Neutrino masses in a left-right mirror model

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Abstract

In the framework of the extension of the Standard Model with gauge symmetry $SU(2)_L \otimes SU(2)_R \otimes U(1)_{Y'}$ and additional exotic fermions known as mirror fermions, the neutrino masses are estimated, which are consistent with the experimental bounds and the hierarchy. Starting from the more general Majorana neutrino mass matrix, the mass of the active and sterile neutrinos is determined with the application of a double seesaw mechanism. The mass scale of a light sterile neutrino is analyzed.

Spontaneous symmetry breaking

$$\mathrm{G} \longrightarrow \mathrm{G}_{SM} \longrightarrow \mathrm{SU}(3)_C \otimes \mathrm{U}(1)_Q \tag{1}$$

whereG_{SM} is the SM group symmetry and $\frac{Y}{2} = T_{3R} + \frac{Y'}{2}$. The Higgs sector to induce the SSB involves two doublets of scalar fields:

$$\Phi = (1,2,1,1) \quad , \quad \hat{\Phi} = (1,1,2,1) \tag{2}$$

with the "Vacuum Expectation Values" (VEV's)

$$< \Phi >= \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v \end{pmatrix} \quad , \quad < \hat{\Phi} >= \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ \hat{v} \end{pmatrix} . \tag{3}$$

The model

The LRMM formulation is based on the gauge group $SU(2)_L \otimes SU(2)_R \otimes U(1)_{Y'}$.
Fermion content is:

$$l^0_{i\,L} = \begin{pmatrix} \nu^0_i \\ e^0_i \end{pmatrix}_L , e^0_{i\,R}, \nu^0_{i\,R}, \; ; \; \widehat{l}^0_{i\,R} = \begin{pmatrix} \widehat{\nu}^0_i \\ \widehat{e}^0_i \end{pmatrix}_R , \widehat{e}^0_{i\,L}, \widehat{\nu}^0_{i\,L},$$

$$Q^0_{i\,L} = \begin{pmatrix} u^0_i \\ d^0_i \end{pmatrix}_L , u^0_{i\,R}, d^0_{i\,R}, \; ; \; \widehat{Q}^0_{i\,R} = \begin{pmatrix} \widehat{u}^0_i \\ \widehat{d}^0_i \end{pmatrix}_R , \widehat{u}^0_{i\,L}, \widehat{d}^0_{i\,L},$$

The most general potential that develops this pattern of VEV's is

$\mathrm{V} = -(\mu\Phi^\dagger\Phi + \hat{\mu}\hat{\Phi}^\dagger\hat{\Phi}) + \frac{\lambda_1}{2}[(\Phi^\dagger\Phi)^2 + (\hat{\Phi}^\dagger\hat{\Phi})^2] + \lambda_2(\Phi^\dagger\Phi)(\hat{\Phi}^\dagger\hat{\Phi})]$.

The scalar Lagrangian for the model is written as

$\mathrm{L}_{sc} = (D_\mu\Phi)^+(D^\mu\Phi) + (\hat{D}_\mu\hat{\Phi})^+(\hat{D}^\mu\hat{\Phi})$

where D_μ and $\hat{D}_\mu$ are the covariant derivatives for the SM and the mirror parts, respectively.

Quantum numbers

The quantum numbers of these fermions under the gauge group G defined above are given by

$$\begin{aligned}
l^0_{iL} \sim (1,2,1,-1)_{iL}, \nu^0_{iR} \sim (1,1,1,0)_{iR}, e^0_{iR} \sim (1,1,1,-2)_{iR} \\
\widehat{\nu}^0_{iL} \sim (1,1,1,0)_{iL}, \widehat{e}^0_{iL} \sim (1,1,1,-2)_{iL}, \widehat{l}^0_{iR} \sim (1,1,2,-1)_{iR} \\
u^0_{iR} \sim (3,1,1,\frac{4}{3})_{iR}, d^0_{iR} \sim (3,1,1,\frac{2}{3})_{iR} \\
\widehat{u}^0_{iL} \sim (3,1,1,\frac{4}{3})_{iL}, \widehat{d}^0_{iL} \sim (3,1,1,\frac{2}{3})_{iL} \\
Q^0_{iL} \sim (3,2,1,\frac{1}{3})_{iL}, \widehat{Q}^0_{iR} \sim (3,1,2,\frac{1}{3})_{iR}
\end{aligned}$$

