Dirac Gaugino as leptophilic dark matter

Stefano Scopel

SEOUL NATIONAL UNIVERSITY

Based on E.J. Chun and J.C. Park, work in progress

Extended Workshop on DM, LHC and Cosmology

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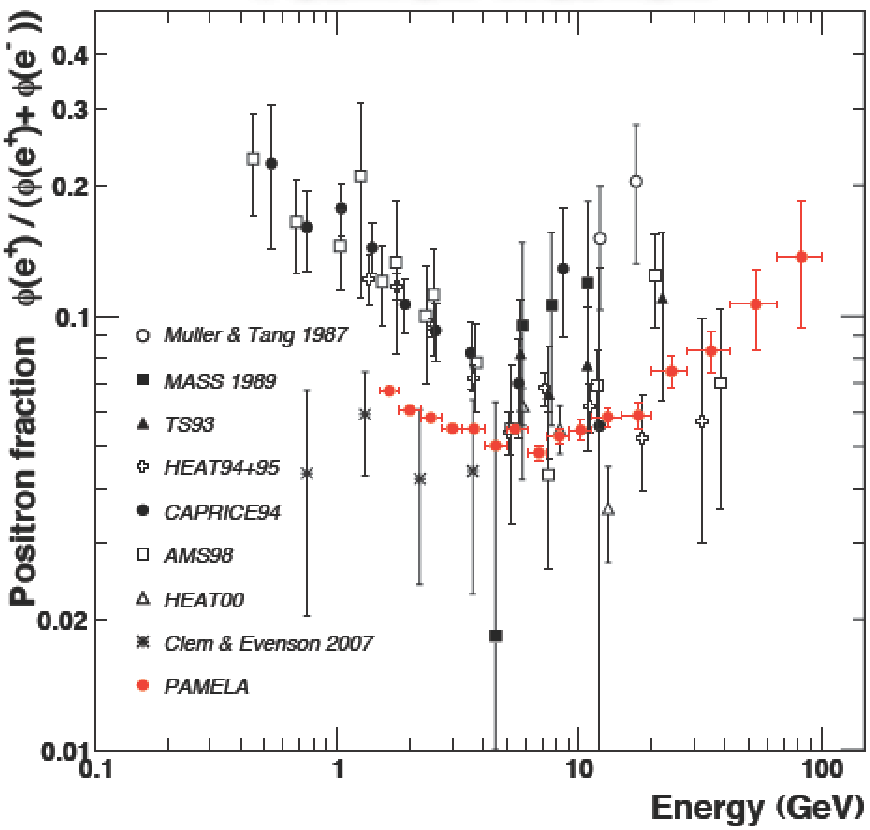
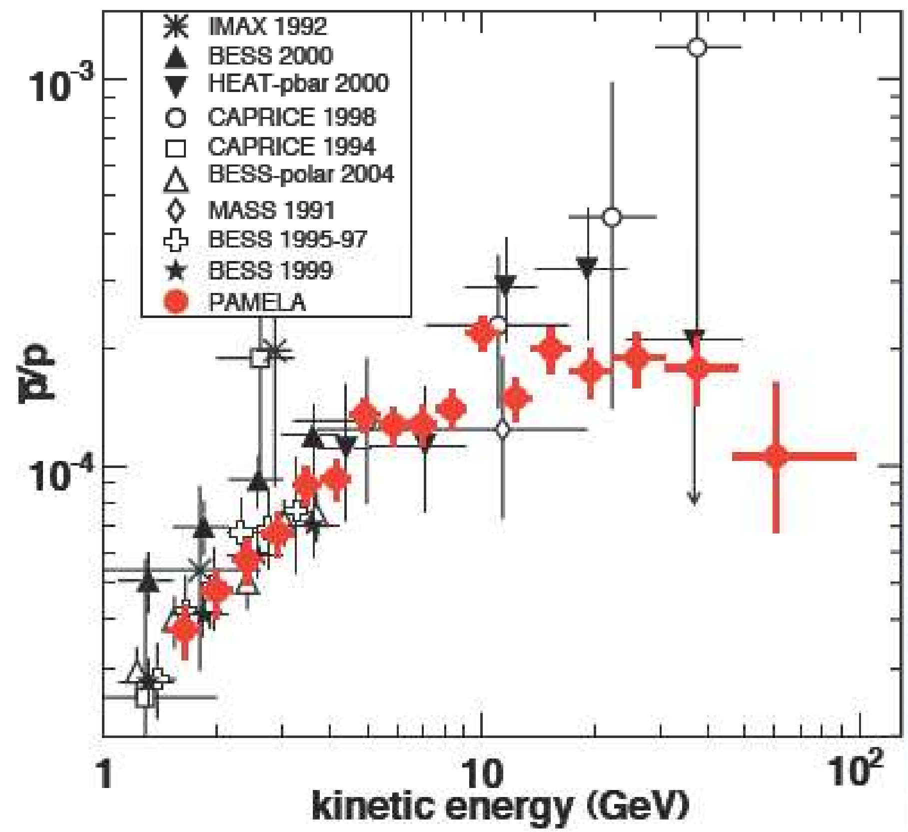
PaMeLa

a Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics

$e^+/(e^+ + e^-)$ arXiv:0810.4995, 4994 [astro-ph] $\bar{p}/p$



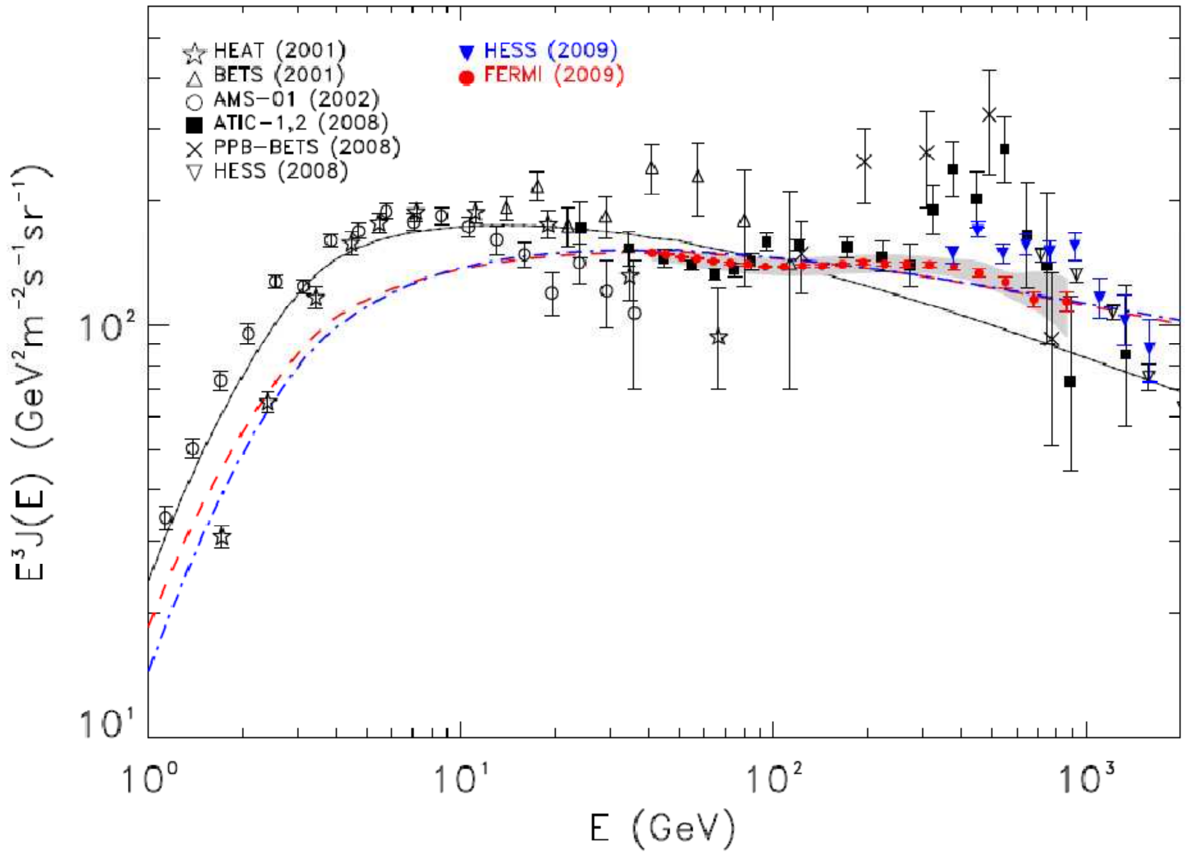


positron excess above 10 GeV. but no excess in antiprotons

Electrons+positrons from Fermi/LAT (Abdo et al., PRL102,181101)

•ATIC peak not confirmed

•spectrum compatible to E^{-3} with **mild excess** @ same energy of ATIC



•Flatness of spectrum disfavours interpretations of PAMELA in terms of a light Dark Matter particle (m≤450 GeV)

Puzzles for DM interpretation

- Excesses in e^+/e^-; not in $\bar{p}$.
- Observed fluxes=(100-1000) x predicted flux for thermal DM:

$$\text{Observed Flux} = \left(\frac{\rho_{DM}}{0.3GeV/cm^3}\right)^2 \left(\frac{\langle\sigma v\rangle_{GAL}}{10^{-6}\,\mathrm{GeV}^{-2}}\right)$$

$$\langle\sigma v\rangle_{FO} \sim 10^{-9}\mathrm{GeV}^{-2}$$

Local clumpiness in DM distribution: ‘Boost Factor’< 10

Lavalle et.al., 0709.3634 [astro-ph]

enhancement of <σv> at small velocities?

