediate vector boson	$W^{\pm}, Z^0$	10^{-3}	10^5
gravitational force	10^{-41}	graviton	g^0	∞	0

Fundamental Forces

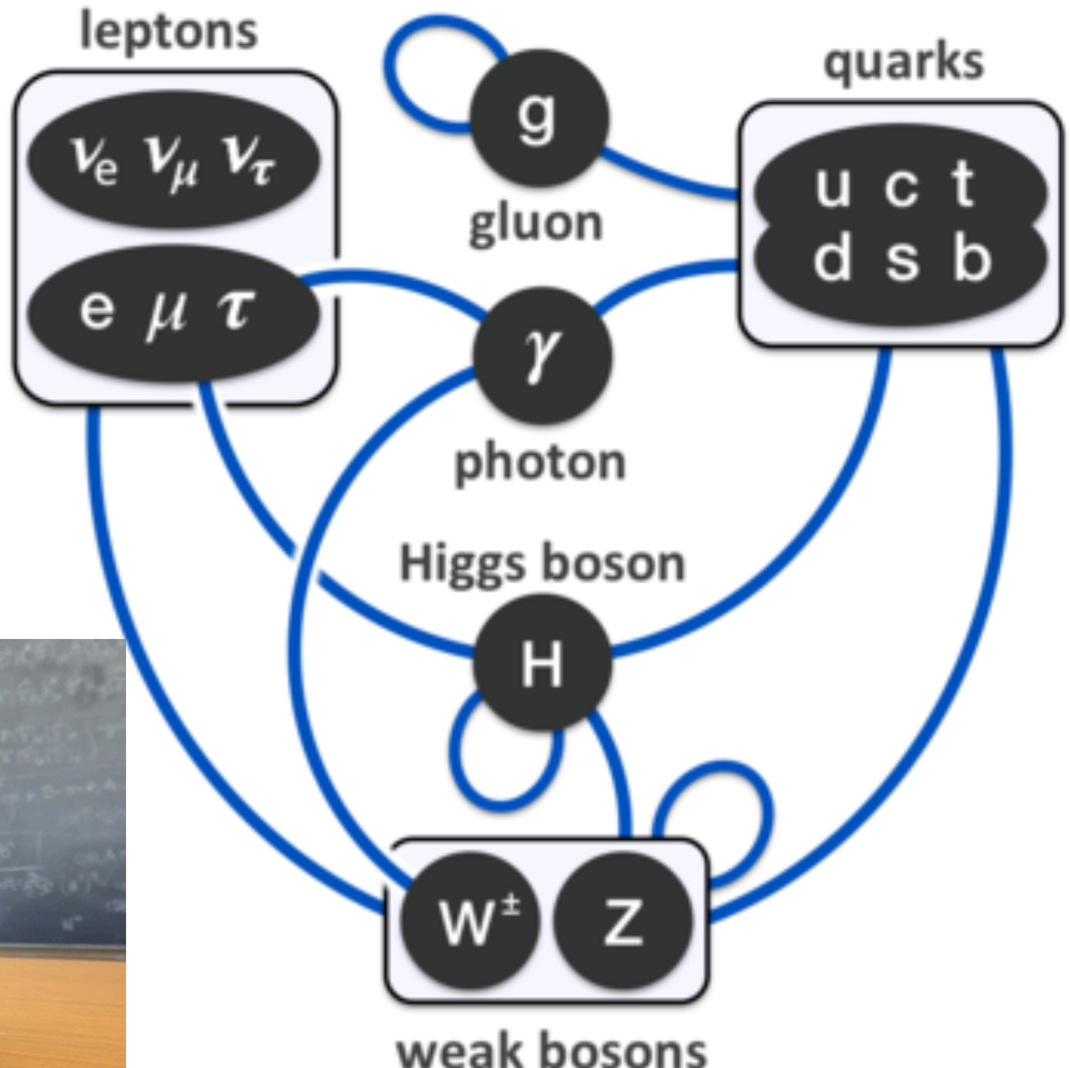
Unification

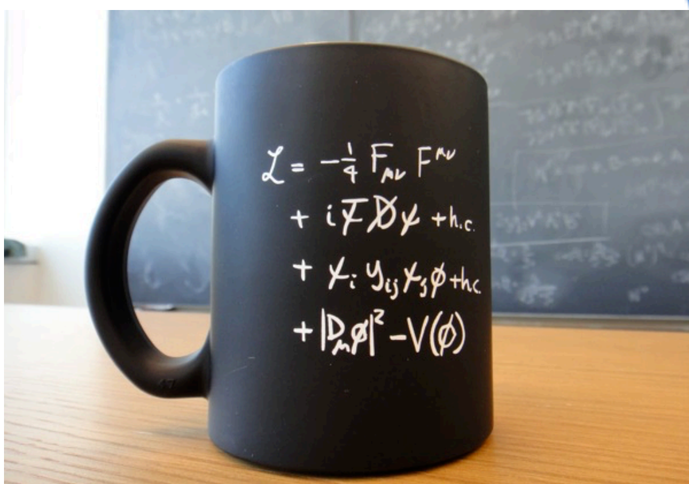
all the forces of Nature should be capable of being described by a single theory. But only at high energies should the behavior of the forces combine, this is called unification



before the unification point, the forces are indistinguishable and have symmetry. After the unification point, the forces act differently and the symmetry is broken.

