Dark matter interpretation of positron and antiproton fluxes

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Workshop "Cosmic Ray Backgrounds in Dark Matter Searches"

Albanova, Stockholm 27.01.2010

Topics:

- Propagation of secondary positrons
  → background **uncertainties**
- Propagation of positrons from DM sources
  → astrophysical **uncertainties**
- DM interpretation of e+/e+e- data: is it a viable solution?

- Propagation of secondary antiprotons
  → background **uncertainties**
- Propagation of antiprotons from DM sources
  → astrophysical **uncertainties**

-DM interpretation of pbar data: non necessary solution

Some perspectives …

Secondary positron/electron production

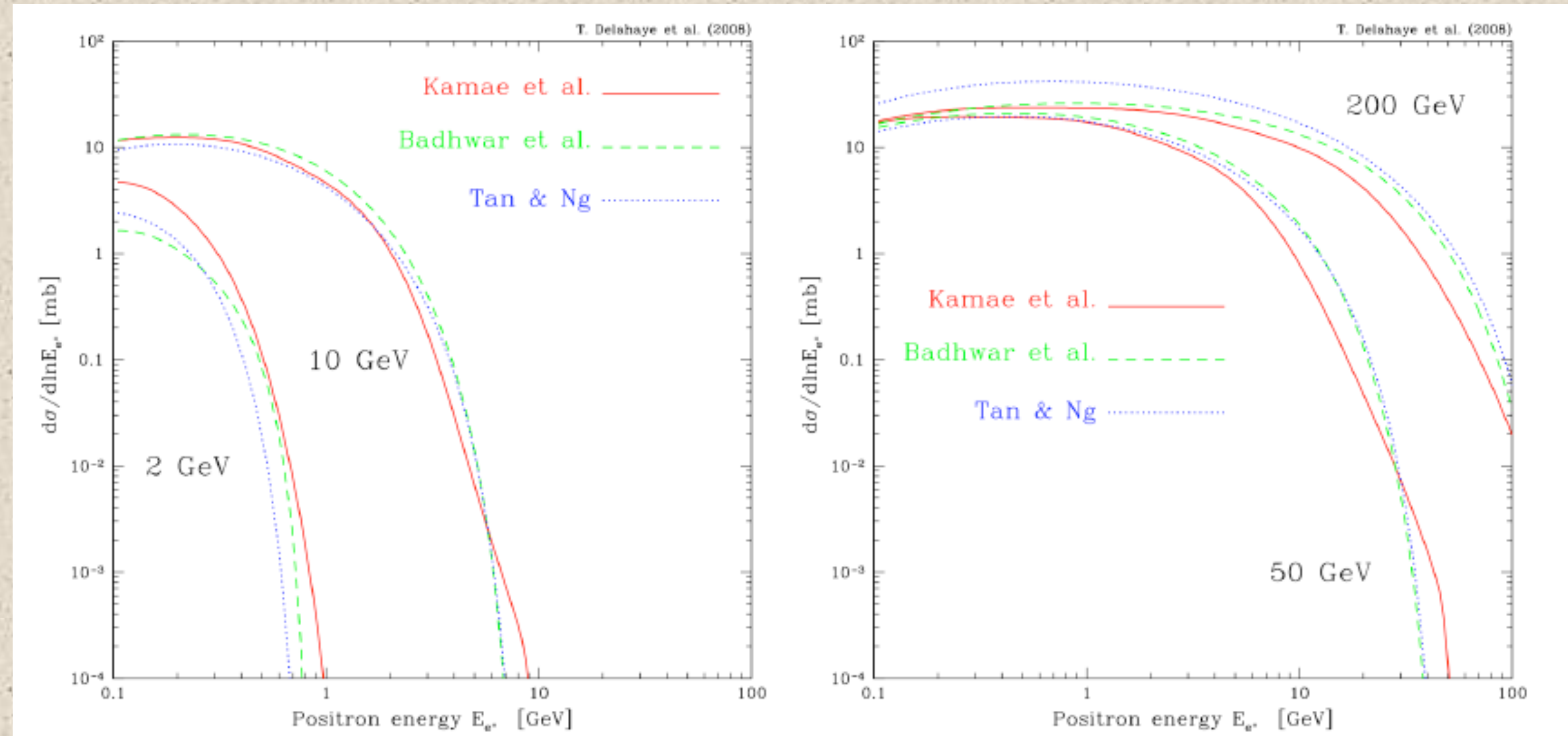
Spallation of proton and helium nuclei on the ISM (H, He)

$p+H \rightarrow p+\Delta^+ \rightarrow p+\pi^0$ & $n+\pi^+$ (mainly below 3 GeV)

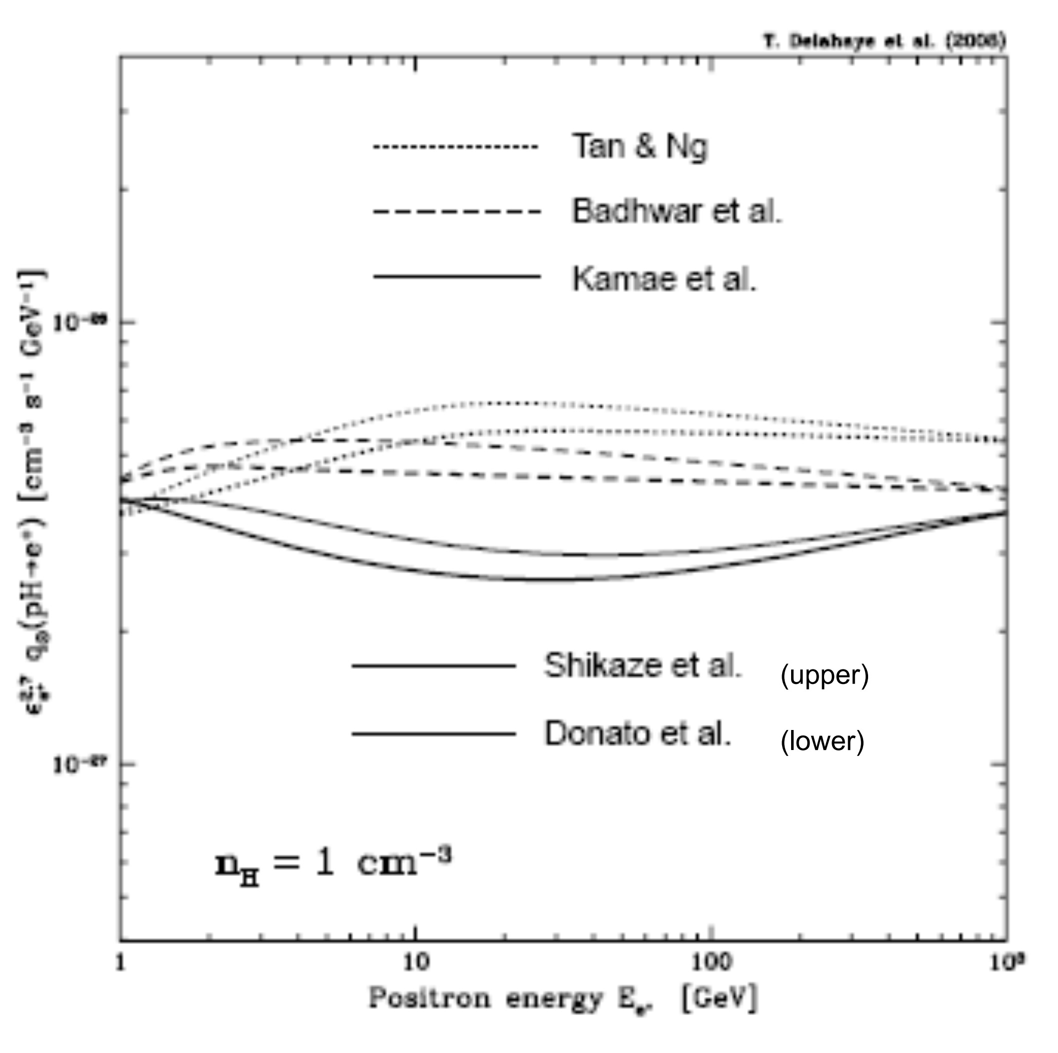
$p+H \rightarrow p+n+\pi^+$

$p+H \rightarrow X + K^\pm$

Different parameterizations of cross sections and incident p energy



The positron source term



Effect of proton flux determination - negligible

Effect of production cross sections is not negligible

Propagation of secondary positrons

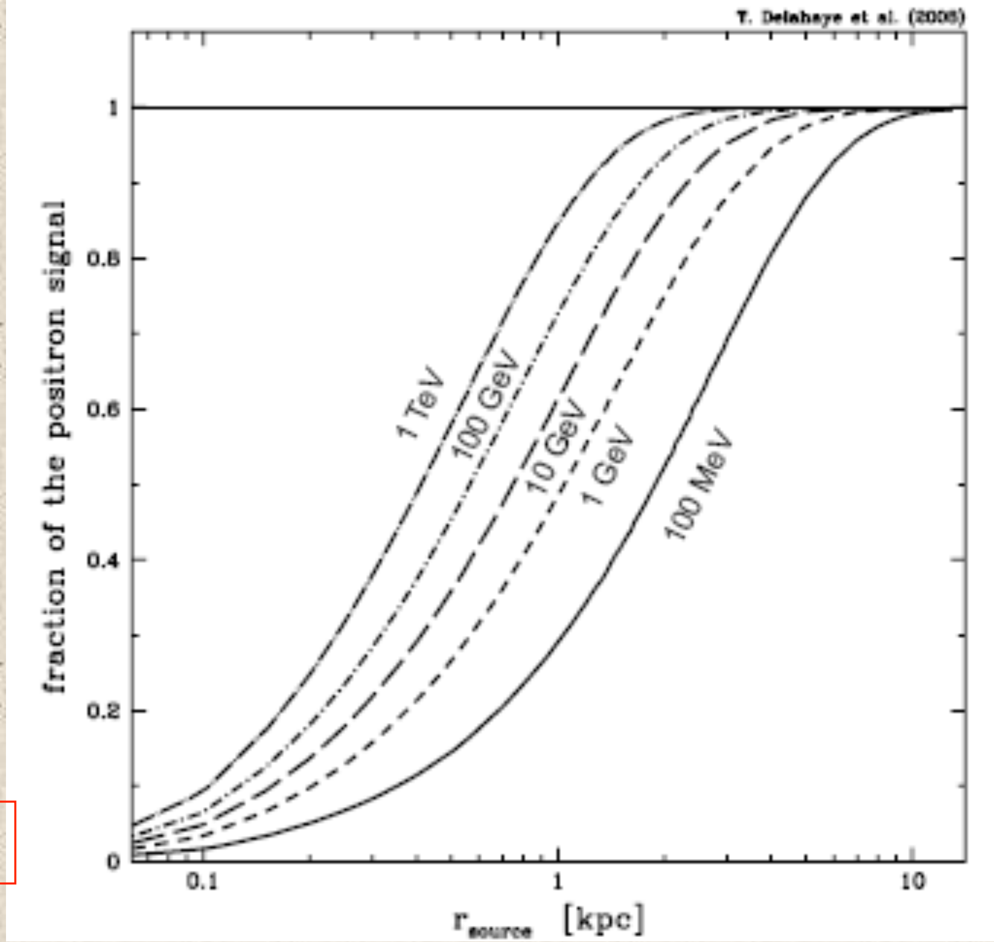
Delahaye, Lavalle, Lineros, FD, Fornengo, Salati, Taillet A&A 2009

Diffusive semi-analytical model: Thin disk and confinement halo
Free parameters fixed by B/C

Above few GeV:
only spatial diffusion and energy losses

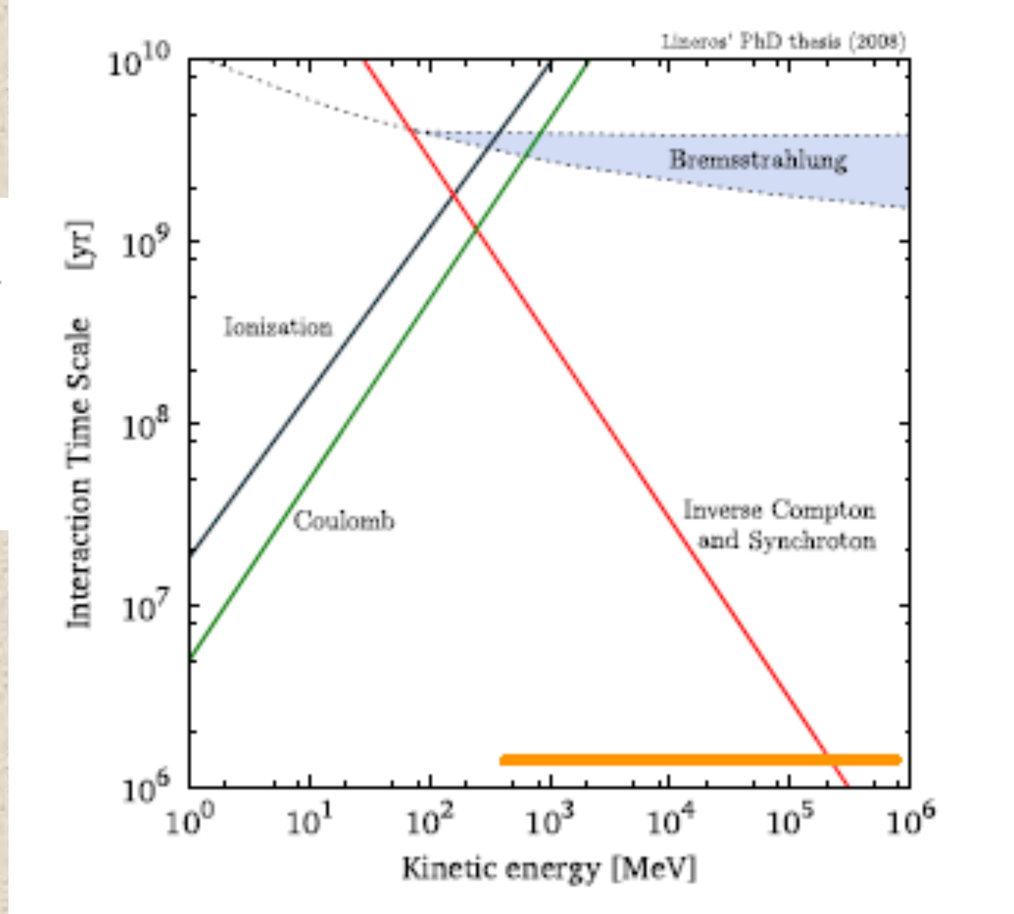
$$-b^{\rm loss}(\epsilon) = \begin{cases} \dfrac{\epsilon^2}{\tau_E} & \text{Inverse Compton and synchrotron} \\ +\nabla \cdot \mathbf{V}_C \, \dfrac{p^2}{6h\epsilon} & \text{Adiabatic losses} \\ +K_b \, n_H \, \epsilon & \text{Bremsstrahlung} \\ +K_i \, n_H \left\{ 3 \ln\left(\dfrac{E}{m_e}\right) + 19.8 \right\} & \text{Ionisation.} \end{cases}$$

Energetic positrons are quite local



Energy losses for positrons/electrons

$$
-b^{\mathrm{loss}}(\epsilon) = \begin{cases} \dfrac{\epsilon^2}{\tau_E} & \text{Inverse Compton and synchrotron} \\ +\nabla \cdot \mathbf{V}_C \, \dfrac{p^2}{6h\epsilon} & \text{Adiabatic losses} \\ +K_b \, n_H \, \epsilon & \text{Bremsstrahlung} \\ +K_i \, n_H \left\{ 3 \ln \left(\dfrac{E}{m_e} \right) + 19.8 \right\} & \text{Ionisation.} \end{cases}
$$



Synchrotron and Inverse Compton* dominate

*IC=scattering of e- on photons (starlight, infrared, microwave)

2-zone Semi-analytic Diffusive Model

Maurin, FD, Taillet, Salati ApJ 2001; Maurin, Taillet, FD A&A 2002

& talks by D. Maurin, A. Putze

+All the effects included ($V_A \neq 0$ & $V_C \neq 0$)

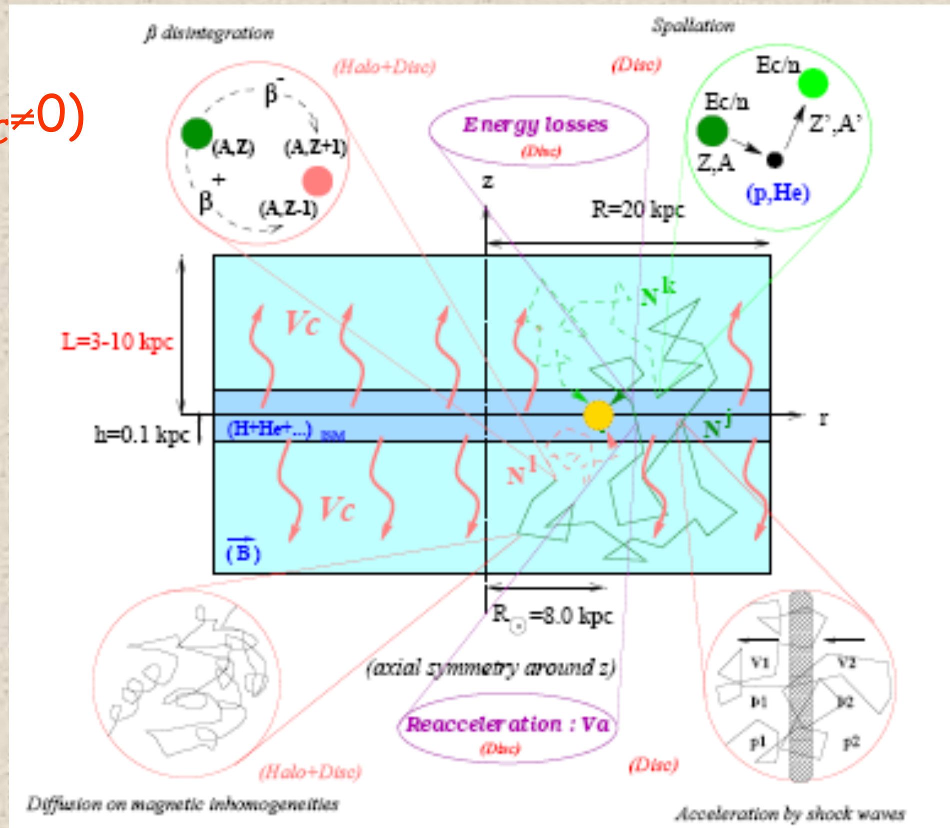
+2D semi-analytic

+ Local Bubble for radioactives

- ISM constant

-V_C constant througout the halo

- V_A in the disk



- Diffusion coefficient $K(R)=K_0\beta R^\delta$
- Convective velocity V_c
- Alfven velocity V_A
- Diffusive halo thickness L
- Acceleration spectrum $Q(E)=p^\alpha$

K_0, δ, V_c, V_A, L, (α)

