A comparative study of $0\nu\beta\beta$ decay in symmetric and asymmetric left-right model

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Open questions in neutrino sector

- What gives neutrinos such a tiny mass?
- What is the absolute scale of neutrino mass?
- Are neutrinos their own anti-particles?
- Are they normal hierarchial or inverted hierarchial?
- Is there lepton number violation in nature?

Journey Towards
Beyond Standard Model Physics

Neutrinoless Double beta Decay

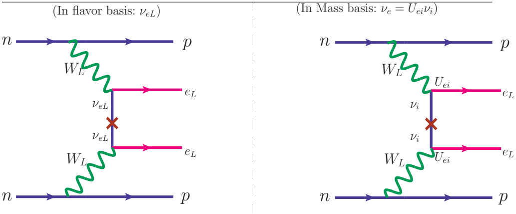
- ★ **Neutrino mass:** through Seesaw Mechanism
- ★ **Seesaw Mechanism:** Majorana Nature of Neutrinos
- ★ **Majorana nature of neutrinos:** Lepton Number Violation
- ★ **Direct consequence of lepton number violation:**
  Neutrinoless Double Beta Decay

$$(A, Z) \rightarrow (A, Z+2) + 2e$$

- ★ Neutrino flavour eigenstates ν_α are related to mass eigenstates ν_i as; $\nu_\alpha = U_{\alpha i}\nu_i$ with mass eigenvalues m_i

$$\mathcal{L}^{\ell}_{\rm CC} = \frac{\mathbf{g_L}}{\sqrt{2}}\, \overline{\mathbf{e}}_{\mathbf{Li}}\, \gamma^{\mu}\, \mathbf{U}_{\alpha \mathbf{i}} \nu_{\mathbf{i}}\, \mathbf{W}_{\mu_{\mathbf{L}}} + \text{h.c.}$$

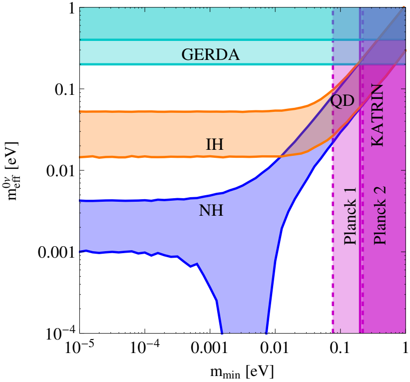
$0\nu\beta\beta$ through standard mechanism



Motivation for new phy contributions to $0\nu\beta\beta$

Isotope	$T_{1/2}^{0\nu}$	$m_{\rm eff}^{0\nu}$ [eV]	Collaboration
^{76}Ge	$> 8.0 \times 10^{25}$ yrs	$< (0.22 - 0.53)$	GERDA-II
^{136}Xe	$> 1.6 \times 10^{26}$ yrs	$< (0.06 - 0.16)$	KamLAND-Zen

$\sum_i m_i < 0.23$eV (Planck 1)
$\sum_i m_i < 1.08$eV (Planck 2)
$m_\beta < 0.2$ eV (KATRIN)