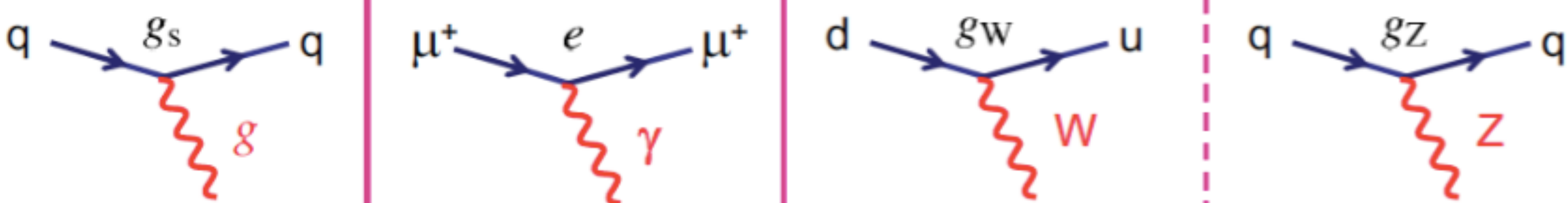
Fundamental Forces





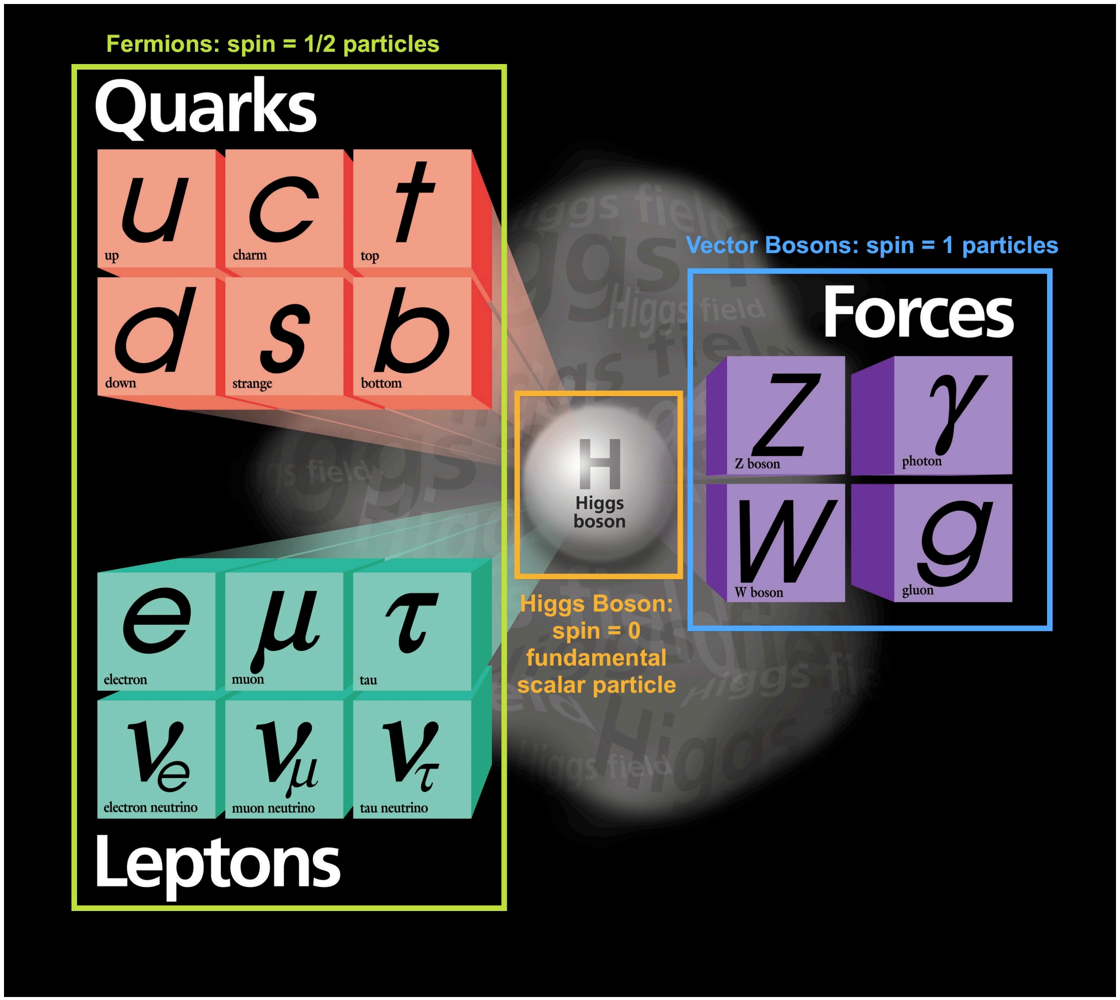
Fundamental Forces

The interaction of gauge bosons with fermions is very well described by the standard model



STRONG	EM	WEAK CC	WEAK NC
Only quarks	All charged fermions	All fermions	All fermions
Never changes flavour	Never changes flavour	Always changes flavour	Never changes flavour
$\alpha_S \sim 1$	$\alpha \simeq 1/137$	$\alpha_{W/Z} \sim 1/40$	
Gluons massless	**Photon** massless	**W+, W-** very massive	**Z^0** very massive

Higgs Boson

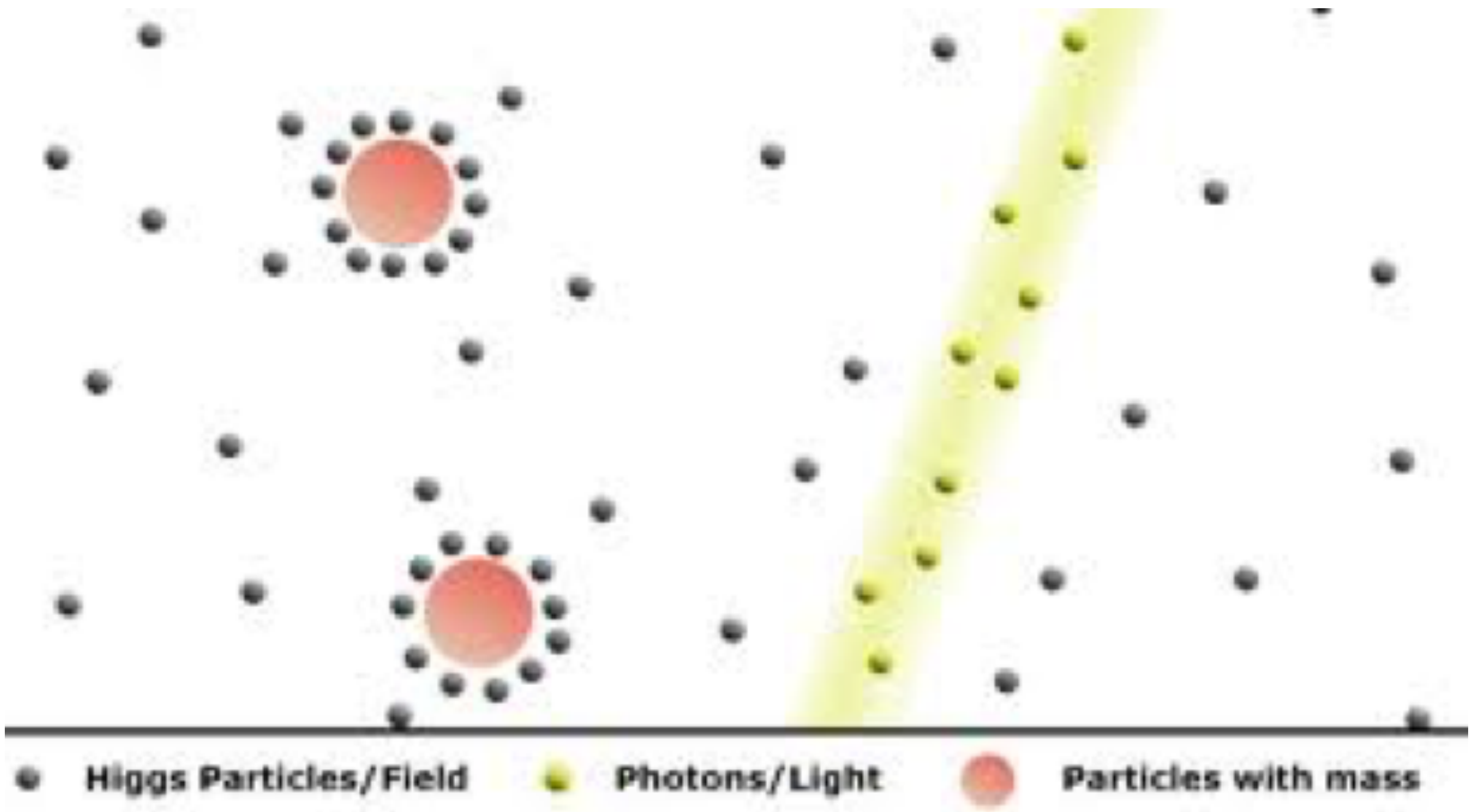


The Higgs boson was the last of the fundamental particles predicted by the Standard Model to be observed.

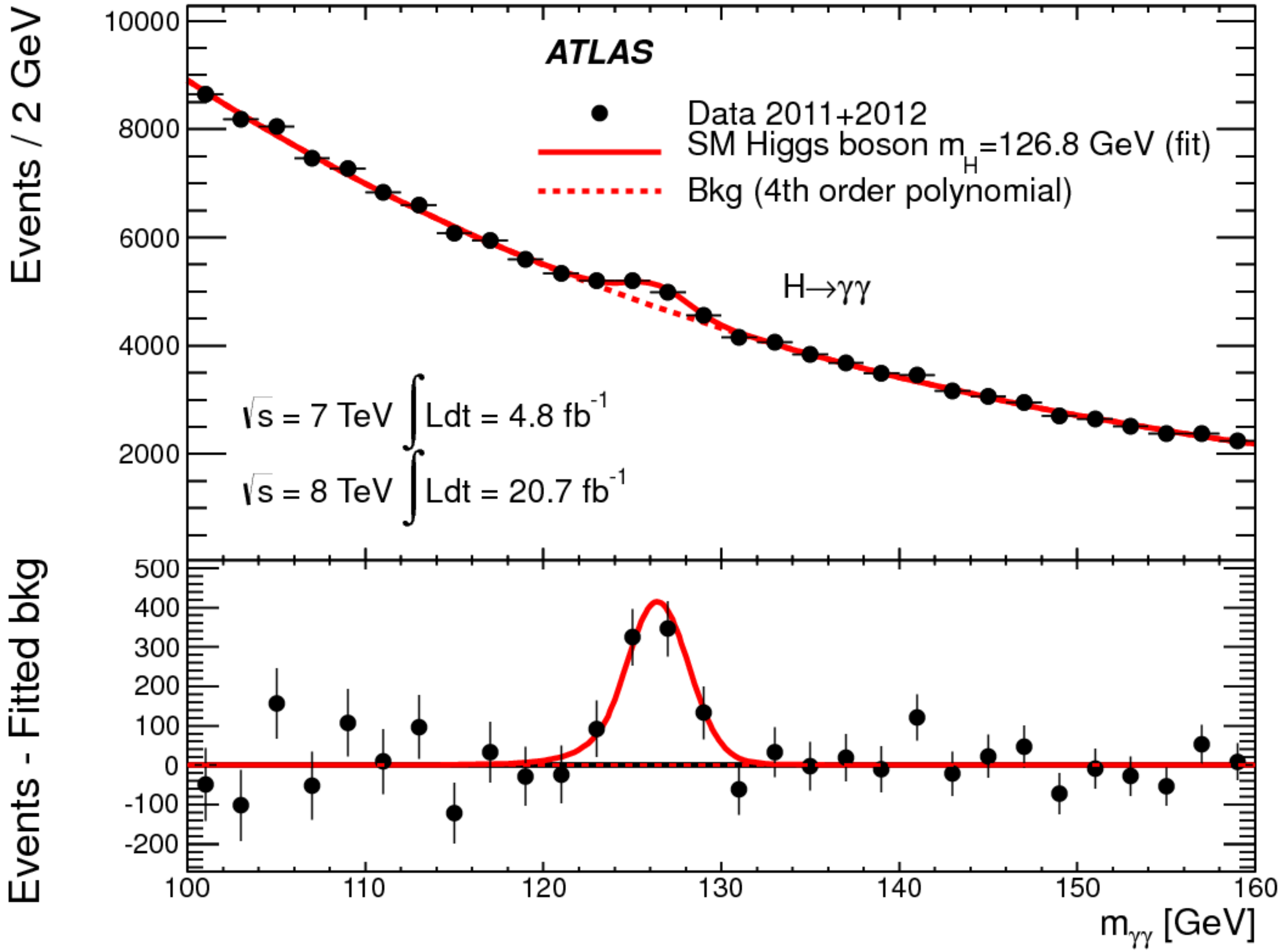
Fundamental particles interact with the Higgs and acquire mass!

