History of Particle Physics

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Today

- Cloud chamber demo
- Review of Standard Model
- History of particle physics

Cloud Chamber Demo

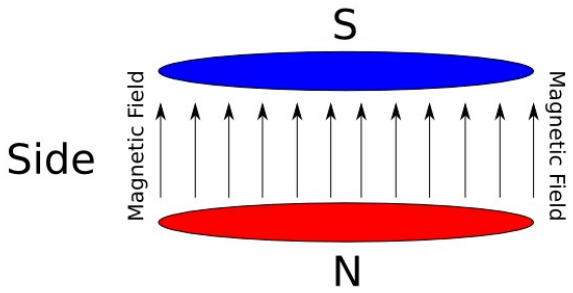
Charged track in cloud chamber

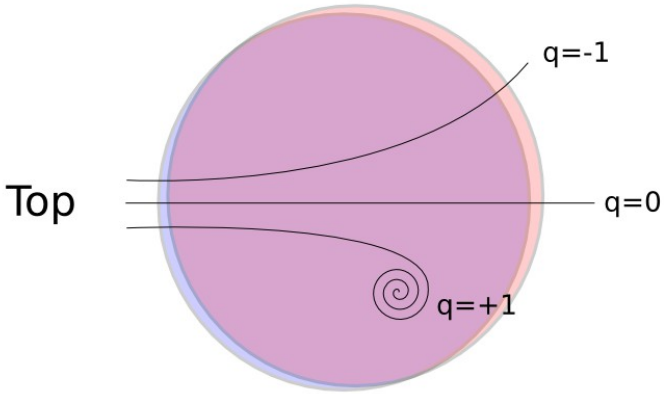
- Vapor in chamber is **super saturated**
- Particle passes through, ionizes some vapor
- Ionization causes the small disturbance needed to form a small cloud in the path of the particle

http://static.ddmcdn.com/gif/blogs/6a00d8341bf67c53ef0148c8402cff970c-800wi.png

Magnetic field

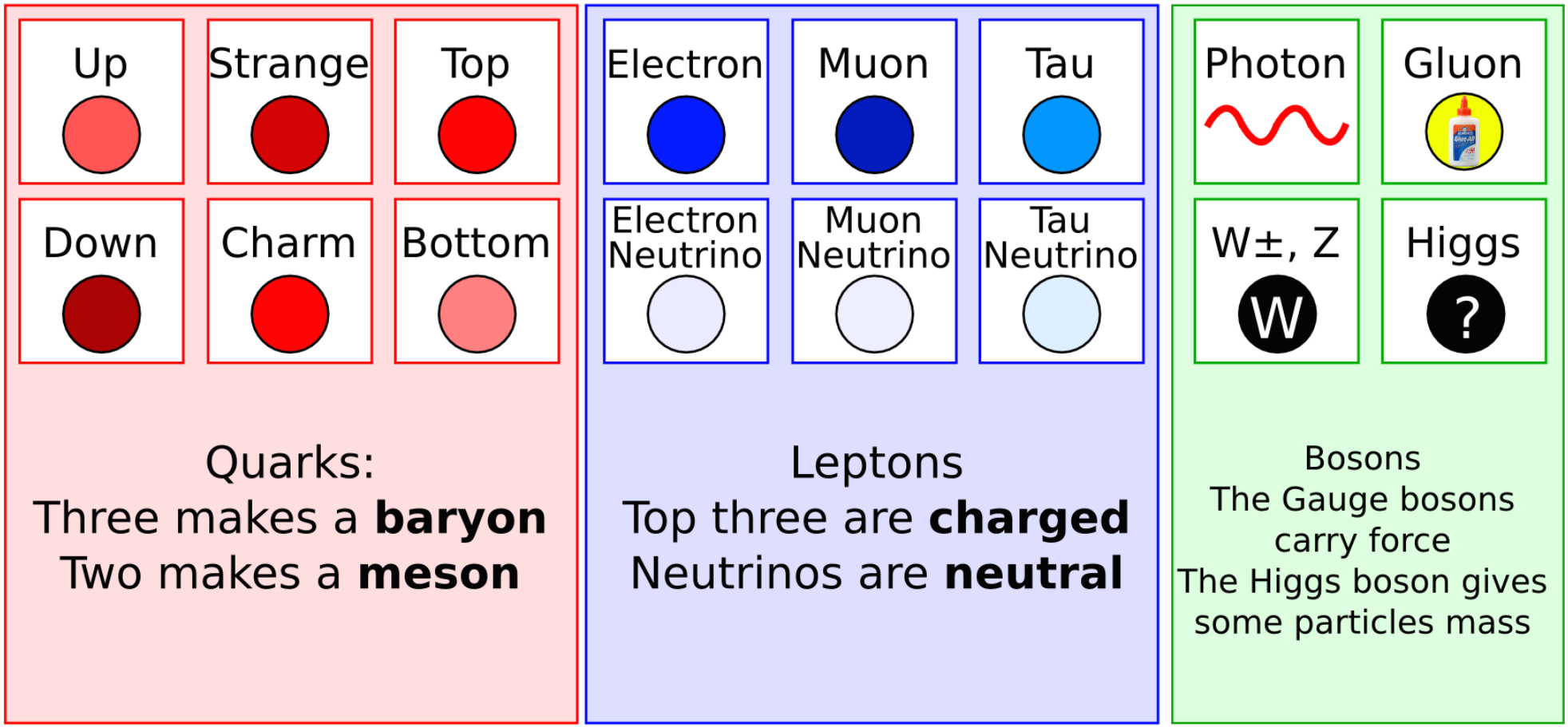
- Magnetic field bends particles ***perpendicular to their velocity***
- The Lorentz force: q • V x B
  - q = charge of particle
  - V = direction vector
  - B = magnetic field direction
- Example



