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

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Abstract

We show how, $L_e - L_\mu$ gauged symmetry is used as the Standard Model (SM) extension with the type (I+II) seesaw mechanism for neutrino mass generation. The particle content of this model involves three extra right handed neutrinos, one scalar triplet and one singlet with the SM spectrum. We discuss about lepton flavour violating decays $\mu \to e\gamma$, $\tau \to \mu\bar{\mu}\mu$ and anomalous magnetic moment of muon.

1 Introduction

Though successful, SM is not able to explain many observed phenomena in particle physics, astrophysics and cosmology. For instance, SM is unable to resolve the puzzle of neutrino physics. These days neutrinos are the most talked about topic in the scientific community as they are believed to contribute both in microscopic and macroscopic world. SM does not include right-handed neutrinos; as a result, neutrinos become unfavorable to have Dirac mass. Therefore to explain neutrino mass, we need to extend the boundary of the Standard Model. Here in this work, we use $U(1)_{L_e-L_\mu}$ gauge symmetry to go beyond SM and add three right handed neutrinos ν_{jR}, where $j = e, \mu, \tau$; one scalar singlet S and one scalar triplet Δ in framework of type (I+II) mechanism [?]. The neutrino mass matrix comes out to be two-zero A_2 texture. 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 decays such as $\mu \to e\gamma$, $\tau \to \mu\bar{\mu}\mu$.

2 The main Ingredients of the Model

As we extend the Standard model through Gauge sector ($U(1)_{L_e-L_\mu}$), fermion sector ($\nu_{eR}, \nu_{\mu R}, \nu_{\tau R}$) and scalar sector (S, Δ), the particle spectrum of the new model is,

Particles	$SU(2)_L$	$U(1)_Y$	$U(1)_{L_e-L_\mu}$
$l_{eL}, l_{\mu L}, l_{\tau L}$	2	-1	$1, 0, -1$
e_R, μ_R, τ_R	1	-2	$1, 0, -1$
$\nu_{eR}, \nu_{\mu R}, \nu_{\tau R}$	1	0	$1, 0, -1$
H	2	1	0
S	1	0	1
Δ	3	-2	-1

Table 1: Particle contents in $U(1)_{L_e-L_\mu}$ model.

and the Lagrangian for leptonic sector, which is invariant under the $SU(2)_L \times U(1)_Y \times U(1)_{L_e-L_\mu}$ symmetry,

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

3 Neutrino Mass Matrix

For the active neutrino mass matrix we implement type (I+II) seesaw mechanics,

$$M_\nu = M_L - M_D M_R^{-1} M_D^T \tag{2}$$

From the Lagrangian given above we can get the forms of M_D, M_R and M_L,

$$M_\text{D} = \frac{v_H}{\sqrt{2}} \begin{pmatrix} y_\nu^e & 0 & 0 \\ 0 & y_\nu^\mu & 0 \\ 0 & 0 & y_\nu^\tau \end{pmatrix} , \quad M_\text{L} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & y_\Delta v_\Delta \\ 0 & y_\Delta v_\Delta & 0 \end{pmatrix} , \tag{3}$$

,

$$M_\text{R} = \begin{pmatrix} 0 & m_R^{e\mu} & |y_S^{e\tau}| \frac{v_S}{\sqrt{2}} e^{i\phi} \\ m_R^{e\mu} & 0 & y_S^{\mu\tau} \frac{v_S}{\sqrt{2}} \\ |y_S^{e\tau}| \frac{v_S}{\sqrt{2}} e^{i\phi} & y_S^{\mu\tau} \frac{v_S}{\sqrt{2}} & m_R^{\tau\tau} \end{pmatrix} . \tag{4}$$

where M_R is the mass matrix of right-handed neutrinos.
Assuming $y_S^{e\tau} \gg y_S^{\mu\tau}$ in M_R to have corerelations between mixing parameters and observables, the active neutrino mass matrix is given by,

$$M_\nu = \begin{pmatrix} 0 & -\frac{v_H^2 y_\nu^e y_\nu^\mu}{2m_R^{e\mu}} & 0 \\ -\frac{v_H^2 y_\nu^e y_\nu^\mu}{2m_R^{e\mu}} & -\frac{v_S^2}{4}\frac{|y_S^{e\tau}|^2 v_H^2 (y_\nu^\mu)^2}{(m_R^{e\mu})^2 m_R^{\tau\tau}} e^{2i\phi} & y_\Delta v_\Delta + \frac{v_H^2 |y_S^{e\tau}| v_S y_\nu^\mu y_\nu^\tau}{2\sqrt{2} m_R^{e\mu} m_R^{\tau\tau}} e^{i\phi} \\ 0 & y_\Delta v_\Delta + \frac{v_H^2 |y_S^{e\tau}| v_S y_\nu^\mu y_\nu^\tau}{2\sqrt{2} m_R^{e\mu} m_R^{\tau\tau}} e^{i\phi} & -\frac{v_H^2 (y_\nu^\tau)^2}{2m_R^{\tau\tau}} \end{pmatrix}, \quad (5)$$

where $(M_\nu)_{ee} = (M_\nu)_{e\tau} = 0$, so M_ν has two-zero A_2 texture.

