

Cosmological challenges for dark sectors with new gauge forces

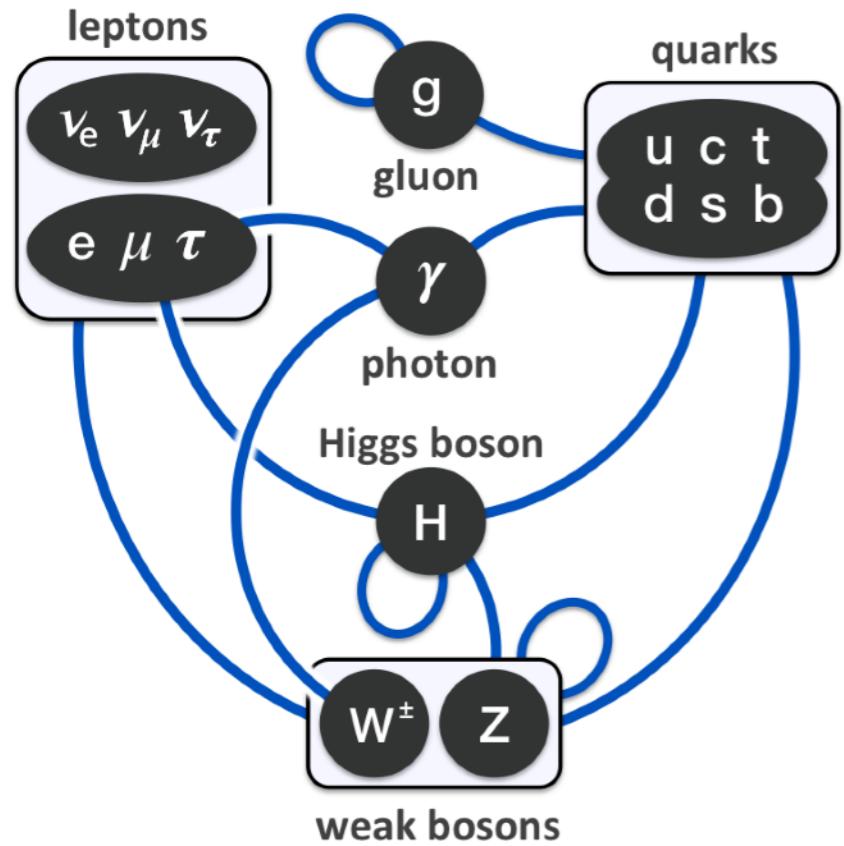
Navin McGinnis

Phenomenology Symposium

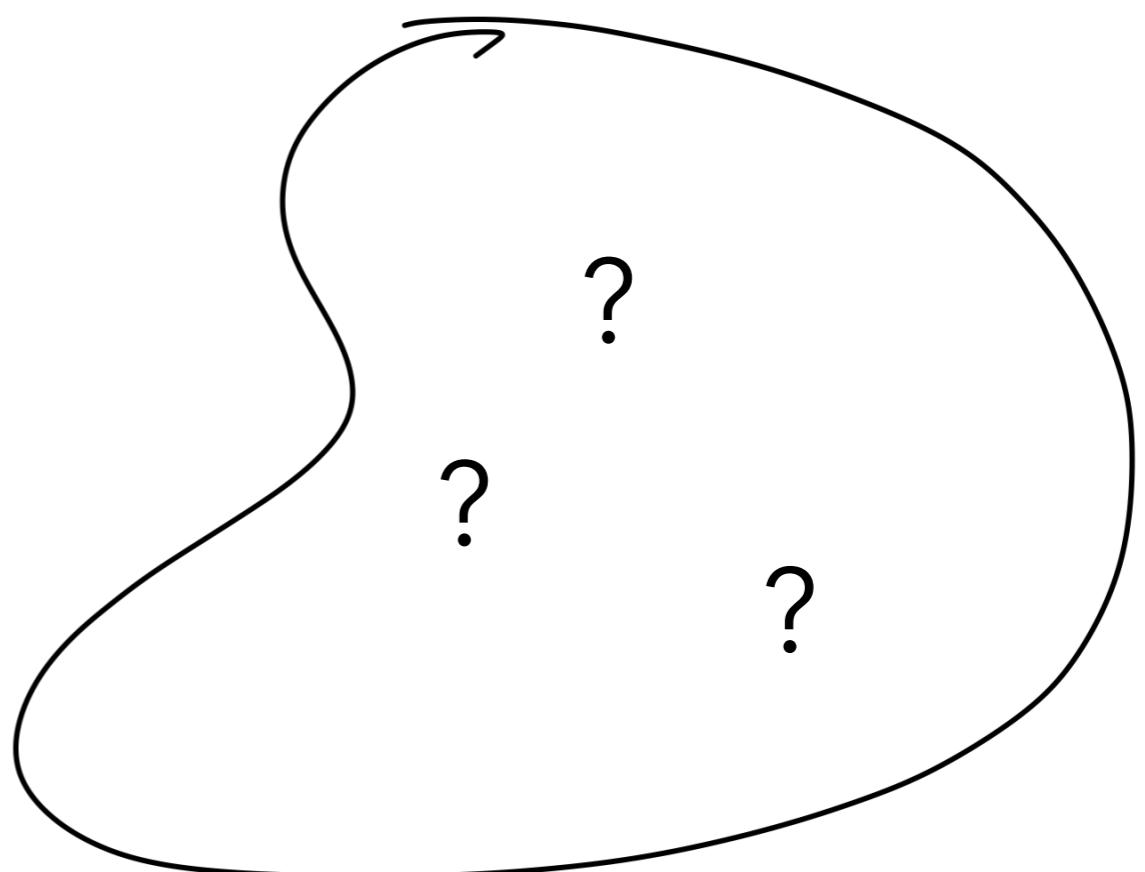
May 9, 2023



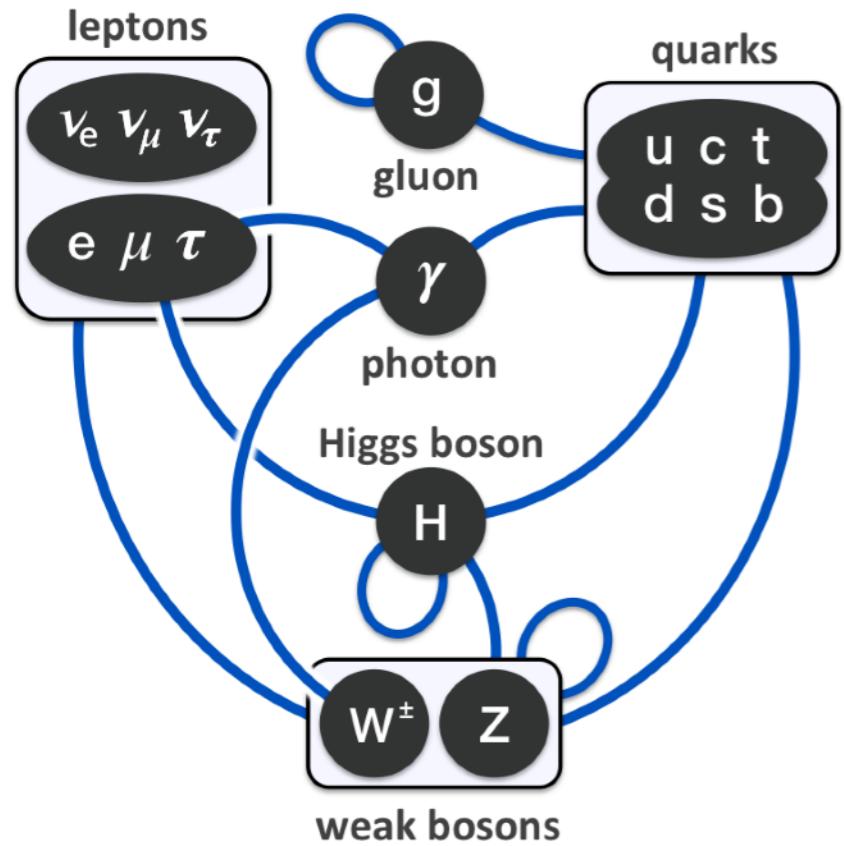
Standard Model



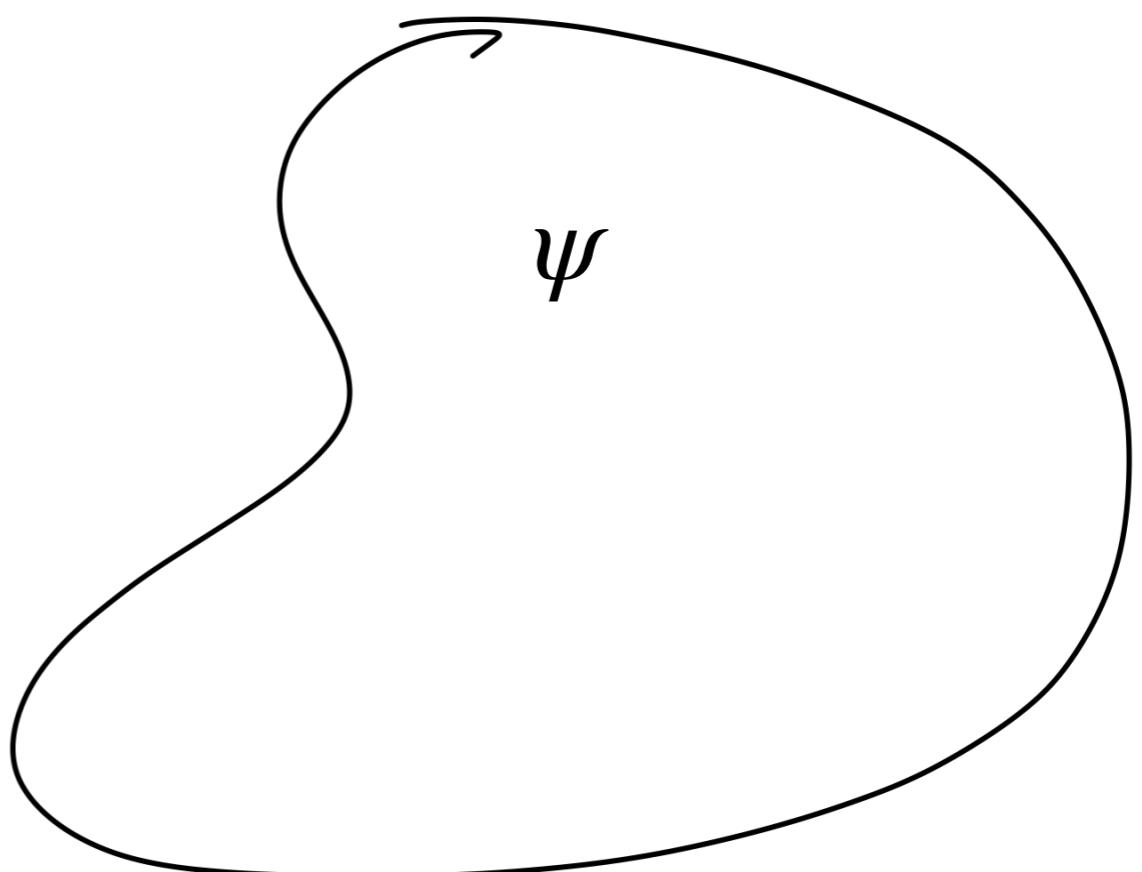
Dark Matter



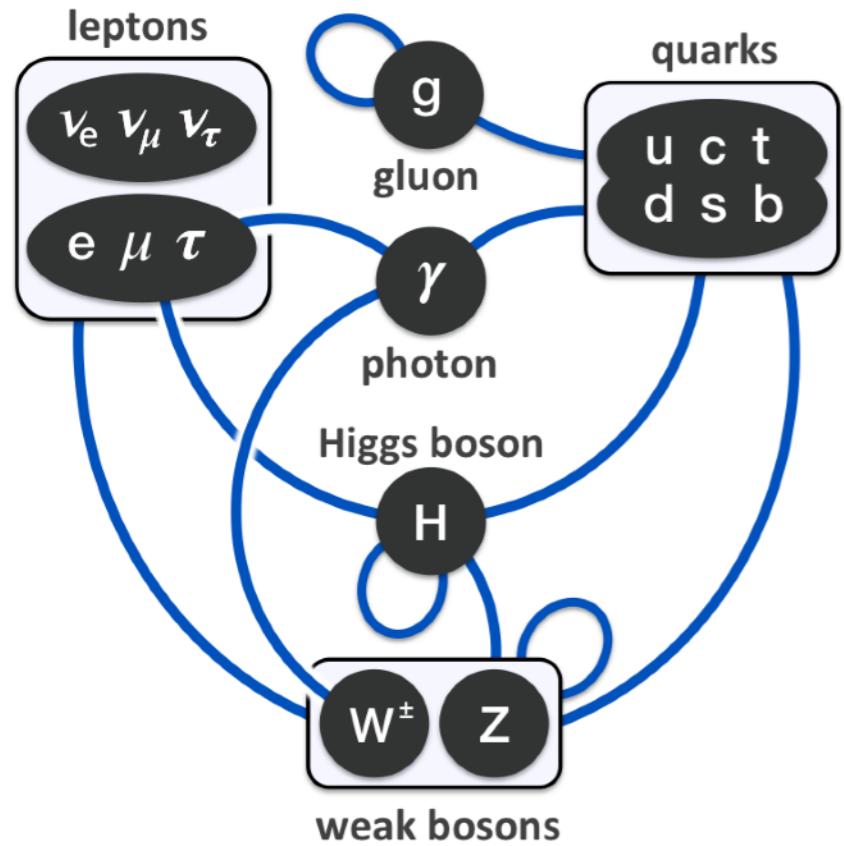
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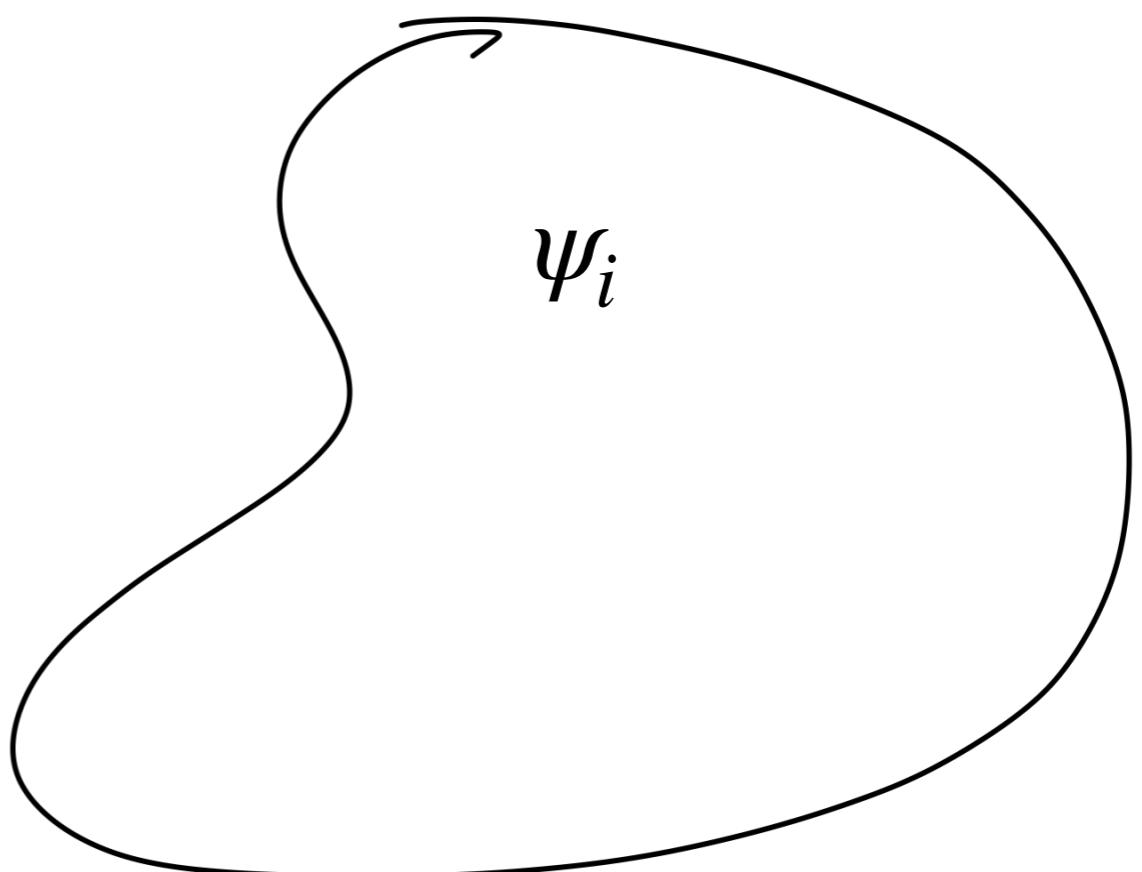
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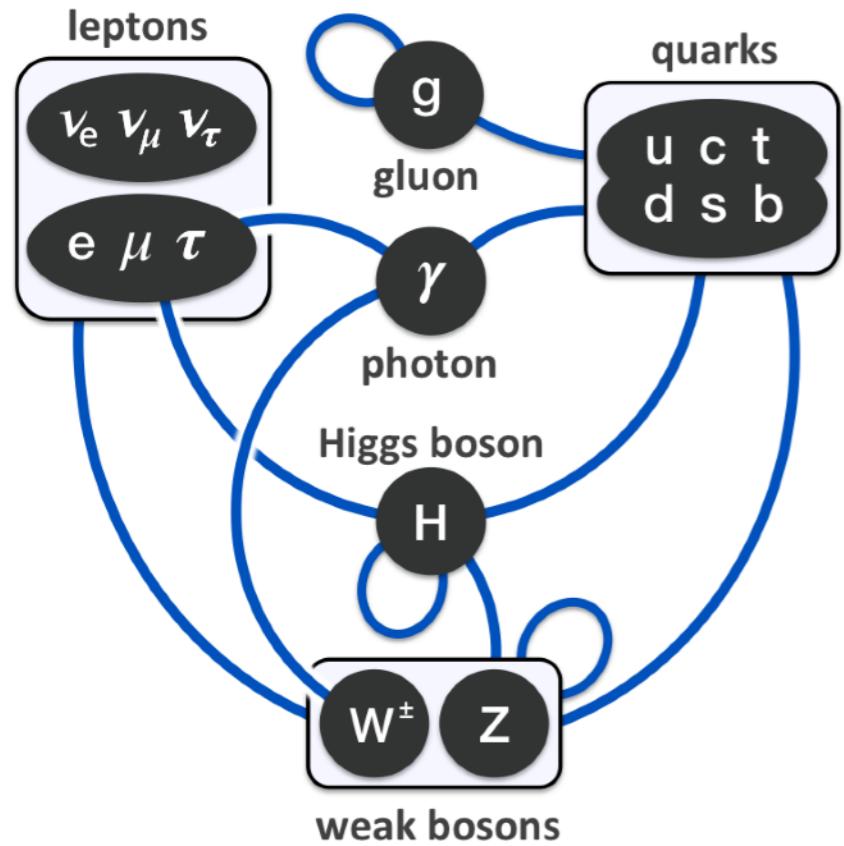
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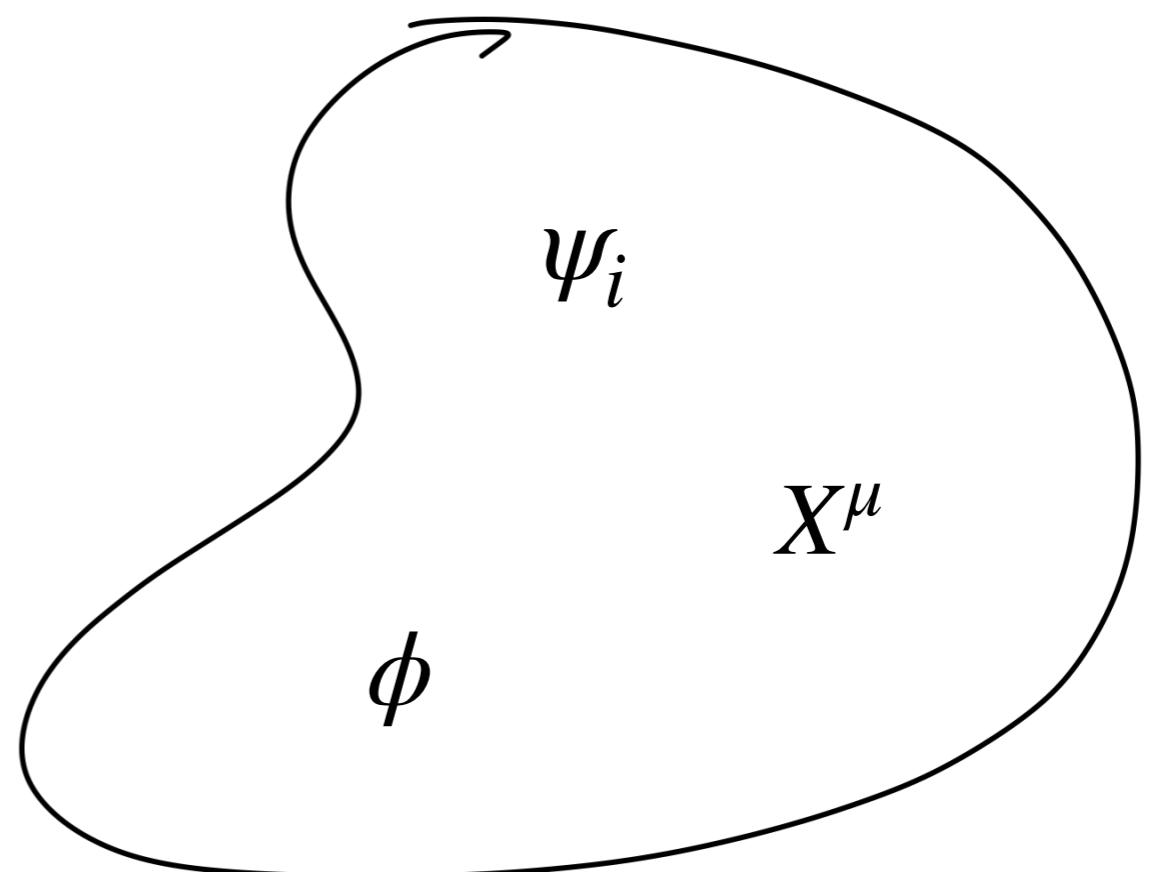
