Exploring new physics signatures in an Alternative Left-Right Model

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Plan of the talk

- Motivation to Alternative Left-Right Model (ALRM)
- Neutrinoless double beta decay signatures
- Leptogenesis in ALRM
- Dark matter in this model
- Summary and conclusion

Left-Right Symmetric Model (LRSM)

- Theoretical predictions of the Standard Model match experimental searches with great accuracy.
- There remain unresolved issues within the SM indicate the existence of the Beyond SM (BSM) frameworks.
- Left-Right Symmetric Model (LRSM) is one of the promising approaches as BSM scenario (Pati et al.’74, Mohapatra et al.’75 and others)..
- Gauge Group : $\mathcal{G}_{LR} \equiv SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$.
- The light neutrino masses can be generated via type-I+II seesaw formula.

$$\Downarrow$$

A very high right-handed breaking scale (>10^{14} GeV).

Motivation to ALRM

- LRSM, while quite successful as a BSM scenario, unfortunately suffers from unavoidable flavor-changing neutral current (FCNC) constraints.

- Unavoidable FCNCs in fermion-neutral Higgs couplings in conventional LRSMs (Ecker *et al.*'83, Y. Zhang *et al.*' 2008).

$$\boxed{\lambda_{ijk}^{H\bar{U}U} = \frac{(v_u(Z_S)_{1k} - v_d(Z_S)_{2k})}{v_u^2 - v_d^2} M_{u_i}\delta_{ij} + \frac{(-v_d(Z_S)_{1k} + v_u(Z_S)_{2k})}{v_u^2 - v_d^2} \sum_{\ell=1}^{3} V_{i\ell}^{L} M_{d_\ell} V_{j\ell}^{R*}}$$

- Possible remedy : High scale LR breaking ⇒ makes framework less interesting phenomenologically !!!

- Need some alternative approach : Low energy fermions belong to 27-representation of E_6 ⇒ fermion structure should be rearranged as compared to conventional LRSM ⇒ Alternative Left-Right Model (ALRM) proposed by Ernest Ma (1987).

- Gauge group : $\mathcal{G}_{ALRM} \equiv SU(3)_C \otimes SU(2)_L \otimes SU(2)_{R'} \otimes U(1)_{B-L} \otimes U(1)_S$.

- ALRM can be embedded in complex rank 6 Lie group E_6. It has two maximal subgroups :

  $SO(10) \otimes U(1)$ and $SU(3) \otimes SU(3) \otimes SU(3)$.

Particle Content :

Quark sector : $Q_L \equiv \begin{pmatrix} u_L \\ d_L \end{pmatrix} : (3,2,1,1/6,0), \;\; Q_R \equiv \begin{pmatrix} u_R \\ d'_R \end{pmatrix} : (3,1,2,1/6,-1/2),$

$d'_L : (3,1,1,-1/3,-1), \;\; d_R : (3,1,1,-1/3,0).$

Lepton sector : $\ell_L \equiv \begin{pmatrix} \nu_L \\ e_L \end{pmatrix} : (1,2,1,-1/2,0), \;\; \ell_R \equiv \begin{pmatrix} n_R \\ e_R \end{pmatrix} : (1,1,2,-1/2,1/2),$

$n_L : (1,1,1,0,1), \;\; N_R : (1,1,1,0,0).$

Scalar sector : $\Phi : (1,2,2,0,-1/2), \;\; \chi_L : (1,2,1,1/2,0), \;\; \chi_R : (1,1,2,1/2,1/2).$

- This model permits an accessible right-handed breaking scale around a few TeV.

- Without invoking supersymmetry, model can provide two scenarios of DMs with generalised lepton number defined either by $L = S - T_{3R'}$ (Dark LR model : DLRM) (S. Khalil *et al.*'2009) or by $L = S + T_{3R'}$ (Dark LR model 2 : DLRM2) (S. Khalil *et al.*'2010).

- Two step symmetry breaking :

1. The vev acquired by the neutral component of χ_R breaks the $SU(2)_{R'} \otimes U(1)_{B-L}$ symmetry down to $U(1)_Y$,

2. $SU(2)_L \otimes U(1)_Y$ is further broken to the electromagnetic gauge symmetry by the vevs of the bidoublet and left-handed doublet fields.

$$\text{vevs : } \langle\Phi\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 0 \\ 0 & v_2 \end{pmatrix}, \quad \langle\chi_{L,R}\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v_{L,R} \end{pmatrix}.$$

- $\langle\phi_1^0\rangle = 0 \Rightarrow$ 1. It avoids unwanted mixing between d, d' and ν_L, n_R.