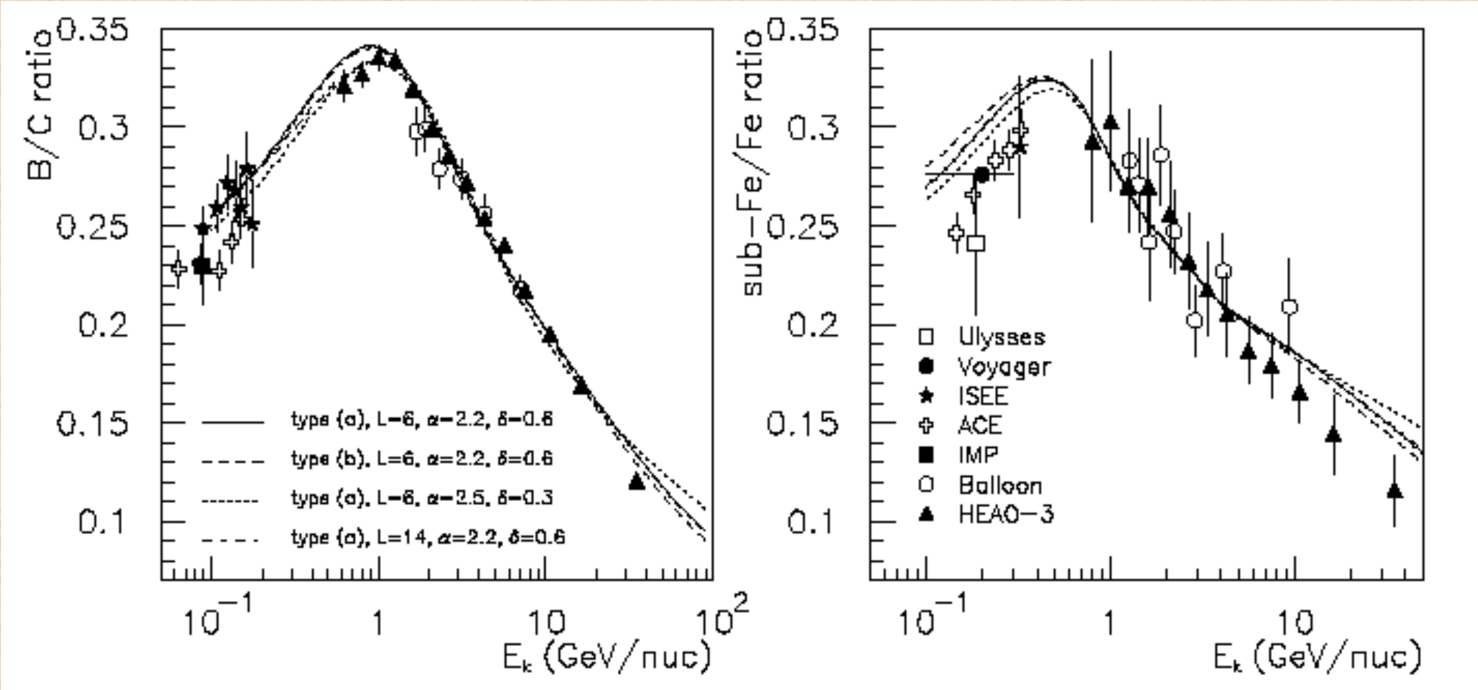
Systematic scan
of parameter space
Evaluation of uncertainties

Results on Observed Prim/Sec

Maurin, FD, Taillet, Salati, ApJ (2001) Maurin, Taillet, FD A&A (2002)

Systematic scan of the parameter space

6 free parameters: diffusion (K_0, δ), convection (V_C), acceleration(α), reacceleration (V_A), diffusive halo (L)



Only model WITH **convection** AND **reacceleration**

Kolmogorov (δ=0.3) spectrum disfavoured, δ ~ 0.6-0.7, **K_0** ~ 0.003-0.1 kpc²/Myr

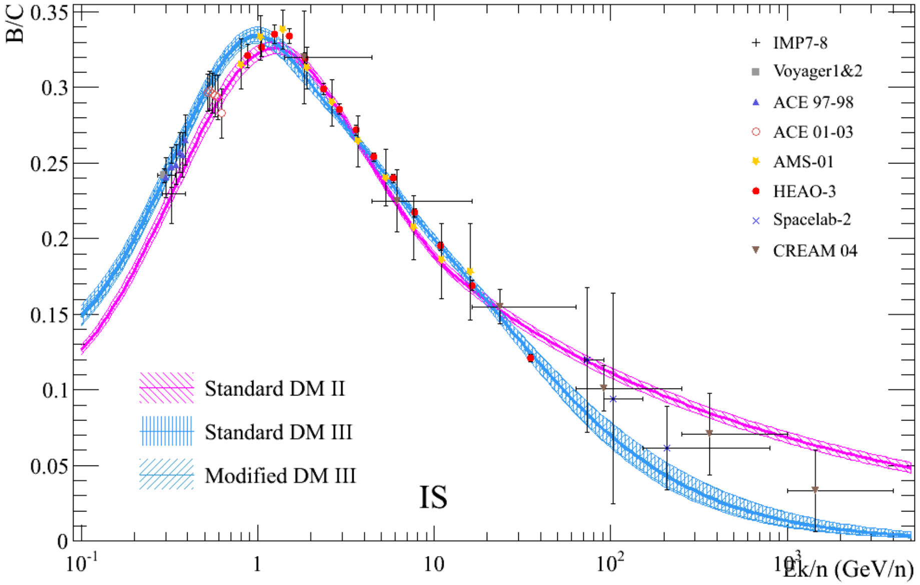
Acceleration spectrum α~2.0

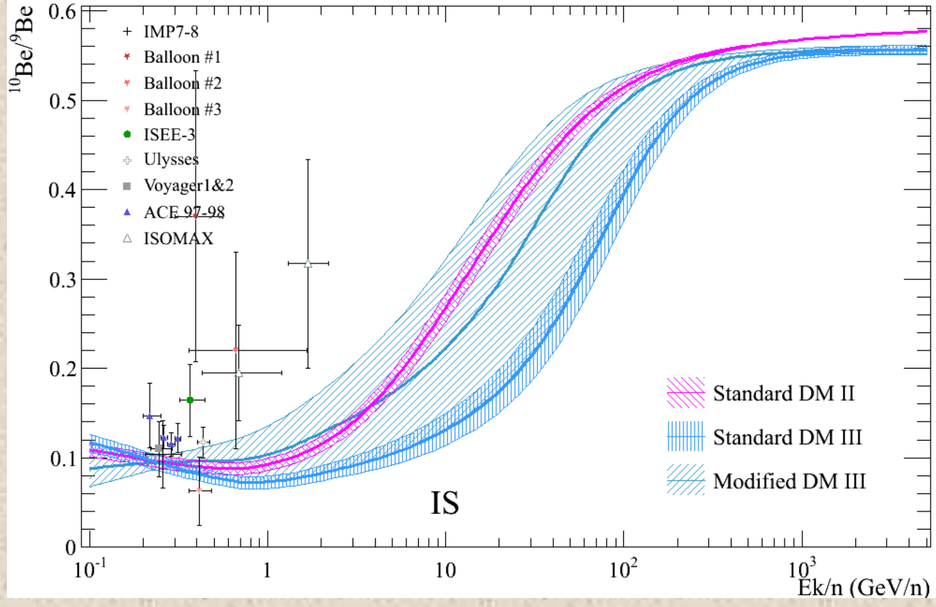
No need for **breaks** in K(E) or Q(E)

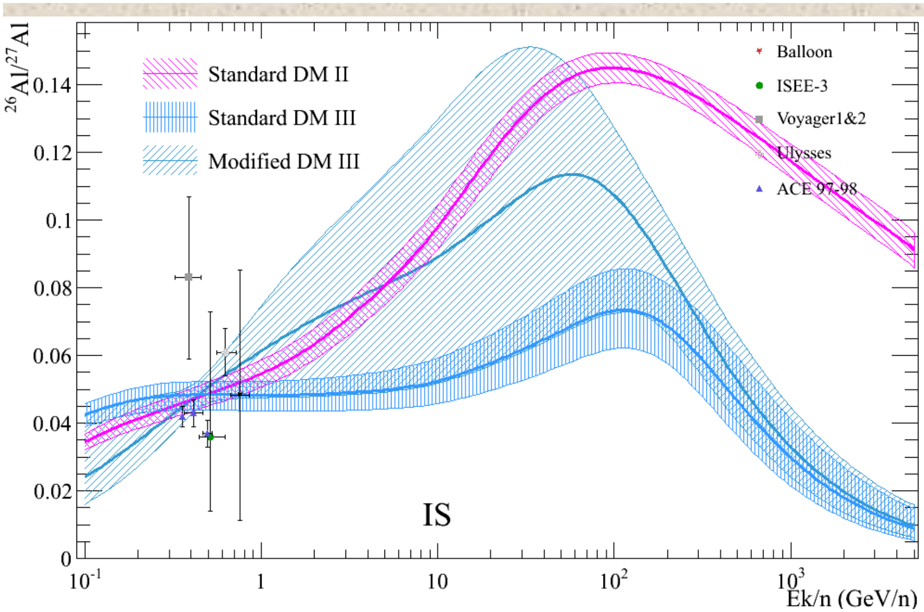
MCMC results on B/C AND radioactive isotopes

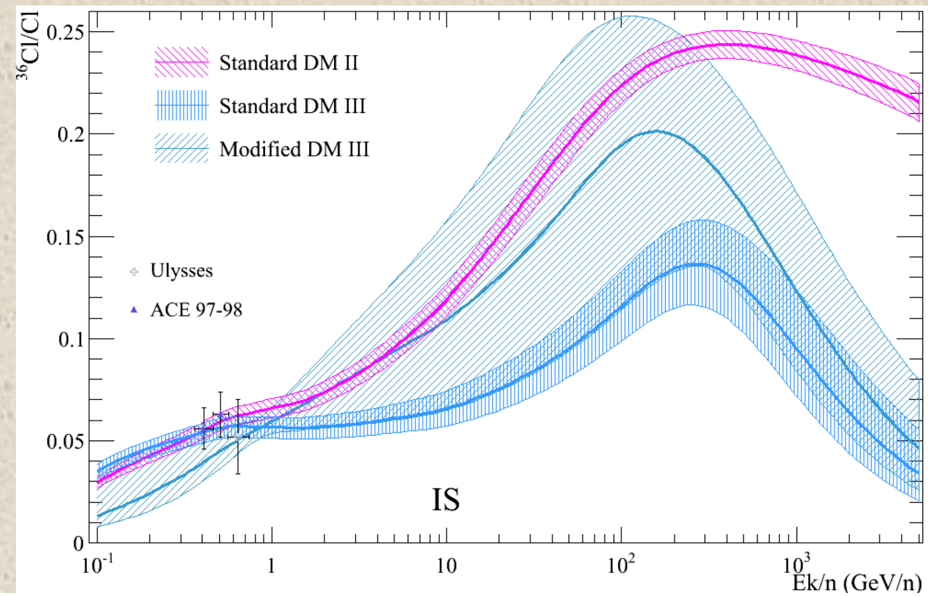
Putze, Derome, Maurin arxiv:1001.0551

(Talks by A. Putze and D. Maurin)









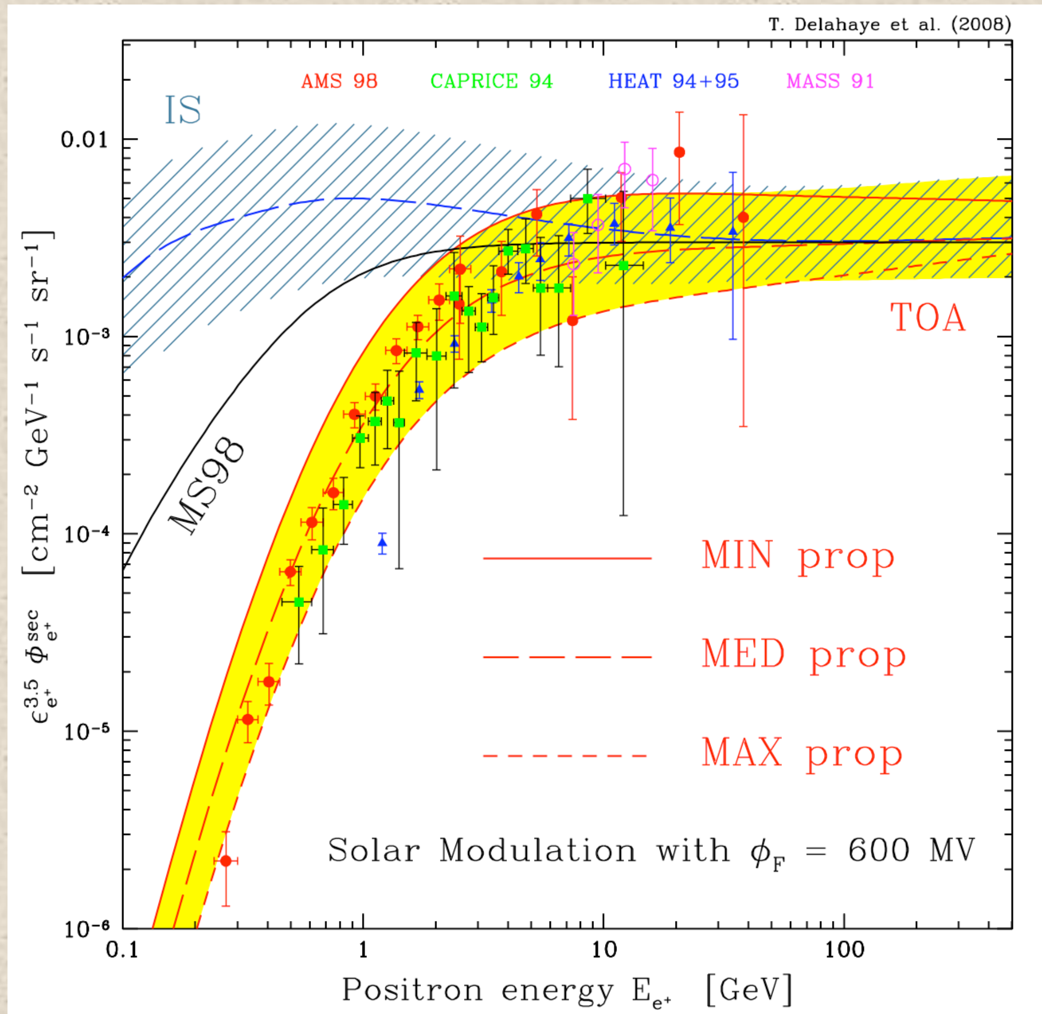
Positron flux: data and predictions

Delahaye et al. A&A 2009

Same propagation models:

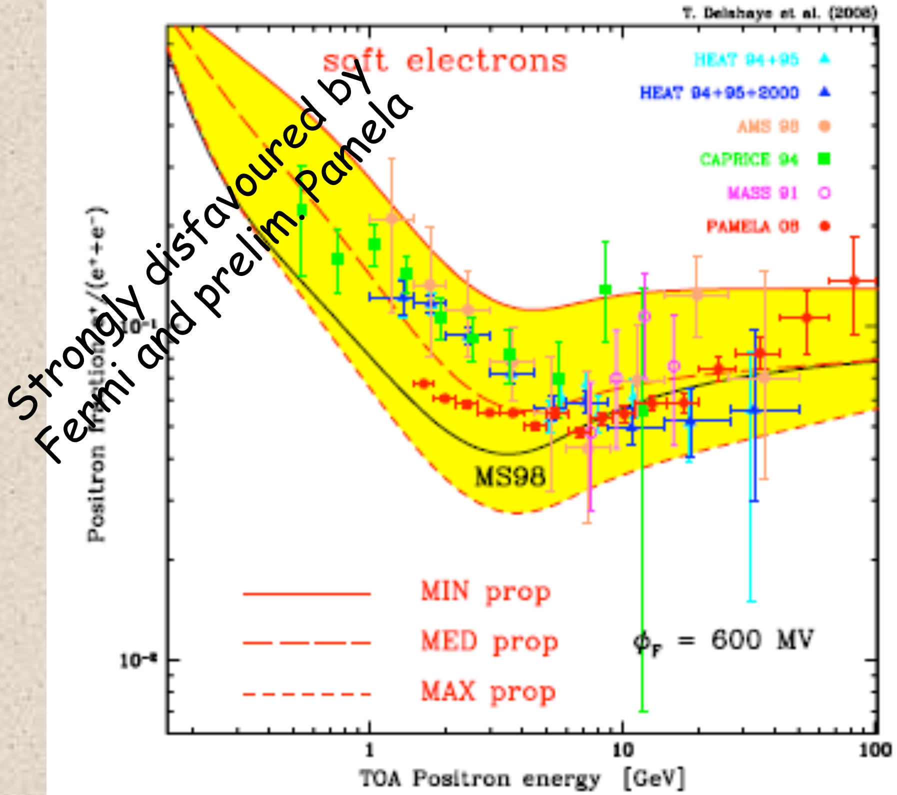
Positrons as secondary CRs are well fit by predictions

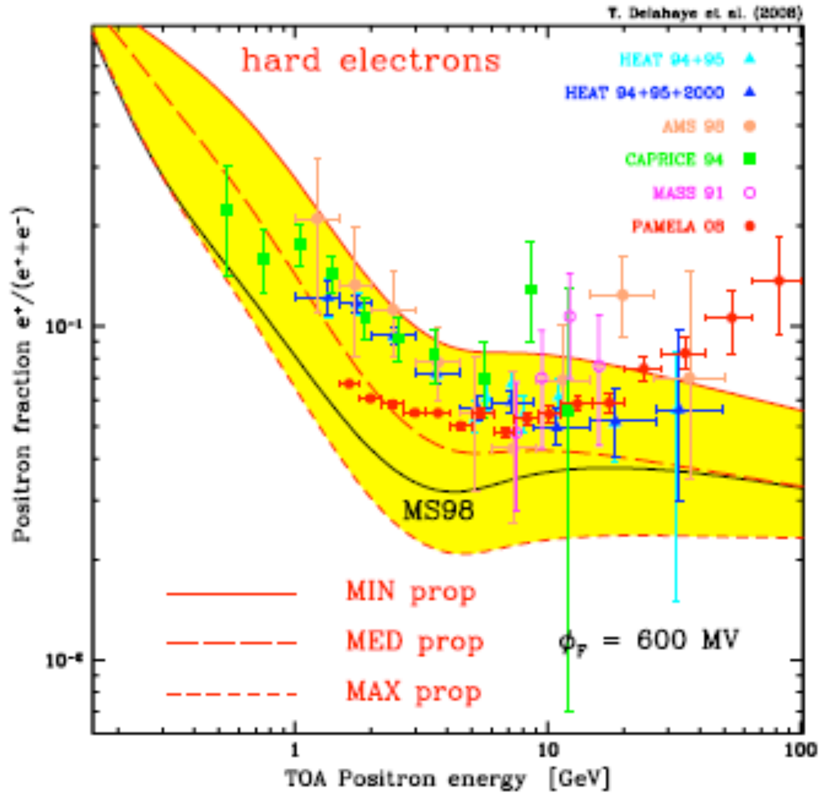
Uncertainties due to propagation: 3-4



Positron/electron: data and predictions

Delahaye et al. A&A 2009





Yellow band: secondary positrons & propagation uncertainties

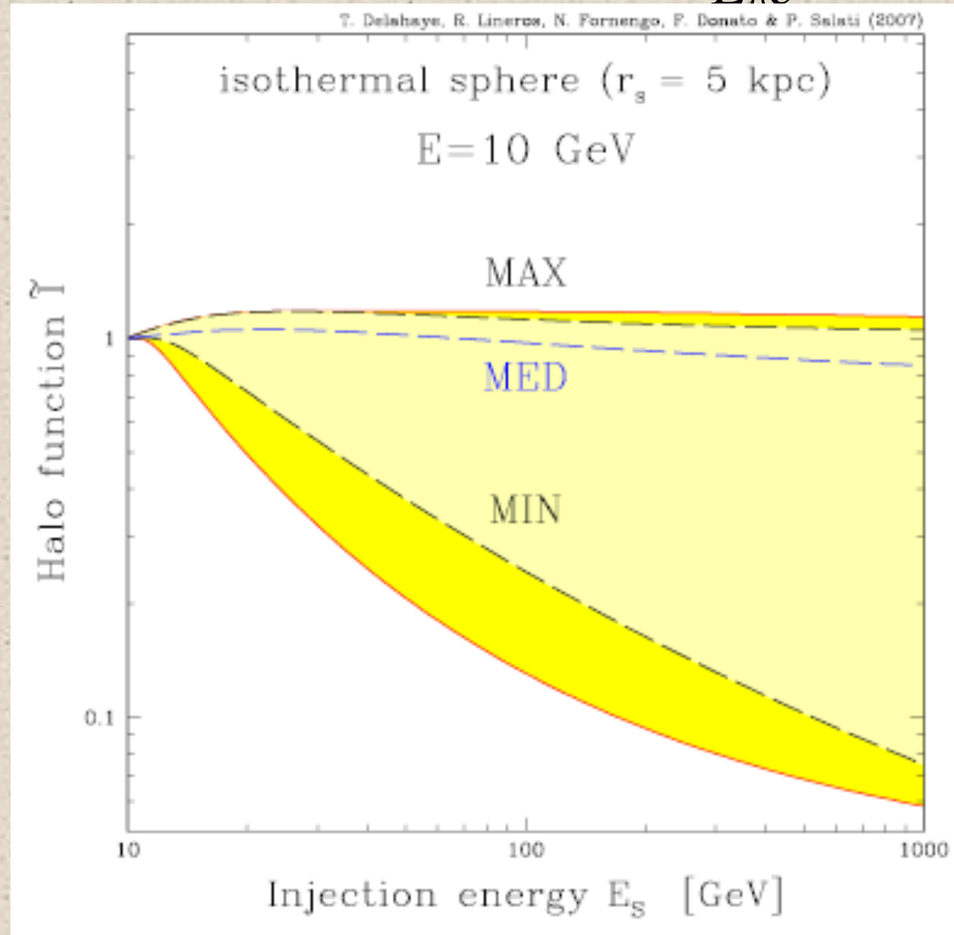
Hard electrons: γ=3.34 & talk by T. Delahaye

