Linking pseudo-Dirac dark matter to radiative neutrino masses in a singlet-doublet scenario

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Based on

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Phys.Rev.D 102 (2020)[arXiv:2001.11325]
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Table of Contents

Motivation

- Singlet fermion dark matter(DM) talks with the standard model(SM) particles by the higher dimensional operator, $\frac{ffHH}{\Lambda}$ and produce over abundance in relic.
- Where doublet fermion DM interacts with the standard model through gauge interaction and give under abundance in relic.
- Can an admixture of doublet and singlet able to give a DM candidate to satisfy correct relic abundance?
- Yes, it gives but constrains the mixing angle very severely which is directly connected to collider search.

Singlet Doublet DM Model and direct detection

Singlet doublet fermionic DM Model

BSM Fields	$SU(3)_C \times SU(2)_L \times U(1)_Y \equiv \mathcal{G}$			Z_2
$\Psi \equiv \begin{pmatrix} \psi^0 \\ \psi^- \end{pmatrix}$	1	2	$-\frac{1}{2}$	$-$
χ	1	1	0	$-$

Table: Charge assignments of fields under the SM gauge symmetry and additional Z_2.

Contd.

- The Lagrangian for fermionic sector and Yukawa interaction

$$\mathcal{L}_f = \underbrace{i\bar{\Psi}\gamma_\mu D^\mu \Psi + i\bar{\chi}\gamma_\mu \partial^\mu \chi}_{\text{kinetic terms}} - \underbrace{M_\Psi \bar{\Psi}\Psi - M_\chi \bar{\chi}\chi}_{\text{mass terms}}$$

$$L_Y = \underbrace{Y\bar{\Psi}\tilde{H}\chi}_{\text{DM interaction}}$$

where, $D^\mu = \partial^\mu - ig\frac{\sigma^a}{2}W^{a\mu} - ig' Y B^\mu$

- The Dirac mass matrix after electroweak symmetry breaking

$$\mathcal{M}_D = \begin{pmatrix} M_\Psi & \frac{Yv}{\sqrt{2}} \\ \frac{Yv}{\sqrt{2}} & M_\chi \end{pmatrix}$$

C. E. Yaguna, Phys. Rev. D92 (2015), J. Fiaschi, M. Klasen, and S. May, JHEP 05 (2019) 015

Contd.

- The new neutral states are

$$\xi_1 = \cos\theta\chi + \sin\theta\psi^0, \qquad \xi_2 = \cos\theta\psi^0 - \sin\theta\chi$$

- The masses are given by

$$M_{\xi_{1,2}} = \frac{M_\chi + M_\Psi}{2} \mp \frac{1}{2}\sqrt{4M_D^2 + M_\chi^2 - 2M_\chi M_\Psi + M_\Psi^2}(\because M_D = \frac{Yv}{\sqrt{2}})$$

- The mixing can be expressed as

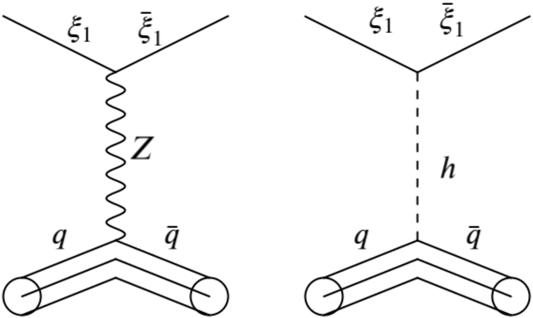
$$\sin 2\theta = \frac{2Yv}{\Delta M}$$

Where $\Delta M = M_\Psi - M_\chi \approx M_{\xi_2} - M_{\xi_1}$ for small Y.

- DM interaction with Z boson and Higgs for DD

$$\mathcal{L} \supset \bar{\Psi} D^{\mu} \Psi + Y \bar{\Psi} \tilde{H} \chi$$
$$\supset \frac{g}{2\cos\theta_W} \sin^2\theta \bar{\xi}_1 \gamma^{\mu} Z_{\mu} \xi_1 + \frac{Y}{\sqrt{2}} \sin\theta\cos\theta h \bar{\xi}_1 \xi_1$$

- The processes contributing to DD are



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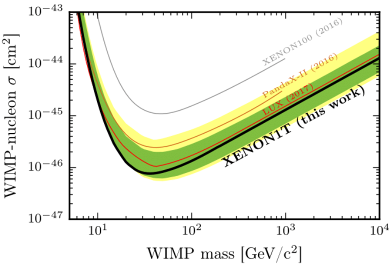
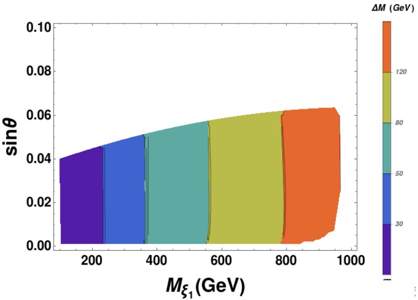
- Direct detection experimental bound on DM-nucleon cross-section.



- Projection of DD bound on $\sin\theta$ and M_{ξ_1} plane, satisfying relic density constraint.

