Dirac gaugino as leptophilic dark matter

Based on : JCAP 02 (2010) 015
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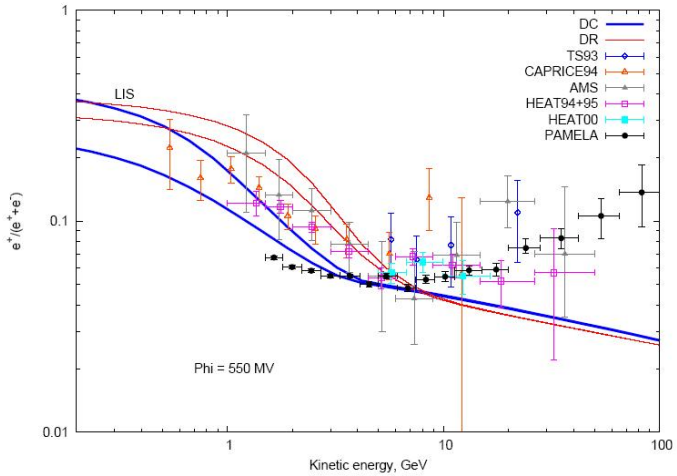
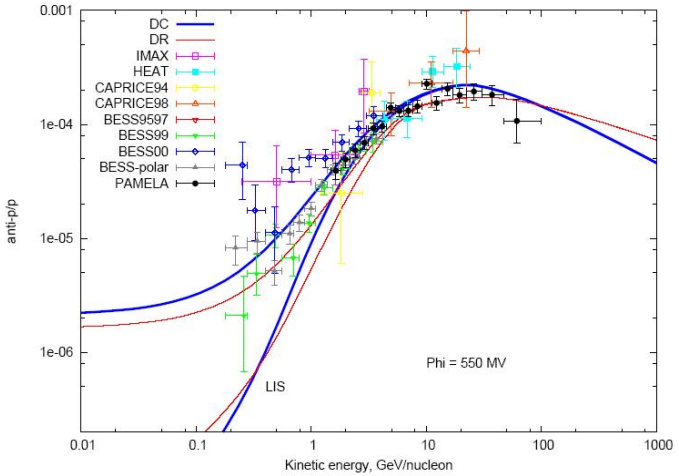
KIAS

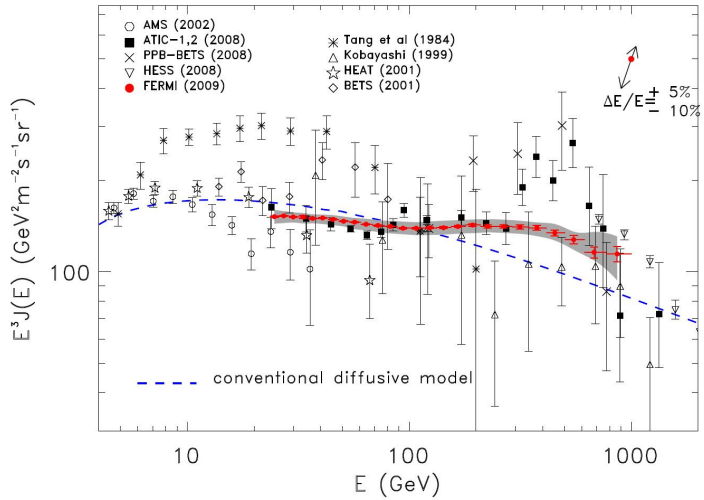
PHENO 2010

Cosmic ray observations





P.F. Yin et al., PRD **79**, 023512 (2009)



[Fermi-LAT] PRL **102**, 181101 (2009)

Candidates of $e^+ \& e^-$ source

- Nearby mature pulsars: Neither too far & young, nor old

  D. Hooper et al., JCAP **01**, 025 (2009); S. Profumo, arXiv:0812.4457 [astro-ph]

- Supernova remnants — N. J. Shaviv et al., PRL **103**, 111302 (2009)
- Dark matter decay: Required lifetime $\sim \mathcal{O}(10^{26}\mathrm{s})$
- Dark matter annihilation
  1. $\frac{\langle\sigma v\rangle_{\mathrm{Gal}}}{\langle\sigma v\rangle_{\mathrm{Relic}}} \sim 10^2 \left(\frac{M_{\mathrm{DM}}}{500\mathrm{GeV}}\right)^2$
  2. Excesses in $e^+ \& e^-$ but not in $\overline{p} \longrightarrow$ Majorana neutralino disfavored: $\langle\sigma v\rangle_{\chi\chi\to f\bar{f}}$ is suppressed by m_f^2/m_χ^2 due to helicity flip.
- Dirac gaugino
  1. No m_f^2/m_χ^2 suppression
  2. A potentially sizable σ_{SI} from $\overline{\chi}\gamma^\mu\chi Z_\mu$

