"Neutrinoless double beta decay in a left-right symmetric model with a double seesaw mechanism"

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Introduction

We discuss a left-right (L-R) symmetric model with the double seesaw mechanism at the TeV scale generating Majorana masses for the active left-handed (LH) flavour neutrinos $\nu_{\alpha L}$ and the heavy right-handed (RH) neutrinos $N_{\beta R}$, $\alpha, \beta = e, \mu, \tau$, which in turn mediate lepton number violating processes, including neutrinoless double beta decay. Working with a specific version of the model in which the $\nu_{\alpha L} - N_{\beta R}$ and the $N_{\beta R} - S_{\gamma L}$ Dirac mass terms are diagonal, and assuming that $m_{N_j} \sim (1-1000)$ GeV and $\max(m_{S_k}) \sim (1-10)$ TeV, $m_{N_j} \ll m_{S_k}$, we study in detail the new "non-standard" contributions to the $0\nu\beta\beta$ decay amplitude and half-life arising due to the exchange of virtual N_j and S_k.

Model For LRSM Double Seesaw

LRSM + Sterile Neutrinos S_L

1. LR Symmetry

$$\mathcal{G}_{LR} \equiv SU(2)_L \times SU(2)_R \times U(1)_{B-L} \times SU(3)_C$$

2. Fermion Sector

$$q_L = \begin{pmatrix} u_L \\ d_L \end{pmatrix};\; q_R = \begin{pmatrix} u_R \\ d_R \end{pmatrix};\; \ell_L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix};\; \ell_R = \begin{pmatrix} N_R \\ e_R \end{pmatrix}$$

$$+$$

$$\underbrace{S_L}_{\text{Singlet \& per gen}}$$

3. Scalar Sector

$$\underbrace{\Phi = \begin{pmatrix} \phi_1^0 & \phi_2^+ \\ \phi_1^- & \phi_2^0 \end{pmatrix}}_{\text{Higgs bidoublet}};\; \underbrace{H_L = \begin{pmatrix} h_L^+ \\ h_L^0 \end{pmatrix}}_{\text{Higgs doublet}};\; \underbrace{H_R = \begin{pmatrix} h_R^+ \\ h_R^0 \end{pmatrix}}_{\text{Higgs doublet}}$$

Double Seesaw (Neutrino Mass Generation)

- Interaction Lagrangian

$$-\mathcal{L}_{LRDSM} = \underbrace{\mathcal{L}_{M_D}}_{\text{Dirac mass term } (\nu_L - N_R)} + \underbrace{\mathcal{L}_{M_{RS}}}_{\text{Dirac mass term } (N_R - S_L)} + \underbrace{\mathcal{L}_{M_S}}_{\text{Majorana mass term}}$$

$$= -\sum_{\alpha,\beta} \overline{\nu_{\alpha L}}[M_D]_{\alpha\beta}N_{\beta R} - \sum_{\alpha,\beta} \overline{S_{\alpha L}}[M_{RS}]_{\alpha\beta}N_{\beta R} - \frac{1}{2}\sum_{\alpha,\beta} \overline{S^c_{\alpha R}}[M_S]_{\alpha\beta}S_{\beta L} + \text{h.c..}$$

- After SSB, the complete 9×9 neutral fermion mass matrix in the flavor basis of (ν_L, N_R^c, S_L):

$$\mathcal{M}_{LRDSM} = \begin{bmatrix} \mathbf{0} & M_D & \mathbf{0} \\ M_D^T & \mathbf{0} & M_{RS} \\ \mathbf{0} & M_{RS}^T & M_S \end{bmatrix}$$

- Block diagonalization with the assumption $|M_D| \ll |M_{RS}| < |M_s|$, gives [1, 2]

DSS RESULTS

$$\begin{aligned} m_\nu &\cong -M_D\left(-M_{RS}M_S^{-1}M_{RS}^T\right)^{-1}M_D^T \\ &= \frac{M_D}{M_{RS}^T}M_S\frac{M_D^T}{M_{RS}}, \\ m_N &\equiv M_R \cong -M_{RS}M_S^{-1}M_{RS}^T, \\ m_S &\cong M_S\,. \end{aligned}$$

Masses and Mixing

- Special choice, $M_D M_{RS}^{-1} = \frac{k_d}{k_{rs}} I$.[3, 4]
- Mass matrices relations, m_ν,m_N and m_S $\rightarrow m_\nu = \frac{k_d^2}{k_{rs}^2} m_S$ and $m_N = -k_d^2 \frac{1}{m_\nu}$.
- Physical masses m_i are related to the mass matrix m_ν in the flavor basis as $m_\nu = U_{\text{PMNS}} m_\nu^{\text{diag}} U_{\text{PMNS}}^T\,.$
- $U_N = i\,U_\nu^* \equiv i\,U_{PMNS}^*\,.$
- $U_S = U_\nu \equiv U_{PMNS}\,.$

$$\boxed{m_i = \frac{k_d^2}{m_{N_j}} = \frac{k_d^2}{k_{rs}^2}\, m_{S_k}\,,\; i, j, k = 1, 2, 3\,.} \tag{1}$$

$0\nu\beta\beta$ in LRSM Double Seesaw

1. If light Majorana neutrinos are the only contribution to the $0\nu\beta\beta$ transition, then we can express the half-life as,

$$\frac{1}{T_{1/2}^{0\nu}} = \left[T_{1/2}^{0\nu}\right]^{-1} = g_A^4\, G_{01}^{0\nu}\, \left|\mathcal{M}_\nu^{0\nu}\right|^2 |\eta_\nu|^2 = G_{01}^{0\nu} \left|\frac{\mathcal{M}_\nu^{0\nu}}{m_e}\right|^2 |m_{\beta\beta}|^2$$

