SUSY interpretation of the PAMELA data

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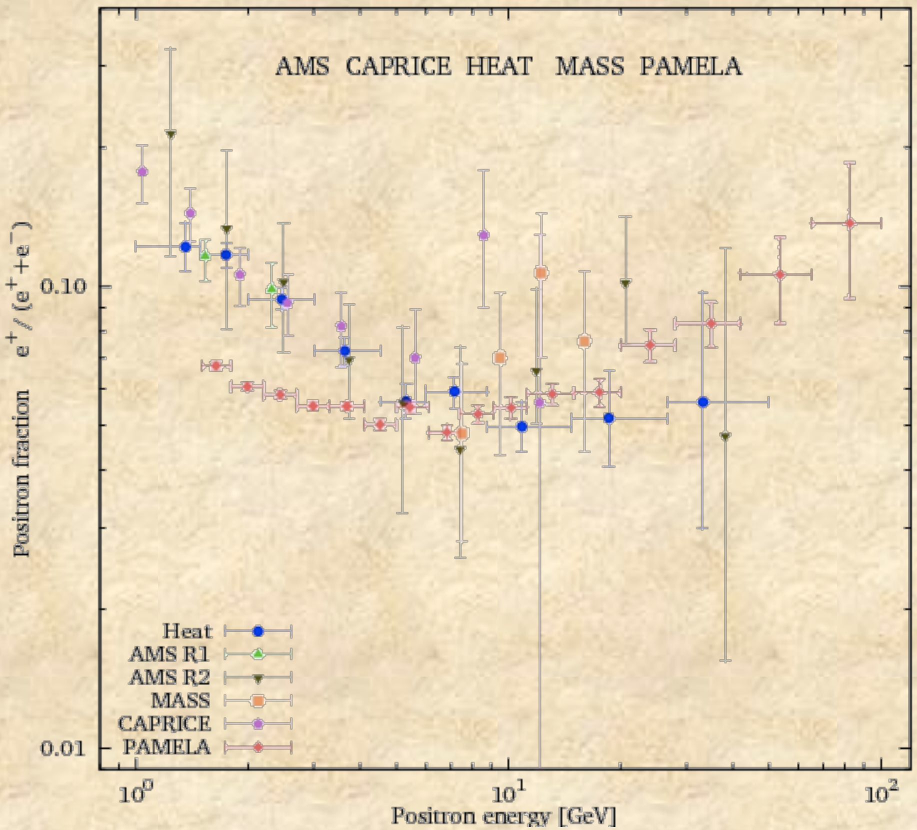
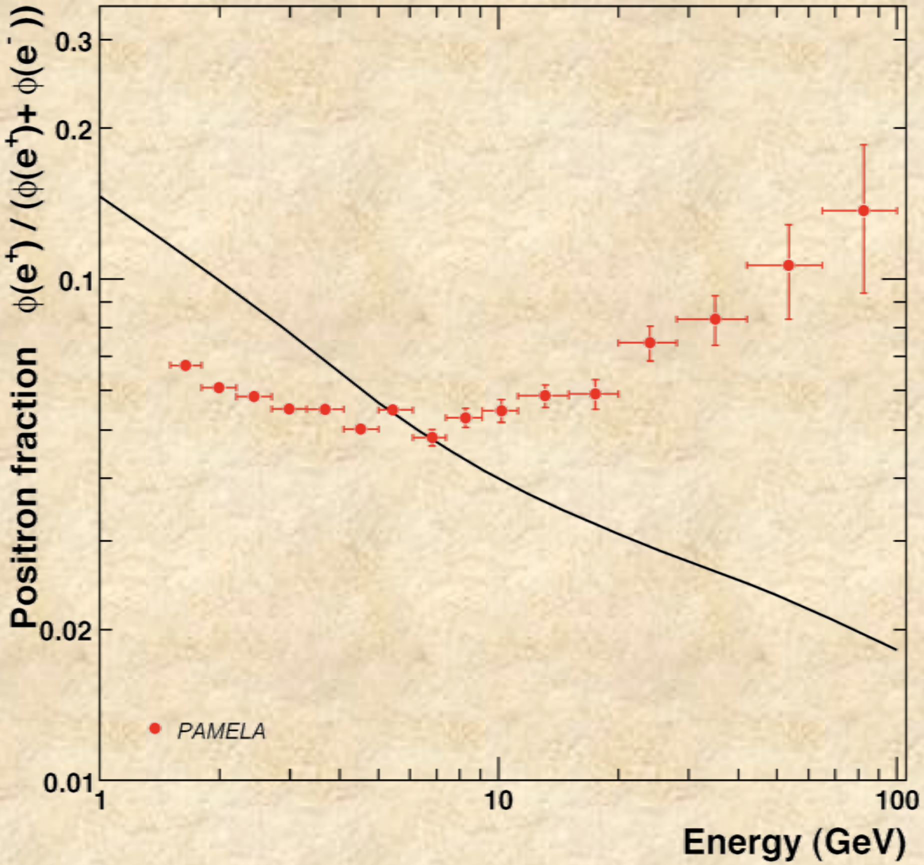
IAP – Paris - 06.05.2009

Positron fraction: experimental data



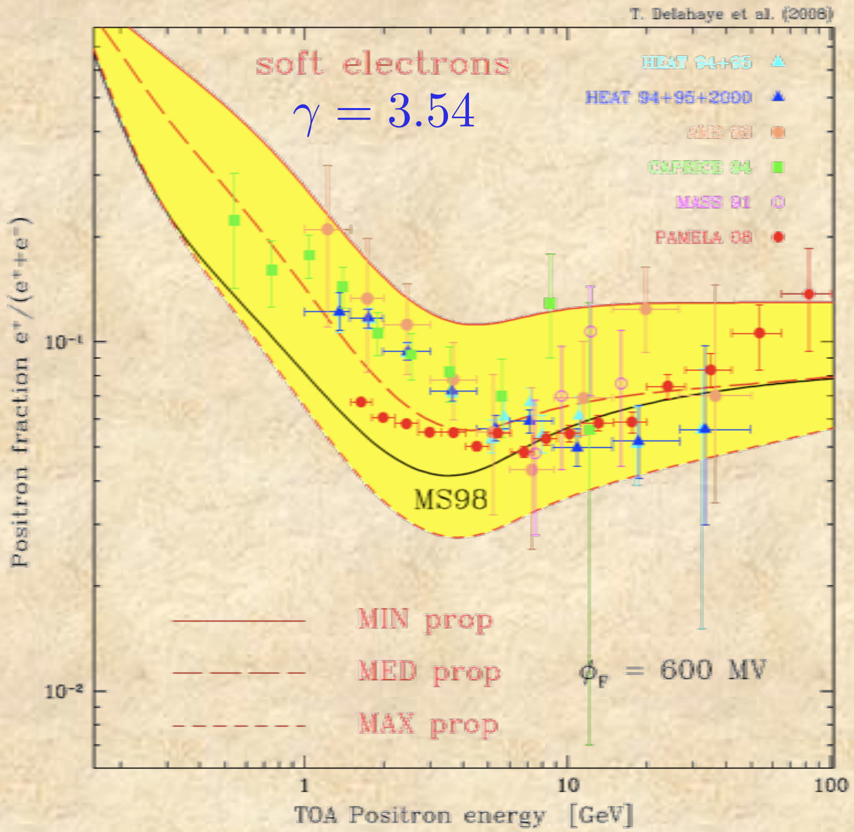
O. Adriani et al. (PAMELA Collab.), arXiv:0810.4995v1 [astro-ph] & Nature