Higgs Boson

The Higgs field exists throughout all of space, and interacts with the elementary particles **giving some of them mass**



Higgs Boson

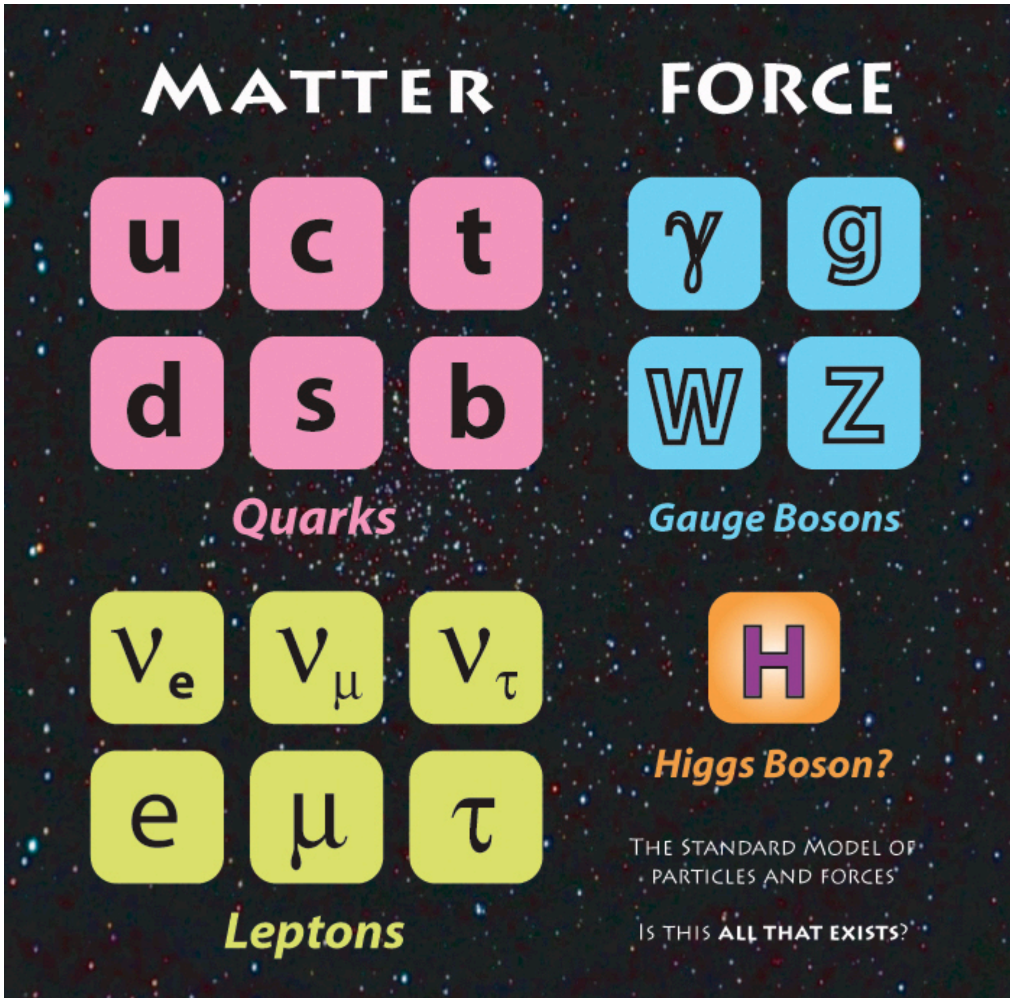

ATLAS
Data 2011+2012
SM Higgs boson m_H=126.8 GeV (fit)
Bkg (4th order polynomial)
H→γγ
√s = 7 TeV ∫Ldt = 4.8 fb^-1
√s = 8 TeV ∫Ldt = 20.7 fb^-1
Events / 2 GeV
Events - Fitted bkg
m_γγ [GeV]
10000
8000
6000
4000
2000
500
400
300
200
100
0
-100
-200
100
110
120
130
140
150
160

Higgs Boson

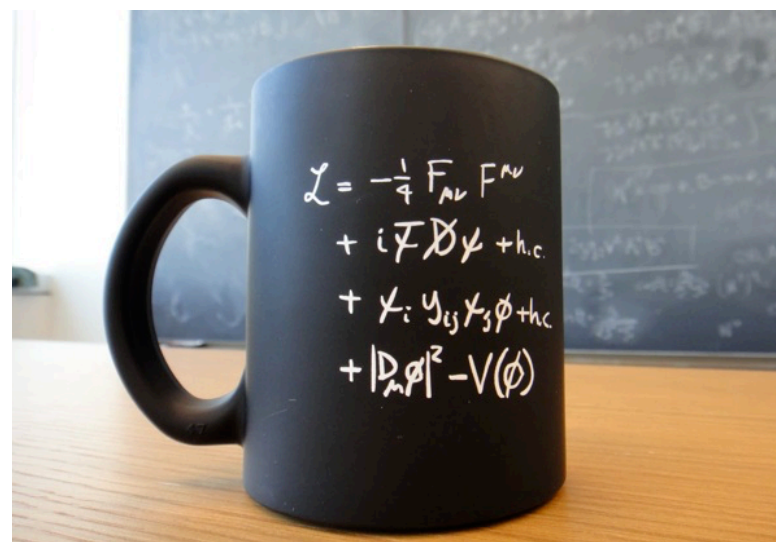
Celebrations on 4 July 2012
CERN and all over the world!

Both CMS and ATLAS reporting 5 sigma evidence for a new particle with mass ~ 125 GeV

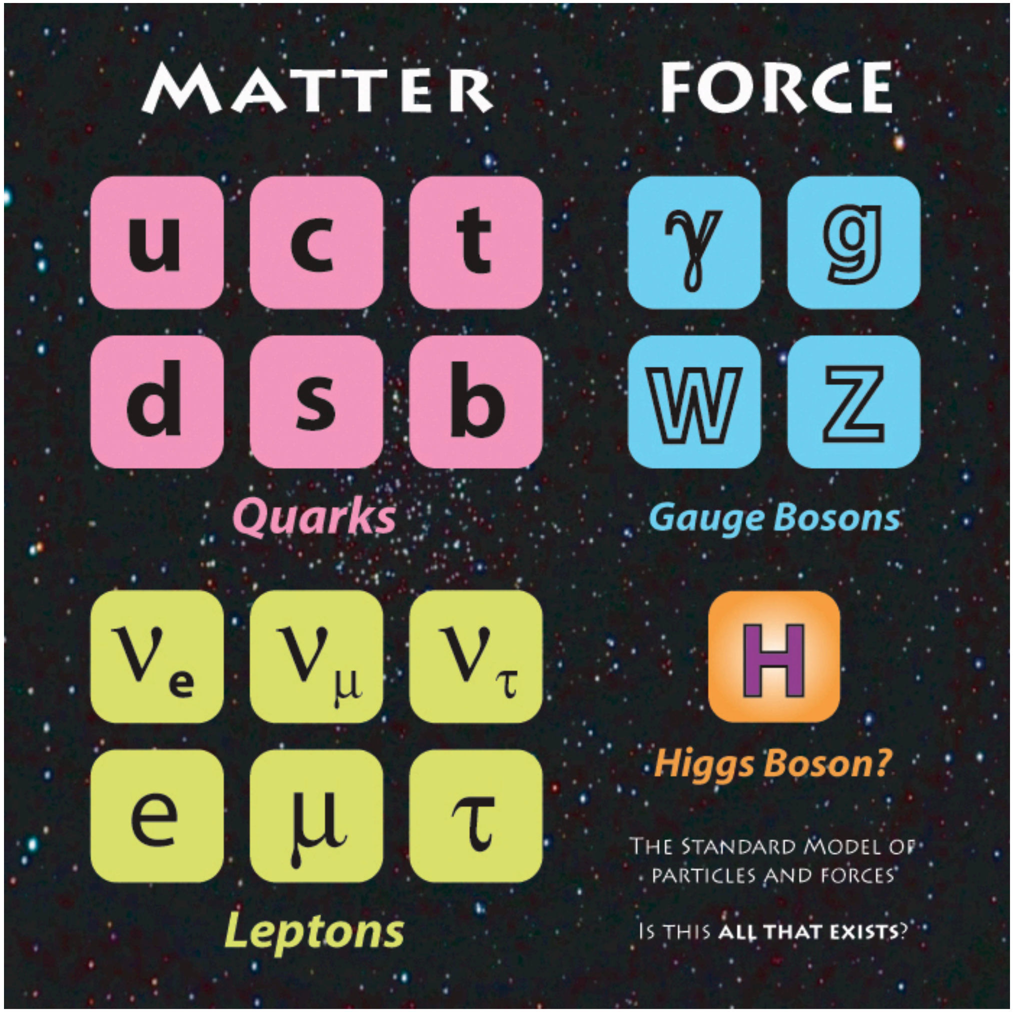
Particle Physics



GREAT JOB PARTICLE PHYSICIS!!!!

