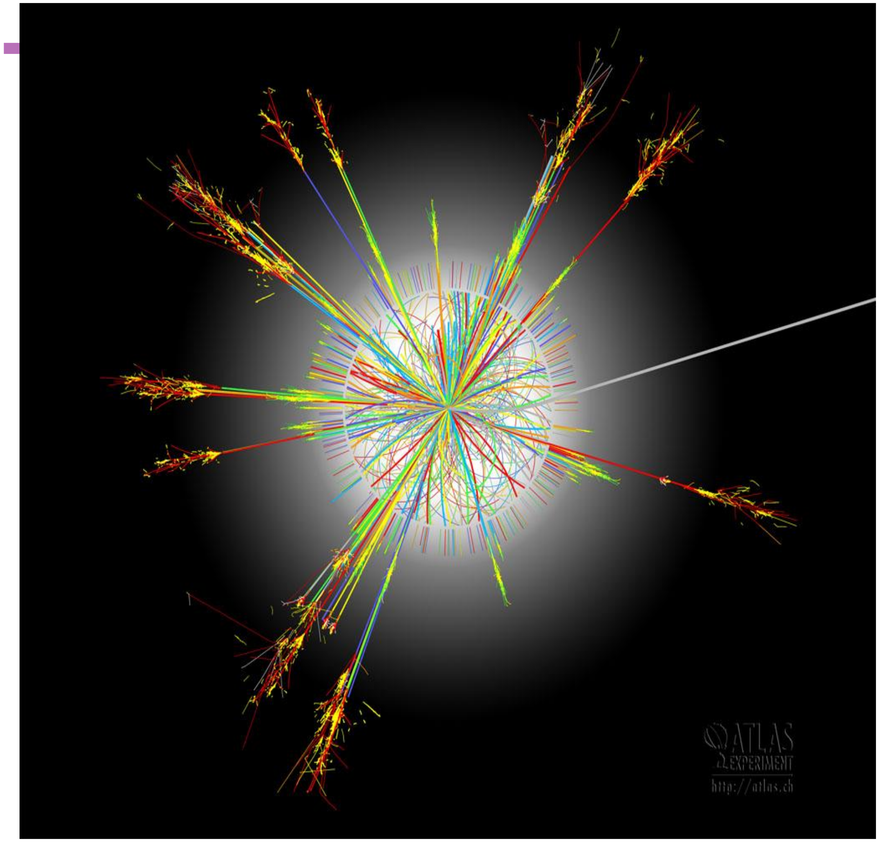
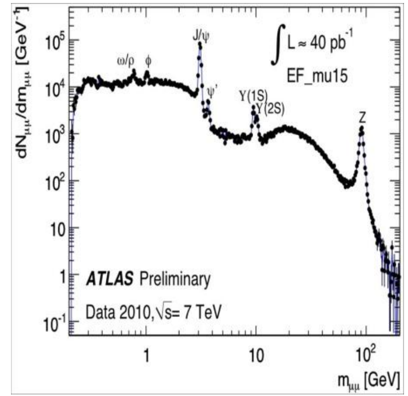
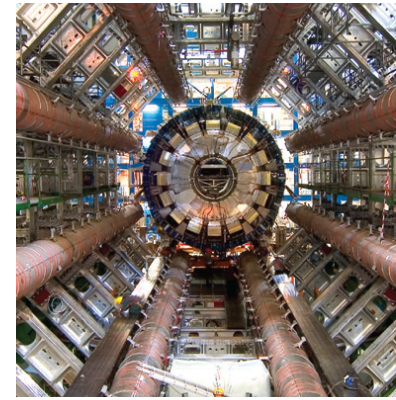
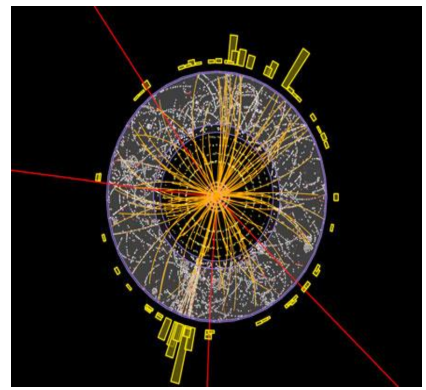
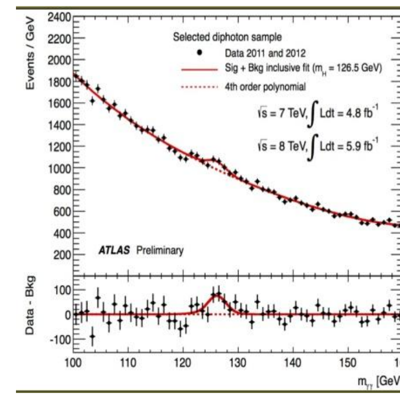










An Introduction to Particle Physics

The Universe started with a Big Bang

The Universe started with a Big Bang

What is our Universe 'made of'?

- Particle physics aims to understand
  - Elementary (fundamental) particles
  - Elementary (fundamental) forces

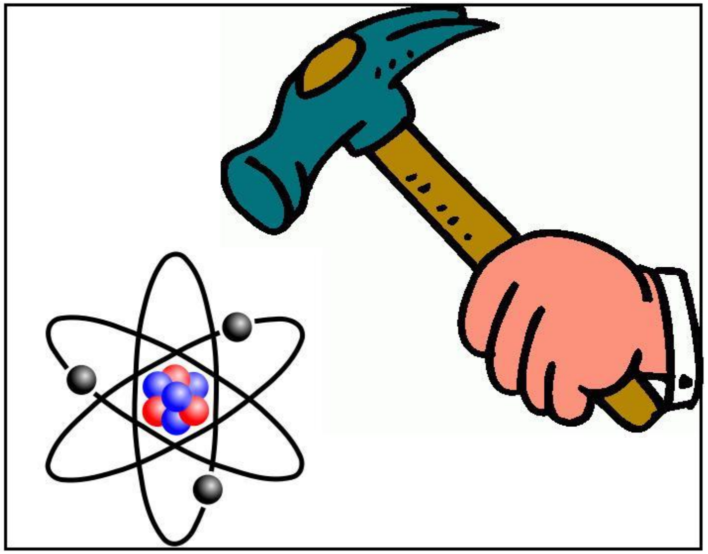
What do we mean when we say a particle or force is 'elementary' or 'fundamental'?

Fundamental Particles

In particle physics, an elementary particle or fundamental particle is a particle **not <u>known to have substructure</u>**

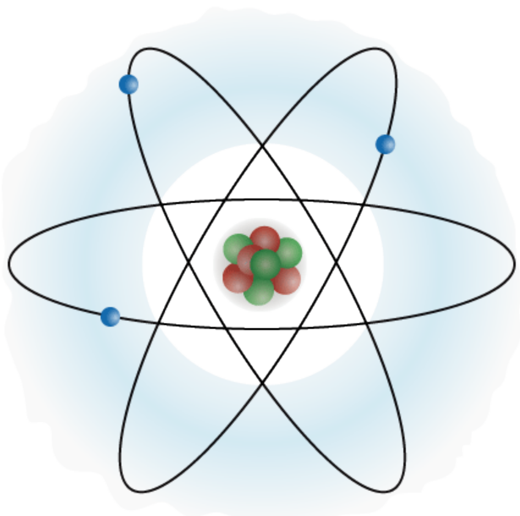
If an elementary particle truly has no substructure, then it is one of the **basic building blocks of the universe** from which all other particles are made.

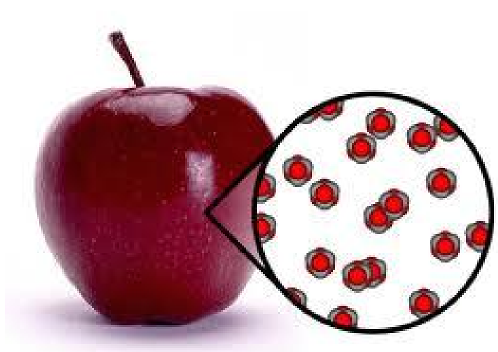
What are the fundamental particles of nature?



Inside the Atom

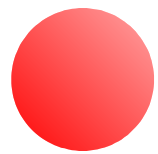
Atom



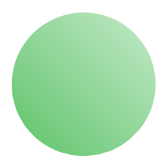


Electron

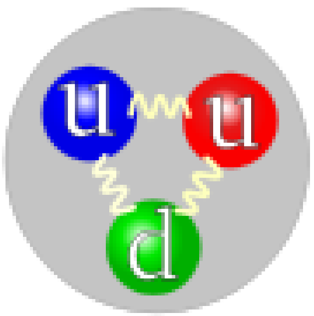
Proton



Neutron

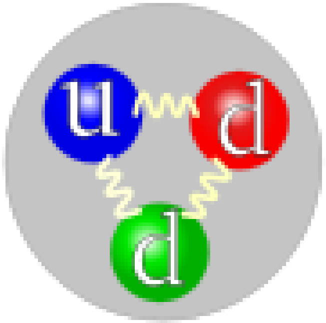


Proton



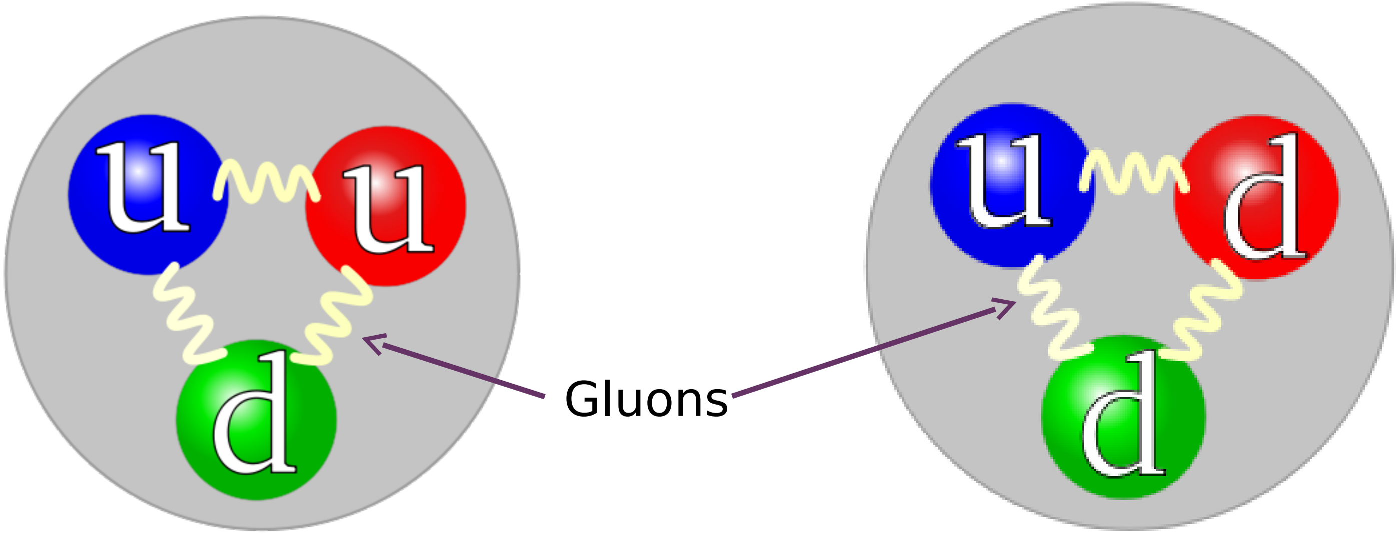
Quarks &
Gluons

Neutron



Particles made of
quarks and gluons
are called **hadrons**

Inside the Atom



Proton

Quarks:
Up (charge 2/3)
Up (charge 2/3)
Down (charge -1/3)

Neutron

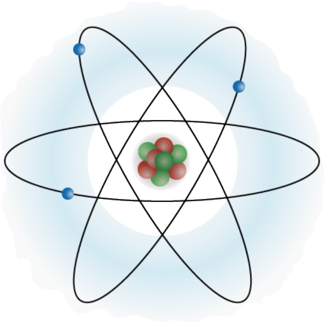
Quarks:
Up (charge 2/3)
Down (charge -1/3)
Down (charge -1/3)

