Discussion around the PAMELA CR anomaly

Tentative Programme

1) Production inside local molecular clouds.

2) Galactic and local pulsars.

3) DM particles – $\sigma_{\mathrm{ann}} v$ is enhanced.

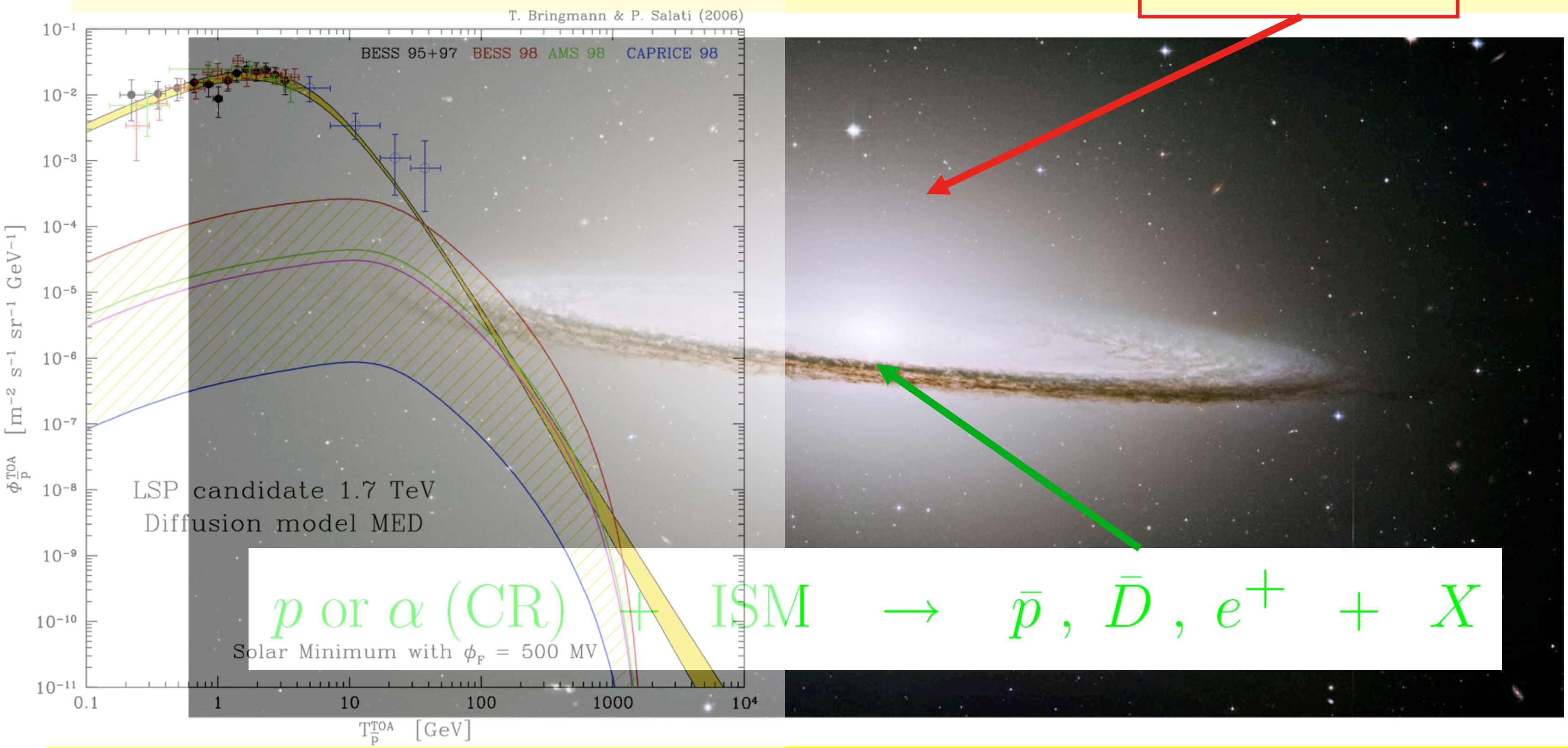
4) DM particles – halo clumpiness.

