TEXTURE ZERO NEUTRINO MASS MATRIX IN LEFT-RIGHT SYMMETRIC MODEL: A PHENOMENOLOGICAL STUDY

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Abstract: Texture zeros play a decisive role in the neutrino phenomenological study as well as in reducing the number of free parameters and correlating them in the beyond Standard Model framework. In this work we study the possibility concerning the origin of texture zero in the neutrino mass matrix in the context of the left-right symmetric model (LRSM). Texture zeros in the light neutrino mass matrix bring about the persistence of allowed and disallowed classes of texture zero classification. In this work we study the lepton number-violating neutrinoless double beta decay (NDBD) corresponding to standard light neutrino, heavy right-handed neutrino and scalar triplet contributions in LRSM. We have also tried to study charged lepton flavor violation (CLFV) within this framework and see if we can simultaneously study these observables within a common parameter space in the model. The study has been carried out for both normal and inverted mass orderings which interestingly rules out certain textures while considering the said observables.

Keywords: Neutrino mass; Flavour symmetry; Texture zero, Left-right symmetric model

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1 Introduction

The Standard Model (SM) [1, 2] of particle physics is contemplated as the most successful theory after the fabled Large Hadron Collider (LHC) at CERN, nailed down the final missing piece of the model in the year 2012. Several experiments have validated the predictions of the SM with exquisite precision. Although this discovery unravels the properties and interactions of the charged fermions and their origin of mass, yet it fails to provide a basis for understanding the light neutral fermions which are the most elusive neutrinos. The milestone breakthrough of neutrino oscillation which brought into light that neutrinos have tiny non-zero mass and they mix during propagation, which bagged the 2015 Nobel Prize in Physics, has brought about a severe crack in the model's elegant edifice, thereby pointing out its incompleteness. Various experiments in the neutrino sector have well established that neutrinos are massive and have large mixing over the past few decades. One can have a review of neutrino mass and mixing at [3, 4]. The recent neutrino experiments like T2K [5], Double Chooz [6], Daya Bay [7], RENO [8] and MINOS [9] have not only given strong affirmations of the results from earlier ones ([10, 11, 12]) but also provided strong evidence for the non-zero reactor mixing angle θ_{13}. However, from the latest global fit ([13]) neutrino data, it is seen that a few of the light neutrino parameters, like the octant of the atmospheric mixing angle and the Dirac CP phase are yet to be perceived experimentally. Further, the ordering of light neutrinos- normal ordering (NO) or inverted ordering (IO) and the intrinsic nature of neutrinos (whether Dirac or Majorana) has not been determined with exquisite precision. The Majorana CP phases that appears if neutrinos are Majorana fermions are not sensitive to the neutrino oscillation experiments and one has to probe them with alternative experiments. Again, data from cosmology (Planck mission) puts constraints on the sum of absolute neutrino masses $\sum_i|m_i| < 0.12$ eV ([14]). Apart from the above-mentioned unknowns, we have sufficient information related to the neutrino sector from the significant experimental observations. Still, the dynamical origin of light neutrino masses and their mixing is something that still remains a mystery. The successful SM is considered an insufficient theory, as it fails to shed light upon some other vital issues like Lepton Flavor Violation (LFV), Lepton Number Violation (LNV), the Baryon Asymmetry of the universe (BAU), Dark matter (DM) etc. [16, 15, 17, 18, 19, 20]. Several beyond standard model (BSM) proposals have been put forward that can address these issues. The simplest amongst the several BSM frameworks is the very popular seesaw mechanism, where the scale of the electroweak and the heavy newly introduced fields have a seesaw that decides how small the neutrino mass is. Among the seesaw models the popular ones have been categorized as type I seesaw [21, 22, 23, 24], type II seesaw [25, 26, 27, 28, 29], type III seesaw [30, 31], inverse seesaw [32, 33] among others like [31, 32] etc.

The left-right symmetric model (LRSM) [34, 35, 36, 37, 38] is another very appealing framework that can address the neutrino mass and other unsolved queries. The gauge symmetry of the LRSM is $\mathrm{SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}}$ where the left and right-handed fermions are treated on equal footing. LRSM can naturally explain the origin of the tiny neutrino mass via the seesaw mechanism and provides a framework to understand the spontaneous breaking of parity. Over the last few years, it has gained indomitable importance among several research groups in various contexts [39, 40, 18, 41, 42, 43, 44, 45, 46]. One important motivation for this model lies in its testability because a TeV scale LRSM can have interesting signatures that are being looked at in the collider experiments. Again, in the absence of any specific flavor symmetry, the seesaw model or the LRSM can predict the most generic neutrino mass matrix structure, which one can fit to the observed neutrino data. However, it would be enthralling if we have a well-motivated symmetry to describe the neutrino mass matrix with the minimum number of free parameters. Texture zero models (a nice review can be found in [47]) are one of such significant models that can reduce the number of free parameters in the neutrino mass matrix. As there is no conceivable set of experiments that has determined a particular structure for the neutrino mass matrix, it is very motivating if we can implement zero elements in the mass matrix within the framework of LRSM. For a symmetric 3×3 mass matrix with nine elements, there are ${}^6C_n$ number of possible structures having $n-0$ textures. If we have a diagonal charged lepton basis, it has been found that zeros not more than two are allowed in the light neutrino mass matrix. In the present study, we put forward an analysis of two zero texture neutrino mass matrices. For realizing the textures, we have used $D_4 \times Z_2$ symmetry ([48]) in the framework of LRSM. Here, we have shown the symmetry realization of the two zero texture B_3 only. Whereas we have shown the phenomenological study of all the allowed two zero textures in this work for both the mass orderings. Out of the fifteen two zero textures, the current neutrino global fit as well as data from cosmology allows only five of them. It would be interesting to study the correlations among the neutrino parameters as well as find the new physics contributions to low energy observables like NDBD, charged lepton flavor violating decay (LFV) processes within the TeV scale LRSM framework considering a two texture zero neutrino mass matrix. There are a bunch of $(0\nu\beta\beta)$ experiments, out of which KamLAND-Zen imposes the best lower limit on the decay half-life ($T^{0\nu}_{1/2} > 1.07 \times 10^{26}$ yr at 90 percent CL [49]). Along with it, with sufficient information about the nuclear matrix element, one can set a limit on the effective Majorana neutrino mass as (0.061-0.165)eV. Again, the new scalar fields in the TeV scale LRSM also contribute to a sizeable amount of CLFV, which is accessible in recent experiments. Notable LFV decays include $\mu \to 3e$ and $\mu \to \gamma e$ which set constraints on the branching ratios as $BR(\mu \to \gamma e) < 4.2 \times 10^{-13}$ and $BR(\mu \to 3e) < 1.0 \times 10^{-12}$ from the MEG [51] and SINDRUM experiments[50], respectively.