The Standard Lore about a steep rise in positrons from DM annihilation:

• most likely from direct annihilation to leptons. In this case Majorana neutralino disfavored - due to chirality flip Born cross section suppressed by m_e^2/m_{susy}^2 – but spin-1 DM particles from UED or little Higgs models are OK, as well as Dirac fermions from mirror DM (also hidden vector DM discussed by Hambye today)

• Constraints from antiprotons

• anyway, typically large boost factors required (clumpiness? – maybe unreasonably too large according to recent numerical simulations)

• otherwise large $\langle \sigma v \rangle$ → (1) non-thermal DM; (2) constraints from other indirect searches (gammas, antiprotons) – however astrophysical uncertainties are larger for the latter (positrons usually come from nearby)

New DM ideas

- Leptophilic property:

1) DM couplings to leptons only.

2) DM annihilates to sub-GeV particles that is forbidden kinematically to decay to proton/anti-p.

- Boosted annihilation in galaxy:

1) Non-thermal DM.

2) Assumed local clumpiness.

3) Breit-Wigner resonance.

4) Sommerfeld enhancement.

5) Dirac gauginos

Large thoretical activity triggered by PAMELA

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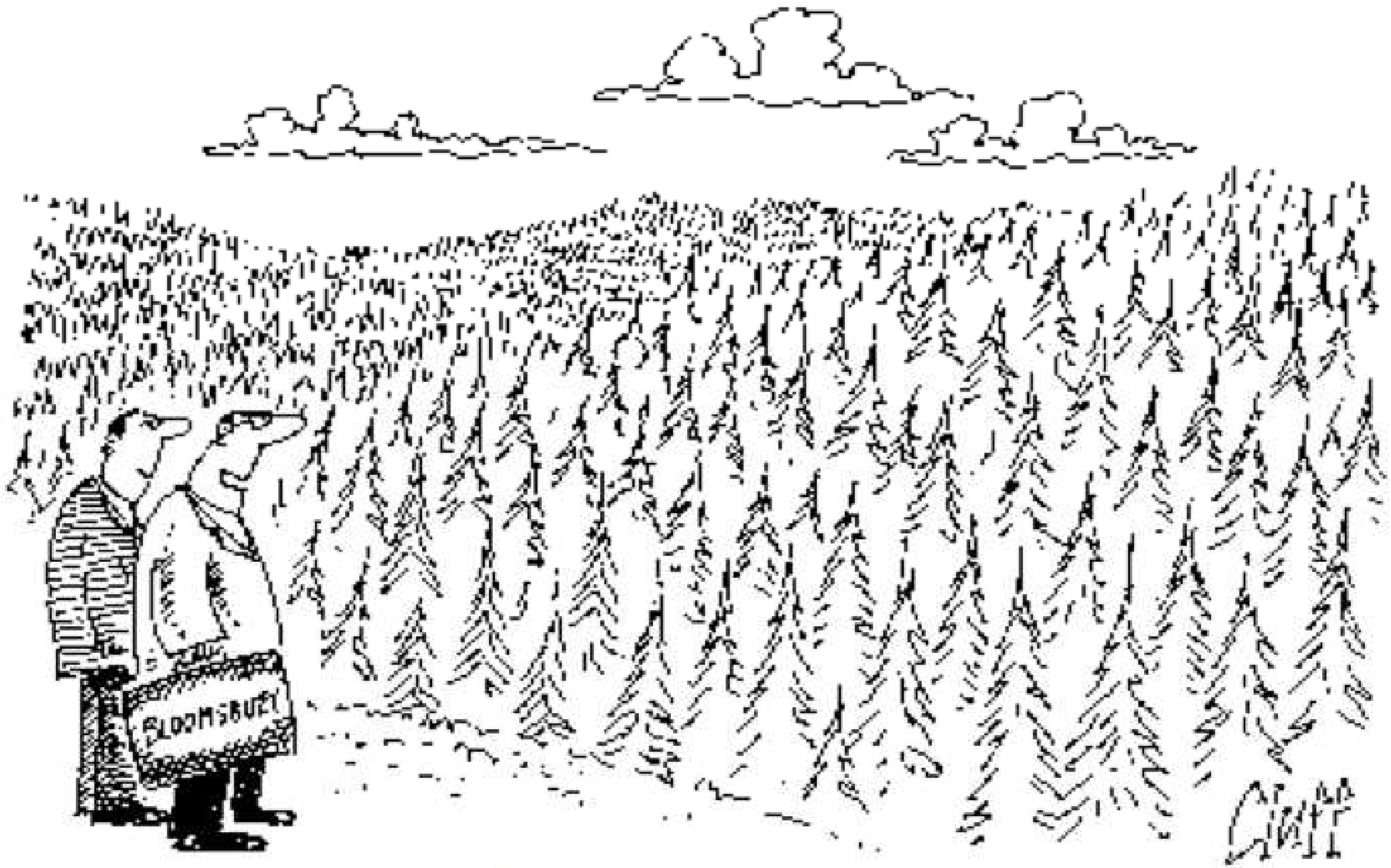
and more….

a small appetizer of the (near!) future awaiting us?

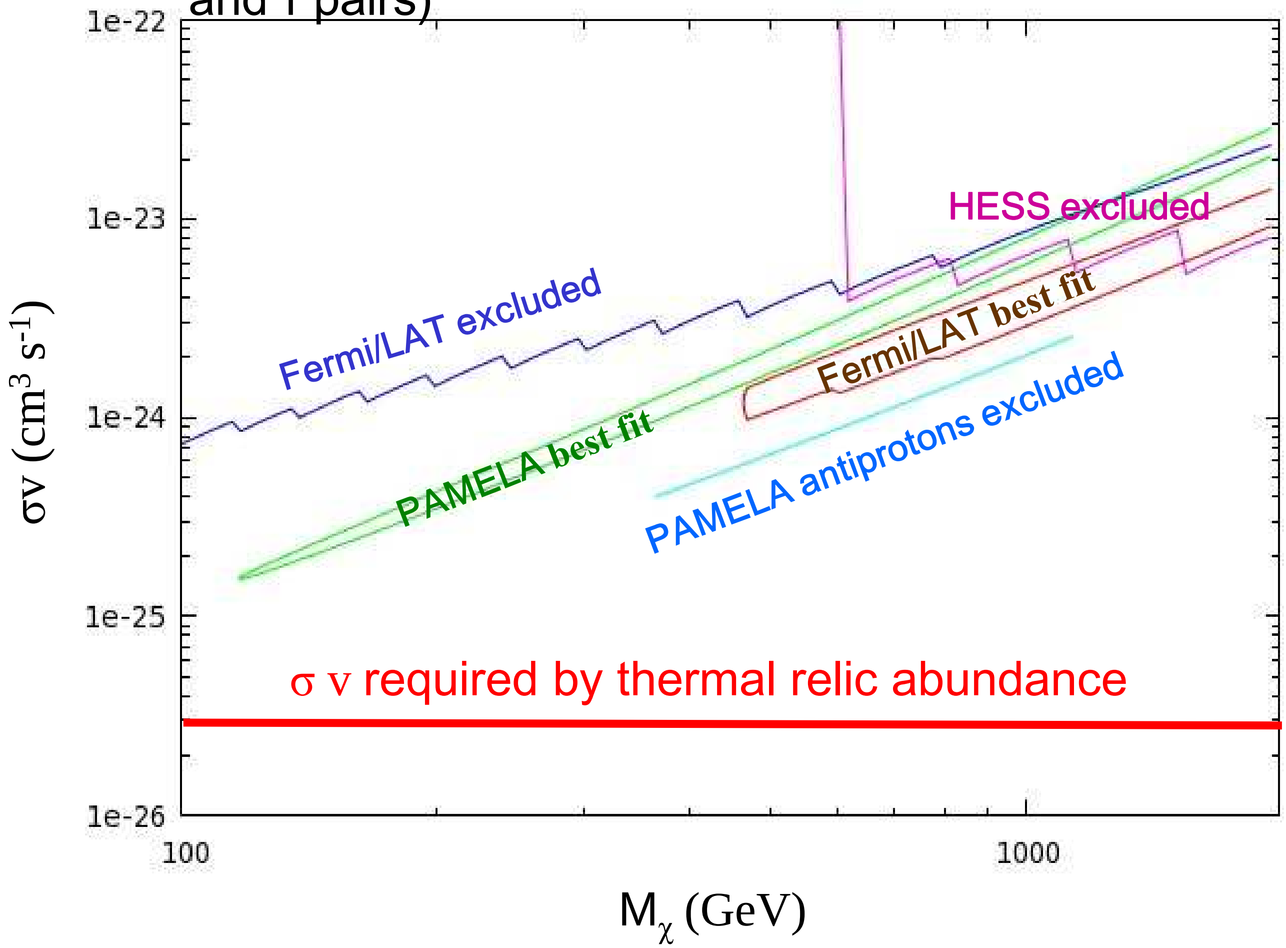


“One day, all these will be LHC phenomenology papers”

Positrons, electrons and antiprotons from space

- PAMELA positron excess fitted by large DM mass range
- Fermi/LAT data disfavor lower masses (m_{DM}<450 GeV)
- PAMELA antiprotons constraint the branching ratio to hadrons

Leptophilic dark matter (democratic annihilation to e, μ and τ pairs)



The values of σ v needed to explain PAMELA are almost two orders of magnitude larger compared to those required by a thermal relic abundance → non-thermal candidate? non-standard cosmology? Sommerfeld enhancement at low temperatures? boost factor from halo clumpiness?