Gaugino-Higgsino masses

- Extended R-symmetric gauge-Higgs sector

$$W' = \mu_1 H_d R_u + \mu_2 R_d H_u - \sqrt{2} g_a (\xi_1 H_d T^a R_u + \xi_2 H_u T^a R_d)\, \Phi^a$$

$\Phi^a = (\phi^a, \psi^a)$: N=2 counterpart of the gauge superfield W^a_α

- Dirac gaugino mass & extended μ term

$$X W^a_\alpha Q_\alpha \Phi^a \big|_F , \quad HR\Phi\big|_F \text{ or } HRX^\dagger\big|_D ,$$

- Neutralino mass matrix in the $(\psi^0, \tilde{B}, \tilde{H}_d, \tilde{R}_u, \tilde{H}_u, \tilde{R}_d)$ basis

$$\mathcal{M} = \begin{bmatrix} 0 & M_1 & 0 & -\xi_1 m_Z s_W c_\beta & 0 & \xi_2 m_Z s_W s_\beta \\ M_1 & 0 & -m_Z s_W c_\beta & 0 & m_Z s_W s_\beta & 0 \\ 0 & -m_Z s_W c_\beta & 0 & \mu_1 & 0 & 0 \\ -\xi_1 m_Z s_W c_\beta & 0 & \mu_1 & 0 & 0 & 0 \\ 0 & m_Z s_W s_\beta & 0 & 0 & 0 & \mu_2 \\ \xi_2 m_Z s_W s_\beta & 0 & 0 & 0 & \mu_2 & 0 \end{bmatrix}$$

- Diagonalization $\mathcal{M}_{diag} = \mathcal{N}^T \mathcal{M} \mathcal{N}$

- Diagonalization matrix

$$\mathcal{N} = \begin{bmatrix} c_1 & 0 & s_1 & 0 & 0 & 0 \\ 0 & c_4 & 0 & s_4 & 0 & 0 \\ -s_1 & 0 & c_1 & 0 & 0 & 0 \\ 0 & -s_4 & 0 & c_4 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} c_2 & 0 & 0 & 0 & s_2 & 0 \\ 0 & c_3 & 0 & 0 & 0 & s_3 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ -s_2 & 0 & 0 & 0 & c_2 & 0 \\ 0 & -s_3 & 0 & 0 & 0 & c_3 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & c_5 & 0 & s_5 & 0 \\ 0 & 0 & 0 & c_6 & 0 & s_6 \\ 0 & 0 & -s_5 & 0 & c_5 & 0 \\ 0 & 0 & 0 & -s_6 & 0 & c_6 \end{bmatrix}$$

6 rotation angles vanish in the limit $|\mu_{1,2}| \gg M_1 > M_Z$ where $\mathcal{N} \simeq 1$.

- Mass matrix in the Dirac basis

$$\mathcal{M}_{diag} = \begin{bmatrix} 0 & M_\chi & 0 & 0 & 0 & 0 \\ M_\chi 0 & 0 & 0 & 0 & 0 & \\ 0 & 0 & 0 & M_{\tilde{H}_1} & 0 & 0 \\ 0 & 0 & M_{\tilde{H}_1} & 0 & 0 & 0 \\ 0 & 0 & & 0 & 0 & M_{\tilde{H}_2} \\ 0 & 0 & 0 & 0 & M_{\tilde{H}_2} & 0 \end{bmatrix}$$