TANGO in Paris – IAP round table – May 5th 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 :

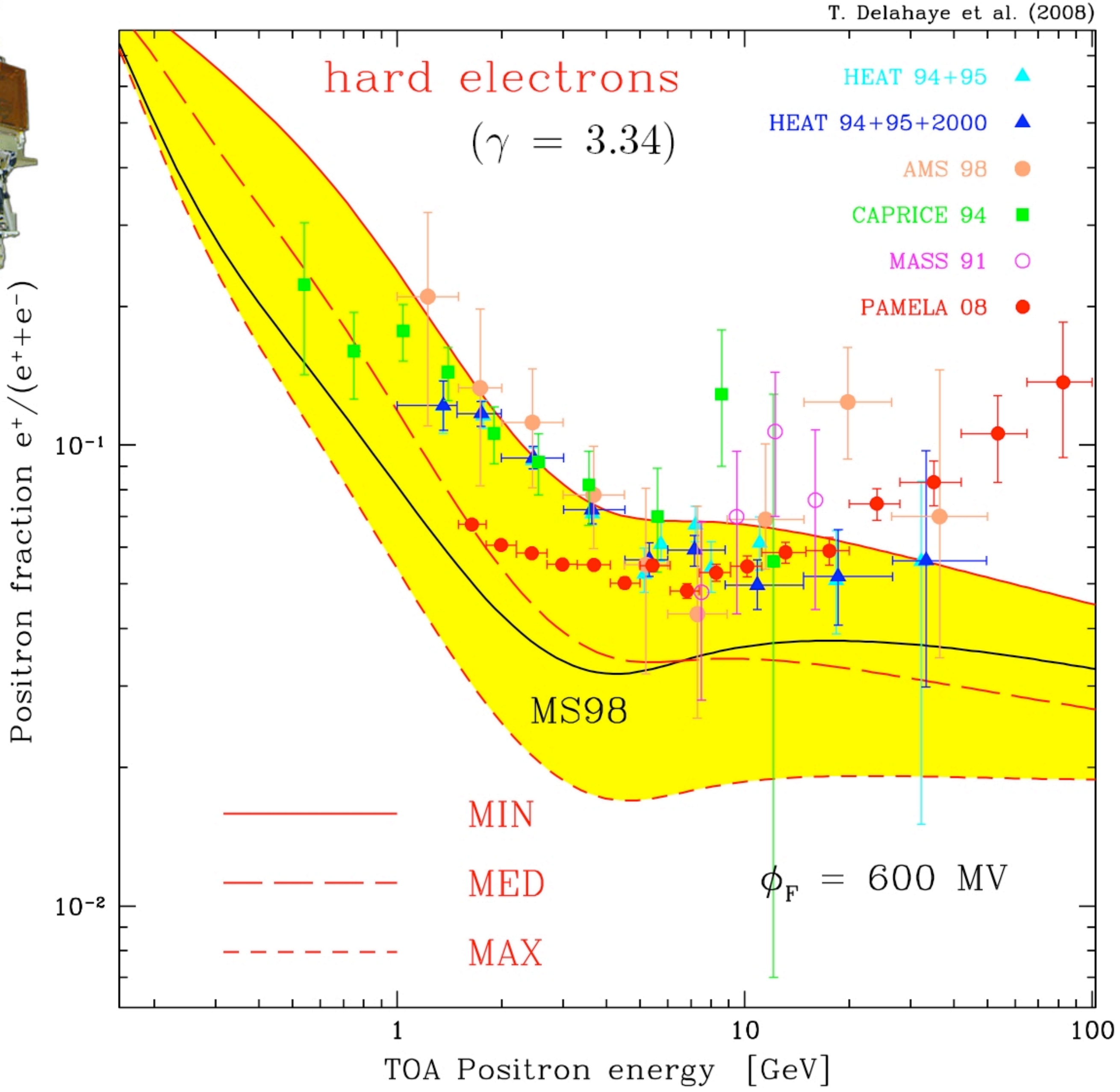
$$\chi + \chi \rightarrow q\bar{q}, W^+W^-, \ldots \rightarrow \gamma, \boxed{\bar{p},\ \bar{D},\ e^+}\ \&\ \nu's$$



$$p \text{ or } \alpha \text{ (CR)} + \text{ISM} \rightarrow \bar{p}\,,\ \bar{D}\,,\ e^+ + X$$

