

Neutrino magnetic moment and inert doublet dark matter in a radiative seesaw scenario

Rukmani Mohanta

University of Hyderabad, Hyderabad-500046, India

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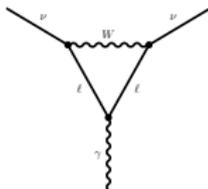
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- Despite its tremendous success, SM can be regarded as a low-energy effective theory of a more fundamental theory
- No direct evidence of NP either in Energy frontier or Intensity frontier
- There are a few open issues, which can not be addressed in the SM
 - Existence of Dark Matter \Rightarrow New weakly interacting particles
 - Non-zero neutrino masses \Rightarrow Right-handed (sterile) neutrinos
 - Observed Baryon Asymmetry of the Universe \Rightarrow Additional CP violating interactions
- It is obvious that SM must be extended.
- As a consequence of $m_\nu \neq 0$, many new avenues beyond SM are expected to exist
- One among them is neutrinos having EM properties, e.g, electric and magnetic moments
- It is extremely hard to measure their EM properties, but limits can be set from various expts.

Neutrino magnetic moment

- Neutrinos being electrically neutral, do not have EM interactions at tree level. However, such ints can be generated at loop-level.



- Study of neutrino electromagnetic interactions may shed light on the underlying theory
- With the loop suppression factor $\frac{m_\ell^2}{m_W^2}$, the contribution turns out to be

$$\mu_\nu \simeq \frac{3eG_F}{4\sqrt{2}\pi^2} m_\nu \simeq 3.2 \times 10^{-19} \left(\frac{m_\nu}{\text{eV}} \right) \mu_B$$

- Thus, $m_\nu \neq 0$ imply non-zero NMM, which can be used to distinguish Dirac and Majorana neutrinos

Neutrino Magnetic moment: Experimental status

- The quest for finding NMM started much before the discovery of neutrinos
- In 1954, Cowan, Reines and Harrison put the upper limit as $10^{-7} \mu_B$ in the process of measuring background for a free neutrino search experiment with reactor neutrinos

Reactor	{	TEXONO (2010)	$\mu_\nu < 2.0 \times 10^{-10} \mu_B,$
		GEMMA (2012)	$\mu_\nu < 2.9 \times 10^{-11} \mu_B,$
		CONUS (2022)	$\mu_\nu < 7.0 \times 10^{-11} \mu_B.$

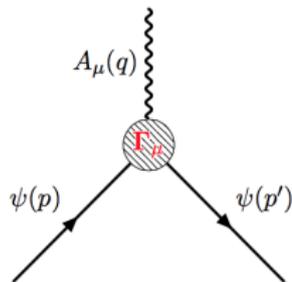
Accelerator	{	LAPMF (1993)	$\mu_\nu < 7.4 \times 10^{-10} \mu_B,$
		LSND (2002)	$\mu_\nu < 6.4 \times 10^{-10} \mu_B.$

Solar	{	Borexino (2017)	$\mu_\nu < 2.8 \times 10^{-11} \mu_B,$
		XENONnT (2022)	$\mu_\nu < 6.4 \times 10^{-12} \mu_B.$

Neutrino Magnetic moment

- Neutrinos can have electromagnetic interaction at loop level
- The effective interaction Lagrangian

$$\mathcal{L}_{\text{EM}} = \bar{\psi} \Gamma_{\mu} \psi A^{\mu} = J_{\mu}^{EM} A^{\mu}$$



- The matrix element of J_{μ}^{EM} between the initial and final neutrino mass states

$$\langle \psi(p') | J_{\mu}^{EM} | \psi(p) \rangle = \bar{u}(p') \Gamma_{\mu}(p', p) u(p)$$

- Lorentz invariance implies Γ_{μ} takes the form

$$\Gamma_{\mu}(p, p') = f_Q(q^2) \gamma_{\mu} + i f_M(q^2) \sigma_{\mu\nu} q^{\nu} + f_E(q^2) \sigma_{\mu\nu} q^{\nu} \gamma_5 + f_A(q^2) (q^2 \gamma_{\mu} - q_{\mu} \not{q}) \gamma_5$$

