Singlet-doublet Dirac dark matter and neutrino masses

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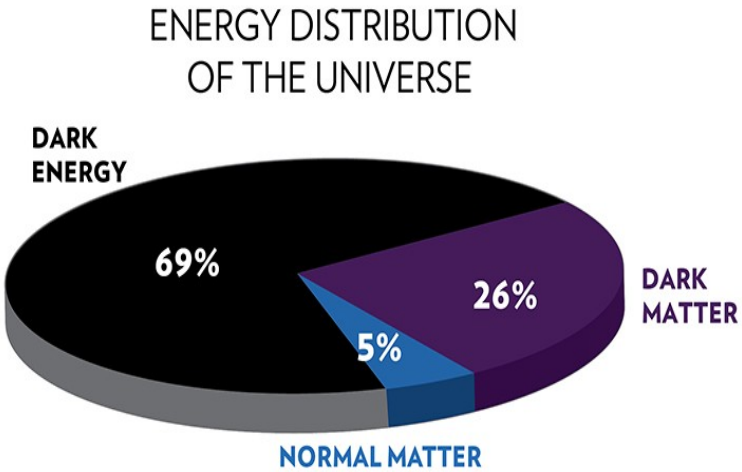
COLCIENCIAS
Ciencia, Tecnología e Innovación