The paper has been organized as follows: in section 2, we describe the Left-Right Symmetric Model (LRSM). In section 3, we discuss neutrinoless double beta decay (NDBD) and lepton flavor violation (LFV) in the LRSM framework. In 4, we discuss in brief the numerical analysis and results obtained in the present work, and then we give the conclusion in the subsequent section 5.

2 LEFT-RIGHT SYMMETRIC MODEL

As suggested by the term, the left-right symmetric model has a symmetric particle content described by the gauge group $SU(3)_C \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$. It is one of the simple extensions of the SM of particle physics. Several groups have already described the model elaborately (one of them is [36]). Here, we give a brief description of the model as we have used it in the present study in describing the neutrino mass. In LRSM, both the right-handed and left-handed sector are treated on the same footing; both transform as doublets under the $SU(2)$ gauge group. The scalar sector consists of two scalar triplets, $\Delta_L(1,3,1,2)$ and $\Delta_R(1,1,3,2)$ and a Higgs bidoublet $\phi(1,2,2,0)$. Both type II and type I seesaws arise naturally in LRSM, and hence the neutrino mass term is a summation of both the seesaw masses.

The Dirac and the Majorana mass terms in LRSM arise when the scalar sectors couple with the particle content of the model, giving rise to the necessary Dirac and Majorana Yukawa couplings. The Yukawa Lagrangians for the Dirac and Majorana mass terms are as given below.

$$\mathcal{L}_{\mathcal{D}} = \overline{l_{iL}}(Y^l_{ij}\phi + \widetilde{Y^l_{ij}}\widetilde{\phi})l_{jR} + \text{h.c.}, \tag{1}$$

$$\mathcal{L}_{\mathcal{M}} = f_{L,ij}\Psi_{L,i}{}^T Ci\sigma_2\Delta_L\Psi_{L,j} + f_{R,ij}\Psi_{R,i}{}^T Ci\sigma_2\Delta_R\Psi_{R,j} + \text{h.c.}. \tag{2}$$

Y^l are the Dirac Yukawa couplings and f_L and f_R are the Majorana Yukawa couplings respectively. σ_2 represents the second Pauli matrix and ψ's represents the left-handed and right-handed fermion fields. The indices i, j run from 1 to 3, which corresponds to the three generations of the leptons. $C = i\gamma_2\gamma_0$ represents the charge conjugation operator, γ_μ being the Dirac matrices and $\widetilde{\phi} = \tau_2\phi^*\tau_2$.

The LRSM gauge group is broken down to the Standard Model gauge group, which is further broken down to the gauge group of the electromagnetic theory in successive steps. After a spontaneous symmetry breaking, the neutral components of the scalar fields (scalar triplets and the bidoublet) acquire vacuum expectation values (VEVs) (v_L, v_R, v) giving rise to the resultant neutrino mass terms via the type I and type II seesaw .

$$M_\nu = M_\nu^I + M_\nu^{II}, \tag{3}$$

where,

$$M_\nu^I = M_D M_R^{-1} M_D^T, \tag{4}$$

$$M_\nu^{II} = M_{LL} \tag{5}$$

are the type-I and type-II seesaw mass terms, respectively. M_D and M_R are the Dirac and Majorana mass matrices which are dependent upon the VEVs of the scalar triplets as shown in the equations below,

$$M_D = \frac{1}{\sqrt{2}}(k_1 Y_l + k_2\tilde{Y_1}), M_l = \frac{1}{\sqrt{2}}(k_2 Y_l + k_1\tilde{Y_1}), \tag{6}$$

$$M_R = \sqrt{2}v_R f_R, M_{LL} = \sqrt{2}v_L f_L. \tag{7}$$

In LRSM, the Majorana Yukawa couplings $f_L = f_R$. The VEVs obeys the relation, $|v_L|^2 < |k_1^2 + k_2^2| < |v_R|^2$, $v = \sqrt{k_1^2 + k_2^2}$. Eq.(3) further takes the form as shown below,

$$M_\nu = M_D M_R^{-1} M_D^T + \gamma\left(\frac{M_W}{v_R}\right)^2 M_{RR}, \tag{8}$$

where, γ is a dimensionless parameter which appears in v_L as given by the induced VEV relation $v_L = \gamma(\frac{v^2}{v_R})$.

3 NEUTRINOLESS DOUBLE BETA DECAY AND LEPTON FLAVOR VIOLATION IN LRSM

The inclusion of several new heavy particles in LRSM brings forth new contributions to $0\nu\beta\beta$ amplitudes in addition to the standard light neutrino contribution. About eight contributions arises within the LRSM framework. It has been extensively described in[43]. However, in the present work we have considered for analysis two of the new physics contributions and the standard light neutrino contributions as has been stated below,

- Standard light neutrino contribution to $0\nu\beta\beta$ in which the mediator particles are the W_L bosons and light neutrinos, the amplitude of the process depends upon the elements of the leptonic mixing matrix and the light neutrino masses.