$f_Q(q^2)$, $f_M(q^2)$, $f_E(q^2)$ and $f_A(q^2)$ are the form factors

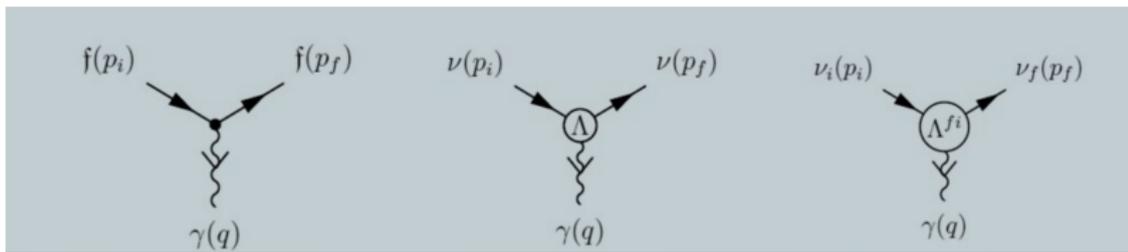
Magnetic moment in minimal extended SM

- For Dirac neutrinos:

$$\begin{cases} \mu_{ij}^D \\ \epsilon_{ij}^D \end{cases} = \frac{eG_F}{8\sqrt{2}\pi^2} (m_i \pm m_j) \sum_{l=e,\mu,\tau} f(x_l) U_{li}^* U_{lj}, \quad x_l = m_l^2/m_W^2$$

- The diagonal electric dipole moment vanishes: $\epsilon_{ii}^D = 0$
- For the Majorana neutrinos both electric and magnetic diagonal moments vanish (matrix is antisymmetric)

$$\mu_{ii}^M = \epsilon_{ii}^M = 0$$



Neutrino Transition moments

- Neutrino transition moments are off-diagonal elements of

$$\begin{cases} \mu_{ij}^D \\ \epsilon_{ij}^D \end{cases} \simeq -\frac{3eG_F}{32\sqrt{2}\pi^2} (m_i \pm m_j) \sum_{l=e,\mu,\tau} \left(\frac{m_l}{m_W}\right)^2 U_{li}^* U_{lj}, \quad \text{for } i \neq j$$

- The transition moments are suppressed wrt diagonal moments

$$\begin{cases} \mu_{ij}^D \\ \epsilon_{ij}^D \end{cases} \simeq -4 \times 10^{-23} \left(\frac{m_i \pm m_j}{\text{eV}}\right) f_{ij} \mu_B$$

- For Majorana neutrinos transition moments may be non-vanishing
- When ν_i and ν_j have opposite CP phase

$$\mu_{ij}^M = -\frac{3eG_F m_i}{16\sqrt{2}\pi^2} \left(1 + \frac{m_j}{m_i}\right) \sum_{l=e,\mu,\tau} \text{Im}(U_{li}^* U_{lj}) \frac{m_l^2}{m_W^2}$$

- Thus we get: $\mu_{ij}^M = 2\mu_{ij}^D$

Neutrino-electron elastic scattering

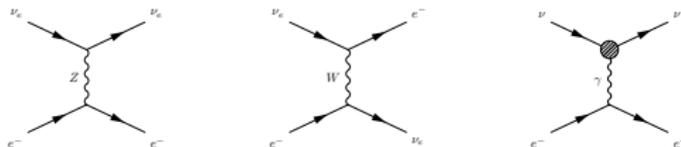
- Most widely used method to determine ν MM is $\nu + e^- \rightarrow \nu + e^-$

$$\left(\frac{d\sigma}{dT_e}\right)_{\text{SM}} = \frac{G_F^2 m_e}{2\pi} \left[(g_V + g_A)^2 + (g_V - g_A)^2 \left(1 - \frac{T_e}{E_\nu}\right)^2 + (g_A^2 - g_V^2) \frac{m_e T_e}{E_\nu^2} \right]$$

$$\left(\frac{d\sigma}{dT_e}\right)_{\text{EM}} = \frac{\pi\alpha^2}{m_e^2} \left(\frac{1}{T_e} - \frac{1}{E_\nu}\right) \left(\frac{\mu_{\text{eff}}}{\mu_B}\right)^2$$

- The cross sections are added incoherently

$$\left(\frac{d\sigma}{dT_e}\right)_{\text{Tot}} = \left(\frac{d\sigma}{dT_e}\right)_{\text{SM}} + \left(\frac{d\sigma}{dT_e}\right)_{\text{EM}} \quad (\propto \frac{1}{T_e} \text{ for low recoil})$$



- Objective is to address the neutrino mass, magnetic moment and dark matter in a common platform
- SM is extended with three vector-like fermion triplets Σ_k and two inert scalar doublets η_j
- An additional Z_2 symmetry is imposed to realize neutrino phenomenology at one-loop and for the stability of the dark matter candidate.