Antimatter is already manufactured inside the galactic disk

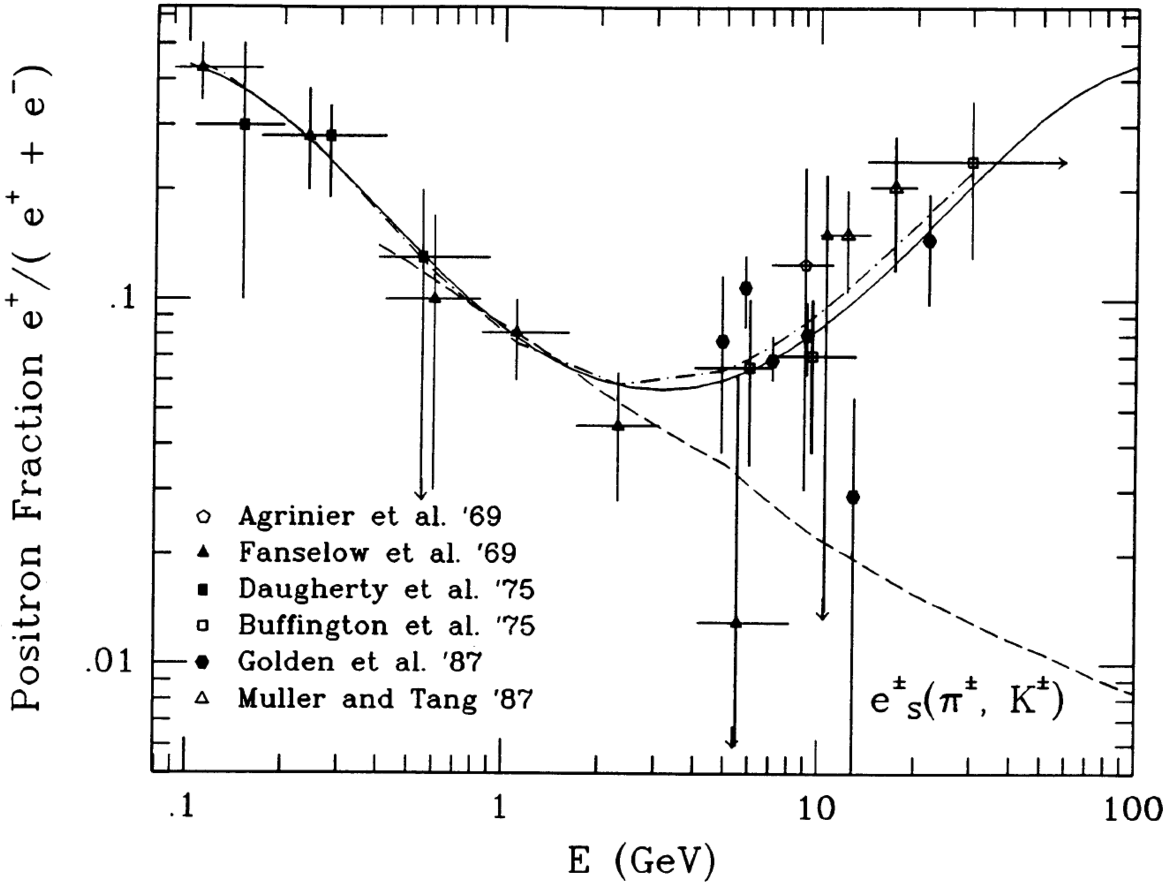
Delahaye T. et al. – arXiv:0809.5268



THE NATURE OF THE COSMIC-RAY ELECTRON SPECTRUM, AND SUPERNOVA REMNANT CONTRIBUTIONS

AHMED BOULARES
Physics Department, Space Physics Laboratory, University of Wisconsin–Madison

Received 1988 October 24; accepted 1988 December 29



THE ASTROPHYSICAL JOURNAL, **342**:807–813, 1989 July 15

The pieces of the puzzle

(1) 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.

(2) Galactic and local pulsars.

- An injection positron spectrum index of 1.5 is necessary ?
- Is it astrophysically possible ?
- Will FERMI confirm the presence of a nearby pulsar ?

Unless first indirect hint of DM species in the MW !

But Γ_{ann} needs to be boosted !

The pieces of the puzzle

(3) DM particles – $\sigma_{\mathrm{ann}} v$ is enhanced.

- 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).

$\chi\,\chi \rightarrow$ std std still allowed ?

Beware of the other messengers !

- Antiprotons are not produced – leptophilic WIMP ?
- Even though, strong constraints from radio and IC

$$\chi\,\chi \rightarrow \phi\,\phi \quad \& \quad \phi \rightarrow e^{+}e^{-}$$

Accelerator constraints soon ?