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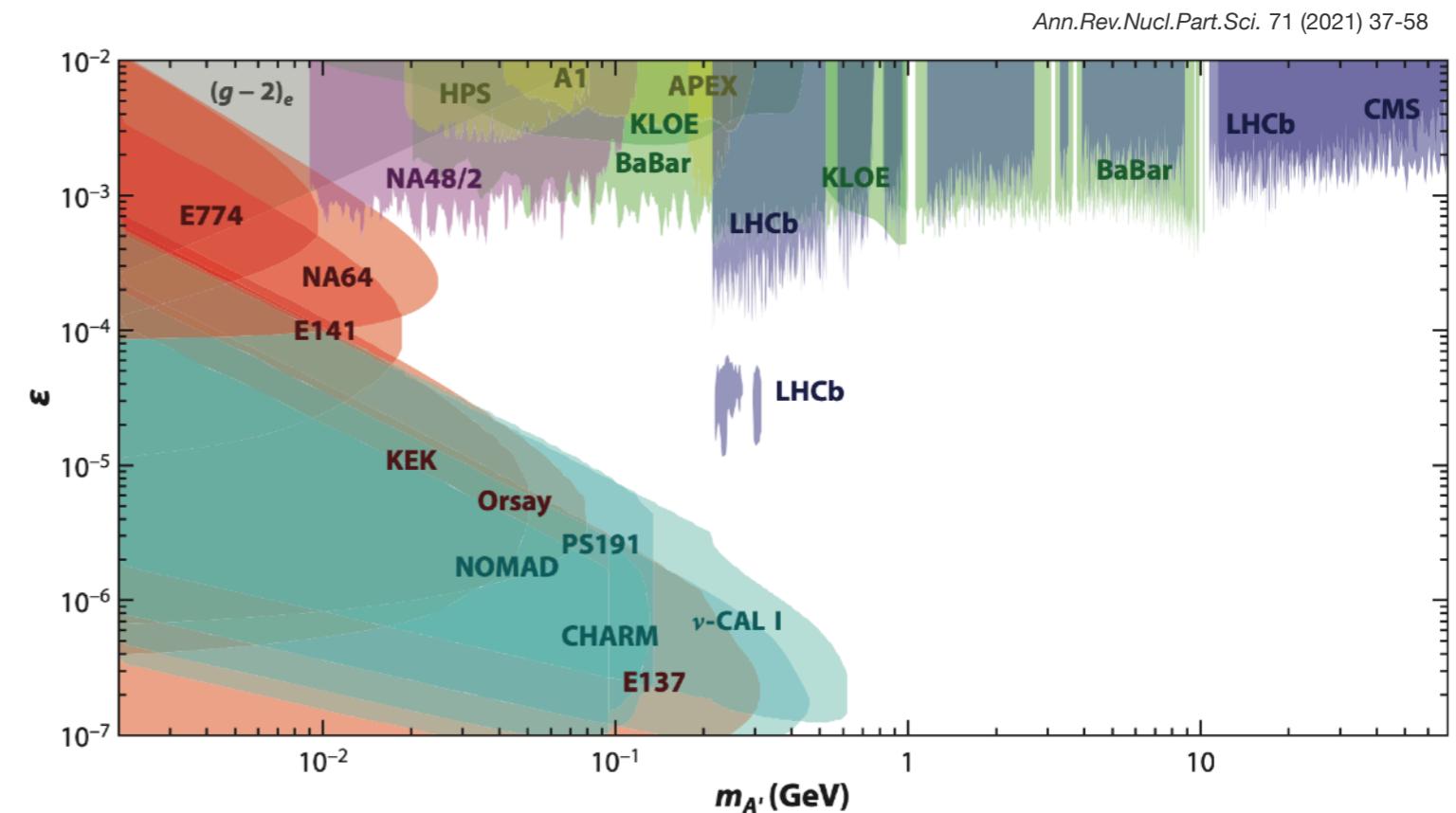


Dark sectors with new gauge forces

$$\mathcal{L} \supset \frac{\epsilon}{2} X^{\mu\nu} F_{\mu\nu} + \frac{1}{2} m_X^2 X^\mu X_\mu$$

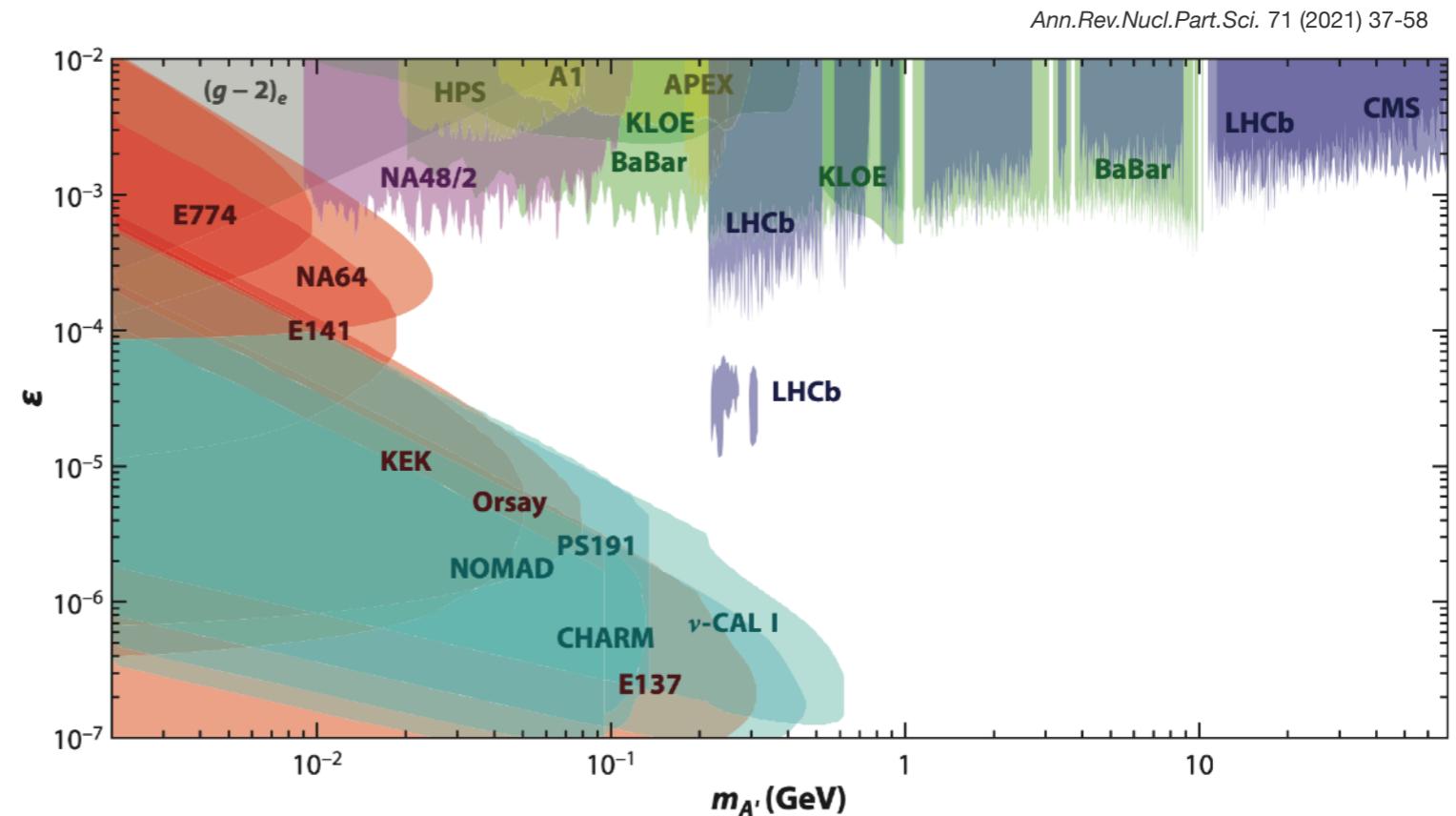
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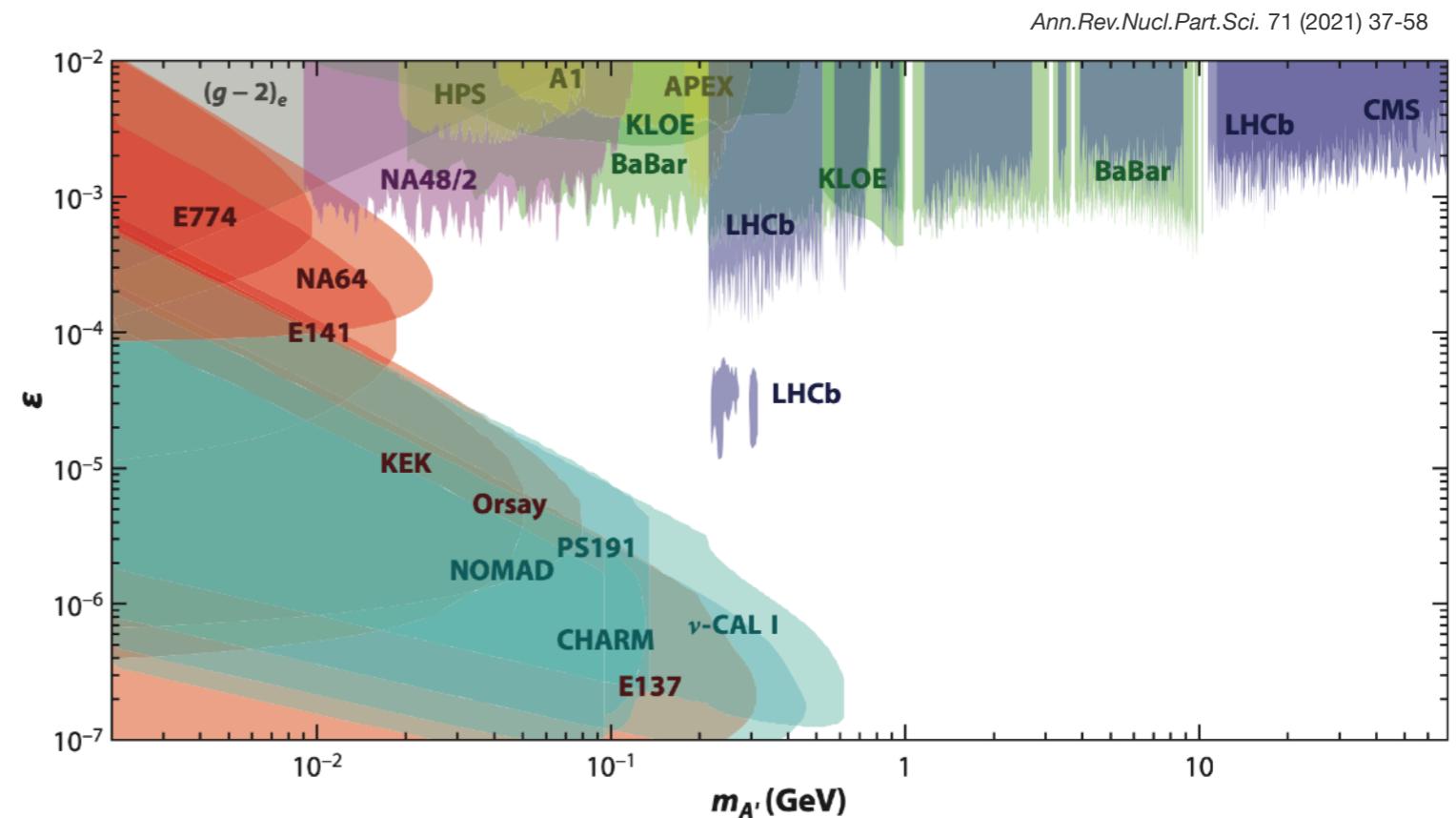
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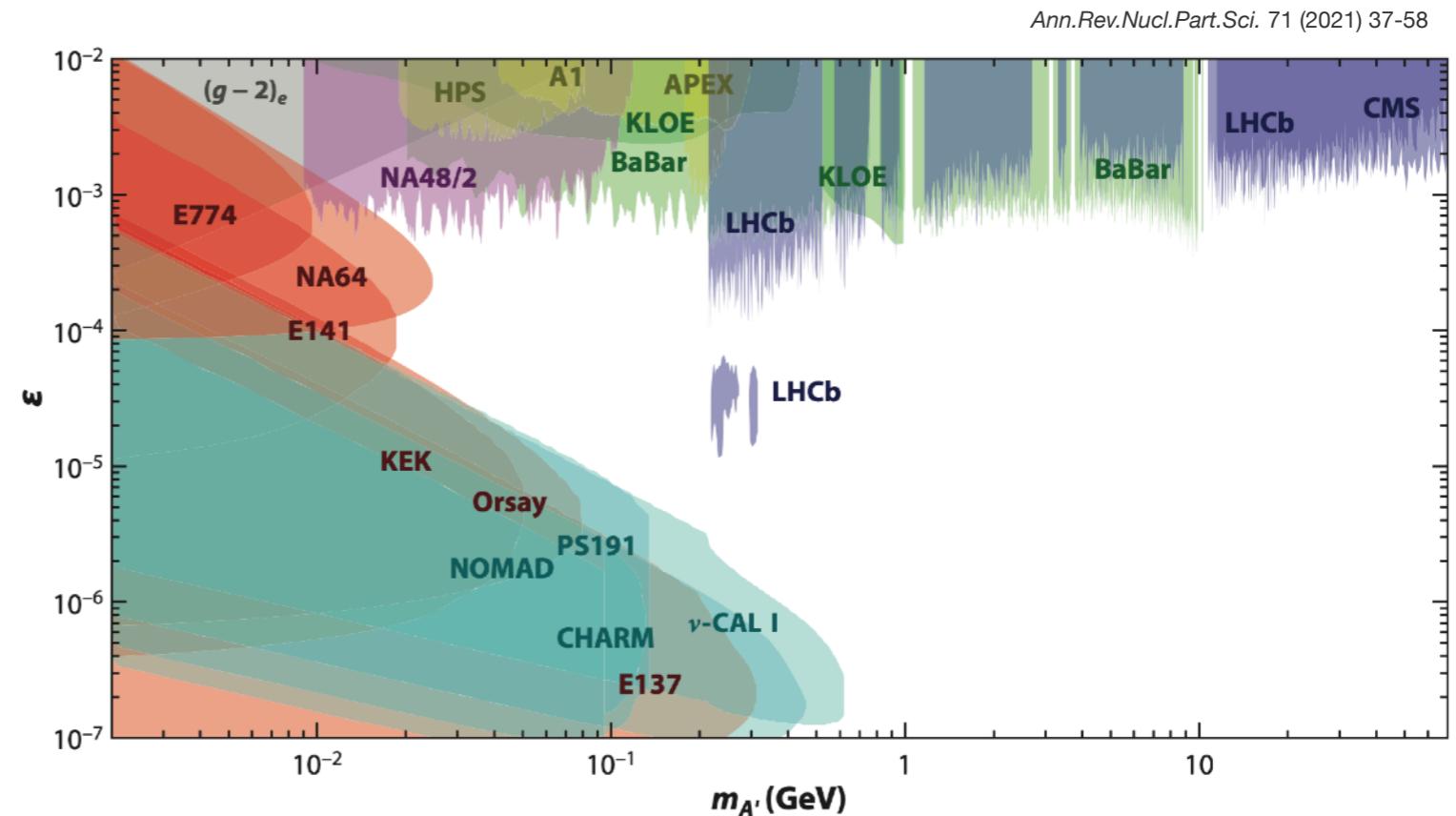
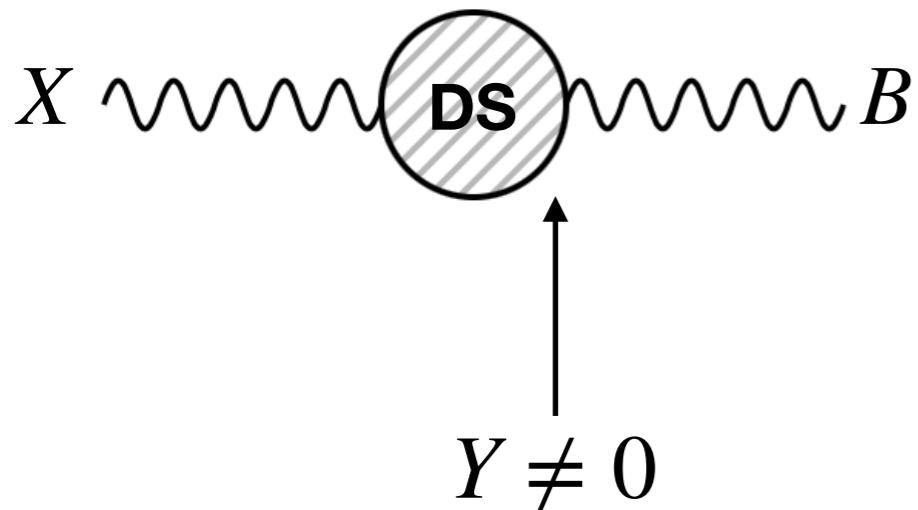
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X **DS** B