$\Omega h^2 = 0.1206 \pm 0.0021$



Pseudo Dirac Nature and It's consequences

Pseudo Dirac DM in Singlet Doublet Model

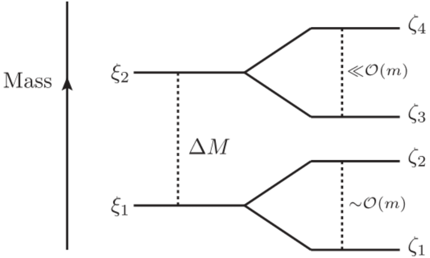
- In presence of Majorana mass term Lagrangian looks like

$$\mathcal{L} \supset -(M_\Psi \bar{\Psi}\Psi + M_\chi \bar{\chi}\chi + Y\bar{\Psi}\tilde{H}\chi) - \frac{m_{\chi_L}}{2}\bar{\chi}^c P_L \chi - \frac{m_{\chi_R}}{2}\bar{\chi}^c P_R \chi$$

$$\supset -(M_{\xi_1}\bar{\xi_1}\xi_1 + M_{\xi_2}\bar{\xi_2}\xi_2) - \cos^2\theta(\frac{m_{\chi_L}}{2}\bar{\xi_1}^c P_L \xi_1 + \frac{m_{\chi_R}}{2}\bar{\xi_1}^c P_R \xi_1)$$

$$-\sin^2\theta(\frac{m_{\chi_L}}{2}\bar{\xi_2}^c P_L \xi_2 + \frac{m_{\chi_R}}{2}\bar{\xi_2}^c P_R \xi_2)$$

- Mass spectra of BSM fields



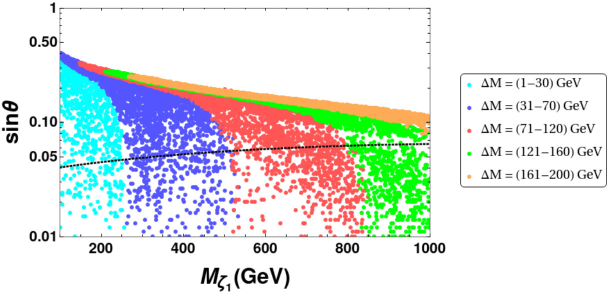
Effects of pseudo Dirac nature on DD constraints

- Let's focus on ξ_1 part

$$\zeta_{1,2} = \zeta^c_{1,2} + \mathcal{O}(\delta), \qquad M_{\zeta_{1,2}} = M_{\xi_1} \mp m + O(\delta^2)$$

where $\delta \equiv (m_{\chi_L} - m_{\chi_R})/M_{\zeta_1} (\ll 1)$ and $m = (m_{\chi_L} + m_{\chi_R})/2$

- At zeroth order in δ the vector current is zero.

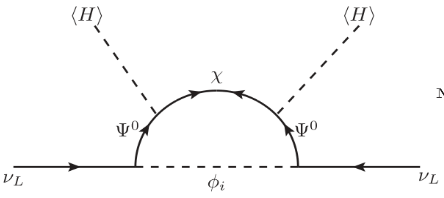


Neutrino mass generation

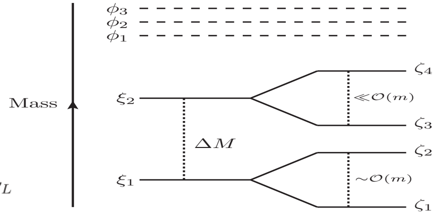
Radiative generation of neutrino mass

- Extended yukawa interaction $\Rightarrow \mathcal{L} \supset Y\bar{\Psi}\tilde{H}\chi + h_{ij}\bar{l}_i\Psi\phi_j$

- Generation of Neutrino mass



- Mass hierarchy of BSM fields



- Neutrino mass $\Rightarrow m_{\nu_{ij}} = h^T_{ki}\Lambda_{kk}h_{jk}$

- Yukawa coupling can be expressed by using Casas-Ibarra parametrization, $h^T = D_{\sqrt{\Lambda^{-1}}}\mathcal{R}D_{\sqrt{m_\nu^{\rm diag}}}U^\dagger$ where $\mathcal{R}$ represents a complex orthogonal matrix,
$D_{\sqrt{m_\nu^{\rm diag}}} = {\rm Diag}(\sqrt{m_{\nu 1}}, \sqrt{m_{\nu_2}}, \sqrt{m_{\nu 3}}), D_{\sqrt{\Lambda^{-1}}} = {\rm Diag}(\sqrt{\Lambda^{-1}_{11}}, \sqrt{\Lambda^{-1}_{22}}, \sqrt{\Lambda^{-1}_{33}})$.

J. A. Casas and A. Ibarra, Nucl. Phys. B618 (2001) 171–204

Conclusion

- Only singlet or only doublet can not be a DM candidate, but an admixture of both can give a viable DM candidate.
- In the singlet doublet DM scenario, the mixing angle is very constrained that can be relaxed in the pseudo-Dirac DM framework.
- The Majorana term that helps to evade the constraints are needed to give Majorana mass of the neutrino.
- One can probe this kind of DM in a collider study.

Thank You