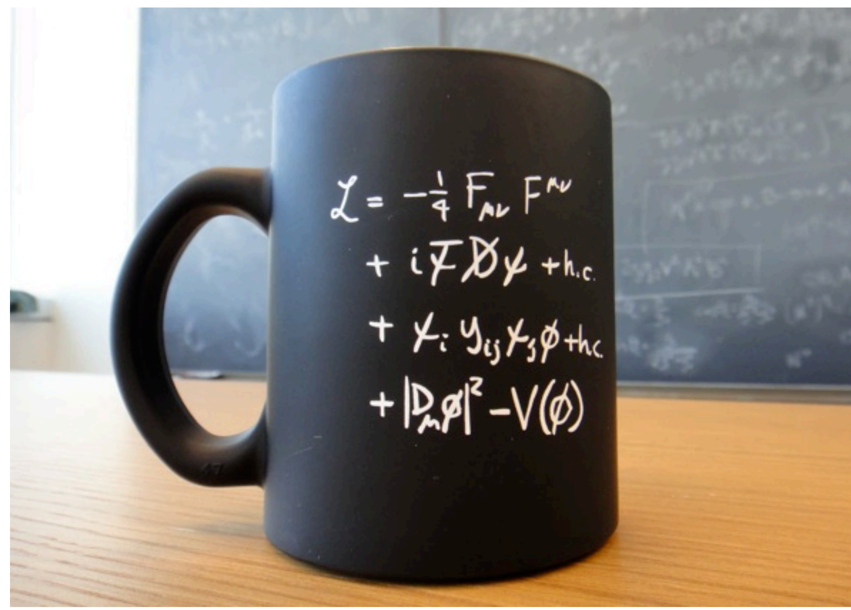


Problems in Particle Physics



Issues:

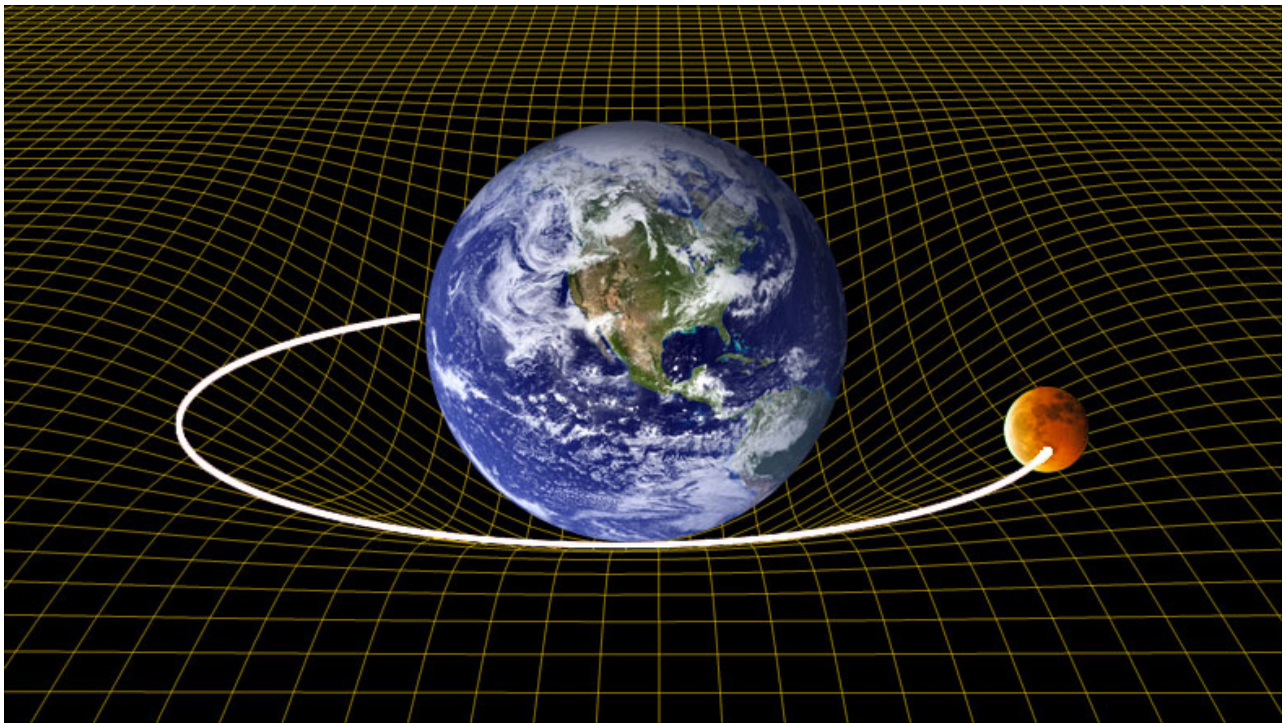
- Gravity
- Dark Energy, Dark Matter
- Neutrino masses
- Matter-antimatter asymmetry
- Hierarchy problem



Problems in Particle Physics – where is gravity?

Gravity is described by General Relativity!

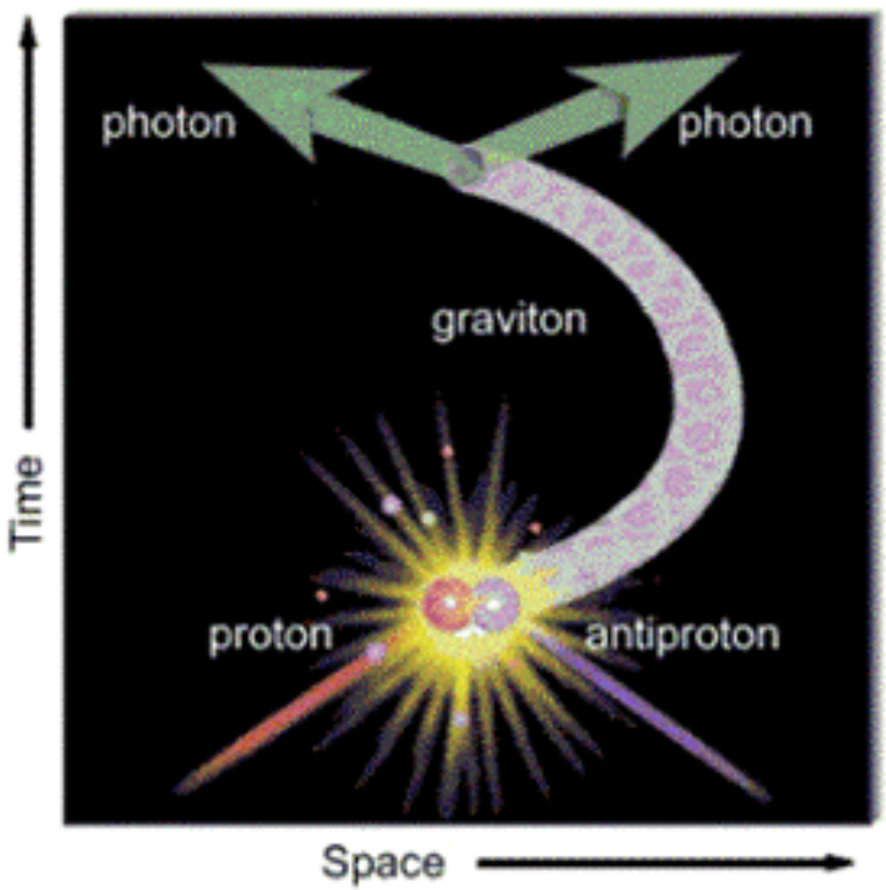
We currently don't have a quantum theory of gravity!



Problem in making a quantum theory of gravity due to something called renormalisation – infinities occur!

Other approaches include string theory and loop quantum gravity

Problems in Particle Physics – where is gravity?



