Decaying Dark Matter from Dark Instantons

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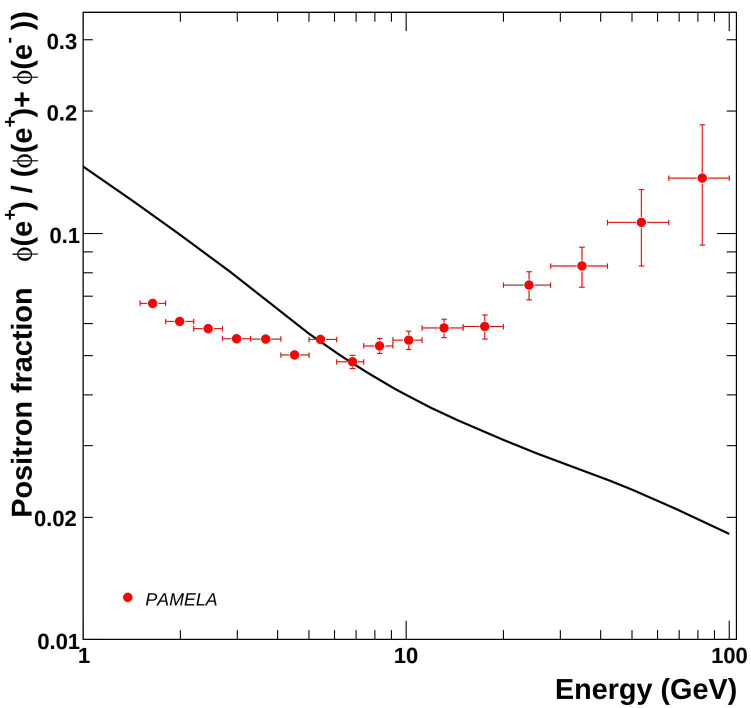
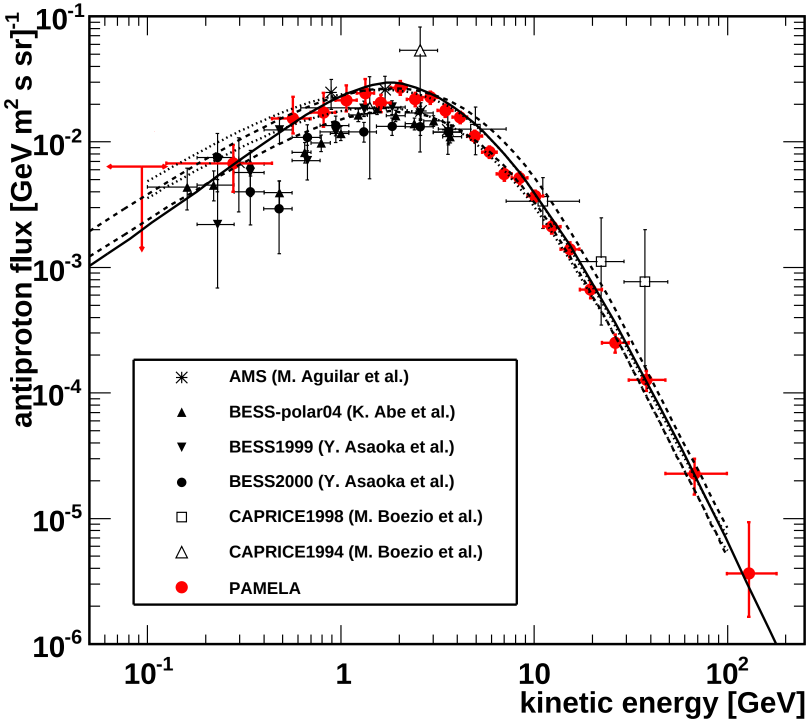
Outline of the Talk

- Cosmic ray positron excess from PAMELA and FERMI-LAT data
- Decaying dark matter
- Dark instantons and decaying dark matter
- Conclusions

