Isospin-violating dark matter in light of CDMS-Si & LUX

G. Belanger, A. Goudelis, **JCP**, A. Pukhov
arXiv: 1311.0022

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Outline

- Dark matter
- Light dark matter:

  Hints from direct searches?
- IVDM model from a double portal
- Conclusion

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- Dark matter → Sorensen, Tseng, Tandean, Sato, Takanishi …
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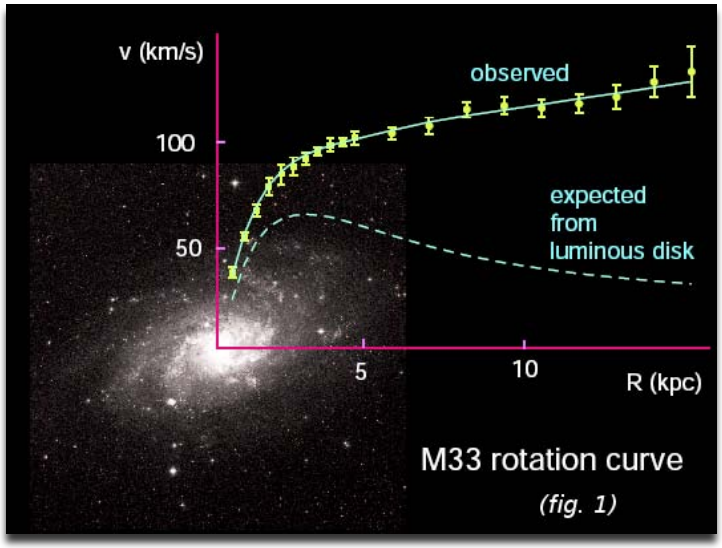
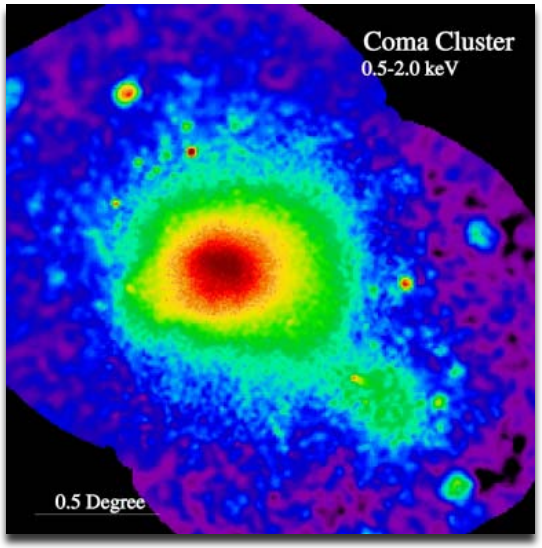
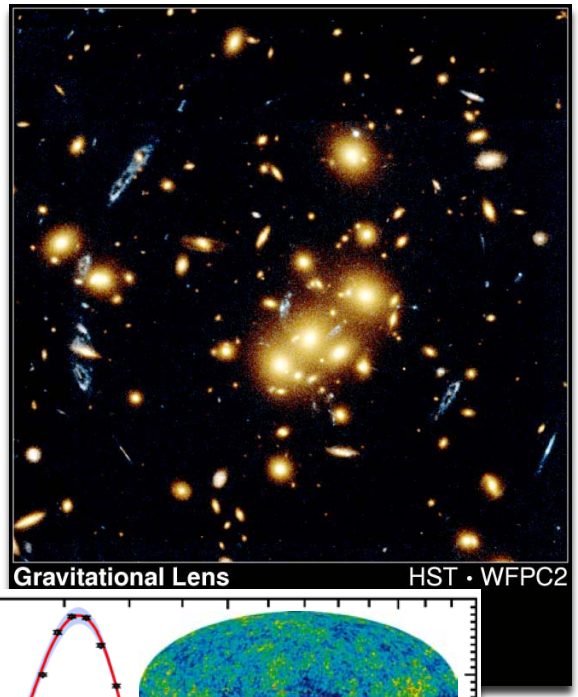
Dark matter

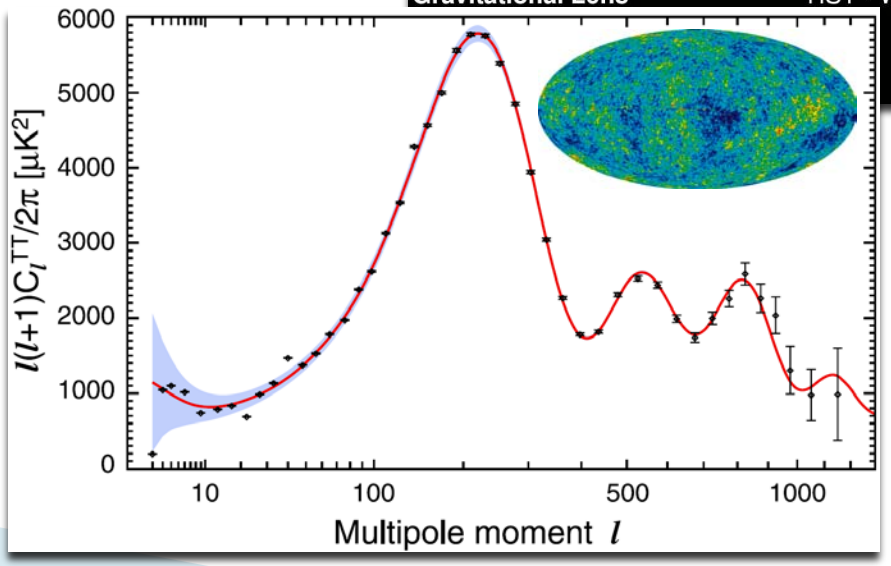
- discovered via gravity

  by Fritz Zwicky (1933) & Vera Rubin (1970)



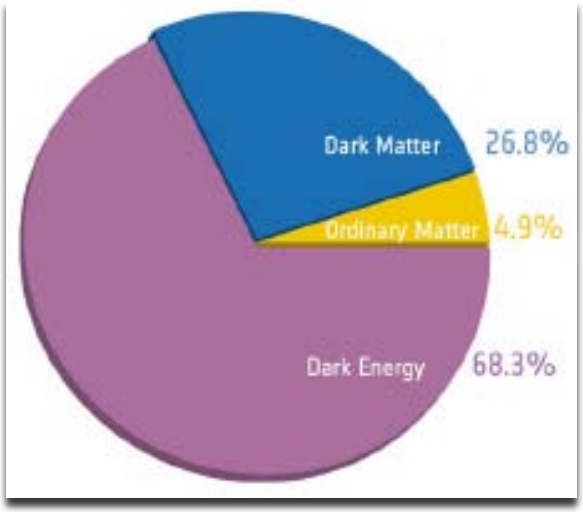


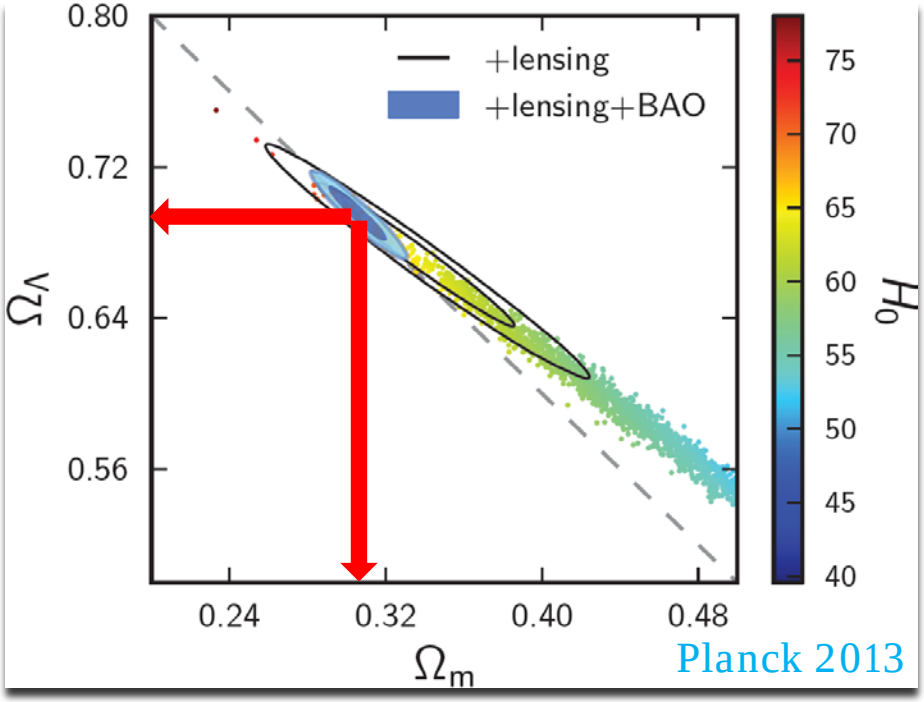




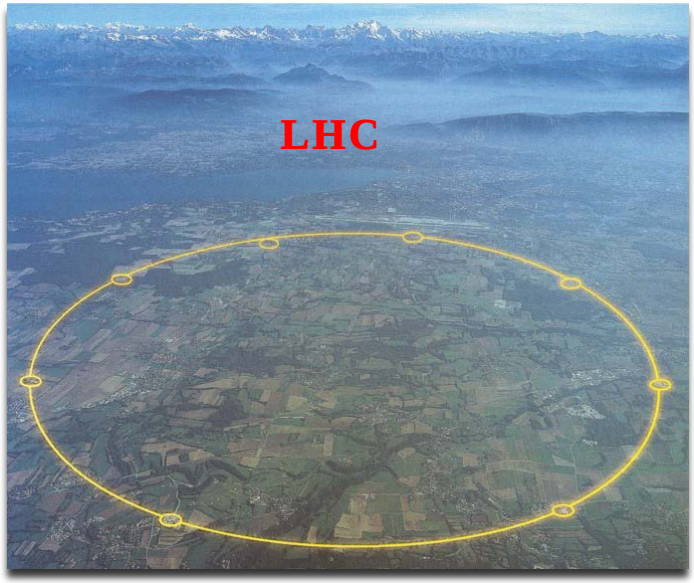
And ...

