CP-violating portal to Dark Sectors

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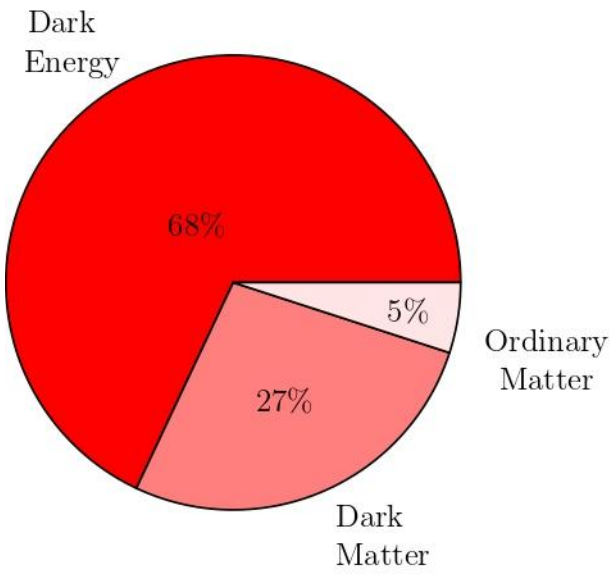
- **Dark Matter** is almost ¼ of the whole energy budget.
- **Dark Matter Production** (usually) requires interaction with SM.
- If DM ∈ DS: **Portals** between the visible and dark sector.



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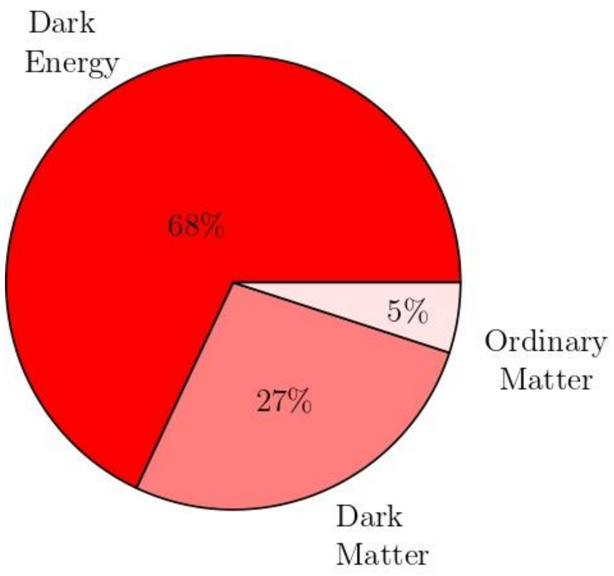

CP-violation:

- The SM of particle physics allows for **CP-violation** (CKM matrix)
- CP-violation in the SM is not enough to explain matter-antimatter asymmetry
- CP-violation in Hidden sectors or **Portals** ?

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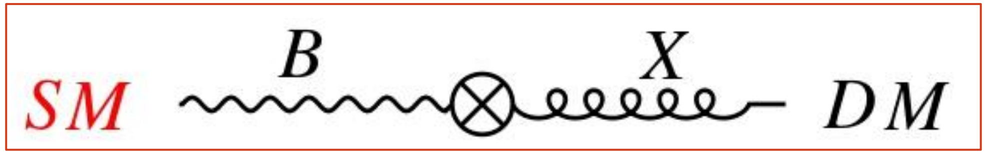
- Additional **U(1) abelian** dark gauge group
- **Kinetic Mixing** at dim 4: $\frac{\epsilon}{2} B^{\mu\nu} X_{\mu\nu}$
- ϵ naturally O(1) but experiments yields ϵ << 1



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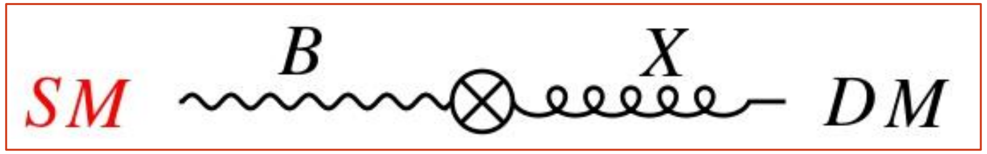
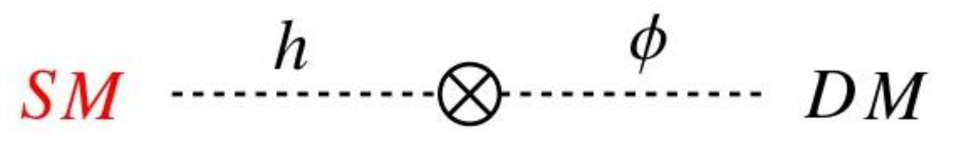


Scalar Mixing:

- Additional **Dark Scalar** neutral under SM
- **Interaction** at renormalizable level: $k\,|H|^2|S|^2$
- $\langle S \rangle \neq 0$ and mixing.