Cosmic Rays Anomalies

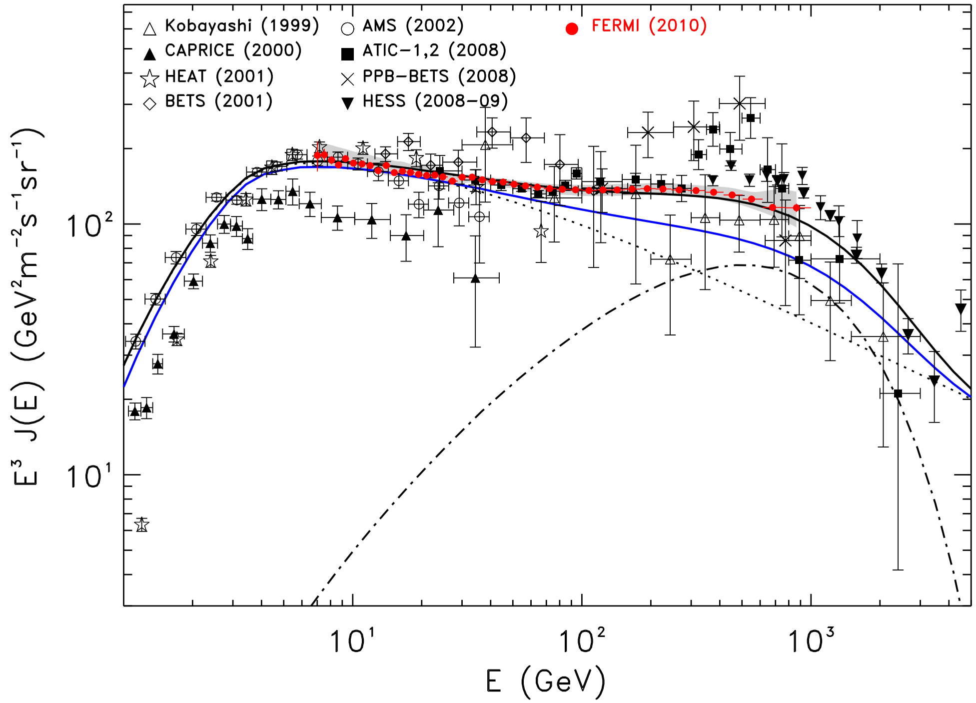


PAMELA positron fraction



PAMELA antiproton flux

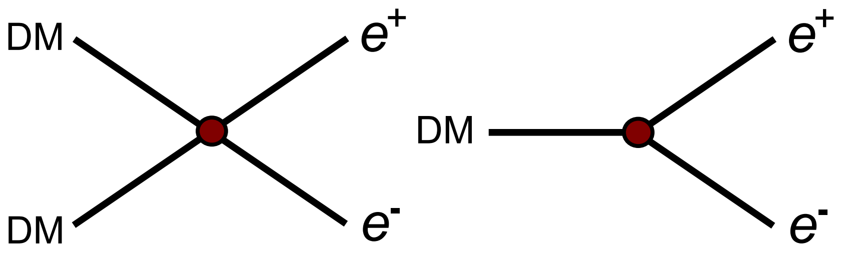
Cosmic Rays Anomalies



FERMI-LAT positron + electron flux

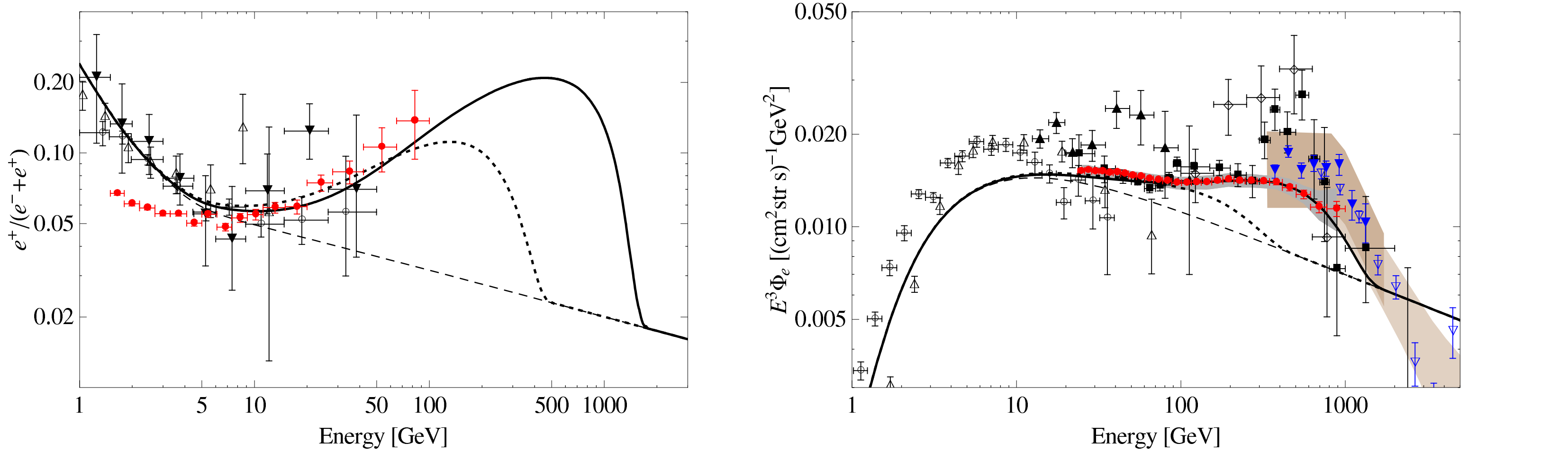
Possible explanations for the anomalies

- Astrophysical: Pulsar.
  Hooper, et.al. JCAP**0901**,025(2009); Yuksel, et.al. Phys.Rev.Lett.**103**,051101(2009).
- Dark matter annihilating/decaying into positrons.
  For a review: Fan, et.al. Int.J.Mod.Phys.D**19**,2011(2010)



Decaying Dark Matter

- Decaying dark matter can explain PAMELA positron excess.
  Ibarra, et.al. JCAP**1001**,009(2010) and references therein.
- DM $\to \ell^+\ell^-, \ell^+\ell^-\nu$; DM $\not\to 2q$, $W\ell$ etc...
- $\mathcal{O}$(TeV) dark matter.
- The lifetime of DM is $\mathcal{O}(10^{26})$ s.