Left-Right Model as New Physics

1. **Gauge Symmetry**

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

with

$$Q = I_{3L} + I_{3R} + \frac{B-L}{2}$$

2. **Particle Content**

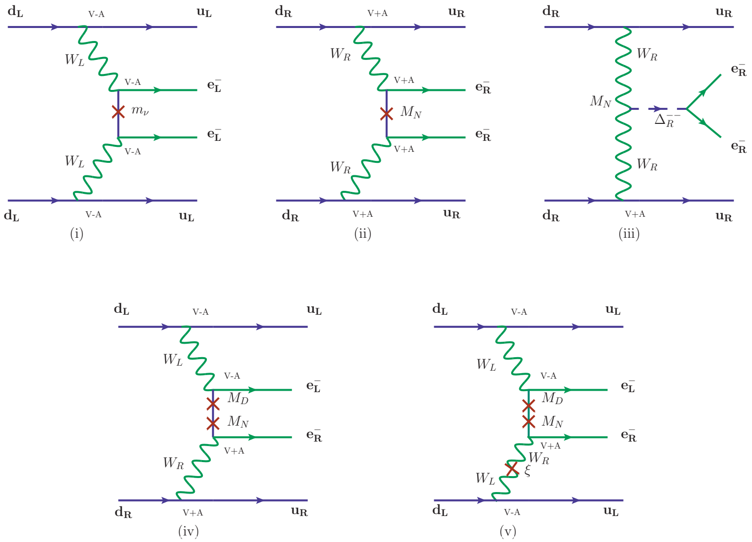
$$q_L = \begin{pmatrix} u_L \\ d_L \end{pmatrix} \equiv [2, 1, \frac{1}{3}, 3], \quad q_R = \begin{pmatrix} u_R \\ d_R \end{pmatrix} \equiv [1, 2, \frac{1}{3}, 3],$$
$$\ell_L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix} \equiv [2, 1, -1, 1], \quad \ell_R = \begin{pmatrix} \nu_R \\ e_R \end{pmatrix} \equiv [1, 2, -1, 1],$$

3. **Symmetry breaking of LRSM**

$$SU(2)_L \times SU(2)_R \times U(1)_{B-L} \xrightarrow{\langle\Delta_R\rangle} SU(2)_L \times U(1)_Y \xrightarrow{\langle\phi\rangle} U(1)_{\rm em}$$

4. When $SU(2)_R \times U(1)_{B-L}$ symmetry breaking occurs at few TeV scale, rich collider phenomenology is expected.

Feynman diagrams for $0\nu\beta\beta$ decay in LRSM



Asymmetric Left-Right Model

1. **Left-Right Model with spontaneous D-parity breaking**

   [Phys. Rev. Lett. 52 (1984) 1072 ; D. Chang, R.N. Mohapatra, M.K. Parida]

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

   where D is the discrete left-right symmetry or D-parity (not Lorentz parity)

2. **Symmetry breaking**
   - $SU(2)_L \times SU(2)_R \times U(1)_{B-L} \times SU(3)_C \times D \xrightarrow{\langle\sigma\rangle} SU(2)_L \times SU(2)_R \times U(1)_{B-L} \times SU(3)_C$
   - $SU(2)_L \times SU(2)_R \times U(1)_{B-L} \times SU(3)_C \xrightarrow{\langle\Delta_R\rangle} SU(2)_L \times U(1)_Y \times SU(3)_C$
   - $SU(2)_L \times U(1)_Y \times SU(3)_C \xrightarrow{\langle\Phi\rangle} U(1)_{\rm em} \times SU(3)_C$

3. D-parity breaks earlier than $SU(2)_R$ gauge symmetry, thereby introducing a new scale.

4. **immediate result:** $SU(2)_L$ and $SU(2)_R$ gauge couplings become unequal i.e, $g_L \neq g_R$.

Asymmetric LR Model with inverse seesaw

1. **Neutrino mass:** through inverse seesaw mechanism $(\nu_L + N_R + S_L)$ [JHEP 08(2013)122 ; R. L Awasthi, M.K. Parida, S. Patra]

$$\mathcal{M} = \begin{pmatrix} 0 & M_D & 0 \\ M_D^T & M_N & M^T \\ 0 & M & \mu_S \end{pmatrix}$$

$$m_\nu = \left(\frac{M_D}{M}\right) \mu_S \left(\frac{M_D}{M}\right)^T$$

2. **what is explained:** neutrino mass, $n - \bar{n}$ oscillation, proton decay
3. **what is not explained:** effect of $g_L \neq g_R$ in $0\nu\beta\beta$ sector
   Our work: Nucl. Phys. B 954 (2020) 115000 S. Senapati, C. Majumdar, P. Pritimita, S. Patra
4. **essence of the work:** how different contributions to $0\nu\beta\beta$ transition in $W_R - W_R$ and $W_L - W_R$ channels are suppressed or enhanced depending on the ratio $\frac{g_R}{g_L}$

