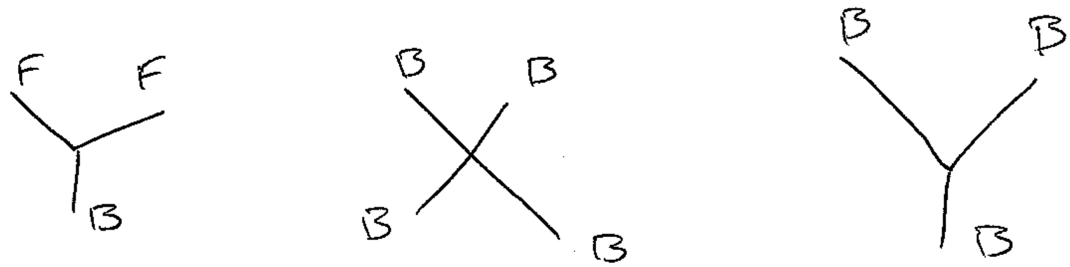
Lecture 19

Standard Model

The version of QFT that our universe is characterized by.

As weve seen much of the world is fixed by the basic principles of Quantum Mechanics and Lorentz Invariance.

0, 1/2, 1, 3/2, 2



Spin-1 must be Yang-Mills (ect)

SM attempts to explain all phenomena of particle physics in terms of small number of particles.

Actually 4 different types

Leptons Spin-1/2 (Left and Right handend fields) Experience Weak and EM interactions

$$\begin{pmatrix}\nu_e\\e\end{pmatrix}\begin{pmatrix}\nu_\mu\\\mu\end{pmatrix}\begin{pmatrix}\nu_\tau\\\tau\end{pmatrix}$$

Quarks Spin-1/2 Strong, Weak and EM interactions

$$\begin{pmatrix}u\\d\end{pmatrix}\begin{pmatrix}c\\s\end{pmatrix}\begin{pmatrix}t\\b\end{pmatrix}$$

Gauge Bosons Spin-1 Force Carriers

$$\gamma \quad g(\times 8) \quad W^\pm \quad Z$$

Higgs Boson Spin-0

$$H$$

All are assumed to be elementary. No internal structure.

Leptons

Quantum Number associated with each generation.

eg:

$$L_e \equiv N(e^-) - N(e^+) + N(\nu_e) - N(\bar{\nu}_e)$$

All other particles has $L_e = 0$.

Electron number is a conserved quantity.

$\Rightarrow$ electrons (ν_e) must be created/destroyed in pairs.

Corrisponding conserved lepton numbers for μs and τs.

$$L_\mu \qquad\qquad L_\tau$$

Leptons masses (GeV):

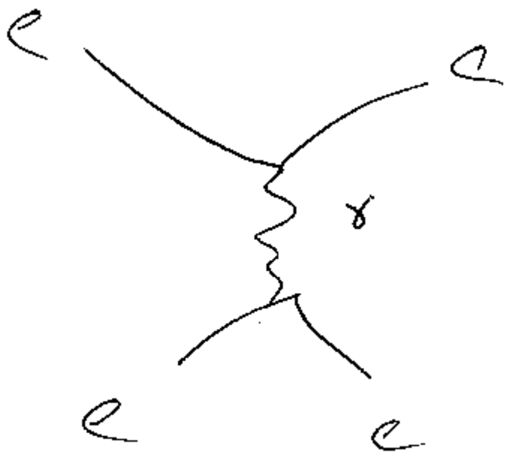
$$\begin{pmatrix} m_\nu \\ 10^{-3} \end{pmatrix} \begin{pmatrix} m_\nu \\ 10^{-1} \end{pmatrix} \begin{pmatrix} m_\nu \\ 1.7 \end{pmatrix}$$

Note: $\sum m_\nu < 10^{-9} GeV$

Once thought to be 0. Now known that at least 2 (maybe all) have $m_\nu > 0$.

W/Z Exchange

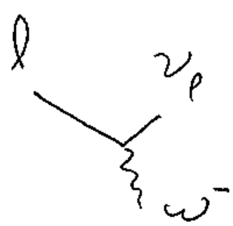
EM mediated by the exchange of a photon.