- Heavy right-handed (RH) neutrino contribution with W_R bosons as the mediator particles of the process. The amplitude of this decay process depends on the mass of W_R, heavy RH ν as well as the elements of the right handed leptonic mixing matrix.

- Right-handed scalar triplet contribution (Δ_R) contribution to NDBD with W_R bosons as the mediator particles. The amplitude for the process depends upon the masses of the W_R bosons, Δ_R, as well as their coupling to the leptons.

In this work, we analyze the standard light neutrino, heavy right-handed neutrino and the scalar triplet (Δ_R) contribution to NDBD considering different allowed cases of texture zeros of neutrino masses.

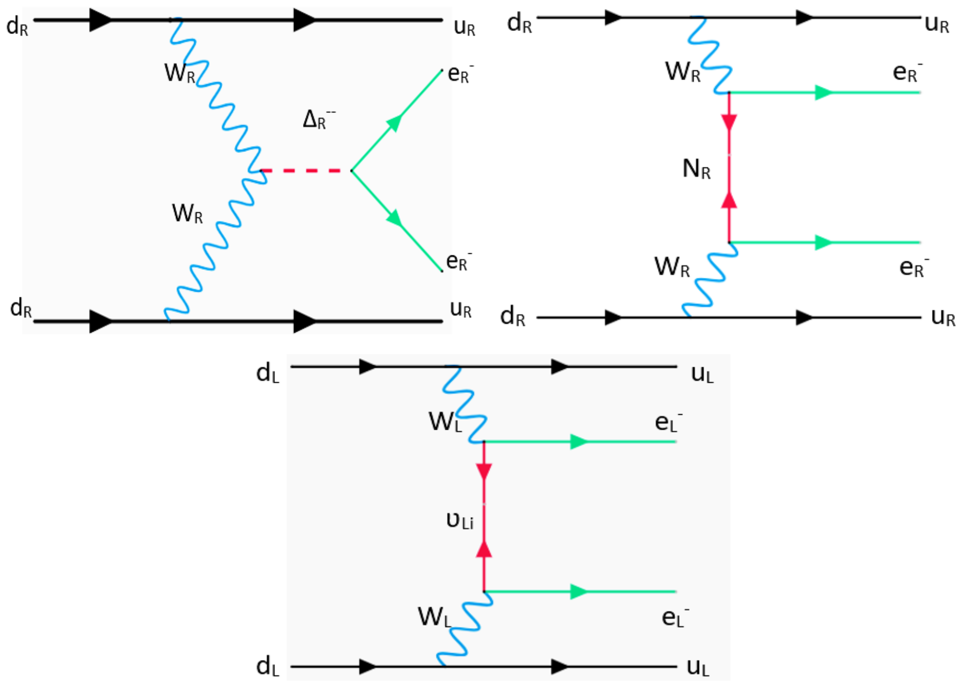

Figure 1: The Feynman diagrams showing the new physics contributions (heavy RH ν and Δ_R) and the standard light neutrino contributions (ν_L).

Furthermore Charged Lepton Flavor Violation (CLFV) is considered one of the prominent signature of new physics, which can directly interpret the physics of flavor and generations. Another motivation lies in the fact that at the TeV scale, the effects of LFV could be realized in many new models. In the framework of LRSM, as the scale of the electroweak sector is dynamically broken, an accessible amount of LFV is anticipated for a bigger parameter space. Out of different lepton flavor violating decays, the ones that are considered as most relevant are the rare leptonic decay models notably, $\mu \to 3e$ and $\mu \to e\gamma$. The relevant branching ratios (BR) for the processes are given as,

$$BR_{\mu\to 3e} \equiv \frac{\Gamma(\mu^+ \to e^+e^-e^+)}{\Gamma_\mu}, \tag{9}$$

$$BR_{\mu\to e\gamma} \equiv \frac{\Gamma(\mu^+ \to e^+\gamma)}{\Gamma_\mu}. \tag{10}$$

4 Numerical Analysis and Results

4.1 Texture zeros in LRSM

Texture zero in the context of LRSM has been studied in our earlier works [52, 53]. In this work, we first express the lepton mass matrices in terms of the variables a_1, a_2, a_3, b_1, b_2, b_3, c_1, c_2, c_3, w, x, y, z. In the light neutrino mass matrix, we aim to re-investigate the different classes of texture zeros using current neutrino data and then studied the observables like NDBD and LFV. As has already been mentioned, in a symmetric 3×3 neutrino mass matrix, there are $\frac{6!}{n!(6-n)!}$ number of possible n zero textures. The textures with $n \geq 3$ could not fit the currently available neutrino data. Out of the fifteen different possible combinations of textures with two zeros, only five of them are found to be compatible with the present existential data, which are shown in table 1.

Table 1 shows the possible combinations of 2-0 textures of the light neutrino mass matrix allowed by recent neutrino data.

Class	Constraints	Mass Matrix
2-0 (A_1)	$M_{ee} = M_{e\mu} = 0$	$M_\nu = \begin{pmatrix} 0 & 0 & \times \\ 0 & \times & \times \\ \times & \times & \times \end{pmatrix}$
2-0 (B_1)	$M_{e\tau} = M_{\mu\mu} = 0$	$M_\nu = \begin{pmatrix} \times & \times & 0 \\ \times & 0 & \times \\ 0 & \times & \times \end{pmatrix}$
2-0 (B_2)	$M_{\tau\tau} = M_{e\mu} = 0$	$M_\nu = \begin{pmatrix} \times & 0 & \times \\ 0 & \times & \times \\ \times & \times & 0 \end{pmatrix}$
2-0 (B_3)	$M_{\mu\mu} = M_{e\mu} = 0$	$M_\nu = \begin{pmatrix} \times & 0 & \times \\ 0 & 0 & \times \\ \times & \times & \times \end{pmatrix}$
2-0 (B_4)	$M_{\tau\tau} = M_{e\tau} = 0$	$M_\nu = \begin{pmatrix} \times & \times & 0 \\ \times & \times & \times \\ 0 & \times & 0 \end{pmatrix}$

Table 1: Five possible combinations of the 2-0 texture of neutrino mass matrix.

