Particle dark matter: advancement in the theoretical predicitons of detection rates

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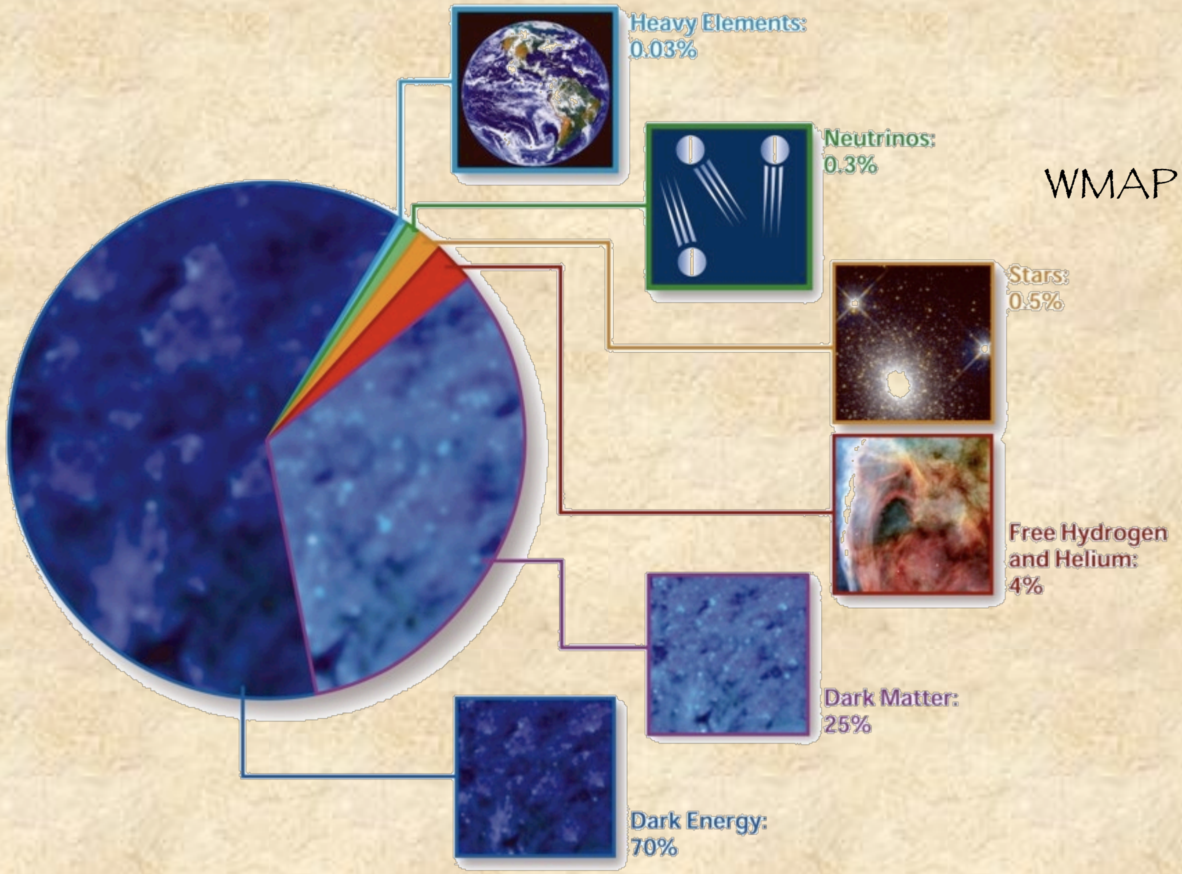
08.05.2009

The Dark Universe



WMAP + SN + BAO + galaxies distribution

Ω_{TOT}	1.0052 ± 0.0064
Ω_Λ	0.721 ± 0.015
Ω_M	0.233 ± 0.013
Ω_b	0.0462 ± 0.0015
h_0	0.701 ± 0.013
$\Omega_M h^2$	0.1369 ± 0.0037
$\Omega_b h^2$	0.02265 ± 0.00059
$\Omega_{DM} h^2$	0.1143 ± 0.0034

E. Komatsu et al., arXiv:0803.0547
J. Dunkley et al., arXiv:0803.0596
G. Hinshaw et al., arXiv:0803.0732

Ω_T CMB temperature anisotropies

Ω_Λ Luminosity distance of high-z SNIa

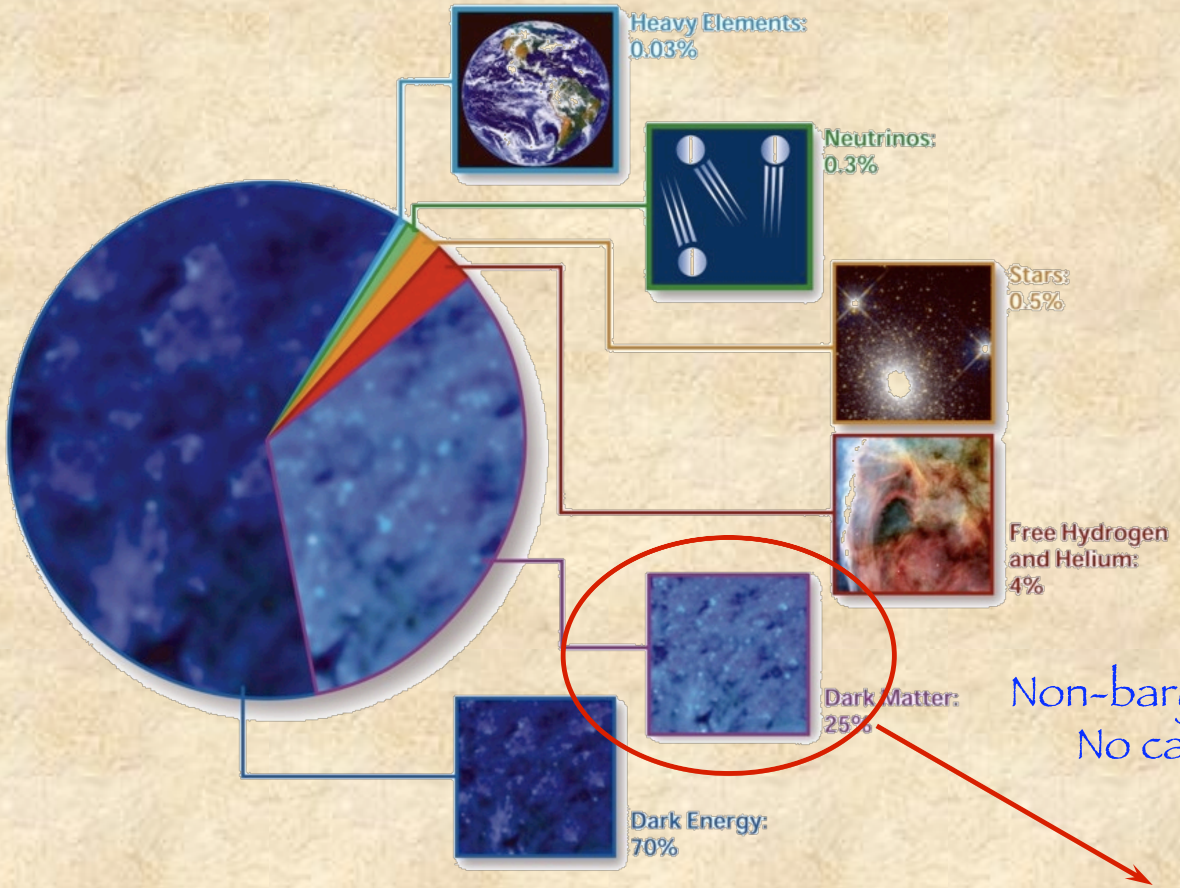
Ω_M Clustered mass abundance

Ω_B Primordial Nucleosynthesis
Amplitude of CMB temperature anisotropies

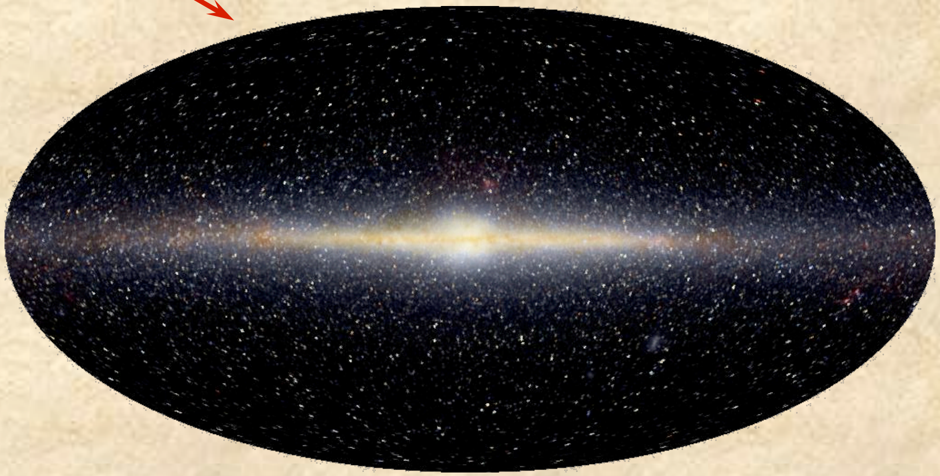
Geometry: the Universe is Flat
Dynamics: the Universe is expanding

- Decelerate for most of its history
- Accelerate since "recent" time and at very "old" times (inflation)

Dark Matter



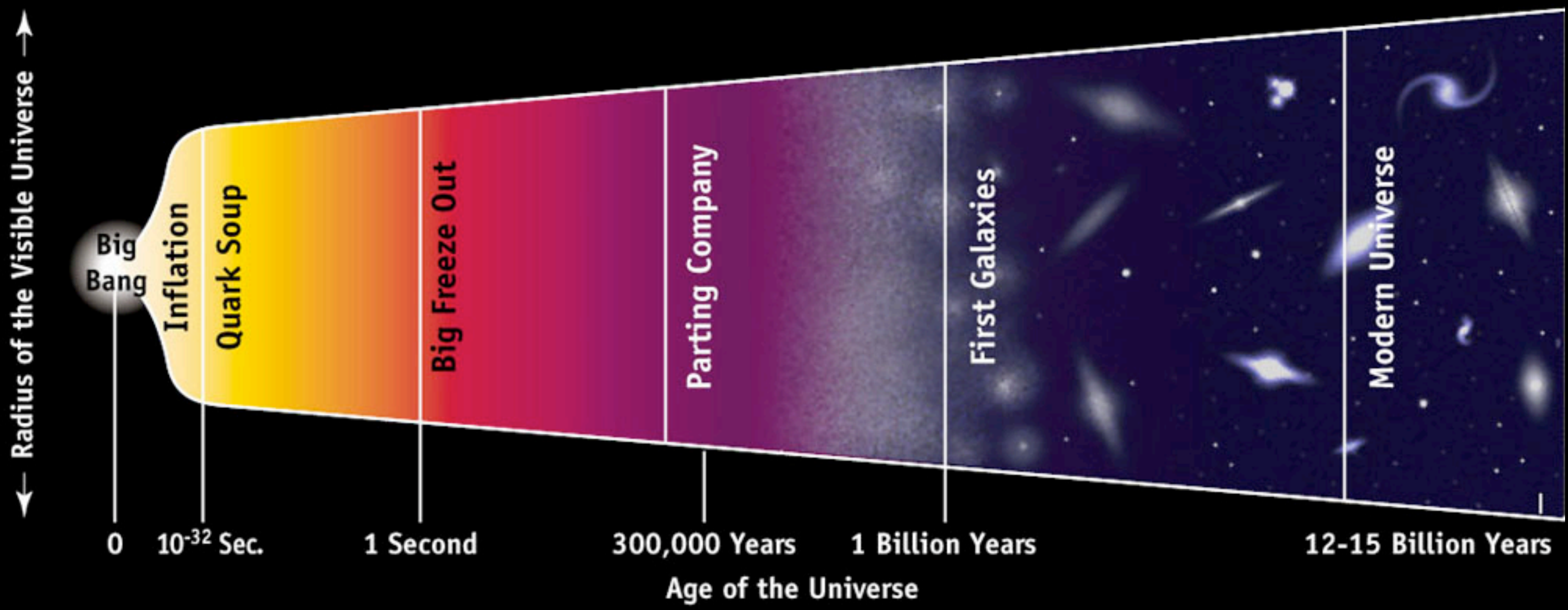
Non-baryonic (cold) dark matter is needed
No candidate in the Standard Model
New fundamental Physics



Dynamics of galaxy clusters
Rotational curves of galaxies
Weak lensing
Structure formation from primordial density fluctuations
Energy density budget

Dark Matter as a relic particle from the Early Universe

Evolution history of the Universe



Dark Matter formation

Particle DM formation

- Thermal relic

$$\Omega h^2 \sim \langle \sigma v \rangle_{\rm ann}^{-1} \longrightarrow \langle \sigma v \rangle_{\rm ann} = 3 \cdot 10^{-26} {\rm cm}^3 {\rm s}^{-1}$$

unless coannihilation occurs

- Thermal relic with non-standard cosmology

$\Omega h^2 \sim \langle \sigma v \rangle_{\rm ann}^{-1}$ with $\langle \sigma v \rangle_{\rm ann} \neq \langle \sigma v \rangle_{\rm ann}^{\rm GR}$

- Non-thermal relic
  - In a low-reheating cosmology
  - From next-to-lightest particle decay

- (...)

Non-baryonic DM candidates

- Non supersymmetric candidates
  - Neutrino: standard, RH MeV, (...)
  - "Minimal" candidates (e.g.: MDM)
  - Axion
  - Kaluza-Klein fields
  - Little Higgs models
  - Mirror baryons

    (...)
- Supersymmetric candidates
  - Neutralino →
  - Sneutrino
  - Gravitino
  - Axino
  - Messenger fields
  - Stable non-topological solitons (Q-balls)
  - Heavy non-thermal relics

    (...)

- Low energy MSSM
  - ➢ Universal mass params
  - ➢ Light neutralinos
- Minimal SUGRA
- Non-minimal SUGRA
  - ➢ Higgs sector
  - ➢ Sfermion sector
  - ➢ Gaugino sector
- NMSSM
- Anomaly mediated ~~SUSY~~
- (...)

Non-baryonic DM candidates

- Non supersymmetric candidates
  - Neutrino: standard, RH MeV, (...)
  - "Minimal" candidates (e.g.: MDM)
  - Axion
  - Kaluza-Klein fields
  - Little Higgs models
  - Mirror baryons
  - (...)
- Supersymmetric candidates
  - Neutralino
  - Sneutrino →
    - With R-handed (s)neutrino
    - With Majorana mass terms
    - In see-saw models
    - NMSSM
    - (...)
  - Gravitino
  - Axino
  - Messenger fields
  - Stable non-topological solitons (Q-balls)
  - Heavy non-thermal relics
  - (...)

Dark matter particles in galaxies

Galactic Dark Matter

CDM in galaxies:

- Massive particle with weak-type interactions (WIMP)
- Distributed to form a halo
  - Thermal component
  - Substructures
  - Non-thermal component

Galactic dark matter detection:

- Identify types of signals
- Exploit specific signatures
- Study relevant backgrounds
- Quantify uncertainties

Signals of Dark Matter Particles

MultiChannel search of dark matter

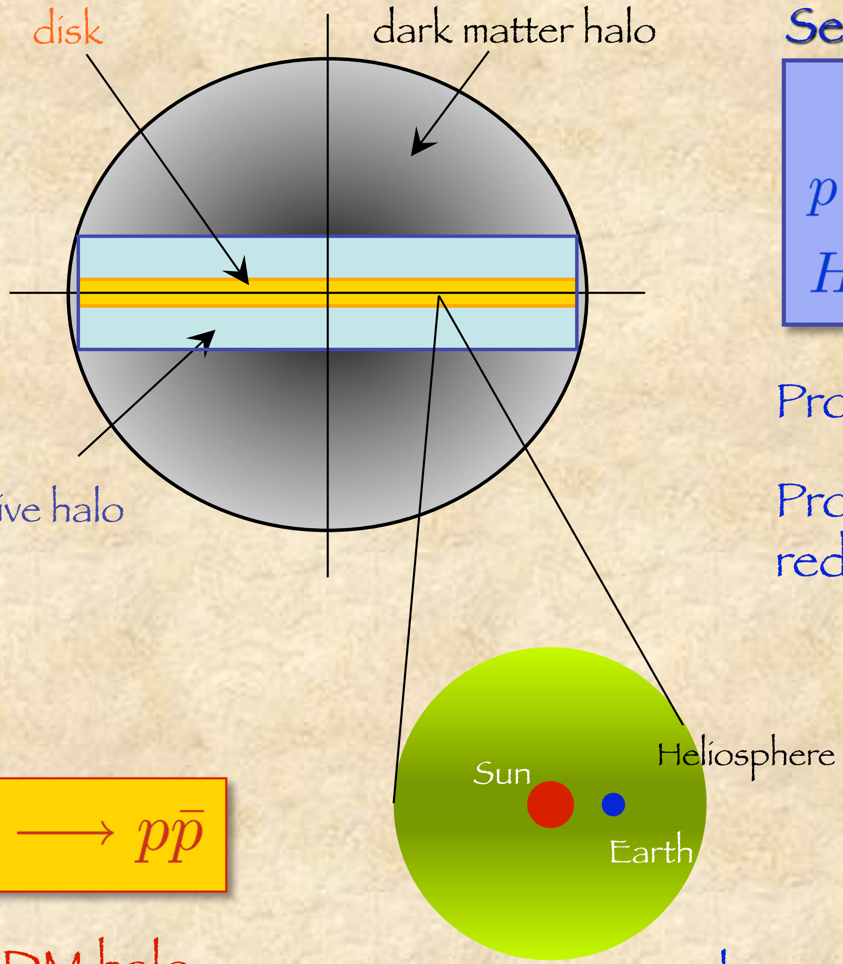
- Direct search: elastic scattering of χ off nuclei in a low background detector
  → recoil energy of the nucleus
  annual modulation of the rate
  directionality of the recoil

- Indirect searches:
  - signals due to $\chi\chi$ annihilation taking place inside celestial bodies (Sun, Earth) where χ have been captured and accumulated
    → Neutrino flux → up-going muons in a neutrino telescope
    source location/some spectral feature