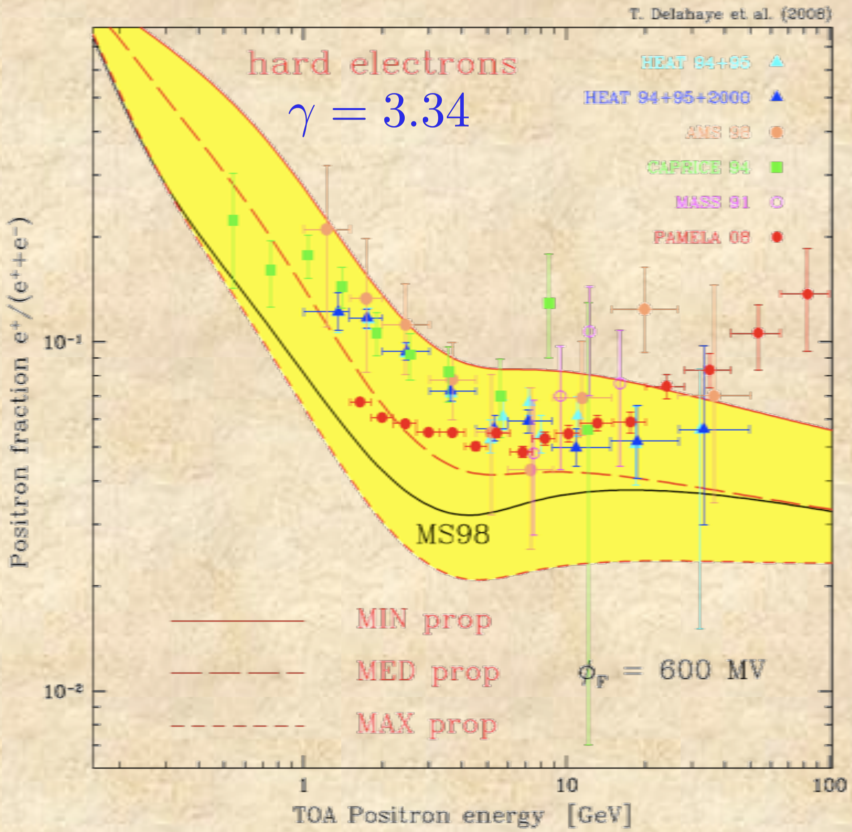
Positron fraction: secondaries



I.V. Moskalenko, A.W. Strong, Ap. J. 493, (1998) 694

Positron fraction: secondaries



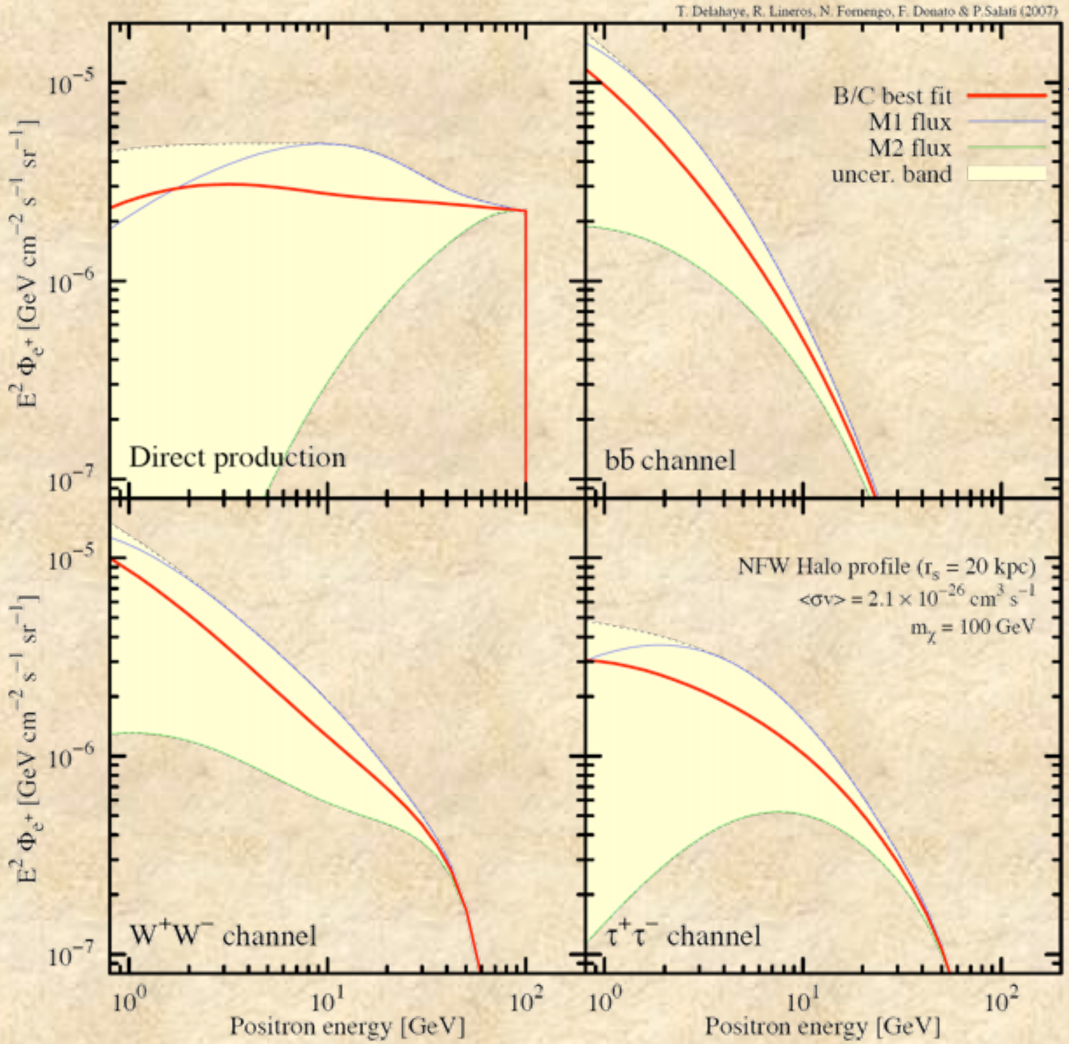


T. Delahaye, R. Lineros, F. Donato, N. Fornengo, J. Lavalle, P. Salati, R. Taillet, arXiv:0809.5268 [astro-ph (to appear in AA)

Primary positrons from DM annihilation

$m_\chi = 100$ GeV

$\langle \sigma v \rangle = 2.1 \cdot 10^{-26} \mathrm{cm}^3 \mathrm{s}^{-1}$



For annihilation cross section consistent with WMAP for a thermal relic

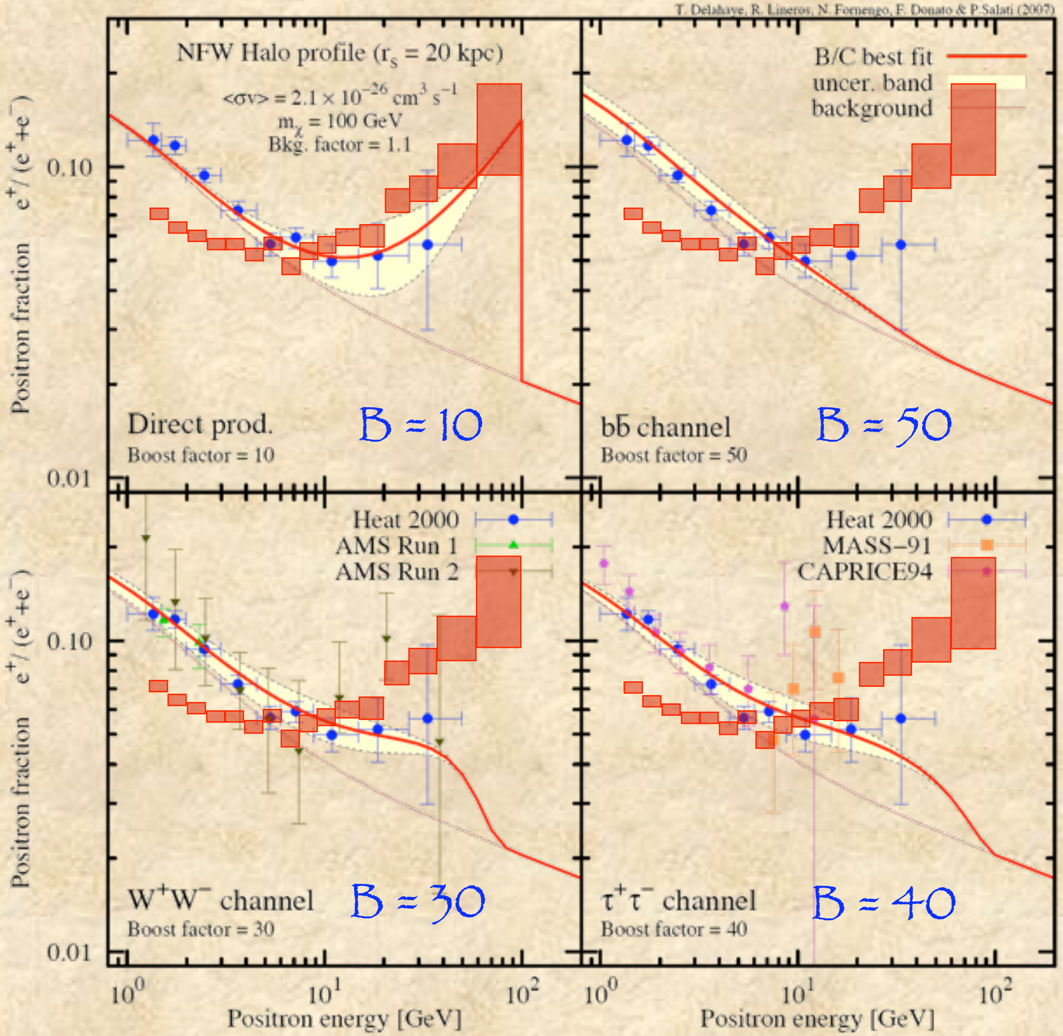
T. Delahaye, R. Lineros, F. Donato, N. Fornengo, P. Salati, Phys. Rev. D 77 (2008) 063527