	Field	$SU(3)_C \times SU(2)_L \times U(1)_Y$	Z_2
Leptons	$\ell_L = (\nu, e)_L^T$	$(\mathbf{1}, \mathbf{2}, -1/2)$	+
	e_R	$(\mathbf{1}, \mathbf{1}, -1)$	+
	$\Sigma_{k(L,R)}$	$(\mathbf{1}, \mathbf{3}, 0)$	-
Scalars	H	$(\mathbf{1}, \mathbf{2}, 1/2)$	+
	η_j	$(\mathbf{1}, \mathbf{2}, 1/2)$	-

Table: Fields and their charges in the present model.

- The $SU(2)_L$ triplet $\Sigma_{L,R}$ and inert doublets can be expressed as

$$\Sigma_{L,R} = \frac{\sigma^a \Sigma_{L,R}^a}{\sqrt{2}} = \begin{pmatrix} \Sigma_{L,R}^0 / \sqrt{2} & \Sigma_{L,R}^+ \\ \Sigma_{L,R}^- & -\Sigma_{L,R}^0 / \sqrt{2} \end{pmatrix}, \quad \eta_j = \begin{pmatrix} \eta_j^+ \\ \eta_j^0 \end{pmatrix}; \quad \eta_j^0 = \frac{\eta_j^R + i\eta_j^I}{\sqrt{2}}$$

- Charged scalars help in attaining neutrino magnetic moment, while Charged and neutral scalars help in obtaining neutrino mass at one loop.
- Scalar components annihilate via SM scalar and vector bosons and their freeze-out yield constitutes dark matter density of the Universe.
- The Lagrangian terms of the fermion sector is given by

$$\mathcal{L}_\Sigma = y'_{\alpha k} \bar{\ell}_{\alpha L} \Sigma_{kR} \tilde{\eta}_j + y_{\alpha k} \bar{\ell}_{\alpha L}^c i\sigma_2 \Sigma_{kL} \eta_j + \frac{i}{2} \text{Tr}[\bar{\Sigma} \gamma^\mu D_\mu \Sigma] - \frac{1}{2} \text{Tr}[\bar{\Sigma} M_\Sigma \Sigma] + \text{h.c.}$$

- The Lagrangian for the scalar sector takes the form

$$\mathcal{L}_{\text{scalar}} = - \sum_{i=1,2} \left| \left(\partial_\mu + \frac{i}{2} g \sigma^a W_\mu^a + \frac{i}{2} g' B_\mu \right) \eta_i \right|^2 - V(H, \eta_1, \eta_2)$$

- The scalar potential is expressed as

$$\begin{aligned} V(H, \eta_1, \eta_2) = & \mu_H^2 H^\dagger H + \mu_1^2 \eta_1^\dagger \eta_1 + \mu_2^2 \eta_2^\dagger \eta_2 + \mu_{12}^2 (\eta_1^\dagger \eta_2 + \text{hc}) + \lambda_H (H^\dagger H)^2 + \lambda_1 (\eta_1^\dagger \eta_1)^2 \\ & + \lambda_2 (\eta_2^\dagger \eta_2)^2 + \lambda_{12} (\eta_1^\dagger \eta_1) (\eta_2^\dagger \eta_2) + \lambda'_{12} (\eta_1^\dagger \eta_2) (\eta_2^\dagger \eta_1) + \frac{\lambda''_{12}}{2} [(\eta_1^\dagger \eta_2)^2 + \text{h.c.}] \\ & + \sum_{j=1,2} \left(\lambda_{Hj} (H^\dagger H) (\eta_j^\dagger \eta_j) + \lambda'_{Hj} (H^\dagger \eta_j) (\eta_j^\dagger H) + \frac{\lambda''_{Hj}}{2} [(H^\dagger \eta_j)^2 + \text{h.c.}] \right). \end{aligned}$$