The last entry corresponds to the hypercharge (Y') with the electric charge defined as $Q = \mathrm{T}_{3L} + \mathrm{T}_{3R} + \frac{Y'}{2}$

Majorana neutrino mass matrix

$$(\overline{\Psi}_{\nu L}, \overline{\Psi^c}_{\nu L}) \begin{pmatrix} M_L & M_D \\ M_D^T & M_R \end{pmatrix} \begin{pmatrix} (\Psi^c_\nu)_R \\ (\Psi_\nu)_R \end{pmatrix} \tag{4}$$

where

$$(\Psi_\nu)_{L,R} = \begin{pmatrix} \nu_i \\ \hat{\nu}_i \end{pmatrix}_{L,R} \quad , \quad (\Psi^c_\nu)_{L,R} = \begin{pmatrix} (\nu^c_i) \\ (\hat{\nu}^c_i) \end{pmatrix}_{L,R} \tag{5}$$

$$M_L = \begin{pmatrix} 0 & \frac{v}{\sqrt{2}}\sigma \\ \frac{v}{\sqrt{2}}\sigma^T & \hat{M} \end{pmatrix} \quad , \quad M_R = \begin{pmatrix} \chi & \frac{\hat{v}}{\sqrt{2}}\pi \\ \frac{\hat{v}}{\sqrt{2}}\pi^T & 0 \end{pmatrix} , \tag{6}$$

$$M_D = \begin{pmatrix} \frac{v}{\sqrt{2}}\lambda & 0 \\ h & \frac{\hat{v}}{\sqrt{2}}\eta \end{pmatrix} , \tag{7}$$

with h, $\hat{M}$, χ, σ, η, λ and π unknown matrices of 3×3 dimension.

Seesaw approximation

The Majorana mass matrix for the left handed neutrinos may be written in this seesaw approximation as

$$M_\nu \approx M_L - M_D\, M_R^{-1}\, M_D^T\, . \tag{8}$$

We assume a scenario where the dominant contribution for the active known neutrinos comes from the M_L matrix having the same structure of a Type I seesaw. We can explicitly write

$$M_\nu \approx M_L = \begin{pmatrix} m & \mu \\ \mu^T & \hat{m} \end{pmatrix} \quad \text{, where} \tag{9}$$

$$m = \begin{pmatrix} 0 & 0 & 0 & \sigma'_{11} \\ 0 & 0 & 0 & \sigma'_{21} \\ 0 & 0 & 0 & \sigma'_{31} \\ \sigma'_{11} & \sigma'_{21} & \sigma'_{31} & \hat{M}_{11} \end{pmatrix} , \; \mu = \begin{pmatrix} \sigma'_{12} & \sigma'_{13} \\ \sigma'_{22} & \sigma'_{23} \\ \sigma'_{32} & \sigma'_{33} \\ \hat{M}_{12} & \hat{M}_{13} \end{pmatrix} , \; \hat{m} = \begin{pmatrix} \hat{M}_{22} & \hat{M}_{23} \\ \hat{M}_{23} & \hat{M}_{33} \end{pmatrix}$$