The pieces of the puzzle

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  - ✓ Antiproton and positron Green functions are different.
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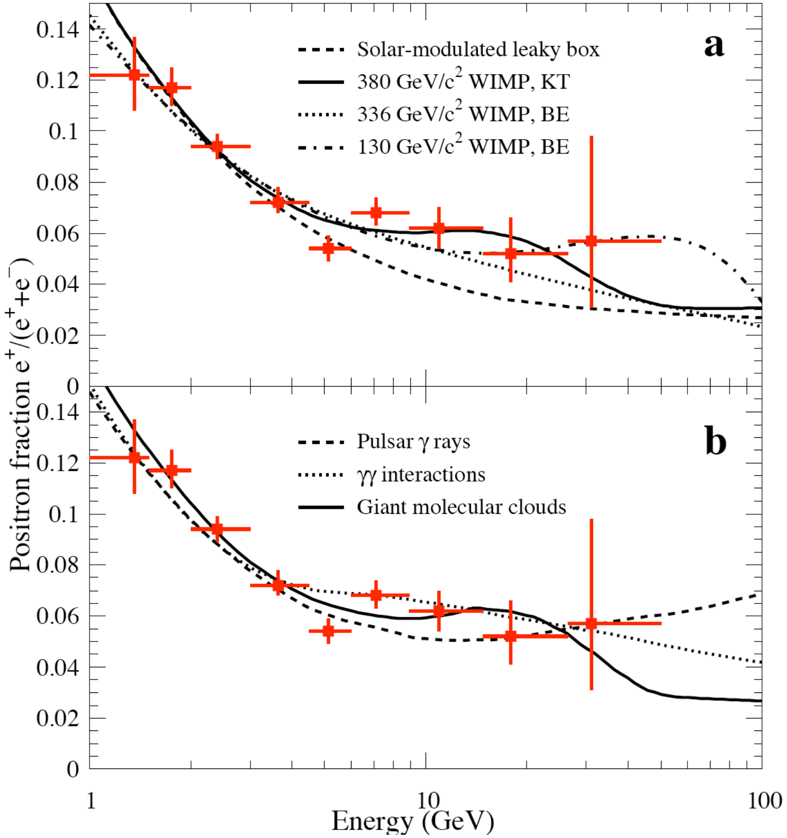
Production inside local molecular clouds



arXiv:astro-ph/9902162v1 10 Feb 1999

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

Local interstellar medium (LISM)

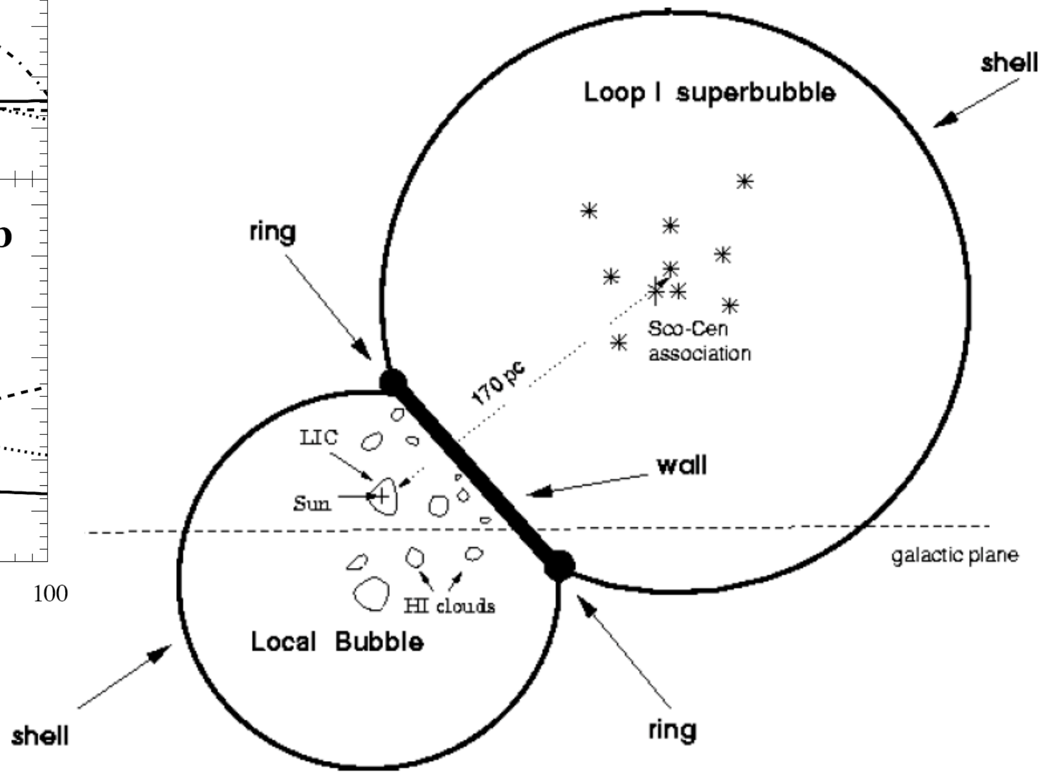


Figure 3: Schematic representation (not drawn to scale) between the local bubble and the neighboring Loop I superbubble (from [40]).

