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Lepton Number Violation in Low Scale Seesaw Mechanism and its Collider Complementarity

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We consider the TeV scale left-right symmetric theory which can accommodate low scale seesaw mechanisms consistent with neutrino oscillation data and find new physics contributions to neutrinoless double beta decay. The model facilitates natural type-II seesaw dominance and the presence of extra particles make the Dirac neutrino mass matrix M_D large that leads to large light heavy neutrino mixing. The spontaneous symmetry breaking through doublets, triplets and bidoublet scalars at TeV scale offers rich phenomenology accessible to LHC. From the numerical studies of the new physics contributions to neutrinoless double beta decay we derive a lower limit on absolute scale of lightest neutrino mass and find that normal hierarchy (NH) pattern is favorable taking into account the cosmology and oscillation data.

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The origin of non-zero neutrino masses can be well-explained with low scale seesaw mechanisms that offer direct testability at LHC. Another low energy phenomenon that seems promising in the view that it can confirm Majorana nature of neutrinos is the neutrinoless double beta decay [1]. Interesting phenomenology can be expected when this process is studied in the framework of TeV scale left-right symmetric model (LRSM) [2, 3]. We consider the extension of this model which comprises of usual quarks and leptons plus a sterile fermion per each generation and doublets, triplets, bidoublet scalars that help in the spontaneous symmetry breaking [4]. The gauge symmetry that governs the left-right symmetric model is $SU(2)_L \times SU(2)_R \times U(1)_{B-L} \times SU(3)_C$. When $SU(2)_R \times U(1)_{B-L}$ breaks at few TeV it leads to interesting collider signatures, neutrinoless double beta decay, lepton flavour violating processes and important implications to cosmology [5, 6, 7, 8, 9, 10, 11, 12, 13]. The neutral lepton mass matrix in the flavor basis of (ν_L, S_L, N_R^c) is given by

$$\mathbb{M} = \begin{pmatrix} & \nu_L & S_L & N_R^c \\ \hline \nu_L & M_L & 0 & M_D \\ S_L & 0 & 0 & M \\ N_R^c & M_D^T & M^T & M_R \end{pmatrix}. \tag{1}$$

where M_D is the Dirac neutrino mass connecting $\nu_L - N_R$, M is the $N_R - S_L$ mixing matrix and $M_L(M_R)$ is the Majorana mass for LH (RH) neutrinos. Using the mass hierarchy $M_R > M > M_D \gg M_L$, the complete diagonalization procedure will lead to physical masses and mixing can be expressed in terms of light neutrino mass $m_\nu^d = \mathrm{diag}\{m_1, m_2, m_3\}$ and oscillation parameters as

$$m_\nu = U_{\mathrm{PMNS}}\, m_\nu^d\, U_{\mathrm{PMNS}}^T, \quad M_N = \frac{v_R}{v_L} U_{\mathrm{PMNS}}\, m_\nu^d\, U_{\mathrm{PMNS}}^T, \quad M_S = -m_S^2 \left[\frac{v_R}{v_L} U_{\mathrm{PMNS}} m_\nu^d U_{\mathrm{PMNS}}^T\right]^{-1} \tag{2}$$

The extra particles substantially make the Dirac neutrino mass matrix M_D large that allows large light-heavy neutrino mixing. The charge current interaction Lagrangian with the physical masses and mixing for neutrinos is given by

$$\sum_{\alpha=e,\mu,\tau} \left[\frac{g_L}{\sqrt{2}} \bar{\ell}_{\alpha L}\, \gamma_\mu\, \nu_{\alpha L} W_L^\mu + \frac{g_R}{\sqrt{2}} \bar{\ell}_{\alpha R}\, \gamma_\mu\, N_{\alpha R} W_R^\mu\right] + \mathrm{h.c.}$$

$$\mathrm{with} \quad \nu_\alpha = V_{\alpha i}^{\nu\nu} \nu_i + V_{\alpha j}^{\nu N} N_j + V_{\alpha k}^{\nu S} S_k$$

$$N_\beta = 0 \times \nu_i + V_{\beta j}^{NN} N_j + V_{\beta k}^{NS} S_k + \mathrm{h.c.}$$

As an immediate result new contributions (displayed in Fig. 1) arise due to;

- purely left-handed currents via exchange of heavy right-handed neutrinos and sterile neutrinos,
- purely right-handed currents via exchange of heavy right-handed neutrinos and doubly charged scalar triplet,
- mixed helicity diagrams called as λ diagrams involving light-heavy neutrino mixing.