❖ DM accounts for 1/4 of the mass-E of the Universe.

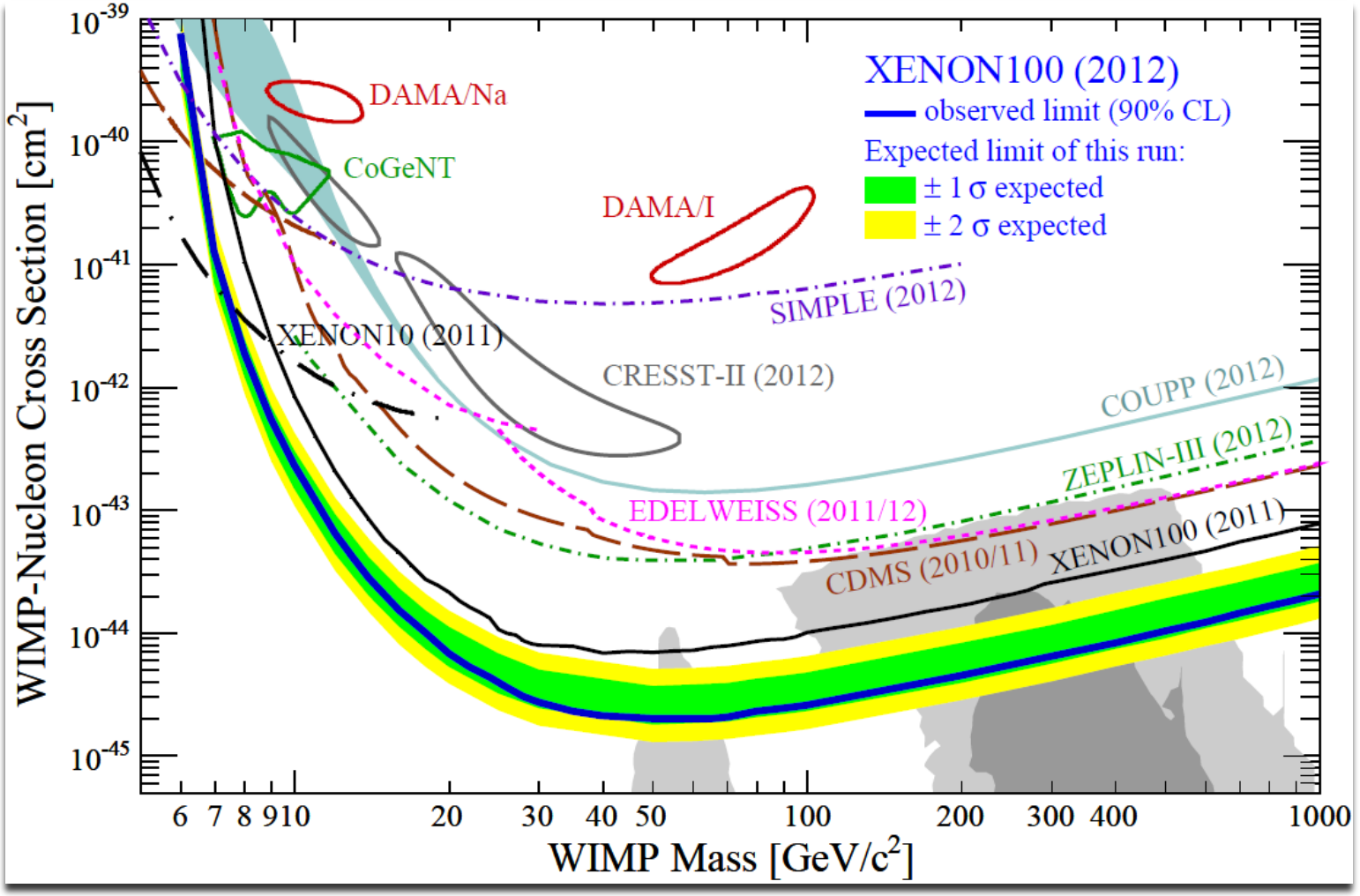




❖ For the particle identification, a discovery via EM, strong or weak probes is needed: e.g. DM direct detection, production, etc.



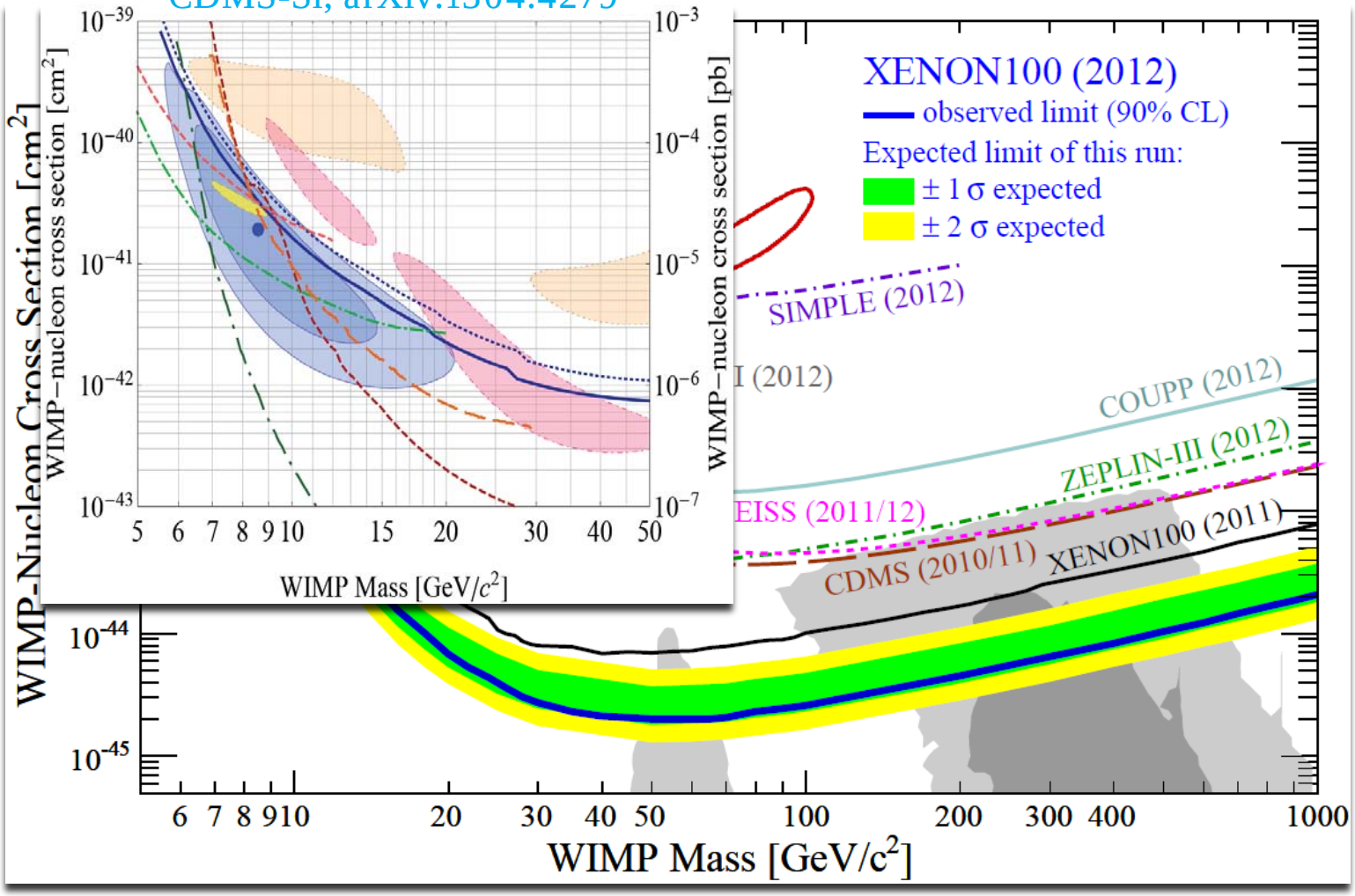
Status of direct detection



XENON100, PRL 109(2012)

