Singlet-Doublet Fermionic Dark Matter with Dirac Neutrino Mass, (g-2) and $\Delta N_{\rm eff}$

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Based on 2310.03721

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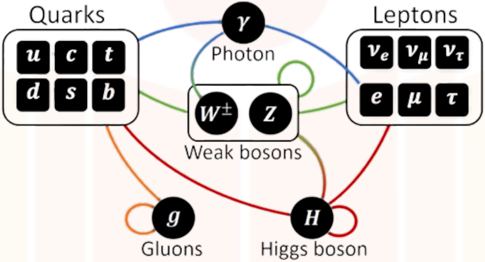
20th December, 2023

Overview of the talk

1. Introduction
2. Dirac Neutrino Mass
3. The Model (Singlet-Doublet Fermionic Dark Matter)
4. Anomalous Magnetic Moment
5. Direct Detection
6. $\Delta N_{\rm eff}$
7. Summary

Introduction

What We Have...



Neutrino Physics

1. Neutrino Mass
2. Type of the Neutrino Field (Majorana/Dirac).
3. Number of Neutrino Species ($N_{\rm eff} = 2.99^{+0.34}_{-0.33}$ at 2σ confidence level)[1807.06209]

Dark Matter

- Non-luminous, Non-baryonic matter
- Evidences from Astrophysical and Cosmologica observations
- $\Omega_{\rm DM} h^2 \simeq 0.12 \pm 0.001$ [1807.06209]

$N_{\rm eff}$

$\mathrm{N_{eff}} = 2.99^{+0.34}_{-0.33}$

- $N_{\rm eff}$ is the effective degrees of freedom, other than photon(γ), present in the Universe.

$$N_{\rm eff} = \left(\frac{11}{4}\right)^{4/3} \sum_{\rm boson} \left(\frac{\rho_{rad} - \rho_\gamma}{\rho_\gamma}\right) + \sum_{\rm fermion} \left(\frac{\rho_{rad} - \rho_\gamma}{\rho_\gamma}\right)$$

- 3 flavours of active neutrinos present in SM contributes only $N_\nu = 3.045$ (hep-ph/0506164)
- Any deviation of SM contribution from $N_{\rm eff}$, can be thought of as from extra relativistic particles/radiation.

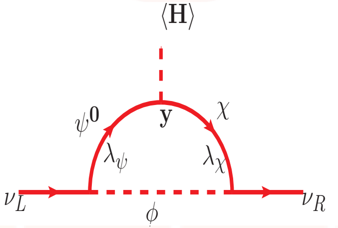
$$\Delta N_{\rm eff} = \left(\frac{\rho_{\nu_R}}{\rho_{\nu_L}}\right)_{T_D(\nu_L)}$$

- Any extra relativistic particle may affect the matter-radiation equality and Hubble expansion rate. And hence, different imprints on CMB spectra.

Assumption: There are as many neutrinos as anti-neutrinos.

Neutrino Mass Generation

Dirac Neutrino



Effective Langrangian term for Dirac Neutrino Mass, $\mathcal{L} \supset \bar{L}_L \tilde{H} \nu_R$

$$\Rightarrow M_\nu \bar{\nu}_L \nu_R$$

- Do not forget about oscillation parameters
  $\Delta m^2_{sol} = 7.54 \pm 0.18 \times 10^{-5}\ \mathrm{eV}^2$,
  $\Delta m^2_{atm} = 2.43 \pm 0.03 \times 10^{-3}\ \mathrm{eV}^2$(N0)[PTET 2022]
  and cosmological mass bound, $\sum m_{\nu_i} \leq 0.12$ eV [1807.06209].

Model

Singlet-Doublet Fermionic DM

Gauge Group	Fermion Fields				Scalar
	L	Ψ	χ	ν_R	ϕ
$SU(2)_L$	2	2	1	1	1
$U(1)_Y$	-1	-1	0	0	0
Z_3	ω	ω^2	ω^2	ω^2	1
Z_2	$+1$	-1	-1	$+1$	-1

We have considered 3 generations of Siglet- Doublet fermion to generate 3 non-zero neutrino mass states.