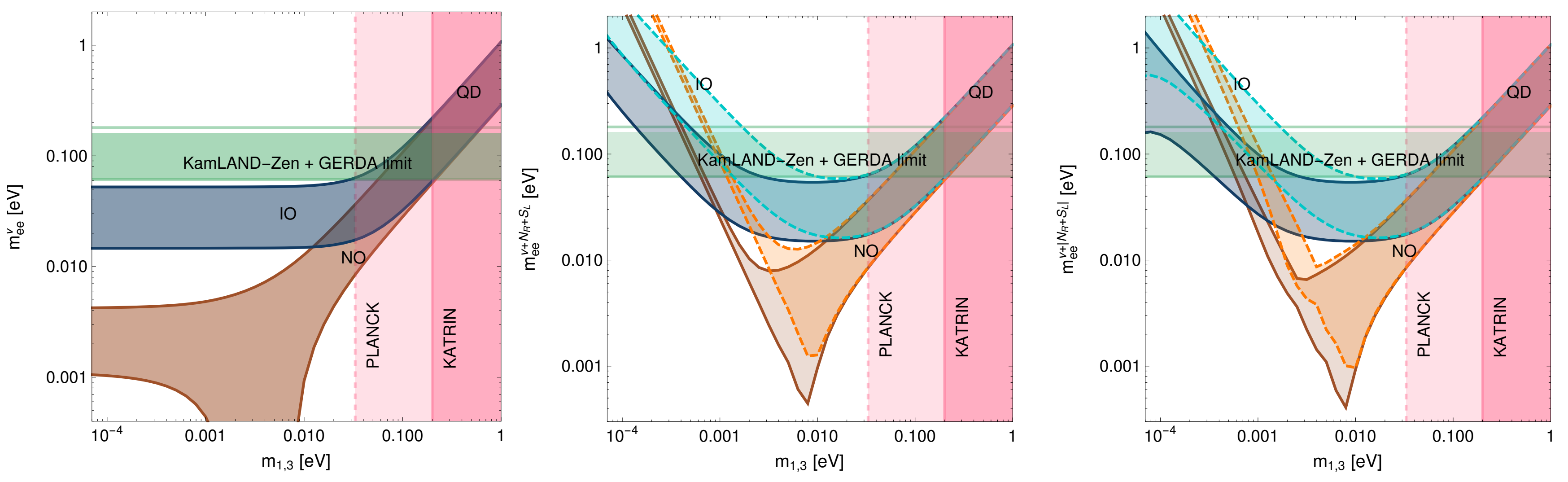
- $m_{\beta\beta} \equiv m_{ee}^\nu \equiv m_e\eta_\nu = \left|\sum_{i=1}^3 U_{ei}^2 m_i\right|$

The **lepton** Lagrangian that is relevant for the dominant contributions to $0\nu\beta\beta$ decay rate is:

$$\begin{aligned} \mathcal{L}_{\text{CC}}^{\ell,\text{mass}} &= \frac{g_L}{\sqrt{2}}\left[\overline{e}_L\,\gamma_\mu\{\text{V}_{e\,i}^{\nu\nu}\,\nu_i\}\,W_L^\mu\right] + \text{h.c.} \\ &\quad + \frac{g_R}{\sqrt{2}}\left[\overline{e}_R\gamma_\mu\{\text{V}_{ej}^{N\,N}N_j + \text{V}_{ek}^{NS}S_k\}W_R^\mu\right] + \text{h.c.} \end{aligned} \tag{2}$$

$$|m_{\beta\beta,L,R}^{\text{eff}}| \equiv m_{ee}^{\nu+|N+S|} = \left(\left|m_{\beta\beta,L}^\nu\right|^2 + \left|m_{\beta\beta,R}^N + m_{\beta\beta,R}^S\right|^2\right)^{\frac{1}{2}} \tag{3}$$

- **Left-panel: Standard Mechanism**
- **Middle-panel: New physics without interference**
- **Right-panel: New physics with interference**



Plots showing effective Majorana mass parameter as a function of lightest neutrino mass, m_1 (NO), m_3(IO).

- We find, in general, that in both NO and IO cases the new non-standard contributions due to N_j and S_k exchange are dominant over the standard light neutrino exchange contribution at values of the lightest neutrino mass $m_{1(3)} \sim (10^{-4} - 10^{-2})$ eV.
- The effective Majorana mass $|m_{\beta\beta,R}^S|$ associated with S_k exchange contribution was shown to be practically independent of the Majorana phases α and β, while that due to exchange of N_j, $|m_{\beta\beta,R}^N|$, exhibits strong dependence on α and β similar to $|m_{ee}^\nu|$.

KEY REFERENCES

[1] R. N. Mohapatra, Phys. Rev. Lett. **56**, 561-563 (1986) doi:10.1103/PhysRevLett.56.561

[2] R. N. Mohapatra and J. W. F. Valle, Phys. Rev. D **34**, 1642 (1986) doi:10.1103/PhysRevD.34.1642

[3] V. Brdar and A. Y. Smirnov, JHEP **02**, 045 (2019) doi:10.1007/JHEP02(2019)045 [arXiv:1809.09115 [hep-ph]].

[4] A. Y. Smirnov and X. J. Xu, Phys. Rev. D **97**, no.9, 095030 (2018) doi:10.1103/PhysRevD.97.095030 [arXiv:1803.07933 [hep-ph]].

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