Interaction vertices

$$
\begin{aligned}
\mathcal{L}_f &= \sqrt{2}g' Y_{f_R} \mathcal{N}_{22} [\overline{f} P_L \chi \widetilde{f}_R + \overline{\chi} P_R f \widetilde{f}_R^*] + \sqrt{2}g' Y_{f_L} \mathcal{N}_{22} [\overline{f} P_R \chi^c \widetilde{f}_L + \overline{\chi}^c P_L f \widetilde{f}_L^*] \,, \\
\mathcal{L}_{h^0} &= \frac{g'}{2} h^0 [C_1 (\overline{\psi}_{H_1} P_R \chi^c + \overline{\chi}^c P_L \psi_{H_1}) + C_2 (\overline{\psi}_{H_2} P_R \chi^c + \overline{\chi}^c P_L \psi_{H_2}) \\
&\quad + C_1' (\overline{\psi}_{H_1} P_L \chi^c + \overline{\chi}^c P_R \psi_{H_1}) + C_2' (\overline{\psi}_{H_2} P_L \chi^c + \overline{\chi}^c P_R \psi_{H_2}) \\
&\quad + 2\delta_S \, \overline{\chi} \chi] \,, \\
\mathcal{L}_Z &= \frac{g}{2 c_W} Z_\mu [\delta_1' (\overline{\psi}_{H_1} \gamma_\mu P_L \chi^c + \overline{\chi}^c \gamma_\mu P_L \psi_{H_1}) + \delta_1 (\overline{\psi}_{H_1} \gamma_\mu P_R \chi^c + \overline{\chi}^c \gamma_\mu P_R \psi_{H_1}) \\
&\quad + \delta_2' (\overline{\psi}_{H_2} \gamma_\mu P_L \chi^c + \overline{\chi}^c \gamma_\mu P_L \psi_{H_2}) + \delta_2 (\overline{\psi}_{H_2} \gamma_\mu P_R \chi^c + \overline{\chi}^c \gamma_\mu P_R \psi_{H_2}) \\
&\quad + \delta_V^2 \, \overline{\chi} \gamma_\mu \chi + \delta_A^2 \, \overline{\chi} \gamma_\mu \gamma_5 \chi] \,,
\end{aligned}
$$

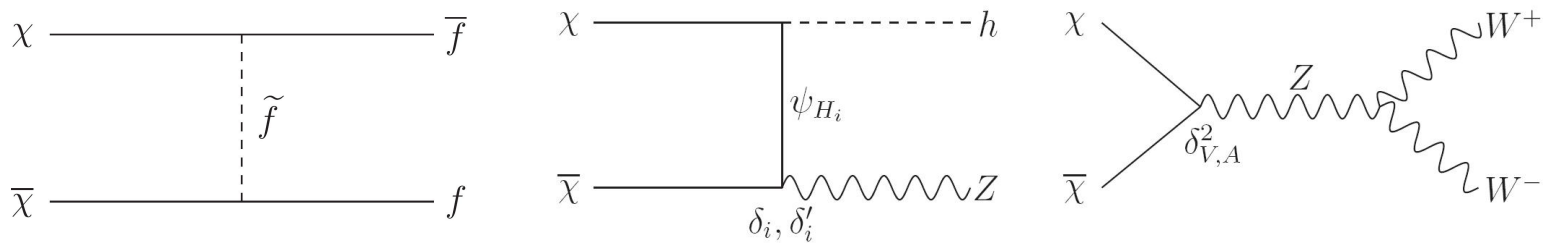
where

$$
\begin{aligned}
&C_1 = s_\alpha \mathcal{N}_{22} \mathcal{N}_{33} + c_\alpha \mathcal{N}_{22} \mathcal{N}_{53} \,, \qquad C_2 = c_\alpha \mathcal{N}_{22} \mathcal{N}_{55} + s_\alpha \mathcal{N}_{22} \mathcal{N}_{35} \,, \\
&C_1' = \xi_1 s_\alpha \mathcal{N}_{11} \mathcal{N}_{44} + \xi_2 c_\alpha \mathcal{N}_{11} \mathcal{N}_{64} \,, \quad C_2' = \xi_2 c_\alpha \mathcal{N}_{11} \mathcal{N}_{66} + \xi_1 s_\alpha \mathcal{N}_{11} \mathcal{N}_{46} \,, \\
&\delta_j(\mathcal{N}_{kl}) \propto s_i \propto m_Z / |\mu_{1,2}| \,.
\end{aligned}
$$