Positron fraction: including a DM signal

m_χ = 100 GeV

$\langle \sigma v \rangle = 2.1 \cdot 10^{-26} \mathrm{cm}^3 \mathrm{s}^{-1}$

PAMELA 2008



T. Delahaye, R. Lineros, F. Donato, N. Fornengo, P. Salati, Phys. Rev. D 77 (2008) 063527

For annihilation cross section consistent with WMAP for a thermal relic

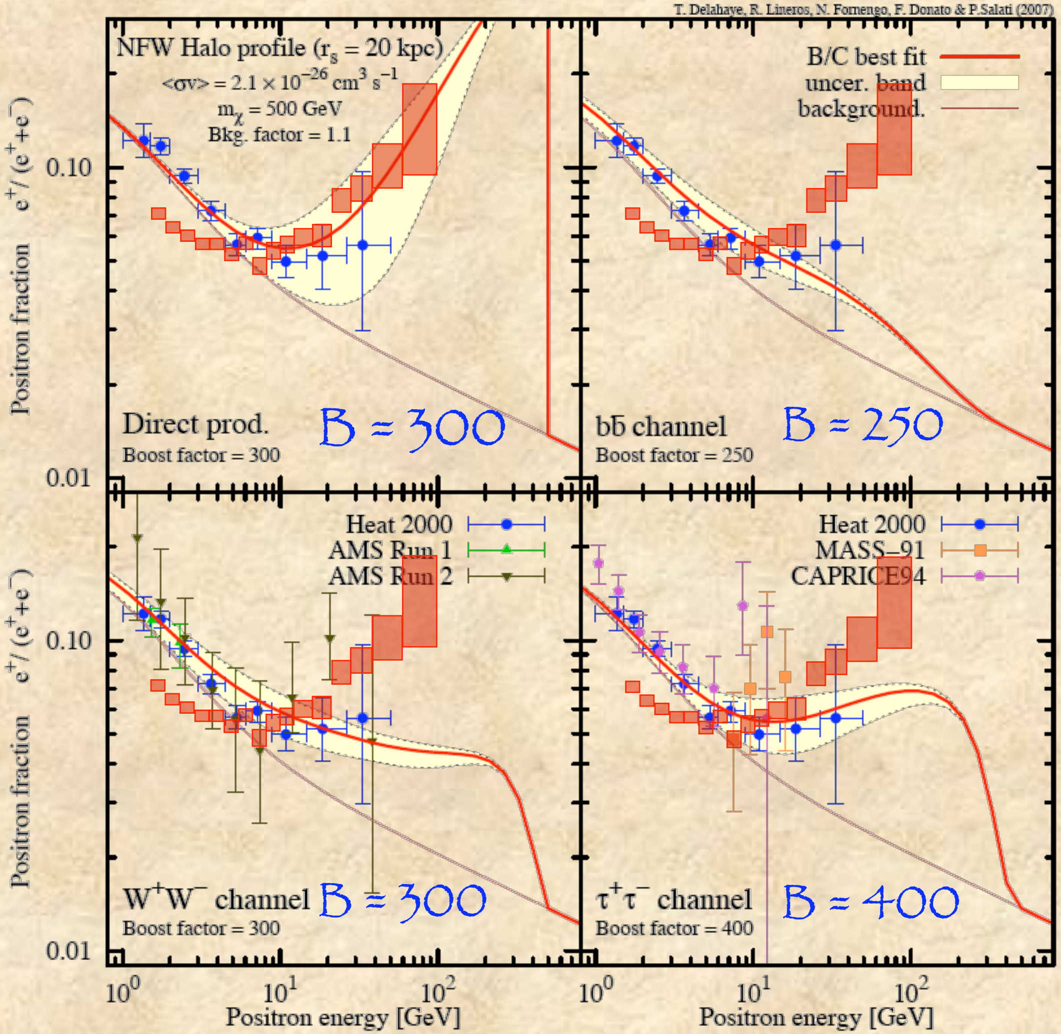
Smooth NFW halo

Positron fraction: including a DM signal

$m_\chi \approx 500$ GeV

$\langle \sigma v \rangle = 2.1 \cdot 10^{-26} \mathrm{cm}^3 \mathrm{s}^{-1}$

■ PAMELA 2008

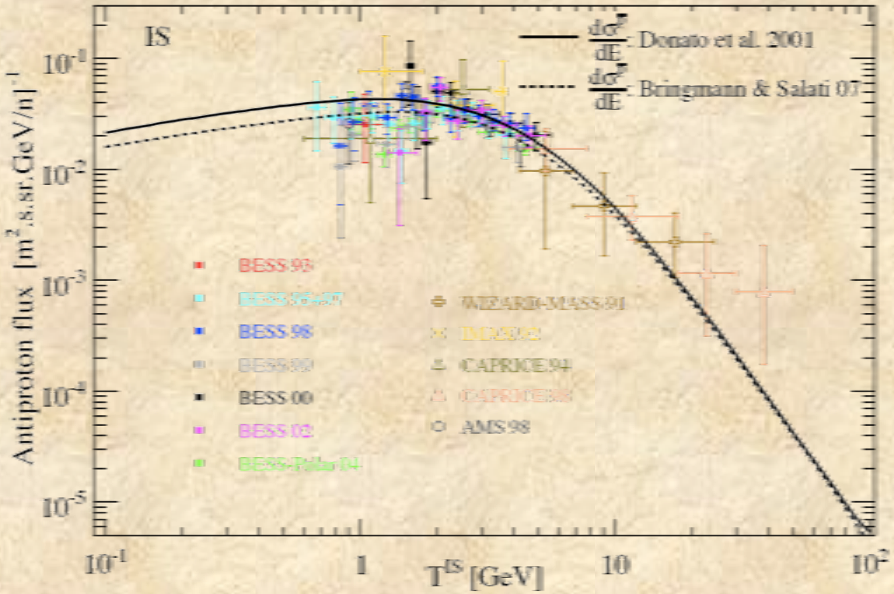


T. Delahaye, R. Lineros, F. Donato, N. Fornengo, P. Salati, Phys. Rev. D 77 (2008) 063527

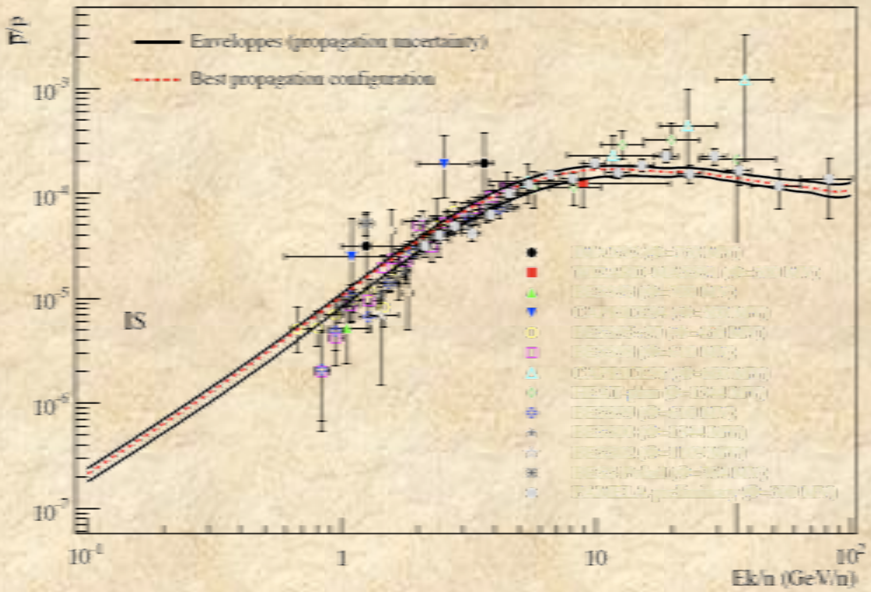
For annihilation cross section consistent with WMAP

Smooth NFW halo

Secondary antiprotons



Antiproton flux

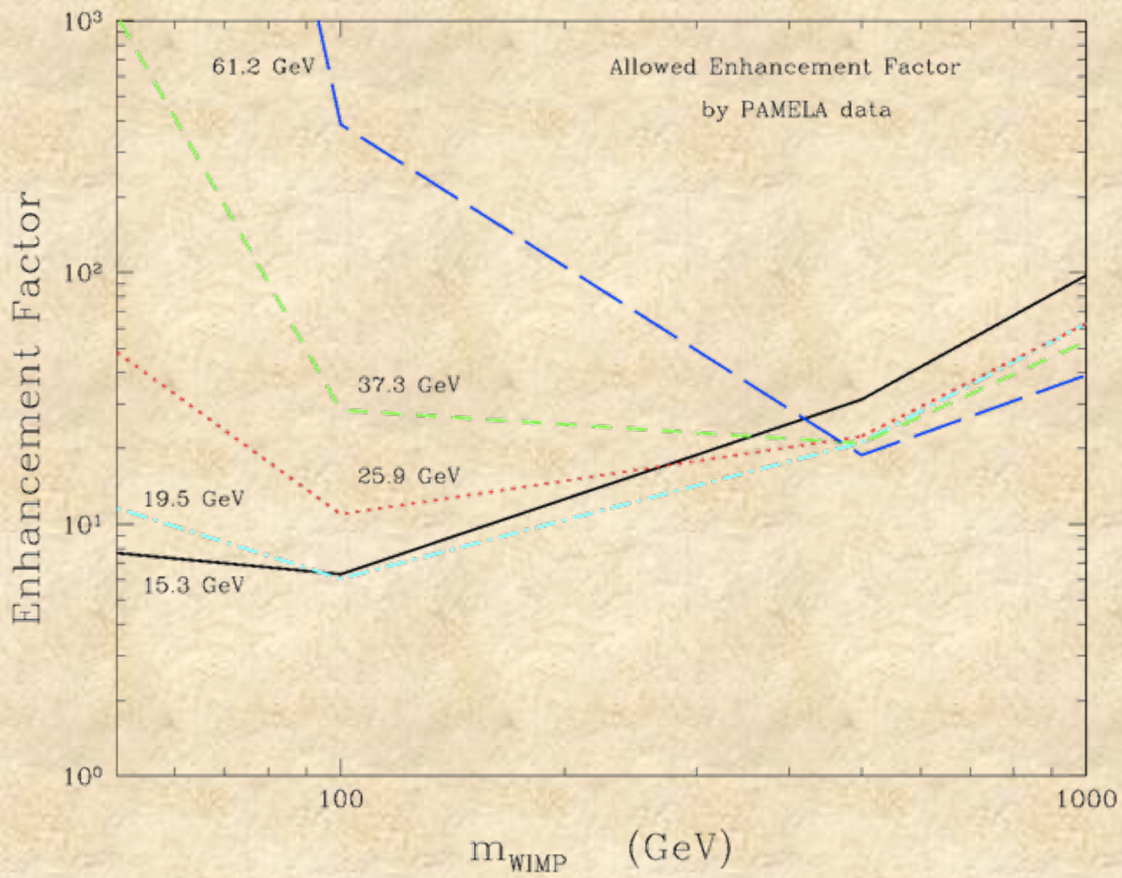


Antiproton/proton fraction

No excess found

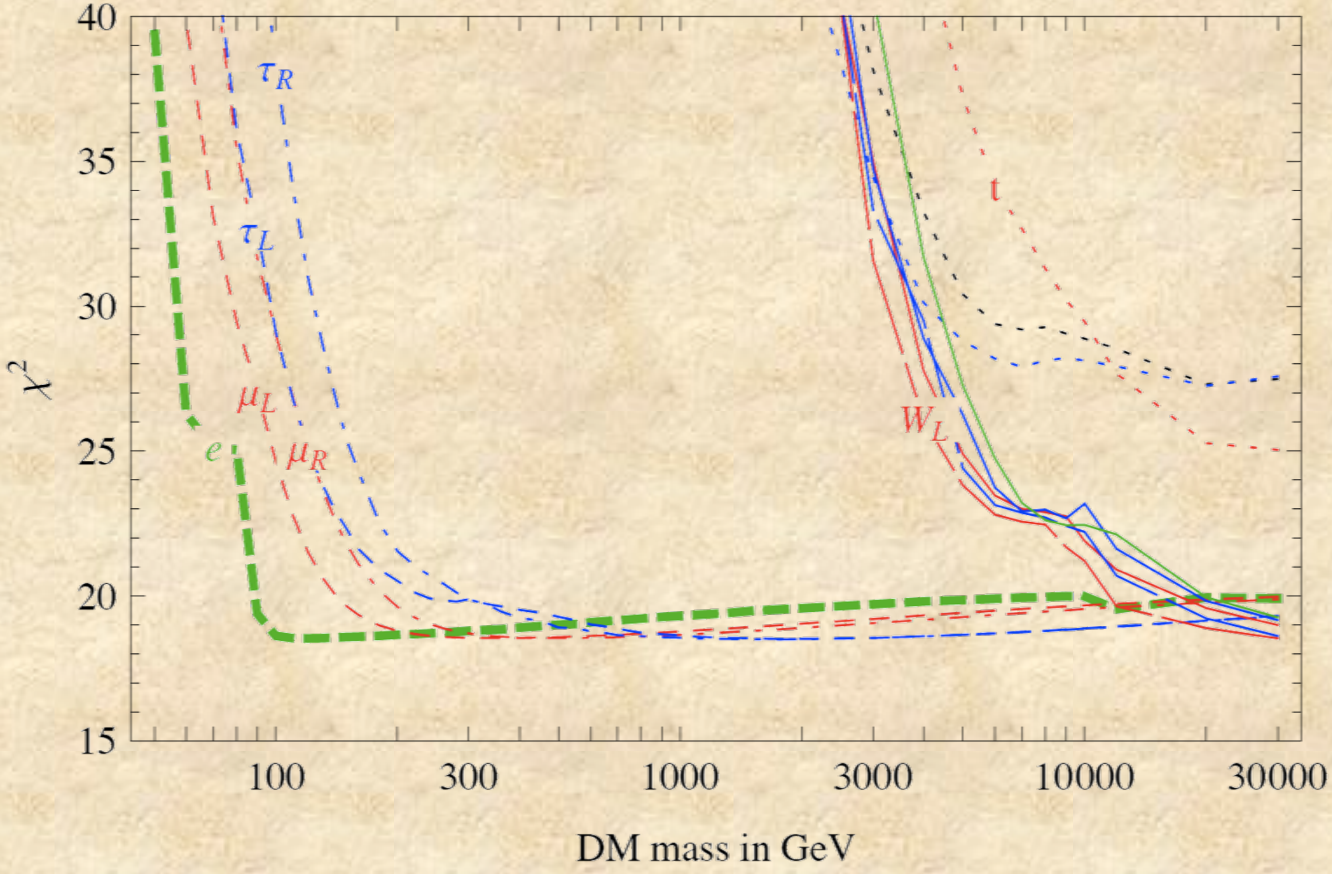
F. Donato, D. Maurin, P. Brun, T. Delahaye, P. Salati, PRL 102 (2009) 071301