We do the comparison for 3 different cases;

1. **Case - I :** Symmetric LR model ($g_L = g_R$)

$$SO(10) \xrightarrow{M_U} \mathcal{G}_{2213D} \xrightarrow{M_R} \mathcal{G}_{SM} \xrightarrow{M_Z} \mathcal{G}_{13}$$

2. **Case - II :** Asymmetric LR model ($g_L \neq g_R$) (without Pati-Salam symmetry in the chain)

$$SO(10) \xrightarrow{M_U} \mathcal{G}_{2213D} \xrightarrow{M_C} \mathcal{G}_{2213} \xrightarrow{M_R} \mathcal{G}_{SM} \xrightarrow{M_Z} \mathcal{G}_{13}$$

3. **Case - III:** Asymmetric LR model ($g_L \neq g_R$) (with Pati-Salam symmetry in the chain)

$$SO(10) \xrightarrow{M_U} \mathcal{G}_{224D} \xrightarrow{M_P} \mathcal{G}_{224} \xrightarrow{M_C} \mathcal{G}_{2213} \xrightarrow{M_R} \mathcal{G}_{SM} \xrightarrow{M_Z} \mathcal{G}_{13}$$

Breaking Chain	g_R	g_L	$\delta = \frac{g_R}{g_L}$
Case I	0.632	0.632	1
Case II	0.589	0.632	0.93
Case III	0.414	0.632	0.65

Comparative study of $0\nu\beta\beta$ decay

1. In an asymmetric LR model, the term $\frac{g_R}{g_L}$ appears in Feynman amplitudes for $0\nu\beta\beta$ via $W_R - W_R$ and $W_L - W_R$ chanels. ex.

$$\mathcal{A}_{\Delta_R} \simeq G_F^2 \left(\frac{M_{W_L}}{M_{W_R}}\right)^4 \left(\frac{g_R}{g_L}\right)^4 \sum_i \frac{V_{ei}^2 M_i}{m^2_{\Delta_R^{--}}}$$

E.M.P.(eV) (**symmetric**)	E.M.P.(eV) (**asymmetric (Case II)**)	Suppression Factor $\mathbf{m}_{\rm ee}^D/\mathbf{m}_{\rm ee}$
$\mathbf{m}_{\rm ee,R}^N = 0.040$	$\mathbf{m}_{\rm ee,R}^{N,D} = 0.030$	$\left(\frac{g_R}{g_L}\right)^4 \simeq 0.75$
$\mathbf{m}_{\rm ee}^{\Delta_R} = 1.74 \times 10^{-20}$	$\mathbf{m}_{\rm ee}^{\Delta_R,D} = 1.30 \times 10^{-20}$	$\left(\frac{g_R}{g_L}\right)^4 \simeq 0.75$
$\mathbf{m}_{\rm ee}^{\lambda,\nu} = 1.142$	$\mathbf{m}_{\rm ee}^{\lambda,\nu,D} = 0.988$	$\left(\frac{g_R}{g_L}\right)^2 \simeq 0.86$
$\mathbf{m}_{\rm ee}^{\lambda,S} = 0.0035$	$\mathbf{m}_{\rm ee}^{\lambda,S,D} = 0.0030$	$\left(\frac{g_R}{g_L}\right)^2 \simeq 0.86$
$\mathbf{m}_{\rm ee}^{\lambda,N} = 4.486 \times 10^{-8}$	$\mathbf{m}_{\rm ee}^{\lambda,S,D} = 3.858 \times 10^{-8}$	$\left(\frac{g_R}{g_L}\right)^2 \simeq 0.86$

Continued..