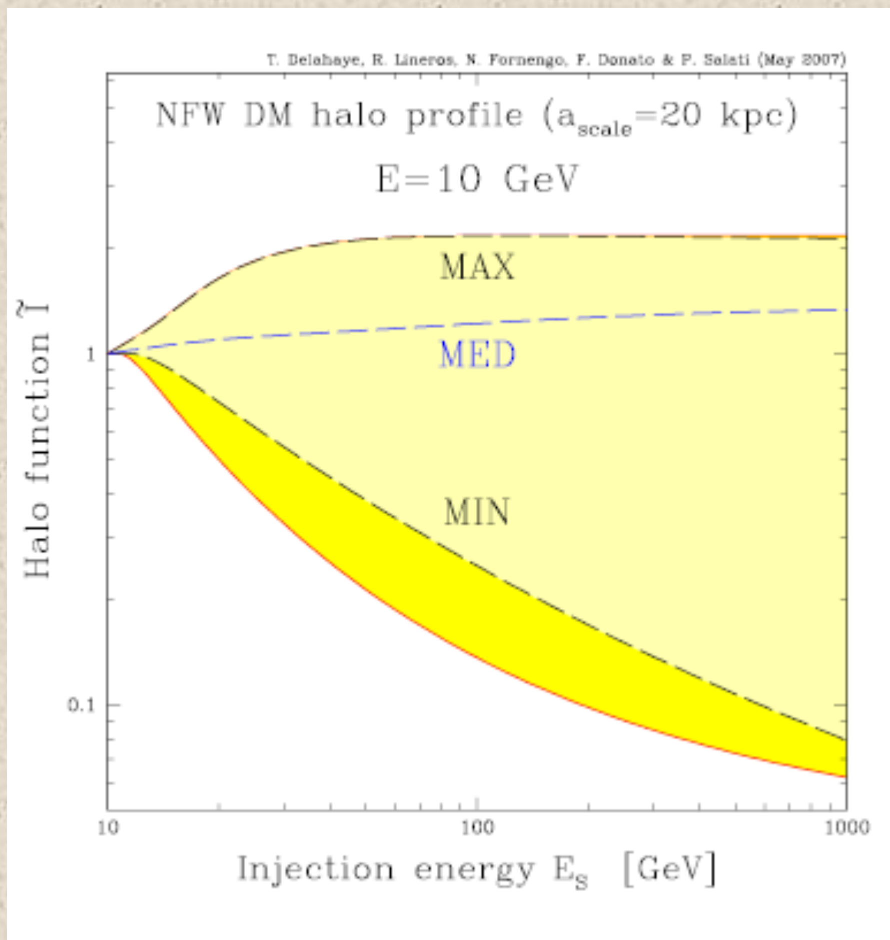
<u>There is no “standard” predicted flux (dashed is B/C best fit)</u>

Propagation of positron from WIMP DM (neutralino) sources

$$\Phi(E) = k_{susy} \frac{\tau_E}{E_0 \varepsilon^2} \int_E^{\infty} dE_S f(E_S) \widetilde{I}(\lambda_D)$$

E_0=1 GeV
ε=E/ E_0
τ=10^{16} s

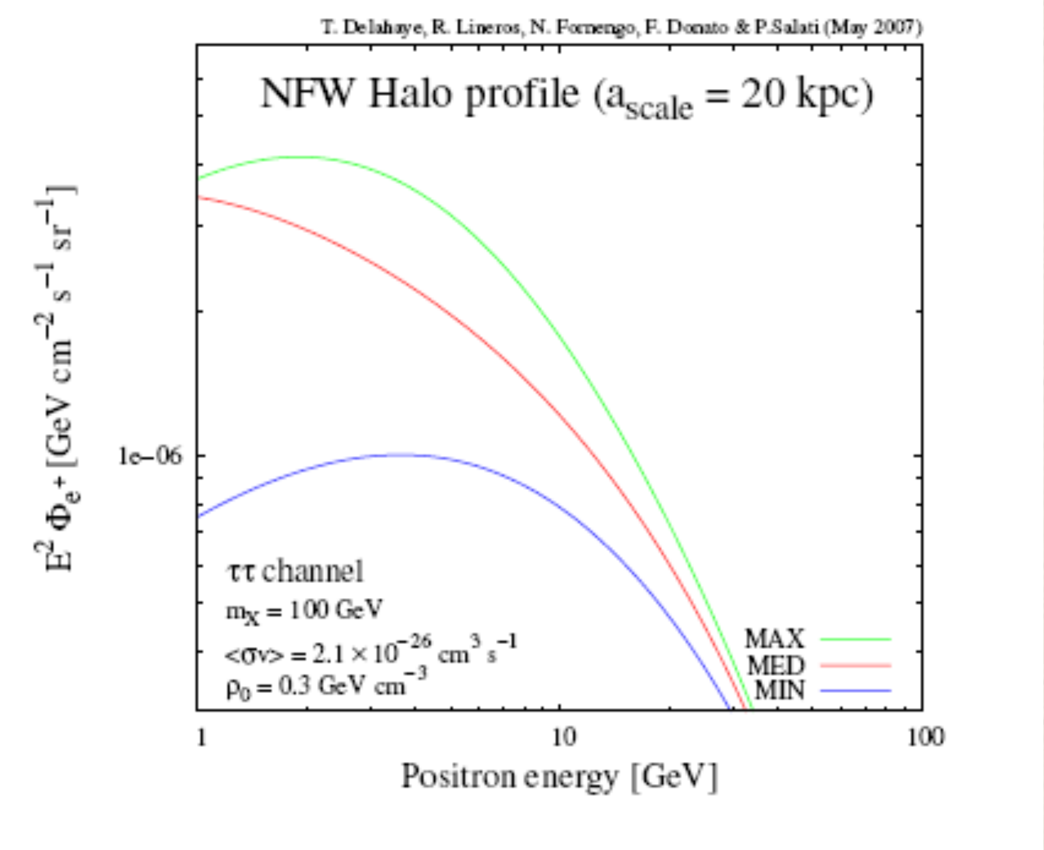




Propagation models allowed by B/C

Delahaye, Lineros, Fornengo, FD, Salati
PRD 2008

Astrophysical uncertainties on primary positrons

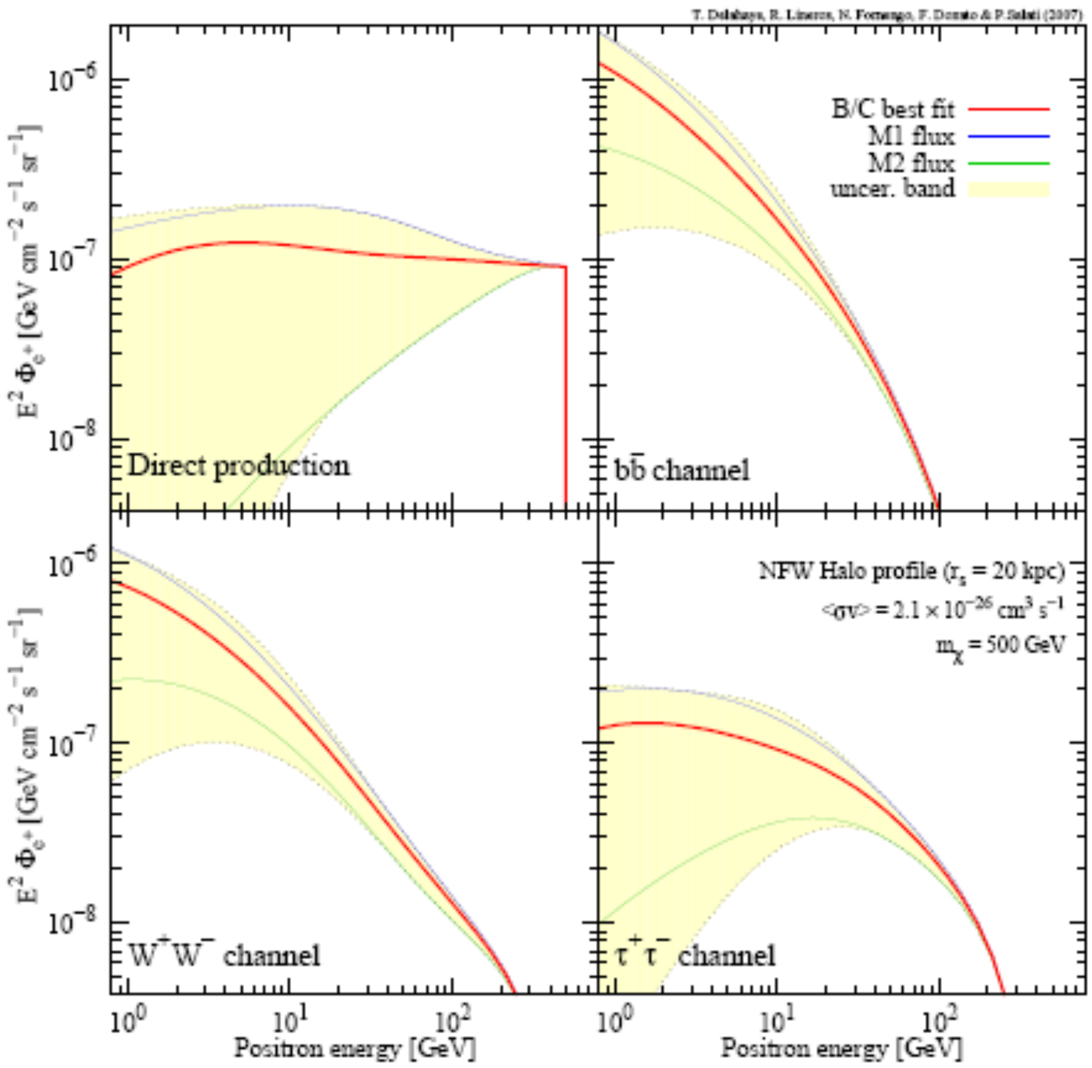


Uncertainties on primaries is 3-5, depending on:

- Energy
- Annihilation mode
- DM distribution in the halo

Positron fluxes: effect of annihilation channels

Delahaye et al. PRD 2008



m=500 GeV

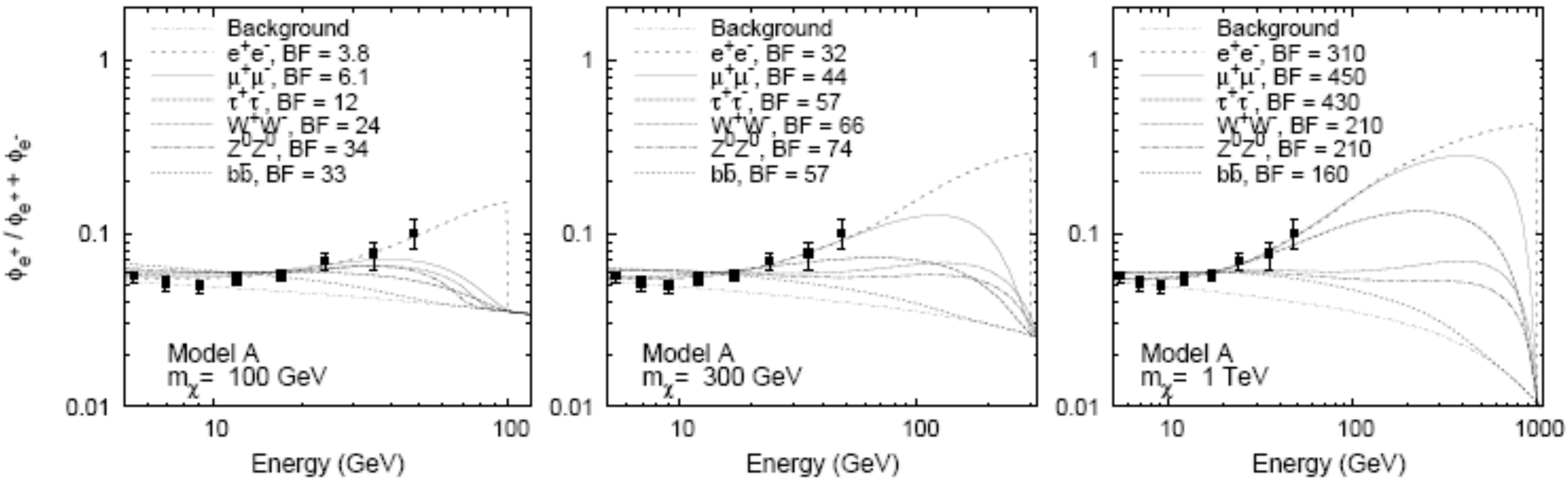
Direct annnihilation in e +, or in tau, are harder than bbar or gauge boson

In typical SUSY models annihilation in leptons is supressed wrt quark production

Effect of spectra on Pamela data

Cholis, Goodenough, Hooper, Simet, Weiner 00809.1683 PRD 2009

(model independent WIMP analysis)

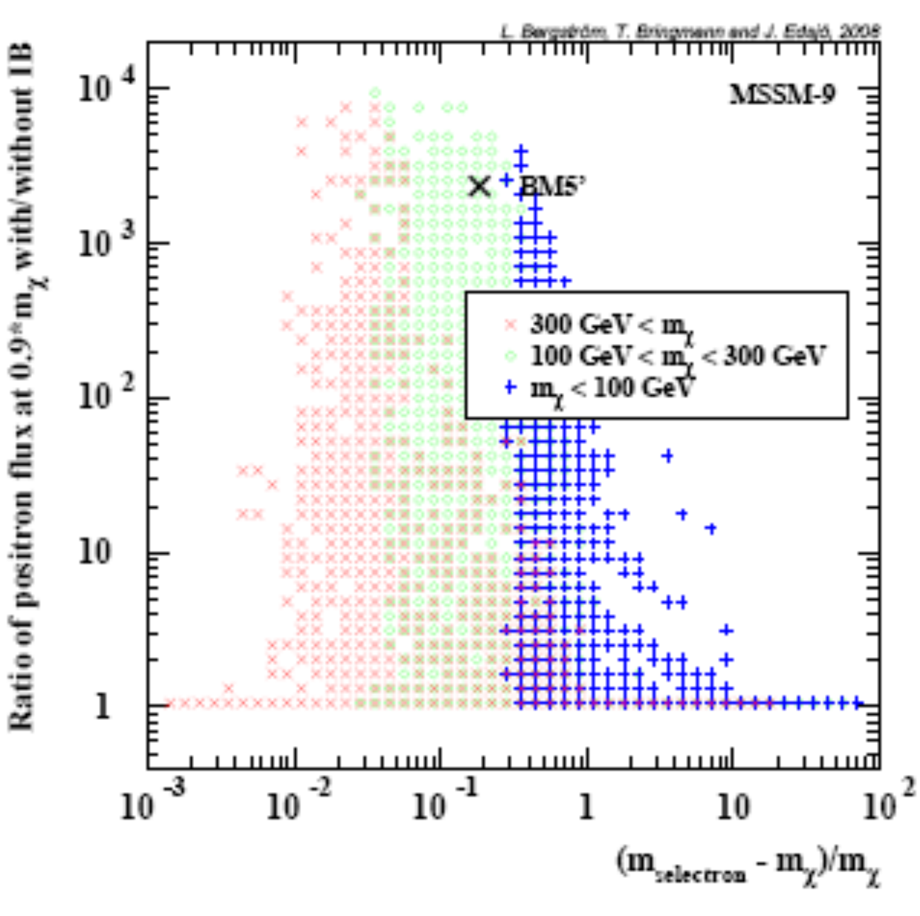


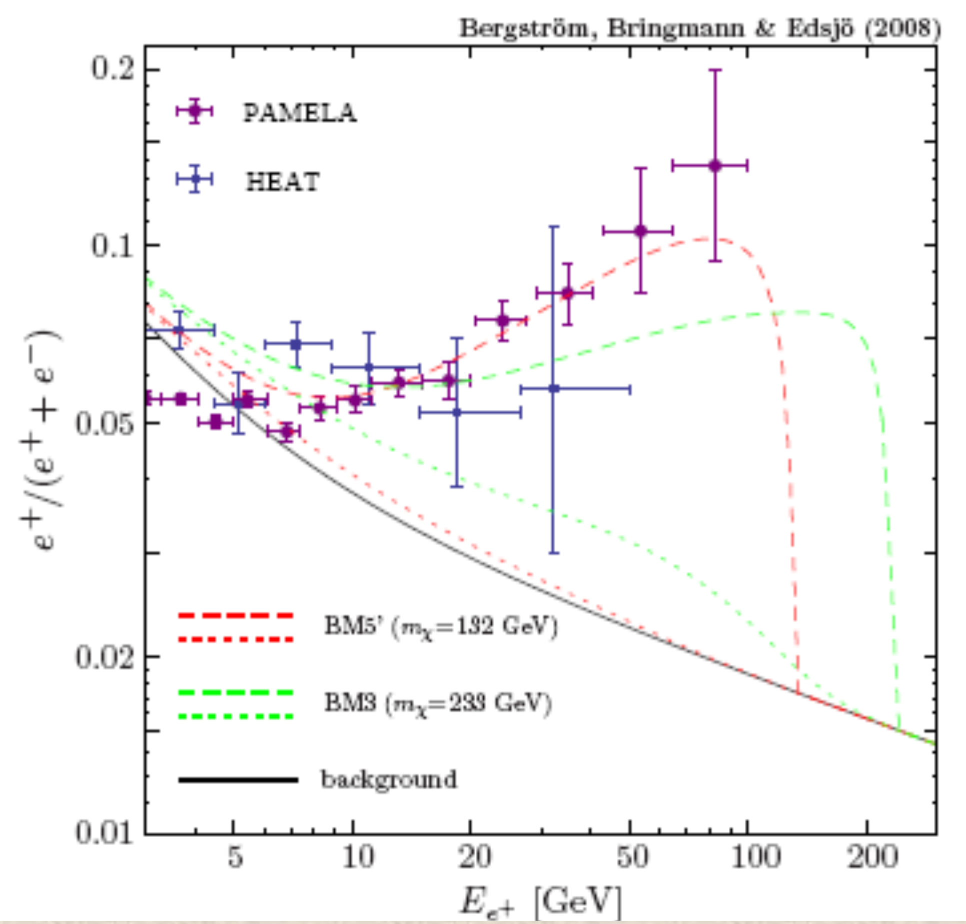
Leptonic final states can in principle reproduce data

