

Positron (& antiproton) flux from DM annihilation

Pierre Salati – Université de Savoie & **LAPTH**

The Menu

- 1) A digest of galactic cosmic ray physics
- 2) Antiprotons – the revenge of orthodoxy
- 3) Positrons – an excess is confirmed
- 4) Discussion – DM or not DM ?



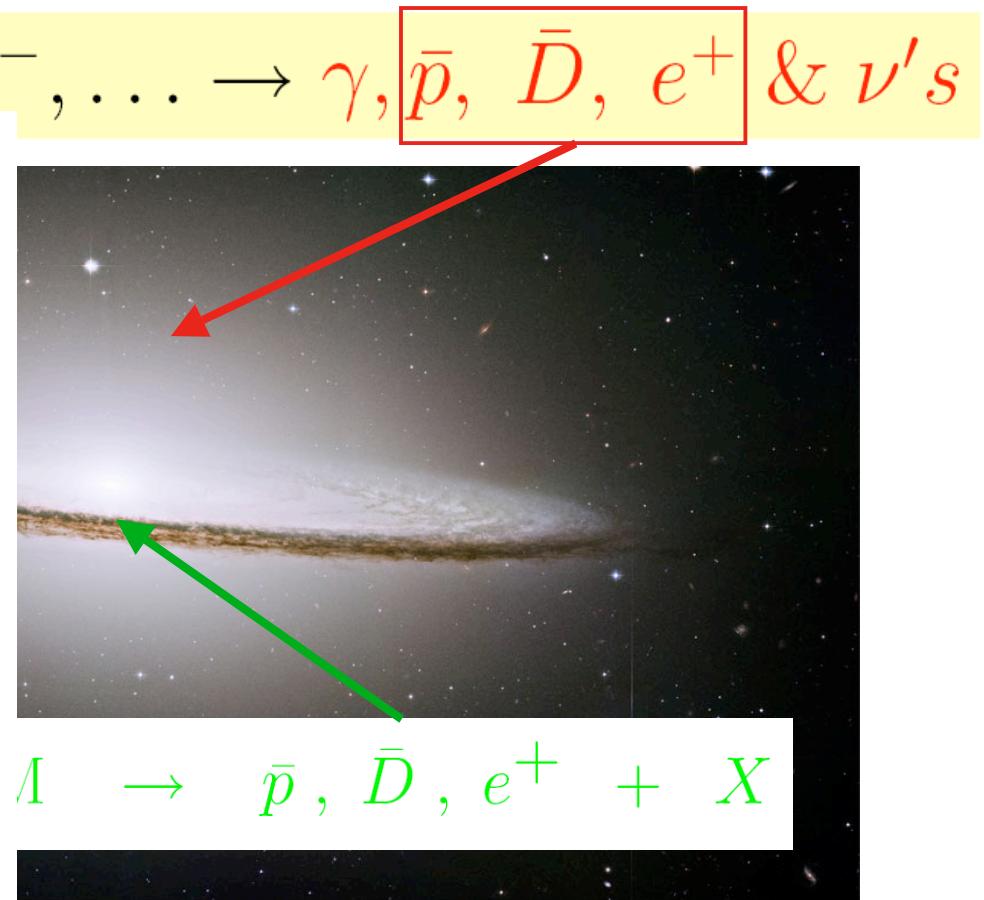
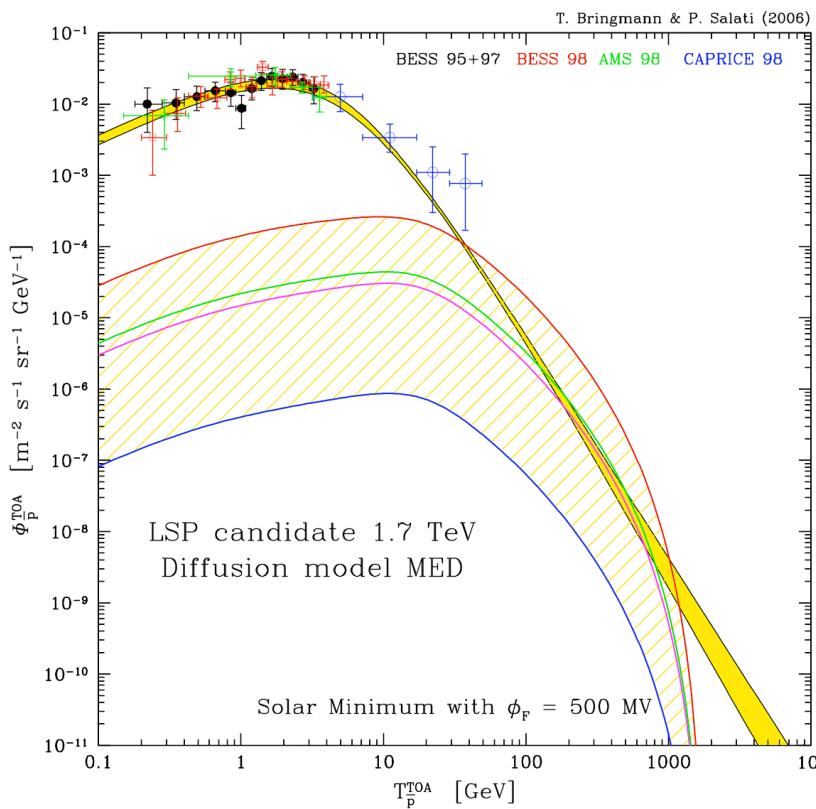
European Organization for Nuclear Research

ENTApP dark matter workshop – CERN – February 2–6 2009

Indirect signatures of DM species

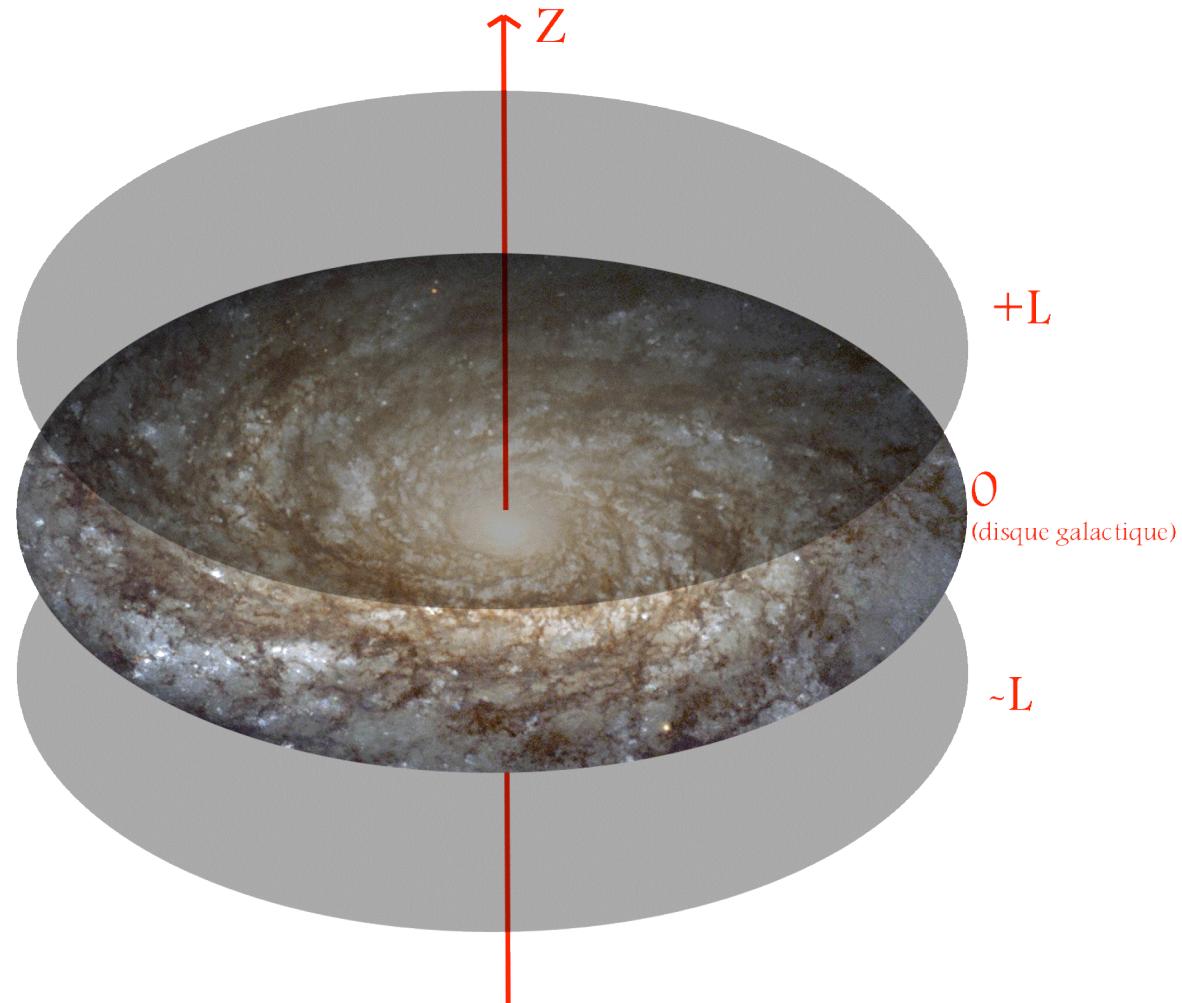
Weakly Interacting Massive particles – WIMPs – may be the major component of the haloes of galaxies. Their mutual annihilations would produce an indirect signature of high-energy cosmic rays :

$$\chi + \chi \rightarrow q\bar{q}, W^+W^- , \dots \rightarrow \gamma, \boxed{\bar{p}, \bar{D}, e^+} \& \nu's$$

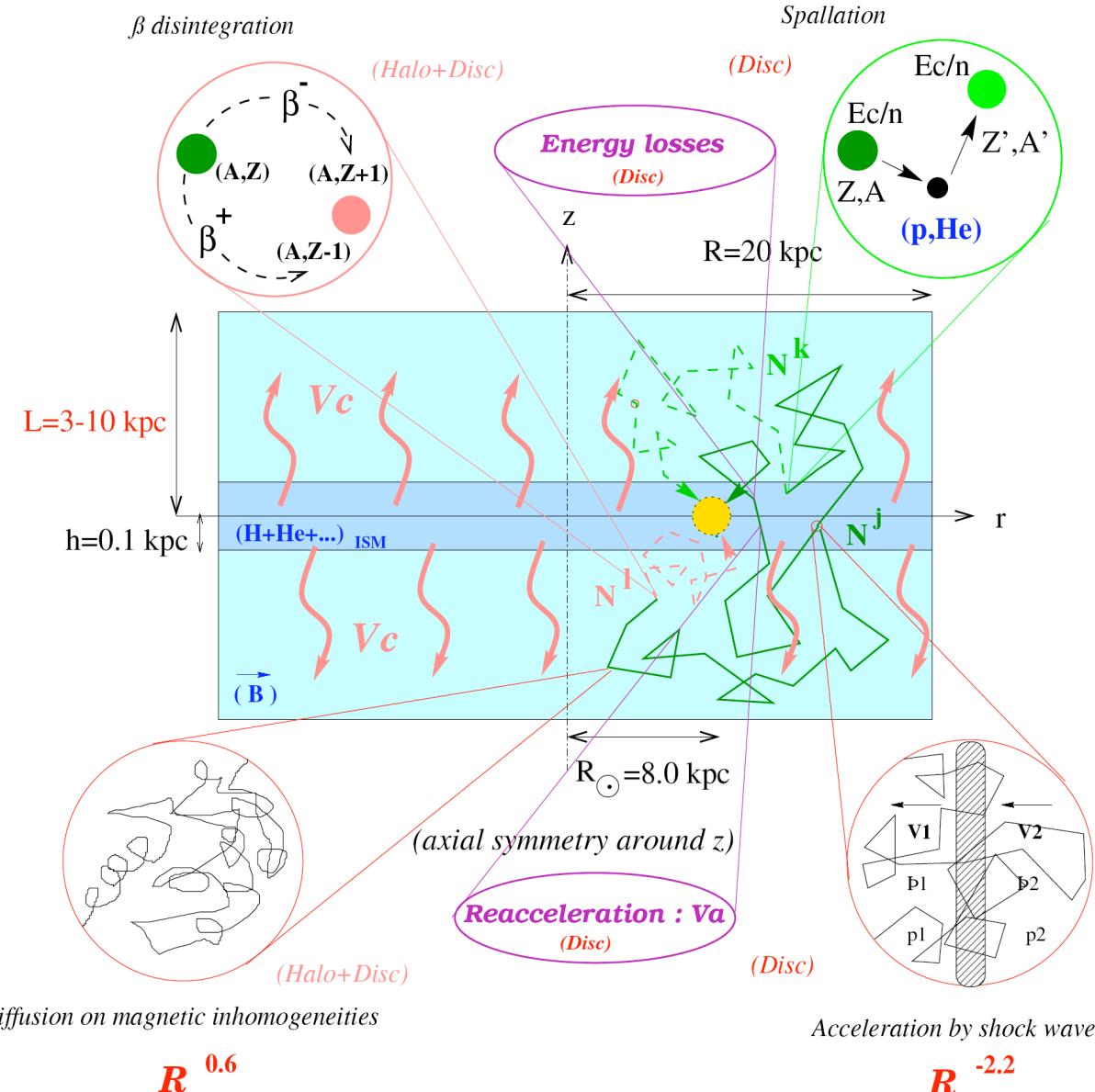


Antimatter is already manufactured inside the galactic disk

1) A digest of galactic cosmic ray physics



Milky-Way seen by a cosmic-ray physicist



D. Maurin, R. Taillet, F. Donato, P. Salati, A. Barrau and G. Boudoul, *Galactic cosmic ray nuclei as a tool for astroparticle physics*, [[astro-ph/0212111](#)].

Cosmic-rays diffuse in space and energy

- A propagation model is characterized by the set δ, K_0, L, V_C, V_a

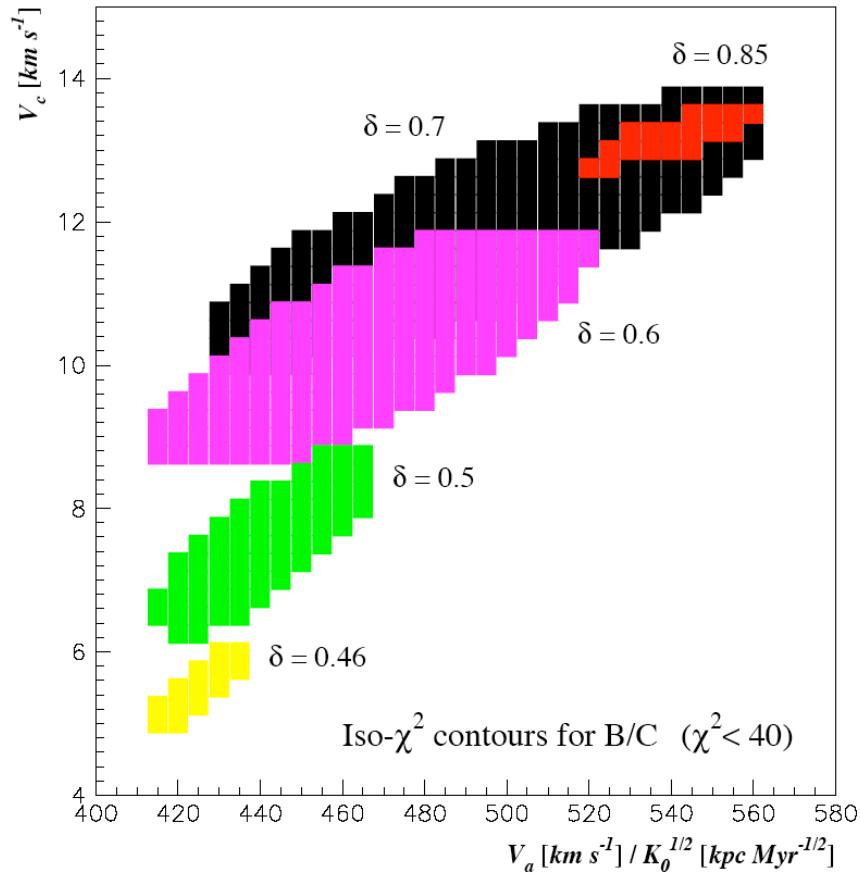
Case	δ	K_0 [kpc 2 /Myr]	L [kpc]	V_C [km/s]	V_a [km/s]
max	0.46	0.0765	15	5	117.6
med	0.70	0.0112	4	12	52.9
min	0.85	0.0016	1	13.5	22.4

- Different methods to solve the CR diffusion equation
 - The semi-analytic approach – radial Bessel expansion & Green functions
 - The numerical Galprop code – Crank–Nicholson semi-implicit scheme
- Constraints from the typical secondary to primary B/C ratio

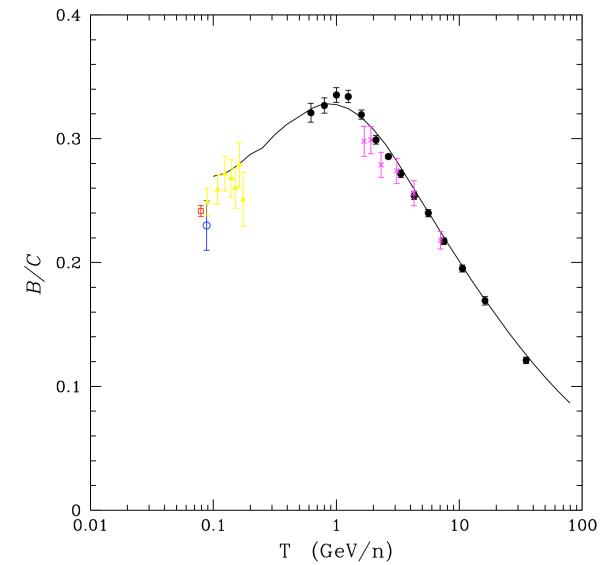
$$\bigcircledcirc_{V_C} \partial_z \Psi - K \Delta \Psi + \partial_E \{ b^{\text{loss}}(E) \Psi - K_{EE}(E) \partial_E \Psi \} = Q$$

B/C ratio analysis – D. Maurin et al.

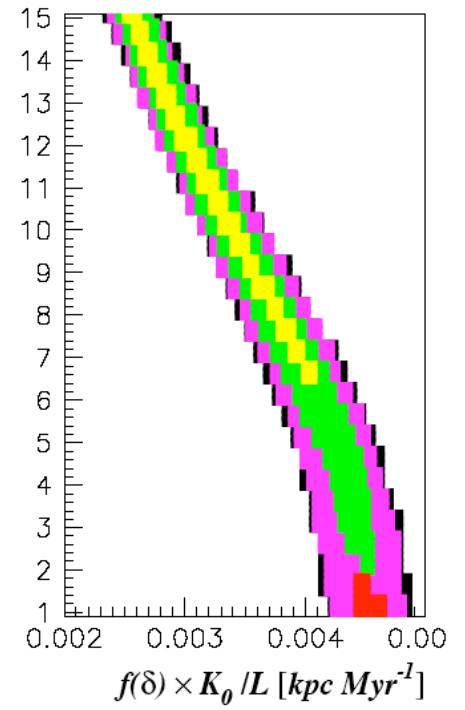
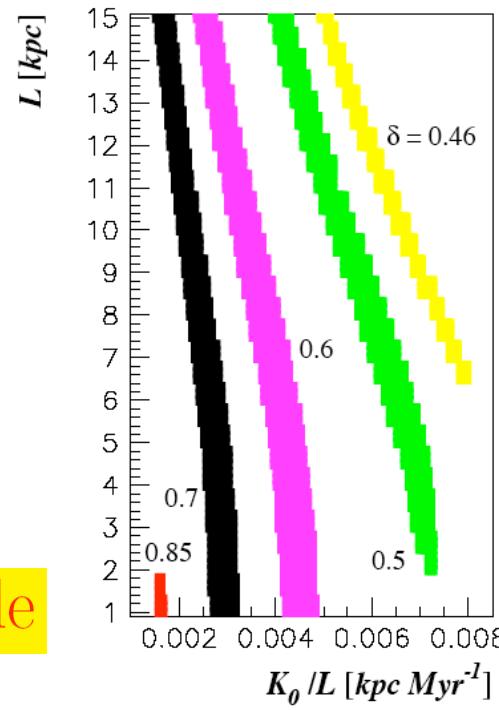
THE ASTROPHYSICAL JOURNAL, 555:585–596, 2001 July 10
 © 2001. The American Astronomical Society. All rights reserved. Printed in U.S.A.

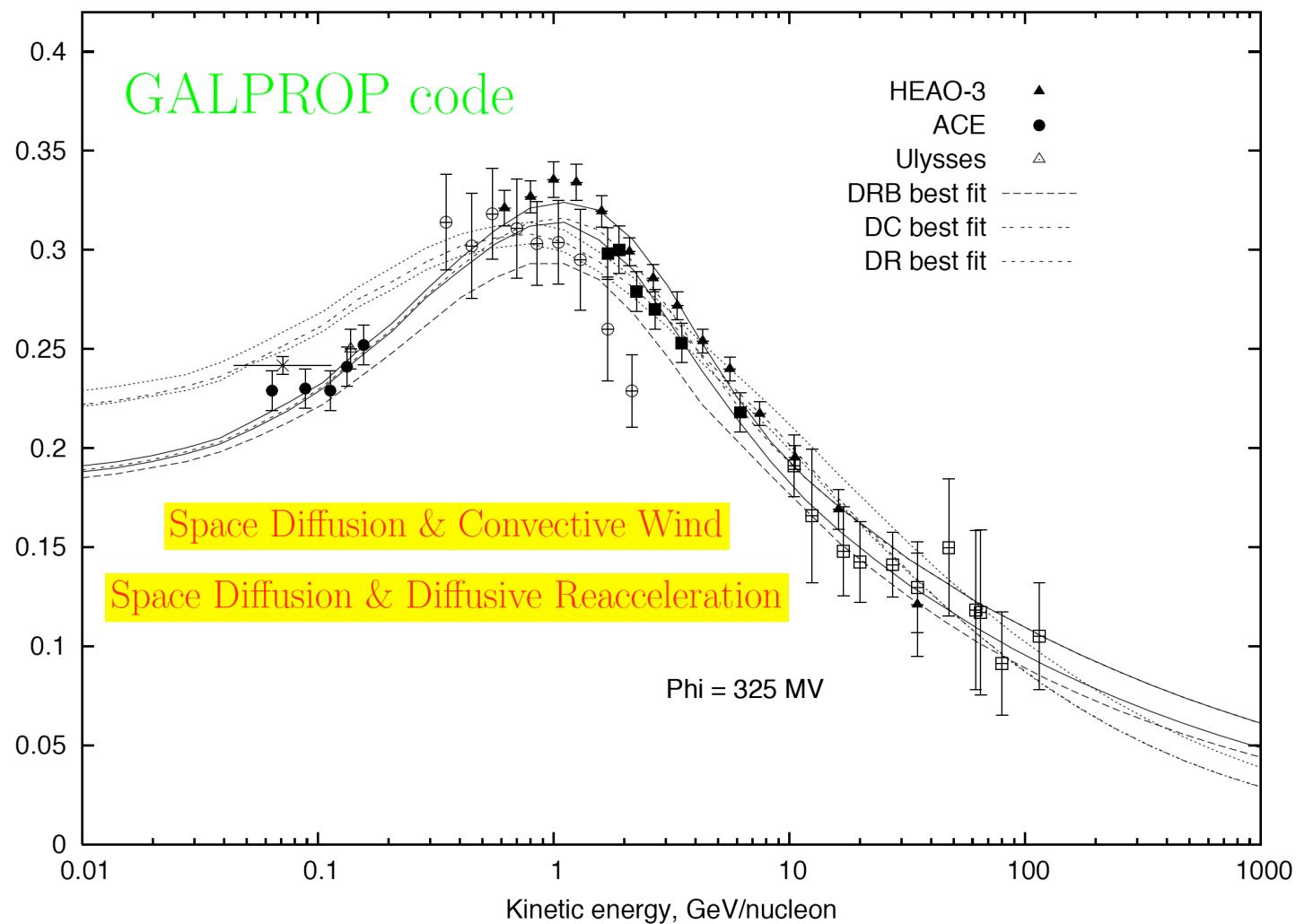


~ 1,600 models are compatible



Iso- χ^2 contours for B/C ($\chi^2 < 40$)

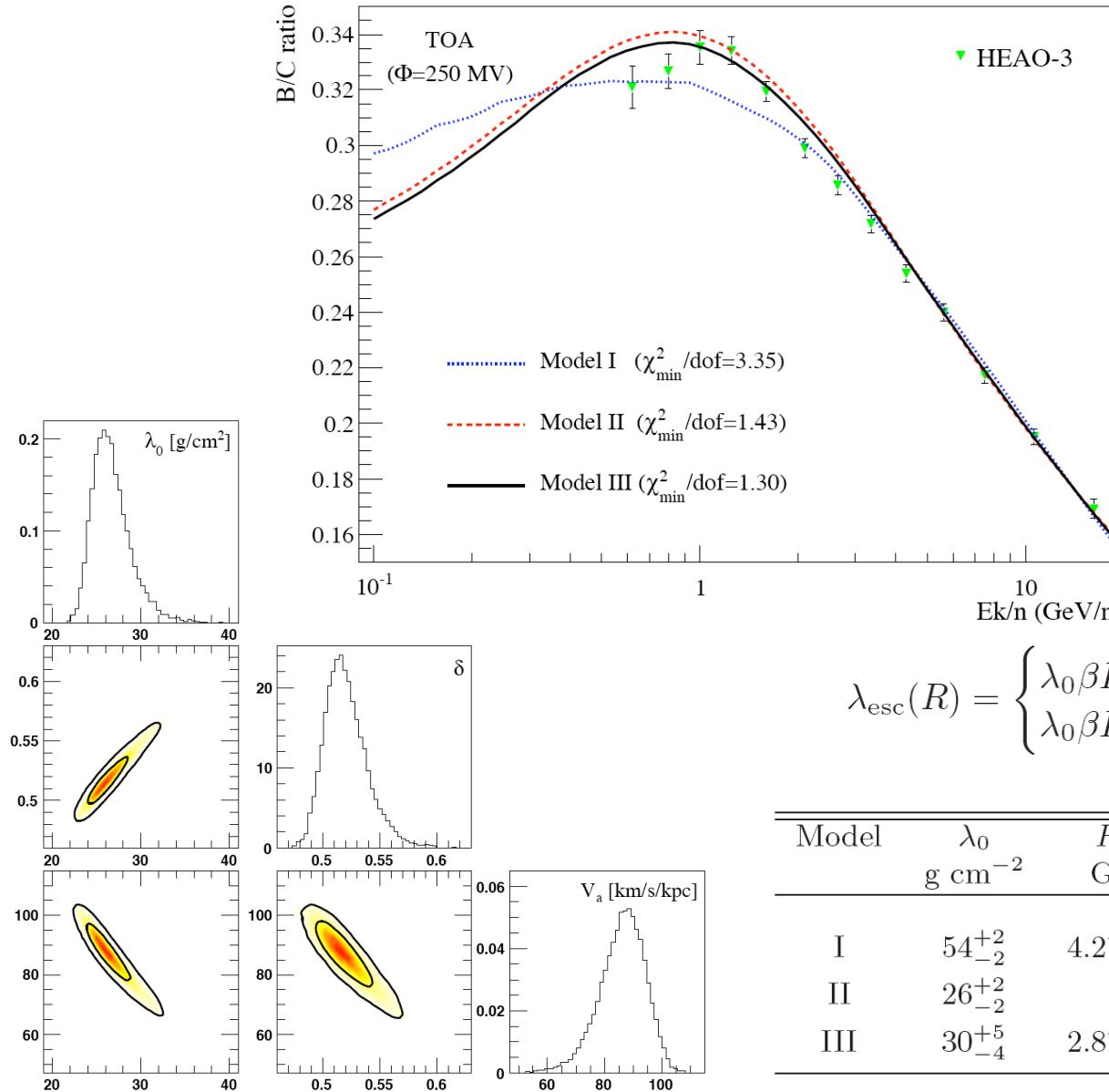




Could not get convection & reacceleration together

A Markov Chain Monte Carlo for Galactic Cosmic Ray physics

A. Putze¹, L. Derome¹, D. Maurin², L. Perotto³, and R. Taillet^{4,5}



$$\lambda_{\text{esc}}(R) = \begin{cases} \lambda_0 \beta R_0^{-(\delta - \delta_0)} R^{-\delta_0} & \text{when } R < R_0 \\ \lambda_0 \beta R^{-\delta} & \text{otherwise;} \end{cases}$$