Status of direct detection

CDMS-Si, arXiv:1304.4279



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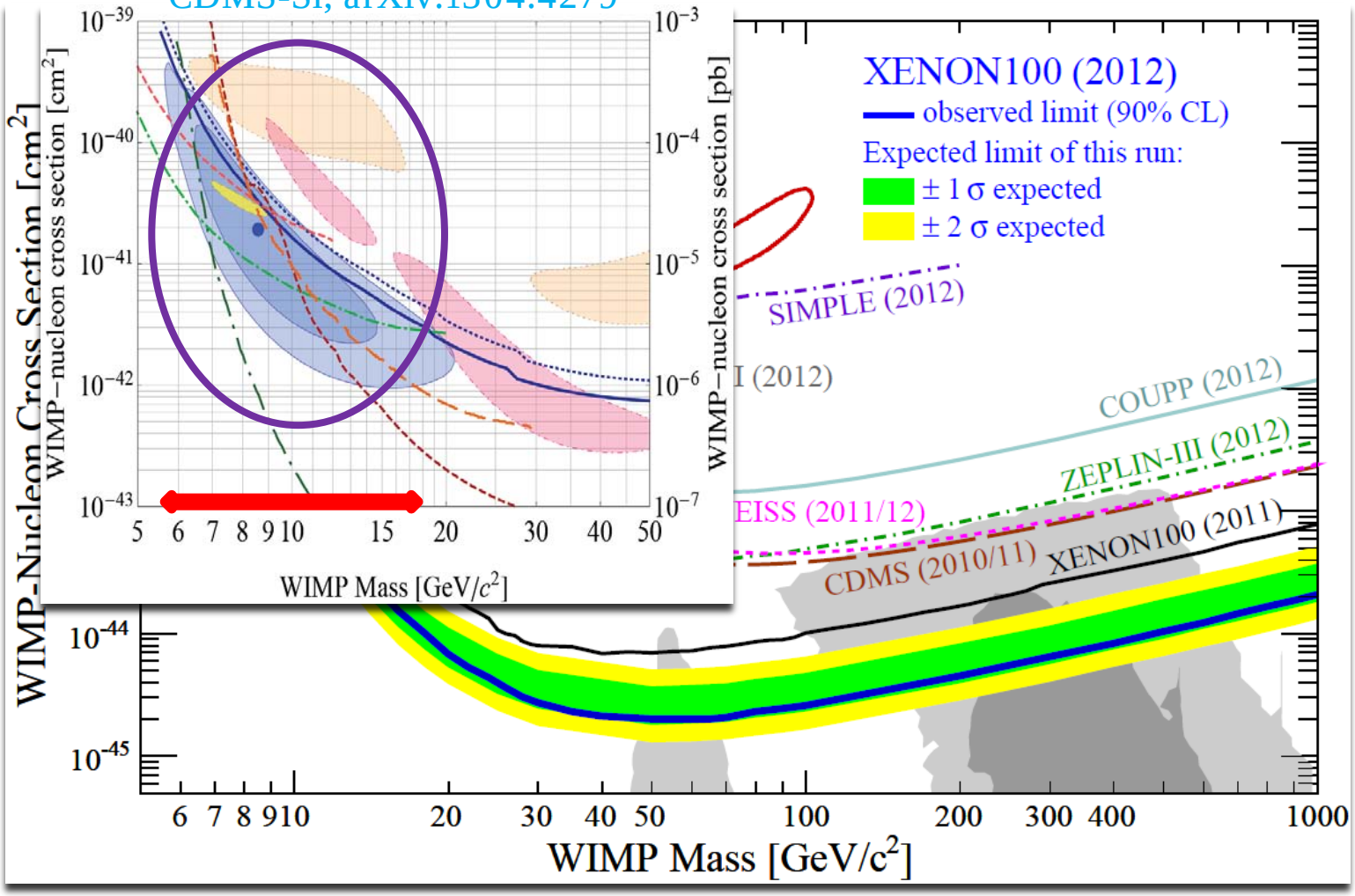

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Hints of ~10 GeV DM?

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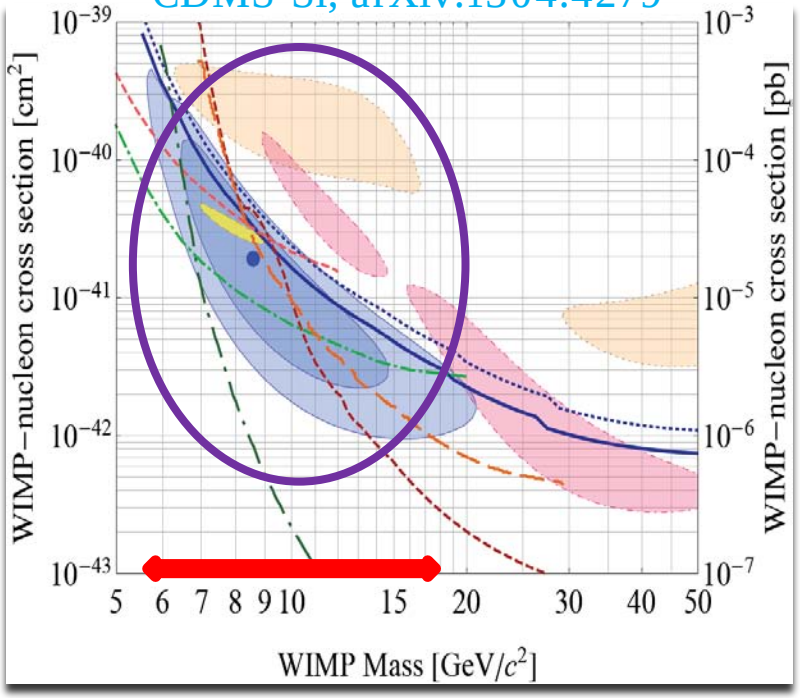

- DAMA: NAI, annual modulation ~ 9σ.
  arXiv:1102.1028
- CRESST: $CaWO_4$, 67 events > 4σ.
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- CoGeNT: Ge, annual modulation ~ 3σ.
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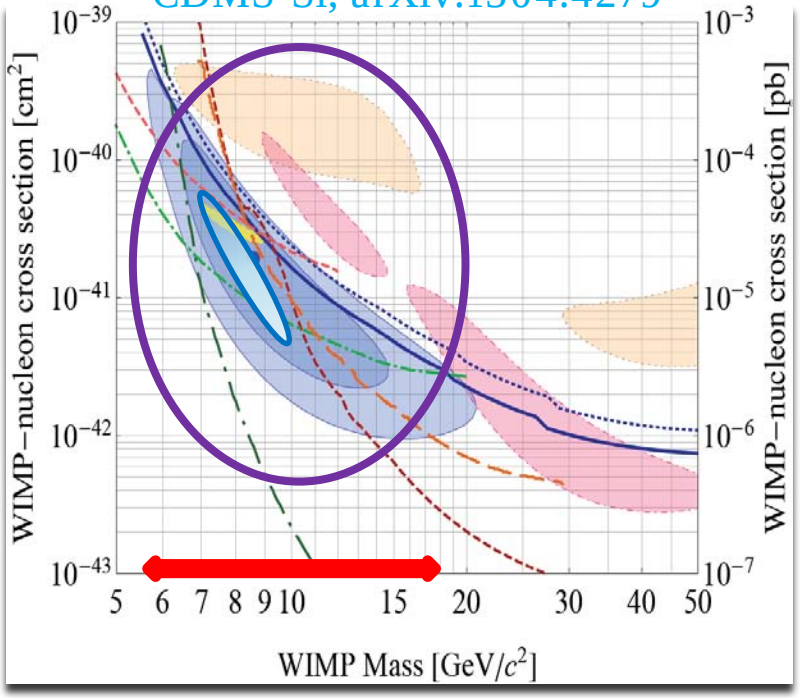

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- CDMS-Si: Si, 3 events with 0.7 BG.
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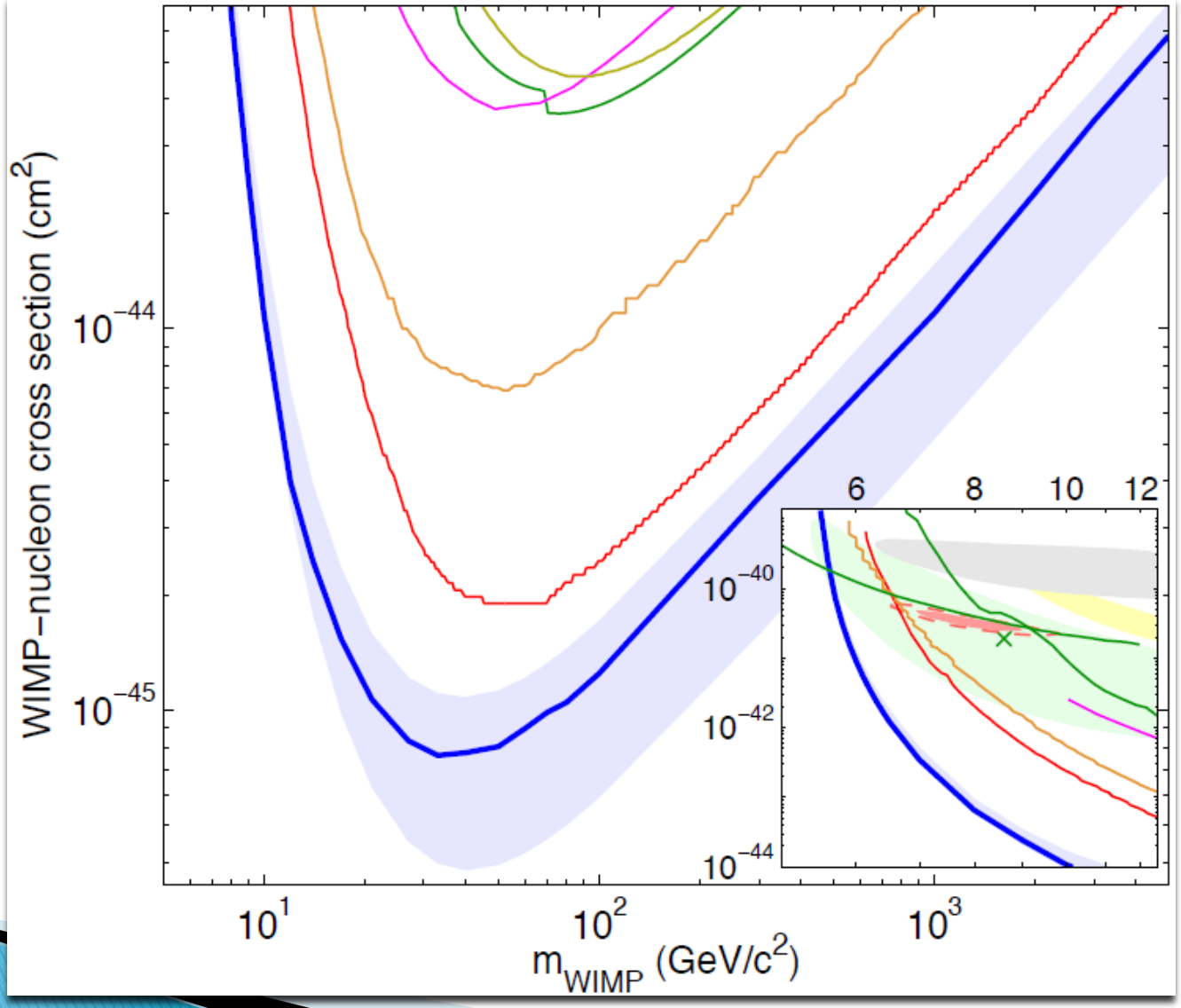
- CDMS-Ge: Ge, exponential excess of events in the nuclear recoil band > 5σ.
  (unofficial) arXiv:1204.3559

