Removing the fog from DM direct detection with isospin violating interactions

Based on a work in progress with
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Adrián Terrones Aragón

IFIC (CSIC-Univ. Valencia)

XVI CPAN Days, Madrid, 19/11/2024

Status of direct detection experiments

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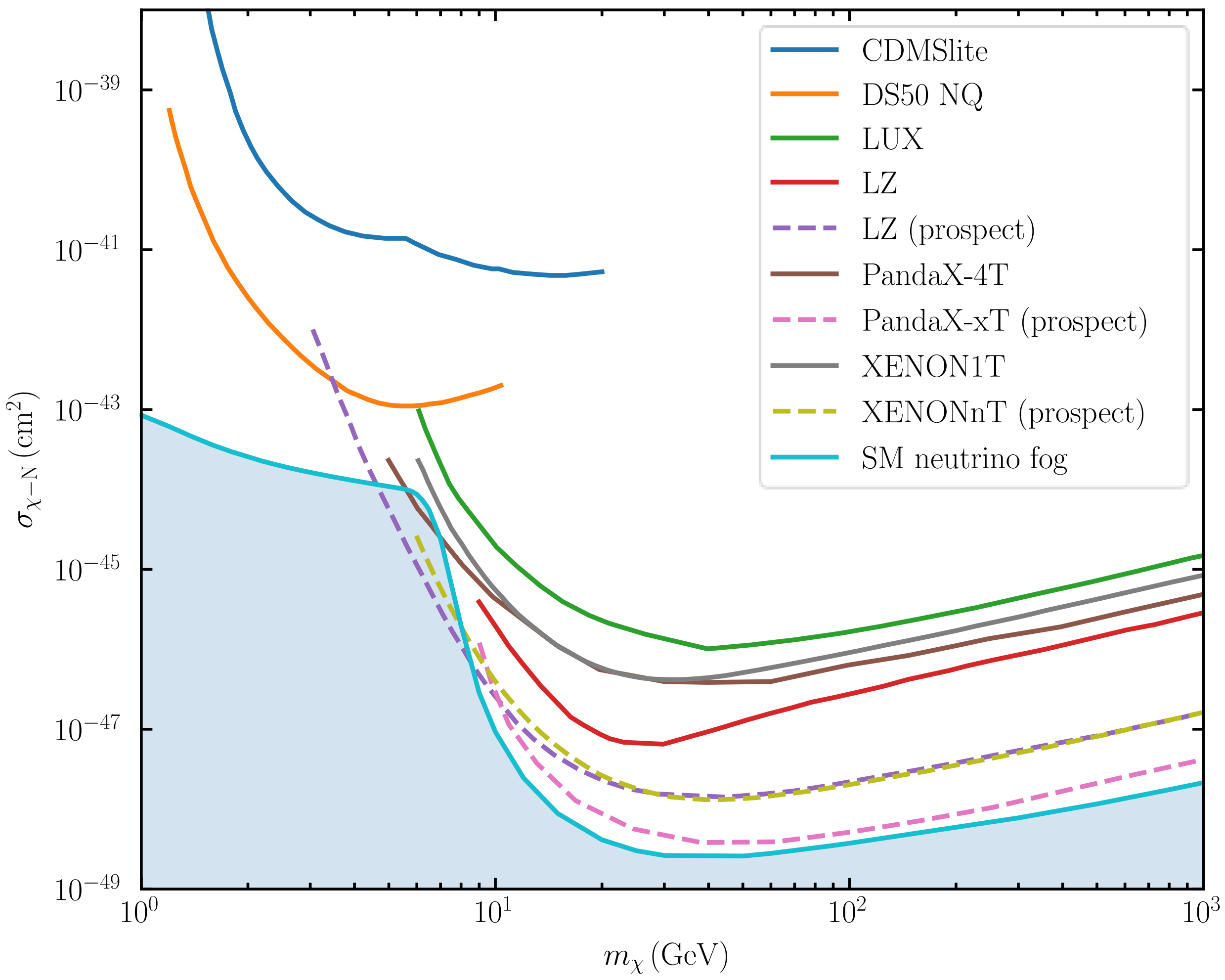

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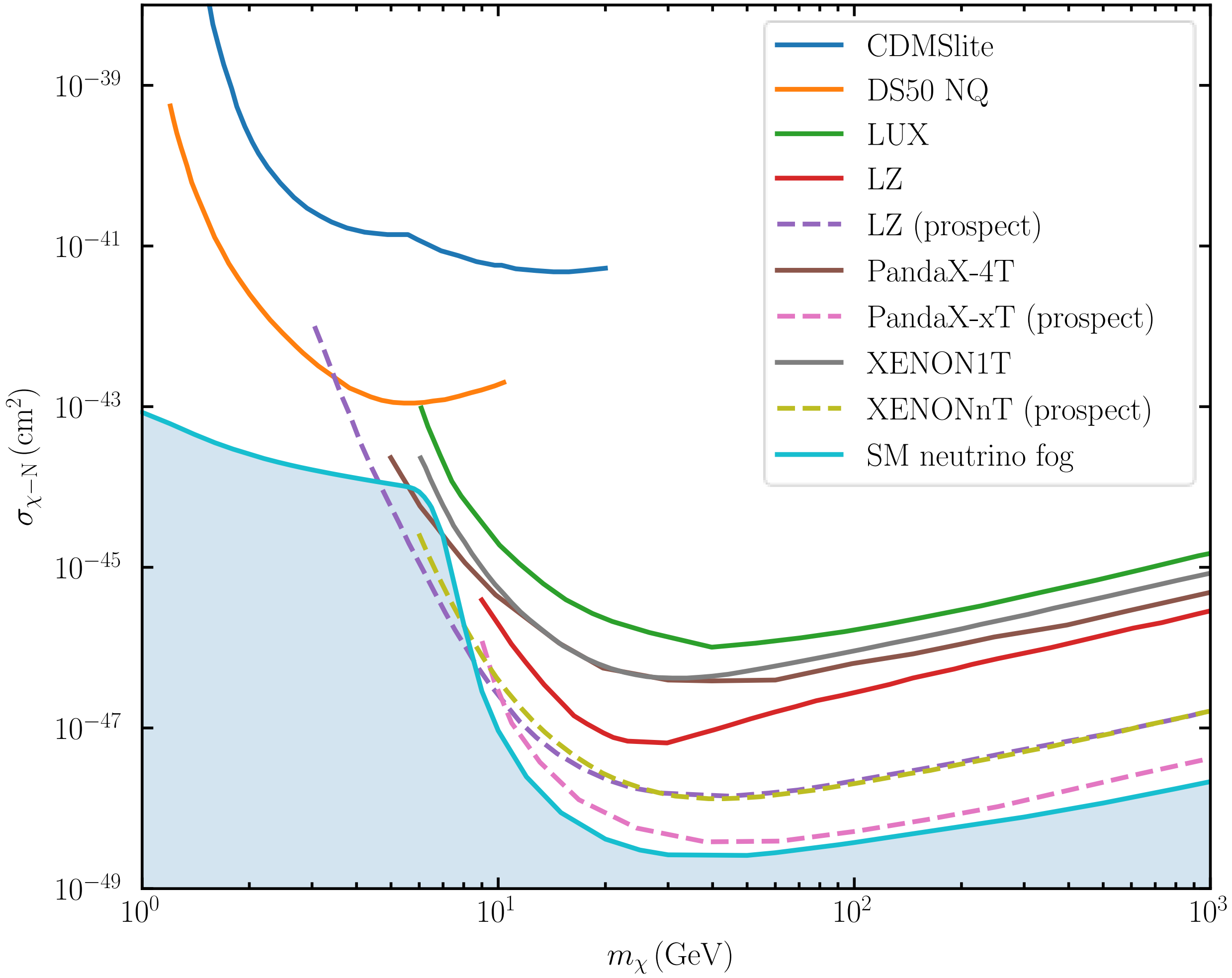

PandaX4T and XENONnT: hints of neutrino fog at **2.64σ** and **2.73σ** !!

PandaX Collab., 2408.02877
XENONnT Collab., 2407.10892

What do we mean by **isospin violation?**

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- Fermionic DM, massive vector boson (Z')

$$\mathcal{L} \supset Z'_\mu \sum_f \bar{f}\gamma^\mu(g_V^f + g_A^f\gamma_5)f + Z'_\mu\bar{\chi}\gamma^\mu(g_V^\chi + g_A^\chi\gamma_5)\chi + \frac{1}{2}m_{Z'}^2 Z'_\mu Z'^\mu + m_\chi\bar{\chi}\chi$$

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- Effective nucleon- Z' couplings:

$$f_{p,n} = \frac{g_V^\chi (2g_V^{u,d} + g_V^{d,u})}{2m_{Z'}^2} \rightarrow \frac{f_n}{f_p} = \frac{2g_V^d + g_V^u}{2g_V^u + g_V^d}$$

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If $f_n/f_p \neq 1$,
isospin violation!

