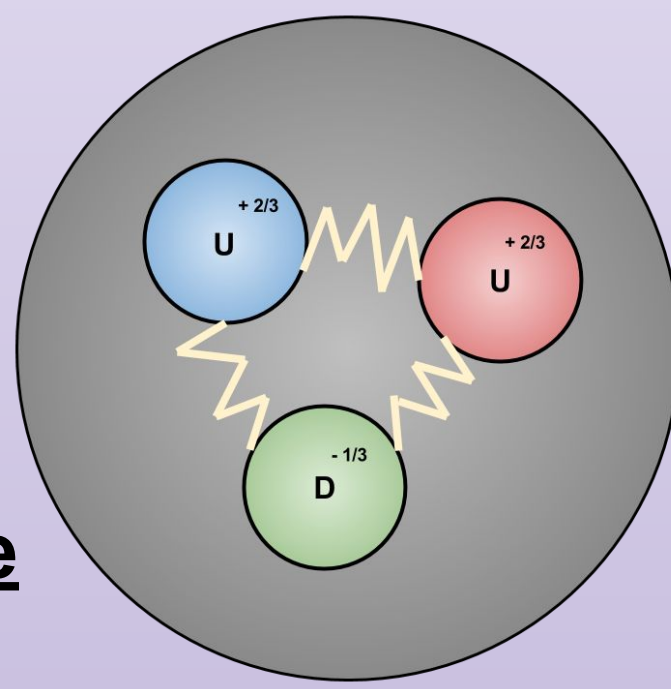


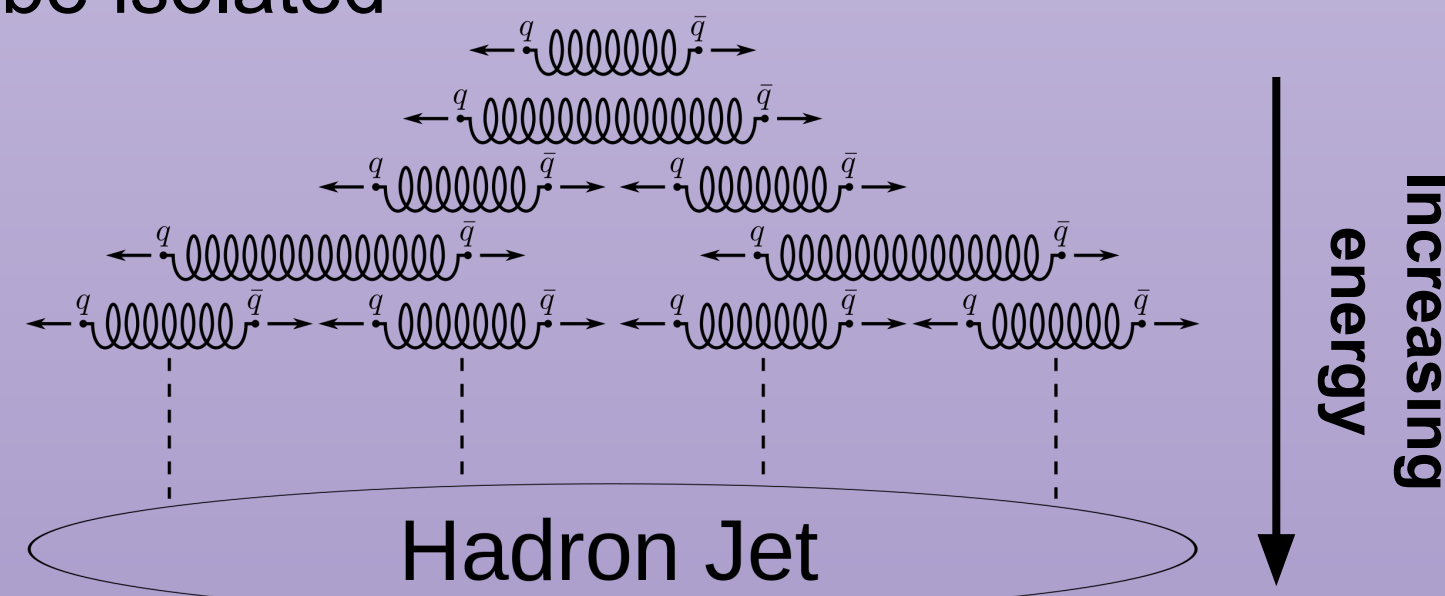
# Standard Model of particle physics

## QUARKS

- A quark is an **elementary particle** and a fundamental element of matter
- Quarks combine to form larger particles such as **hadrons** or **mesons**
  - Protons and Neutrons are hadrons
- **Color confinement** prohibits a quark to be isolated



PROTON