4.2 Symmetry realization

Symmetry place a decisive role in obtaining a specific structure for the neutrino mass matrix. Several earlier works has established the two zero textures using different symmetry groups. In the framework of LRSM, to realize the textures of the neutrino mass matrix, here we have extended the LRSM with a $D_4 \times Z_2$ symmetry. Two flavon fields η and χ are introduced which transforms as doublet and singlet respectively under D_4 symmetry. The preferred textures of Dirac and Majorana mass matrix, M_D and M_{RR} which leads to the two zero texture neutrino mass are obtained using the $D_4 \times Z_2$ symmetry. Here we have shown the symmetry realizations for two of the two zero textures namely, B_3 and B_4.

Class B_3: For the two zero texture B_3, the symmetry realization for the particle contents of the model are tabulated as shown below,

Fields	L_e	$(L_\mu, L_\tau$	e_R	$(\mu,\tau)_R$	$(\nu_e)_R$	$(\nu_\mu,\nu_\tau)_R$	$\Delta_{L,R}$	Φ	η	χ
$D_4 \times Z_2$	1^+	2^+	1^+	2^+	1^+	2^+	1^+	1^-	2^-	1^-

Table 2: Particle assignments for B_3

The corresponding Dirac and the Majorana mass terms are,

$$M_{RR} = \begin{bmatrix} w & 0 & 0 \\ 0 & 0 & x \\ 0 & x & 0 \end{bmatrix}, M_D = \begin{bmatrix} a_1 & 0 & a_3 \\ 0 & 0 & b_3 \\ c_1 & 0 & c_3 \end{bmatrix}. \tag{11}$$

The neutrino mass matrix obtained from equation (8) has the form,

$$M^\nu = \begin{bmatrix} \times & 0 & \times \\ 0 & 0 & \times \\ \times & \times & \times \end{bmatrix}, \tag{12}$$

which is the two zero structure B_3 where $\times$ denotes non-vanishing entries. The corresponding Dirac Yukawa Lagrangian is,

$$\begin{aligned}\mathcal{L_D} = \overline{L}_{L_e}(y_1\frac{\chi}{\lambda_F}\Phi + \tilde{y_1}\frac{\chi}{\lambda_F}\tilde{\Phi})\overline{L}_{R_e} + \overline{L}_{L_e}(y_2\frac{\chi}{\lambda_F}\Phi + \tilde{y_2}\frac{\chi}{\lambda_F}\tilde{\Phi})\overline{L}_{R_\tau} + \overline{L}_{L_\tau}(y_3\frac{\chi}{\lambda_F}\Phi + \tilde{y_3}\frac{\chi}{\lambda_F}\tilde{\Phi})\overline{L}_{R_e} \\ + \overline{L}_{L_\tau}(y_4\frac{\chi}{\lambda_F}\Phi + \tilde{y_4}\frac{\chi}{\lambda_F}\tilde{\Phi})\overline{L}_{R_\tau} + \text{h.c..}\end{aligned} \tag{13}$$

The Majorana Yukawa Lagrangian is,

$$\mathcal{L}_{\mathcal{MR}} = \frac{Y_{L1}}{2} L_{Le}{}^{T} Ci\sigma_2 \Delta_L L_{l\tau} + \frac{Y_{L1}}{2} L_{L\tau}{}^{T} Ci\sigma_2 \Delta_L L_{Le} + \frac{Y_{L2}}{2} L_{Le}{}^{T} Ci\sigma_2 \Delta_L L_{le} + \frac{Y_{R1}}{2} L_{Re}{}^{T} Ci\sigma_2 \Delta_R L_{l\tau} + \frac{Y_{L2}}{2} L_{Le}{}^{T} Ci\sigma_2 \Delta_R L_{le} + \text{h.c.}. \quad (14)$$

4.3 Neutrinoless Double Beta Decay with texture zeros in LRSM

As has already been mentioned, we have a total of eight different contributions to $0\nu\beta\beta$ in the framework of LRSM arising due to the presence of new scalar particles and gauge bosons that includes, RH gauge bosons, RH neutrinos, Higgs triplets as well as contributions from heavy-light neutrino exchange, left-right mixing contributions. However for the present study, we have taken into account the new physics contributions arising due to the exchange of heavy RH neutrino and the scalar triplet along with the standard contribution to $0\nu\beta\beta$ due to light Majorana neutrino exchange while ignoring the left-right mixing and the heavy light neutrino mixing contributions. The standard light neutrino contribution is given by,

$$m_v^{eff} = U_{Li}^2 m_i, \quad (15)$$

where, U_{Li} represents the elements of the first row of the neutrino mixing matrix U_{PMNS} (as given by equation 16)

$$U_{PMNS} = \begin{bmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -c_{23}s_{12} - s_{23}s_{13}c_{12}e^{i\delta} & -c_{23}c_{12} - s_{23}s_{13}s_{12}e^{i\delta} & s_{23}c_{13} \\ s_{23}s_{12} - c_{23}s_{13}c_{12}e^{i\delta} & -s_{23}c_{12} - c_{23}s_{13}s_{12}e^{i\delta} & c_{23}c_{13} \end{bmatrix} U_{Maj}, \quad (16)$$

that depends on the known parameters, the mixing angles θ_{13} , θ_{12} and the CP phases δ, α and β. The abbreviations used are c_{ij}= $\cos\theta_{ij}$, s_{ij}=$\sin\theta_{ij}$, $(i, j = 1, 2, 3)$ for the three generations of leptons.

