Seesaw dominance effects for neutrinoless double beta decay in left-right symmetric lens

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Event: XXV DAE-BRNS HEP SYMPOSIUM, IISER Mohali

Abstract

Within Neutrino Physics, the Seesaw mechanism is an essential pillar known to all. Various Seesaw types make it an interesting phenomenon to include and verify its validity in several low-energy processes. Such low energy and LNV ($\Delta L = 2$) process is the neutrinoless double beta decay ($0\nu\beta\beta$). If the $0\nu\beta\beta$ decay process is being observed in the Left-right symmetric model, the effective mass of electron neutrino ($m_{eff}^{<0\nu\beta\beta>}$) would be a function of v_R (vev of right-handed Higgs triplet) and Majorana phases (α and β). This v_R is basically the high energy scale (Weinberg's dim = 5 operators), which allows exploring new physics beyond the Standard model. The Left-right symmetric model generally includes Seesaw type-I and type-II mass terms as a hybrid mass for light neutrino and the percentage of type-I and II contributions (termed as dominance) differs for different solutions. We are studying different dominance patterns ($2^n, n = 3(gen)$) for the effective mass of ($0\nu\beta\beta$) decay with given experimental bounds (Kamland-Zen & GERDA).

I.Introduction

- Standard Model derives neutrino mass, $m_\nu = 0$
- Seesaw mechanism enters into the picture.
- Type-I $\rightarrow$ $m_{\nu_I} = -(y_D \frac{1}{M_R} y_D^T)$
- Type-II $\rightarrow$ $m_{\nu_{II}} = Y_\Delta v_\Delta$, where $v_\Delta \simeq \frac{\mu v_H^2}{m_\Delta^2}$

II.Left-Right symmetric model

- Gauge group, $SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$
- 1 bidoublet, $\phi = \begin{pmatrix} \phi_1^0 & \phi_1^+ \\ \phi_2^- & \phi_2^0 \end{pmatrix} \longrightarrow <\phi> = \begin{pmatrix} k_1 & 0 \\ 0 & k_2 \end{pmatrix}$.
- 2 scalar triplets, $\Delta_L = \begin{pmatrix} \frac{\delta_L^+}{\sqrt{2}} & \delta_L^{++} \\ \delta_L^0 & \frac{\delta_L^+}{\sqrt{2}} \end{pmatrix}$, $\quad \Delta_R = \begin{pmatrix} \frac{\delta_R^+}{\sqrt{2}} & \delta_R^{++} \\ \delta_R^0 & \frac{\delta_R^+}{\sqrt{2}} \end{pmatrix}$
- After SSB, $<\Delta_L> = \begin{pmatrix} 0 & 0 \\ v_L & 0 \end{pmatrix}$, $\quad <\Delta_R> = \begin{pmatrix} 0 & 0 \\ v_R & 0 \end{pmatrix}$.
- Constraint, $k_1^2 + k_2^2 = v_H^2$.

III.Neutrino mass formula

- The Yukawa lagrangian, (L-R symmetric model)

$$L_Y = y_D \bar{\psi}_L^i \phi \psi_R^j + y_D^T \bar{\psi}_L^i \tilde{\phi} \psi_R^j + i(f_L)_{ij} \psi_L^{iT} C \sigma_2 \Delta_L \psi_L^j + i(f_R)_{ij} \psi_R^{iT} C \sigma_2 \Delta_R \psi_R^j + h.c$$

- Under parity transformation,

$$\psi_L \longleftrightarrow \psi_R, \quad \Delta_L \longleftrightarrow \Delta_R, \quad \phi \longleftrightarrow \phi^\dagger$$

- After SSB, the neutrino masses stand as,

$$m_\nu \simeq f_L v_L - \frac{v^2}{v_R} y_D^T f_R^{-1} y_D \quad \& \quad M_R \simeq f_R v_R$$

- By the virtue of L-R symmetry, $[f_L = f_R = f]$.
- So,using $y_D = y_\nu$, the Type-(I+II) hybrid seesaw mass formula becomes,

$$m_\nu \simeq f v_L - \frac{v^2}{v_R} y_\nu^T f^{-1} y_\nu$$

IV.Majorana type Yukawa coupling matrix and dominance patterns

- Now, we will solve the mass formula for the Majorana type Yukawa coupling matrix "f".
- Using eqn(1), for n=1-generation case the solutions are,

$$f_+(II) = \frac{m_\nu}{2v_L}[1 + (1+d)^{\frac{1}{2}}], \quad f_-(I) = \frac{m_\nu}{2v_L}[1 - (1+d)^{\frac{1}{2}}]$$

introducing the dominance parameter, [d $= \frac{4v^2 v_L y_\nu^2}{v_R m_\nu^2}$].