Constraint on boost from antiprotons



F. Donato, D. Maurin, P. Brun, T. Delahaye, P. Salati, PRL 102 (2009) 071301

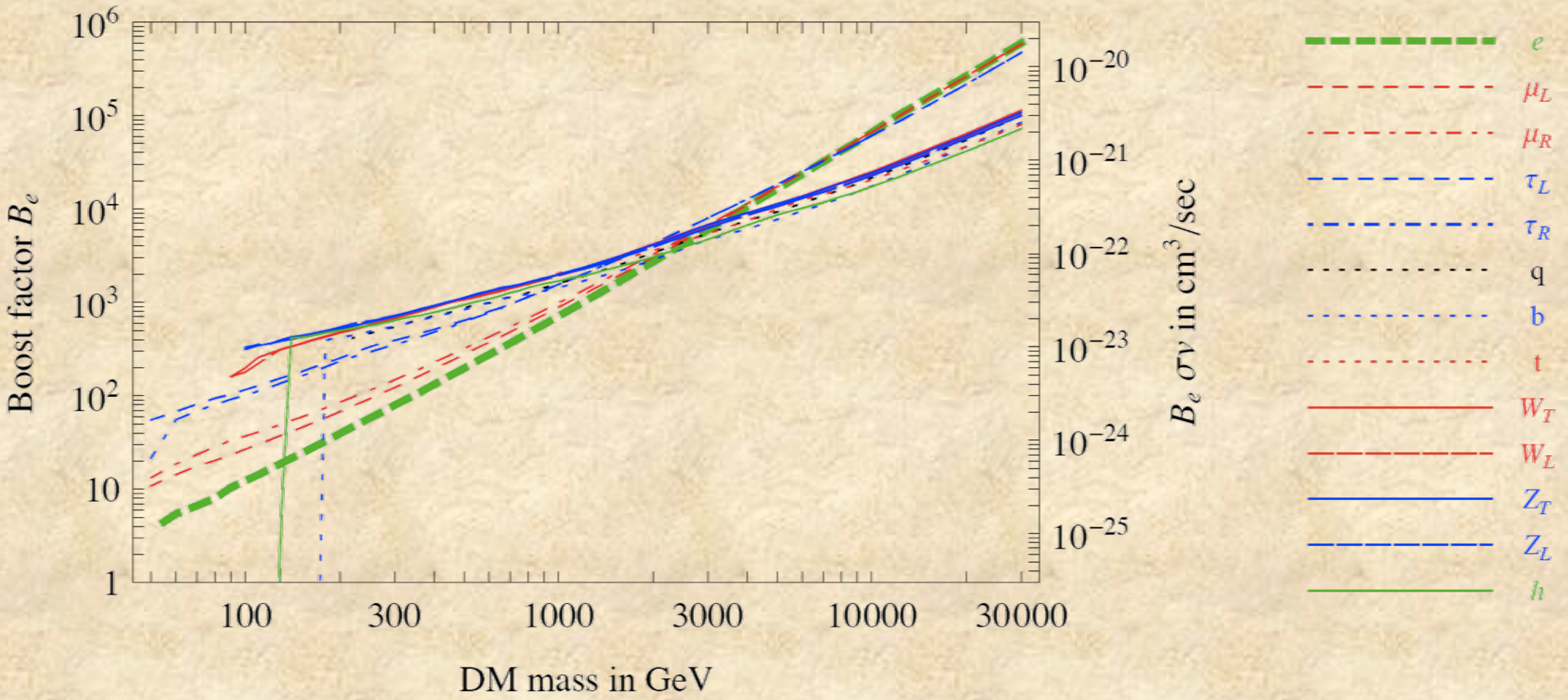
Model independent analysis



Fit on positron and antiproton data (with S&M background)

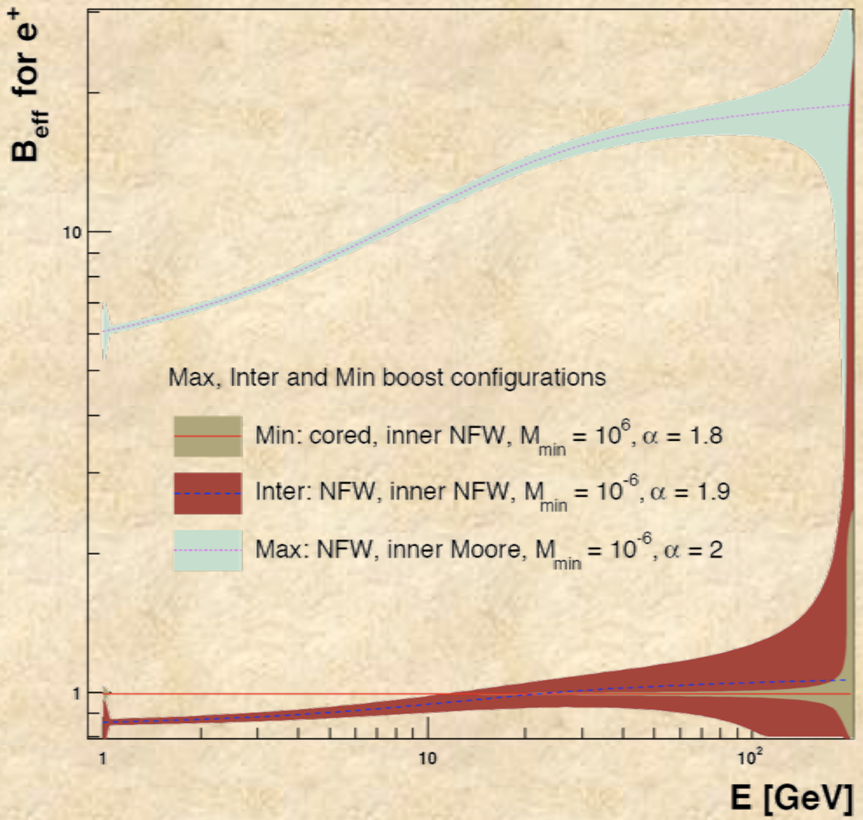
M. Cirelli, M. Kadastik, M. Raidal, A. Strumia, arXiv:0809.2409v3 [hep-ph]
See also: V. Barger, W.-Y. Keung, D. Marfatia, G. Shaughnessy, arXiv:0809.0162v2 [hep-ph]