Supersymmetric interpretation of Pamela data

Example: Internal bremsstrahlung: $\chi\chi \rightarrow e+e-\gamma$

Bergstrom, Bringmann, Edsjo PRD2008

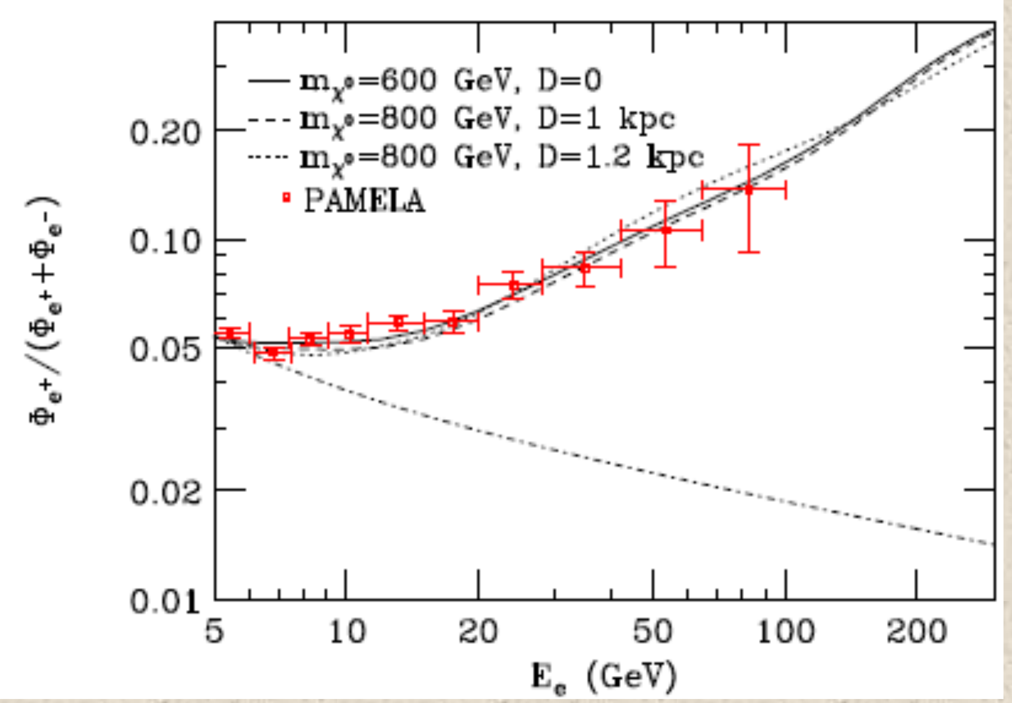




No elicity suppression for <σv>: α/π instead of $(me/m\chi)^2$

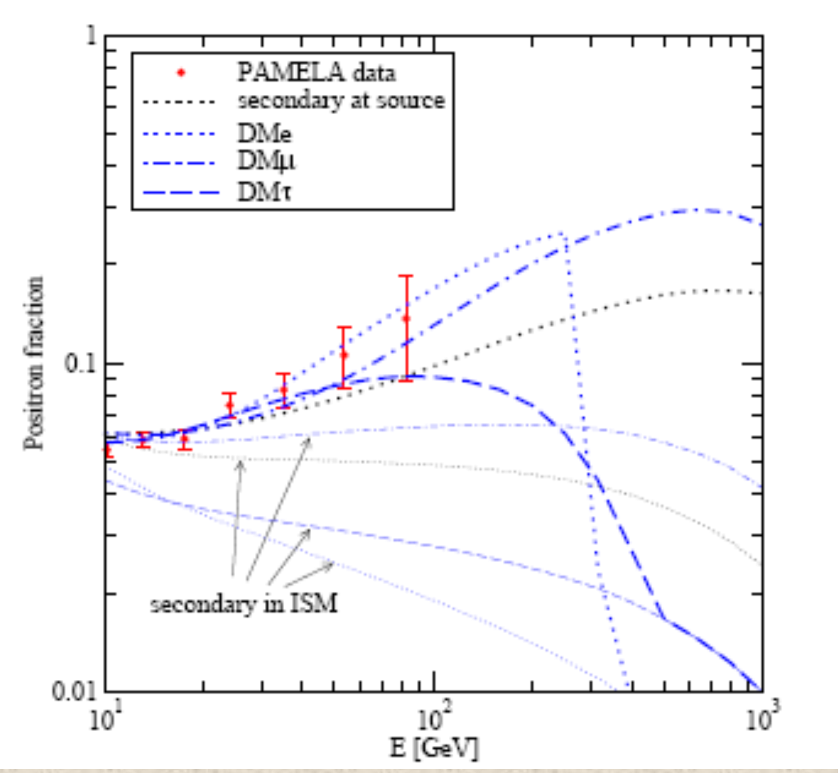
Supersymmetric interpretation of Pamela data

WW final state and very close clumps



Hooper, Stebbins, Zurek PRD 2009

	M_χ [GeV]	$\sigma_a v$ [$cm^3 s^{-1}$]	annihilation modes	spatial profile	line coding
DMe	300	$2.5 \cdot 10^{-24}$	e^+e^-	Burkert	dotted
DMτ	400	$6.6 \cdot 10^{-24}$	$\tau^+\tau^-$	Burkert	dashed
DMμ	1500	$2.5 \cdot 10^{-23}$	$\mu^+\mu^-$	Burkert	dashed-dotted



Regis & Ullio PRD 2009

Boundless literature....

SUSY interpretation (neutralino, gravitino, sneutrino):

- leptophilic DM

Non-thermal DM production

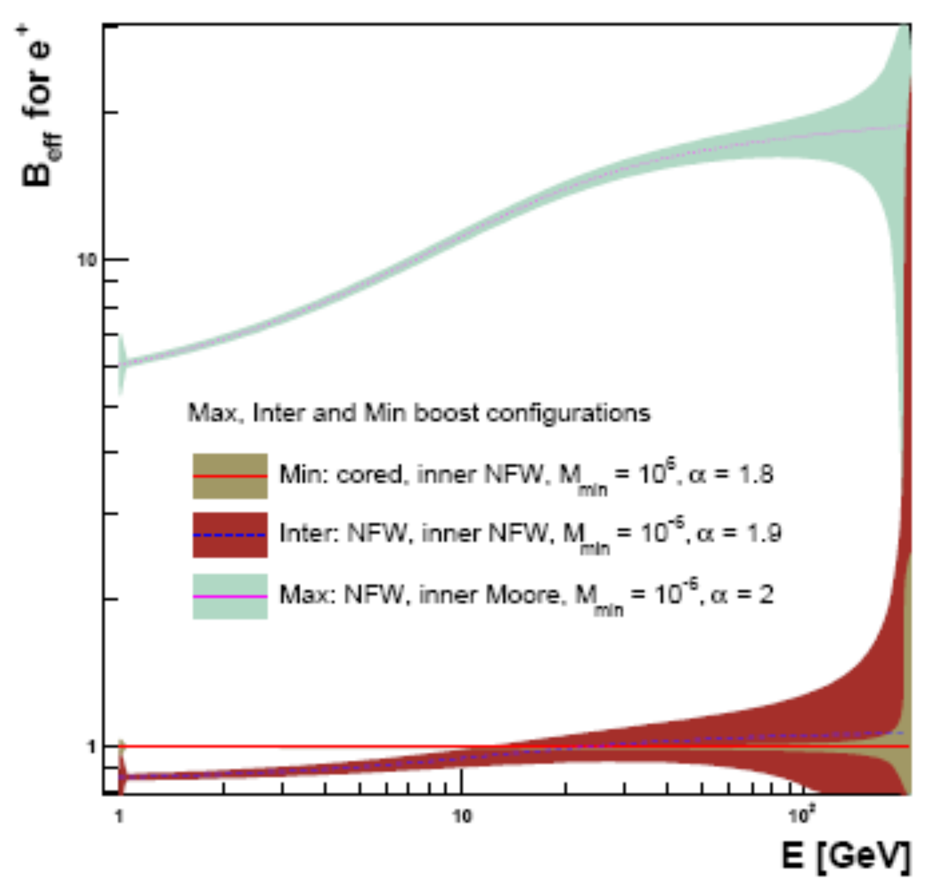
Dirac particles in NMSSM / KK / Minimal DM / Dark sectors

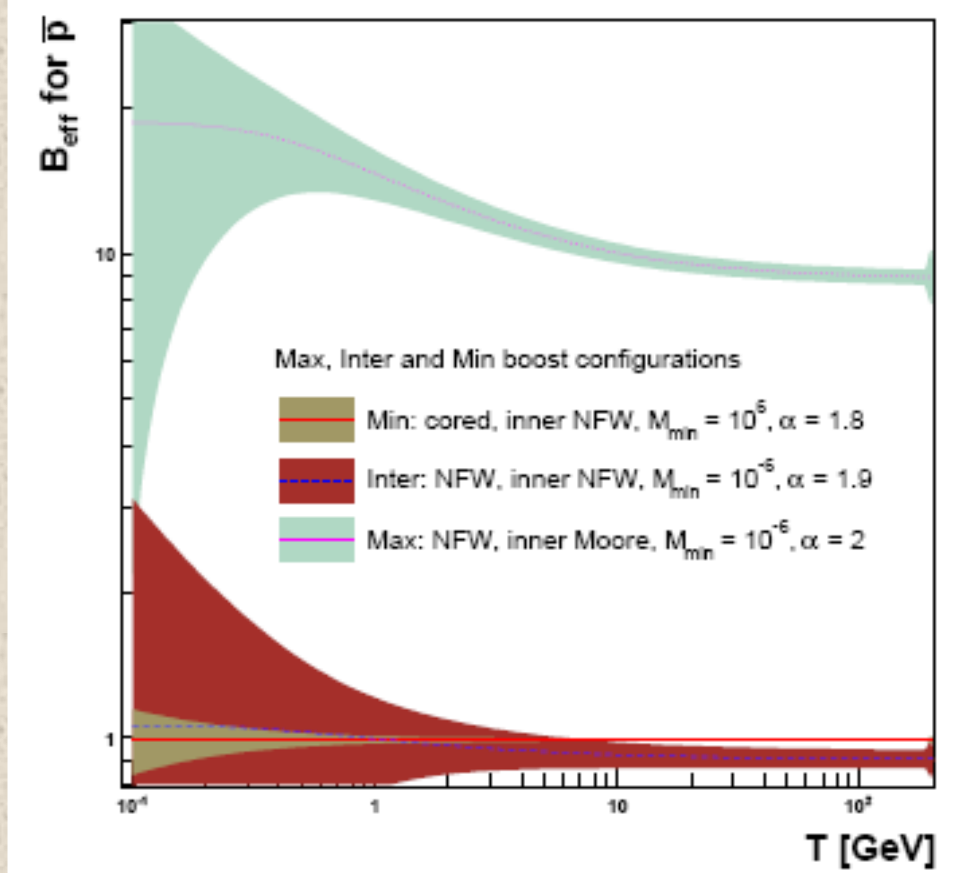
New symmetries / New interactions / Nambu Goldston DM / Inert Doublet /.......

In order to reproduce data, a BOOST is required and can be got in:

- astrophysics
- particle pysics
- cosmology

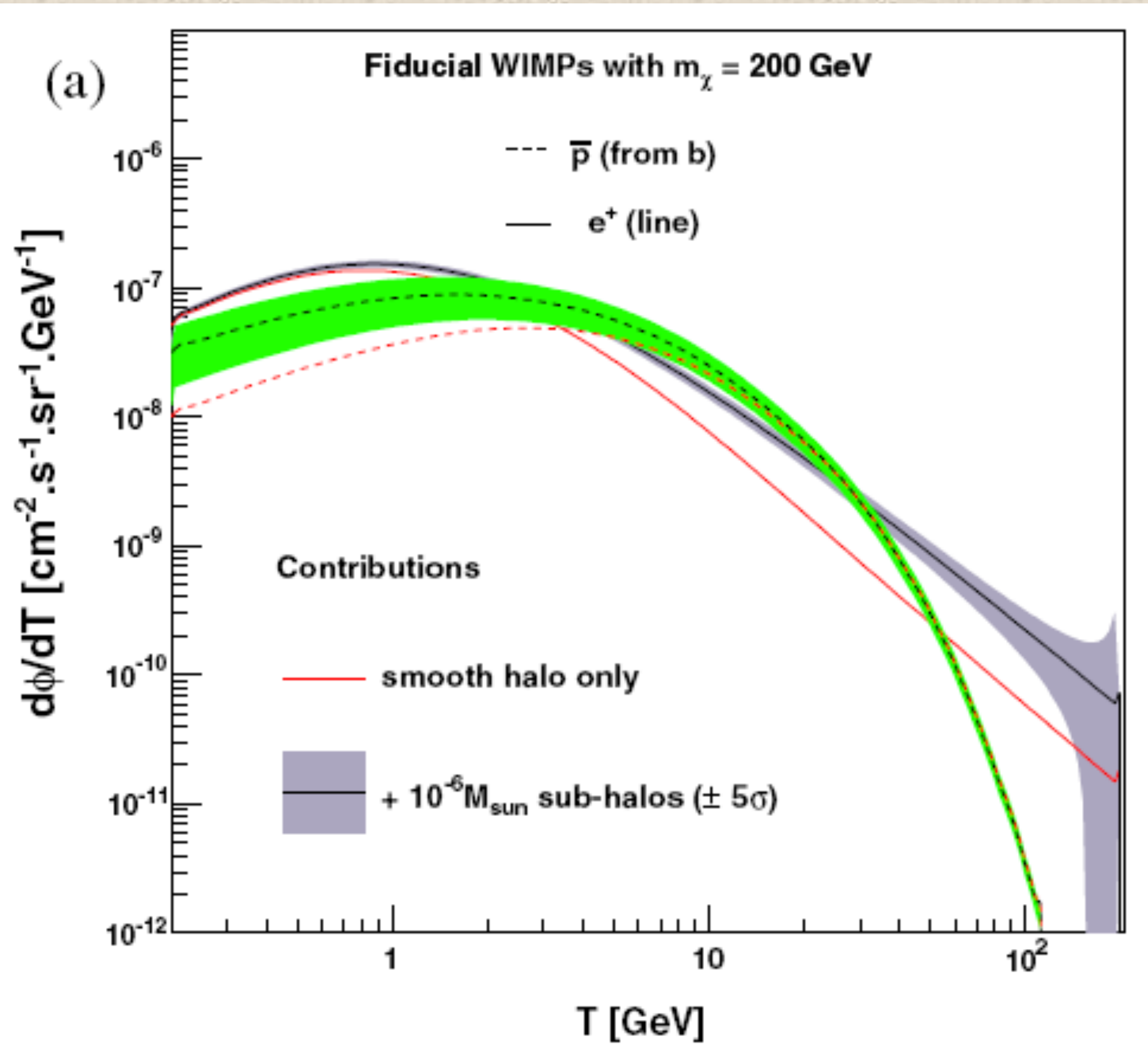
Astrophysical boosts: numerical simulations and propagation
Energy dependent enhancements





Lavalle, Yuan, Maurin, Bi A&A 2008

Possible astrophysical boost factors



Horizon simulation
(similar results
For via lactea)
Lavalle, Nezri, Ling, Athanassoula, Theyssier PRD 2008

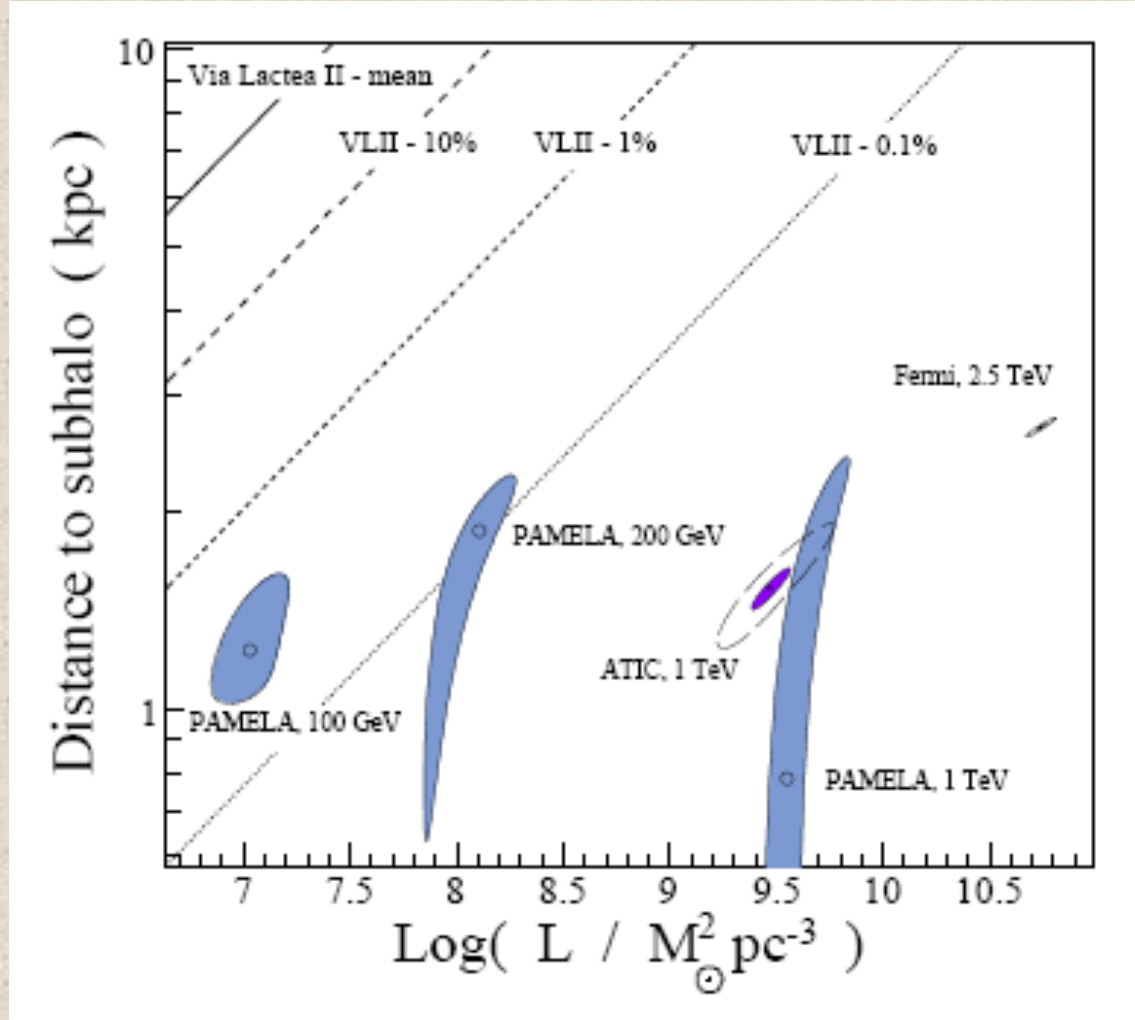
A big boost from DM substructure is not predicted