What's the effect of IV on **exclusion bounds?**

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- Nucleon- Z' cross section:

$$\sigma_N^Z = \sigma_p \frac{\sum_i \eta_i \mu_{A_i}^2 [Z + (A_i - Z) f_n/f_p]^2}{\sum_i \eta_i \mu_{A_i}^2 A_i^2}$$

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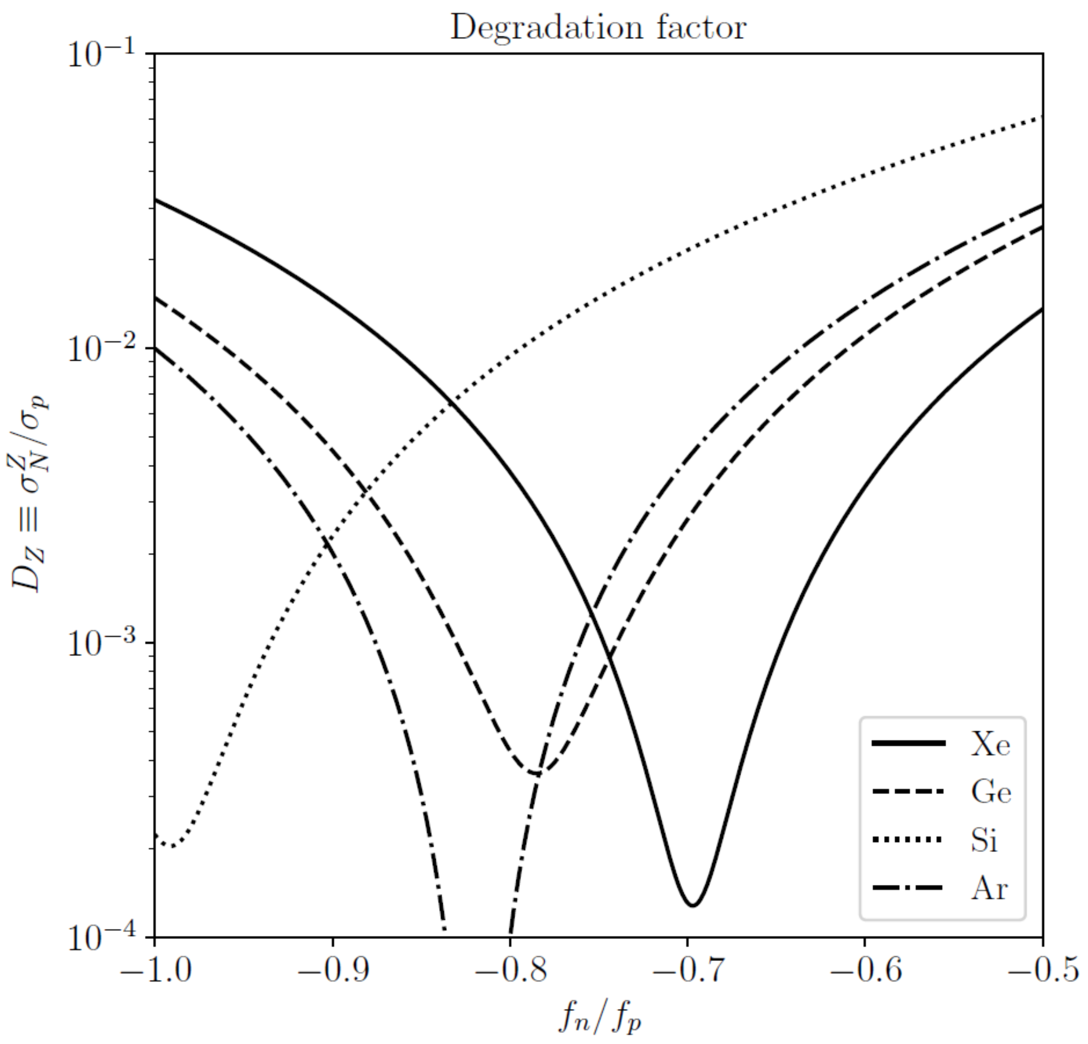

Image credits: V. Martín Lozano

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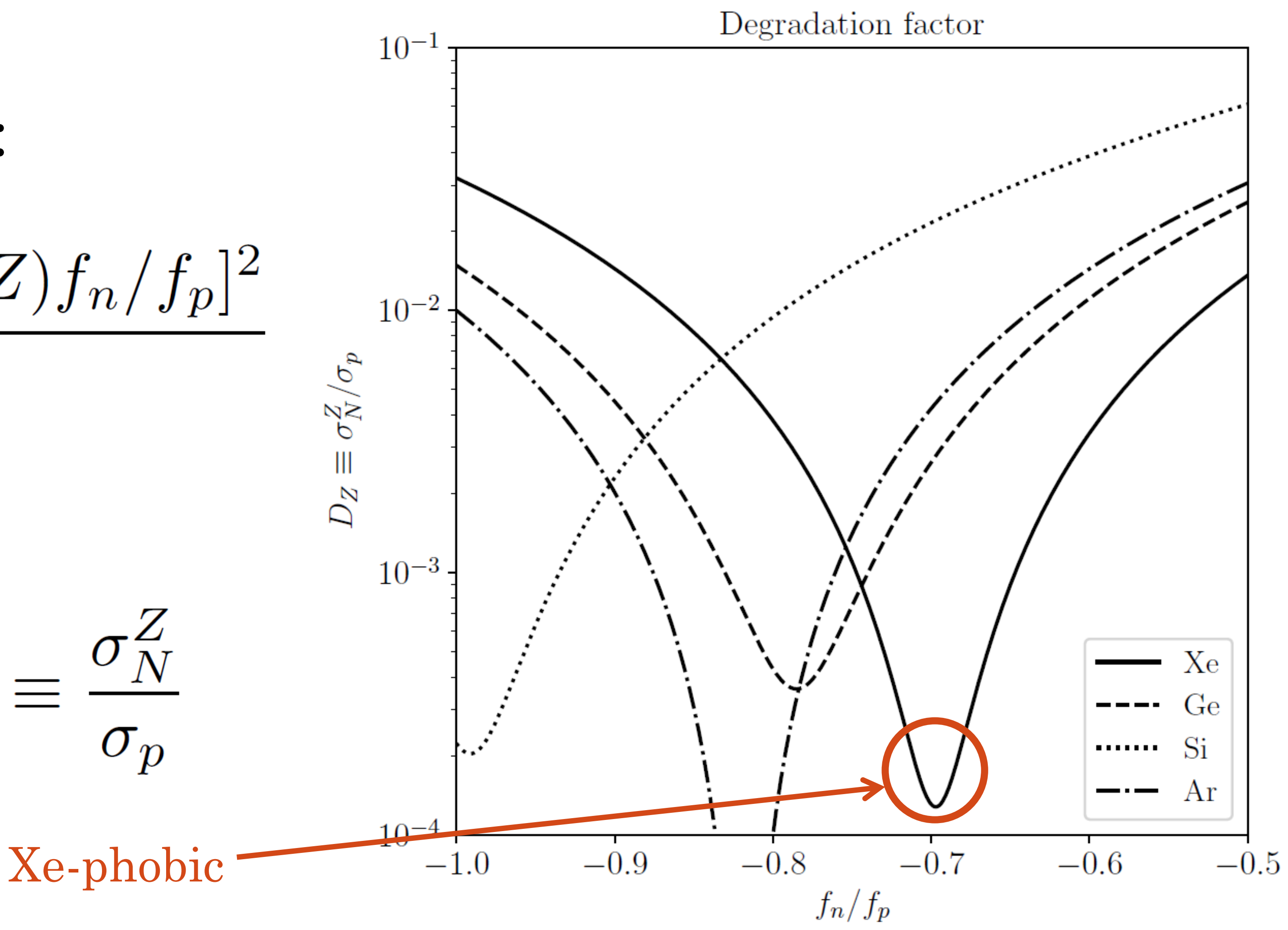

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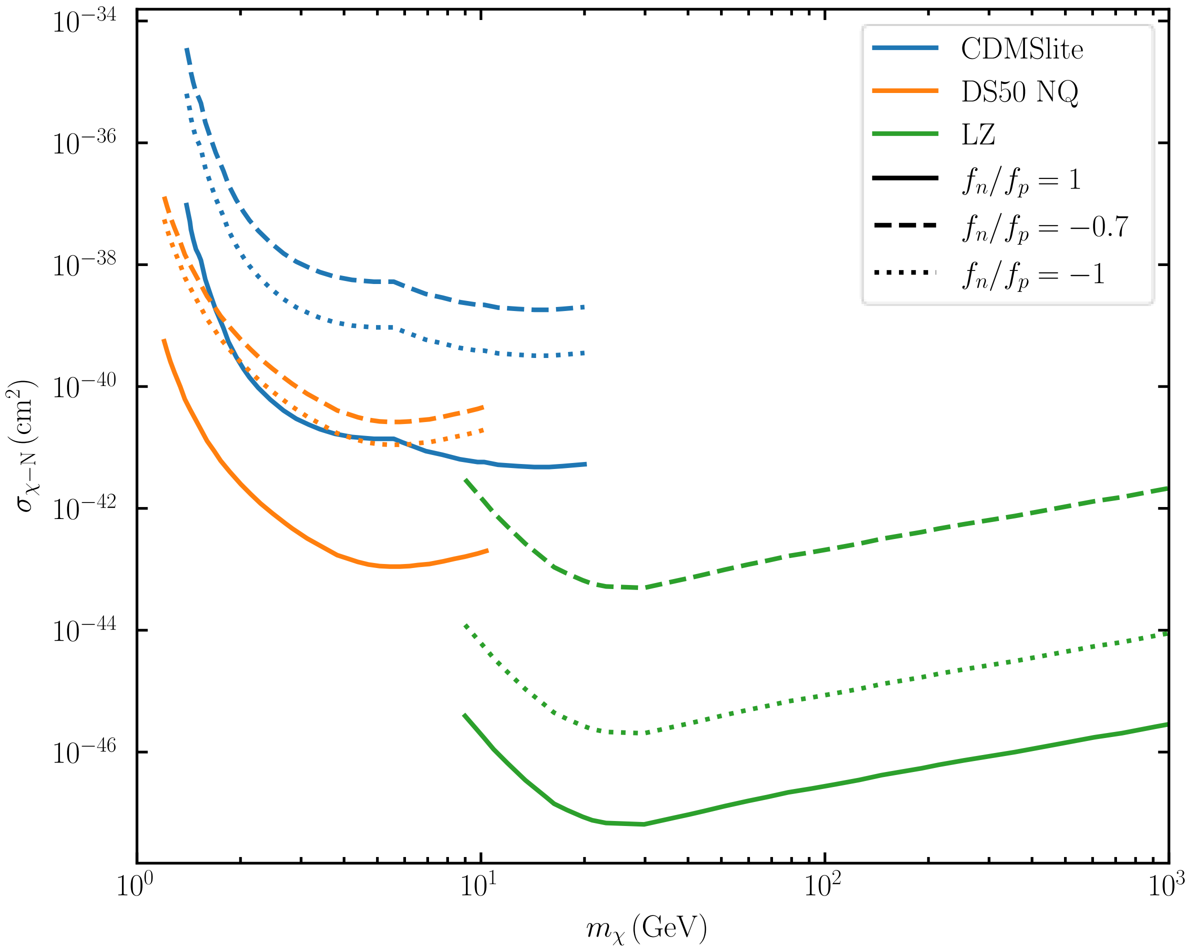