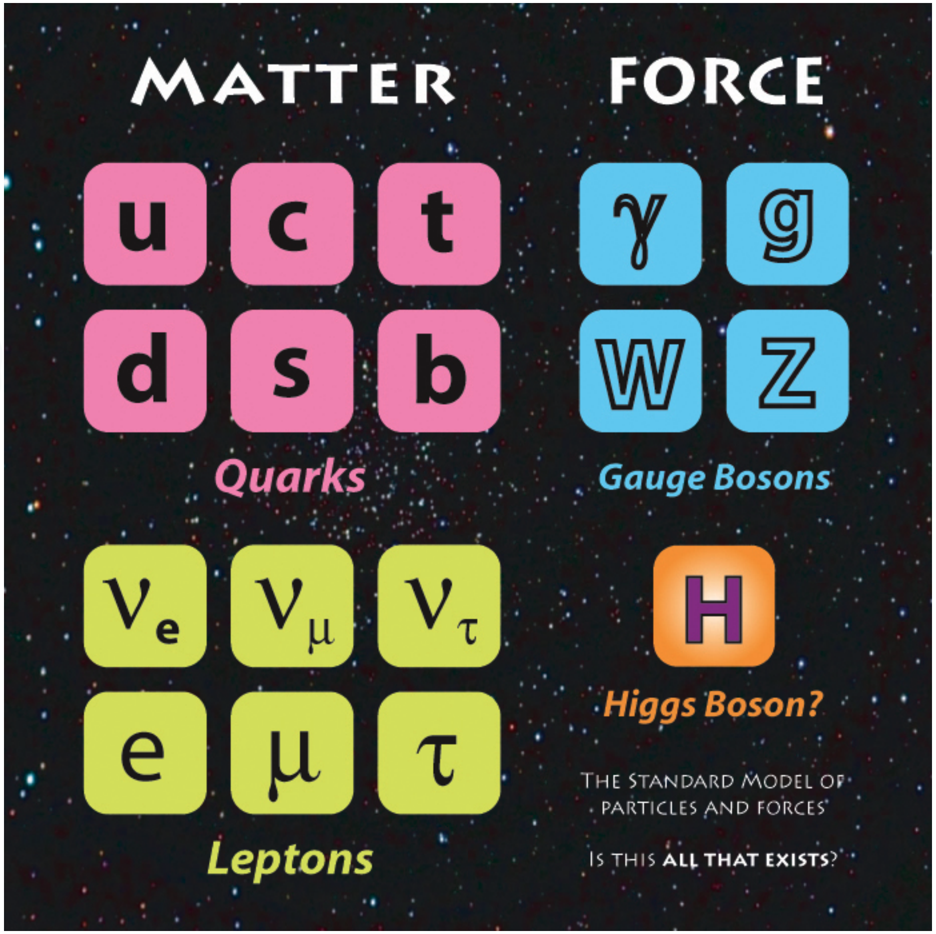
What is the electric charge of the Proton and the neutron?

The Standard Model of Particle Physics

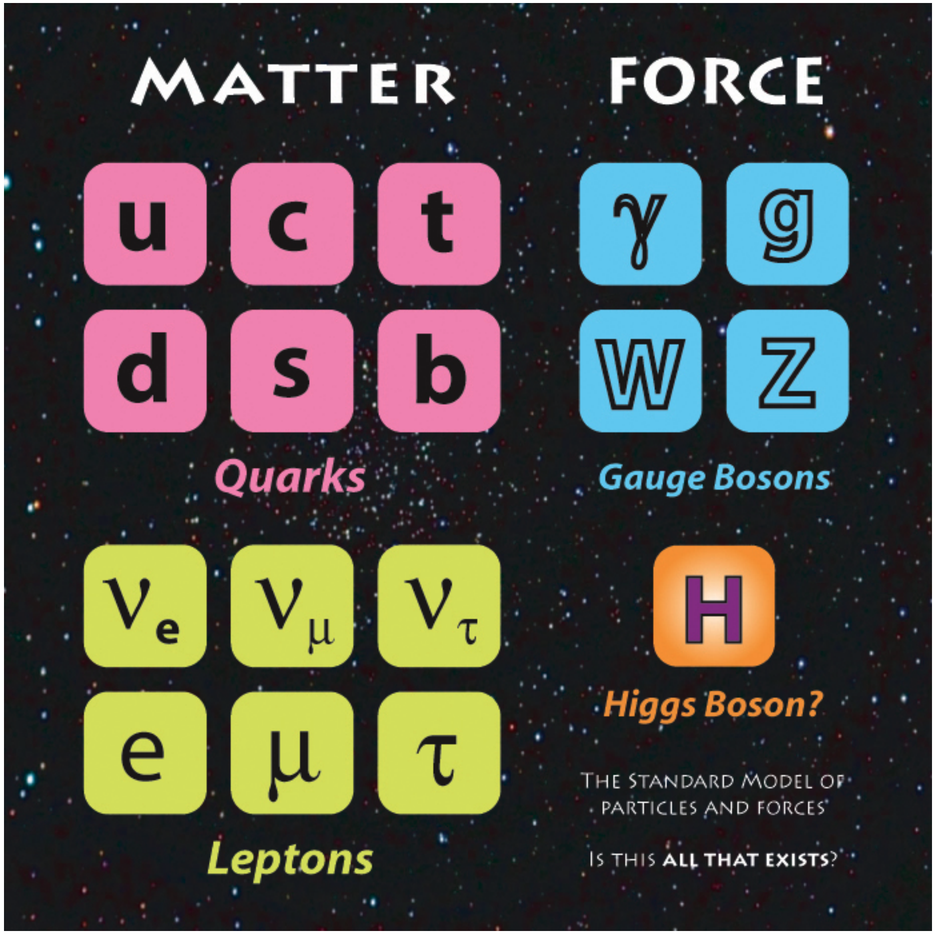
Fundamental Particles:

- ☑Electron (e)
- ☑Up Quark (u)
- ☑Down Quark (d)
- ☑Gluon (g)





The Standard Model of Particle Physics



Quarks and Leptons

Matter particles:

Fermions - spin ½ particles

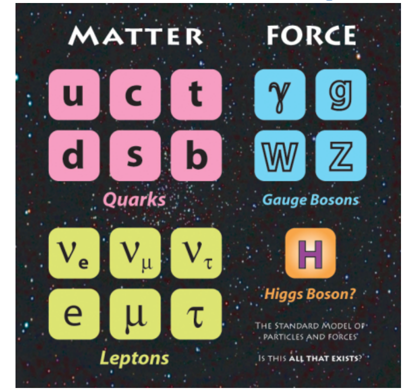
Force carriers

Mediate the forces

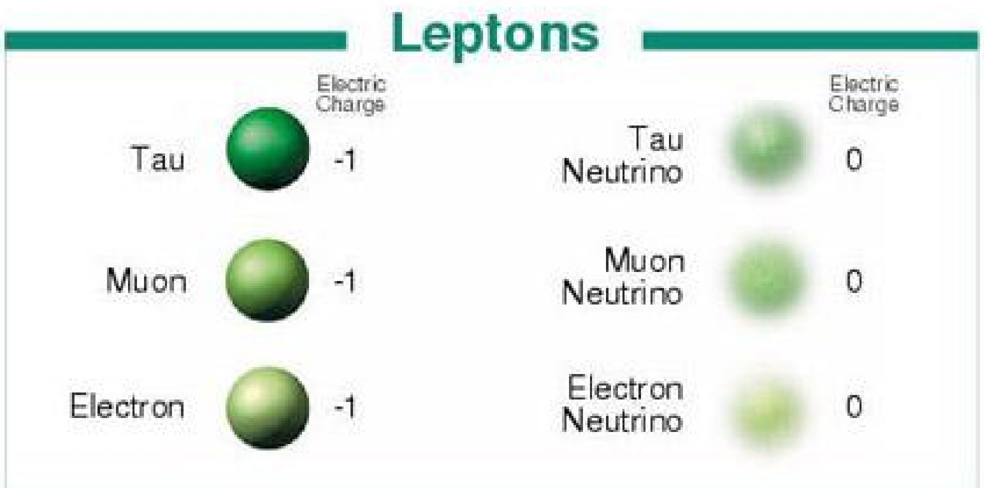
Bosons – spin integer particles (0, 1,…)

Higgs **responsible for mass**

The Standard Model of Particle Physics



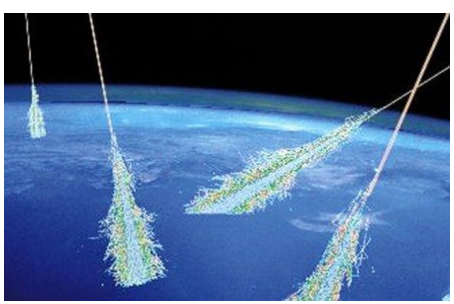
Leptons



Electrically Charged **Electrically Neutral**

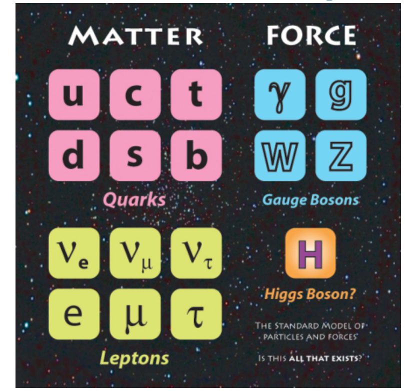
Only electrons are **stable**!
Muon(μ) lifetime = 2 x 10-6 s
Tau (τ) lifetime = 3 x 10-13 s

Neutrinos have almost no mass and are electrically neutral



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

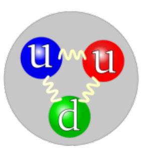
The Standard Model of Particle Physics



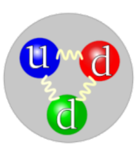
Quarks

Electrically Charged

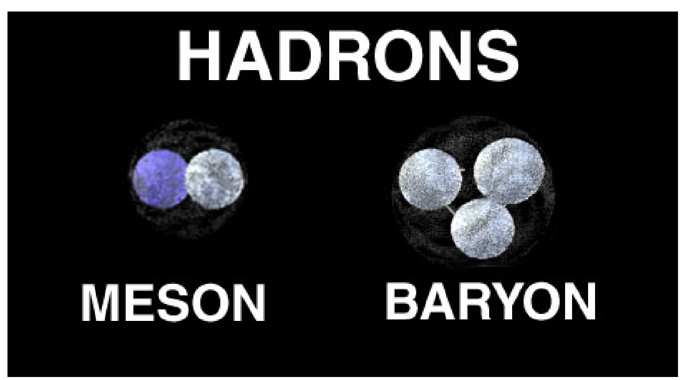
Quarks **must** exist as Hadrons in groups of TWO (Mesons) of THREE (Baryons)*



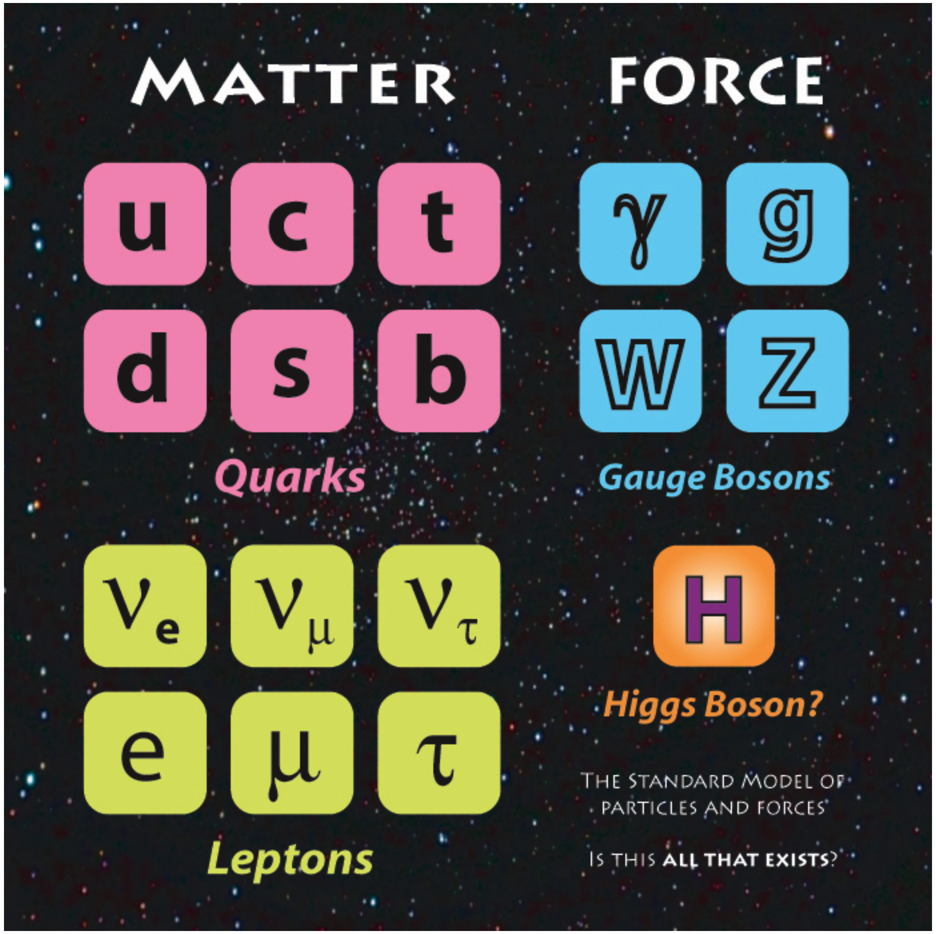
Proton



Neutron

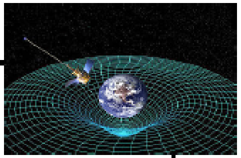


The Standard Model of Particle Physics



The Standard Model of Particle Physics

Fundamental Forces



Gravity:

- the first known force, occurs between all objects that carry energy
- long range force related to space and time
- responsible for the movements of the planets, stars and galaxies
- well described by general relativity (GR)