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- Kinetic Mixing parameters **naturally** small
- New source of **CP-violation**

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Expect significant improvements of the current JILAeEDM sensitivity in the coming years!

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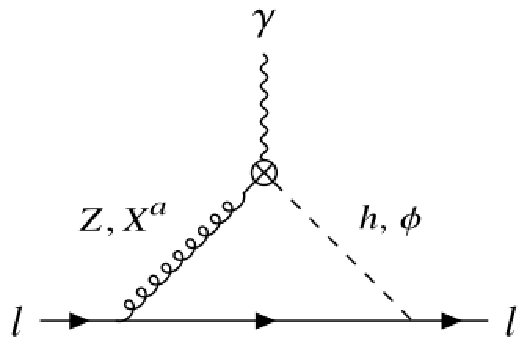

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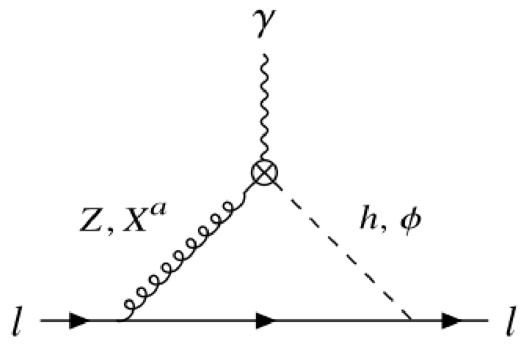

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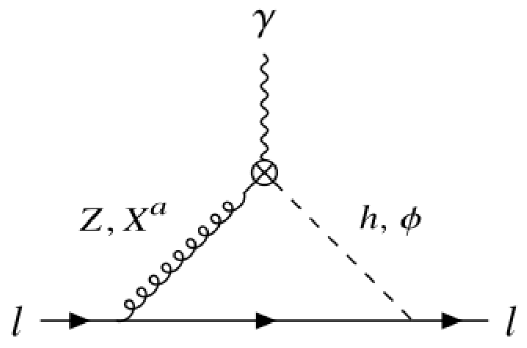

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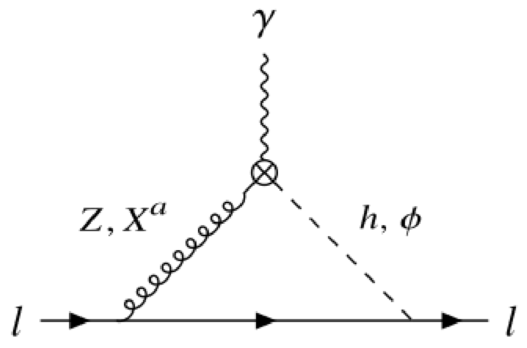

