Goldstini as the Decaying Dark Matter

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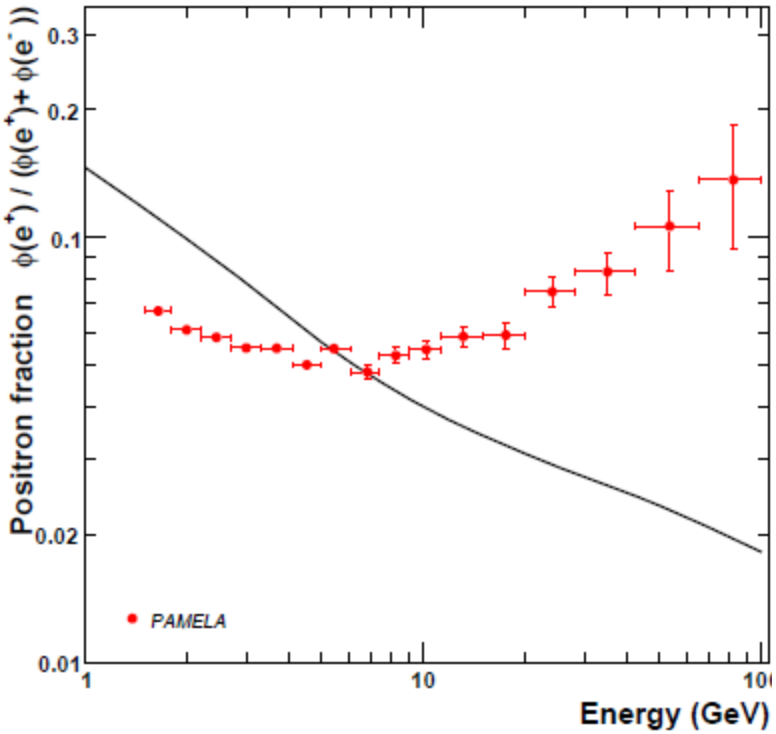
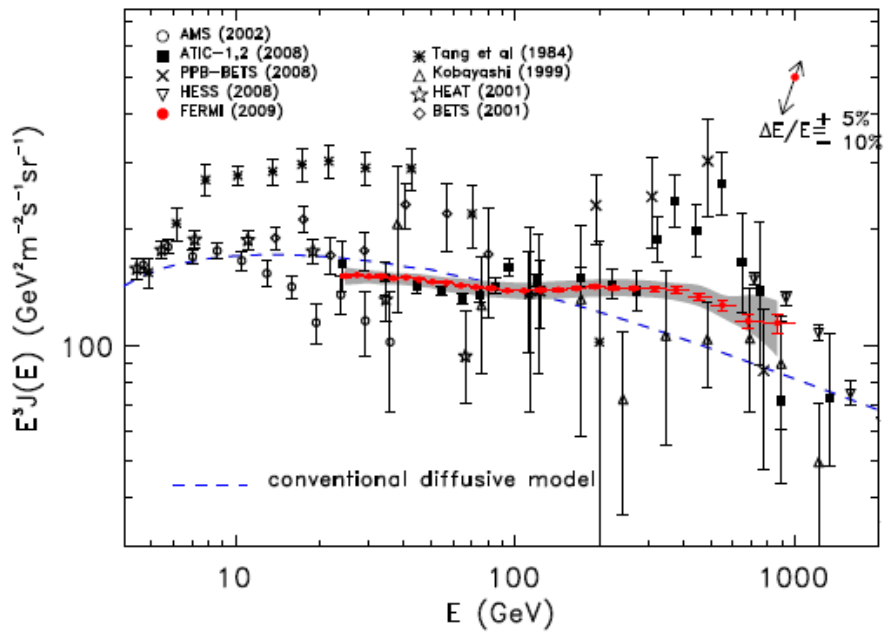
arXiv:1012.5300 with Hsin-Chia , Ian and Arjun
arXiv:1109.XXXX with Hsin-Chia , Ian and Gabe

Goldstini outline

- Motivations
- Formalism
- PAMELA and FERMI data
- Conclusions

Motivations





arXiv:0810.4995

arXiv:0905.0025

Formalism (single breaking)

$$X = \tilde{x} + \sqrt{2}\theta\eta + \theta^2 F_X \ , \qquad Q = \tilde{q} + \sqrt{2}\theta q + \theta^2 F_Q \ ,$$

$$\mathcal{L} = \int d^4\theta \, K + \int d^2\theta \, W + \int d^2\overline{\theta} \, \overline{W} \ .$$

$$W = fX$$

$$K = X\overline{X} + Q\overline{Q} - \frac{c}{\Lambda^2} X^2 \overline{X}^2 - \frac{\hat{c}}{\Lambda^2} Q\overline{Q} X\overline{X}$$

X: superfield in the hidden sector (the SUSY breaking sector)
Q: superfield in the SSM