- The mass matrices of the charged and neutral scalar components are:

$$\mathcal{M}_C^2 = \begin{pmatrix} \Lambda_{C1} & \mu_{12}^2 \\ \mu_{12}^2 & \Lambda_{C2} \end{pmatrix}, \quad \mathcal{M}_R^2 = \begin{pmatrix} \Lambda_{R1} & \mu_{12}^2 \\ \mu_{12}^2 & \Lambda_{R2} \end{pmatrix}, \quad \mathcal{M}_I^2 = \begin{pmatrix} \Lambda_{I1} & \mu_{12}^2 \\ \mu_{12}^2 & \Lambda_{I2} \end{pmatrix}$$

$$\Lambda_{Cj} = \mu_j^2 + \frac{\lambda_{Hj}}{2} v^2,$$

$$\Lambda_{Rj} = \mu_j^2 + \left(\lambda_{Hj} + \lambda'_{Hj} + \lambda''_{Hj} \right) \frac{v^2}{2},$$

$$\Lambda_{Ij} = \mu_j^2 + \left(\lambda_{Hj} + \lambda'_{Hj} - \lambda''_{Hj} \right) \frac{v^2}{2}.$$

- The flavor and mass eigenstates can be related by $U_\theta = \begin{pmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{pmatrix}$

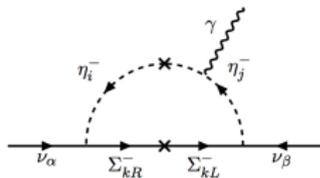
$$\begin{pmatrix} \eta_1^+ \\ \eta_2^+ \end{pmatrix} = U_{\theta_C} \begin{pmatrix} \phi_1^+ \\ \phi_2^+ \end{pmatrix}, \quad \begin{pmatrix} \eta_1^R \\ \eta_2^R \end{pmatrix} = U_{\theta_R} \begin{pmatrix} \phi_1^R \\ \phi_2^R \end{pmatrix}, \quad \begin{pmatrix} \eta_1^I \\ \eta_2^I \end{pmatrix} = U_{\theta_I} \begin{pmatrix} \phi_1^I \\ \phi_2^I \end{pmatrix}.$$

- Invisible decays of Z and W^\pm at LEP, limit the masses as

$$M_{Ci} > M_Z/2, \quad M_{Ri} + M_{li} > M_Z, \quad M_{Ci} + M_{Ri,li} > M_W.$$

Neutrino Magnetic Moment

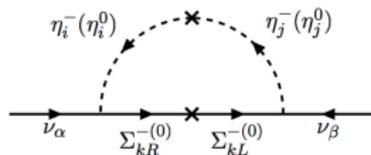
- In this model, the magnetic moment arises from one-loop diagram, and the expression of corresponding contribution takes the form



$$(\mu_\nu)_{\alpha\beta} = \sum_{k=1}^3 \frac{(Y^2)_{\alpha\beta}}{8\pi^2} M_{\Sigma_k^+} \left[(1 + \sin 2\theta_C) \frac{1}{M_{C2}^2} \left(\ln \left[\frac{M_{C2}^2}{M_{\Sigma_k^+}^2} \right] - 1 \right) + (1 - \sin 2\theta_C) \frac{1}{M_{C1}^2} \left(\ln \left[\frac{M_{C1}^2}{M_{\Sigma_k^+}^2} \right] - 1 \right) \right],$$

where $y = y' = Y$ and $(Y^2)_{\alpha\beta} = Y_{\alpha k} Y_{k\beta}^T$.

- Contribution to neutrino mass can arise at one-loop: with charged/neutral scalars and fermion triplet in the loop