- Quarks are the only particles to experience all **4 fundamental forces**
  - Strong Interaction
  - Electromagnetism
  - Weak Interaction
  - Gravitation
- Quarks are the only particles to have non-integer multiples of the elementary charge

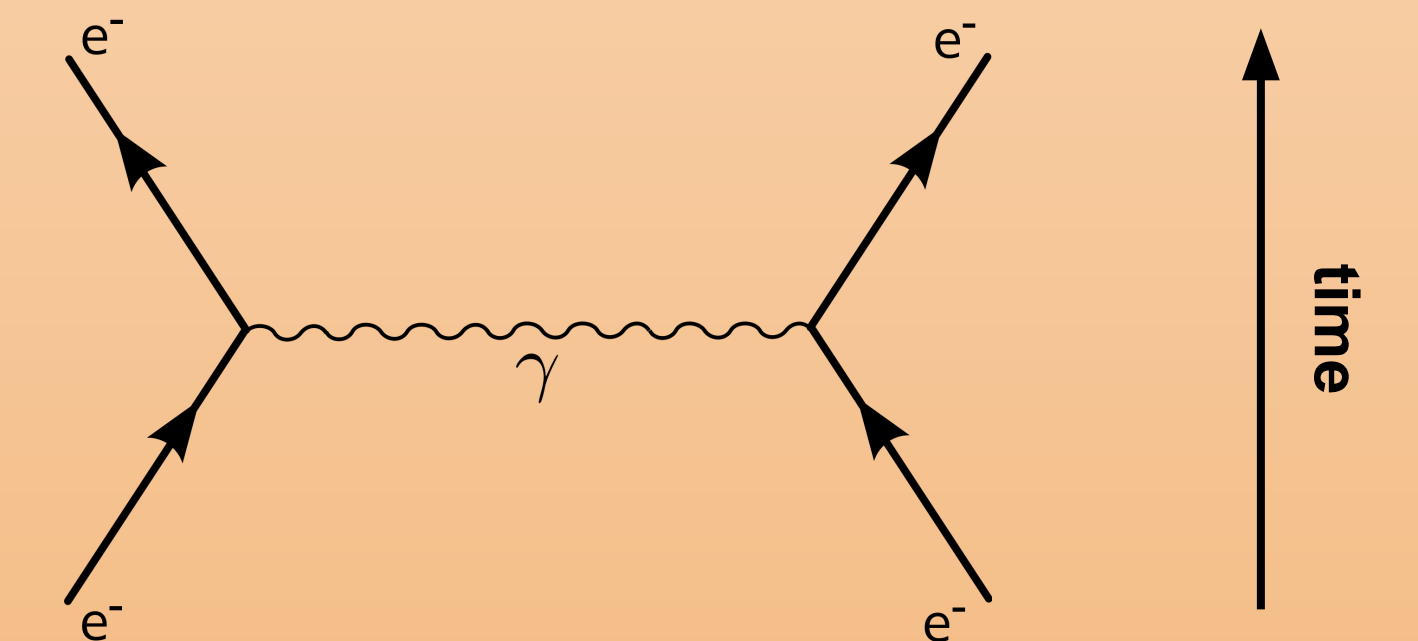
**Elementary Particle** - (noun) a particle whose substructure is unknown. It is unknown whether an elementary particle is composed of other particles.