$\sigma'_{ij} = \frac{v}{\sqrt{2}}\,\sigma_{ij}$. In this scenario we explore the possibility that one of the mirror neutrinos obtains a mass of the order of a few eV. Therefore, applying the seesaw approximation again to M_L, Eq.(9), we obtain

$$(M^{light})_{4\times 4} = m - \mu\, \hat{m}^{-1}\, \mu^T \tag{10}$$

By assuming the natural hierarchy $|(M_L)_{ij}| \ll |(M_D)_{ij}| \ll |(M_R)_{ij}|$ for the mass terms, the mass matrix $\begin{pmatrix} M_L & M_D \\ M_D^T & M_R \end{pmatrix}$ can approximately be diagonalized, yielding

$$\left(\overline{\Psi'}_{\nu L}, \overline{\Psi'^c}_{\nu L}\right) \begin{pmatrix} M_\nu & 0 \\ 0 & M_R \end{pmatrix} \begin{pmatrix} (\Psi'^c_\nu)_R \\ (\Psi'_\nu)_R \end{pmatrix} ,$$

where, neglecting $\mathcal{O}\,(M_D\, M_R^{-1})$ terms, we may write in good approximation $\Psi'_{\nu L,R} \approx \Psi_{\nu L,R}$, and $\Psi'^{\,c}_{\nu L,R} \approx \Psi^c_{\nu L,R}$.

The matrix M_L in Eq.(9), may be diagonalized by using a unitary transformation $\mathrm{U}^\dagger\, M_L\, U = Diag\,(m_1, m_2, m_3, \hat{m}_1, \hat{m}_2, \hat{m}_3)$,

where the mixing matrix U compatible with our framework is written in good approximation as

$$\mathrm{U}_{6\times 6} \approx \begin{pmatrix} U_{4\times 4} & \mu\, \hat{m}^{-1} \\ -(\mu\, \hat{m}^{-1})^T & I_{2\times 2} \end{pmatrix} , \text{ donde}$$

$$\mathrm{U}_{4\times 4} \approx \begin{pmatrix} & & & U_{14} \\ & (U_{TB})_{3\times 3} & & U_{24} \\ & & & U_{34} \\ U_{41} & U_{42} & U_{43} & O(\lesssim 1) \end{pmatrix} \quad , \quad |U_{i4}| \approx |U_{4i}| \lesssim 0.1$$

Heavy neutrino signals

Heavy Majorana neutrino singlets can be produced in the process $\mathrm{q} \to W^* \to l^\pm H$ with $l = e, \mu, \tau$, which cross sections depend on M_N and the small mixing V_{lN}.

Heavy Majorana neutrino decays in the channels $N \to W^\pm l^\mp$, $N \to Z\nu_l$ and $N \to H\nu_l$.

The partial widths for the N decays are

$$\begin{aligned}
\Gamma(N \to W^+ l^-) &= \Gamma(N \to W^- l^+) \\
&= \frac{e^2}{64\pi s^2_{\theta_w}} |U_{lN}|^2 \frac{m_N^3}{M_W^2}\left(1 - \frac{M_W^2}{m_N^2}\right) \\
&\quad \times\left(1 + \frac{M_W^2}{m_N^2} - 2\frac{M_W^4}{m_N^4}\right)
\end{aligned}$$

$$\Gamma(N \to Z\nu_l) = \frac{e^2}{64\pi s^2_{\theta_w} c^2_{\theta_w}} |U_{lN}|^2 \frac{m_N^3}{M_Z^2}\left(1 - \frac{M_Z^2}{m_N^2}\right)\left(1 + \frac{M_Z^2}{m_N^2} - 2\frac{M_Z^4}{m_N^4}\right)$$

$$\Gamma(N \to H\nu_l) = \frac{e^2}{64\pi s^2_{\theta_w}} |U_{lN}|^2 \frac{m_N^3}{M_W^2}\left(1 - \frac{M_H^2}{m_N^2}\right)^2$$

Conclusions

- Applying a double seesaw approximation to the more general Majorana-type neutrino mass matrix, an approximate analytical diagonalization was performed for light neutrinos, allowing the possibility that one mirror neutrinos play the role of a sterile neutrino with mass on the scale of eV, that is, $\hat{m}_1 \approx O(1\, eV)$.
- We are currently doing a detailed numerical analysis to accommodate the masses and mixing angles of the light neutrinos consistent with the neutrino oscillation data.

References

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