Model	λ_0 g cm ⁻²	R_0 GV	δ	\mathcal{V}_a km s ⁻¹ kpc ⁻¹	$\chi^2_{\text{min}}/\text{dof}$
I	54^{+2}_{-2}	$4.2^{+0.3}_{-0.9}$	$0.70^{+0.01}_{-0.01}$	-	3.35
II	26^{+2}_{-2}	-	$0.52^{+0.02}_{-0.02}$	88^{+6}_{-11}	1.43
III	30^{+5}_{-4}	$2.8^{+0.6}_{-0.8}$	$0.58^{+0.01}_{-0.06}$	75^{+10}_{-13}	1.30

2) Antiprotons – the revenge of orthodoxy

Space diffusion dominates in the master equation

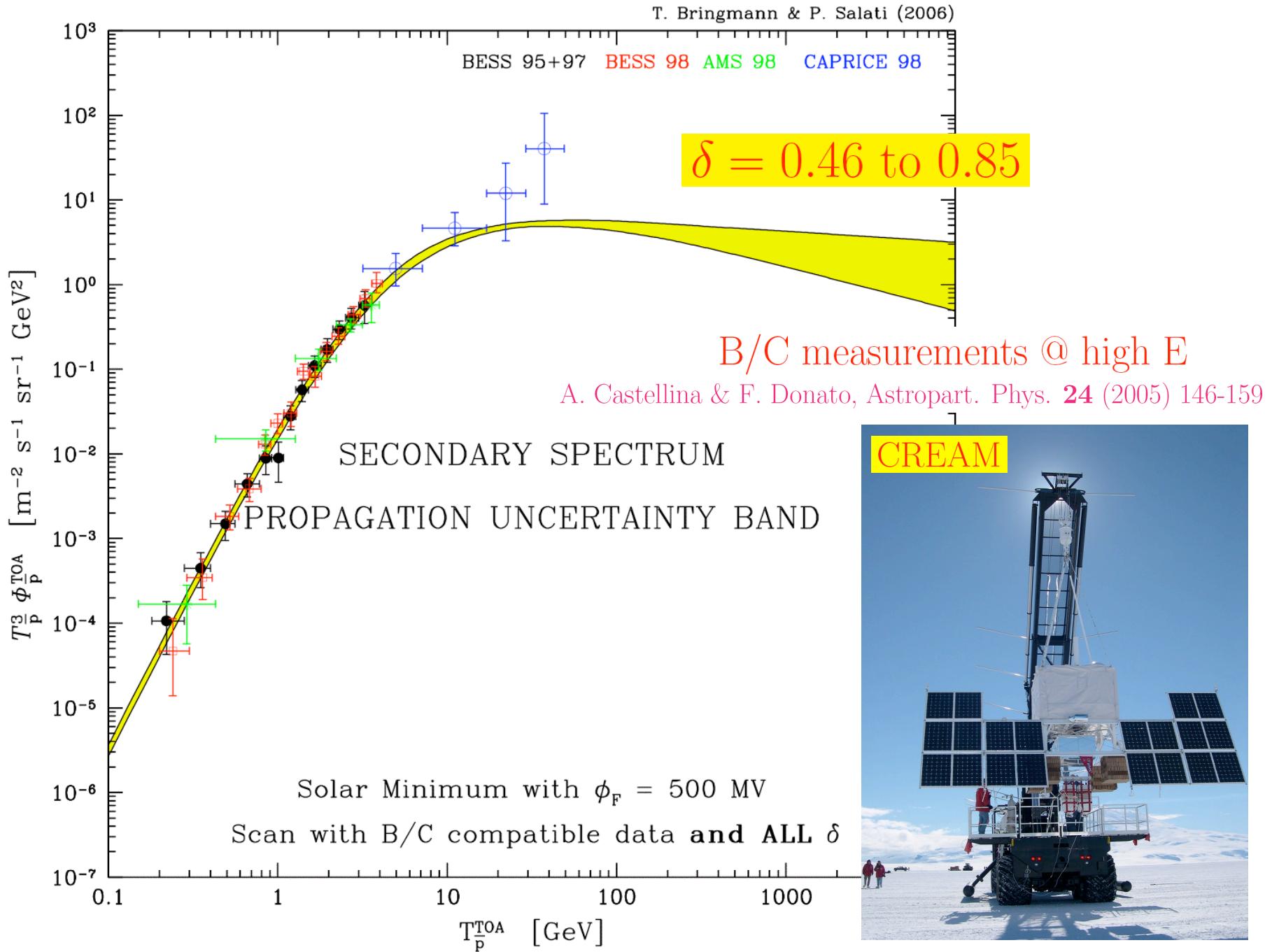
$$V_C \partial_z \Psi - K \Delta \Psi + \partial_E \{ b^{\text{loss}}(E) \Psi - K_{EE}(E) \partial_E \Psi \} = Q$$

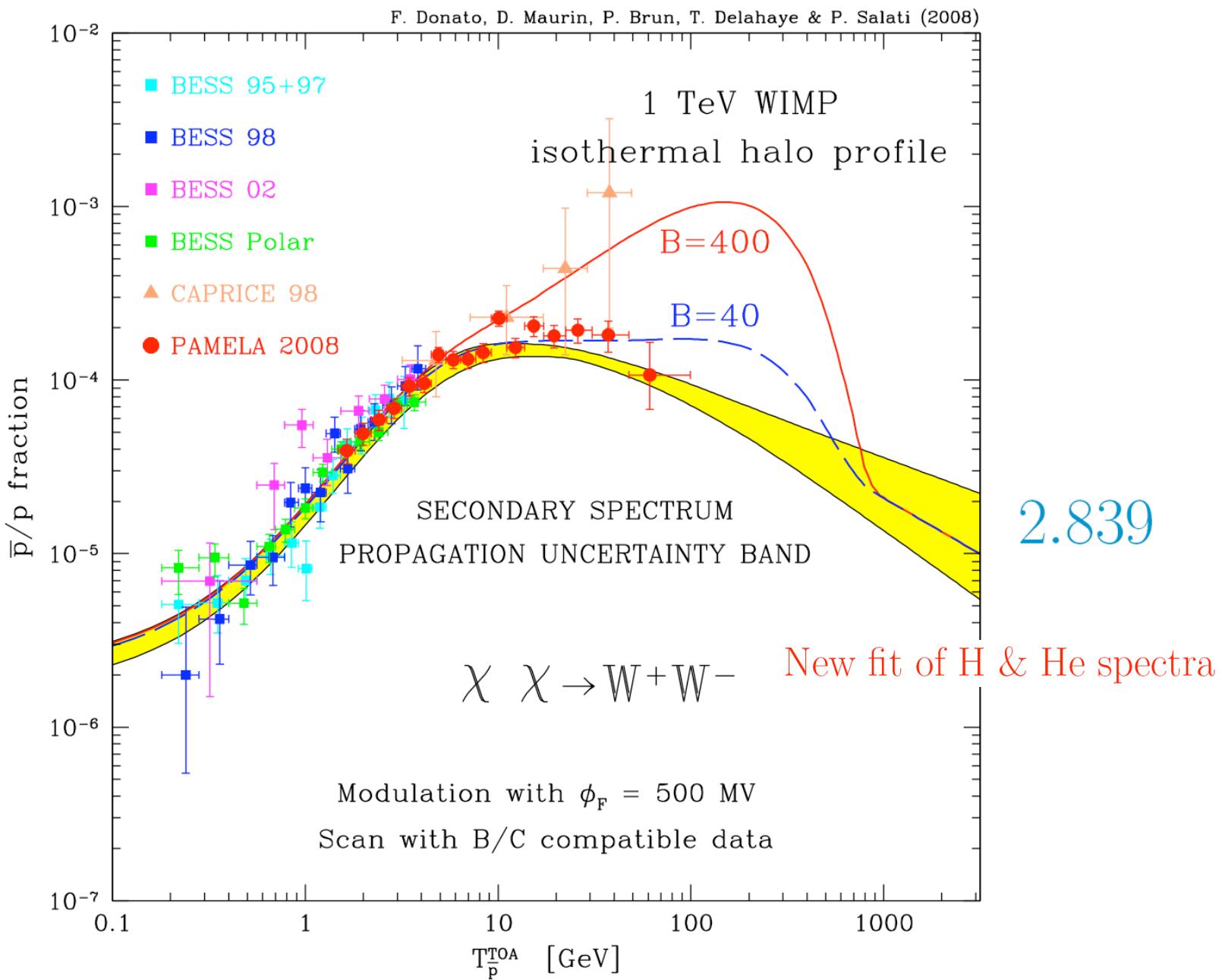
Poisson equation $K \Delta \Psi + Q = 0$

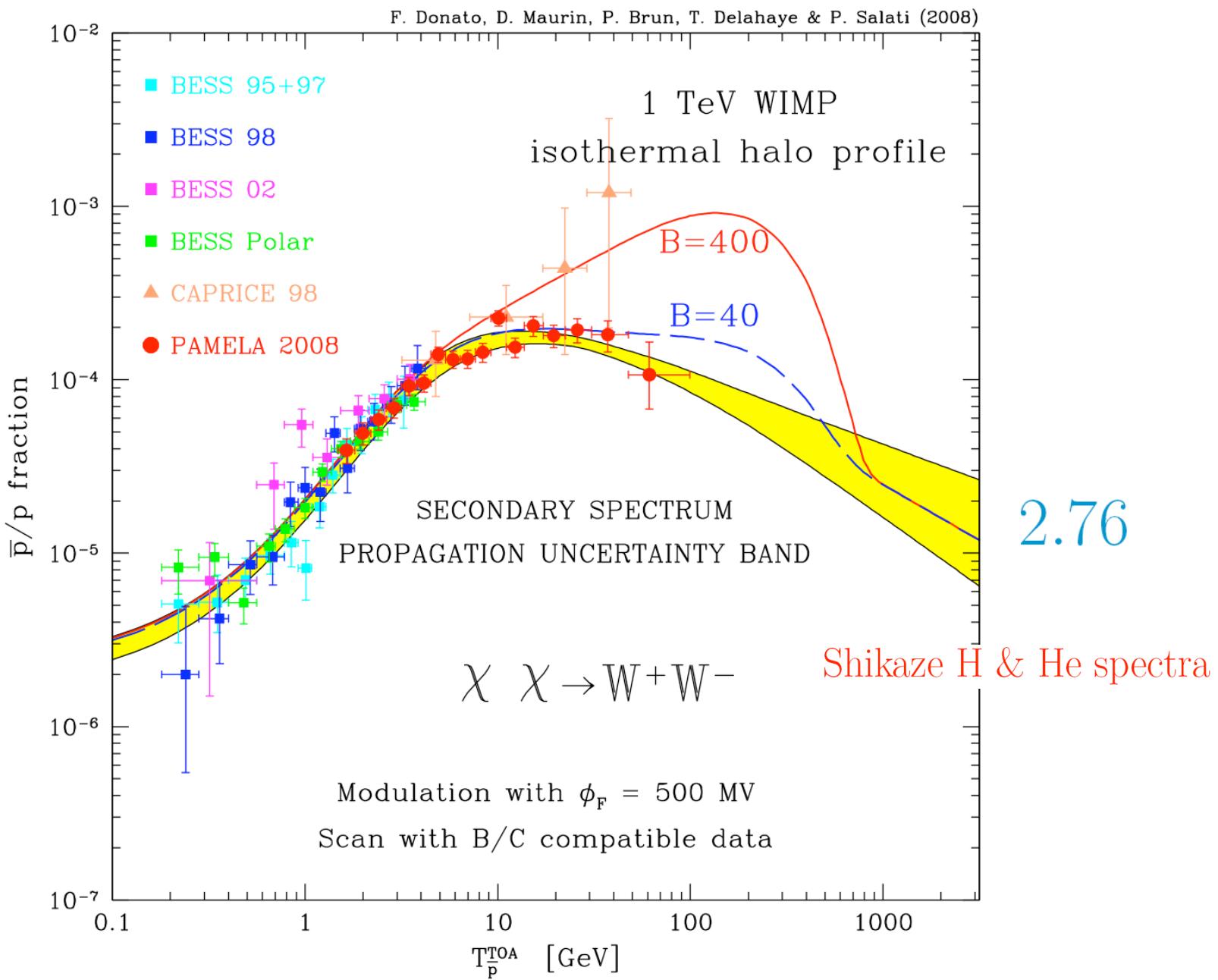


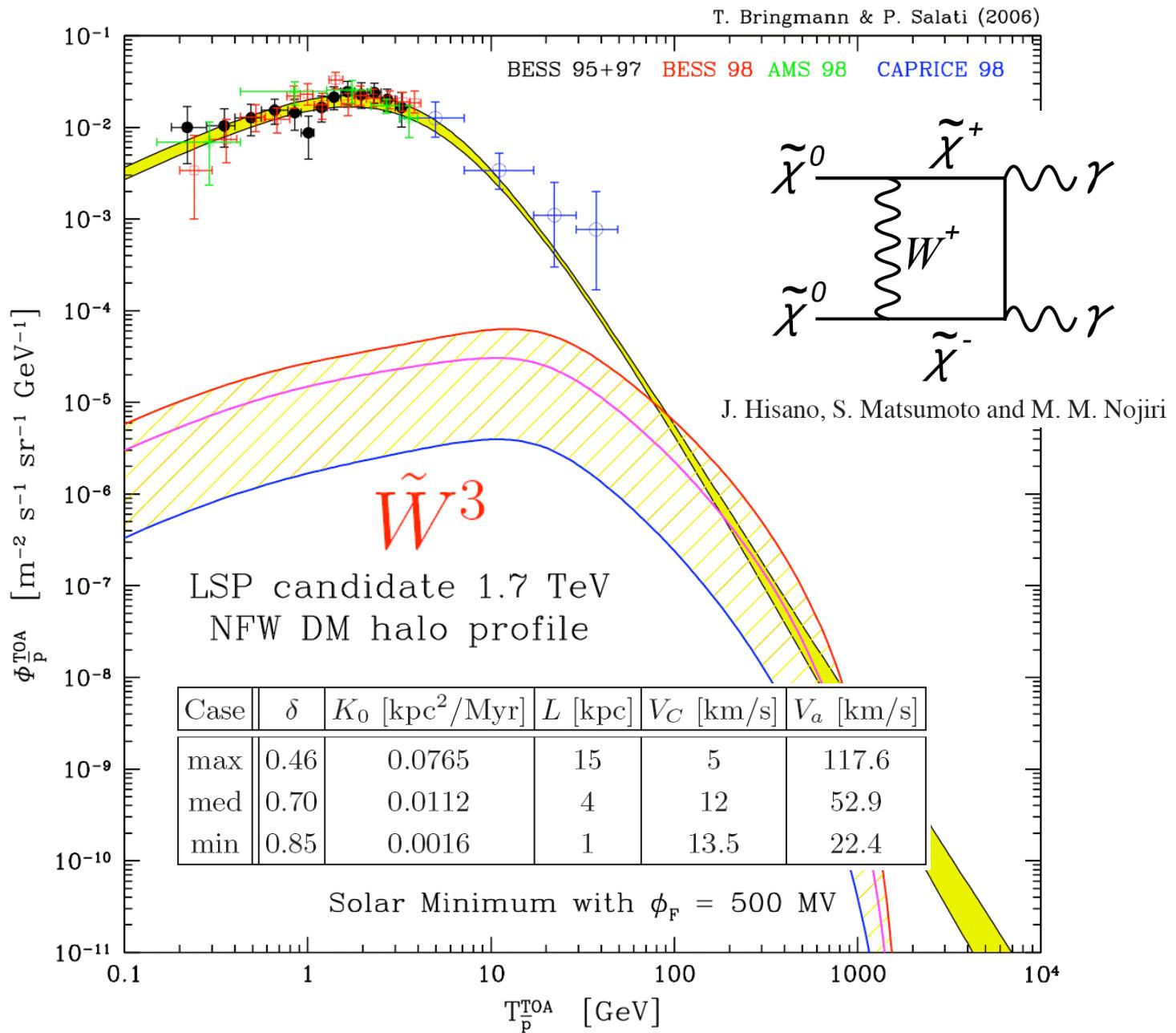
Long range with $G_{\bar{P}}^{\text{3D}}(r) = \frac{Q}{4\pi Kr}$

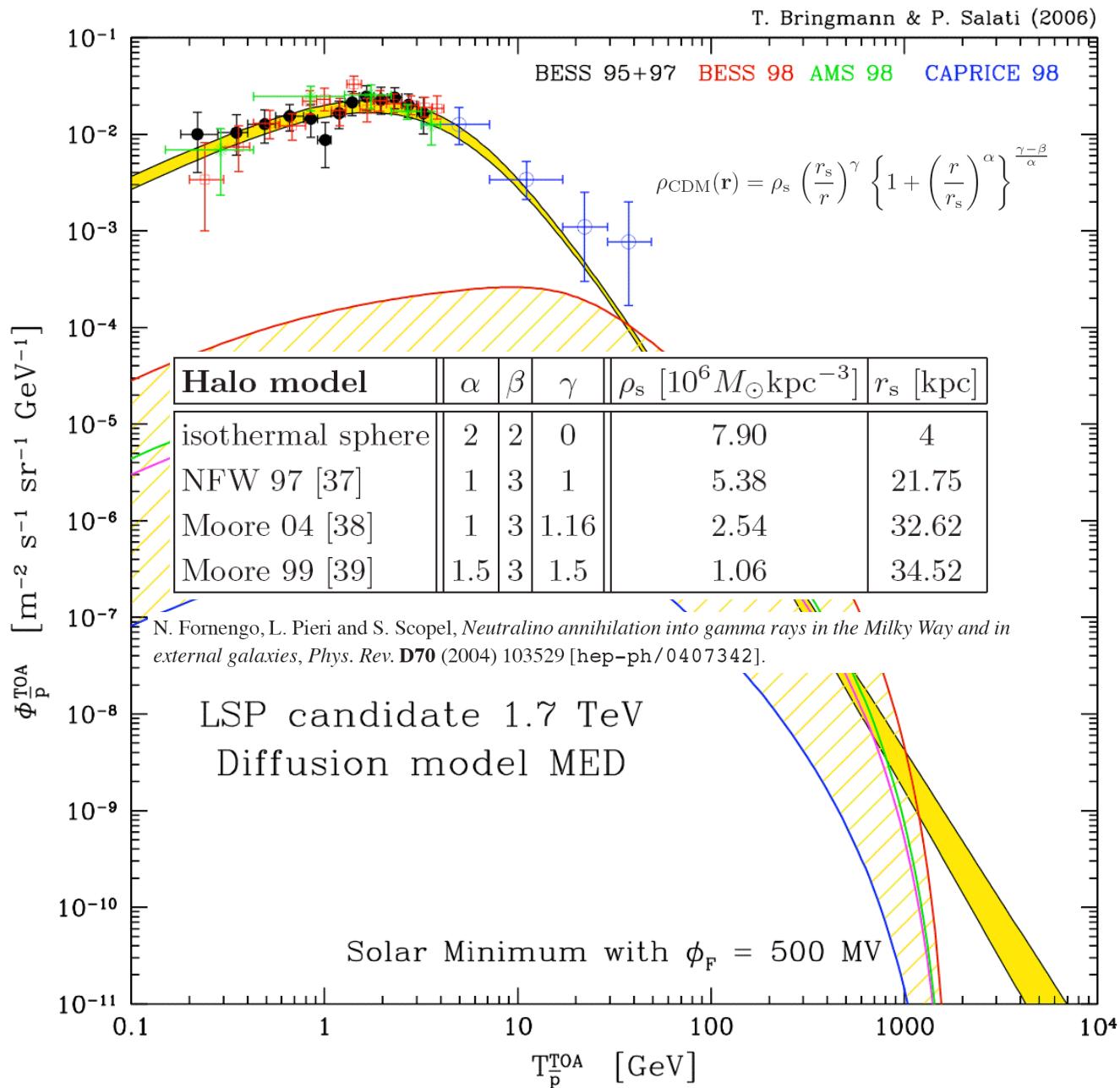
- Evaporation at the vertical boundaries $\pm L$
- Leakage at the radial boundaries $R = 20$ kpc
- Evaporation from convective wind V_C
- Annihilations inside the MW gaseous disk
- Energy losses and mild diffusive reacceleration











3) Positrons – an excess is confirmed

Mostly sensitive to the local region

Energy losses dominate

IC on stellar light and CMB – synchrotron

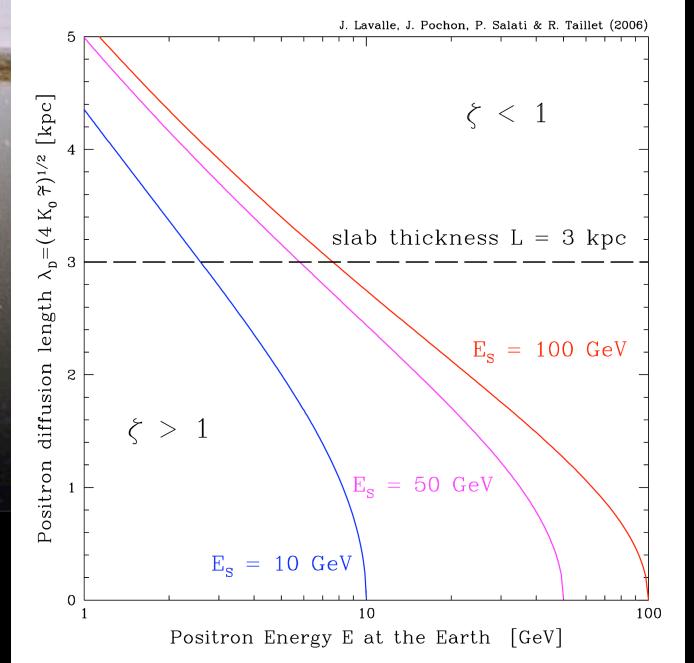
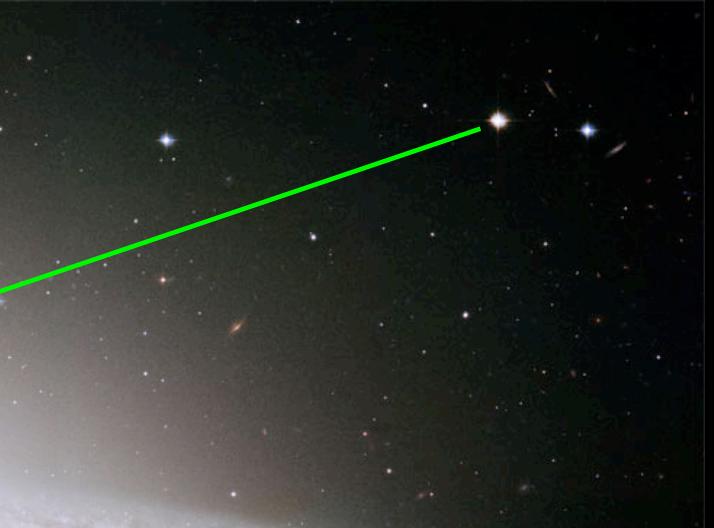
$$E_{\text{obs}} \leq E_S$$



$$G_{e^+}(\vec{x}_\odot, E \leftarrow \vec{x}, E_S) = \frac{\tau_E}{E_0 \epsilon^2} \tilde{G}(\vec{x}_\odot, \tilde{t} \leftarrow \vec{x}, \tilde{t}_S)$$

$$\tilde{G}(\vec{x}_\odot, \tilde{t} \leftarrow \vec{x}, \tilde{t}_S) = \frac{\theta(r_S - r)}{V_S}$$

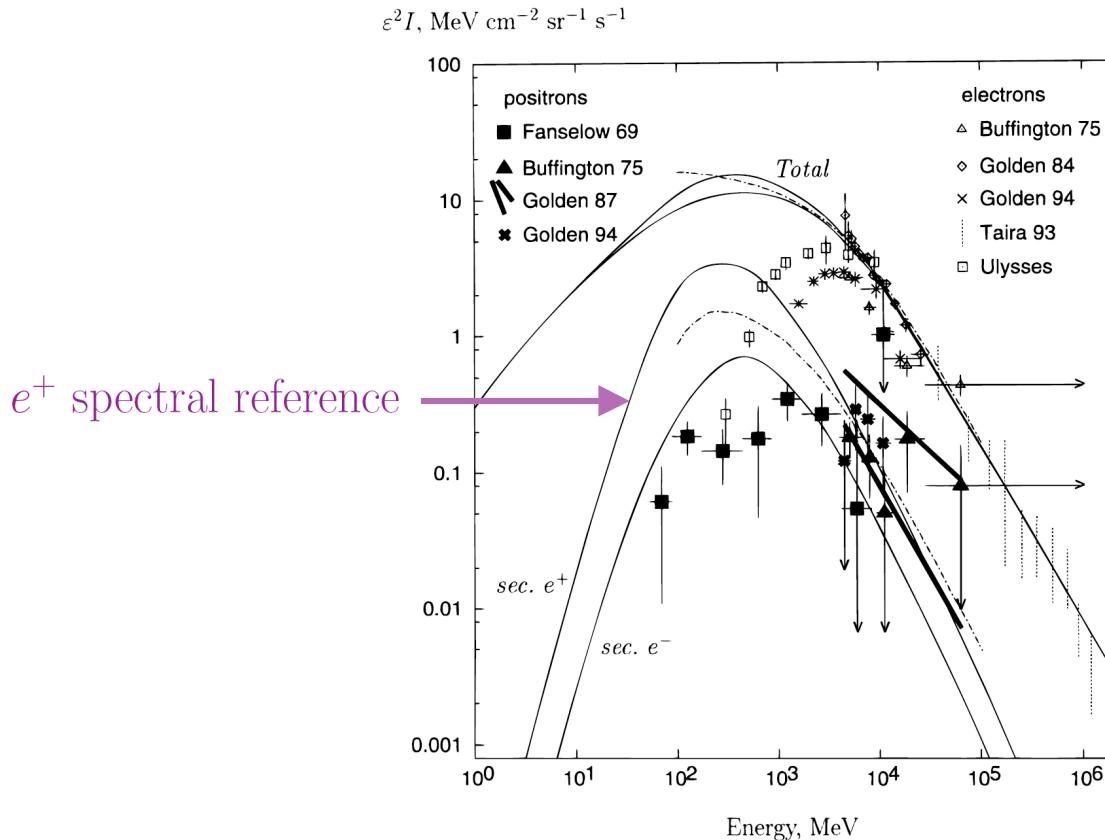
$$V_S = (\sqrt{2\pi} \lambda_D)^3$$



The secondary e^+ spectrum so far used has been computed in 1998

I. V. Moskalenko and A. W. Strong, *Production and propagation of cosmic ray positrons and electrons*, *Astrophys. J.* **493** (1998) 694 [[astro-ph/9710124](#)].

E. A. Baltz and J. Edsjö, *Positron propagation and fluxes from neutralino annihilation in the halo*, *Phys. Rev.* **D59** (1999) 023511 [[astro-ph/9808243](#)].