Determining the Majorana/Dirac nature of gauginos will be an interesting task for future experiments looking for supersymmetric CP and flavor violation, collider signatures and dark matter properties

Paul Dirac

Ettore Majorana

important distinctions between Majorana and Dirac gauginos:

1. Annihilation of a Dirac gaugino into a fermion-antifermion pair, $\chi\chi \rightarrow ff$, has a non-vanishing s-wave contribution even in the limit of vanishing fermion masses, and thus the leptonic final states are not suppressed
2. Dirac gauginos can have a vector coupling with the Z gauge boson, $\chi\gamma^{\mu}\chi Z$, leading to a potentially sizable <u>spin-independent</u> coherent scattering with nuclei (proportional to A^2)

For recent analyses on the subject of Dirac gauginos see for instance: Choi, Drees, Freitas, Zerwas, PRD78(2008)095007, K. Hsieh, PRD77, 015004 (2008); R.Harnik and G.D.Kribs, arXiv:0810.5557, G.Belanger, K.Benakli, M.Goodsell, C.Moura and A.Pukhov, arXiv:0905.1043.

•In the minimal supersymmetric standard model (MSSM) gauge supermultiplets are built up by two components, bosonic gauge fields and fermionic gaugino fields. Since neutral vector fields are self-conjugate, the corresponding supersymmetric partners are Majorana fields.

•fermionic components can be paired with two additional fermionic fields in N=2 supersymmetric theories - if the fields are mixed maximally the four fermionic degrees of freedom can join to a Dirac field and its charge-conjugate companion

In order to ensure such Dirac nature of dark matter, Majorana mass terms, which give mass splitting between Dirac components, have to be highly suppressed.

Otherwise, the heavier component of two quasi-degenerate Majorana gauginos will decay to the lighter one and the galactic dark matter will consist of pure Majorana gauginos.

If one assumes the N=2 structure in the Higgs sector, that is, the two Higgses H_u and H_d form a N=2 hypermultiplet, the Dirac structure imposed at the tree level is spoiled by a large amount due to the radiative corrections with the Higgs-Higgsino and fermion-sfermion in the loop.

$$\tilde{B}_2 \to \tilde{B}_1 \gamma \quad : \quad \Gamma \approx \frac{\alpha}{4\pi} \left(\frac{\alpha'}{4\pi} \frac{m_{\tilde{B}}^2}{\tilde{m}^2} \right)^2 \delta m_M$$

δm_M = splitting between two Majorana gauginos needs to be ≲10^{-33} GeV to ensure stability of Dirac state on cosmological scales

$$\Rightarrow \quad \delta m_M \ll \frac{m_{3/2}^3}{M_P^2}$$

large fine-tuning required

A way to enforce this property is to assume a continuous R symmetry which forbids the usual term for the Higgs bilinear $H_u H_d$ and the *A*-term soft breaking (Kribbs, Poppitz and Weiner, PRD78(2008)055010)

For the MSSM, writing all operators consistent with the SM gauge symmetries and the extended R-symmetry:

1. Majorana gaugino masses are forbidden.
2. The -term, and hence Higgsino mass, is forbidden.
3. A-terms are forbidden.
4. Left-right squark and slepton mass mixing is absent (no -term and no A-terms)

Absence of μ term → extended Higgs sector:

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

$\Phi^a=(\varphi^a, \psi^a)$ N=2 counterpart of the gauge superfield W_α^a

$\zeta_{1,2}$ arbitrary parameters breaking N=2 susy (in the following we assume $\zeta_{1,2}=1$)

Neutralino mass matrix in the $(\psi^0, \widetilde{B}, \widetilde{H}_d, \widetilde{R}_u, \widetilde{H}_u, \widetilde{R}_d)$ 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 matrix with neutralino mixings from:

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

The Dirac structure has 6 mass eigenvalues grouped two-by-two in three degenerate subspaces:

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

switch the basis to Dirac-type combinations:

$$\left(\frac{\tilde{\psi}^0 \pm \tilde{B}}{\sqrt{2}}, \frac{\tilde{H}_d \pm \tilde{R}_u}{\sqrt{2}}, \frac{\tilde{H}_u \pm \tilde{R}_d}{\sqrt{2}} \right)$$

where:

$$\mathcal{M}'_{diag} = \mathcal{N}^T_{Dirac} \mathcal{M} \mathcal{N}_{Dirac}$$

with:

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

In this basis the rotation matrix which contains the neutralino components can written in the form:

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

which in general depends on 6 rotation angles which vanish in the limit $|\mu| \gg M_1 > M_Z$ where $\mathcal{N}_{Dirac} = 1$

Approximate expressions for the rotation angles in the limit $M_1, |\mu| \gg M_Z$:

$$s_1 \approx \frac{c_1 m_Z s_W c_\beta (M_1 + \xi_1 \mu_1)}{M_1^2 - \mu_1^2} \qquad s_2 \approx -\frac{c_1 c_2 m_Z s_W s_\beta (c_4^2 M_1 + \xi_2 \mu_2)}{c_1^2 c_4^2 M_1^2 - \mu_2^2}$$

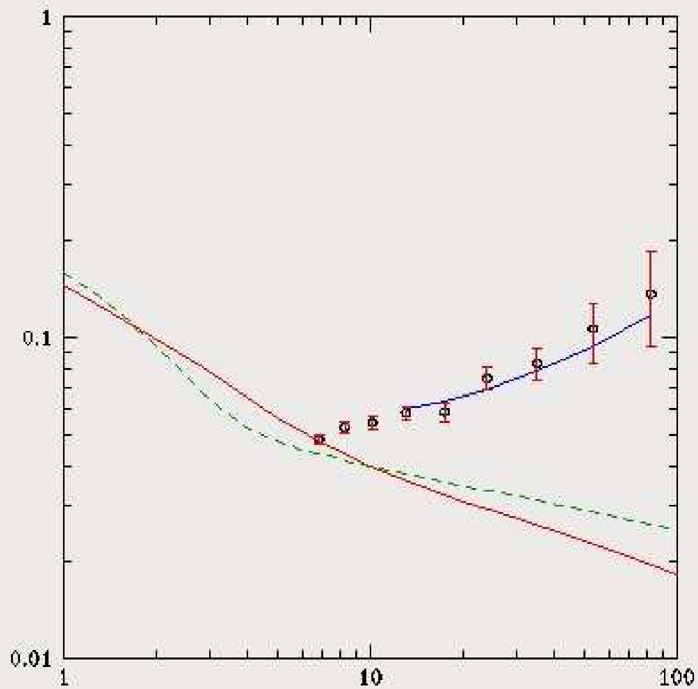
$$s_3 \approx -\frac{c_3 c_4 m_Z s_W s_\beta (c_1^2 \xi_2 M_1 + \mu_2)}{c_1^2 c_4^2 M_1^2 - \mu_2^2} \qquad s_4 \approx \frac{c_4 m_Z s_W c_\beta (\xi_1 M_1 + \mu_1)}{M_1^2 - \mu_1^2}$$

$$s_5 \approx s_6 \approx \frac{m_z^2 s_W^2 s_\beta}{\mu_1 - \mu_2} \left(\frac{c_\beta}{\mu_1} + \frac{1}{\mu_2} \right)$$

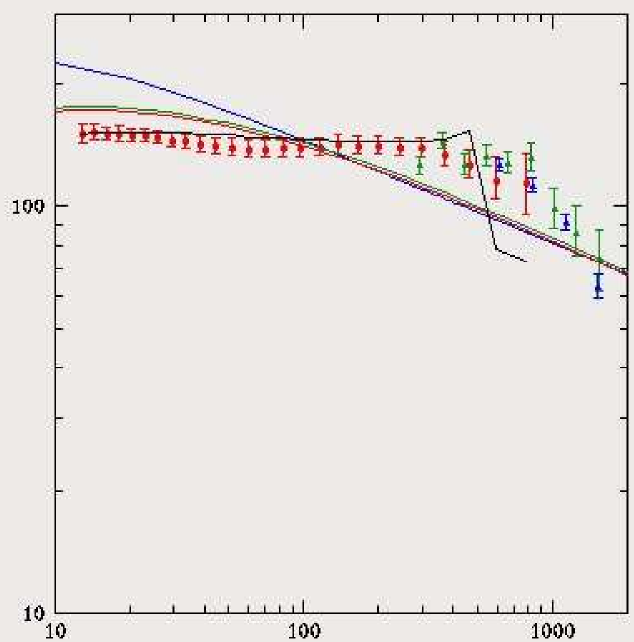
Fittting both PAMELA and FERMI

M_χ=460 GeV
$\sigma v=1.5\times10^{-24}\ \mathrm{cm^3s^{-1}}$

PAMELA ($e^+/[e^+ + e^-]$)