If the scalar components of X and Q are much heavier than the fermion components, we can integrate out the scalar components of X and Q and find the low-energy effective Lagrangian. (arXiv:0907.2441)

$$\tilde{q}F_X + \tilde{x}F_Q - \eta\, q = 0 \ ,$$

$$2\,\tilde{x}F_X - \eta^2 = 0 \ ,$$

$$X_{NL} \ = \ \frac{\eta^2}{2F_X} + \sqrt{2}\theta\eta + \theta^2 F_X \ ,$$

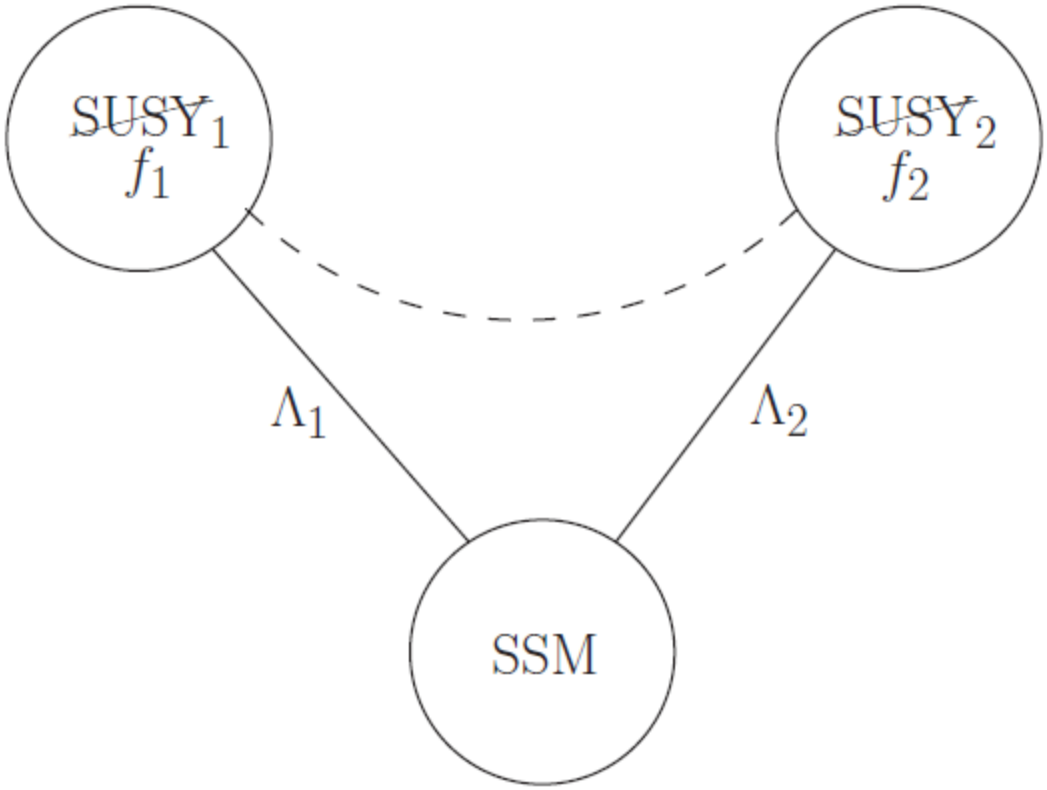
$$Q_{NL} \ = \ \frac{q\eta}{F_X} - \frac{\eta^2}{2F_X^2}F_Q + \sqrt{2}\theta q + \theta^2 F_Q$$

$$X_{NL}^2 = 0 \ , \qquad Q_{NL}\, X_{NL} = 0 \ .$$

$$\mathcal{L}_{eff} = \frac{1}{f^2}\partial_\mu(\overline{\eta}\,\overline{q})\partial^\mu(\eta\,q) + \cdots \ .$$

The 4-fermion interaction is universal in flavors and only depends on the SUSY-breaking scale f (= F_X)

Formalism (multiple breaking)



$$K = \sum_{i=1,2} \left(X_i \overline{X}_i - \frac{c_i}{\Lambda^2} X_i^2 \overline{X}_i^2 - \frac{1}{\Lambda_i^2} X_i \overline{X}_i Q \overline{Q} \right) + Q\overline{Q}$$

$$W = \sum_{i=1,2} f_i X_i \ .$$

$$\begin{pmatrix} \eta_1 \\ \eta_2 \end{pmatrix} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} \widetilde{G}_L \\ \zeta \end{pmatrix}$$

$$\tan\theta = \frac{f_2}{f_1} \ , \qquad f_{eff} = \sqrt{f_1^2 + f_2^2}$$

$\widetilde{G}_L$ is the gravitino, i.e. the component being eaten

ζ is the goldstino, i.e. the unbroken component

arXiv:1002.1967

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If we turn on gravity, we have

$$m_\zeta = 2m_{\widetilde{G}_L}$$

$$\tilde{x}_1 = \frac{\eta_1^2}{2f_1^2}\,, \qquad \tilde{x}_2 = \frac{\eta_2^2}{2f_2^2}\,,$$

$$\begin{aligned}\tilde{q} &= \frac{1}{f_1^2/\Lambda_1^2 + f_2^2/\Lambda_2^2}\left(\frac{f_1}{\Lambda_1^2}\,\eta_1 q + \frac{f_2}{\Lambda_2^2}\,\eta_2 q\right) \\ &= \frac{1}{f_{eff}}\left[\widetilde{G}_L - \left(\frac{\widetilde{m}_1^2\tan\theta - \widetilde{m}_2^2\cot\theta}{m_{\widetilde{q}}^2}\right)\zeta\right] q,\end{aligned}$$

$\widetilde{m}_i^2 = f_i^2/\Lambda_i^2$ is the contribution from each SUSY-breaking sector to the scalar mass of Q and $m_{\widetilde{q}}^2 \equiv \widetilde{m}_1^2 + \widetilde{m}_2^2$.