Annihilation channels & direct detection

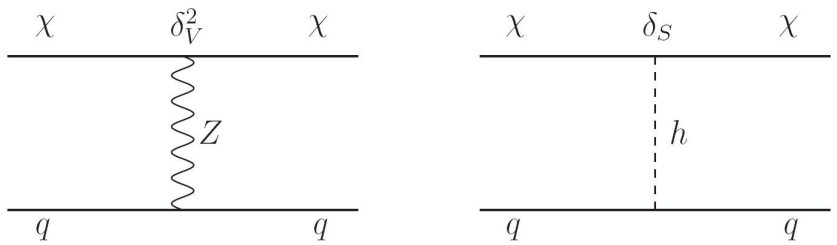
- Dominant annihilation channels

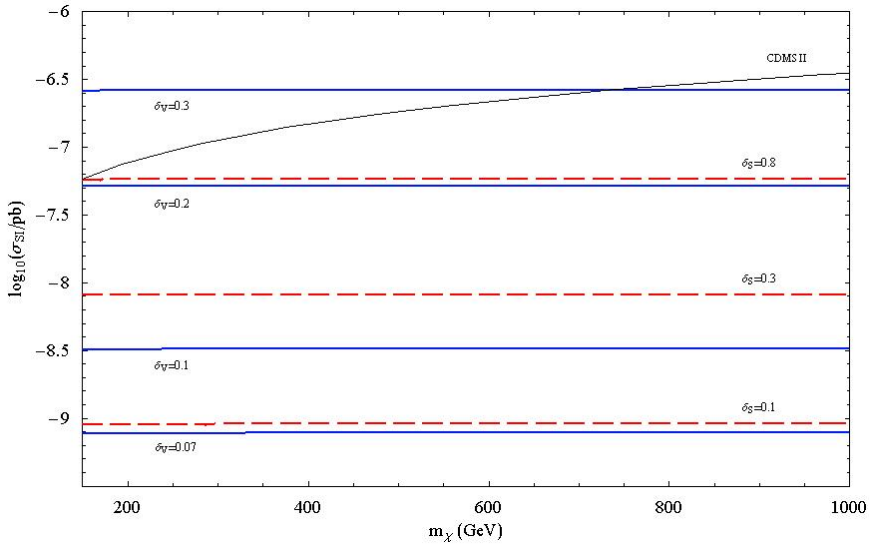
$$\langle \sigma v \rangle_{l\bar{l}} \simeq \frac{2\pi\alpha^2}{c_W^4} Y_l^4 \frac{m_\chi^2}{(m_{\tilde{l}}^2 + m_\chi^2)^2}$$