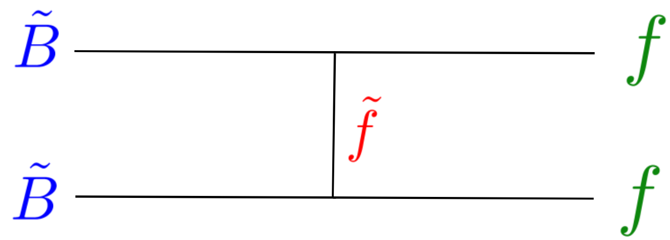
FERMI ($E^3[e^+ + e^-]$)



N.B. Sensitive to the standard background assumed

Dirac Bino couplings to fermions

$$\mathcal{L}_{\chi-f} = \sqrt{2} g' Y_{f_R} \mathcal{N}_{22} [\overline{f} P_L \chi \widetilde{f}_R + \overline{\chi} P_R f \widetilde{f}_R^*] + \sqrt{2} g' Y_{f_L} \mathcal{N}_{22} [\overline{f} P_R \chi^c \widetilde{f}_L + \overline{\chi}^c P_L f \widetilde{f}_L^*] \, ,$$

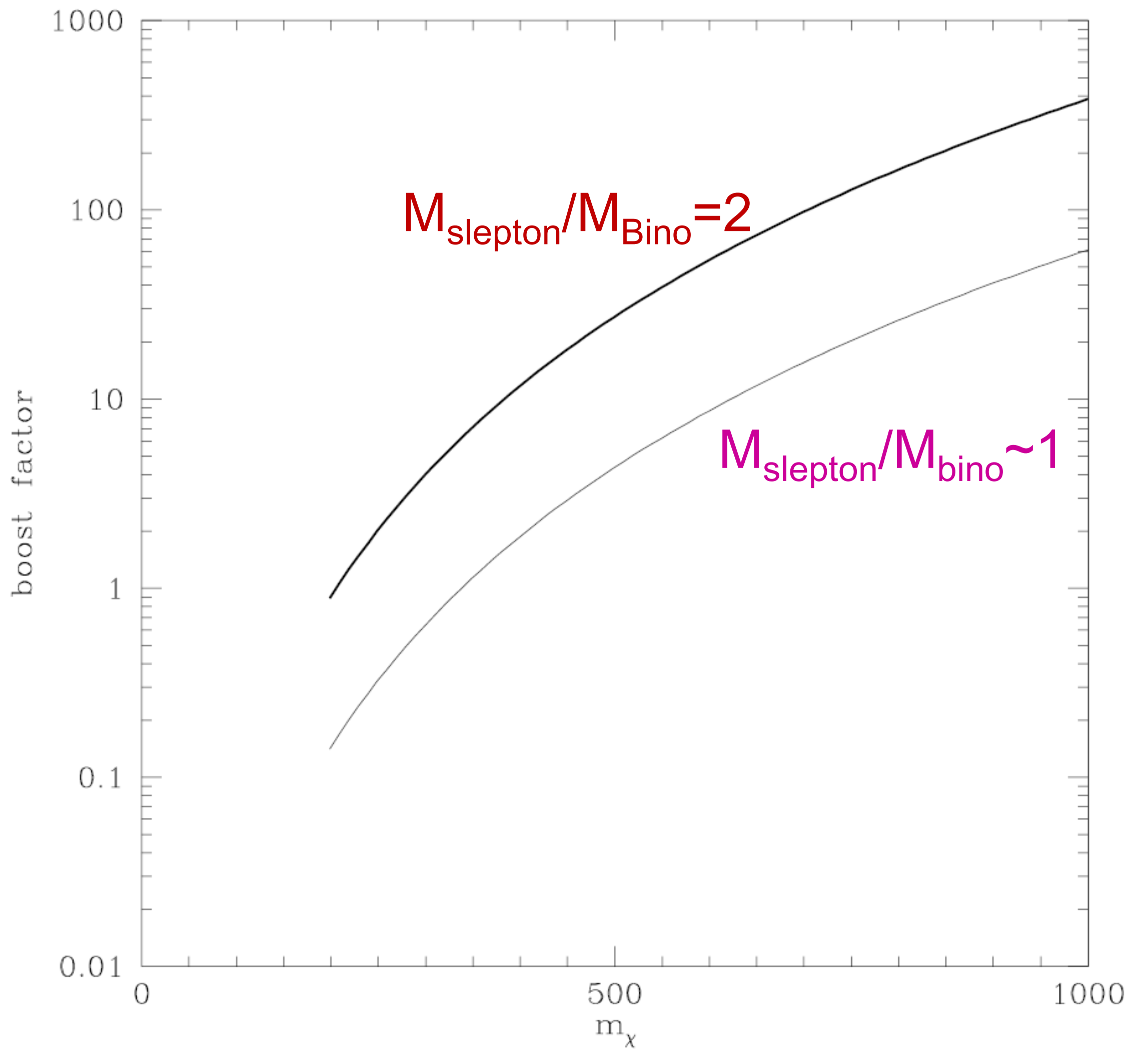


Suppress quark production by assuming $m_{squark} >> m_{sleptons}$

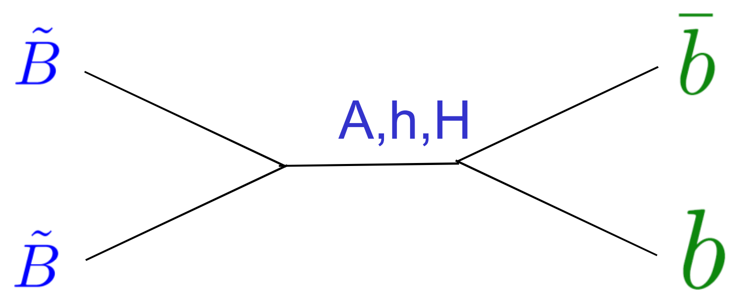
Enhance prompt lepton production assuming $m_{slepton} \gtrsim m_{Bino}$

$$\langle \sigma v \rangle_{l\bar{l}} \simeq \mathcal{N}_{22}^4 \frac{2\pi\alpha^2}{c_W^4} \, Y_l^4 \, \frac{m_\chi^2}{(m_{\tilde{l}}^2 + m_\chi^2)^2}$$

Boost factor vs. mass for Dirac Bino:



In this scenario annihilations through Higgs particles are suppressed:



small if m_A is large

in h exchange s-wave velocity suppressed

Dirac Bino couplings to light scalar Higgs

$$\begin{aligned}\mathcal{L}_{\chi-h^0} = \frac{g'}{2}h^0[&C_1(\overline{\psi}_{H_1}P_R\chi^c + \overline{\chi}^c P_L\psi_{H_1}) \\ &+ C_2(\overline{\psi}_{H_2}P_R\chi^c + \overline{\chi}^c P_L\psi_{H_2}) \\ &+ C_1'(\overline{\psi}_{H_1}P_L\chi^c + \overline{\chi}^c P_R\psi_{H_1}) \\ &+ C_2'(\overline{\psi}_{H_2}P_L\chi^c + \overline{\chi}^c P_R\psi_{H_2}) \\ &+ 2\delta_S\,\overline{\chi}\chi]\end{aligned}$$

$$C_1 = s_\alpha \mathcal{N}_{22}\mathcal{N}_{33} + c_\alpha \mathcal{N}_{22}\mathcal{N}_{53}\ , \qquad C_2 = c_\alpha \mathcal{N}_{22}\mathcal{N}_{55} + s_\alpha \mathcal{N}_{22}\mathcal{N}_{35}\ ,$$

$$C_1' = \xi_1 s_\alpha \mathcal{N}_{11}\mathcal{N}_{44} + \xi_2 c_\alpha \mathcal{N}_{11}\mathcal{N}_{64}\ , \quad C_2' = \xi_2 c_\alpha \mathcal{N}_{11}\mathcal{N}_{66} + \xi_1 s_\alpha \mathcal{N}_{11}\mathcal{N}_{46}\ ,$$

$$\delta_S = \frac{1}{2}\left(s_\alpha \mathcal{N}_{22}\mathcal{N}_{31} + c_\alpha \mathcal{N}_{22}\mathcal{N}_{51} + \xi_1 s_\alpha \mathcal{N}_{11}\mathcal{N}_{42} + \xi_2 c_\alpha \mathcal{N}_{11}\mathcal{N}_{62}\right)\ ,$$