Electromagnetic:

- occurs between all objects that carry electric charge (quarks and charged leptons)
- responsible for almost all phenomena countered in the daily life: chemistry biology, friction, etc.
- long range force and well described by Maxwell's equations

Fundamental Forces

Strong force:

- occurs between all objects that carry colours (**only quarks**)
- very short range force ~ 1 fm
- responsible:
  - holding quarks together inside hadrons
  - the stability of the nuclei (glues protons together)

Weak Force:

- occurs between quark and between leptons including neutrinos
- very short range force ~ 0.001 fm
- responsible:
  - for radioactive decay (manufacturing new elements)
  - hydrogen fusion inside stars

Force Mediators

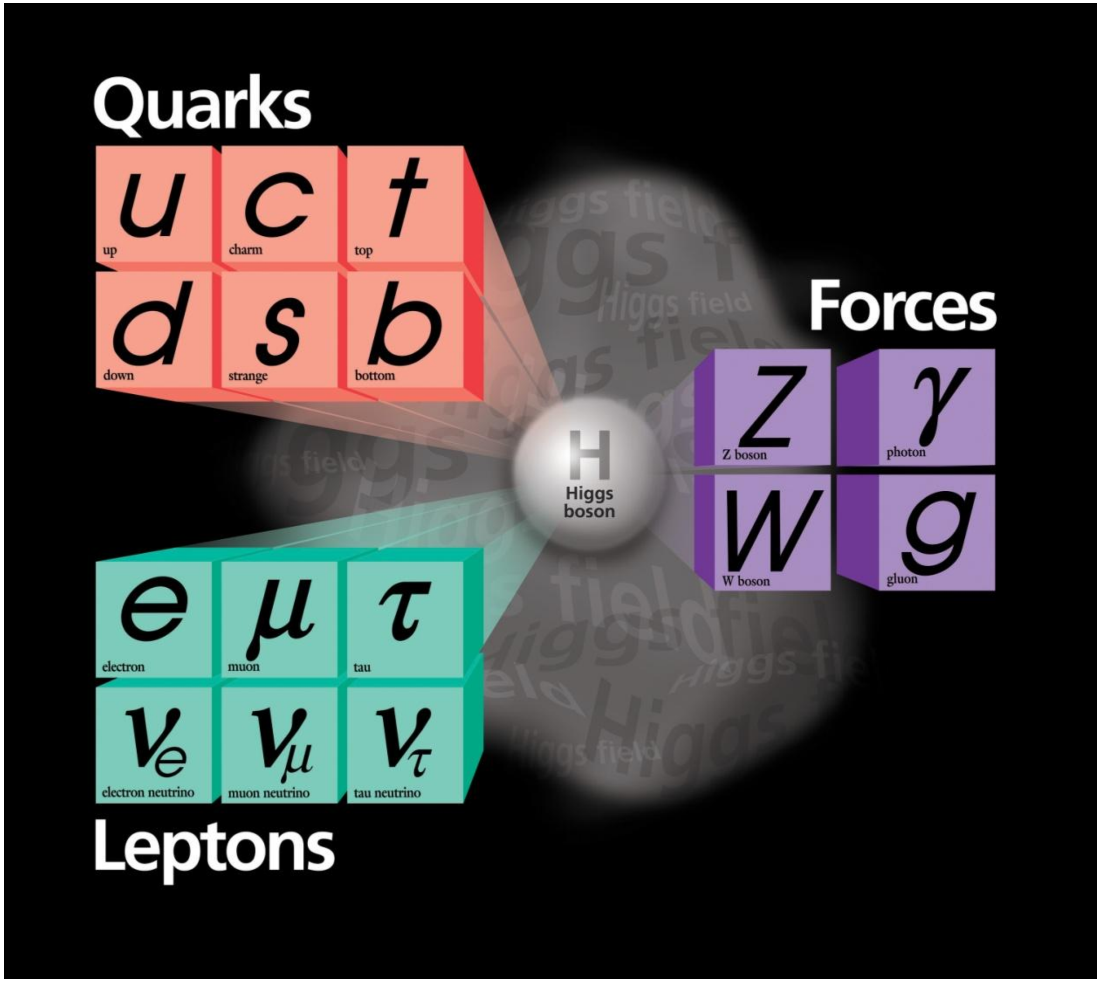
Force	Carrier	Mass	Charge	Spin
EM	photon	0	0	1
Strong	gluon	0	0	1
Weak	W^-,W^+,Z	80.3 and 91.2 GeV	-1,1,0	1

These forces are described by a well established theory called the Standard Model theory (SM)

Did we forget a force?

The Standard Model of Particle Physics

Higgs Boson



July 2012 the experiments at the LHC finally found our missing part of the Standard Model

The Higgs Boson

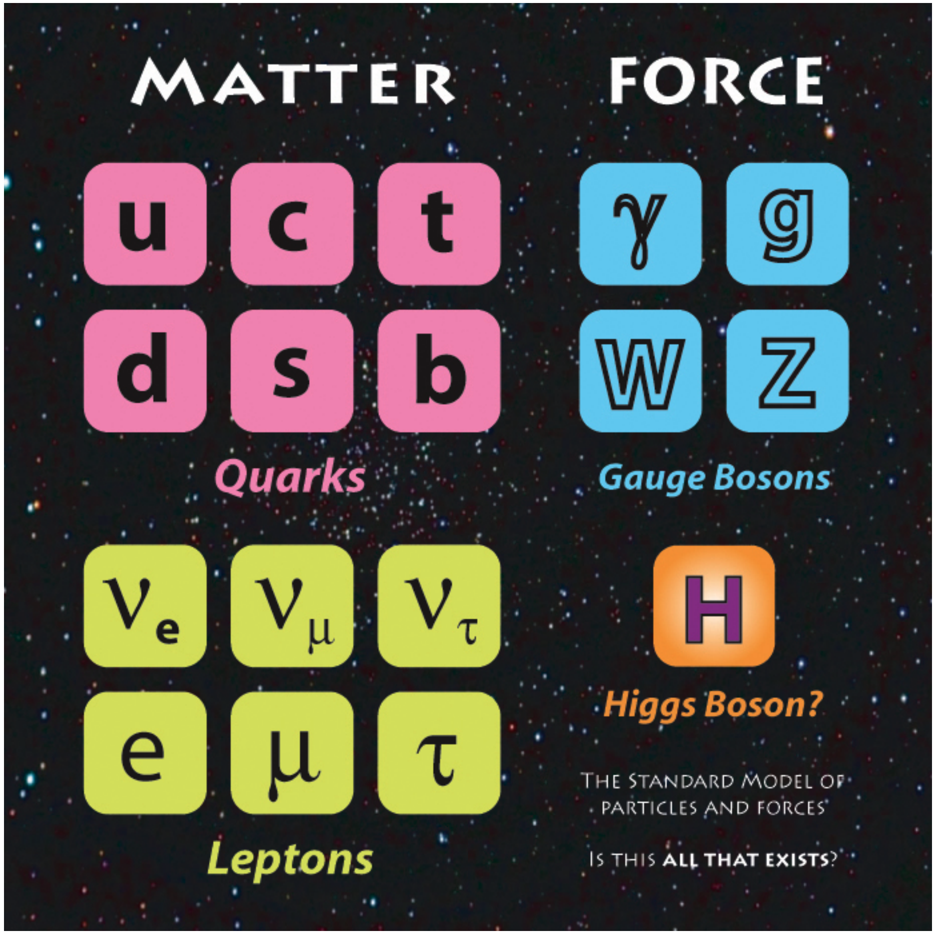
This particle gives mass to all other fundamental particles

The Standard Model of Particle Physics

Higgs Boson

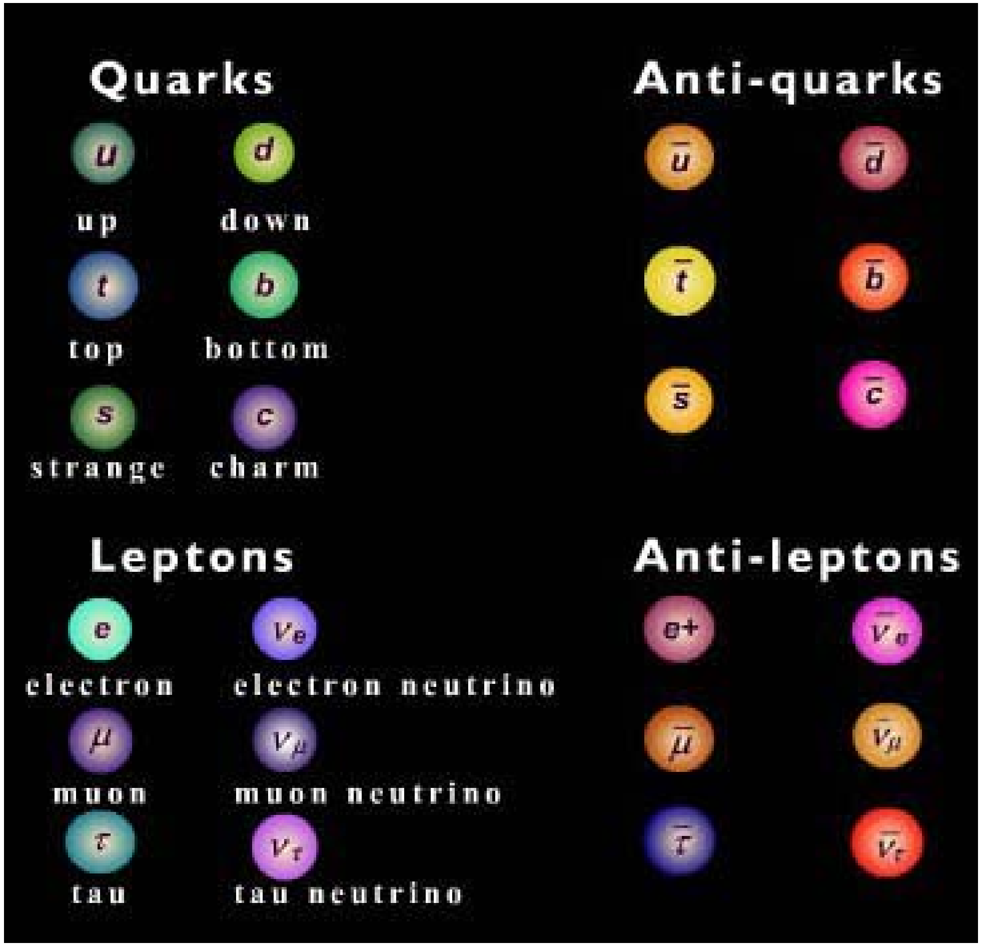
On the 8th October 2013 the Nobel Prize for Physics was awarded to Francois Englert and Peter Higgs for their contribution to the development of the theory that predicted the Higgs boson