4 Numerical analysis

We have diagonalised the neutrino mass matrix which came out to be two-zero A_2 texture and hence supporting the normal hierarcy in neutrino masses [?]. We assume model parameters in the following region,

$$\begin{aligned} & y_\nu^\alpha \in \; [10^{-6}, 10^{-7}], \quad y_\Delta \in [0.01, 1], \quad v_\Delta \in [10^{-2}, 10^{-1}] \text{ eV}, \\ & M_\Delta \in [1, 2] \text{ TeV}, \quad M_1, M_2, M_3 \in [1, 10] \text{ TeV} \end{aligned} \quad (6)$$

which can show that the neutrino oscillation parameters are in good agreement with experimental data from NuFit [?] at 3σ range.

We show the plots between cosmic bound ($\sum m_i < 0.12\ eV$) for neutrino mass and mixing angle for the allowed range of parameters, correlation between mixing angles, CP violating phase and Jarlskog invariant with $sin^2\theta_{13}$.

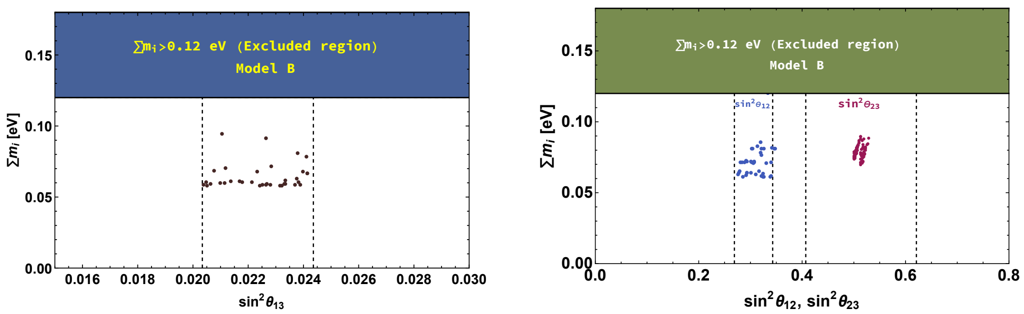


Figure 1: Left(right) plot shows the variation of $\sum_i m_i$ with $sin^2\theta_{13}(sin^2\theta_{12}, sin^2\theta_{23})$

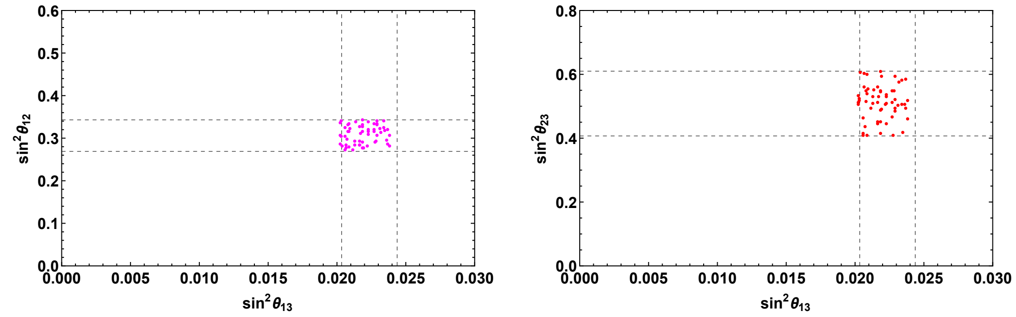


Figure 2: Left(right) plot shows the variation of $sin^2\theta_{12}(sin^2\theta_{23})$ with respect to $sin^2\theta_{13}$.

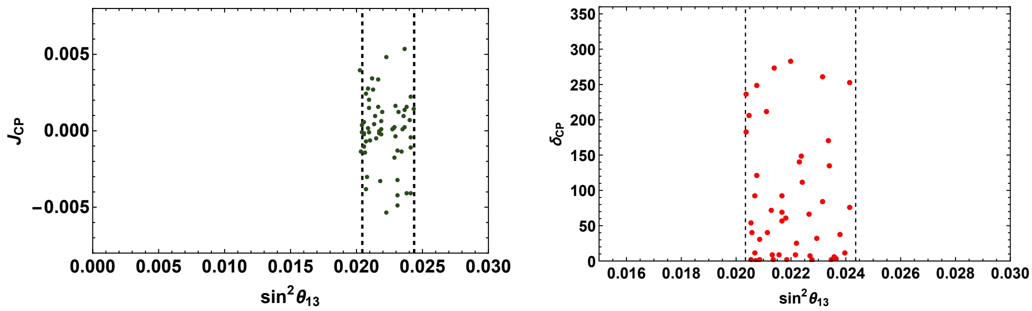


Figure 3: Left(right) plot shows the variation of $J_{CP}(\delta_{CP})$ with $sin^2\theta_{13}$