Assume decoupling limit with heavy m_A

Dirac Bino couplings to Z boson

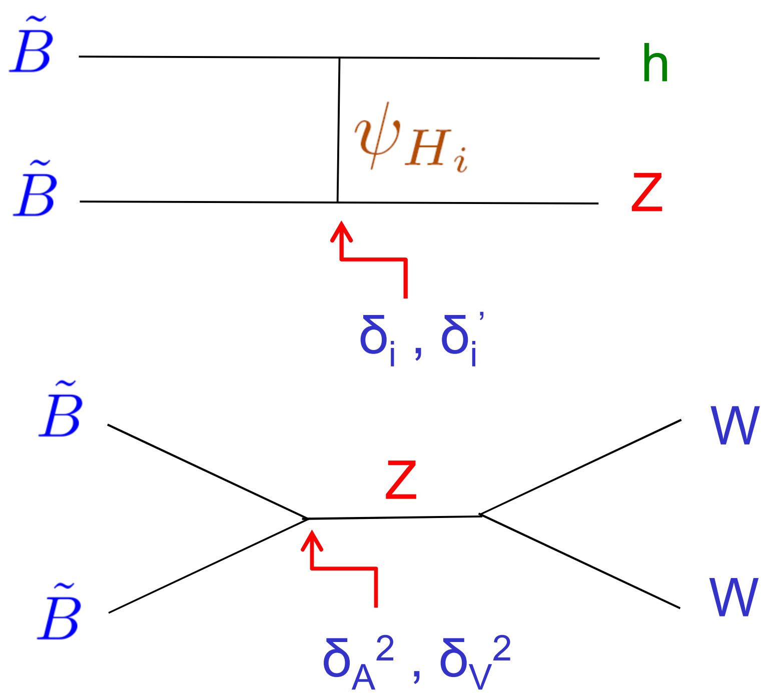
$$\mathcal{L}_{\chi-Z} = \frac{g}{2c_W} Z_\mu [\delta_1' (\overline{\psi}_{H_1}\gamma_\mu P_L \chi^c + \overline{\chi}^c \gamma_\mu P_L \psi_{H_1})$$
$$+ \delta_1 (\overline{\psi}_{H_1}\gamma_\mu P_R \chi^c + \overline{\chi}^c \gamma_\mu P_R \psi_{H_1})$$
$$+ \delta_2' (\overline{\psi}_{H_2}\gamma_\mu P_L \chi^c + \overline{\chi}^c \gamma_\mu P_L \psi_{H_2})$$
$$+ \delta_2 (\overline{\psi}_{H_2}\gamma_\mu P_R \chi^c + \overline{\chi}^c \gamma_\mu P_R \psi_{H_2})$$
$$+ \delta_V^2 \, \overline{\chi}\gamma_\mu \chi + \delta_A^2 \, \overline{\chi}\gamma_\mu \gamma_5 \chi] \ ,$$

$$\delta_1 = -\mathcal{N}_{44}\mathcal{N}_{42} + \mathcal{N}_{64}\mathcal{N}_{62} \ , \quad \delta_2 = +\mathcal{N}_{66}\mathcal{N}_{62} - \mathcal{N}_{46}\mathcal{N}_{42} \ ,$$
$$\delta_1' = -\mathcal{N}_{33}\mathcal{N}_{31} + \mathcal{N}_{53}\mathcal{N}_{51} \ , \quad \delta_2' = +\mathcal{N}_{55}\mathcal{N}_{51} - \mathcal{N}_{35}\mathcal{N}_{31} \ ,$$
$$\delta_V^2 = \frac{1}{2} (\mathcal{N}_{31}^2 - \mathcal{N}_{51}^2 + \mathcal{N}_{42}^2 - \mathcal{N}_{62}^2) \ ,$$
$$\delta_A^2 = \frac{1}{2} (\mathcal{N}_{31}^2 - \mathcal{N}_{51}^2 - \mathcal{N}_{42}^2 + \mathcal{N}_{62}^2) \ .$$

Ψ_{H1}, Ψ_{H2} next-to-lightest Higgsinos

In the limit $|\mu| \gtrsim M_1$ the coefficients δ_i , δ_i' , δ_A , δ_V are small

Dominant annihilation channels of Dirac Binos to hadrons



Linear in δ parameters

Additional δ factor suppression compensated by enhancement when $m_{Bino} \gg m_W$

(Z exchange leads also to subdominant contributions of ff, HZ and hh final states)

Relevant cross sections for antiproton production:

$$\langle \sigma v \rangle_{h^0 Z} \simeq \frac{\pi \alpha^2}{8 c_W^4 s_W^2} \frac{\sqrt{m_\chi^2 - \overline{m}_Z^2}}{m_\chi^3} \tag{3.3}$$

$$\left\{ \left(\frac{m_\chi^2}{m_Z^2} - 1 \right) \left[(y - z)^2 + (y' - z')^2 - \frac{1}{2} \frac{m_Z^2}{m_\chi^2} (z + z')^2 \right] + \frac{3}{2} (y + y')^2 \right\}$$

$$y = \sum_i \frac{m_\chi m_{\widetilde{H}_i} C_i \delta_i}{m_i^2}, \; y' = \sum_i \frac{m_\chi m_{\widetilde{H}_i} C_i' \delta_i'}{m_i^2}, \; z = \sum_i \frac{m_\chi^2 C_i' \delta_i}{m_i^2}, \; z' = \sum_i \frac{m_\chi^2 C_i \delta_i'}{m_i^2}$$

$$\langle \sigma v \rangle_{W+W-} \simeq \frac{\pi \alpha^2}{s_W^4} \frac{m_\chi \sqrt{m_\chi^2 - m_W^2}}{(4 m_\chi^2 - m_Z^2)^2} \left(4 \frac{m_\chi^4}{m_W^4} + 16 \frac{m_\chi^2}{m_W^2} - 17 - 3 \frac{m_W^2}{m_\chi^2} \right) \delta_V^4$$

The antiproton constraint

PAMELA data on pbars agree with standard secondary production disfavoring excessive exotic pbars

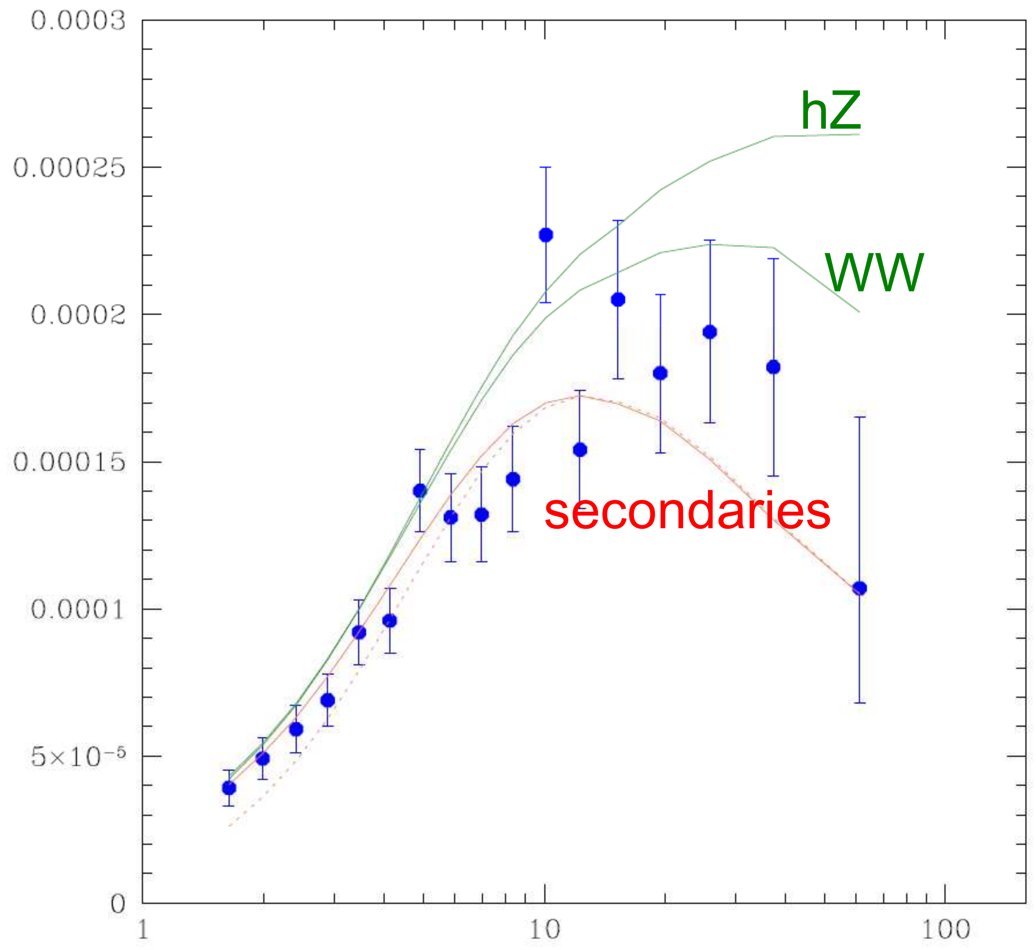
17 dof:

secondaries:
χ^2=20 with 17 dof

Primaries with
M_χ=460 GeV
$\sigma v = 8 \times 10^{-25}$ cm^{3}s^{-1}:

