An Introduction to Standard Model of Particle Physics

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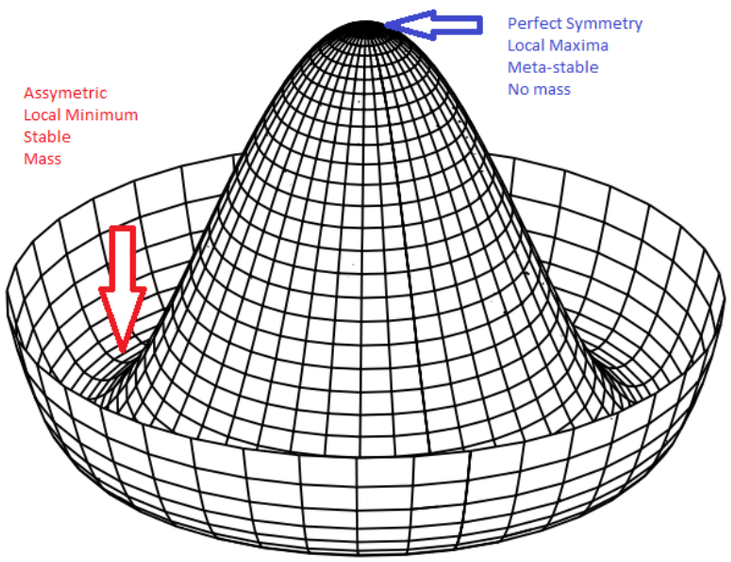
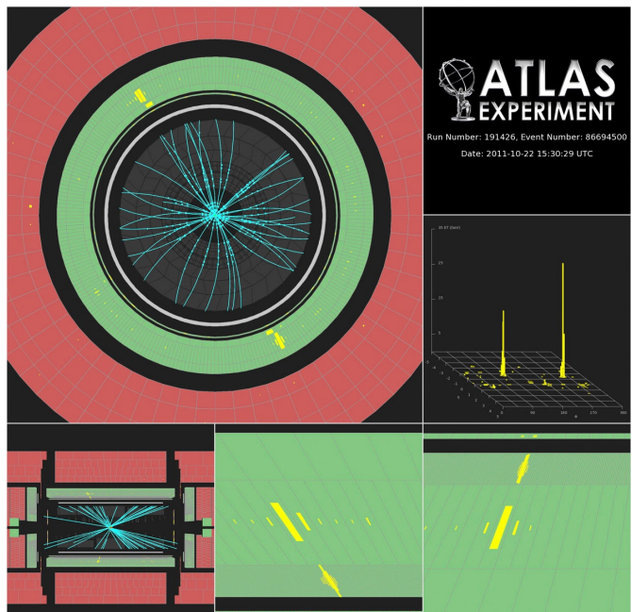
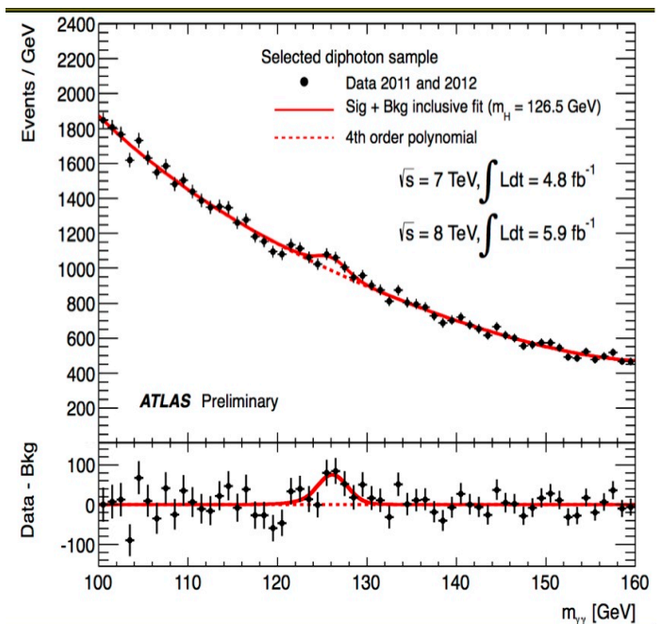
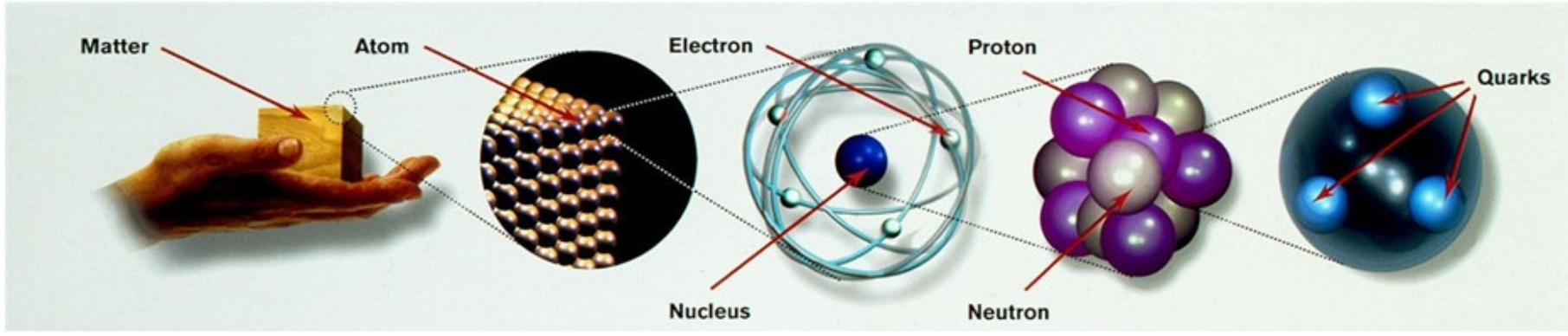