Lagrangian

$$\mathcal{L} \supset i\overline{\Psi}\gamma^\mu D_\mu \Psi + i\overline{\chi}\gamma^\mu \partial_\mu \chi - M_\Psi \overline{\Psi}\Psi - M_\chi \overline{\chi}\chi - y\overline{\Psi}\tilde{H}\chi - \lambda_\Psi \overline{\ell}\Phi\Psi - \lambda_\chi \overline{\nu_R}\Phi\chi + h.c.$$

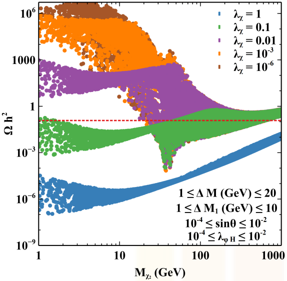
Where $D_\mu = \partial_\mu - g_1 \frac{\tau_i}{2} W^i_\mu - g_2 \frac{Y}{2} B_\mu$, $\Psi = (\psi^0 \ \psi^-)^T$

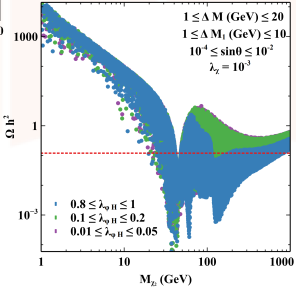
$$\begin{pmatrix} \psi^0 \\ \chi \end{pmatrix} = U \begin{pmatrix} \chi_1 \\ \chi_2 \end{pmatrix} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} \chi_1 \\ \chi_2 \end{pmatrix}, \quad (1)$$

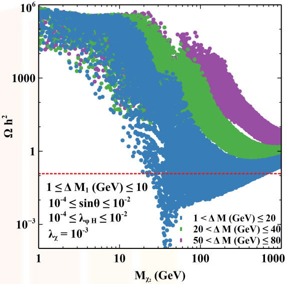
Parameter space is spanned by $(\lambda_\chi, \lambda_\psi, sin\theta, M_{\chi_2}, \Delta M = M_{\chi_1} - M_{\chi_2}, \Delta M_1 = M_\phi - M_{\chi_2})$

Model

Relic Density







Model

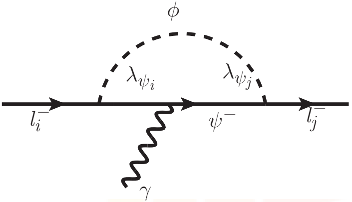
Anomalous Magnetic Moment

$$\vec{\mu_\mu} = g\frac{e}{2m_\mu}\vec{s}$$

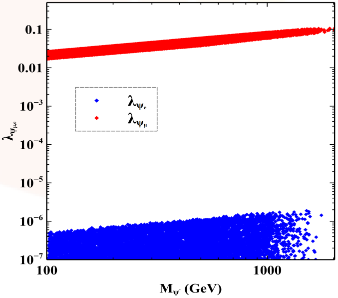
g-value is basically the sum of internal degrres of freedom and effects from quantum corrections.

$$\Delta a_\mu = a_\mu^{\rm exp} - a_\mu^{\rm SM} = 249(48)\times 10^{-11}[2308.06230]$$

Where a_μ^{SM} includes all quantum corrections from SM.