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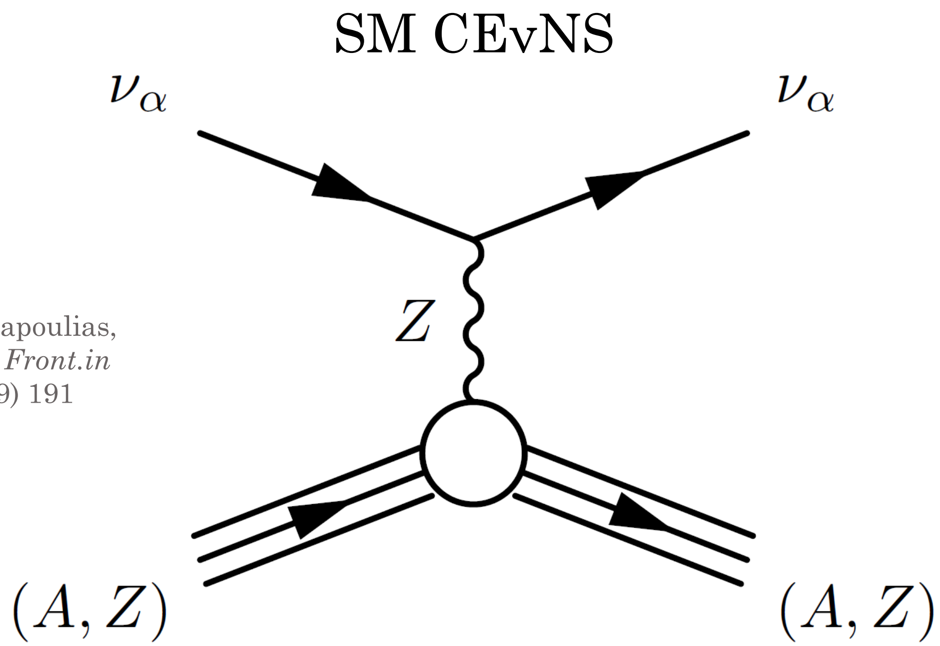

Image source: Papoulias, Kosmas, Kuno, *Front.in Phys.* 7 (2019) 191

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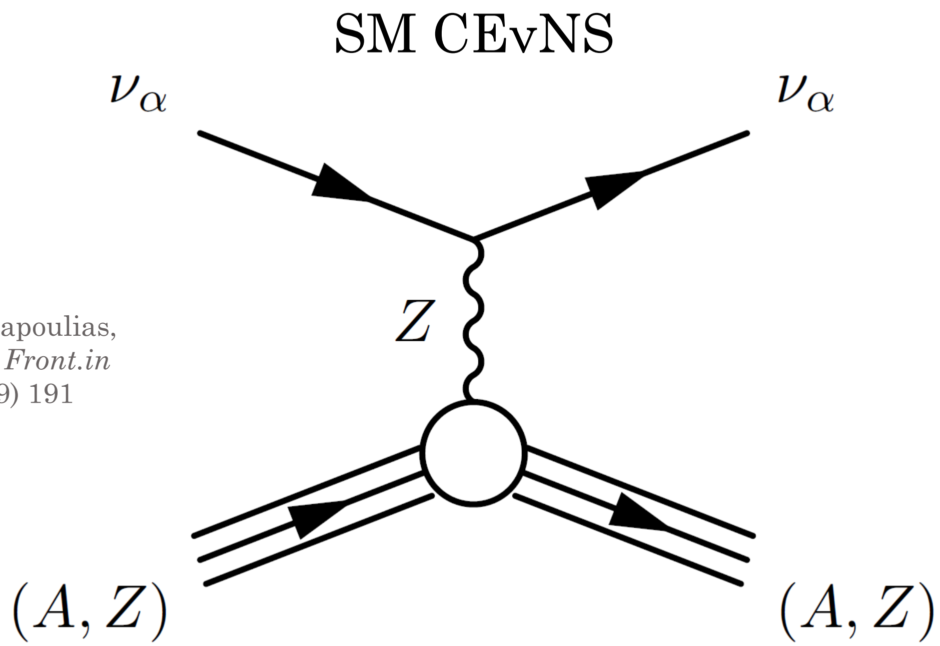

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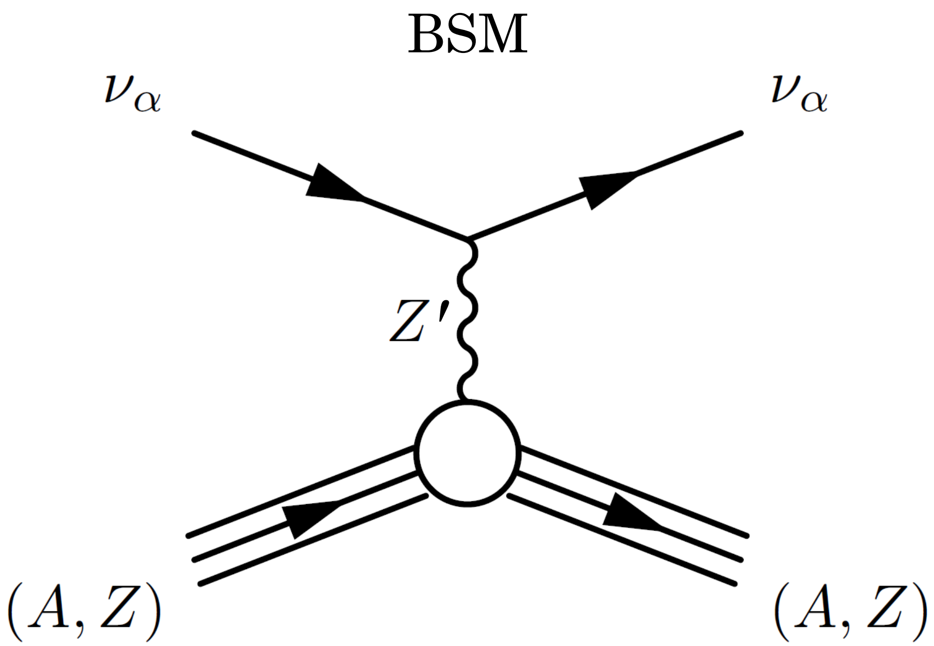

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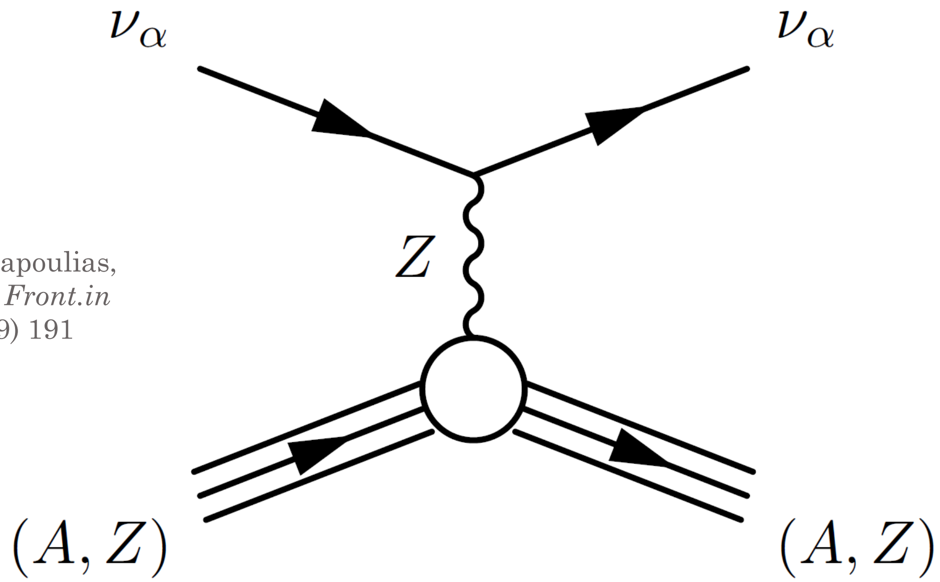
SM CEvNS