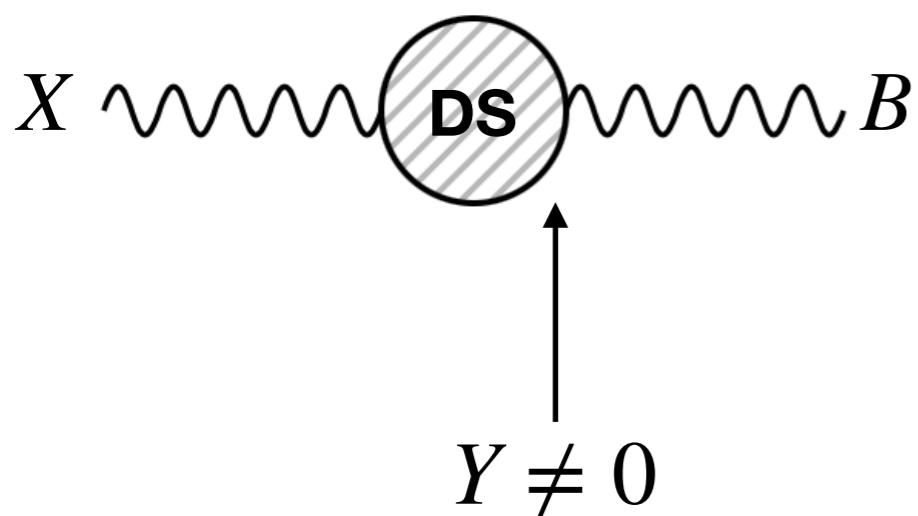
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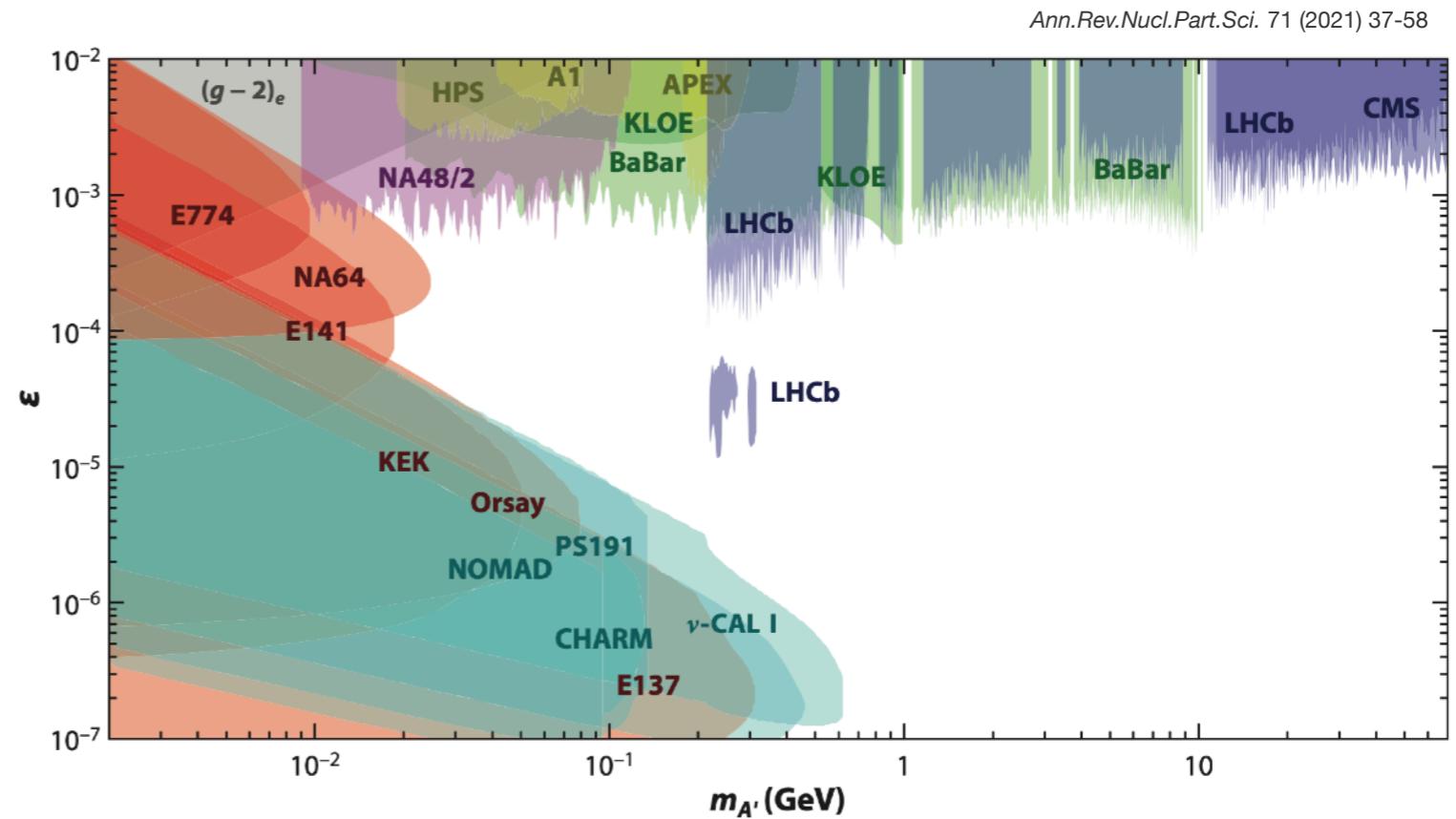


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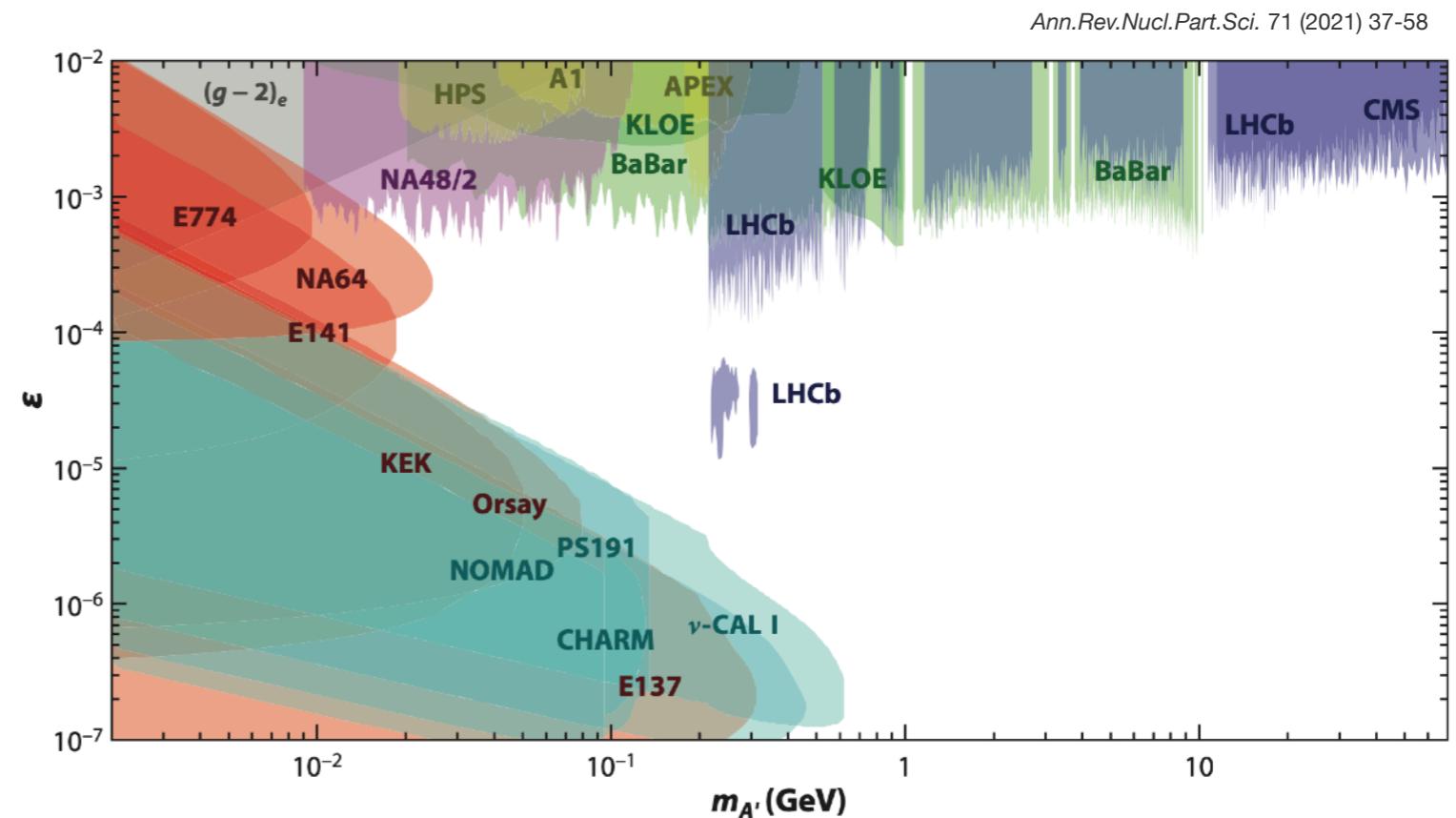