PARAMETERS OF MODELS

MODEL	z_h (kpc)	D_0 (cm ² s ⁻¹)	ρ_0 (MV/c)	δ	v_A (km s ⁻¹)	PROTONS		HELIUM			
						γ	p_0^a	I_0^b	γ	p_0^a	I_0^b
08-005.....	3	2.0×10^{28}	3.0×10^3	0.60	0	2.15	10^4	3×10^{-6}	2.35	4×10^4	4×10^{-8}
08-006.....	3	4.2×10^{28}	3.0×10^3	0.33	20	2.25	10^4	3×10^{-6}	2.45	4×10^4	4×10^{-8}
08-009.....	3	2.0×10^{28}	3.0×10^3	0.60	0	2.00	10^4	3×10^{-6}	2.00	4×10^4	4×10^{-8}

A consistent investigation is necessary !

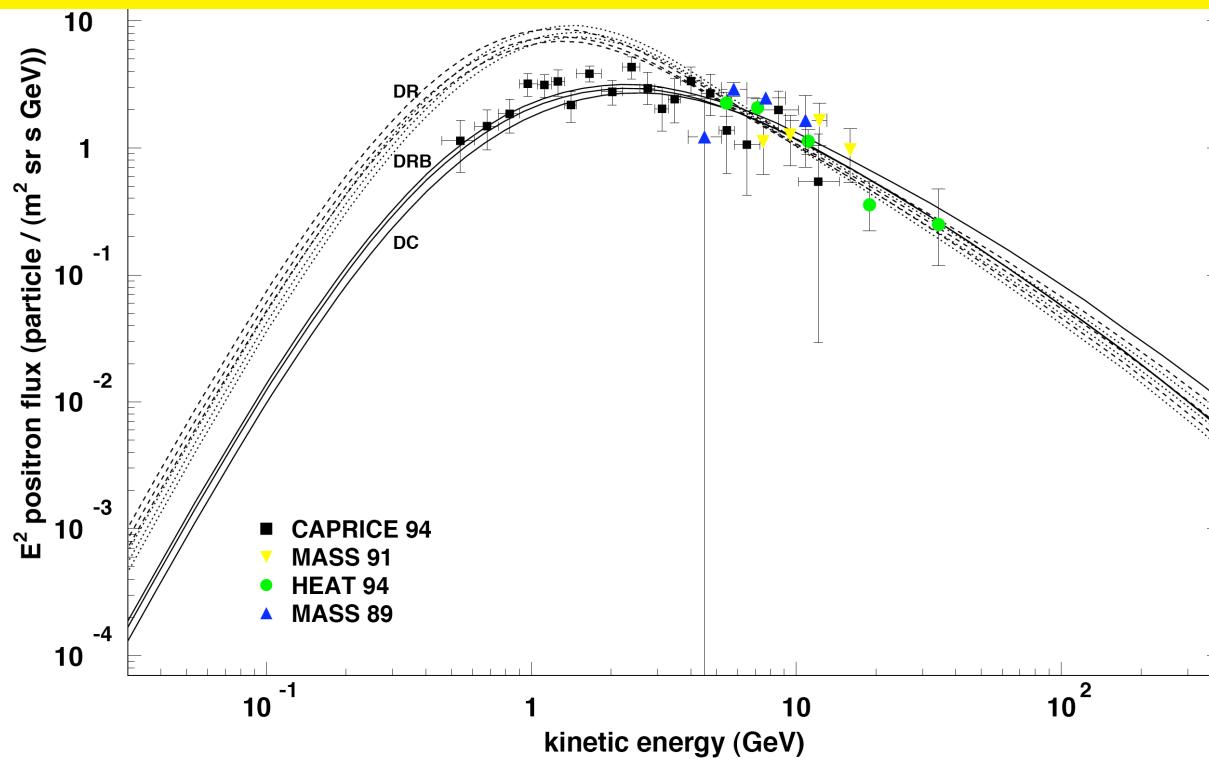
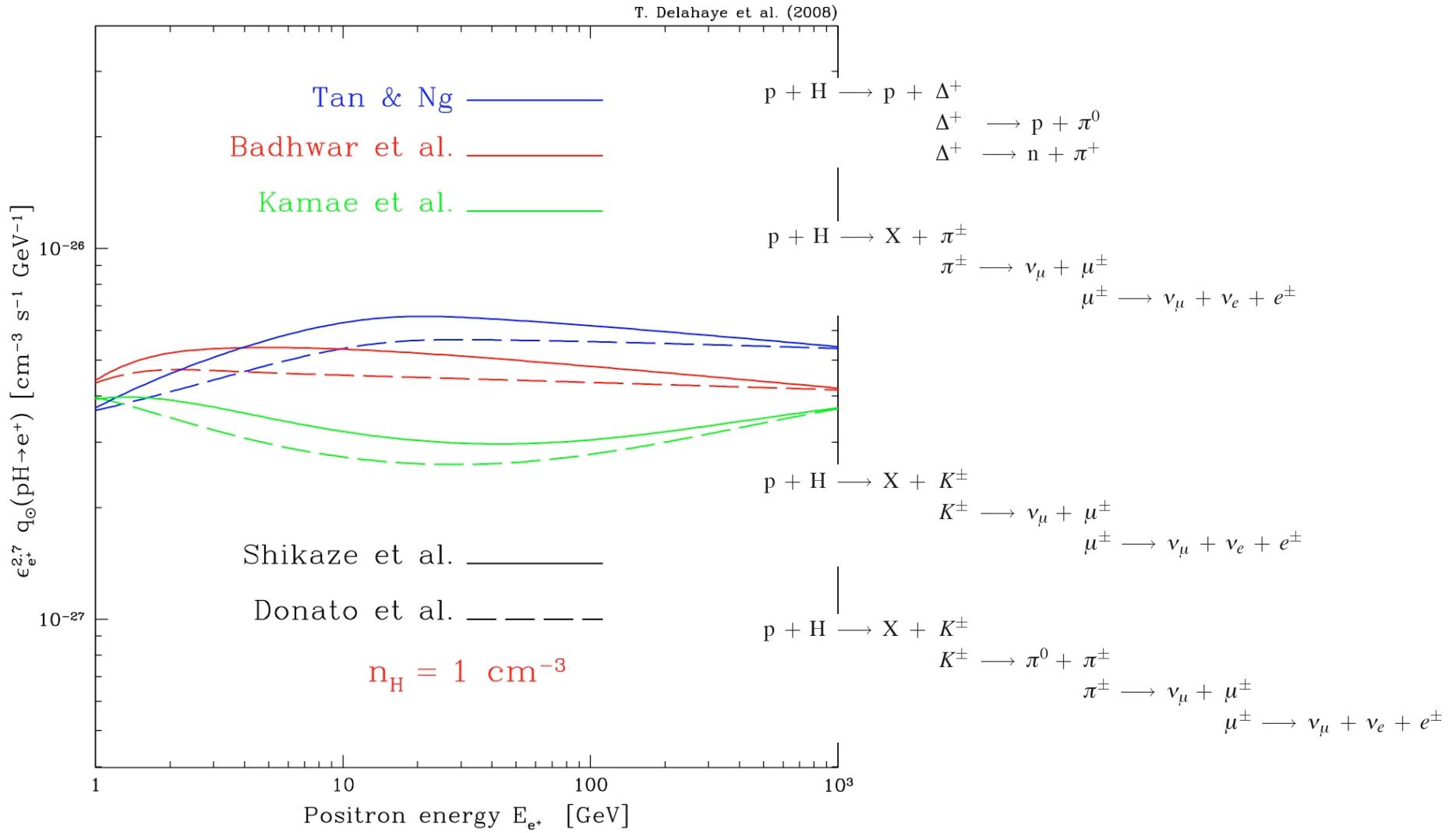


Figure 8. Total uncertainties of positron fluxes and spectra that correspond to the parameters of the best B/C fit for DC model (solid lines around the best fit curve, also solid), DR model (dashed lines around the best fit curve, also dashed) and DRB model (dotted lines around the best fit curve, also dotted). Experimental data are taken from [52]

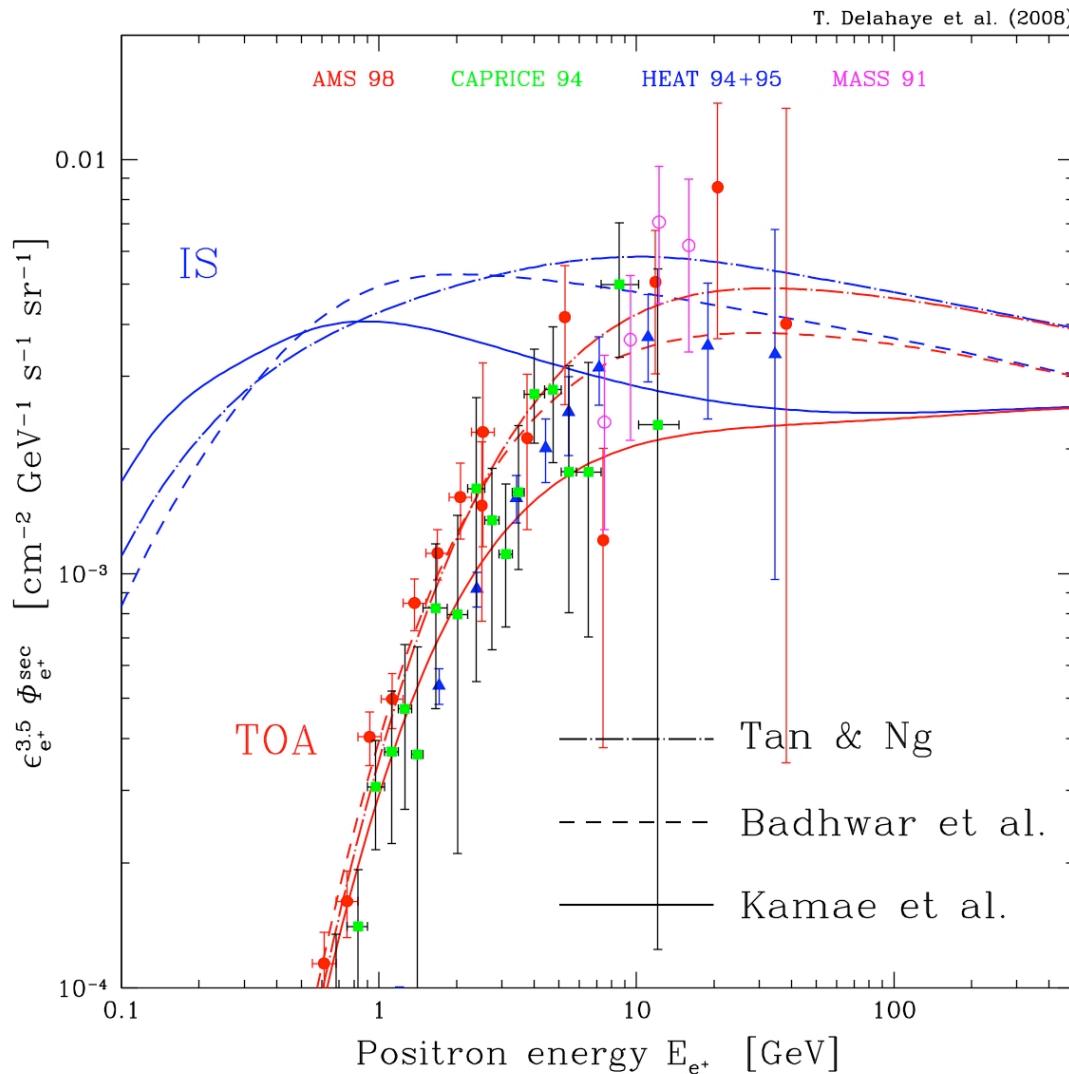
Positron source term

Delahaye T. et al. – arXiv:0809.5268



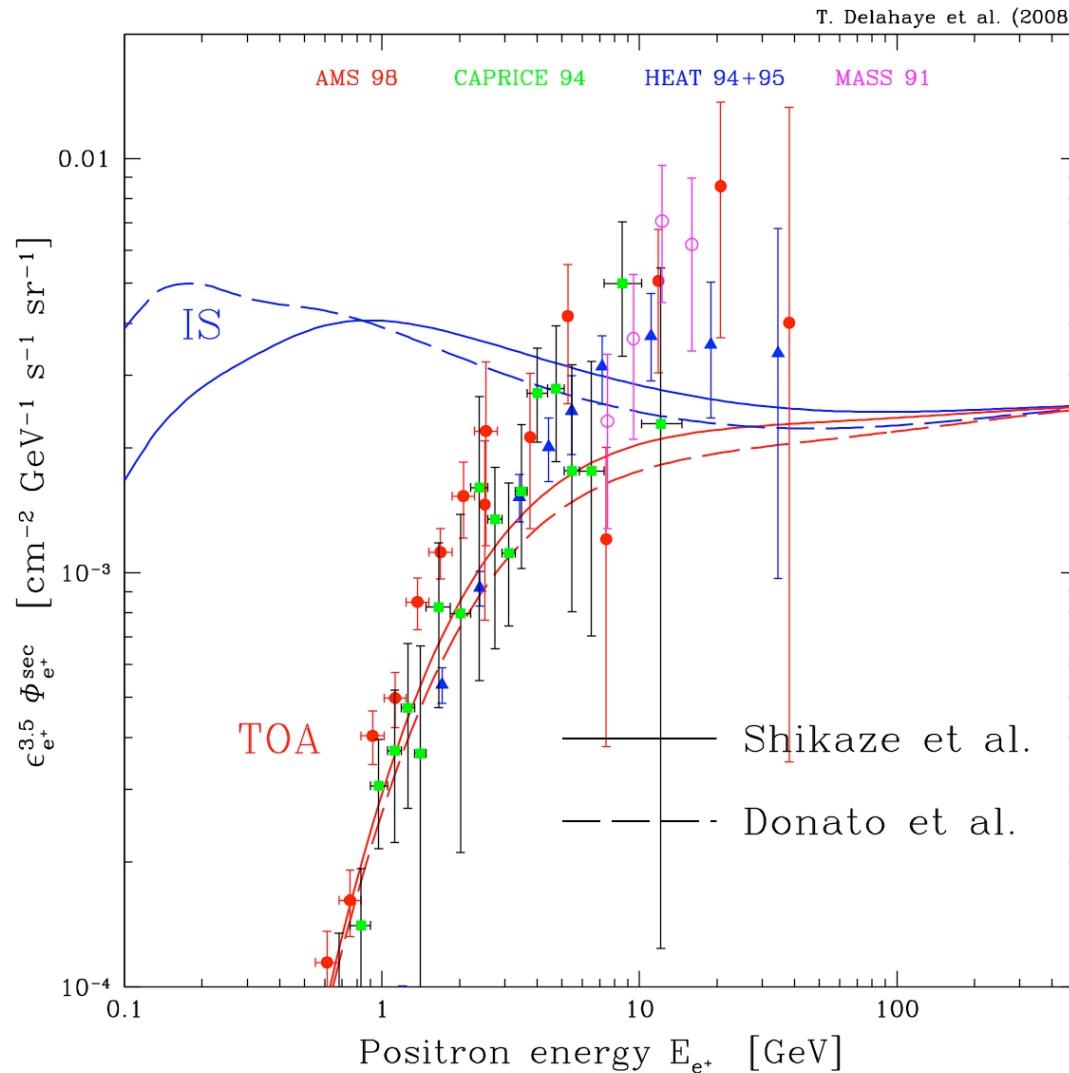
Cross sections

Delahaye T. et al. – arXiv:0809.5268



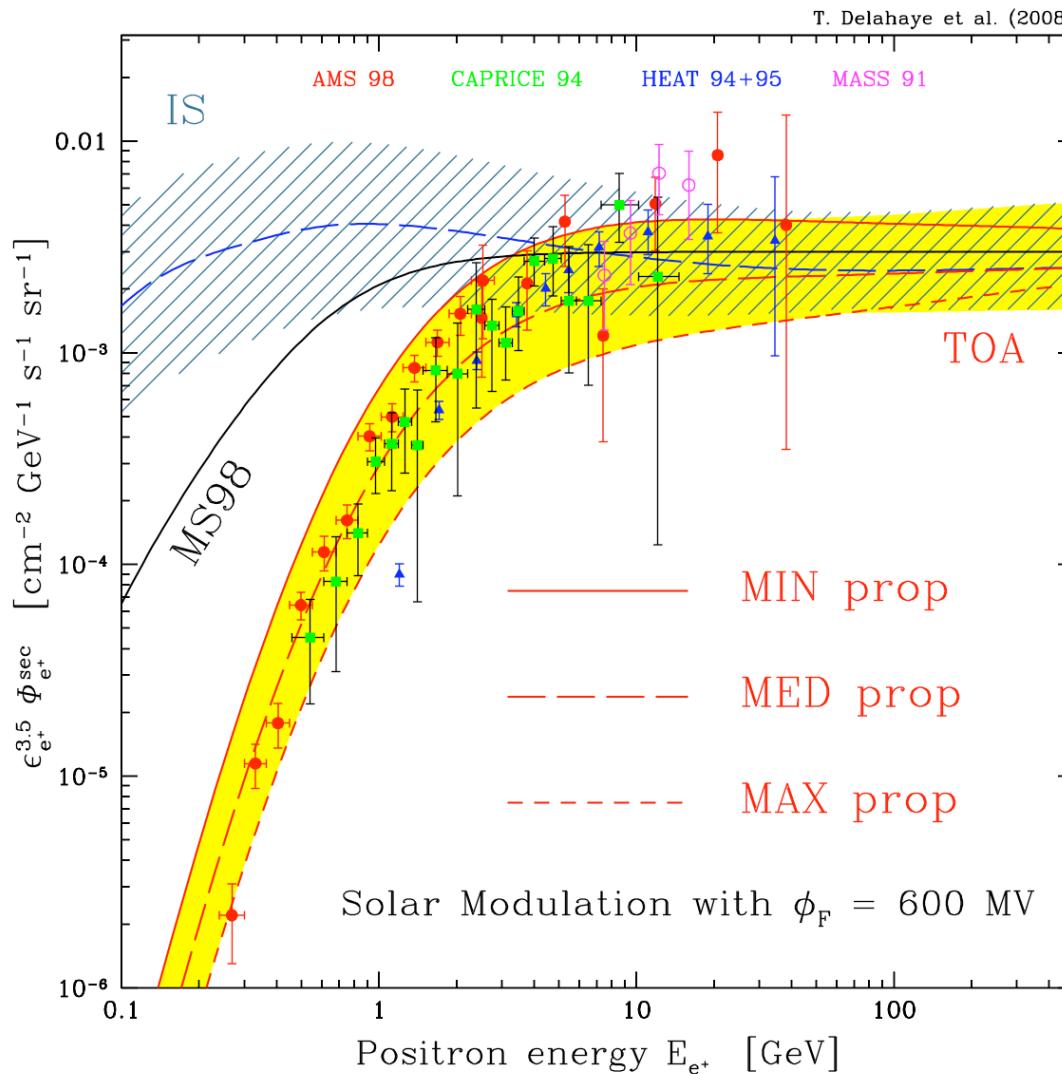
Proton & Helium fluxes

Delahaye T. et al. – arXiv:0809.5268



Galactic CR propagation

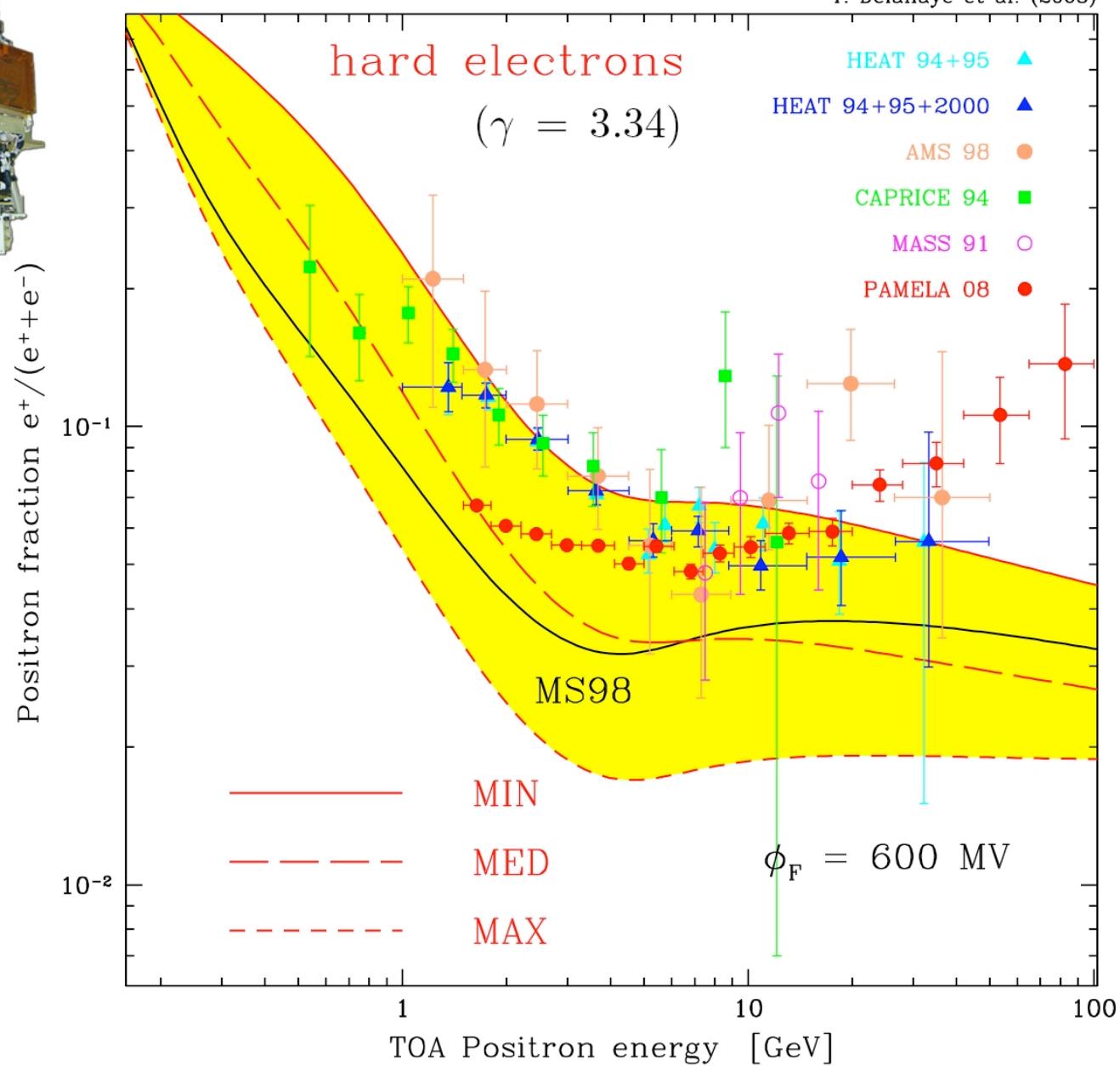
Delahaye T. et al. – arXiv:0809.5268





Delahaye T. et al. – arXiv:0809.5268

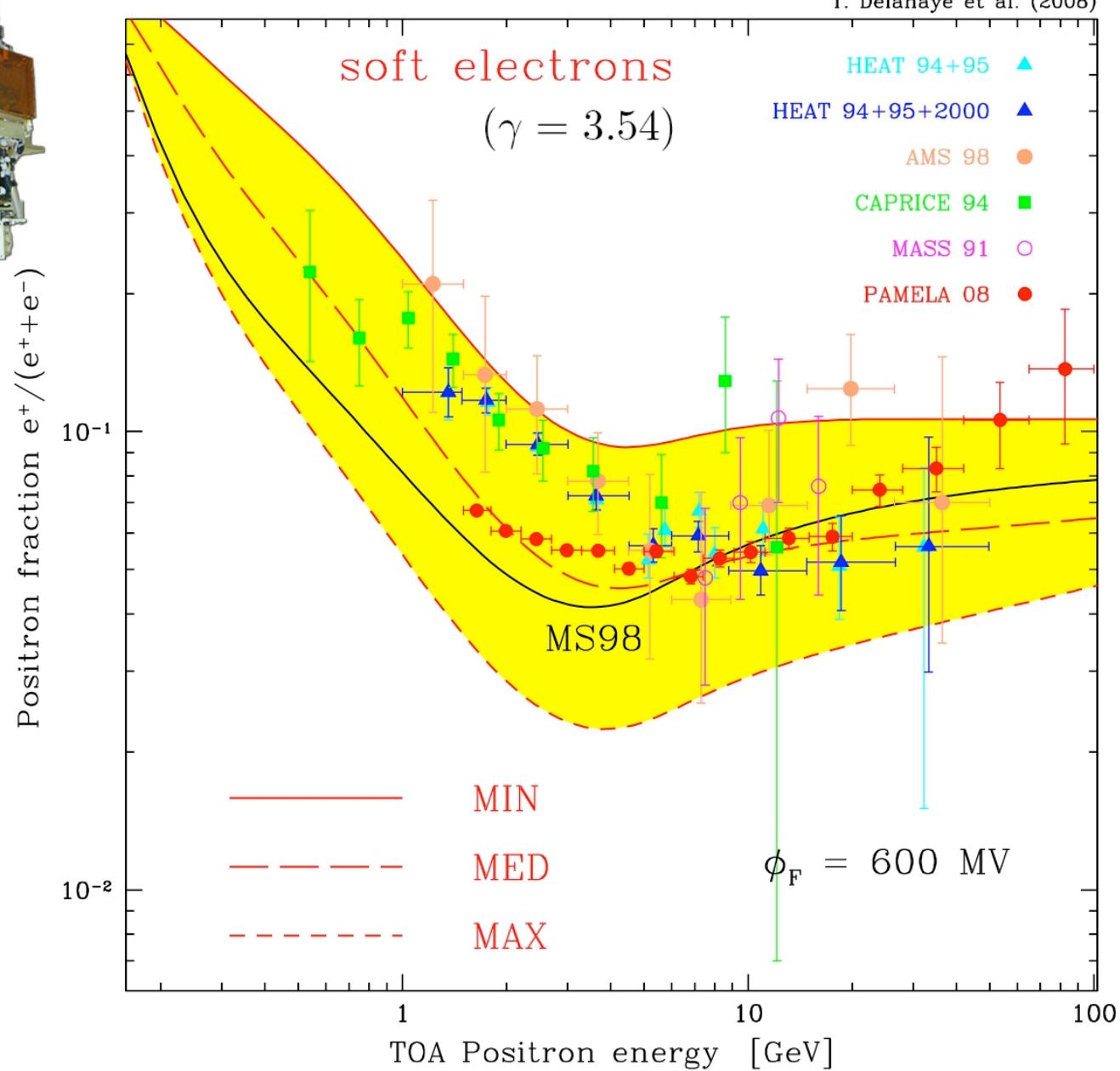
T. Delahaye et al. (2008)





Delahaye T. et al. – arXiv:0809.5268

T. Delahaye et al. (2008)



4) Discussion – DM or not DM ?

(i) Production inside local molecular clouds.

- The sun is located inside a H depleted local bubble.
- No **B** confinement above 10 GeV and no PF excess above 30 GeV.

(ii) Galactic and local pulsars – could work very well !