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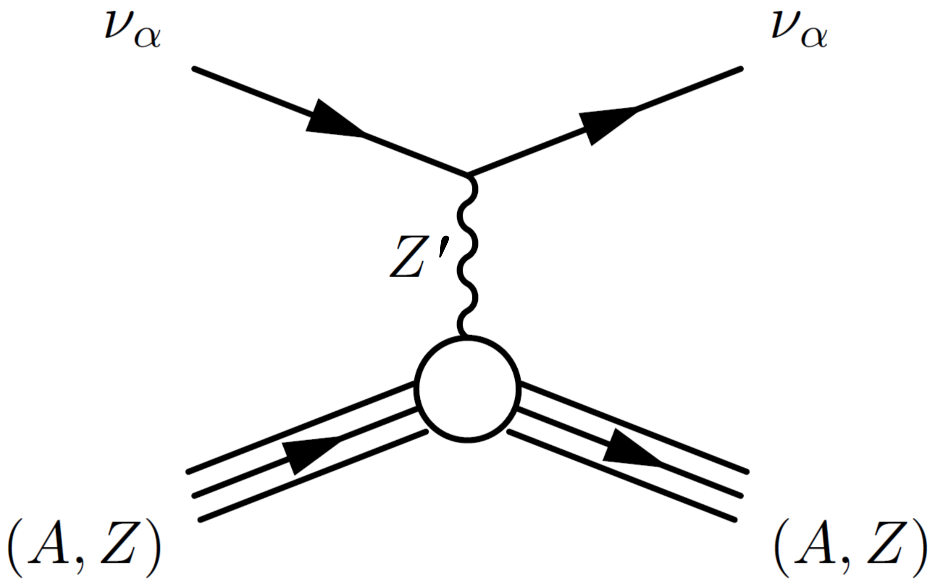
BSM



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$$\frac{d\sigma_V}{dE_R} = \mathcal{G}_V \frac{d\sigma_{SM}}{dE_R}\,, \qquad \mathcal{G}_V = 1 - \frac{2\sqrt{2}}{G_F}\frac{Q_V}{Q_V^{SM}}\frac{g_V^\nu - g_A^\nu}{2m_N E_R + m_{Z'}^2} + \left(\frac{2}{G_F}\right)^2\left(\frac{Q_V}{Q_V^{SM}}\right)^2 \frac{(g_V^\nu)^2 + (g_A^\nu)^2}{(2m_N E_R + m_{Z'}^2)^2}$$

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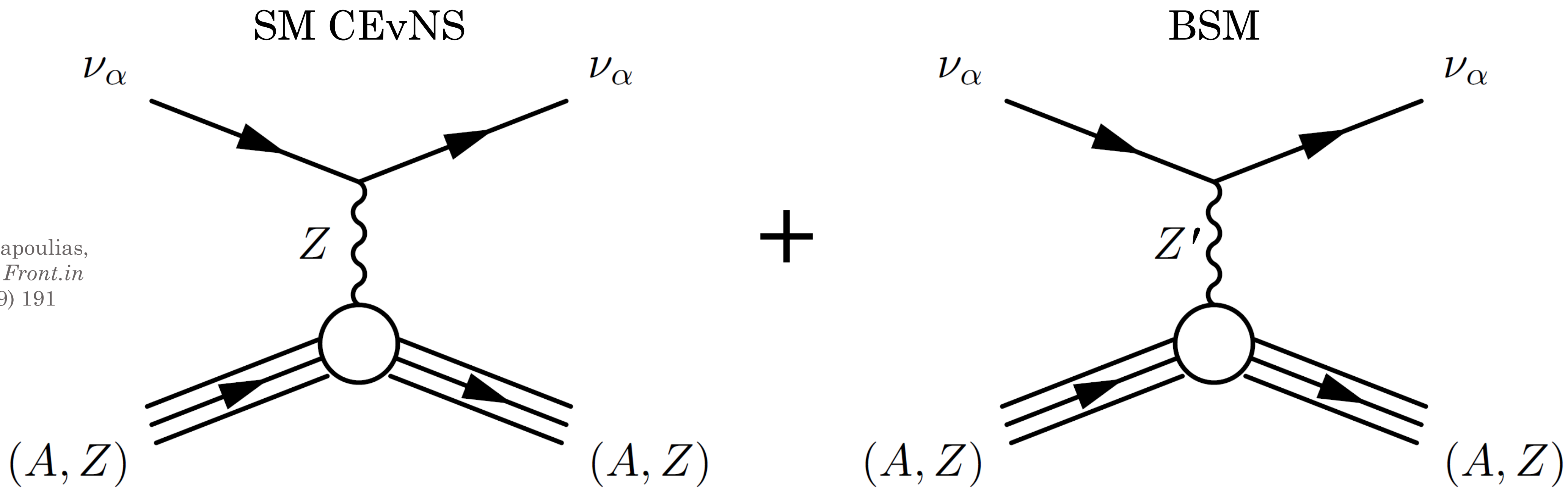

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$$\frac{d\sigma_V}{dE_R} = \mathcal{G}_V \frac{d\sigma_{SM}}{dE_R}\,, \qquad \mathcal{G}_V = \overset{\text{SM}}{1} \overbrace{- \frac{2\sqrt{2}}{G_F}\frac{Q_V}{Q_V^{SM}}\frac{g_V^\nu - g_A^\nu}{2m_N E_R + m_{Z'}^2}}^{\text{Constructive / destructive}} + \overbrace{\left(\frac{2}{G_F}\right)^2\left(\frac{Q_V}{Q_V^{SM}}\right)^2\frac{(g_V^\nu)^2 + (g_A^\nu)^2}{(2m_N E_R + m_{Z'}^2)^2}}^{\text{Constructive}}$$

What's the effect of IV on the **neutrino fog?**

- Many free parameters: $m_{Z'},\, g_u,\, g_d,\, g_\nu^V,\, g_\nu^A$

$$g_u, g_d \leftrightarrow f_n/f_p$$

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- Many free parameters: $m_{Z'},\ g_u,\ g_d,\ g_\nu^V,\ g_\nu^A$

$$g_u \updownarrow f_n/f_p$$

- Benchmark points:

Name	f_n/f_p	g_ν^A
1a	-0.7	0
1b	-0.7	$-g_\nu^V$
2a	-1.0	0
2b	-1.0	$-g_\nu^V$

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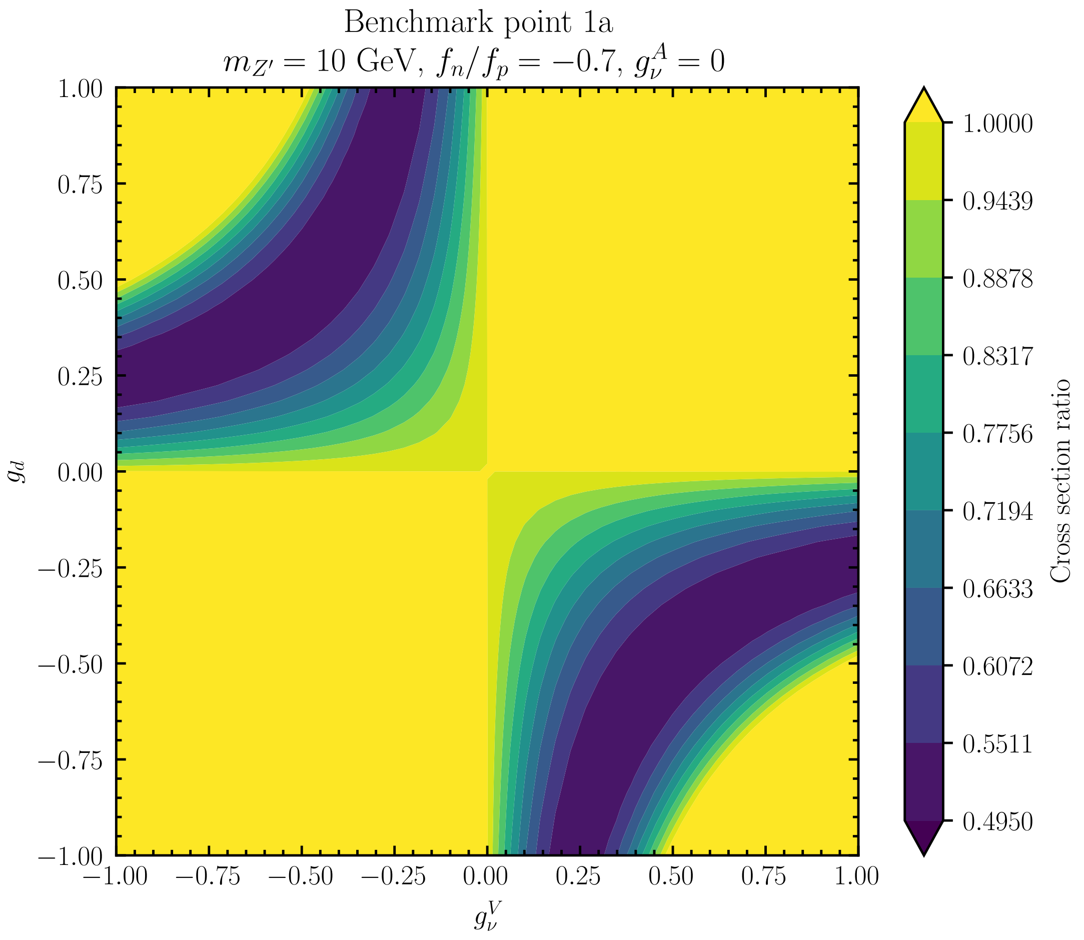