The Standard Model of Particle Physics



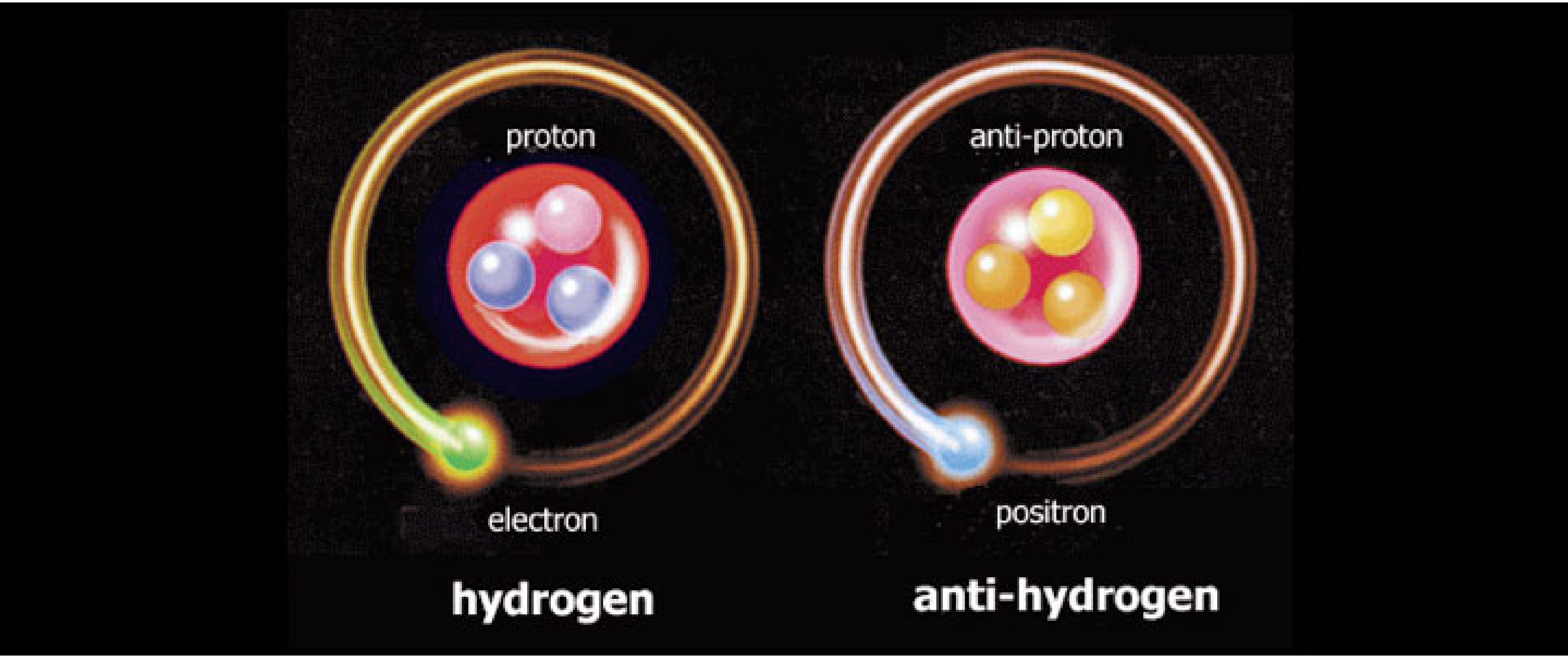
Matter and Antimatter

Antiparticles



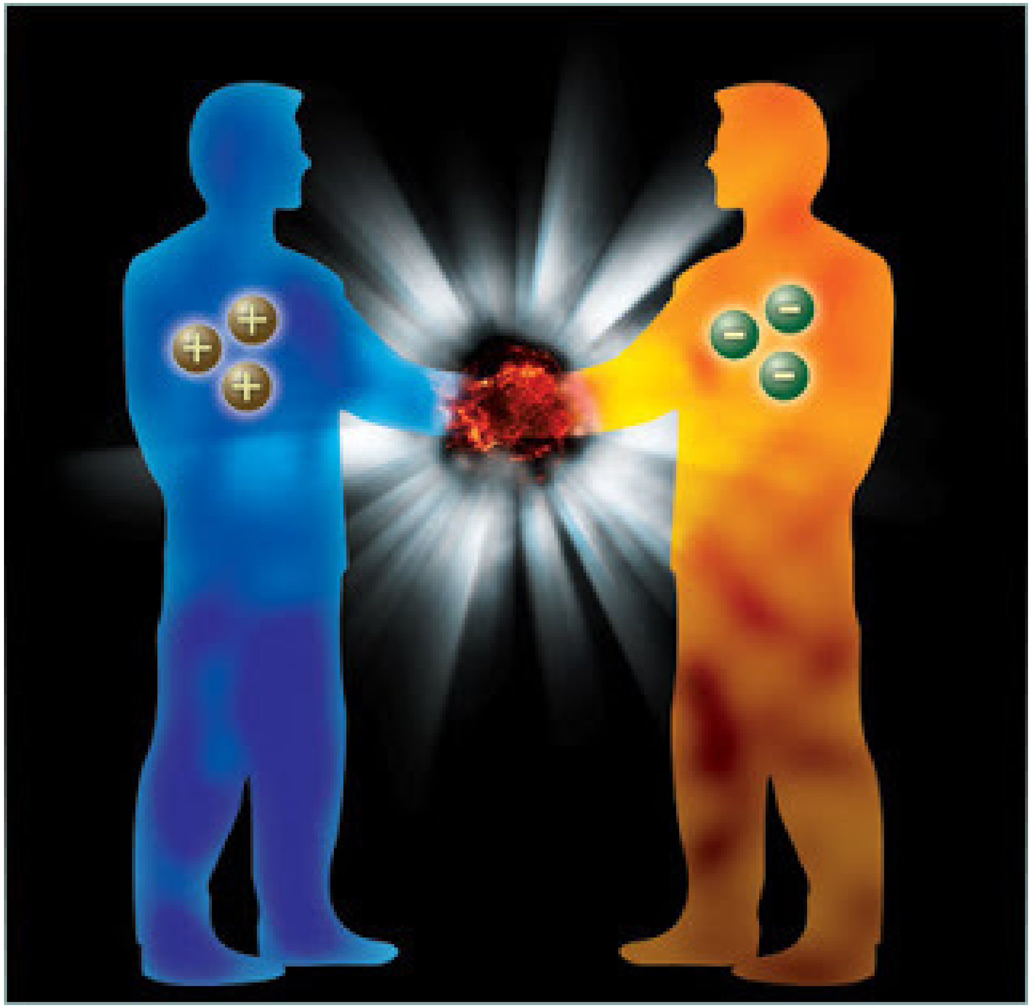
Each particle has a partner with the same mass (and other properties) but **OPPOSITE** charges

Anti Matter


proton
electron
hydrogen
anti-proton
positron
anti-hydrogen

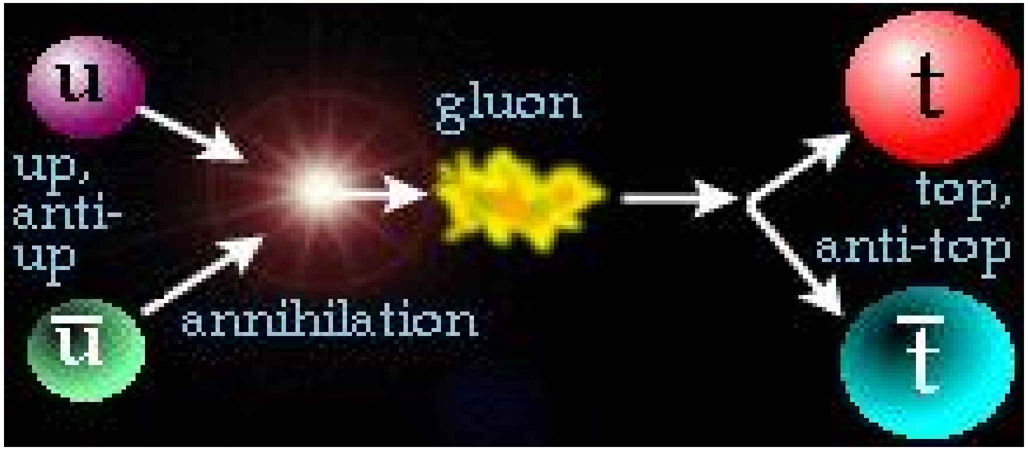
Matter and Antimatter

Anti Matter



Matter and Antimatter

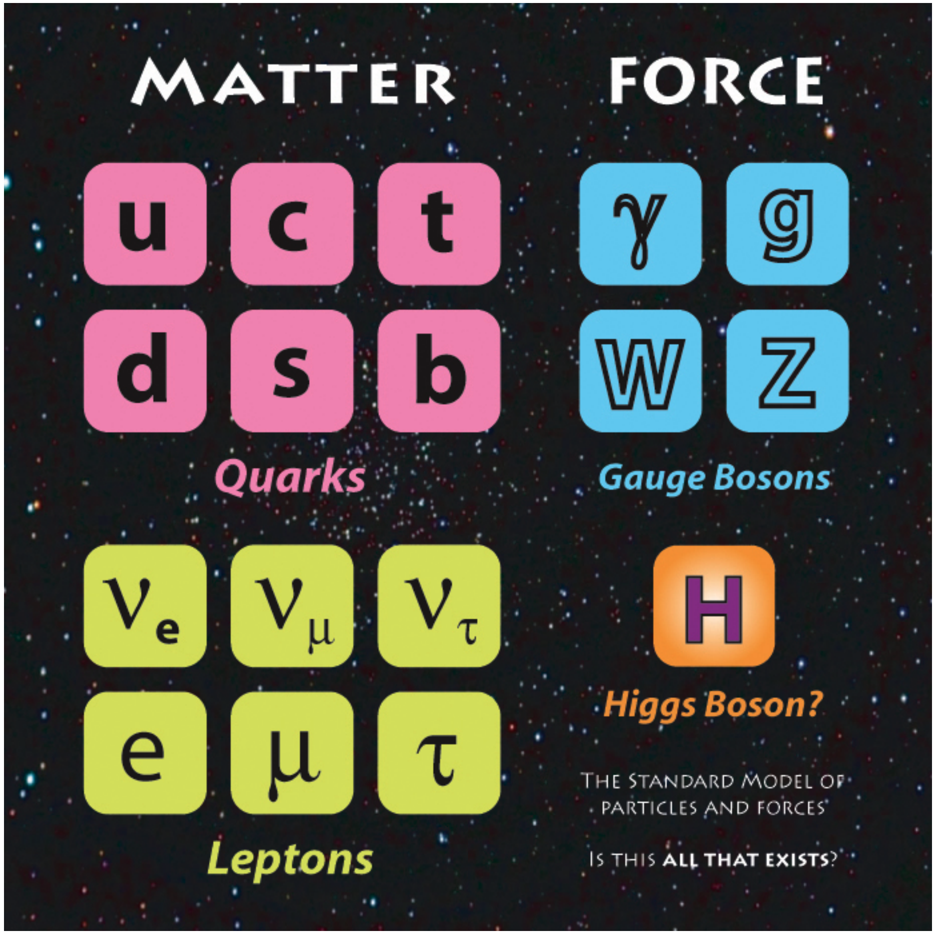
Antiparticles



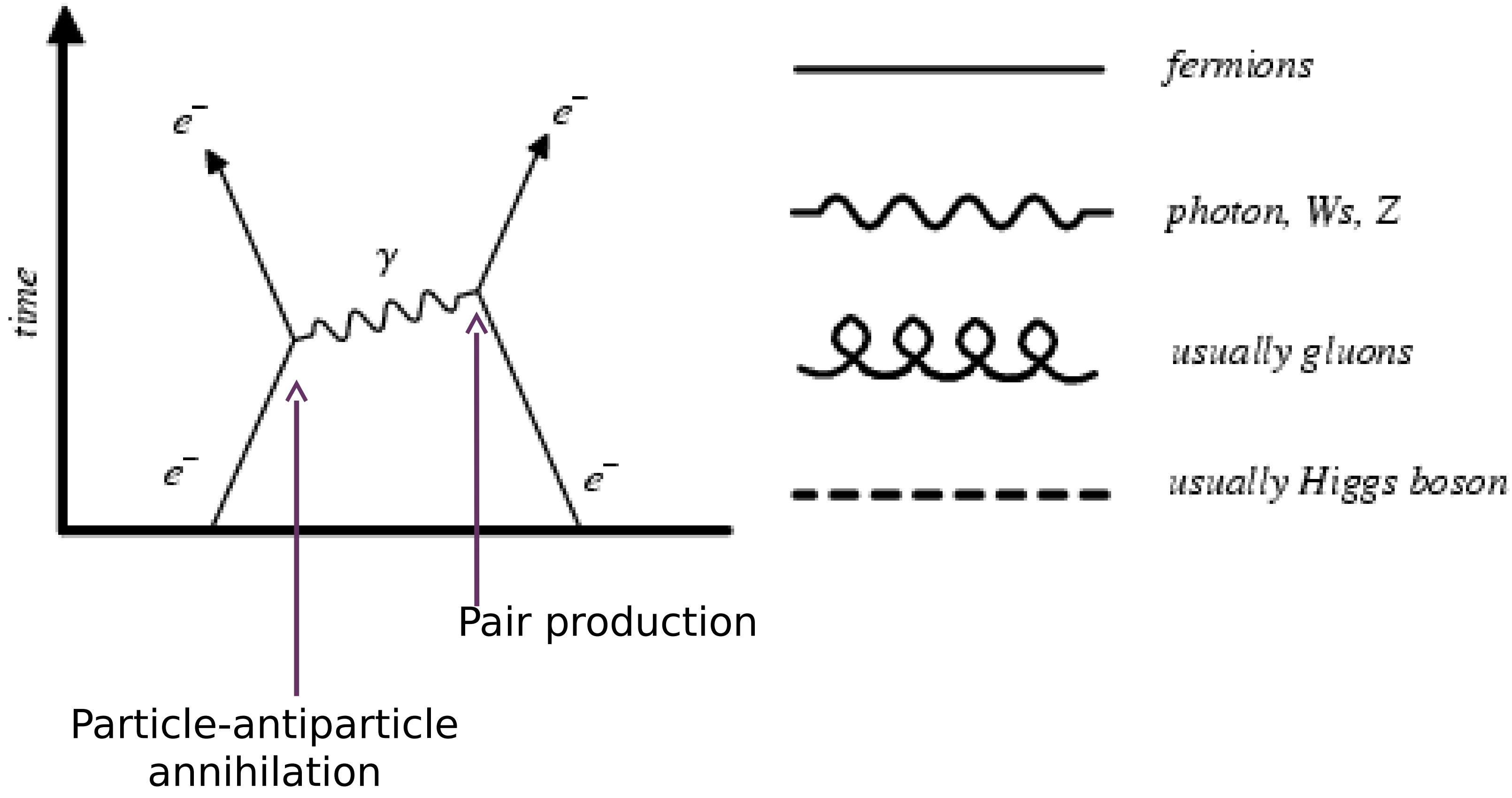
Annihilation of a particle and its antiparticle into a force mediator, a photon, gluon or W or Z