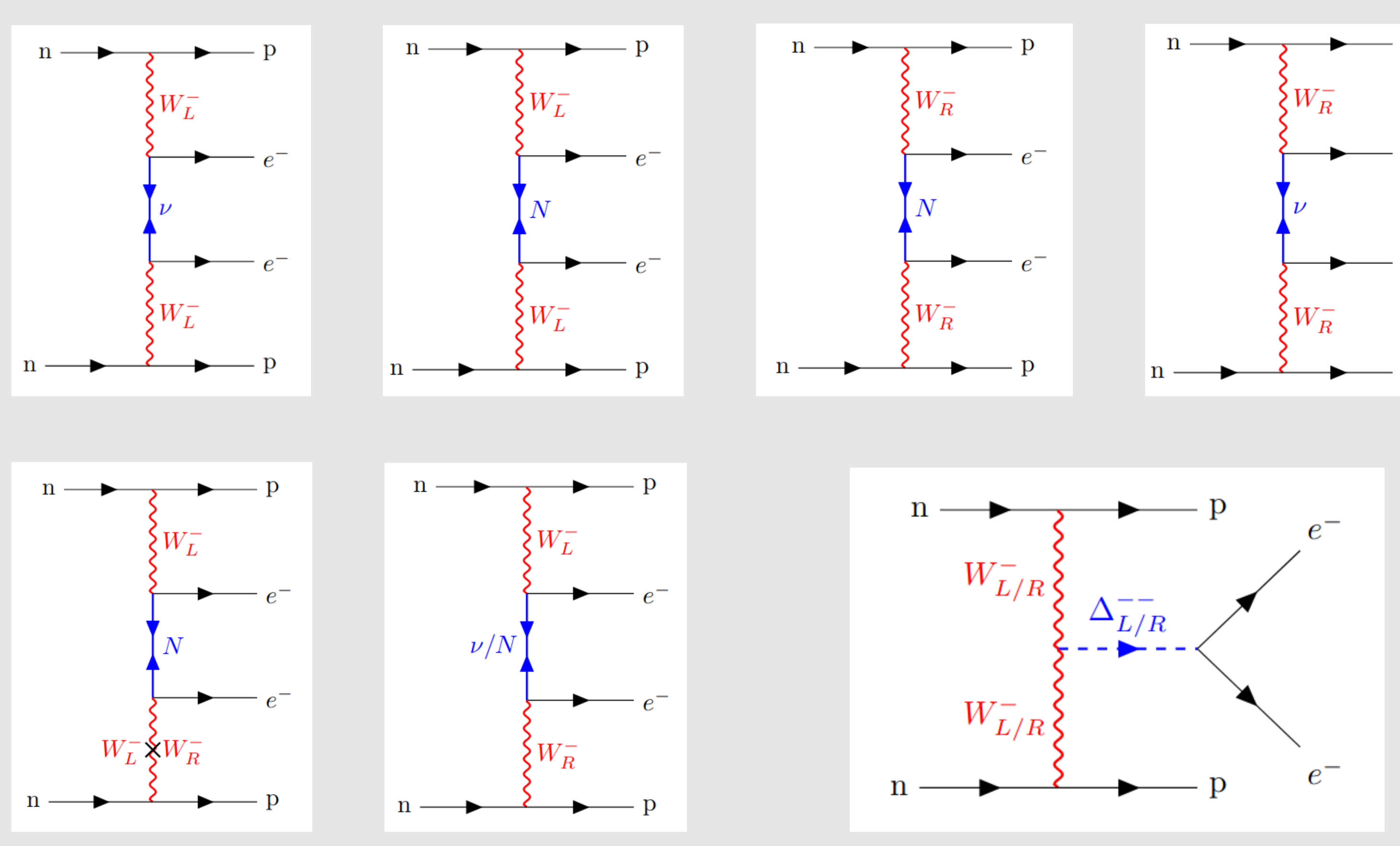
- For n=3 case 8 solutions for "f" matrix. To visualize the patterns,

$$Diag(f) = \begin{pmatrix} \pm & 0 & 0 \\ 0 & \pm & 0 \\ 0 & 0 & \pm \end{pmatrix}$$