5 Lepton flavor violation

After the discovery of neutrino oscillations, it is evident that neutrino oscillates from one flavour to the other and if so in charged lepton sector, that lead to go beyond Standard Model. Here in our present model we show branching ratios (BR) for $\mu \to e\gamma, \tau \to \mu\bar{\mu}\mu$ deacys are in good agreement with their current experimental limits. The BR for the lepton flavor violating decay modes are [?], [?]

$$\text{Br}(\mu \to e\gamma) = \frac{27\alpha_{em}|\left\langle m^2\right\rangle_{e\tau}|^2}{256\pi G_F^2 v_\Delta^4 M_\Delta^4} < 4.2 \times 10^{-13} \, , \tag{7}$$

$$\text{Br}(\tau \to \mu\bar{\mu}\mu) = \frac{|m_{\tau\mu}|^2|m_{\mu\mu}|^2}{16 G_F^2 v_\Delta^4 M_\Delta^4} < 2.1 \times 10^{-8} \, , \tag{8}$$

where fine stucture constant α_{em} is $\frac{1}{137}$ and fermi coupling G_F is $1.17 \times 10^{-5}\ GeV^2$.

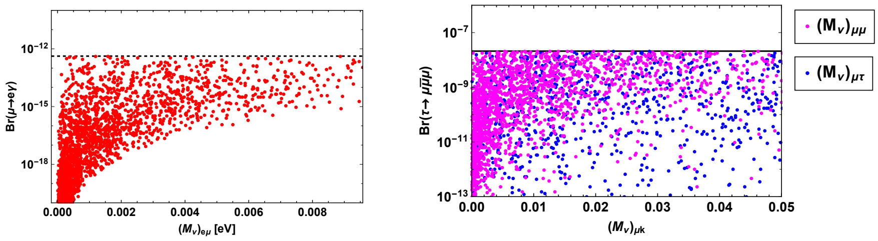


Figure 4: Left plot shows the correlation between the BR of $\mu \to e\gamma$ with respect to $m_{e\mu}$ and right one shows BR for $\tau \to \mu\bar{\mu}\mu$ with the mass element $m_{\mu\mu}$ and $m_{\mu\tau}$.

6 Muon g-2

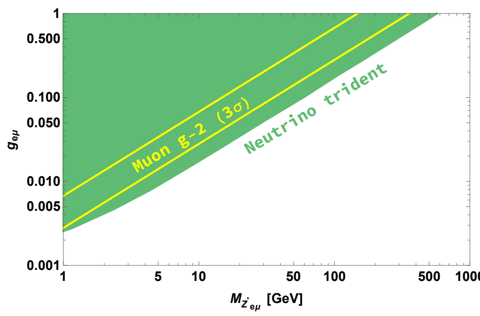
The muon g-2 data reported by BNL has a discrepancy at 3.7σ level [?] and the data from E989 experiment at Fermilab [?] has deviation at 4.2σ level from the prediction of SM. In our present model, $Z'_{e\mu}$ couples to muon and hence the expression for Δa_μ in presence of $Z'_{e\mu}$ is,

$$\begin{aligned}\Delta a_\mu &= \frac{g'^2}{4\pi^2}\int_0^1 \frac{x^2(1-x)}{x^2+(M_{Z'}^2/m_\mu^2)(1-x)}\mathrm{d}x \\ &\approx \frac{m_\mu^2}{12\pi^2}\frac{g'^2_{e\mu}}{M^2_{Z'_{e\mu}}} \end{aligned} \tag{9}$$

The value of $\frac{M_{Z'_{e\mu}}}{g'_{e\mu}}$ in terms of Δa_μ,

$$\frac{M_{Z'_{e\mu}}}{g'_{e\mu}} = \sqrt{\frac{m_\mu^2}{12\pi^2 \Delta a_\mu^{\mathrm{FNAL}}}},$$

and its required value to have muon magnetic moment in 3σ range is $148 < \frac{M_{Z'_{e\mu}}}{g'_{e\mu}} < 357$ in GeV. The plot is showing the gauge parameter space of g-2 of muon in the $(M_{Z'_{e\mu}} - g'_{e\mu})$ plane. Green region is excluded by neutrino trident production.



7 Conclusion

We have formulated two-zero A_2 texture neutrino mass matrix and shown the correlation plots with mixing parameters for allowed range of model parameter space and upper bound for LFV deacys $\mu \to e\gamma, \tau \to \mu\bar{\mu}\mu$. Also, we discussed muon g-2 and the results are in favor of E989 experiment of Fermilab. Hence we demonstrated Neutrino phenomenology in extended SM with type (I+II) seesaw mechanism.

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