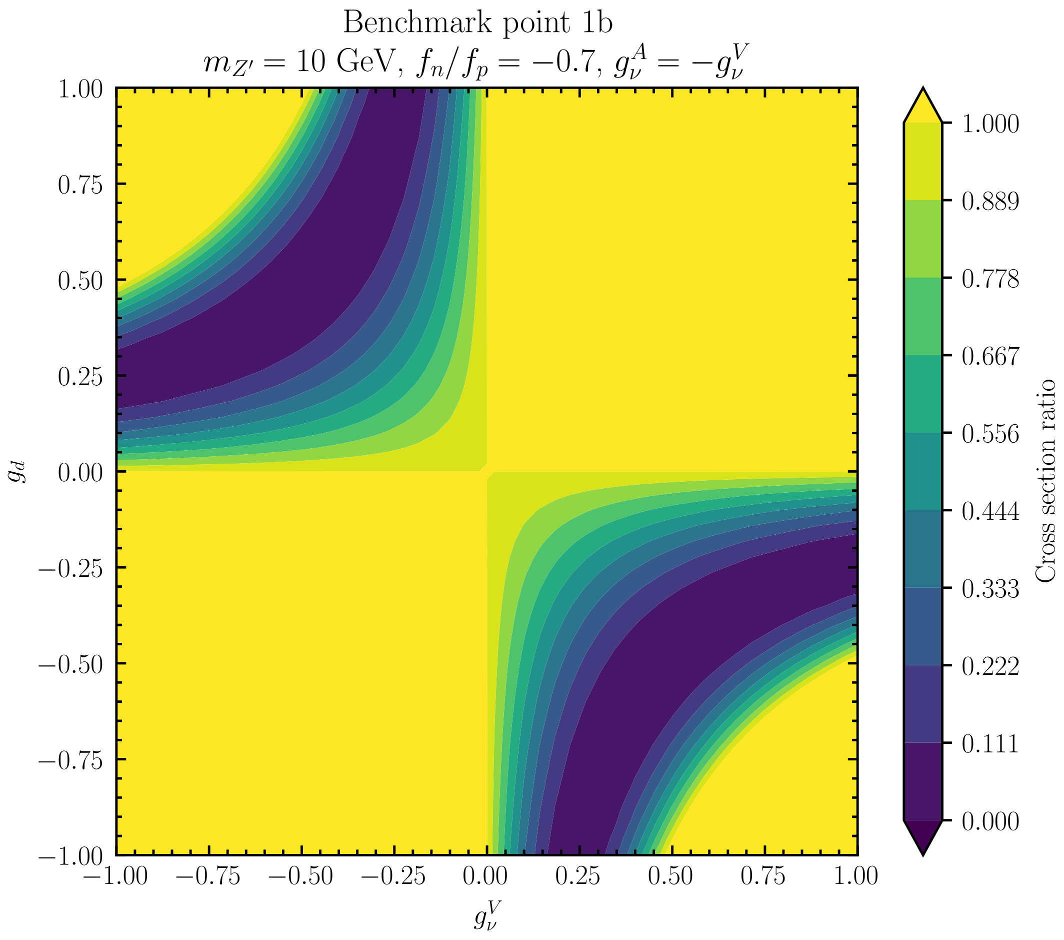

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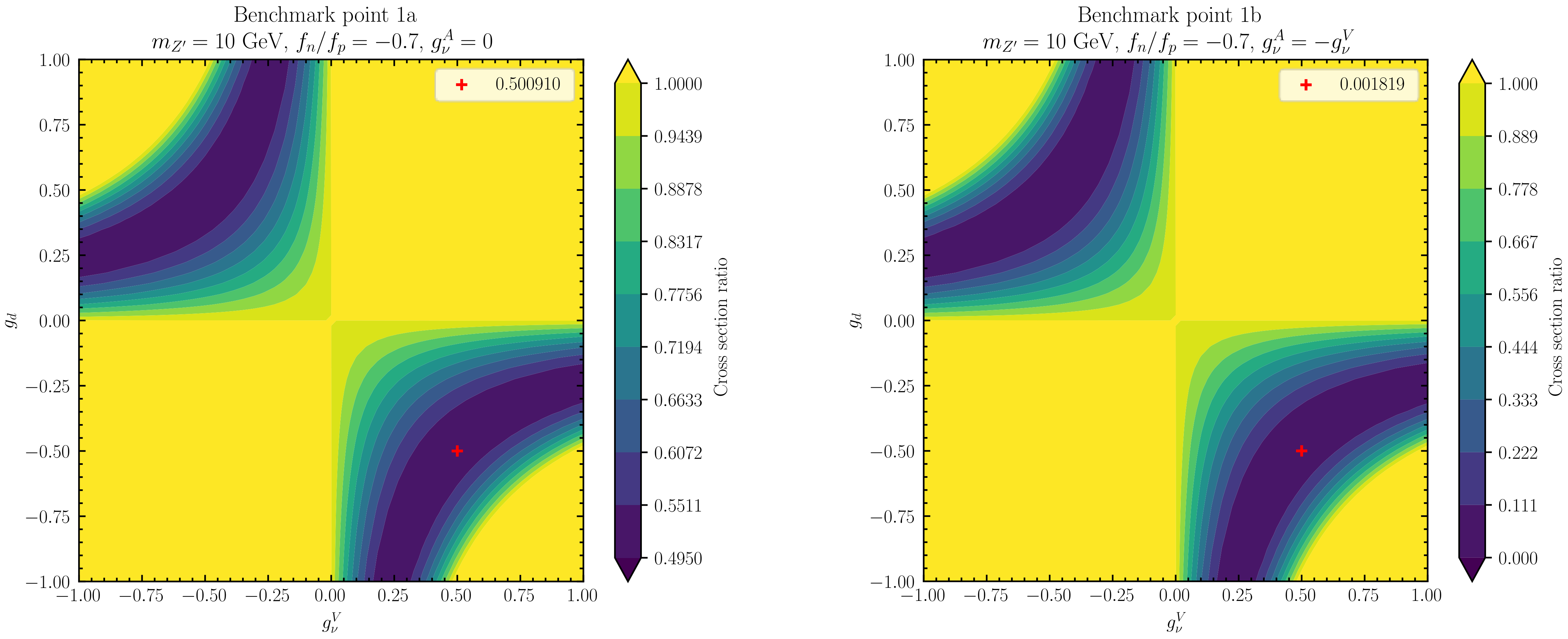

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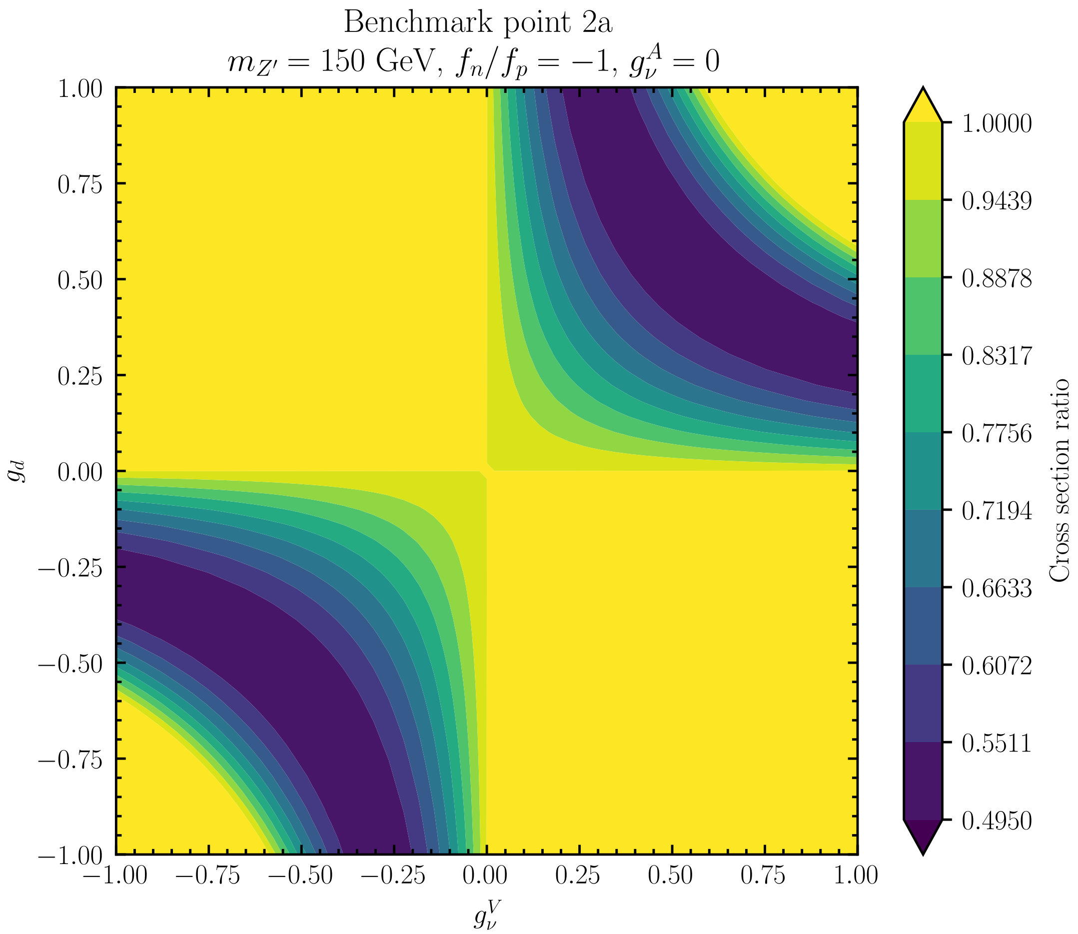