Elementary Particles



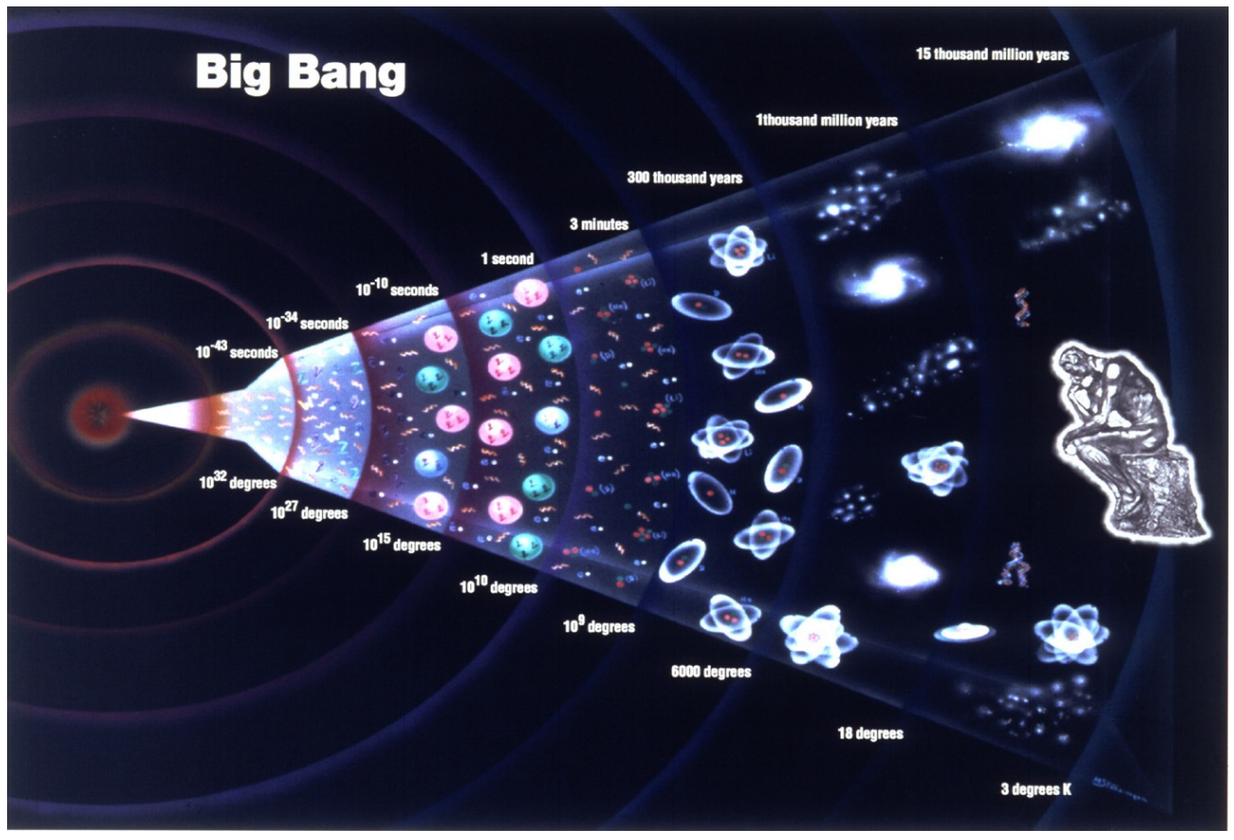
Elementary particles cannot be broken down

Truly point like particles

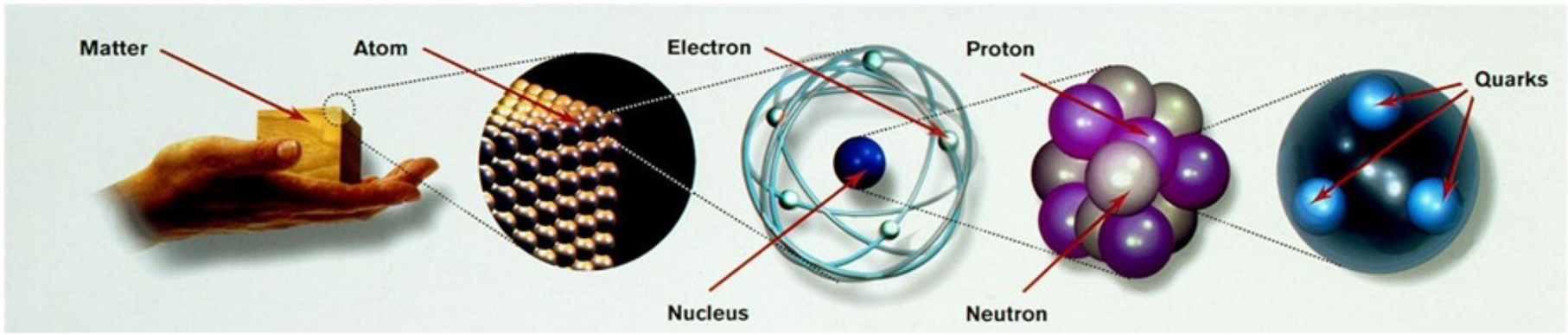
- Form the basic structure of all **matter**
- Are the **force carriers** of the fundamental interactions

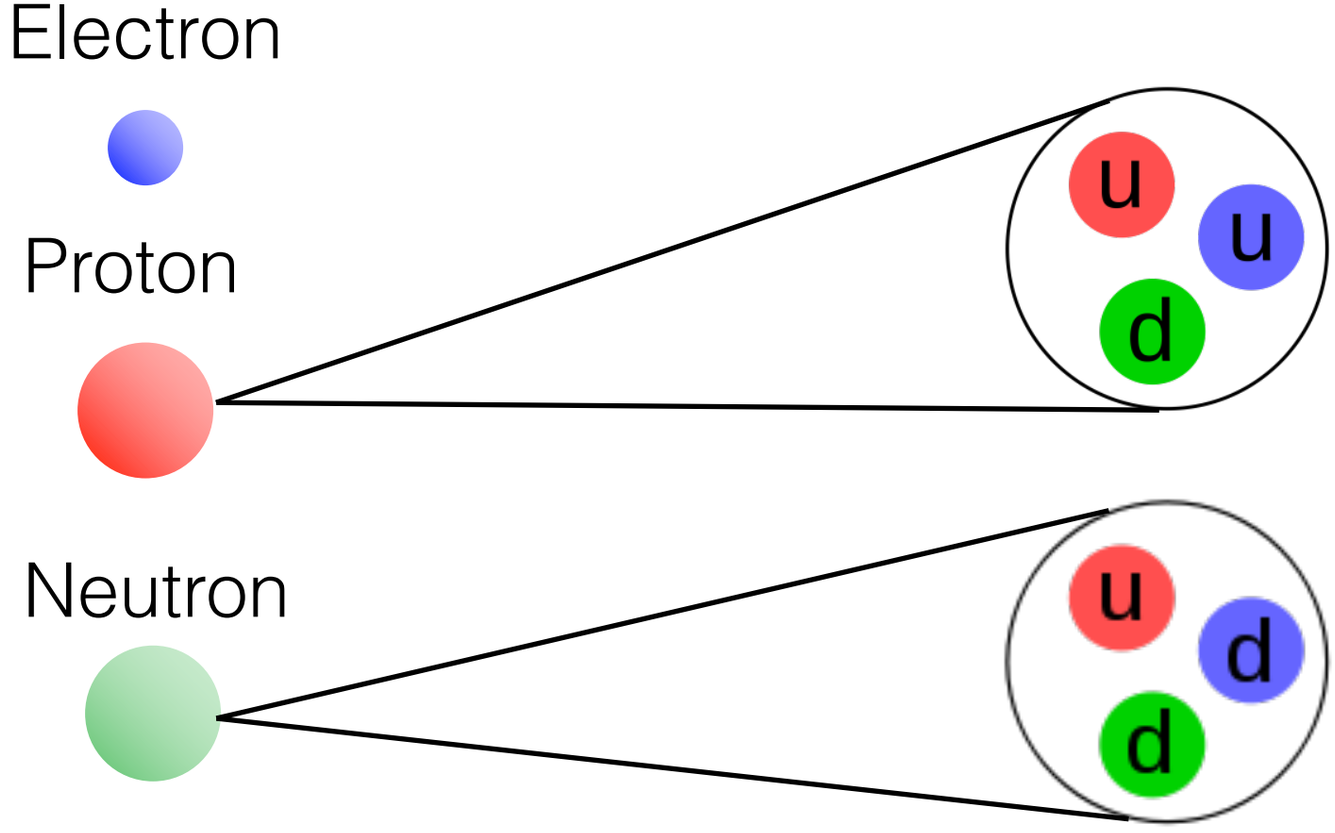
The Universe Started with a Big Bang

- The universe started ~13.8 billion years ago with a big bang
- It was a super hot universe
- Only elementary particles existed
- As time evolved the universe expanded and cooled down
- Energy converted into matter