	Fermions			Bosons		
	I	II	III			
QUARKS	mass: 2.4 MeV/c <sup>2</sup> charge: 2/3 spin: 1/2 u up	mass: 1.275 GeV/c <sup>2</sup> charge: 2/3 spin: 1/2 c charm	mass: 172.44 GeV/c <sup>2</sup> charge: 2/3 spin: 1/2 t top	mass: 0 eV/c <sup>2</sup> charge: 0 spin: 1 g gluon	mass: 1.25.09 GeV/c <sup>2</sup> charge: 0 spin: 0 H Higgs	
	mass: 4.8 MeV/c <sup>2</sup> charge: -1/3 spin: 1/2 d down	mass: 95 MeV/c <sup>2</sup> charge: -1/3 spin: 1/2 s strange	mass: 4.18 GeV/c <sup>2</sup> charge: -1/3 spin: 1/2 b bottom	mass: 0 eV/c <sup>2</sup> charge: 0 spin: 1 γ photon	SCALAR BOSONS	
	mass: 0.511 MeV/c <sup>2</sup> charge: -1 spin: 1/2 e electron	mass: 105.67 MeV/c <sup>2</sup> charge: -1 spin: 1/2 μ muon	mass: 1.7768 MeV/c <sup>2</sup> charge: -1 spin: 1/2 τ tau			mass: 91.19 GeV/c <sup>2</sup> charge: 0 spin: 1 Z Z boson
	LEPTONS	mass: < 2.2 eV/c <sup>2</sup> charge: 0 spin: 1/2 ν <sub>e</sub> electron neutrino	mass: < 1.7 MeV/c <sup>2</sup> charge: 0 spin: 1/2 ν <sub>μ</sub> muon neutrino	mass: < 15.5 MeV/c <sup>2</sup> charge: 0 spin: 1/2 ν <sub>τ</sub> tau neutrino	mass: 80.39 GeV/c <sup>2</sup> charge: ± 1 spin: 1 W W boson	GAUGE BOSONS

## BOSONS

- Bosons are the **force-carrier particles** of the standard model

Force	Force Carrier
Strong Interaction	Gluon
Electromagnetism	Photon
Weak Interaction	W and Z bosons
Gravitation	Graviton ??

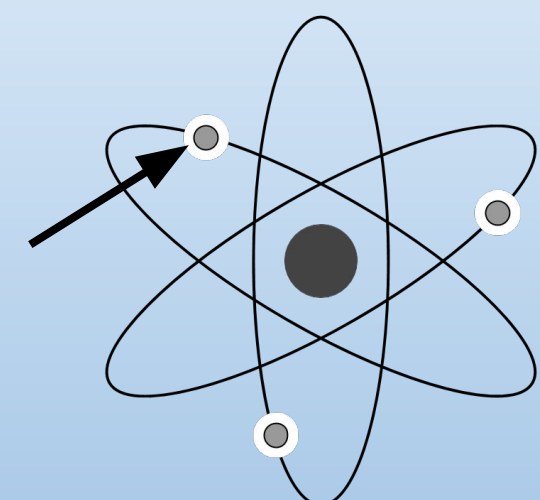


electron - electron collision visualized using a Feynman diagram

- Gauge bosons are mathematically described as **massless particles**
- W and Z bosons appear to have mass by the **Higgs mechanism**

## LEPTONS

- Leptons experience **3 of the 4 fundamental forces** (leptons do not experience the strong interaction)
- The family of leptons is split into two categories
  - Charged leptons, or electron-like
  - Neutral leptons, or neutrinos