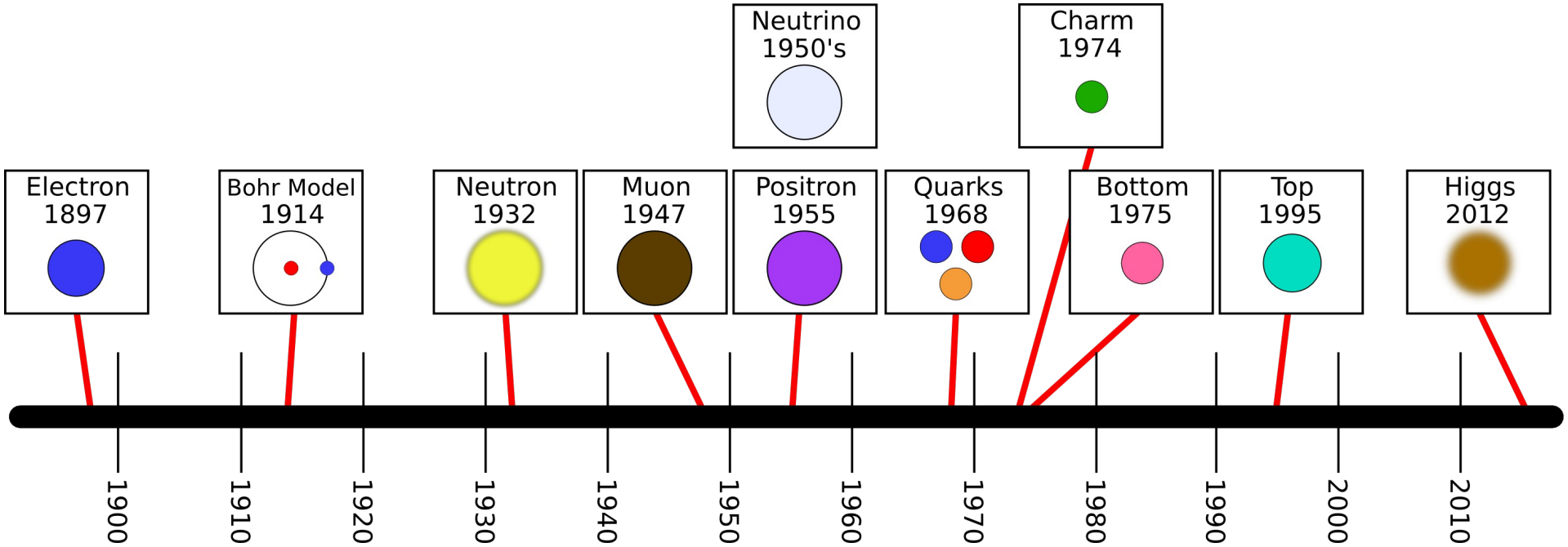


History of Particle Physics

Review
Particles of the Standard Model



Timeline


Electron
1897
Bohr Model
1914
Neutron
1932
Muon
1947
Neutrino
1950's
Positron
1955
Quarks
1968
Charm
1974
Bottom
1975
Top
1995
Higgs
2012
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