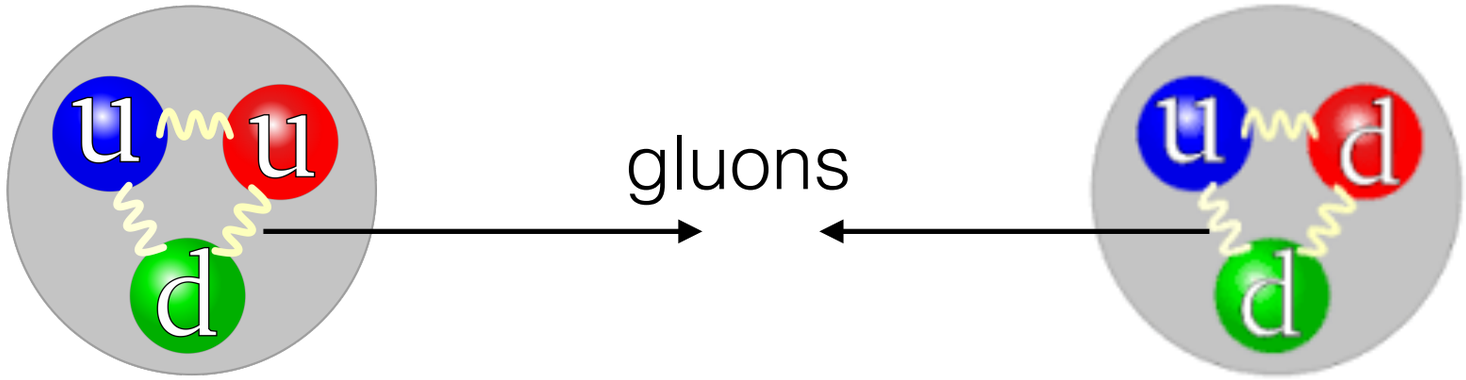
Ordinary Matter





- Protons and neutrons are composite objects, made of:
  - **valence quarks** (uud, udd)
  - gluons
- Particles composed of quarks are called **hadrons**

Inside Hadrons



Proton:

- Up quark(charge +2/3)
- Up quark(charge +2/3)
- Down quark(charge -1/3)

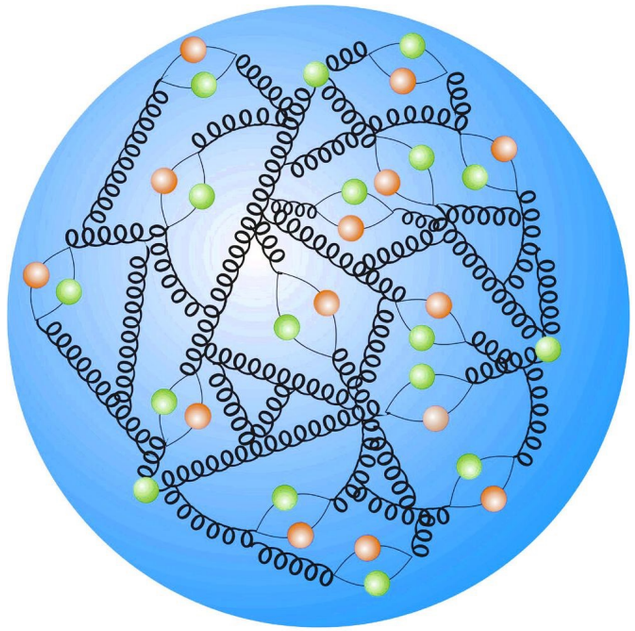
Neutron:

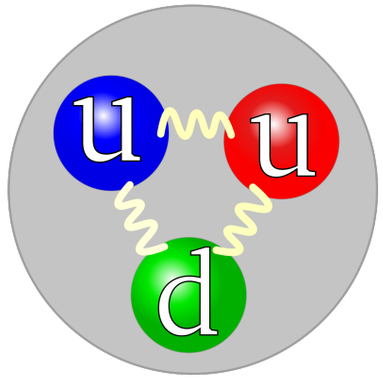
- Up quark(charge +2/3)
- Down quark(charge -1/3)
- Down quark(charge -1/3)

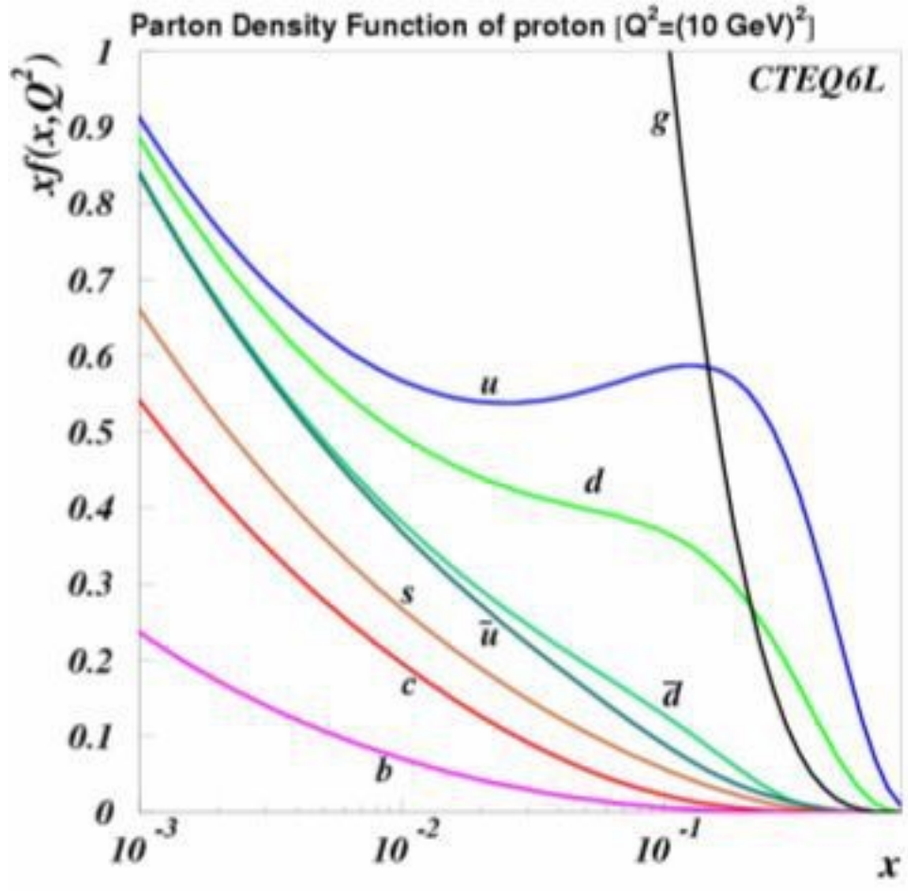
- Quarks have three colours (quantum charges)
- What is the electric charge of the Proton? unit?
- What is the colour of the proton?