$$\mathcal{L}_{2f}^{(0)} = \frac{f_{eff}^2}{f_1^2\Lambda_2^2 + f_2^2\Lambda_1^2}\,\overline{\zeta}\overline{q}\,\zeta q = \frac{1}{m_{\widetilde{q}}^2}\left(\frac{\widetilde{m}_1^2}{\Lambda_2^2} + \frac{\widetilde{m}_2^2}{\Lambda_1^2}\right)\overline{\zeta}\overline{q}\,\zeta q\ ,$$

$$\begin{aligned}\mathcal{L}_{2f}^{(1)} &= \frac{1}{f_{eff}^2}\partial_\mu(\overline{\widetilde{G}_L\,\overline{q}})\partial^\mu(\widetilde{G}_L\,q) + \frac{1}{f_{eff}^2}\left(\frac{\widetilde{m}_1^2\tan\theta - \widetilde{m}_2^2\cot\theta}{m_{\widetilde{q}}^2}\right)^2\partial_\mu(\overline{\zeta}\overline{q})\partial^\mu(\zeta q)\\ &\quad -\frac{1}{f_{eff}^2}\left(\frac{\widetilde{m}_1^2\tan\theta - \widetilde{m}_2^2\cot\theta}{m_{\widetilde{q}}^2}\right)\partial_\mu(\overline{\zeta}\overline{q})\partial^\mu(\widetilde{G}_L q) + \mathrm{h.c.}\ .\end{aligned}$$

Note that the gravitino is always derivatively coupled while the goldstino is NOT.

The decay width of the goldstino into the gravitino and two SM particles (fermion and anti-fermion)

$$\Gamma_{\zeta\to\widetilde{G}_L f\bar{f}} = \frac{N_c m_\zeta^9}{15360\pi^3 f_{\rm eff}^4}\left(\frac{\widetilde{m}_1^2\tan\theta - \widetilde{m}_2^2\cot\theta}{m_{\widetilde{q}}^2}\right)^2 F_f(x)$$

$$x = m_{\widetilde{G}_L}/m_\zeta$$

$$\tan\theta = \frac{f_2}{f_1}\,, \qquad f_{eff} = \sqrt{f_1^2 + f_2^2}\,.$$

Dark matter

- For ζ to be the dark matter, its lifetime has to be comparable with or larger than the age of the universe.

$$\tau \approx 4 \times 10^{26}\ \mathrm{s} \left(\frac{1\ \mathrm{TeV}}{m_\zeta}\right)^9 \left(\frac{\sqrt{f_1}}{10^{11}\ \mathrm{GeV}}\right)^4 \left(\frac{\sqrt{f_2}}{10^{7}\ \mathrm{GeV}}\right)^4 \left(\frac{m^2_{\tilde{\ell}}}{\tilde{m}^2_{\tilde{\ell}2}}\right)^2 \left(\frac{0.8}{F_f(x)}\right)$$

Dark matter relic density

- For ζ to be the dark matter, its relic density should be Ω_m=0.228.
- Upper bounds on the reheating temperature:
  1. goldstino density
  2. the relic density of sleptons which decay into ζ

$$\Gamma_{\tilde{\ell}} = \frac{m_{\tilde{\ell}}}{16\pi}\left(\frac{\widetilde{m}^2_{\tilde{\ell}1}\tan\theta - \widetilde{m}^2_{\tilde{\ell}2}\cot\theta}{f_{\rm eff}}\right)^2\left(1-\frac{m^2_\zeta}{m^2_{\tilde{\ell}}}\right) \approx \frac{m_{\tilde{\ell}}}{16\pi}\left(\frac{\widetilde{m}^2_{\tilde{\ell}2}}{f_2}\right)^2\left(1-\frac{m^2_\zeta}{m^2_{\tilde{\ell}}}\right)$$

$$\frac{\Gamma_{\tilde{\ell}}}{H(T)} \approx 0.04\left(\frac{50\,\mathrm{GeV}}{T}\right)^2\left(\frac{10^7\,\mathrm{GeV}}{\sqrt{f_2}}\right)^4\left(\frac{m_{\tilde{\ell}}}{1\,\mathrm{TeV}}\right)\left(\frac{\widetilde{m}_{\tilde{\ell}2}}{500\,\mathrm{GeV}}\right)^4\left(1-\frac{m^2_\zeta}{m^2_{\tilde{\ell}}}\right)$$

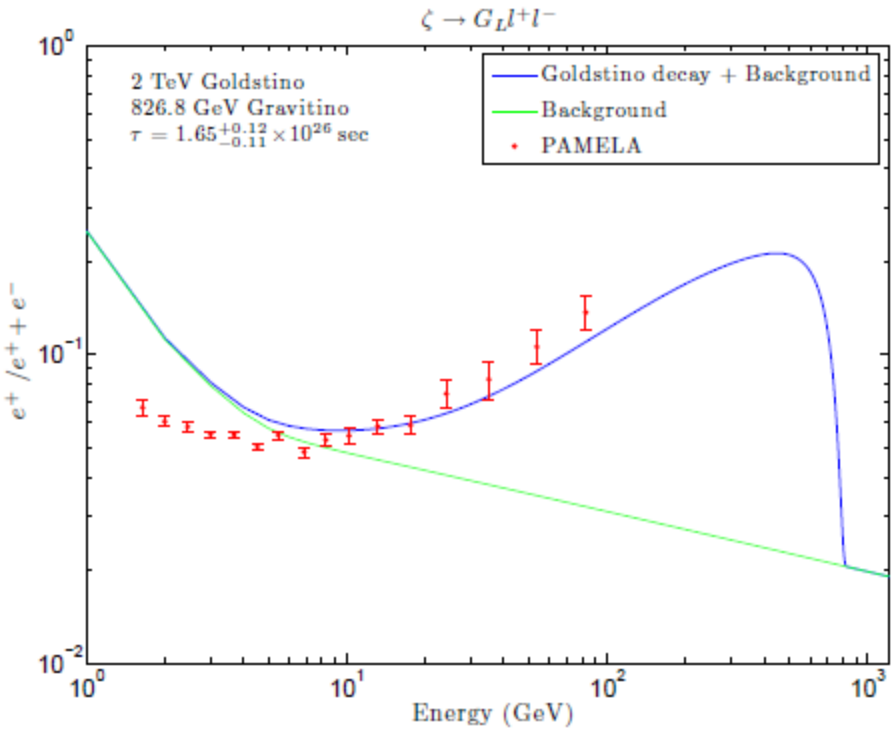
$$T_R \lesssim \mathrm{Min}\left\{\frac{m_{\tilde{\ell}}}{20},\ \frac{m_\zeta}{8}\right\}$$

