PARTICLE INTERACTIONS AND FUNDAMENTAL FORCES

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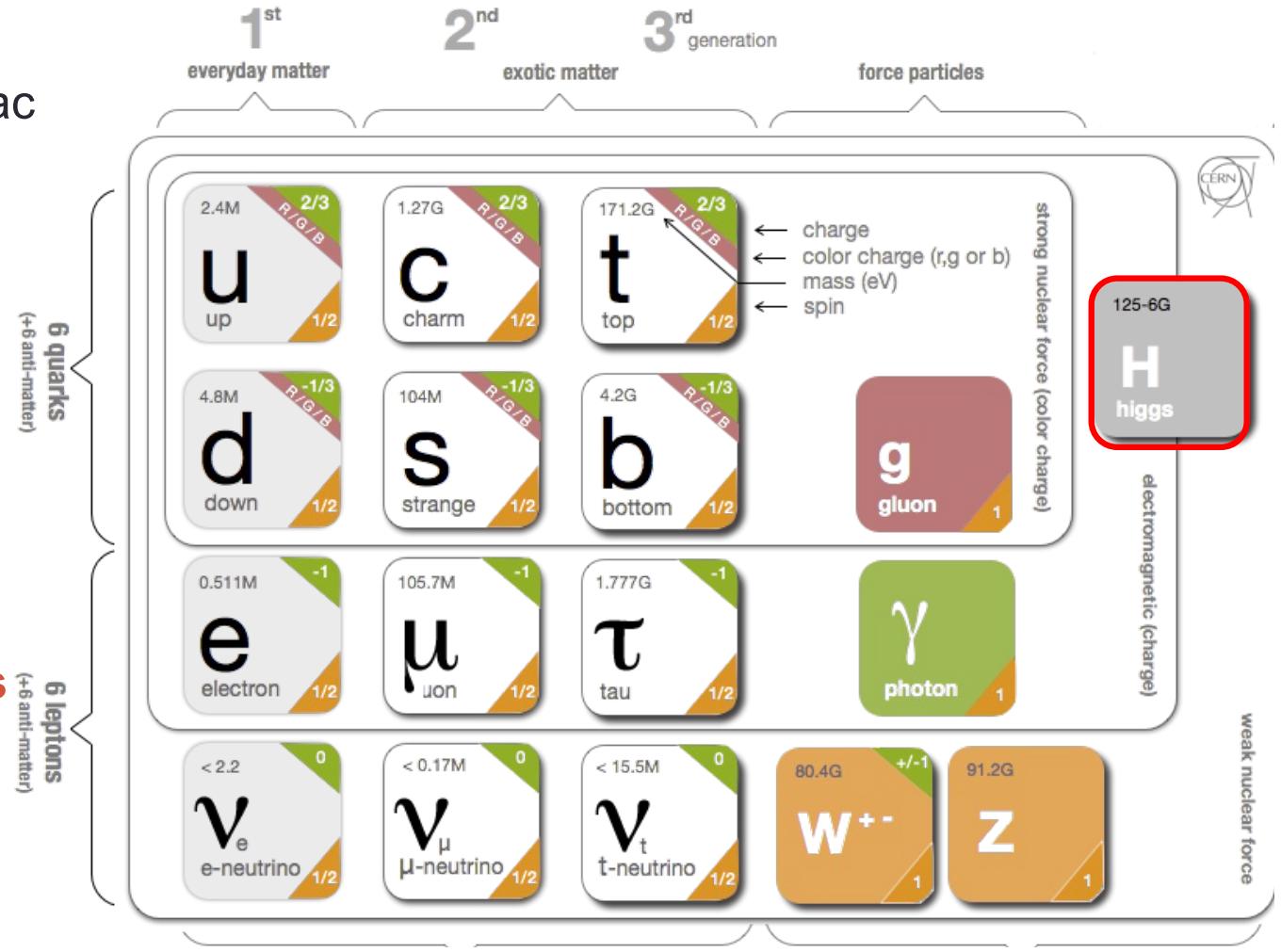
Obey Dirac Equation

Quarks

Leptons



Spin 0 Boson

Force carrying particles (gauge bosons)