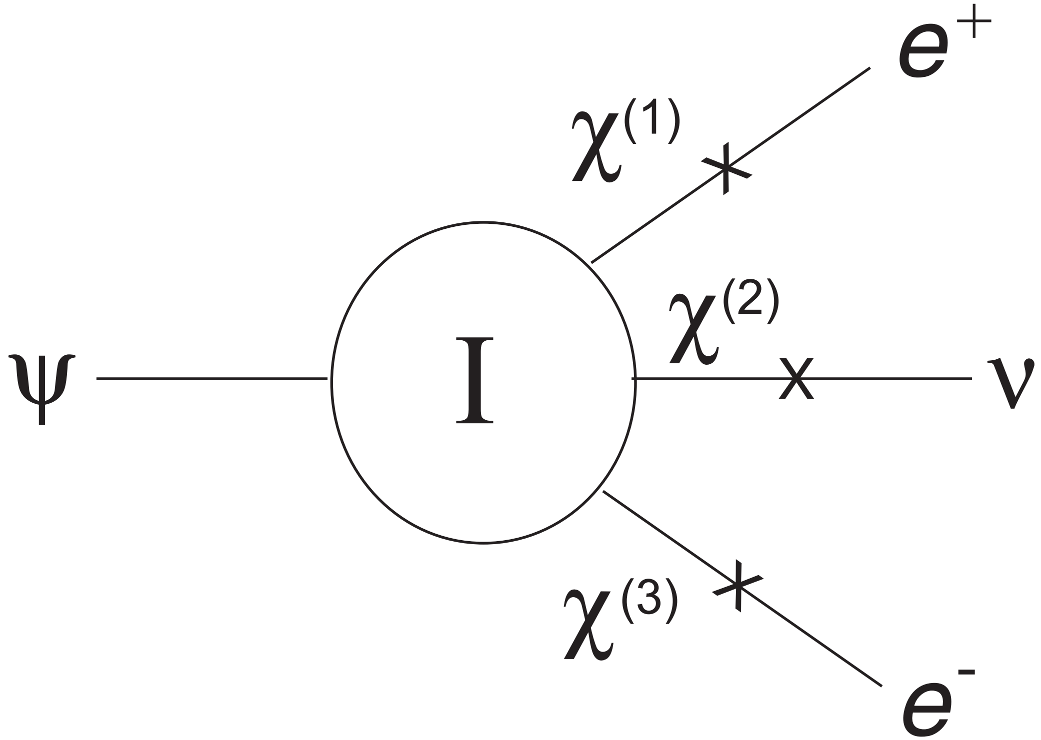


Instanton

- Consider a set of N_f massless fermions, ψ_s^α, transform in fundamental representation of $SU(N)$.
- The global symmetry of the model is $SU(N_f)_L \times SU(N_f)_R \times U(1)_V \times U(1)_A$.
- 't Hooft pointed out that an instanton-induced operator violates the anomalous $U(1)_A$ global symmetry.
  't Hooft, Phys.Rev.Lett.**37**,8(1976)
- The effective operator is given by

$$\begin{aligned}\mathcal{L}^{eff} &= Cg^{-8}e^{-\frac{8\pi^2}{g^2}}(2\delta_{\alpha_1\beta_1}\delta\alpha_2\beta_2 - \delta_{\alpha_1\beta_2}\delta_{\alpha_2\beta_1})\epsilon^{st} \\ &\quad \times \bar{\psi}_1^{\alpha_1}(1+\gamma^5)\psi_s^{\beta_1}\bar{\psi}_2^{\alpha_2}(1+\gamma^5)\psi_t^{\beta_2} + \text{h.c} \ .\end{aligned}$$

The Model



The Model

- The gauge group is $G_{SM} \times SU(2)_D \times U(1)_D$.
- New particles charge assignments:

ψ_L	$(\mathbf{2}, -1/2)_0$	$\psi_{uR},\ \psi_{dR}$	$(\mathbf{1}, -1/2)_0$
$\chi_L^{(1)}$	$(\mathbf{2}, +1/6)_+$	$\chi_{uR}^{(1)},\ \chi_{dR}^{(1)}$	$(\mathbf{1}, +1/6)_+$
$\chi_L^{(2)}$	$(\mathbf{2}, +1/6)_0$	$\chi_{uR}^{(2)},\ \chi_{dR}^{(2)}$	$(\mathbf{1}, +1/6)_0$
$\chi_L^{(3)}$	$(\mathbf{2}, +1/6)_-$	$\chi_{uR}^{(3)},\ \chi_{dR}^{(3)}$	$(\mathbf{1}, +1/6)_-$
E_L	$(\mathbf{1}, 0)_-$	E_R	$(\mathbf{1}, 0)_-$
H_D	$(\mathbf{2}, 0)_0$	η	$(\mathbf{1}, 1/6)_0$

$U(1)_\psi$ ***Accidental Symmetry***

- With the charge assignments, there is an accidental global $U(1)_\psi$ symmetry.

Combination	$U(1)_\psi$	$U(1)_D$
$\bar{\chi}\psi$	$+1$	$-1/3$
$\bar{\chi}\psi^c$	-1	$+2/3$

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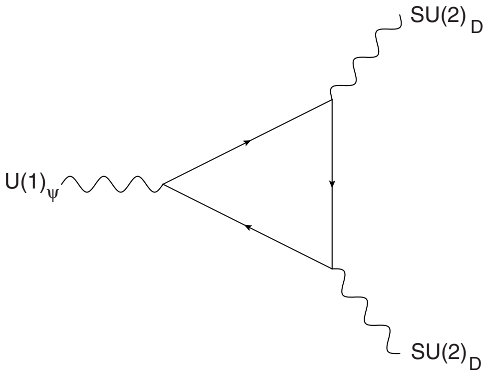
- Decay of the lightest ψ is prevented in all order of perturbation theory.

Instanton Induced Operator

Triangle anomaly for $SU(2)^2_D U(1)_\psi$.