Hypothetical force carrier for Gravity: **The Graviton**

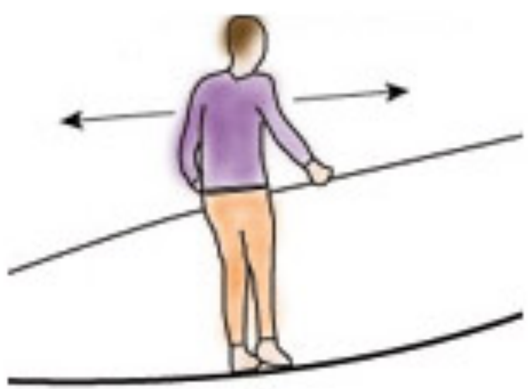
- Graviton: spin 2 massless (tensor) boson
- Cross-section would be very low!
- ATLAS and CMS at the Large Hadron Collider are still searching for it!

Problems in Particle Physics – where is gravity?

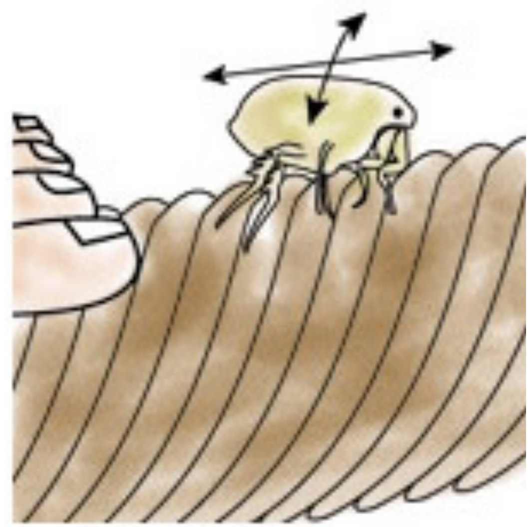
Extra Dimensions

Einstein's general theory of relativity tells us that space can expand, contract, and bend.

If one dimension were to contract to a size smaller than an atom, it would be hidden from our view.



An acrobat can only move in one dimension along a rope..



...but a flea can move in two dimensions.

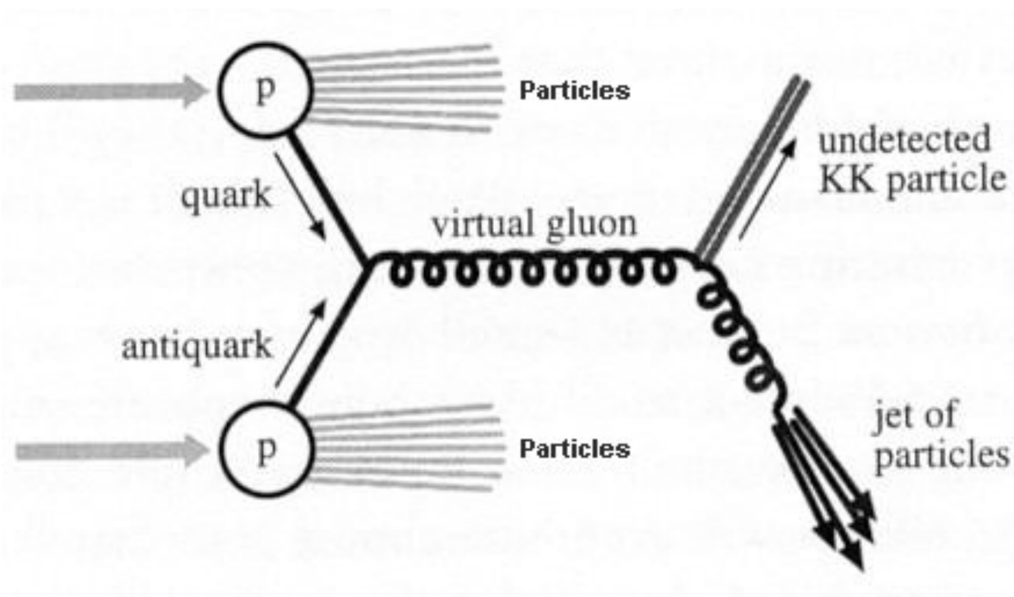
Problems in Particle Physics – where is gravity?

Extra Dimensions

One possibility for gravity being so weak is because part of it spreads to extra dimensions

If gravitons exist, it should be possible to create them at the LHC, but they would rapidly disappear into extra dimensions.

Example – Graviton produced in association with a jet



The Graviton propagates in the extra dimensions

Only one jet of hadrons would be observed in our four-dimensional world.

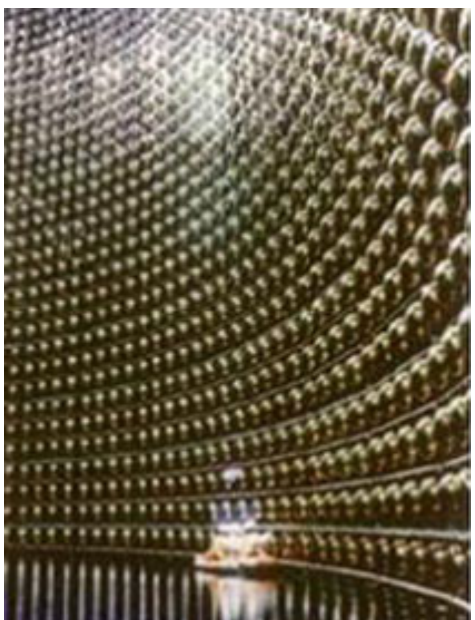
We would see of monojet events at colliders.

Problems in Particle Physics – Neutrino Masses

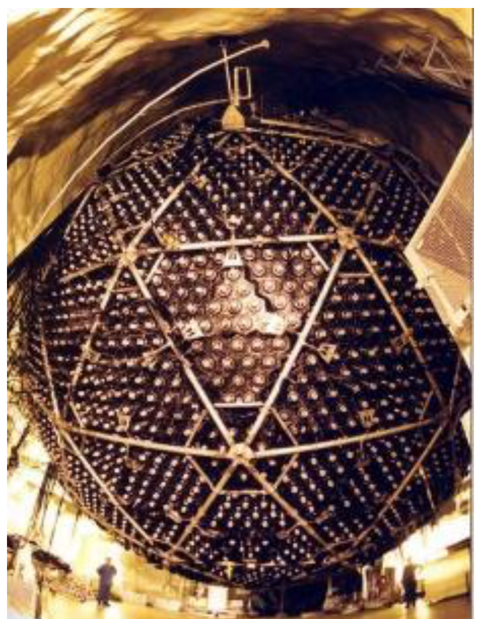
Neutrinos are the least understood particles in the standard model.
They come in 3 flavours, were found to oscillate between these flavours in the 90's and 00's, indicating they have a **non-zero mass!**

This is not predicted by the Standard Model.

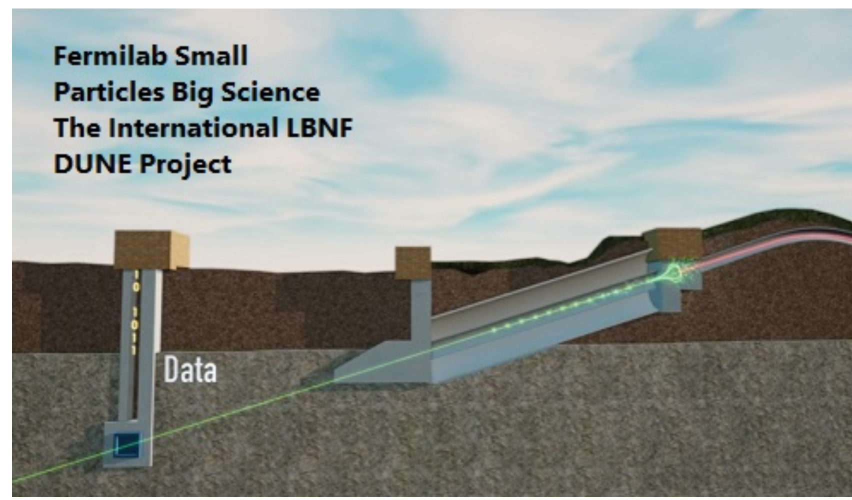
Scientists are studying these elusive particles in numerous experiments.