  - signals due to $\chi\chi$ annihilation taking place in the galactic halo
    → Neutrinos — source location/some spectral feature
    → Photons
      - continuous gamma-ray flux — source location/some spectral feature
      - gamma-ray line — very good spectral feature
    → Positrons — spectral feature
    → Antiprotons — spectral feature
    → Antideuterons — very good spectral feature
    → Electrons/positrons → multiwavelength search (radio, X, gamma rays; SZ on CMB)

Antiprotons

Antiproton signal



solar modulation

Secondaries

$$p_{\rm CR} + p_{\rm ISM} \longrightarrow \bar{p}$$
$$p_{\rm CR} + He_{\rm ISM} \longrightarrow \bar{p}$$
$$He_{\rm CR} + p_{\rm ISM} \longrightarrow \bar{p}$$

Produced in the disk

Propagation and energy redistribution in the diffusive halo

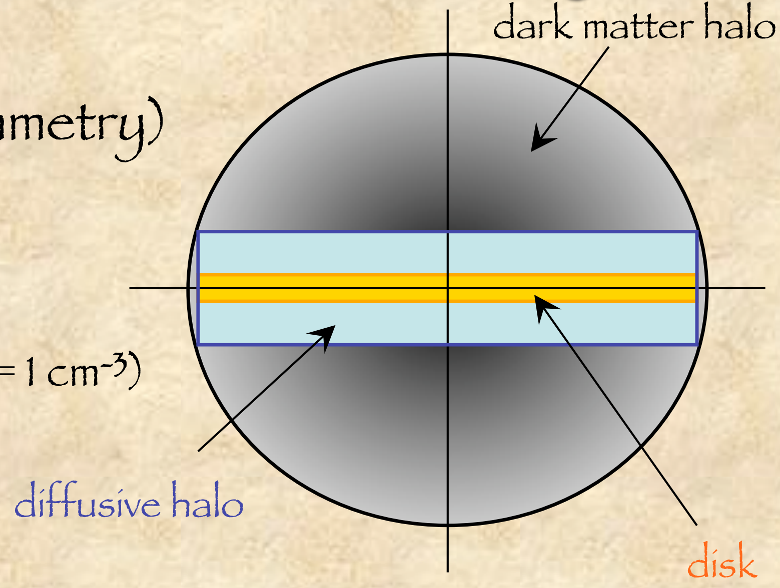
DM signal

$$\chi\chi \longrightarrow (\ldots) \longrightarrow p\bar{p}$$

Produced in the DM halo

Propagation and energy redistribution in the diffusive halo

Diffusion and propagation in the Galaxy



- Two-zone diffusion model (cylindrical symmetry)
  - Thin disk
    - ✓ Radius R = 20 kpc
    - ✓ Thickness h = 100 pc
    - ✓ Surface density of IS gas: $\Sigma = 2hn_{ISM}$ ($n_{ISM} = 1\ cm^{-3}$)
  - Diffusive halo
    - ✓ Radius R
    - ✓ Height L

- Physical processes
  - Diffusion: uniform in the whole (disk + diffusive halo) volume
  - Inelastic (non-annihilating) scattering and annihilation
  - Galactic wind away from the disk in vertical direction
  - Energy losses:
    - ✓ Ionization: interaction with the neutral IS matter
    - ✓ Coulomb scattering: interaction with ionized plasma (thermal electrons)
  - Reacceleration on random hydrodynamic waves (in the disk only)

$q_{\bar{p}}^{\mathrm{DM}}(r, z, T_{\bar{p}})$ — Propagation in the Galaxy → $\Phi^{\bar{p}}(r, z, T_{\bar{p}})$

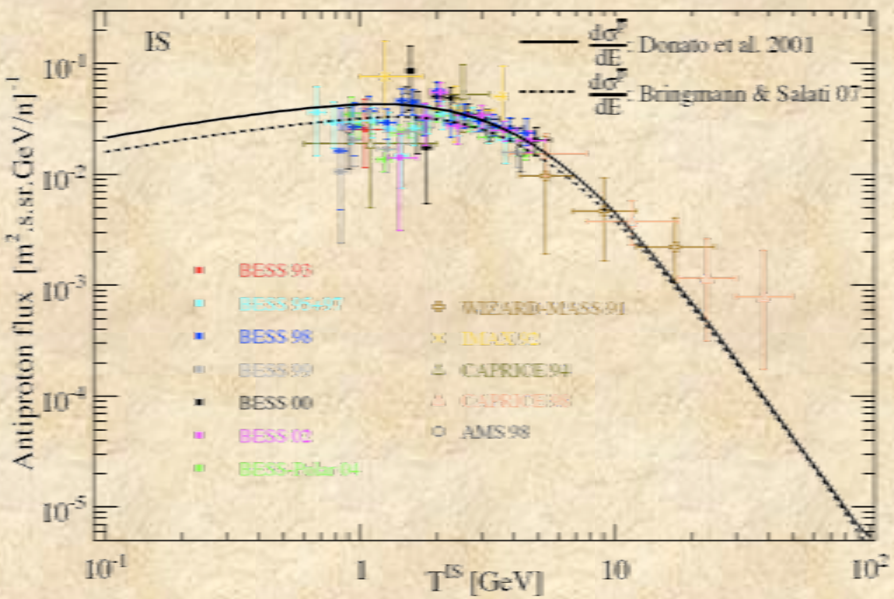
- solution of the steady-state diffusion equation with energy losses and reacceleration
- depends on a number of astrophysical parameters:
  - diffusion coefficient $K(E) = K_0 \beta (\mathcal{R}/1\,\mathrm{GV})^{\delta}$
  - height of the diffusive halo L
  - galactic wind velocity V_c
  - Alfven velocity (reacceleration) V_A

The params are constrained by stable nuclei propagation, mainly B/C

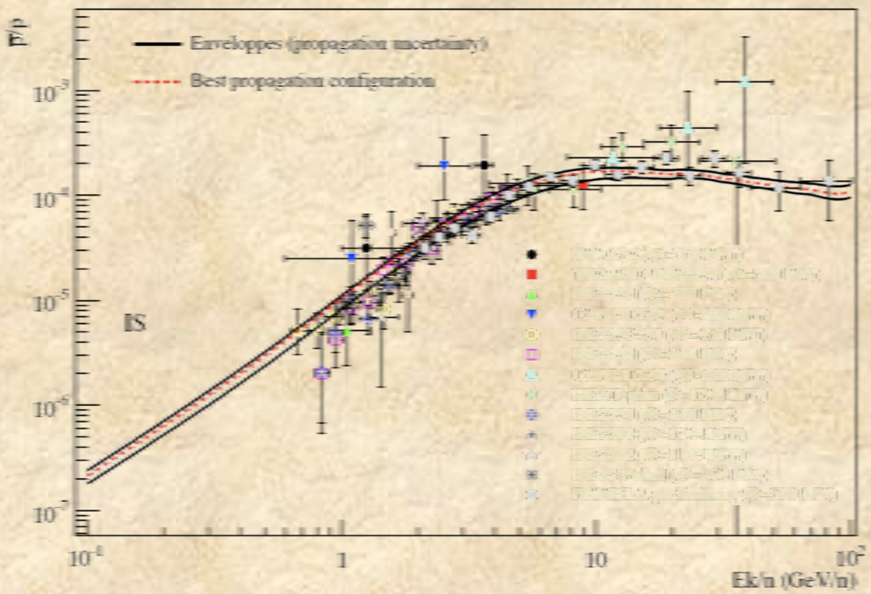
[D. Maurin et al. Astron. Astrophys. 381 (2002) 539]

case	δ	K_0 (kpc^2/Myr)	L (kpc)	V_c (km/sec)	V_A (km/sec)	$\chi^2_{\mathrm{B/C}}$
max	0.46	0.0765	15	5	117.6	39.98
med	0.70	0.0112	4	12	52.9	25.68
min	0.85	0.0016	1	13.5	22.4	39.02

Secondary antiprotons



Antiproton flux



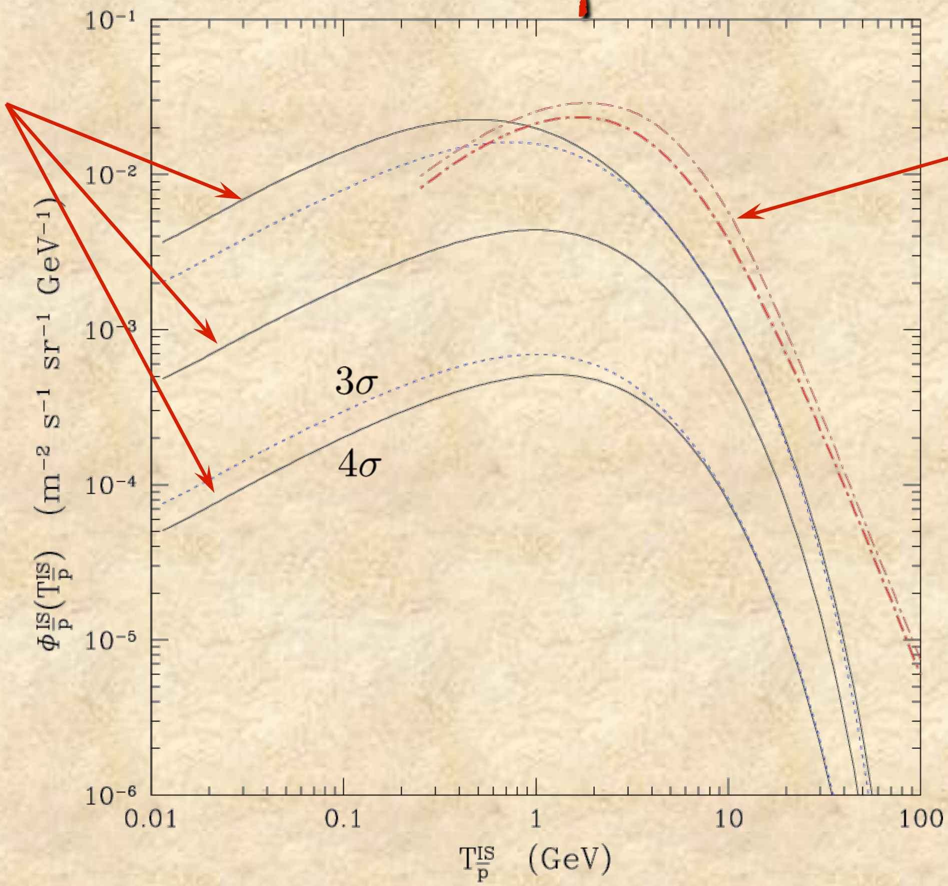
Antiproton/proton fraction

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

Interstellar antiproton fluxes

Primaries [1]
(DM signal)

$m_\chi = 100$ GeV



Secondaries [2]
(background)

< 25% uncertainty

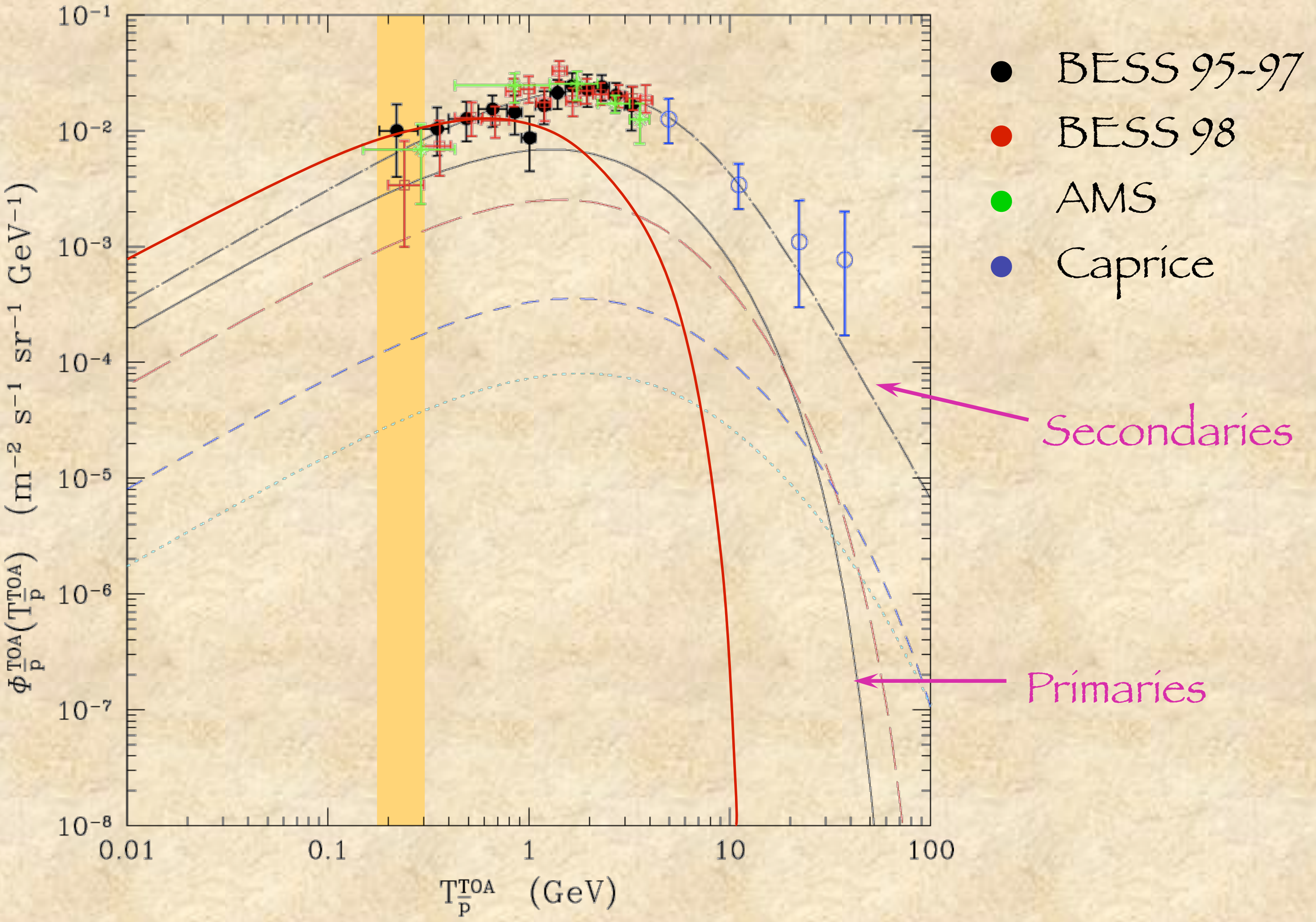
case	δ	K_0 (kpc^2/Myr)	L (kpc)	V_c (km/sec)	V_A (km/sec)	$\chi^2_{B/C}$
max	0.46	0.0765	15	5	117.6	39.98
med	0.70	0.0112	4	12	52.9	25.68
min	0.85	0.0016	1	13.5	22.4	39.02

(1) F. Donato, N. Fornengo, D. Maurin, P. Salati, R. Taillet, PRD 69 (2004) 0603501

(2) D. Maurin et al. Astron. Astrophys. 381 (2002) 539

TOA fluxes and comparison with data

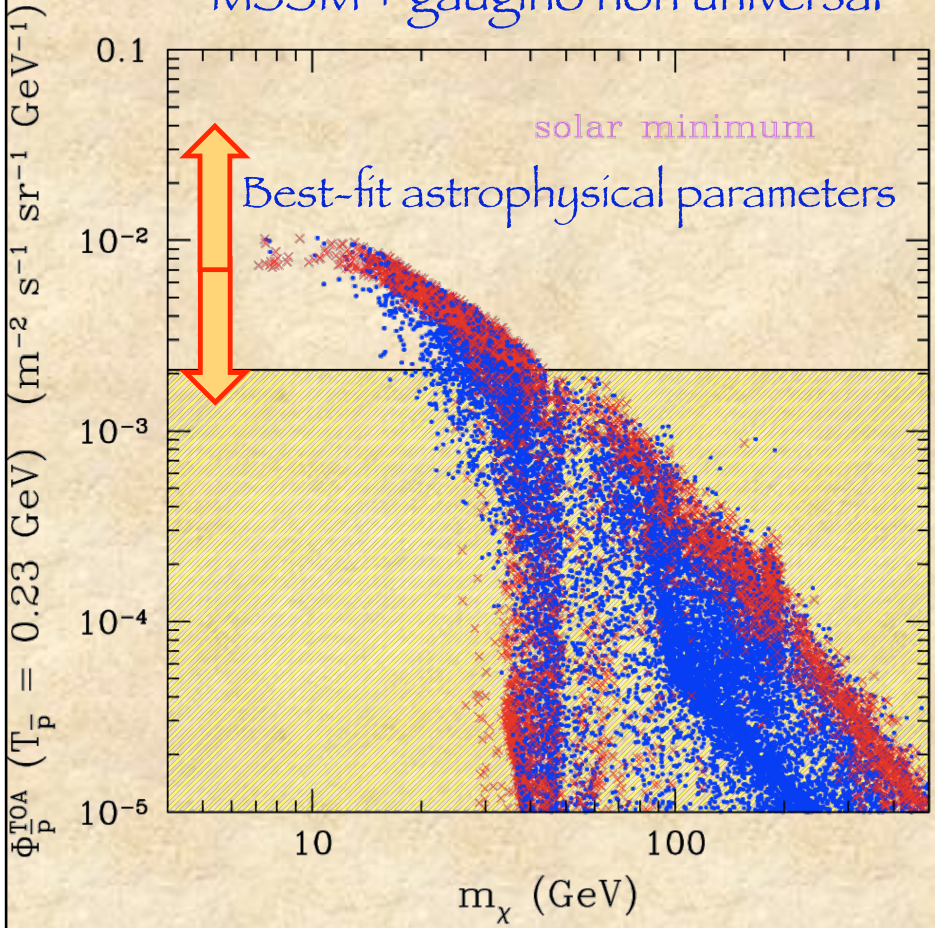
solar minimum



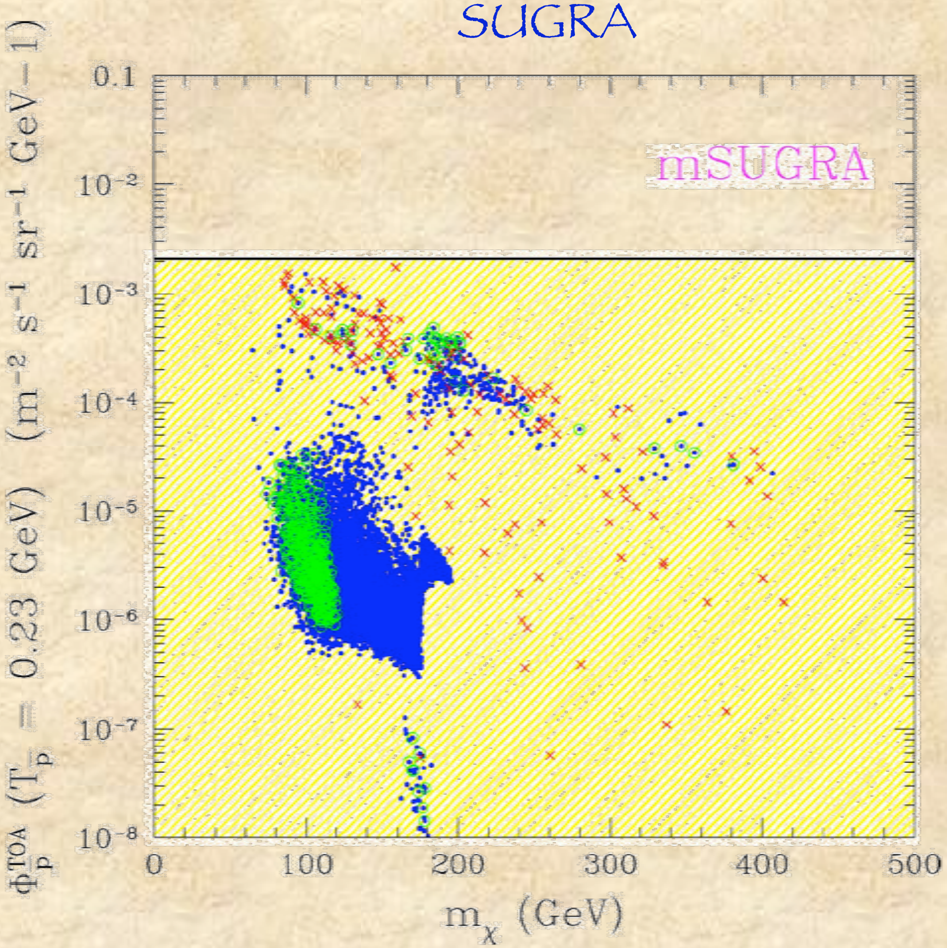
F. Donato, N.Fornengo, D. Maurin, P. Salati, R. Taillet, PRD 69 (2003) 063501