The effective mass corresponding to heavy right-handed neutrino contribution and the scalar triplet contribution is given by,

$$\mathrm{m_{N+\Delta}}^{\mathrm{eff}} = \mathrm{p}^2 \left(\frac{\mathrm{M_{W_L}}}{\mathrm{M_{W_R}}}\right)^4 \left(\frac{\mathrm{U_{Rei}}^{*2}}{\mathrm{M_i}} + \frac{\mathrm{U_{Rei}}^2 \mathrm{M_i}}{\mathrm{M_{\Delta_R}}^2}\right). \quad (17)$$

In the above equation p represents the average momentum transferred during the decay process. U_{Rei} refers to the elements in the first row of the diagonalizing matrix of the RH neutrino and M_i are its eigenvalues. For a TeV scale LRSM, we have considered the values as $M_{W_R} = 10$ TeV , $M_{W_L} = 80$ GeV , $M_{\Delta_R} \approx 3$ TeV which leads to heavy RH neutrino in the scale of TeV. The allowed value of p lies in the range $(100 - 200)$ MeV and so we have considered, $p \approx 180$ MeV. Thus, we get,

$$\langle p^2 \rangle \frac{M_{W_L}^2}{M_{W_R}^4} = 10^{10}\,\text{eV}. \quad (18)$$

For the allowed 2-0 textures, we do not consider the texture A_1 for analysis of $0\nu\beta\beta$ as it consist in $M_{ee} = 0$ which means its standard light contribution for $0\nu\beta\beta$ is negligible. The results obtained are as shown in figure 2 and figure 3.

4.4 Lepton Flavor Violation with texture zeros in LRSM

For the present study, we have considered the most prominent LFV decay of muons, namely $\mu \to 3e$ and $\mu \to e\gamma$. The relevant branching ratios for these decay processes are given as follows:

- For the decay $BR(\mu \to 3e)$, the BR is given as,

$$BR_{\mu\to 3e} = \frac{1}{2}|h_{\mu e}h_{ee}^*|^2 \left(\frac{{m_{W_L}}^4}{M_{\Delta_L{}^{++}}^4} + \frac{{m_{W_R}}^4}{M_{\Delta_R{}^{++}}^4}\right), \quad (19)$$

where, h_{ij} describes the respective lepton-scalar couplings given by,

$$h_{ij} = \sum_{n=1}^{3} V_{in}V_{jn}\left(\frac{M_n}{M_{W_R}}\right), \quad (20)$$

where, $i, j = e, \mu, \tau$.

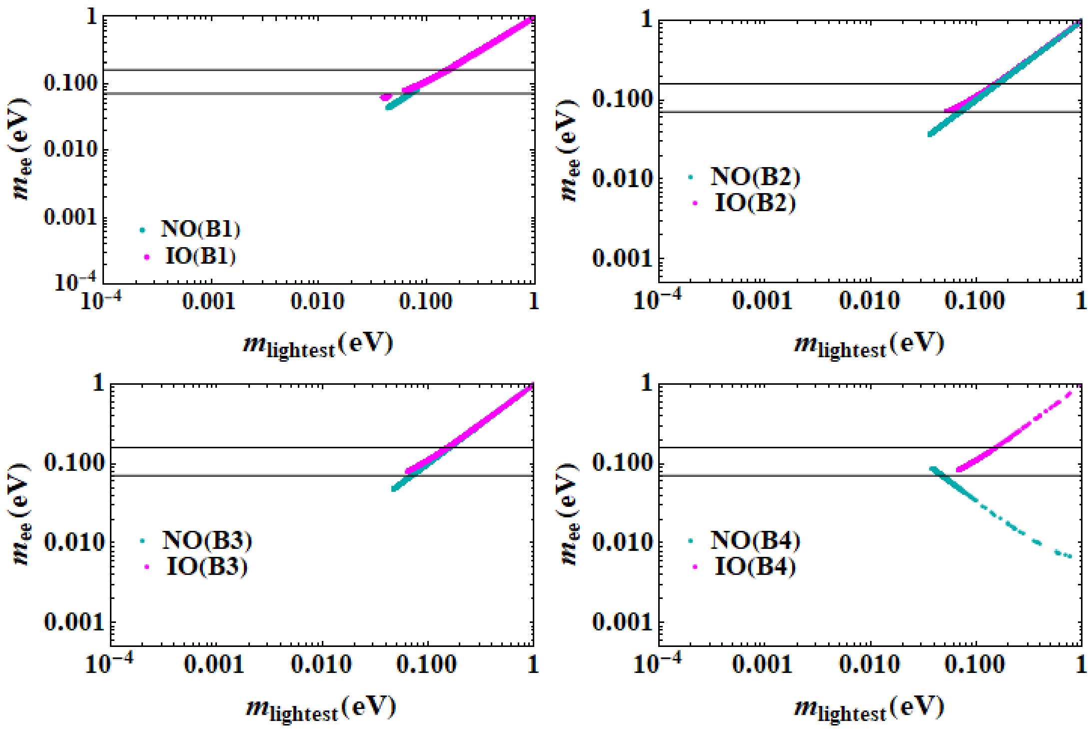

Figure 2: Variation of effective neutrino mass with $m_{lightest}$ for normal hierarchy and inverted hierarchy (right) for 2-0 texture. The horizontal lines represents the range of upper bound on the effective neutrino mass as propounded by KamLAND-Zen experiment.

- For the decay $BR(\mu \to e\gamma)$, the BR is given as,

$$BR_{\mu \to e\gamma} = 1.5 \times 10^{-7} |g_{lfv}|^2 \left(\frac{1TeV}{M_{W_R}} \right)^4, \tag{21}$$

where,

$$g_{lfv} = \sum_{n=1}^{3} V_{\mu n} V_{en}{}^* \left(\frac{M_n}{M_{W_R}} \right)^2 = \frac{[M_R M_R{}^*]_{\mu e}}{M_{W_R}}. \tag{22}$$

The sum being over heavy neutrino. V is the neutrino mixing matrix for RH neutrino and $M^{++}_{\Delta_{L,R}}$ represents the mass of the doubly charged bosons.