E.M.P.(eV) (**symmetric**)	E.M.P.(eV) (**asymmetric (Case III)**)	Suppression Factor $\mathbf{m}_{\text{ee}}^{D}/\mathbf{m}_{\text{ee}}$
$\mathbf{m}_{\text{ee,R}}^{N} = 0.040$	$\mathbf{m}_{\text{ee,R}}^{N,D} = 0.0052$	$\left(\frac{g_R}{g_L}\right)^4 \simeq 0.13$
$\mathbf{m}_{\text{ee}}^{\Delta_R} = 1.74 \times 10^{-20}$	$\mathbf{m}_{\text{ee}}^{\Delta_R,D} = 2.58 \times 10^{-21}$	$\left(\frac{g_R}{g_L}\right)^4 \simeq 0.13$
$\mathbf{m}_{\text{ee}}^{\lambda,\nu} = 1.142$	$\mathbf{m}_{\text{ee}}^{\lambda,\nu,D} = 0.411$	$\left(\frac{g_R}{g_L}\right)^2 \simeq 0.36$
$\mathbf{m}_{\text{ee}}^{\lambda,S} = 0.0035$	$\mathbf{m}_{\text{ee}}^{\lambda,S,D} = 0.0013$	$\left(\frac{g_R}{g_L}\right)^2 \simeq 0.37$
$\mathbf{m}_{\text{ee}}^{\lambda,N} = 4.486 \times 10^{-8}$	$\mathbf{m}_{\text{ee}}^{\lambda,S,D} = 1.615 \times 10^{-8}$	$\left(\frac{g_R}{g_L}\right)^2 \simeq 0.36$

Continued..

1. The expression for inverse half-life in terms of effective mass parameter;

$$\left[T^{0\nu}_{1/2}\right]^{-1} = G^{0\nu}_{01} \left|\frac{\mathcal{M}^{0\nu}_{\nu}}{m_e}\right|^2 \left[|\mathbf{m}^{\nu}_{\rm ee}|^2 + |\mathbf{m}^{S,N}_{\rm ee,L}|^2 + |\mathbf{m}^{S,N}_{\rm ee,R}|^2 + |\mathbf{m}^{\Delta_R}_{\rm ee}|^2 + |\mathbf{m}^{\lambda}_{\rm ee}|^2 + |\right.$$

$$\mathbf{m}^{N}_{\rm ee,R} = \sum_{i=1}^{3} \left(\frac{m_{W_L}}{m_{W_R}}\right)^4 \left(\frac{g_R}{g_L}\right)^4 \mathcal{V}^{NN^2}_{e\,i} \frac{|p|^2}{M_{N_i}}$$

Half Life	Enhancement Factor **(Case-I vs Case-II)** $\left[\mathbf{T}^{0\nu}_{1/2}\right]_D / \left[\mathbf{T}^{0\nu}_{1/2}\right]$	Enhancement Fac **(Case-I vs Case-I** $\left[\mathbf{T}^{0\nu}_{1/2}\right]_D / \left[\mathbf{T}^{0\nu}_{1/2}\right.$
$\left[\mathbf{T}^{0\nu}_{1/2}\right]_N = \mathbf{1}/\left(\mathcal{K}_{0\nu}\|\mathbf{m}^{N}_{\rm ee}\|^2\right)$	$\left(\frac{g_L}{g_R}\right)^8 \simeq 1.78$	$\left(\frac{g_L}{g_R}\right)^8 \simeq 59.29$
$\left[\mathbf{T}^{0\nu}_{1/2}\right]_{\Delta_R} = \mathbf{1}/\left(\mathcal{K}_{0\nu}\|\mathbf{m}^{\Delta_R}_{\rm ee}\|^2\right)$	$\left(\frac{g_L}{g_R}\right)^8 \simeq 1.78$	$\left(\frac{g_L}{g_R}\right)^8 \simeq 59.29$
$\left[\mathbf{T}^{0\nu}_{1/2}\right]_{\lambda} = \mathbf{1}/\left(\mathcal{K}_{0\nu}\|\mathbf{m}^{\lambda}_{\rm ee}\|^2\right)$	$\left(\frac{g_L}{g_R}\right)^4 \simeq 1.33$	$\left(\frac{g_L}{g_R}\right)^4 \simeq 7.7$

