

A Radiative Neutrino Mass Model with Semi-annihilating Boosted Dark Matter

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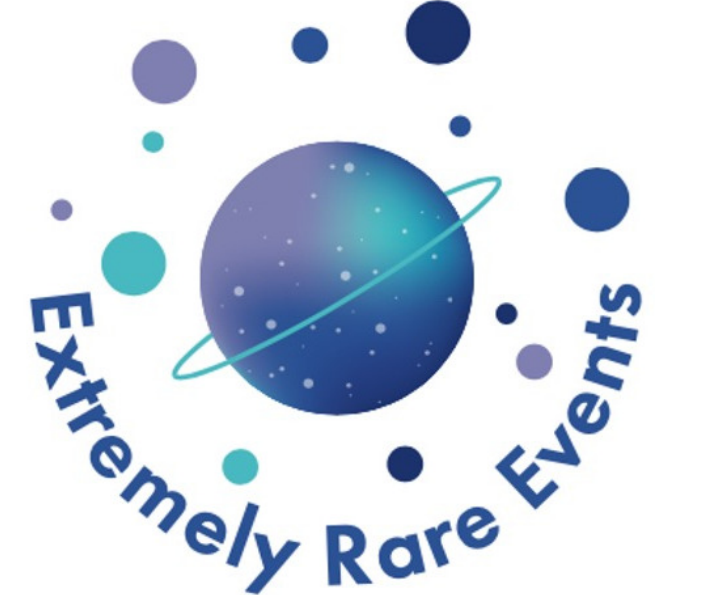
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Based on JHEP **08** 207, [arXiv:2606.02751 [hep-ph]]

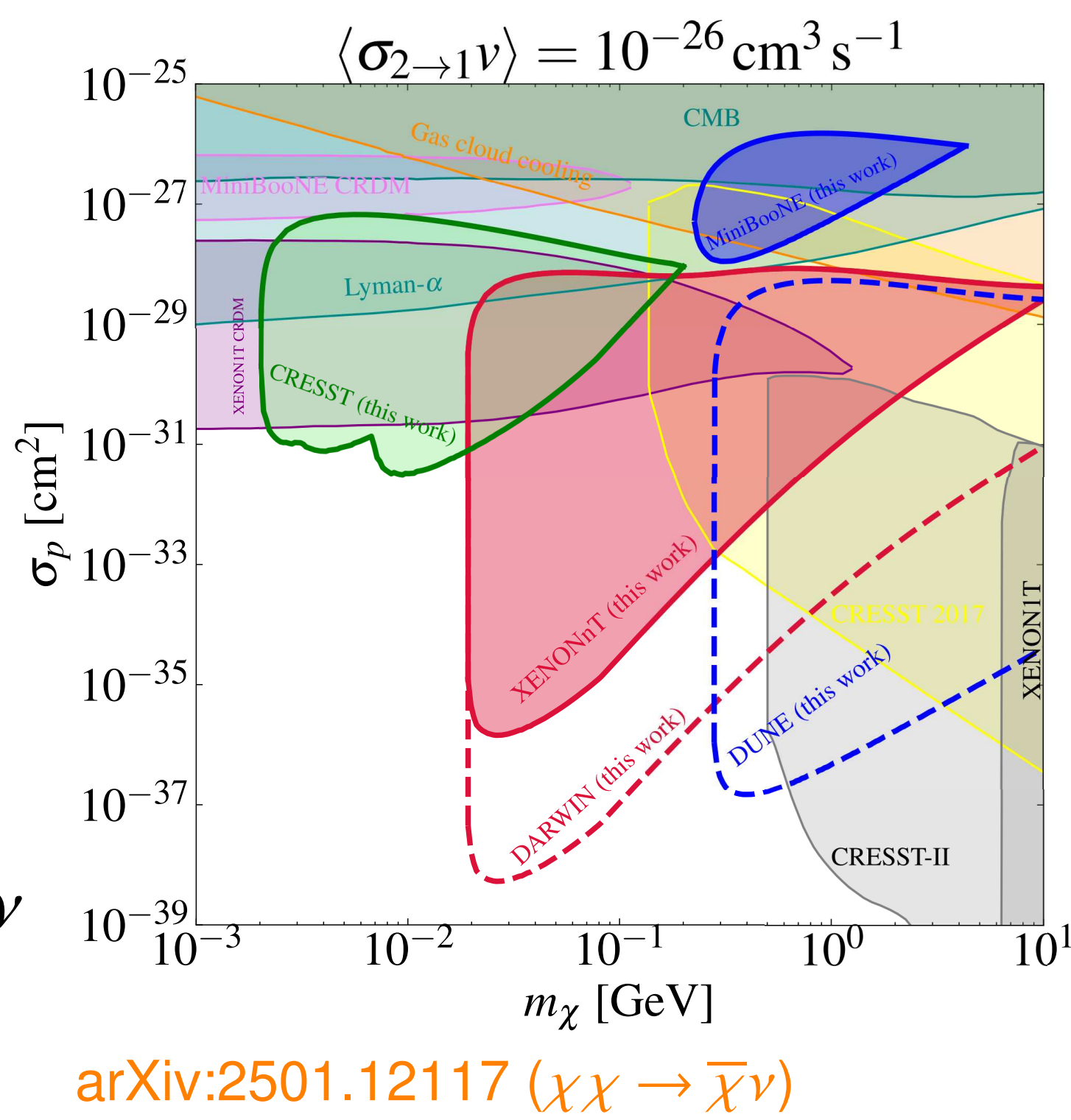
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Introduction