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Galactic and local pulsars

D. Hooper, P. Blasi & P. D. Serpico, **arXiv:0810.1527**

S. Profumo, **arXiv:0812.4457**

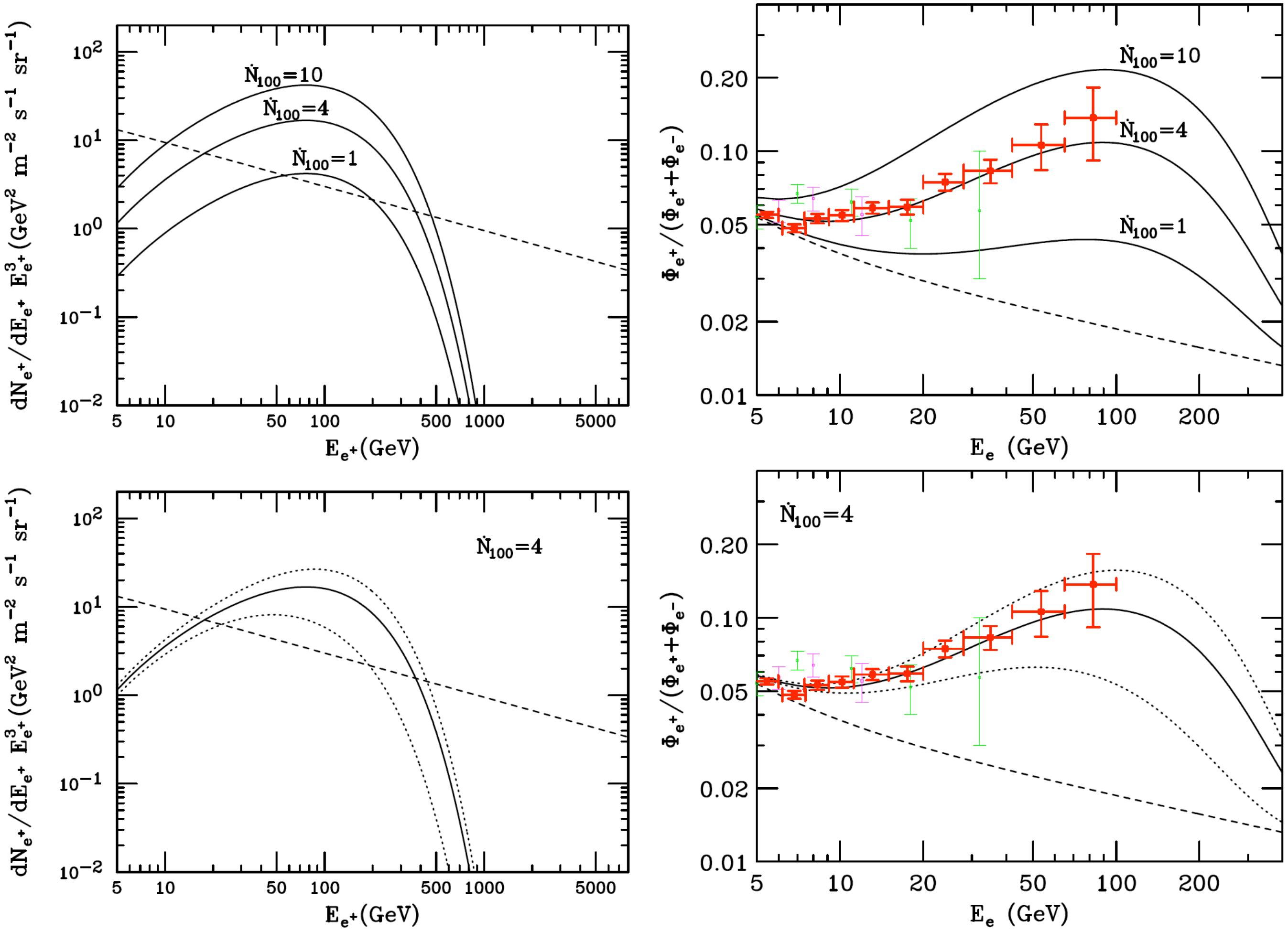

FIG. 1: The spectrum of cosmic ray positrons (left) and the positron fraction (right) resulting from the sum of all pulsars throughout the Milky Way. Also shown as a dashed line is the prediction for secondary positrons (and primary and secondary electrons in the right frames) as calculated in Ref. [27]. 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** S. Profumo, **arXiv:0812.4457**