WW: χ^2=40

hZ: χ^2=62



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Prediction for the secondary antiproton background ~ 20-30 % astrophysical uncertainty

Prediction for primaries from has much larger uncertainties (> one order of magnitude)

WHY?

degeneracies are the problem

let’s see it in a very simple model

1 dimensional diffusion model (in cylindrical coordinates R, z, only dependence on z is retained)

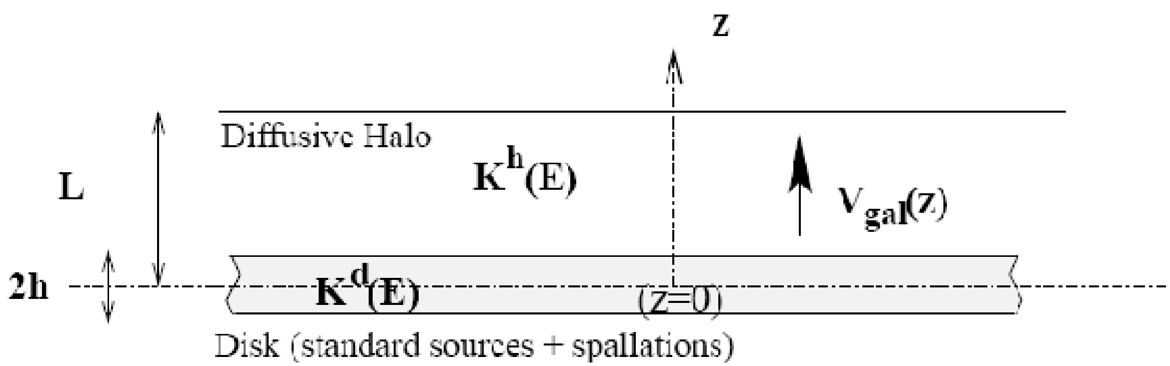


FIG. 10: Upper half-plane of the 1D infinite disk along r (half-thickness h) with standard sources $q(r,z) = q(z)$ and gas $n(r,z) = n(z)$ in the disk. Cosmic rays diffuse in the disk (diffusion coefficient $K^{\mathrm{disk}}(E)$) and in the halo $K^{\mathrm{halo}}(E)$. The boundary condition translates into $N(z=L)=0$. No quantities depend on r and no boundaries in this direction so that the differential density N only depends on z.

CR's diffusion equation in the disk:

$$-KN'' + n\Theta(h - |z|)v\sigma \times N = q\Theta(h - |z|),$$

Analytical solution to a second-order differential equation:

$$N(0) = \frac{q}{nv\sigma} \cdot \left(1 - \frac{1}{[1 - \alpha(h - L)\tanh(\alpha h)]\cosh(\alpha h)}\right)$$

with:

$$\alpha = \sqrt{nv\sigma / K^d} \qquad \mu \equiv 2hn\bar{m}$$

=surface mass density in the disk

In the thin-disk limit:

$$< x > (h << L) = \frac{\mu v L}{2K^d} = \lambda_{esc}$$

grammage does not depend on K^h

$\lambda_{\rm esc}(E) = \lambda_0 \beta \mathcal{R}^\delta$ ($\mathcal{R}$ =rigidity=p/Z, $\beta = v/c$)

is determined from a fit of LBM to B/C data, so the diffusion coefficient in the disc can be inferred from:

$$K^d(E) = \frac{\mu v L}{2\lambda_{esc}(E)}$$

diffusion equation in the halo for exotic antiprotons (constant source term):

$$\left\{K^h\Theta(h-|z|)+K^d\Theta(|z|-h)\right\}N''+(V_{\rm gal}N)'$$

$$+n\delta(z).v.\sigma\times N=q$$

source term for exotic primaries

At sufficiently high energy (pure diffusive regime, no convection):

$$\begin{cases} N(z)=\dfrac{q(L^2-z^2)}{2K^h}\,, \\ N(0)=\dfrac{qL^2}{2K^h}\,. \end{cases}$$

Comparing uncertainties in the disk and in the halo in the 1 dim model

Assume $K^d = K^h = K$:

$$\lambda = \frac{\mu v L}{2K}$$ (fixed by B/C ratio)

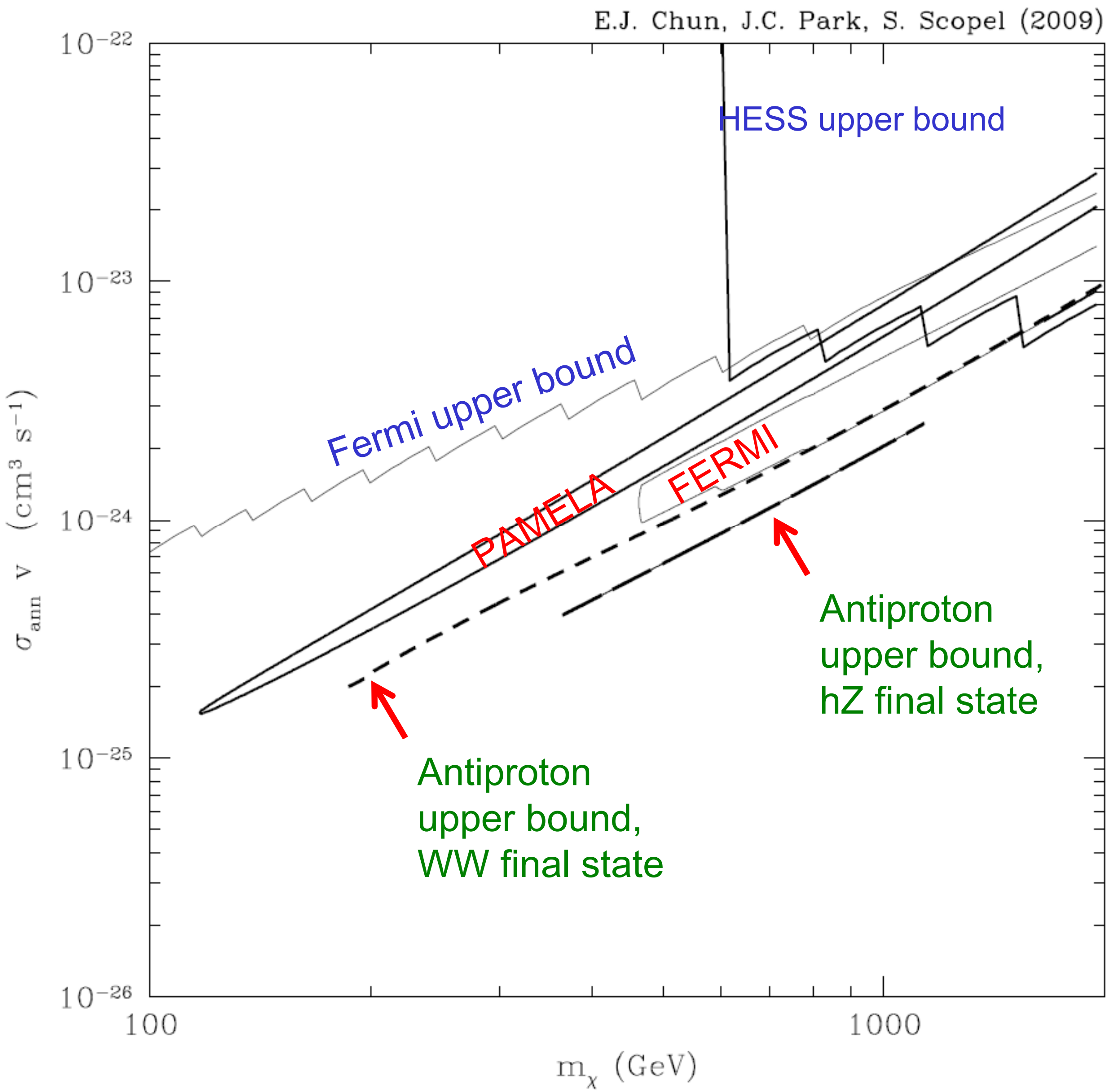
$$N^{DM} = \frac{q L^2}{2K}$$ (exotic signal)

if $L \rightarrow 10\ L$, λ is the same if $K \rightarrow 10\ K$ (B/C fit still OK)