- Thermal freeze-out mechanism via $\chi\chi \rightarrow \text{SM particles}$ is one of well-motivated scenarios for dark matter (DM) production.
- Once dark sectors are non-minimally extended, DM particles can be boosted in final states via $\chi\chi \rightarrow \bar{\chi}\phi$, $\chi\chi\chi \rightarrow \chi\bar{\chi}$ etc.
- Such boosted DM (BDM) is an interesting signal of non minimal dark sectors.
- $\sigma_p \gtrsim O(10^{-38}) \text{ cm}^2$ is needed for BDM detection ($\chi\chi \rightarrow \bar{\chi}\nu$).
- Question: How can we build a concrete model?**
- Possible ways:
Radiative ν mass models
 $\Rightarrow$ coupling between DM and ν
 $\Rightarrow$ Natural to obtain $\chi\chi \rightarrow \bar{\chi}\nu$
(Boost factor: $E_\chi/m_\chi = 1.25$)



Model

	L_L	e_R^c	ψ_L	ψ_R^c	H	Σ	η	χ
$SU(2)_L$	2	1	1	1	2	1	2	1
$U(1)_Y$	$-1/2$	1	0	0	$1/2$	0	$1/2$	0
$U(1)_L$	1	-1	$-1/3$	$-5/3$	0	2	$2/3$	$2/3$
Residual $\mathbb{Z}_3$	0	0	1	-1	0	0	1	1
Spin	$1/2$	$1/2$	$1/2$	$1/2$	0	0	0	0

New

New

$$\mathcal{L} \supset -(y_\nu)_{i\alpha} \eta \bar{\psi}_i P_L L_\alpha - \frac{(y_L)_{ij}}{2} \chi \bar{\psi}_i^c P_L \psi_j - (y_\Sigma)_i \Sigma \bar{\psi}_i P_L \psi_i + \text{h.c.}$$

$$\mathcal{V} \supset \tilde{\mu}_\chi (H^\dagger \eta) \chi^\dagger + \frac{\tilde{\lambda}_\chi}{3!} \Sigma^\dagger \chi^3 + \text{h.c.}$$