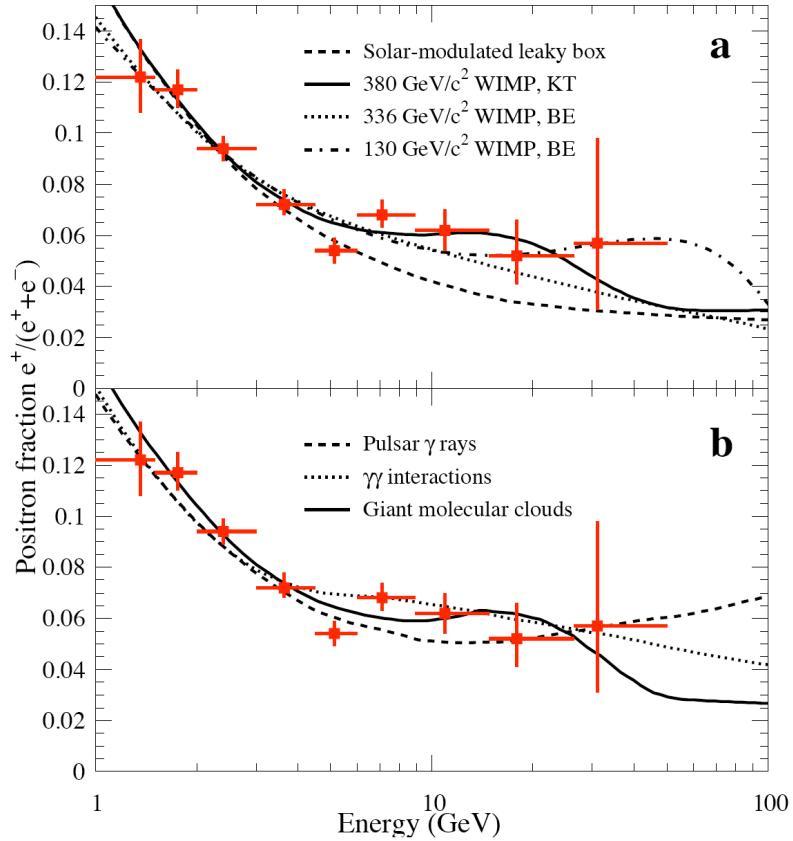
(iii) DM particles.

- The annihilation rate needs to be considerably boosted.
 - ✓ Internal bremsstrahlung from charged external legs or virtual internal particles.
 - ✓ Sommerfeld effect – a non-perturbative enhancement of σ_{ann} at low velocity.
 - ✓ Non-thermal relic (gravitino decay) or modified thermal decoupling (quintessence).
 - ✓ Substructures are characterized by $\langle \rho^2 \rangle \geq \langle \rho \rangle^2$.

$$\boxed{\text{But } B_{\text{Milky Way}} \leq 10}$$

- ✓ A single nearby clump – how probable is it ?
- Other signals should not be overproduced – the example of antiprotons.
 - ✓ Quark channels are suppressed – purely leptophilic DM candidate – UED – ad hoc models.
 - ✓ Very heavy DM particle – should lead to a large $\Phi_{\bar{p}}$ at high E .
 - ✓ Antiproton depletion wrt positrons – $B_{\text{Milky Way}}$ different – CR propagation.

Production inside local molecular clouds



$\text{CR } p + \text{IS H} \rightarrow e^+$

Local interstellar medium (LISM)

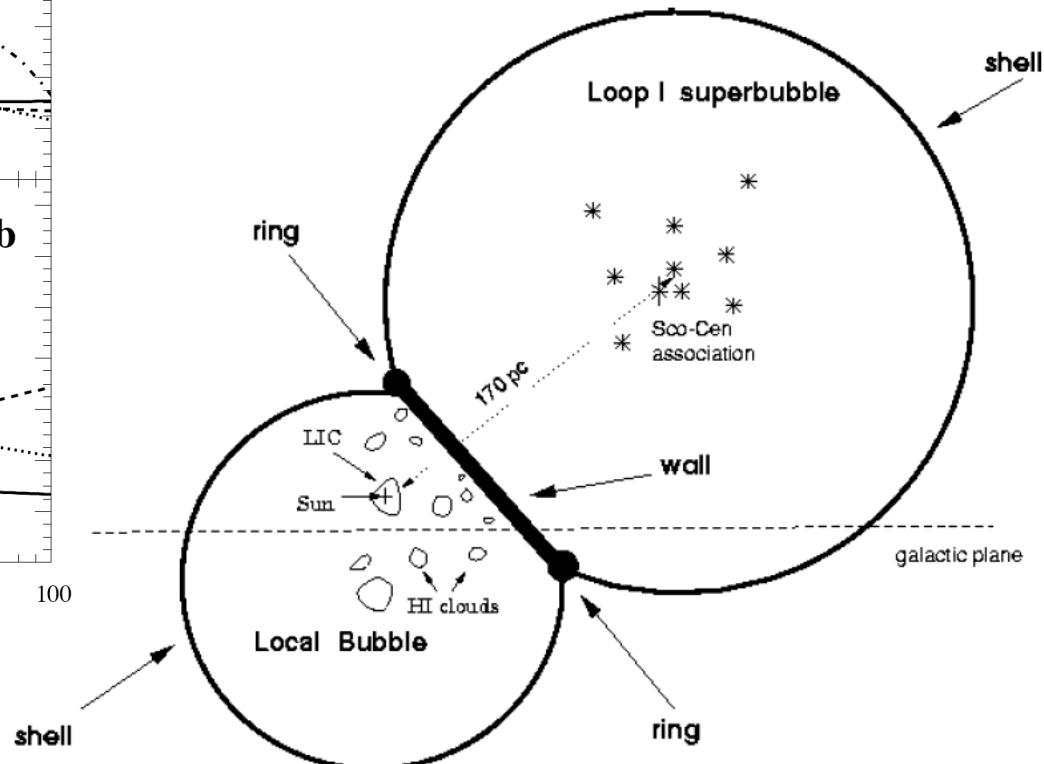


Figure 3: Schematic representation (not drawn to scale) between the local bubble and the neighboring Loop I superbubble (from [40]).

Galactic and local pulsars

D. Hooper, P. Blasi & P. D. Serpico, [arXiv:0810.1527](https://arxiv.org/abs/0810.1527)

S. Profumo, [arXiv:0812.4457](https://arxiv.org/abs/0812.4457)

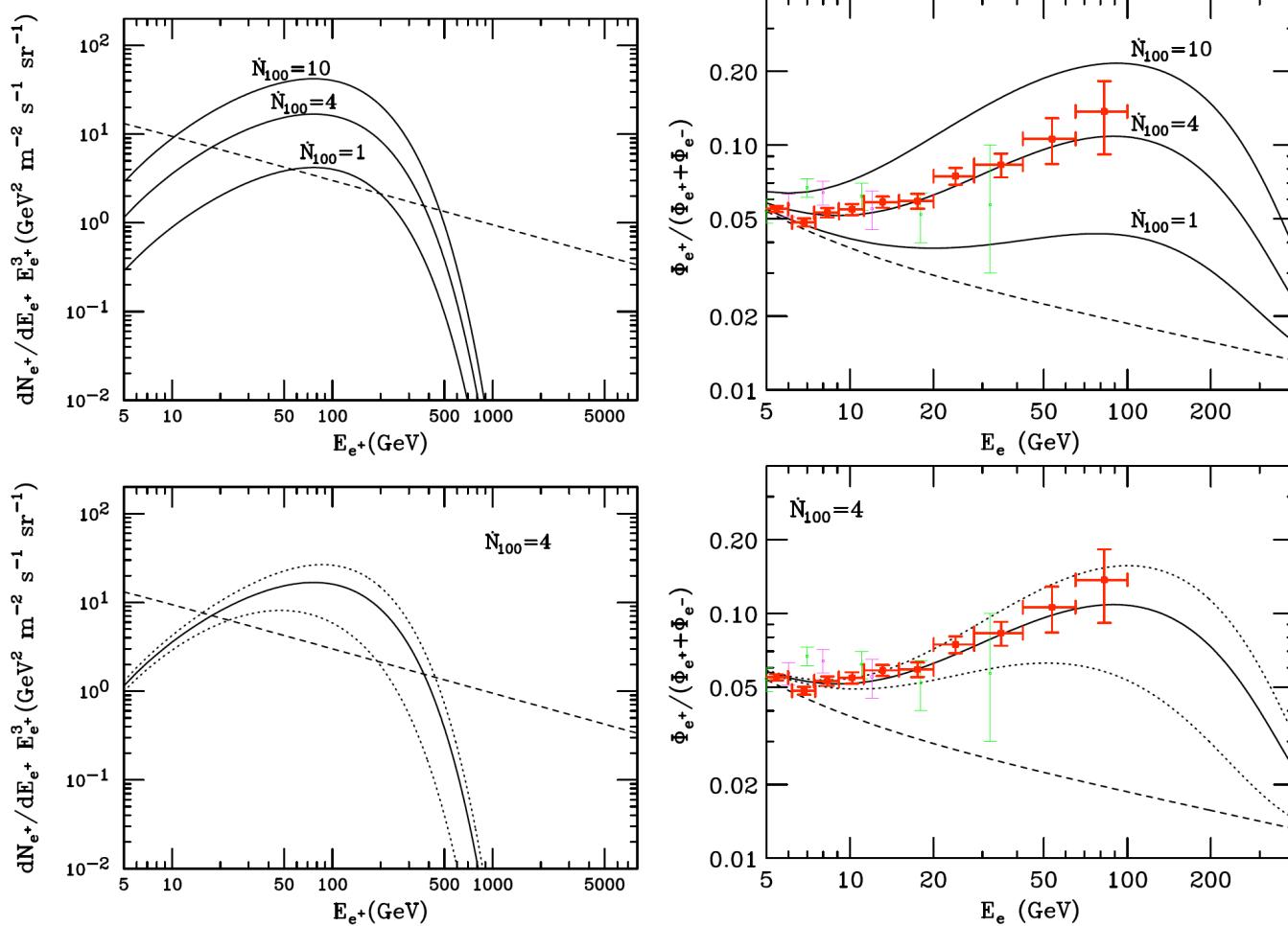


FIG. 1: The spectrum of cosmic ray positrons (left) and the positron fraction (right) resulting from the sum of all pulsars throughout the Milky Way. Also shown as a dashed line is the prediction for secondary positrons (and primary and secondary electrons in the right frames) as calculated in Ref. [27]. In the right frames, the measurements of HEAT [3] (light green and magenta) and measurements of PAMELA [2] (dark red) are also shown. We have used the injected spectrum reported in Eq. (7). In the lower frames, the upper (lower) dotted line represents the case in which the injection rate within 500 parsecs of the Solar System is doubled (neglected), providing an estimate the variance resulting from the small number of nearby pulsars contributing to the spectrum.

Galactic and local pulsars

D. Hooper, P. Blasi & P. D. Serpico, [arXiv:0810.1527](https://arxiv.org/abs/0810.1527)

S. Profumo, [arXiv:0812.4457](https://arxiv.org/abs/0812.4457)

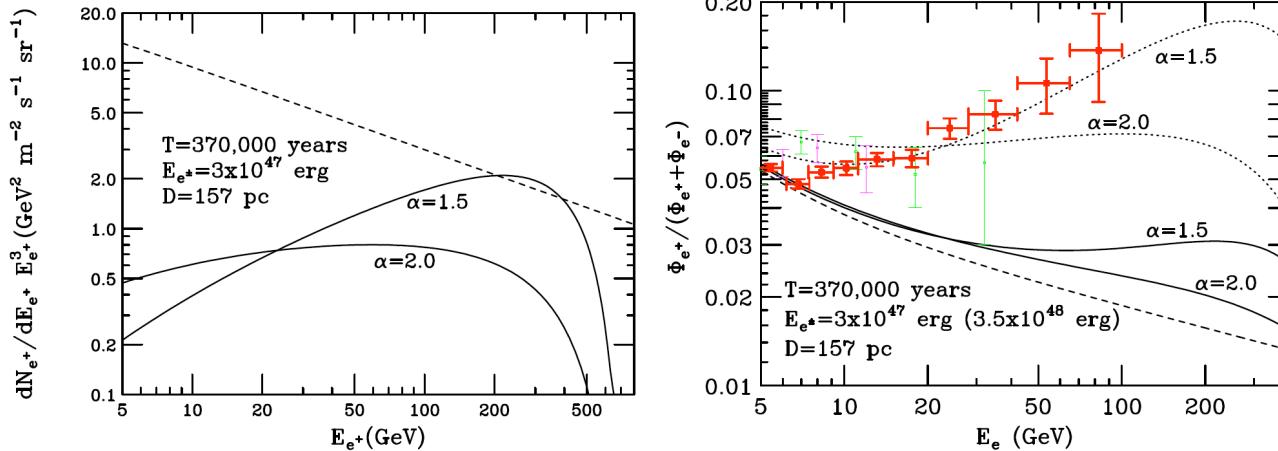


FIG. 2: The spectrum of positrons (left) and ratio of positrons to electrons plus positrons (right) from the pulsar Geminga, with the dashed lines as in Fig. 1. In the right frames, the measurements of HEAT [3] (light green and magenta) and measurements of PAMELA [2] (dark red) are also shown. Here we have used an injected spectrum such that $dN_e/dE_e \propto E^{-\alpha} \exp(-E_e/600 \text{ GeV})$, with $\alpha = 1.5$ and 2.2 . The solid lines correspond to an energy in pairs given by 3.5×10^{47} erg, while the dotted lines require an output of 3×10^{48} erg.

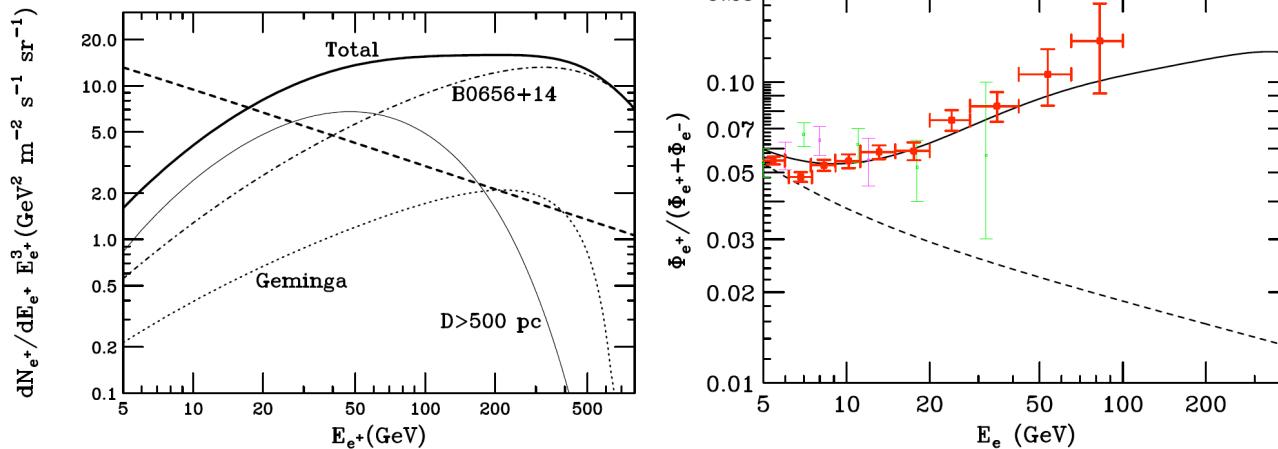


FIG. 4: The positron spectrum and positron fraction from the sum of contributions from B0656+14, Geminga, and all pulsars farther than 500 parsecs from the Solar System.

DM particles

The annihilation rate needs to be considerably boosted

L. Roszkowski, R. Ruiz de Austri, J. Silk & R. Trotta, [arXiv:0707.0622](https://arxiv.org/abs/0707.0622)

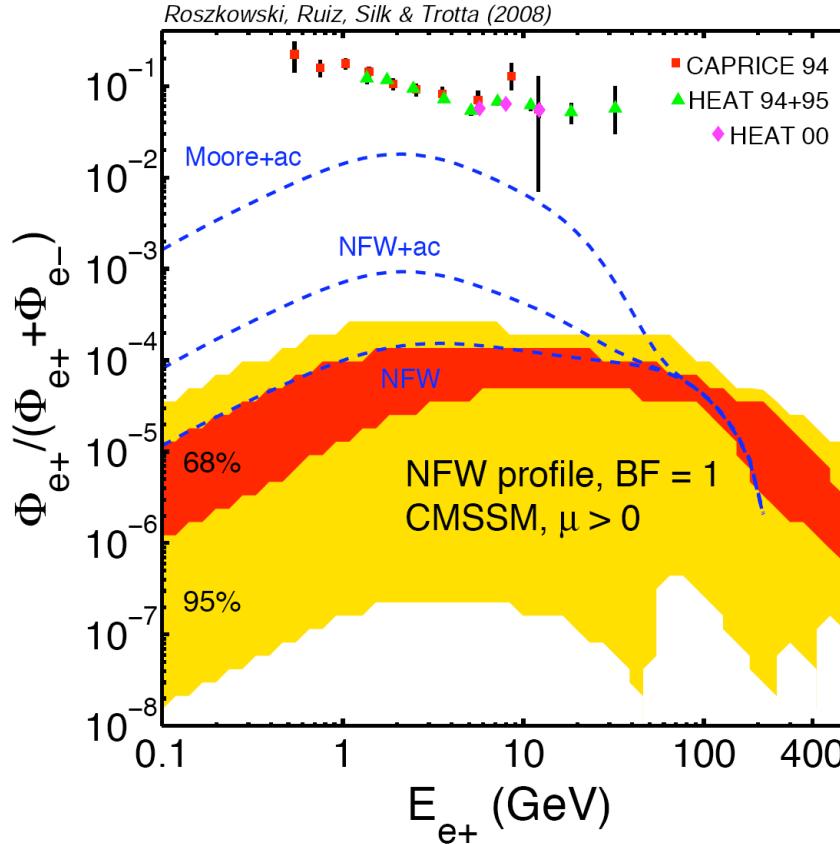
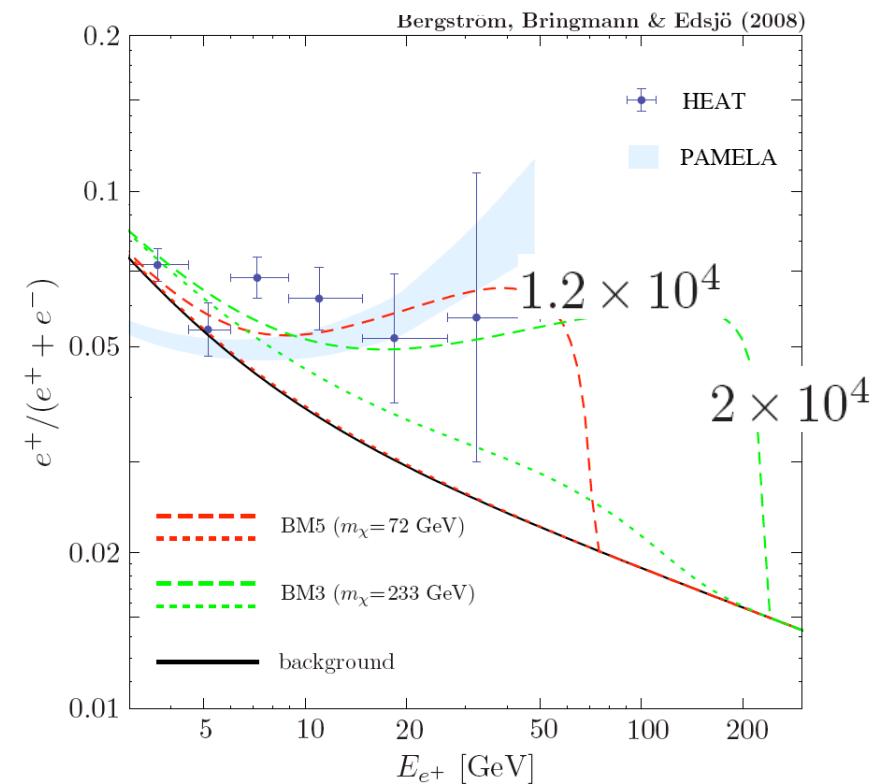
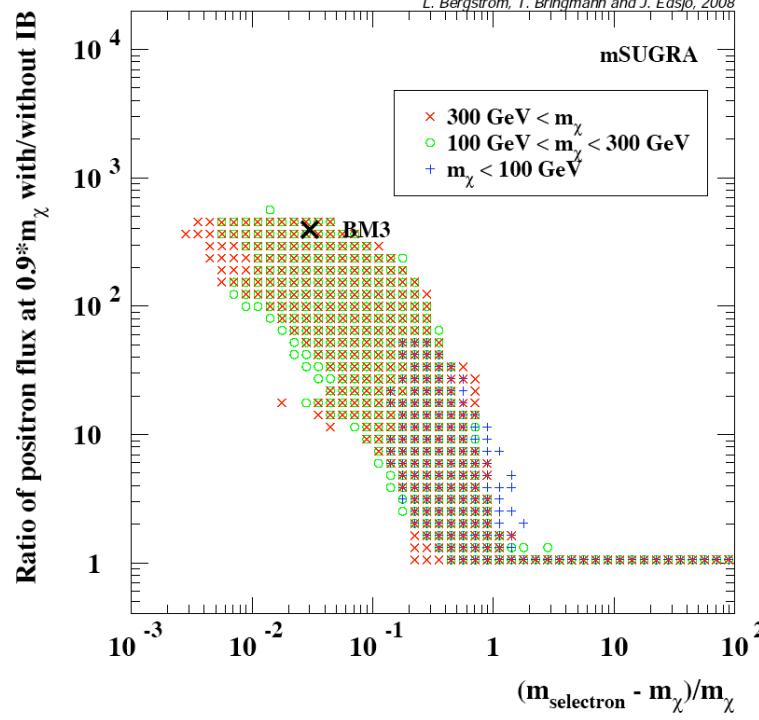
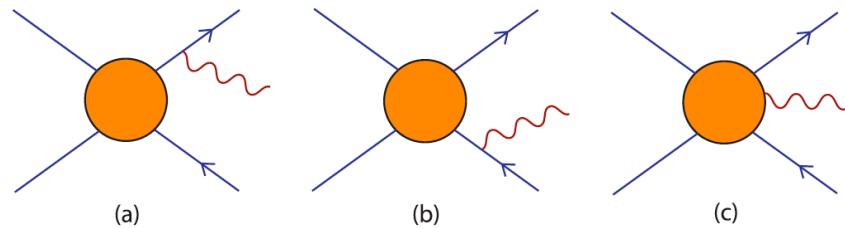


Figure 3: Predicted positron flux fraction in the CMSSM. The 68% (dark/red) and 95% (light/yellow) regions are for an NFW profile with a boost factor $BF=1$ and a specific choice of propagation model. We also show for comparison some of the current data. To illustrate the dependency of the spectral shape at low energies on the halo model, we plot the spectrum for the same choice of CMSSM parameters (with $m_\chi = 229$ GeV) for three different halo models as indicated. In absence of a large boost factor, the signal appears too small to be detected by PAMELA.

New Positron Spectral Features from Supersymmetric Dark Matter - a Way to Explain the PAMELA Data?

Lars Bergström,* Torsten Bringmann,† and Joakim Edsjö‡



Unrealistic boost factors required

Sommerfeld effect – a non-perturbative enhancement of σ_{ann} at low velocity

J. Hisano, S. Matsumoto and M. M. Nojiri

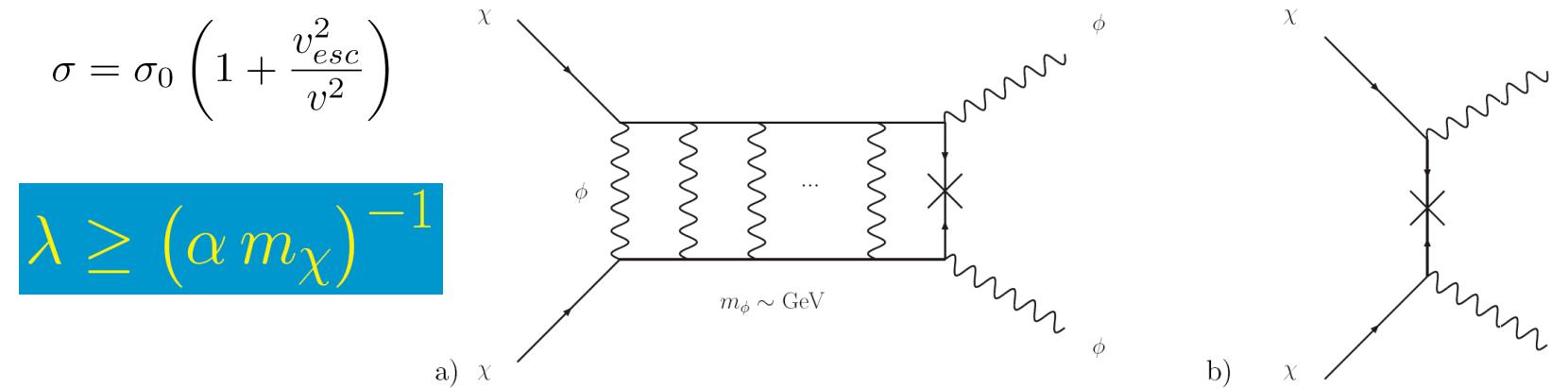
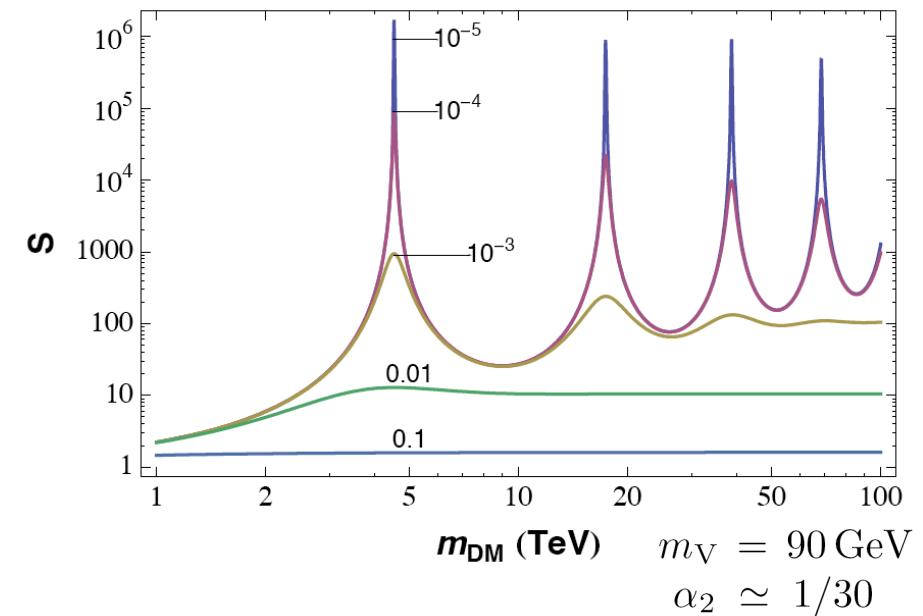
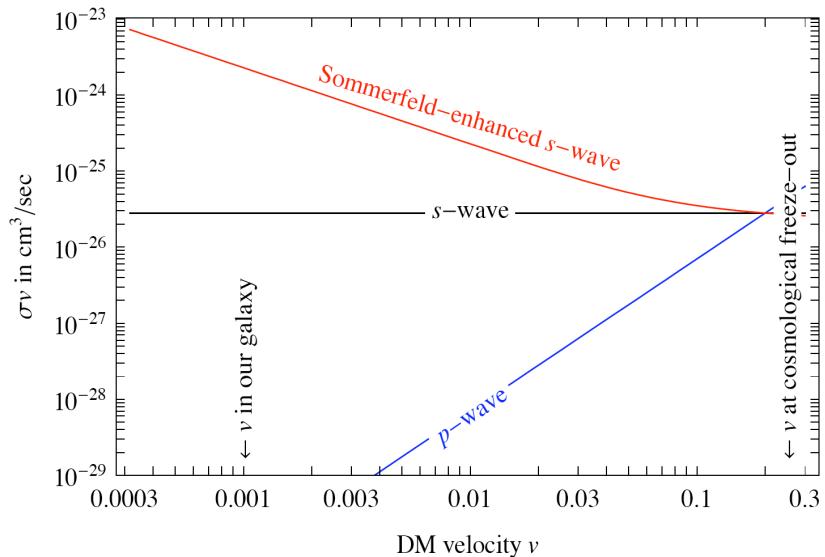
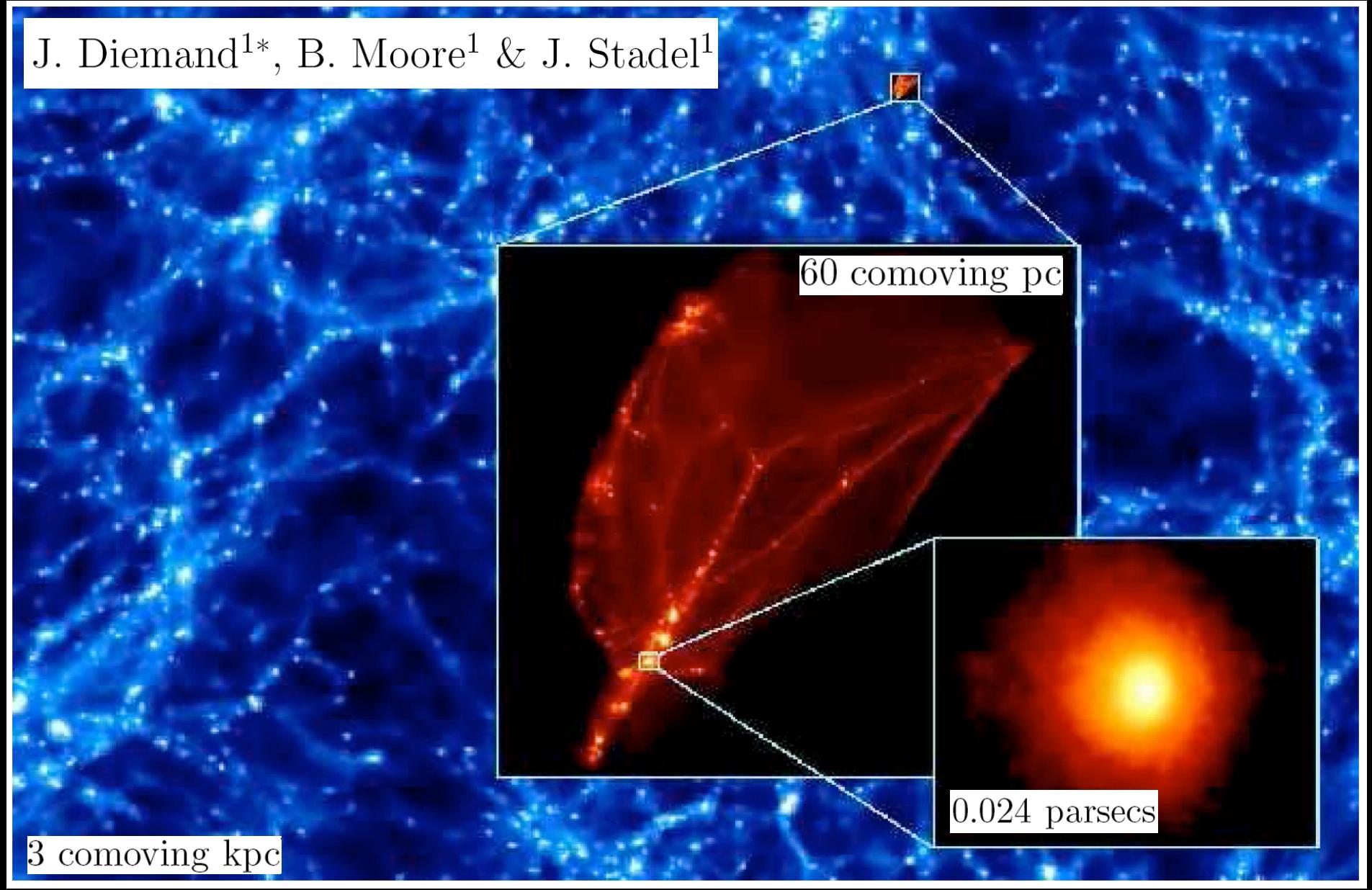


FIG. 3: The annihilation diagrams $\chi\chi \rightarrow \phi\phi$ both with (a) and without (b) the Sommerfeld enhancements.