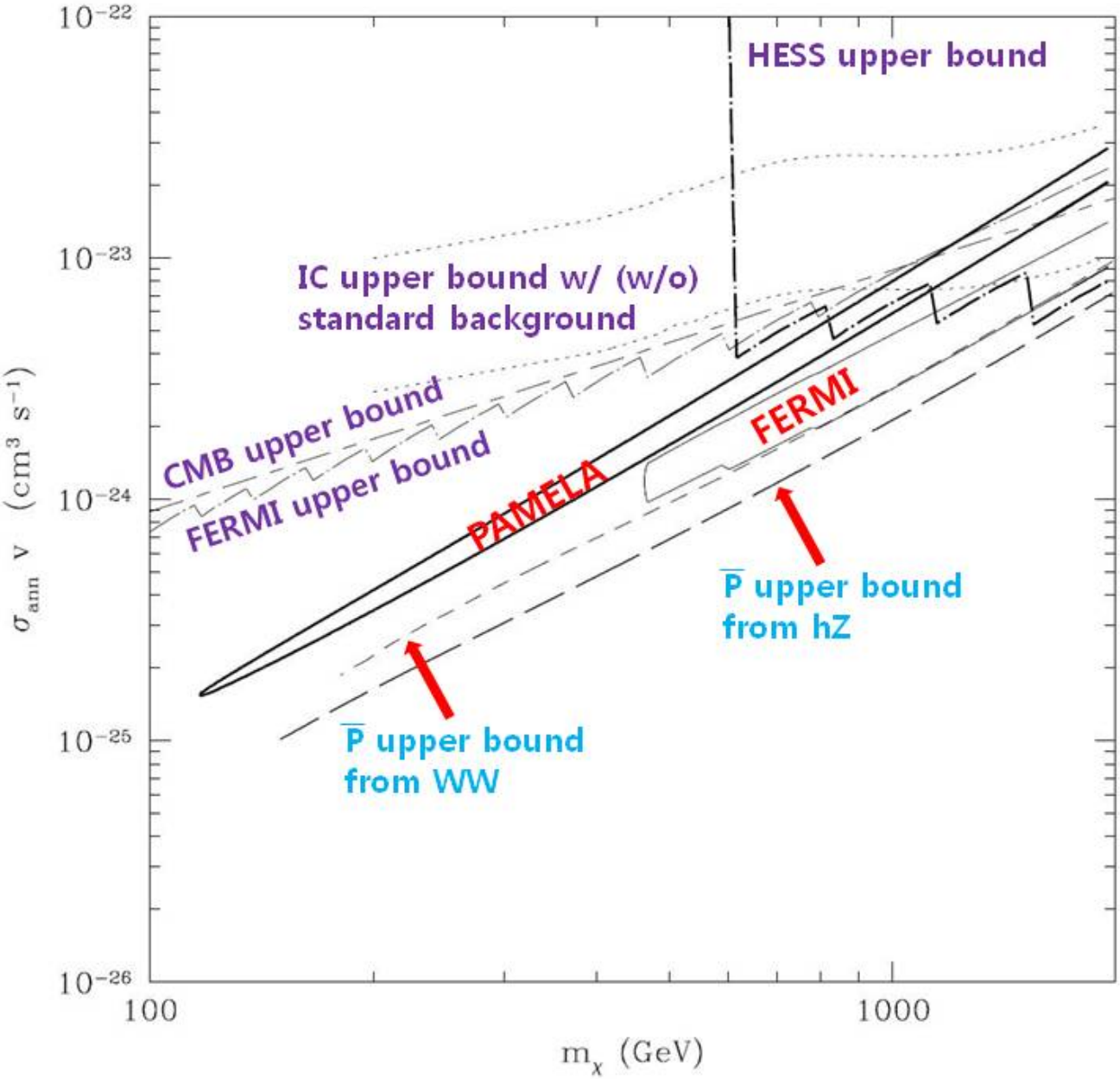
$\chi\overline{\chi} \to h \to f\overline{f}, hZ, W^+W^-$ & $\chi\overline{\chi} \to \psi_{H_i} \to 2h$: suppressed by $\delta_S^2 v^2$ or v^2