Stringent limit from LUX

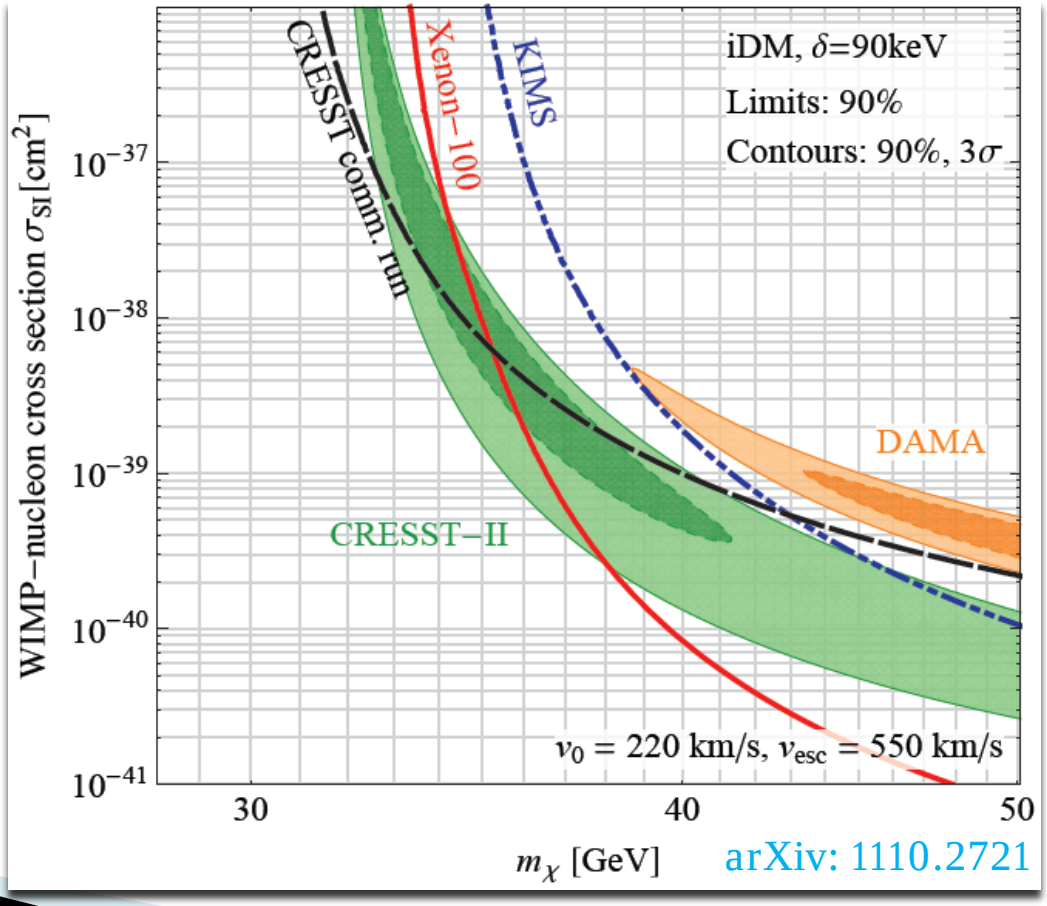
arXiv: 1310.8214



Suggested ideas

- **Inelastic DM**: More than two states with mass splittings, i.e. EWDM.

hep-ph/0101138



arXiv: 1110.2721

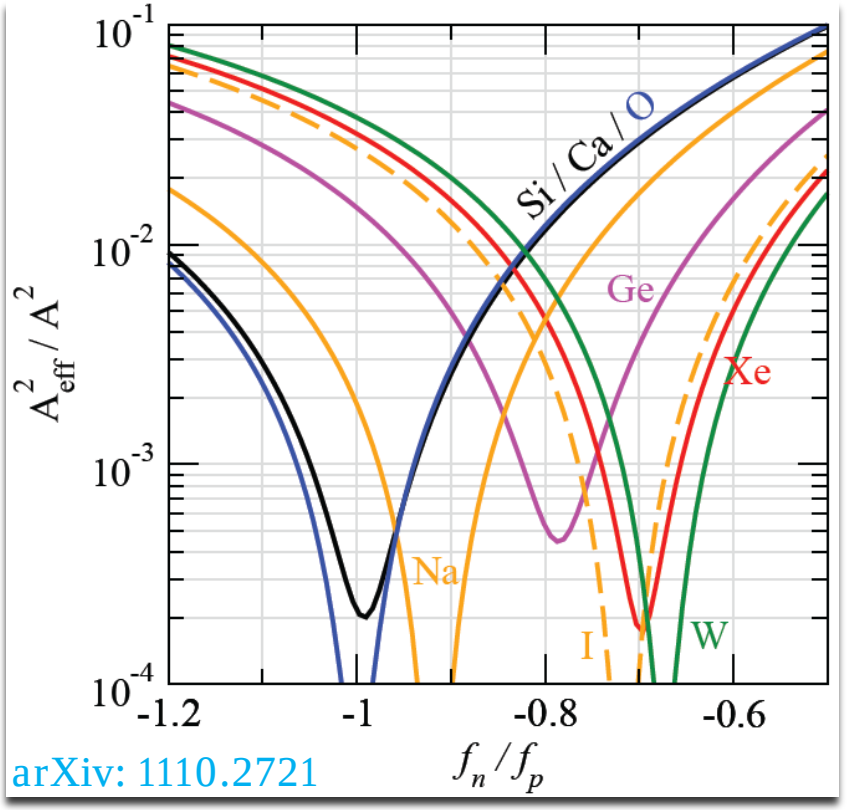
Suggested ideas

- **Isospin-violating DM (IVDM)**: hep-ph/0504157

  In general, DM can couple differently to p's and n's, $f_p \neq f_n$.
  Moreover, if $f_p f_n < 0$, cancellation between two contributions,
  depending on the number of p's and n's in a target.

$$A_{\rm eff}^2 \equiv \sum_{i \in \text{isotopes}} 2 r_i [Z \cos\theta + (A_i - Z)\sin\theta]^2$$

$\tan\theta = f_n/f_p$ and
r_i is the relative abundance.



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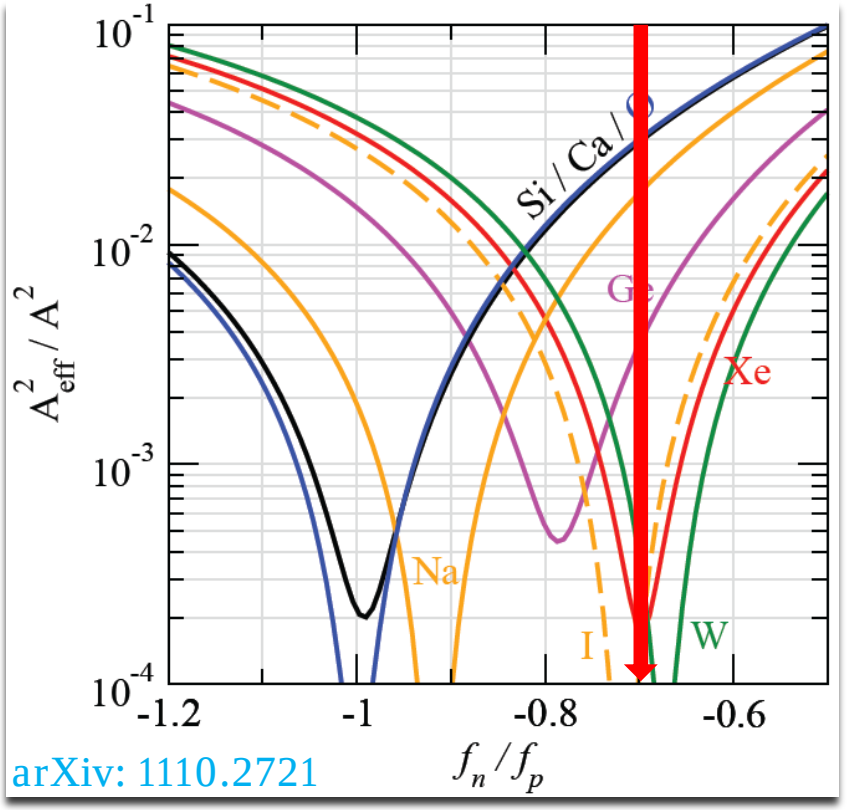

DM with a double portal

Belanger, Goudelis, JCP, Pukhov
arXiv: 1311.0022

- A hidden DM with a double portal interaction:

$$\mathcal{L} = \mathcal{L}_{SM} - \frac{1}{2}\sin\epsilon\,\hat{B}_{\mu\nu}\hat{X}^{\mu\nu} - \frac{1}{4}\hat{X}_{\mu\nu}\hat{X}^{\mu\nu} + \frac{1}{2}m_{\hat{X}}^2\hat{X}^2 + y_\psi S\bar{\psi}\psi + g_X\hat{X}_\mu\bar{\psi}\gamma^\mu\psi$$
$$- \lambda_{SH}S^\dagger S H^\dagger H + \frac{1}{2}\mu_S^2 S^\dagger S - \frac{1}{4}\lambda_S(S^\dagger S)^2 + \frac{1}{2}\mu_H^2 H^\dagger H - \frac{1}{4}\lambda_H(H^\dagger H)^2$$