Pair Production into two new particles with opposite charge

The Standard Model of Particle Physics



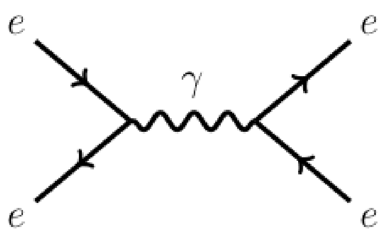
Feynman Diagrams

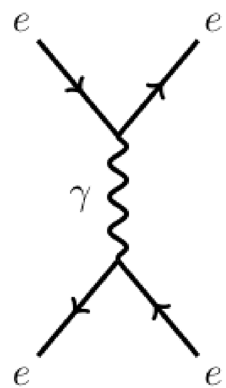


Feynman Diagrams

Electromagnetic force

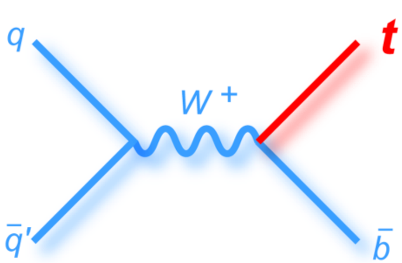
Exchange of a photon g between electrically charged particles

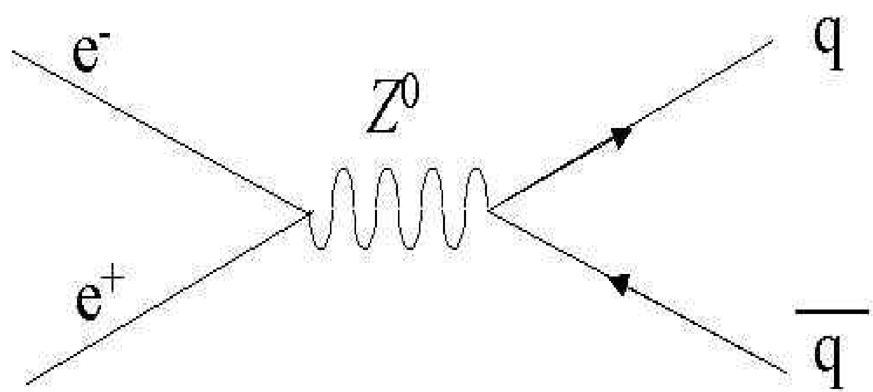




Weak force

Exchange of a W^+ W^- or Z^0 between particles

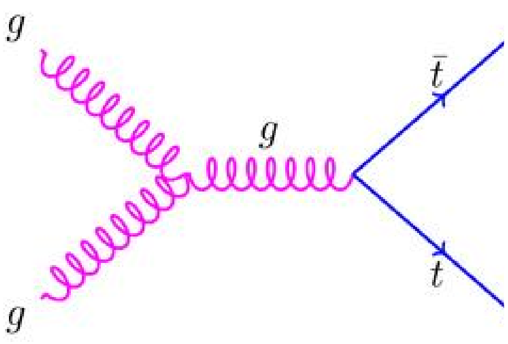


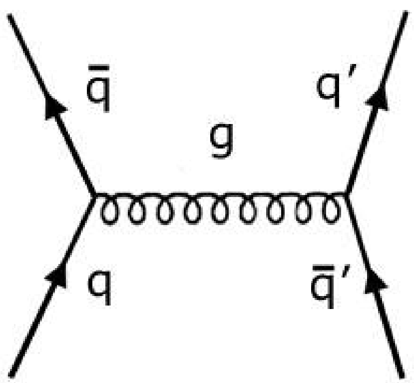


Feynman Diagrams

Strong Force

Exchange of a photon g between quarks or other gluons
This is the strongest force
And acts a little differently to the others…





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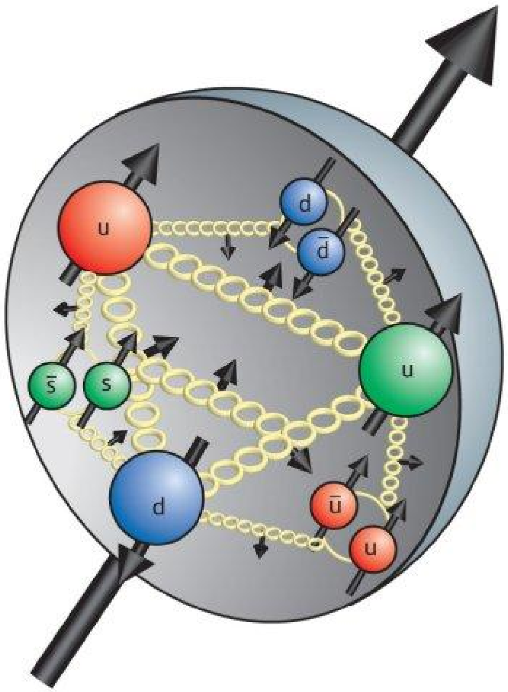
The Standard Model of Particle Physics

Strong Force

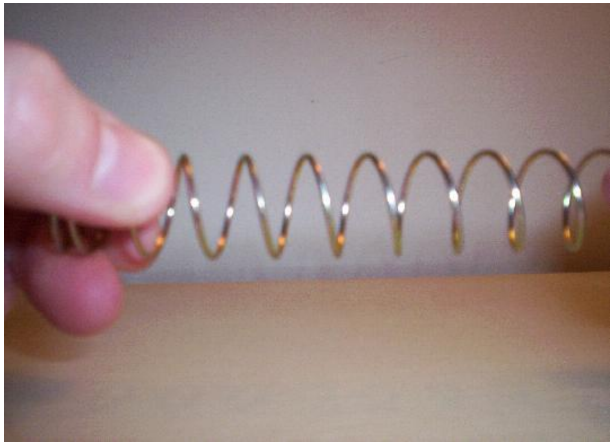
Strong force is found inside hadrons (protons and neutrons)



- The gluon ‘glues’ the hadrons together

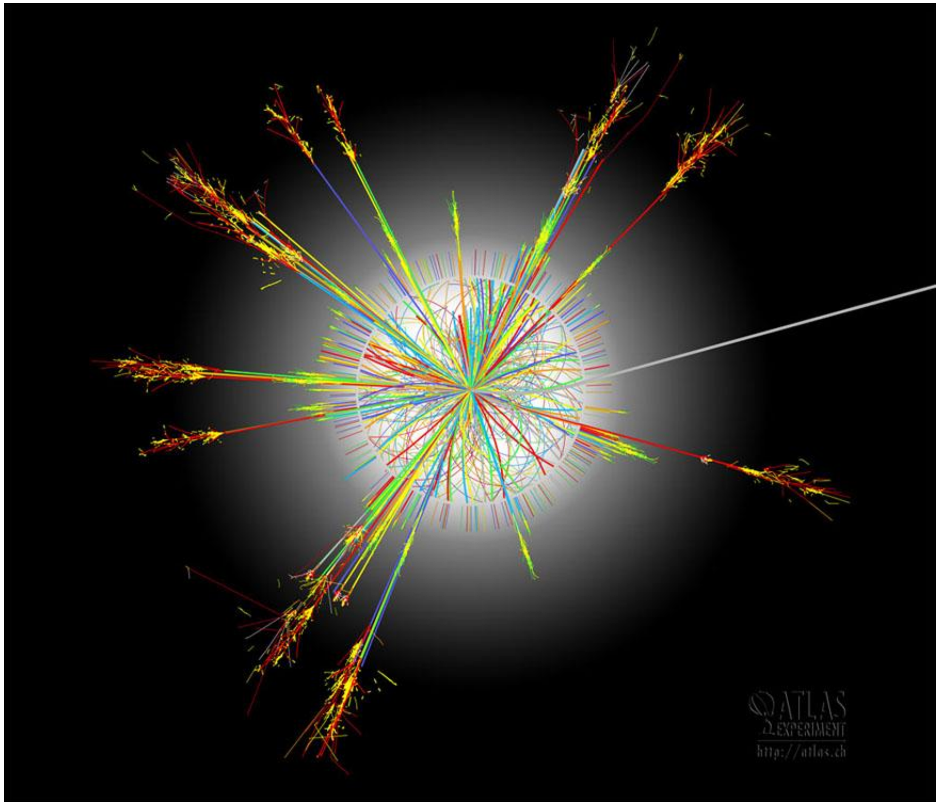
- The strong force is different because as particles get further away from one another…

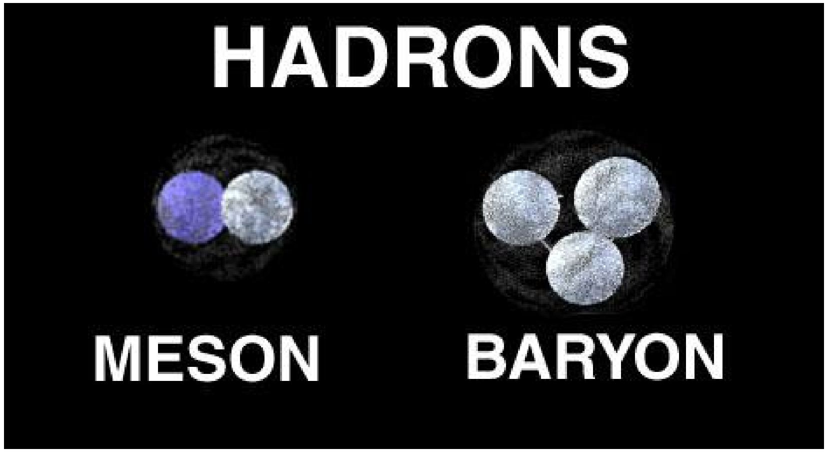
The force gets stronger!



The Standard Model of Particle Physics

Strong Force





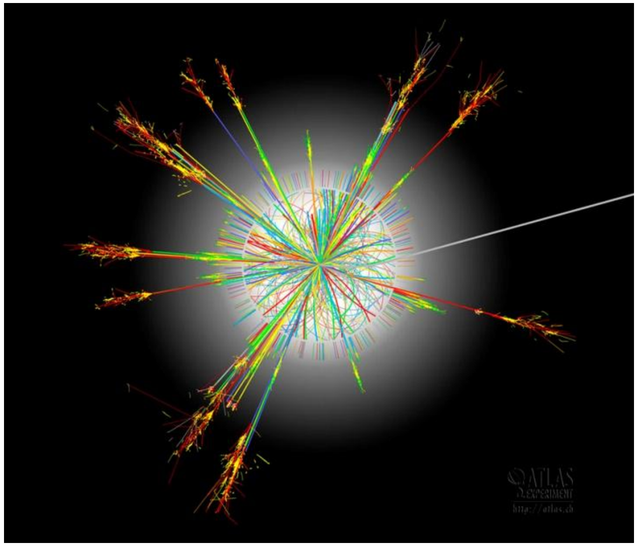
So what happens when we collide particles at high energies?

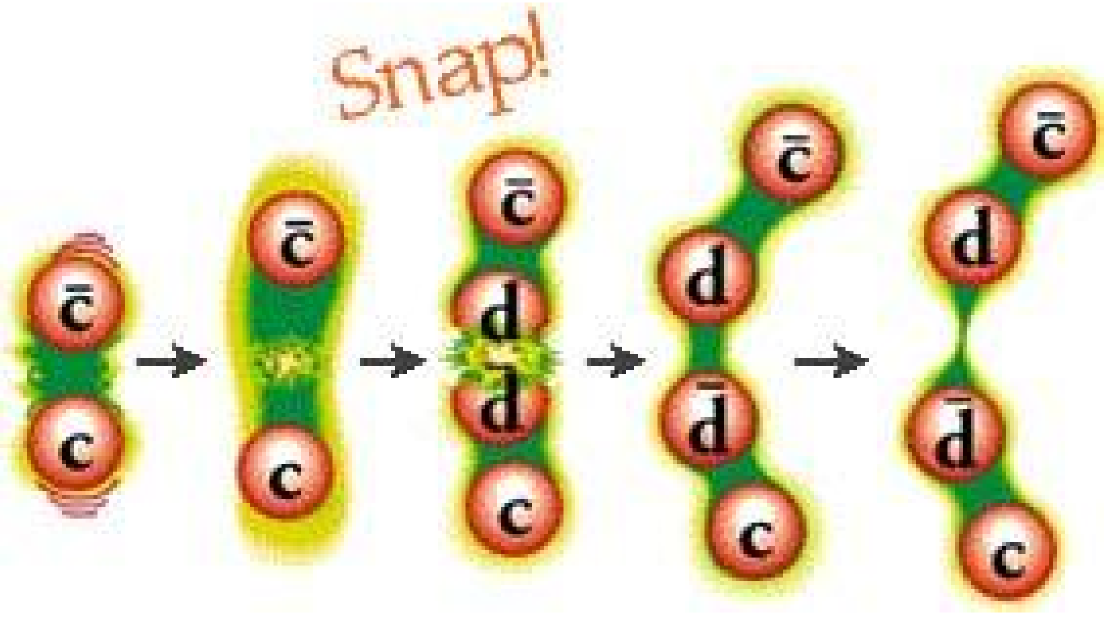
Don't we pull the quarks inside the hadrons apart?