T2K, Japan

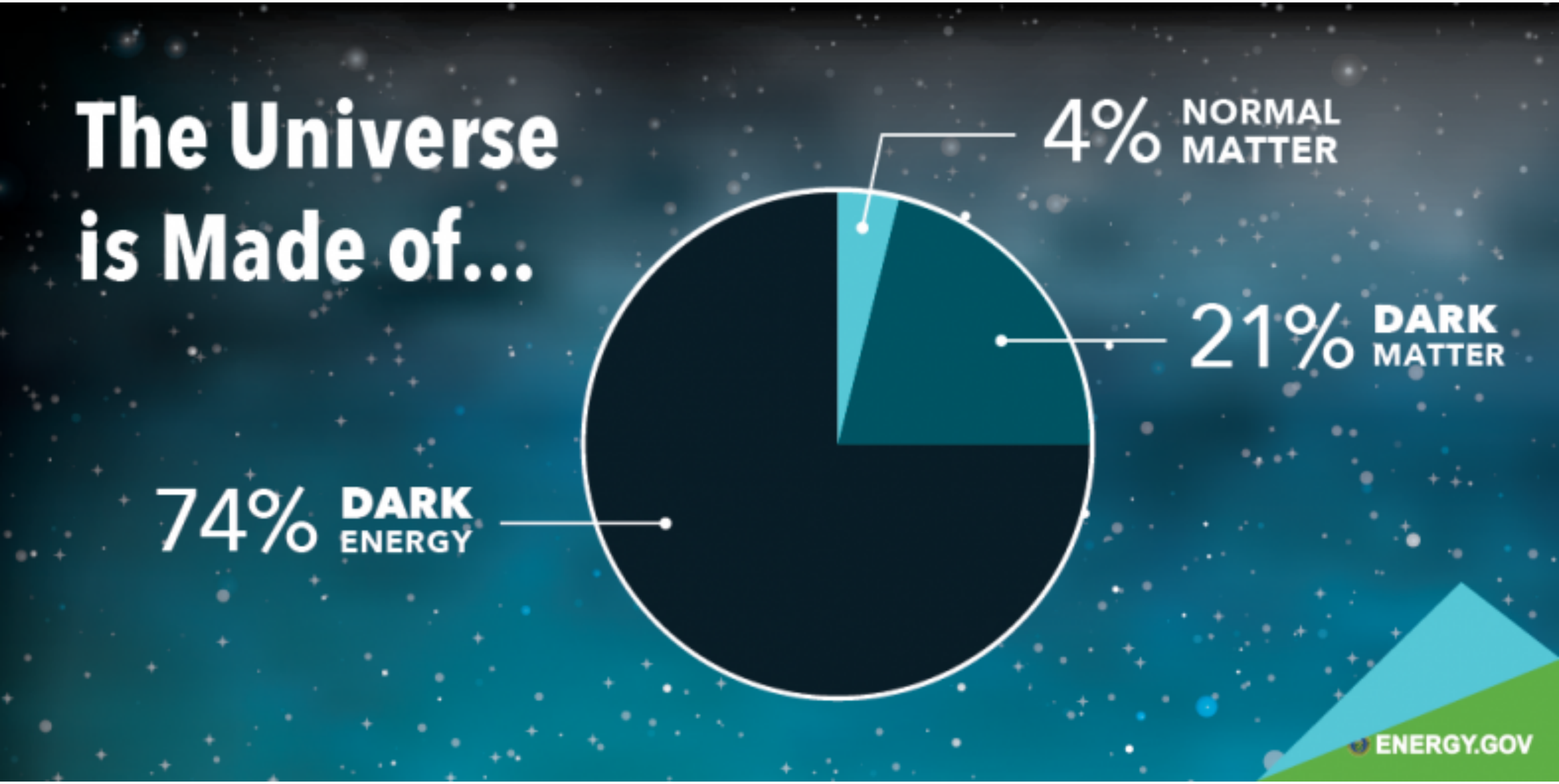


SNO+, Canada

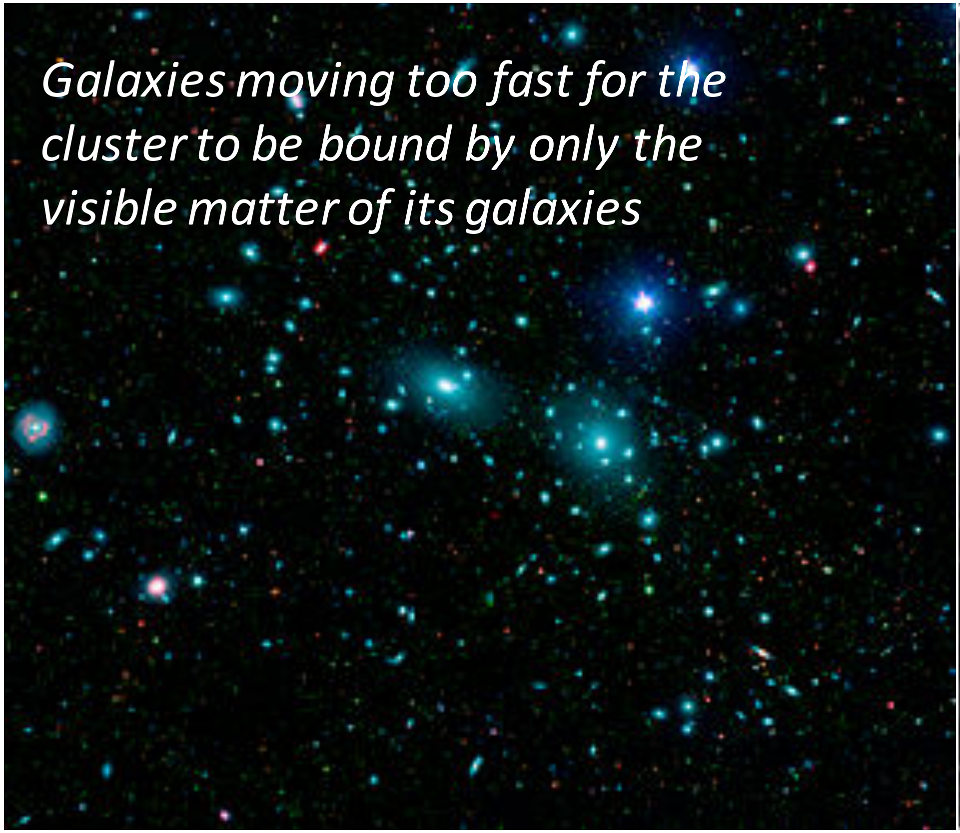


Dune, US

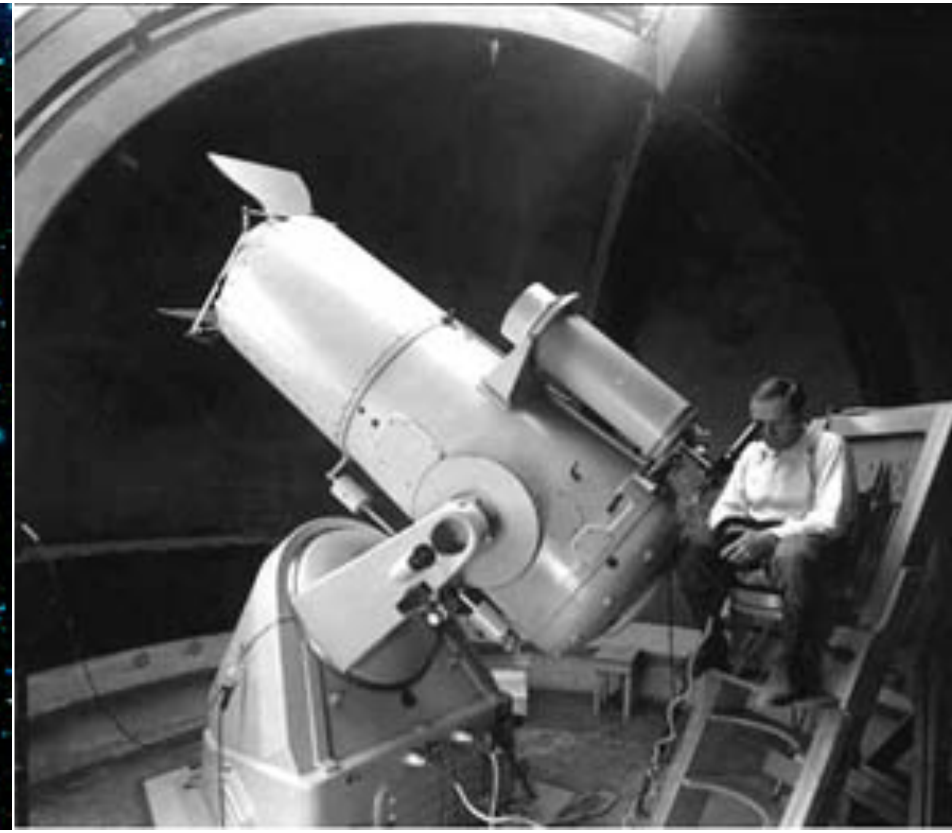
Problems in Particle Physics – Dark Matter