Outline

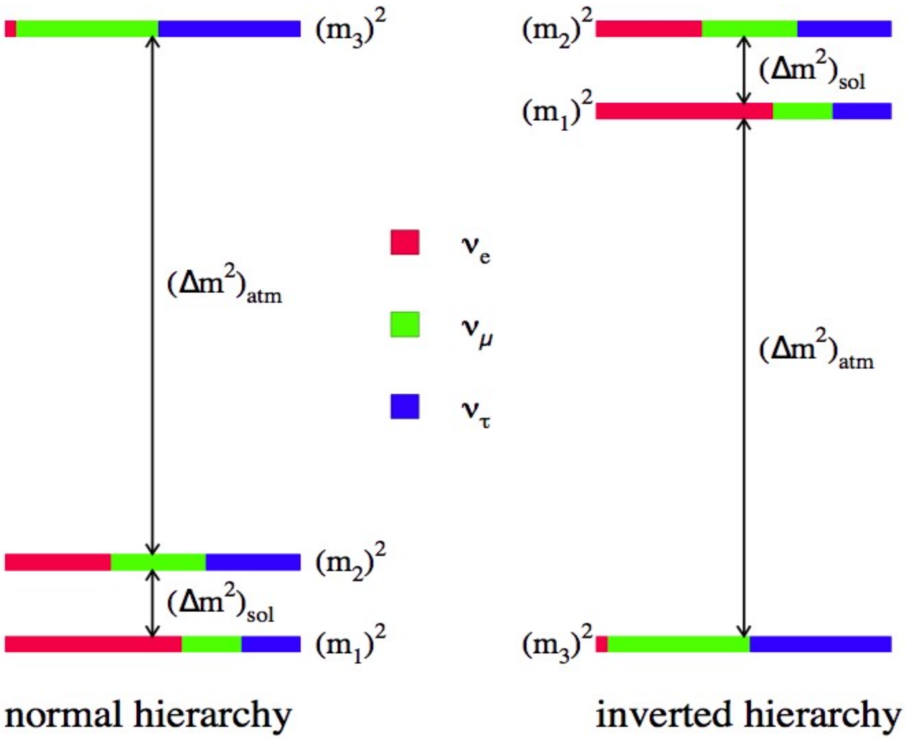
1. Problems

Neutrinos masses

Dark matter



https://chandra.harvard.edu
Plank 2018



ARXIV:1307.5487

Scotogenic models

Ma,
Phys.Rev.D73:077301,2006

Singlet-doublet: Majorana case

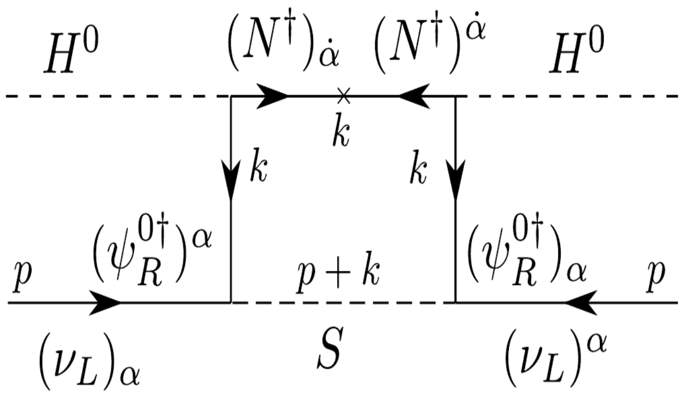
~MSSM ~ Bino-higgsino

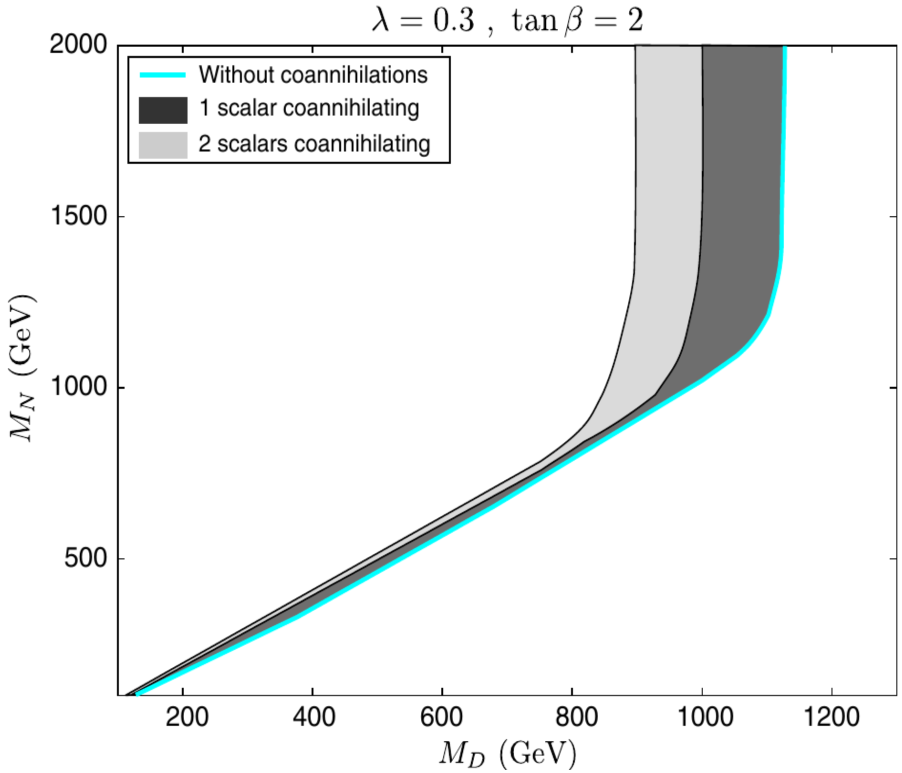
$$\mathcal{L} \supset M_D \epsilon_{ab} R_d^a \widetilde{R}_u^b - \frac{1}{2} M_N N N + \text{h.c}$$

Neutrinos (Weinberg operator)

PRD 43.1566 (1979)

$$\mathcal{L} = \Lambda^{d=5}\, \bar{L}^c \tilde{H}^* H L$$





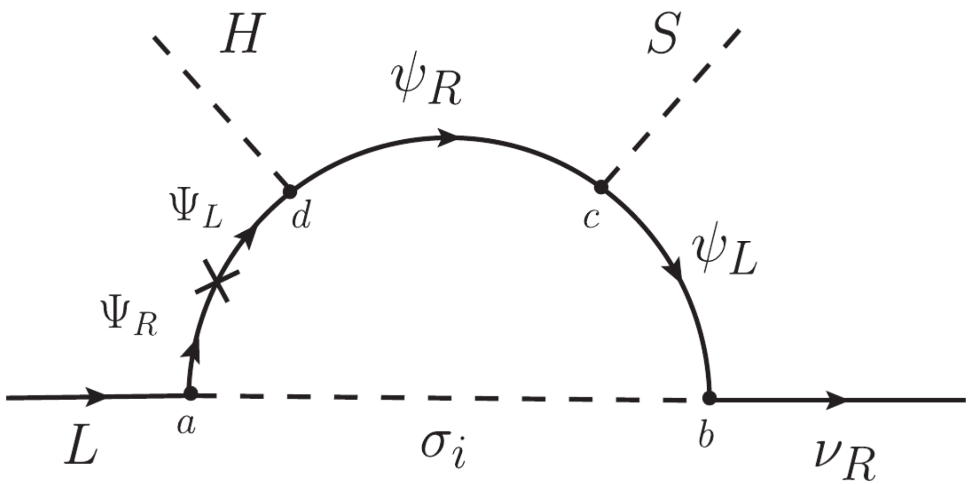
PRD 92, 013005 (2015)

MOCa - 01/10/2019

2. Dirac case

$$\mathcal{L}_5^D = -\frac{g_{\alpha\beta}}{\Lambda}\bar{L}_\alpha \tilde{H} \nu_{R\beta} S + \text{H.c.}$$

PRD 97, 095092 (2018)



$$= \sum_{i=1}^{2} h_b^{\alpha i} \times \Lambda_i \times h_a^{\beta i}$$

$$\mathcal{M}_{\alpha\beta} = (U_{\text{PMNS}})_{\alpha\beta}(m_\nu)_\beta$$

The new model: SDFDM

Particle content

Leptons and scalars fields	$(\mathrm{SU}(2)_L, \mathrm{U}(1)_Y)$	$\mathbb{Z}_2$ (DM)	$\mathbb{Z}_2'$	$U(1)_{B-L}$
$L_\beta = \begin{pmatrix} \nu_L \\ l_L \end{pmatrix}_\beta$	$(2, -1/2)$	$+$	$+$	-1
l_R^α	(1,0)	$+$	$+$	-1
$H = (H^+, \frac{h^0+v}{\sqrt{2}})^T$	$(2, 1/2)$	$+$	$+$	0
S	(1,0)	$+$	$-$	0
σ_i	(1,0)	$-$	$-$	0
ψ_L	(1,0)	$-$	$+$	-1
ψ_R	(1,0)	$-$	$-$	-1
$\Psi = \begin{pmatrix} \Psi^0 \\ \Psi^- \end{pmatrix}$	$(2, -1/2)$	$-$	$-$	-1
ν_R^α	(1,0)	$+$	$-$	-1