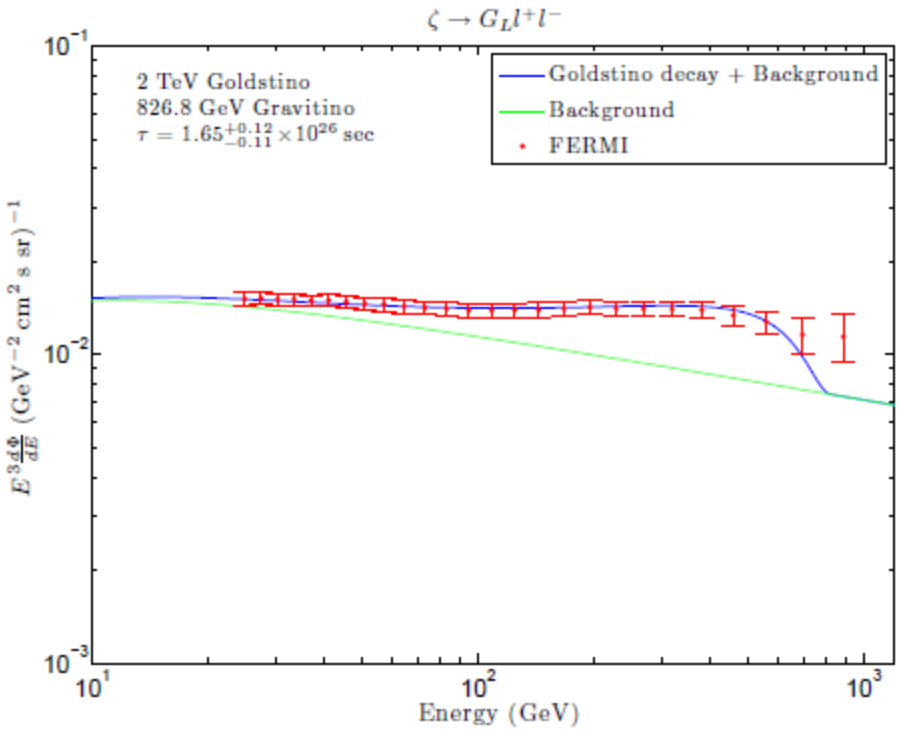
Dark matter relic density

- Lower bound on the reheating temperature:
  the relic density of the lightest observable-sector supersymmetric particle (LOSP)

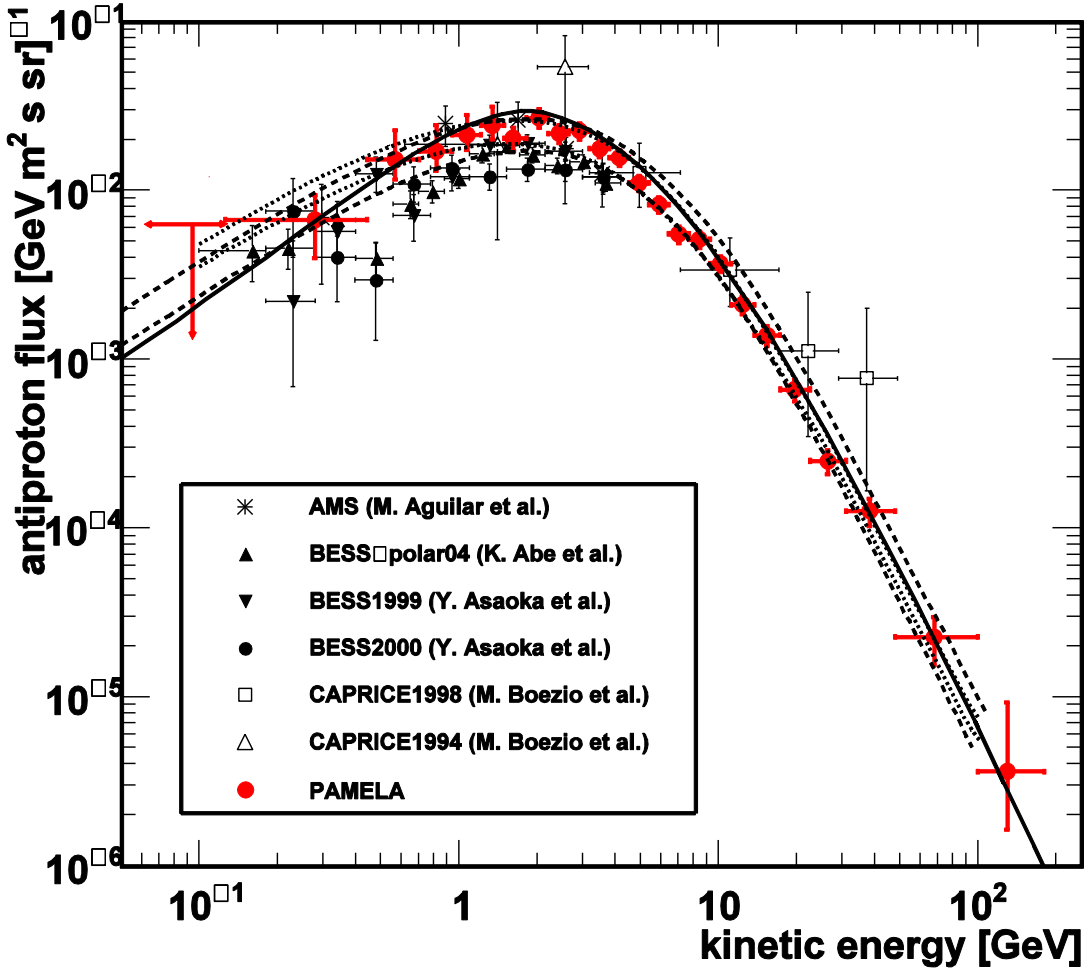
$$T_F \left(\sim \frac{m_{\rm LOSP}}{25} \text{ for a weakly interacting LOSP} \right) \lesssim T_R \lesssim \text{Min} \left\{ \frac{m_{\tilde{\ell}}}{20}, \frac{m_\zeta}{8} \right\}$$