$$\begin{aligned}
 (\mathcal{M}_\nu)_{\alpha\beta} = & \sum_{k=1}^3 \frac{(Y^2)_{\alpha\beta}}{32\pi^2} M_{\Sigma_k^+} \left[(1 + \sin 2\theta_C) \frac{M_{C2}^2}{M_{\Sigma_k^+}^2 - M_{C2}^2} \ln \left(\frac{M_{\Sigma_k^+}^2}{M_{C2}^2} \right) \right. \\
 & \left. + (1 - \sin 2\theta_C) \frac{M_{C1}^2}{M_{\Sigma_k^+}^2 - M_{C1}^2} \ln \left(\frac{M_{\Sigma_k^+}^2}{M_{C1}^2} \right) \right] \\
 & + \sum_{k=1}^3 \frac{(Y^2)_{\alpha\beta}}{32\pi^2} M_{\Sigma_k^0} \left[(1 + \sin 2\theta_R) \frac{M_{R2}^2}{M_{\Sigma_k^0}^2 - M_{R2}^2} \ln \left(\frac{M_{\Sigma_k^0}^2}{M_{R2}^2} \right) \right. \\
 & \left. + (1 - \sin 2\theta_R) \frac{M_{R1}^2}{M_{\Sigma_k^0}^2 - M_{R1}^2} \ln \left(\frac{M_{\Sigma_k^0}^2}{M_{R1}^2} \right) \right] \\
 & - \sum_{k=1}^3 \frac{(Y^2)_{\alpha\beta}}{32\pi^2} M_{\Sigma_k^0} \left[(1 + \sin 2\theta_I) \frac{M_{I2}^2}{M_{\Sigma_k^0}^2 - M_{I2}^2} \ln \left(\frac{M_{\Sigma_k^0}^2}{M_{I2}^2} \right) \right. \\
 & \left. + (1 - \sin 2\theta_I) \frac{M_{I1}^2}{M_{\Sigma_k^0}^2 - M_{I1}^2} \ln \left(\frac{M_{\Sigma_k^0}^2}{M_{I1}^2} \right) \right].
 \end{aligned}$$

Inert scalar doublet dark matter : Relic density

- The model provides scalar dark matter candidates and we study their phenomenology for dark matter mass up to 2 TeV range.
- All the inert scalar components contribute to the dark matter density of the Universe through annihilations and co-annihilations.

$$\phi_i^R \phi_j^R \longrightarrow f\bar{f}, W^+W^-, ZZ, hh \quad (\text{via Higgs mediator})$$

$$\phi_i^R \phi_j^I \longrightarrow f\bar{f}, W^+W^-, Zh, \quad (\text{via Z boson})$$

$$\phi_i^\pm \phi_j^{R/I} \longrightarrow f'\bar{f}'', AW^\pm, ZW^\pm, hW^\pm, \quad (\text{through } W^\pm \text{ bosons})$$

- The abundance of dark matter can be computed by

$$\Omega h^2 = \frac{1.07 \times 10^9 \text{ GeV}^{-1}}{M_{\text{Pl}} g_*^{1/2}} \frac{1}{J(x_f)}, \quad \text{where } J(x_f) = \int_{x_f}^{\infty} \frac{\langle \sigma v \rangle(x)}{x^2} dx$$

$$\langle \sigma v \rangle(x) = \frac{x}{8M_{\text{DM}}^5 K_2^2(x)} \int_{4M_{\text{DM}}^2}^{\infty} \hat{\sigma} \times (s - 4M_{\text{DM}}^2) \sqrt{s} K_1 \left(\frac{x\sqrt{s}}{M_{\text{DM}}} \right) ds$$

Dark Matter Direct Searches

- The scalar dark matter can scatter off the nucleus via the Higgs and the Z boson.
- The DM-nucleon cross section in Higgs portal can provide a SI Xsection and the effective interaction Lagrangian takes the form

$$\mathcal{L}_{\text{eff}} = a_q \phi_1^R \phi_1^R q \bar{q}, \quad \text{where}$$

$$a_q = \frac{M_q}{2M_h^2 M_{R1}} (\lambda_{L1} \cos^2 \theta_R + \lambda_{L2} \sin^2 \theta_R) \quad \text{with } \lambda_{Lj} = \lambda_{Hj} + \lambda'_{Hj} + \lambda''_{Hj}.$$

- The corresponding cross section is

$$\sigma_{\text{SI}} = \frac{1}{4\pi} \left(\frac{M_n M_{R1}}{M_n + M_{R1}} \right)^2 \left(\frac{\lambda_{L1} \cos^2 \theta_R + \lambda_{L2} \sin^2 \theta_R}{2M_{R1} M_h^2} \right)^2 f^2 M_n^2$$

- Sensitivity can be checked with stringent upper bound of LZ-ZEPLIN experiment.