$$Q = T^3 + Y = 0$$

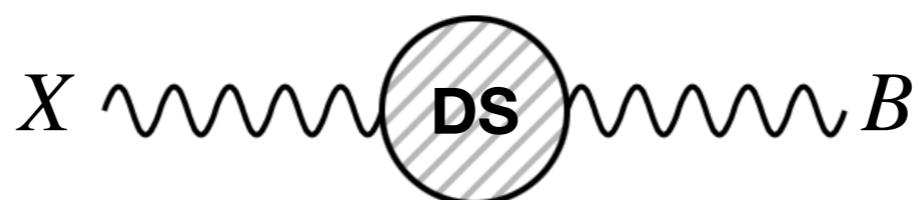


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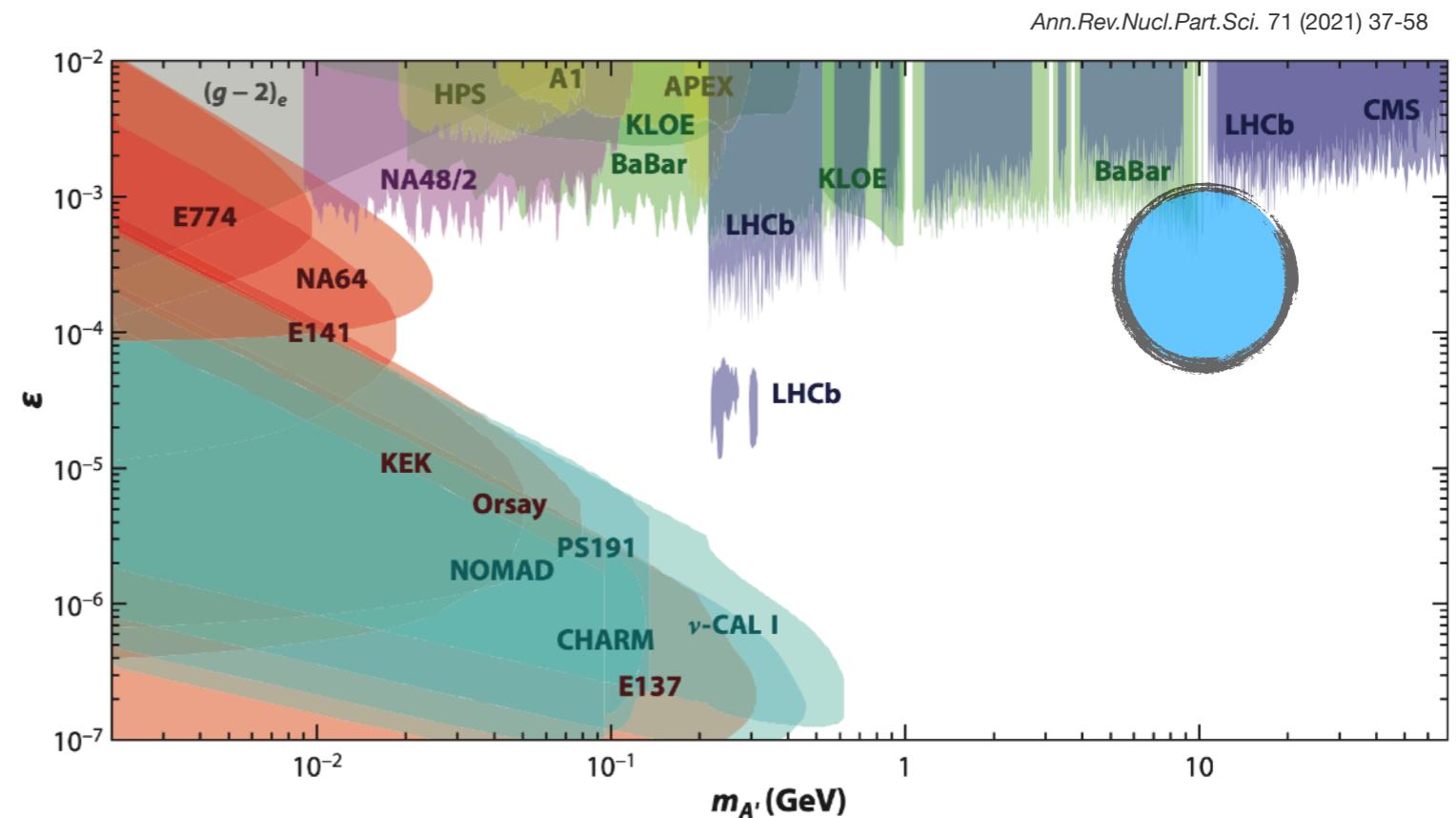
New TeV-scale mediator fermions generate: $\epsilon \sim 10^{-3} - 10^{-4}$



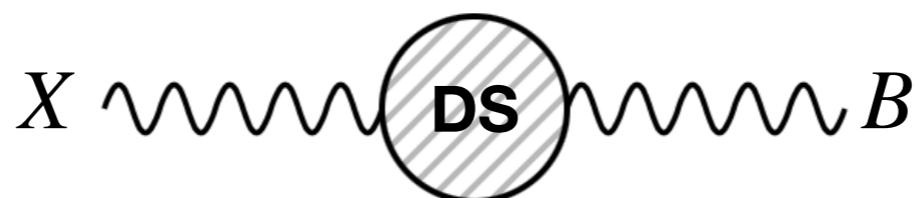
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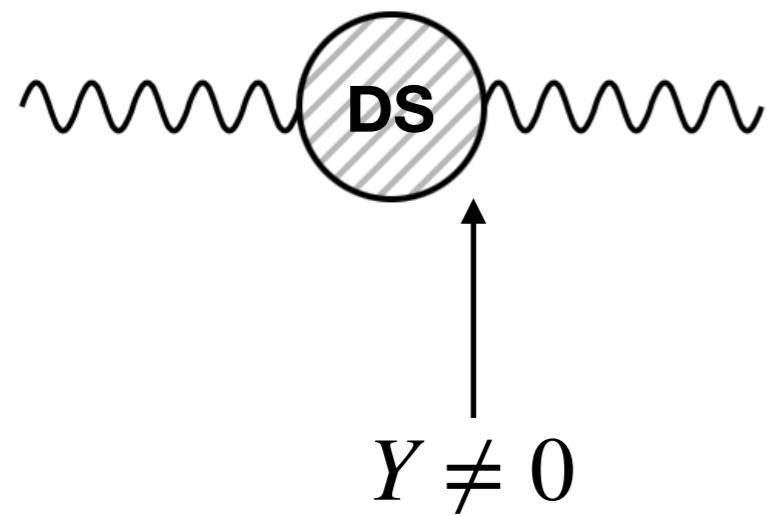
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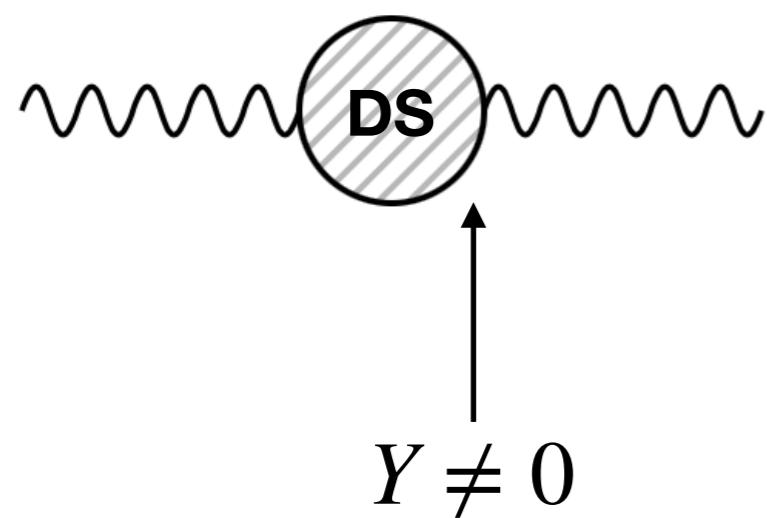
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Generic requirements

WIMP $\times U(1)$

- $\psi_{DM}, Q = 0, T_{RH} > M_{DM}$
- Standard cosmological history: $m_{DM} \leq \mathcal{O}(10)$ TeV (avoiding overclosure)
 - More like $m_{DM} \leq \mathcal{O}(1)$ TeV for perturbatively weak annihilation sections
- Abelian dark gauge force: Dirac fermions/complex scalars

$$\mathcal{L} \supset \frac{\epsilon}{2} X^{\mu\nu} B_{\mu\nu} + \frac{1}{2} m_X^2 X^\mu X_\mu$$



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- Abelian dark gauge force: Dirac fermions/ complex scalars
- “Natural” - no small parameters

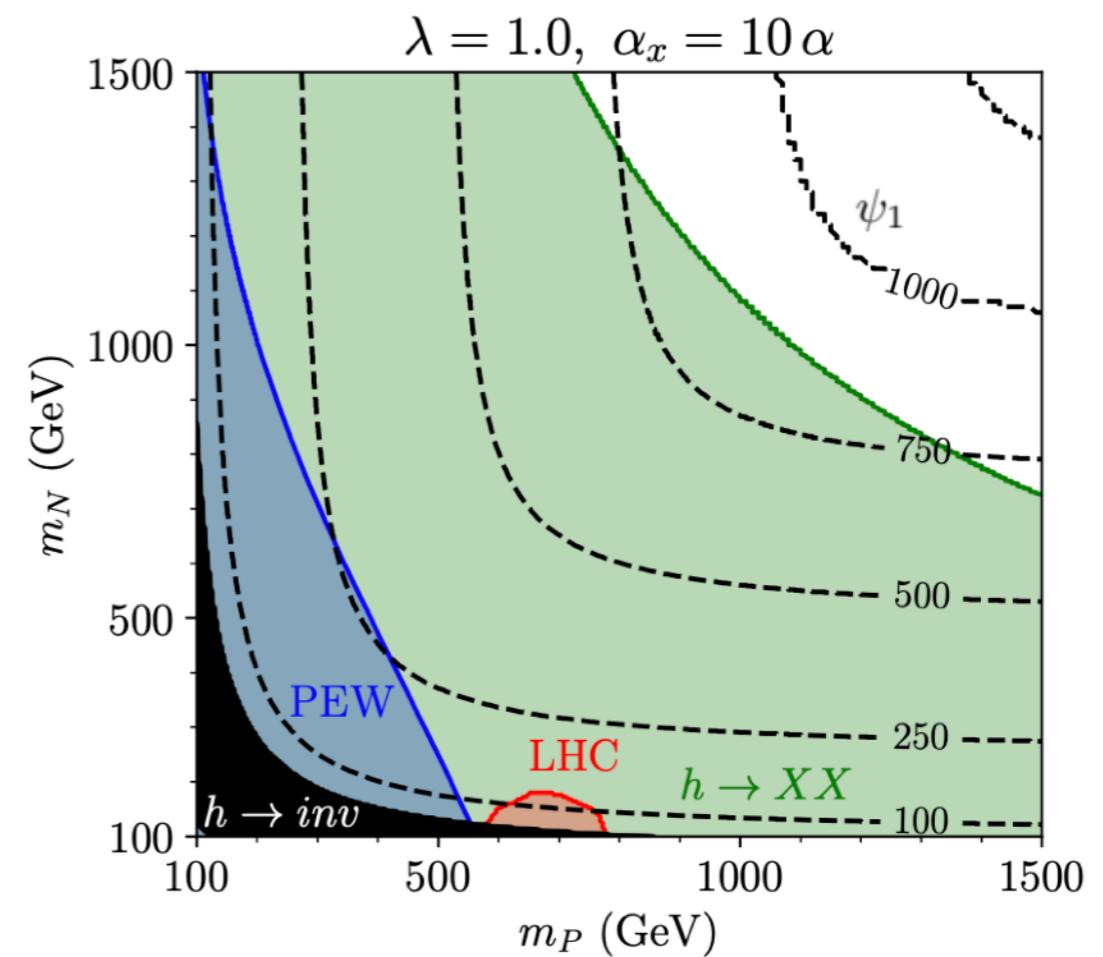
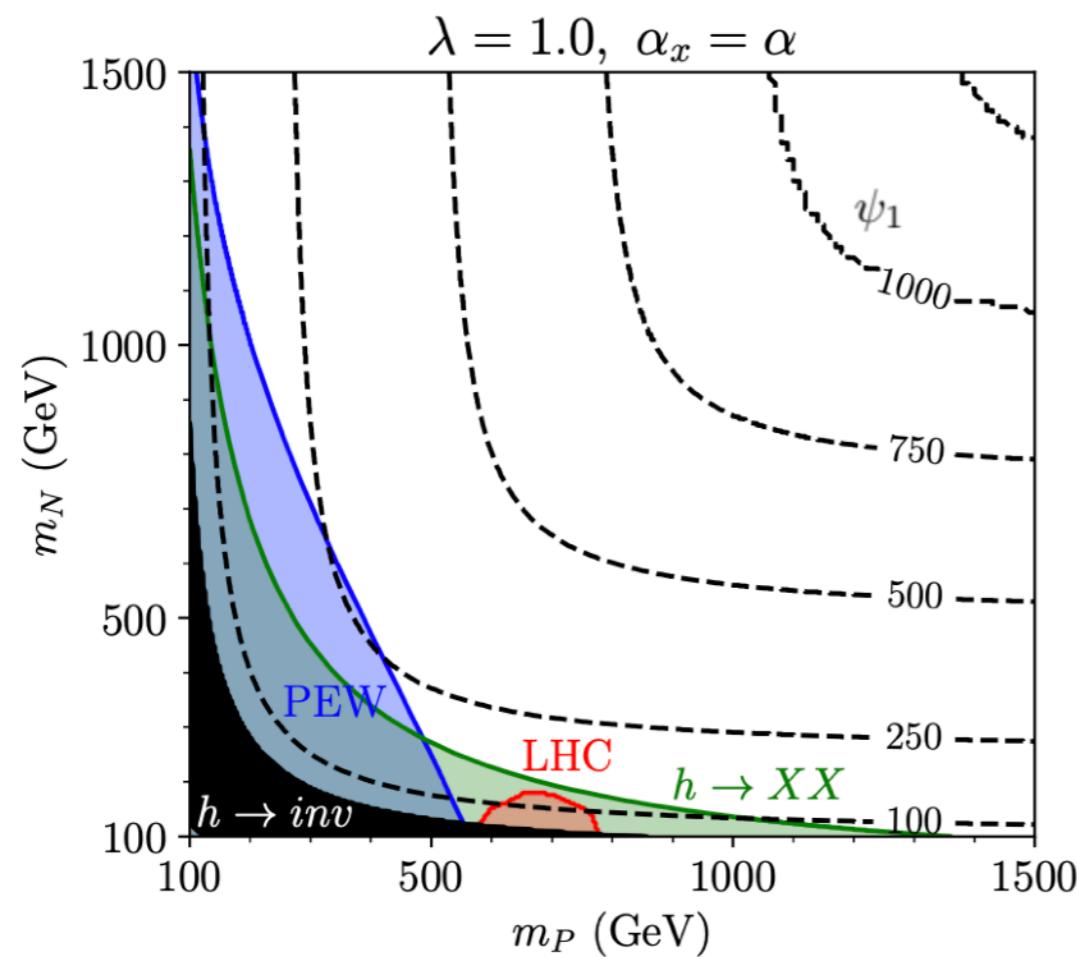
Generic scenarios lead us to models with connector matter light enough to be potentially observable in existing experiments

WIMP \times $U(1)$: LHC bounds

Benchmark model

$$-\mathcal{L} \supset \left(\lambda \bar{P} \tilde{H} N + h.c. \right) + m_P \bar{P} P + m_N \bar{N} N$$

$N = (1, 1, 0; q_x)$ and $P = (1, 2, -1/2; q_x)$.