L and V

$$\mathcal{L} \supset -M_\Psi \bar{\Psi}\Psi - V(H, \sigma_i, S)$$
$$+ [h_a^{\beta i} \bar{L}_\beta \Psi \sigma_i + h_b^{\alpha i} \overline{\psi_L} \nu_{R\alpha} \sigma_i + h_c \overline{\psi_R} \psi_L S$$
$$+ h_d \bar{\Psi} \tilde{H} \psi_R + \mathrm{H.c.}],$$

➡ Radiative neutrino masses

$$V(H, \sigma_i, S) = -\mu^2 H^\dagger H + \frac{\lambda_1}{2}(H^\dagger H)^2 + \frac{1}{2} m_{\sigma_i}^2 \sigma_i^2$$
$$+ \lambda_i^{\sigma H} H^\dagger H \sigma_i^2 + \frac{\lambda_i^\sigma}{2} \sigma_i^4 + \frac{1}{2} m_S^2 S^2$$
$$+ \lambda_{SH} H^\dagger H S^2 + \lambda^{S\sigma_i} S^2 \sigma_i^2 + \frac{\lambda^S}{2} S^4.$$

➡ Higgs Mixing

- EWPT: STU

$$\mathcal{L} \supset \frac{h_1 \cos\alpha + h_2 \sin\alpha}{v} \times \left(2m_W^2 W_\mu^+ W^{\mu-} + m_Z^2 Z_\mu Z^\mu - \sum_f m_f \bar{f} f \right)$$

- DM particle

$$m_{\psi^0} = \begin{pmatrix} M_\Psi & \frac{h_d v}{\sqrt{2}} \\ 0 & M_N \end{pmatrix}$$

Where: $M_N = h_c v_S / \sqrt{2}$

- Bi-unitary diagonalization

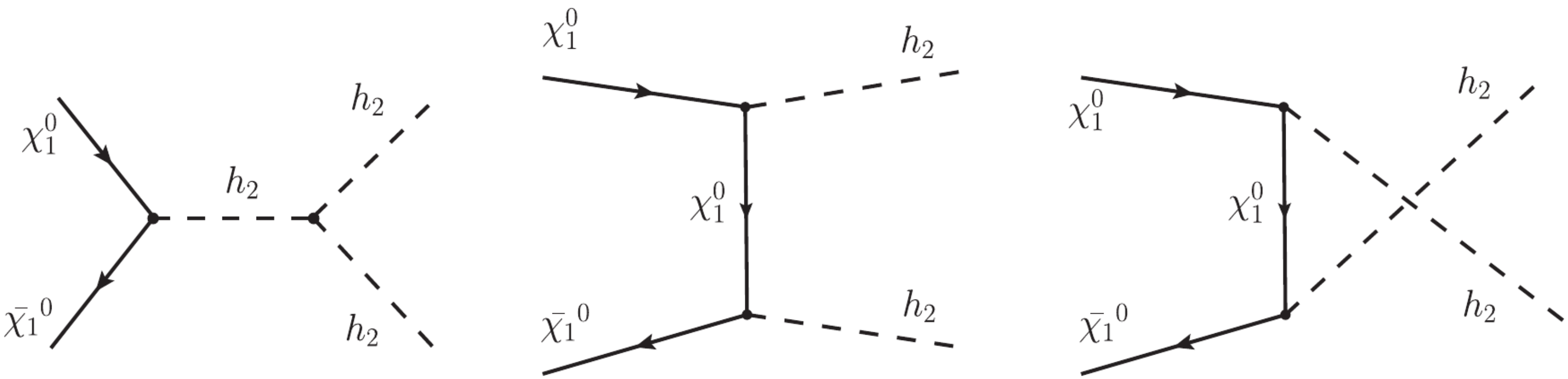
$$V^* m_{\psi^0} U^\dagger = m_{\chi_i^0}^{\text{diag}}$$