CR lepton puzzle in the light of cosmological N-body simulations

Brun, Delahaye, Diemand, Profumo, Salati 0904.0812 PRD2009

Luminosity vs distance
A statistical analysis

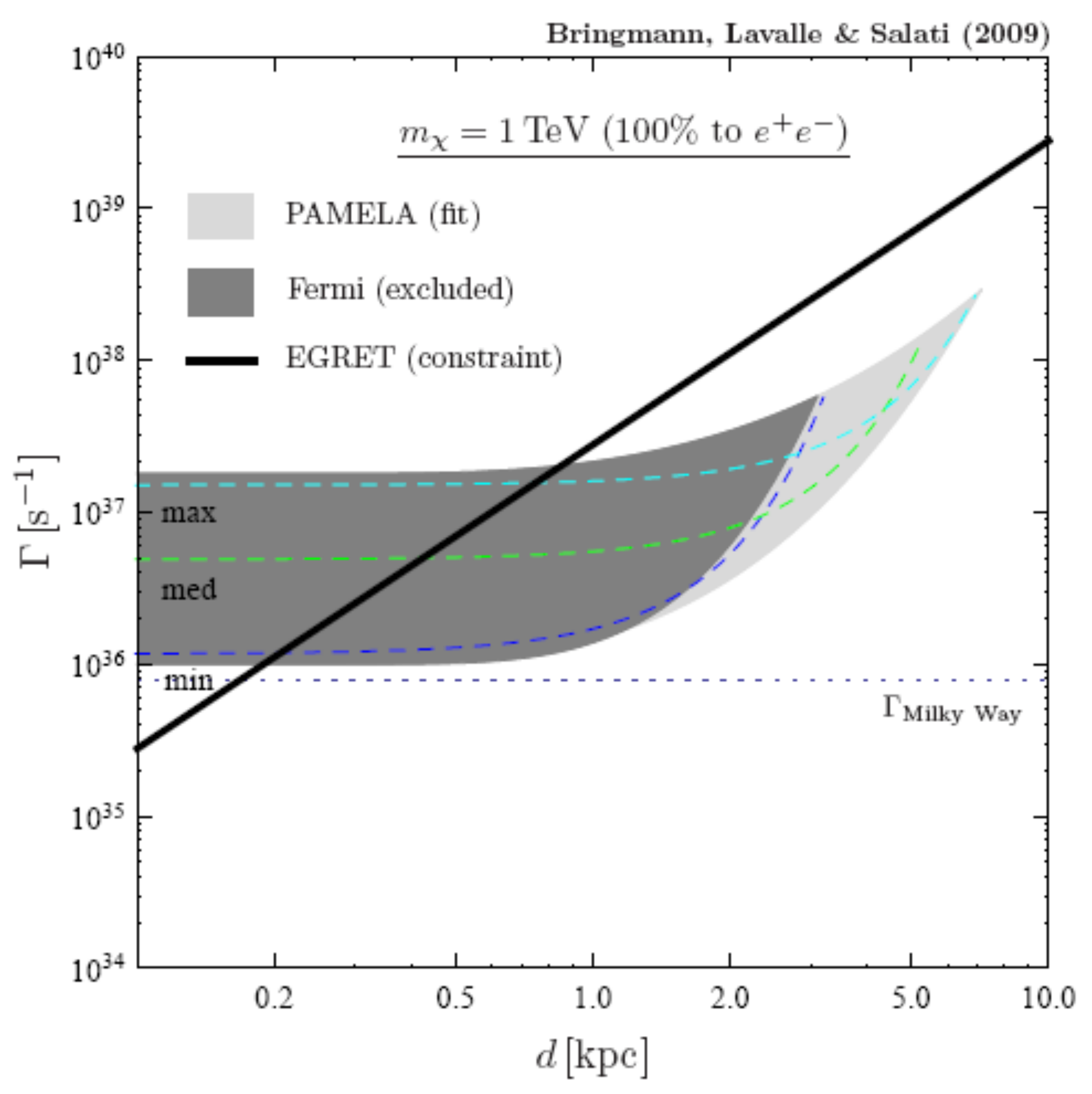
Unlikely scenarios



Possible astrophysical boost factors

Γ is the annihilation rate

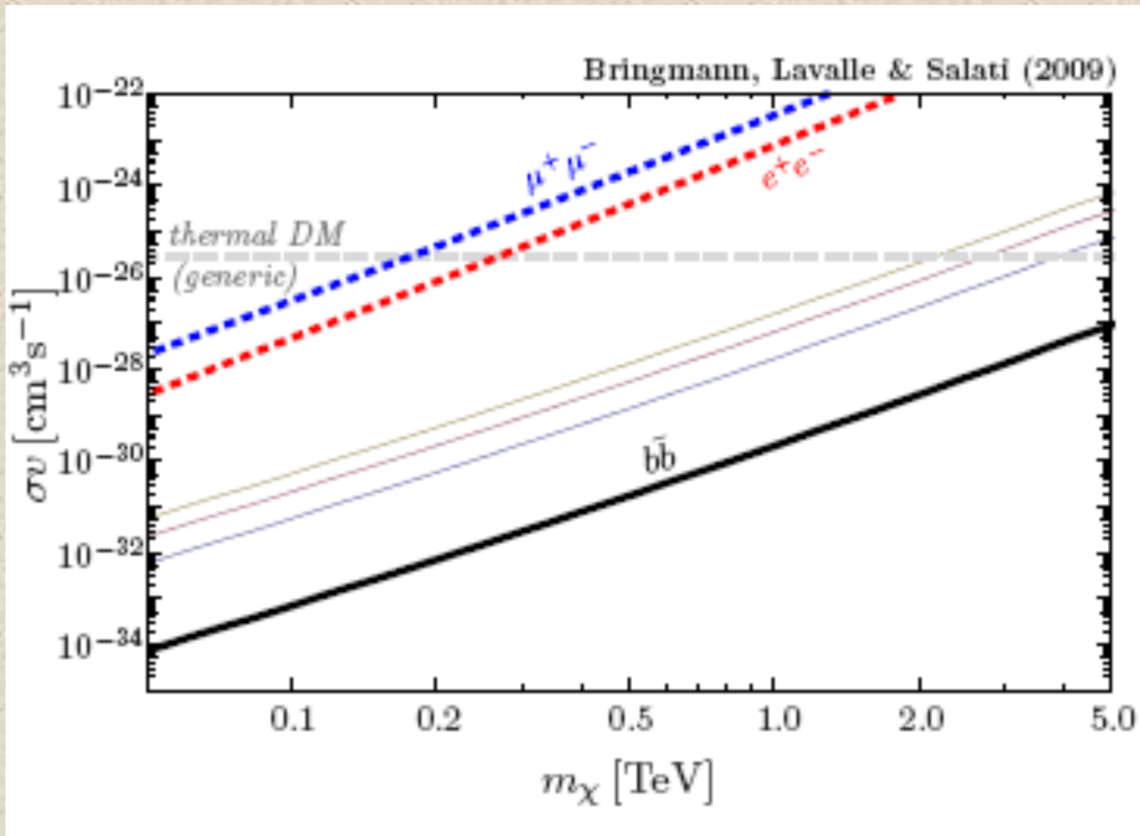
d is the distance to a nearby DM source (i.e. clump)



Bringmann, Lavalle, Salati PRL 2009

Possible boosts from IMBHs?

Large DM densisty enhancements (mini-spikes)
around intermediate mass black holes



Constraints from EGRET
Unlike scenario

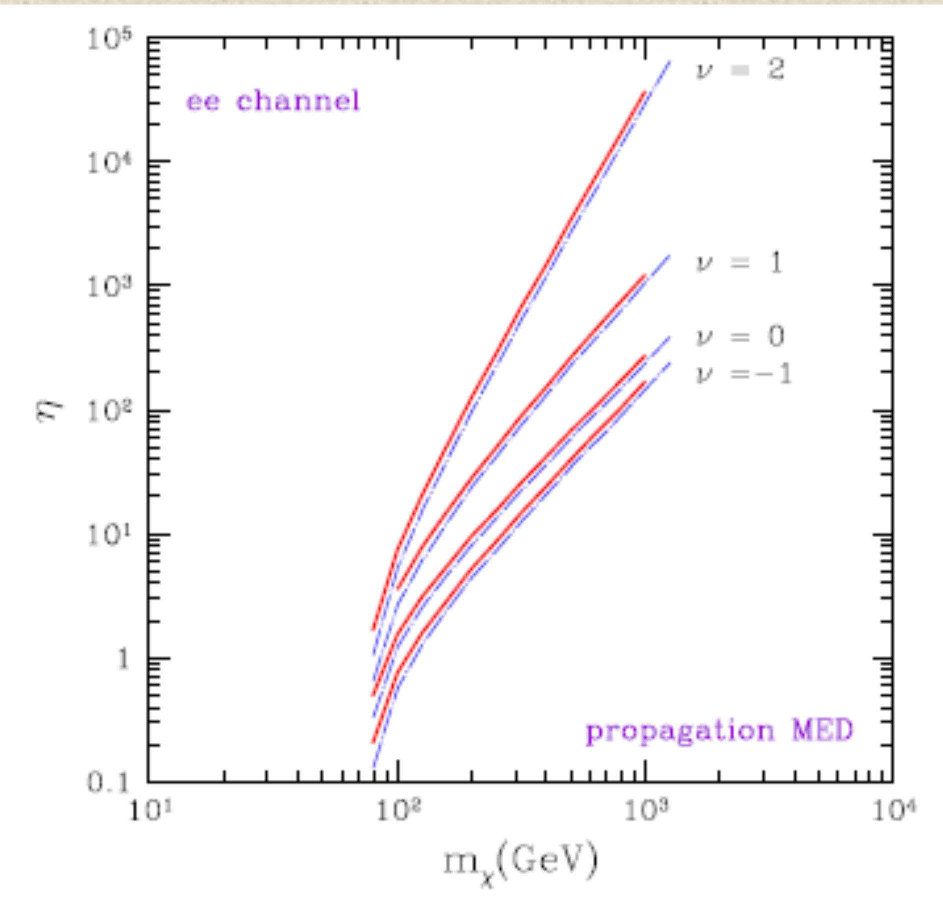
Bringmann, Lavalle, Salati, PRL 2009

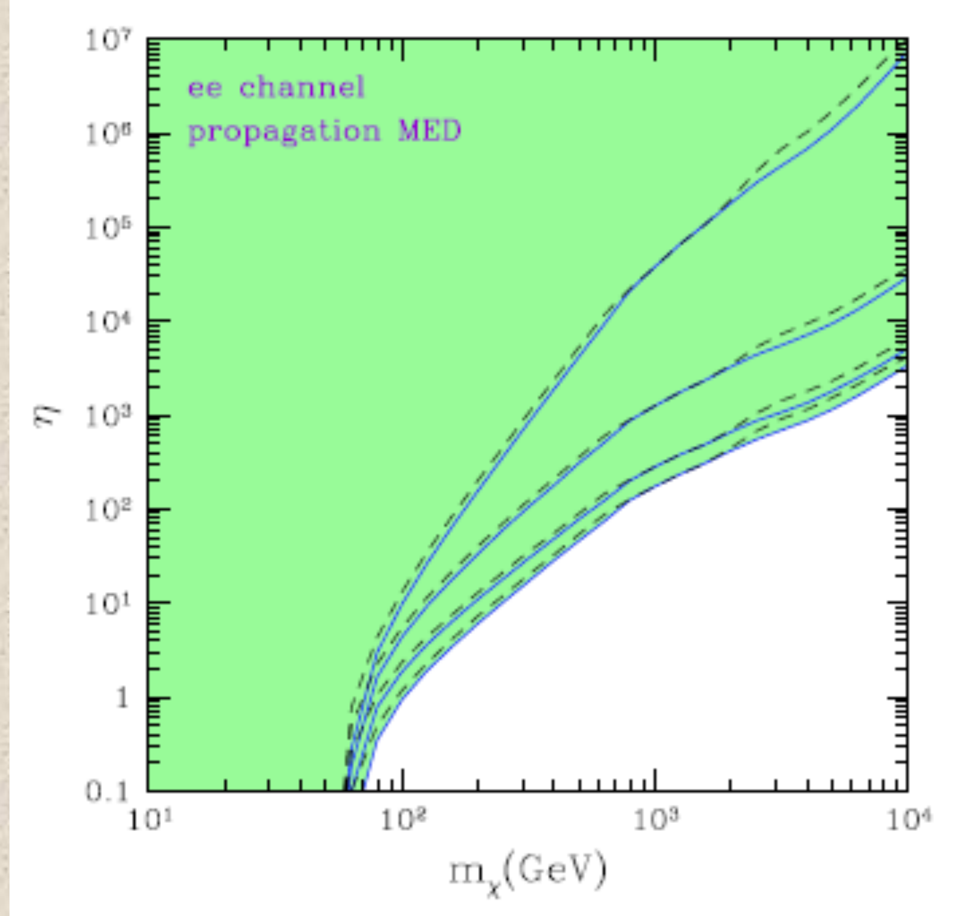
Cosmological Boosts

large <σv> provided by modified cosmologies

Catena, Fornengo, Pato, Pieri, Masiero arxiv:0912.4421

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

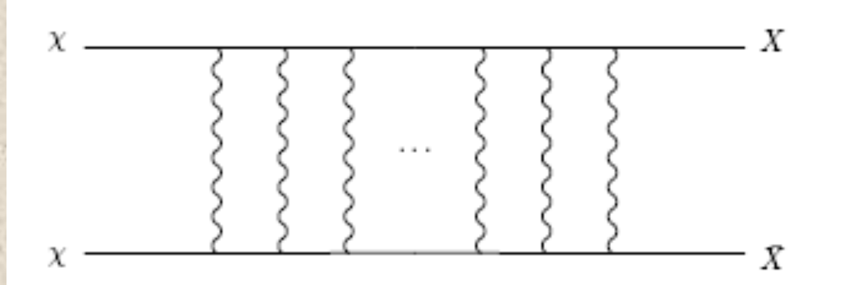




Boost required by Pamela

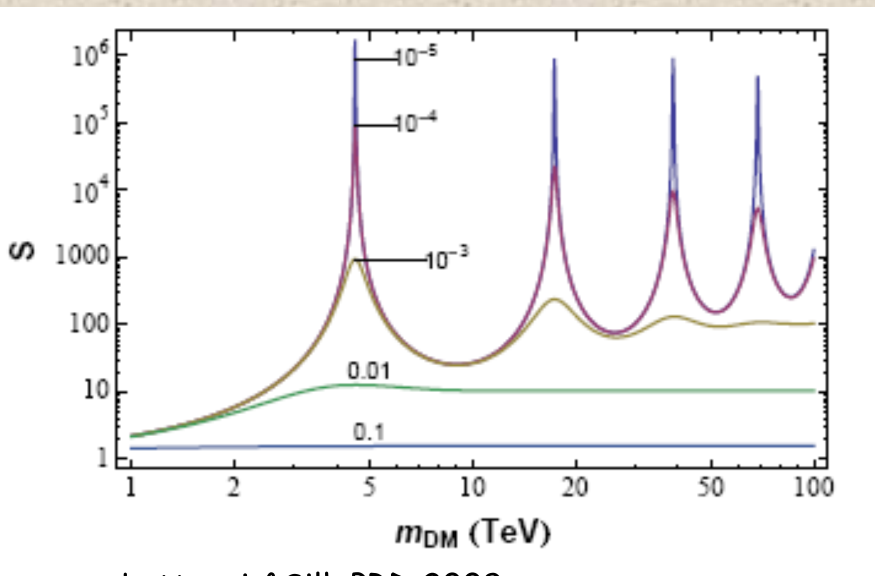
Astrophysical bounds

Boosts from Particle Physics
Sommerfeld effct

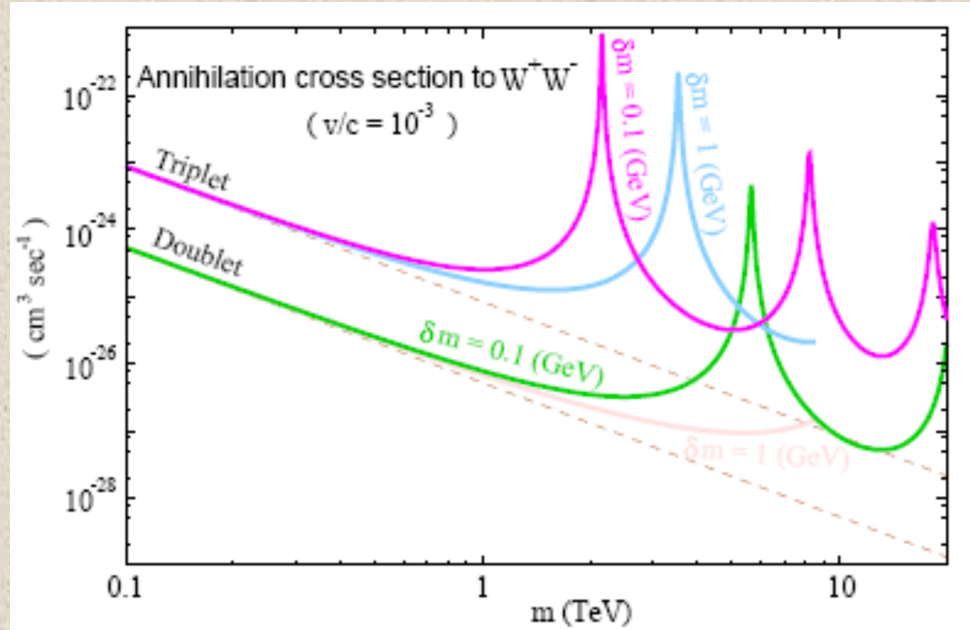


$$S = \frac{\pi\alpha}{\beta}(1 - e^{-\pi\alpha/\beta})^{-1}$$

Hisano, Matsumoto, Nojiri PRL 2004



Lattanzi &Silk PRD 2009



Analysis of e+e- data usually DO NOT consider astrophysical uncertainties on the signal AND on the background.

Similarly, to constrain models by crossed analysis, uncertainties on the signals and all the backgrounds must be included.