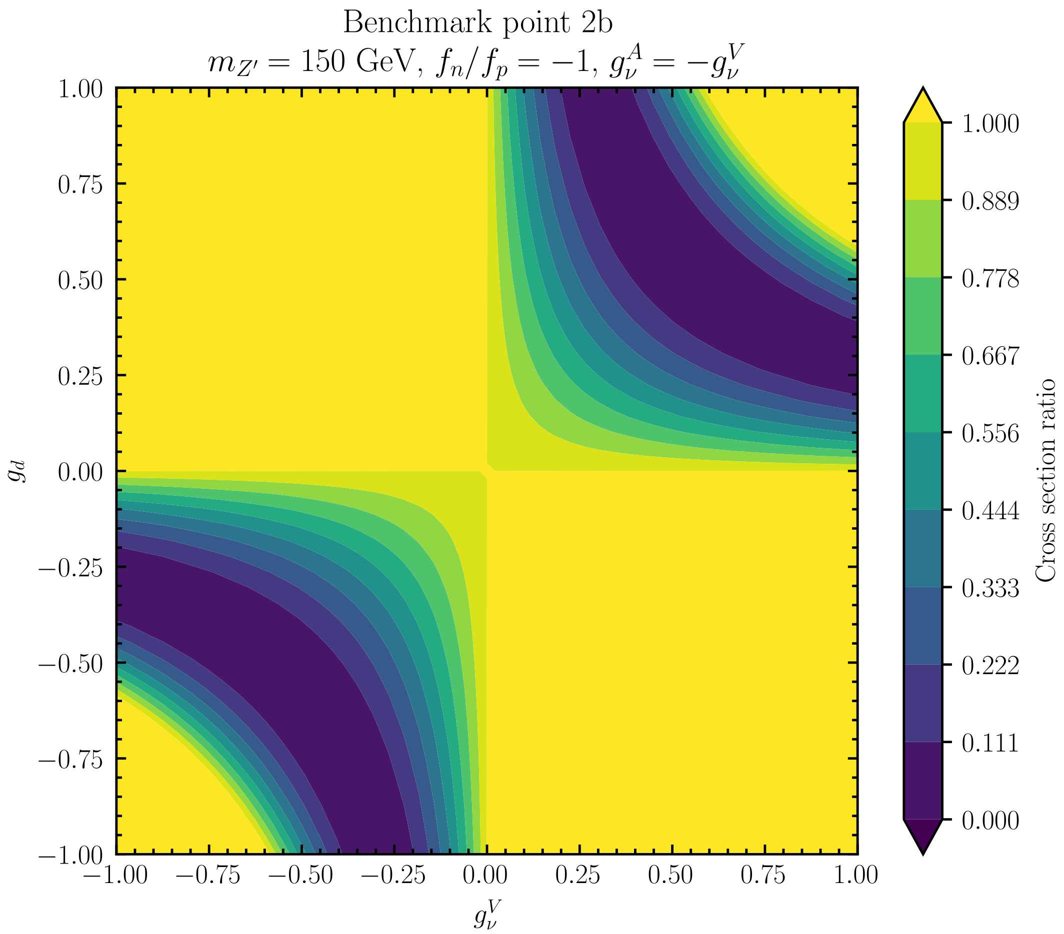

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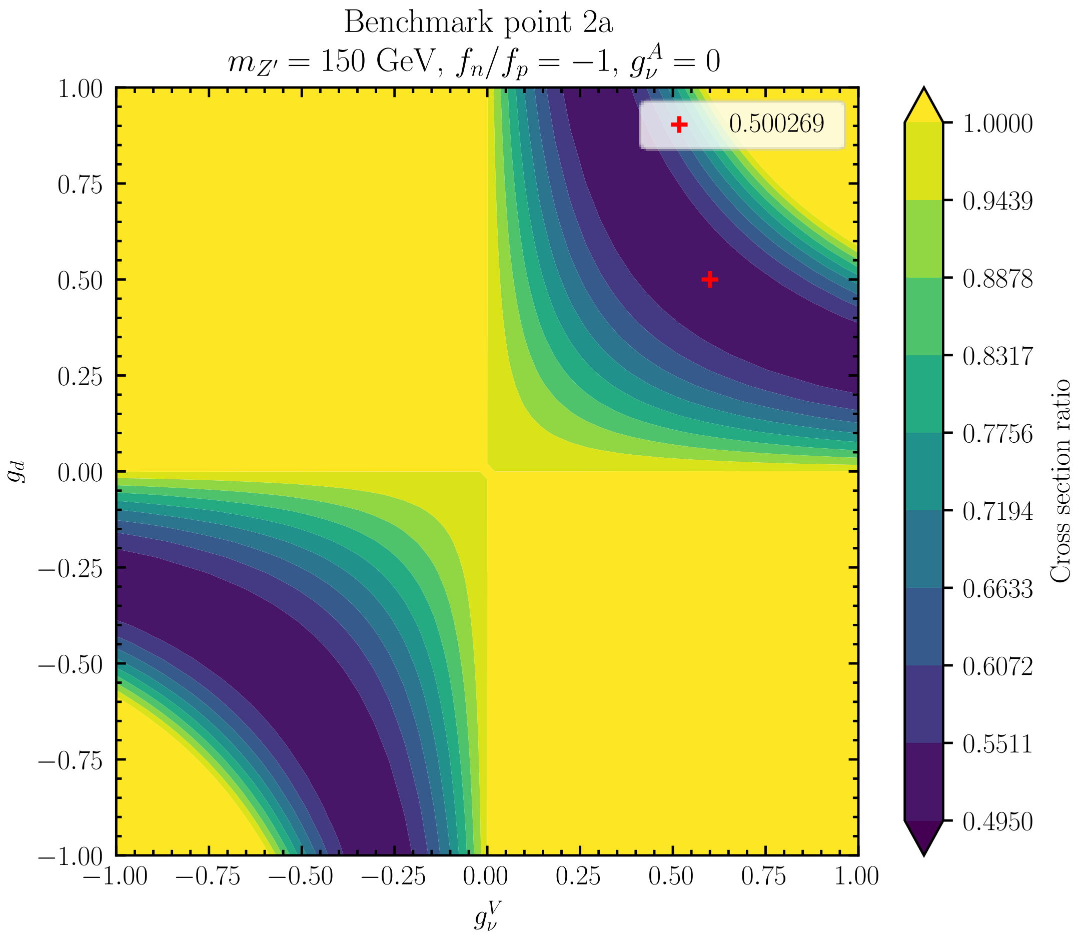

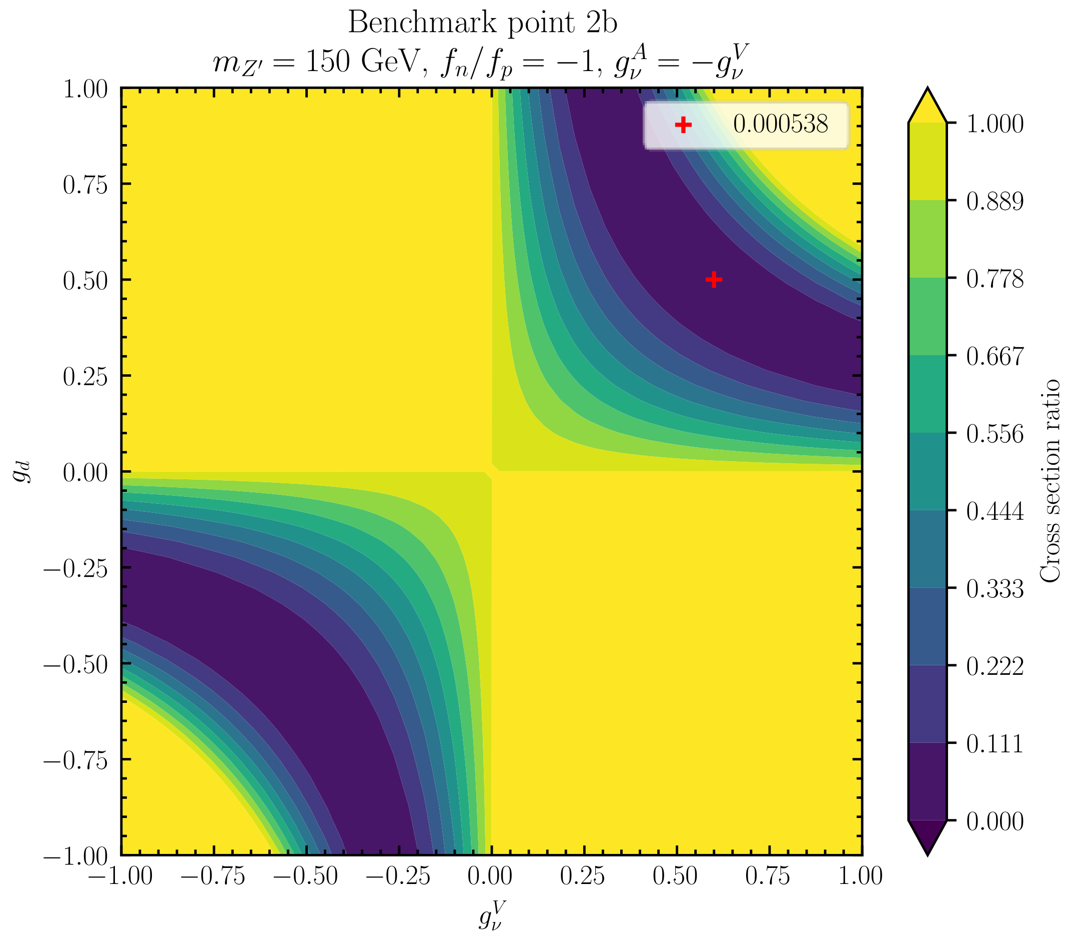

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- Benchmark points:

Name	$m_{Z'}$ (GeV)	f_n/f_p	g_d	g_ν^V	g_ν^A
1a	10	-0.7	-0.5	0.5	0
1b	10	-0.7	-0.5	0.5	-0.5
2a	150	-1.0	0.5	0.6	0
2b	150	-1.0	0.5	0.6	-0.6

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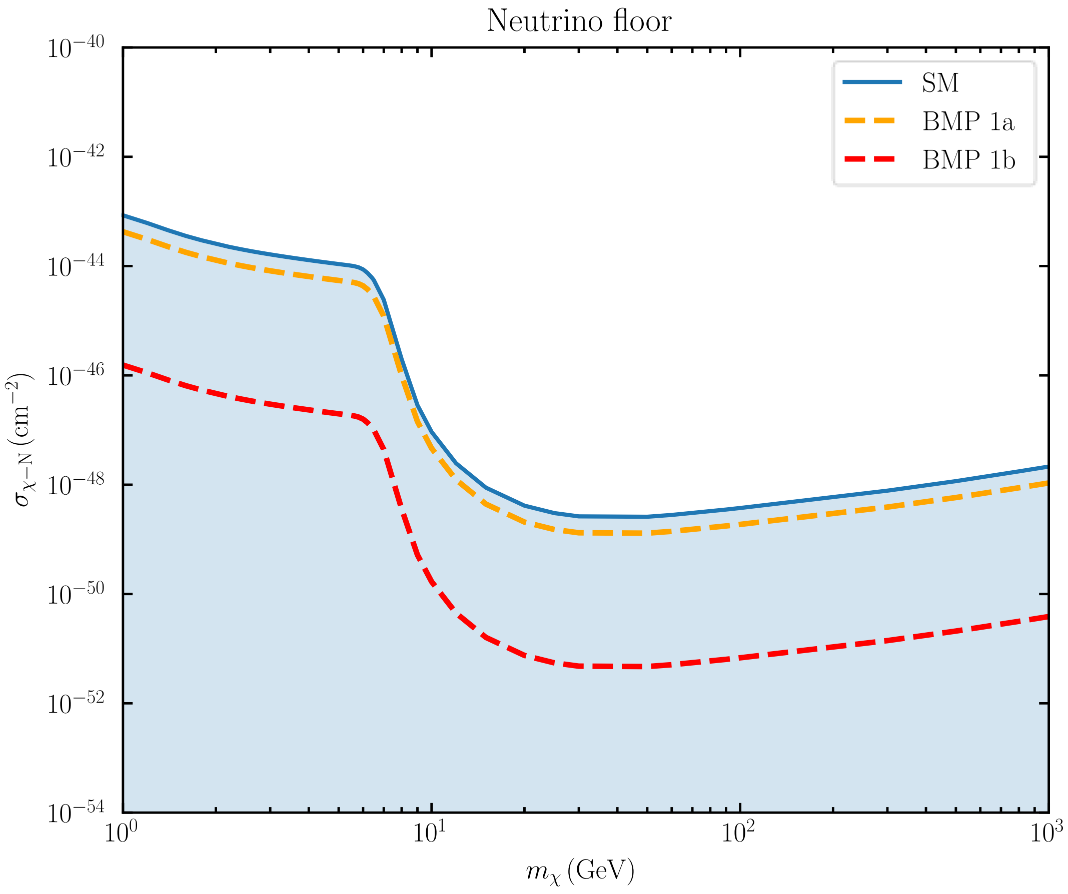