→ $\chi_j^0 = (\chi_L, \chi_R^\dagger)_j$

χ_1^0, χ_2^0

Dark matter

New channel $\chi_1^0\bar{\chi}_1^0 \to h_2 h_2$

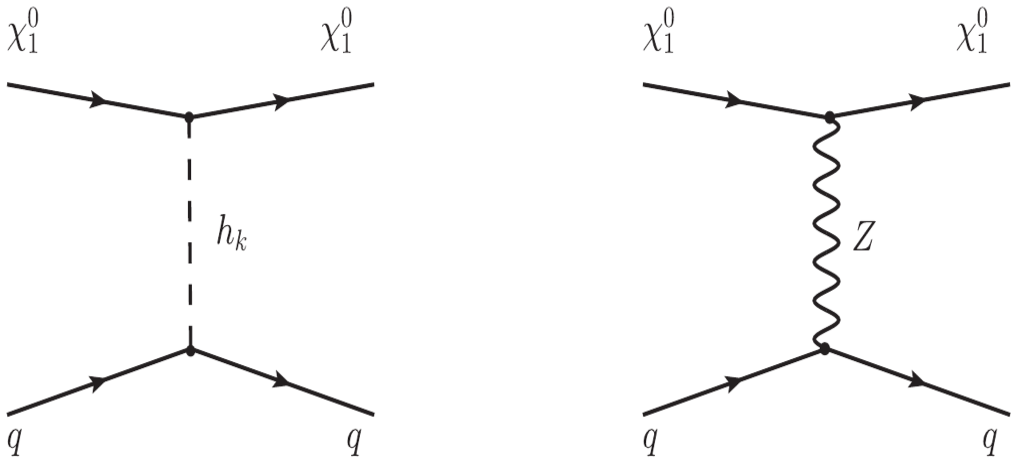


$$\Omega_\chi h^2 \approx 2\frac{1.04\times 10^9 x_f}{M_{\rm Pl}\sqrt{g_*(m_\chi)}(a+3b/x_f)}$$

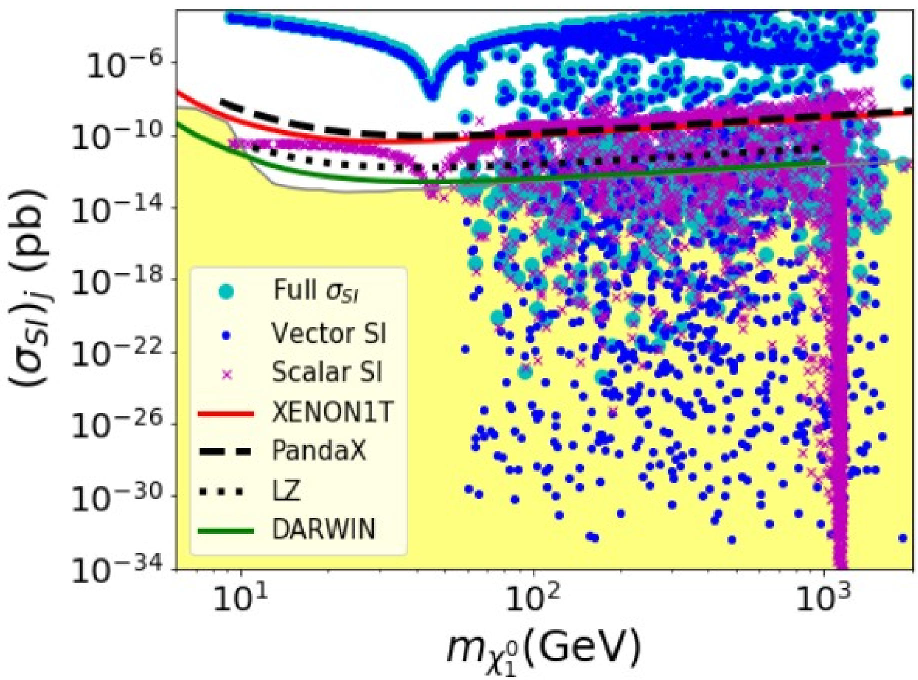
$$\langle\sigma v\rangle \approx a + b v^2 + \mathcal{O}(v^4)$$

➡ MicrOmegas — Comput. Phys. Commun. 176, 367 (2007)