Otherwise, results have restricted validity

Constraints / Crossed checks in

- Antiprotons (see later)
- Multi-wavelength: Radio, IR,X-ray, Gamma rays (diffuse, IC, point sources,…)

talks by Ullio & Cuoco   i.e.: only Italians matter ☺

Primary positrons and electrons from pulsars

Pulsars can be the sources of energetic e^+ and e^-: pair production in the strong pulsar magnetoshpere

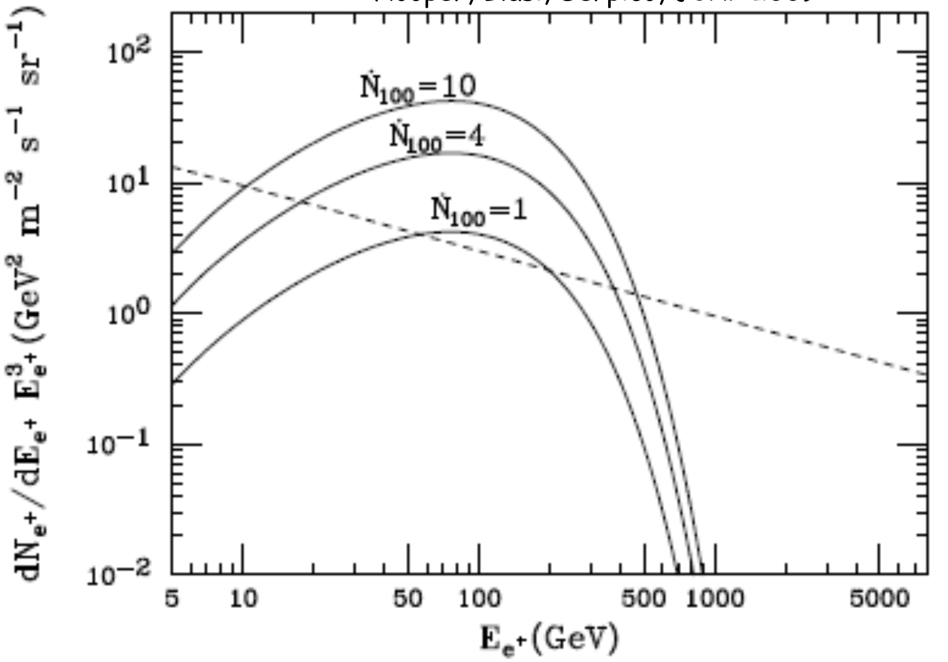
Polar cap (disfavoured by recent Fermi data) and outer gap models

High energy e- are accelerated by the strong pulsar electric field

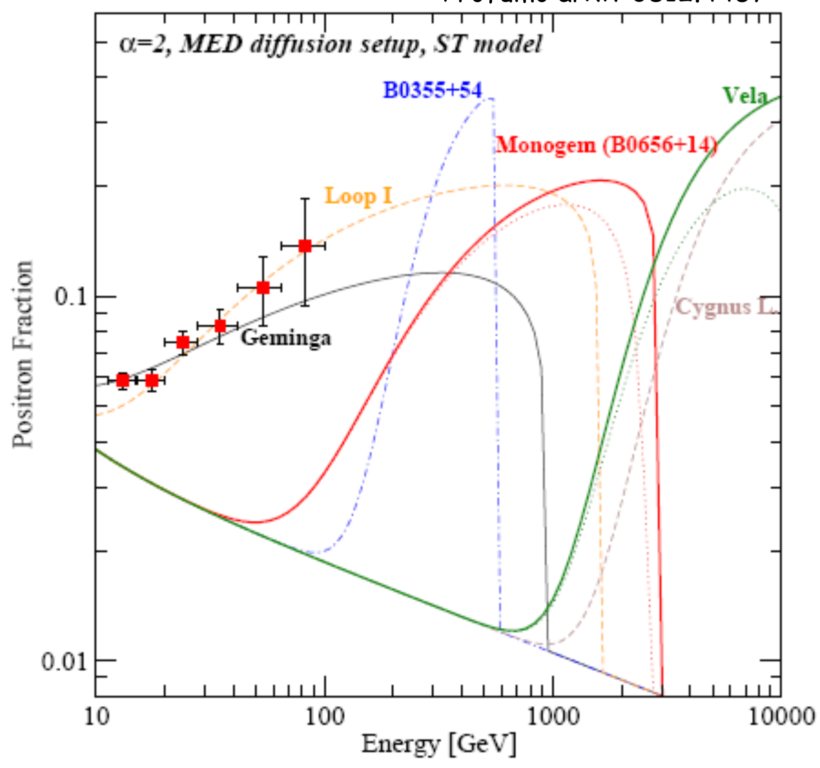
e- synchrotron radiate gamma rays

e^+/e^- are produced by pair conversion in strong magnetic fileds of the PSR or scattering off of thermal X-rays

Hooper, Blasi, Serpico, JCAP 2009

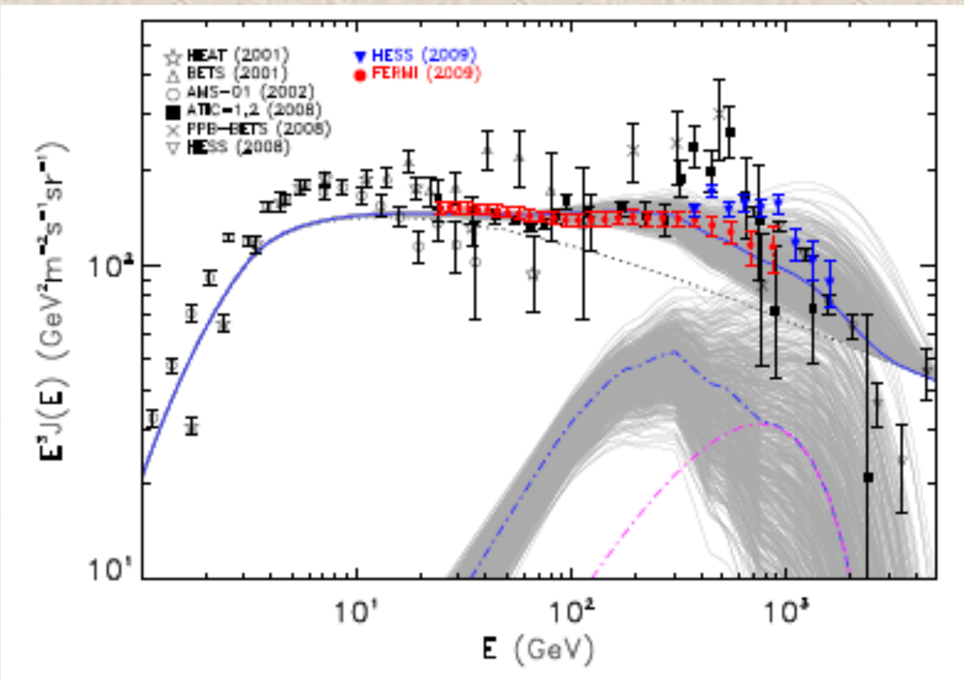


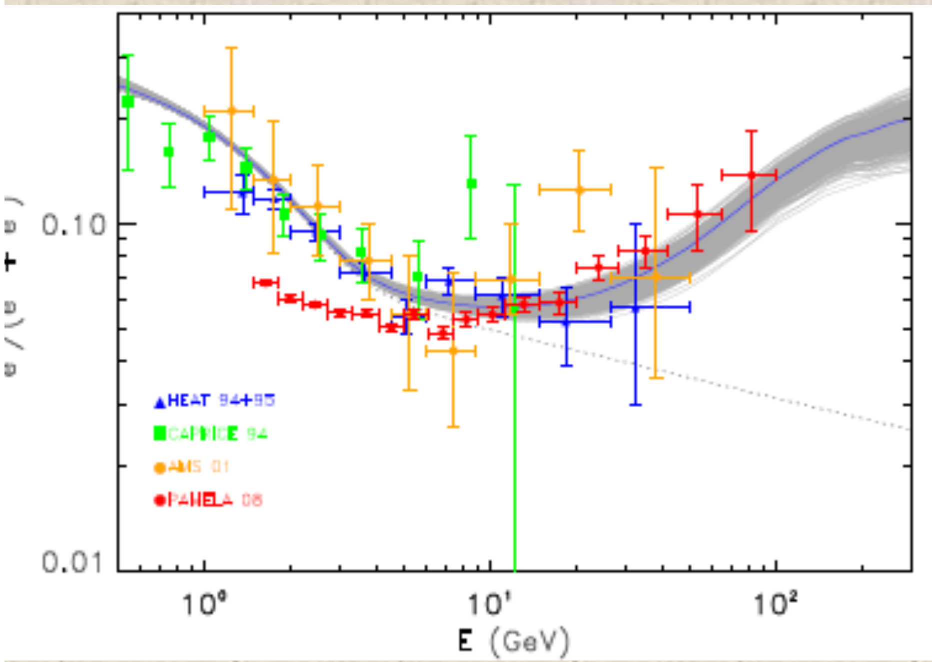
Profumo arxiv:0812.4457



FERMI Electrons and PAMELA positron fraction: contribution from local pulsars (d<3 kpc)

(Grasso et. al 0905.0636)

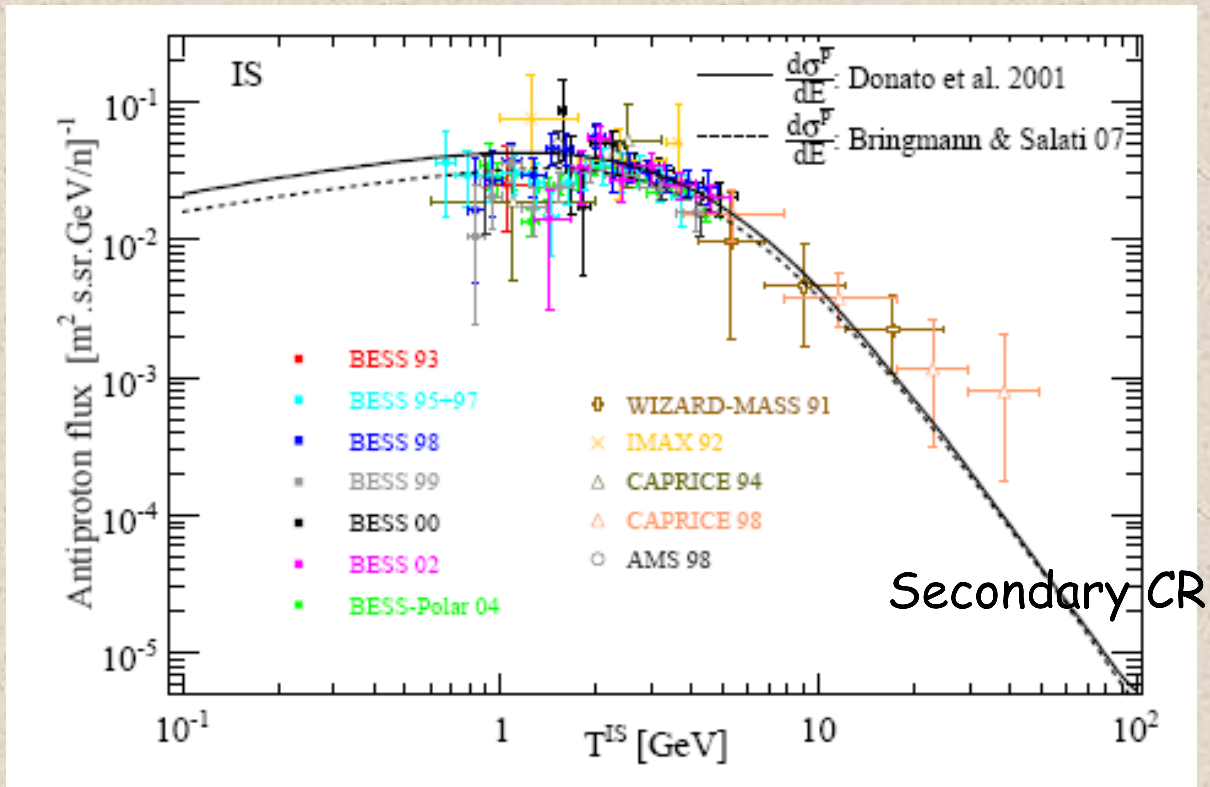




Good description of both e- and e+/(e+e-)

Antiprotons data

FD, Maurin, Brun, Delahaye, Salati PRL 2009



Secondary CR production

Demodulated data cover ~ 0.7 ÷40 GeV

All experiments from **ballons** (residual atmosphere) except **AMS98**

Pamela: preliminary data 3-10 GeV, and expected in 0.08 ÷ 190 GeV

Antiproton/proton: data and models

Theoretical calculations with the semi-analytical DM, compatible with stable and radioactive nuclei

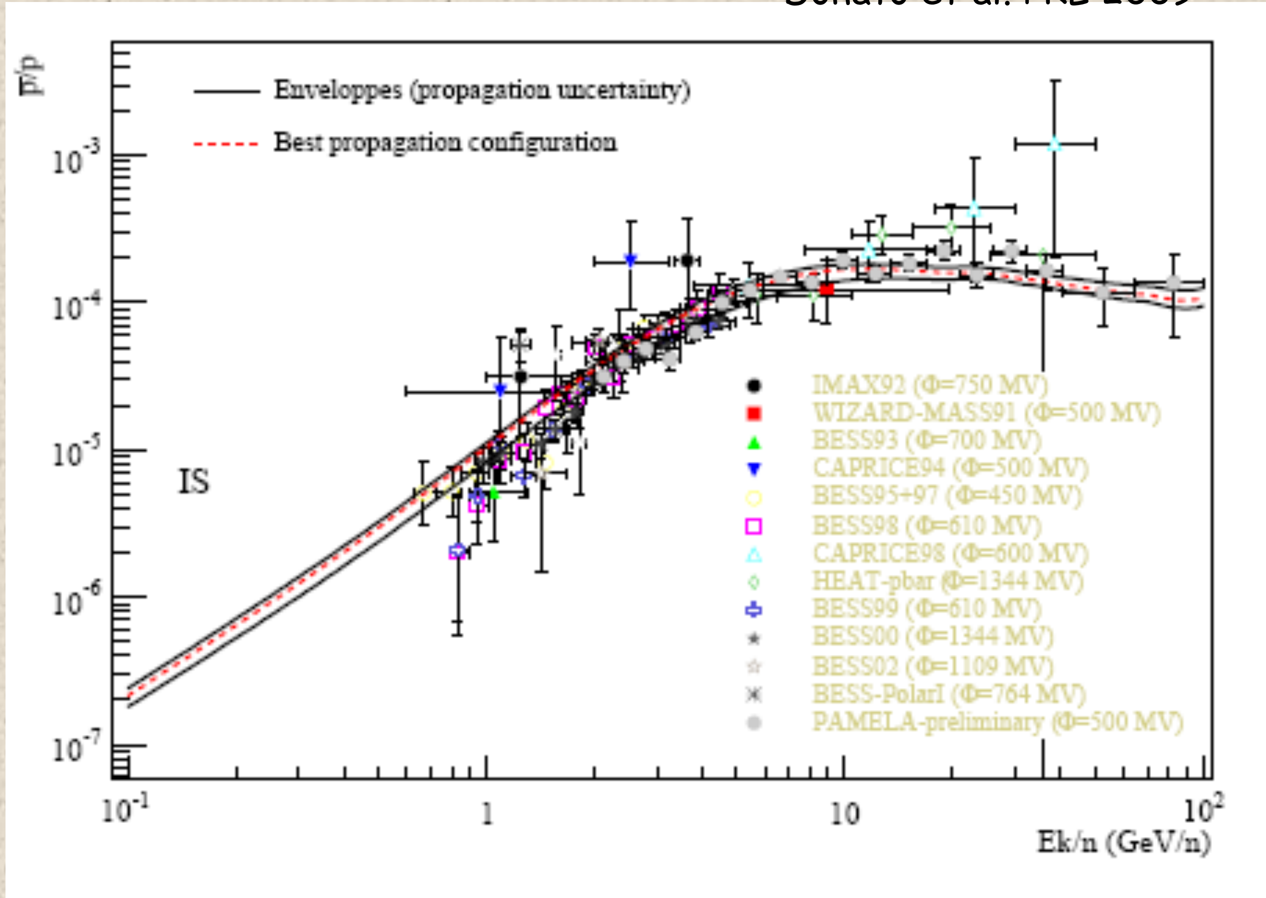
Donato et al. PRL 2009

PROTON flux:

$\Phi = A\beta^{-P1}R^{-P2}$

- T<20 GeV: Bess 1997-2002
(Shikaze et al. Astropart. Phys. 2007)

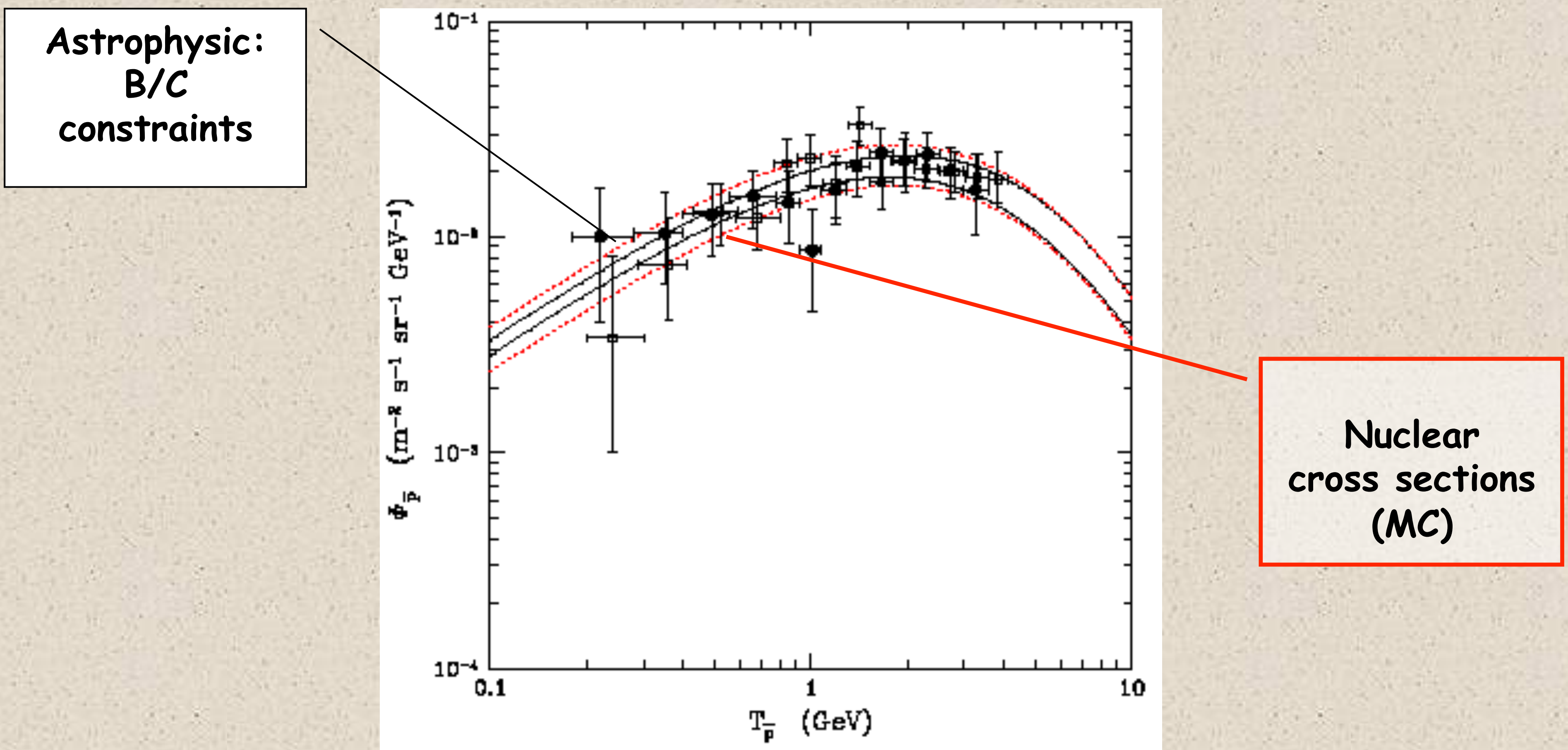
- T>20 GeV, our fit (Bess98, BessTeV&AMS):
{24132; 0; **2.84**}



NO need for new phenomena (astrophysical / particle physics)