However, while taking into consideration the texture zeros into LRSM, the lepton flavor violating decay $\mu \to 3e$ is realizable only for texture B_2 (IO) and B_3 while $\mu \to e\gamma$ is realizable for all the allowed two zero textures as shown in the figure 4 relating branching ratio with the lightest neutrino mass. The branching ratio for the same has been calculated using the relations given in equation (19) and equation (21). We have also tried to see the correlation by plotting some density plots among the neutrino parameters and the low energy observable in the present study NDBD effective neutrino mass and LFV (BR) as shown in figures 5. The results for present phenomenological study using texture zeros in LRSM has been summarized in table 3.

5 Conclusions

Texture zeros in the context of LRSM has been studied extensively in several earlier works. In addition, in this work, we study texture zero in LRSM framework by firstly checking the effectiveness of different possible texture zero structures in three neutrino scenario using the recent global fit data from neutrino oscillation experiments along with the cosmological upper bound on sum of absolute neutrino masses. As expected, zeros $n \geq 3$ are ruled out by current datas. Interestingly the present neutrino global fit data did not satisfy the two zero textures

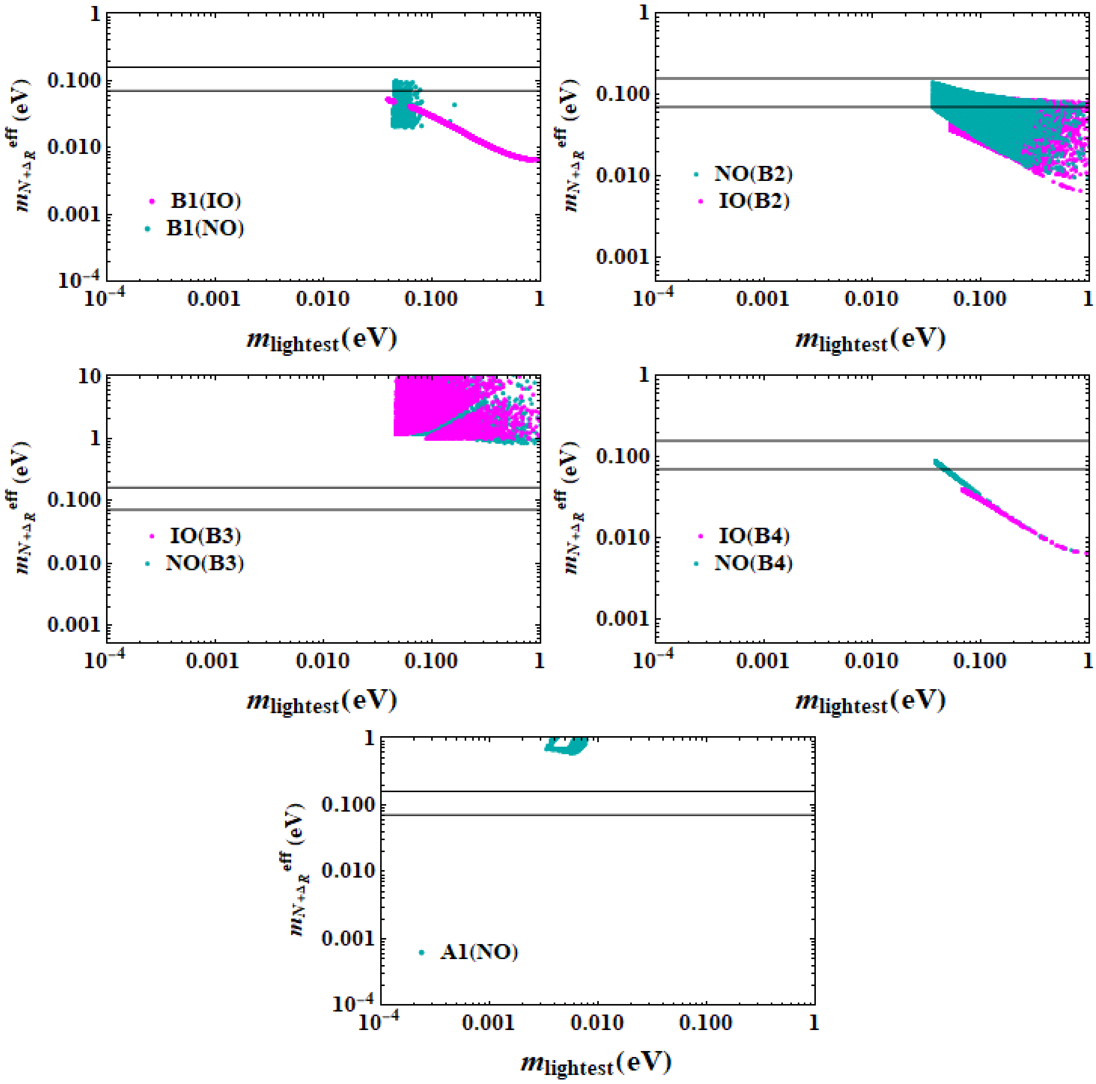

Figure 3: Variation of effective neutrino mass (heavy right handed neutrino and scalar triplet contribution)with $m_{lightest}$ for normal hierarchy and inverted hierarchy (right) for 2-0 texture neutrino mass. The horizontal lines represents the range of upper bound on the effective neutrino mass as propounded by KamLAND-Zen experiment.