J. Diemand^{1*}, B. Moore¹ & J. Stadel¹



Full Calculation of Clumpiness Boost factors for Antimatter Cosmic Rays in the light of Λ CDM N-body simulation results

Abandoning hope in clumpiness enhancement?

J. Lavalle¹, Q. Yuan², D. Maurin³, and X.-J. Bi²

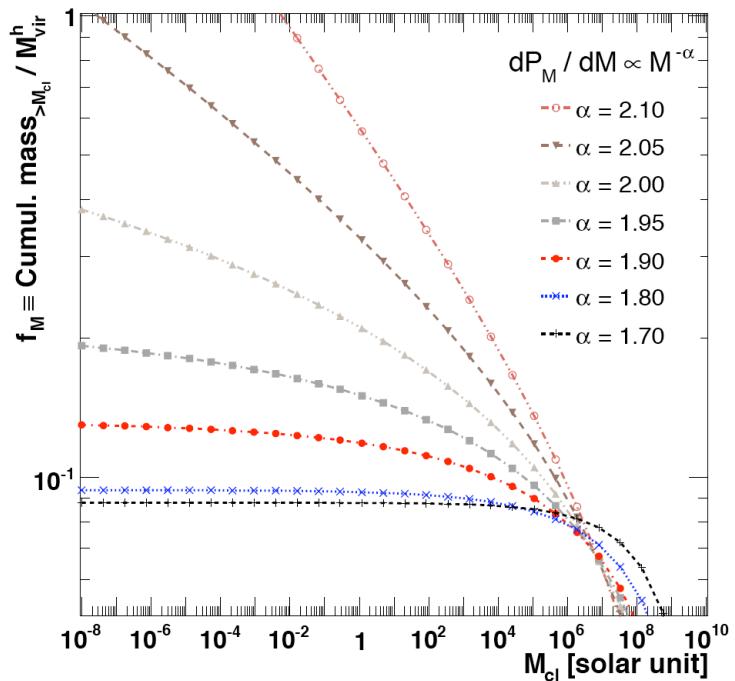


Fig. 1. The mass fraction f_M of DM in clumps is set once M_{min} and α_m are chosen. This fraction can be directly read off the graph for various α_m (from 2.1 down to 1.7—top to bottom curves) and various M_{min} (from $10^8 M_\odot$ down to $10^{-8} M_\odot$, x-axis).

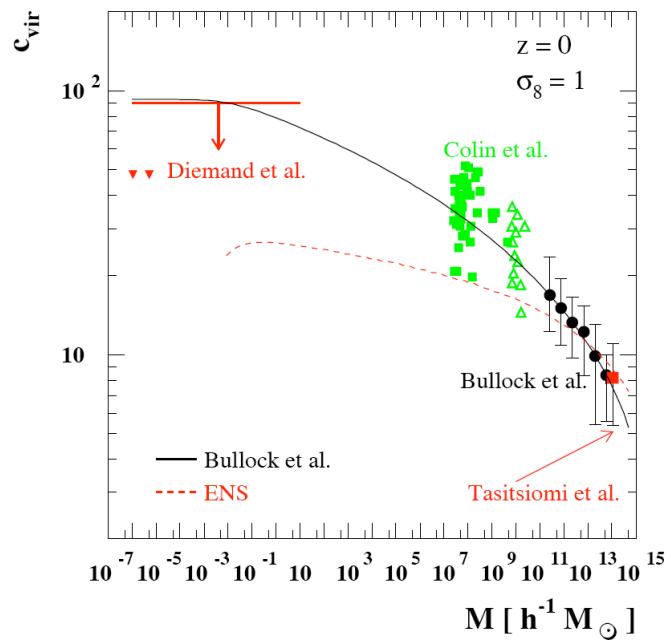


Fig. 1. The dependence of c_{vir} on the halo mass M , at $z = 0$, as in the Bullock et al. toy model (solid line) and in the ENS toy model (dashed line); predictions are compared to a few sets of simulation results in different mass ranges. A flat, vacuum-dominated cosmology with $\Omega_M = 0.3$, $\Omega_\Lambda = 0.7$, $h = 0.7$ and $\sigma_8 = 1$ is assumed here.

$$B_{\text{Milky Way}} \leq 10$$

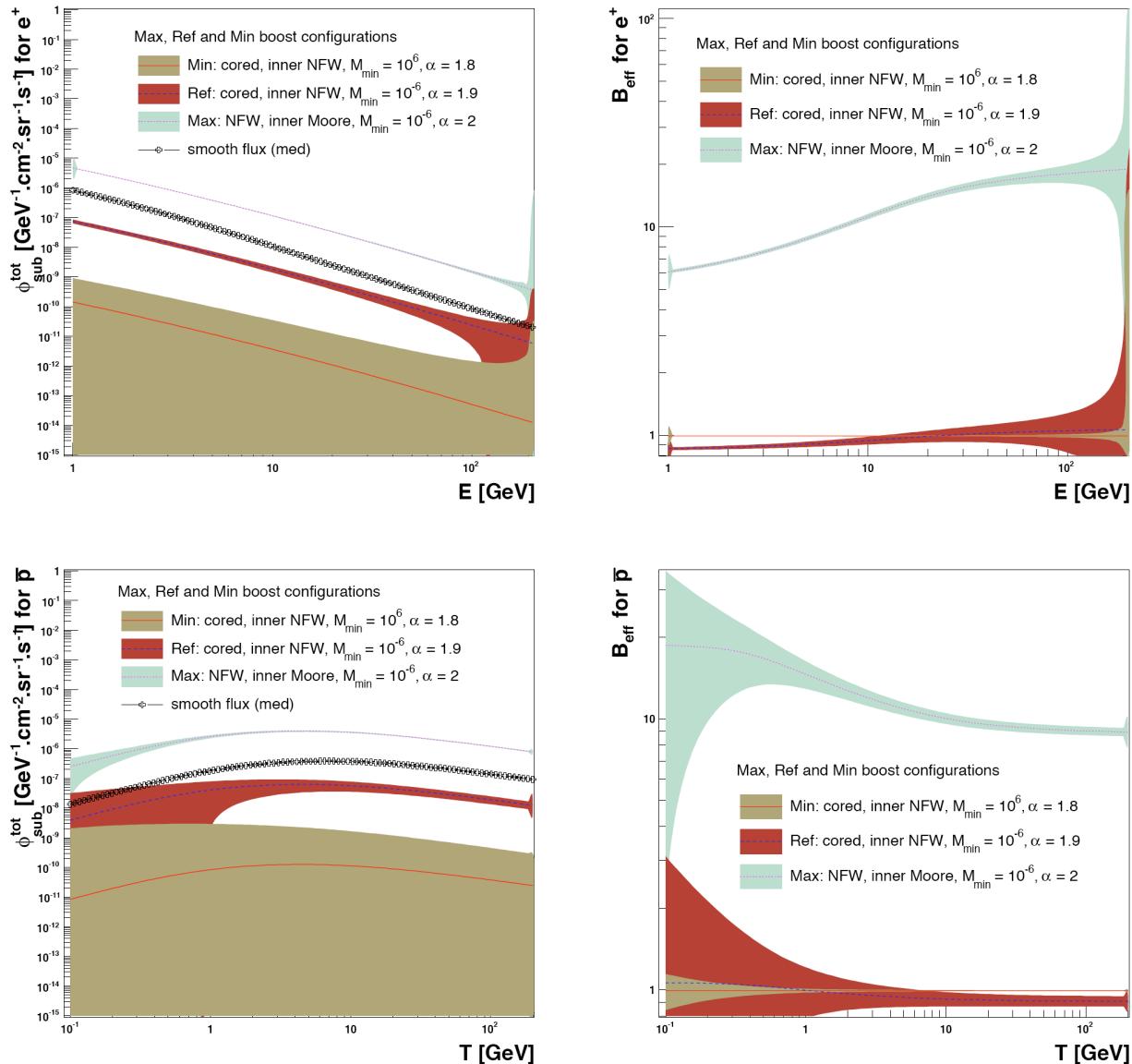
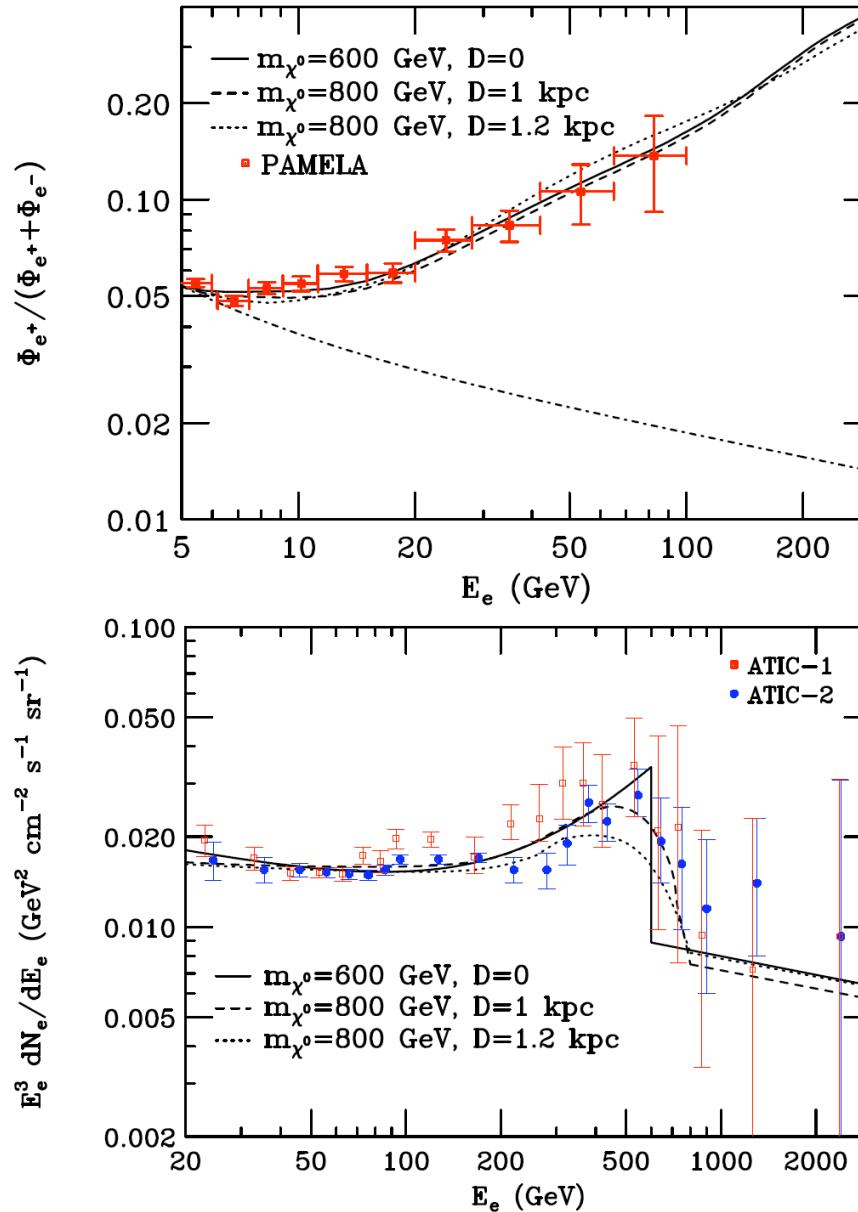
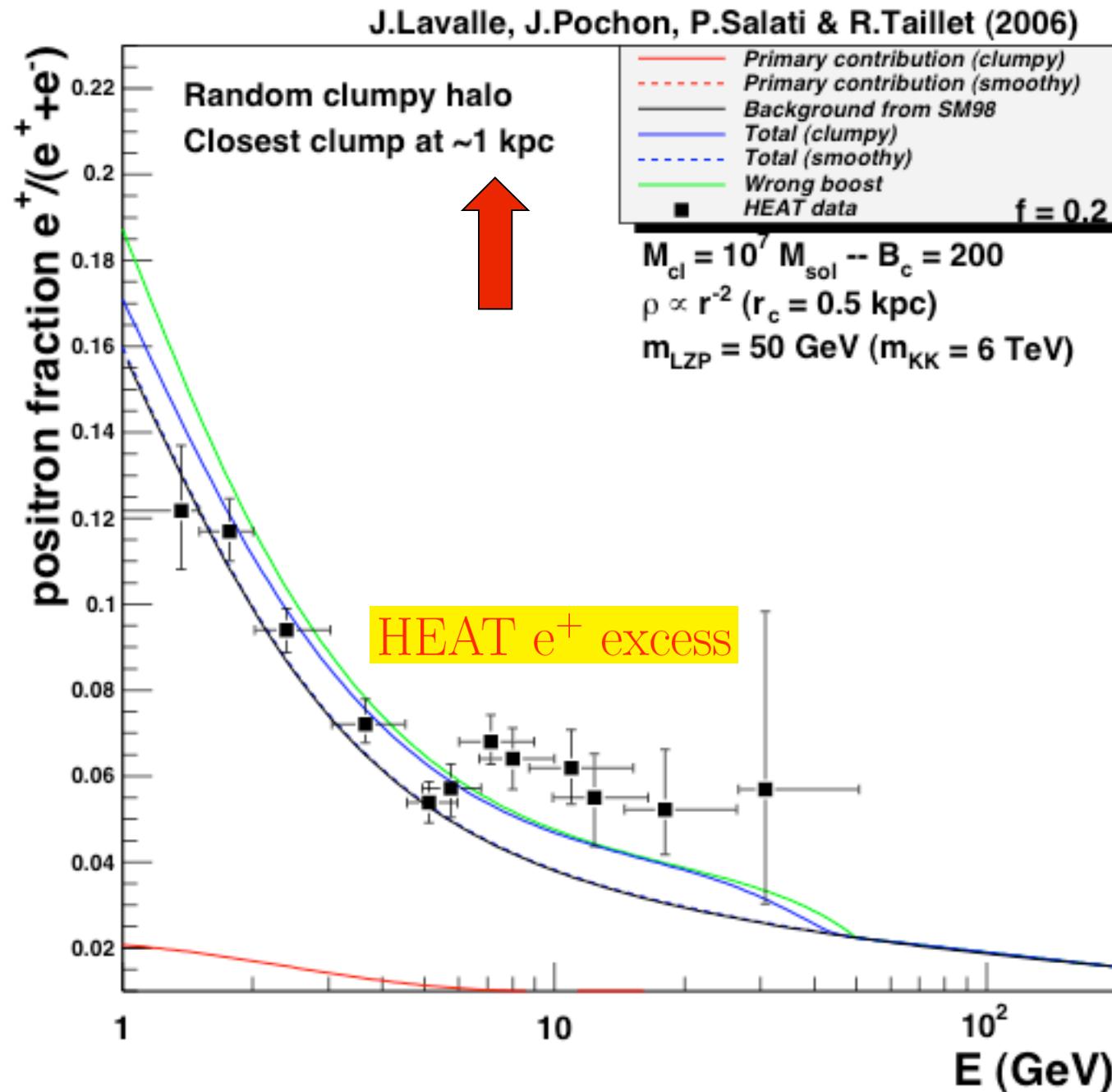
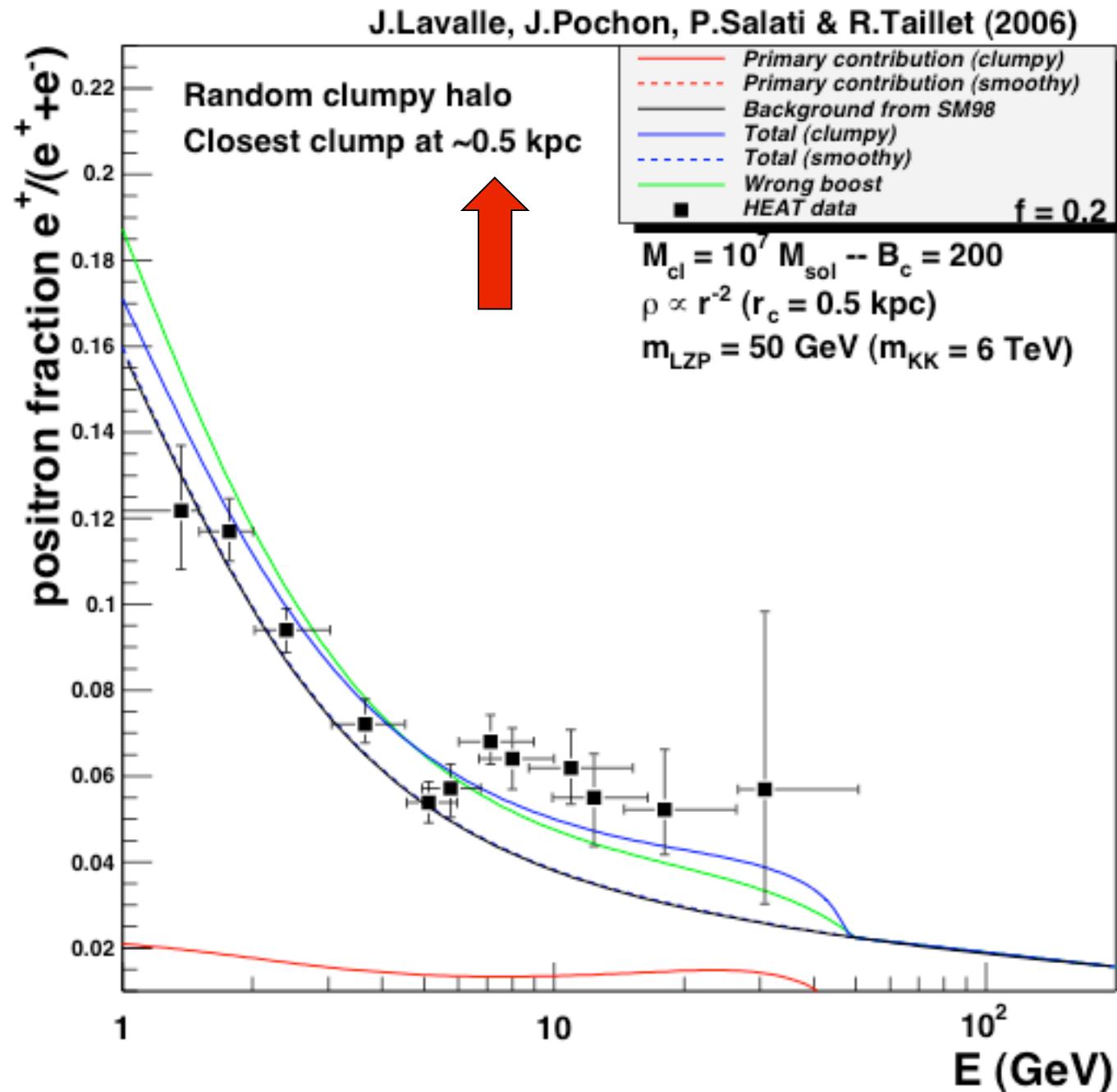


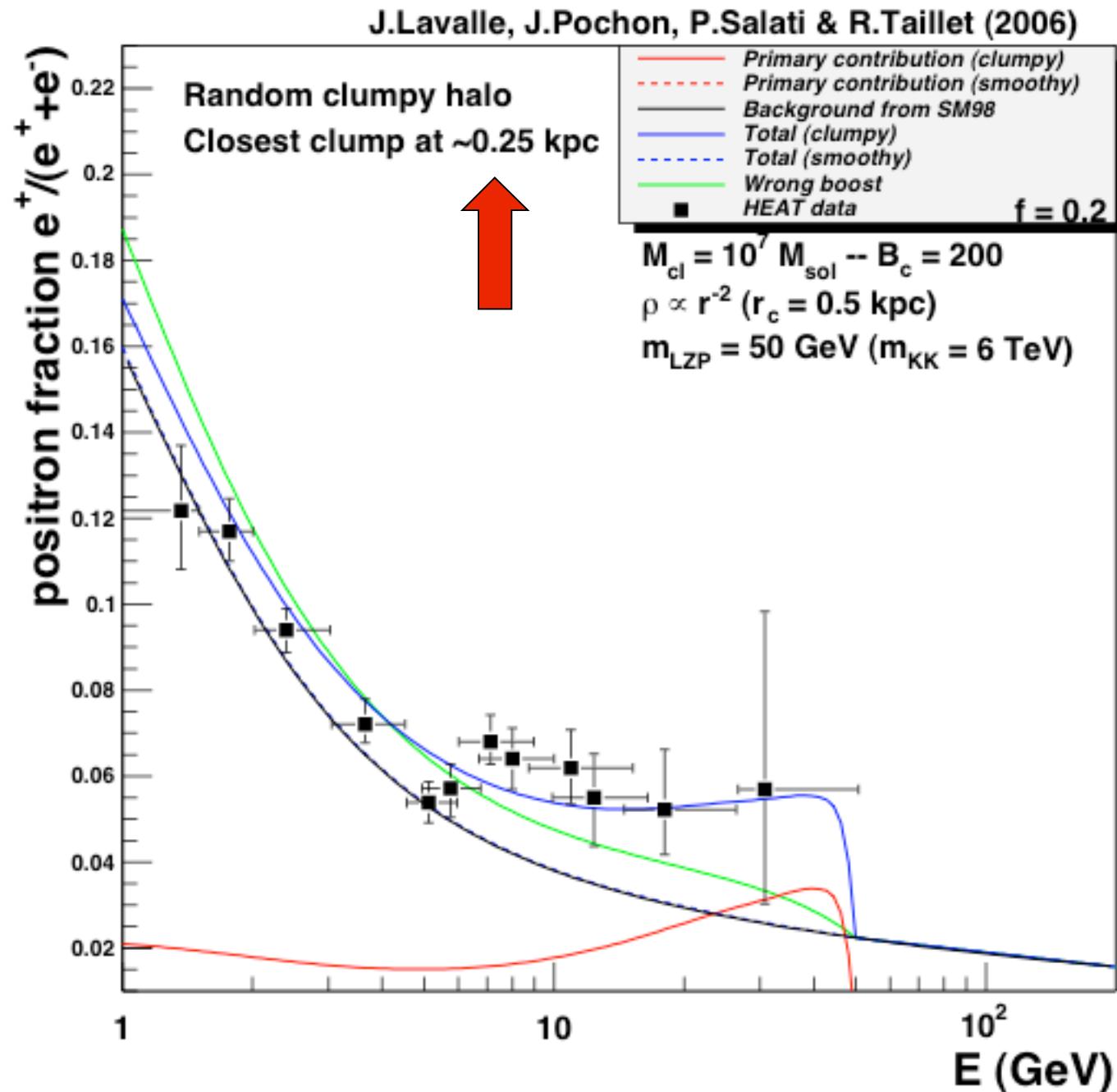
Fig. 6. Extreme cases for the DM configurations: sub-halo antimatter fluxes associated with the maximal, reference and minimal DM configurations (medium set of propagation parameters). Left/right: fluxes/boosts and corresponding $1-\sigma$ contours. Top/bottom: positrons/anti-protons. See details in the text.