PAMELA and FERMI



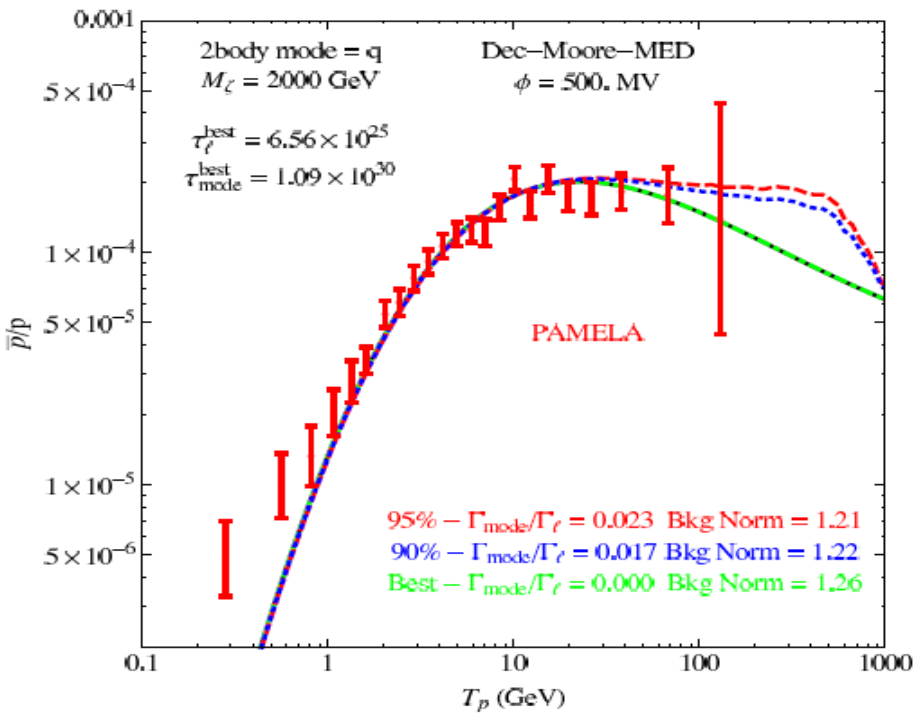


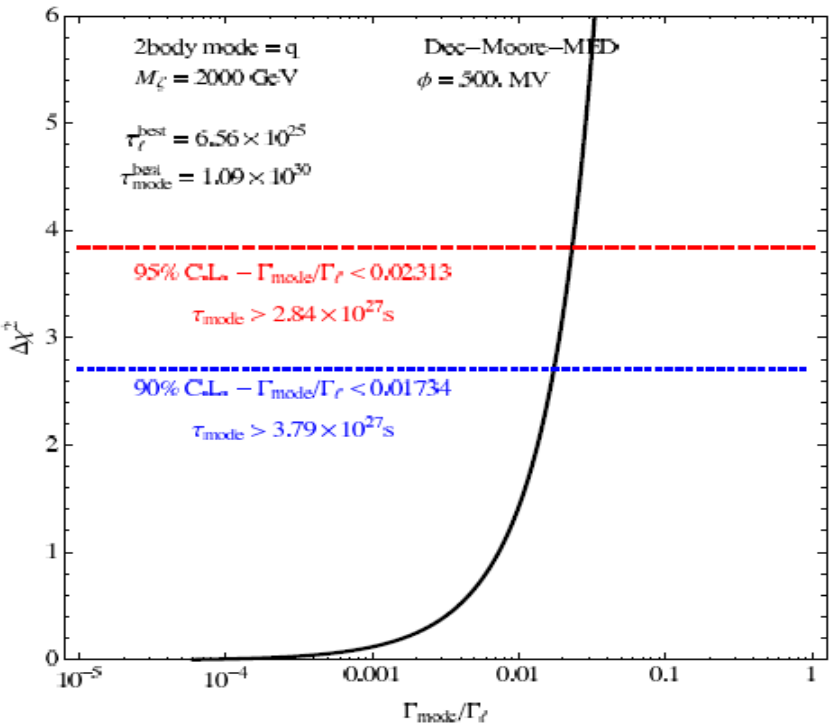
PAMELA antiproton



arXiv:1007.0821

PAMELA and FERMI





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