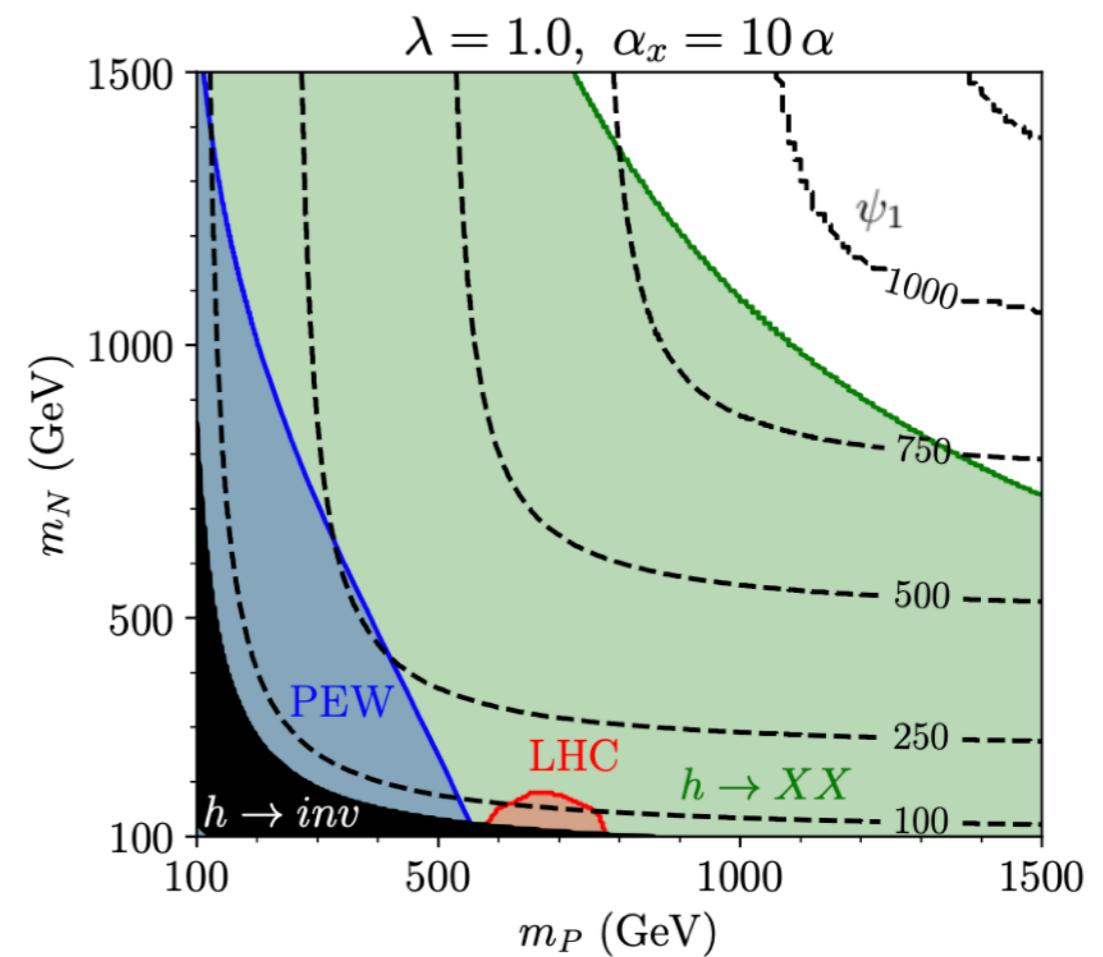
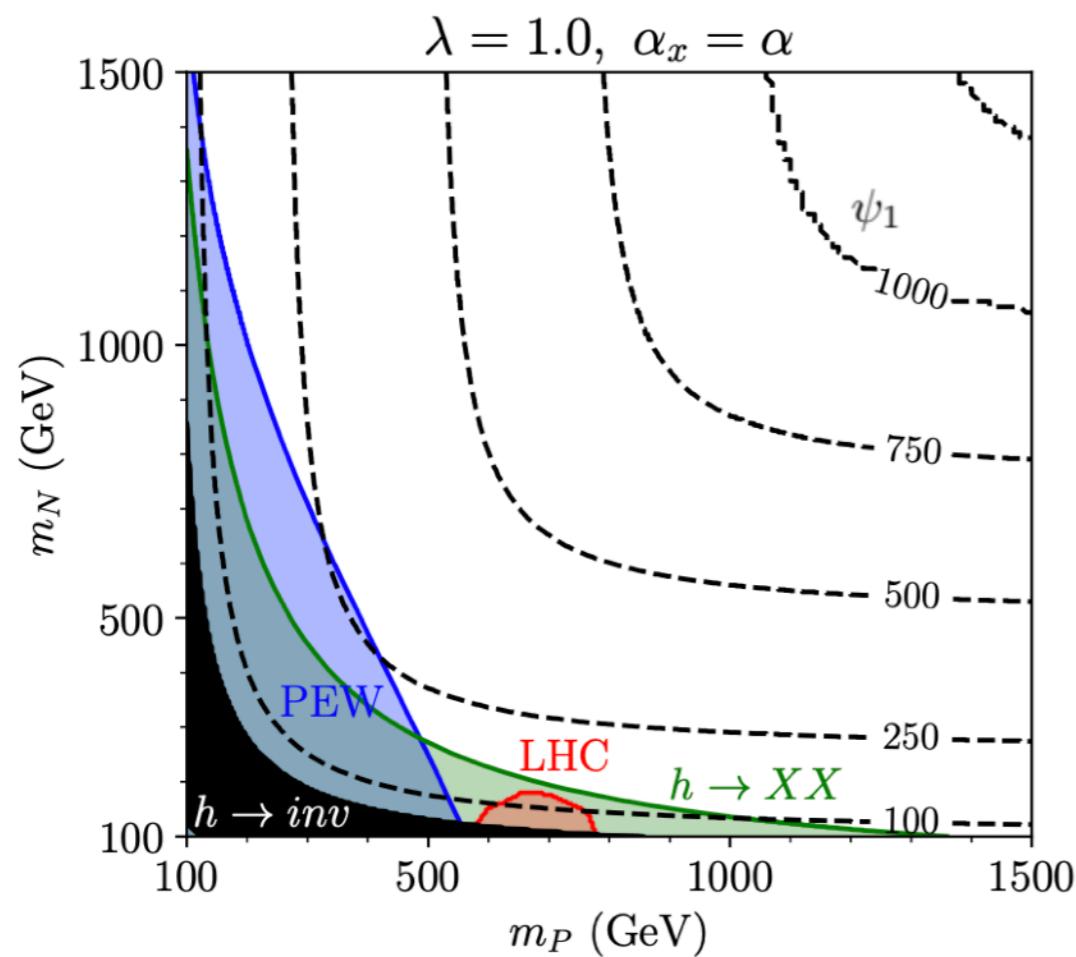
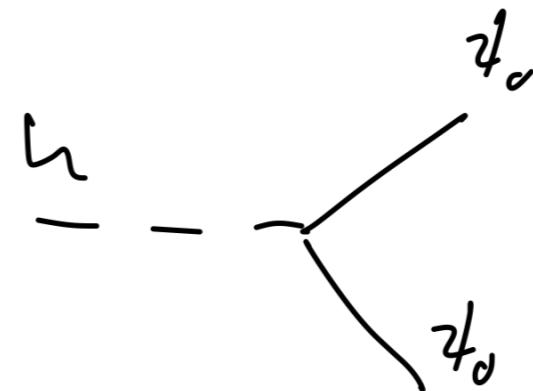


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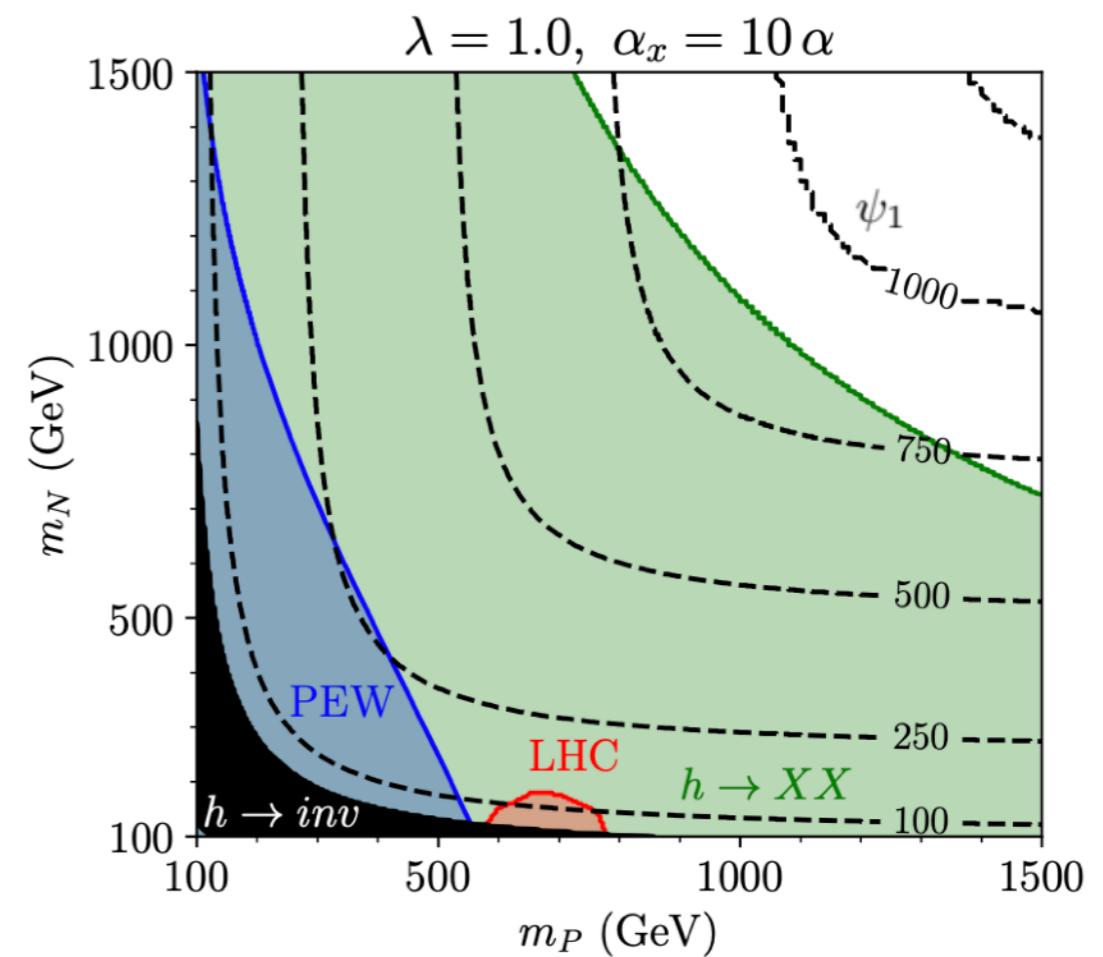
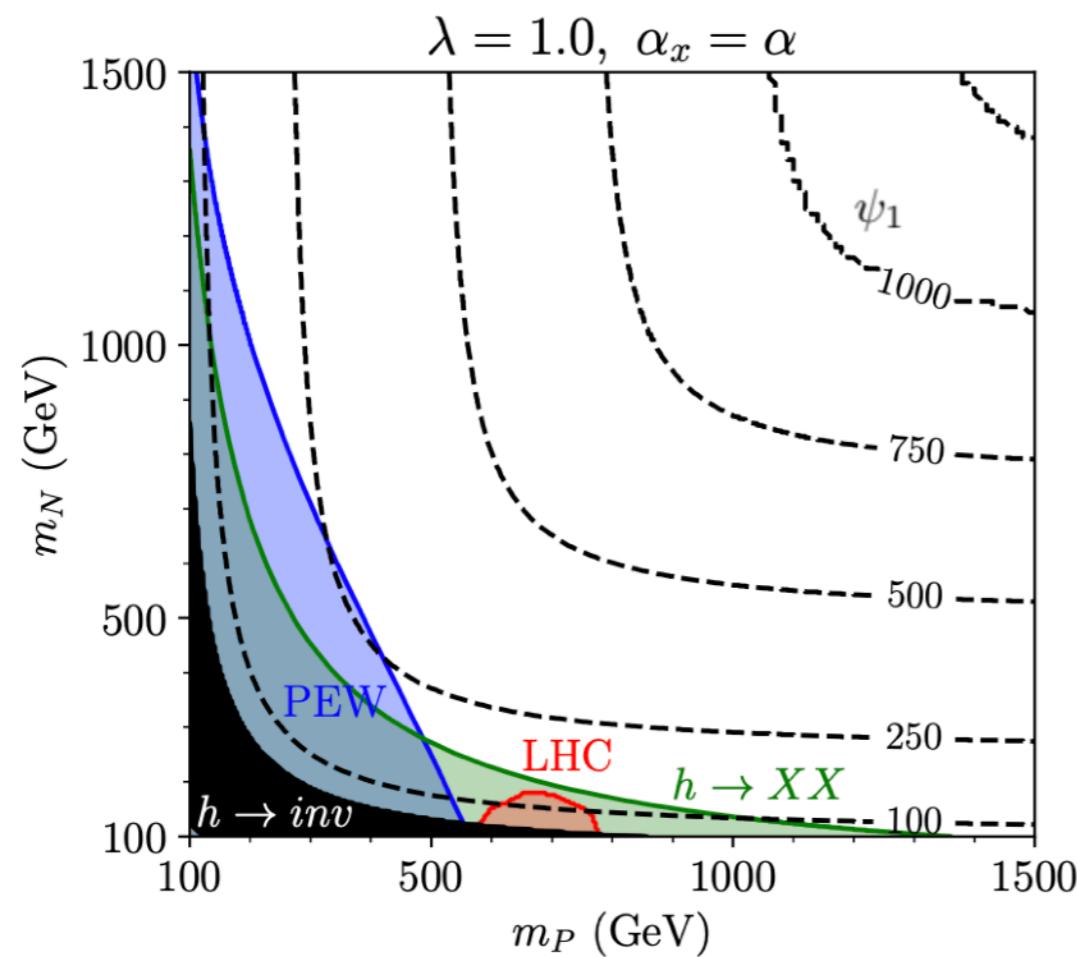


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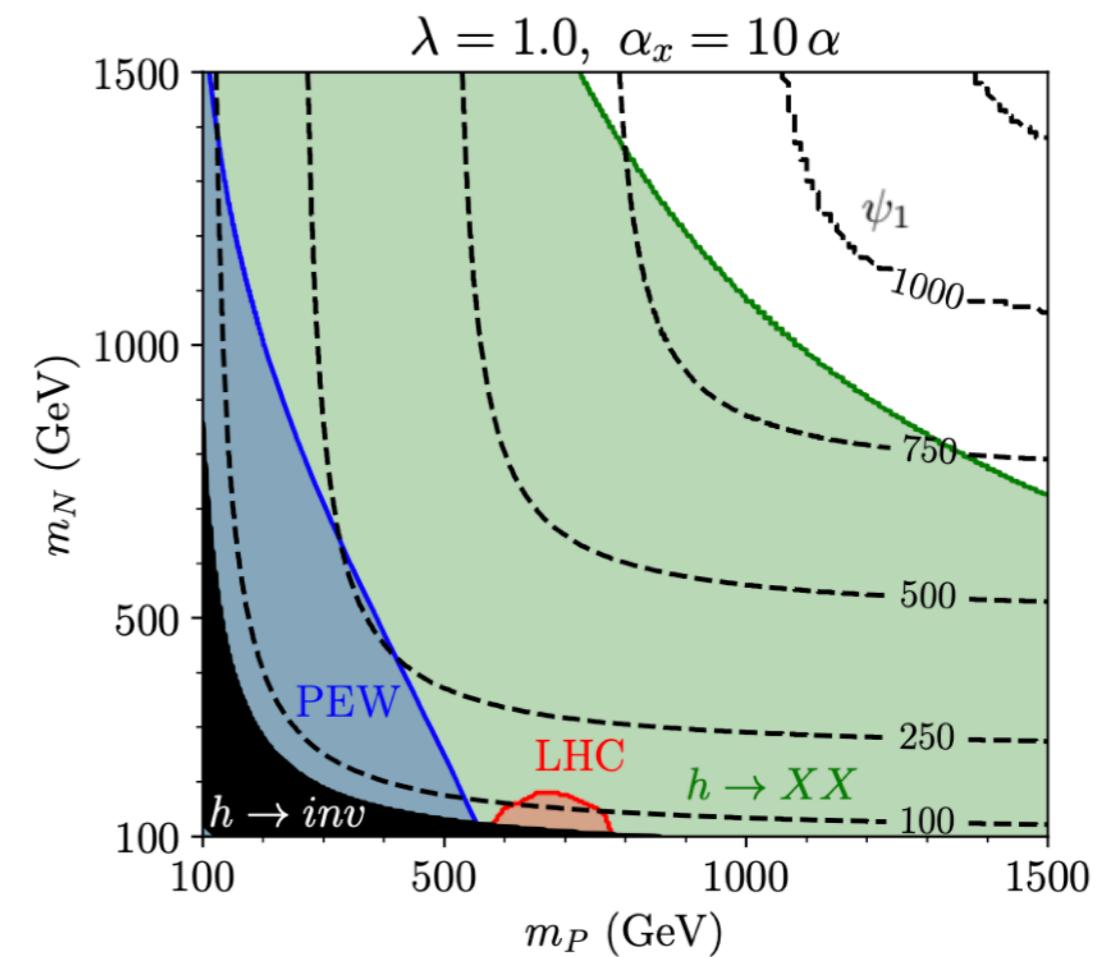
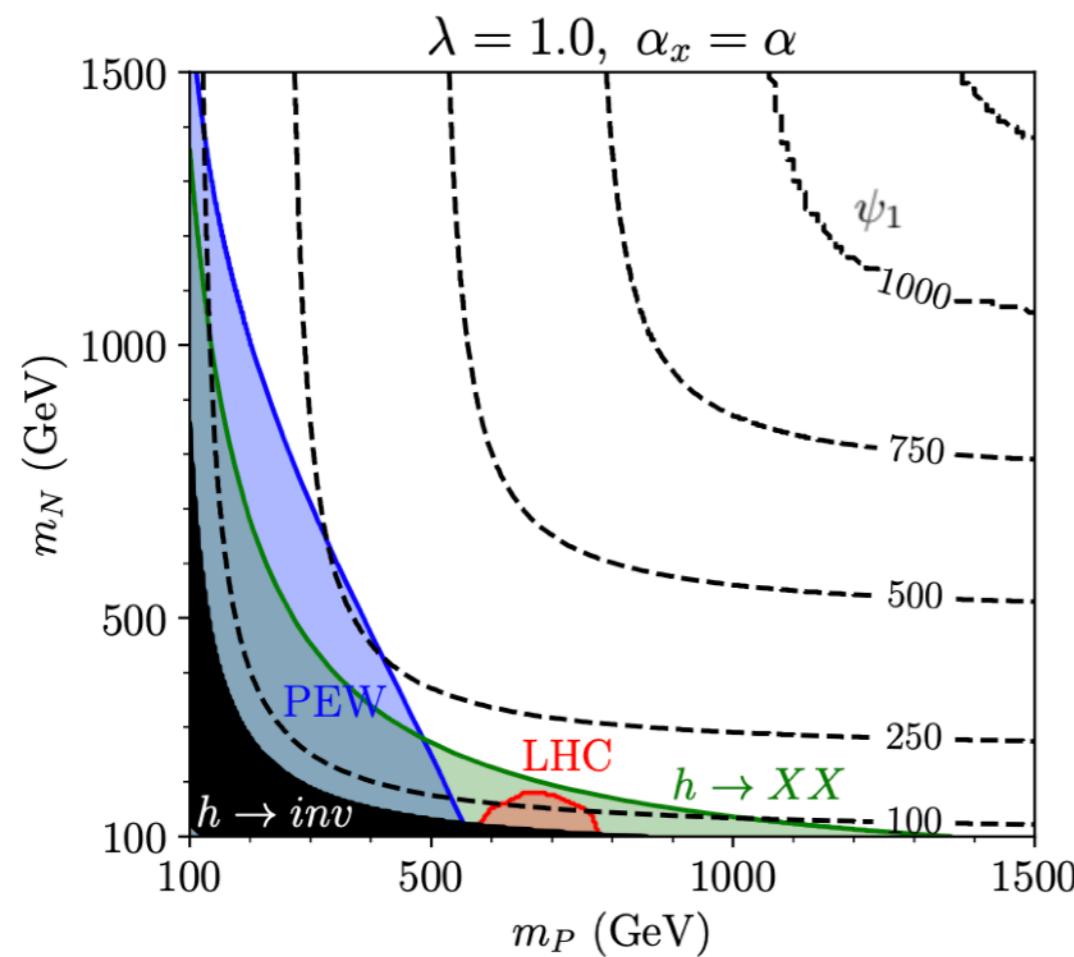