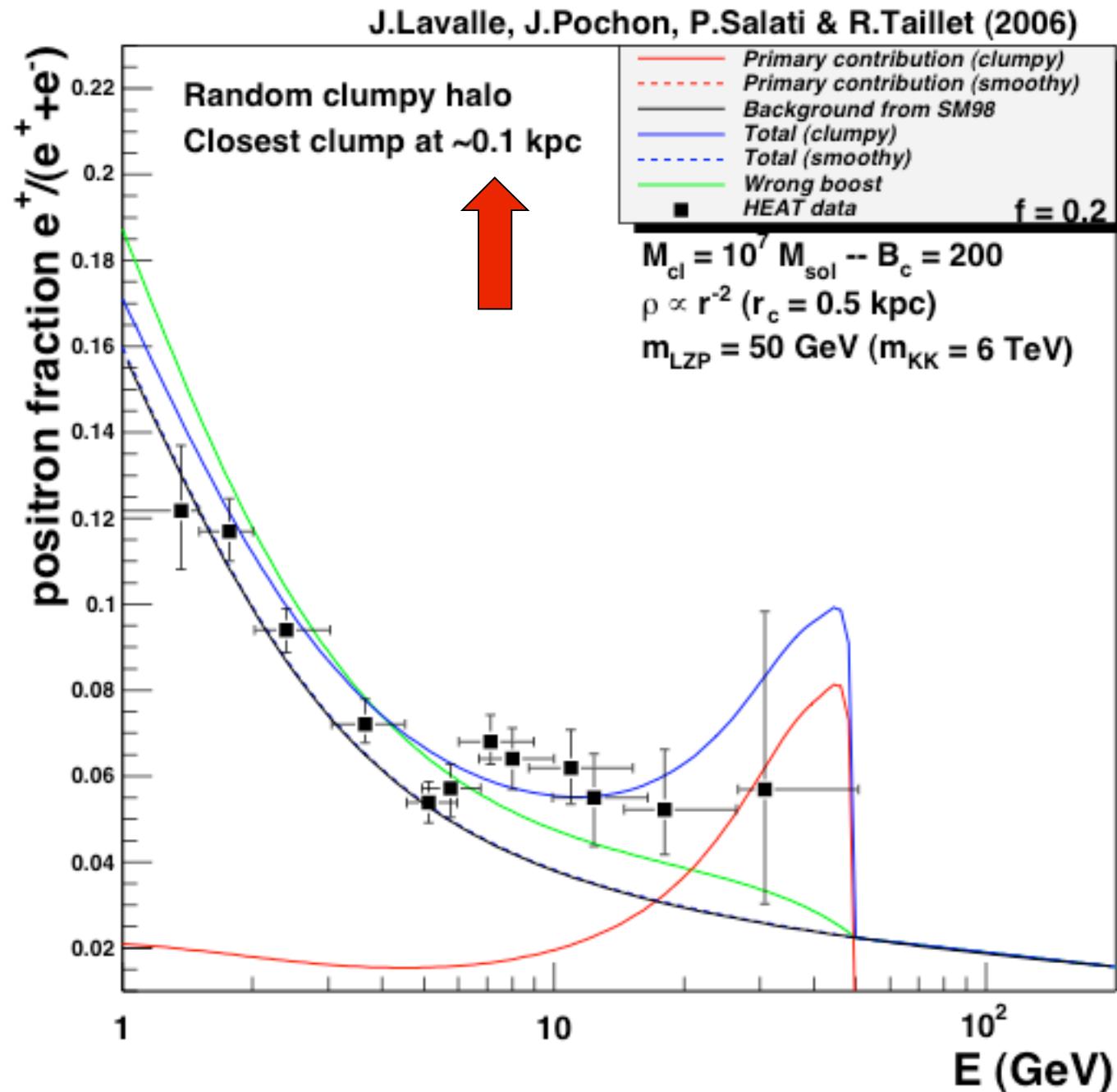
The PAMELA and ATIC Excesses From a Nearby Clump of Neutralino Dark Matter

Dan Hooper^{1,2}, Albert Stebbins¹, and Kathryn M. Zurek¹

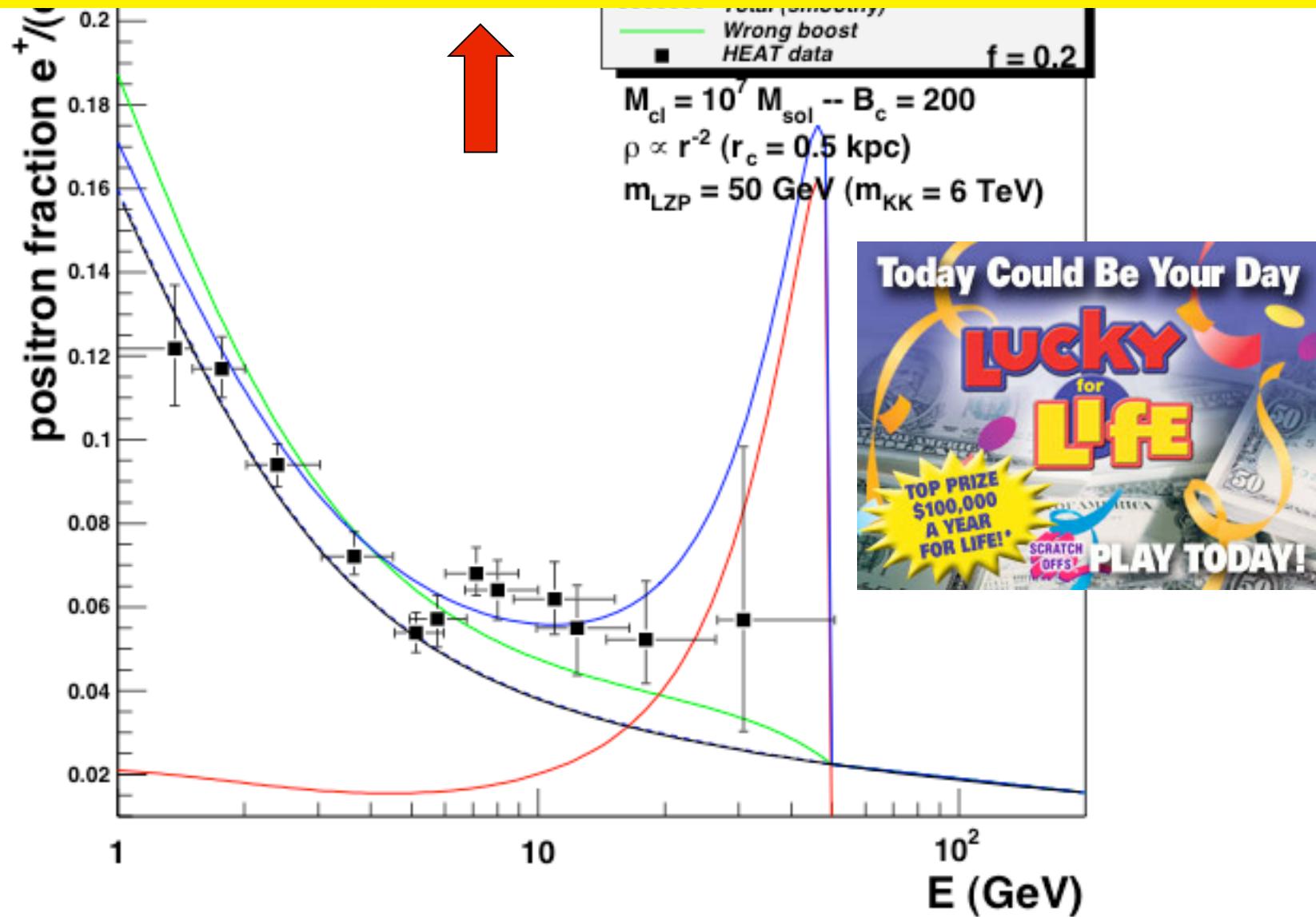








How probable is that ?



Recipe for a statistical analysis

- Without clumps – with the smooth DM distribution ρ_s

$$\phi_s = \left\{ \mathcal{S} \equiv \frac{\beta \delta}{4\pi} \langle \sigma_{\text{ann}} v \rangle \frac{\rho_\odot^2}{m_\chi^2} \frac{dN}{dE} \right\} \times \left\{ \mathcal{I} \equiv \int_{\text{DZ}} G(\mathbf{x}) \frac{\rho_s^2(\mathbf{x})}{\rho_\odot^2} d^3\mathbf{x} \right\}$$

- With clumps – with the DM distribution $\rho = \rho'_s + \delta\rho$

$$\phi = \{\phi'_s \simeq \phi_s\} + \left\{ \phi_r = \sum_i \varphi_i \right\}$$

$$\varphi_i = \mathcal{S} \times G(\mathbf{x}_i) \times \left\{ \xi_i = \frac{B_i M_i}{\rho_\odot} = \int_{\text{ith clump}} \frac{\delta\rho^2(\mathbf{x})}{\rho_\odot^2} d^3\mathbf{x} \right\}$$

random behaviour !

$$\text{Boost factor } B \equiv \frac{\phi}{\phi_s}$$

Recipe for a statistical analysis

(i) The actual distribution of DM substructures is one particular realization \in statistical ensemble of all the possible **random** distributions.

$$\langle \phi_r \rangle \quad \text{and} \quad \sigma_r^2 = \langle \phi_r^2 \rangle - \langle \phi_r \rangle^2$$

$$B_{\text{eff}} = \langle B = \phi/\phi_s \rangle \quad \text{and} \quad \sigma_B = \sigma_r/\phi_s$$

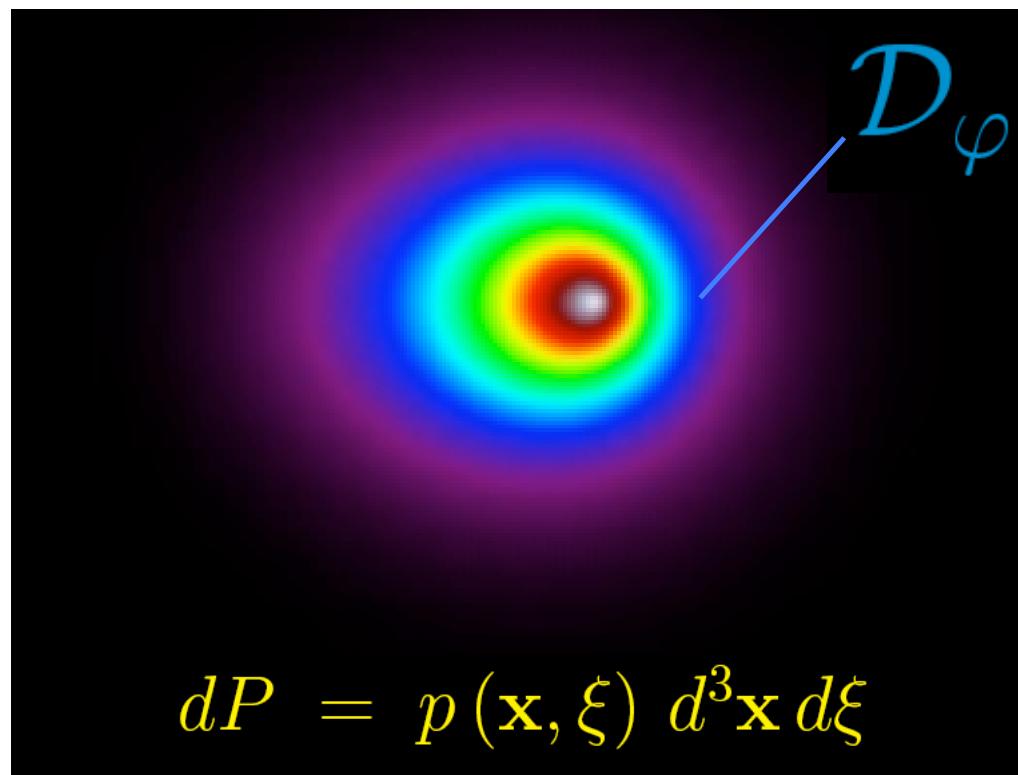
(ii) **Clumps are distributed independently of each other.** Therefore, we just need to determine how a single clump is distributed inside the galactic halo in order to derive the statistical properties of an entire constellation of N_H such substructures.

$$\langle \phi_r \rangle = N_H \langle \varphi \rangle \quad \text{and} \quad \sigma_r^2 = N_H \sigma^2 = N_H \{ \langle \varphi^2 \rangle - \langle \varphi \rangle^2 \}$$

(iii) The set of the random distributions of one single clump inside the domain \mathcal{D}_H forms the statistical ensemble \mathcal{T} which we need to consider. An event from that ensemble consists in a clump characterized by the annihilation volume ξ up to $d\xi$ and located at position \mathbf{x} within the elementary volume $d^3\mathbf{x}$.

$$\mathcal{P}(\varphi) d\varphi = dP = \int_{\mathcal{D}_\varphi} p(\mathbf{x}, \xi) d^3\mathbf{x} d\xi$$

$$\langle \mathcal{F} \rangle = \int \mathcal{F}(\varphi) \mathcal{P}(\varphi) d\varphi = \int_{\mathcal{D}_H} \mathcal{F}\{\varphi(\mathbf{x}, \xi)\} p(\mathbf{x}, \xi) d^3\mathbf{x} d\xi$$



(iv) This naturally leads to the effective boost factor

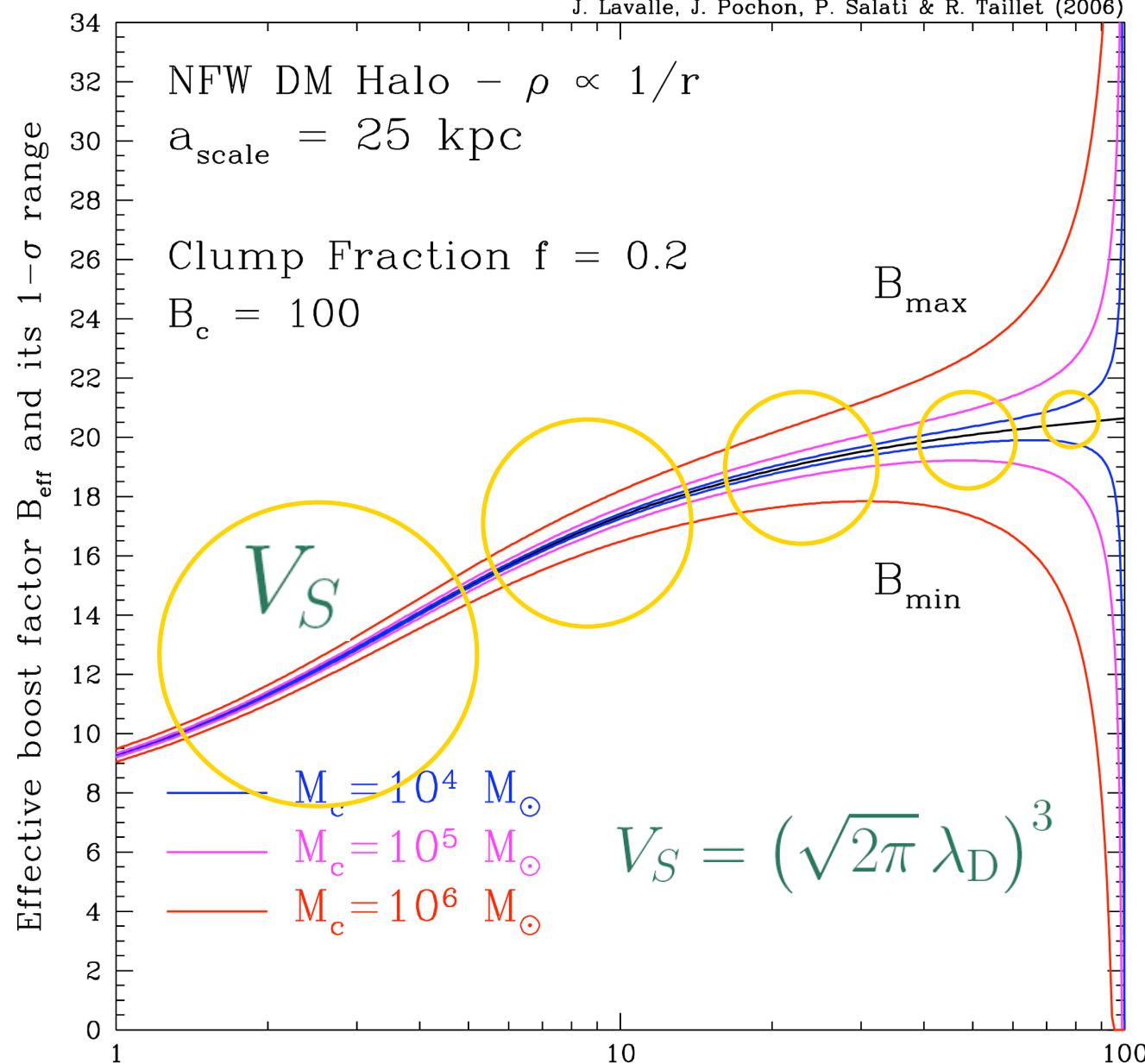
$$B_{\text{eff}} = \left\{ \frac{\phi'_s}{\phi_s} \simeq 1 \right\} + \frac{\langle \phi_r \rangle}{\phi_s} = 1 + N_H \frac{\langle \xi G \rangle}{\mathcal{I}}$$

and to the boost variance

$$\frac{\sigma_B}{B_{\text{eff}}} = \frac{\sigma_r / \phi_s}{1 + \langle \phi_r \rangle / \phi_s} \simeq \frac{\sigma_r}{\langle \phi_r \rangle}$$

where

$$\frac{\sigma_r^2}{\langle \phi_r \rangle^2} = \frac{1}{N_H} \left\{ \frac{\langle \xi^2 G^2 \rangle}{\langle \xi G \rangle^2} - 1 \right\}$$



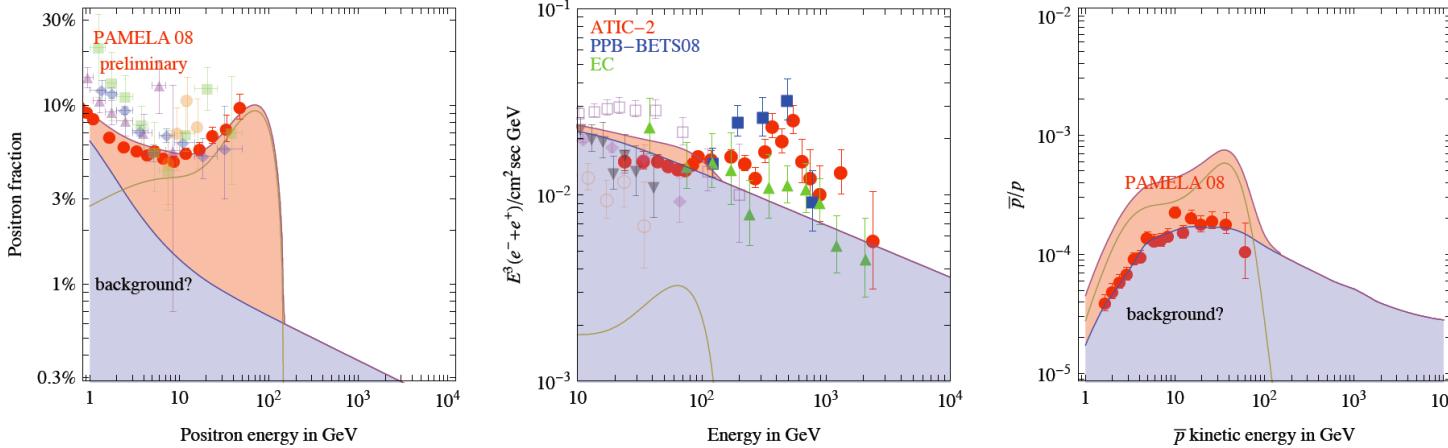
V_S increases as E decreases

Other signals should not be overproduced

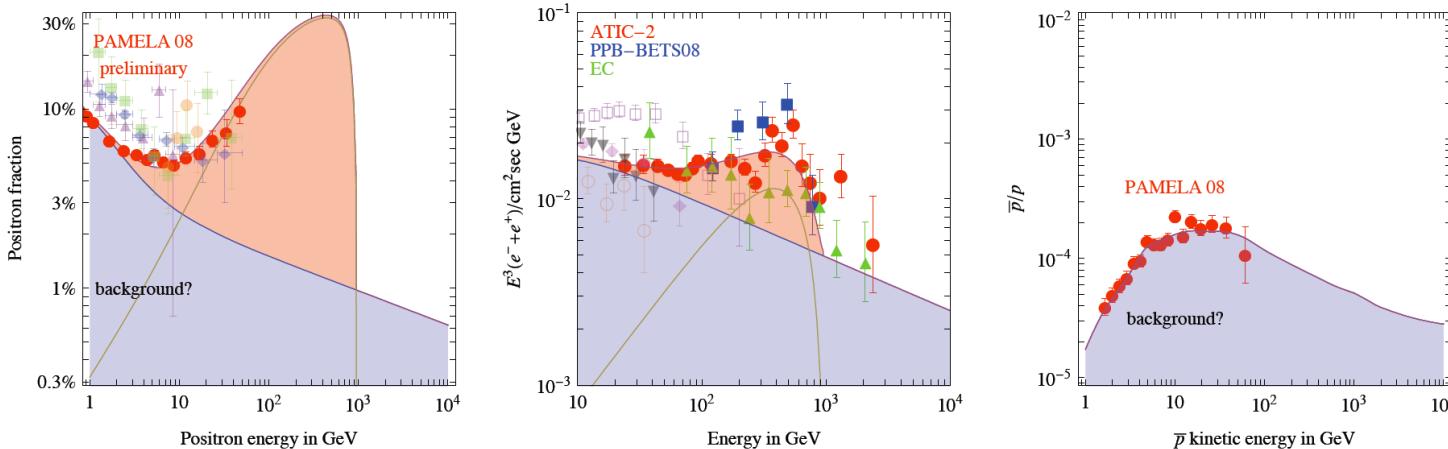
Quark channels are suppressed – purely leptophilic DM candidate

M. Cirelli^a, M. Kadastik^b, M. Raidal^b, A. Strumia^c

DM with $M = 150$ GeV that annihilates into W^+W^-



DM with $M = 1$ TeV that annihilates into $\mu^+\mu^-$



Constraints on WIMP Dark Matter from the High Energy PAMELA \bar{p}/p data

F. Donato, D. Maurin, P. Brun, T. Delahaye & P. Salati, [arXiv:0810.5292](https://arxiv.org/abs/0810.5292)

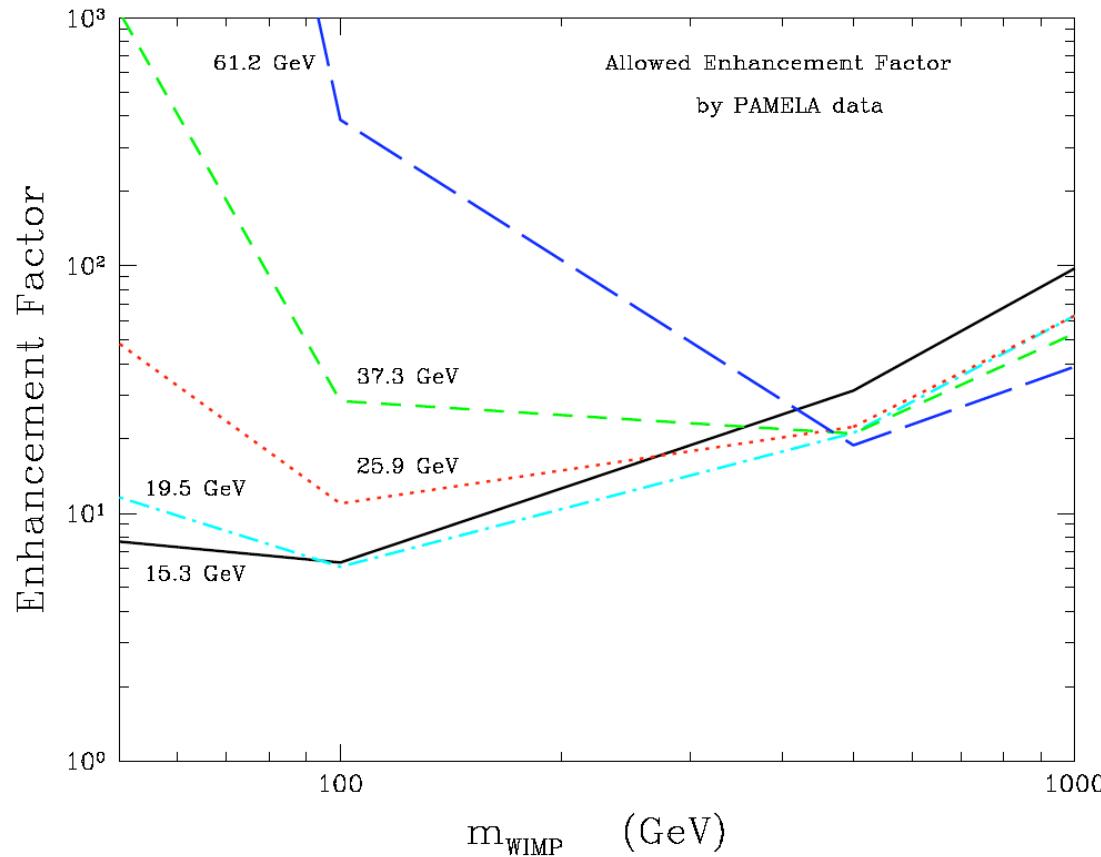


FIG. 2: Upper limits on the enhancement factor to the primary \bar{p} flux as a function of the WIMP mass, derived from a comparison with PAMELA high energy data. Each curve is labelled according to the corresponding PAMELA energy bin.