Direct detection



$$\sigma_N^{\rm SI} = \sigma_{N,e}^{\rm SI} + \sigma_{N,o}^{\rm SI}$$



3. Numerical results

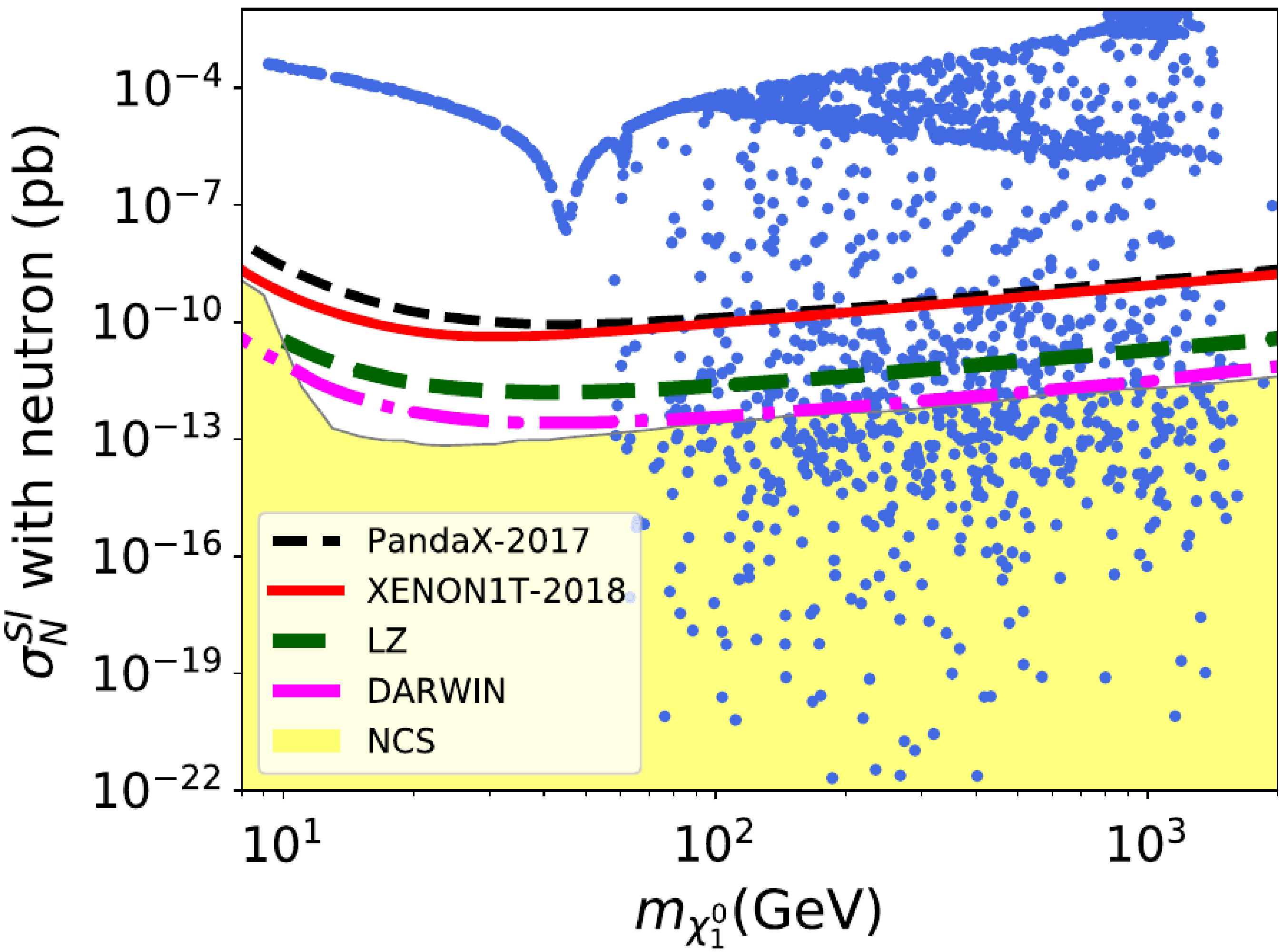
Scan: SHARA + MicrOmegas + SPHENO

- DM
- Neutrino physics
- STU
- Potencial perturbativity
- LFV ...

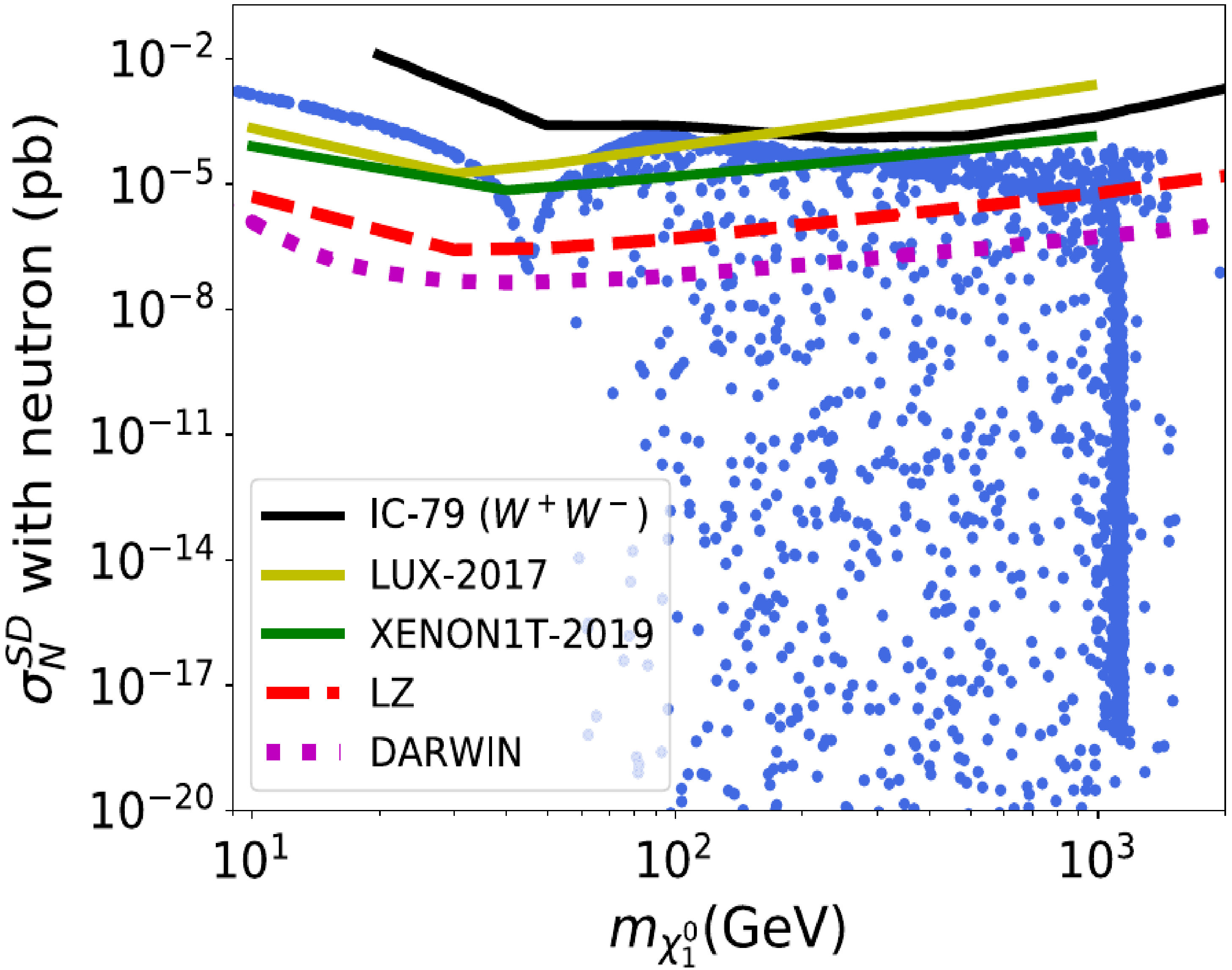
Comput. Phys. Commun. 185, 1773 (2014)