- Their dominance patterns are,

$$(+++), \quad (+-+), \quad (++-), \quad (+--)$$
$$(-++), \quad (--+), \quad (-+-), \quad (---)$$

V.Diagrams of $0\nu\beta\beta$ decay in Left-right symmetric model



VI. Effective electron neutrino mass for $0\nu\beta\beta$

- The time period for neutrinoless double beta decay is,

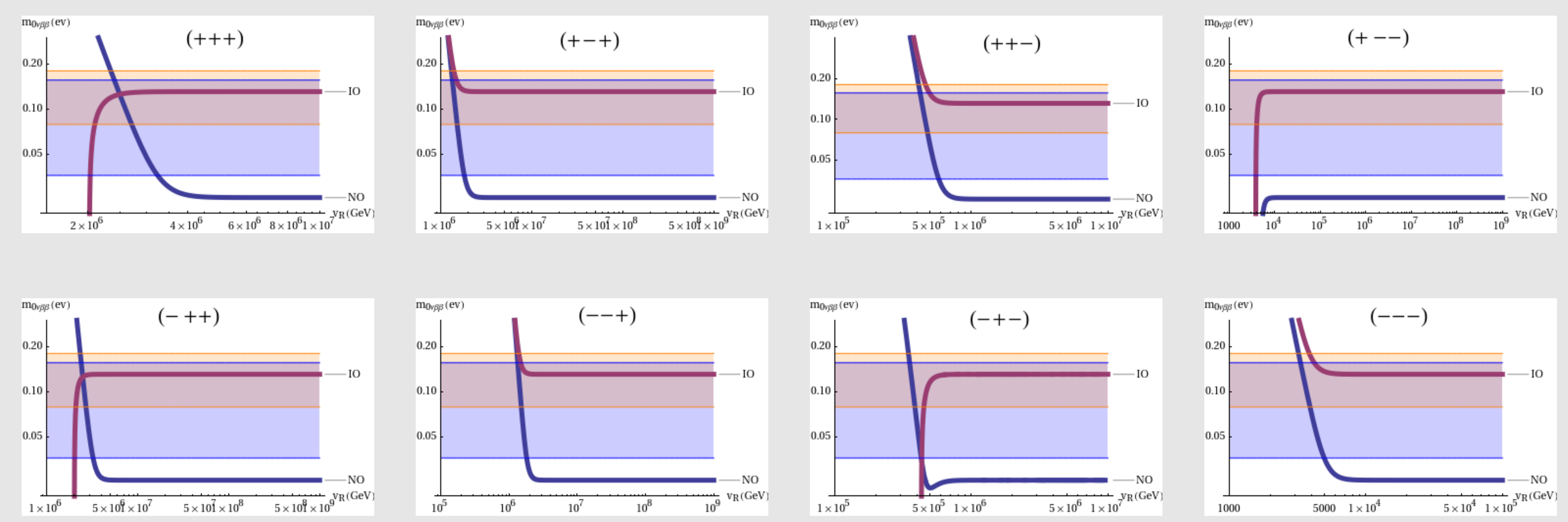
$$\frac{\Gamma_{0\nu\beta\beta}}{ln2} = \frac{G^{0\nu}}{m_e^2} |m_{ee}^{eff}|^2$$