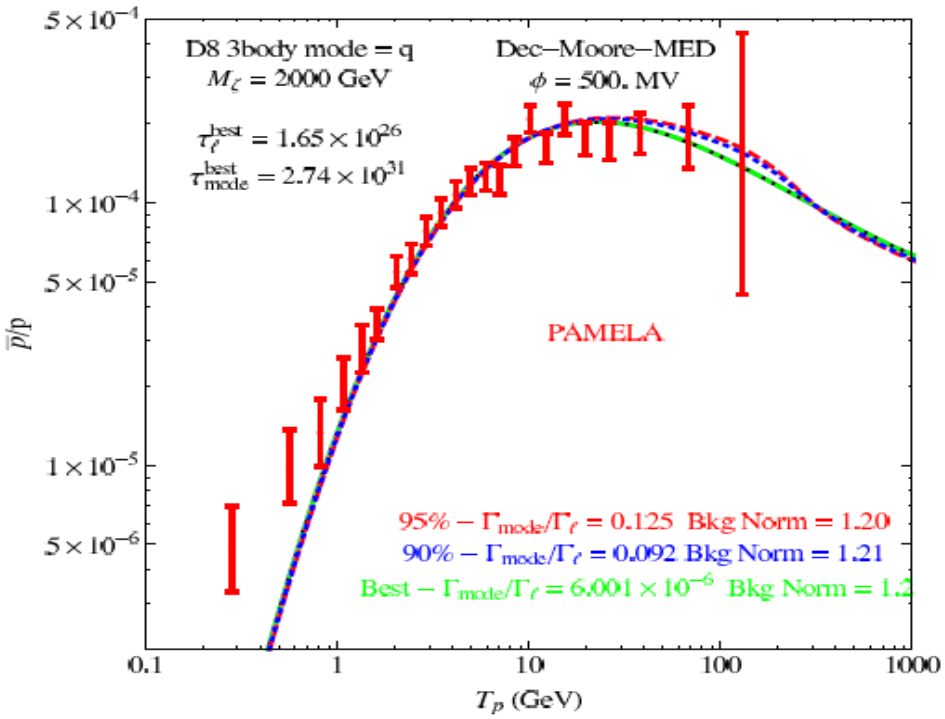

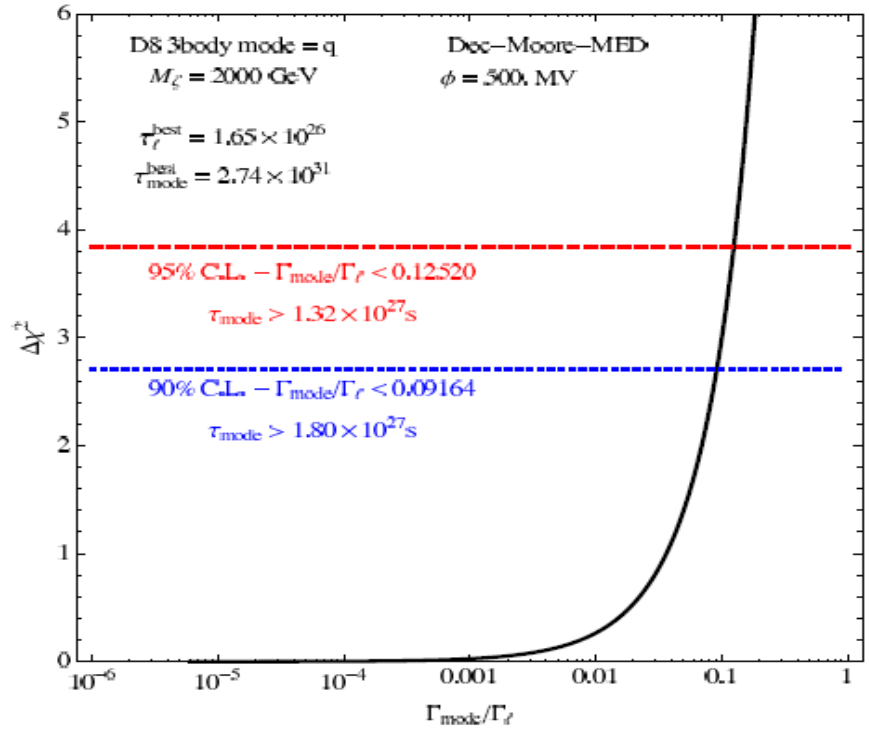

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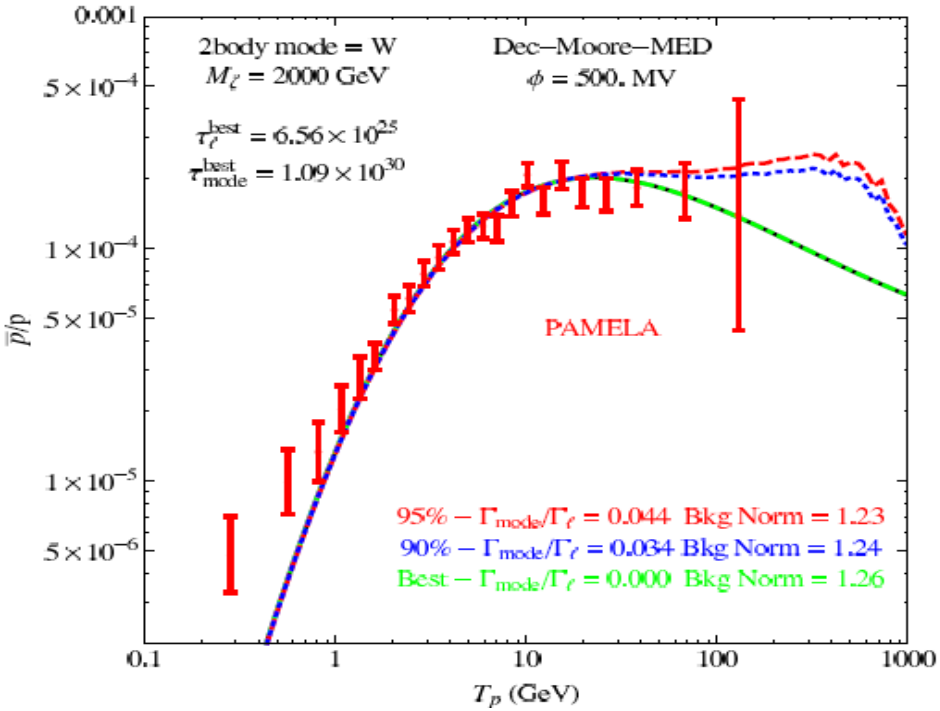