Parameters	(A_1)NO	(B_1)NO(IO)	(B_2)NO(IO)	(B_3) NO(IO)	(B_4) NO(IO)
$0\nu\beta\beta$(standard)	$\times$	()	()	()	()
$0\nu\beta\beta(N+\Delta_R)$	$\times$	()	()	$\times(\times)$	()
$BR(\mu\to\gamma e)$	()	()	()	()	()
$BR(\mu\to 3e)$	$\times(\times)$	$\times(\times)$	$\times()$	()	$\times(\times)$
Cosmology,LFV and $0\nu\beta\beta$	$\times(\times)$	$\times(\times)$	$\times()$	$\times(\times)$	$\times(\times)$

Table 3: Results for $0\nu\beta\beta$, Lepton Flavor Violation (LFV) summarized where denotes the results are within and $\times$ denotes the results outside the experimental bounds.

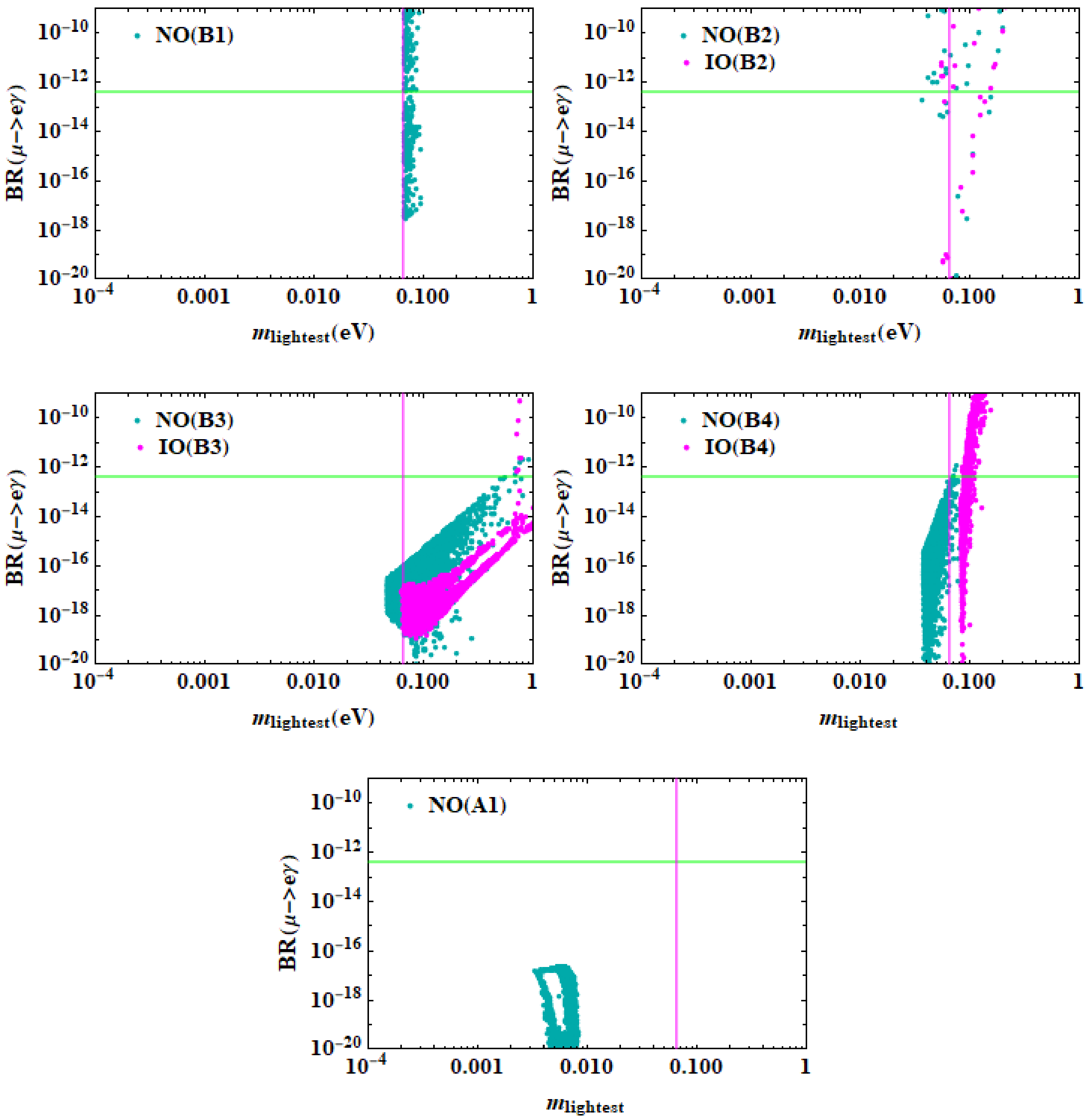

Figure 4: Variation of branching ratio (BR ($\mu \rightarrow e\gamma$)) with $m_{lightest}$ is shown for 2-0 texture neutrino mass. NO/IO represents the normal and inverted ordering of neutrino mass. The horizontal line represents the upper bound on the BR as given by MEG experiment.