Inside Hadrons

Proton





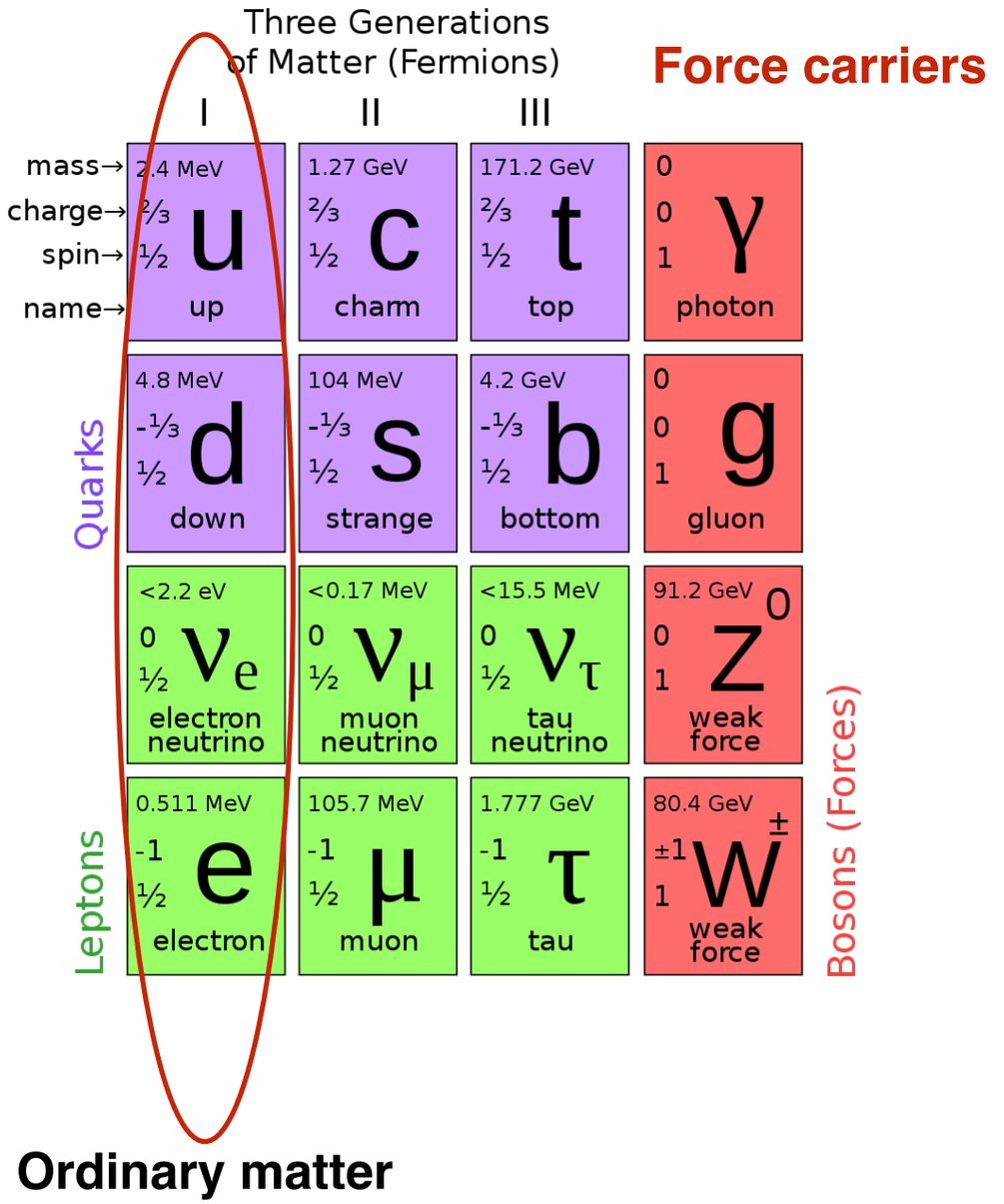


- **Quarks** and **gluons** collide with each other and produce more quarks and gluons
- **Sea** of quark and antiquark pairs
- Most of the body **mass is pure kinetic energy** of the proton constituents!

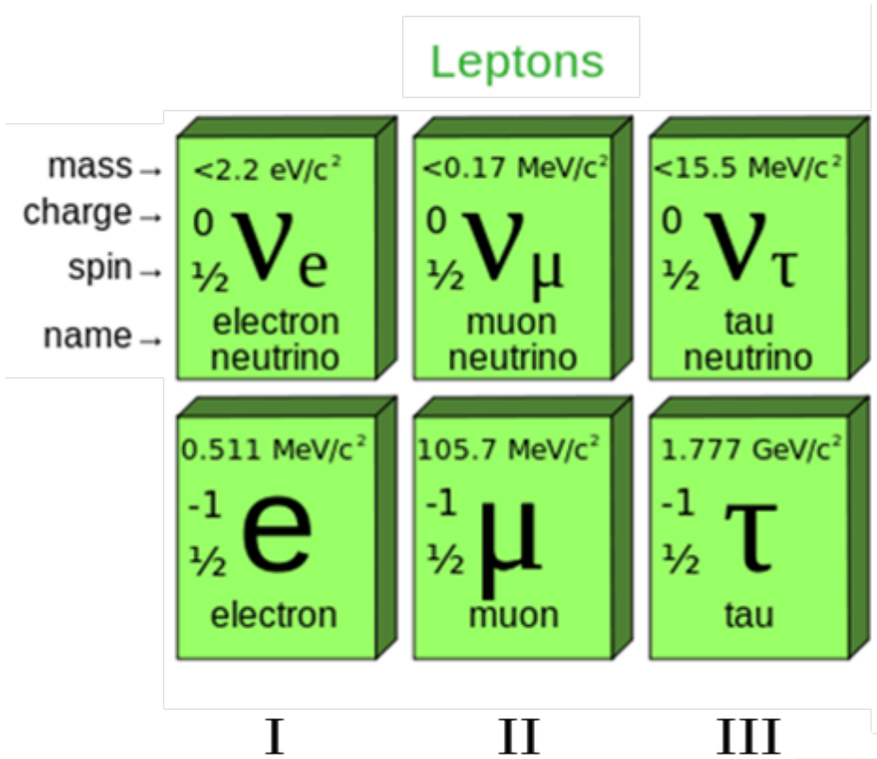
$$E^2 = M^2C^4 + P^2C^2$$

Elementary Particles

- Spin 1/2 particles called fermions:
  - **Quarks**
    - electric charge 2/3 or -1/3
    - three colours
      - cannot be found isolated in nature, must exist as **Hadrons** in groups of **TWO** (**Mesons**) or THREE (**Baryons**)
- **Leptons**:
  - neutrinos, **electrically neutral**
  - **charged leptons**, -1



Leptons

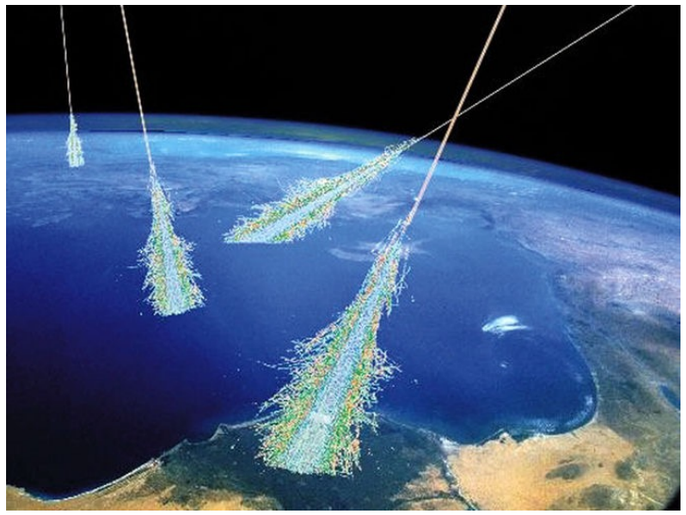


- Neutrinos, electrically neutral
  - almost massless
- Charged leptons, -1
  - only electrons are stable,

    muons and tau-leptons are unstable:

