Neutrino phenomenology via Type-(I+II) seesaw in a $U(1)_{L_e-L_\mu}$ model

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Abstract

- It is expected that the neutrino masses provided by neutrino experiments can be explained with the help of extension of the Standard Model(SM).
- In this work we extend the SM with the gauge symmetry $U(1)_{L_e-L_\mu}$ with type (I+II) seesaw.
- We constrain the model parameters consistent with current neutrino oscillation data. Furthermore, we obtain new contributions to muon g-2 and also charged lepton flavor violating decay $\mu \to e\gamma$.

Introduction

- The model involves three right handed neutrinos, a scalar singlet along with a scalar triplet in addition to the SM particle spectrum.
- The Lagrangian of the model can be written as:

$$\begin{aligned}\mathcal{L}_{\rm lepton} \;=\; & -y_\alpha^l \overline{\ell_{\alpha \rm L}} \alpha_{\rm R} H - \frac{1}{2} y_\Delta \left(\overline{\ell_{\tau \rm L}} \Delta i\sigma_2 \ell_{\mu \rm L}^{\rm C} + \overline{\ell_{\mu \rm L}} \Delta i\sigma_2 \ell_{\tau \rm L}^{\rm C} \right) - y_\alpha^\nu \overline{\ell_{\alpha \rm L}} \widetilde{H} \nu_{\alpha \rm R} \\ & - \frac{1}{2} y_S^{e\tau} \left(\overline{\nu_{e\rm R}^{\rm C}} \nu_{\tau \rm R} + \overline{\nu_{\tau \rm R}^{\rm C}} \nu_{e\rm R} \right) S^\dagger - \frac{1}{2} y_S^{\mu\tau} \left(\overline{\nu_{\mu\rm R}^{\rm C}} \nu_{\tau \rm R} + \overline{\nu_{\tau \rm R}^{\rm C}} \nu_{\mu\rm R} \right) S \\ & - \frac{1}{2} \left[m_{\rm R}^{\tau\tau} \overline{\nu_{\tau \rm R}^{\rm C}} \nu_{\tau \rm R} + m_{\rm R}^{e\mu} \left(\overline{\nu_{\mu\rm R}^{\rm C}} \nu_{e\rm R} + \overline{\nu_{e\rm R}^{\rm C}} \nu_{\mu\rm R} \right) \right] + \text{h.c.}\,. \end{aligned} \tag{1}$$

- Mass matrix of active neutrino is:

$$M_\nu = \begin{pmatrix} 0 & 0 & -\frac{v_H^2 y_\nu^e y_\nu^\tau}{2 m_R^{e\tau}} \\ 0 & \frac{v_H^2 (y_\nu^\mu)^2}{2 m_R^{\mu\mu}} & y_\Delta v_\Delta + \frac{v_H^2 |y_S^{e\mu}| v_S y_\nu^\mu y_\nu^\tau}{2\sqrt{2} m_R^{e\tau} m_R^{\mu\mu}} e^{i\phi} \\ -\frac{v_H^2 y_\nu^e y_\nu^\tau}{2 m_R^{e\tau}} & y_\Delta v_\Delta + \frac{v_H^2 |y_S^{e\mu}| v_S y_\nu^\mu y_\nu^\tau}{2\sqrt{2} m_R^{e\tau} m_R^{\mu\mu}} e^{i\phi} & -\frac{v_S^2}{2} \frac{|y_S^{e\mu}|^2 v_H^2 (y_\nu^\tau)^2}{(m_R^{e\tau})^2 m_R^{\mu\mu}} e^{2i\phi} \end{pmatrix}. \tag{2}$$

Muon $(g-2)$

- The model can also explain muon anomalous magnetic momenta, $(g-2)_\mu$. The expression for $(g-2)_\mu$ in presence of $Z_{e\mu}$ reads as

$$\Delta a_\mu \;=\; \frac{g_{e\mu}^2}{4\pi^2} \int_0^1 \frac{x^2(1-x)}{x^2 + (M_{Z_{e\mu}}^2/m_\mu^2)(1-x)} dx \approx \frac{m_\mu^2}{12\pi^2} \frac{g_{e\mu}^2}{M_{Z_{e\mu}}^2} \tag{3}$$

- To have consistent with Fermilab experiment on $(g-2)_\mu$, the value of $v_{e\mu}$ should be $194 GeV$.
- For explaination of $(g-2)_e$, we need $v_{e\mu}$ 50 GeV (which is not satisfactory) as current bound on electron (g-2) is:

$$\Delta a_e^{exp} = -(8.7 \pm 3.6) \times 10^{-13} \tag{4}$$

Lepton Flavor violation

- The model can explain the lepton flavor violation $\mu \to e\gamma$ with brancing ratio:

$$\text{Br}(\mu \to e\gamma) = \frac{27 \alpha_{em} |\langle m^2 \rangle_{e\mu}|^2}{256 \pi G_F^2 v_\Delta^4 M_\Delta^4} < 4.2 \times 10^{-13}\,, \tag{5}$$