The Standard Model of Particle Physics

- The (relativistic) quantum field electro-weak theory is described by the SU(2)×U(1) Weinberg-Salam Model (QED+Weak)
  - Responsible for electricity, magnetism, and radioactive decay
  - Couplings via electric charge, and weak hypercharge and isospin
  - 4 bosons: γ, Z, W^+, W^-
- The quantum field theory of the strong force is described by SU(3) Quantum Chromodynamics (QCD)
  - How quarks bind into protons and neutrons, and how nucleons bind in the nucleus
  - Coupling via strong charge (3 "colors", and 8 gluons)
- Collectively, they are referred to as the "Standard Model"
- However, all masses are zero unless we introduce a scalar field
  - Generates mass for the vector bosons (W, Z)
  - Generates mass for the fermions
  - Generates a massive neutral scalar: the Higgs boson

Interactions

- The fields associated with the fundamental forces are conveyed via particles
  - Known as “second quantization” in relativistic quantum mechanics (quantum field theory)

- EM: photon – γ 

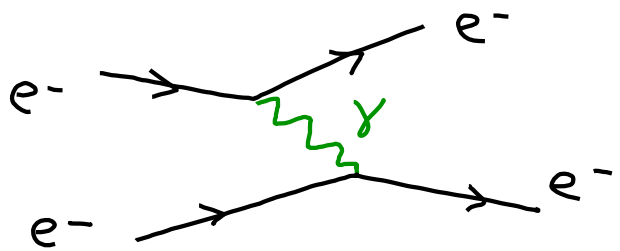
- Weak: Z^0, $W^{\pm}$ 

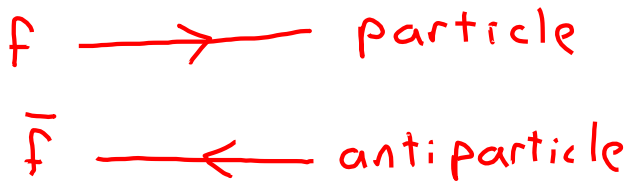
- Strong: gluons – g 

- (Gravity: gravitons)

Feynman Diagrams

- Interactions between particles can be denoted by space-time diagrams:

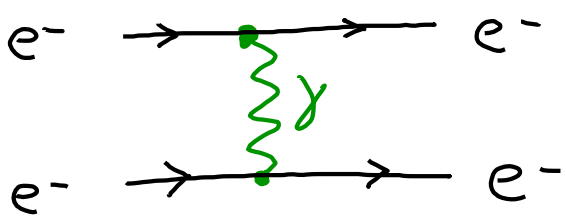




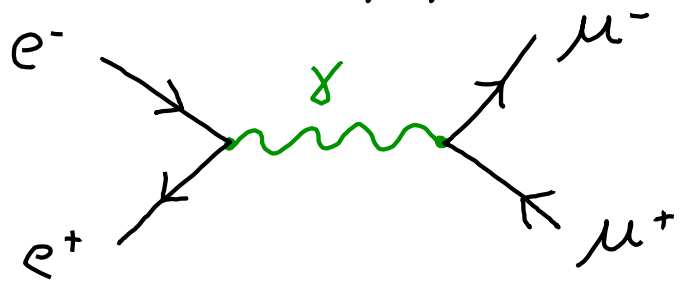
- **Feynman diagrams** graphically represent terms in a perturbative expansion of a field theory calculation, where the terms have been integrated over all space and time
  - *The time ordering within a scattering should not be inferred*