    Muon (μ) lifetime = 2×10^{-6} s

    Tau (τ) lifetime = 3×10^{-13} s
  - much heavier than electrons

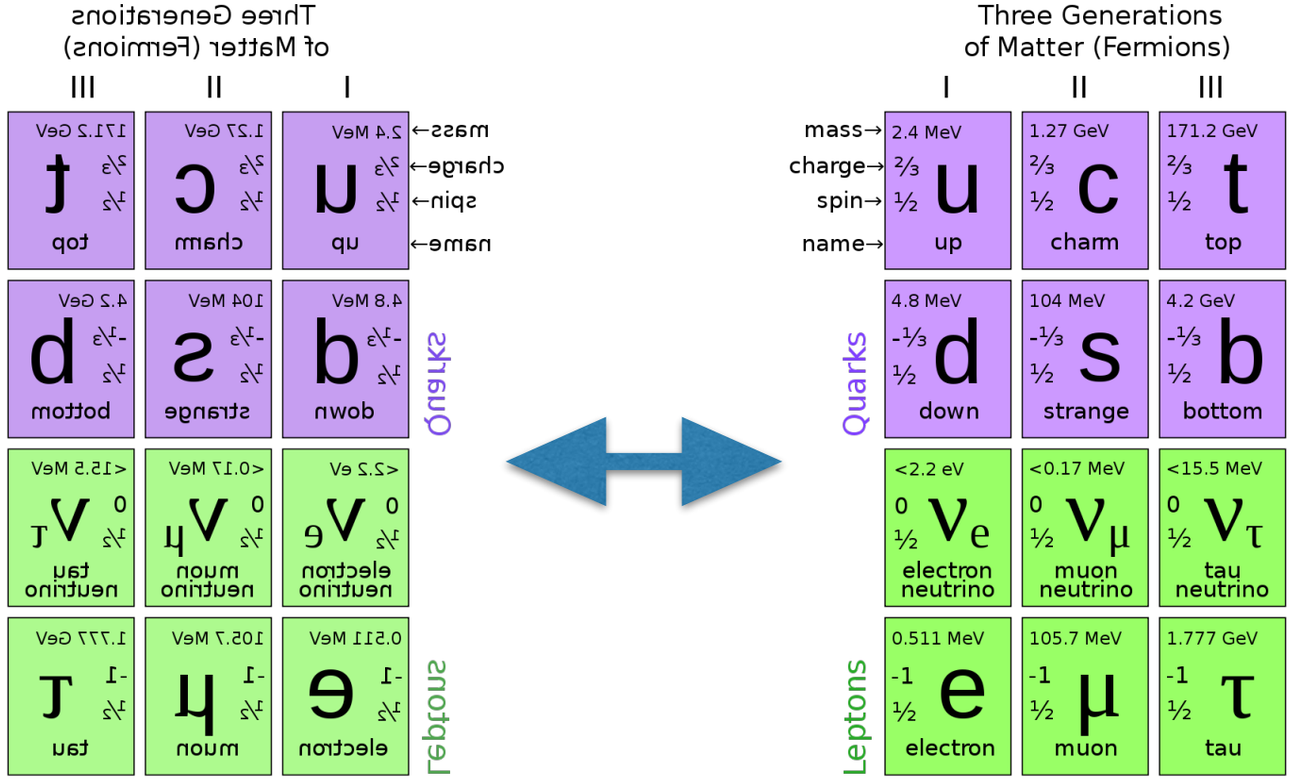


- muons are produced when cosmic rays hit the atmosphere (15 km above the earth surface, **How can muon arrive the earth with the very short lifetime?!**

  1 muon/sec/cm² hit your body

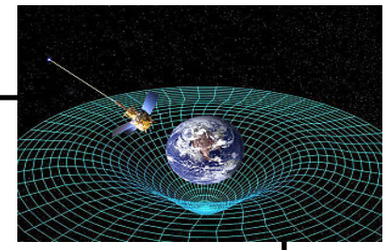
Antimatter

- For every elementary particle there is an anti particle



- Anti particles are exactly the same as particle except the charge
- What is the difference between neutrinos and anti neutrinos?!

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

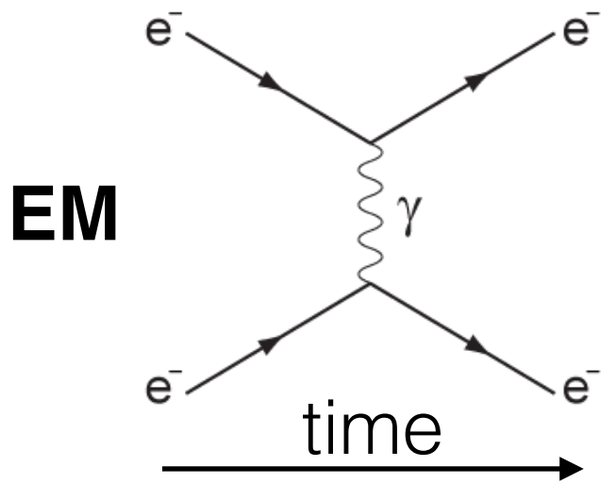
Force Mediators

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**

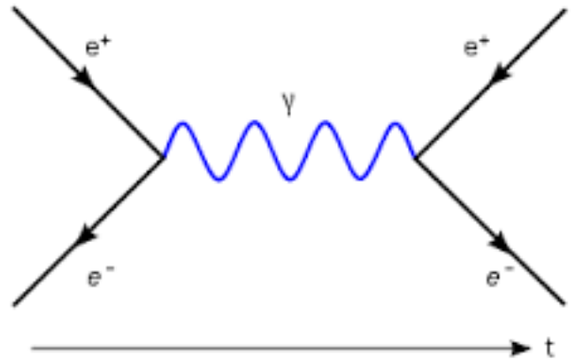
These forces are described by a well established theory called the Standard Model theory (SM)