- Diagonalization of kinetic & mass mixing terms:

$$\hat{B} = c_{\hat{W}}A - (t_\epsilon s_\xi + s_{\hat{W}}c_\xi)Z + (s_{\hat{W}}s_\xi - t_\epsilon c_\xi)Z_X$$
$$\hat{W}_3 = s_{\hat{W}}A + c_{\hat{W}}c_\xi Z - c_{\hat{W}}s_\xi Z_X\,,$$
$$\hat{X} = \frac{s_\xi}{c_\epsilon}Z + \frac{c_\xi}{c_\epsilon}Z_X\,,$$

Chun, JCP & Scopel, arXiv: 1011.3300

- Diagonalization of scalar field mixing:

$$\mathcal{M}_{sh}^2 = \begin{pmatrix} \lambda_S v_S^2/2 & \lambda_{SH}vv_S \\ \lambda_{SH}vv_S & \lambda_H v^2/2 \end{pmatrix} \qquad \begin{pmatrix} h_1 \\ h_2 \end{pmatrix} = \begin{pmatrix} c_\alpha & -s_\alpha \\ s_\alpha & c_\alpha \end{pmatrix}\begin{pmatrix} s \\ h \end{pmatrix}$$

$$m_{h_1,h_2}^2 = \frac{1}{4}\lambda_H v^2 + \frac{1}{4}\lambda_S v_S^2 \mp \sqrt{\left(\frac{1}{4}\lambda_H v^2 - \frac{1}{4}\lambda_S v_S^2\right)^2 + (\lambda_{SH}vv_S)^2}$$

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IVDM via a double portal

- $\mathbf{f_p^V >> f_n^V}$:

$$g_f^{Z_X} = \frac{g_{fL}^{Z_X} + g_{fR}^{Z_X}}{2} \simeq \frac{ec_\xi t_\epsilon \sqrt{1-s_W^2}\,[(8s_W^2-4)Q + s_W^2 t_\epsilon^2 T_3]}{8s_W^2-4} + \mathcal{O}(r_X)$$

$$\approx ec_\xi t_\epsilon c_W Q$$

$t_\varepsilon << 1$ & $r_X = m_{Zx}^2/m_Z^2 < 1$

: General in models with a kinetic mixing between $U(1)_Y$ & $U(1)_X$.

- $\mathbf{f_p^{hi} \approx f_n^{hi}}$: interactions of h_1 & h_2 with the SM $f \sim y_f$ and $\sum f_p^{Tq} \approx \sum f_n^{Tq}$

: General feature in models via a Higgs portal.

- Isospin-violating interactions through a interference of a scalar and $U(1)_X$ gauge boson contribution.

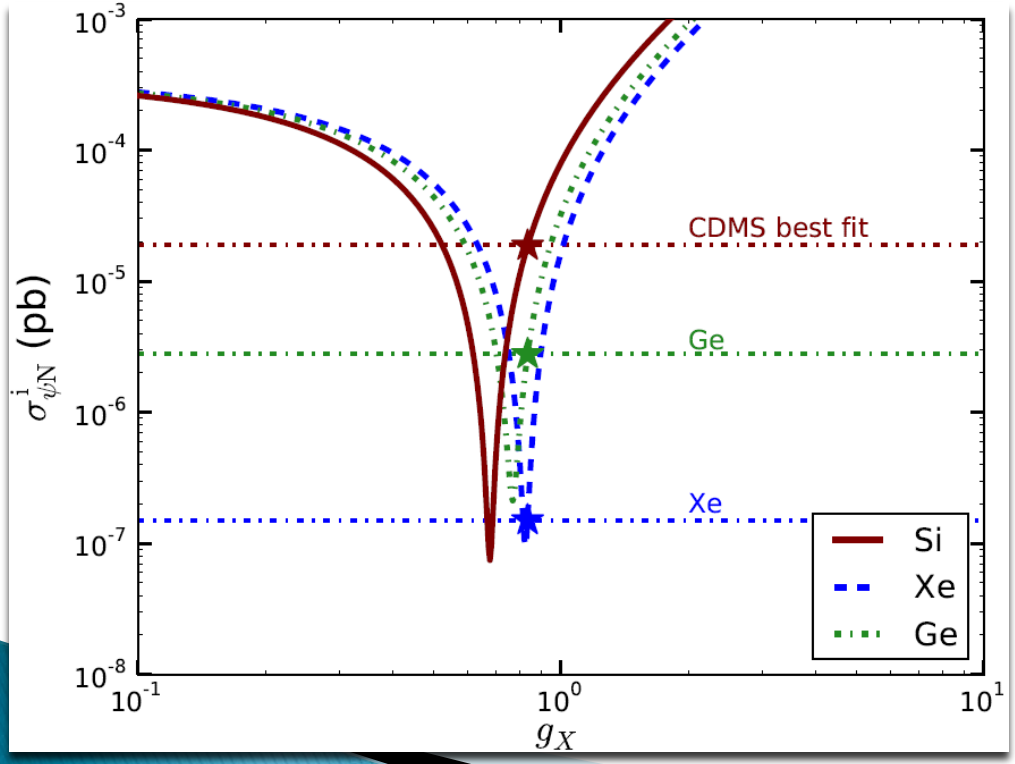
- One can find some region of parameter space satisfying

$\mathbf{f_n/f_p} \approx (f_n^{hi} + f_n^{Zx}) / (f_p^{hi} + f_p^{Zx}) \approx f_p^{hi} / (f_p^{hi} + f_p^{X}) \approx \mathbf{-0.7}$

Relative suppresions

- General formula for a multi-isotope material

$$\sigma_{\psi N^Z} = \sigma_{\psi p}\left[c\frac{\sum \eta_i \mu_{A_i}^2 (f_p Z + f_n(A^i - Z))^2}{\sum \eta_i \mu_{A_i}^2 f_p^2} + \bar{c}\frac{\sum \eta_i \mu_{A_i}^2 (\bar{f}_p Z + \bar{f}_n(A^i - Z))^2}{\sum \eta_i \mu_{A_i}^2 \bar{f}_p^2}\right]$$



Parameter	Left panel	Right panel
m_Z	91.1813	91.1813
m_W	80.340	80.340
m_{Z_X}	18	18
ρ	0.9992	0.9992
m_ψ	8.6	8.6
ϵ	7×10^{-3}	7×10^{-3}
m_{h_1}	1	1
m_{h_2}	126	126
α	8×10^{-4}	8×10^{-4}
g_X	-	8.3×10^{-1}
y_ψ	3.1	-

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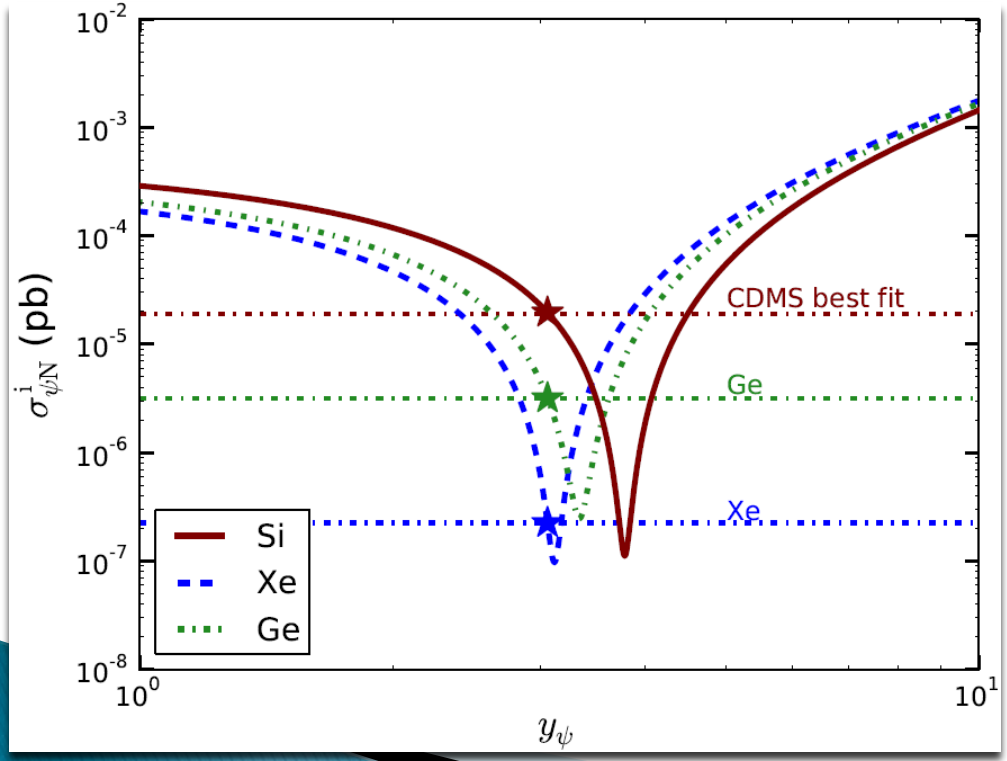