Constraints on WIMP Dark Matter from the High Energy PAMELA \bar{p}/p data

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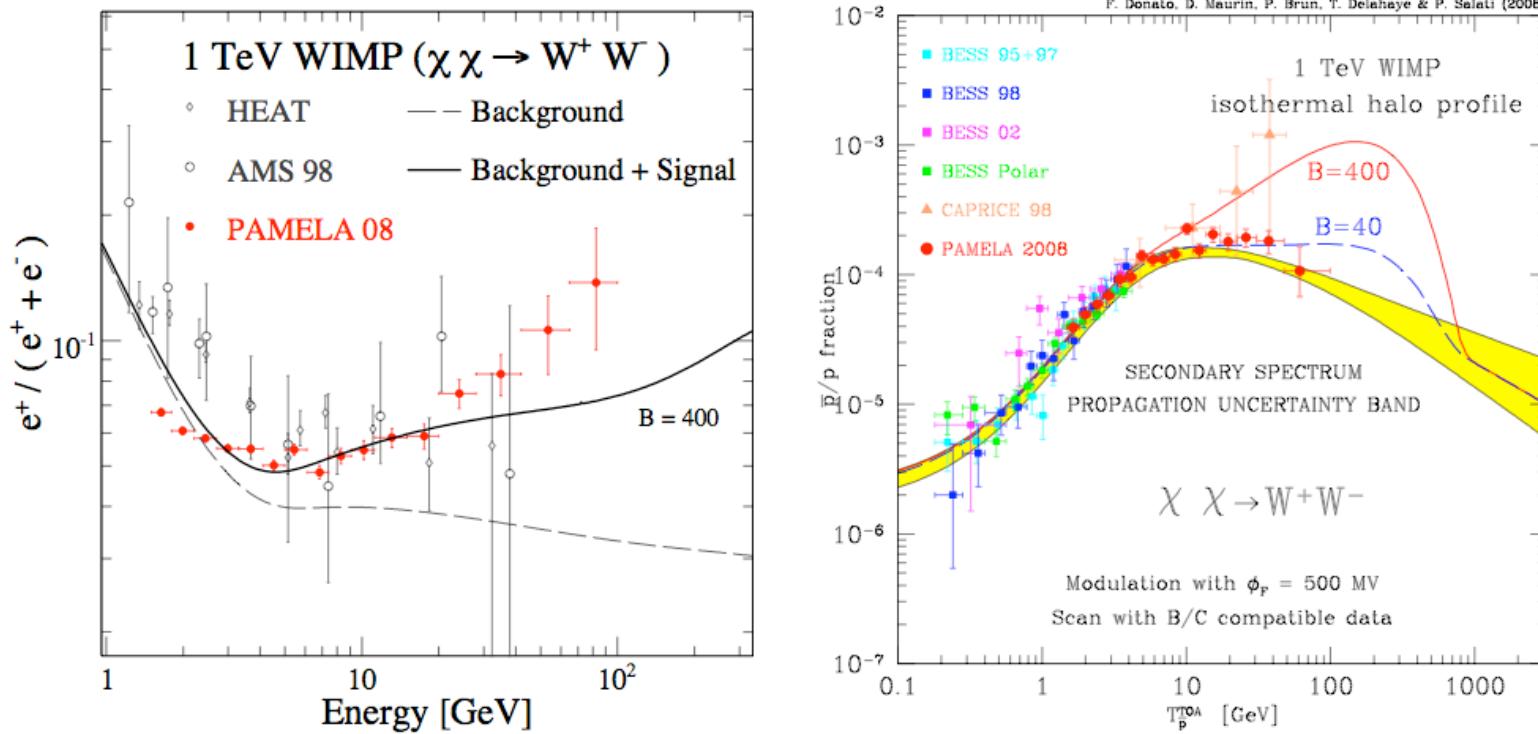
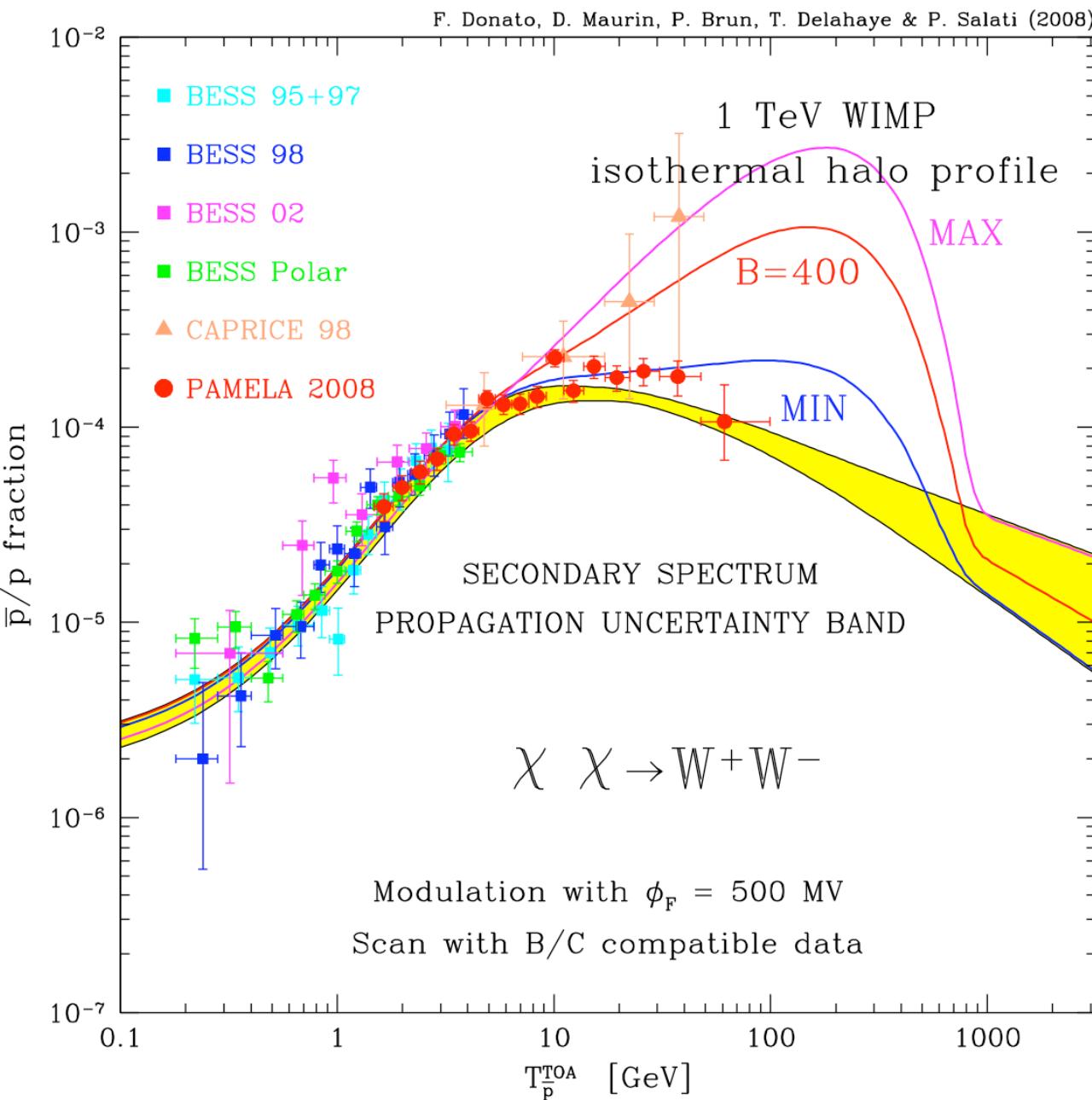


FIG. 3: The fiducial case of a 1 TeV LSP annihilating into a W^+W^- pair is featured. In the left panel, the positron signal which this DM species yields has been increased by a factor of 400, hence the solid curve and a marginal agreement with the PAMELA data. Positron fraction data are from HEAT [18], AMS-01 [5, 22] and PAMELA [2]. If the so-called Sommerfeld effect [7] is invoked to explain such a large enhancement of the annihilation cross section, the same boost applies to antiprotons and leads to an unacceptable distortion of their spectrum as indicated by the red solid line of the right panel.

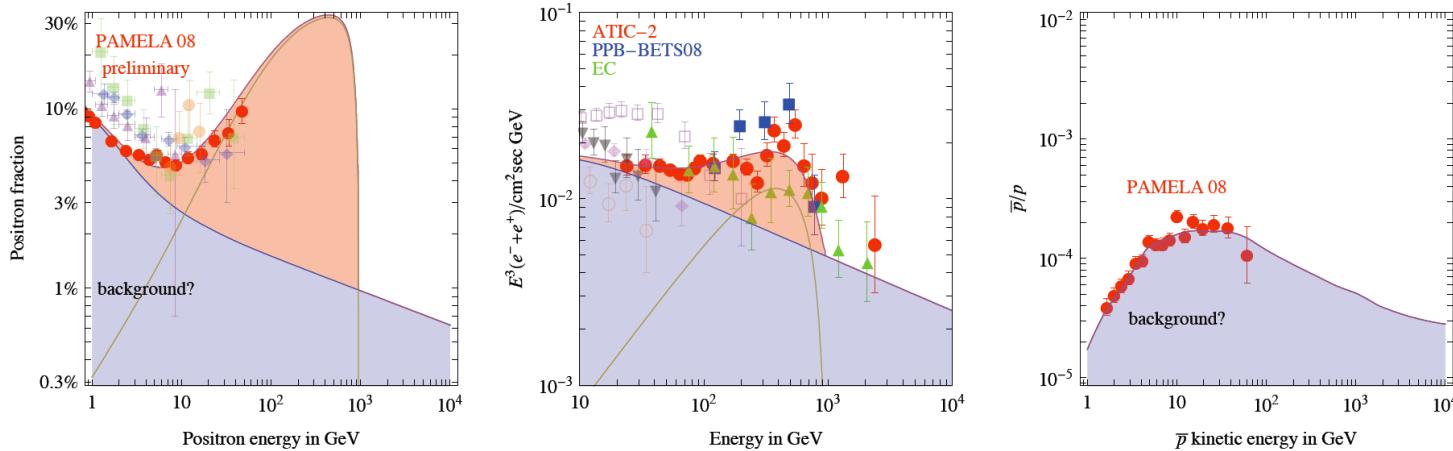


Other signals should not be overproduced

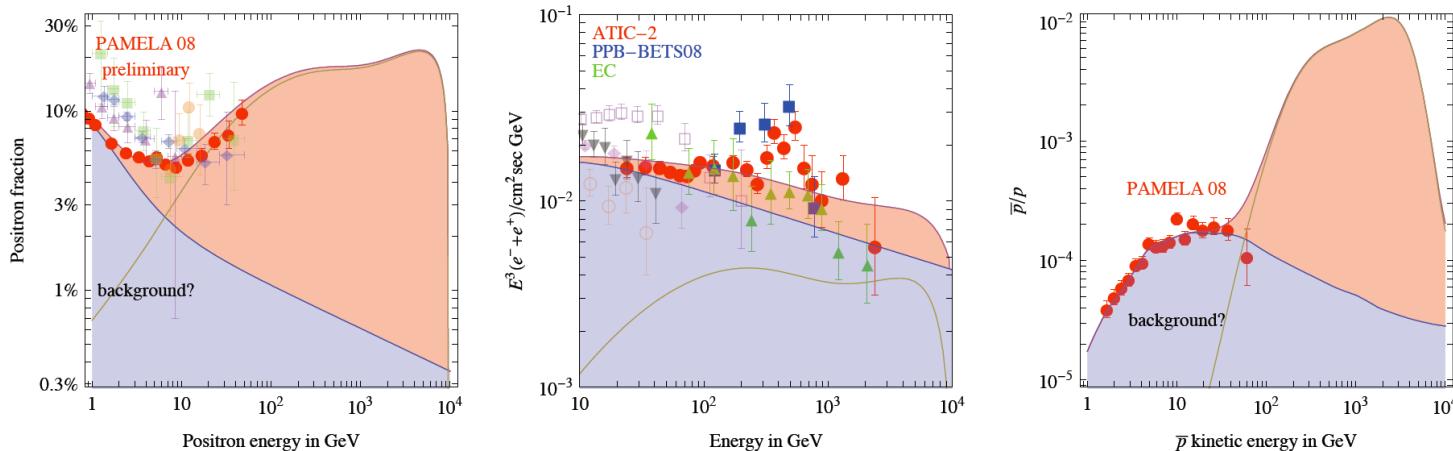
Very heavy DM particle – should lead to a large $\Phi_{\bar{p}}$ at high E

M. Cirelli^a, M. Kadastik^b, M. Raidal^b, A. Strumia^c

DM with $M = 1$ TeV that annihilates into $\mu^+ \mu^-$



DM with $M = 10$ TeV that annihilates into $W^+ W^-$



Distinguishing Between Dark Matter and Pulsar Origins of the ATIC Electron Spectrum With Atmospheric Cherenkov Telescopes

Jeter Hall^{1,*} and Dan Hooper^{2,3,†}

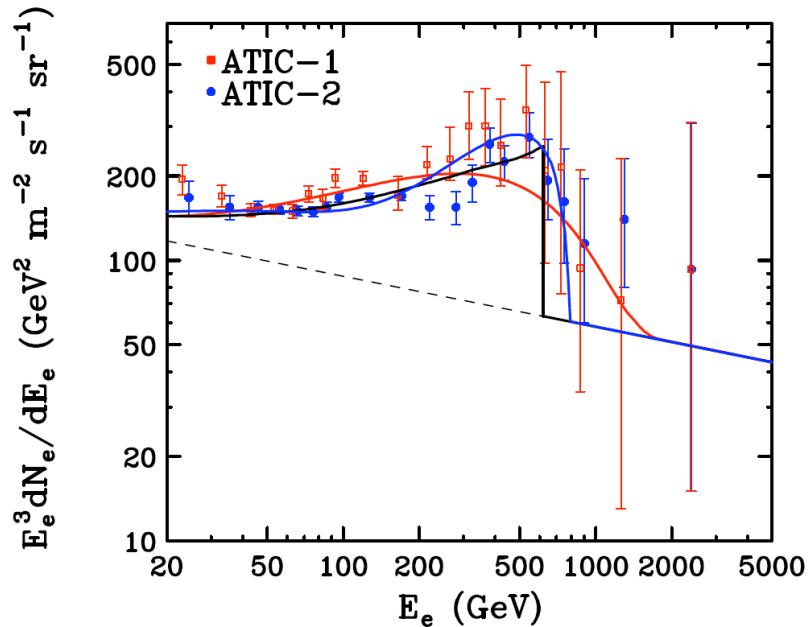
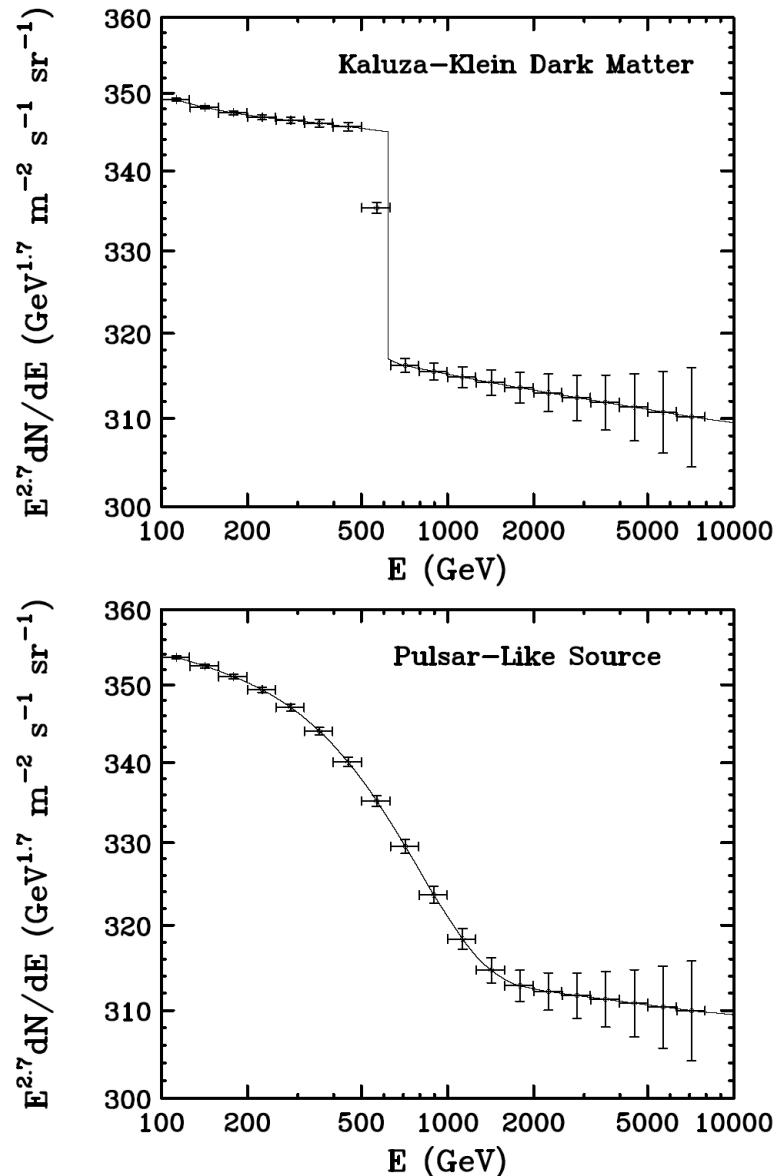


FIG. 1: The cosmic ray electron spectrum as measured by ATIC [1] compared to the spectrum predicted from three possible sources: a nearby pulsar (red), annihilation of 800 GeV dark matter annihilating to W^+W^- (blue), and annihilation of 620 GeV Kaluza-Klein dark matter (which annihilates to e^+e^- , $\mu^+\mu^-$, and $\tau^+\tau^-$ 20% of the time each). In each case, the source spectrum was added to a background power-law spectrum with a spectral slope of -3.2 (dashed).



4) Discussion – DM or not DM ?

(i) Production inside local molecular clouds.

- The sun is located inside a H depleted local bubble.
- No **B** confinement above 10 GeV and no PF excess above 30 GeV.

(ii) Galactic and local pulsars – could work very well !

(iii) DM particles.

- The annihilation rate needs to be considerably boosted.
 - ✓ Internal bremsstrahlung from charged external legs or virtual internal particles.
 - ✓ Sommerfeld effect – a non-perturbative enhancement of σ_{ann} at low velocity.
 - ✓ Non-thermal relic (gravitino decay) or modified thermal decoupling (quintessence).
 - ✓ Substructures are characterized by $\langle \rho^2 \rangle \geq \langle \rho \rangle^2$.

$$\boxed{\text{But } B_{\text{Milky Way}} \leq 10}$$

- ✓ A single nearby clump – how probable is it ?
- Other signals should not be overproduced – the example of antiprotons.
 - ✓ Quark channels are suppressed – purely leptophilic DM candidate – UED – ad hoc models.
 - ✓ Very heavy DM particle – should lead to a large $\Phi_{\bar{p}}$ at high E .
 - ✓ Antiproton depletion wrt positrons – $B_{\text{Milky Way}}$ different – CR propagation.

Transport of Cosmic Rays in Chaotic Magnetic Fields

F. Casse, M. Lemoine & G. Pelletier, PRD **D65** (2002) 023002

Magnetic turbulence $\delta\mathbf{B}(\mathbf{x}) = \int \frac{d\mathbf{k}}{(2\pi)^3} e^{-i\mathbf{k}\cdot\mathbf{x}} \delta\mathbf{B}(\mathbf{k})$ whose power spectrum is defined by

$$\langle \delta\mathbf{B}(\mathbf{k})\delta\mathbf{B}^\dagger(\mathbf{k}') \rangle = (2\pi)^3 \delta(\mathbf{k} - \mathbf{k}') S_{3d}(\mathbf{k})$$

and follows between k_{\min} and k_{\max} the power law

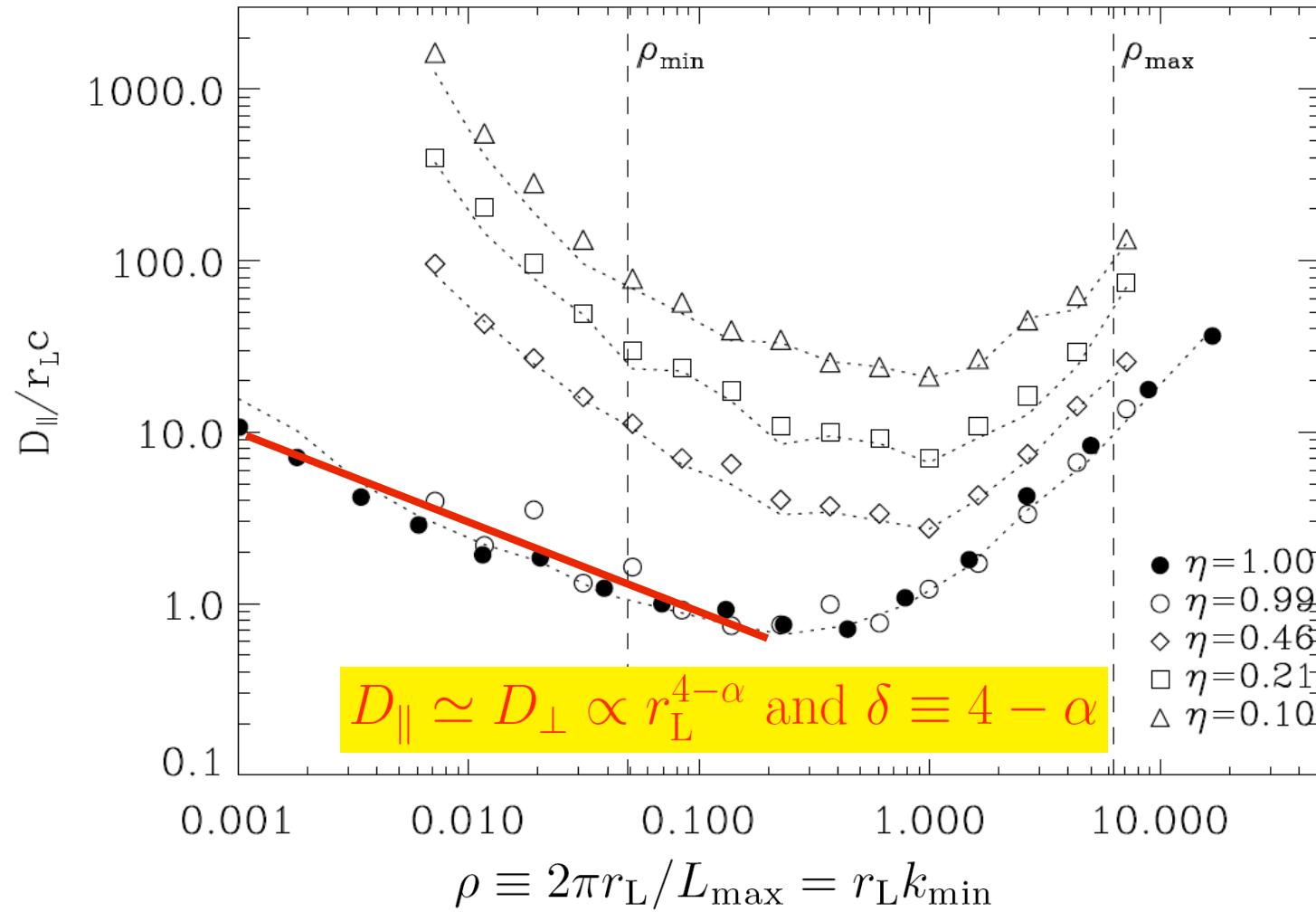
$$S_{3d}(\mathbf{k}) \propto k^{-\alpha}$$

The level of turbulence wrt to the homogeneous field \mathbf{B}_0 is defined by

$$\eta = \frac{\langle \delta\mathbf{B}^2 \rangle}{\mathbf{B}_0^2 + \langle \delta\mathbf{B}^2 \rangle}$$

Transport of Cosmic Rays in Chaotic Magnetic Fields

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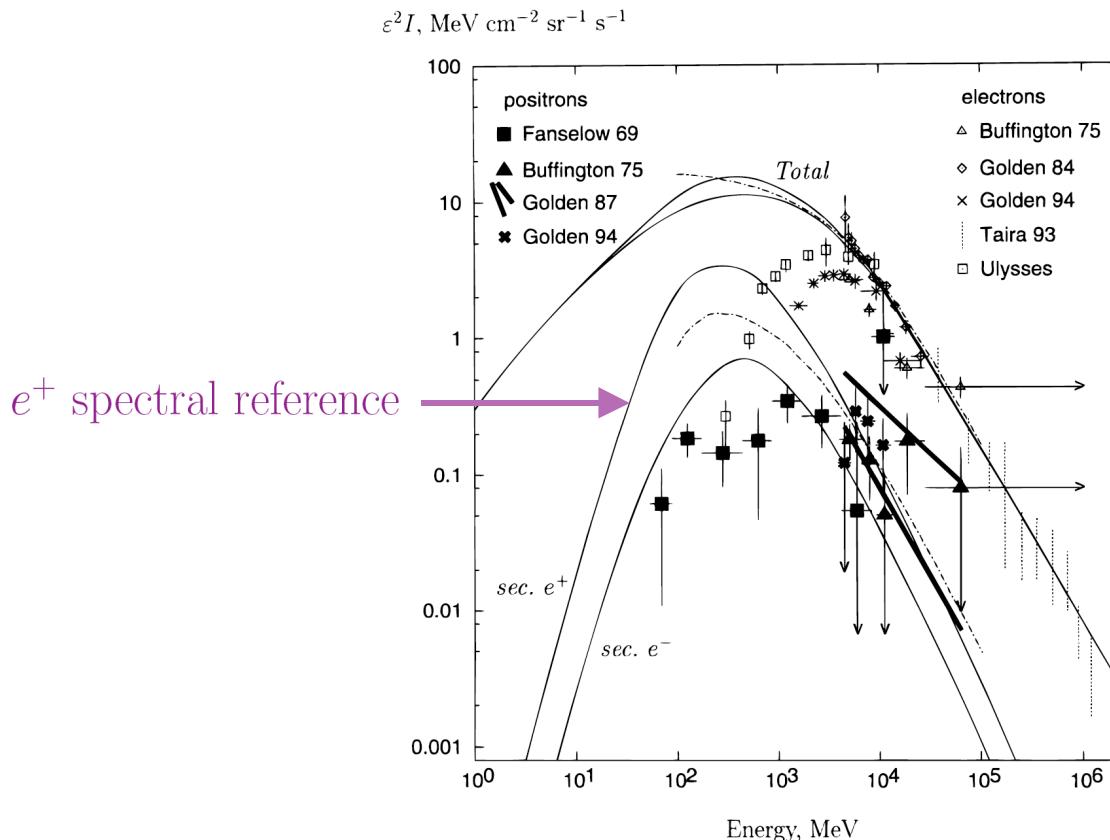


$\delta = 1/3$ (Kolmogorov) or $\delta = 1/2$ (Iroshnikov, Kraichnan)

The secondary e^+ spectrum so far used has been computed in 1998

I. V. Moskalenko and A. W. Strong, *Production and propagation of cosmic ray positrons and electrons, Astrophys. J.* **493** (1998) 694 [[astro-ph/9710124](#)].

no diffusive reacceleration



PARAMETERS OF MODELS

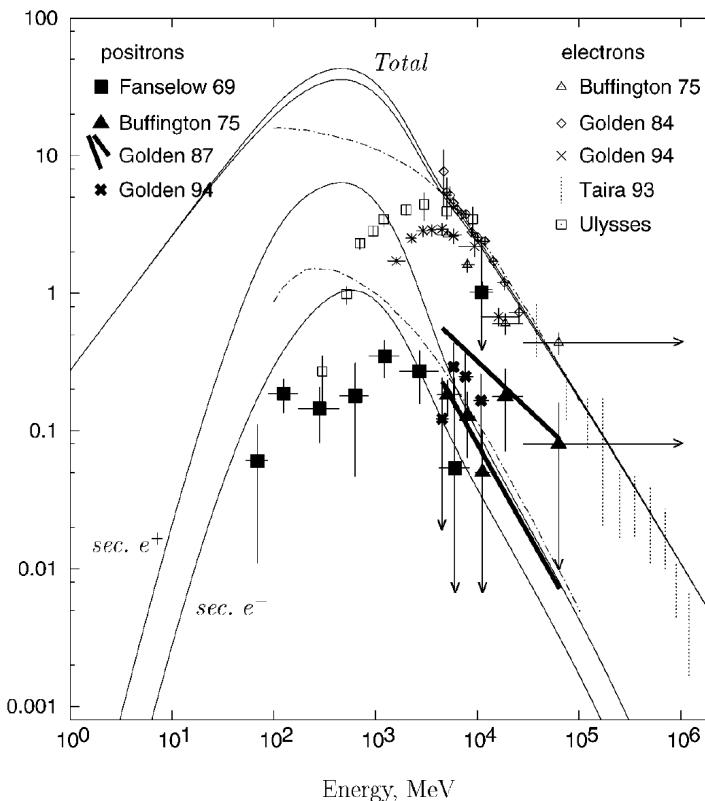
MODEL	z_h (kpc)	D_0 (cm ² s ⁻¹)	ρ_0 (MV/c)	δ	v_A (km s ⁻¹)	PROTONS		HELIUM			
						γ	p_0^a	I_0^b	γ	p_0^a	I_0^b
08-005.....	3	2.0×10^{28}	3.0×10^3	0.60	0	2.15	10^4	3×10^{-6}	2.35	4×10^4	4×10^{-8}
08-006.....	3	4.2×10^{28}	3.0×10^3	0.33	20	2.25	10^4	3×10^{-6}	2.45	4×10^4	4×10^{-8}
08-009.....	3	2.0×10^{28}	3.0×10^3	0.60	0	2.00	10^4	3×10^{-6}	2.00	4×10^4	4×10^{-8}