EM Interactions

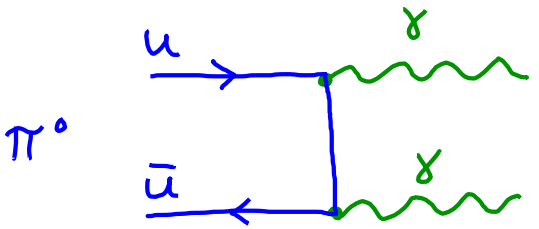
$e^- e^- \rightarrow e^- e^-$



$e^+ e^- \rightarrow \mu^+ \mu^-$

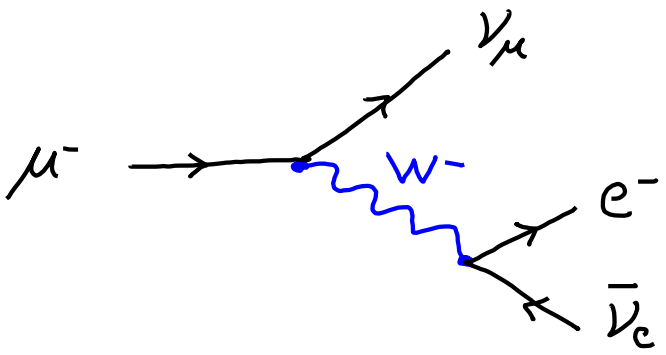


$\pi^0 \rightarrow \gamma\gamma$



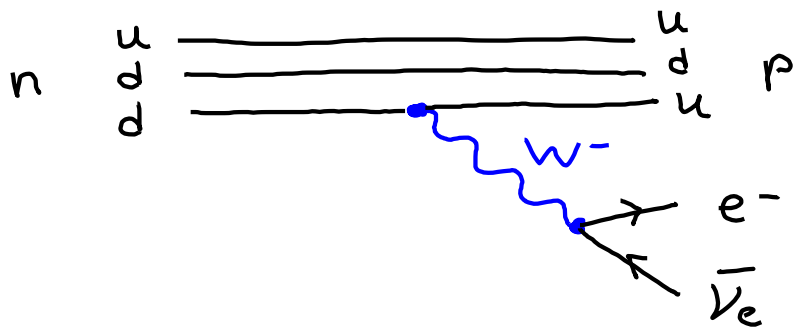
Weak Interactions

$\mu^- \rightarrow e^- \nu_\mu \bar{\nu}_e$



"β Decay"

$n \rightarrow p\ e^-\ \bar{\nu}_e$

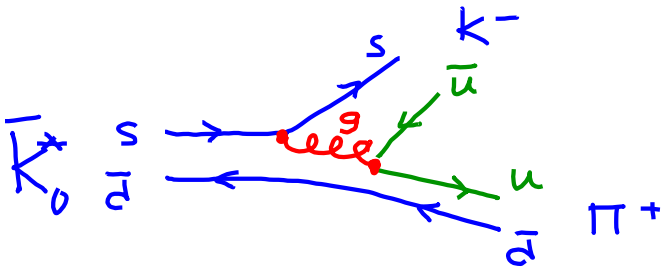


The weak force is the only force that can change the type ("flavor") of a fundamental particle
e.g. μ → *ν*, or d → u

Also very short range (large W/Z mass)

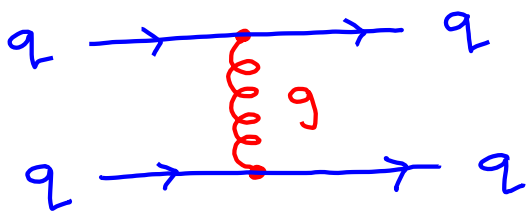
Strong Interactions

$$\bar{K}_0^* \rightarrow K^- \pi^+$$

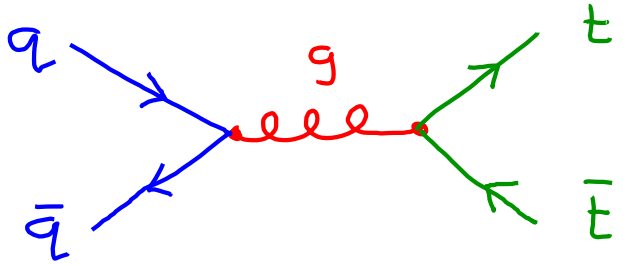


The strong force gets stronger with increasing separation between “color” charged objects. Gluons are massless like the photon, but carry charge

$$qq \rightarrow qq$$



$$q\,\bar{q} \rightarrow t\,\bar{t}$$



THE FEYNMAN VAN

Nobel Prize-winning physicist Richard Feynman purchased this Dodge Tradesman minivan in 1975, outfitting it with drawings of his famous Feynman diagrams and a personalized license plate reading QANTUM. The diagrams are used in almost every simulation and analysis of particle interactions that physicists at Fermilab conduct. When asked why the van was adorned with Feynman diagrams, he would say, "Because I'm Richard Feynman." The Feynman family took several trips in the van, camping out in remote areas of the American west, and Richard used it to commute to the California Institute of Technology, where he worked.