Result

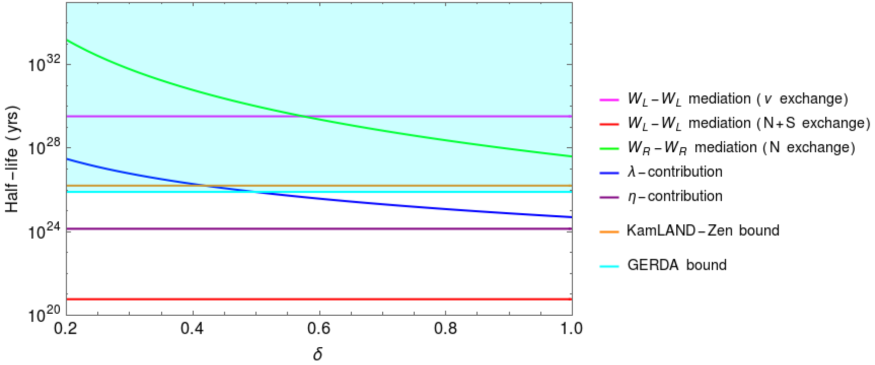


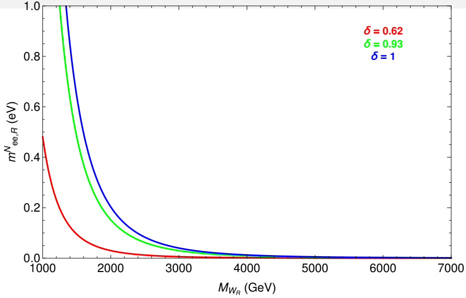
Figure: Half life of $0\nu\beta\beta$ process due to all possible channels in the model vs $\delta\ (= \frac{g_R}{g_L})$.

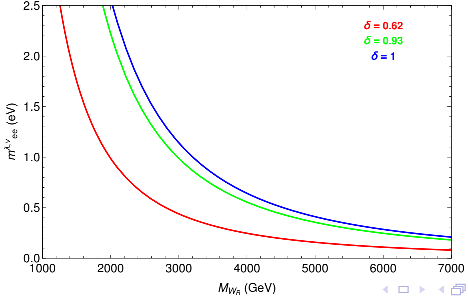
Summary

1. Left-Right models in which D-parity breaking and $SU(2)_R$ breaking scales are decoupled give rise to $g_L \neq g_R$.
2. Thus the analytic expressions for $0\nu\beta\beta$ contributions in $W_R - W_R$ and $W_L - W_R$ channels become different.
3. We have considered an asymmetric LR model where neutrino mass is explained via inverse seesaw mechanism.
4. Inverse seesaw allows large light-heavy neutrino mixing which facilitates λ and η diagrams in $0\nu\beta\beta$ sector.
5. We have considered 3 different cases for the comparative study of $0\nu\beta\beta$ decay.
6. When Pati-Salam symmetry appears in the symmetry breaking chain of SO(10) GUT, the enhancement factor for the decay increases significantly.


Thank
you!

some more plots





some more plots

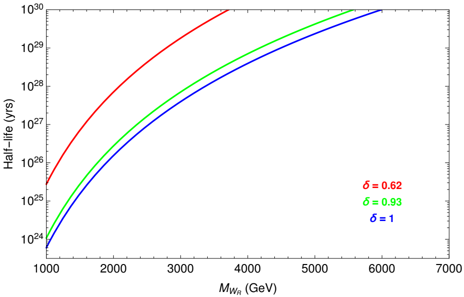


Figure: Plot shows half life due to N exchange in $W_R - W_R$ channel vs mass of W_R.