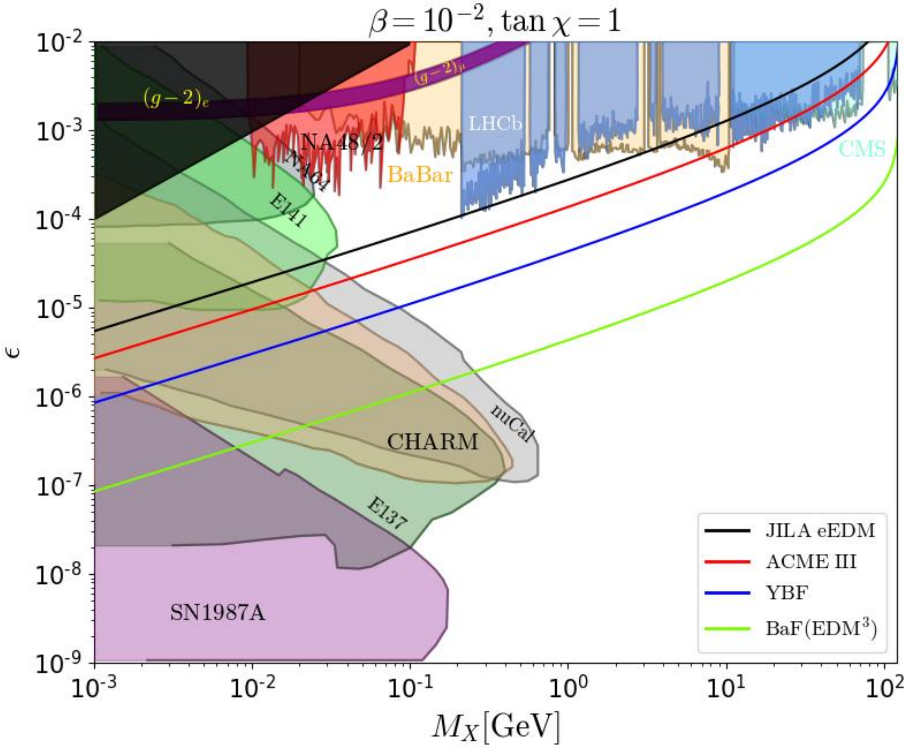

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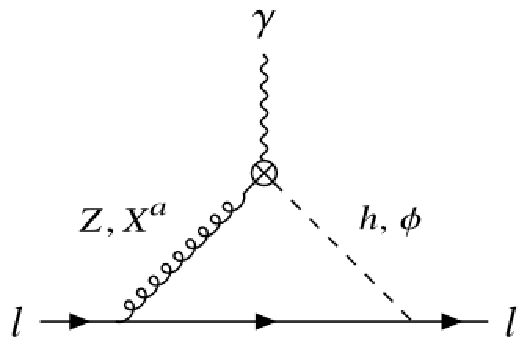

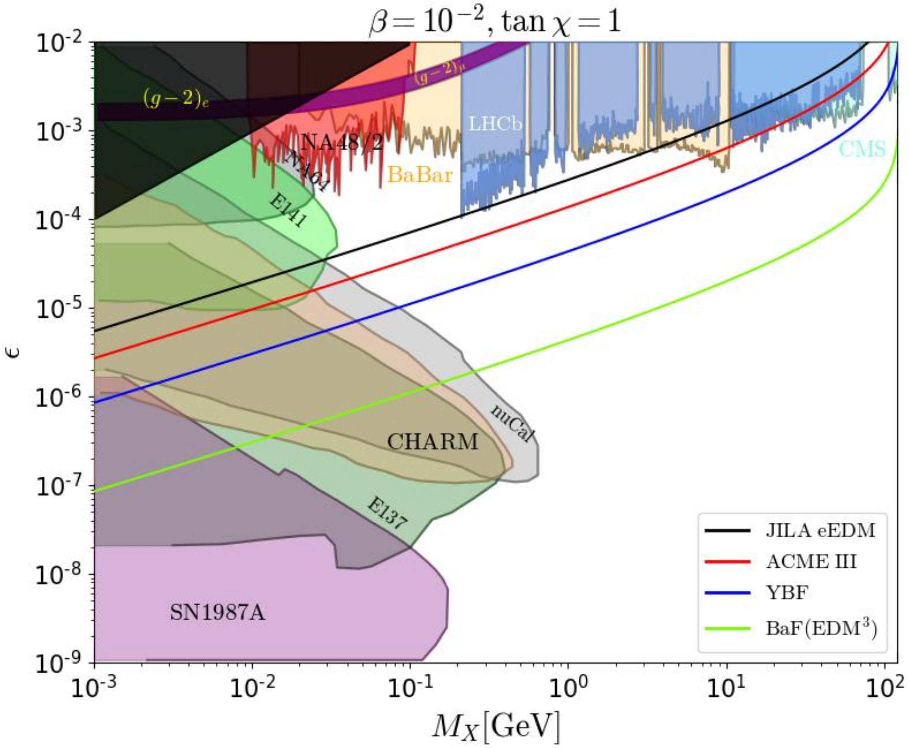

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No DM annihilation →	No I-D bounds
$\Delta m \gtrsim$ 1MeV →	Negligible D-D bounds