- Mass eigenstates: (s, h) and $(\varphi, \tilde{\varphi})$

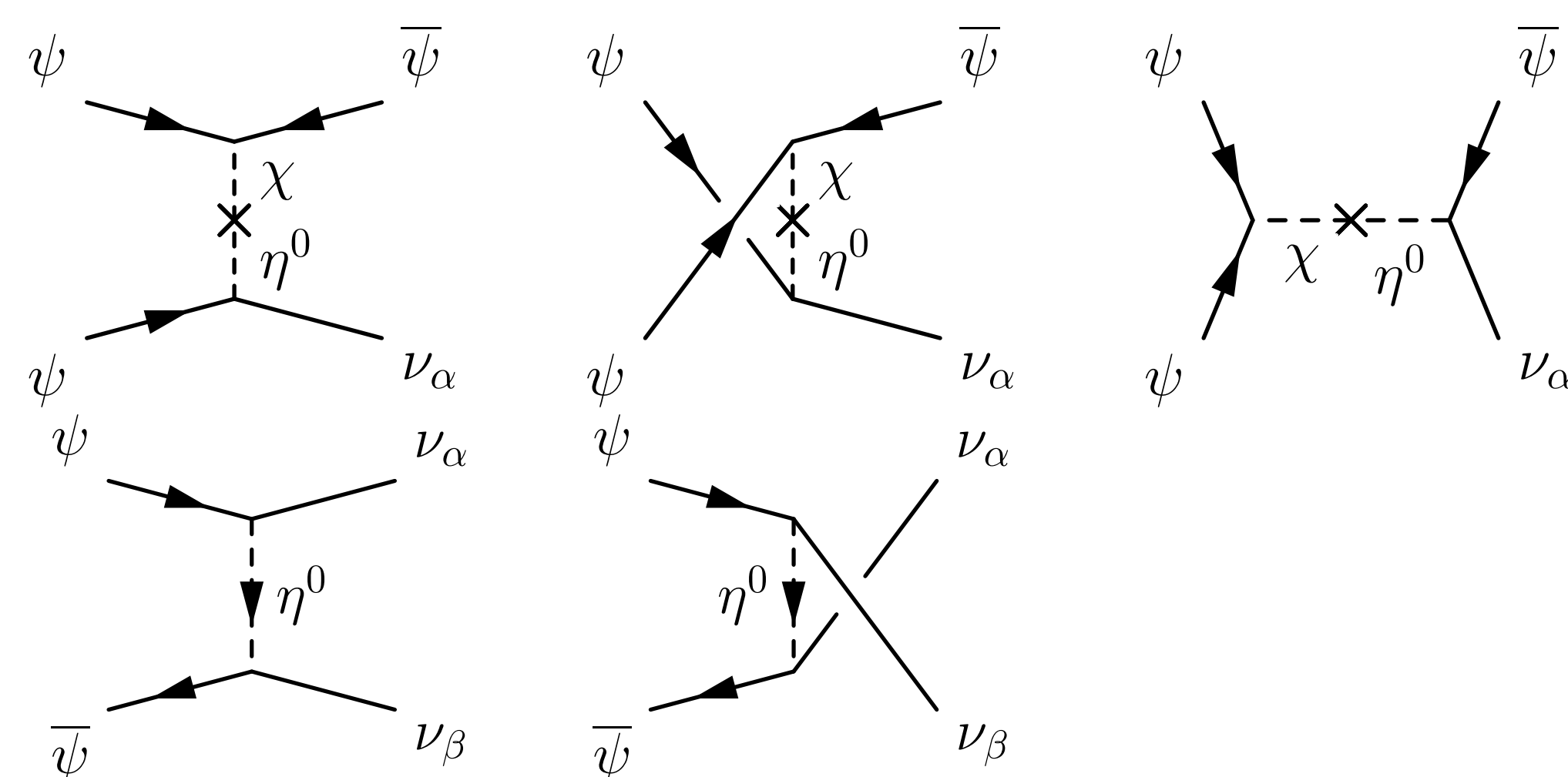
$$\begin{pmatrix} \chi \\ \eta^0 \end{pmatrix} = \begin{pmatrix} \cos \alpha & -\sin \alpha \\ \sin \alpha & \cos \alpha \end{pmatrix} \begin{pmatrix} \varphi \\ \tilde{\varphi} \end{pmatrix}$$

$$\begin{pmatrix} \sigma \\ h_{\text{SM}} \end{pmatrix} = \begin{pmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{pmatrix} \begin{pmatrix} s \\ h \end{pmatrix}$$