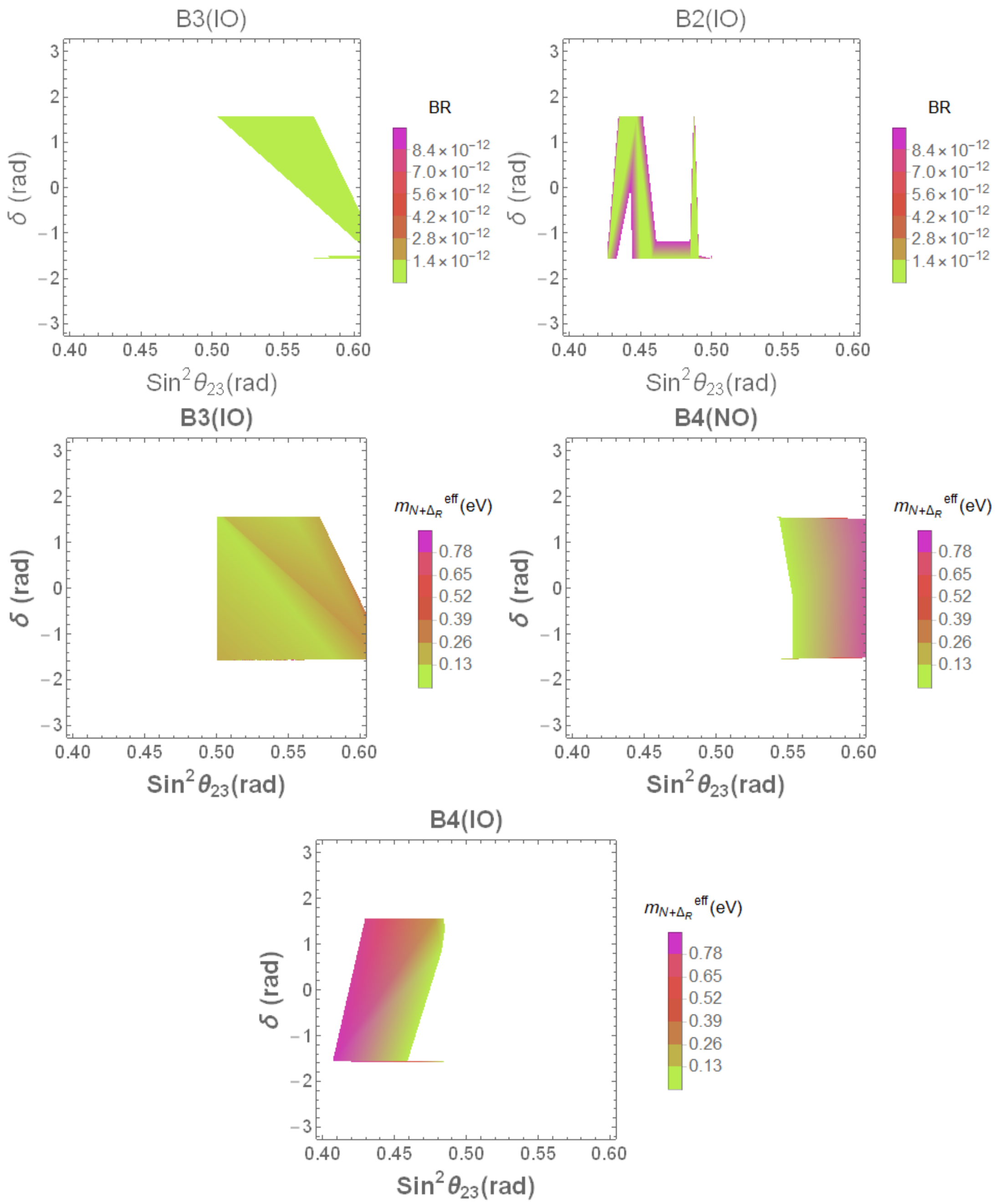

Figure 5: Density plots showing the correlations between the neutrino parameters and the low energy observables NDBD and LFV.

$A_1(IO)$ and $A_2(NO/IO)$. After finding the allowed cases of two zero textures, we here attempt to study low scale observable like NDBD and CLFV within a TeV scale LRSM framework which is accessible at the colliders. It is seen that LFV decay process $\mu \to \gamma e$ satisfies the experimental bounds for all the allowed two zero textures whereas for $\mu \to 3e$, sizeable amount of BR has been obtained only for $B_2(IO)$ and $B_3(NO/IO)$. In the present work we have implemented the $D_4 \times Z_2$ symmetry to realize the texture zero neutrino mass matrix. From our analysis, we see that one can account for successful lepton number violation and lepton flavor violation simultaneously considering experimental bounds for NDBD and LFV as well as cosmology bounds on sum of neutrino mass only for the texture B_2 (IO) (table 3). The less precisely determined neutrino parameter θ_{23} has also been obtained in the first quadrant for B_2 and second quadrant for B_1, B_3, B_4 and A_1. However, both low scale LFV and effective mass governing NDBD can be simultaneously obtained for some parameter space only. However, we have kept an extensive phenomenological exploration of texture zero structures of neutrino mass using an appropriate flavor symmetry for our subsequent works.

A Symmetry group(D_4)

The dihedral D_4 group is one of the non-Abelian group of order 8. It has five irreducible representations, a doublet 2 and four singlets and five conjugacy classes . The character table of the group is as given in table A.1. Here, n

Class	n	h	χ_{++}	χ_{+-}	χ_{-+}	χ_{--}	χ_2
C_1	1	1	1	1	1	1	2
C_2	1	2	1	1	1	1	-2
C_3	2	4	1	-1	-1	1	0
C_4	2	2	1	1	-1	-1	0
C_5	2	2	1	-1	1	-1	0

Table A.1: Character table of the group D_4.

and h represents the order of the class C_i and order of the elements of the class C_i where $i = 1, 2, 3, 4, 5$. The Kronecker products of the one-dimensional representations of D_4 are given in table A.2.

	$\underline{1}_1$	$\underline{1}_2$	$\underline{1}_3$	$\underline{1}_4$
$\underline{1}_1$	$\underline{1}_1$	$\underline{1}_2$	$\underline{1}_3$	$\underline{1}_4$
$\underline{1}_2$	$\underline{1}_2$	$\underline{1}_1$	$\underline{1}_4$	$\underline{1}_3$
$\underline{1}_3$	$\underline{1}_3$	$\underline{1}_4$	$\underline{1}_1$	$\underline{1}_2$
$\underline{1}_4$	$\underline{1}_4$	$\underline{1}_3$	$\underline{1}_2$	$\underline{1}_1$

Table A.2: The Kronecker products of the one-dimensional representations of D_4.

The products $\underline{1}_i \times 2 = 2 \forall i$ and $2 \times 2 = \underline{1}_1, \underline{1}_2, \underline{1}_4$ (symmetric part) and $2 \times 2 = \underline{1}_3$ (antisymmetric part).

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