Model independent analysis

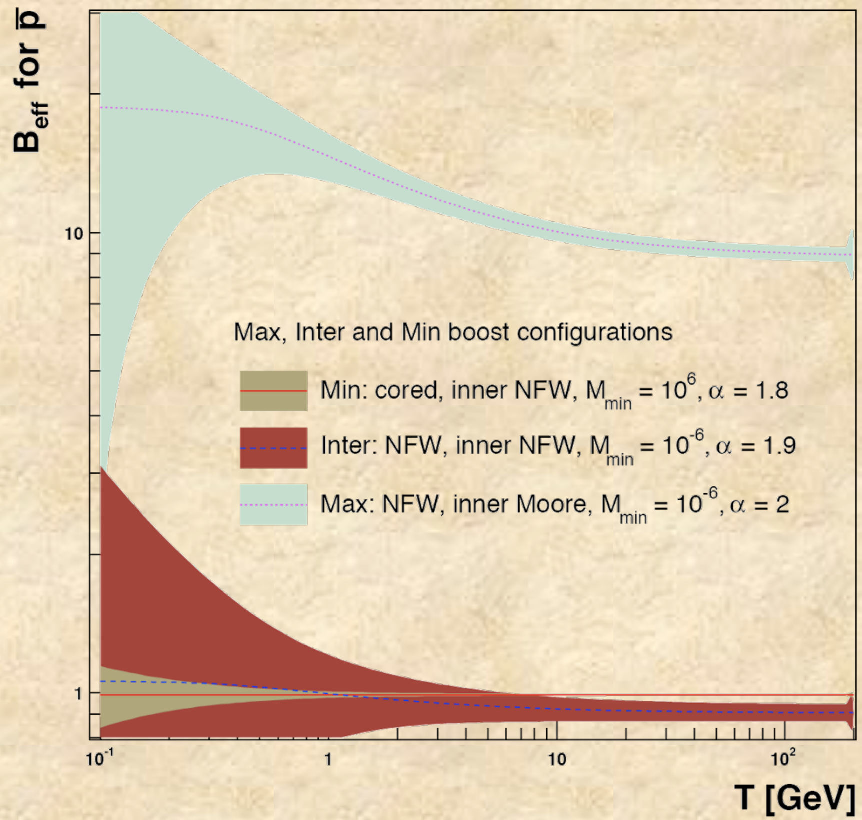


M. Cirelli, M. Kadastik, M. Raidal, A. Strumia, arXiv:0809.2409v3 [hep-ph]

Astrophysical boost



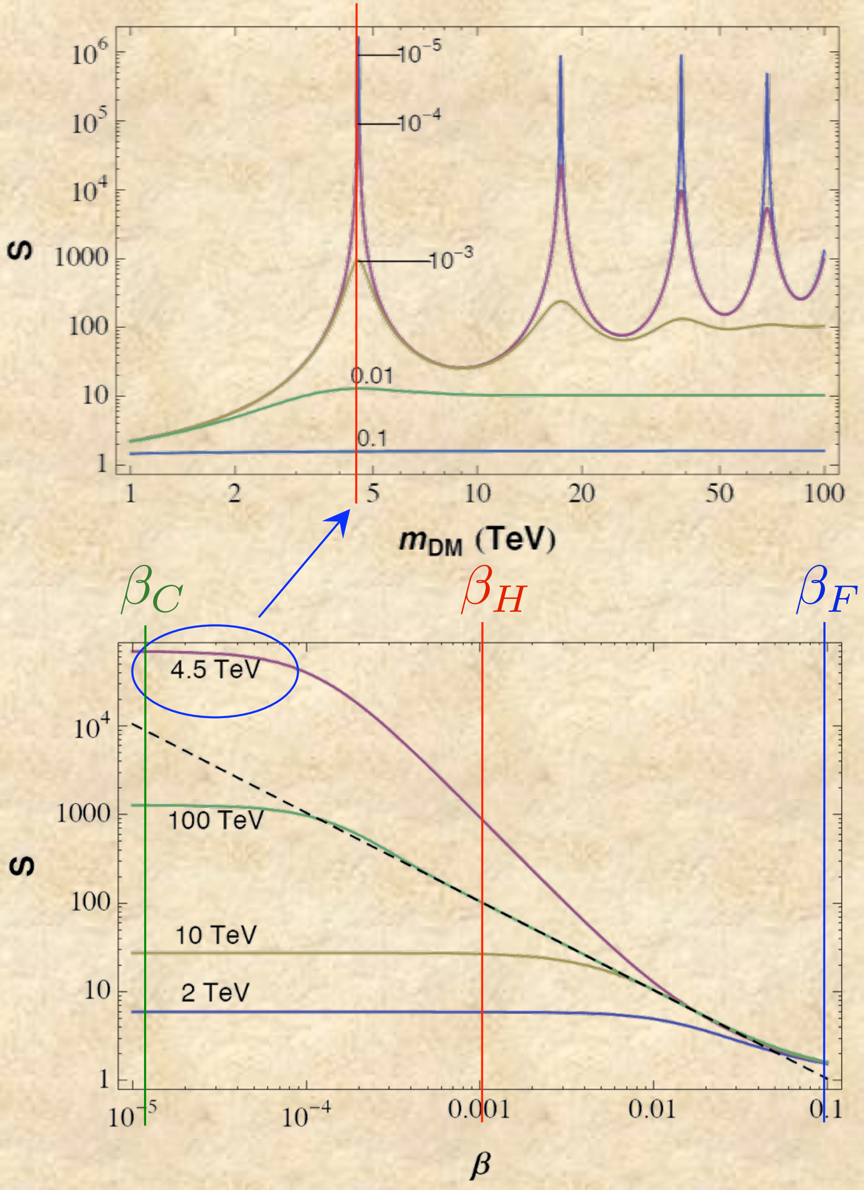
Positrons



Antiprotons

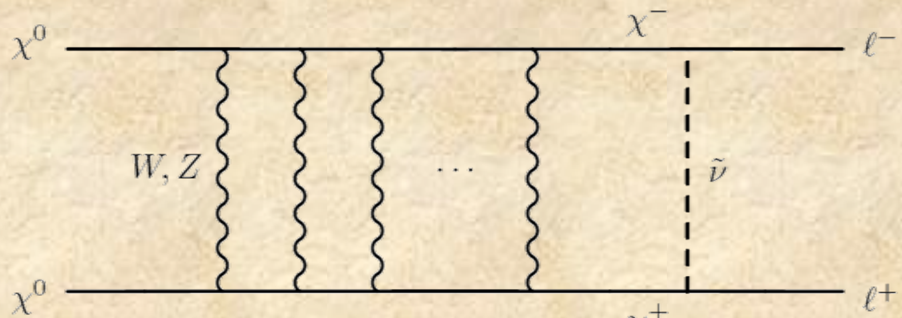
J. Lavalle, Q. Yuan, D. Maurin, X.J. Bi, A&A 479 (2008) 427

Particle physics boost: Sommerfeld effect



M. Lattanzi, J. Silk, arXiv:0812.0360v1 [astro-ph]

It may work differently for different annihilation channles (e.g. fermions wrt gauge bosons)



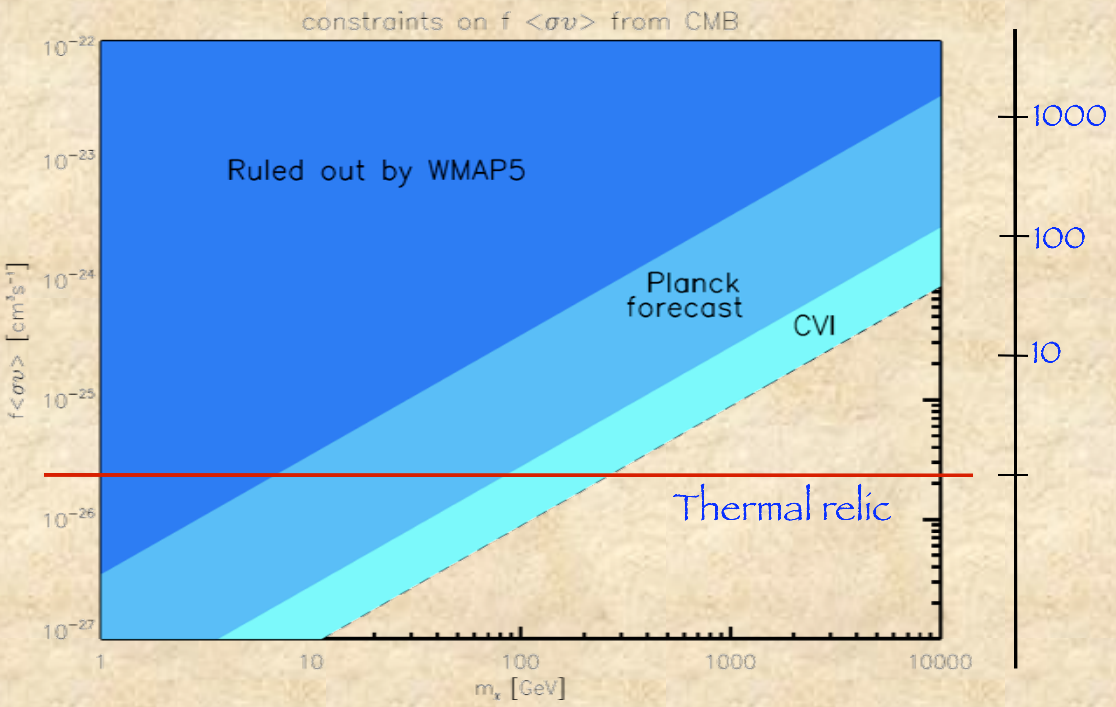
For X^0 and X^+ strongly degenerate

See also:

J. Hisano, M. Nagai, M. Nojiri, M. Senami, PRL 92 (2004) 031303
J. Hisano, S. Matsumoto, M. Nojiri, S. Saito, PRD, 71 (2005) 063528
M. Cirelli, A. Strumia, M. Tamburini, NPB 787 (2007)
J. March-Russell, S. M. West, D. Cumberbatch, D. Hooper, JHEP 0807 (2008) 058
N. Arkani-Hamed, D. P. Finkbeiner, T. Slatyer, N. Weiner, arXiv:0810.0713 [hep-ph]
M. Cirelli, M. Kadastik, M. Raidal, A. Strumia, arXiv:0809.2409v3 [hep-ph]