The Electron - 1897

- Thomson
- Heat metal in vacuum, emits cathode ray
- Based on the distance traveled through air, Thomson surmised cathode ray made up of particles
- Measure mass/charge ratio with deflection in electric and magnetic fields

The Nucleus

- Rutherford
- Fired alpha (2 neutrons, 2 protons) at gold foil
- Most alpha pass through foil, but some alpha deflected back at beam, indicates that occasionally alpha hit a massive target
- Concluded existence of atomic nuclei
- 1914 Bohr suggested the nucleus orbited by electron

The Neutron

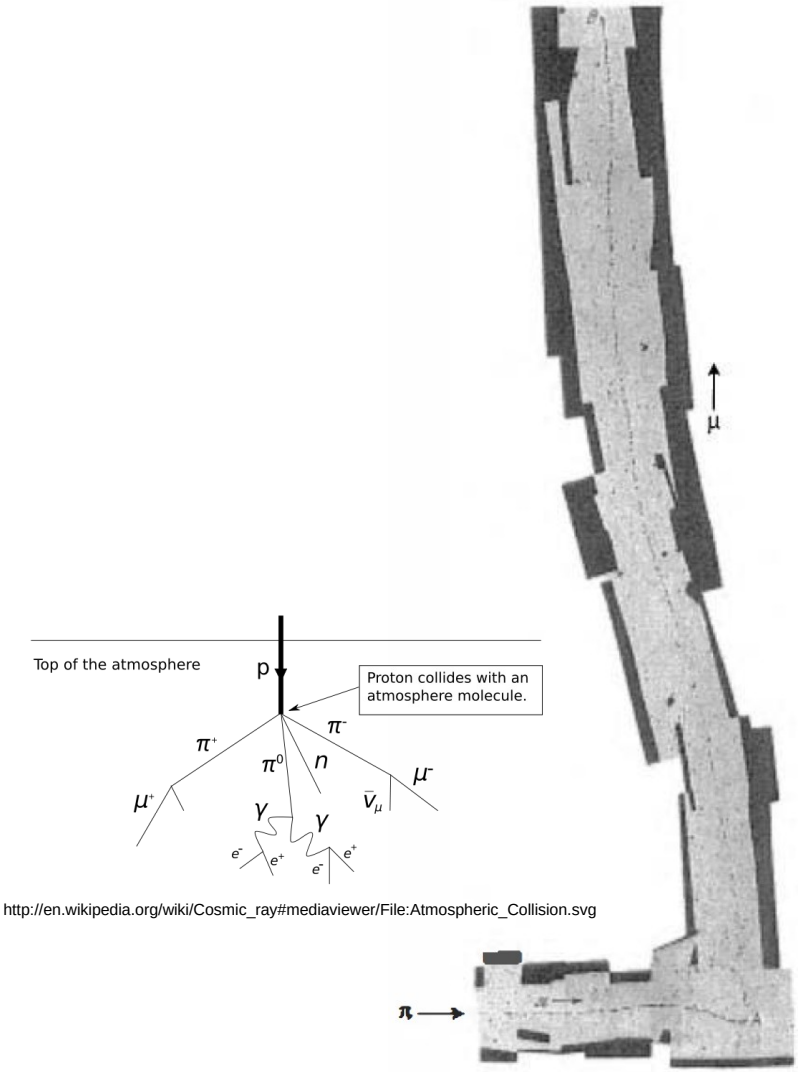
- Chadwick
- Beryllium target, hit with alpha, emits neutrons
- Analyzed mass and charge, new particle
- For a long time, these were the only particles:

Yukawa's Problem

- What keeps the **positively charged** protons constrained to the nucleus?
- There must be another force, but this force can only act on small scales
- This requires a massive force carrier that can't travel far
- Yukawa predicts the Pi meson. Pi mason not discovered yet.