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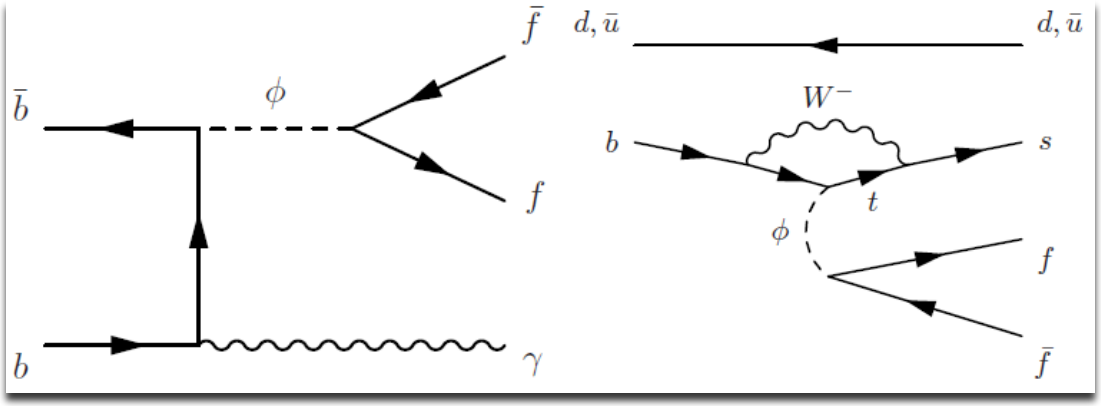
Constraints from B physics

arXiv: 1310.6752



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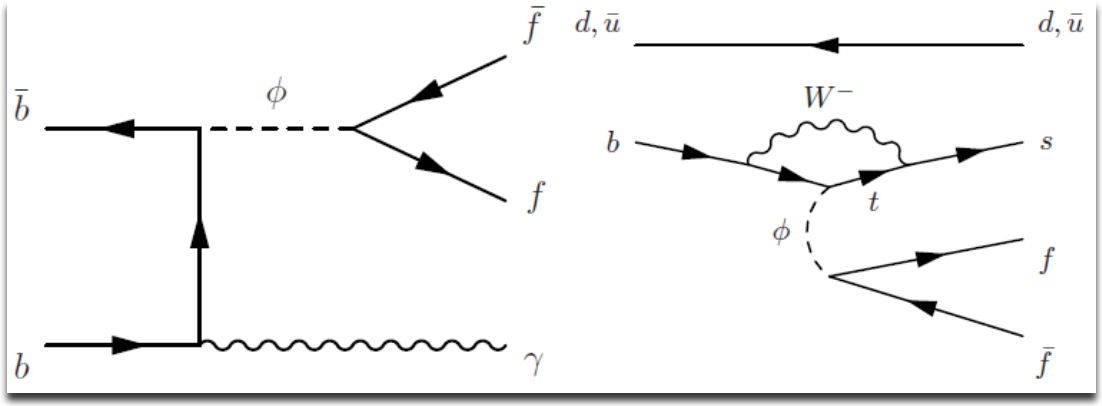
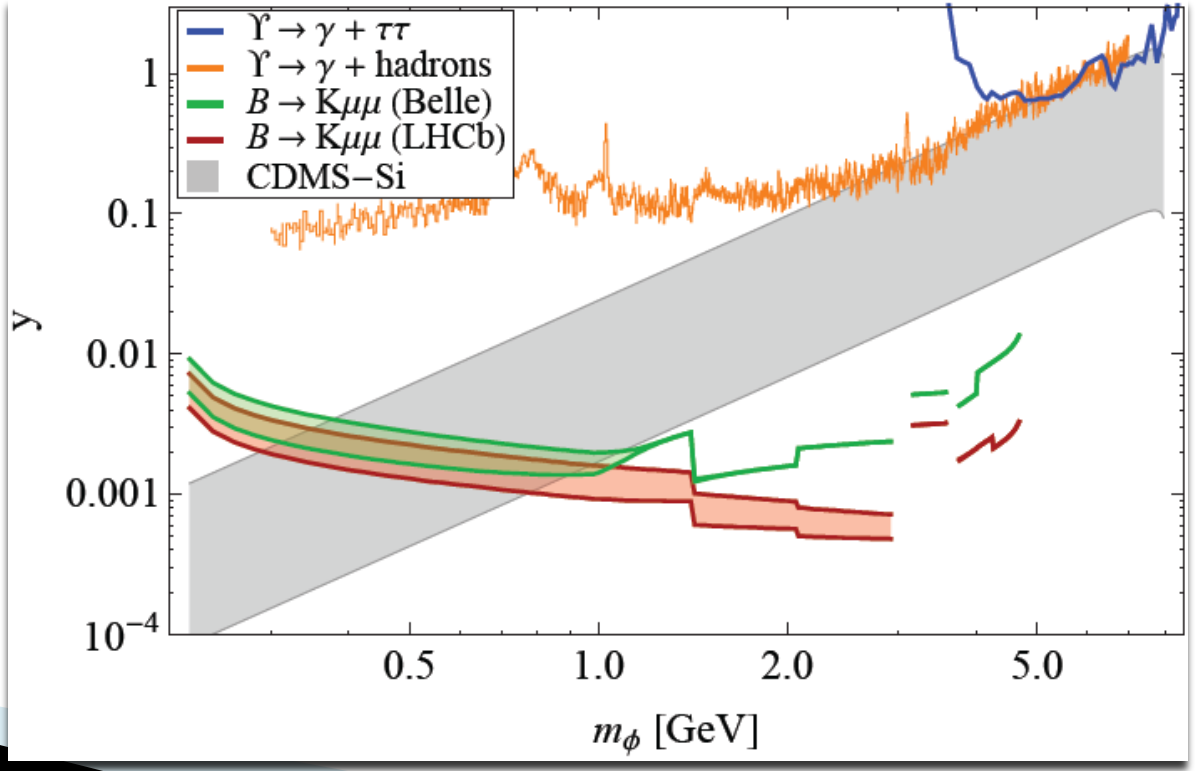


❖ $\alpha \cdot y_f^{SM} \leftrightarrow y \cdot y_f^{SM}$



Scan over the parameter space

$$91.1813 < m_Z < 91.1939$$
$$80.340 < m_W < 80.430$$
$$0.9992 < \rho < 1.0016$$
$$0.003 < \epsilon < 0.04$$
$$5 < m_\psi < 25$$
$$2m_\psi - 7 < m_{Z_X} < 2m_\psi + 7$$
$$0.005 < y_\psi < 10$$
$$0.1 < g_X < 10$$
$$123 < m_{h_2} < 129$$
$$0.2 < m_{h_1} < 5$$
$$1 \times 10^{-4} < \alpha < 5 \times 10^{-3}$$

- EWPT, Z → ψψ, h → invisibles
- LHCb: B → Kμμ (arXiv: 1310.6752)

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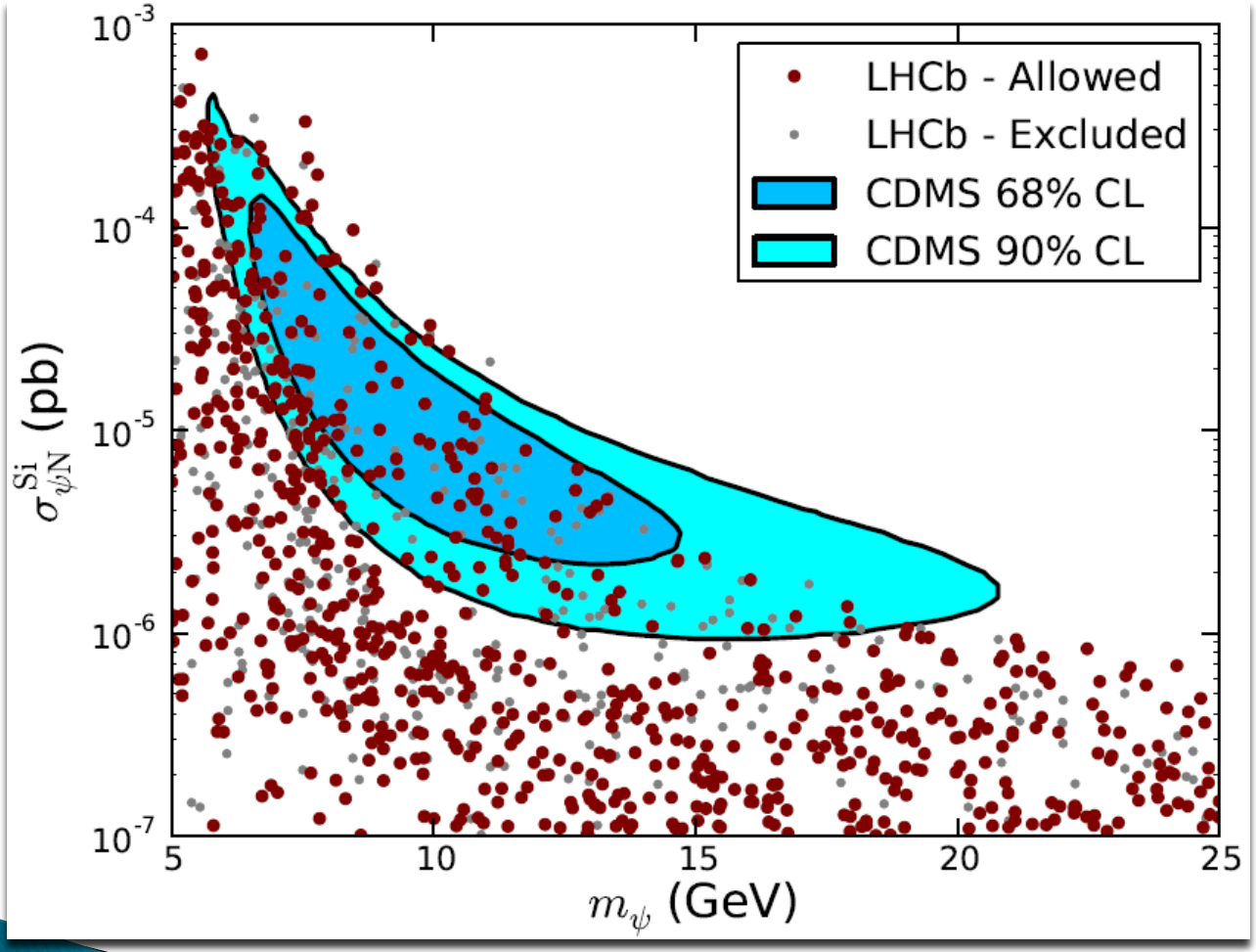