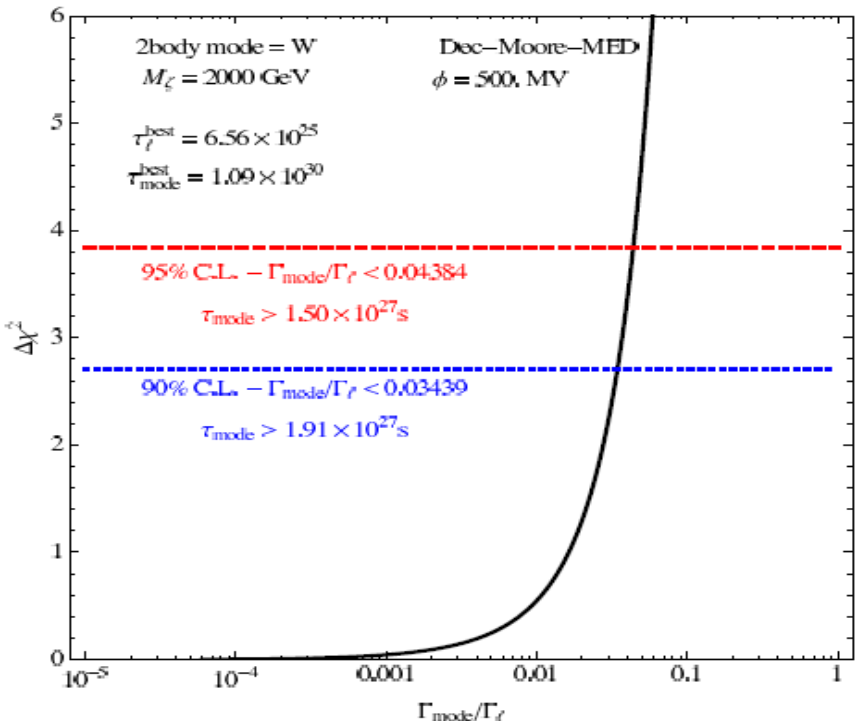

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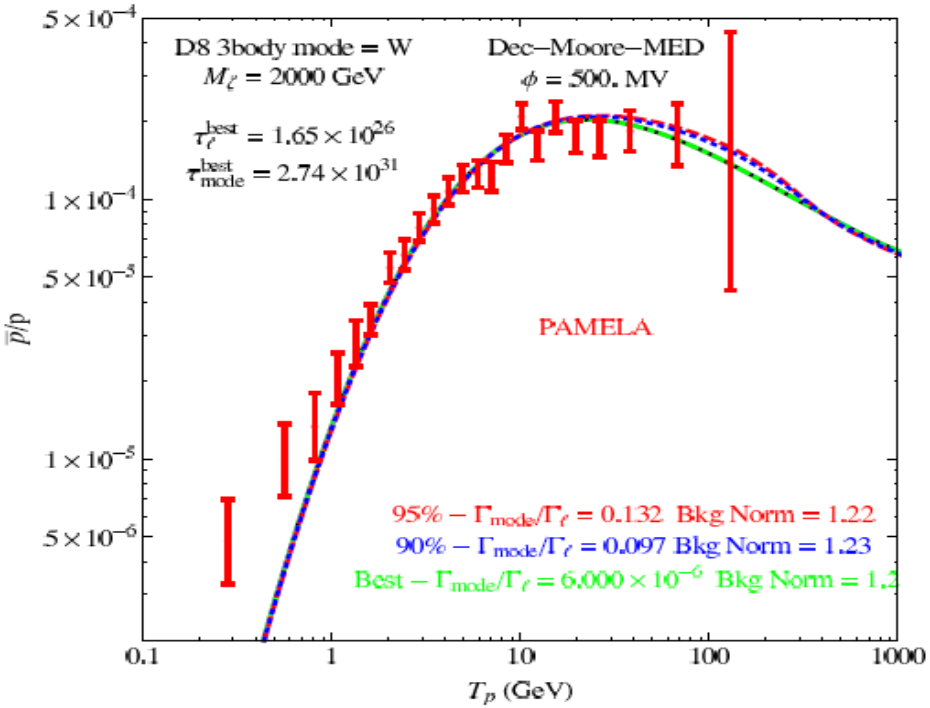