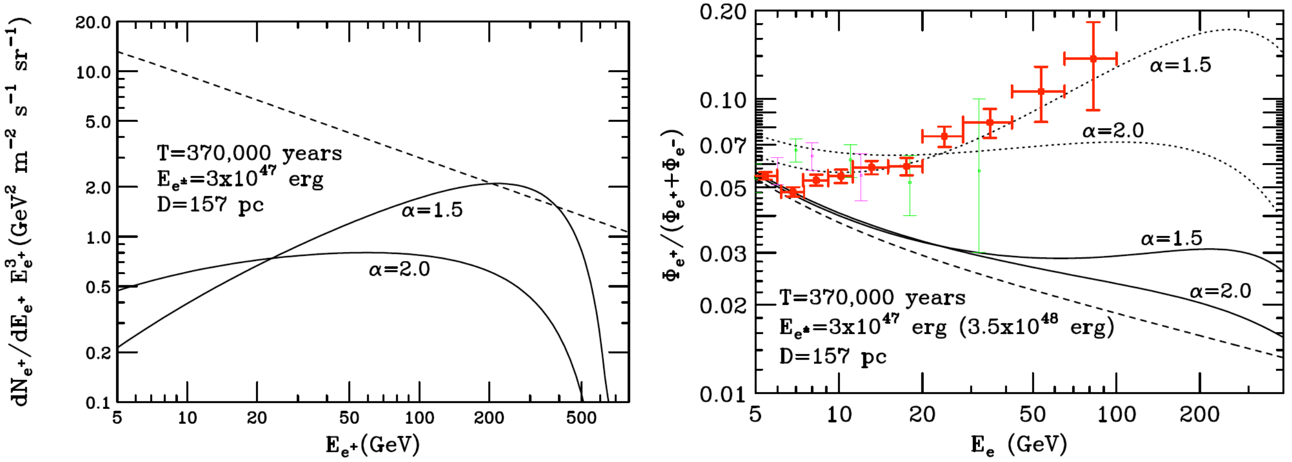

FIG. 2: The spectrum of positrons (left) and ratio of positrons to electrons plus positrons (right) from the pulsar Geminga, with the dashed lines as in Fig. 1. In the right frames, the measurements of HEAT [3] (light green and magenta) and measurements of PAMELA [2] (dark red) are also shown. Here we have used an injected spectrum such that $dN_e/dE_e \propto E^{-\alpha}\ \exp(-E_e/600\,\mathrm{GeV})$, 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.

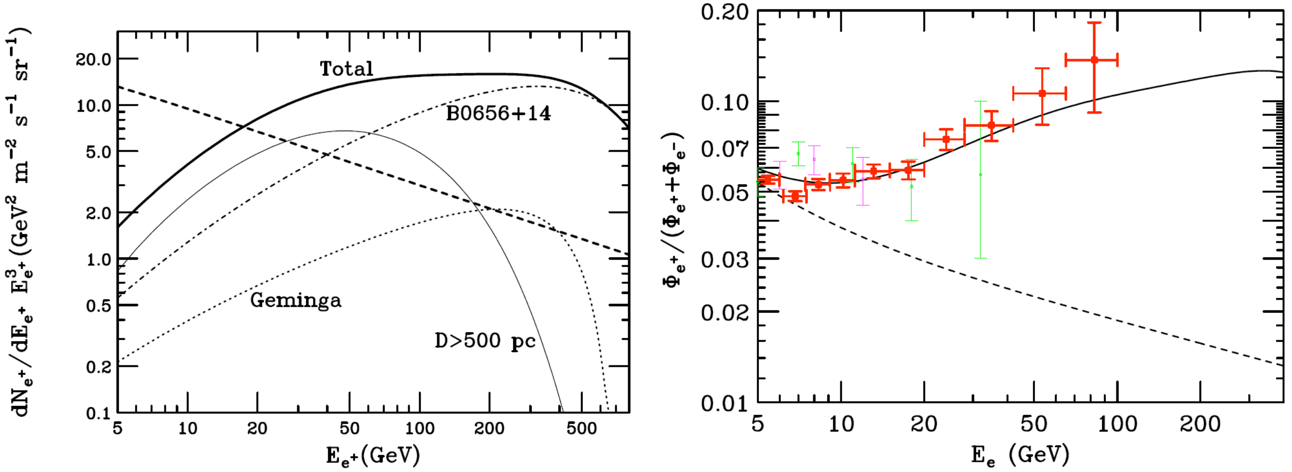

FIG. 4: The positron spectrum and positron fraction from the sum of contributions from B0656+14, Geminga, and all pulsars farther than 500 parsecs from the Solar System.