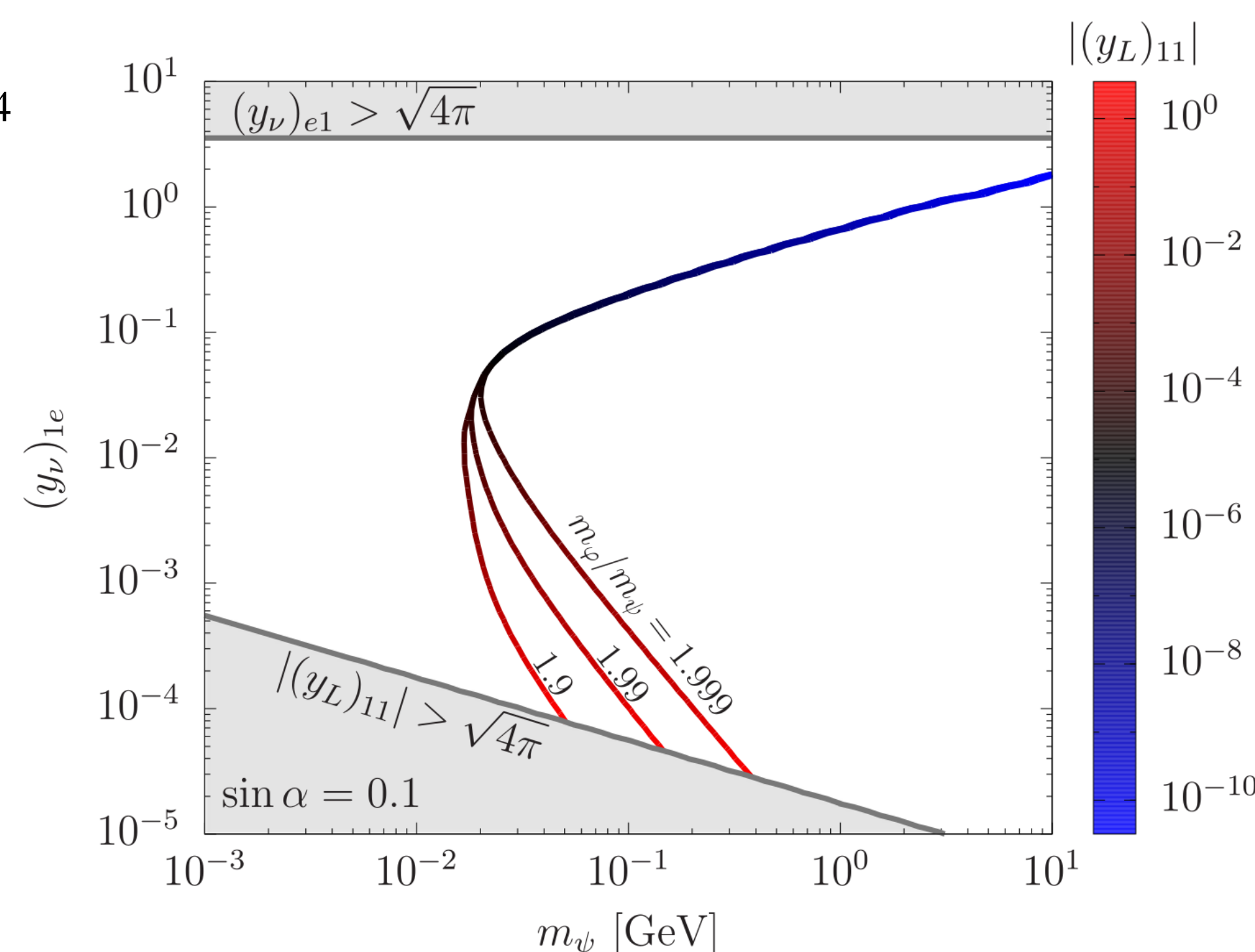
$$m_\nu \sim \frac{y_\nu^T y_L y_\nu}{(4\pi)^4} \sin^2 2\alpha \tilde{\lambda}_\chi \langle \Sigma \rangle$$