  2. It forbids mixing between $W_L - W_R$ gauge bosons.

- Fermion masses : $$\boxed{m_u = \frac{Y^q v_2}{\sqrt{2}}, \quad m_d = \frac{Y_L^q v_L}{\sqrt{2}}, \quad m_\ell = \frac{Y^\ell v_2}{\sqrt{2}}, \quad m_\nu = \frac{1}{m_N}\left(\frac{Y_L^\ell v_L}{\sqrt{2}}\right)^2}$$

$$\Downarrow$$

No liberty to take $v_L \to 0$.

$0\nu\beta\beta$ in ALRM

- W_R does not couple to usual N_R, d_R rather connects with exotics $\Rightarrow$ No W_R mediation contribution present.
- Absence of $W_L - W_R$ mixing $\Rightarrow$ No mixed helicity η diagram.
- Heavier charged Higgs $H_1^\pm$ relevant for $0\nu\beta\beta$ decay as it connects with quarks and leptons.
- $H_2^\pm$ connects with exotics $\Rightarrow$ not relevant here.

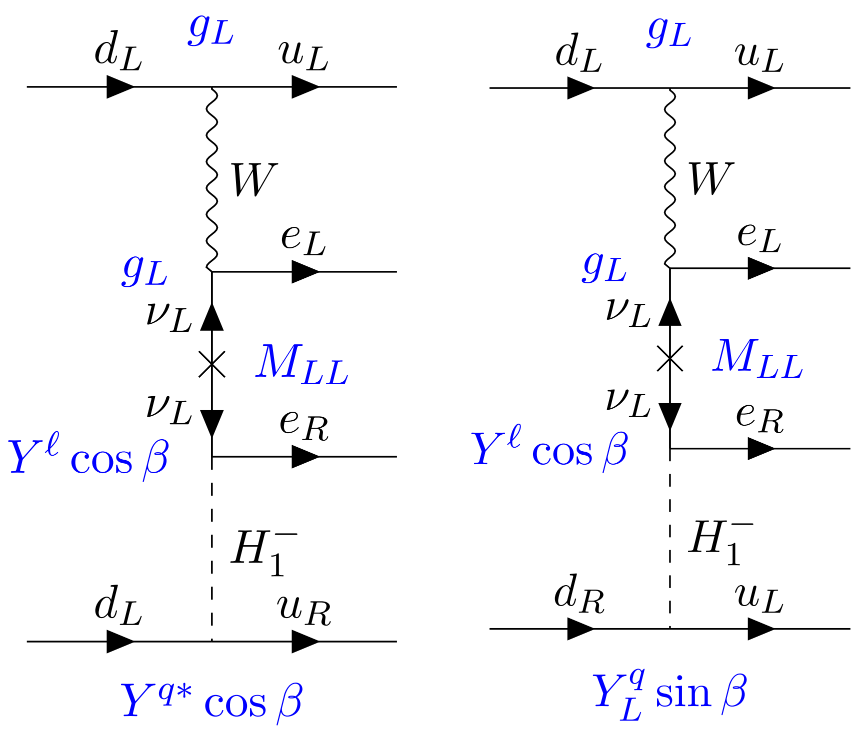
- Standard vector-vector mediation with $e_L - e_L$ emission.

- Scalar-Scalar $(H_1 - H_1)$ mediation with $e_R - e_R$ emission (Mohapatra'95, M. Doi *et al.*'85) .

- Scalar-Scalar $(H_1 - H_1)$ mediation with $e_L - e_L$ emission .

- Vector-Scalar $(W_L - H_1)$ mediation with $e_L - e_L$ emission (Mohapatra'95, K. Babu & Mohapatra'95) .