Comput. Phys. Commun. 176, 367 (2007)

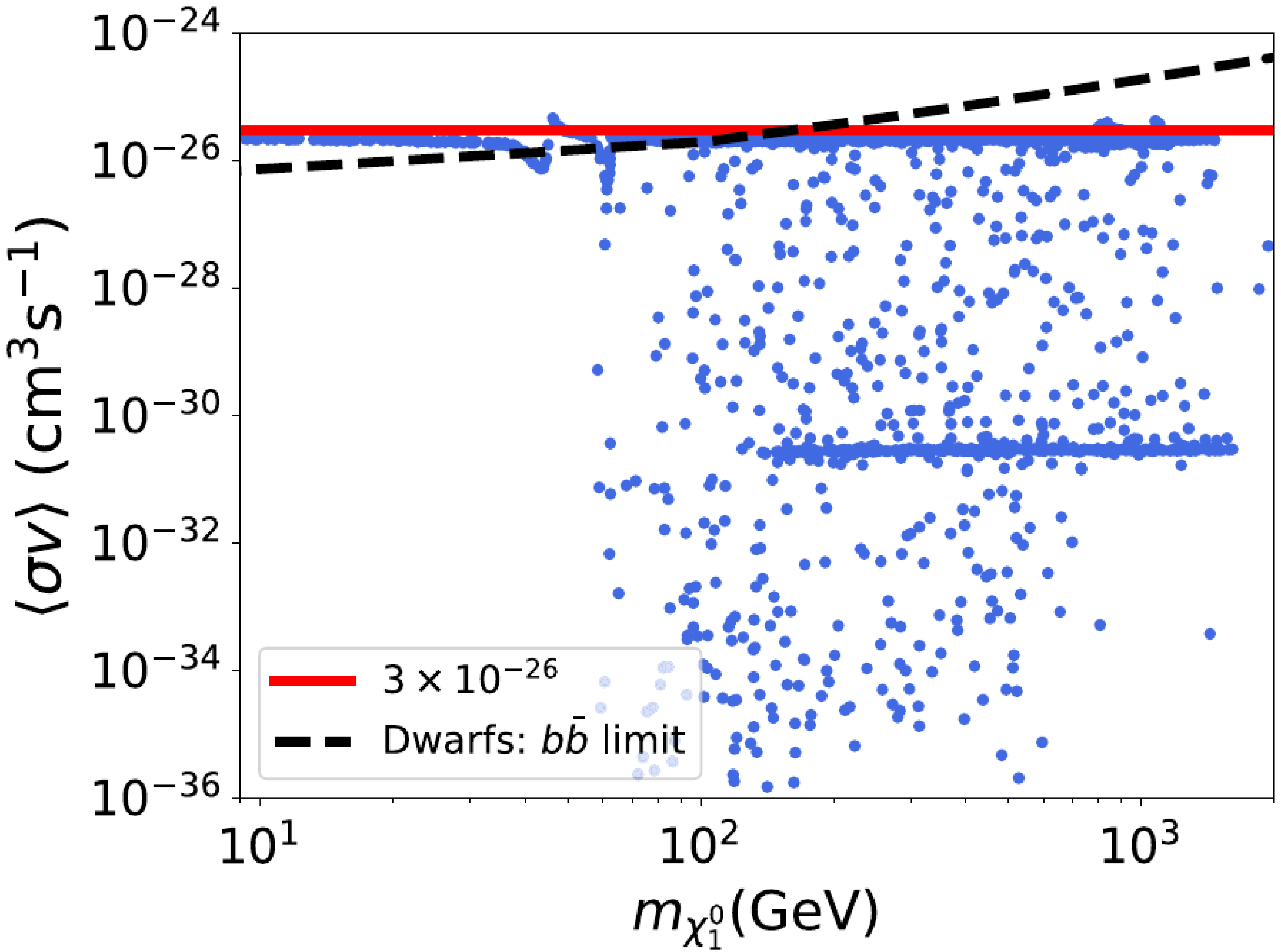
Comput. Phys. Commun. 183, 2458 (2012)