Constraints and thermal relic abundance of DM

- Constraints: cLFV, EWPT, Higgs mixing $\sin \theta$
 $\Rightarrow$ diagonal y_ν , $m_\varphi \ll m_{\tilde{\varphi}} \approx m_{\eta^\pm}$, $10^{-5} \lesssim \sin \theta \lesssim 10^{-4}$
- Mass hierarchy assumption: $m_s \gtrsim 1.4 m_\psi$
- Two main channels (ψ : DM): $\psi\psi \rightarrow \bar{\psi}\nu$, $\psi\bar{\psi} \rightarrow \nu\nu$



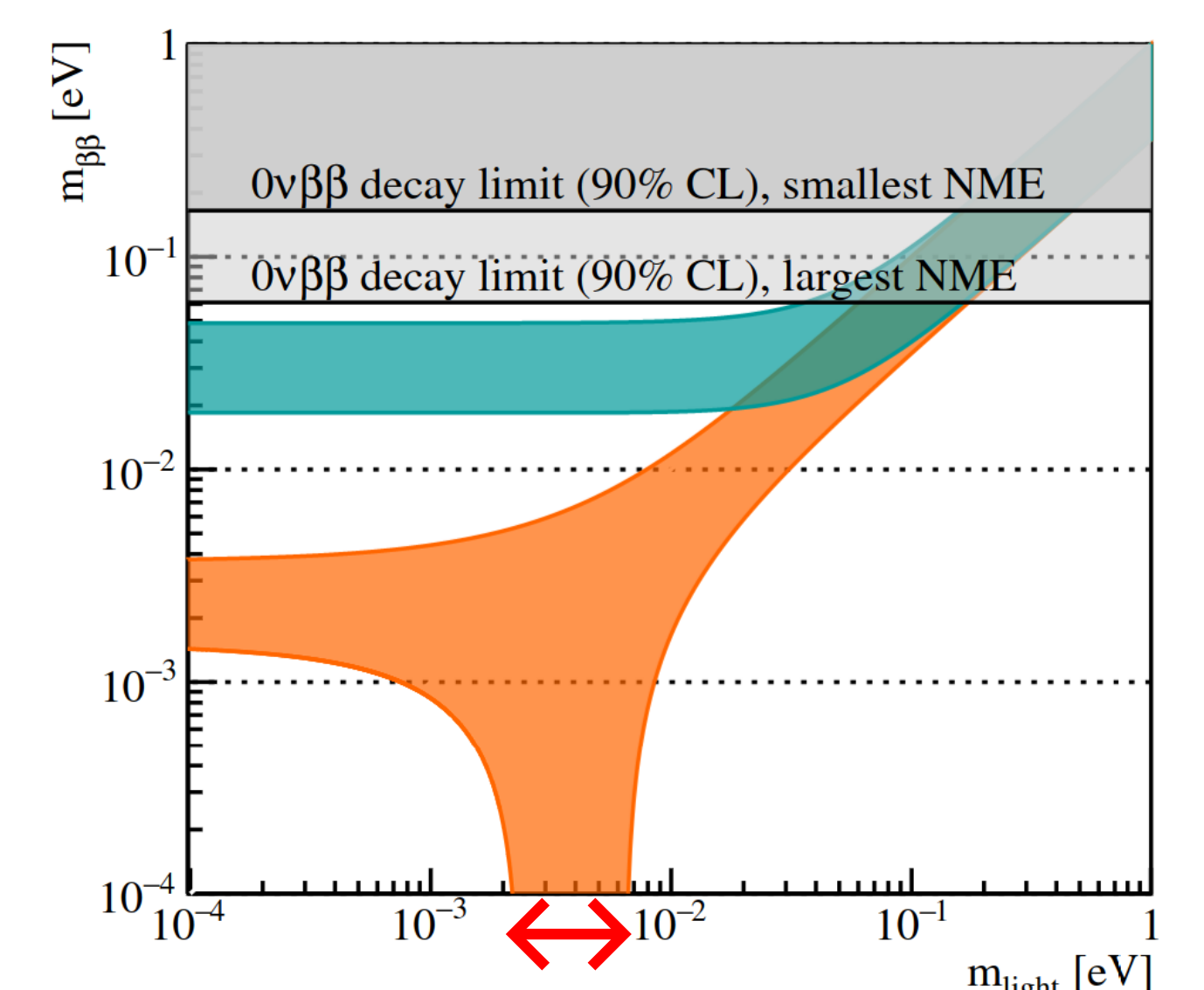
- $\psi\psi \rightarrow \bar{\psi}\nu$ is enhanced if $m_\varphi \approx 2m_\psi$.