- Vector-Scalar $(W_L - H_1)$ mediation with $e_L - e_R$ emission : Significant contributions in comparison to Standard one.



$$\boxed{\frac{1}{T^{0\nu}_{1/2}} = G_{01}\,|\mathscr{M}^W_{\nu_L}\eta^W_{\nu_L}|^2 + G^R_{HH}\,|\mathscr{M}^H_{\nu_L}\eta^H_{\nu_L}|^2 + G^L_{HH}\,|\mathscr{M}^H_{\nu_R}\eta^H_{\nu_R}|^2 + G^{LL}_{WH}\,|\mathscr{M}^{WH}_{\lambda}\eta^{WH}_{\lambda}|^2 + G^{LR}_{WH}\,|\mathscr{M}^{WH}_{\nu_L}\eta^{WH}_{\nu_L}|^2}$$

$$\left|\eta^{\nu_i W_L W_L}_{LL,\nu_L}\right| \sim 2\times 10^{-8}$$

$$\left|\eta^{\nu_i W_L H_1}_{LL,\nu_L}\right| \sim 1.7\times 10^{-8}$$

$$\left|\eta^{\nu_i W_L H_1}_{LR,\nu_L}\right| \sim 3.2\times 10^{-12}$$

$$T^{0\nu}_{1/2}(^{76}\text{Ge}) = 3.6\times 10^{26}\left(\frac{200\text{ MeV}}{|p|}\right)^2\left(\frac{M_{H_1}}{200\text{ GeV}}\right)^4\ \text{yrs},$$

$$T^{0\nu}_{1/2}(^{136}\text{Xe}) = 3.0\times 10^{26}\left(\frac{200\text{ MeV}}{|p|}\right)^2\left(\frac{M_{H_1}}{200\text{ GeV}}\right)^4\ \text{yrs}\,.$$

⇒ well within the sensitivity expected by future experiments.

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Resonant Leptogenesis

- Lepton number violation in this framework : $N_{iR} \to e^-_{iL}(H_1^+), \quad N_{iR} \to e^+_{iL}(H_1^-).$

- Two lightest RHNs have almost degenerate masses ⇒ mass limits on RHNs can be significantly relaxed (A. Pilaftsis & T.E.Underwood'2004).

- Self-energy diagram will be the dominant one $\Rightarrow \epsilon_s \gg \epsilon_v$.

$$\epsilon_s^i = \frac{Im\left[\sum_\alpha \left(h^*_{\alpha i} h_{\alpha j}\right) \sum_\beta \left(h^*_{\beta i} h_{\beta j}\right)\right]}{\left(\sum_\alpha |h_{\alpha i}|^2\right)\left(\sum_\beta |h_{\beta j}|^2\right)} \frac{\left(m^2_{N_i} - m^2_{N_j}\right) m_{N_i} \Gamma_{N_j}}{\left(m^2_{N_i} - m^2_{N_j}\right)^2 + m^2_{N_i} \Gamma^2_{N_j}}$$

. with $h^*_{\alpha i} = (Y_L^{\ell\alpha *})\mathscr{V}^{NN*}_{\alpha i} sin\beta$.

- Condition to achieve required BAU in ALRM : $\Delta B \leq 10^{-4} \epsilon_s^i$ and we have

$$\frac{Im\left[\sum_\alpha \left(h^*_{\alpha i} h_{\alpha j}\right) \sum_\beta \left(h^*_{\beta i} h_{\beta j}\right)\right]}{\left(\sum_\alpha |h_{\alpha i}|^2\right)\left(\sum_\beta |h_{\beta j}|^2\right)} \simeq 10^{-7}$$

- Unlike LRSM, right handed neutrino masses are not related to W_R masses here ⇒ W_R mediation does not contribute to wash-out efficiency.

- We assume two right-handed neutrinos N_1 and N_2, which are quasi- degenerate, only contributing maximally to leptogenesis.
- Lepton Asymmetry : $\epsilon_s^{\nu N1} \simeq \dfrac{S_{13}^2 C_{23}\left(S_{12}^2 S_{13} + C_{12}^2 S_{23}\right)\left[C_{23}\left(S_{12}^2 S_{13} - C_{12}^2 S_{23}\right) + S_{12} C_{12}\left(S_{23} - C_{23}^2 S_{12}\right)\right]}{\left(S_{12} S_{13} - C_{12} C_{23} S_{13}\right)^2 \left(C_{12} S_{23} + S_{12} C_{23} S_{13}\right)^2} \sin\delta_N.$
- Thus, leptogenesis imposes limits on the phases of the mixing matrix for right-handed neutrinos.