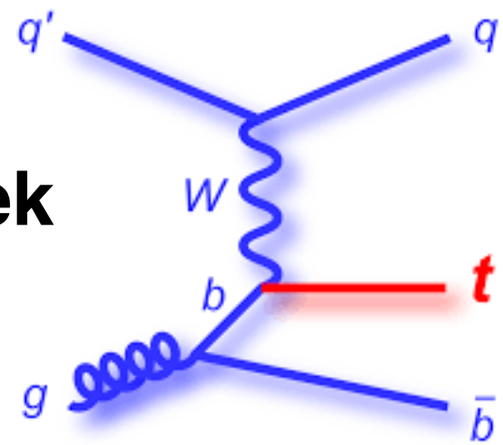
Feynman Diagrams

- When particles (objects) interact, they exchange other elementary particles

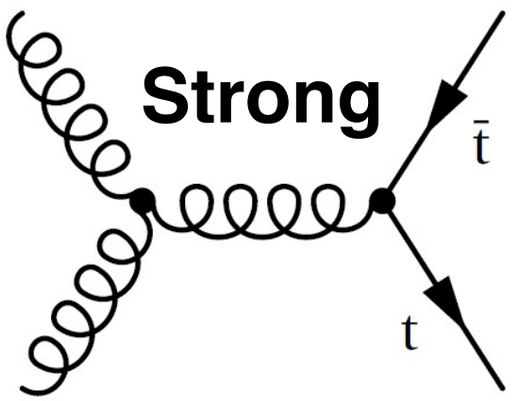


EM



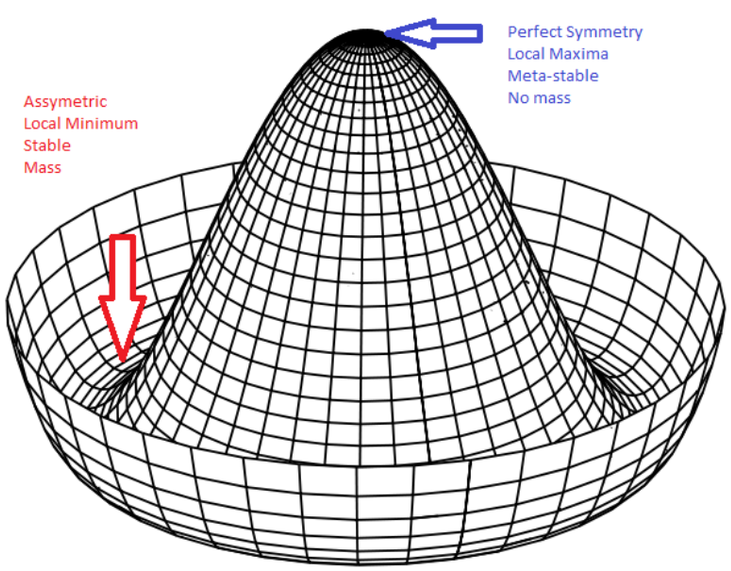


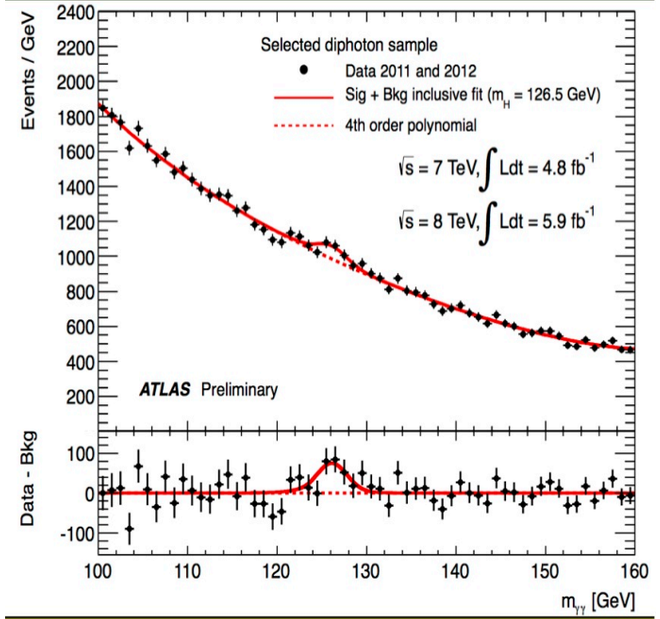
Week



Higgs Particle

- Petter Higgs predicted in 1964 the existence of a particle with spin 0
- This particle plays an important rule in SM

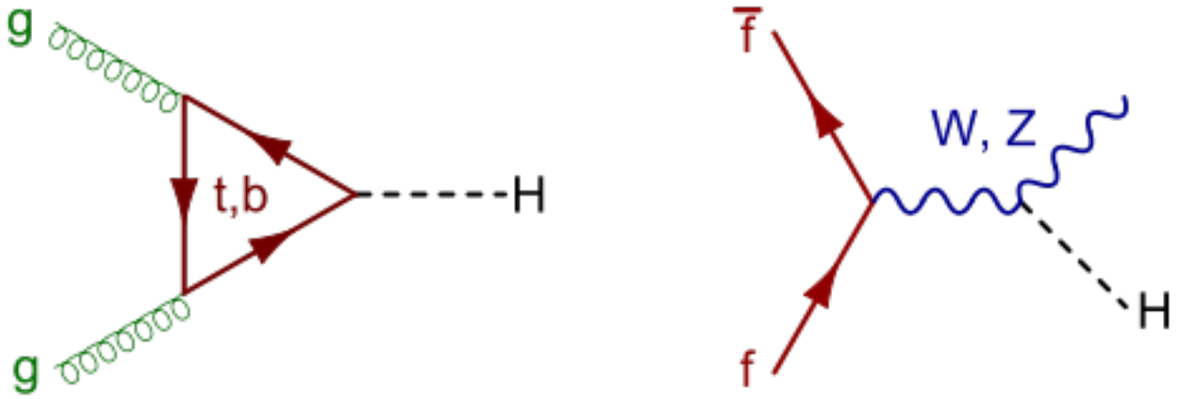




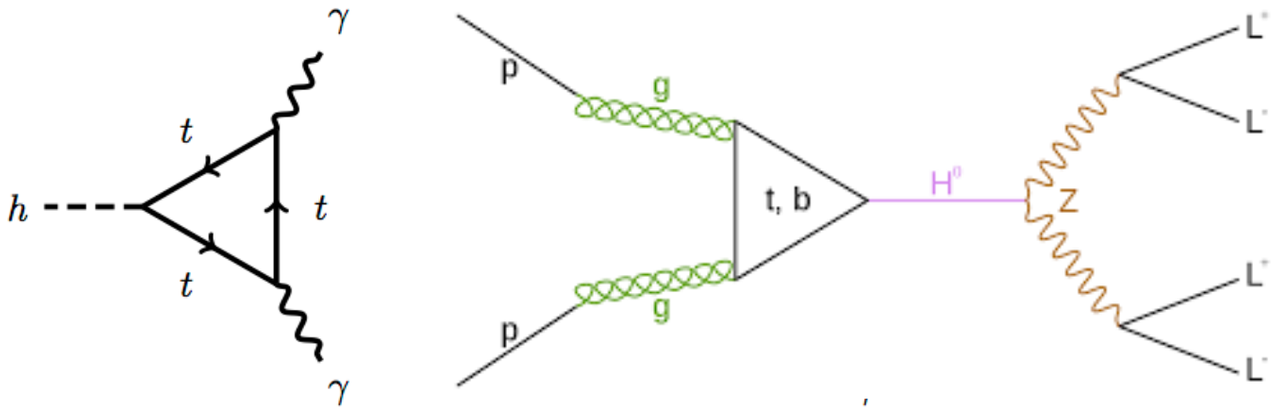
- In 2012 this particle was discovered by ATLAS and CMS Collaborations