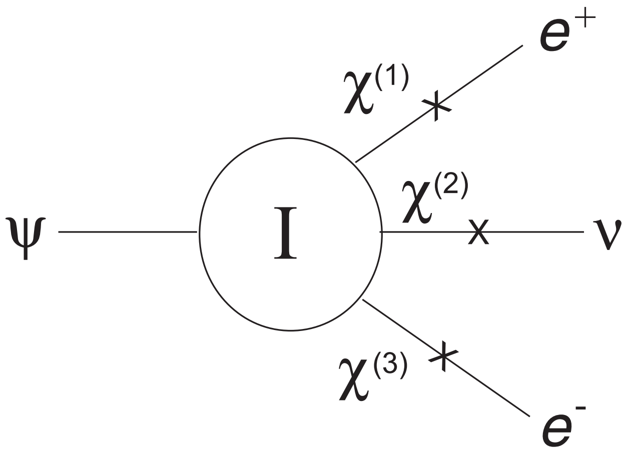
$$\text{tr}[t^a t^b N_\psi] = \frac{1}{2}\delta^{ab}\sum N_\psi$$

Instanton Induced Operator

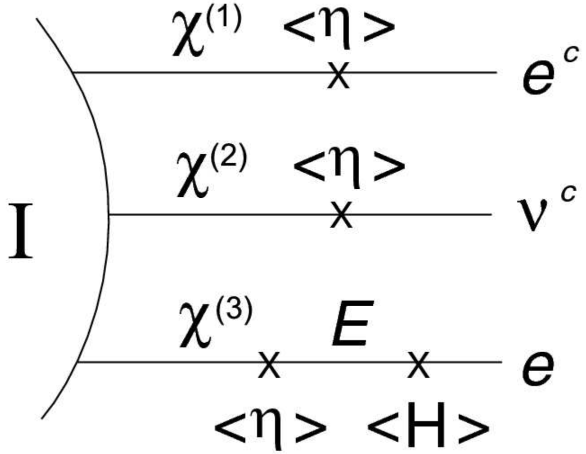
Following ’t Hooft

’t Hooft, Phys.Rev.D14,3432(1976)

$$\mathcal{L}_I = \frac{C}{6\,g_D^8}\exp\left(-\frac{8\pi^2}{g_D^2}\right)\left(\frac{m_\psi}{v_D}\right)^{35/6}\frac{1}{v_D^2}\left(2\,\delta_{\alpha\beta}\delta_{\gamma\sigma}-\delta_{\alpha\sigma}\delta_{\beta\gamma}\right)$$
$$\cdot\left[(\overline{\chi_{L\,\beta}^{(2)\,c}}\psi_L^\alpha)(\overline{\chi_{L\,\sigma}^{(1)\,c}}\chi_L^{(3)\,\gamma})-(\overline{\chi_{L\,\beta}^{(1)\,c}}\psi_L^\alpha)(\overline{\chi_{L\,\sigma}^{(2)\,c}}\chi_L^{(3)\,\gamma})\right]+\text{ h.c.}\,.$$



Leptons-χ Mixings



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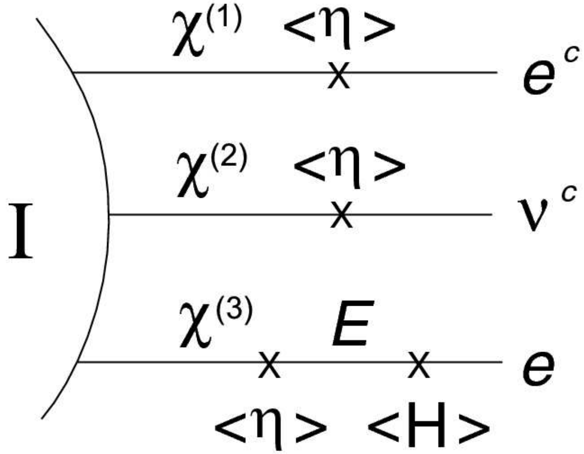

Example: $\mathcal{L} \supset \eta \overline{\chi}^{(1)}_{dR} e^c_R$.