The Standard Model of Particle Physics

Strong Force

Hadronic Jets

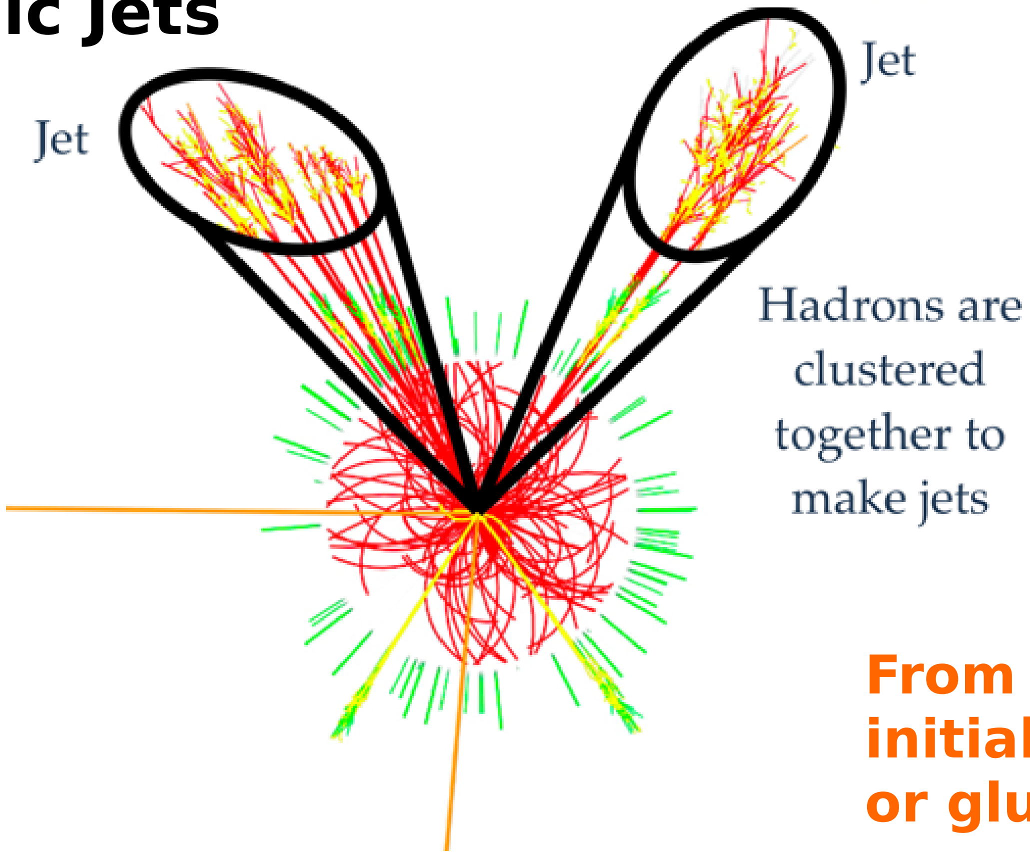




The Standard Model of Particle Physics

Strong Force

Hadronic Jets



From two initial quarks or gluons

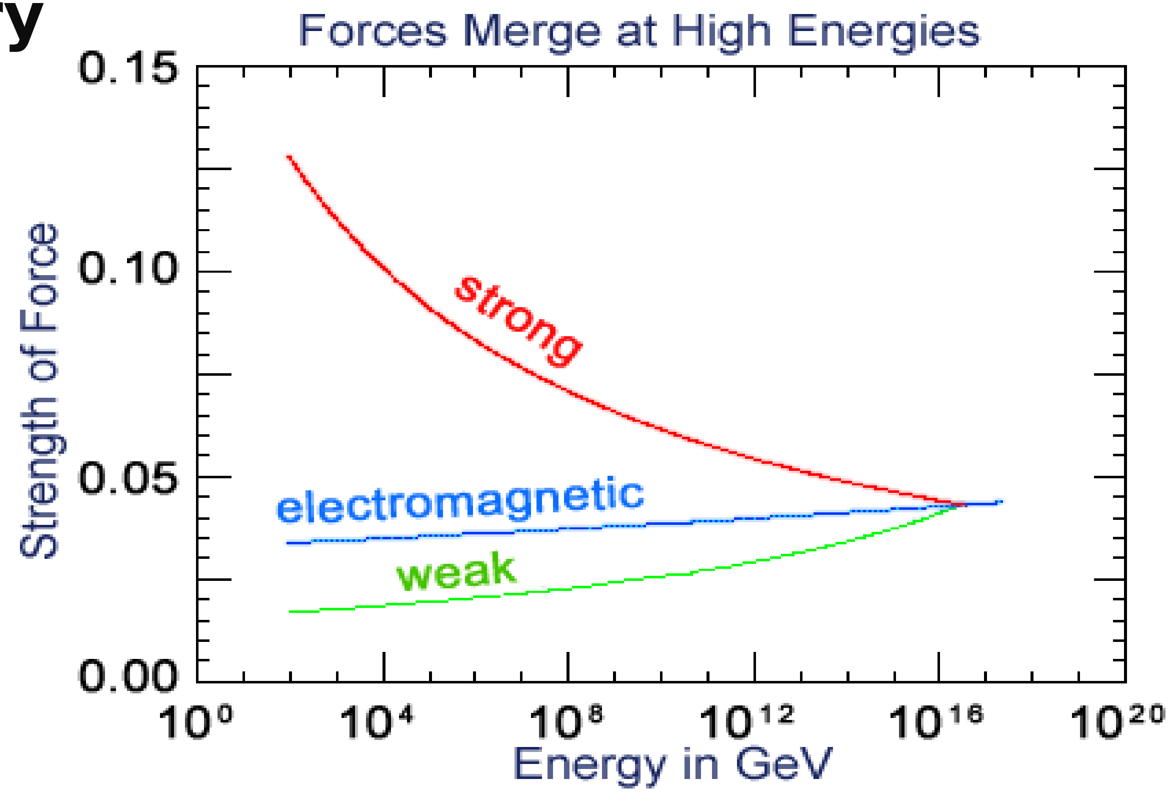
The Standard Model of Particle Physics

So, are we all done in particle physics now?

Beyond the Standard Model

Beyond the Standard Model

Grand Unified Theory



Finally we must incorporate Gravity (described by General Relativity) to form what physicists call **The Theory of Everything!**

Beyond the Standard Model

Matter Antimatter Asymmetry

The Universe we see seems to be dominantly made from matter (not antimatter)

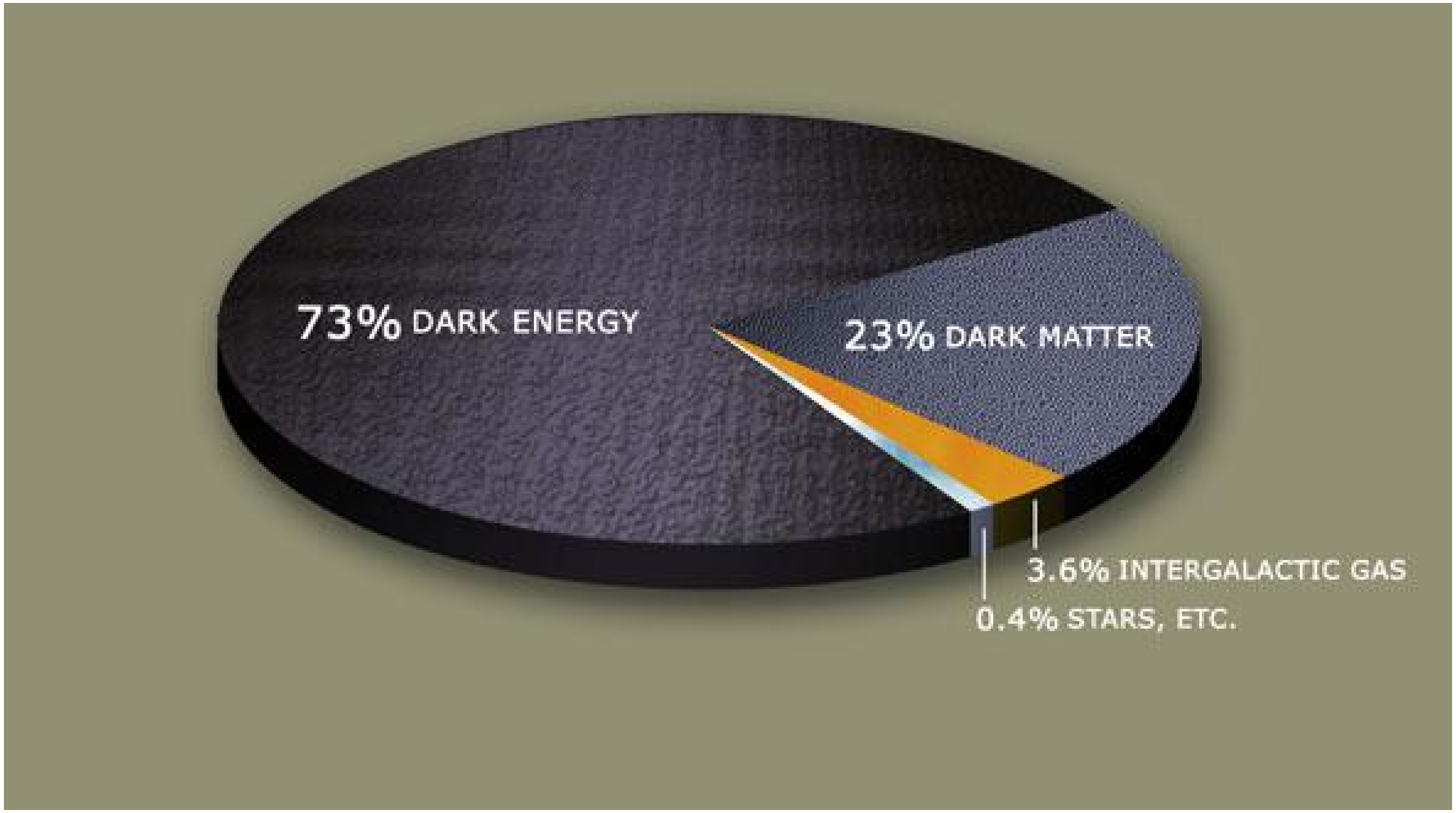
However the Standard Model predicts that they should have been created in equal amounts....

which would have annihilated each other as the Universe cooled

Beyond the Standard Model

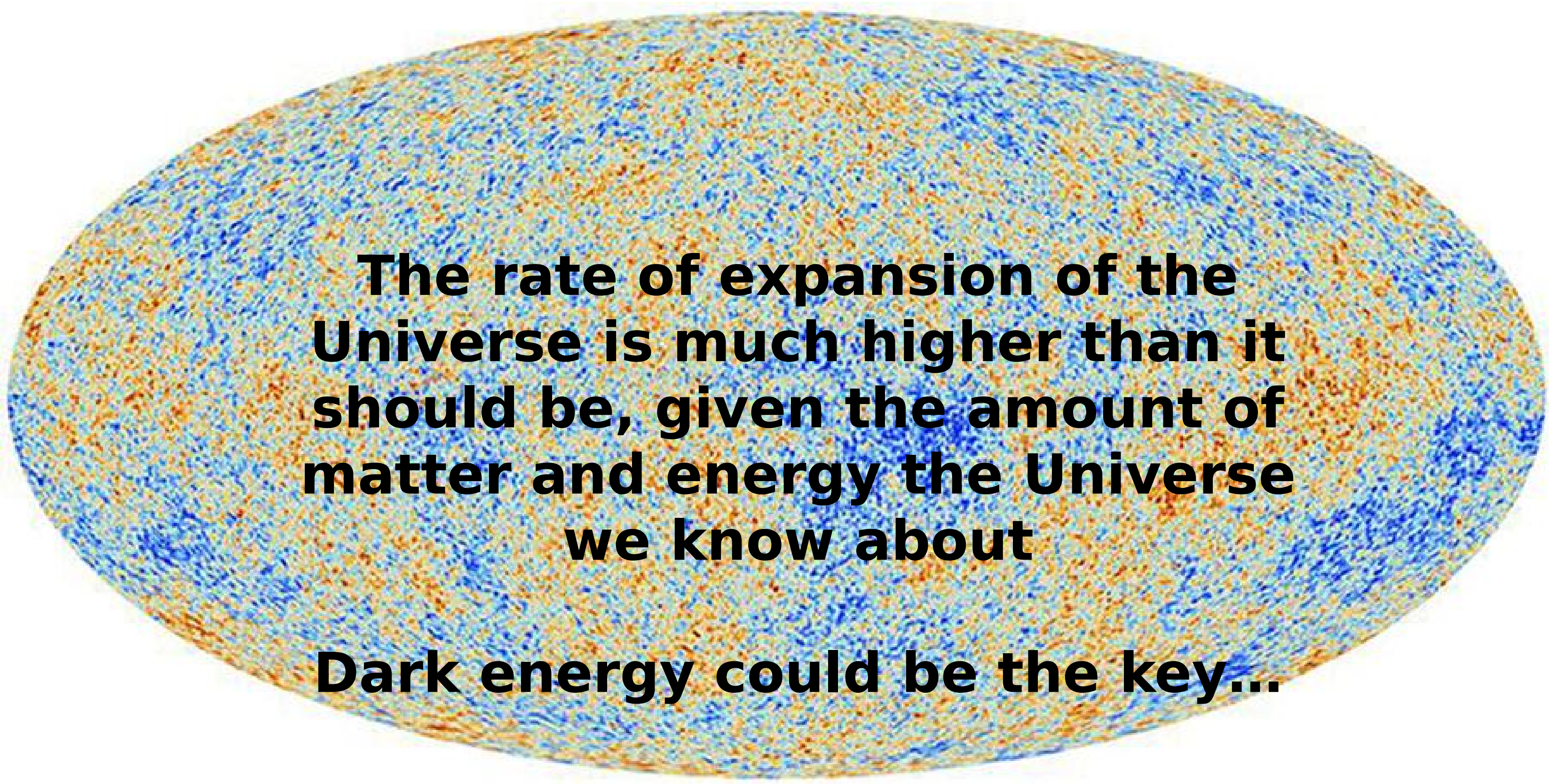
Dark Energy and Dark Matter

Cosmological observations have shown that the Standard Model explains only ~4% of the energy of our Universe!