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diffusive reacceleration

$\varepsilon^2 I$, MeV cm $^{-2}$ sr $^{-1}$ s $^{-1}$



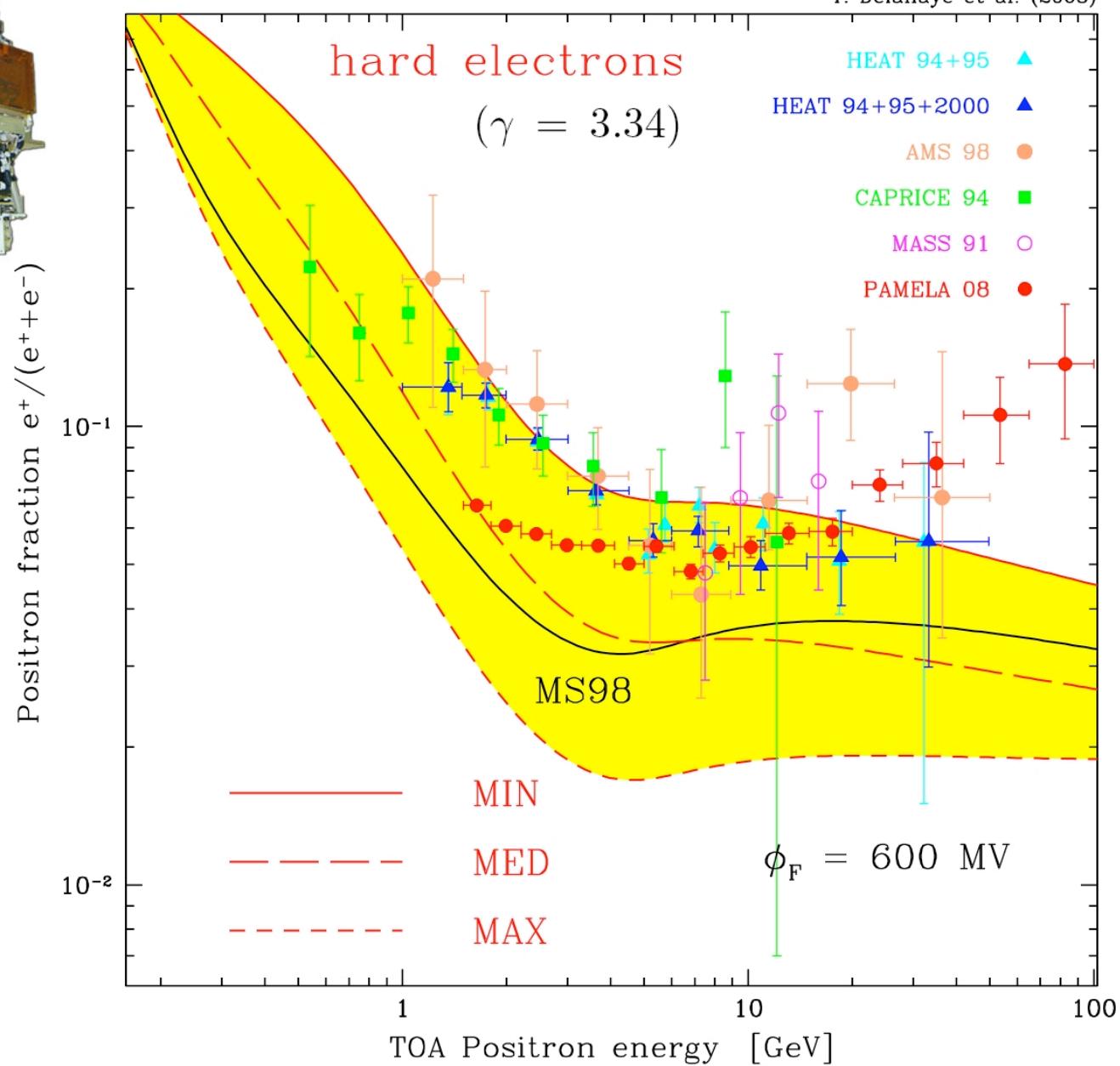
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Delahaye T. et al. – arXiv:0809.5268

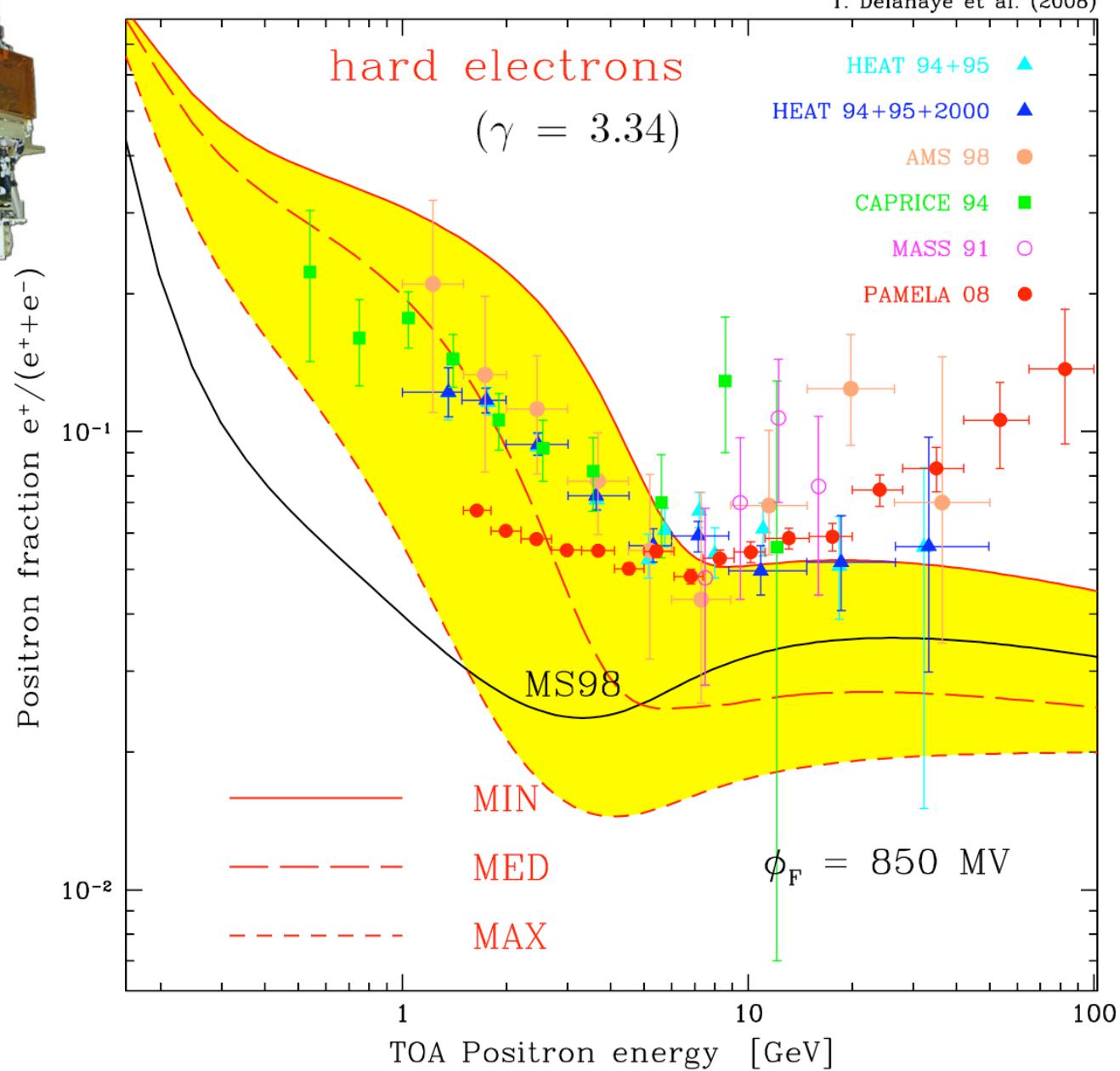
T. Delahaye et al. (2008)





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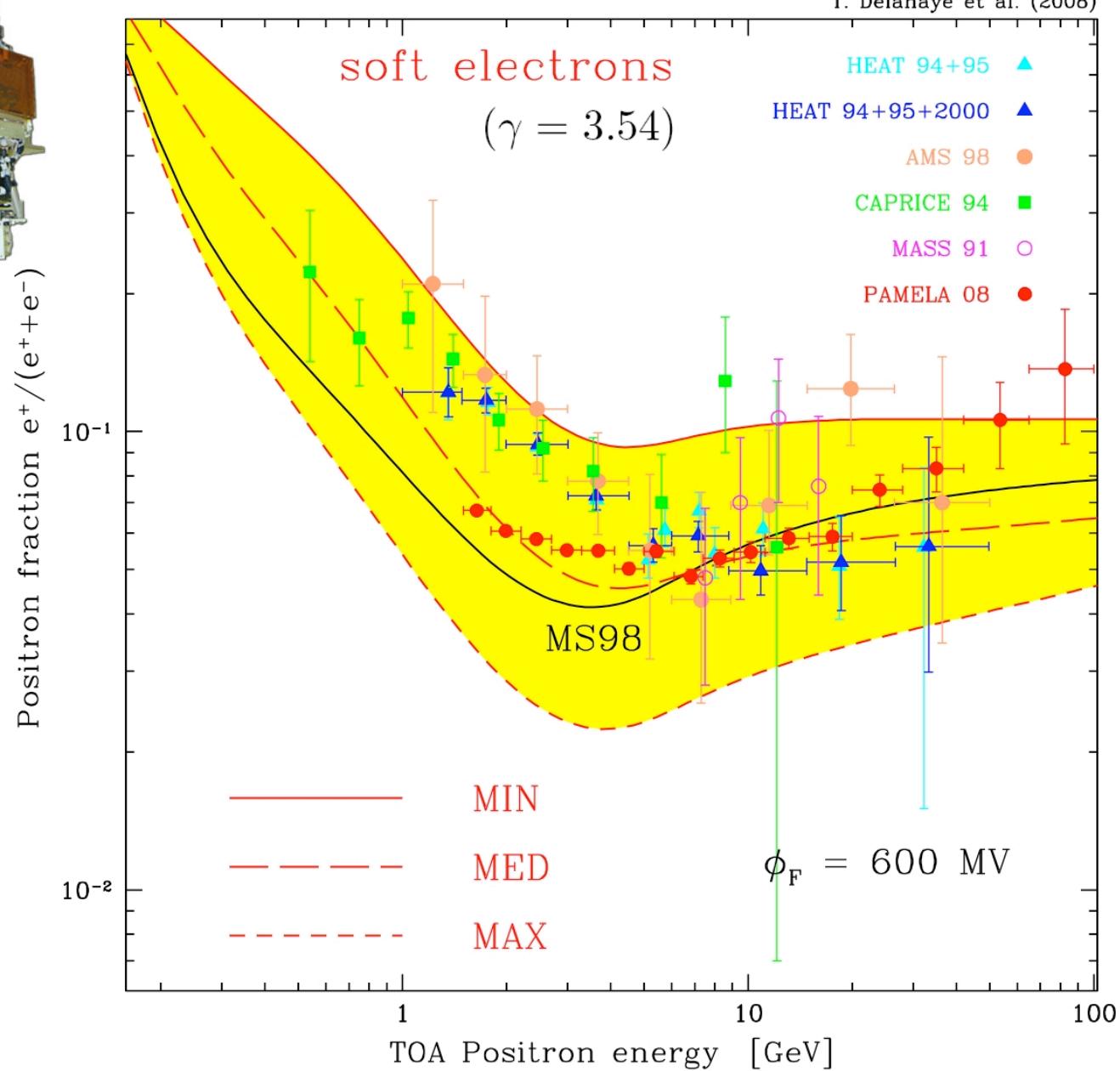
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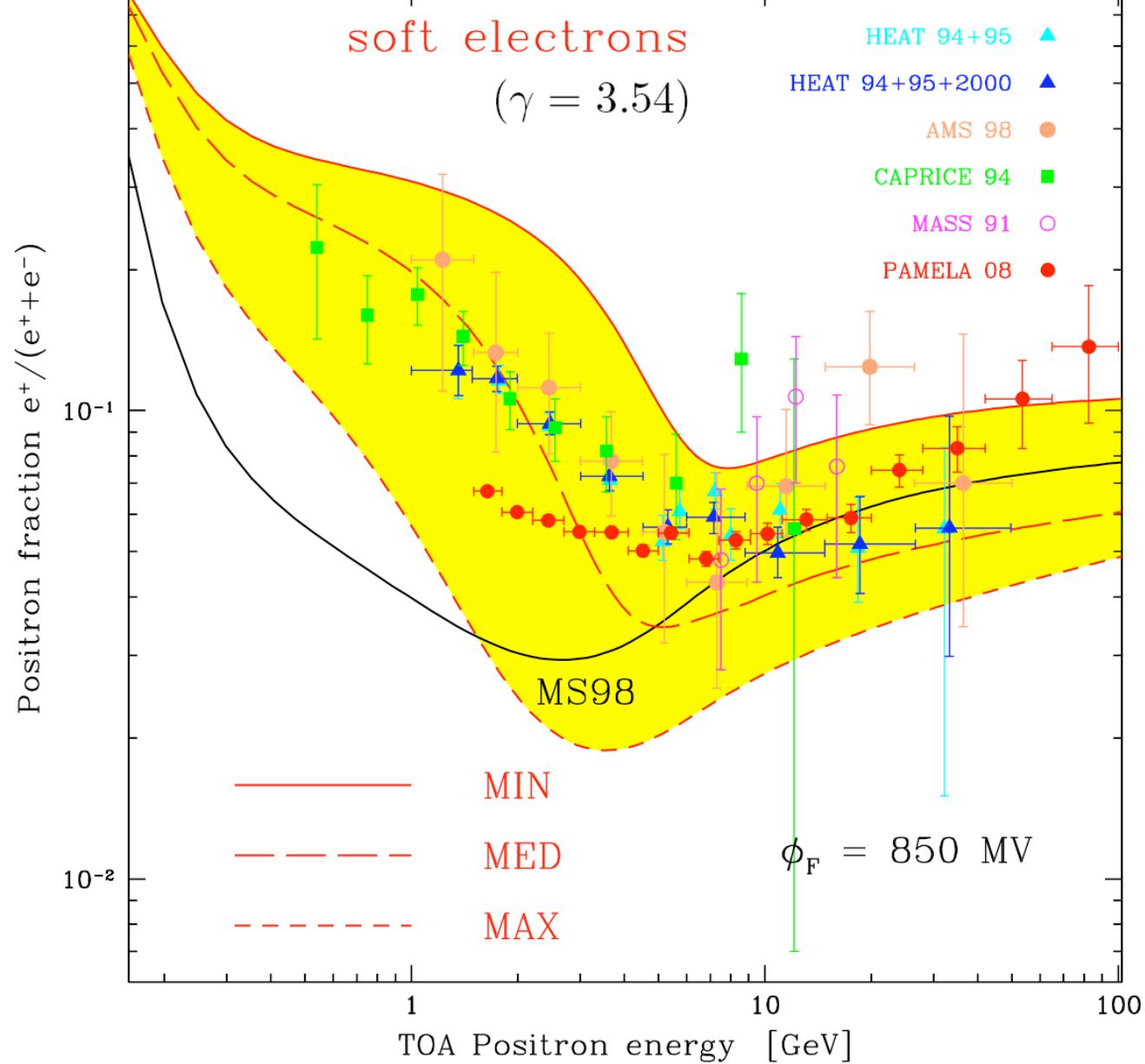
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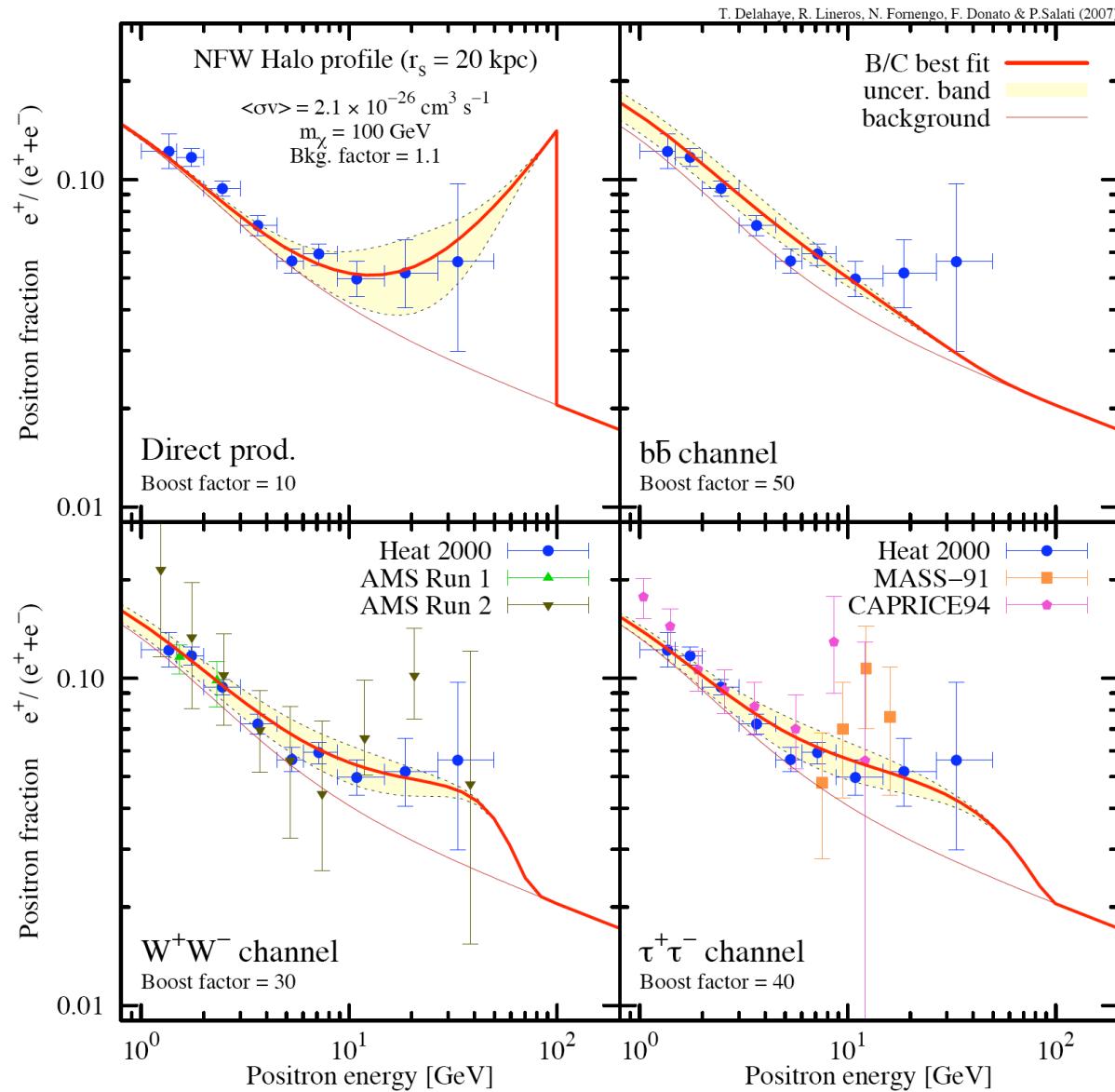
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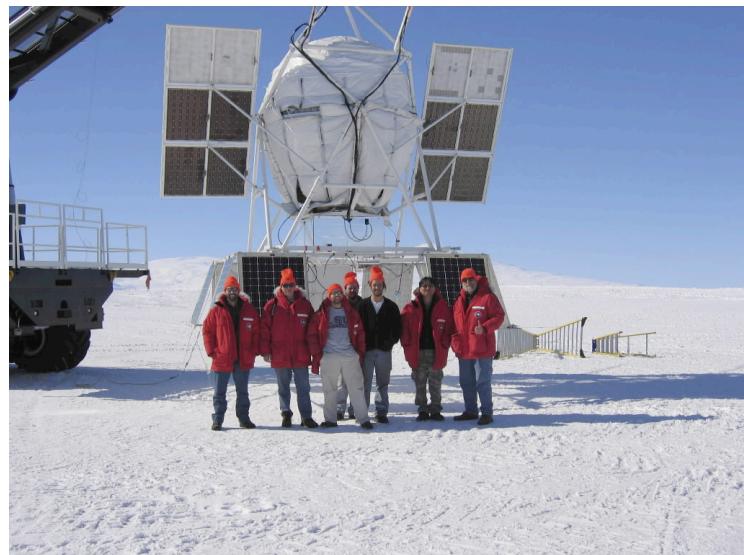
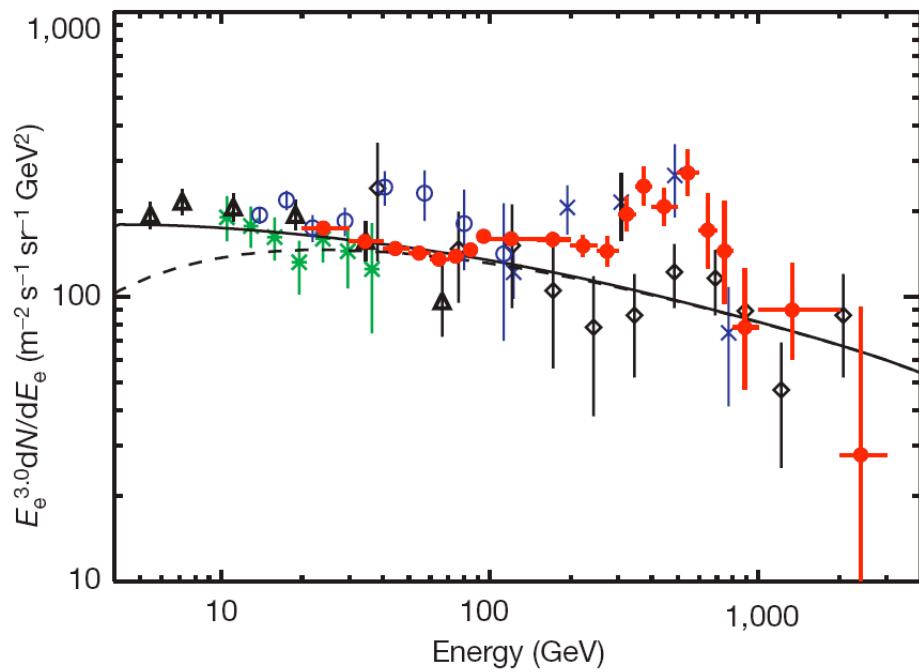


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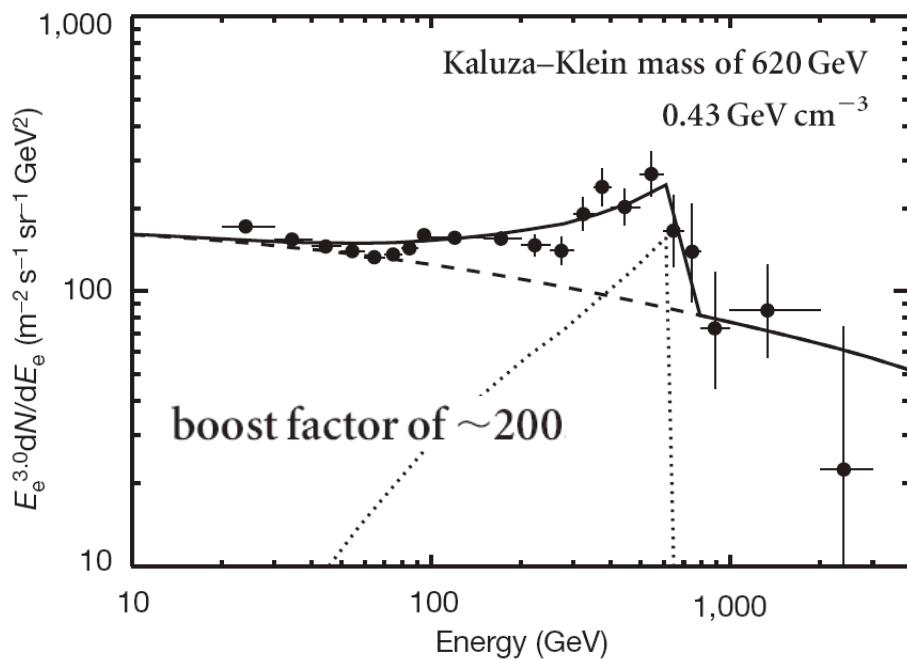
T. Delahaye, R. Lineros, F. Donato, N. Fornengo & P. Salati Phys. Rev. D77 (2008) 063527



An excess of cosmic ray electrons at energies of 300–800 GeV

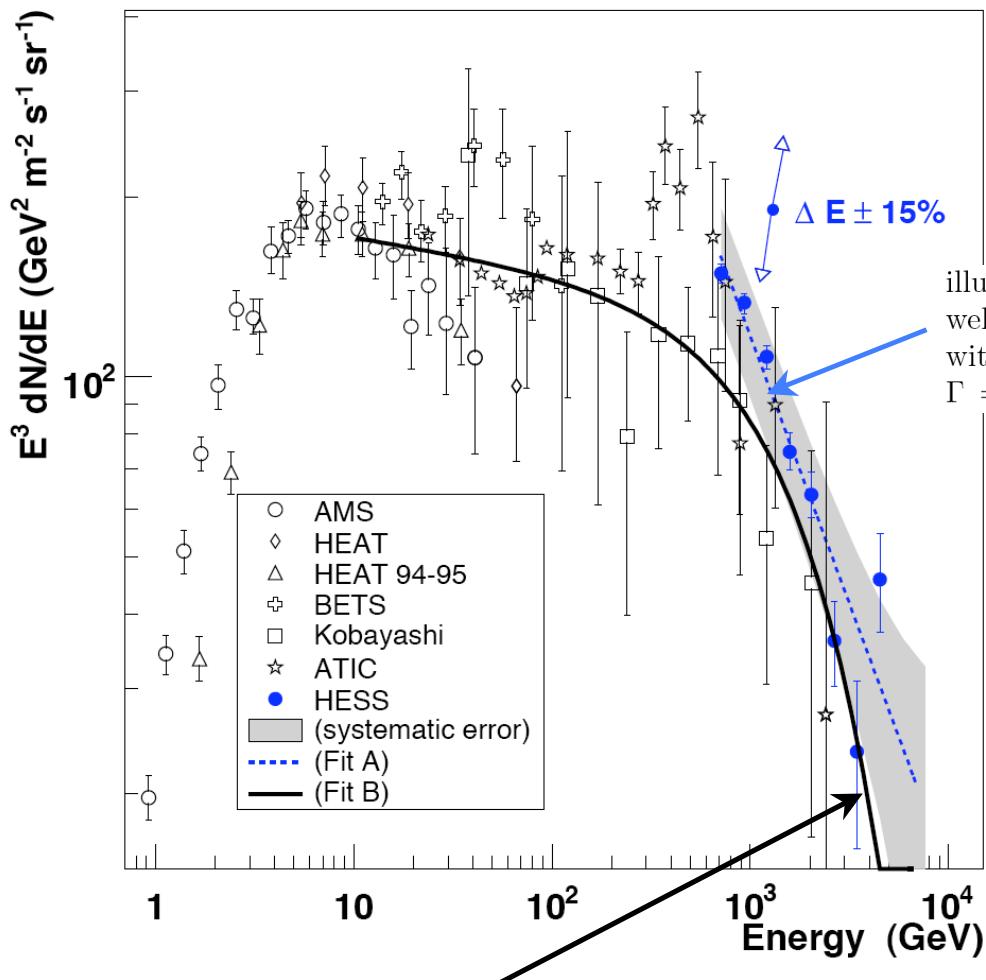


Vol 456 | 20 November 2008 | doi:10.1038/nature07477



HESS measurement of the high-energy e^\pm spectrum

arXiv:0811.3894v1 [astro-ph] 24 Nov 2008



by an exponentially cutoff powerlaw with an index of -3.05 ± 0.02 and a cutoff at 2.1 ± 0.3 TeV, combined with a scale adjustment of -11% (Fit B). H.E.S.S. data

illustrated by the shaded band in Fig. 3. Our data are well described by a power-law: $dN/dE = k(E/1\text{TeV})^{-\Gamma}$ with $k = (1.17 \pm 0.02) \times 10^{-4} \text{ TeV}^{-1} \text{m}^{-2} \text{sr}^{-1} \text{s}^{-1}$ and $\Gamma = 3.9 \pm 0.1$ (stat) ($\chi^2/\nu = 3.6$, $p = 10^{-3}$, Fit A),