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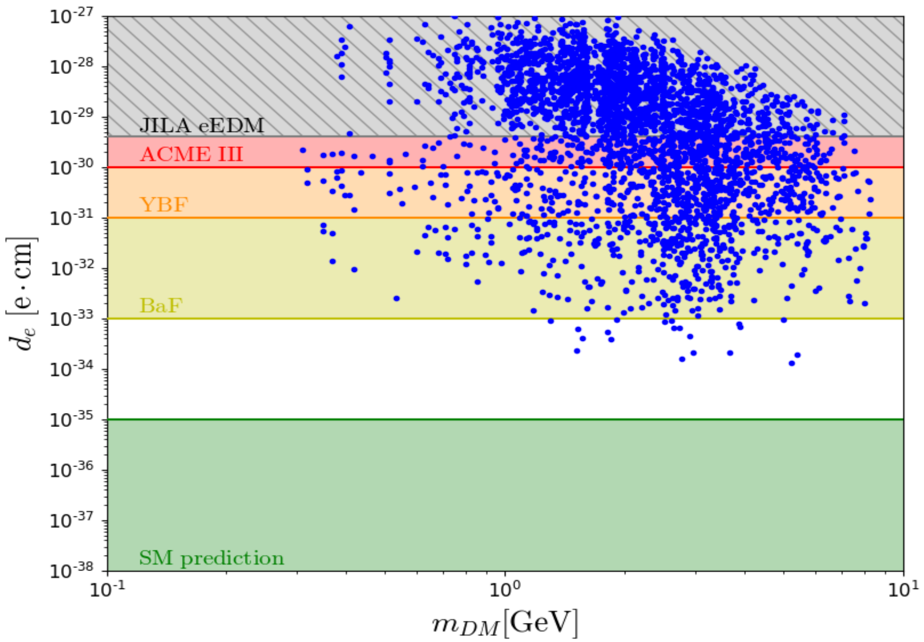

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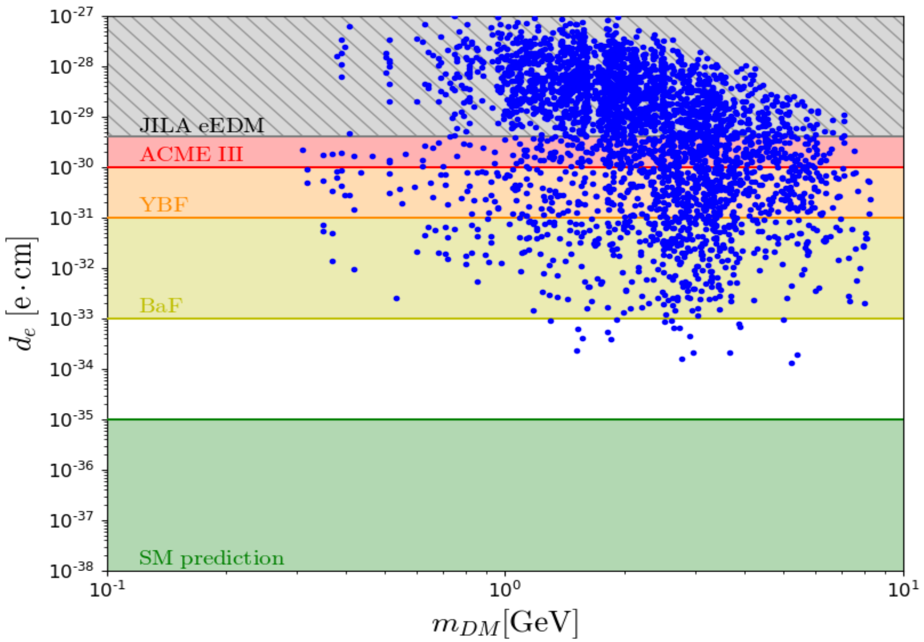

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- Future eEDM sensitivities can probe the model

Summary

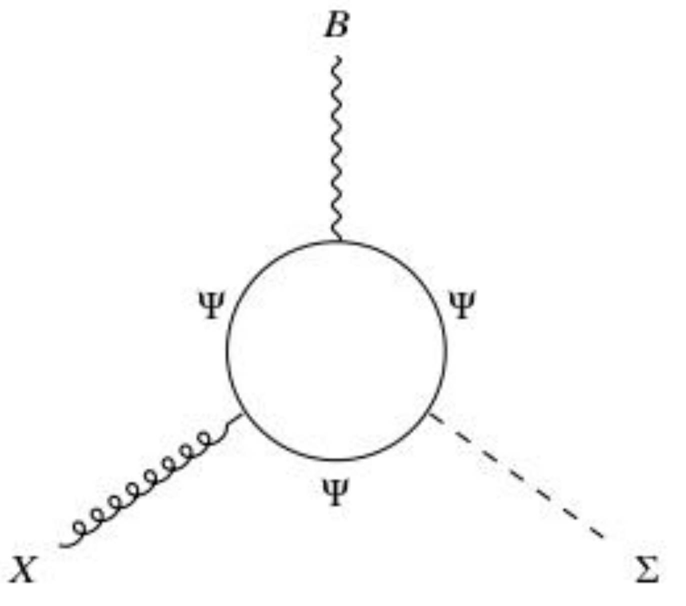
- Non-abelian Dark sector allows for kinetic portals with small ϵ
- Non-abelian Dark sector allows for a CP-violating phase in portals
- Scalar and kinetic mixing + CP-violation signals can be traced in EDMs
- Model of iDM can be probed by future searches for a permanent eEDM!