- We consider ϕ_1^R to be the lightest inert scalar eigen state and there are five other heavier scalars.
- We consider one parameter M_{R1} and three mass splittings namely δ , δ_{IR} and δ_{CR} .
- The masses of the rest of the inert scalars can be obtained from:

$$\begin{aligned}M_{R2} - M_{R1} &= M_{I2} - M_{I1} = M_{C2} - M_{C1} = \delta, \\M_{Ri} - M_{Ii} &= \delta_{IR}, \quad M_{Ri} - M_{Ci} = \delta_{CR},\end{aligned}$$

- Scanning over model parameters as given below

$$\begin{aligned}100 \text{ GeV} &\leq M_{R1} \leq 2000 \text{ GeV}, \quad 0 \leq \sin \theta_R \leq 1, \\0.1 \text{ GeV} &\leq \delta < 200 \text{ GeV}, \quad 0.1 \text{ GeV} \leq \delta_{IR}, \delta_{CR} \leq 20 \text{ GeV}.\end{aligned}$$

Results on Neutrino oscillations

- For diagonalization of neutrino mass matrix, we take

$$U_\nu = U_{\text{TBM}} \cdot U_{13} = \begin{pmatrix} \cos \Theta & \sin \Theta & 0 \\ -\frac{\sin \Theta}{\sqrt{2}} & \frac{\cos \Theta}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{\sin \Theta}{\sqrt{2}} & -\frac{\cos \Theta}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix} \cdot \begin{pmatrix} \cos \varphi & 0 & e^{-i\zeta} \sin \varphi \\ 0 & 1 & 0 \\ -e^{i\zeta} \sin \varphi & 0 & \cos \varphi \end{pmatrix}$$

which gives

$$\mathcal{M}_\nu = Y \cdot \text{diag}(\Lambda'_1, \Lambda'_2, \Lambda'_3) \cdot Y^T, \quad \mu_\nu = Y \cdot \text{diag}(\Lambda_1, \Lambda_2, \Lambda_3) \cdot Y^T$$

where Y is the 3×3 Yukawa matrix

- Diagonalizing the matrices using U_ν , gives three unique solutions where the Yukawa couplings of different flavors become linearly dependent,

$$Y_{e1/e3} = \left(\frac{\sqrt{2} \cos \Theta \cos \varphi}{\sin \Theta \cos \varphi \mp e^{-i\zeta} \sin \varphi} \right) Y_{\tau 1}, \quad Y_{e2} = -\frac{\sqrt{2} \sin \Theta}{\cos \Theta} Y_{\tau 2},$$
$$Y_{\mu 1/\mu 3} = \left(\frac{e^{-i\zeta} \sin \varphi + \sin \Theta \cos \varphi}{e^{-i\zeta} \sin \varphi \mp \sin \Theta \cos \varphi} \right) Y_{\tau 1}, \quad Y_{\mu 2} = -Y_{\tau 2}.$$

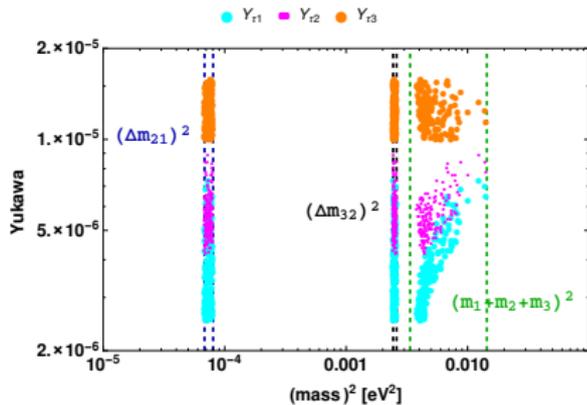
- Thus, the obtained diagonalized matrices are

$$\mathcal{M}_\nu^D / \mu_\nu^D = \begin{pmatrix} a_1 Y_{\tau 1}^2 \Lambda'_1(\Lambda_1) & 0 & 0 \\ 0 & a_2 Y_{\tau 2}^2 \Lambda'_2(9\Lambda_2) & 0 \\ 0 & 0 & a_3 Y_{\tau 3}^2 \Lambda'_3(9\Lambda_3) \end{pmatrix},$$

where,

$$a_1 = \frac{2e^{2i\zeta}}{(-e^{i\zeta} \cos \varphi \sin \Theta + \sin \varphi)^2}, \quad a_2 = \frac{2}{\cos^2 \Theta}, \quad a_3 = \frac{2e^{-2i\zeta}}{(e^{-i\zeta} \cos \varphi + \sin \Theta \sin \varphi)^2}.$$

- Using the best-fit values on θ_{12} , θ_{13} and θ_{23} , we fix $\Theta = 33.04^\circ$, $\varphi = 10.18^\circ$ and $\zeta = 180^\circ$.