Problems in Particle Physics – Dark Matter



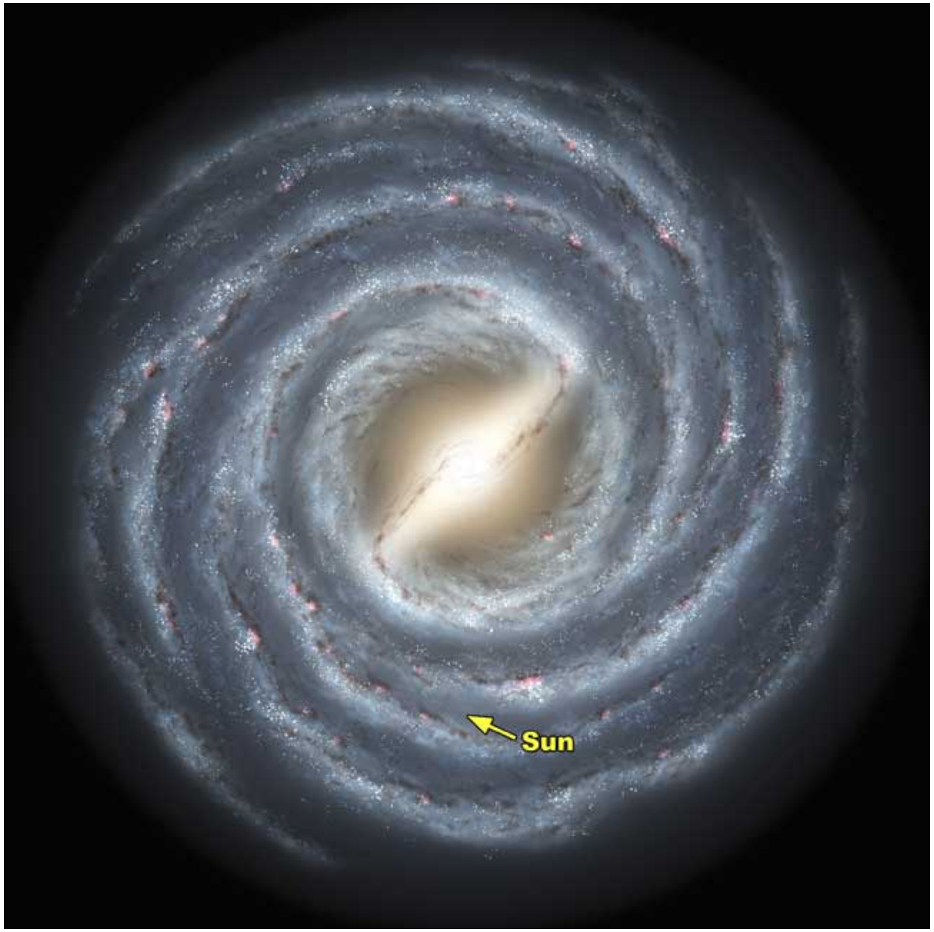
Coma Cluster, contains over 1000 identified galaxies, 321 million light years away from Earth, ~ 90 % dark matter

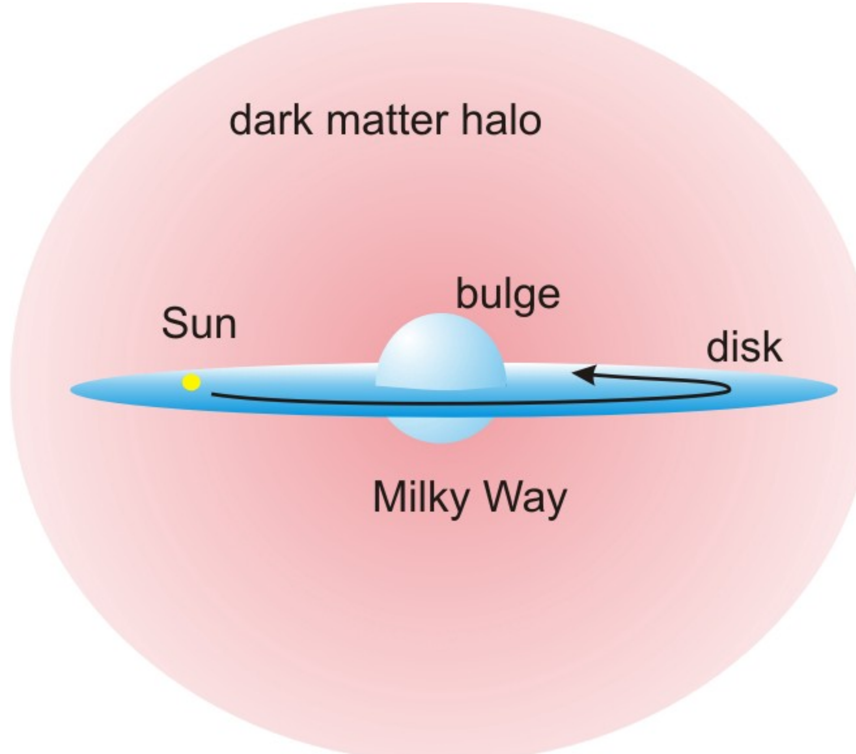


Fritz Zwicky, Swiss Astronomer
In 1933 inferred existence of *dunkle Materie*

Galaxies must be held together by some dunkle Materie

Problems in Particle Physics – Dark Matter



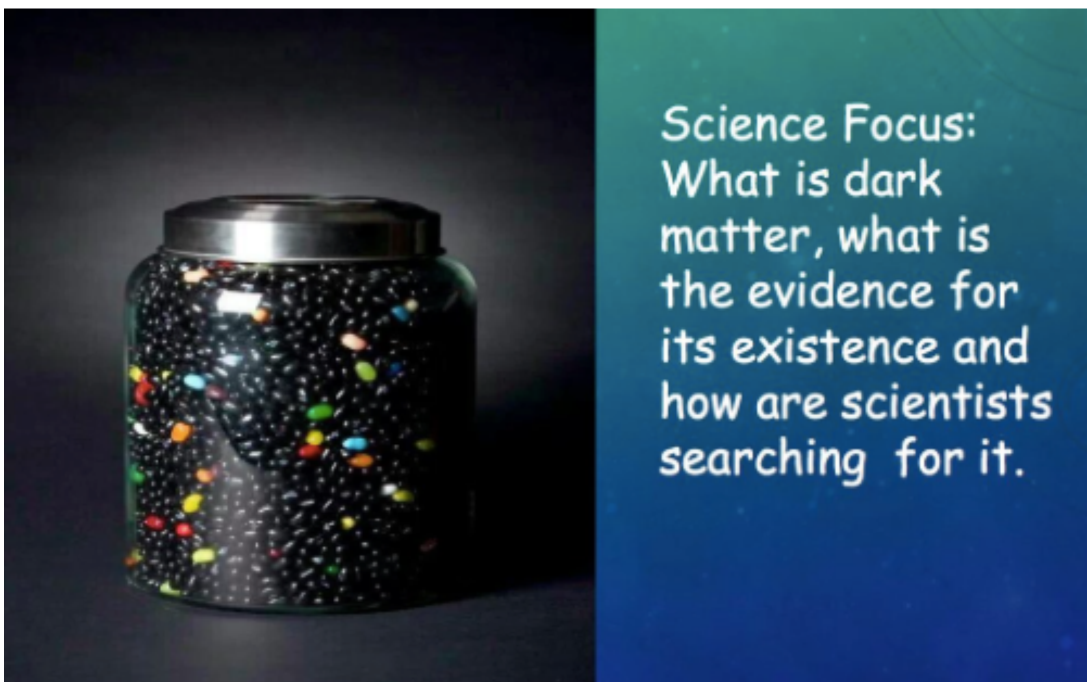


Problems in Particle Physics – Dark Matter

By 1980 Dark Matter was widely recognised as an unsolved problem in astronomy

What do we know about dark matter?