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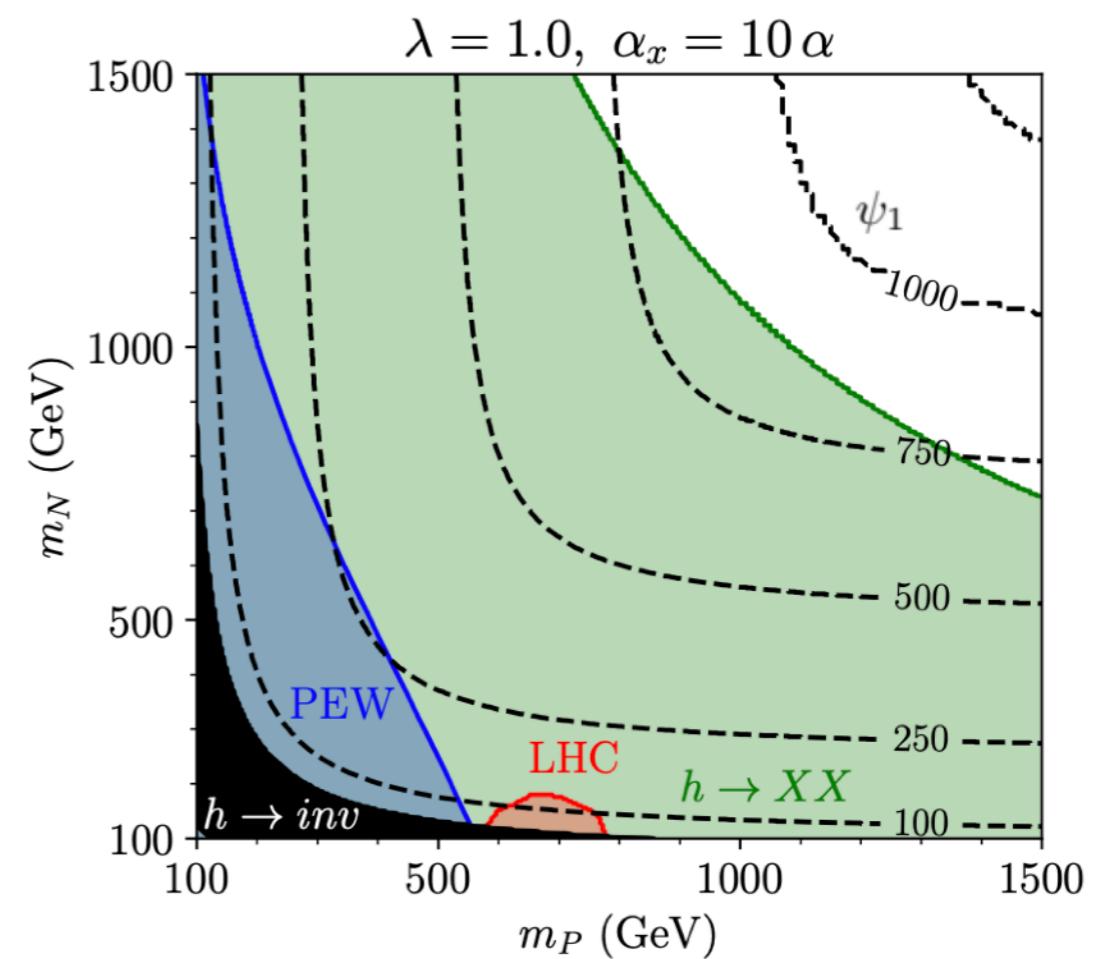
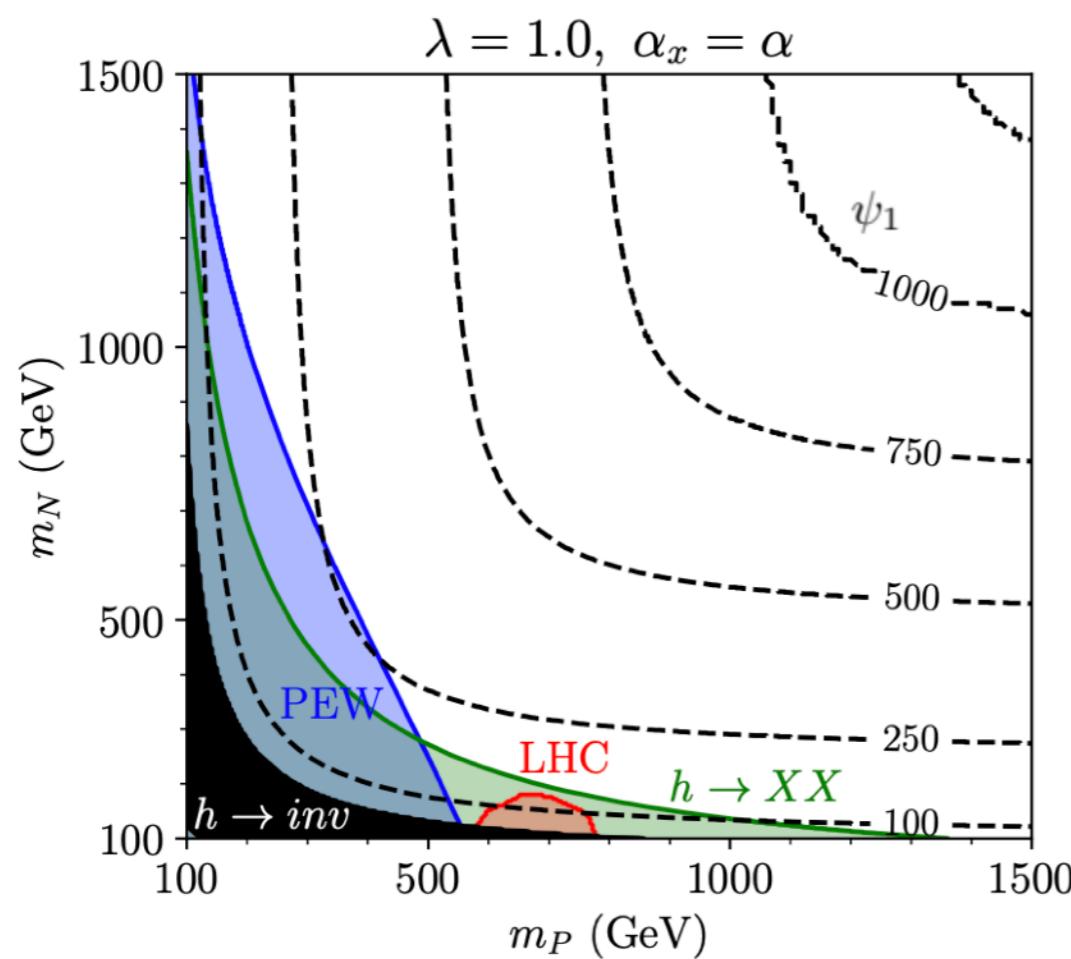
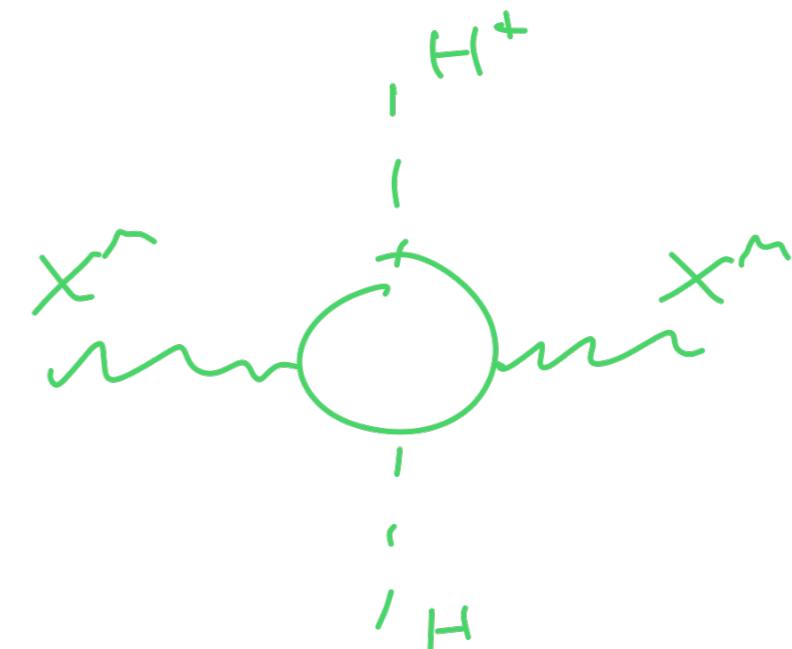


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WIMP \times $U(1)$: Cosmo bounds

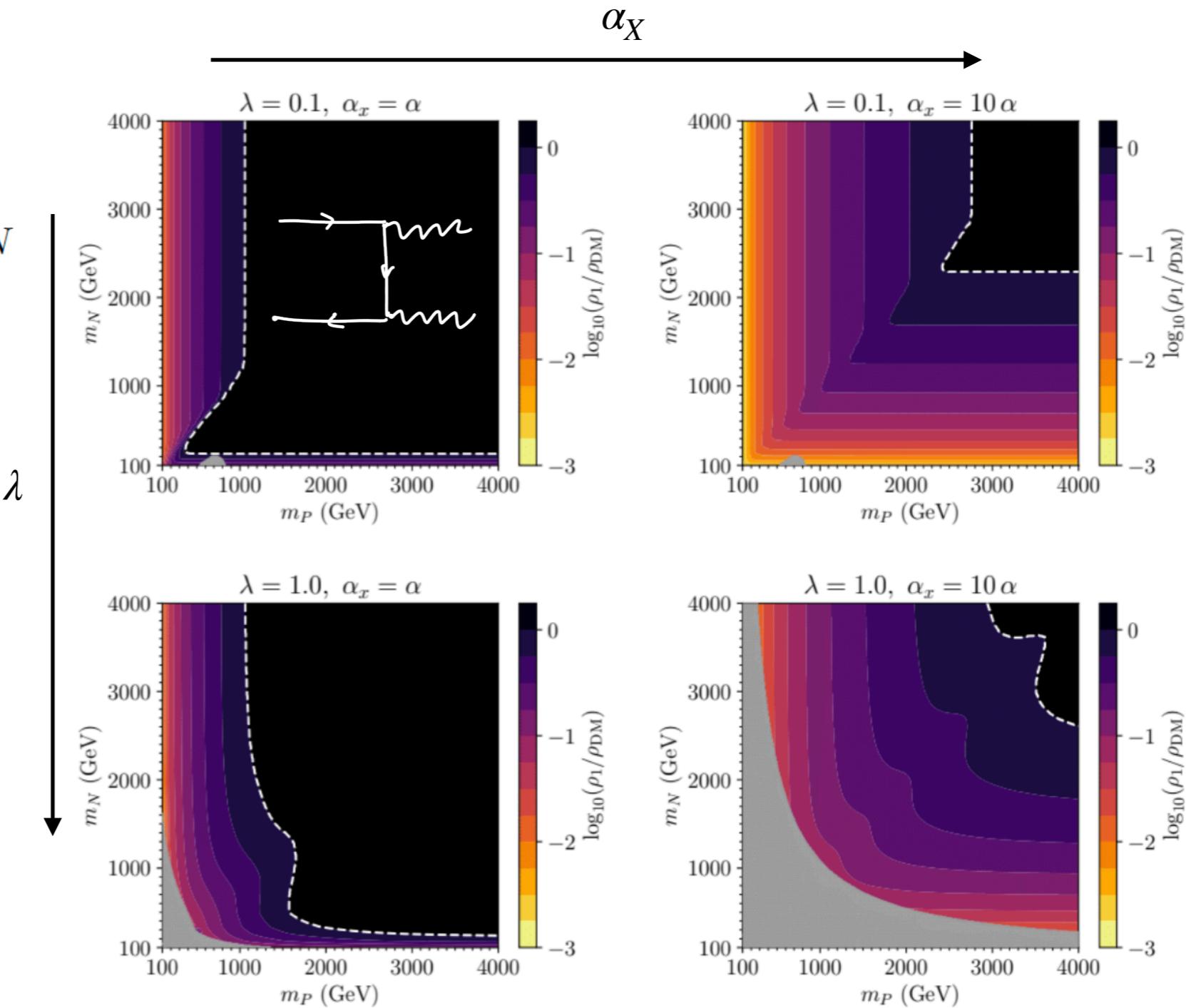
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$$N = (1, 1, 0; q_x) \text{ and } P = (1, 2, -1/2; q_x)$$

 EW precision, $h \rightarrow XX$, direct searches

 Relic density $\rho_1/\rho_{DM} > 1$



WIMP \times $U(1)$: Cosmo bounds

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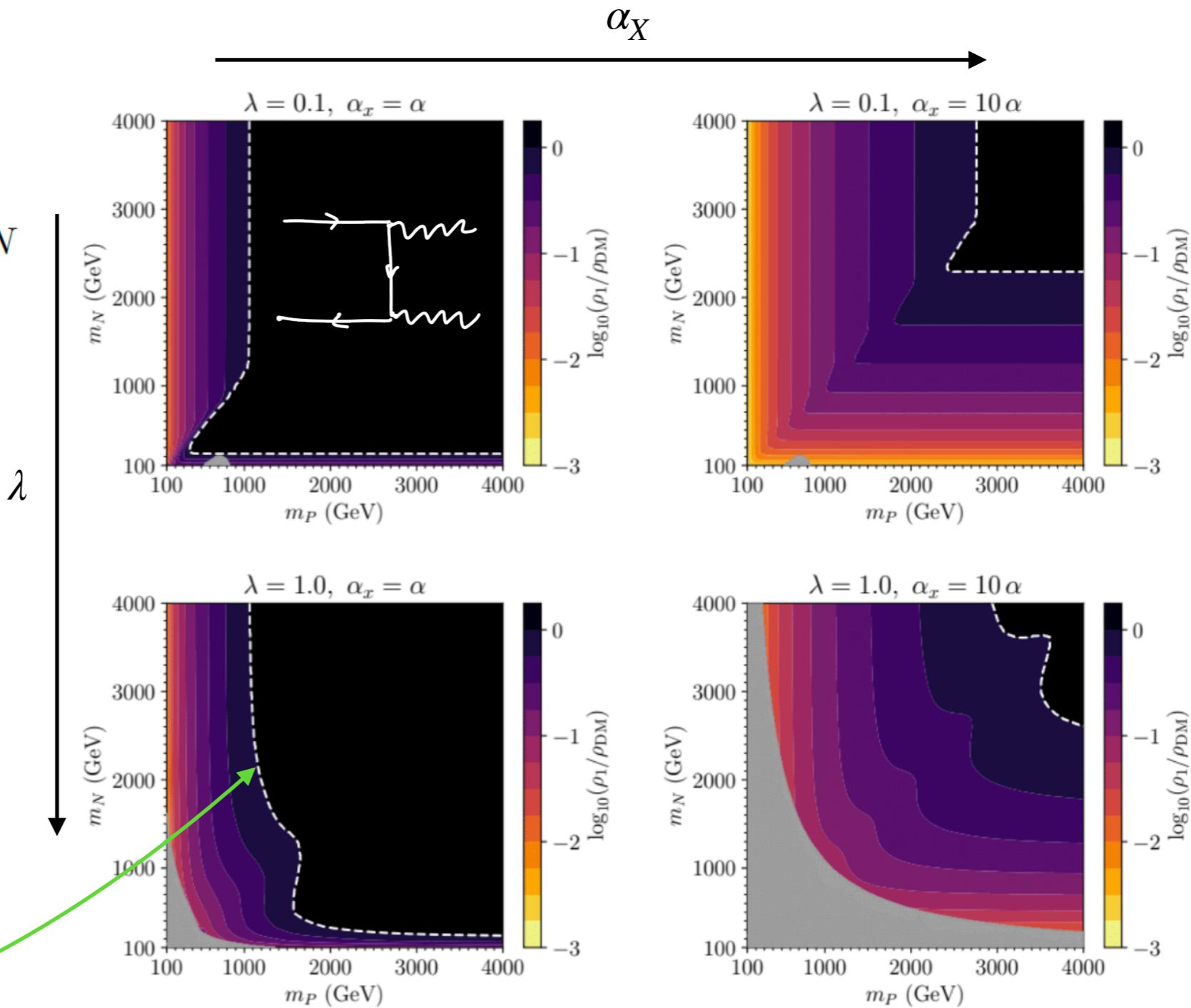
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"Higgsino" DM (see C. Dessert et al. arXiv:2209.14305)