The Pion and Muon - 1947

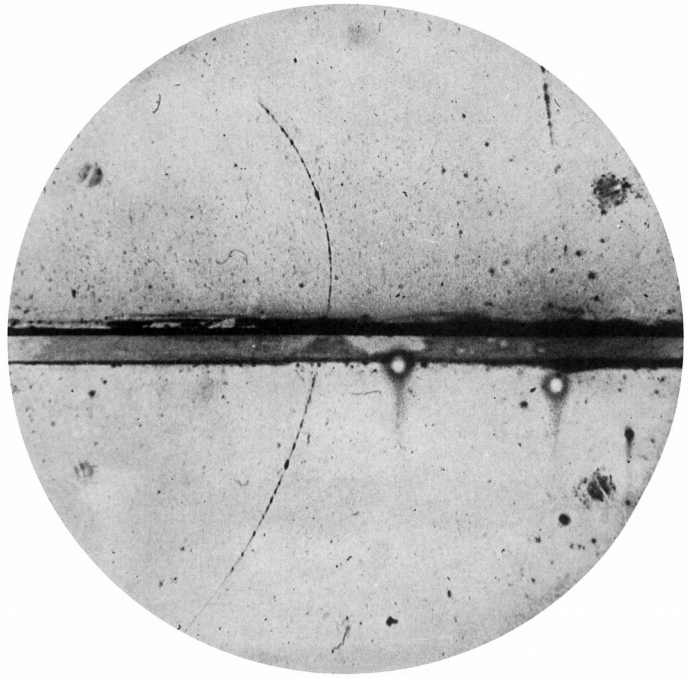
- Powell uses cloud chambers to look at particles in **cosmic rays**
- Cloud chambers on mountains, sea level. One particle decays before reaching the ground – **Yukawa's Pi meson**
- Pictured: track of Pi decay to Muon
- Muon behaves like a **heavy electron**, reaches ground



http://en.wikipedia.org/wiki/Cosmic_ray#mediaviewer/File:Atmospheric_Collision.svg

Antiparticles

- $E=mc^2$, right?
- Actually $E^2 = m^2c^4 + p^2c^2$
  - Has *two* solutions, ±!
- Dirac kept the negative solution
- In 1931 Anderson discovered the **Positron** (pictured)
- Same as electron, + charge

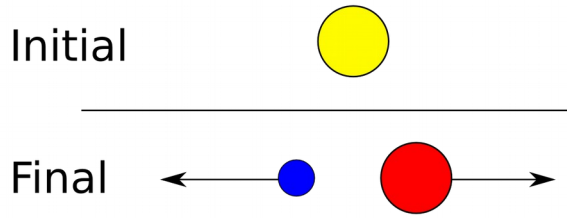


Positron bends the opposite way!