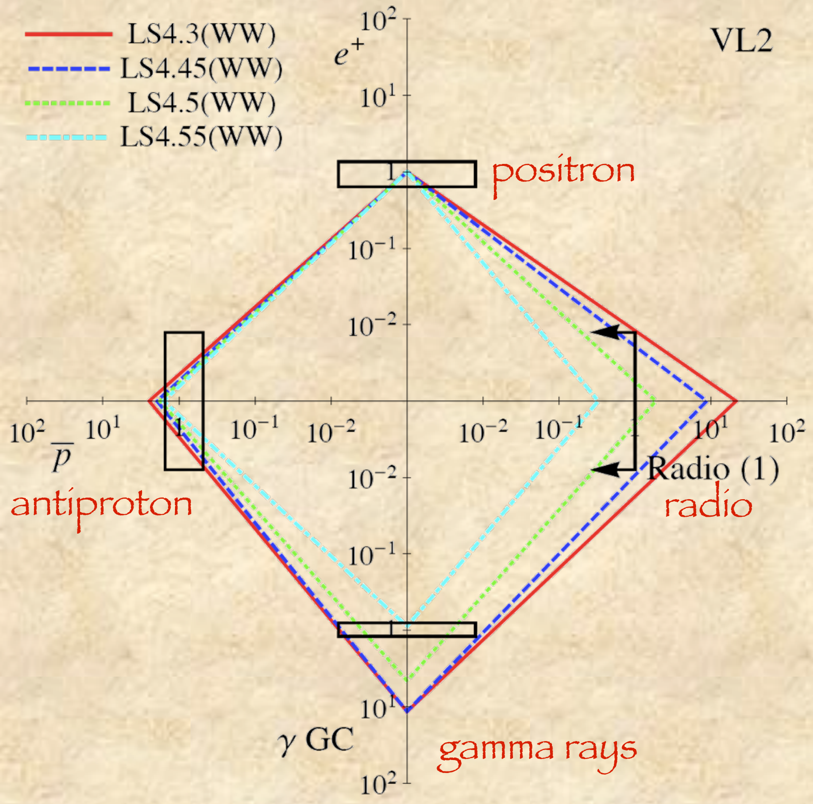
Bounds on Sommerfeld boost

From CMB



S. Galli, F. Iocco, G. Bertone, A. Melchiorri, arXiv:0905.0003v1 [astro-ph]

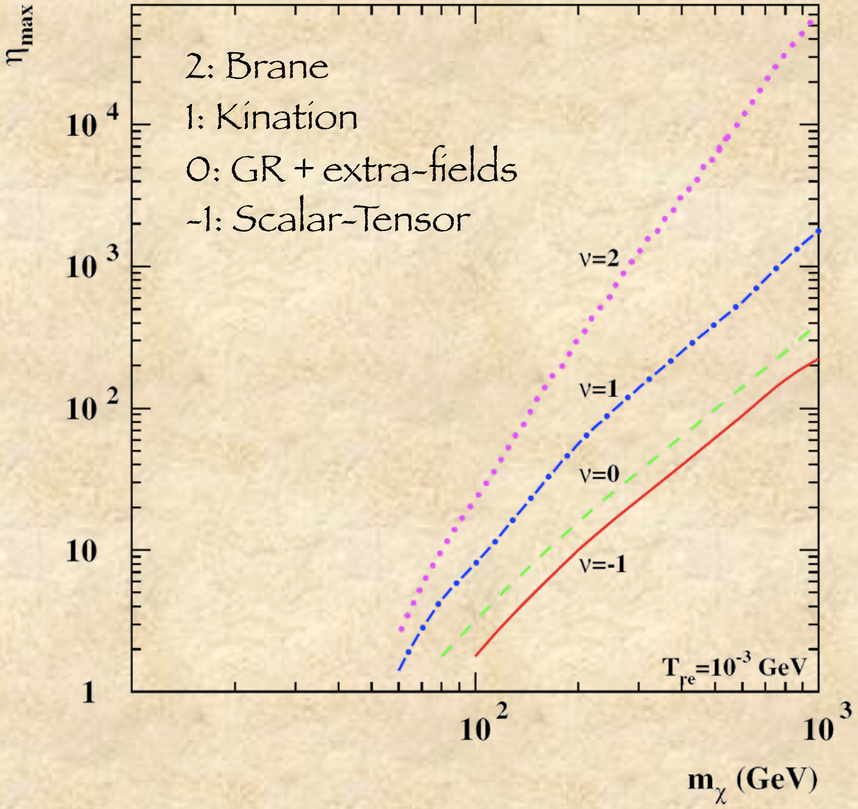
From multiwavelength



M. Pato, L. Pieri, G. Bertone, 0905.0372v1 [astro-ph.HE]

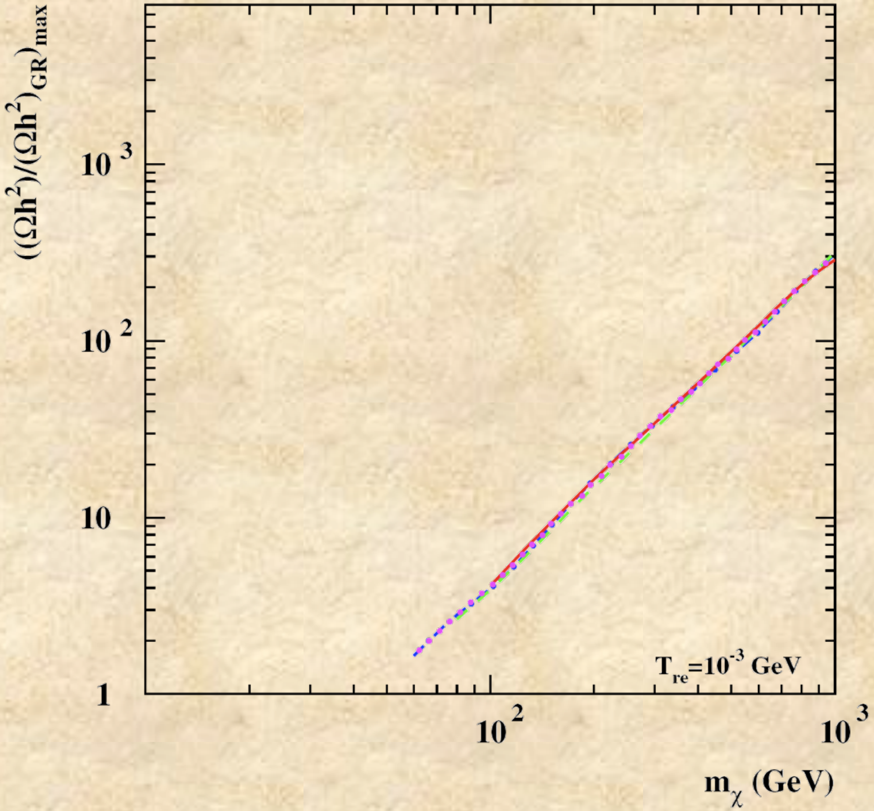
Cosmological boost

$H = H_{\mathrm{GR}}[1 + \eta(T/T_F)^\nu] \quad (\text{for } T > T_{\mathrm{BBM}})$



Maximal enchancement of
Hubble rate at freeze-out
consistent with antiproton data

$B = \langle \sigma v \rangle^{\mathrm{WMAP}} / \langle \sigma v \rangle^{\mathrm{WMAP}}_{\mathrm{GR}}$



Induced boost

Boosts equally leptonic and hadronic channels

M. Schelke, R. Catena, N. Fornengo, A. Masiero, M. Pietroni, PRD 74 (2006) 083505

Summarizing

- A boost is always required

- Annihilation into leptons (but not into "hadronic" channels)

$$m_\chi \gtrsim 100 \text{ GeV}$$

$$B \sim 10 \left(\frac{m_\chi}{100 \text{ GeV}} \right)^{1.7}$$

- Annihilation into gauge bosons

$$m_\chi \gtrsim 10 \text{ TeV}$$

$$B \sim 2 \times 10^4 \left(\frac{m_\chi}{10 \text{ TeV}} \right)^{1.4}$$

SUSY interpretation?

- Annihilation into leptons (but not into "hadronic" channels) ⟶ Unusual for typical candidates

$m_\chi \gtrsim 100 \text{ GeV}$ ⟶ Natural mass range

$B \sim 10 \left(\frac{m_\chi}{100 \text{ GeV}}\right)^{1.7}$ ⟶ Astrophysical (up to 10)
Sommerfeld
Cosmological

- Annihilation into gauge bosons

$m_\chi \gtrsim 10 \text{ TeV}$ ⟶ Naturalness ?

$B \sim 2 \times 10^4 \left(\frac{m_\chi}{10 \text{ TeV}}\right)^{1.4}$ ⟶ Not astrophysical
Sommerfeld
Cosmological ?

“Canonical” SUSY candidates

- Neutralino: s=1/2 Majorana fermion
- Sneutrino: s=0 boson
- Gravitino: s=3/2 fermion
- Axino: s=1/2 fermion

Neutralino

Majorana fermion: the non-relativistic annihilation cross section into leptons (especially positrons) is helicity suppressed

$$\langle \sigma v \rangle_{\rm ann} \propto m_f^2$$

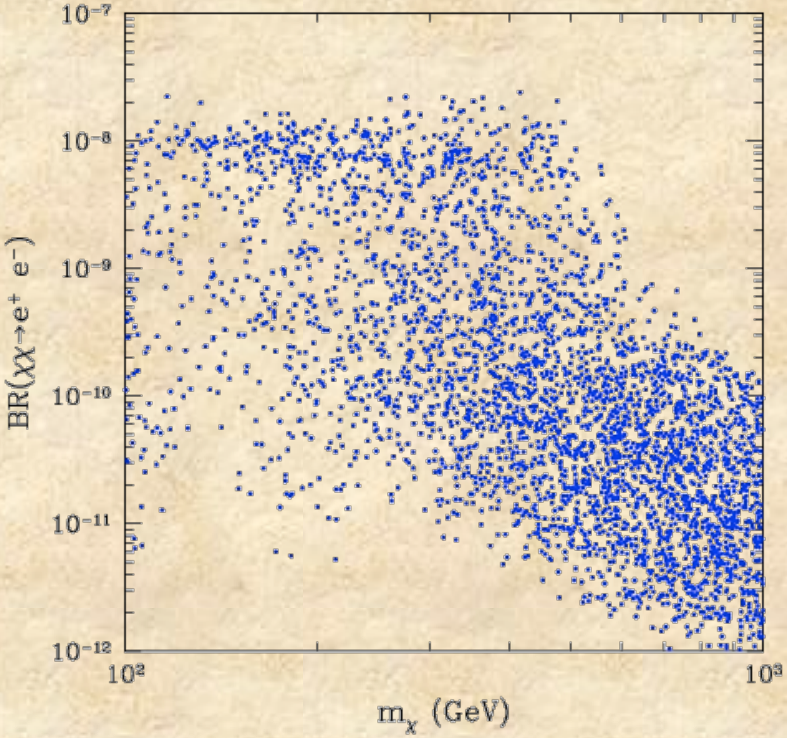
Preferred channels: quark production (also gauge or hisggs bosons)

Hard to produce leptons without producing also a large amount of antiprotons

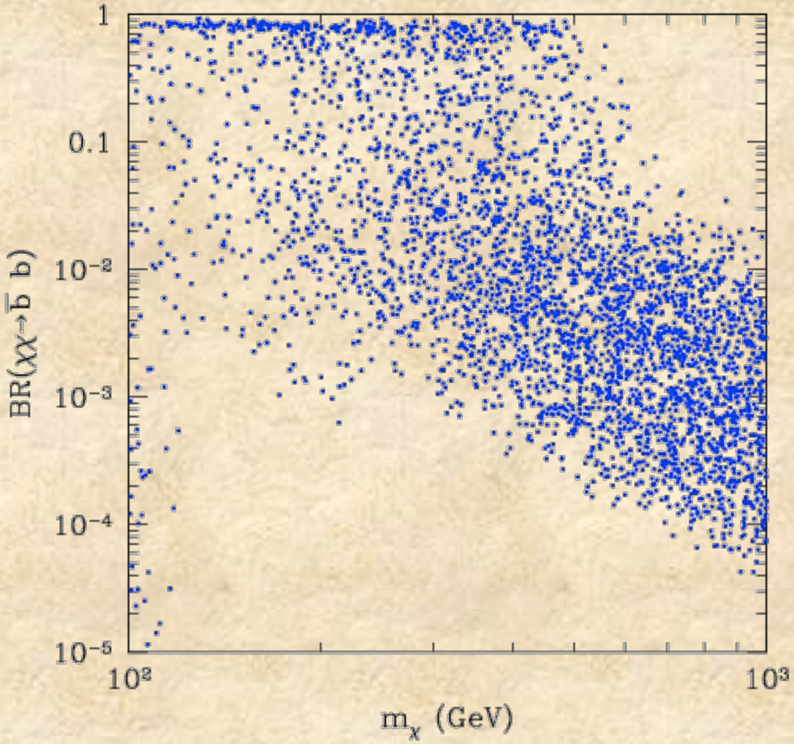
Positrons spectra are too soft to explain PAMELA raise