Some Results

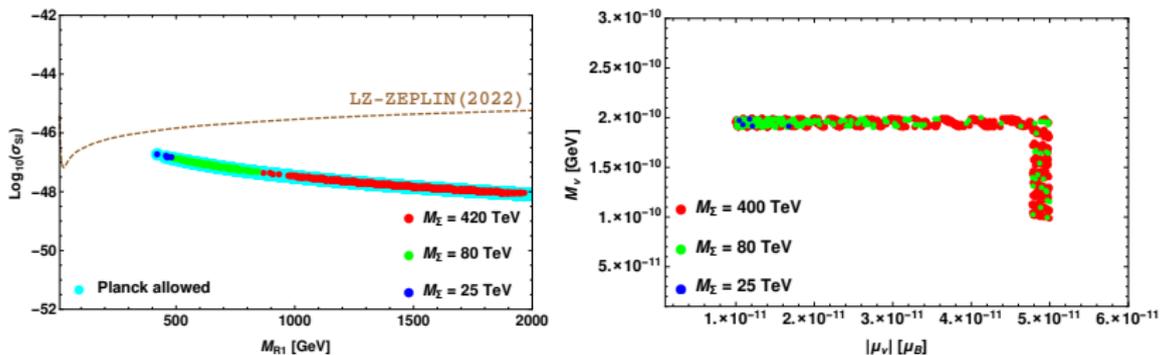


Figure: Left panel: Projection of SI WIMP-nucleon cross section as a function M_{R1} . Right panel: ν MM and light neutrino mass for suitable Yukawas.

Some Results

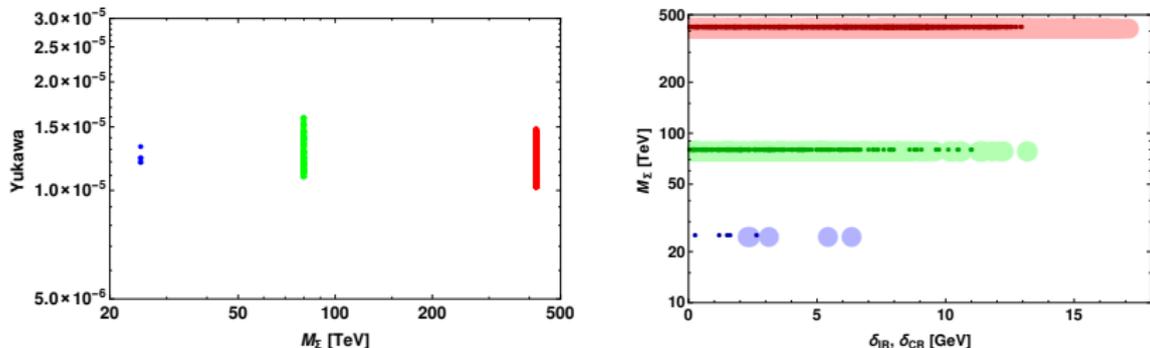
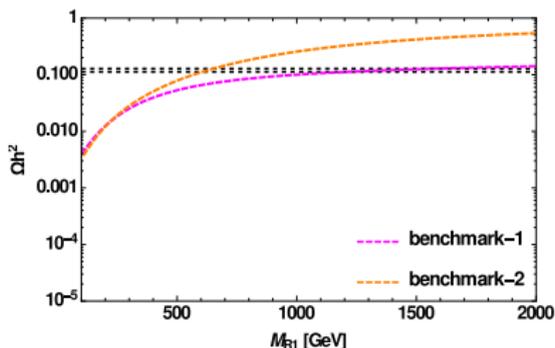


Figure: Left panel: Suitable region for triplet mass and Yukawa to explain neutrino phenomenology. Right panel: allowed region for scalar mass splittings, thick (thin) bands correspond to δ_{IR} (δ_{CR}) respectively.

