$$\overline{\nu^c} = -\nu^T C^+$$

$p, q, r, s \rightarrow$ spinor indices

$\alpha, \beta, \gamma, \delta \rightarrow$ Dirac (spacetime)

$a, b, c \rightarrow SU(2)$ indices

$i, j, k \rightarrow$ flavour indices

$$\mathcal{M}_{\mathcal{L}} = \underline{\nu^T} \underline{M_M} \underline{\nu}$$

$$\mathcal{L} = (\nu_e \ \nu_\mu \ \nu_\tau) \begin{pmatrix} & M_M & \end{pmatrix} \begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix}$$

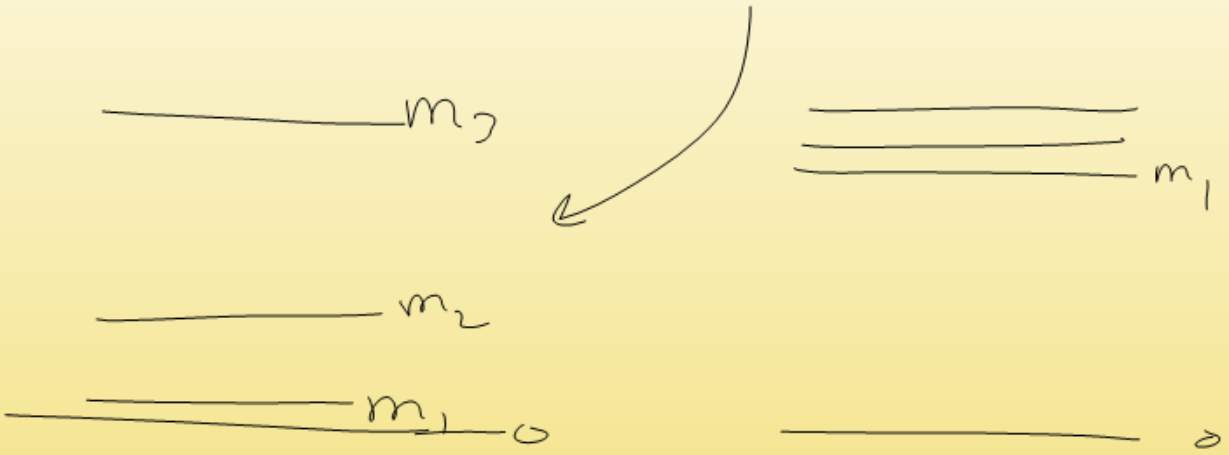
Seesaw type I

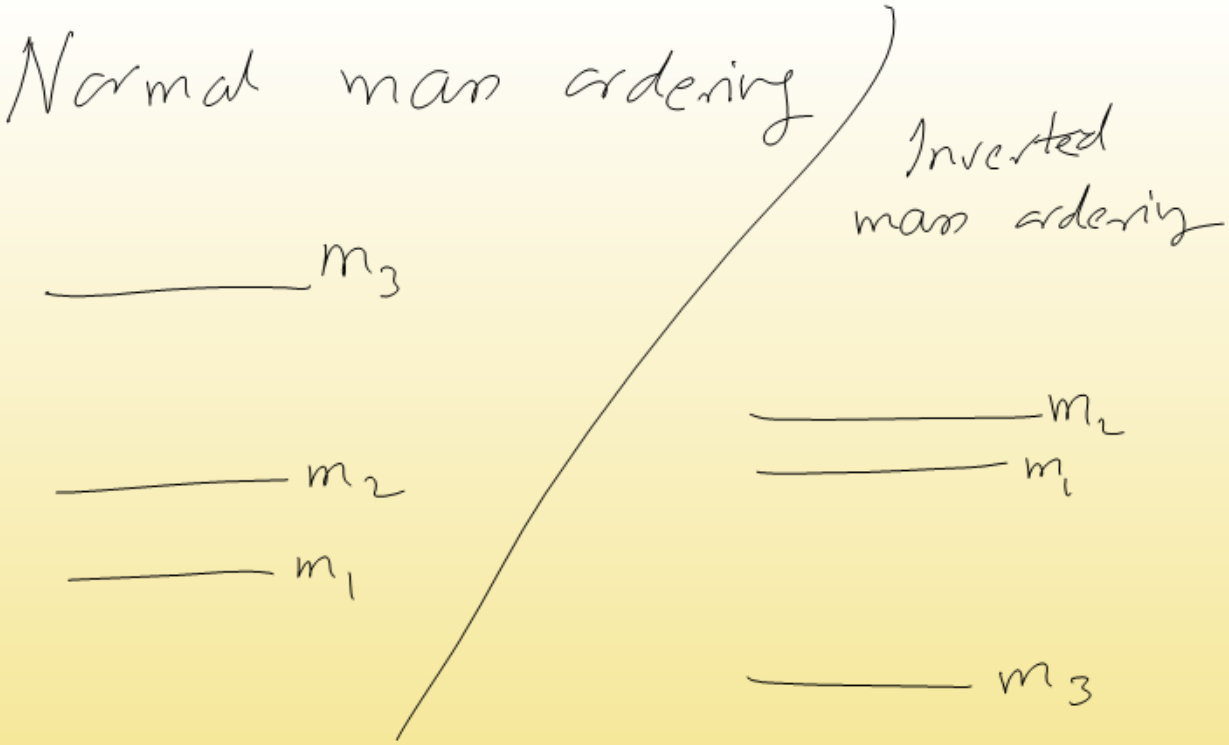
$$\mathcal{L} = \begin{pmatrix} \overline{\nu_L} & \overline{\nu_R^c} \end{pmatrix} \begin{pmatrix} \overbrace{0}^{3\times 3} & \overbrace{m_D}^{3\times n} \\ \underbrace{m_D^T}_{n\times 3} & \underbrace{m_R}_{n\times n} \end{pmatrix} \begin{pmatrix} \nu_L^c \,|_3 \\ \nu_R \,|_n \end{pmatrix}$$

~~$\begin{pmatrix} \nu_L & \nu_R \end{pmatrix}$~~

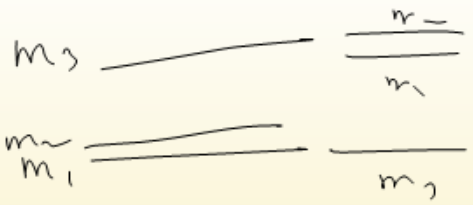