Positron BR for neutralinos in MSSM

BR into electrons



BR into bottoms

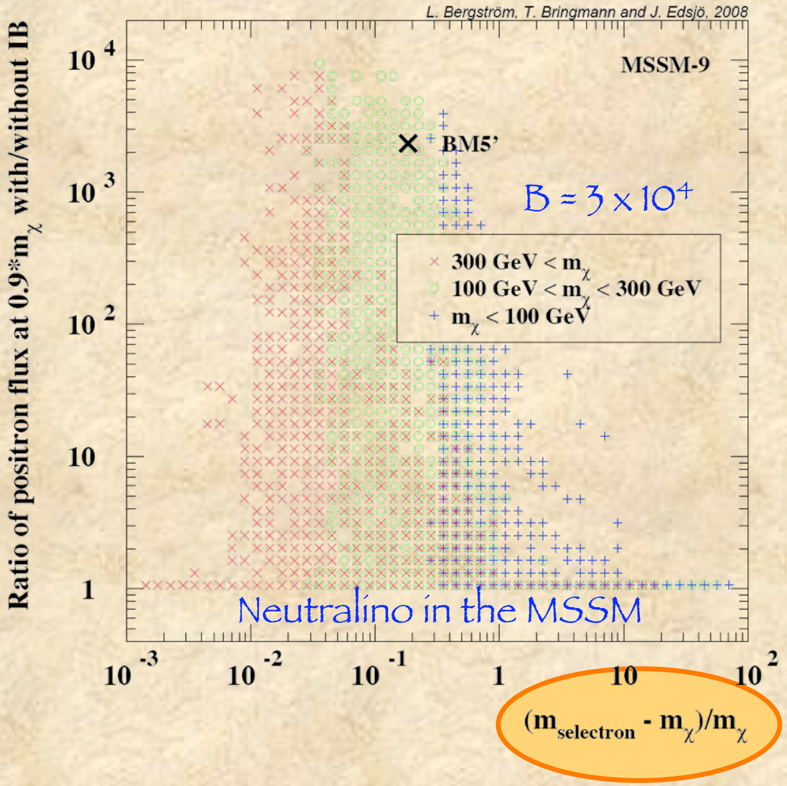


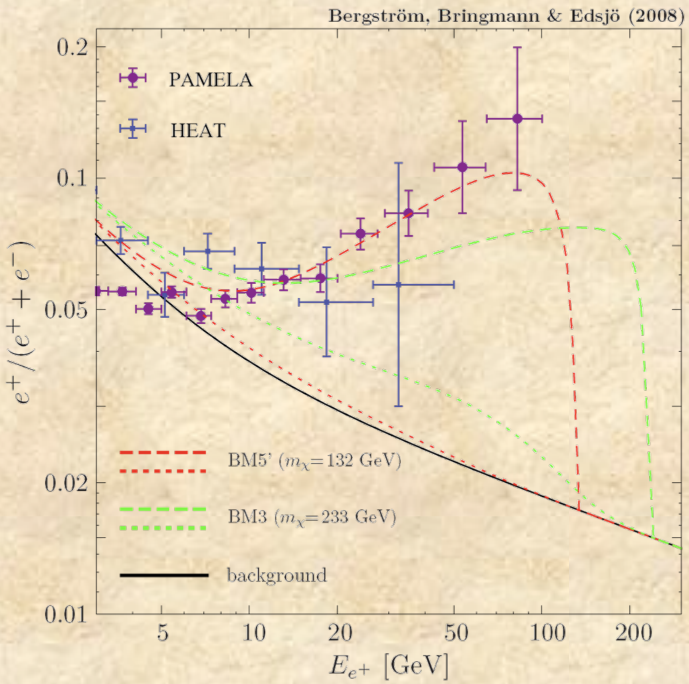
Configurations with WMAP relic abundance

Internal bremsstrahlung: spectral feature

$\chi\chi \longrightarrow e^+e^-\gamma$ No helicity suppression

$\langle\sigma v\rangle_{\rm ann}$ suppressed by (α/π) instead of (m_e^2/m_χ^2)





Large boost factors still needed

L. Bergstrom, T. Bringmann, J. Edsjo, arXiv:0808.3725v3 [astro-ph]

Sneutrino

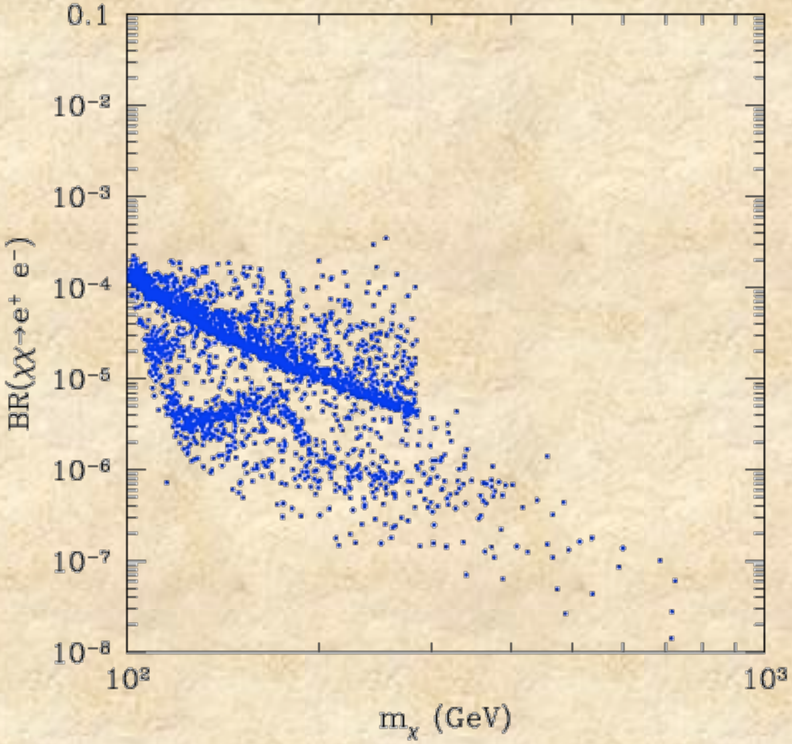
Scalar boson: the non-relativistic annihilation cross section into leptons is suppressed

Sneutrino carry lepton number, therefore their interactions may exhibit preference toward leptons and W (Z-coupling has to be suppressed for viable sneutrino DM)

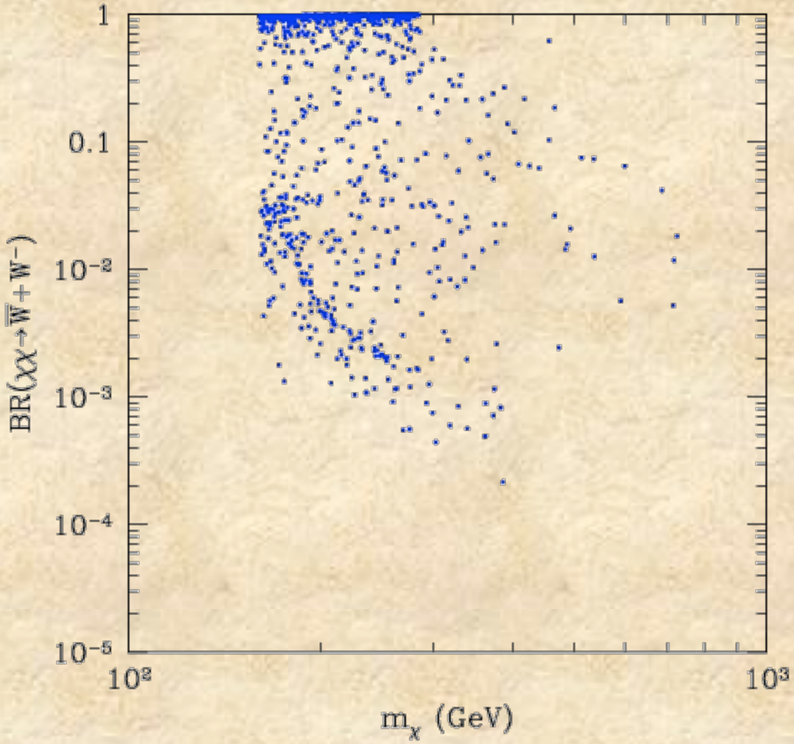
Dominantly annihilate into WW or mixed states

BR for sneutrino in a LR model

BR into electrons



BR into WW



Configurations with WMAP relic abundance

Possible solutions

- Non-minimalities are required:
  - Additional fields which change the nature of the DM candidate
  - Additional symmetries which induce preference toward leptons
  - Additional interaction which induce preference toward leptons
  - (...)