however $N^{DM} \rightarrow 10\ N^{DM}$

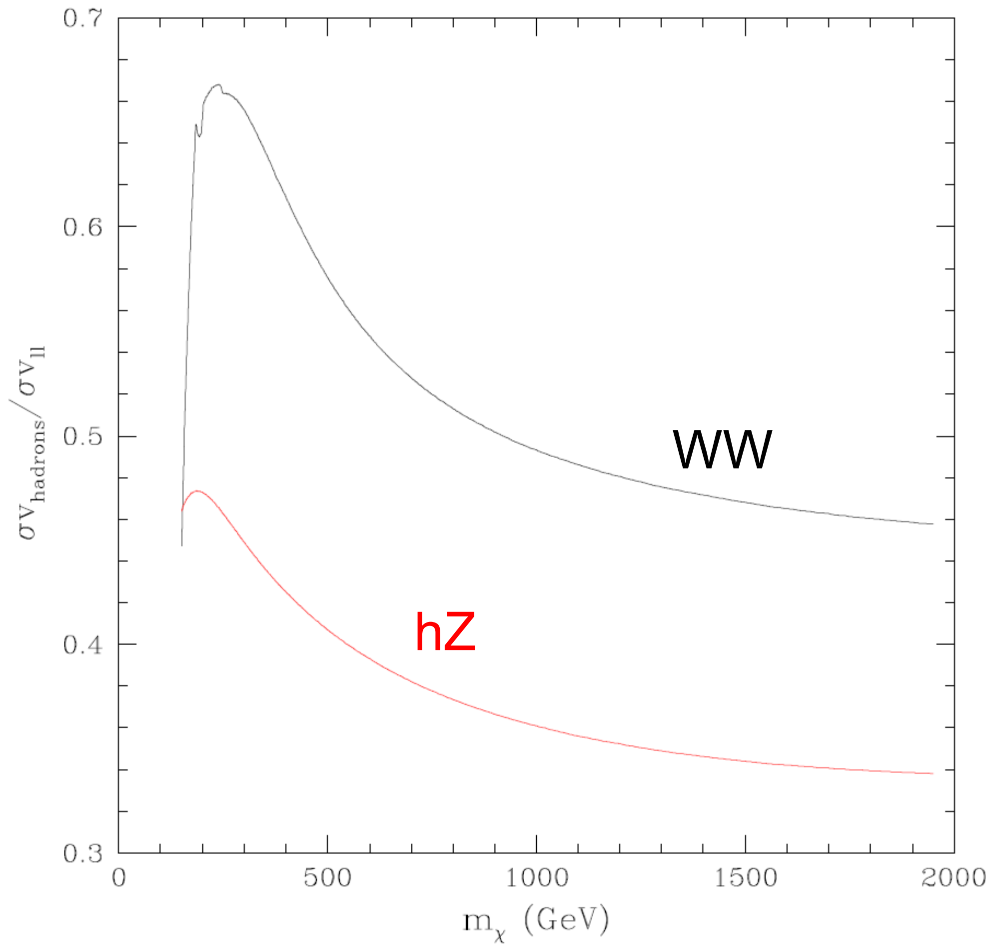
even worse if $K^d \neq K^h$

)


E.J. Chun, J.C. Park, S. Scopel (2009)
HESS upper bound
Fermi upper bound
PAMELA
FERMI
Antiproton upper bound, hZ final state
Antiproton upper bound, WW final state
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
100
1000
m_χ (GeV)
σ_{ann} v (cm^3 s^{-1})

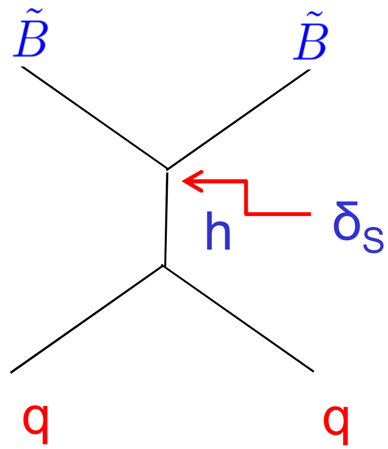
$$< \sigma v >_{hadrons} \; / < \sigma v >_{ll}$$

upper bound from antiprotons

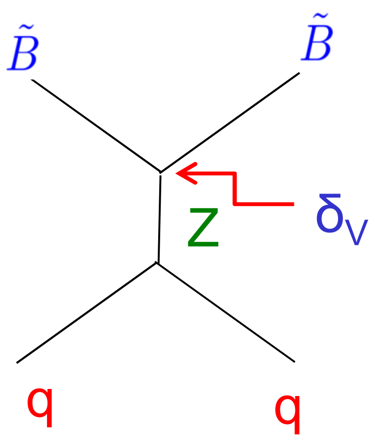


Direct detection

A non-vanishing neutralino-nucleus coherent cross section requires a non-zero Higgsino component both in h and Z exchange diagrams:



$$\sigma^{\chi-n,p}_{\rm scalar} \simeq \delta_S^2 \, \frac{0.14^2 \times 4 g'^2 h^2_{hss}}{\pi} \, \frac{\mu_n^2 m_n^2}{m_h^4 m_s^2}$$



$$\sigma^{\chi-n,p}_{\rm vector} \simeq \delta_V^4 \, \frac{\pi \alpha^2}{64 s_W^4 c_W^4} \, \frac{\mu_n^2}{m_Z^4} \, \left[\frac{Z}{A}(1-2s_W^2) - \frac{1}{2} \right]^2$$

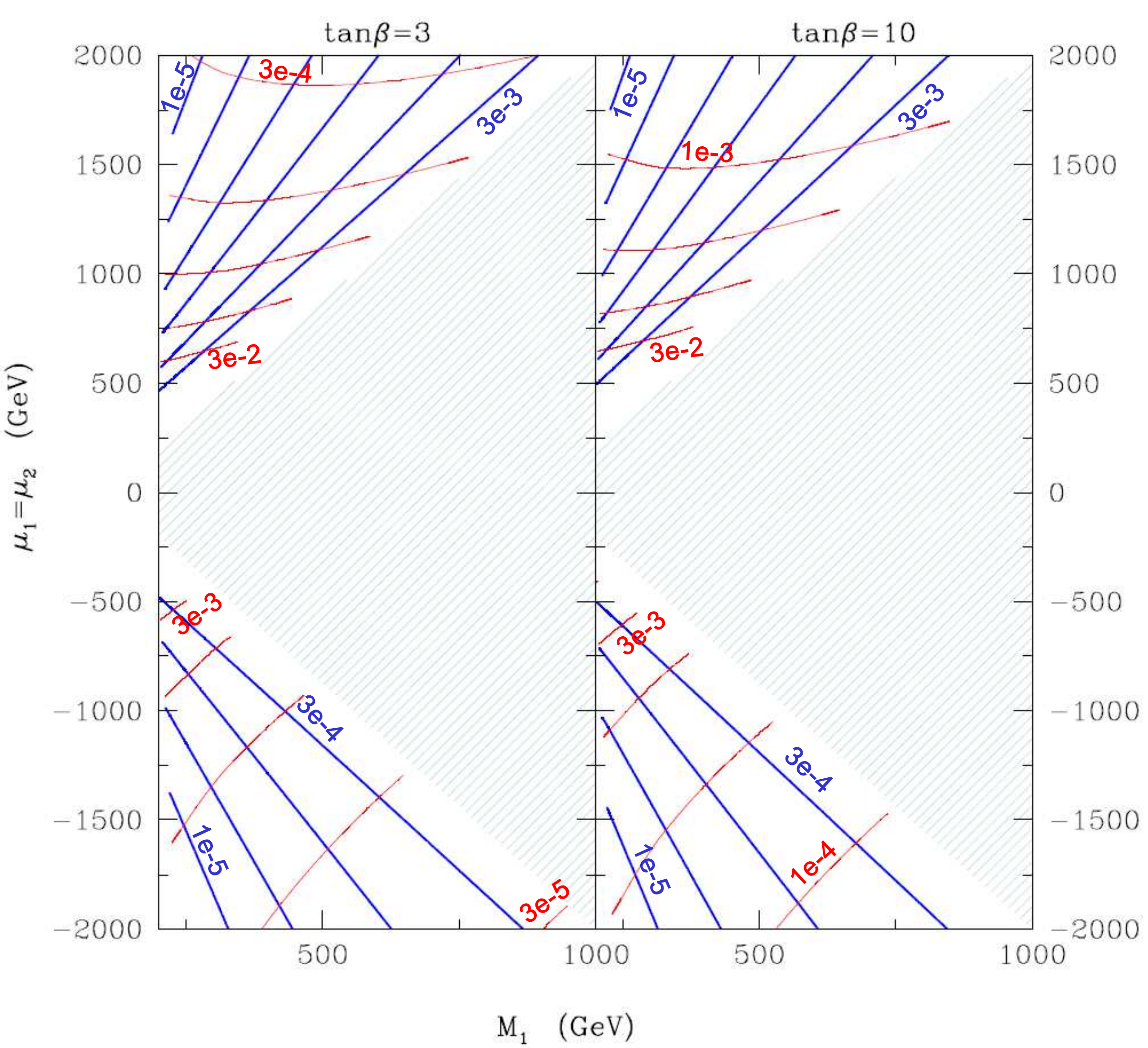
Coherent contibution from Z exchange only for a Dirac particle. For a Majorana neutralino this diagram contributes only to the spin-dependent cross-section.