WIMP \times $U(1)$: Cosmo bounds

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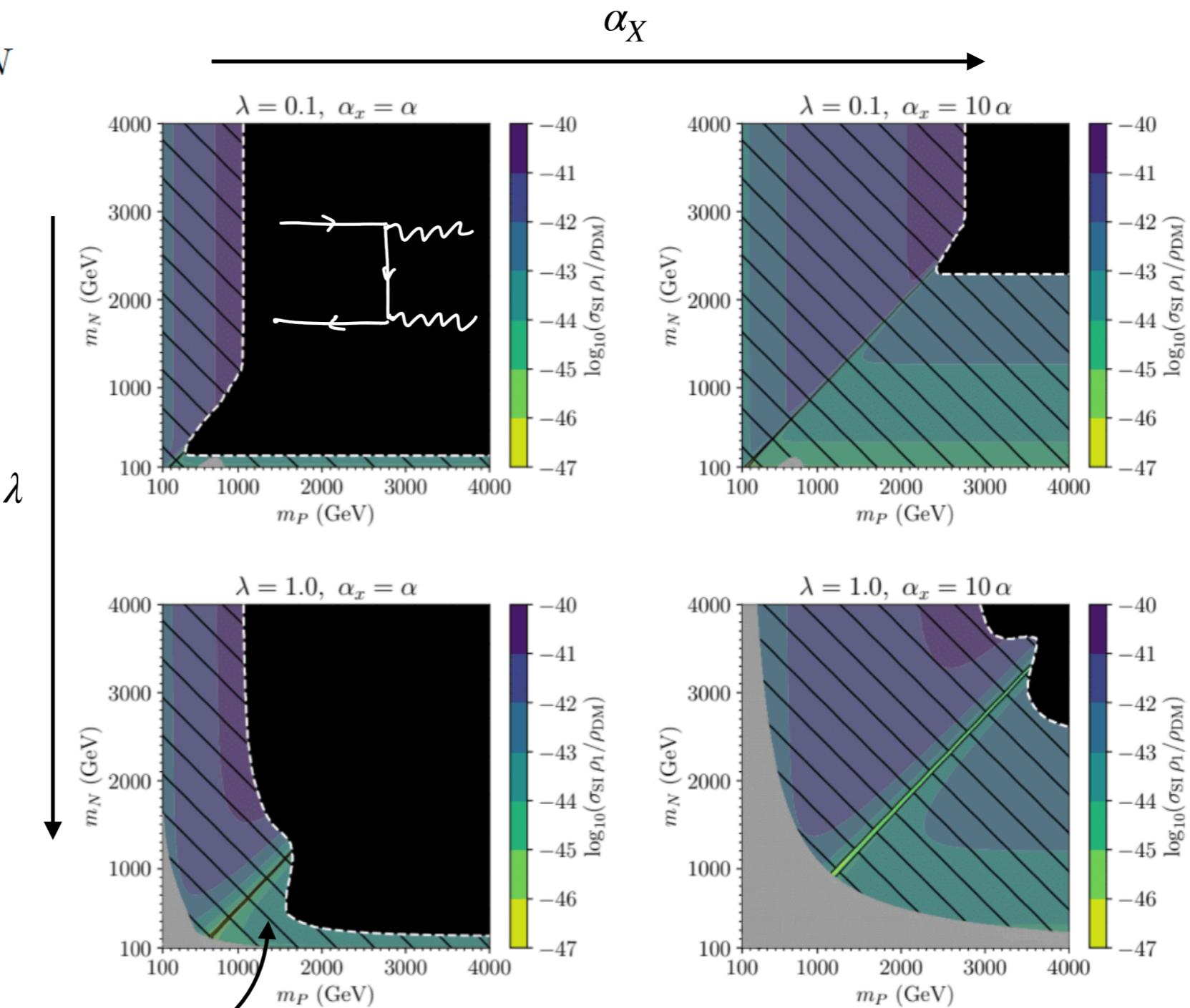
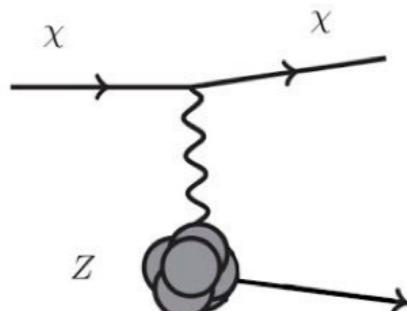
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$$\sigma_{\text{SI}} = \frac{\mu_n^2}{\pi} \left[\frac{Z f_p + (A - Z) f_n}{A} \right]^2$$

$$f_p = \frac{G_F}{\sqrt{2}} s_\alpha^2 (1 - 4 s_W^2) - \frac{4\pi}{m_x^2} \epsilon \sqrt{\alpha \alpha_x} - \tilde{d}_p \left[\frac{2}{9} + \frac{7}{9} \sum_q f_q^p \right]$$

$$f_n = -\frac{G_F}{\sqrt{2}} s_\alpha^2 + 0 - \tilde{d}_n \left[\frac{2}{9} + \frac{7}{9} \sum_q f_q^n \right].$$



Ruled out by direct detection

Possible solution #1

$$-\mathcal{L} \supset \left(\lambda \bar{P} \tilde{H} N + h.c. \right) + m_P \bar{P} P + m_N \bar{N} N$$

$$-\mathcal{L} \supset \frac{1}{2} y_N \Phi \bar{N^c} N + h.c.$$

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$\langle \Phi \rangle \neq 0$: splits Dirac components into Majorana

$$P^0 \quad \psi_2 \\ \Rightarrow$$

$$N = \begin{pmatrix} N_1 \\ N_2 \end{pmatrix}$$

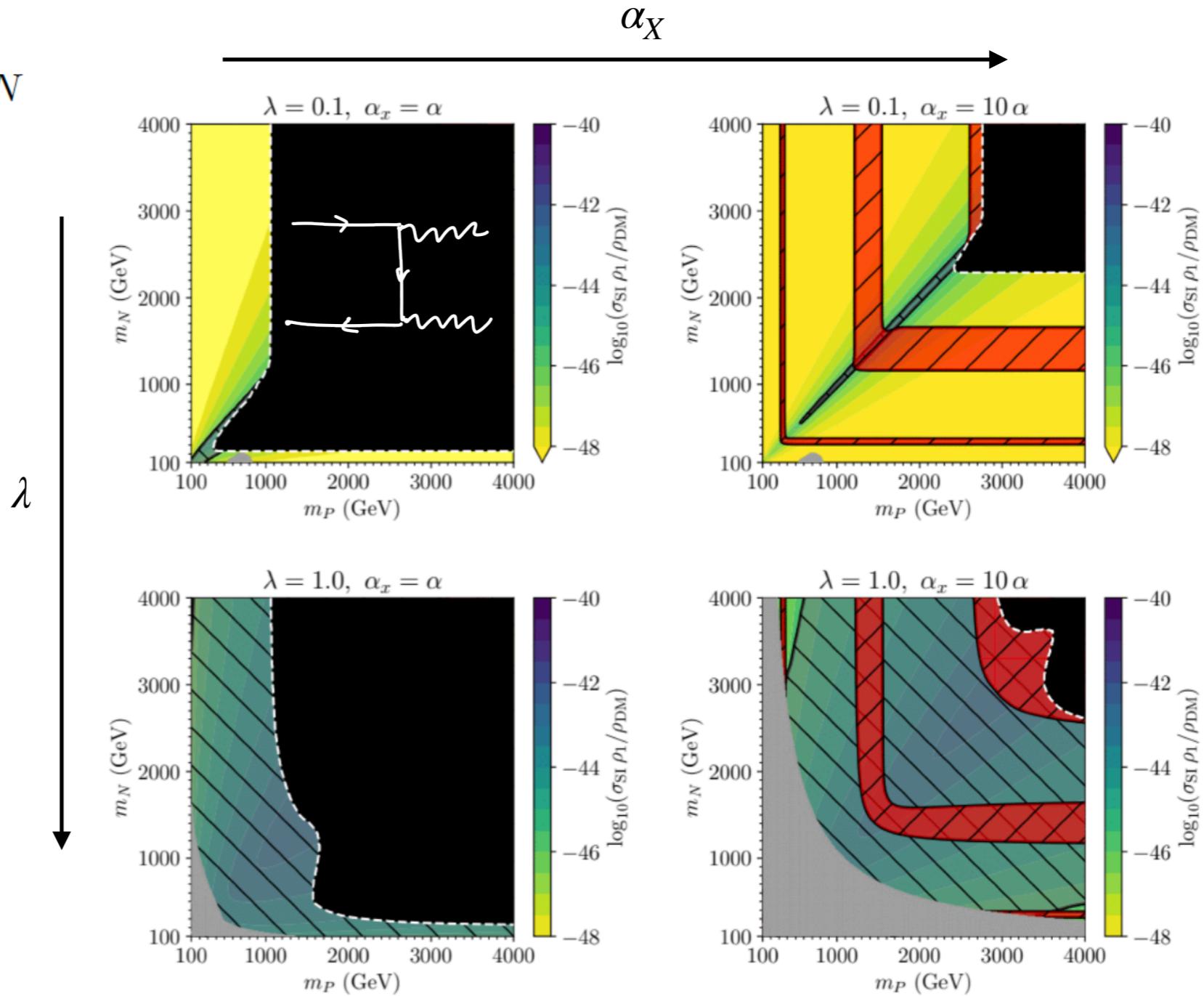
$$\psi_{1+} \\ \psi_{1-}$$

- Suppressed diagonal vector couplings for $(M_N - M_{N^c})/m_i \ll 1$
- Extra freeze-out modes
 $\psi_{1+} \rightarrow \psi_{1-} + ff$
 $\psi_{1+} + f \rightarrow \psi_{1-} + f$

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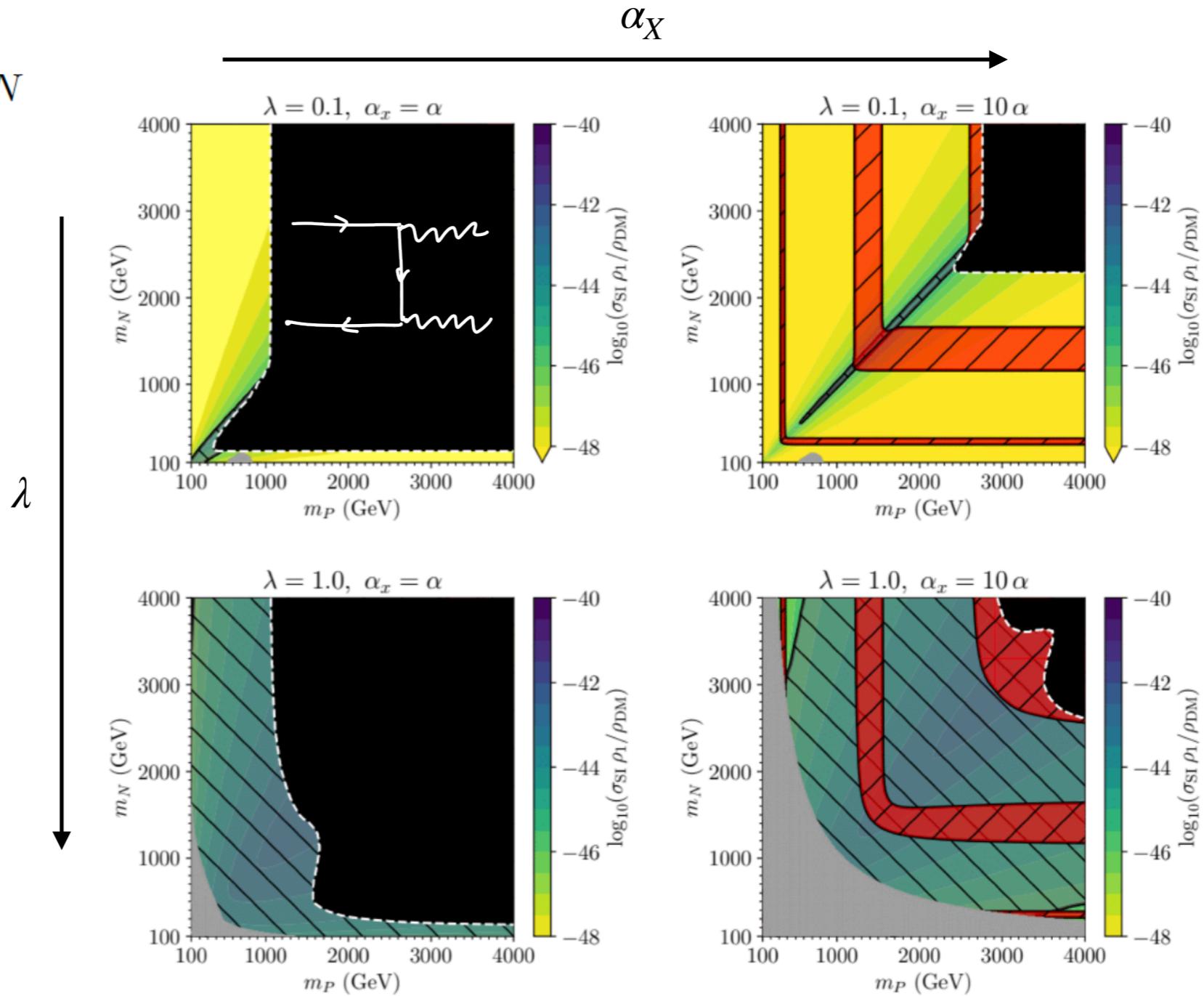


- Suppressed diagonal vector couplings reduces elastic scattering σ_{SI}
- Relic freeze-out \sim same