- The necessity of a boost is nevertheless present
  - If a strong preference for leptons is obtained, it may be large without conflicting with antiprotons
  - Multiwavelength emission may instead be limiting

"Dirac bino"

- Bino with a Dirac mass arising from coupling to a gauge singlet fermion
  - Dirac fermion: no helicity suppression for annihilation
- Possible with D-term SUSY-breaking
- Preference of annihilation into leptons due to:
  - Coupling through hypercharge: larger for leptons than for quarks
  - Sleptons have to be sufficiently smaller than squarks

$$\frac{BR(\chi\chi \to ll)}{BR(\chi\chi \to qq)} \sim \left(\frac{Y_l}{Y_q} \frac{m_{\tilde{q}}}{m_{\tilde{l}}} \right)^4$$

R. Harnik, G.D. Kribs, arXiv:0810.5557v1 [hep-ph]

Additional symmetries

MSSM + gauged $U(1)_{B-L}$

- The new gauged symmetry introduces:
  - 3 right-handed neutrinos
  - 1 new gauge boson Z'
  - 2 new higgses H'_1 and H'_2 ⟶ lightest ϕ
  - New neutralinos from SUSY partners of Z', H'_1 and H'_2
    - ➢ They can be arranged to be lighter than standard neutralinos

R. Allahverdi, B. Dutta, K. Richardson-McDaniel, Y. Santoso, arXiv:0812.2196v1 [hep-ph]

Dominant annihilation cross section

$$\chi\chi \xrightarrow{\phi} \phi\phi$$

Dictates relic abundance
Not suppressed

$$\Gamma(\phi \to \bar{f} f) \sim g_{B-L}^6 \, m_f^2$$

$$g_{B-L}^{\text{leptons}} = 3 g_{B-L}^{\text{quarks}}$$

ϕ Light:

decays only into light fermions
produces the required Sommerfeld enhancement

Alternatively, the cross-section enhancement can be due to a modified cosmology with a low-reheating temperature

The mechanism can be made work also for sneutrino DM in the same MSSM + gauged $U(1)_{B-L}$ framework

B. Dutta, L. Leblond, K. Signa, arXiv:0904.3773v1 [hep-ph]

Dark Sectors for Dark Matter

- DM couples to a GeV-scale dark gauge boson, kinematically mixed to SM photons
- DM annihilates to the dark gauge boson, which then decays into electrons and muons
- The new GeV-scale boson:
  - Produces Sommerfeld enhancements
  - No antiprotons due to kinematics
- Not necessarily SUSY
  - If implemented, it can induce SUSY breaking

N. Arkani-Hamed, D. P. Finkbeiner, T. Slatyer, and N. Weiner, arXiv:0810.0713
M. Baumgart, C. Cheung, J. Ruderman, L-T. Wang, I. Yavin, arXiv:0901.0283v2 [hep-ph]

Other proposals

- Model with Majorana or Dirac Neutrino Masses and Mixings from Radiative Corrections or Seesaw mechanism
  - Do not require to be SUSY

  Xiao-Jun Bi1,* Pei-Hong Gu2,† Tianjun Li3,‡ and Xinmin Zhang, arXiv:0901.0176v1 [hep-ph]

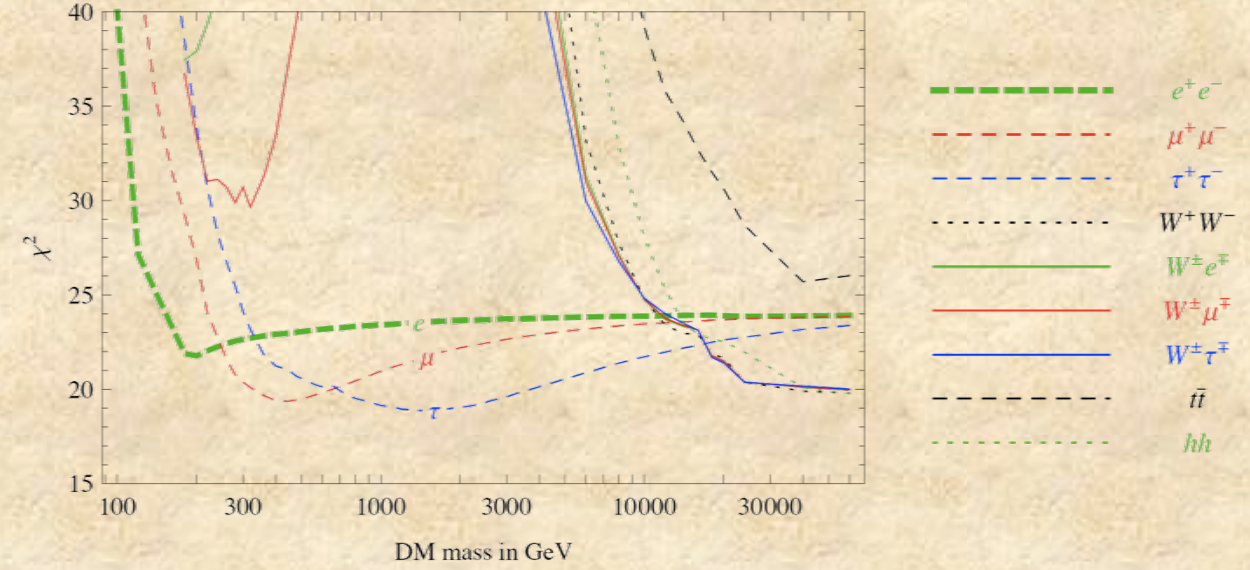
- Multi-component dark matter

  K. Zurek, arXiv:0811.4429v3 [hep-ph]
  J.-H. Huh, J.E. Kim, Bumseok Kyae, arXiv:0812.5004v2 [hep-ph]

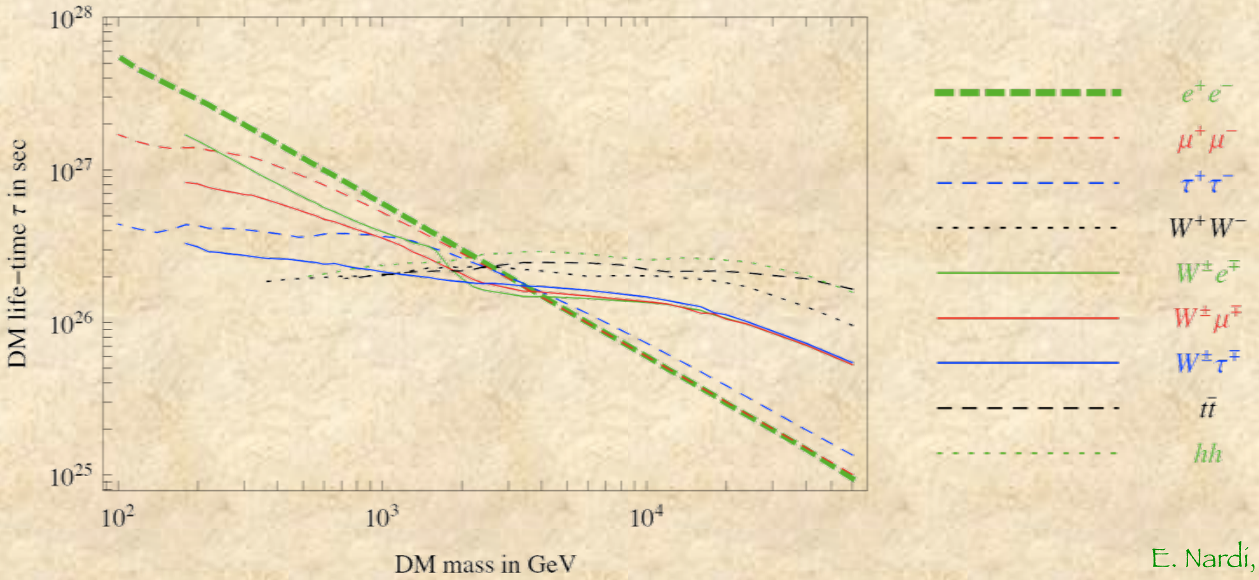
- Scenario with heavy vector-like dark matter in association with a hidden $U(1)_X$ sector in GMSB below GeV scale

  E.J. Chun, J.-C. Park, arXiv:0812.0308v2 [hep-ph]

Decaying dark matter



Fit on positron and antiproton data (with S&M background)



E. Nardi, F. Sannino, A. Strumia, arXiv:0811.4153v1 [hep-ph]

R-parity violation

- Binlinear RPV

$$\mathcal{L}_{\rm RPV} = B_i \tilde{L}_i H_u + m^2_{\tilde{L}_i H_d} \tilde{L}_i H_d^* + \text{h.c.}$$

$$\chi \to Z\nu,\ Wl,\ h\nu$$

$$\tau_{\tilde{B}} \simeq 2 \times 10^{25}\ \text{sec} \times \left(\frac{\kappa}{10^{-25}}\right)^{-2} \left(\frac{m_{\tilde{B}}}{1\ \text{TeV}}\right)^{-1}$$ Neutralino (Bino)

$$\tau_{3/2} \simeq 6 \times 10^{25}\ \text{sec} \times \left(\frac{\kappa}{10^{-10}}\right)^{-2} \left(\frac{m_{3/2}}{1\ \text{TeV}}\right)^{-3}$$ Gravitino

RPV coupling extremeley small (RPV in RH neutrino sector may help)
Antiprotons are also produced

- Trilinear RPV

$$W_{\rm RPV} = \frac{1}{2}\lambda_{ijk} \hat{L}_i \hat{L}_j \hat{E}^c_k$$

$$\tilde{B} \to \nu l^{\pm}_L l^{\mp}_R$$

C.-H. Chen1, C.-Q. Geng, D.V. Zhuridov, arXiv:0905.0652v1 [hep-ph]
M. Endo, T. Shindonu, arXiv:0903.1813v1 [hep-ph]
K. Ishiwata, S. Matsumoto, T. Moroi, arXiv:0903.0242v1 [hep-ph]
S. Shirai1, F. Takahashi, T.T. Yanagida1, arXiv:0902.4770v2 [hep-ph]
B.Kyae, arXiv:0902.0071v2 [hep-ph]
K. Hamaguchi1, F. Takahashi,T.T. Yanagida1, arXiv:0901.2168v2 [hep-ph]
M. Pospelov1, M. Trott, arXiv:0812.0432v3 [hep-ph]
A. Ibarra, D. Tran, arXiv:0811.1555v1 [hep-ph]
K. Ishiwata, S. Matsumoto, T. Moroi, arXiv:0811.0250v1 [hep-ph]
P. Yin, Q.Yuan, J. Liu, J. Zhang, X. Bi, S. Zhu, X. Zhang, arXiv:0811.0176v2 [hep-ph]
C.-R. Chen, F. Takahashi, arXiv:0810.4110v2 [hep-ph]

Conclusions

PAMELA data are not easily interpreted in a SUSY DM framework

Requirements:

- Boost factor (valid in general)
  - Astrophysical: small (factor of 10 max)
  - Particle Physics (Sommerfeld, Breit-Wigner): can be sizeable for specific situations
    - Occurrence of resonances
    - Subhalo population (cold)
    - Limited by CMB
  - Cosmological: can be sizeable
- Preference for leptonic production
  - Requires non-minimal models
    - Additional interactions
    - Additional symmetries