Different Cases :

(a) $C_{ij} \sim \mathcal{O}(1) \gg S_{kl} \sim \mathcal{O}(0.01) \Rightarrow sin\delta_N \simeq 10^{-6}$, (b) $S_{ij} \sim \mathcal{O}(1) \gg C_{kl} \sim \mathcal{O}(0.01) \Rightarrow sin\delta_N \simeq 10^{-6}$,

(c) $C_{ij}, S_{ij} \sim \mathcal{O}(0.1) \Rightarrow sin\delta_N \simeq 10^{-5}$, (d) $S_{13} \sim S_{23} \sim \mathcal{O}(0.01),\ C_{12} \sim S_{12} \sim \dfrac{1}{\sqrt{2}} \Rightarrow sin\delta_N \simeq 6 \times 10^{-12}.$

Minuscule Dirac CP phase in RHN sector can generate required leptogenesis to satisfy BAU constraint.

Dark Matter (DM) in ALRM

- The ALRM augmented by the extra $U(1)_S$ symmetry allows the introduction of the generalised lepton number $L = S + T_{3R'}$.

- Similarly, one can introduce a generalised R-parity, similar to the one existing in the supersymmetry, defined in a similar way as $(-1)^{3B+L+2S}$.

- The odd R-parity particles are as follows:

  Scalar sector : $\chi_R^\pm, \phi_1^\pm, \mathfrak{R}(\phi_1^0), \mathfrak{I}(\phi_1^0)$

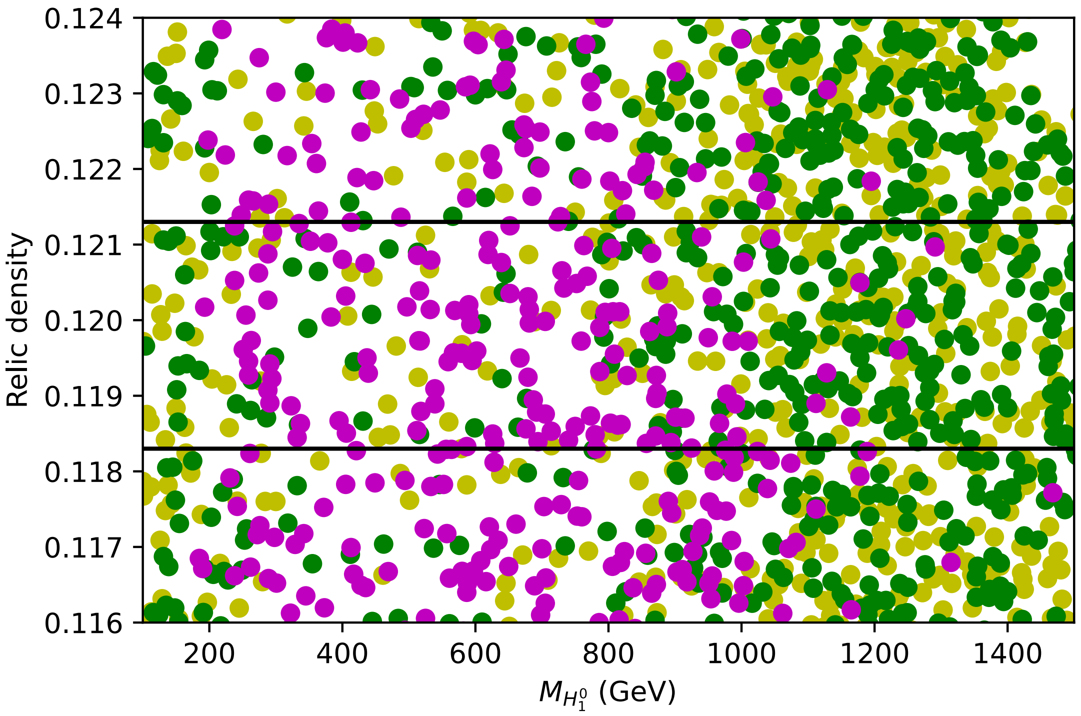
  Fermion sector : the scotinos n_L, n_R, and the exotic quarks, d'_L, d'_R