$< \sigma v >_{hadrons} / < \sigma v >_{ll}$

$< \sigma_{direct} > /\mathrm{CDMS\ \ limit}$

$|\mu_1|=|\mu_2| > 2 \times M_1$

E.J. Chun, J.C. Park, S. Scopel (2009)

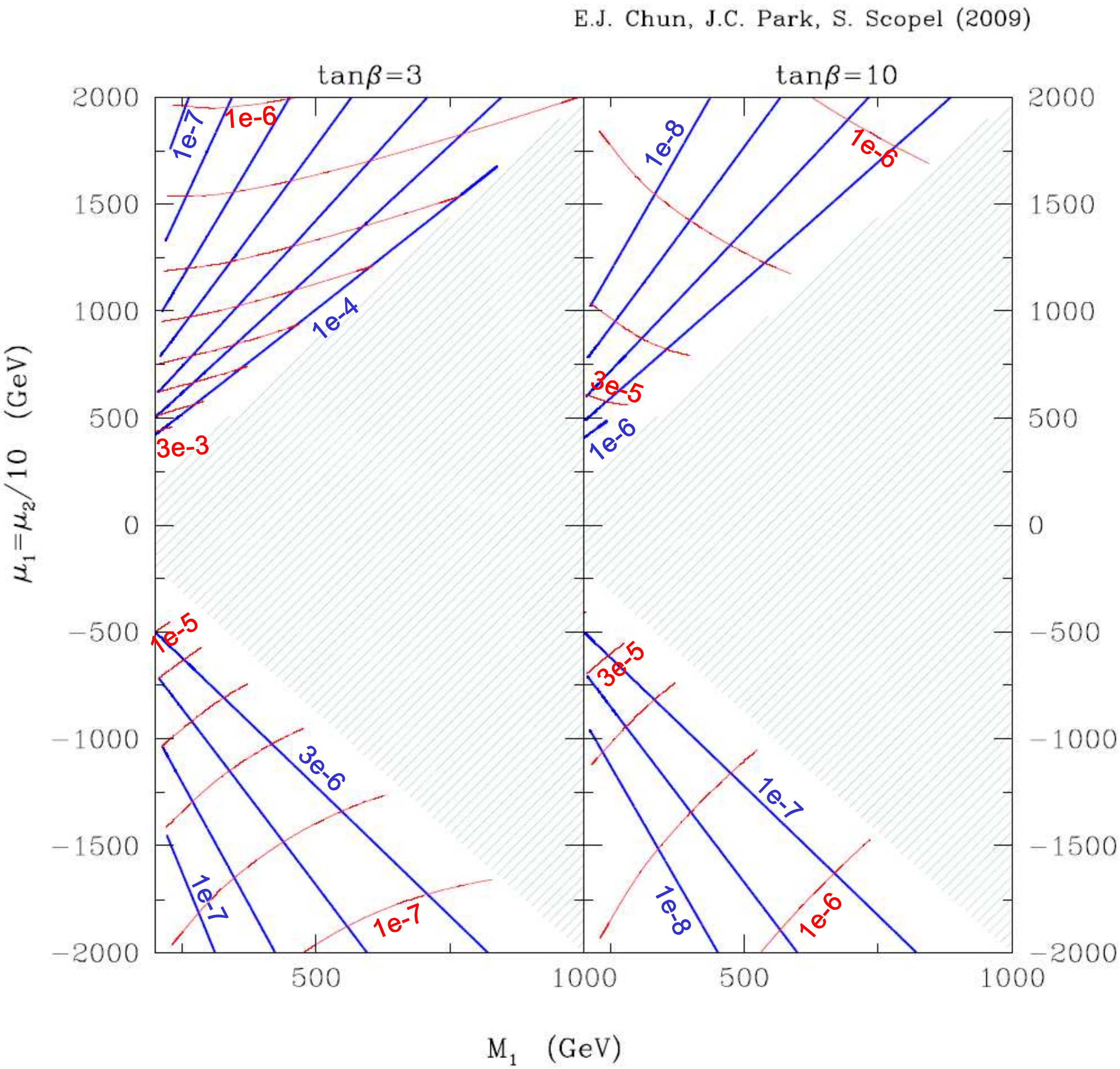


$M_{slepton}/M_{bino}\sim 1$

$< \sigma v >_{hadrons} / < \sigma v >_{ll}$

$< \sigma_{direct} > /\text{CDMS limit}$

$|\mu_1|=|\mu_2|/10 > 2 \times M_1$

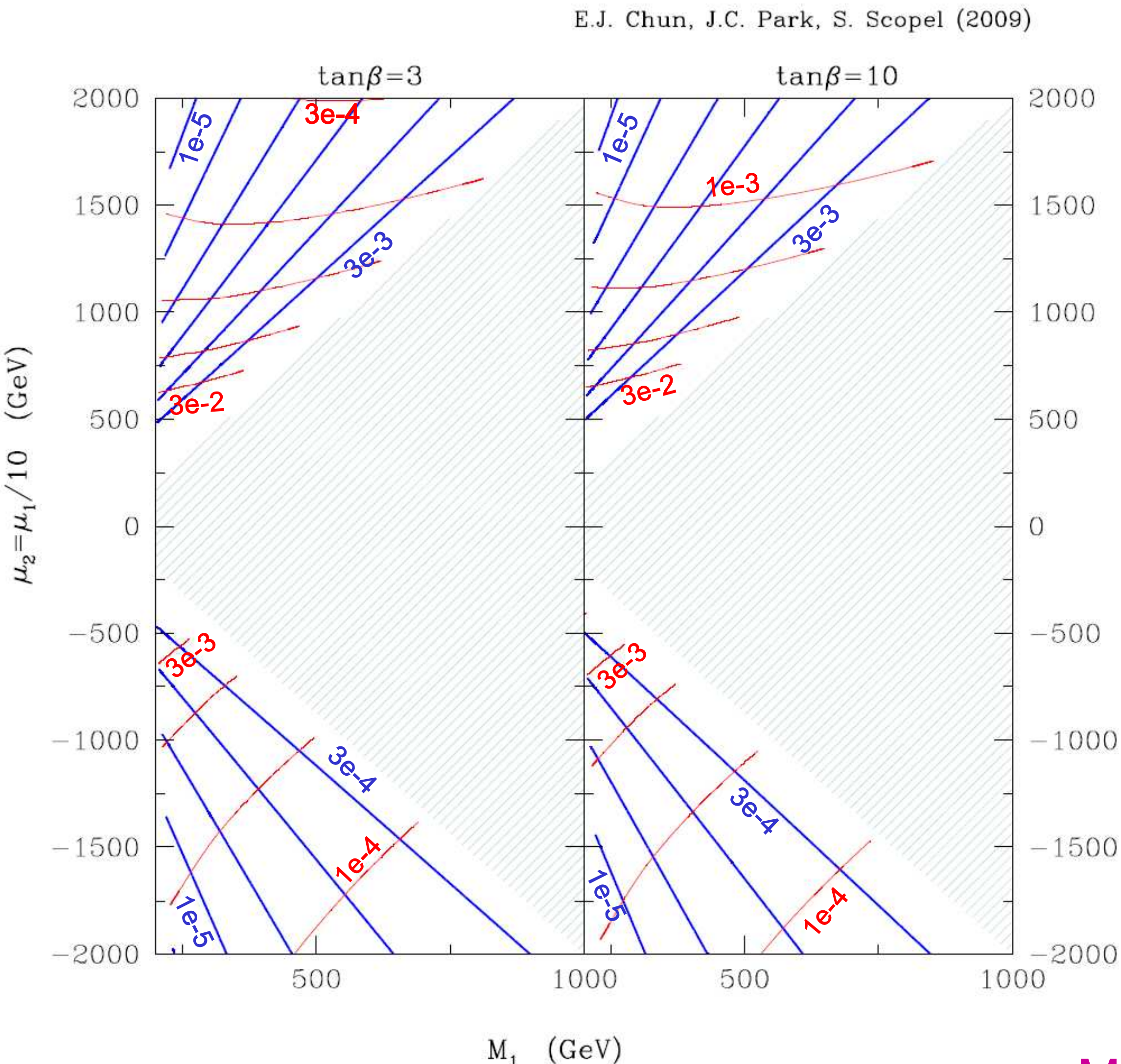


$M_{slepton}/M_{bino} \sim 1$

$< \sigma v >_{hadrons} / < \sigma v >_{ll}$

$< \sigma_{direct} > /\mathrm{CDMS\ \ limit}$

$|\mu_2|=|\mu_1|/10 > 2 \times M_1$



$M_{slepton}/M_{bino} \sim 1$

Conclusions

1. Dirac gauginos are a viable possibility worth exploring for it's own sake…
2. PAMELA positron excess seems to disfavour a Majorana particle due to chirality-flip suppression– Dirac Dark Matter a viable alternative
3. Dirac Gauginos with 400 GeV <M<700 GeV can explain the PAMELA positron excess and FERMI data with boost factors <10
4. as long as the Higgsino fraction is small antiprotons are OK with present bounds
5. annihilation cross section is not compatible with standard thermal CDM. This is not specific of Dirac Gauginos
6. direct detection cross section a factor of ~30 below present sensitivities
7. work in progress