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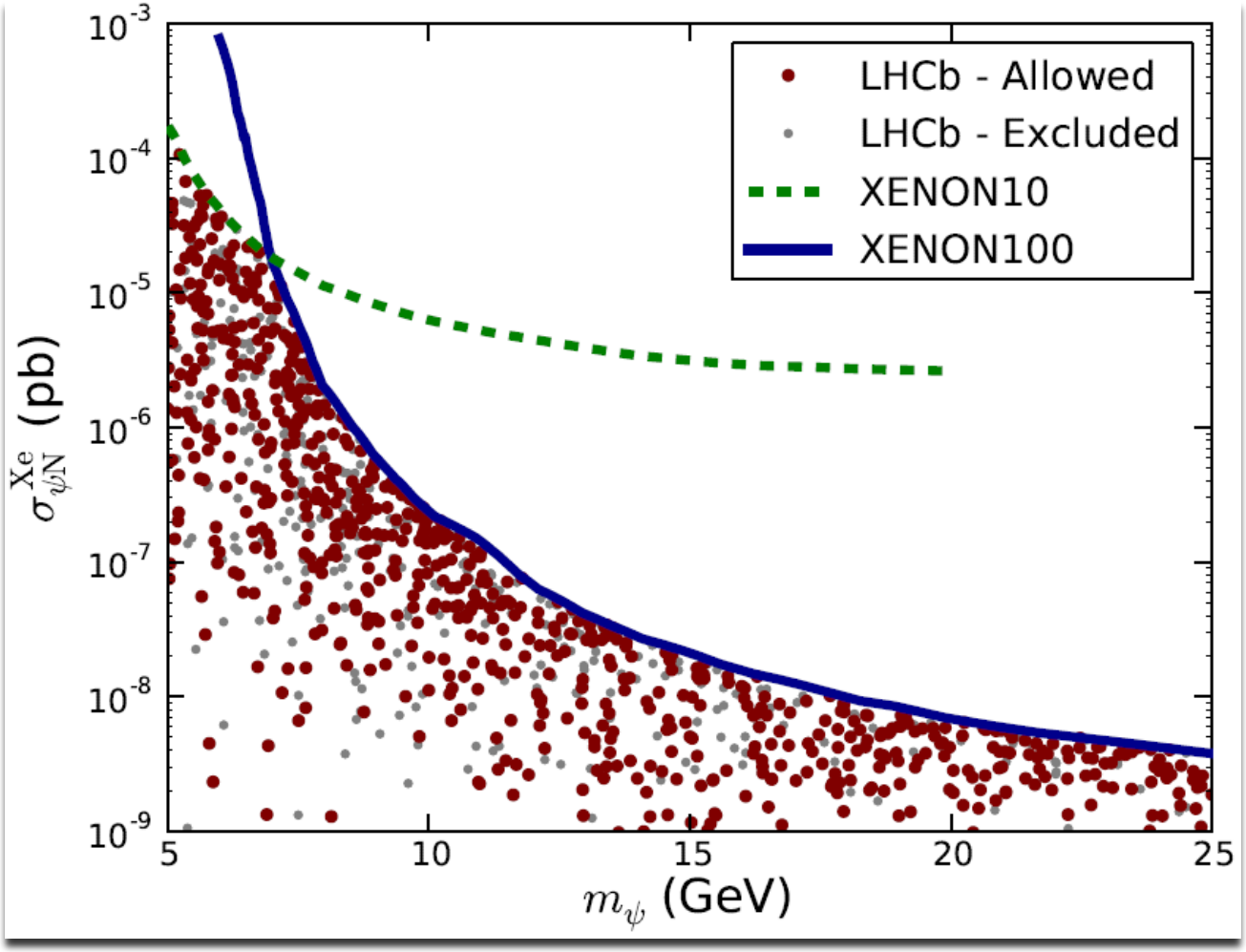
Cross section for Xe



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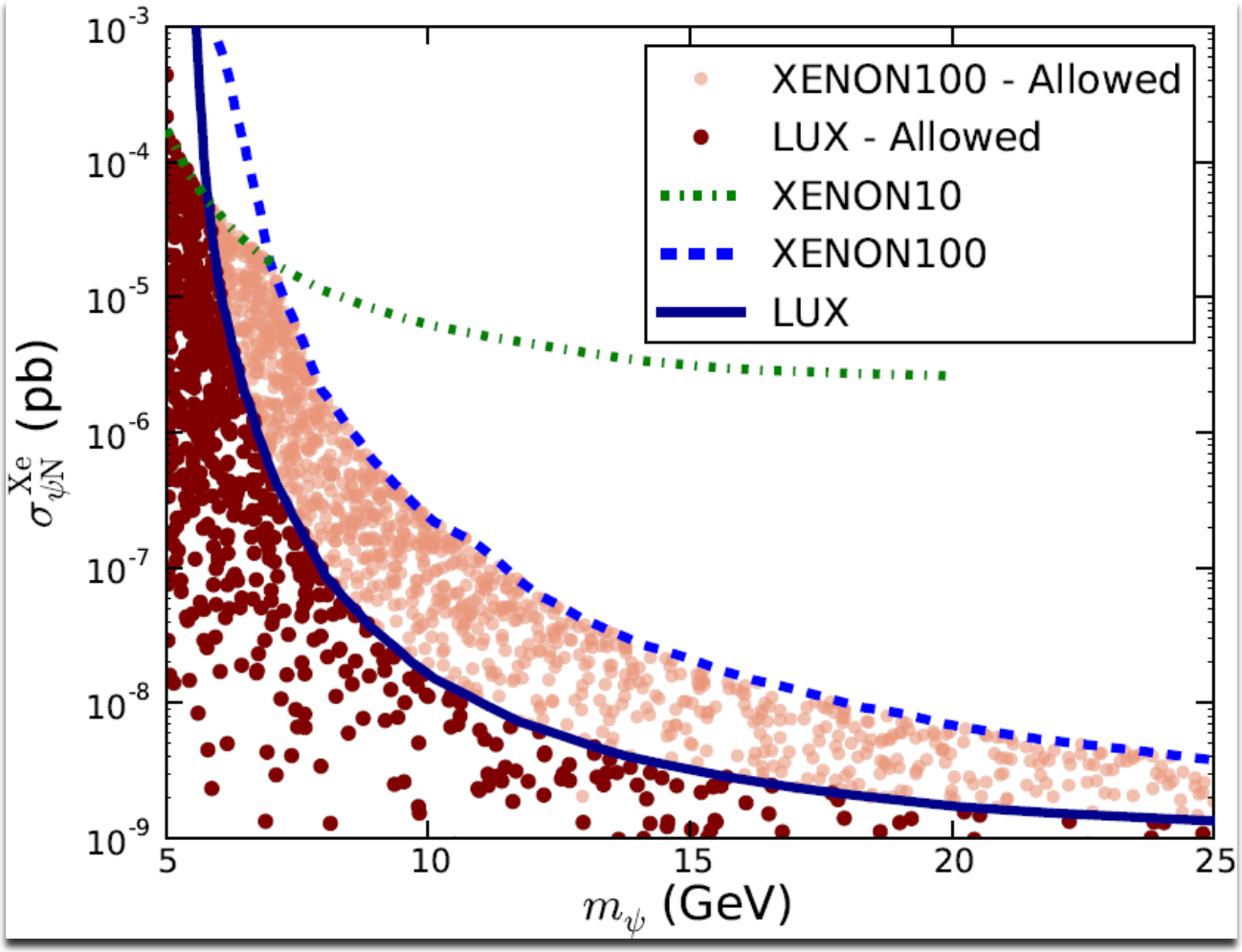

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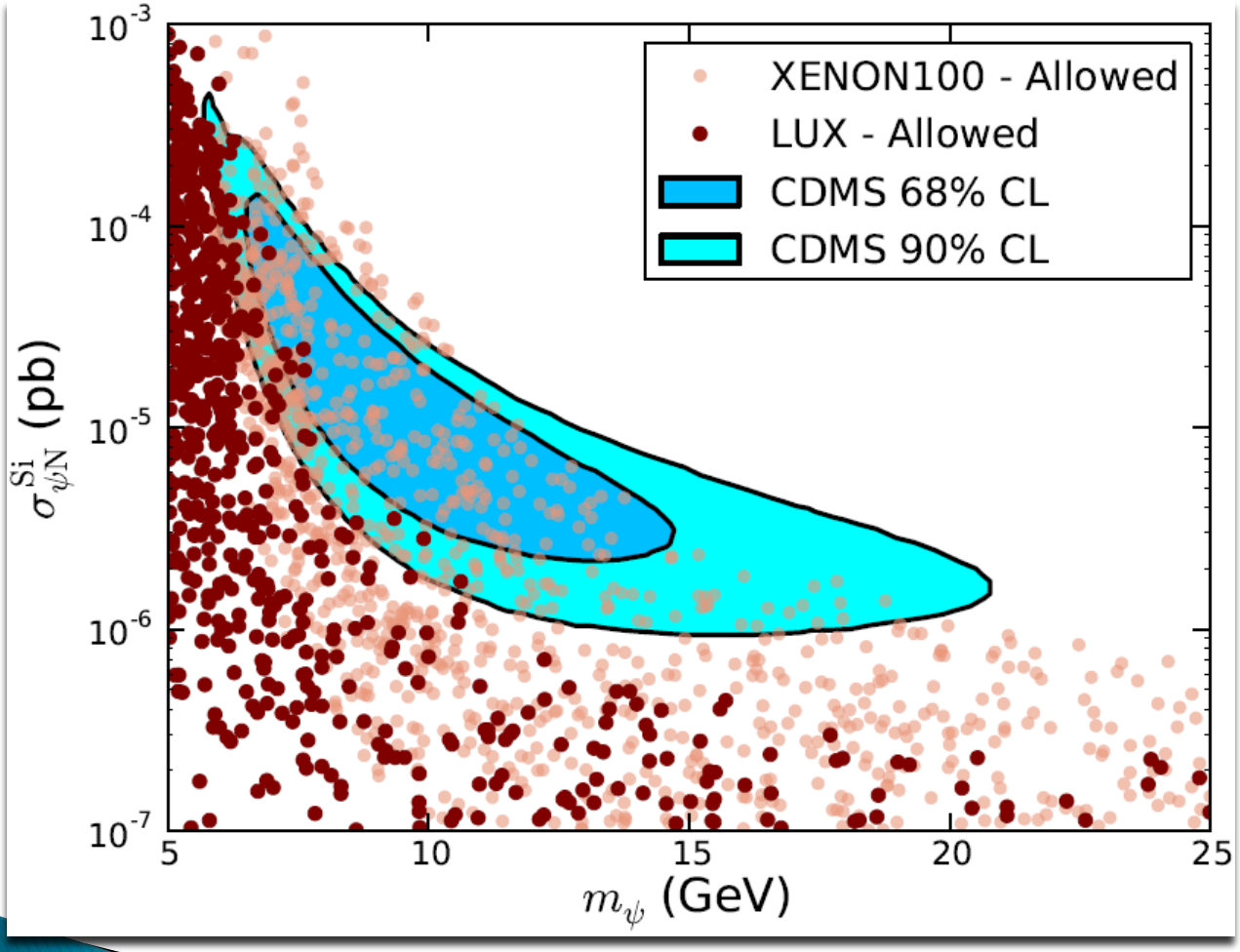