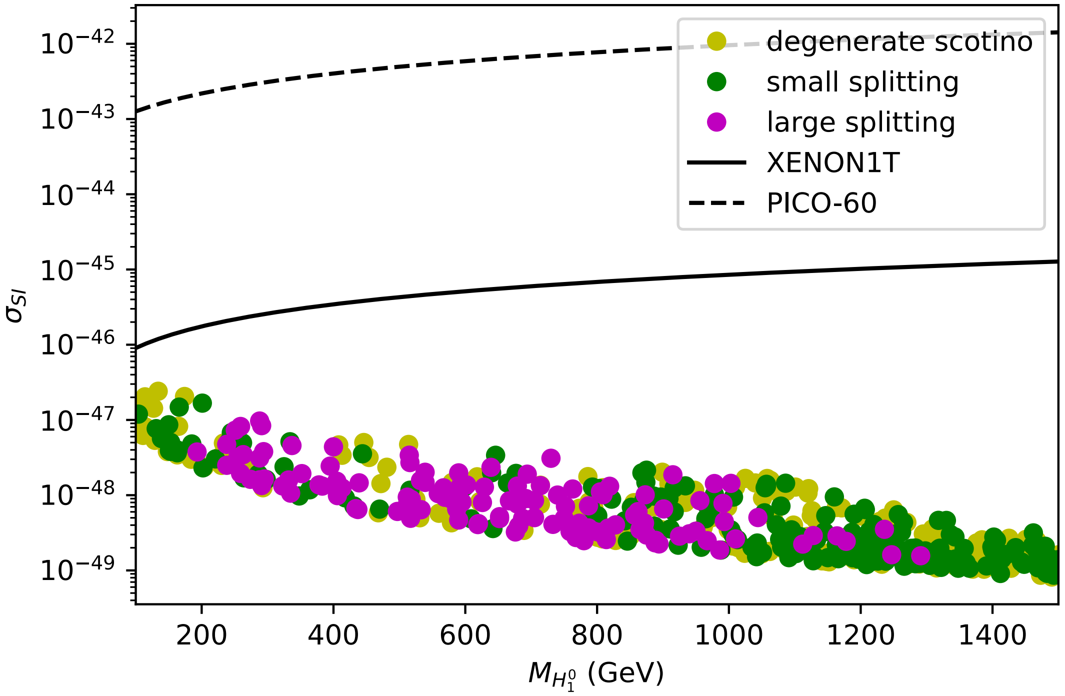
  Gauge sector : W_R

- The possible DM candidate is either the R-parity odd Higgs boson (scalar or pseudoscalar), or the scotino(s), or both .

Scalar Dark Matter

m_{n_e} and m_{n_μ}	
Case (i) (degenerate)	$m_{n_e} = m_{n_\mu} = m_{n_\tau}$
Case (ii) (small splitting)	$(m_{n_e} = m_{n_\mu}) - m_{n_\tau}$ = Range (10 keV–20 MeV)
Case (iii) (large splitting)	$(m_{n_e} = m_{n_\mu}) - m_{n_\tau}$ = Range (100 MeV–10 GeV)





- In this case, the relic is sensitive to variations in $\tan\beta = v_2/v_L$.