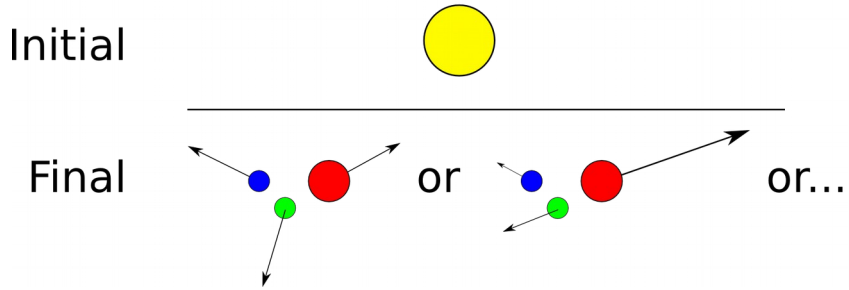
The Neutrino is Suggested

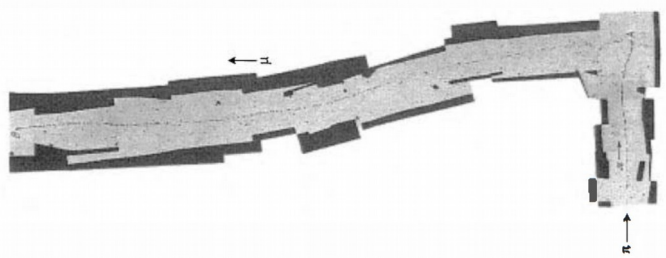
- Neutrino is very hard to detect
  - No gravity
  - No electric charge
  - No strong force
  - Only weak force
- Neutron decays to electron (e) and proton (p)...
  - If just e and p, e must have same momentum as p
  - Measurements suggest that e has a **spectrum**
  - This means there must be an **invisible third particle**
- Go back to pion decay, clear that that's a neutrino
- Cowan and Reines officially discover neutrinos in 1950's

Two body decay



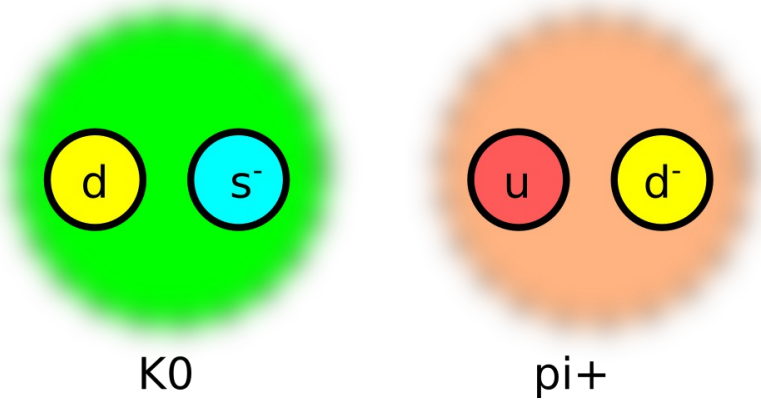
Three body decay





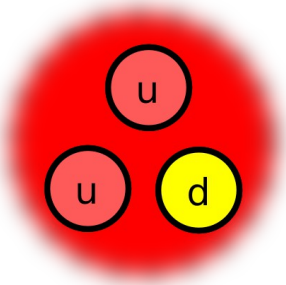
The Kaon - 1949

- Rochester and Butler
- The Kaon is an example of a meson
- Meson is a bound state of two quarks
- One particle, one anti particle
- Many, many other mesons
- K0 decays into 2 pions

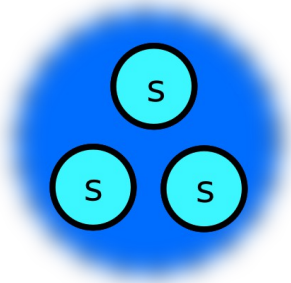


Baryons suggest weak force

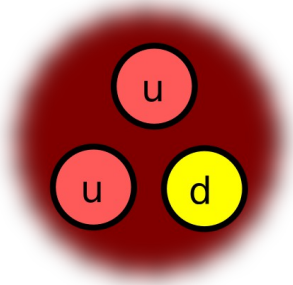
- Baryons have 3 quarks
- Sometimes, same quarks w/ different energy is a different baryon
- **Many, many baryons**
- High energy baryons **decay** into lower energy states
- Decay takes longer than production – indicates another mechanism
- Decay process is carried out via weak force