Theoretical predictions for neutralinos

MSSM + gaugino non universal



SUGRA

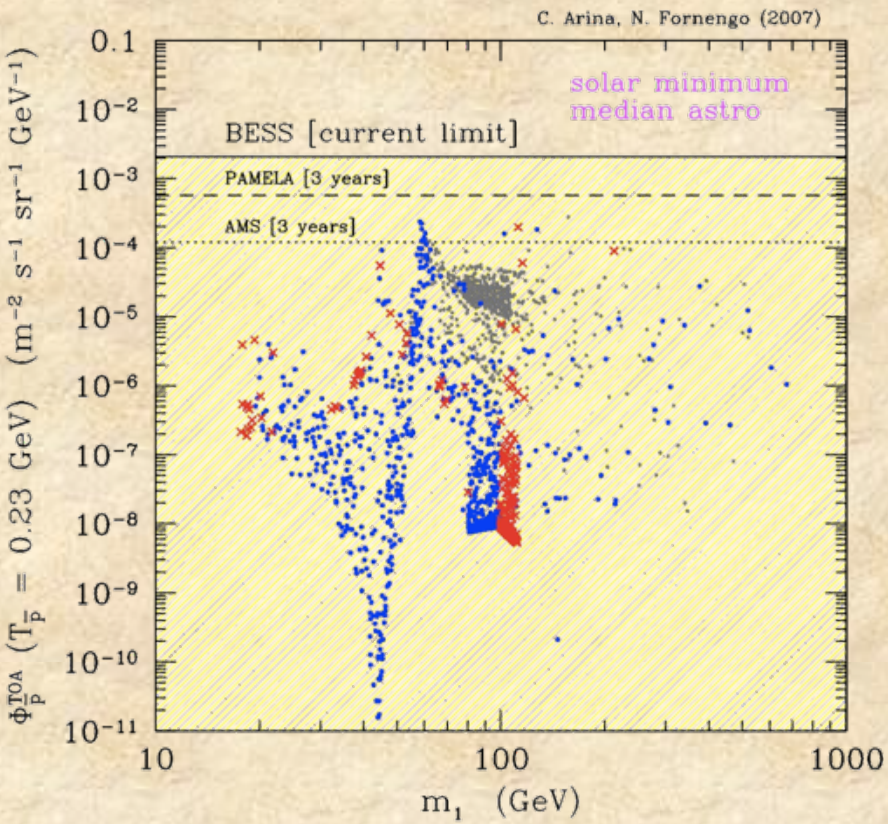


- cosmologically dominant neutralinos $0.095 \leq \Omega_\chi h^2 \leq 0.131$
- cosmologically subdominant neutralinos $\Omega_\chi h^2 < 0.095$

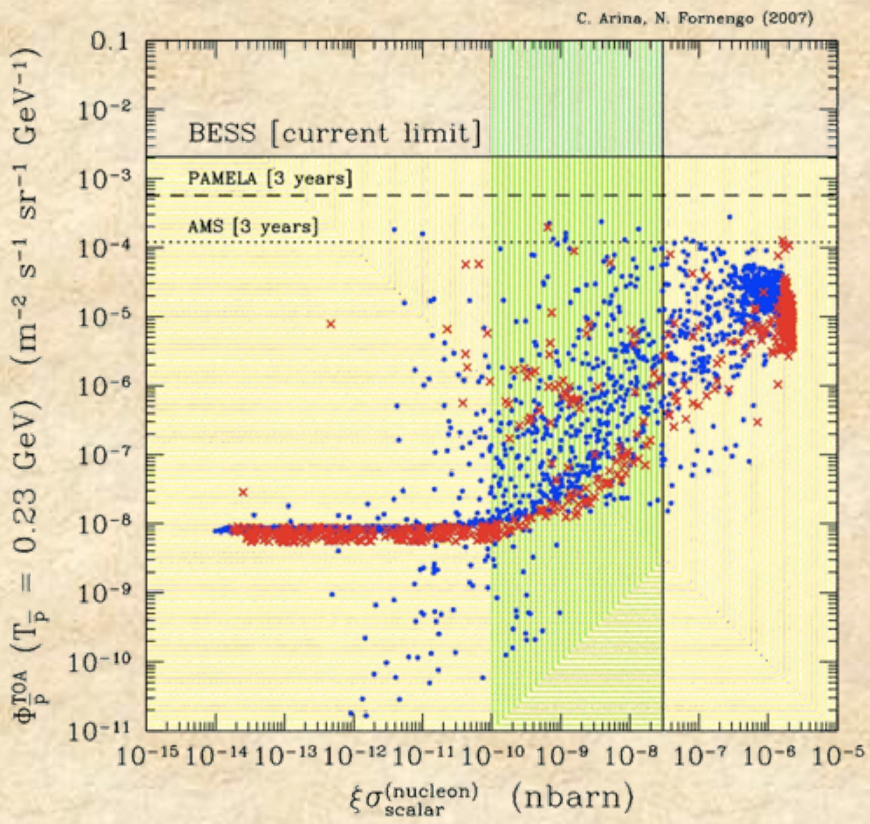
A. Bottino, F. Donato, N.F., S. Scopel, PRD 70 (2004) 015005

F. Donato, N.F., D. Maurin, P. Salati, R. Taillet, PRD 69 (2003) 063501

Sneutrinos in Left-Right models



antiprotons vs. mass

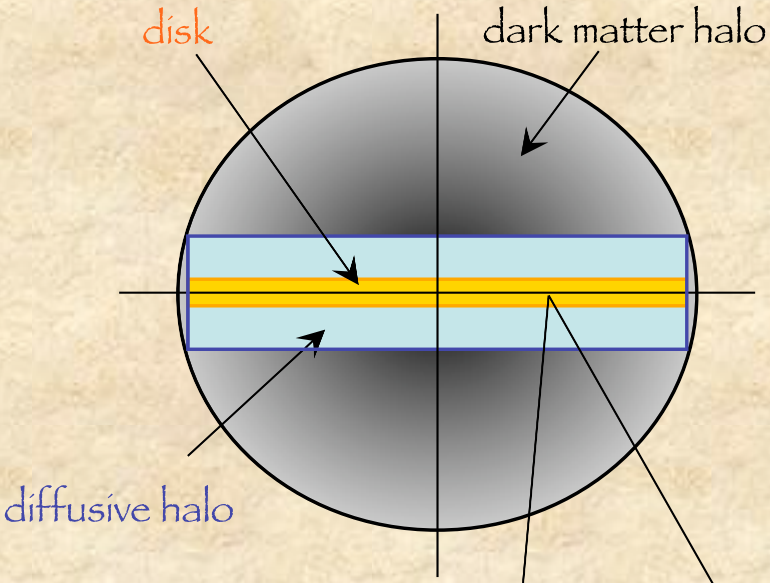


antiprotons vs. direct detection

Antideuterons

Cosmic antideuterons

F. Donato, N. Fornengo, P. Salati, PRD 62 (2000) 043003



Secondaries

$$p_{\,\mathrm{CR}} + p_{\,\mathrm{ISM}} \longrightarrow \bar{D}$$
$$p_{\,\mathrm{CR}} + He_{\,\mathrm{ISM}} \longrightarrow \bar{D}$$
$$He_{\,\mathrm{CR}} + p_{\,\mathrm{ISM}} \longrightarrow \bar{D}$$

Produced in the disk

Propagation and energy redistribution in the diffusive halo

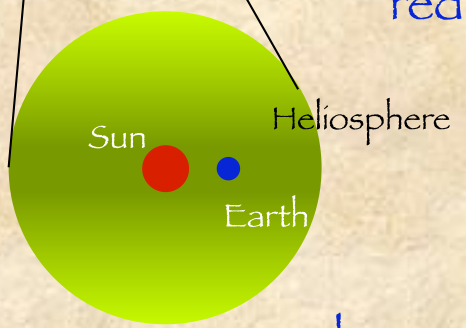
DM signal

$$\chi\chi \longrightarrow (.....) \longrightarrow p\bar{p}\ n\bar{n}$$

$$\bar{p} + \bar{n} \longrightarrow \bar{D}$$ Coalescence

Produced in the DM halo

Propagation and energy redistribution in the diffusive halo



solar modulation

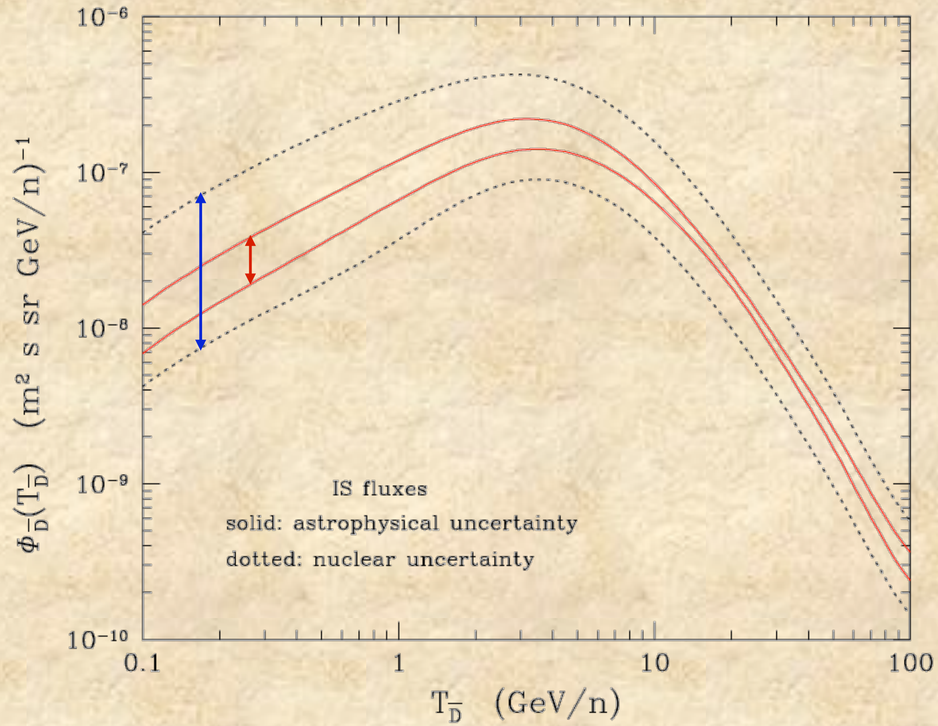
Secondaries and their uncertainties

Astrophysical:

- Transport
- Energy losses and redistribution

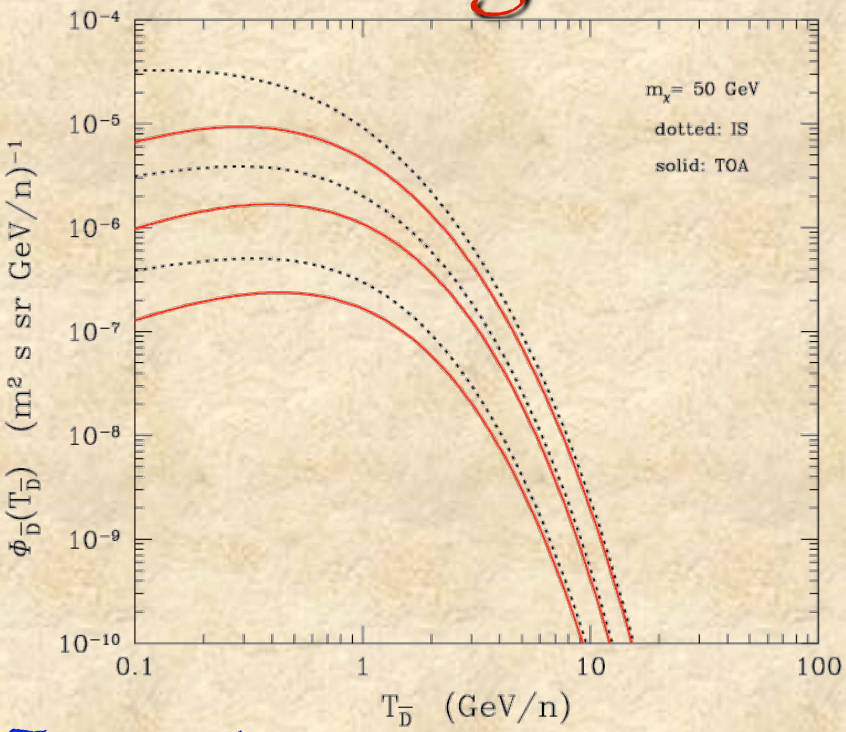
Nuclear (very conservative):

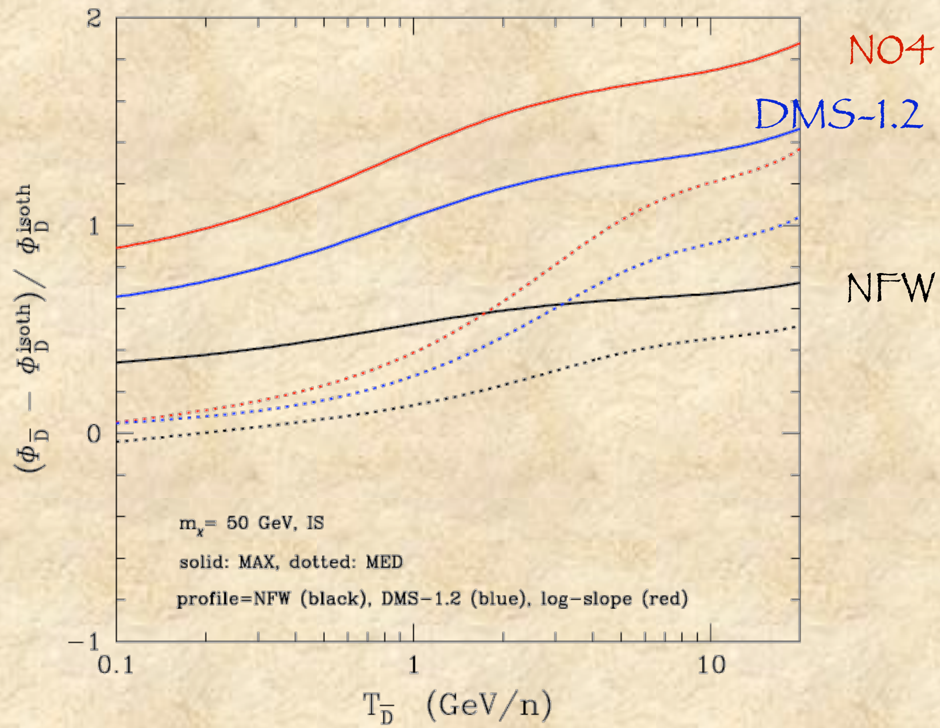
- Elementary production processes
- Coalescence



A. Donato, N. Fornengo, D. Maurin, PRD *78* (2008) 043506

Signal and its uncertainties





Transport:

- High-energies: diffusive halo size L
- Low-energies: L + galactic wind

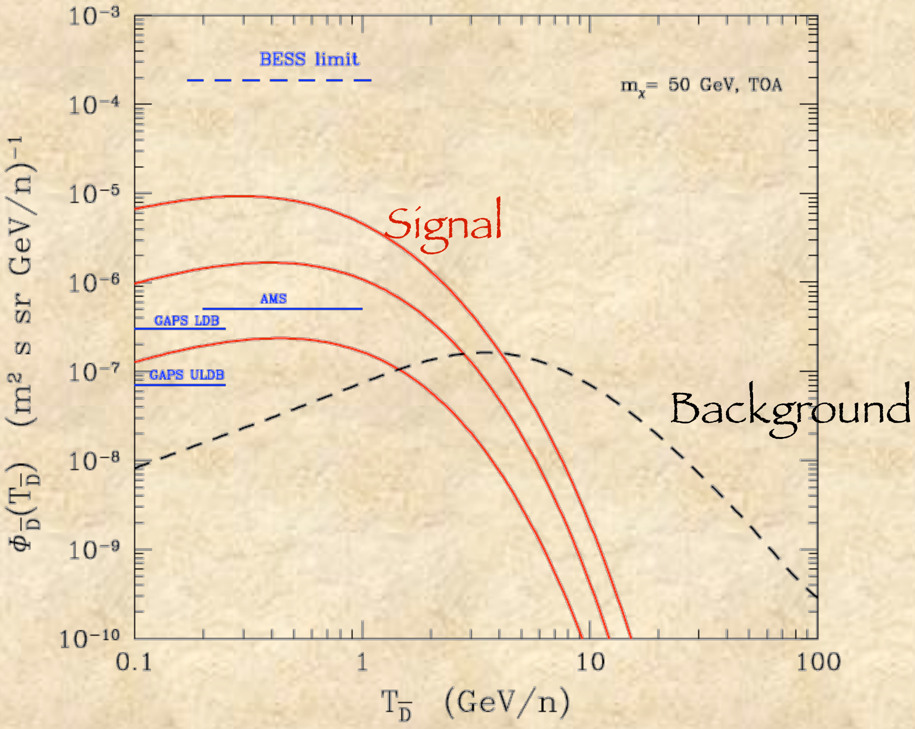
Energy redistribution (not dramatic):