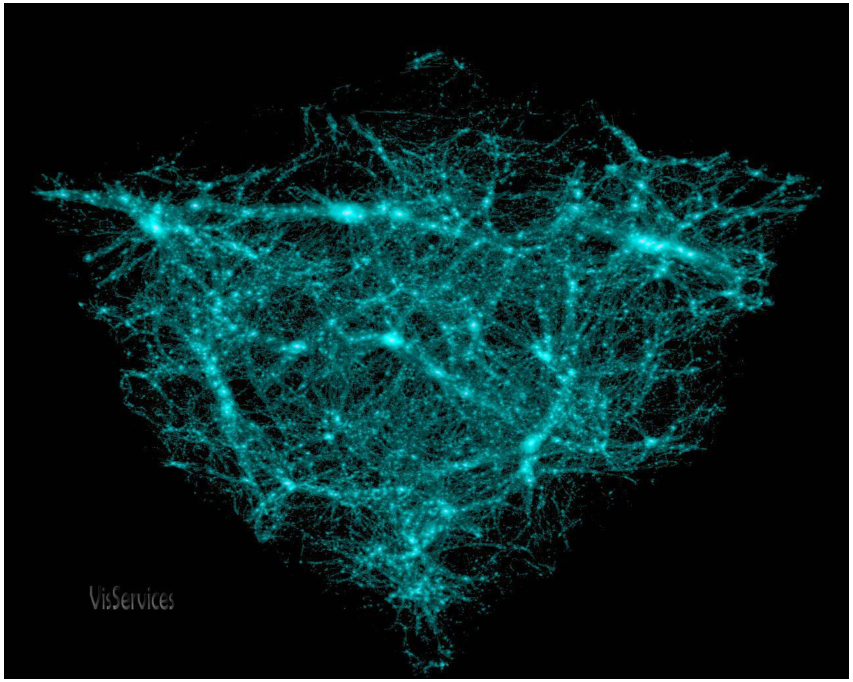
Dark Energy

Planck Telescope map of the universe



Dark Matter

By studying Galaxy motion Cosmologists have estimated there should be *~23% of matter in the Universe that we cannot see*



…meaning that it does not interact electromagnetically (give off light)

Thus it feels the gravitation force and weak force only (weakly interacting)

Beyond the Standard Model

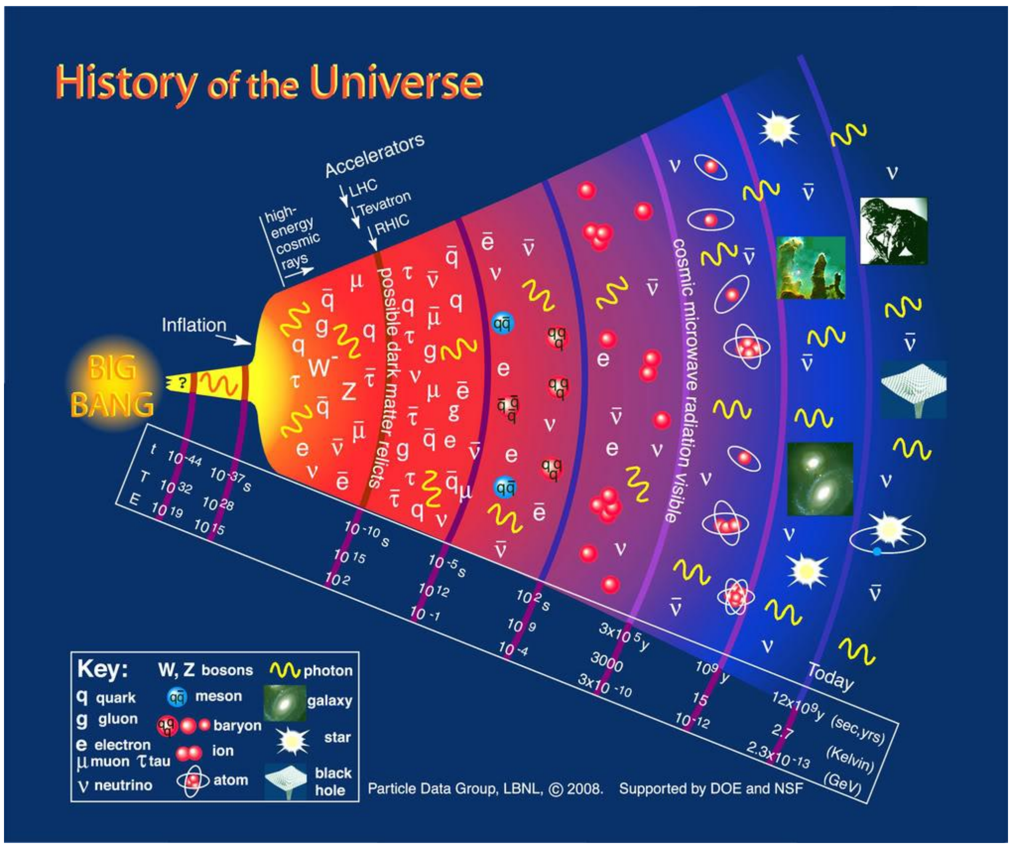
Dark Matter

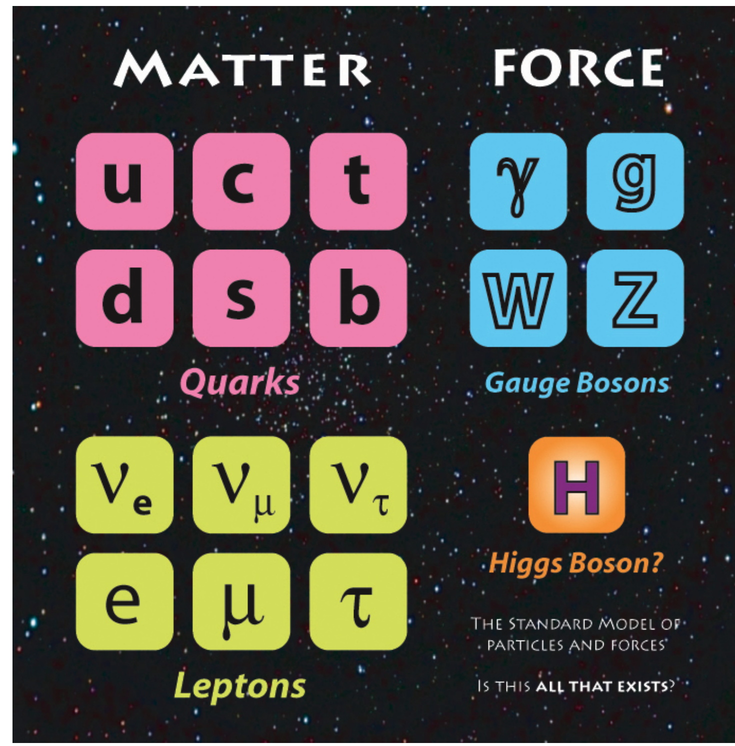
We are looking for Dark Matter in lots of underground experiments

And hoping to find it at the LHC…

It could be a Supersymmetric particle!