Proton



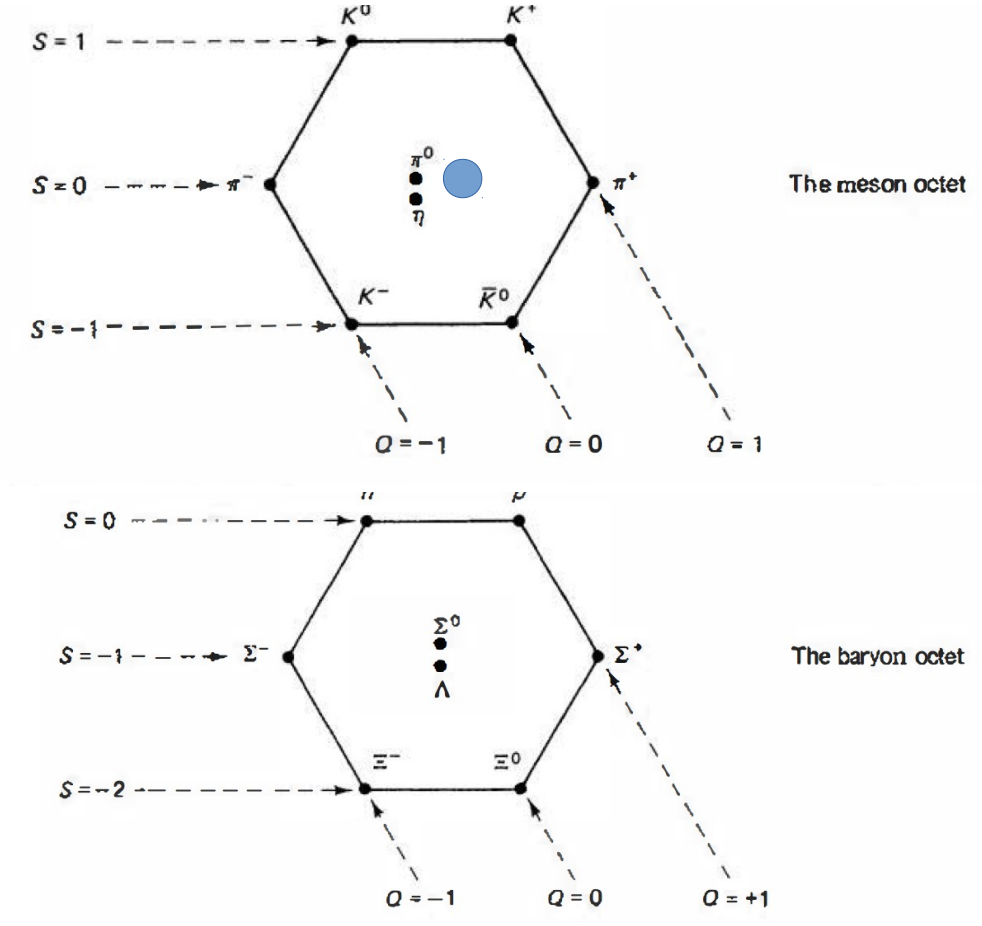
Omega-



Delta+

The Eightfold Way - 1961

- Gell-Mann organized Baryons and Mesons into “Octets” and “Dectuplets”
- Allowed prediction of Omega- (sss)
- For three quarks, there are 9 quark/antiquark combinations – **just like the meson octet**
- So maybe baryons and mesons are made of 3 kinds of quark?



Griffiths

Quarks!

- Deep inelastic scattering
  - Shoot an e- at a proton, it bounces off
  - Shoot an e- at a proton *fast enough* and all sorts of strange things happen (destroy p, excite p, change electron energy)
  - Bjorken and Feynman: this indicates the proton has structure! (1968)
- Believe the Eightfold Way now: **3 quarks**
- But why can't you see a single quark (as we can see single e-)???
  - Quarks are **confined** to the meson or baryon. An external quark has ***so much energy, it makes a partner quark***
  - Like a rubber band snapping into two pieces

The November Revolution

The discovery of **J/ψ** kicked off the **1974 November Revolution** in particle physics. Ting was working in Brookhaven National Lab. After his discovery, he waited to collect more statistics before announcing it publicly. Apparently, SLAC physicist Richter learned the mass of the **J/ψ** and tuned his machine to the proper energy to discover it. The two groups published at the same time, Richter picking ψ for the shape of the decay products, and Ting for after the character for his name. Ting, born in AA, is the best, so if you have to pick one, pick J.

In the wake of the discovery, many charmed mesons were discovered.

The Tau, Bottom, and Top

- The **Tau**, heavier than electron or Muon, discovered 1975
- The **Bottom quark** is discovered next
- *… a lot of time passes*
- In 1995, the **Top quark** is discovered at Fermilab's Tevatron