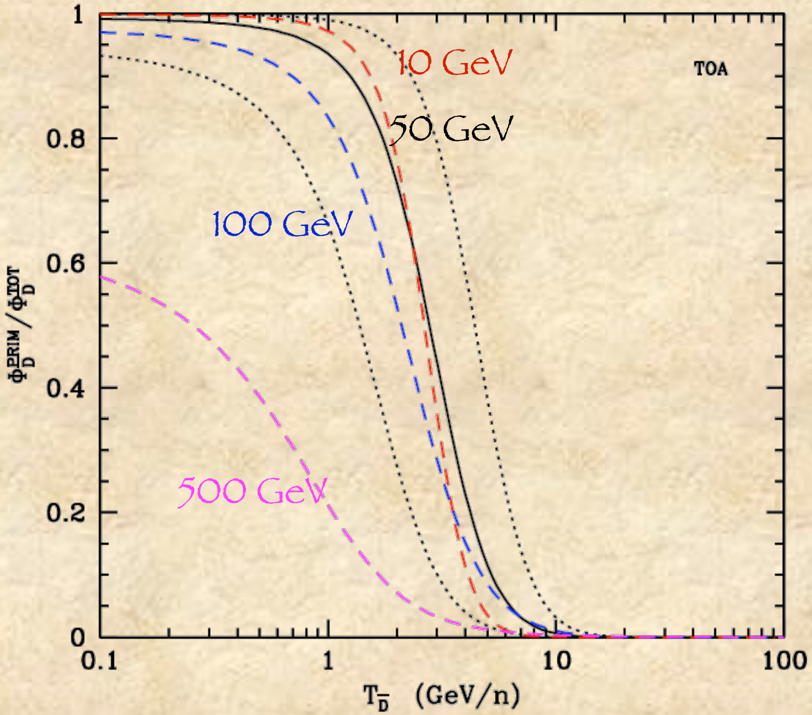
- Loss
- Reacceleration
- Tertiary redistribution

Change of DM halo profile
[fixed local density]

A. Donato, N. Fornengo, D. Maurin, PRD 78 (2008) 043506

TOA fluxes and S/B gain





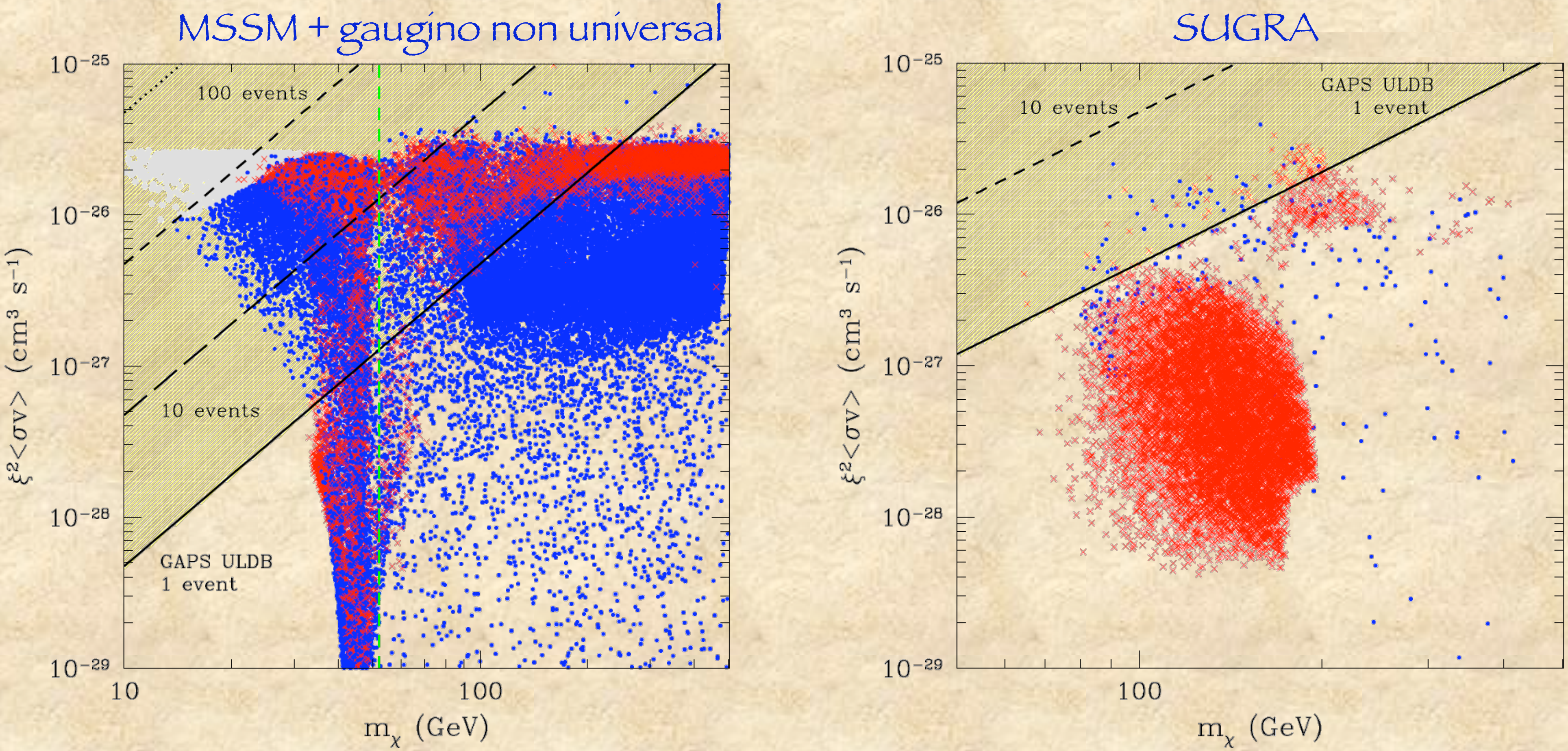
Signal with uncertainty band for:

- 50 GeV WIMP mass
- WMAP relic abundance

Signal/(Back+Signal) ratio

A. Donato, N. Fornengo, D. Maurin, PRD 78 (2008) 043506

Theoretical predictions



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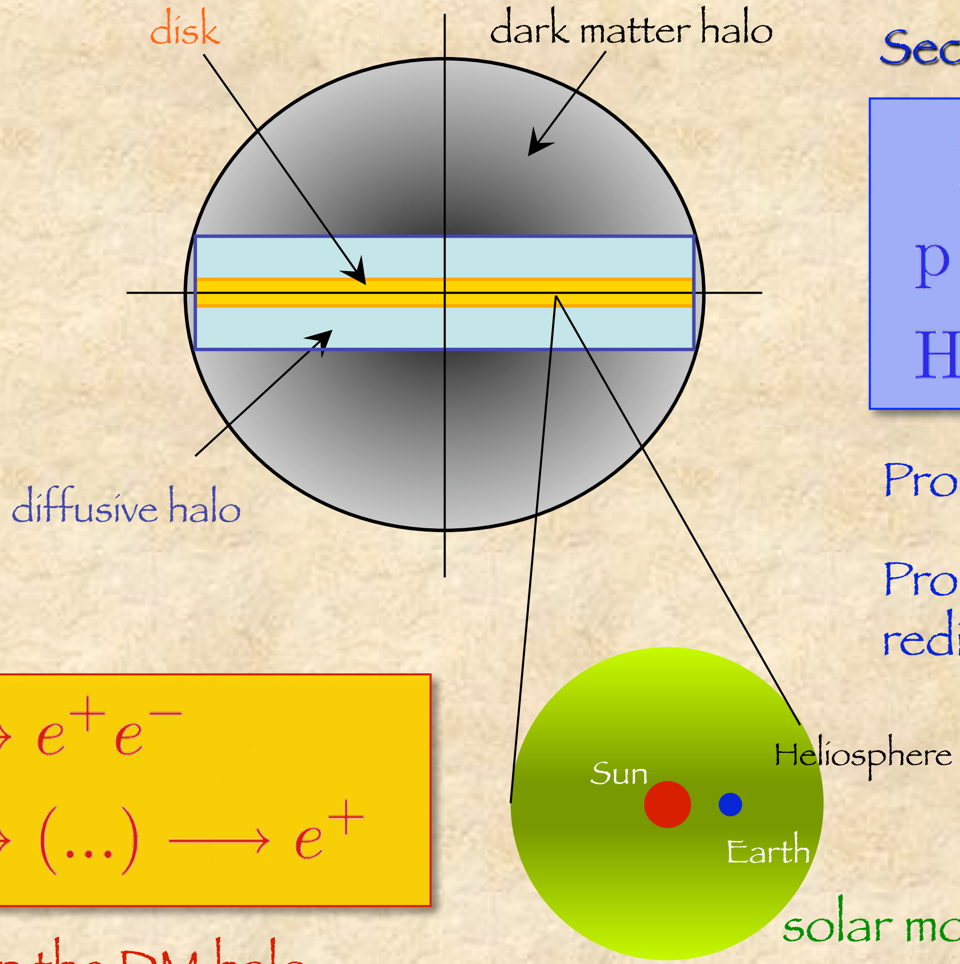
- cosmologically subdominant neutralinos $\Omega_\chi h^2 < 0.095$

A. Donato, N. Fornengo, D. Maurin, PRD 78 (2008) 043506

Positrons

Cosmic positrons



Secondaries

$$\mathrm{p}_{\mathrm{CR}} + \mathrm{p}_{\mathrm{ISM}} \longrightarrow e^+$$
$$\mathrm{p}_{\mathrm{CR}} + \mathrm{He}_{\mathrm{ISM}} \longrightarrow e^+$$
$$\mathrm{He}_{\mathrm{CR}} + \mathrm{p}_{\mathrm{ISM}} \longrightarrow e^+$$

Produced in the disk

Propagation and energy redistribution in the diffusive halo

DM signal

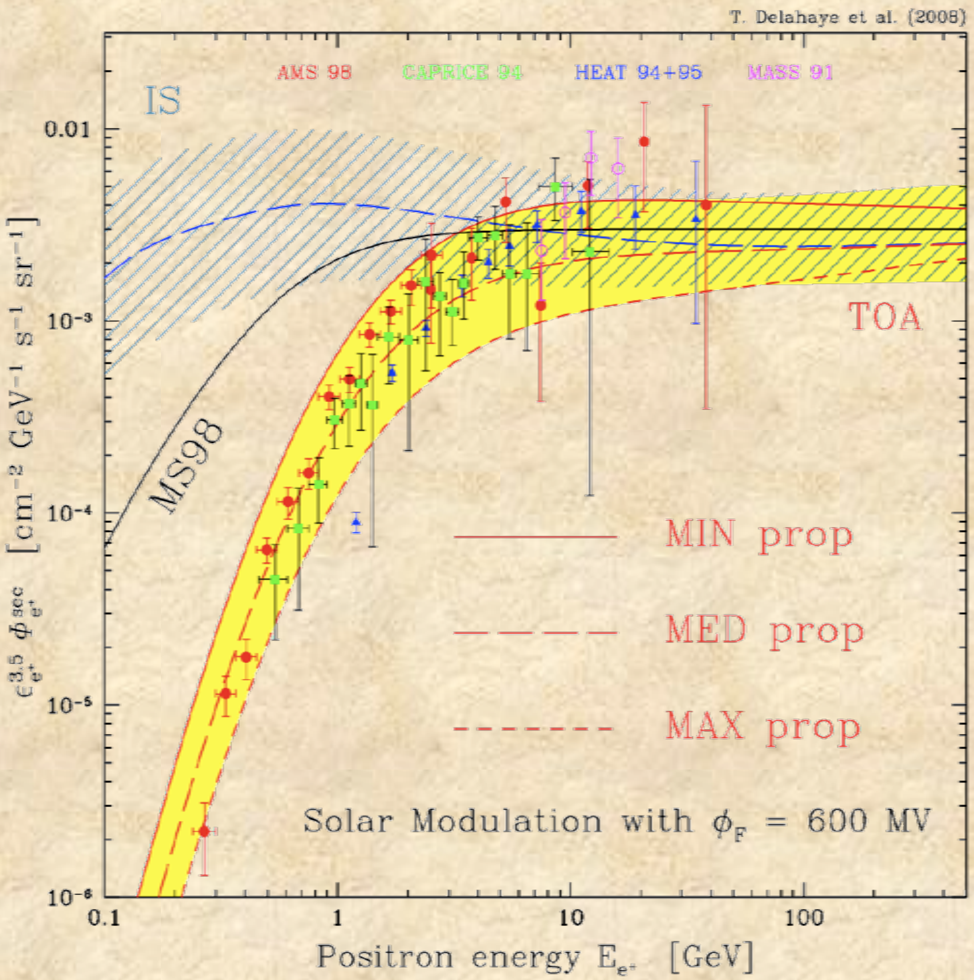
$$\chi\chi \longrightarrow e^+e^-$$
$$\chi\chi \longrightarrow (\ldots) \longrightarrow e^+$$

Produced in the DM halo

Propagation and energy redistribution in the diffusive halo

Astrophysical sources
(e.g.: pulsars)

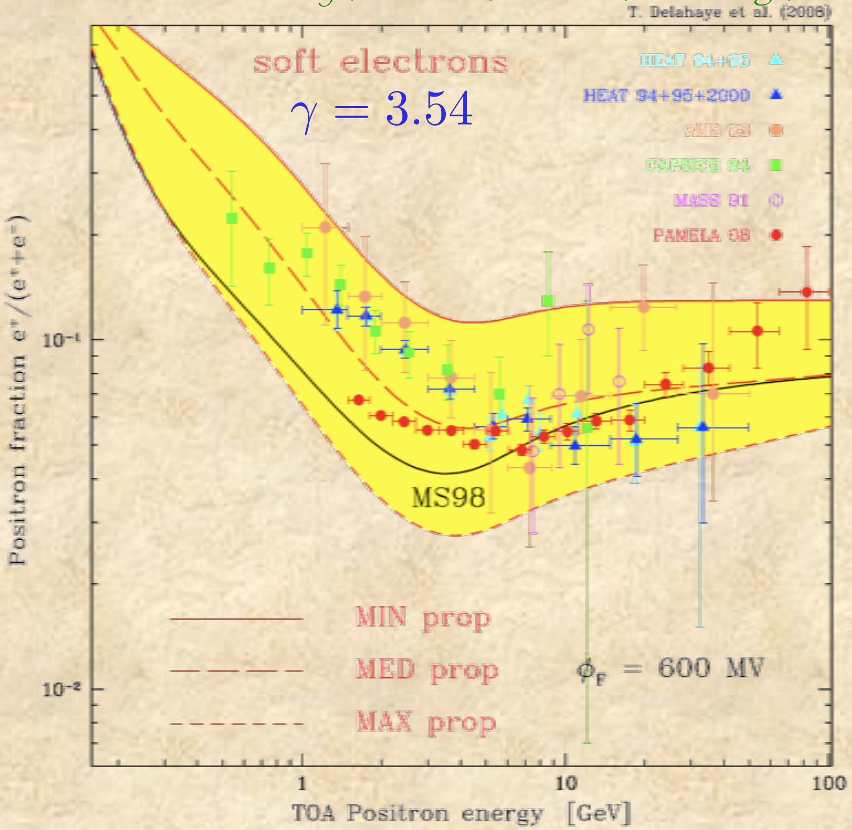
Secondaries: astrophysical uncertainties