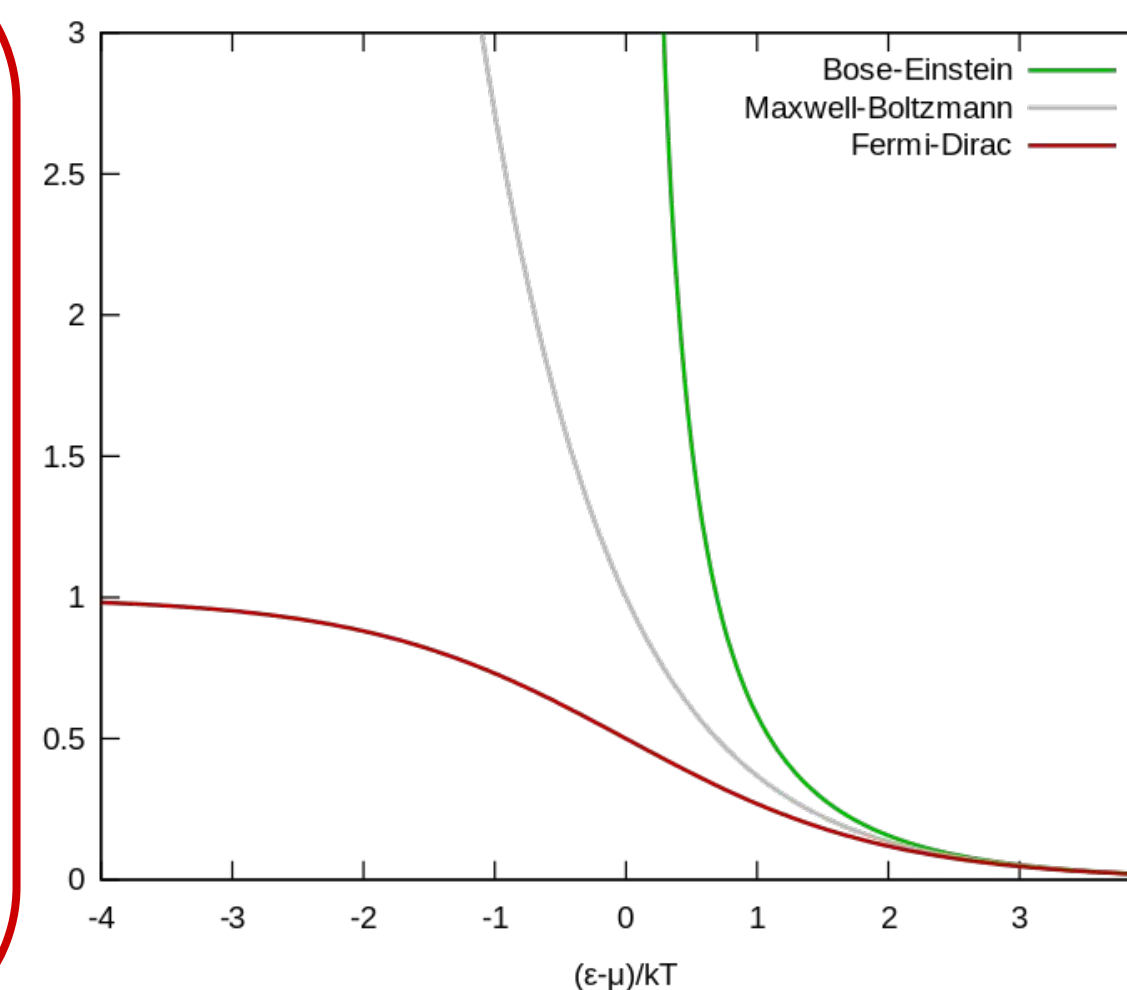


### Fermions

- Half-integral spin
- Fermi - Dirac Statistics

$$f(E) = \frac{1}{e^{\left(\frac{E-E_F}{kT}\right)} + 1}$$

- Obey Pauli Exclusion Principle



### Bosons

- Integral spin
- Bose - Einstein Statistics

$$f(E) = \frac{1}{Ae^{\left(\frac{E}{kT}\right)} - 1}$$

- Multiple particles allowed in the same state