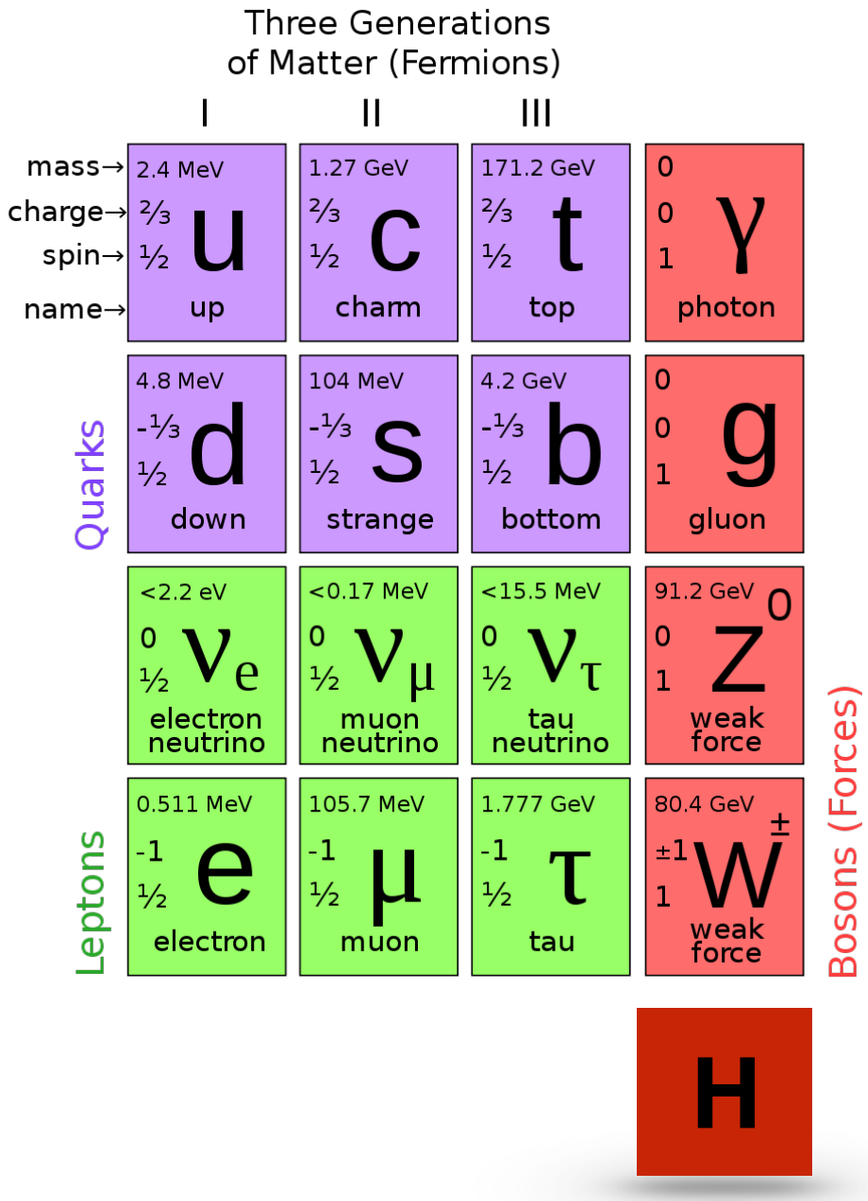
Higgs Particle

- Production

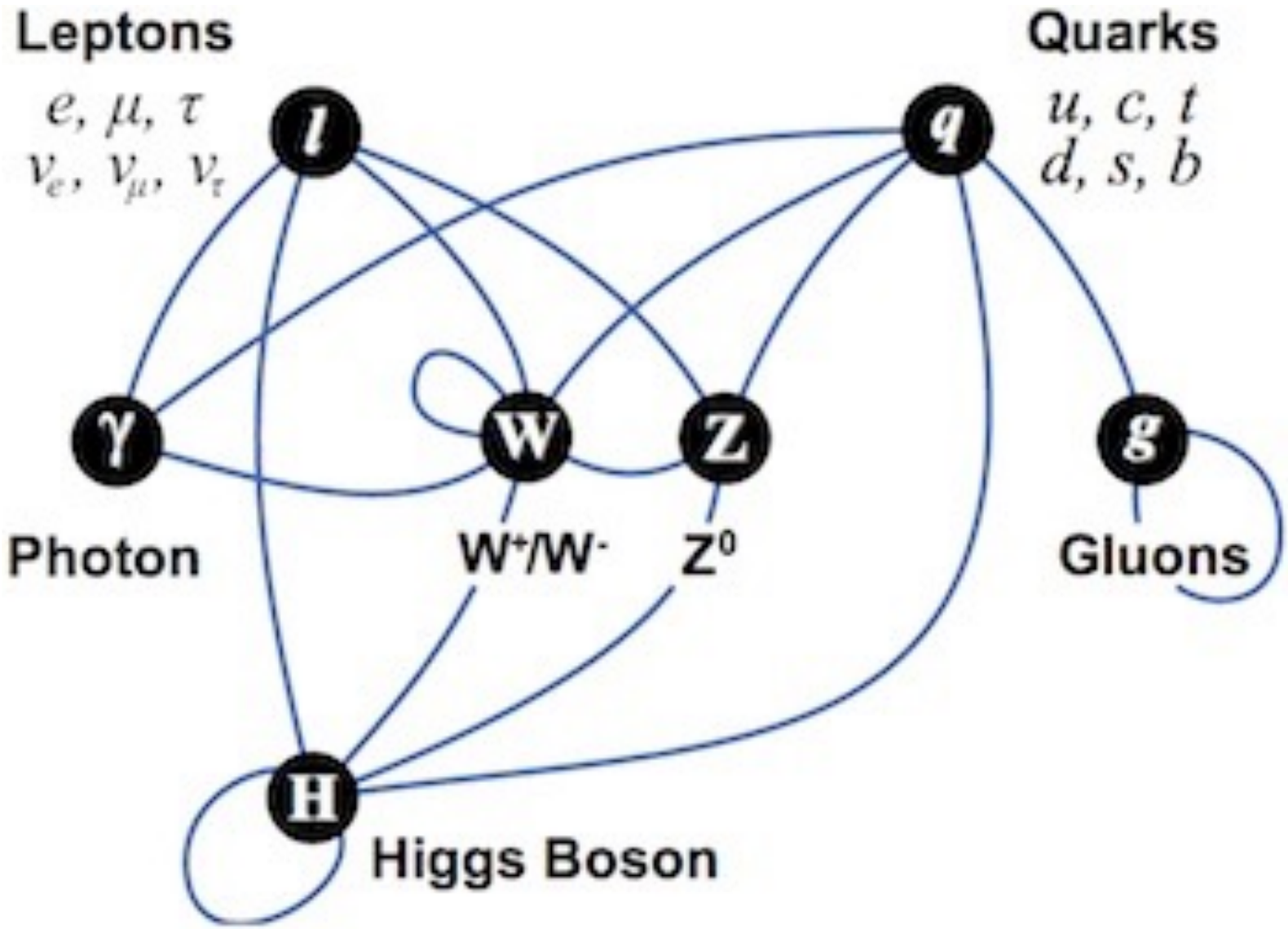


- Decays within 10^{-20}





Fundamental Interactions

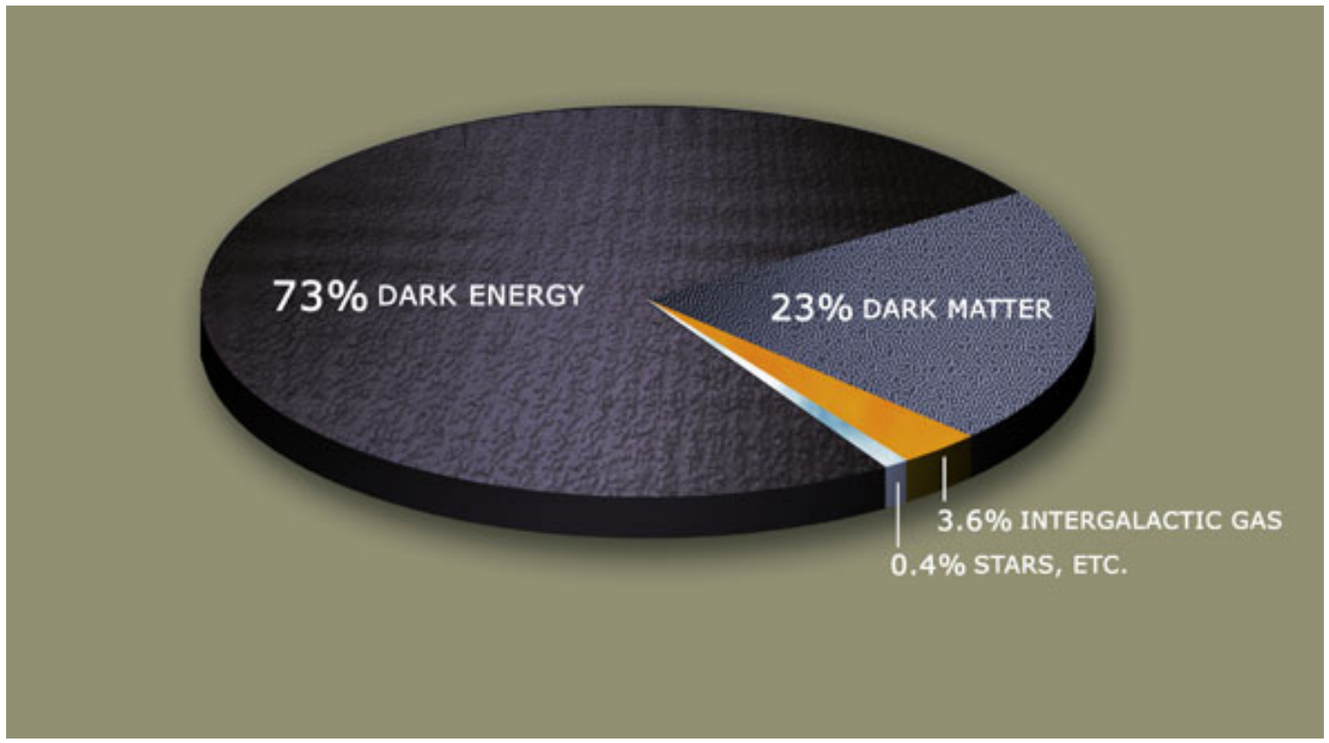


Beyond the SM

- There many things cannot be answered by the SM
  - how many quarks and leptons in nature?
  - how many fundamental interactions?