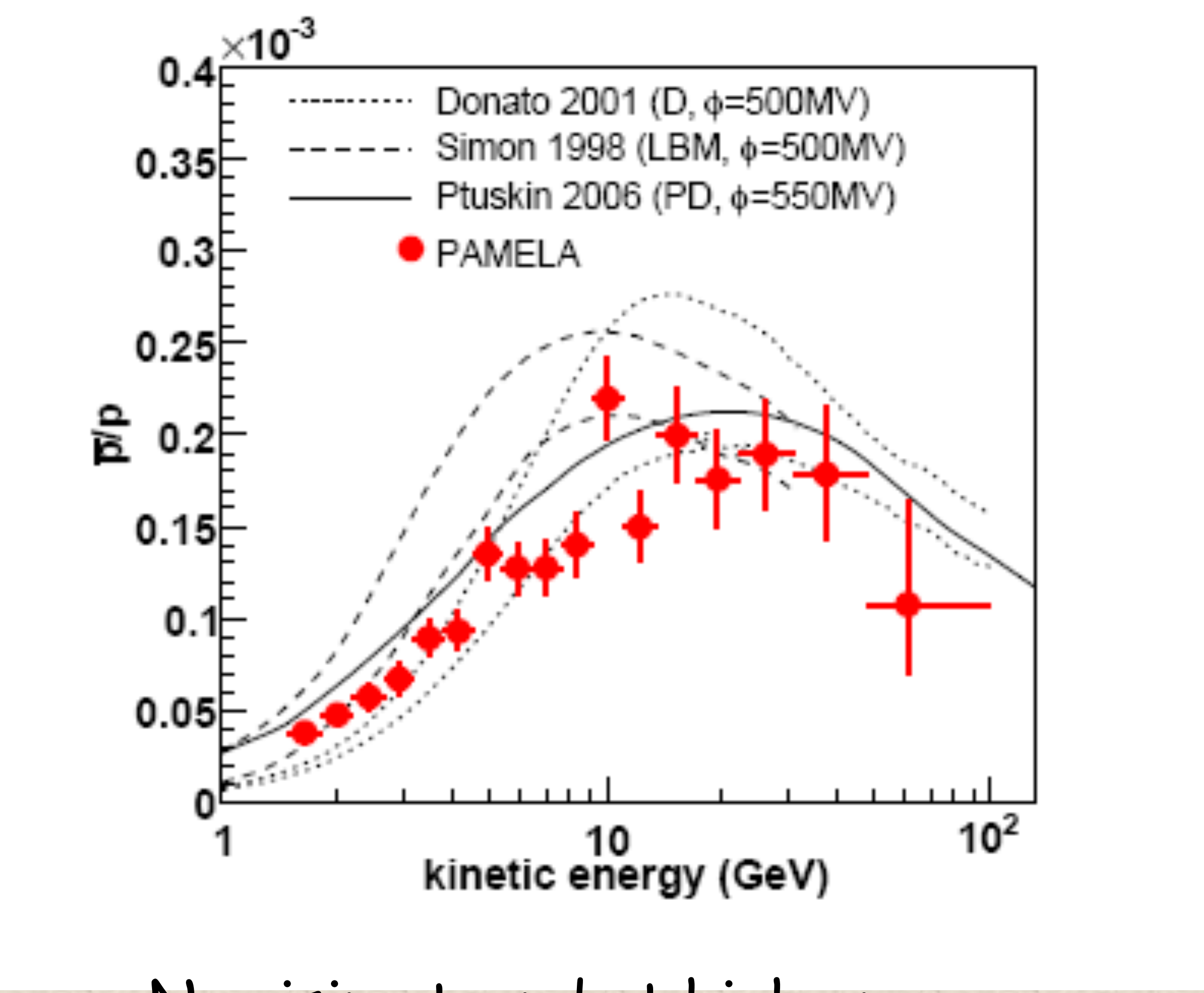
Uncertainties on the Secondary Antiproton Flux

Donato, Maurin, Salati, Barrau, Boudou, Tailletl ApJ 2001



Pbar/p data by PAMELA

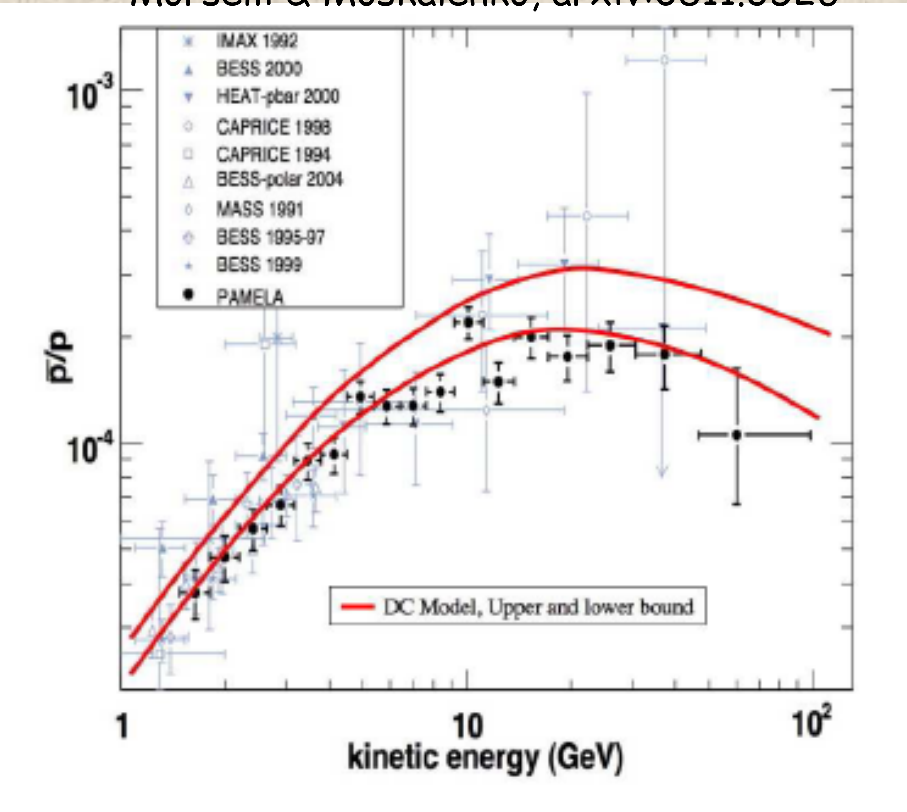
Adriani et al. PRL 2009



No rising trend at high energy

Compatibility with data – more (Galprop)

Morselli & Moskalenko, arxiv:0811.3526



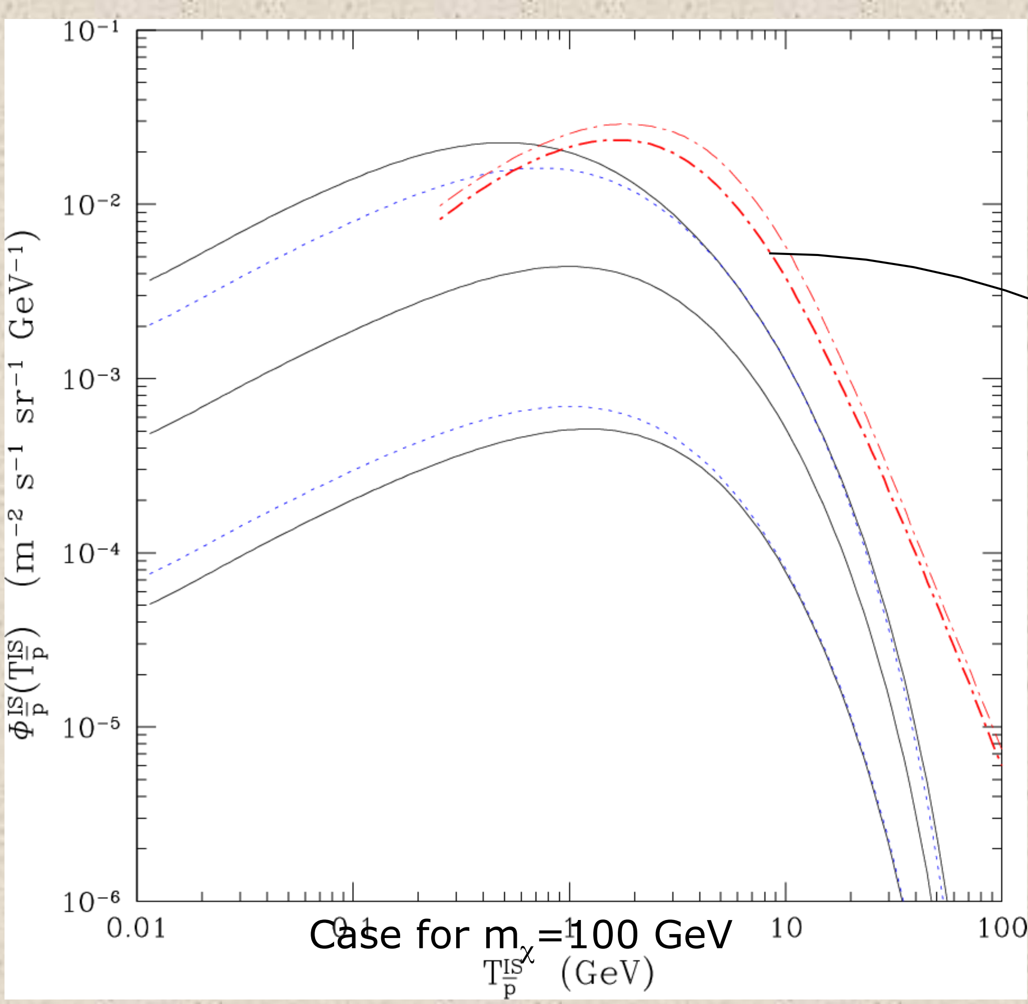
Band: approximate range expected for secondary production with Galprop

PRIMARY FLUXES and UNCERTAINTIES

Solid: $\chi^2_{B/C}<40$

Dotted: $\chi^2_{B/C}<30$

(22 DF)

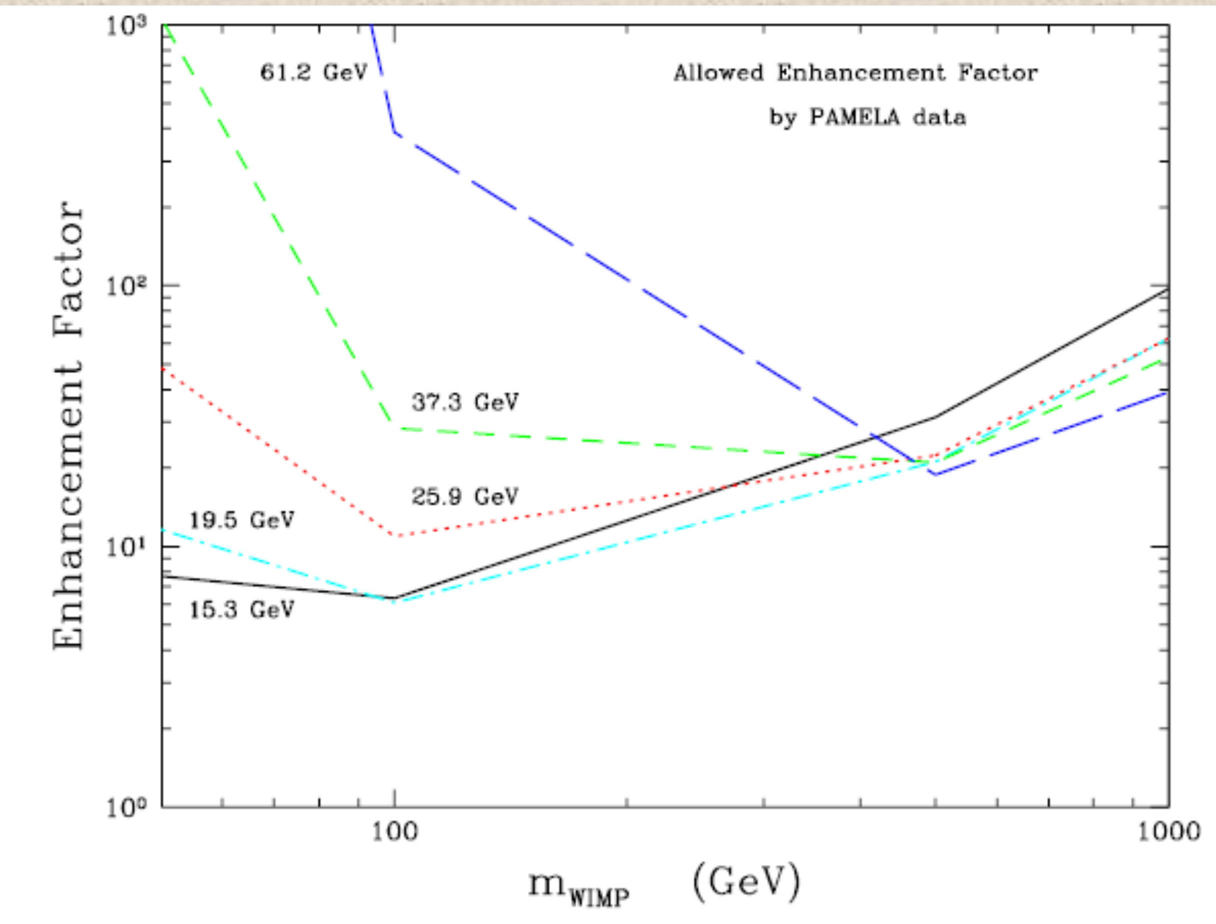


Case for m_χ=100 GeV

Secondary flux

CASE	δ	K_0 (kpc^2/Myr)	L (kpc)	V_c (km/sec)	V_A (km/sec)	$\chi^2_{B/C}$ (22 DF)
MAX	0.46	0.077	15	5	118	39.98
MED	0.70	0.011	4	12	53	25.68
MIN	0.85	0.002	1	13.5	22	39.02

Allowed Enhancement factors from pbar data



Limits obtained for:

- $\langle\sigma v\rangle = 3\cdot 10^{-26}$ cm^3/s
- MED prop parameters
- Cored Isoth DM
- $\rho = 0.3$ GeV/cm^3
- 2σ error bars, T>10 GeV

Boost < 6-20-40 for m=0.1-0.5-1 TeV

Limits get weaker for increasing masses

Enhancement of the antiproton flux?

- Clumpiness in the DM distribution in the Milky Way: energy dependent (Lavalle, Yaun, Maurin, Bi A&A 2008)

  → boost factors may be different for positrons, antiprotons, gamma rays, ..

  (Lavalle, Pochon, Salati, Taillet A&A 2006)

  → a low boost factor (for gamma rays) emerges from most recent N-body simulations (Diemand et al. 2008; Springel et. MNRAS 2008)

- Enhancement of the annihilation cross section

  (Bergstrom PLB 1989; Hisano et al. PRL 2004)

  → depends on the mass (> TeV)

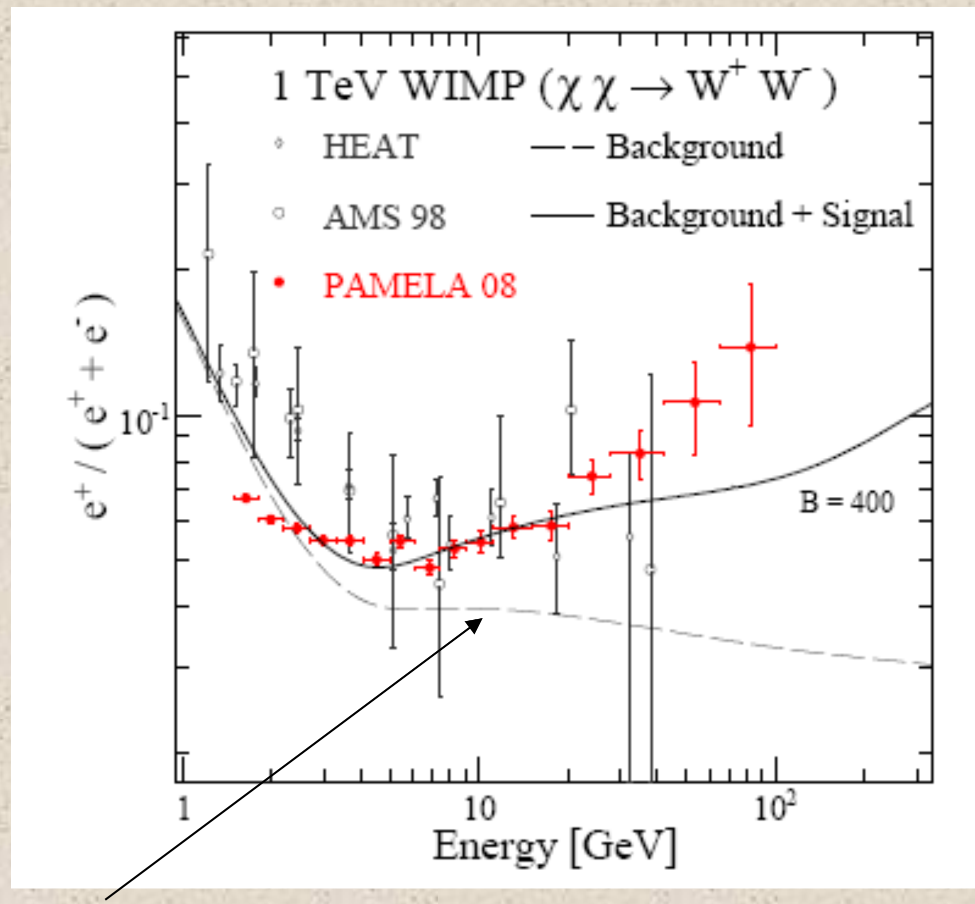
Compatibility with positron data?

Constraints from positron/electron data

Donato et al. PRL 2009

Example: m=1 TeV, WW
fit improves, but highest points in E not explained

High boost factor required ☹



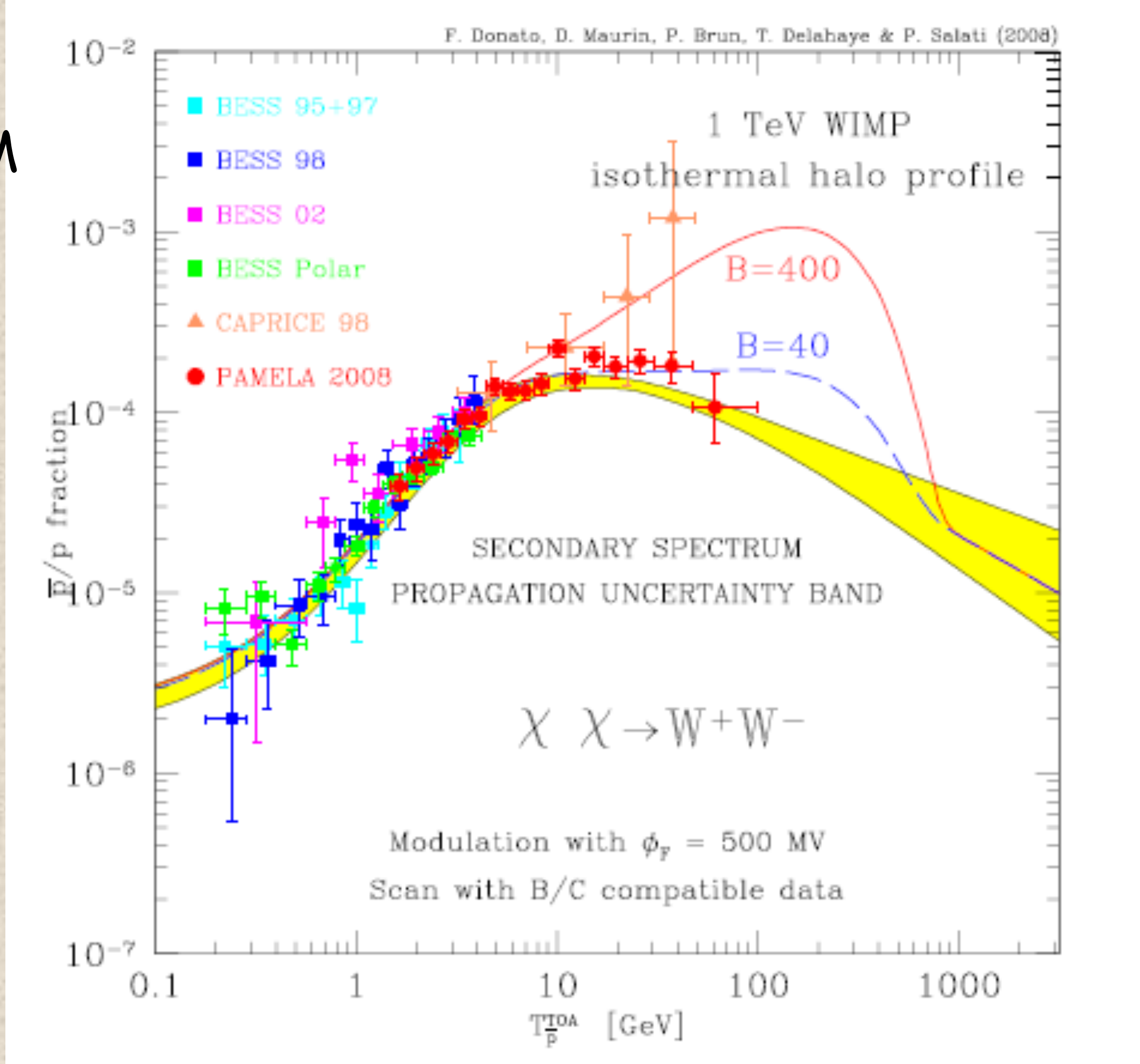
Secondary positrons
Best fit propagation parameters