- Direct detection



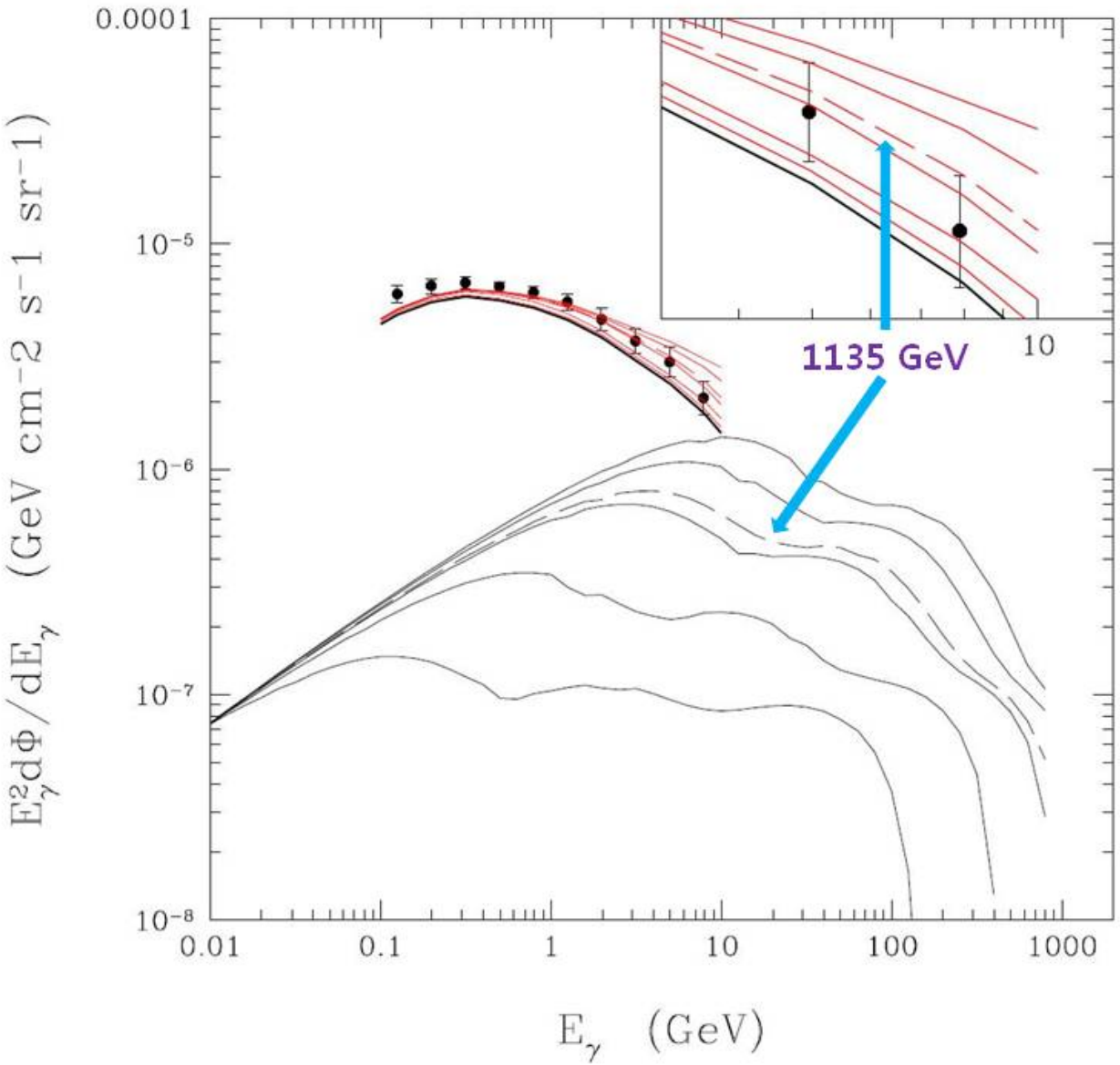


Constraints on $\langle \sigma v \rangle$



Diffuse $\gamma-$ray by IC scattering

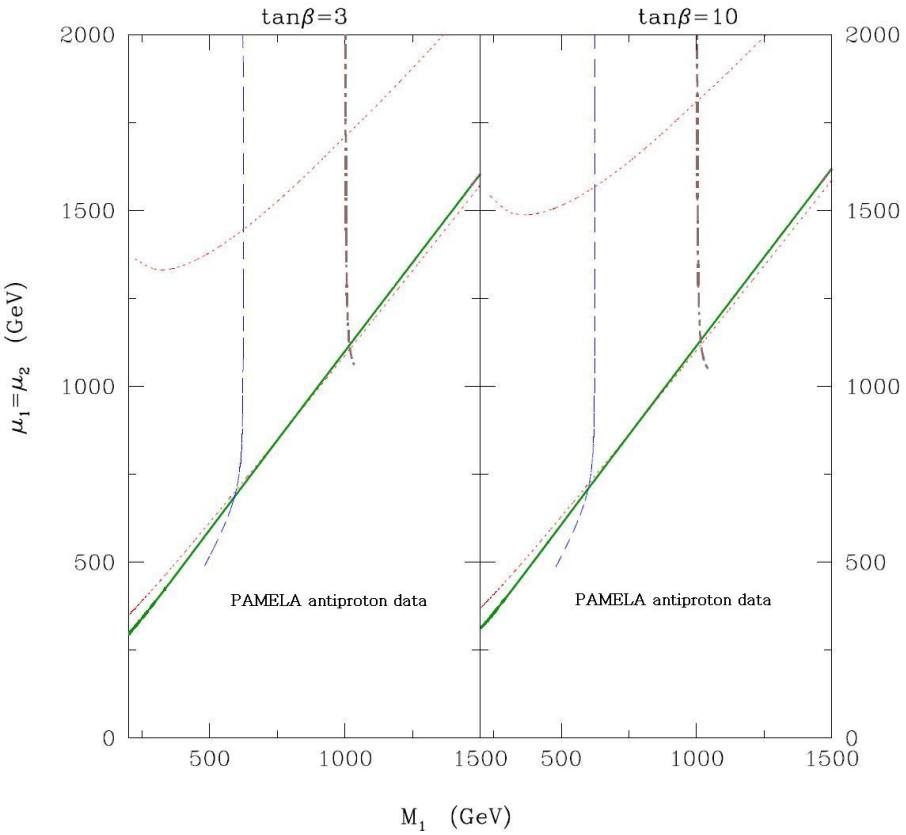
m_χ=200, 500, 1000, 1135, 1500, 2000 GeV