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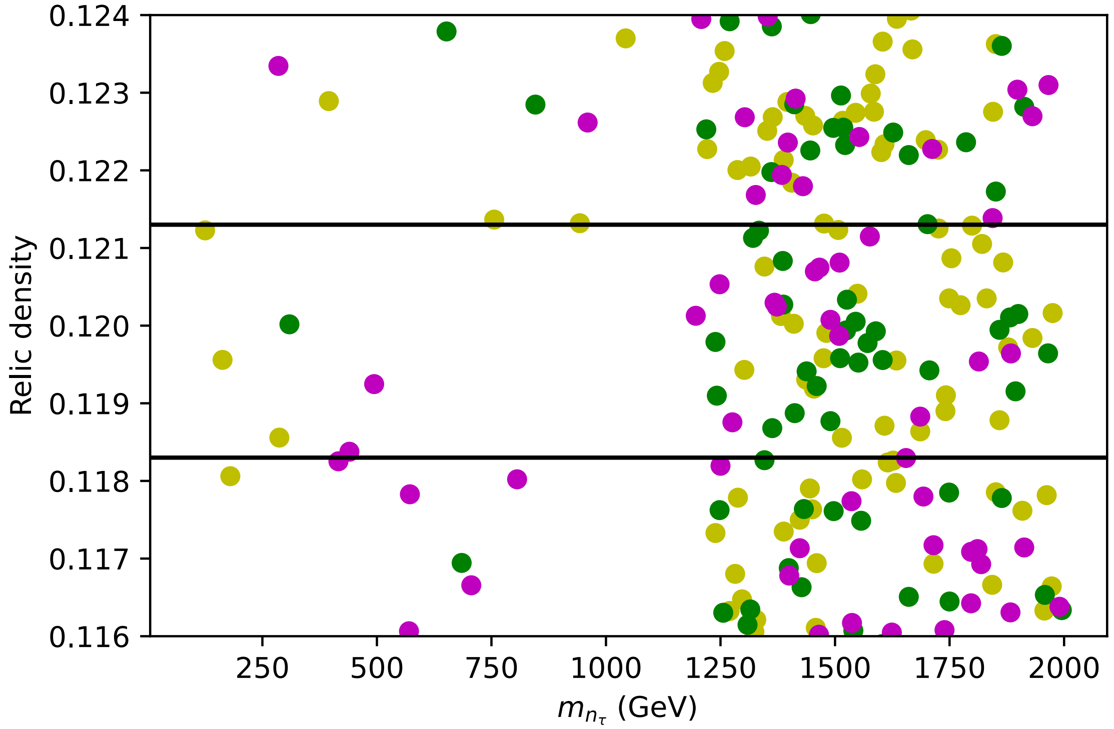
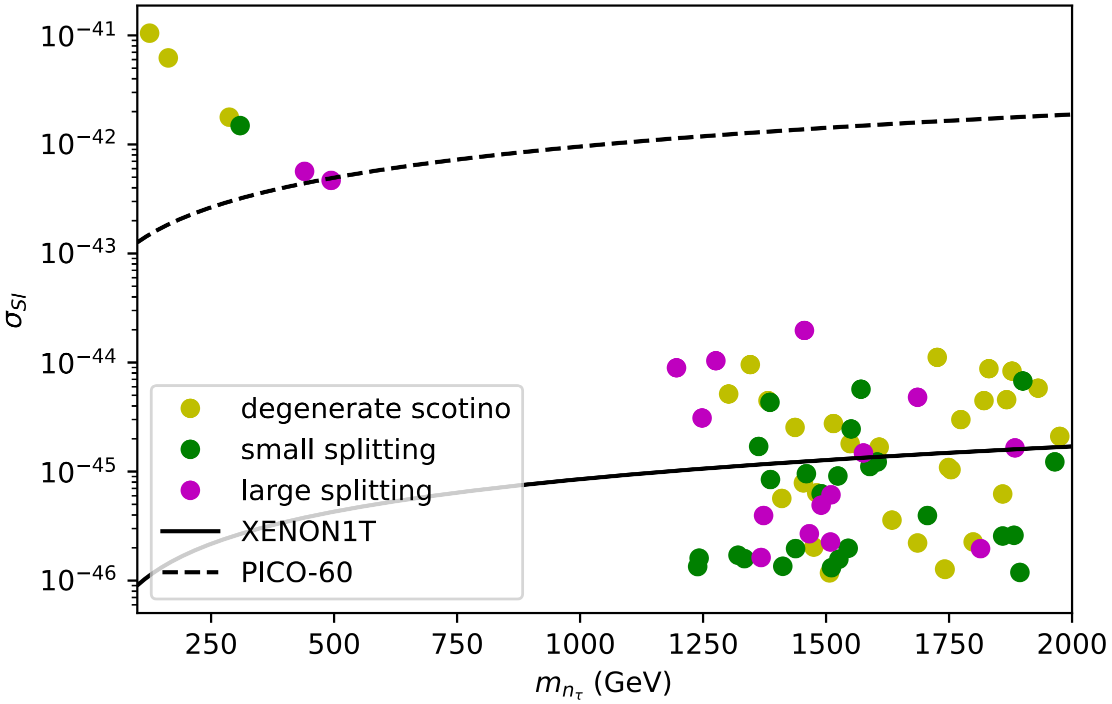
Fermion Dark Matter





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- The relic is sensitive to $v' = \sqrt{v_2^2 + v_R^2}$, as $Y_{n_\tau} = m_{n_\tau}/v_R$, so we have varied both v' and m_{n_τ}.

Summary

- The ALRM is a BSM framework with similar gauge structure as the conventional LRSM, but free from the unavoidable FCNC constraints.
- This model can generate significant contributions to the $0\nu\beta\beta$ decay through vector-scalar (WH) mediation.
- Invoking the resonant leptogenesis, the required CP violation can be obtained, even for a small Dirac phase in the right-handed neutrino mixing matrix.
- The existence of a dark matter sector stabilised by R-parity is another attractive feature of this model, and an advantage over the usual LRSM.
- Depending on the mass hierarchy, the model allows either a scalar dark matter (neutral R-parity odd scalar and pseudoscalar) or a fermion (scotino) dark matter.

Thank you!

Comments, questions, Suggestions!!!