Mass Matrix and mixing angles

$$M_\ell = \begin{pmatrix} y_l^e & 0 & 0 \\ 0 & y_l^\mu & 0 \\ 0 & 0 & y_l^\tau \end{pmatrix}, \qquad M_D = \frac{v_H}{\sqrt{2}} \begin{pmatrix} y_\nu^e & 0 & 0 \\ 0 & y_\nu^\mu & 0 \\ 0 & 0 & y_\nu^\tau \end{pmatrix}, \qquad M_L = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & y_\Delta v_\Delta \\ 0 & y_\Delta v_\Delta & 0 \end{pmatrix}$$

$$M_R = \begin{pmatrix} 0 & m_R^{e\mu} & |y_S^{e\tau}| \frac{v_S}{\sqrt{2}} e^{i\phi} \\ m_R^{e\mu} & 0 & 0 \\ |y_S^{e\tau}| \frac{v_S}{\sqrt{2}} e^{i\phi} & 0 & m_R^{\tau\tau} \end{pmatrix} [|y_S^{e\tau}| >> |y_S^{\mu\tau}|]$$

$$\sin^2\theta_{13} = |U_{13}|^2, \quad \sin^2\theta_{23} = \frac{|U_{23}|^2}{1-|U_{13}|^2}, \quad \sin^2\theta_{12} = \frac{|U_{12}|^2}{1-|U_{13}|^2}. \;[U \text{ diagonalizes matrix (2)}]$$

Results

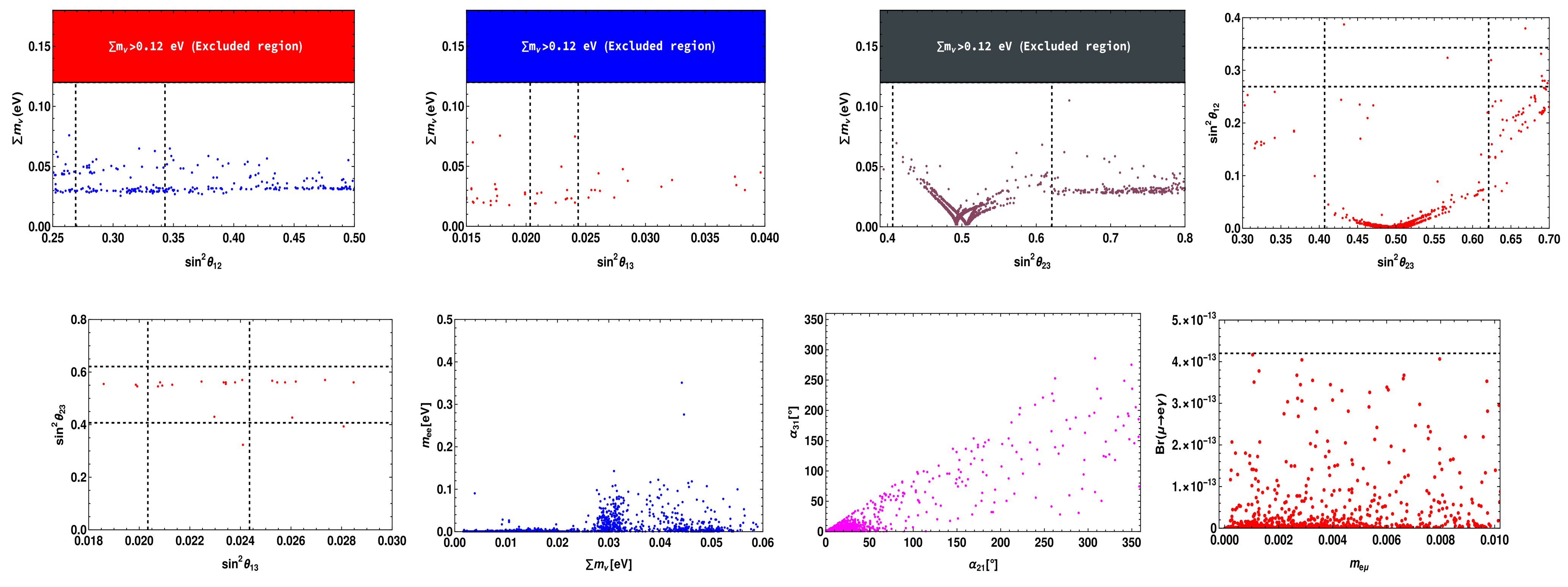

Figure 1: These plots (first three)are showing the variation of $sin^2\theta_{12}$, $sin^2\theta_{13}$, $sin^2\theta_{23}$ with respect to sum of active mass neutrinos, next two plots show the corelation of $sin^2\theta_{12}$, $sin^2\theta_{23}$ and $sin^2\theta_{23}$, $sin^2\theta_{13}$, 6th plot shows $0\nu\nu\beta\beta$ decay, 7th plot has the relation between two Majorana phases, and last one is for lepton flavor violation $\mu \to e\gamma$

Conclusion

- We have explained the neutrino oscillation parameters with the help of type-(I+II) seesaw in $U(1)_{L_e-L_\mu}$ gauged symmetry model.
- We have also explained successfully neutrinoless double beta decay, lepton flavor violation $\mu \to e\gamma$ within experimental range.
- The muon (g-2) is also illustrated in our model.

References

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