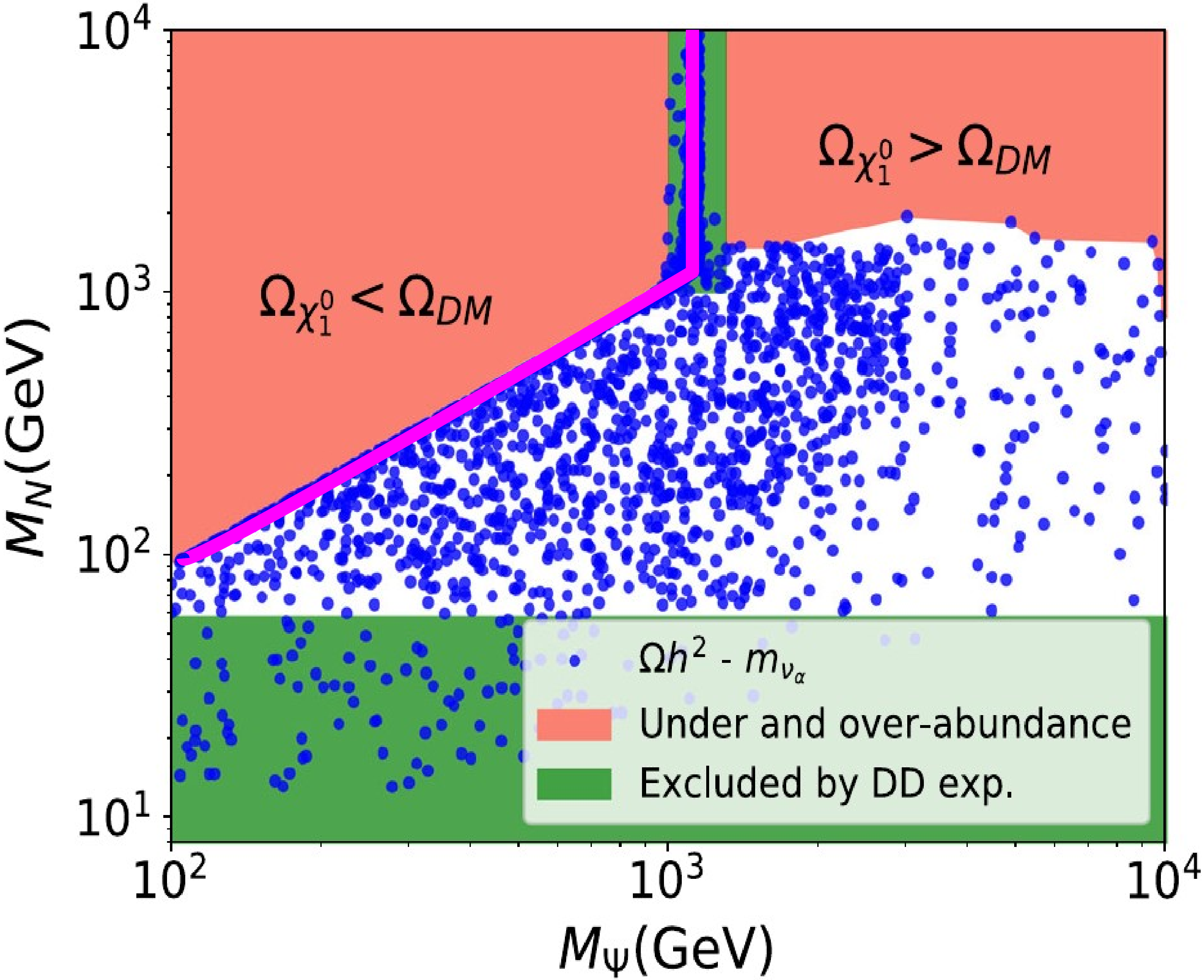
Spin dependent cross-section



$\langle\sigma v\rangle$ cross-section



4. Majorana vs Dirac DM



Conclusions

- We were able to have Dirac DM and Dirac neutrinos in the SDFDM model.
- The new **S** Higgs-scalar plays an important role in order to get the relic abundance and also for the neutrino physics.
- The model has signals for direct-indited, LFV …
- The model could be tested in the future by experiments such as DARWIN. J. Cosmol. Astropart. Phys. 11 (2016) 017
- We find that the allowed parameter space of this model is broader than the well-known Majorana dark matter scenario.

Thank you!

Backup

V co-positivity

$$\lambda_1 \geq 0, \qquad \lambda_i^\sigma \geq 0, \qquad \lambda^S \geq 0, \tag{3}$$

$$\frac{\lambda_i^{\sigma H}}{2} + \sqrt{\lambda_1 \lambda_i^\sigma} \geq 0, \quad \frac{\lambda_{SH}}{2} + \sqrt{\lambda_1 \lambda^S} \geq 0, \quad \frac{\lambda^{S\sigma}}{2} + \sqrt{\lambda_i^\sigma \lambda^S} \geq 0, \tag{4}$$

$$\sqrt{\lambda_1 \lambda_i^\sigma \lambda^S} + \frac{\lambda_i^{\sigma H}}{2}\sqrt{\lambda^S} + \frac{\lambda_{SH}}{2}\sqrt{\lambda_i^\sigma} + \frac{\lambda_i^{S\sigma_i}}{2}\sqrt{\lambda_1} + \sqrt{2\left(\frac{\lambda_i^{\sigma H}}{2} + \sqrt{\lambda_1 \lambda_i^\sigma}\right)\left(\frac{\lambda_{SH}}{2} + \sqrt{\lambda_1 \lambda^S}\right)\left(\frac{\lambda^{S\sigma_i}}{2} + \sqrt{\lambda_i^\sigma \lambda^S}\right)} \geq 0. \tag{5}$$