- mixed helicity diagrams called as η diagrams involving $W_L - W_R$ mixing.
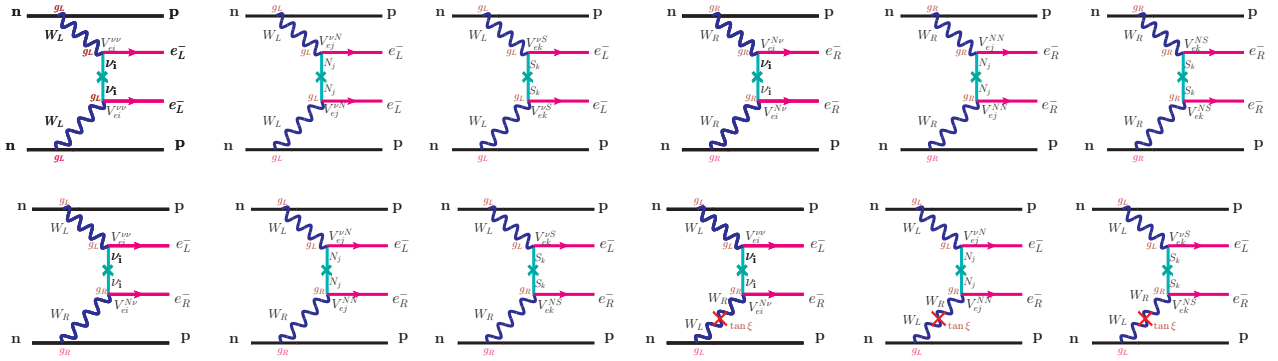
Figure 1: Feynman diagrams for neutrinoless double beta decay with TeV spectrum of W_R, Z_R gauge bosons, heavy neutrinos.

We minutely analyze these new physics contributions and derive the absolute scale of lightest neutrino mass using cosmology [14] and oscillation data [15]. The calculations looks simple since we have expressed all the physical masses and mixing in terms of lightest neutrino mass and neutrino oscillation parameters. We derive the lower limit on the absolute scale of light neutrino mass by saturating the experimental limit from GERDA [16] and KamLAND-ZEN experiment [17] as displayed in Fig. 2.
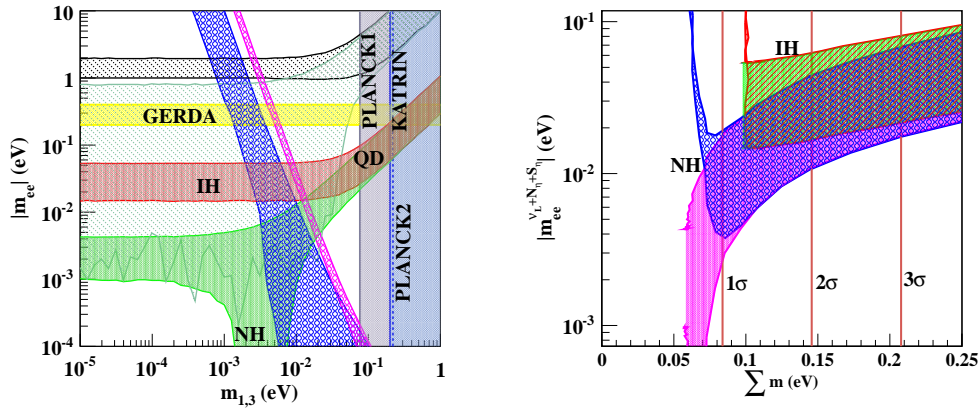

Figure 2: New Physics contributions to neutrinoless double beta decay within TeV scale LRSM. The left-panel shows effective mass parameters vs lightest neutrino mass whereas the right-panel is for effective mass parameters vs sum of light neutrino masses.

We have discussed natural realization of type-II seesaw dominance within a TeV scale LRSM. We have expressed all the physical masses and mixings like ν_L, N_R and S_L in terms of oscillation parameters and mass of lightest neutrino. We have derived the lower limit on absolute scale of

lightest neutrino mass by numerically estimating new physics contributions to $0\nu\beta\beta$ transition saturating the current experimental limit. The effective mass vs sum of light neutrino masses shows that NH pattern of light neutrinos is favorable.

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