Red: $\psi\psi \rightarrow \bar{\psi}\nu$ is dominant Blue: $\psi\bar{\psi} \rightarrow \nu\nu$ is dominant
 $\langle \sigma_{\psi\psi \rightarrow \bar{\psi}\nu} v_{\text{rel}} \rangle \propto (y_\nu)_{1e}^2 (y_L)_{11}^2$ $\langle \sigma_{\psi\bar{\psi} \rightarrow \nu\nu} v_{\text{rel}} \rangle \propto (y_\nu)_{1e}^4$

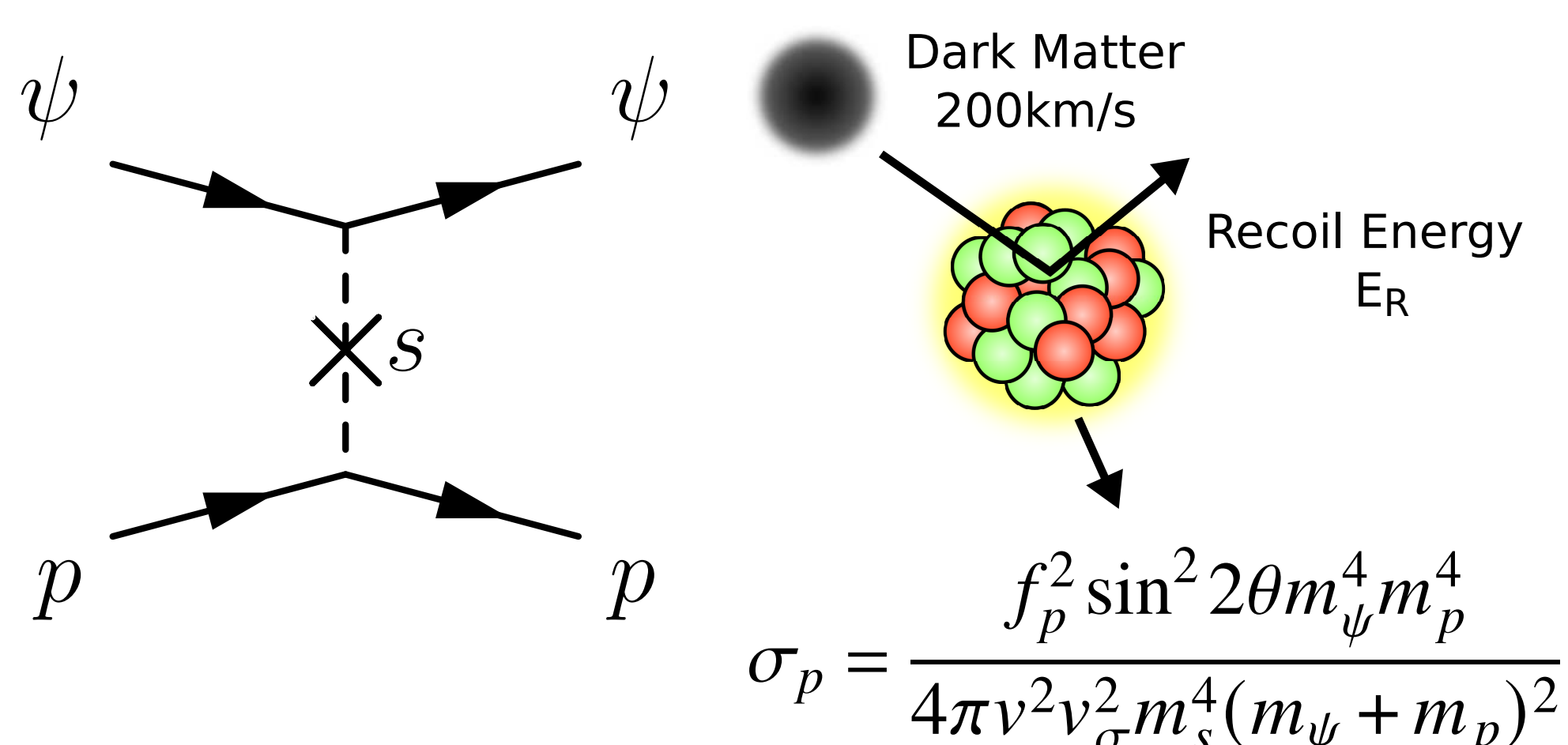
- $(y_L)_{11} \approx 0.2 \left(\frac{0.01}{(y_\nu)_{1e} \sin 2\alpha} \right)^2 \left(\frac{1 \text{ GeV}}{\tilde{\lambda}_\chi \langle \Sigma \rangle} \right) \left(\frac{0.1}{\text{loop } t} \right) \left(\frac{(m_\nu)_{ee}}{10^{-2} \text{ eV}} \right)$ through radiative ν masses