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Dark Matter Lifetime

- The decay width of the dark matter is

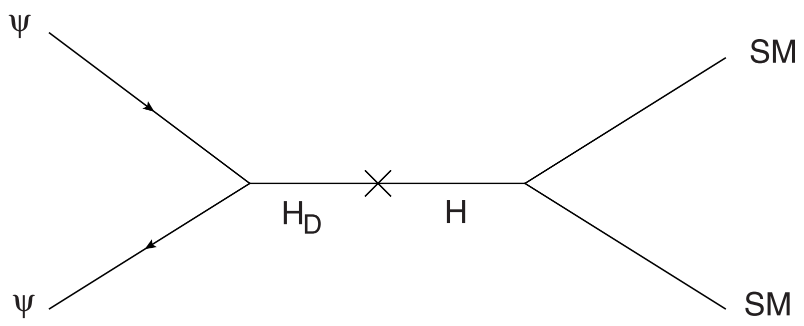
$$\Gamma(\psi \to \ell^+\ell^-\nu) \approx \frac{1}{g_D^{16}} \exp(-16\pi^2/g_D^2) \left(\frac{m_\psi}{v_D}\right)^{47/3} m_\psi \quad .$$

- For $m_\psi = 3.5$ TeV and $v_D = 4$ TeV, we need $g_D \approx 1.15$.

Relic Density

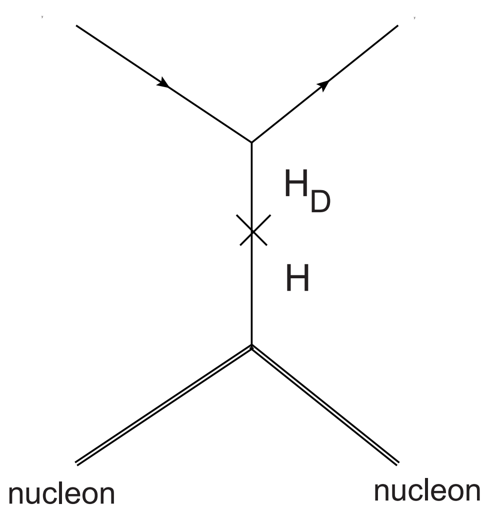
- Dark matter thermal equilibrium in the early universe is maintained by Higgs portal.

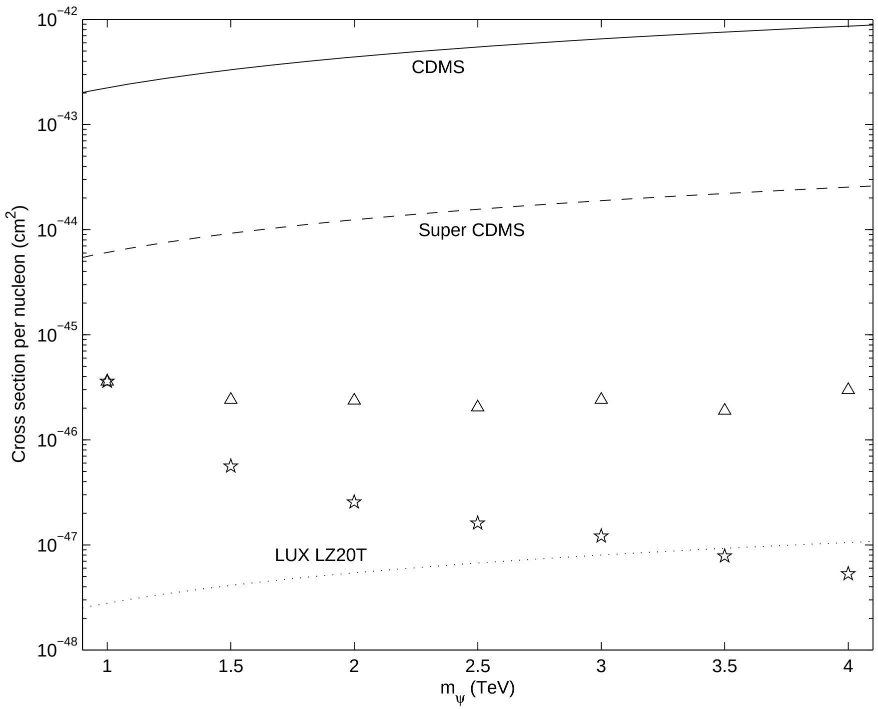
$$\begin{aligned} V &= -\mu^2 H^\dagger H + \lambda (H^\dagger H)^2 - \mu_D^2 H_D^\dagger H_D + \lambda_D (H_D^\dagger H_D)^2 \\ &\quad + \lambda_{mix} (H^\dagger H)(H_D^\dagger H_D). \end{aligned}$$



