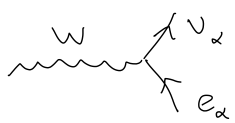
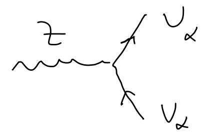
Neutrino Masses

Tuesday, 17 September 2024 08:45

$$\mathcal{L} \supset \sum_{\alpha=e,\mu,\tau} \left[\frac{g}{\sqrt{2}} W^{\mu+} \overline{\nu}_{\alpha,L} \gamma_\mu e_{\alpha,L} + h.c. + \frac{g}{\cos\theta_W} Z^\mu \overline{\nu}_{\alpha,L} \gamma_\mu \nu_{\alpha L} \right] + \text{mass terms}$$





$$\mathcal{L}_{mass} \equiv \sum_{\alpha,\beta} m_{\alpha\beta} \overline{\nu}_{\alpha L} \nu_{\beta R}$$

$\nu_{\beta R} = \begin{pmatrix} 0 \\ 0 \\ * \\ * \end{pmatrix}$

$\nu_{\alpha L} = \frac{1-\gamma^5}{2} \nu = \begin{pmatrix} * \\ * \\ 0 \\ 0 \end{pmatrix}$

Intuitive reason for 4 dof

Question: if this arises from an interaction with the Higgs field, $y \bar{L} \tilde{H} \nu_R$, why are ν masses so small?

Majorana mass terms

Could the anti-particle of ν_L play the role of ν_R in the mass term?

charge conjugation: $\hat{C}: \psi \to \psi^c \equiv -i\gamma^2\gamma^0 \overline{\psi}^T = -i\gamma^2 \psi^*$

[check: $\gamma^5 \psi^c = +i\gamma^2\gamma^5\psi^* = -(\gamma^5\psi)^c$

Identify $\boxed{\nu_R \equiv \nu_L^c}$

$\begin{pmatrix} 0 \\ 0 \\ * \\ * \end{pmatrix}$ $\begin{pmatrix} * \\ * \\ 0 \\ 0 \end{pmatrix}$

$\nu_{\alpha L} = \begin{pmatrix} \chi \\ 0 \end{pmatrix}$

$\nu_{\alpha L}^c = \begin{pmatrix} 0 \\ i\sigma^2\chi^* \end{pmatrix}$

$$\boxed{\mathcal{L}_{mass} = \sum_{\alpha,\beta} m_{\alpha\beta} \overline{(\nu_{\alpha L})^c} \nu_{\beta L}}$$ Majorana mass term

Problems: – Why are ν masses so small?
– how does this arise from an $SU(2)$-invariant UV completion

The seesaw mechanism

Introduce RH neutrino fields N_R

$$\mathcal{L} \supset \underbrace{\sum_{\alpha,\beta} m_{D,\alpha\beta} \overline{\nu_{\alpha L}} N_{R\beta}}_{\substack{\text{Dirac mass term} \\ \text{arises from coupling} \\ \bar{L}\tilde{H} N_R}} + \underbrace{\sum_{\alpha,\beta} m_{M,\alpha\beta} \overline{(N_{R\alpha})^c} N_{R\beta}}_{\substack{\text{Majorana mass} \\ N_R \text{ is SM-singlet} \\ \to \text{ no problem with SM} \\ \text{symmetries}}}$$

$n \equiv \begin{pmatrix} \nu_L \\ N_R^c \end{pmatrix}$

$$= \overline{n^c} M n$$

$$M = \begin{pmatrix} 0 & m_D \\ m_D^T & m_M \end{pmatrix}$$

$\Rightarrow$ eigenvalues of M are of $\mathcal{O}(m_M)$ and $\mathcal{O}\left(\frac{m_D^2}{m_M}\right)$

we expect $m_D \sim 100$ GeV; m_M can be extremely large

for $m_M \sim 10^{14}$ GeV $\Rightarrow$ $\frac{m_D^2}{m_M} \sim 0.1$ eV