$$\begin{pmatrix} \underbrace{\overline{\nu_e}\ \overline{\nu_\mu}\ \overline{\nu_\tau}}_{3} & \underbrace{\overline{\nu_{R_1}^c}\ \overline{\nu_{R_2}^c}\ \ldots}_{n} \end{pmatrix}$$

$$m_e = \frac{m_D^2}{M_{R1}} \qquad m_\nu = \frac{m_D^2}{M_{R2}} \qquad m_\tau = \frac{m_D^2}{M_{R3}}$$




Normal mass ordering
m_3
m_2
m_1
Inverted mass ordering
m_2
m_1
m_3

Hierarchy



quasi-hierarchical inverted ordering

normal hierarchy

quasi-degenerate

Type I + II

$$m_e = m_{Le} + \frac{m_D^2}{M_{R2}} \qquad m_\mu = m_{L\mu} + \frac{m_D^2}{M_{R2}}$$

$\downarrow$

quasi-degenerate.

$$U^T M_M U = M^D = \begin{pmatrix} m_1 & & \\ & m_2 & 0 \\ 0 & & m_3 \end{pmatrix}$$

$$\boxed{M_M} = U^* M^D U^+$$

$$\begin{pmatrix} e^{i\varphi_1} & & \\ & e^{i\varphi_2} & \\ & & 1 \end{pmatrix} \begin{pmatrix} m_1^2 & & \\ & m_2^2 & \\ & & m_3^2 \end{pmatrix} \begin{pmatrix} e^{-i\varphi_1} & & \\ & e^{-i\varphi_2} & \\ & & 1 \end{pmatrix}$$

$$\downarrow$$

$$\begin{pmatrix} m_1^2 & & \\ & m_2^2 & \\ & & m_3^2 \end{pmatrix}$$