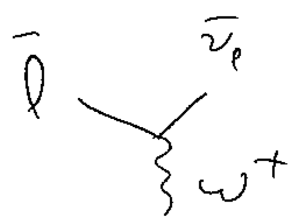


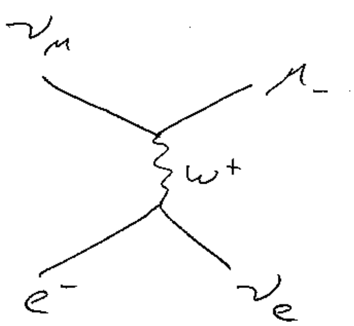
Similarly for the weak interaction, force mediated by $W^{\pm}$ or Z.

When drawing diagrams, must remember to conserve Lepton numbers and EM charge.

eg:



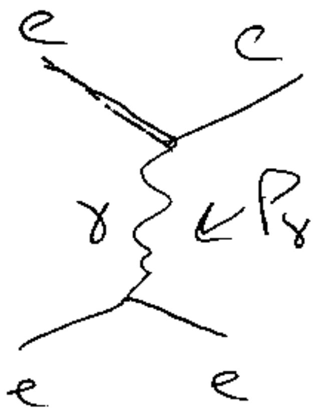




Lepton Universality All data consistent with hypothesis that interaction of all generations are the same. (Modulo mass differences)

$$m_z = 90GeV \qquad m_W = 80GeV \text{which} \neq 0!$$

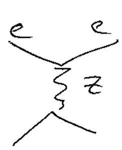
This has a major implication for the range, or effective strength of the interaction.



By uncertianty principle

$$\begin{aligned} E \times t &\sim 1 \\ E \times x &\sim 1 \\ x &\sim \frac{1}{E} \\ x &\sim \frac{1}{p_\gamma} \end{aligned}$$

$\frac{1}{p_\gamma}$ can be arbitrarily large for small p_γ.

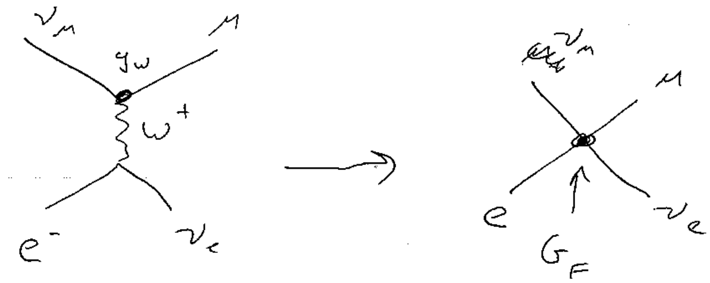
However, for the weak interaction. 

$$x \sim \frac{1}{E_z} \sim \frac{1}{\sqrt{p_z^2 + m_z^2}}$$

At max can be of range $\frac{1}{m_z}$

At low energies the wavelengths of all particles are large compared to the range of the wak force $(\frac{1}{m_Z})$

Can be approximated by a $\left| \begin{array}{l} \text{0-range} \\ \text{“point”} \end{array} \right.$ interaction, whose strength is characterized by the “Fermi constant”



$$
\begin{aligned}
G_F &\sim 10^{-5}\ \mathrm{GeV}^{-2} \\
&= \frac{g_W^2}{m_W^2} \\
&= \frac{4\pi\alpha_W^2}{m_W^2}
\end{aligned}
$$

where $\alpha_W = 4.26 \times 10^{-3} \sim 0.5\alpha_{EM}$

Weak and EM interactions of similar strength.

The apparent difference between Weak and EM interaction is a long distance <u>illusion</u>.

<u>Branching Ratios</u>

$$
\mathrm{Br}(Z \to ll) = \frac{\Gamma(Z \to ll)}{\Gamma_{\mathrm{total}}}
$$

where $\Gamma(Z \to ll)$ is the decay rate $\Gamma = \frac{1}{2E}|M|^2 d\Pi_{LIPS}$

and $\Gamma_{\mathrm{total}} = \sum_i \Gamma(Z \to XX)$

$$\frac{\mathrm{Br}(Z \to ee)}{\mathrm{Br}(Z \to \mu\mu)} = \frac{\Gamma(Z \to ee)}{\Gamma(Z \to \mu\mu)} = \frac{\frac{1}{2E}|M(Z \to ee)|^2 d\Pi_{LIPS}}{\frac{1}{2E}|M(Z \to \mu\mu)|^2 d\Pi_{LIPS}} = \frac{|M(Z \to ee)|^2}{|M(Z \to \mu\mu)|^2}$$

$$= \underbrace{1}_{\text{by lepton universality}}$$