Direct Detection

- We found that DM-nucleon cross section is $\mathcal{O}(10^{-46})\text{cm}^2$.
- Three orders of magnitude lower than the current bound.





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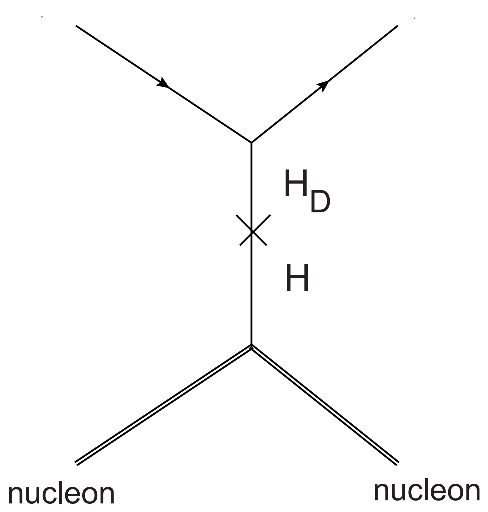

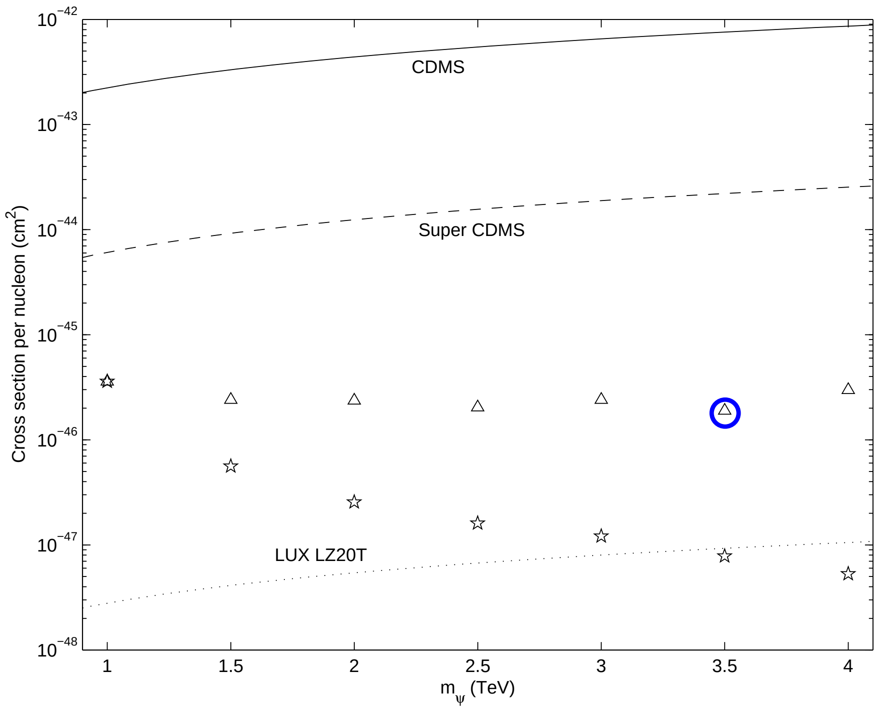

Conclusions

- PAMELA positron excess can be explained by decaying dark matter.
- The lifetime of the dark matter is $\mathcal{O}(10^{26})$ s.
- Instanton-induced operator can explain the long lifetime of the dark matter.
- We constructed a model of decaying dark matter inspired by instanton-induced operator.
- The model gives the correct dark matter relic density and satisfies direct detection bounds.

Thank You