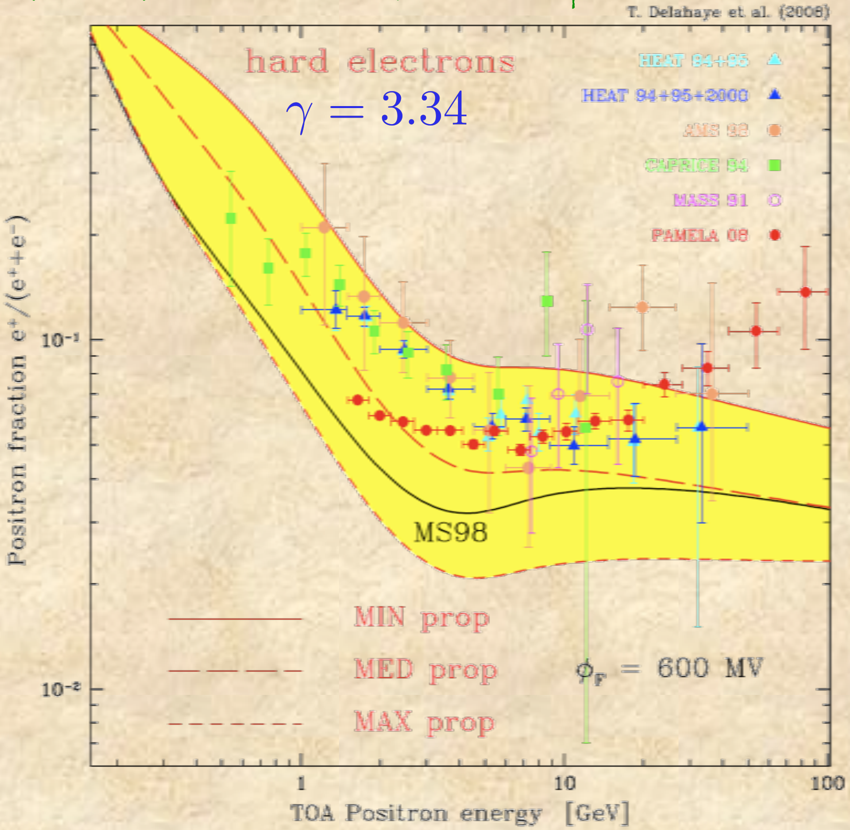


T. Delahaye, R. Lineros, F. Donato, N. Fornengo, J. Lavalle, P. Salati, R. Taillet, arXiv:0809.5268 [astro-ph]

Positron fraction: CR background

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

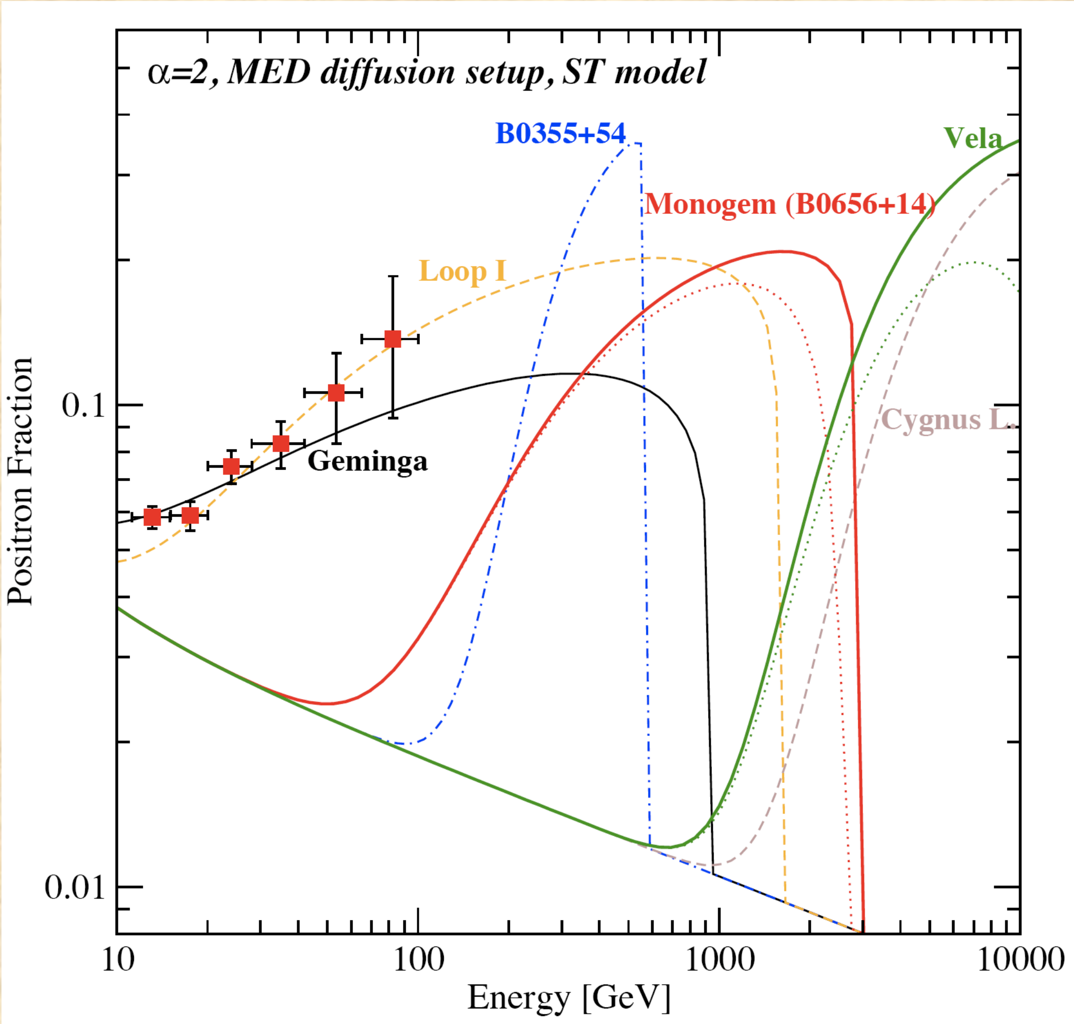




PAMELA data point toward a "excess"

O. Adriani et al. (PAMELA Collab.) Nature 458 (2009) 607

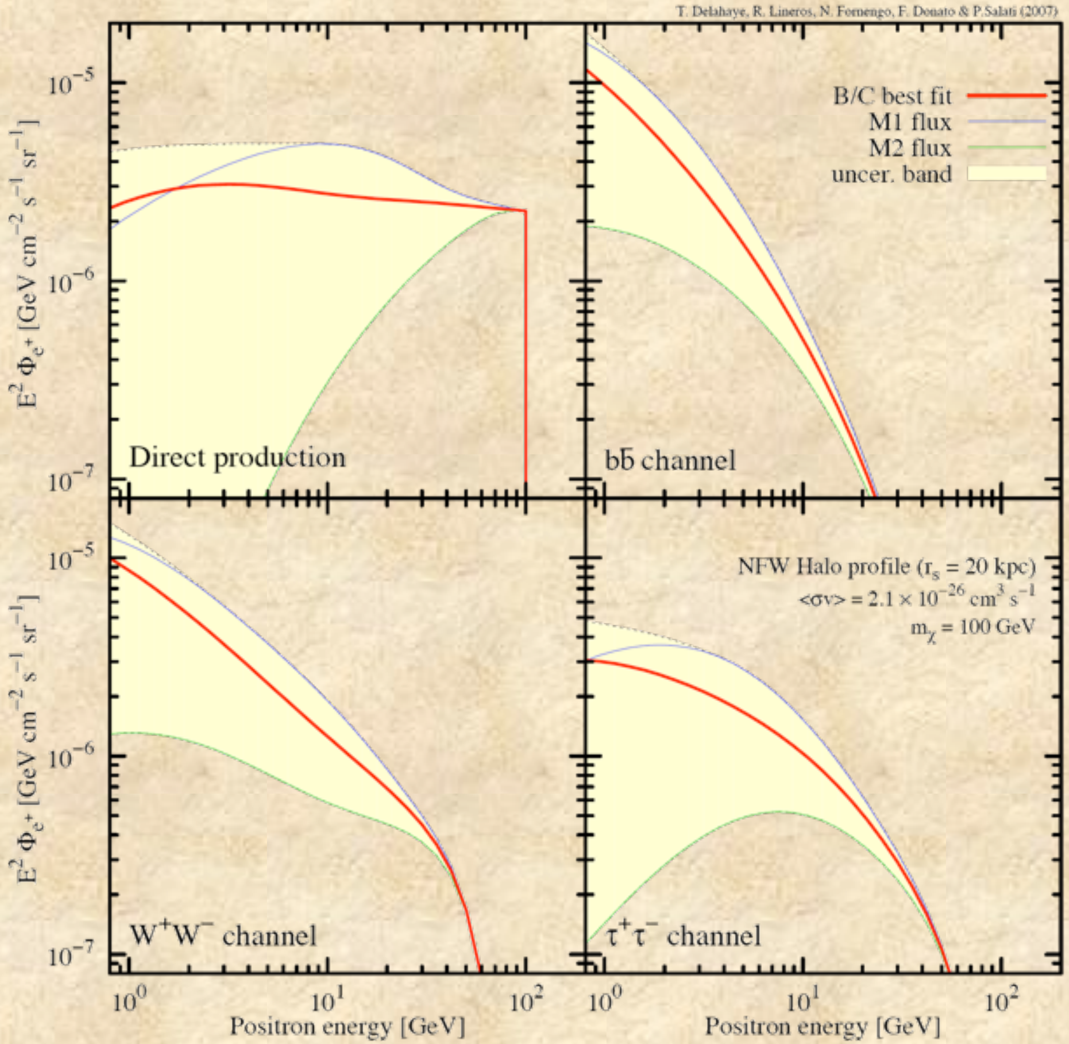
Positrons from astrophysical sources



S. Profumo, arXiv:0812.4457v2 [astro-ph]

DM signal: astrophysical uncertainties

m_χ = 100 GeV

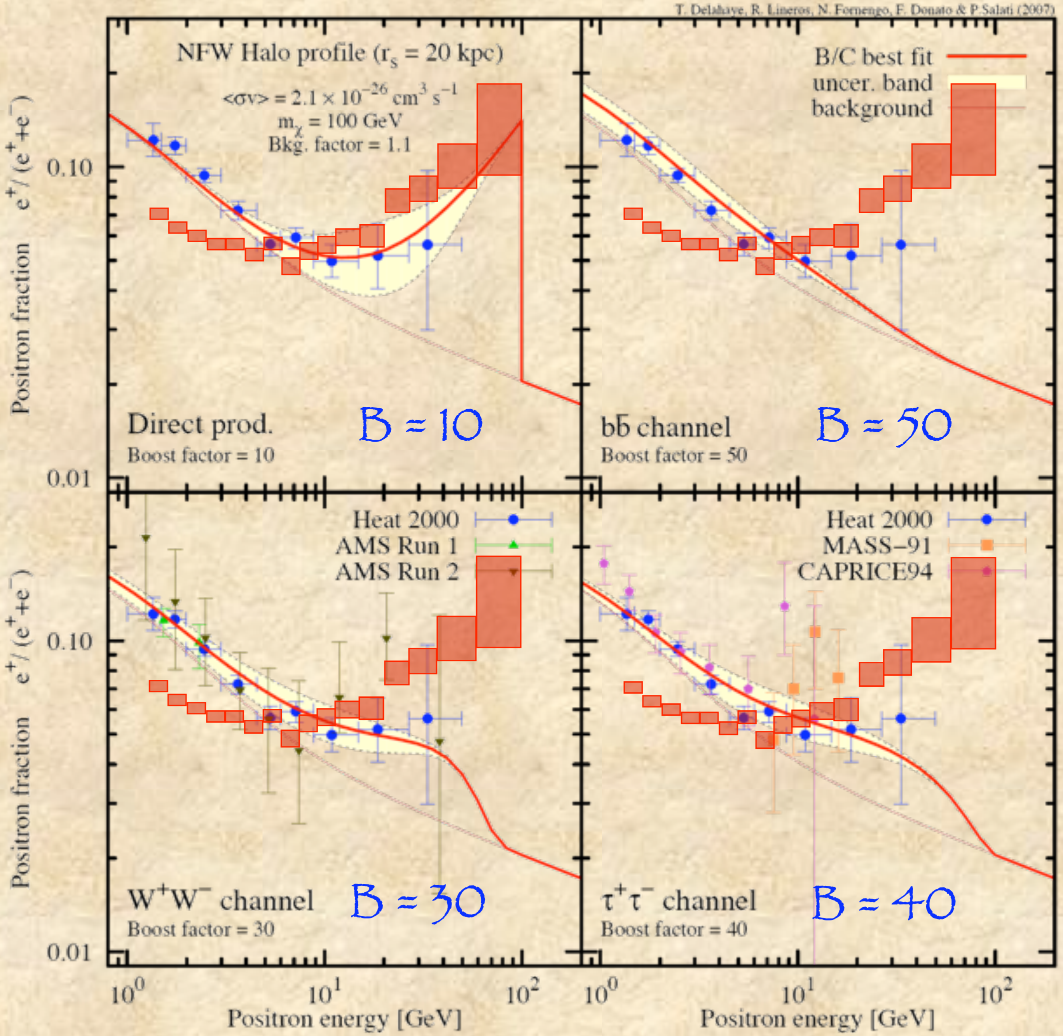


T. Delahaye, R. Lineros, F. Donato, N. Fornengo, P. Salati, Phys. Rev. D 77 (2008) 063527

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

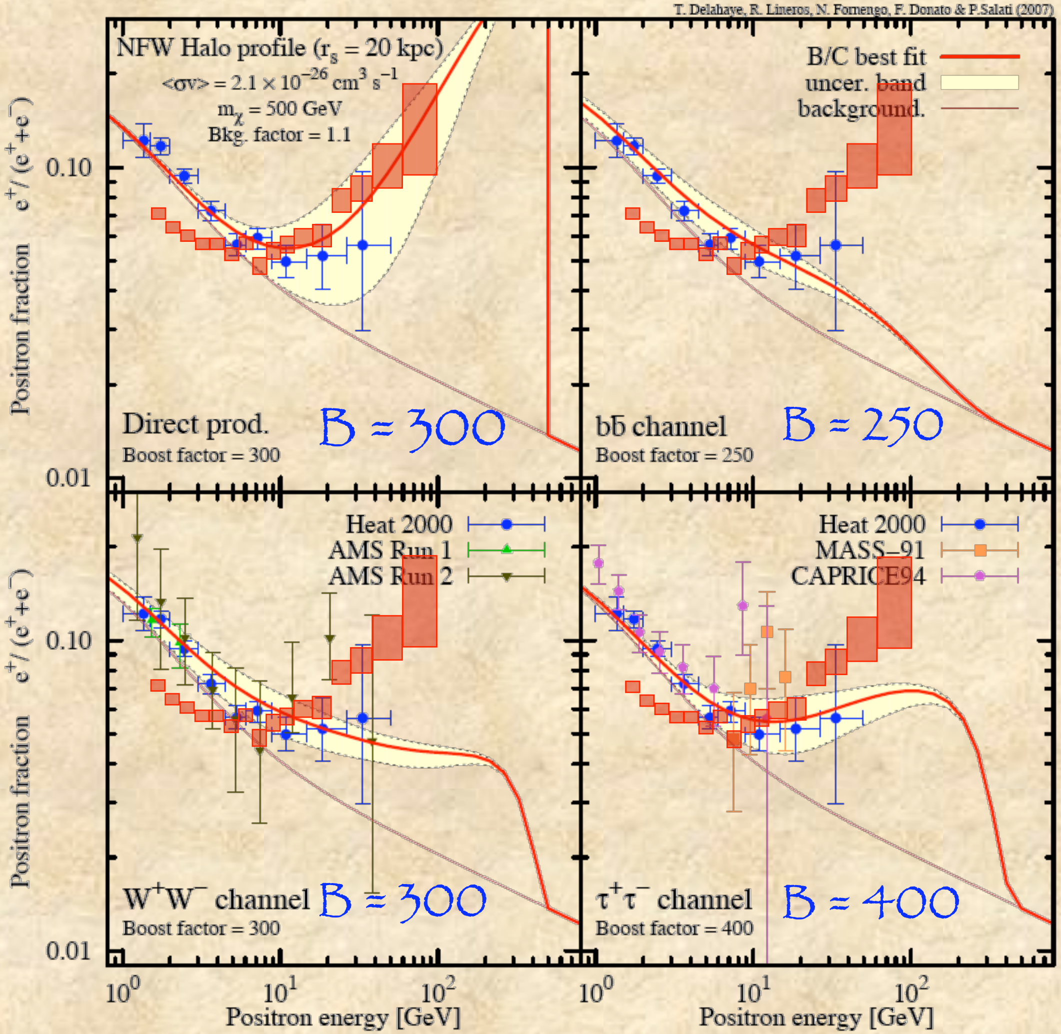
For annihilation cross section consistent with WMAP for a thermal relic

