Lecture 19
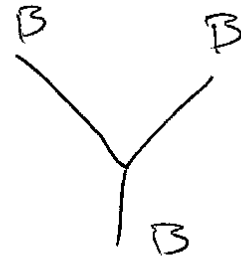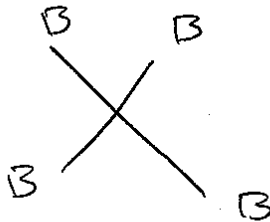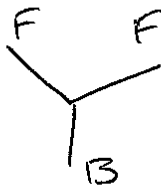
<u>Standard Model</u>

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

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

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

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

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

<u>Gauge Bosons</u> 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):
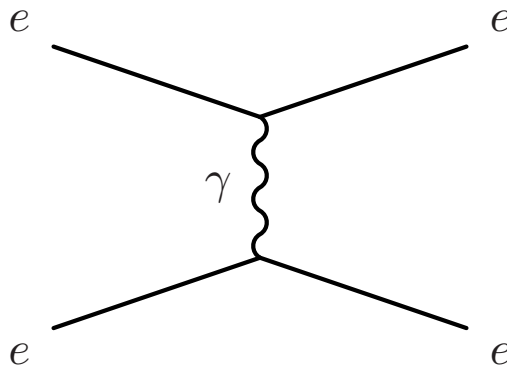
$$\begin{pmatrix} m_\nu \\ 10^{-3} \end{pmatrix} \begin{pmatrix} m_\nu \\ 10^{-1} \end{pmatrix} \begin{pmatrix} m_\nu \\ 1.7 \end{pmatrix}$$

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

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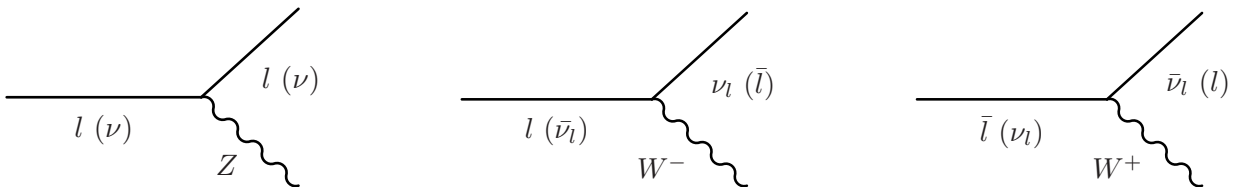
W/Z Exchange

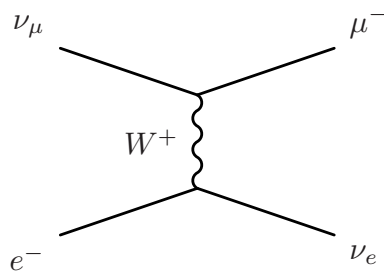EM mediated by the exchange of a photon.

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

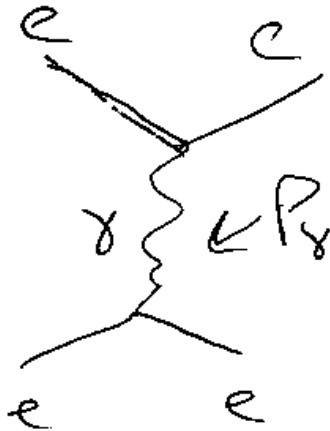When drawing diagrams, must remember to conserve Lepton numbers and EM charge.

eg:

eg:

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

Now, $m_Z = 90$ GeV and $m_W = 80$ GeV which $\neq 0$!

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

By uncertainty principle

$$E \times t \sim 1$$
$$E \times x \sim 1$$
$$x \sim \frac{1}{E}$$
$$x \sim \frac{1}{p_\gamma}$$

$\frac{1}{p_\gamma}$ can be arbitrarily large for small p_γ.
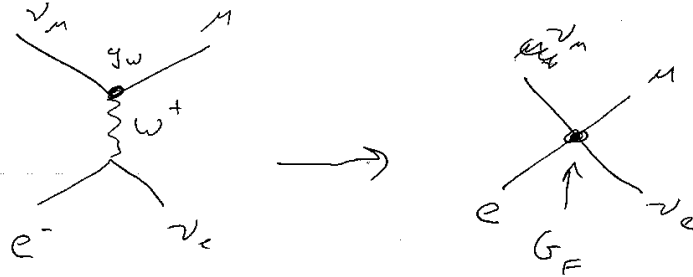
However, for the weak interaction.

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

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 $\left|\begin{array}{c}\text{0-range}\\\text{"point"}\end{array}\right.$ interaction, whose strength is characterized by the "Fermi constant"

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

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>

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

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

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

$$\frac{\text{Br}(Z \to ee)}{\text{Br}(Z \to \mu\mu)} = \frac{\Gamma(Z \to ee)}{\Gamma(Z \to \mu\mu)} = \frac{\frac{1}{2E}|M(Z \to ee)|^2 d\Pi_{LIPS}}{\frac{1}{2E}|M(Z \to \mu\mu)|^2 d\Pi_{LIPS}} = \frac{|M(Z \to ee)|^2}{|M(Z \to \mu\mu)|^2}$$
$$= \underbrace{1}_{\text{by lepton universality}}$$