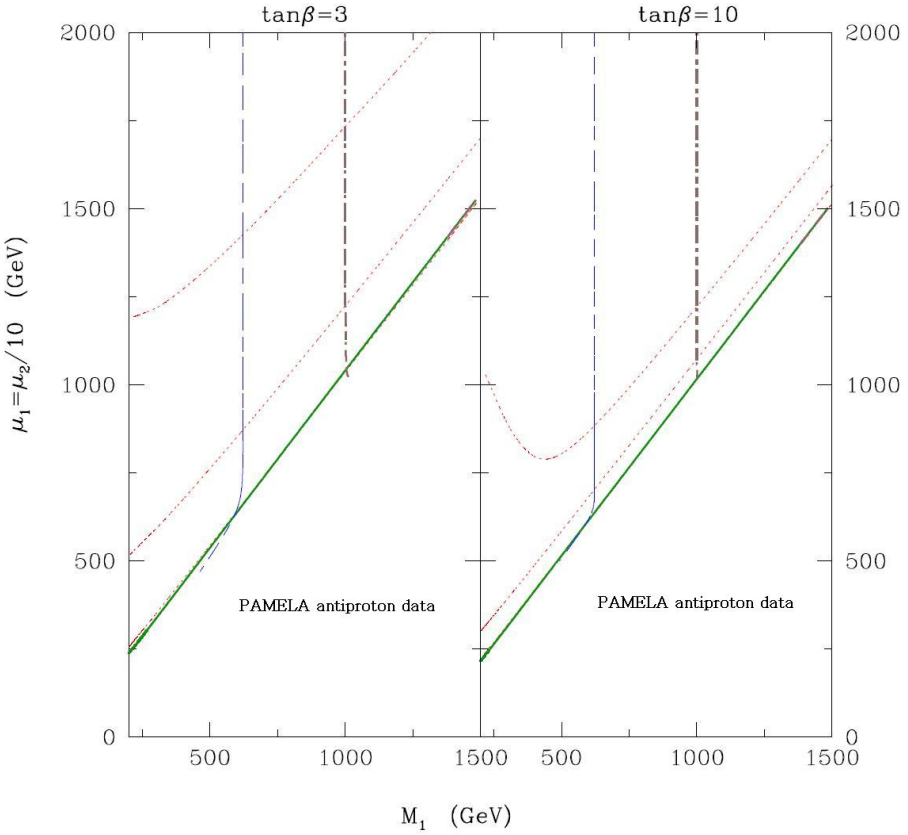


Parameter space

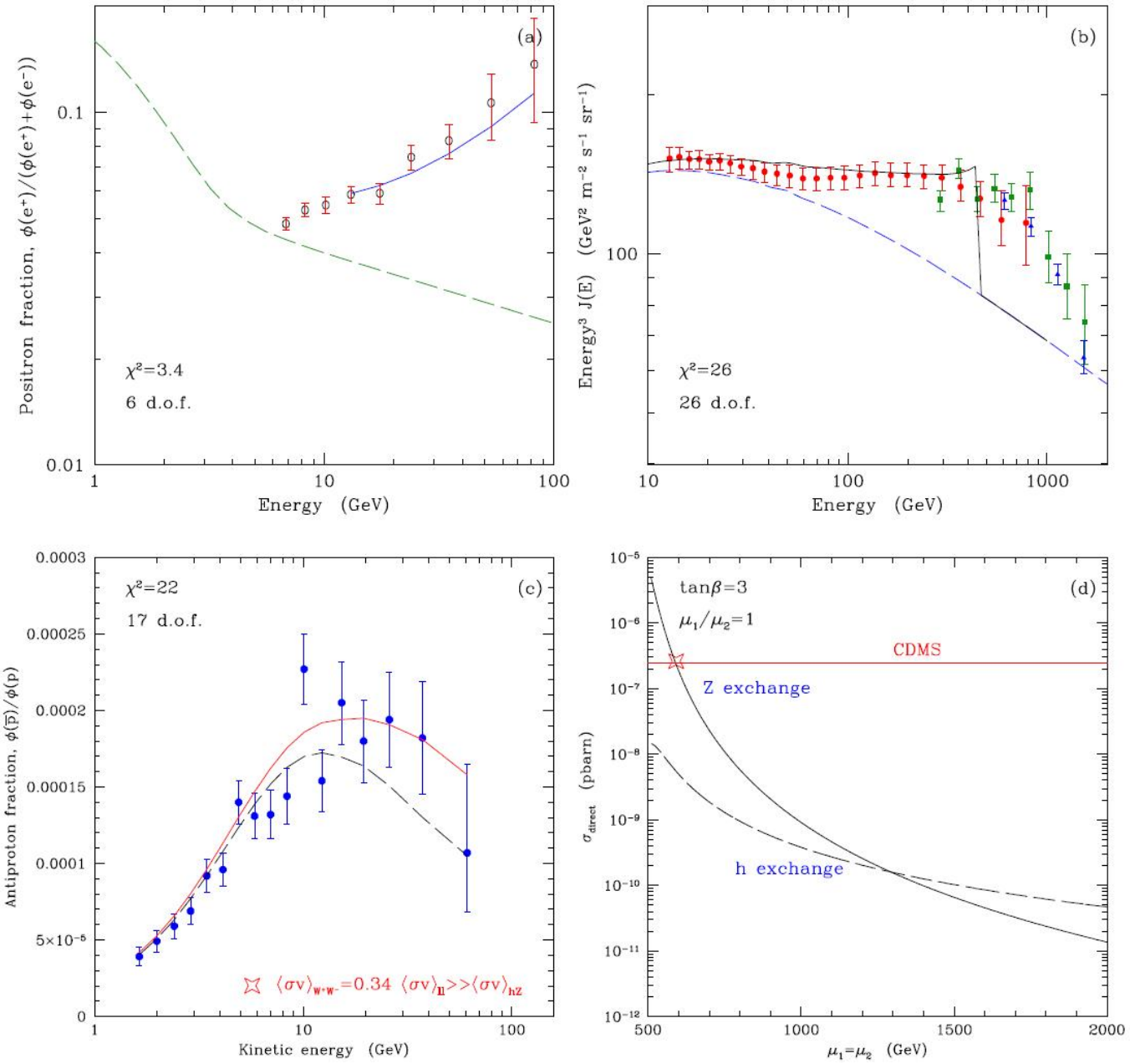
Dashed line: boost factor $= 10$

Dotted lines: $\sigma_{\rm SI}/\sigma_{\rm CDMSII} = 1, 10^{-3}, 10^{-5}$ (from lower curve)





Various observables for $m_\chi = 465$ GeV



Conclusion

- Leptonic excesses in cosmic rays may reveal the identity of DM.
  $\longrightarrow$ Require brand new ideas?
- Dirac gauginos can be natural realizations of leptophilic DM .
- Light ($m_\chi \lesssim 500$ GeV) DG can explain the PAMELA data with moderate or no boost factor for light ($\gtrsim m_\chi$) slepton masses.
- DG with a non-vanishing Higgsino fraction can have a vector coupling with the Z boson. $\longrightarrow$ Sizable $\sigma_{\rm SI}$
- Present constraints on the Higgsino fraction of DG from direct searches are at the same level of those coming from antiproton data.
  $\longrightarrow$ DG signal is potentially at the level of the sensitivity of direct detection experiments at present and in the near future.
- Determining the Majorana/Dirac nature of gauginos will be an interesting task for future experiments to look for SUSY.

Thank You!

Boost factors for the democratical annihilation case

Solid: boost factors, dashed: $\Omega_{min}h^2/\Omega_{DG}h^2$, thin: $m_{\tilde{l}}/m_\chi = 1$, thick: $m_{\tilde{l}}/m_\chi = 2$, $|\mu| \gg M_1$