- $2 \times 10^{-3} \text{ eV} \lesssim (m_\nu)_{\text{highest}} \lesssim 7 \times 10^{-3} \text{ eV}$ for NO



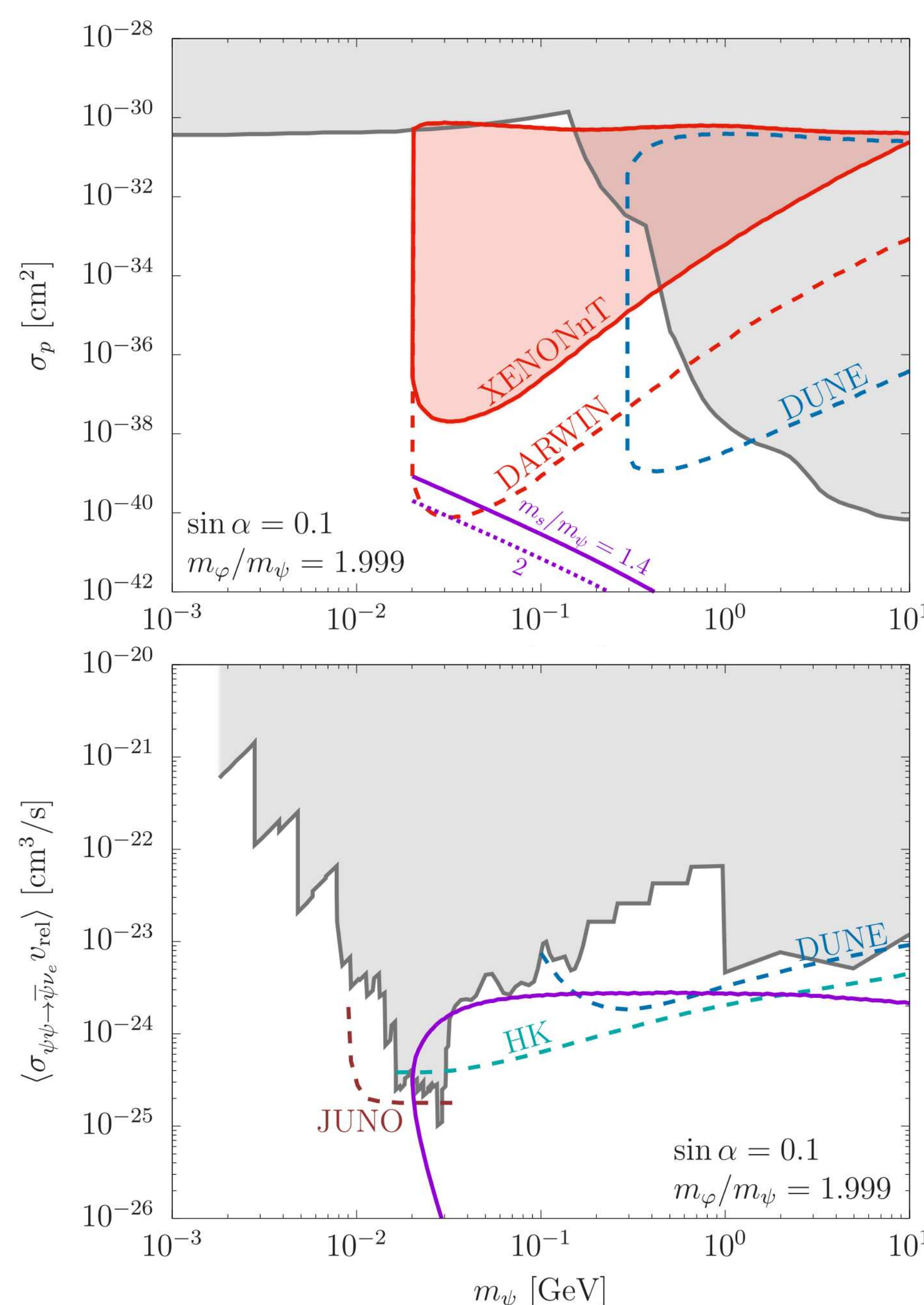
arXiv:2202.01787

Boosted DM and monochromatic neutrinos through $\psi\psi \rightarrow \bar{\psi}\nu$



$$\sigma_p = \frac{f_p^2 \sin^2 2\theta m_\psi^4 m_p^4}{4\pi v^2 v_\sigma^2 m_s^4 (m_\psi + m_p)^2}$$

- $N_{\text{event}} \sim \Phi_{\text{BDM}} \sigma_p N_p t_{\text{exp}}$ where $\Phi_{\text{BDM}} \propto \langle \sigma_{\psi\psi \rightarrow \bar{\psi}\nu} v_{\text{rel}} \rangle$
- s is a mediator for direct detection.
- Parameters: $\sin \theta = 10^{-4}$, $v_\sigma \approx m_\psi$, $m_s \gtrsim 1.4 m_\psi$
- Thermal DM through $\psi\psi \rightarrow \bar{\psi}\nu$ (purple lines)
- $\langle \sigma_{\psi\psi \rightarrow \bar{\psi}\nu} v_{\text{rel}} \rangle \approx 10^{-24} \text{ cm}^3/\text{s}$ is obtained through resonances in our Galaxy.
- BDM can be searched for $20 \text{ MeV} \lesssim m_\psi \lesssim 50 \text{ MeV}$ by DARWIN.
- Monochromatic ν can be search for $30 \text{ MeV} \lesssim m_\psi \lesssim 2 \text{ GeV}$ by Hyper-K.
- Simultaneous detection of both BDM and ν is possible with a $O(0.1) \%$ fine tuning.



Summary

- In this work, we embedded BDM in the framework of a radiative neutrino mass model.
- Small neutrino masses are generated at two-loop level.
- Parameters relevant to DM physics are correlated with neutrino mass generation.
- The relic abundance is determined by the semi-annihilation $\psi\psi \rightarrow \bar{\psi}\nu$ and the standard annihilation $\psi\bar{\psi} \rightarrow \nu\nu$.
- The semi-annihilation can be enhanced by the resonance $m_\psi \approx 2m_s$.
- Only normal ordering can be consistent with BDM detection.
- We can test both signals of BDM and monochromatic neutrinos if $30 \text{ MeV} \lesssim m_\psi \lesssim 50 \text{ MeV}$ with $O(0.1) \%$ parameter tuning.