Smooth NFW halo

Positron fraction: including a DM signal

$m_\chi \simeq 500$ GeV

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



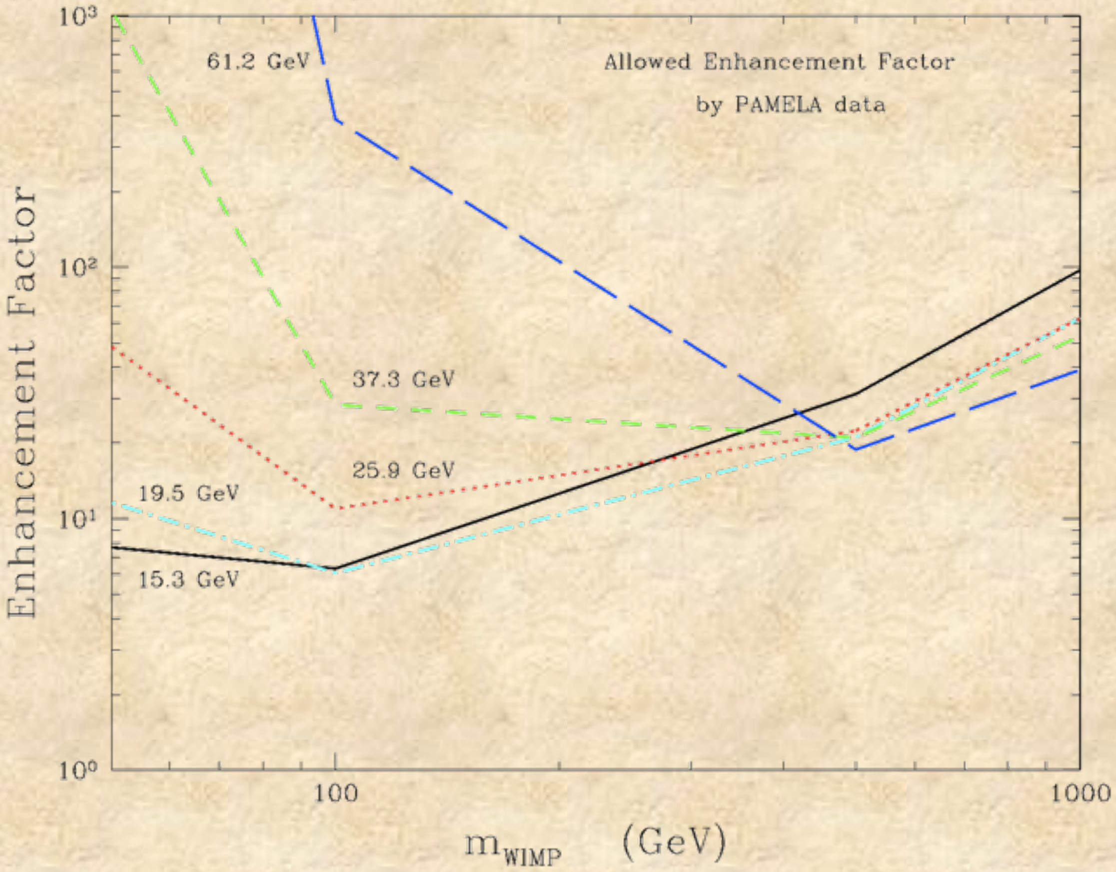
■ PAMELA 2008

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

For annihilation cross section consistent with WMAP

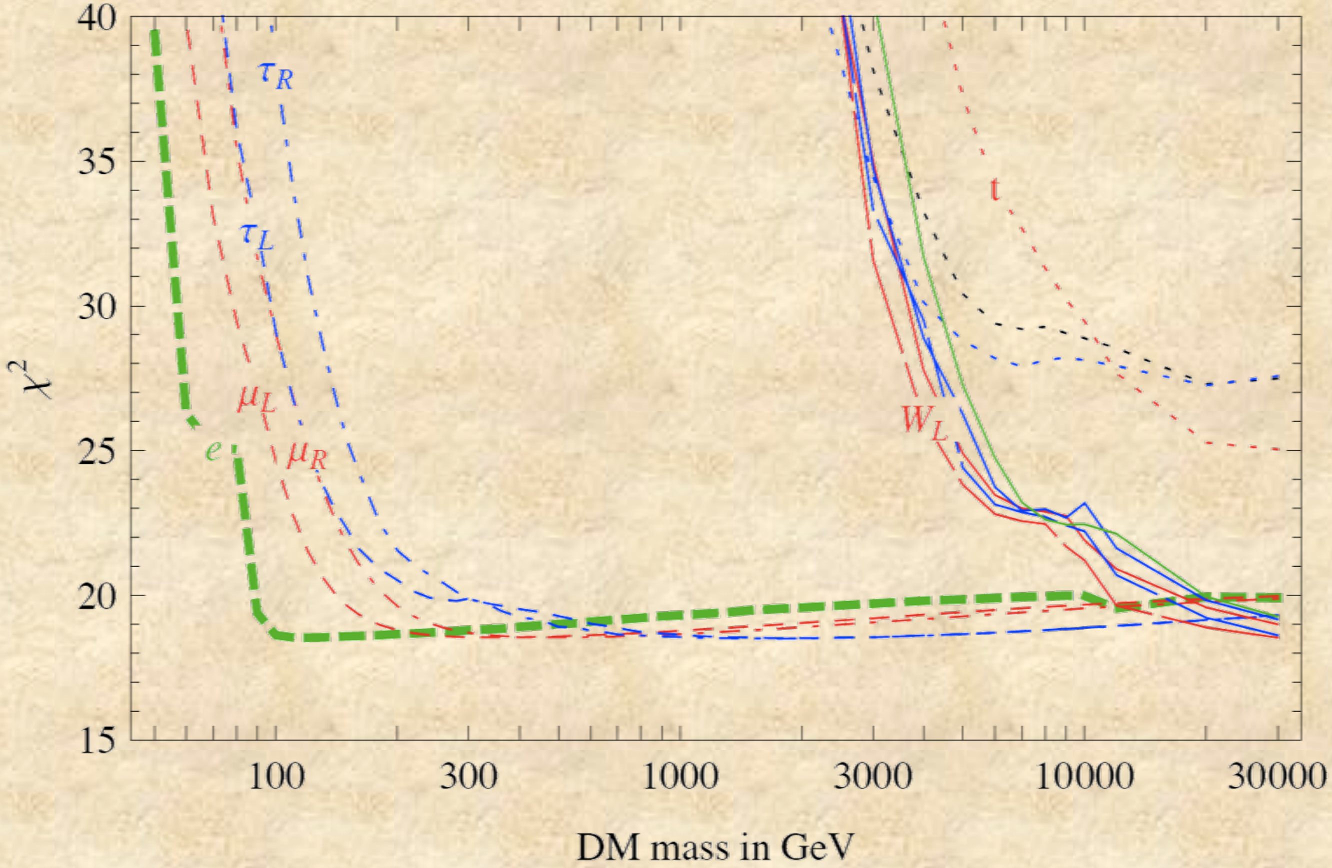
Smooth NFW halo

Constraint on boost from antiprotons



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

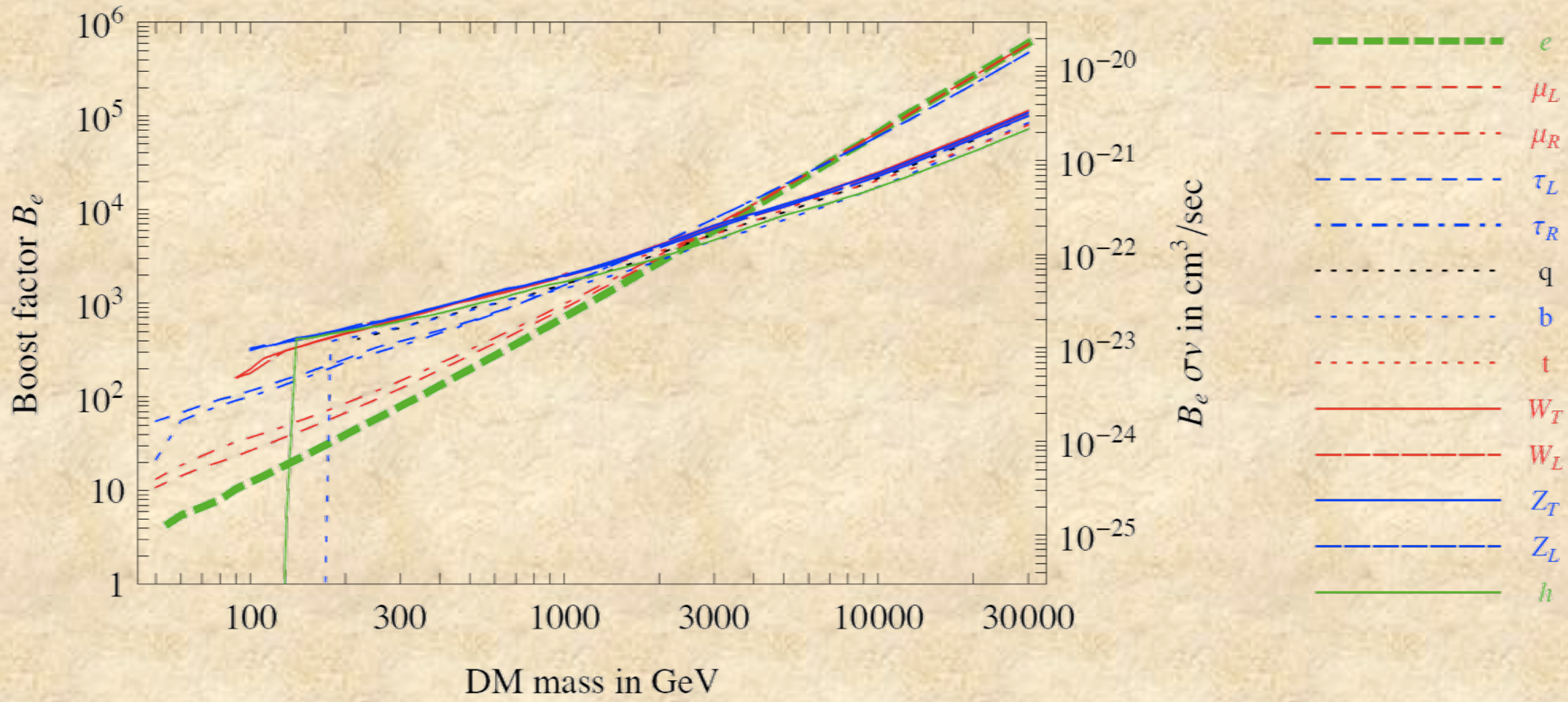
Model independent analysis



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

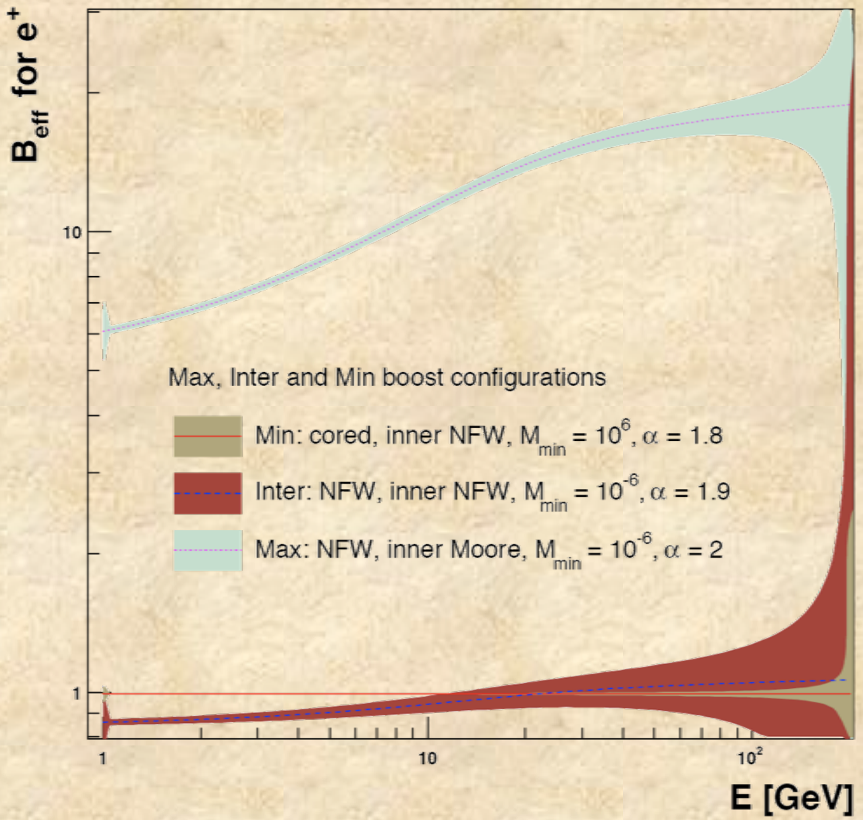
M. Cirelli, M. Kadastik, M. Raidal, A. Strumia, arXiv:0809.2409v3 [hep-ph]
See also: V. Barger, W.-Y. Keung, D. Marfatia, G. Shaughnessy, arXiv:0809.0162v2 [hep-ph]

Model independent analysis

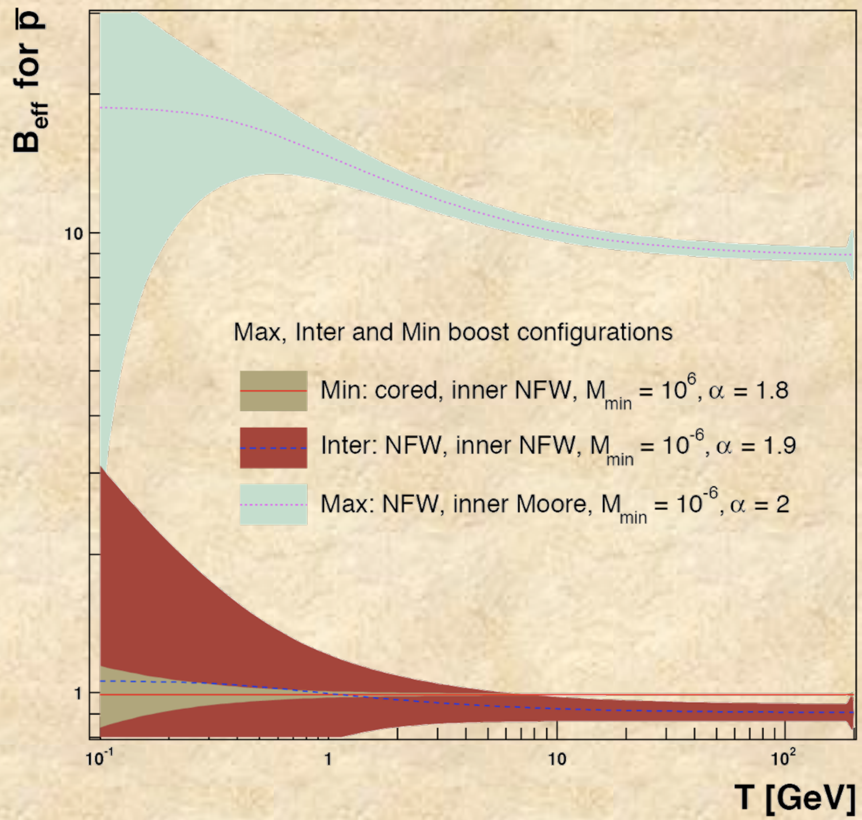


M. Cirelli, M. Kadastik, M. Raidal, A. Strumia, arXiv:0809.2409v3 [hep-ph]

Astrophysical boost



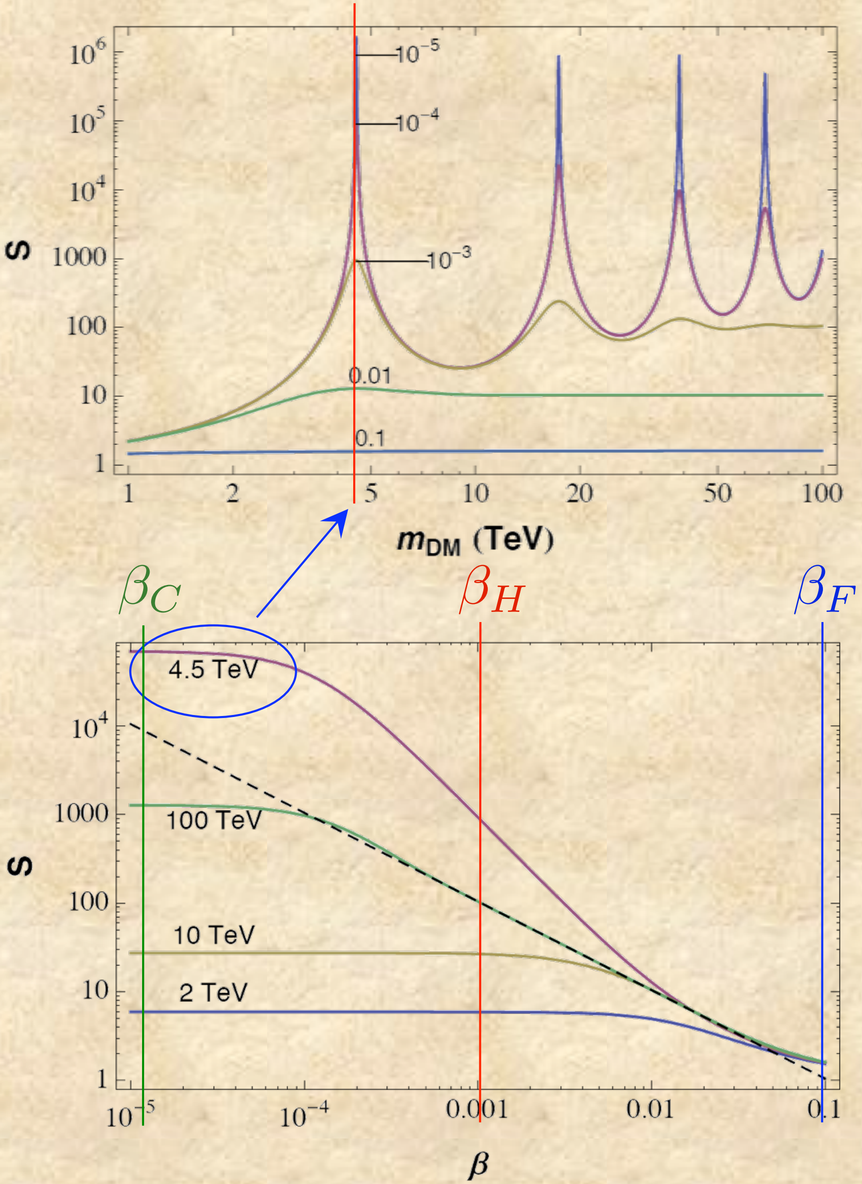
Positrons



Antiprotons

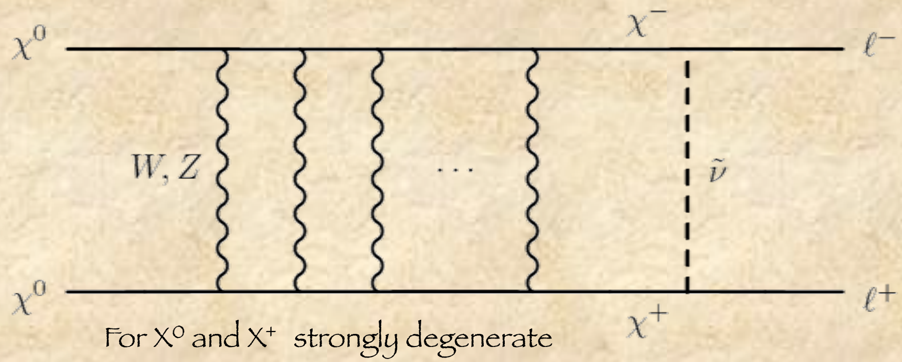
J. Lavalle, Q. Yuan, D. Maurin, X.J. Bi, A&A 479 (2008) 427

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)