Effect on antiprotons

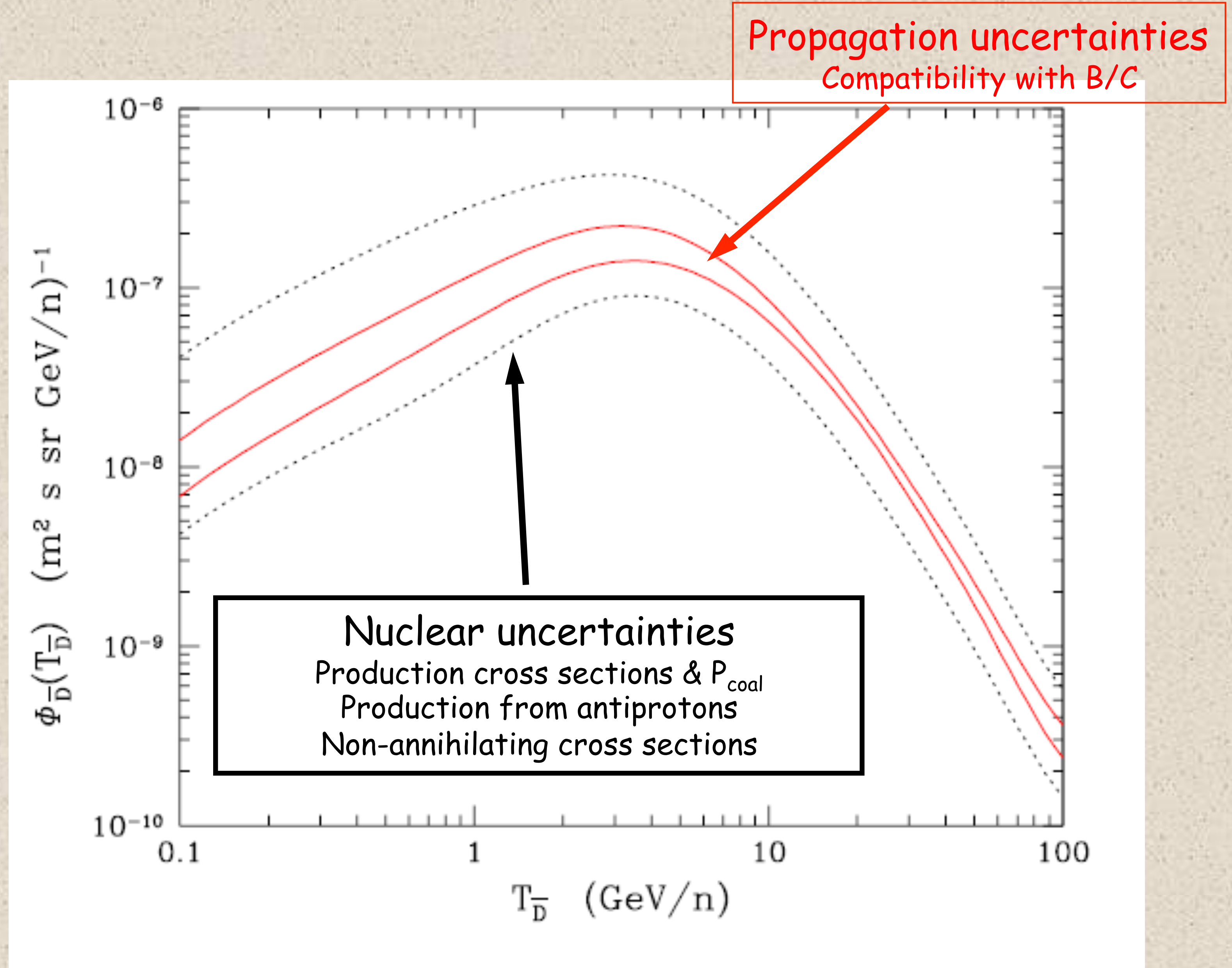
The same example: 1 TeV DM candidate

B=400 largely excluded by Pamela!

B=40 marginally allowed

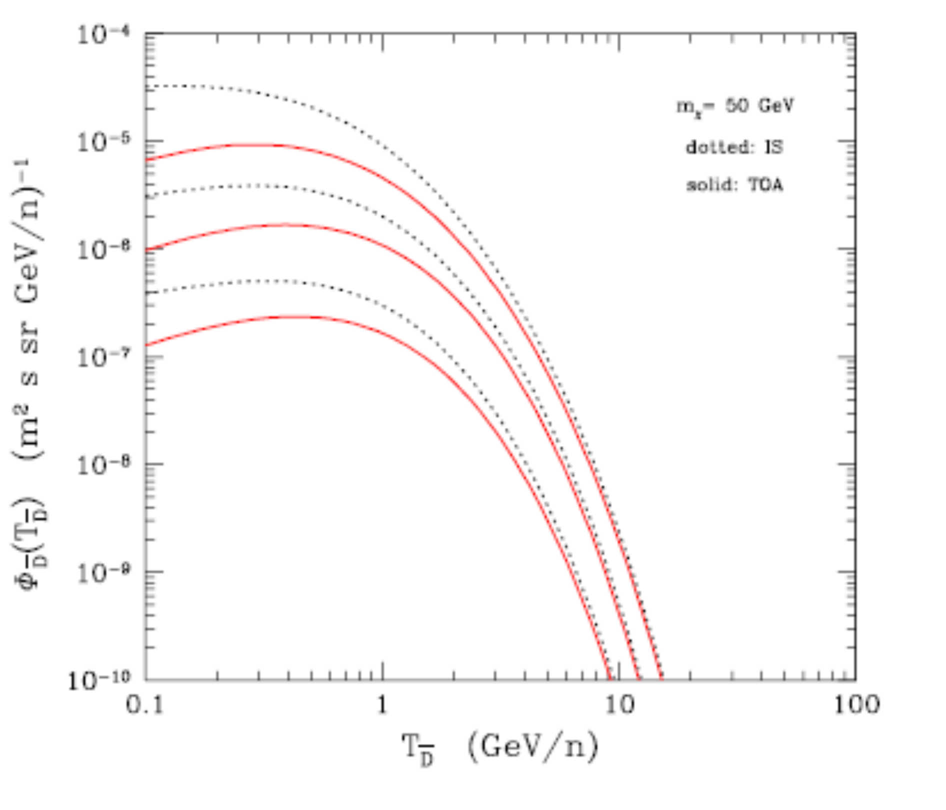


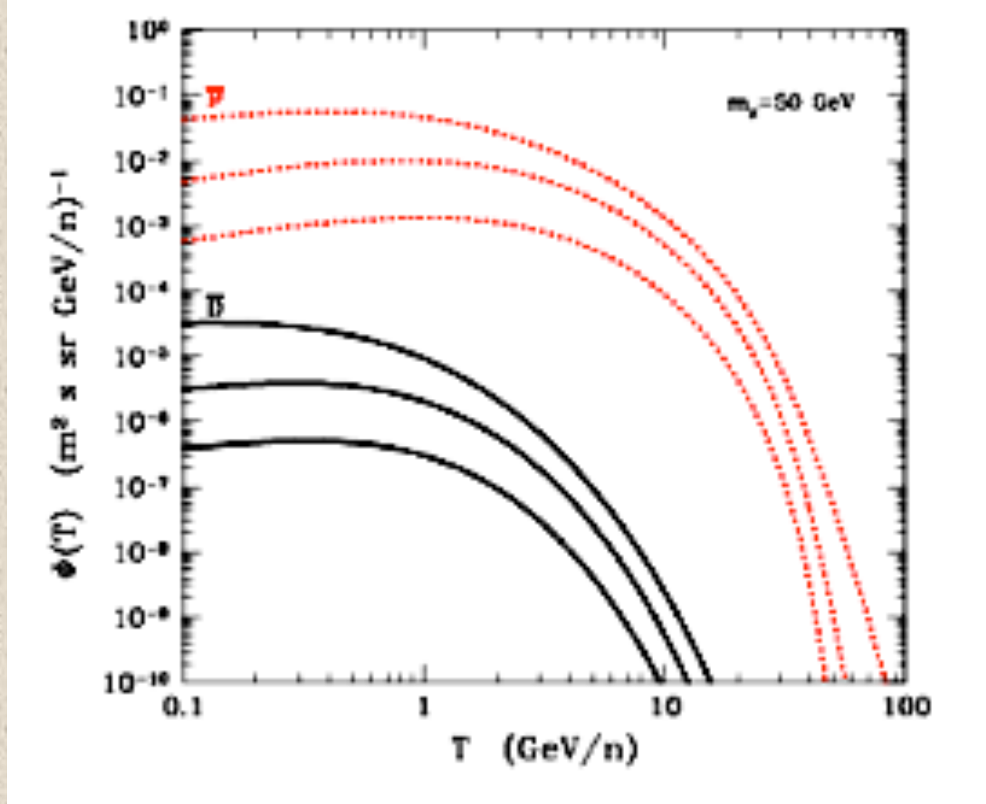
Secondary Antideuterons



Antideuterons from DM Annihilations

FD, Fornengo, Maurin PRD 2008; FD, Fornengo, Salati PRD 2000

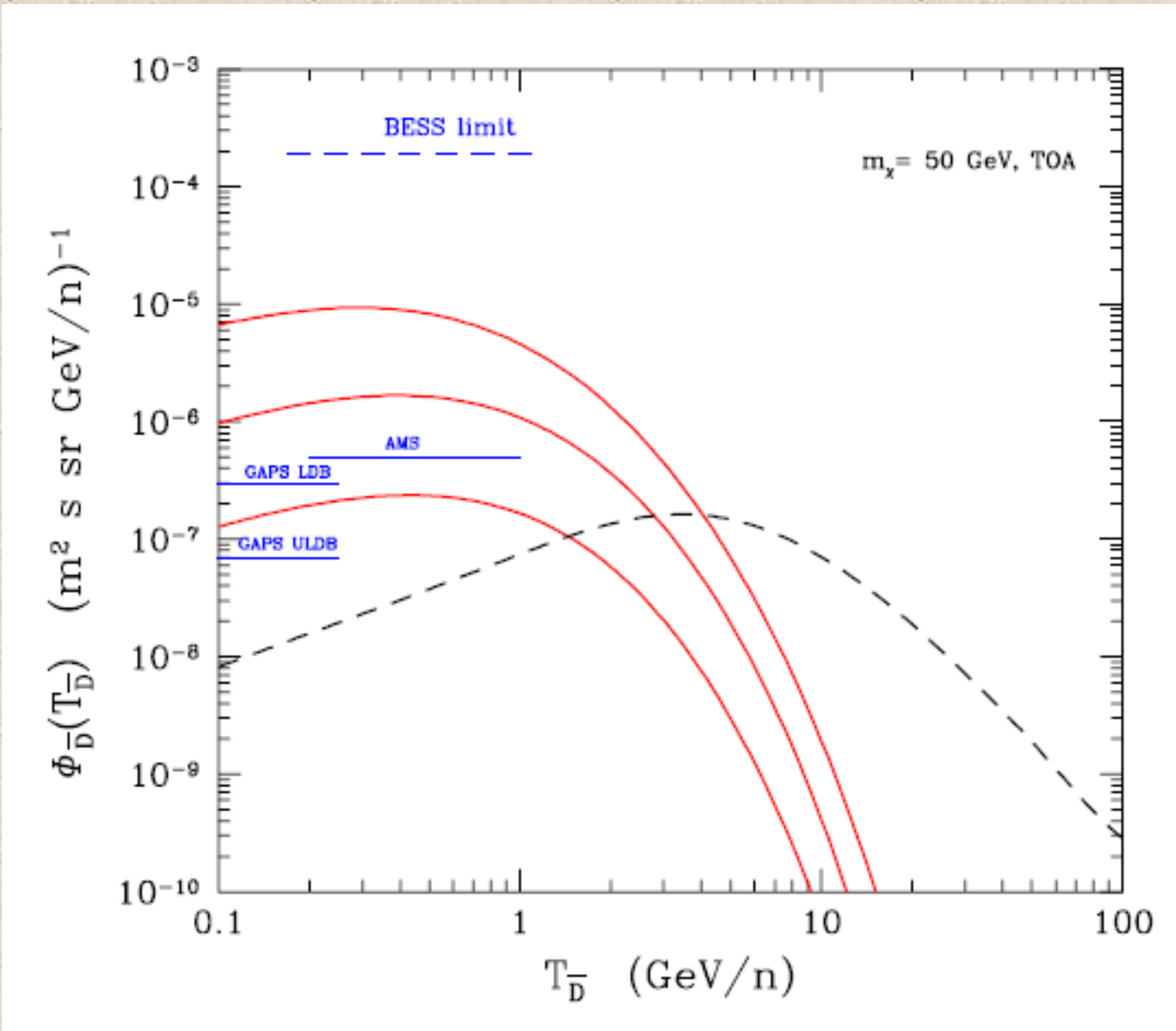




Propagation uncertainties driven by L
At lower energies, also effect from V_C

Antiprotons & Antideuterons
Propagation Uncertainties

ANTIDEUTERONS & future experiments



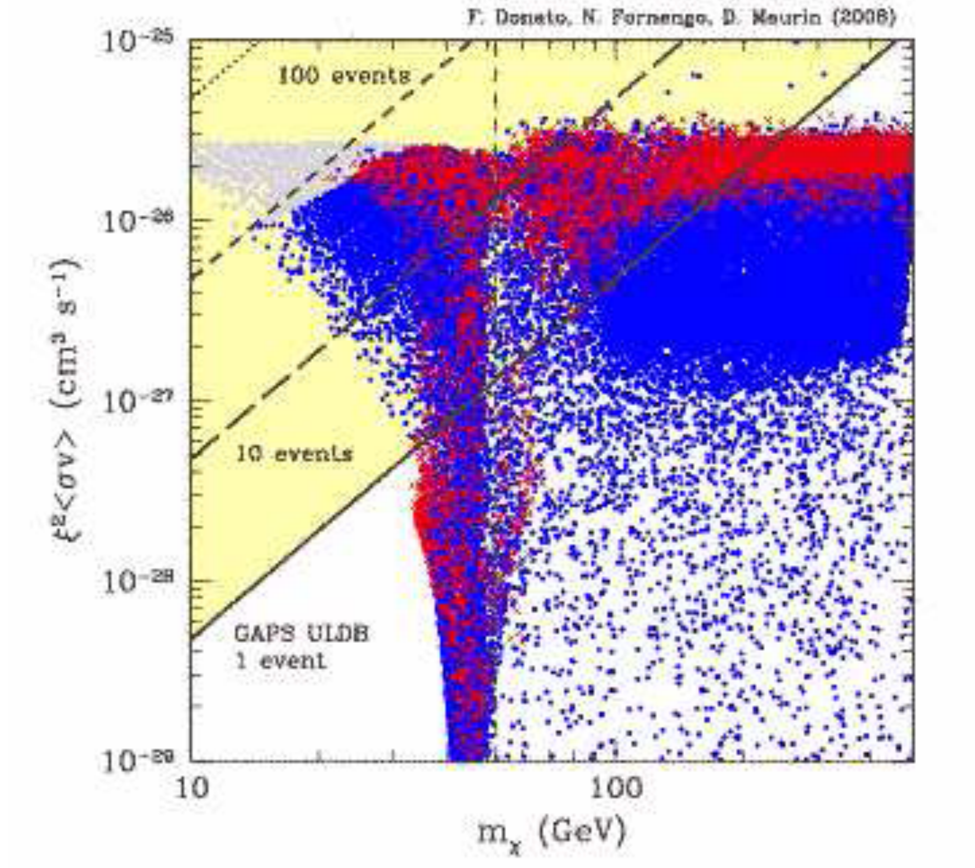
effMSSM neutralino dark matter can be detected by means of next generation space instruments measuring antideuterons in CRs

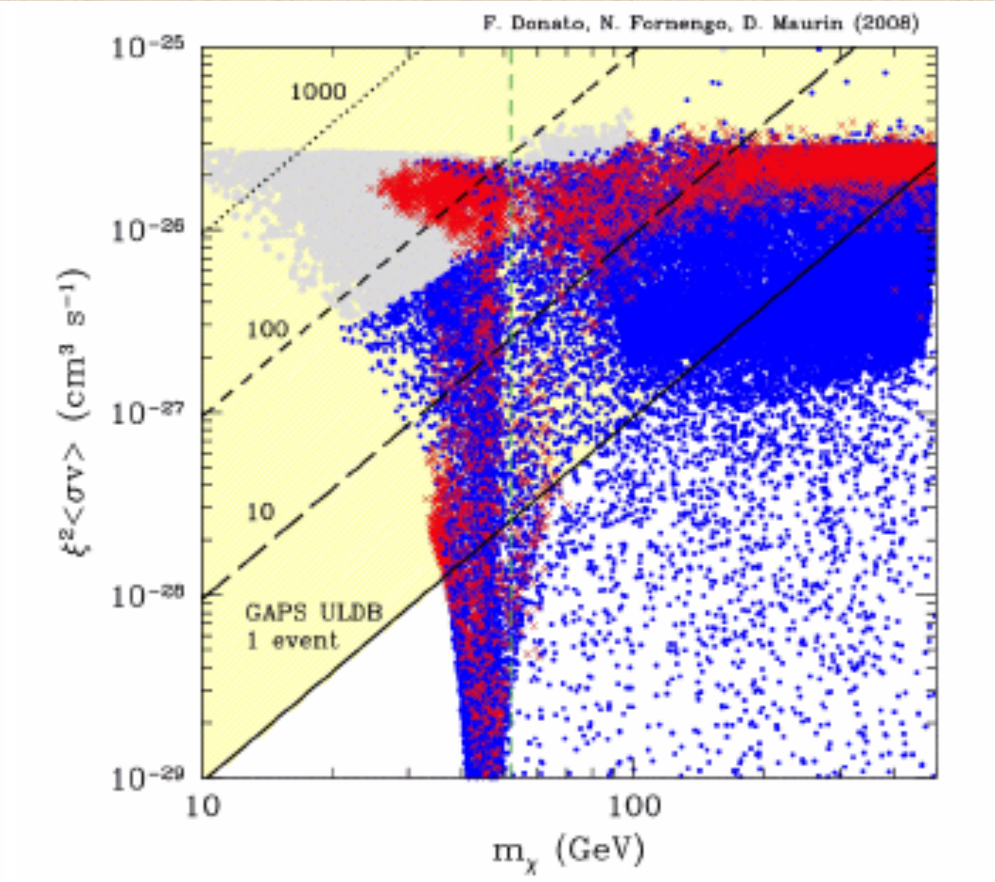
MSSM Inspections with Antideuterons

Median propagation Parameters

GAPS ULDB reach

Maximal propagation Parameters





Red: dominant neutralinos Blue: sub-dominant neutralinos

Grey: constraints from antiprotons

Theoretical astrophysical uncertainties **seriously** affect predictions for cosmic antimatter :

- Secondary positrons ~ 2-4
- Secondary antiprotons ~ 20-30%
- Seconday antideuterons up to 10 (also nuclear)

- Primary positrons ~ 5
- Primary antiprorons up to 100
- Primary antideuterons up to 100

Antiprotons perfectly fit by purely secondary…

Positrons nicely fit by primary astrophysical sources….

DM constributions are possible, but less natural

- Analysis of e+e- data MUST consider astrophysical uncertainties on the signal AND on the background.

- Similarly, to constrain models by crossed analysis, uncertainties on the signals and all the backgrounds must be included.
- Otherwise, results have restricted validity

- Research od DM hints in CRs is not
- Hopeless, is not dead, it is simply
- DIFFICULT!