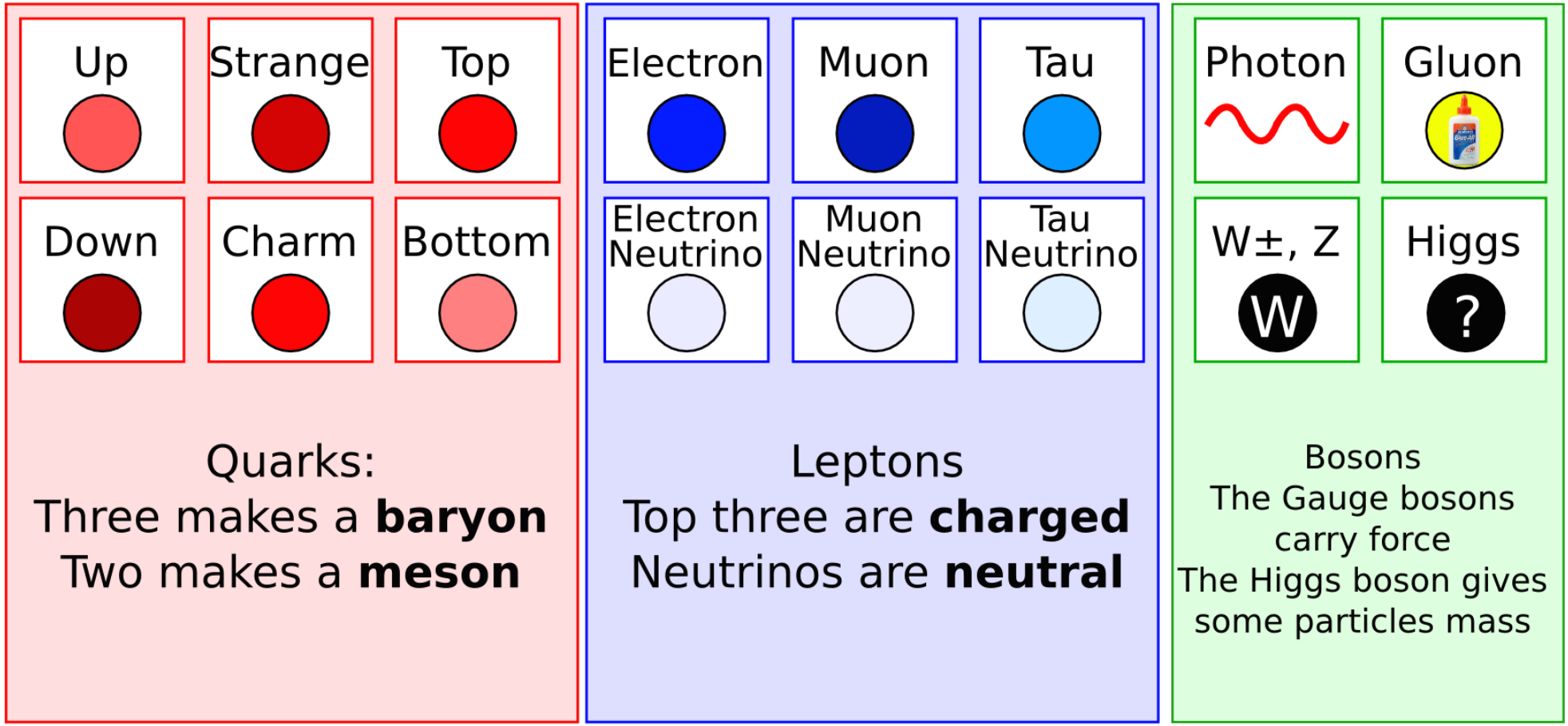
Gauge Bosons

- Gauge bosons convey the forces
- **Photon**: electromagnetic force
  - Binds electron to proton
- **Gluon**: strong force
  - Holds quarks inside a baryon or meson
  - Massive, so limited range
- **W± and Z** bosons: the weak force

The Higgs Boson

- Not much is known about it yet
- **Officially discovered July 4th, 2012**
- Over 6 *thousand* physicists involved in discovery
- The final particle predicted by the standard model
- So are we done? **No!**

Summary


Up
Strange
Top
Down
Charm
Bottom
Quarks:
Three makes a **baryon**
Two makes a **meson**
Electron
Muon
Tau
Electron Neutrino
Muon Neutrino
Tau Neutrino
Leptons
Top three are **charged**
Neutrinos are **neutral**
Photon
Gluon
W±, Z
W
Higgs
?
Bosons
The Gauge bosons carry force
The Higgs boson gives some particles mass

We've caught up to the present