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DM particles

The annihilation rate needs to be considerably boosted

L. Roszkowski, R. Ruiz de Austri, J. Silk & R. Trotta, **arXiv:0707.0622**

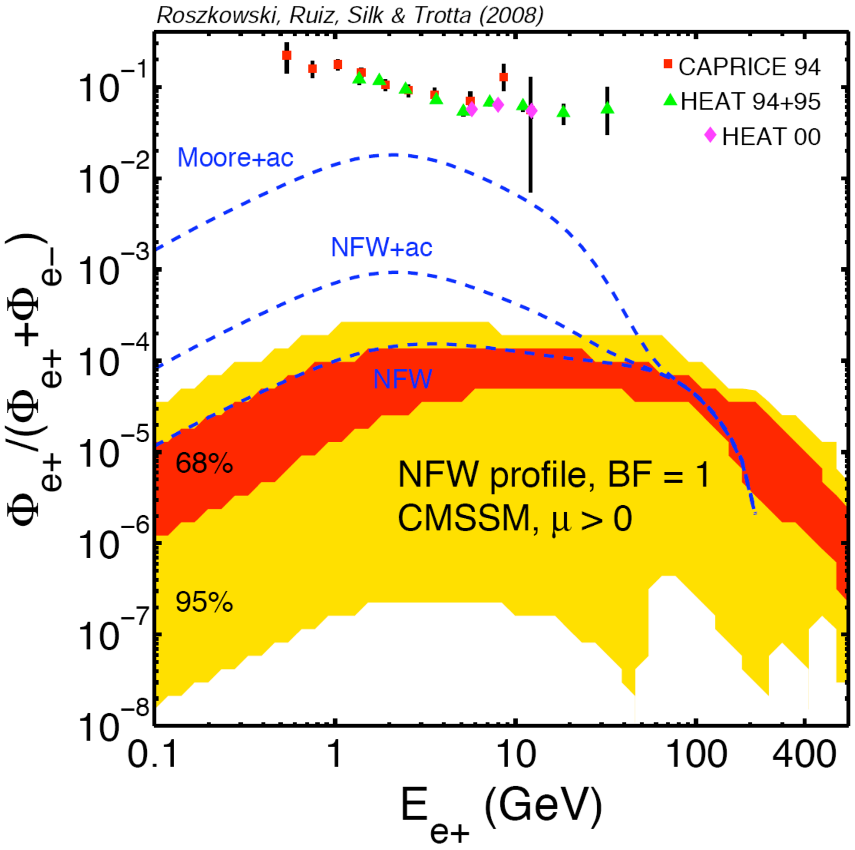

Figure 3: Predicted positron flux fraction in the CMSSM. The 68% (dark/red) and 95% (light/yellow) regions are for an NFW profile with a boost factor BF=1 and a specific choice of propagation model. We also show for comparison some of the current data. To illustrate the dependency of the spectral shape 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.

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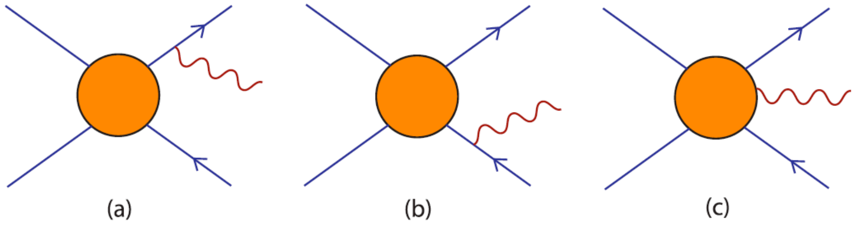
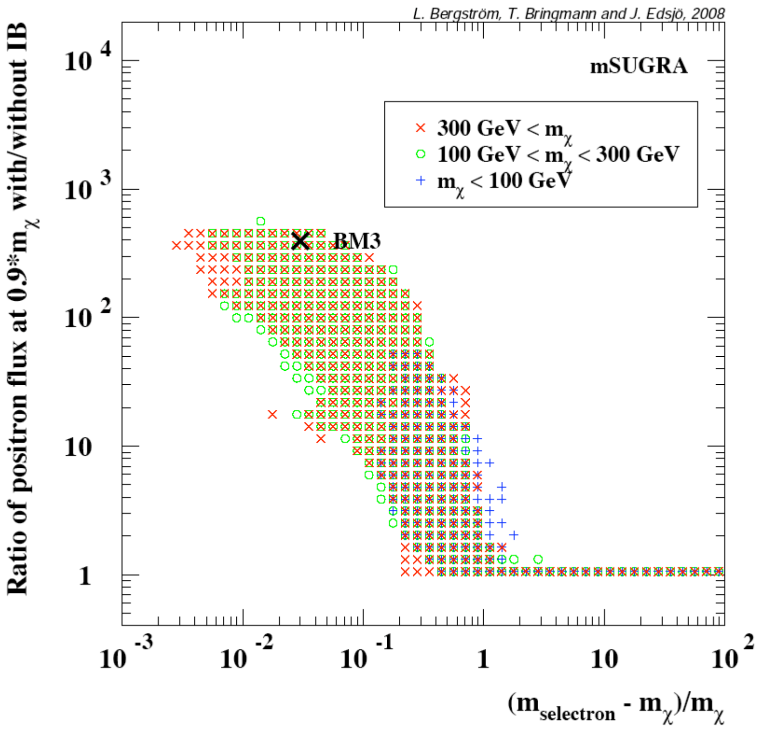
$$\chi\,\chi \rightarrow \phi\,\phi \quad \& \quad \phi \rightarrow e^+ e^-$$