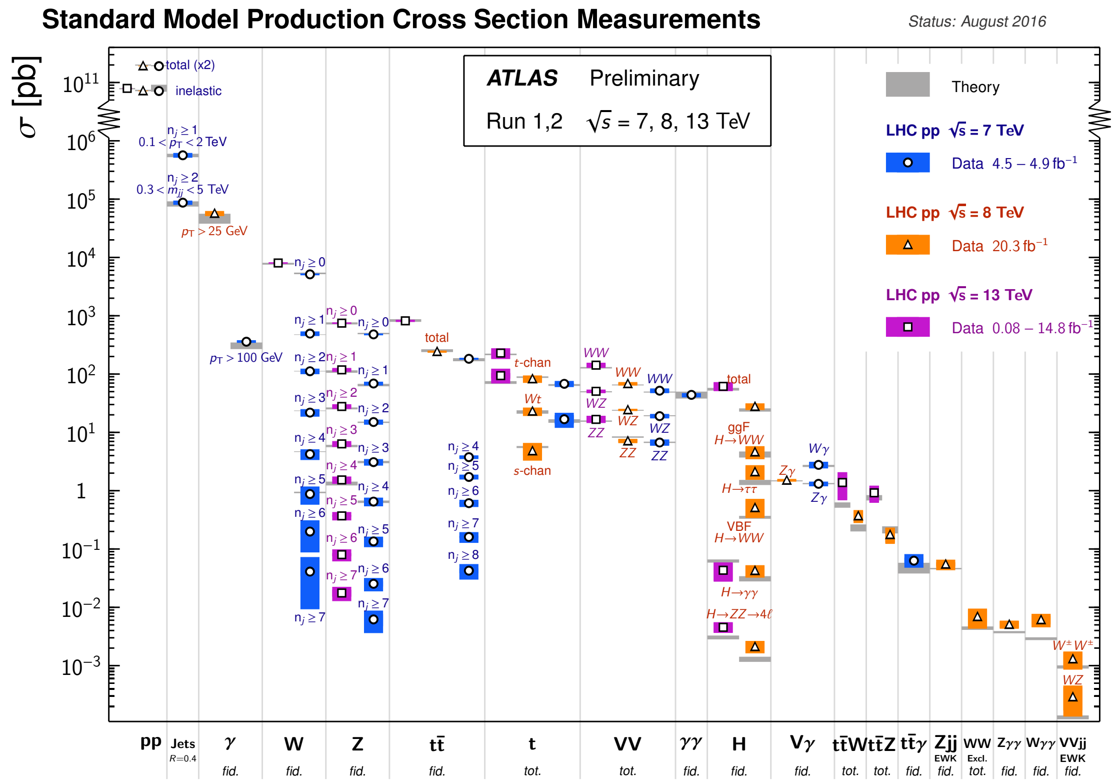
- Its dark, it does not absorb, reflect or emit light! This means it does not interact with the electromagnetic force
- It interacts with Gravity



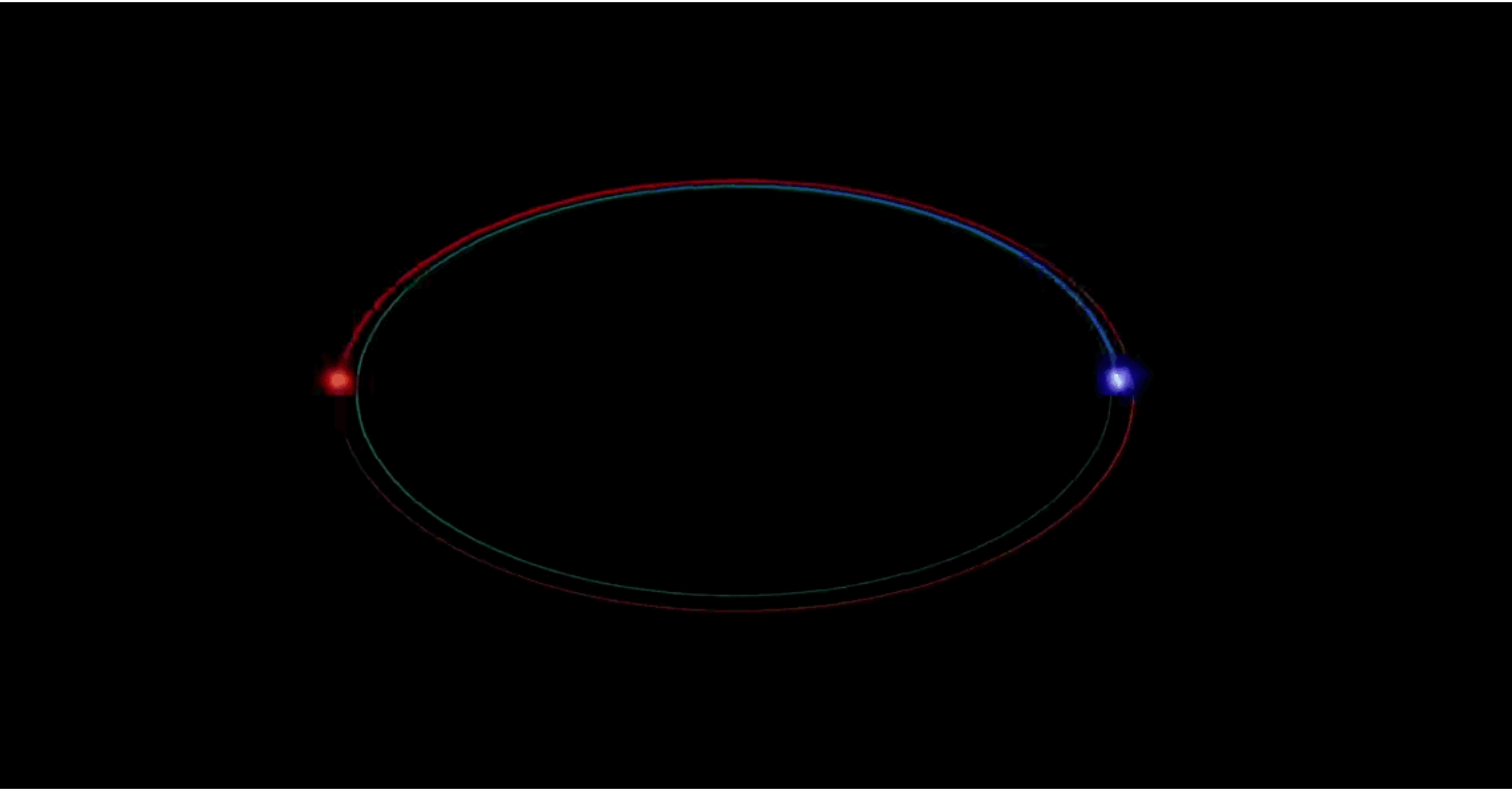
Problems in Particle Physics – Cracks in SM

Testing Standard Model predictions at the LHC

Using the Higgs, the Top and others and a probe for New Physics!

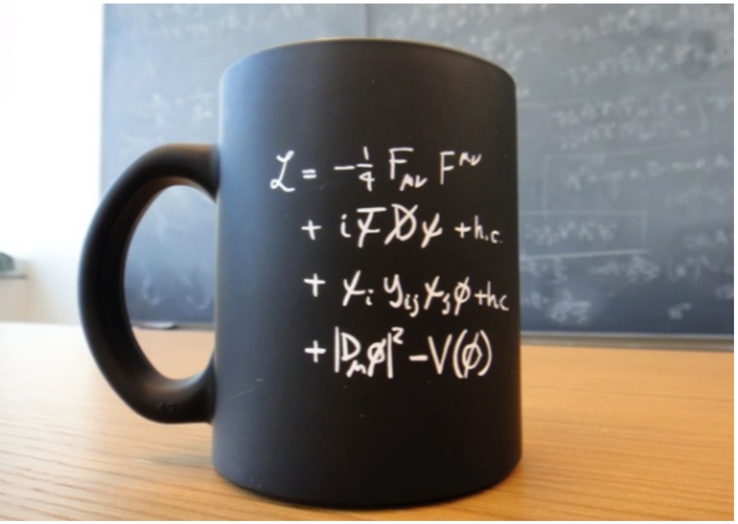


Studying Particle Physics

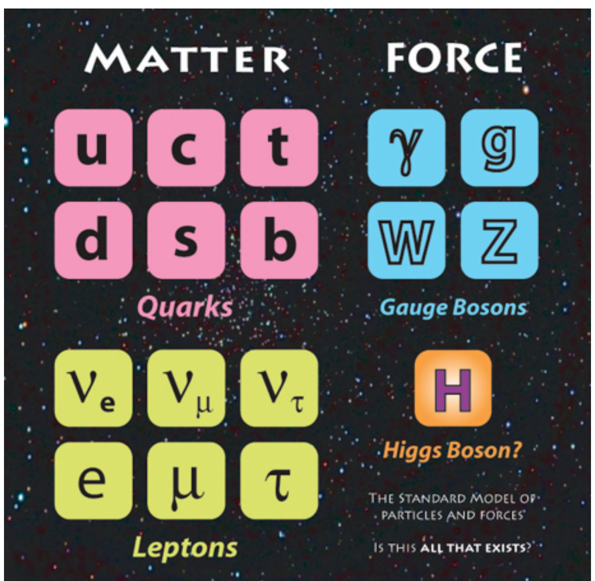


THANK YOU!

The Standard Model



- **First line provides information about force carrying particles and how they interact**
- Second line shows how fermion matter particles interact via by the force carriers
- **Third line shows how the matter particles couple to the Higgs field ϕ ,**



- **Notice the Yukawa matrix y_{ij} which represents the coupling parameter to the Higgs field, and is directly proportional to the mass of a particle**
- **Last line shows how vector bosons couple to the Higgs field , and the Higgs field potential**