Neutrino matrix

$$\mathcal{M}_{\alpha\beta} = \sum_{i=1}^{2}\sum_{j=1}^{2} \frac{U_{j1}V_{j2}}{16\pi^2} \times h_b^{\alpha i} h_a^{\beta i} m_{\chi_j^0} \times \left[\frac{m_{\chi_j^0}^2 \ln(m_{\chi_j^0}^2) - m_{\sigma_i}^2 \ln(m_{\sigma_i}^2)}{(m_{\chi_j^0}^2 - m_{\sigma_i}^2)}\right], = \sum_{i=1}^{2} h_b^{\alpha i} \times \Lambda_i \times h_a^{\beta i}, \quad (19)$$

where Λ_i is the loop factor, defined as

$$\Lambda_i = \sum_{j=1}^{2} \frac{U_{j1}V_{j2}}{16\pi^2} \times m_{\chi_j^0} \times \left[\frac{m_{\chi_j^0}^2 \ln(m_{\chi_j^0}^2) - m_{\sigma_i}^2 \ln(m_{\sigma_i}^2)}{(m_{\chi_j^0}^2 - m_{\sigma_i}^2)}\right], = \sum_{j=1}^{2} \frac{U_{j1}V_{j2}}{16\pi^2} \times m_{\chi_j^0} \times \left[\frac{m_{\chi_j^0}^2}{(m_{\chi_j^0}^2 - m_{\sigma_i}^2)} \ln\left(\frac{m_{\chi_j^0}^2}{m_{\sigma_i}^2}\right)\right]. \quad (20)$$

Yukawa couplings

$$h_a^{1i} = 0,$$

$$h_a^{2i,3i} = \text{free},$$

$$h_b^{\alpha 1} = -\frac{1}{\Lambda_1}\left(\frac{h_a^{32} m_{\nu 2} U_{\alpha 2} - h_a^{22} m_{\nu 3} U_{\alpha 3}}{h_a^{22} h_a^{31} - h_a^{21} h_a^{32}}\right),$$

$$h_b^{\alpha 2} = -\frac{1}{\Lambda_2}\left(\frac{h_a^{31} m_{\nu 2} U_{\alpha 2} - h_a^{21} m_{\nu 3} U_{\alpha 3}}{h_a^{22} h_a^{31} - h_a^{21} h_a^{32}}\right).$$

SI cross sections

$$\sigma_{N,o}^{\rm SI} = \frac{G_F^2 m_N^2}{4\pi A^2}(\cos\theta_L^2 + \cos\theta_R^2)^2 \times [(1-4\sin^2\theta_W)Z-(A-Z)]^2,$$

$$\chi_{Lj} = V_{ji}N_{Li} = \begin{pmatrix} \cos\theta_L & \sin\theta_L \\ -\sin\theta_L & \cos\theta_L \end{pmatrix}\begin{pmatrix} \Psi_L^0 \\ \psi_L \end{pmatrix},$$

$$\chi_{Rj}^\dagger = U_{ji}N_{Ri}^\dagger = \begin{pmatrix} \cos\theta_R & \sin\theta_R \\ -\sin\theta_R & \cos\theta_R \end{pmatrix}\begin{pmatrix} (\Psi_R^0)^\dagger \\ (\psi_R)^\dagger \end{pmatrix},$$

$$\sigma_{N,e}^{\rm SI} \approx \frac{m_N^4 f_N^2}{\pi v^2}\left(\frac{g_{\chi_1^0\chi_1^0 h_1}}{m_{h_1}^2} + \frac{g_{\chi_1^0\chi_1^0 h_2}}{m_{h_2}^2}\right)^2,$$

$$g_{\chi_1^0\chi_1^0 h_k} = \frac{-i}{\sqrt{2}}\sin\theta_R(h_d\cos\theta_L Z_{k1}^H + h_c\sin\theta_L Z_{k2}^H).$$

Scan

Parameter	Range
M_Ψ (GeV)	10^2–10^4
m_{σ_i} (GeV)	10^3–2×10^4
v_S (GeV)	10^2–10^5
$\lvert h_c\rvert$, $\lvert h_d\rvert$	10^{-6}–3
$\lambda^{H\sigma_i}$, λ^S, $\lambda^{S\sigma_i}$, λ_{SH}, λ^{σ_i}	10^{-4}–3
$\lvert h_a^{2i,3i}\rvert$	10^{-6}–1

Symbol	$(SU(2)_L, U(1)_Y)$	Z_2	Spin
N	$(1,0)$	$-$	$1/2$
$\widetilde{R}_u,$	$(2,+1/2)$	$-$	$1/2$
R_d	$(2,-1/2)$	$-$	$1/2$

$$\mathcal{L} = \frac{1}{2} c^{d=5}_{\alpha\beta} \left(\overline{L^c_\alpha} \widetilde{H}^*\right)\left(\widetilde{H}^\dagger L_\beta\right) + \text{h.c.}$$