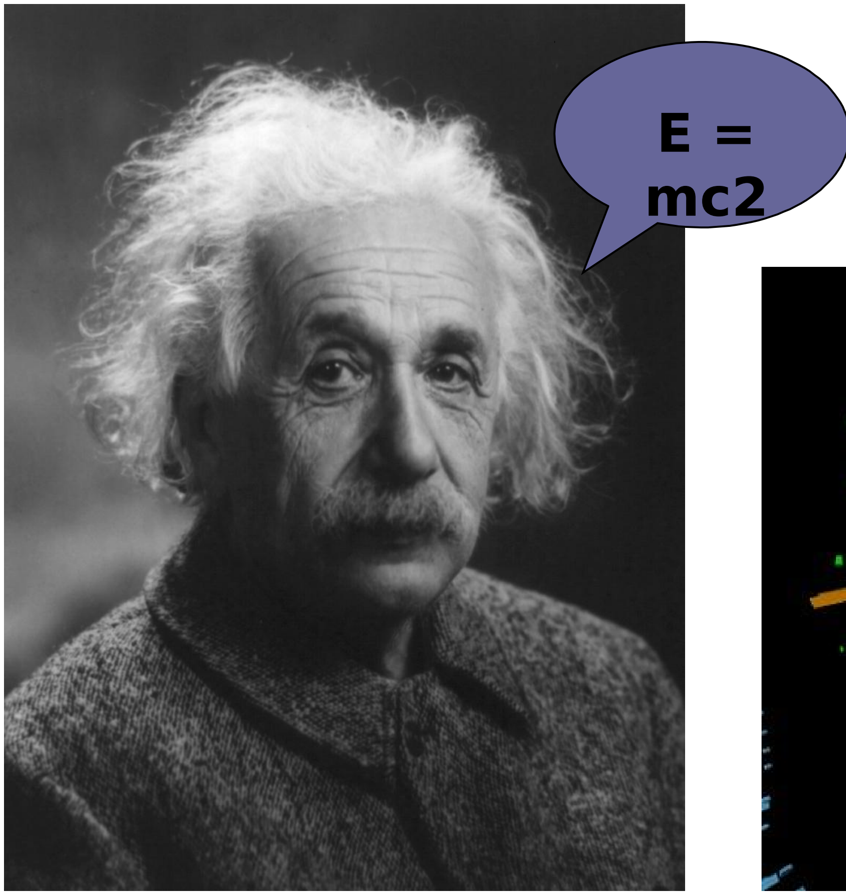
Finding New Particles



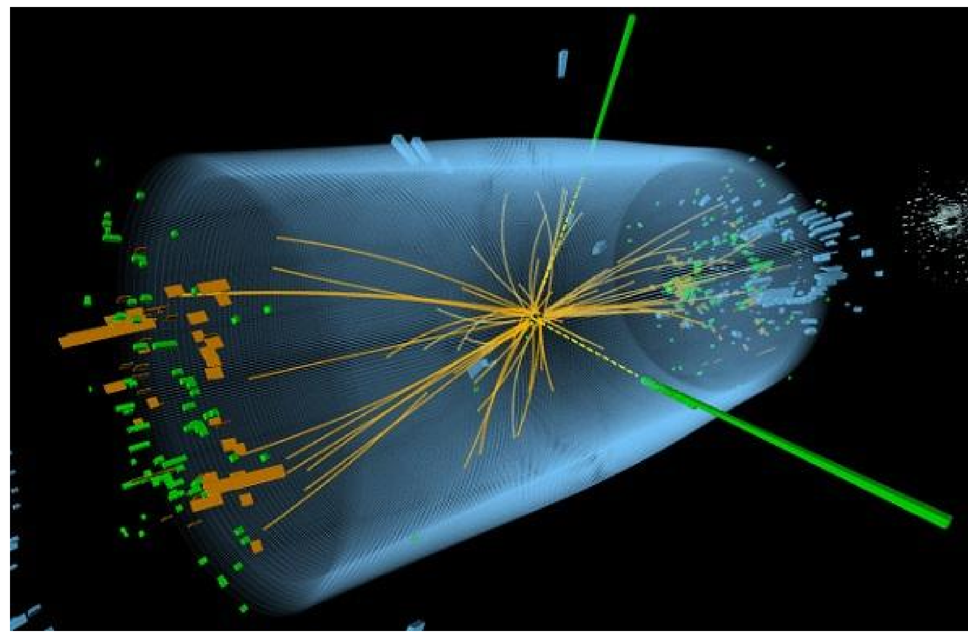


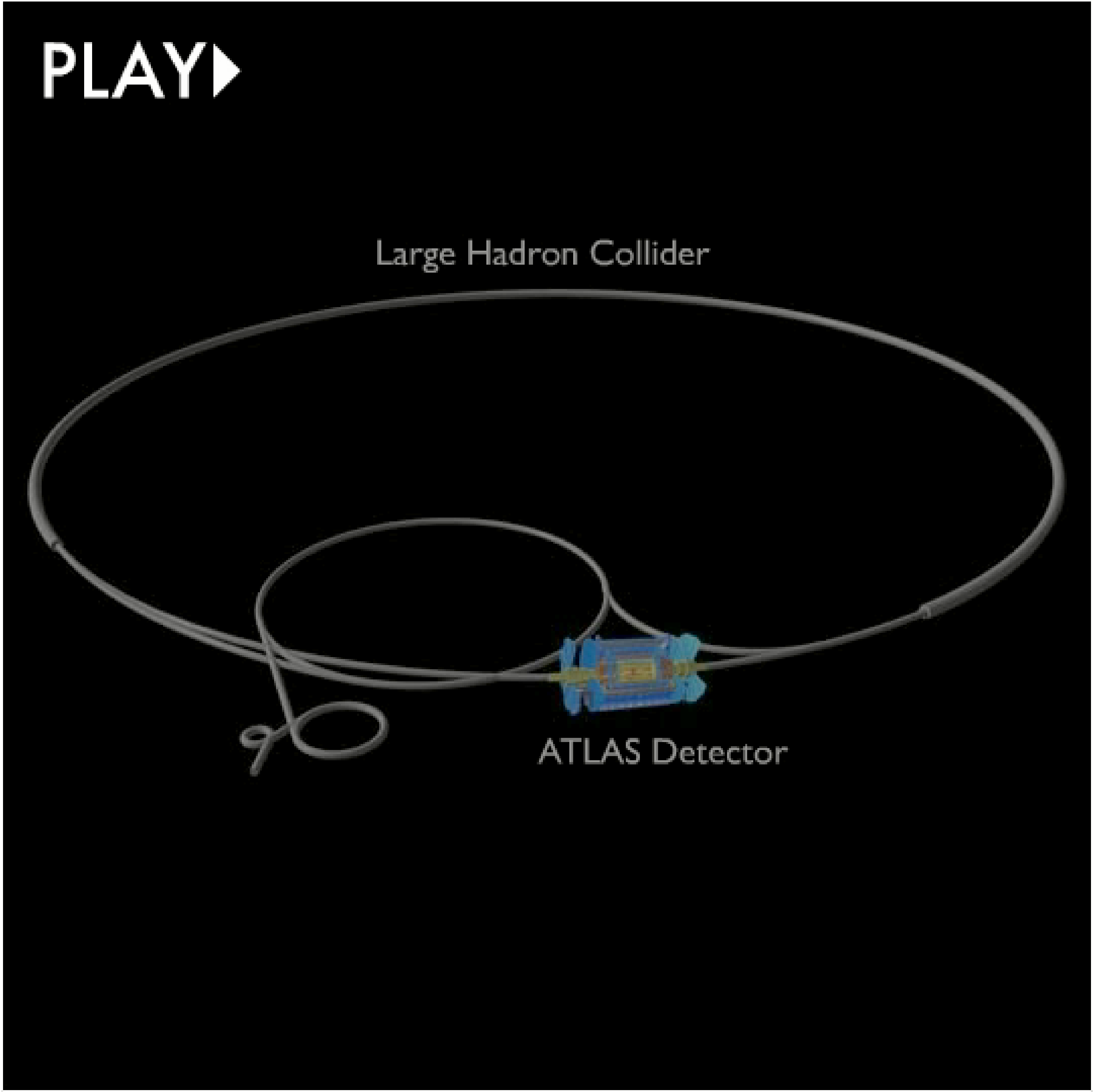
Finding New Particles

Colliding Particles



By using particle accelerators to collide particles together at **higher energies** we can provide more energy to make more massive particles

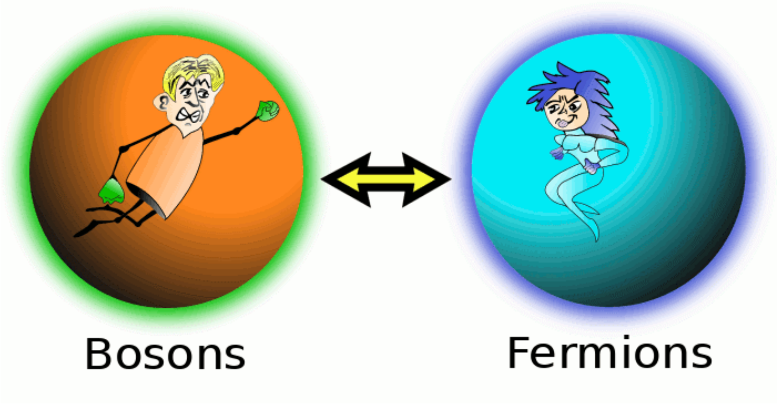


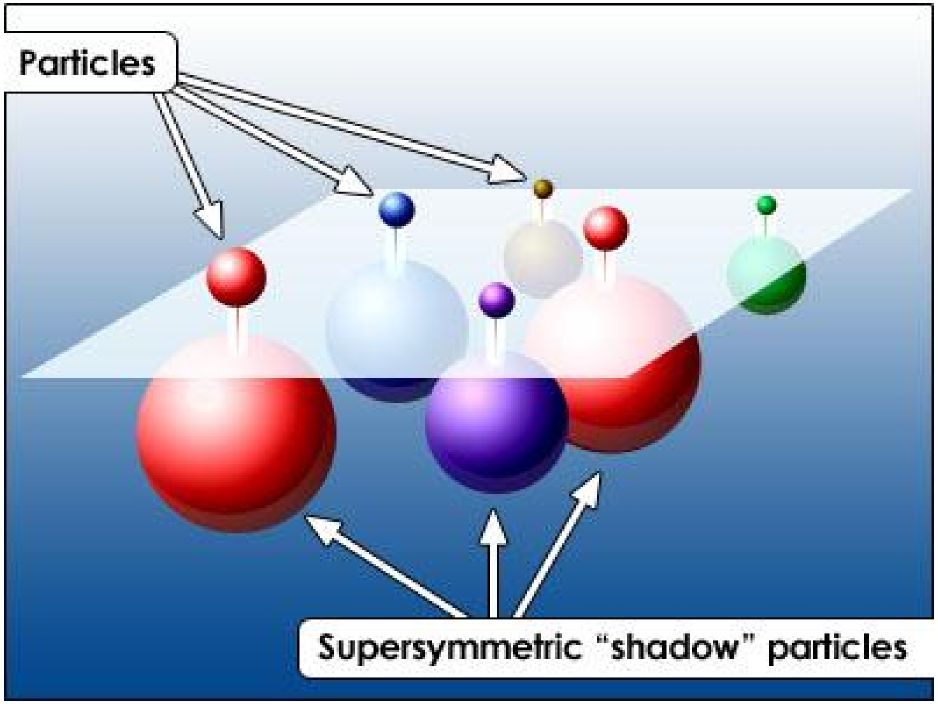

PLAY
Large Hadron Collider
ATLAS Detector


THANK YOU!

Supersymmetry

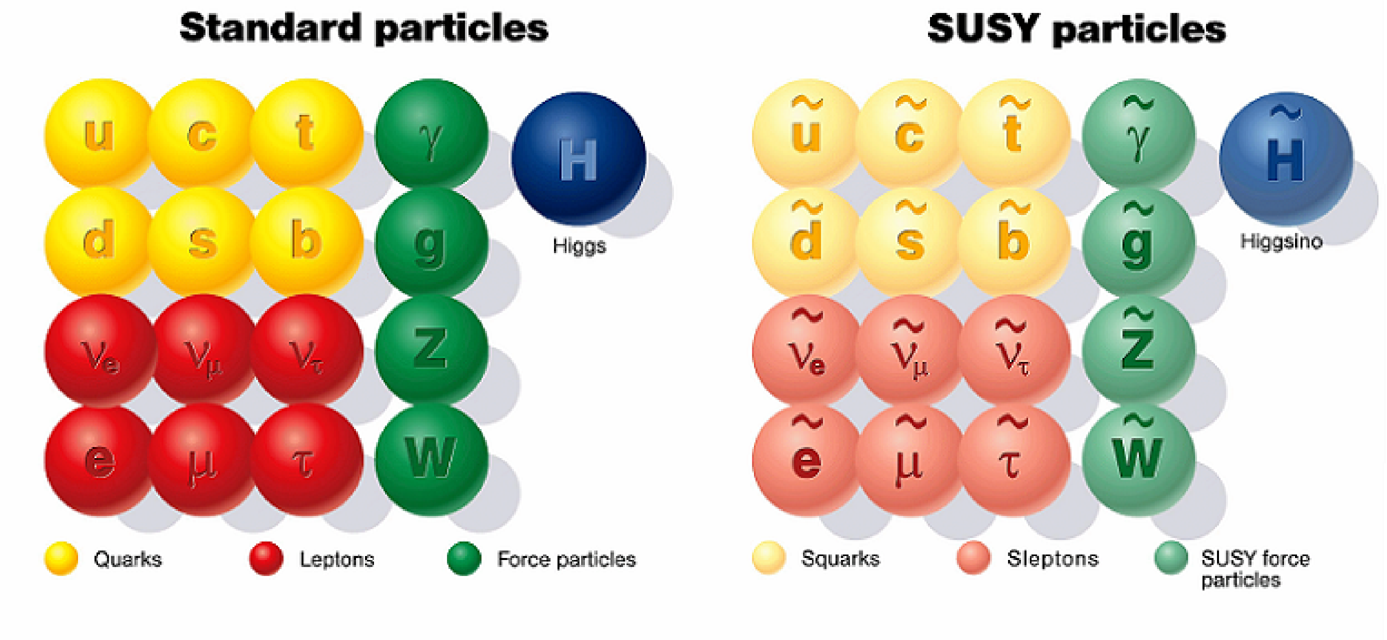
Supersymmetry proposes that every fundamental particle, has a supersymmetric partner with the same properties except its **SPIN**





Physics Beyond the Standard Model

Supersymmetry

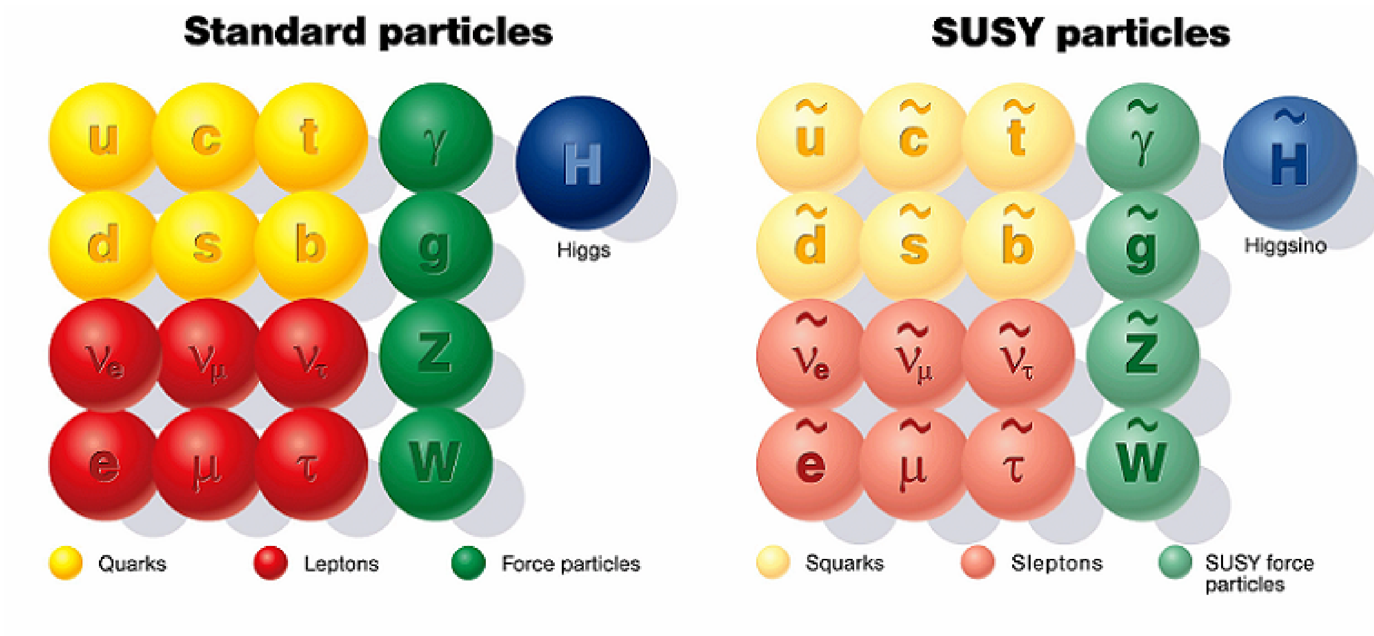


However… none of the particles we know about, using the particle accelerators, could be superpartners of other particles

The symmetry must be broken

Physics Beyond the Standard Model

Supersymmetry



- Thus superparticles must be **MASSIVE**

- And they must only be **weakly interacting**

A Good Candidate for Dark Matter!!!

- We have to search higher energies to find them!

Recent events about CERN