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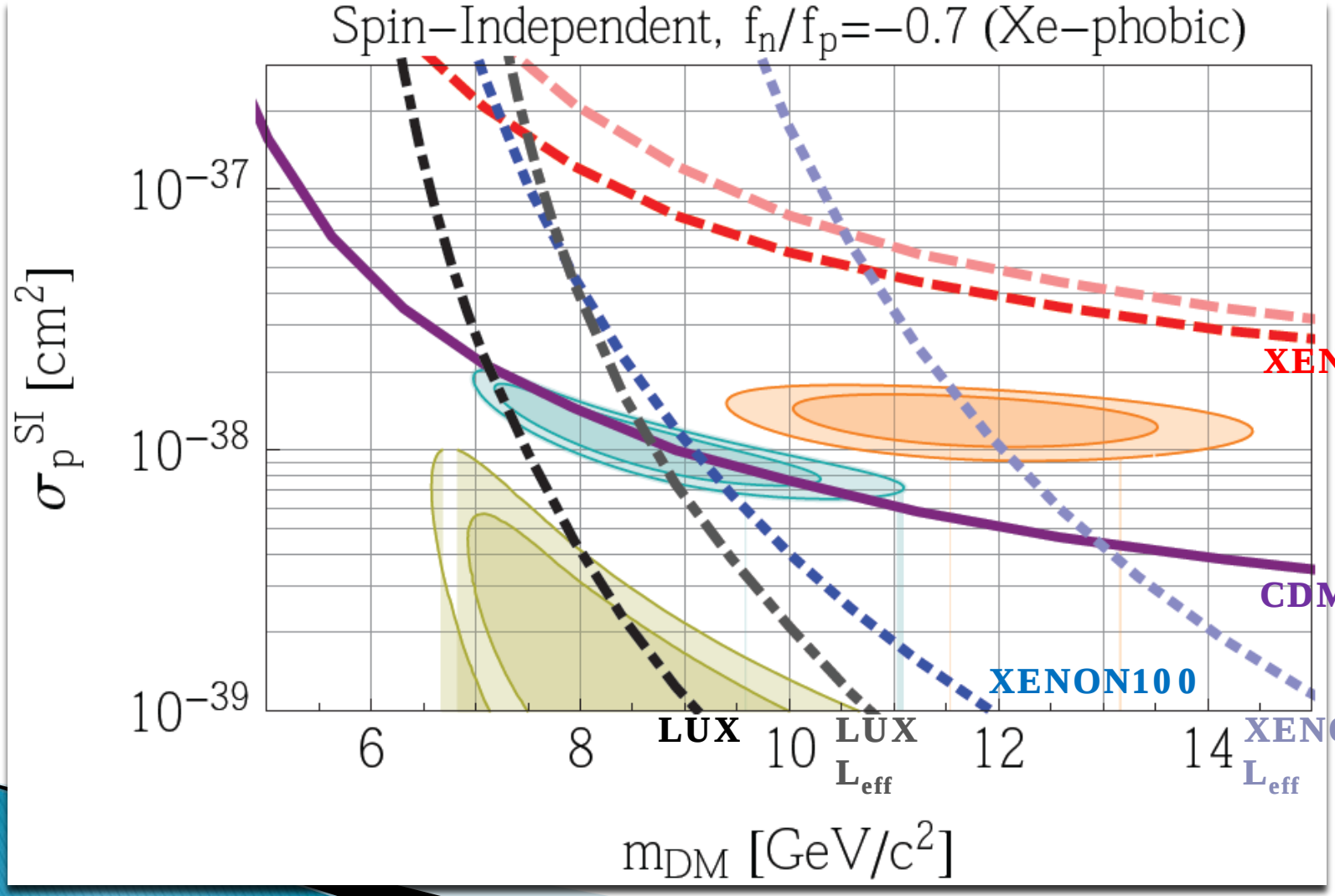
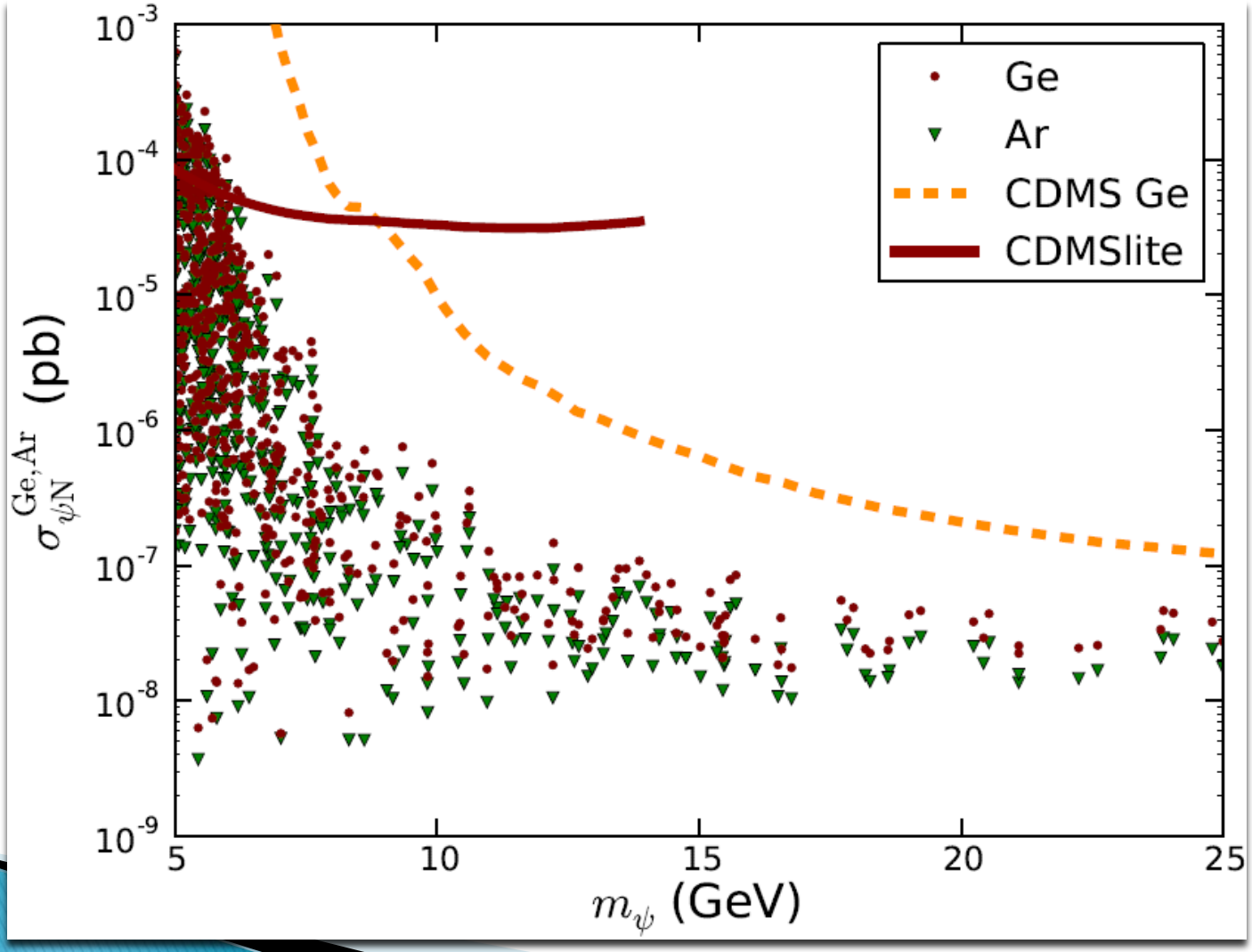
Cross section for IVDM

M. Gresham & K. Zurek,
arXiv: 1311.0022



Cross section for Ge & Ar

- Points falling close to the CDMS-Si compatible region satisfying all Exp. constraints



Conclusion

- Several positive reports on ~10 GeV DM

  : DAMA, CRESST, CoGeNT, CDMS-Si (CDMS-Ge)

  But, null results from XENON, LUX, ...

- Is it real ???

- IVDM is natural in a double portal model.

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  satisfying EWPT, Z width, 126 GeV Higgs, LHCb, ...

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Thank you

Backup

Symmetric vs Asymmetric

- Symmetric DM
  - ✓ DM: $f_n/f_p=(S_n-V_n)/(S_p-V_p)\approx S_p/(S_p-V_p)$
    - → can be < 0 depending on relative size of S_p & V_p.
  - ✓ Anti-DM: $f_n/f_p=(S_n+V_n)/(S_p+V_p)\approx S_p/(S_p+V_p)$
    - → always > 0.
- Asymmetric DM: one component dominates.

Relic density is mostly determined by asymmetry.