Thank you for your attention!

BACK UP

UV completion

- **EFTs** call for UV completion
- Heavy vector-like fermion charged under $SU(N) \otimes U(1)_Y$
- Physical phase χ in Yukawa-like scalar couplings $\mathcal{Y}$



UV Lagrangian:

$$\mathcal{L}_\Theta \supset -g_1 Y \bar{\Theta}_i \gamma_\mu \Theta_i B^\mu - g_D \bar{\Theta}_i T^a \gamma_\mu \Theta_i X_a^\mu - M_{ii} \bar{\Theta}_{iR} \Theta_{iL} - \mathcal{Y}_{ij} \bar{\Theta}_{iR} \Sigma^a T^a \Theta_{jL} + \text{h.c.}$$

UV-EFT matching

$$\frac{C}{\Lambda} = \frac{g_D g_1 Y \,\text{Re}[\mathcal{Y}]}{12\pi^2 M}; \qquad \frac{\tilde{C}}{\Lambda} = \frac{g_D g_1 Y \,\text{Im}[\mathcal{Y}]}{16\pi^2 M}$$

$$\tilde{\epsilon} = \frac{3\,\text{Im}[\mathcal{Y}]}{4\,\text{Re}[\mathcal{Y}]}\epsilon \equiv (\tan\chi)\,\epsilon$$