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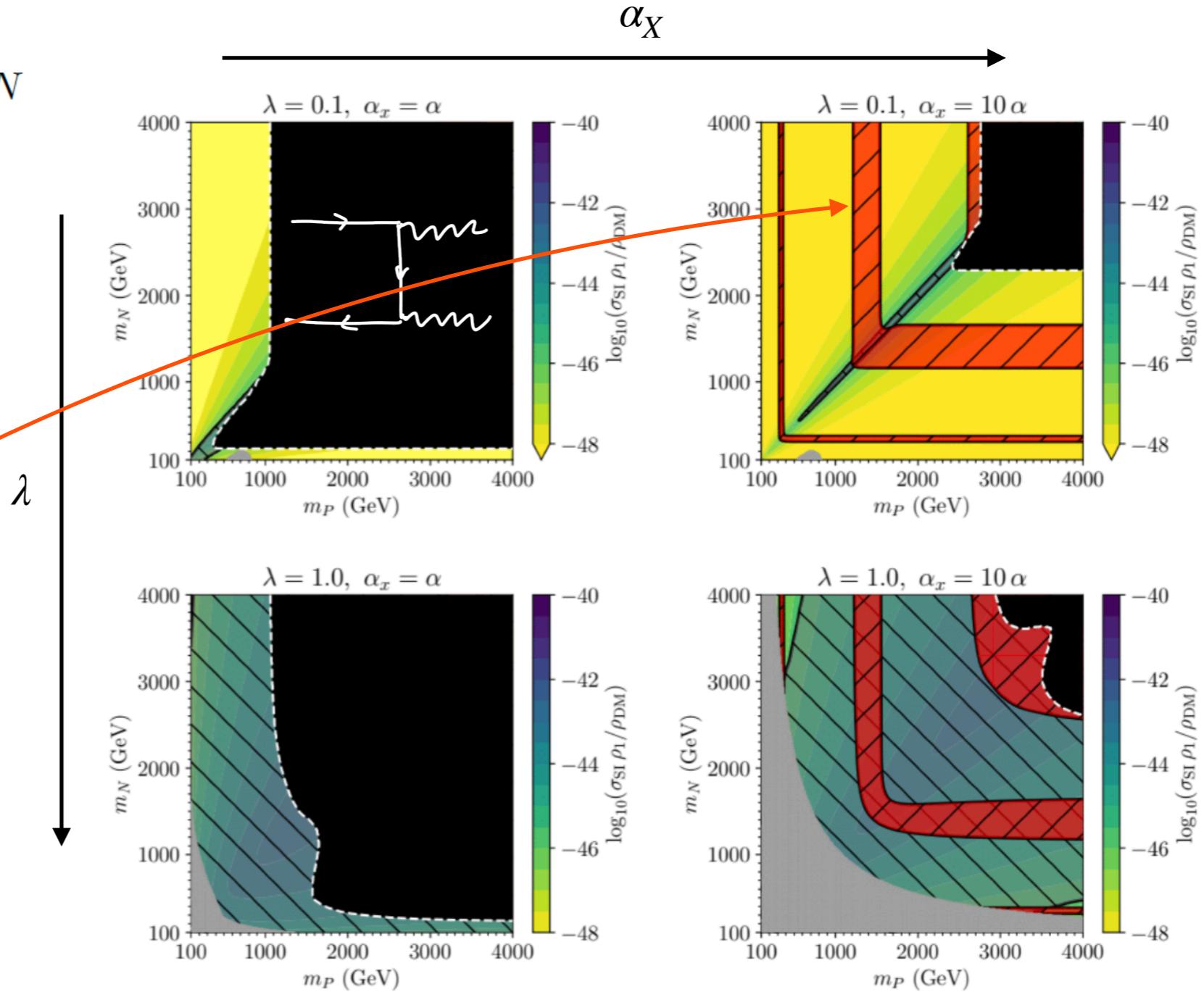
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Inelastic scattering still possible,
but tiny for $\Delta m \gtrsim 200\text{--}500\,\text{keV}$

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Relevant constraints from
late-time decay (CMB/ γ rays),
dependent on m_X/m_{ψ_1}

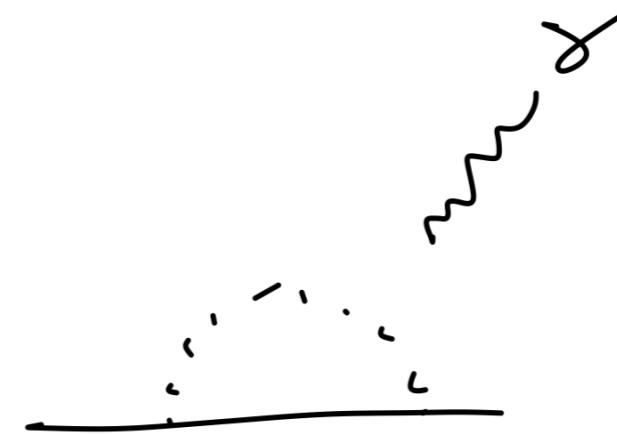
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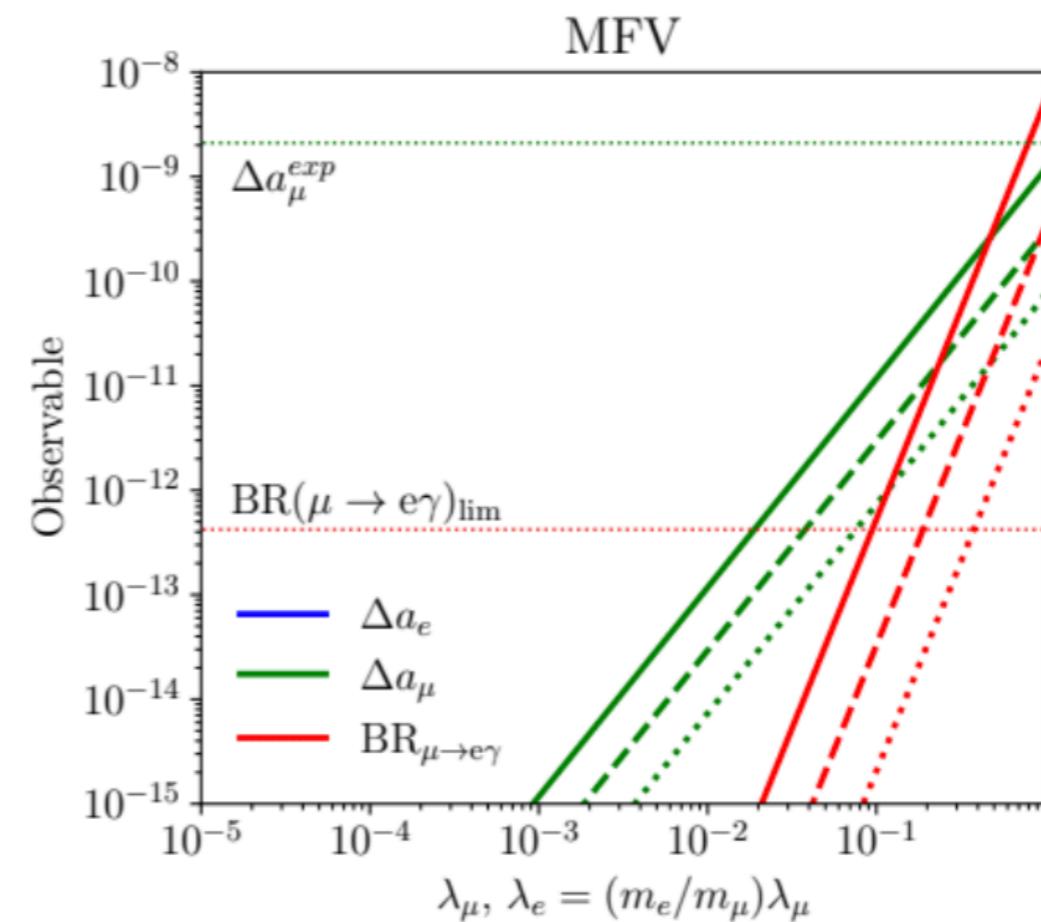
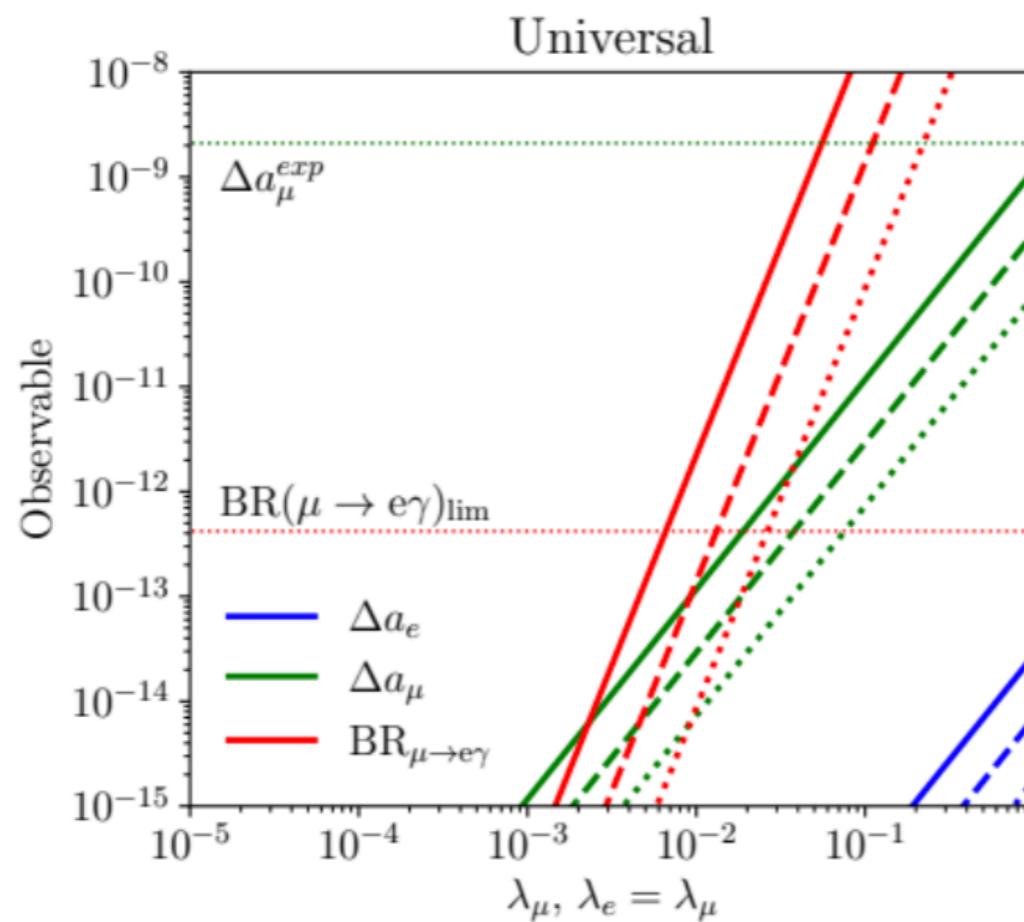
$$-\mathcal{L} \supset \lambda_a \phi \bar{P}_R L_{La} + (h.c.)$$

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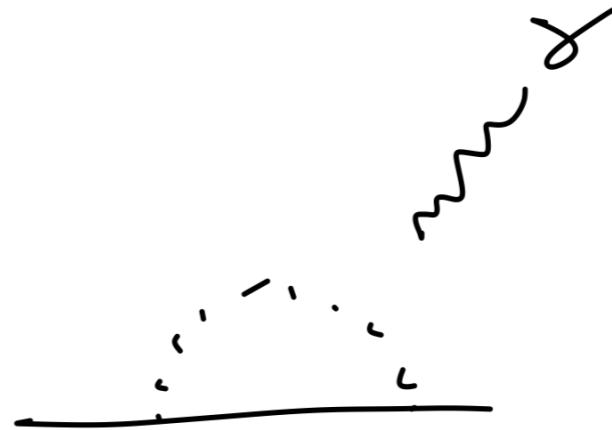


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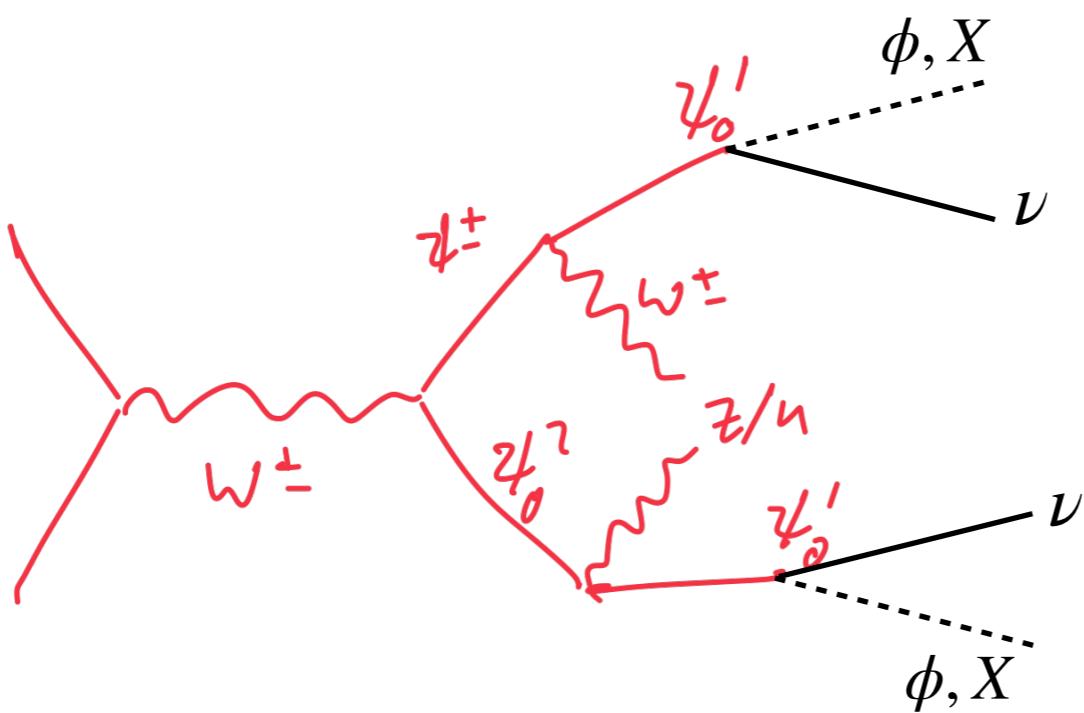


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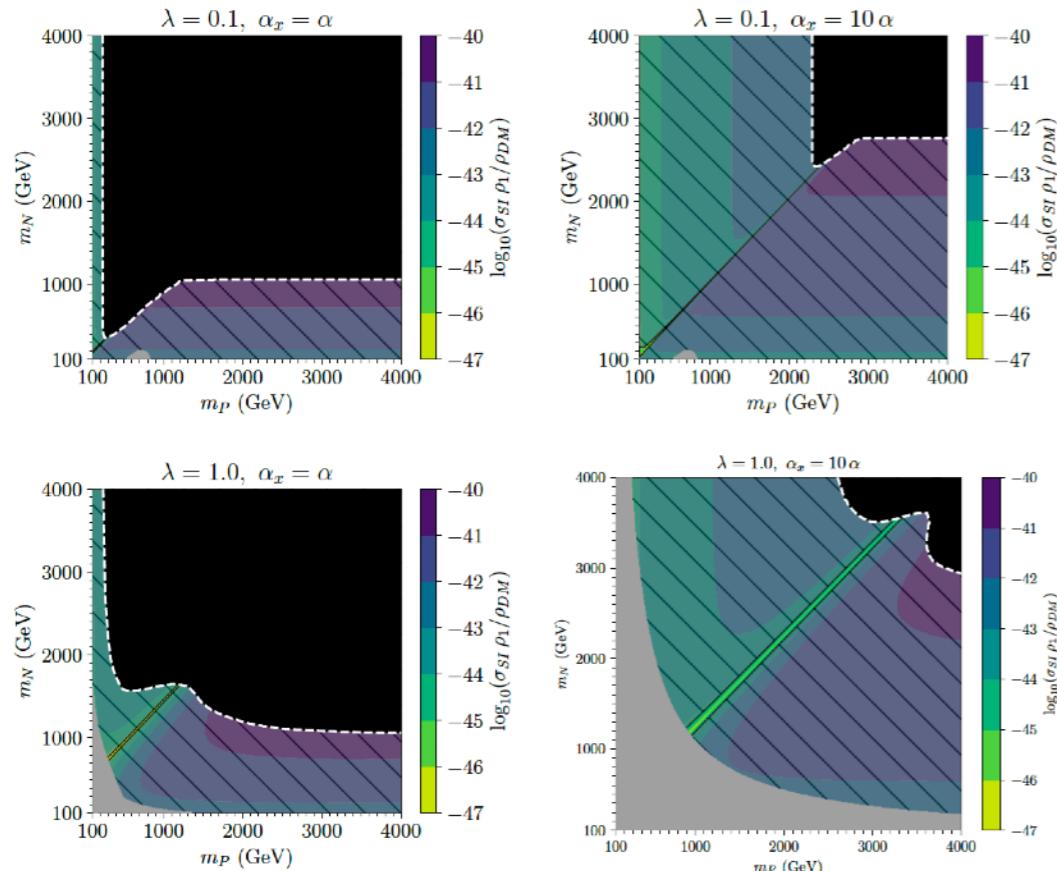
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$$-\mathcal{L} \supset \lambda_a \phi \bar{P}_R L_{La} + (h.c.)$$



WIMP \times $U(1) \times \phi$



$$\mathcal{L} \supset \frac{\epsilon}{2} X^{\mu\nu} B_{\mu\nu} + \frac{1}{2} m_X^2 X^\mu X_\mu + \dots$$

- Without Higgsing, scenario inconsistent w/ cosmology
- Cosmo-compatibility informs structure of the $U(1)_X$ EFT (see Kribs et. al. PRD 106 (2022) 5, 055020)
- Significant implications for inflationary production of dark photons (e.g. P. Graham et. al. PRD 93 (2016) vs M. Redi & A. Tesi JHEP 10 (2022) 167)

Summary

- Dark photon one of most well-motivated extensions of the SM and connector to the dark sector
- Kinetic mixing naturally suggests heavy mediators which are highly constrained from cosmo + DD bounds on stable relics
- Simplest solutions involve $\cancel{U(1)}$ which can have further significant implications for EFT, inflation, model building...