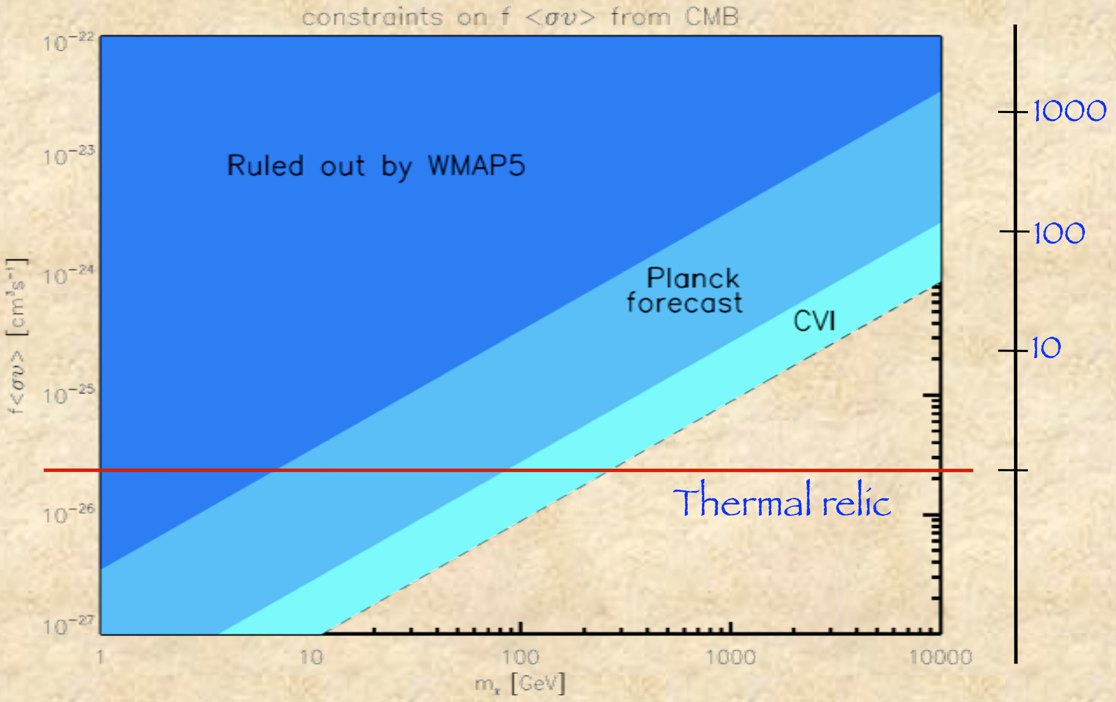


For X^0 and X^+ strongly degenerate

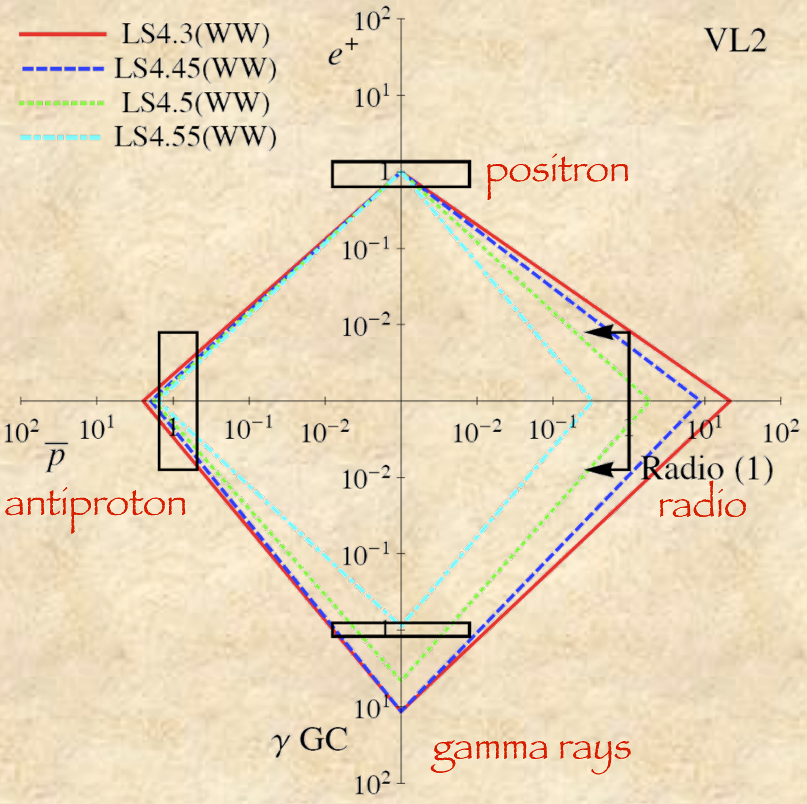
See also:
- J. Hisano, M. Nagai, M. Nojiri, M. Senami, PRL 92 (2004) 031303
- J. Hisano, S. Matsumoto, M. Nojiri, S. Saito, PRD, 71 (2005) 063528
- M. Cirelli, A. Strumia, M. Tamburini, NPB 787 (2007)
- J. March-Russell, S. M. West, D. Cumberbatch, D. Hooper, JHEP 0807 (2008) 058
- N. Arkani-Hamed, D. 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



From multiwavelength

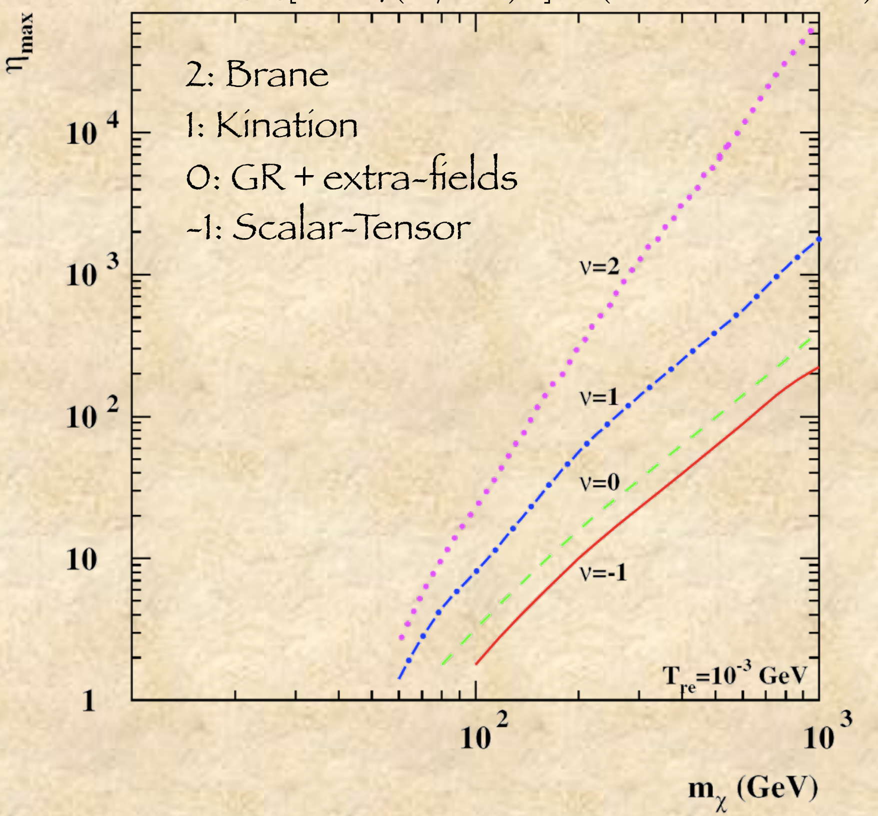


S. Galli, F. Iocco, G. Bertone, A. Melchiorri, arXiv:0905.0003v1 [astro-ph]

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

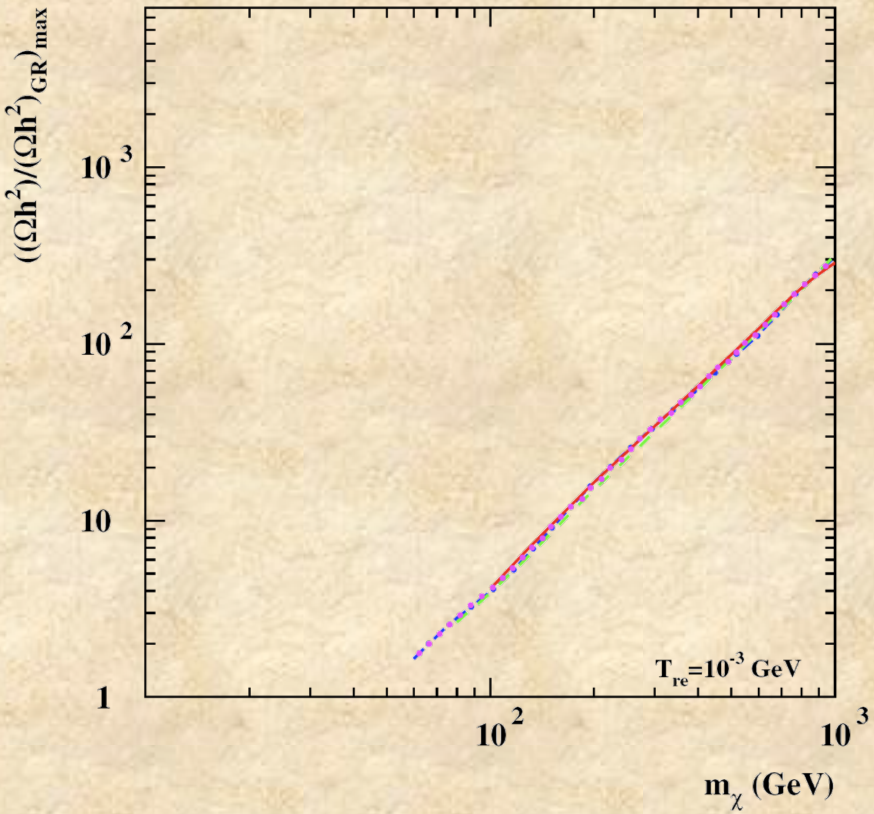
Cosmological boost

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



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

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



Induced boost

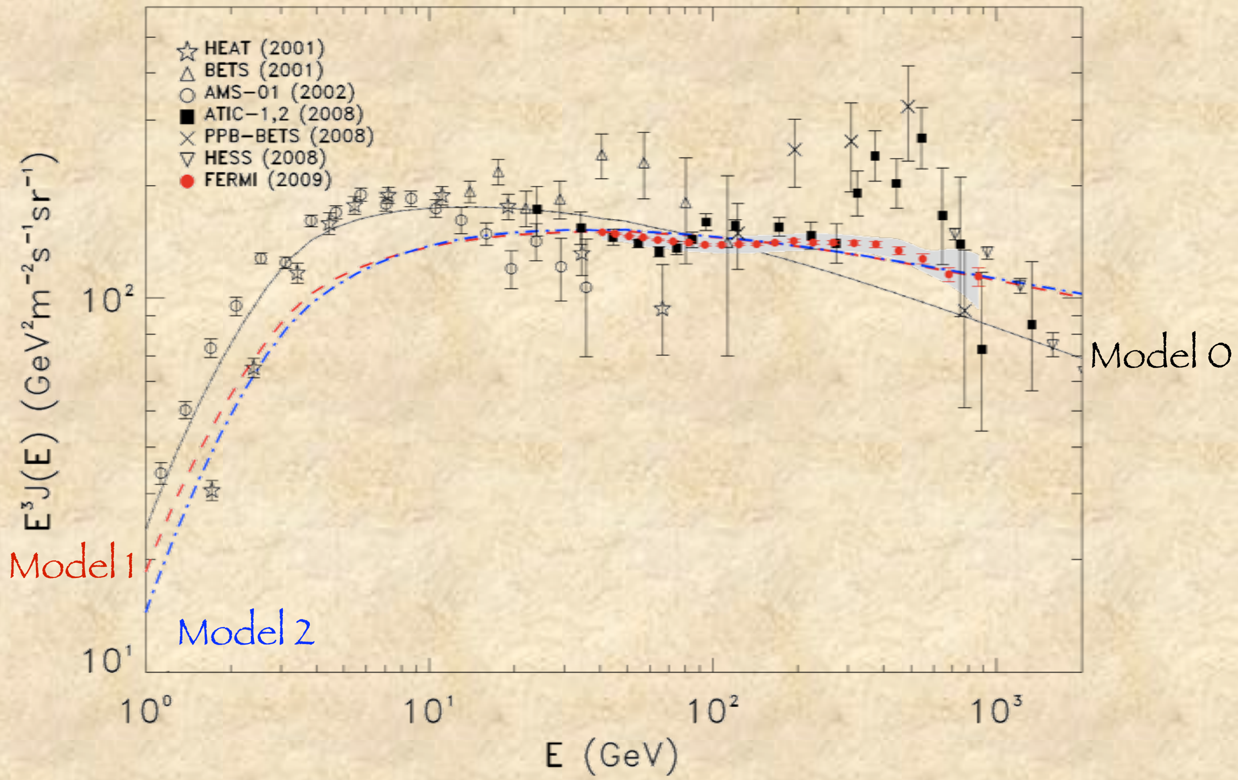
Boosts equally leptonic and hadronic channels

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

Positrons + electrons

Positrons + electrons

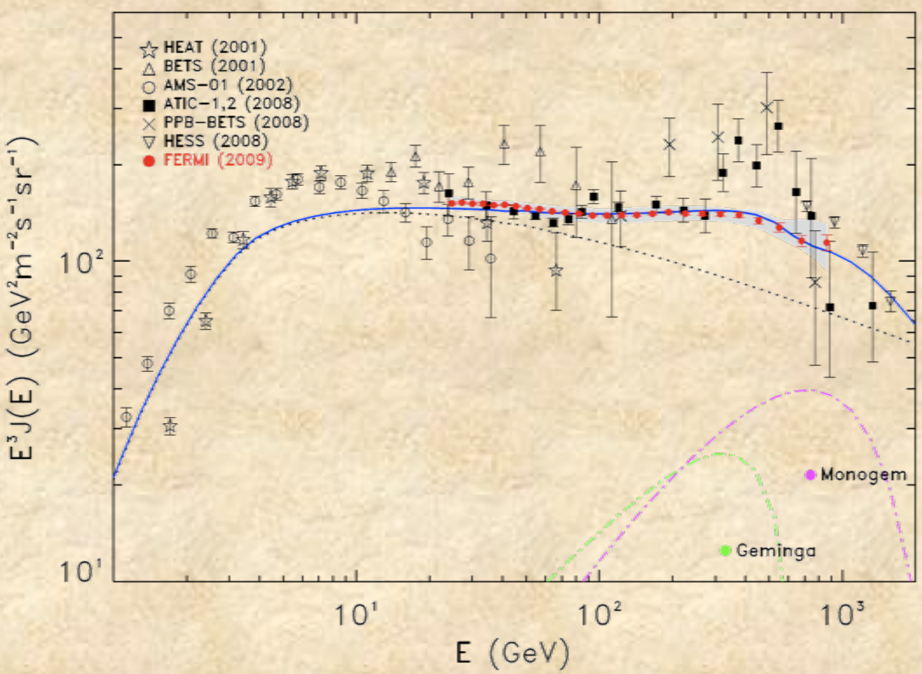
Electrons + Positrons: FERMI data

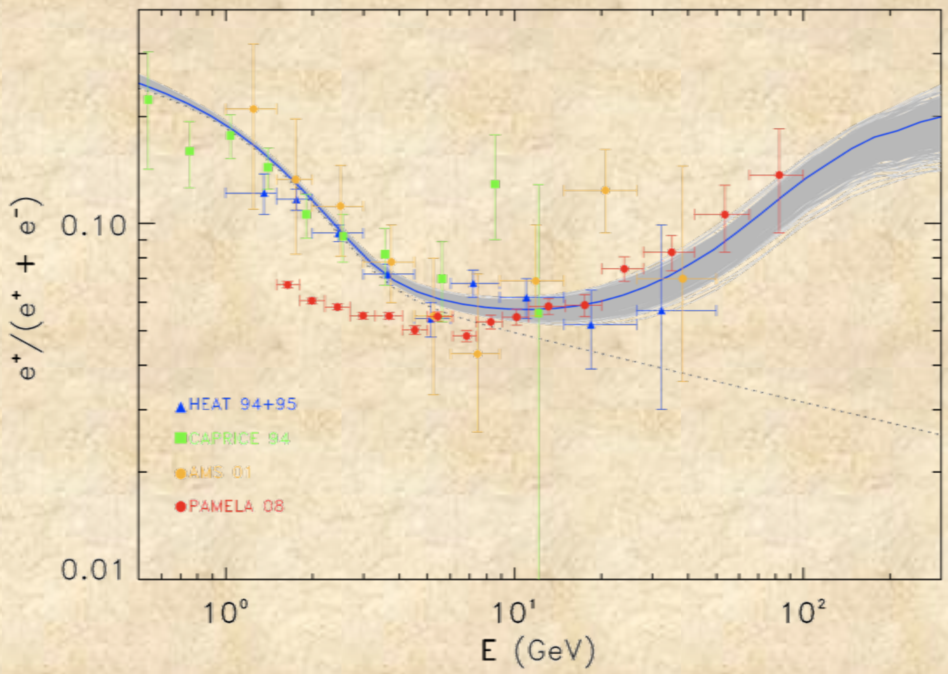


Model #	D_0 $(cm^2 s^{-1})$	δ	z_h (kpc)	γ_0	N_{e^-} $(m^{-2}s^{-1}\mathrm{sr}^{-1}\mathrm{GeV}^{-1})$	γ_0^p
0	3.6×10^{28}	0.33	4	2.54	1.3×10^{-4}	2.42
1	3.6×10^{28}	0.33	4	2.42	1.3×10^{-4}	2.42
2	1.3×10^{28}	0.60	4	2.33	1.3×10^{-4}	2.1