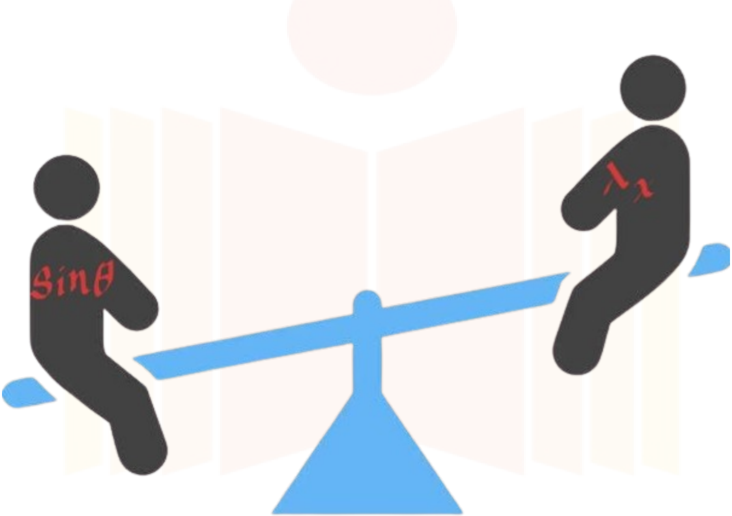


Loop diagram for (g-2) and LFV



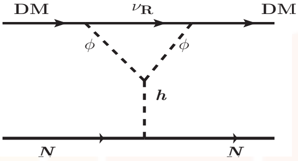
Allowed parameter space from $(g-2)_\mu$ and LFV$(\mu^- \to \gamma e^-)$

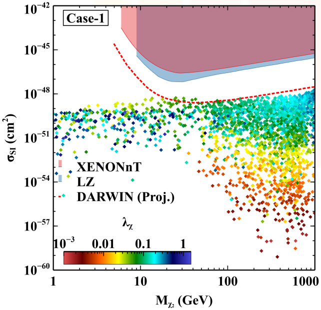
Model



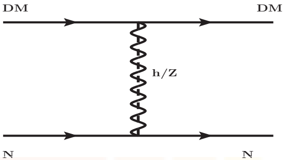
Trade-off between λ_χ and $\sin\theta$.

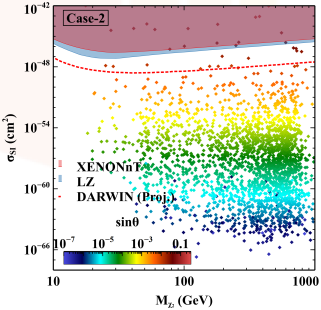
$\sqrt{4\pi} > \lambda_\chi > 10^{-3}$





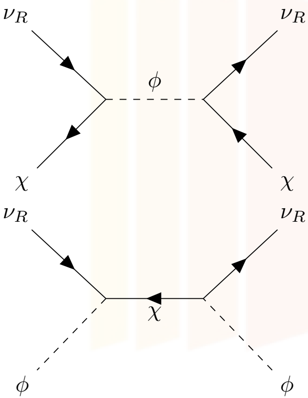
$10^{-3} \geq \lambda_\chi > 10^{-11}$





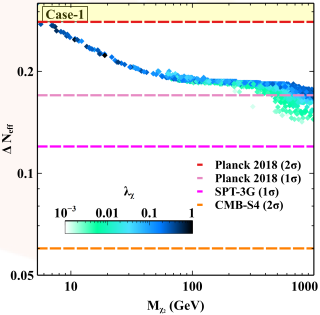
Model

ΔN_{eff} (Thermal)



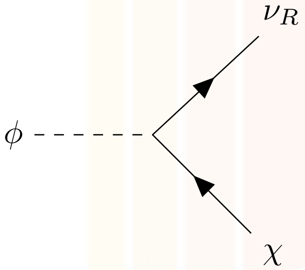
$$\sqrt{4\pi} > \lambda_\chi > 10^{-3}$$

Thermal Production of ν_R



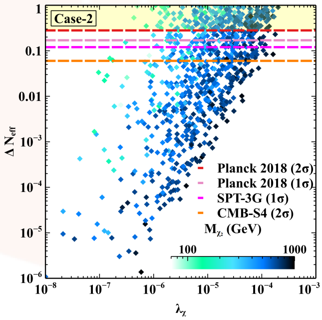
Model

$\Delta N_{\rm eff}$ (Non-thermal)



$$10^{-3} \geq \lambda_\chi > 10^{-11}$$

Non-thermal Production of ν_R



Summary

- We incorporated Dirac neutrino mass in Singlet-Doublet fermionic DM model.
- Analysed our model parameters with muon (g-2) and LFV bounds.
- The extended model gives more freedom on singlet-doublet mass splitting than the usual SD model to satisfy Relic Density.
- Both thermal and non-thermal production of RHN has been done for $\Delta N_{\rm eff}$ analysis.

Thank You !!!