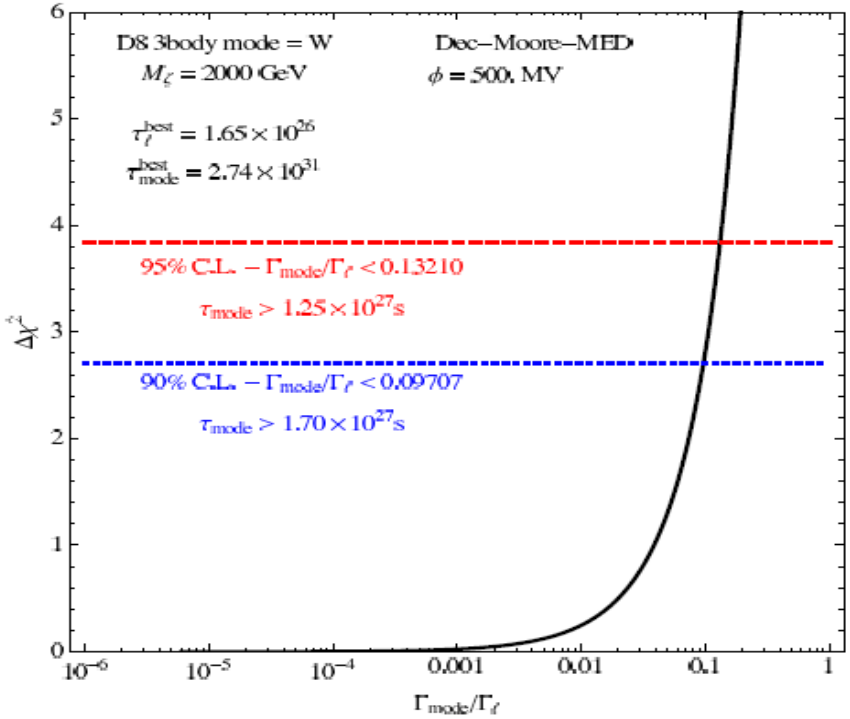

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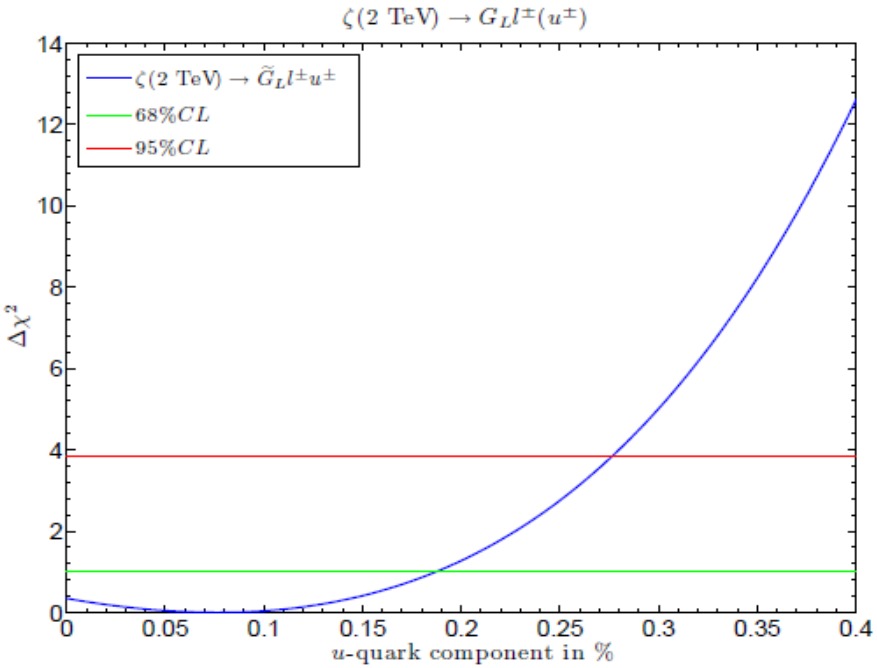

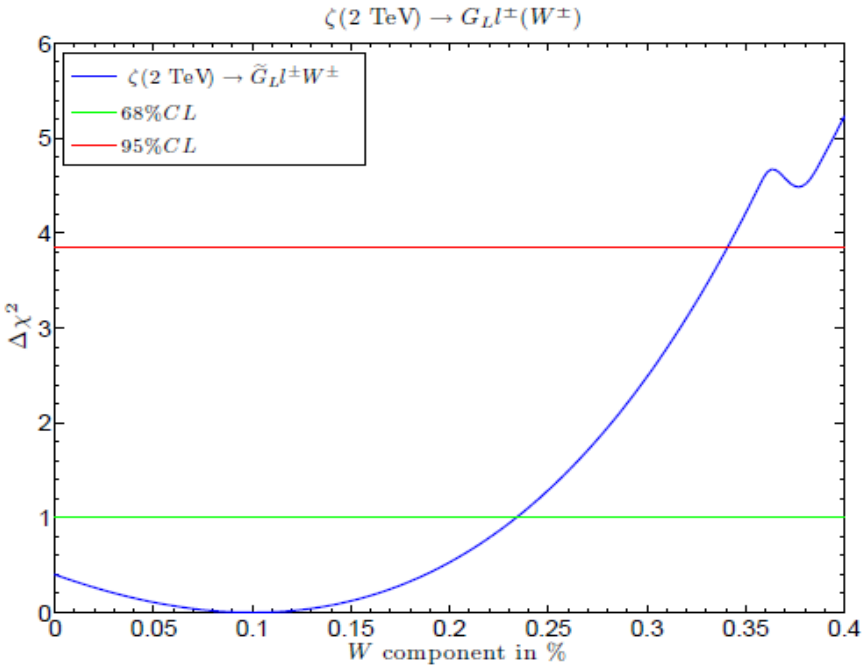

Conclusions

- Multiple SUSY breaking sectors provide a supersymmetric decaying dark matter in theories with goldstini.
- The decay of goldstino through dimension-8 operators naturally has a long lifetime capable of explaining the positron excess observed by the PAMELA.
- Compared to 2-body decays, the goldstino decay has softer spectra and therefore can accommodate more quark or W(Z) final states.