Benchmark values of parameters

	M_{R1} [GeV]	δ [GeV]	δ_{CR} [GeV]	δ_{IR} [GeV]	M_{Σ} [TeV]	Yukawa	$\sin \theta_R$
benchmark-1	1472	101.69	9.03	0.35	420	$10^{-4.89}$	0.09
benchmark-2	628	36.40	4.38	3.45	80	$10^{-4.85}$	0.06

	$ \mu_{\nu} $ [μ_B]	\mathcal{M}_{ν} [GeV]	$\text{Log}_{10}^{[\sigma_{SI}]} \text{ cm}^{-2}$	Ωh^2
benchmark-1	2.73×10^{-11}	1.99×10^{-10}	-47.78	0.123
benchmark-2	3.03×10^{-11}	1.92×10^{-10}	-47.04	0.119

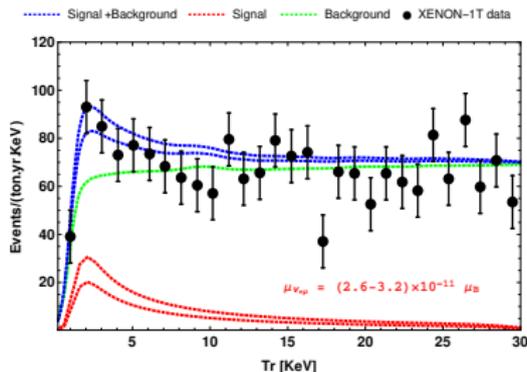


Excess in electron recoil events

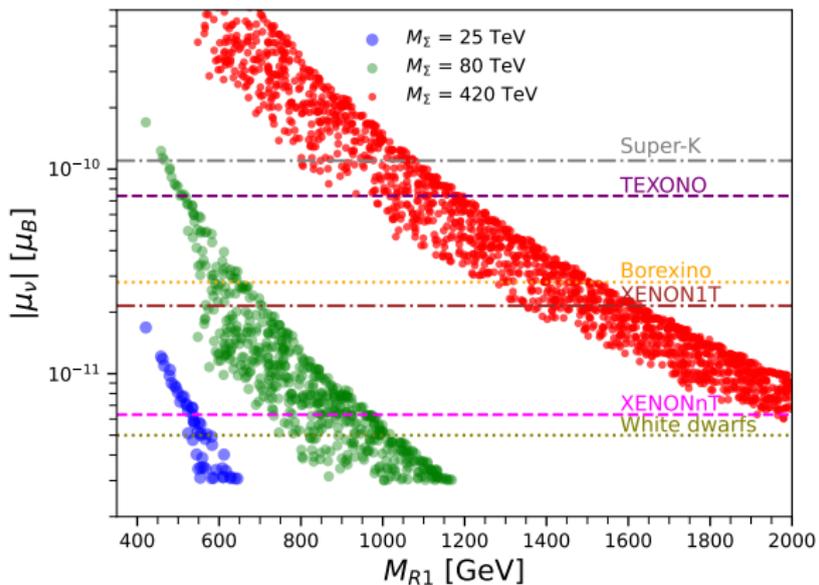
$$\frac{dN}{dT_r} = n_{te} \times \int_{E_\nu^{\min}}^{E_\nu^{\max}} dE_\nu \int_{T_{th}}^{T_{\max}} dT_e \left(\frac{d\sigma^{\nu e e}}{dT_e} P_{ee} + \cos^2 \theta_{23} \frac{d\sigma^{\nu \mu e}}{dT_e} P_{e\mu} \right) \times \frac{d\phi_s}{dE_\nu} \times \epsilon(T_e) \times G(T_e, T_r).$$

where, $E_\nu^{\max} = 420$ KeV and $E_\nu^{\min} = [T + (2m_e T + T^2)^{\frac{1}{2}}]/2$.

- $T_{th} = 1$ KeV and $T_{\max} = 30$ KeV stand for the threshold and maximum recoil energy of detector.



Variation of ν Magnetic Moment with DM Mass



Conclusion

- Primary objective is to address neutrino mass, magnetic moment and dark matter phenomenology in a common framework.
- SM is extended with three vector-like fermion triplets and two inert scalar doublets to realize Type-III radiative scenario.
- A pair of charged scalars help in obtaining neutrino magnetic moment,
- All charged and neutral scalars come up in getting light neutrino mass at one-loop level.
- All the inert scalars participate in annihilation and co-annihilation channels to provide dark matter relic density consistent with Planck data
- The model is able to provide neutrino magnetic moment in a wide range ($10^{-12} \mu_B$ to $10^{-10} \mu_B$), in the same ballpark of Borexino, Super-K, TEXONO, XENONnT and white dwarfs.

Thank you for your attention !