A. Abdo et al. (FERMI Collab.), PRL 102 (2009)
D. Grasso et al., arXiv:0905.0636v1 [astro-ph.HE]

Electrons + Positrons: FERMI data

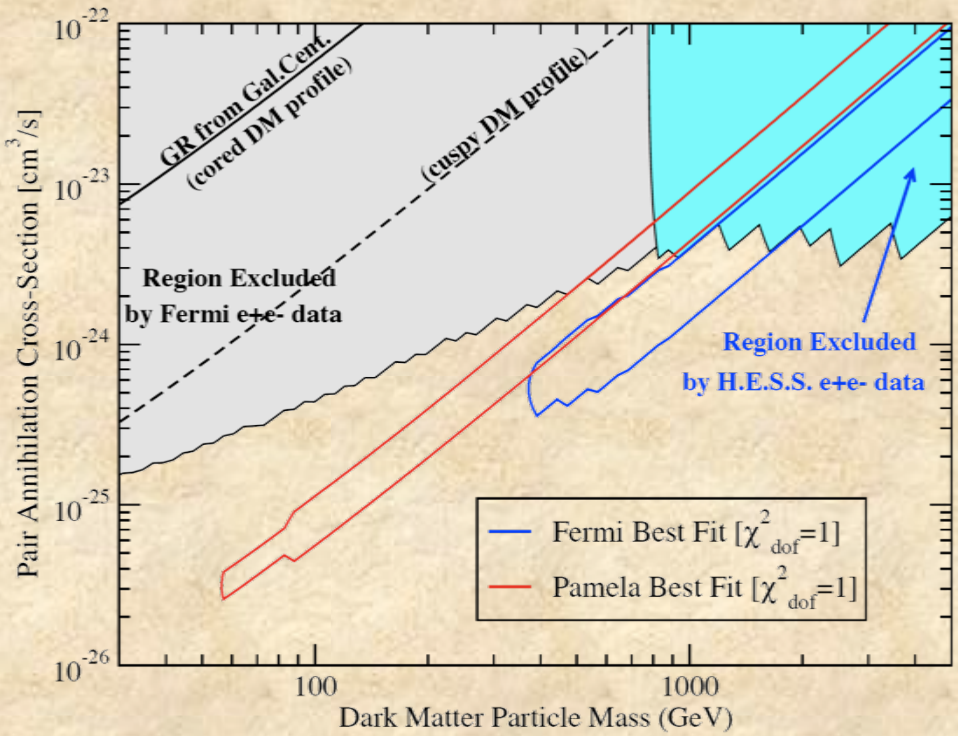




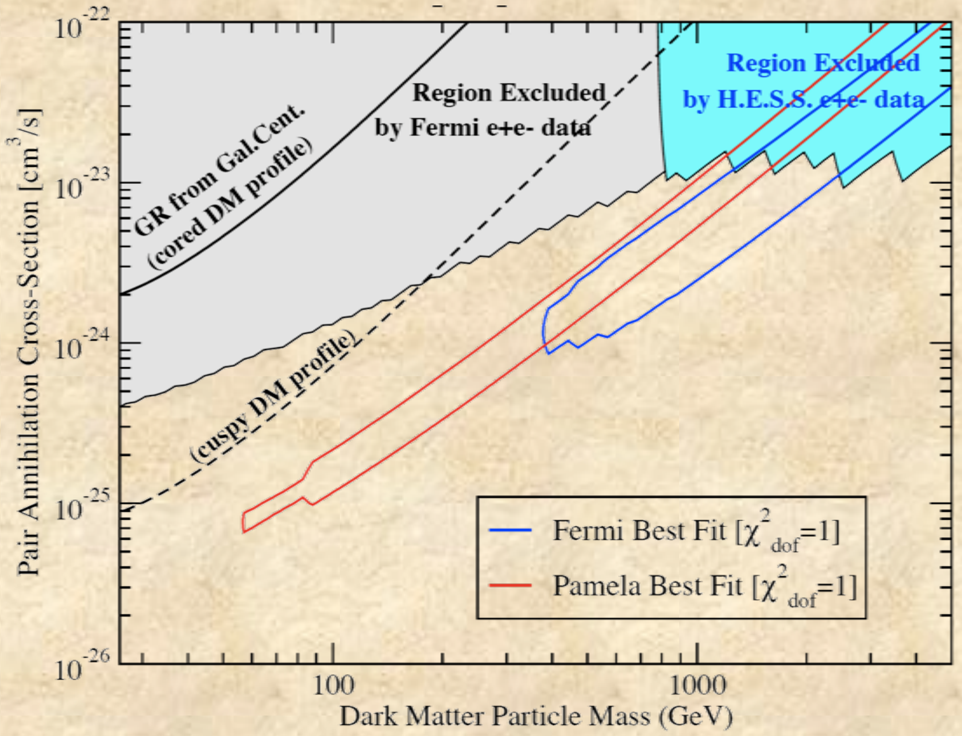
Adding d < 1 Kpc pulsars

A. Abdo et al. (FERMI Collab.), PRL 102 (2009)
D. Grasso et al., arXiv:0905.0636v1 [astro-ph.HE]

DM interpretation



Annihilation into e^+e^-



"Democratic annihilation into leptons"

D. Grasso et al., arXiv:0905.0636v1 [astro-ph.HE]

See also: L. Bergstrom, J. Esjo, G. Zaharijas, arXiv:0905.0333 [astro-ph.HE]
P. Meade, M. Papucci, A. Strumia, T. Volansky, arXiv:0905.0480 [hep-ph]

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

$m_\chi \gtrsim 100$ 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

$m_\chi \gtrsim 10$ TeV ⟶ Naturalness ?

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

Neutralino

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

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

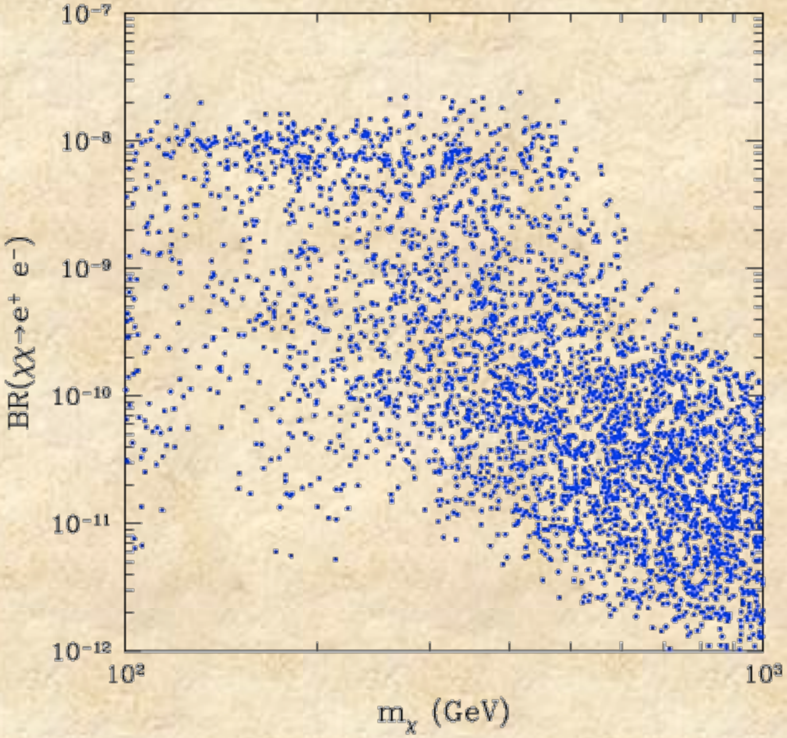
Preferred channels: quark production (also gauge or hisggs bosons)

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

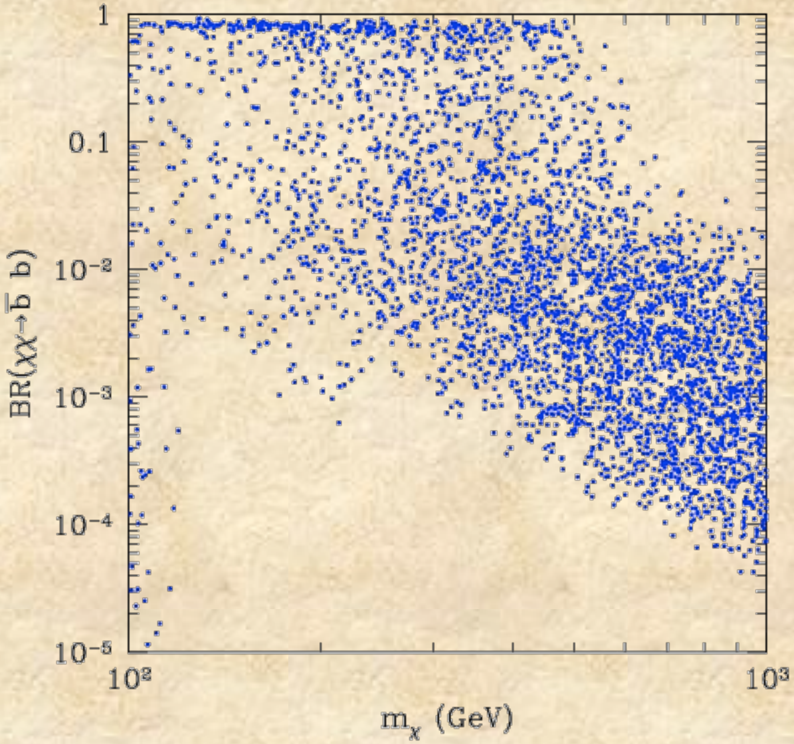
Positrons spectra are too soft to explain PAMELA raise

Positron BR for neutralinos in MSSM

BR into electrons



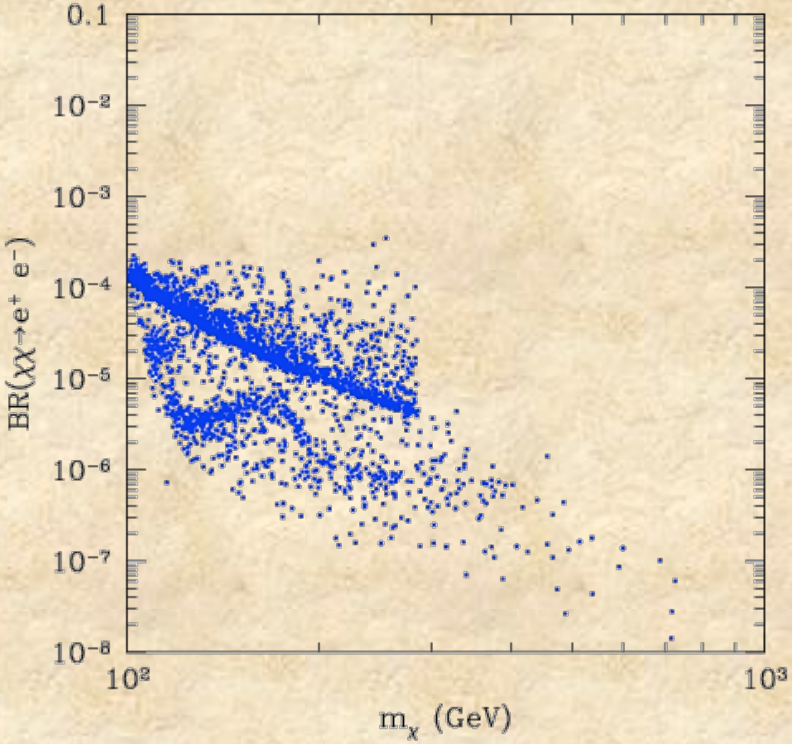
BR into bottoms



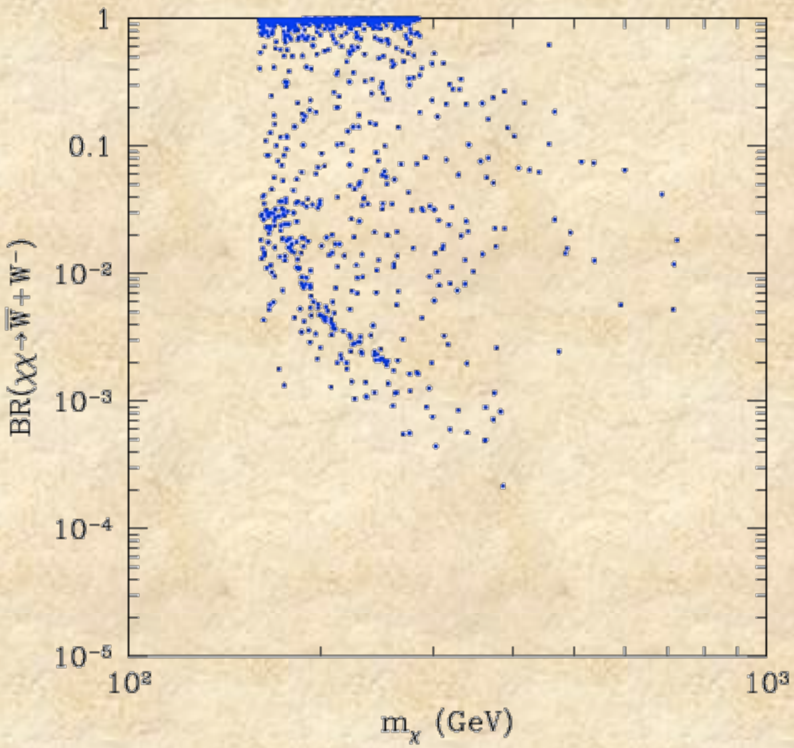
Configurations with WMAP relic abundance

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 $U(1)_{B\text{-}L}$

- 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]

Non SUSY candidates

- Inert Doublet Model
  - Tho Higgs-doublet model with unbroken Z_2 symmetry

$$H_1 \to H_1 \text{ and } H_2 \to -H_2$$

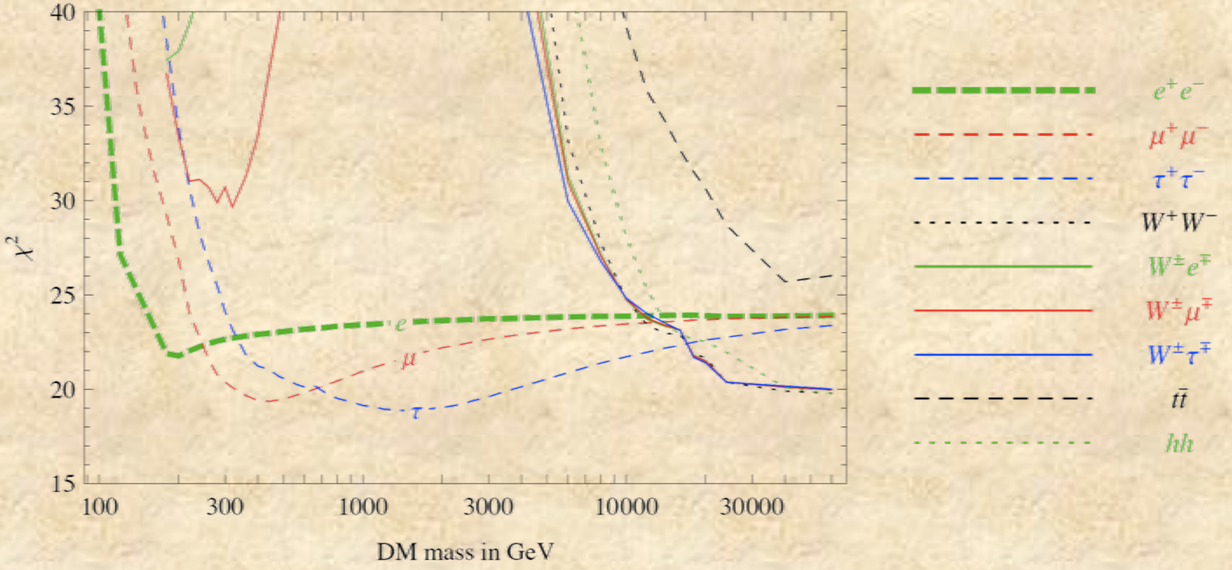
  - Candidate: H_0, with m > 10 TeV
  - Large boost required

E. Nezri, M. Tytgat, G. Vertongen, arXiv:0901.2556v2 [hep-ph]
S. Andreas, T. Hambie, M. Tytgat, JCAP 0810:034,2008
L. Honorez, E. Nezri, J. Oliver, H. Tytgat, JCAP 0702:028,2007

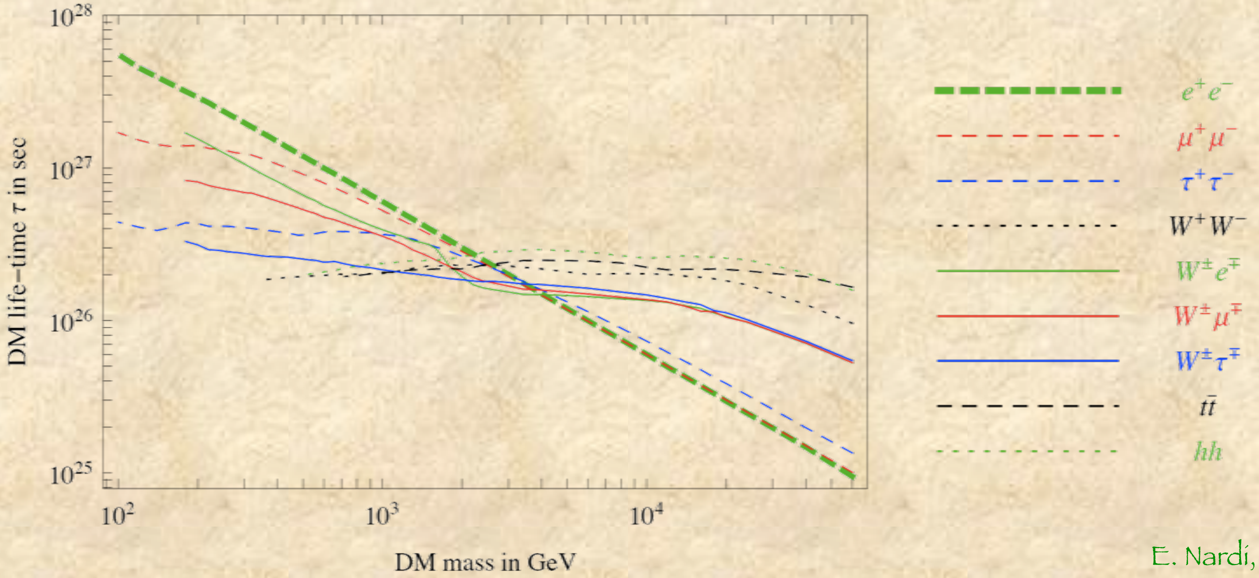
- Minimal Dark Matter
  - Extra multiplets with minimal spin, charge, hypercharge
  - Candidate: lightest particle in the multiplet (neutral), m > few TeV
  - Large boost required

M. Cirelli, R. Franceschini, A. Strumia, Nucl.Phys.B800:204-220,2008
M. Cirelli, N. Fornengo, A. Strumia, Nucl.Phys.B753:178-194,2006
M. Cirelli, A. Strumia, arXiv:0808.3867

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

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

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

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

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

Summary: Direct Detection

- Direct detection
  - Signature offered by annual modulation of the rate
    - DAMA/NaI and DAMA/Libra observe annual modulation in low-energy single-hit events
    - In susy models, this effect is compatible with relic dark matter candidates, like:
      - Neutralinos both in the MSSM and in gaugino non-universal schemes
      - Sneutrinos in LR models or models with L-violation and see-saw neutrino mass generation
  - Total counting rate: allows to set bounds
    - CDMS, Xenon10 and others currently probe a fraction of MSSM parameter space for neutralino or sneutrino dark matter
    - Extension of the probe depends on astrophysical (galactic halo properties) and nuclear physics (DM-nucleus interaction) assumptions
  - Other possible signatures: directionality of the recoil, diurnal effects

Summary: Indirect Detection

- AntiDeuterons
  - strong feature at low-energies: offer the best possibility to detect a signal

- AntiProtons
  - mild feature at low energies, but suitable to set (potentially relevant) bounds
  - data show no anomaly (latest from PAMELA)

- Positrons
  - may posses spectral features, typically require "boosts"
  - PAMELA data on positron fraction exhibit "anomalous" rise (may be astrophysical: e.g. pulsars)
  - FERMI data on electron+positrons exhibit a mild bump (may be astrophysical)

- Gamma Rays
  - may posses spectral features
  - line: amazing signature, but typically strongly suppressed (very hard for some DM candidates)
  - with FERMI currently no anomaly above the galactic center
  - astrophysical background quite relevant, especially at the galactic center

- Neutrinos from Earth and Sun
  - spectral and angular features
  - events induced by the ν_τ component potentially "background free" (if accessible)

Coming data from:

Low-background experiments underground
Neutrino telescopes
Large area detectors
Balloon experiments
Space detectors

Tevatron, LHC, B Factories

The near future promises to be very exiciting!