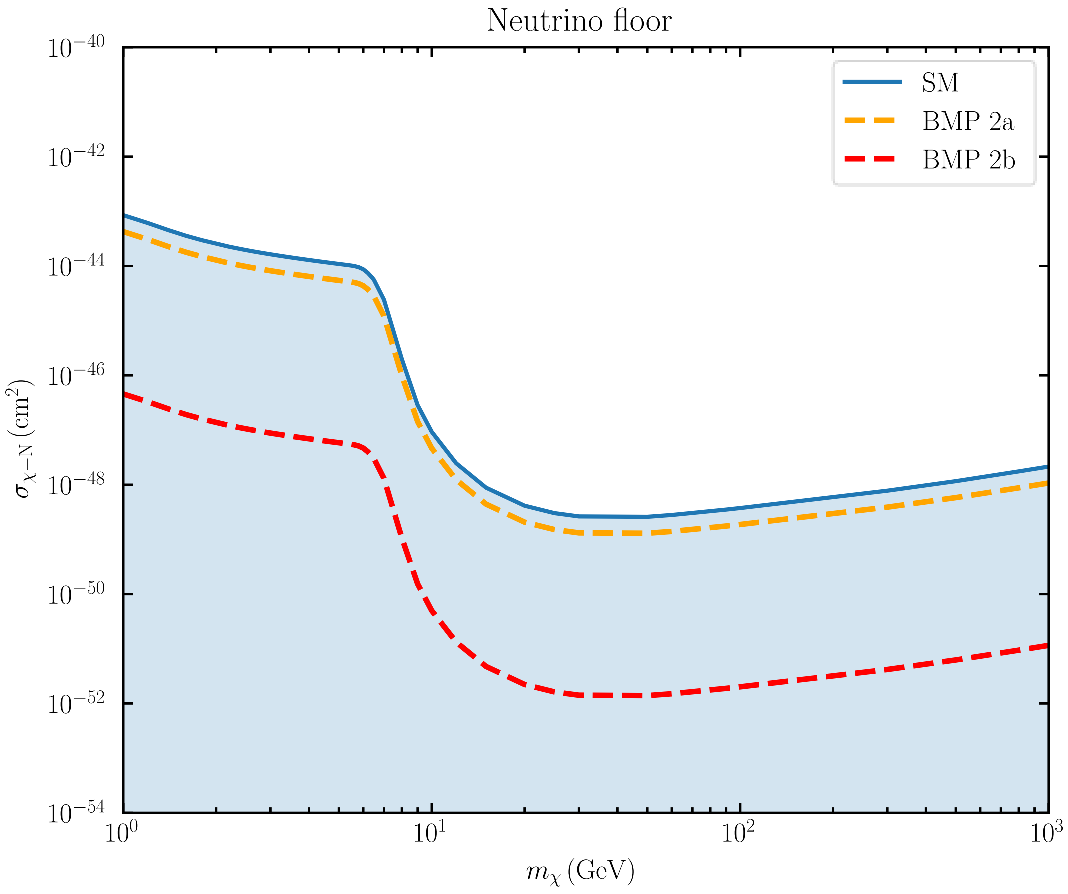

In summary

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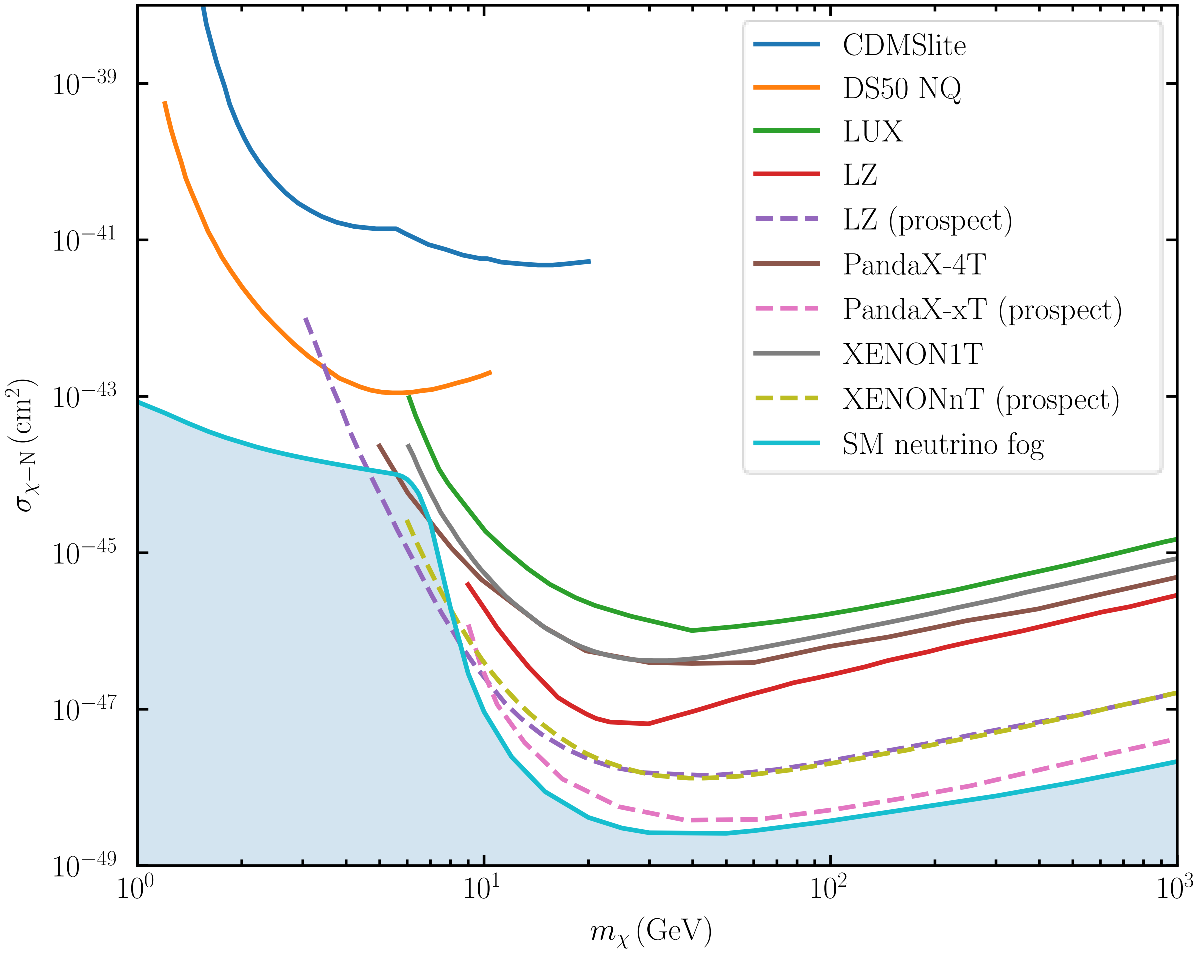
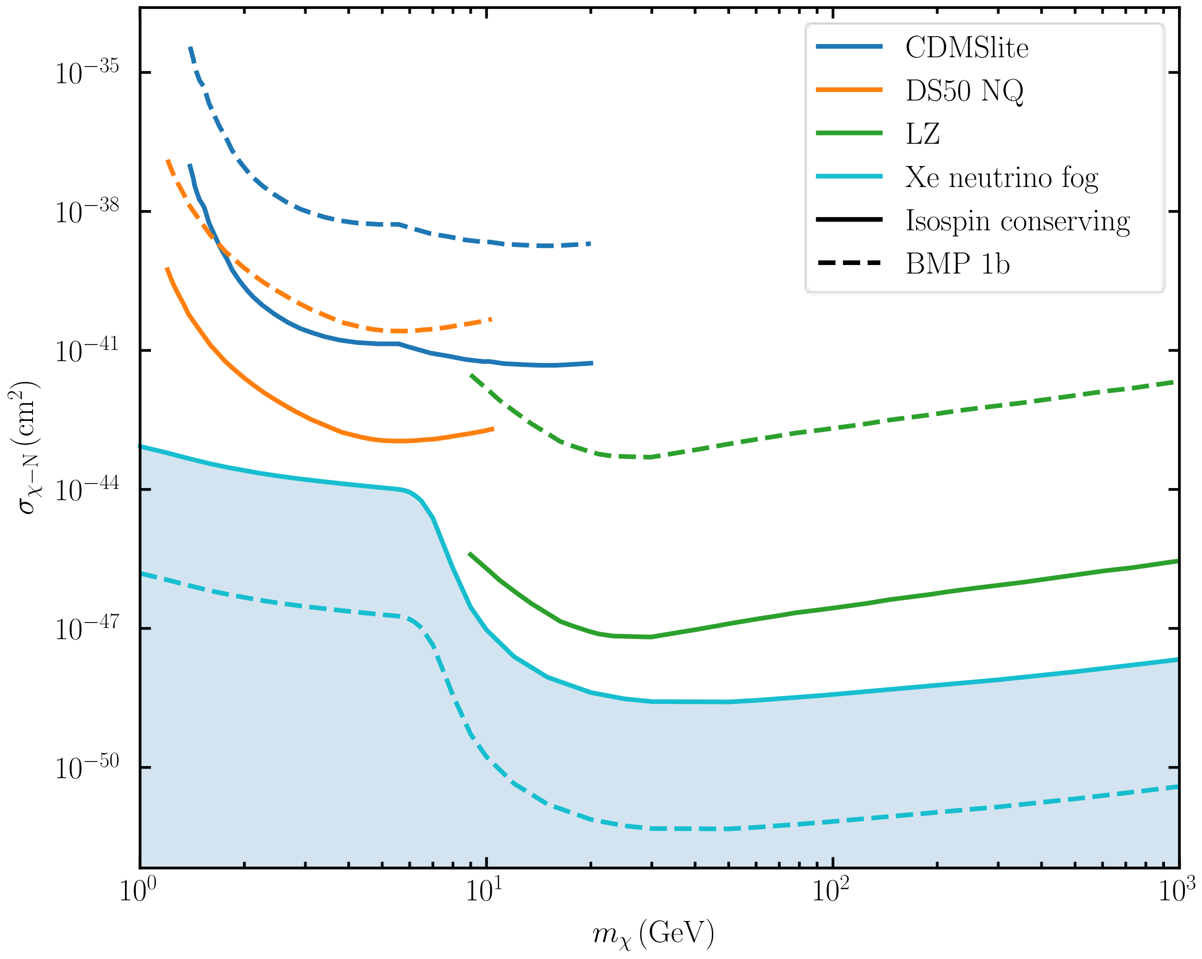


CDMSlite
DS50 NQ
LUX
LZ
LZ (prospect)
PandaX-4T
PandaX-xT (prospect)
XENON1T
XENONnT (prospect)
SM neutrino fog
10^{-39}
10^{-41}
10^{-43}
10^{-45}
10^{-47}
10^{-49}
$\sigma_{\chi-N}\,(\mathrm{cm}^2)$
10^0
10^1
10^2
10^3
$m_\chi\,(\mathrm{GeV})$

In summary



CDMSlite
DS50 NQ
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Xe neutrino fog
Isospin conserving
BMP 1b
10^{-35}
10^{-38}
10^{-41}
10^{-44}
10^{-47}
10^{-50}
$\sigma_{\chi-N}\,(\mathrm{cm}^2)$
10^0
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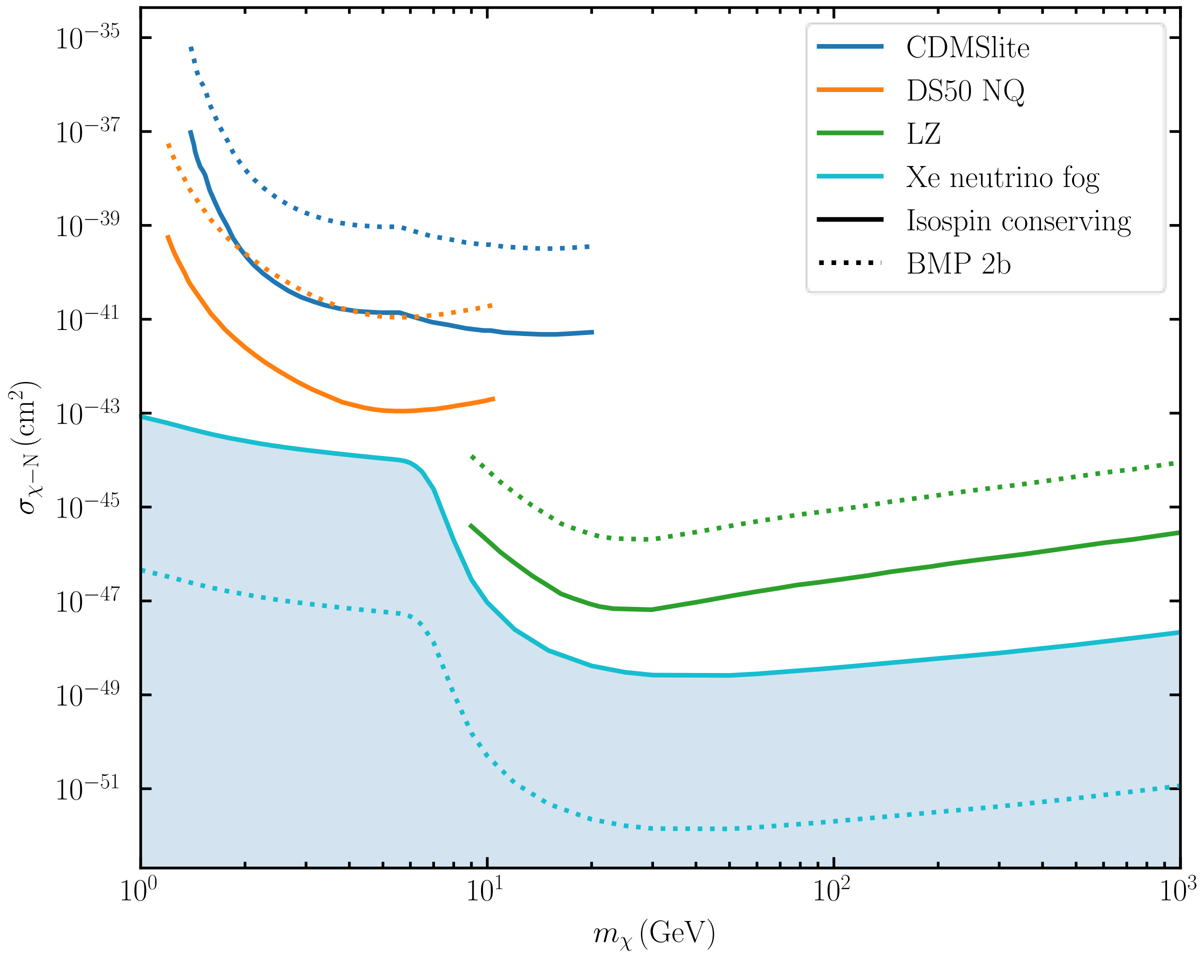

CDMSlite
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10^{-35}
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10^{-43}
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10^{-51}
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10^2
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- Neutrino floor → Affected by more parameters and can be **relaxed/enhanced**

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- Exclusion bounds $\longrightarrow$ Only affected by f_n/f_p and only **relaxed**

- Neutrino floor $\longrightarrow$ Affected by more parameters and can be **relaxed/enhanced**

- For some choices of parameters, separation between them can reach **~7-8 orders of magnitude more** than in the isospin conserving case

Thank you!

Questions and comments appreciated :)