  - why the electron is extremely light particle compared to the top quark

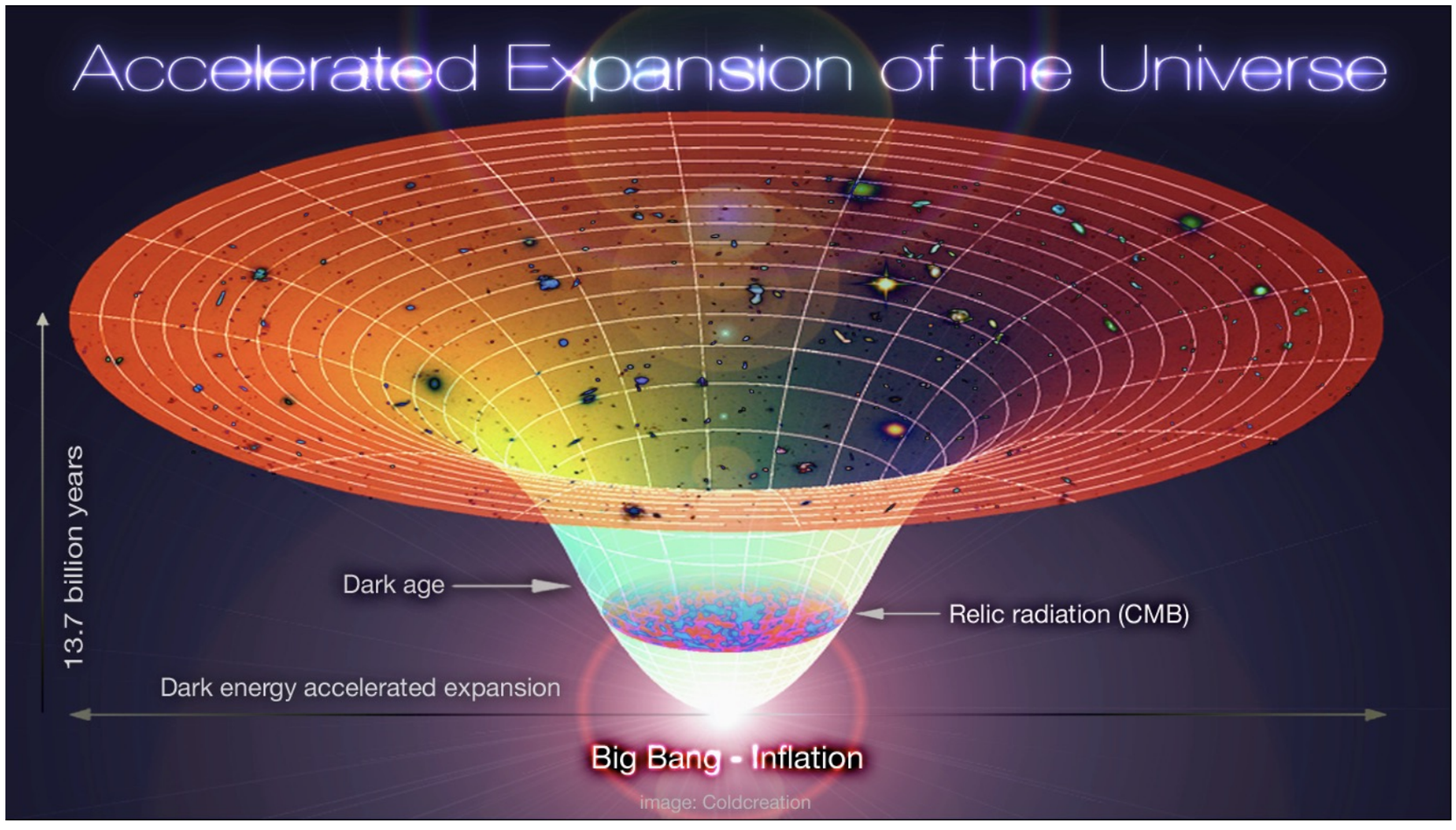
Beyond the SM

- Cosmological observations have shown that 96% of the universe is dark!
  - has gravity effects
  - cannot interact with light (dark)



Beyond the SM

- Accelerated expansion of the universe, where does the energy come from?!



Beyond the SM

- Matter and antimatter asymmetry