- The effective electron neutrino mass is,

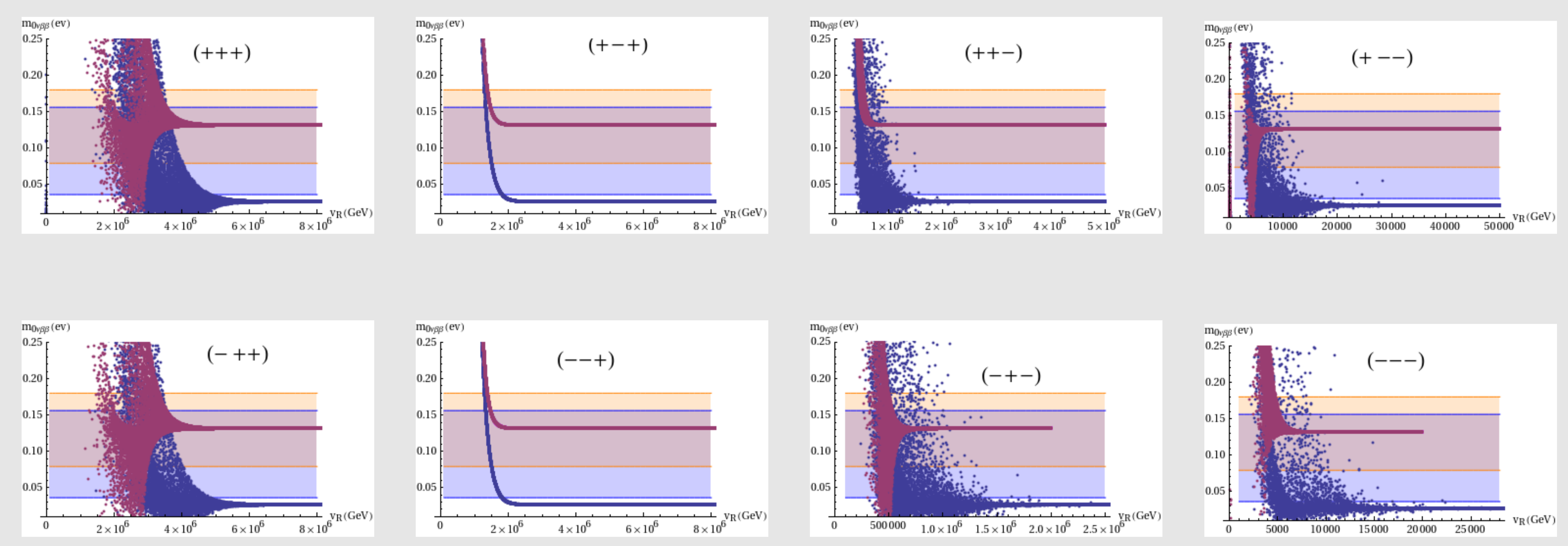
$$|m_{ee}^{eff}|^2 = m_e^2 (|\mathbf{M}_\nu^{0\nu}(\eta_\nu^{LL} + \eta_\nu^{RR} + \eta_{\Delta_L}^{LL})|^2 + |\mathbf{M}_N^{0\nu}(\eta_N^{LL} + \eta_N^{RR} + \eta_{\Delta_R}^{RR})|^2 + |\mathbf{M}_\lambda^{0\nu} \eta_\lambda + \mathbf{M}_\eta^{0\nu} \eta_\eta|^2)$$

- η's terms proportional to the amplitudes of the diagrams shown, i=1,2,3.
- **M**'s are the nuclear matrix elements.

VII.Results of $0\nu\beta\beta$



1. For Majorana phases $\alpha = \beta = 0$, the lightest neutrino mass is fixed at 0.01 eV.



2. For varying Majorana phases, with the lightest neutrino mass value as 0.01 eV.

VIII.Conclusion

- Normal ordered effective mass has lesser points within the experimental bounds (Gerda - (79-180) meV, KamLand-Zen - (36-156) meV).
- (IO) is more favorable than (NO) for both cases.
- For each pattern a specific saturation point exists, after which the Majorana phases have no effect on the effective mass, both for inverted and normal hierarchy.
- For $(+++)$,$(-++)$,$(+-+)$,$(--+)$ cases the effective mass has no dependence on the seesaw type $(\pm)$.
- Maybe near future HEP experiments will get proof for the profiles shown above.

X. Acknowledgments

I would like to thank my supervisor, Dr. Sasmita Mishra, for her immense guidance and help. My work is supported by MHRD, Government of India.

X.References

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