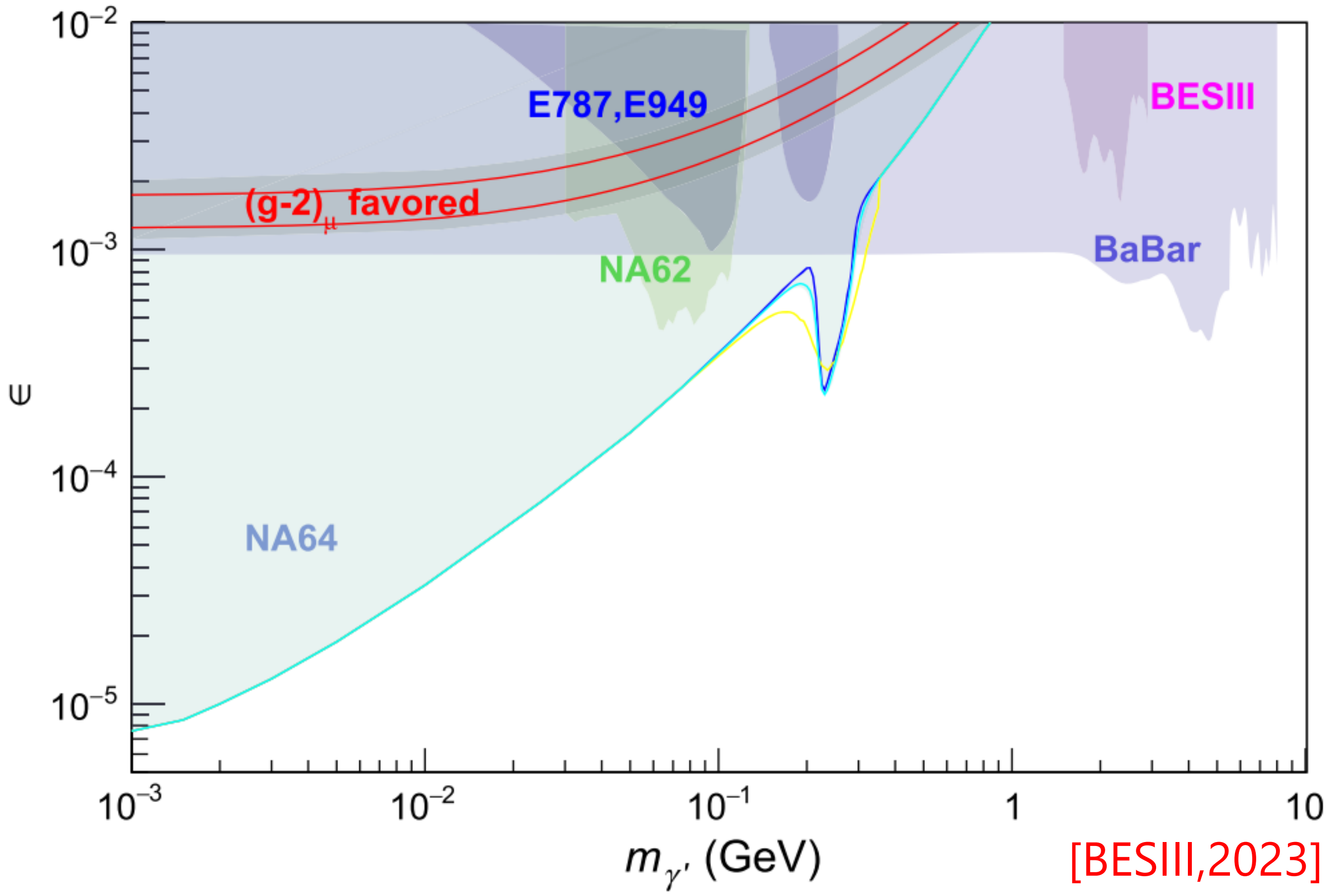
A model for Inelastic Dark Matter

- SU(2) Dark group with matter content:
  - 3 gauge fields X_i^μ
  - 2 scalar fields in the adj. Σ_2^a, Σ_3^a
  - 2 Majorana SU(2) doublet
    - $\chi_L = (\chi_L^1, \chi_L^2)$
    - $\psi_R = (\psi_R^1, \psi_R^2)$
- Mass term:

$$\mathcal{L} \supset -m_D \overline{\chi_L}\psi_R - \sum_{i=1,2} Y_{D,i}\overline{\chi_L}\Sigma_i\psi_R - \sum_{i=1,2} Y_{L,i}\overline{\chi_L^c} i\sigma_2\Sigma_i\chi_L - \sum_{i=1,2} Y_{R,i}\overline{\psi_R^c} i\sigma_2\Sigma_i\psi_R + \text{h.c.}$$
$$- \frac{g_D}{2}\overline{\chi_L}\gamma_\mu\sigma^a X_a^\mu\chi_L - \frac{g_D}{2}\overline{\psi_R}\gamma_\mu\sigma^a X_a^\mu\psi_R. \quad \text{(C.2)}$$

- SU(2) fully broken by: $\langle\Sigma_2\rangle = (0, v_2, 0); \langle\Sigma_3\rangle = (0, 0, v_3)$
- Dirac masses: $M_1 = m_D + vY_1 - vY_2; M_2 = m_D + vY_1 + vY_2$
- Off-diagonal currents with X_2 and X_1 and inelastic dark matter scenario
- X_3 diagonal current suppressed by either small eps or large M_{X_3} .

Laboratory bounds



[BESIII,2023]

$$\sum_f \Gamma(\Psi_H \to \Psi_S f \bar{f}) = \sum_f \frac{4\epsilon^2 \alpha \alpha_D \delta_\Psi^5}{15\pi M_X^4}$$

- Small mass splitting: favoured for DM a and long life time
- $\delta_\Psi > 2m_e$ to avoid too much long lifetime
- X to invisible searches: model independent constraints

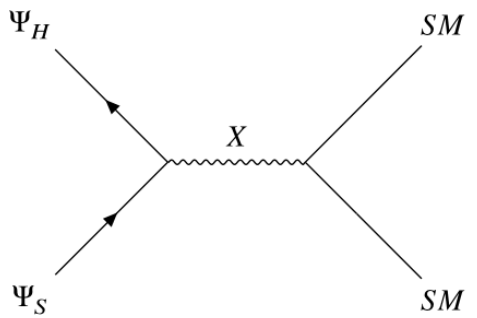
Inelestic DM set up

Scatter plot parameters:

Parameter	Lower limit	Upper limit
$\beta_{1,2}$	10^{-4}	10^{-2}
ϵ	10^{-6}	[102–106]
g_D	10^{-2}	1
$\tan\chi$	10^{-2}	1
v_D	1 GeV	20 GeV
m_ϕ	0.1 GeV	50 GeV

$$\langle \sigma_{eff} v \rangle \sim \frac{\langle \sigma v \rangle}{2} \sim 1.7 \times 10^{-9} \mathrm{GeV}^{-2}$$

Total cross section $\chi\chi \rightarrow SM$



- Random values of parameters of the model and Mχ chosen to fulfill the relation above.
- eEDM computed with the formula slides 5