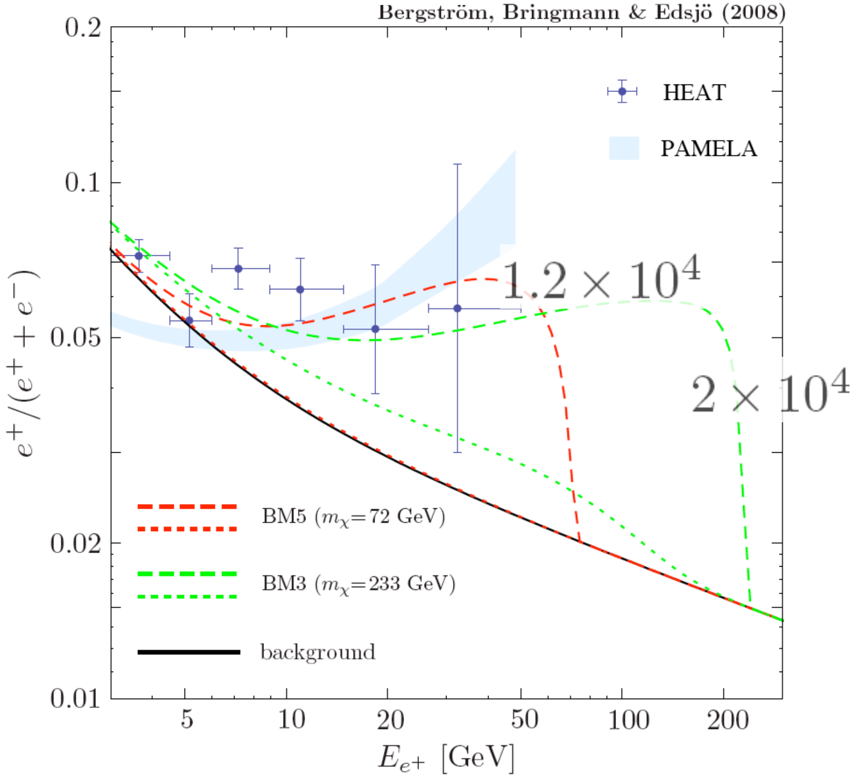
Accelerator constraints soon ?

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

$$\sigma = \sigma_0 \left(1 + \frac{v_{esc}^2}{v^2}\right)$$

$$\lambda \geq (\alpha\, m_\chi)^{-1}$$

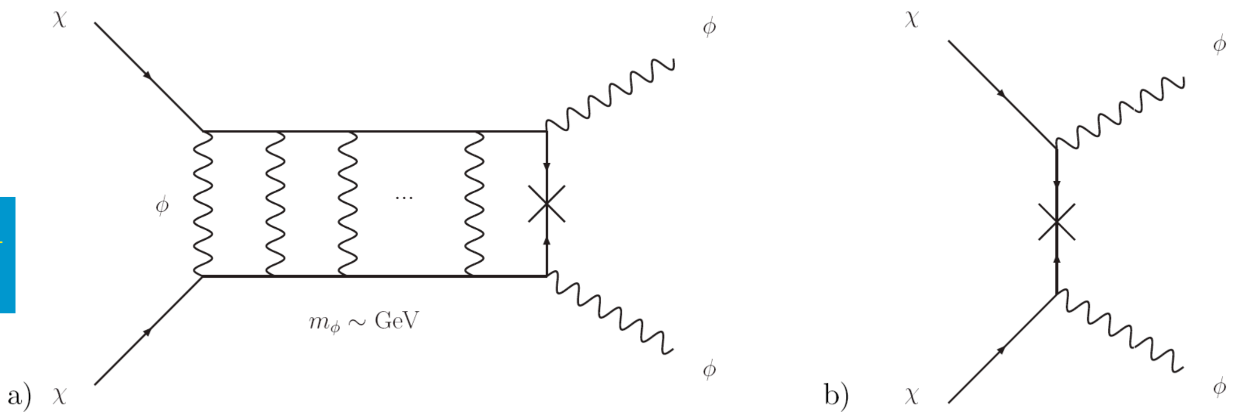
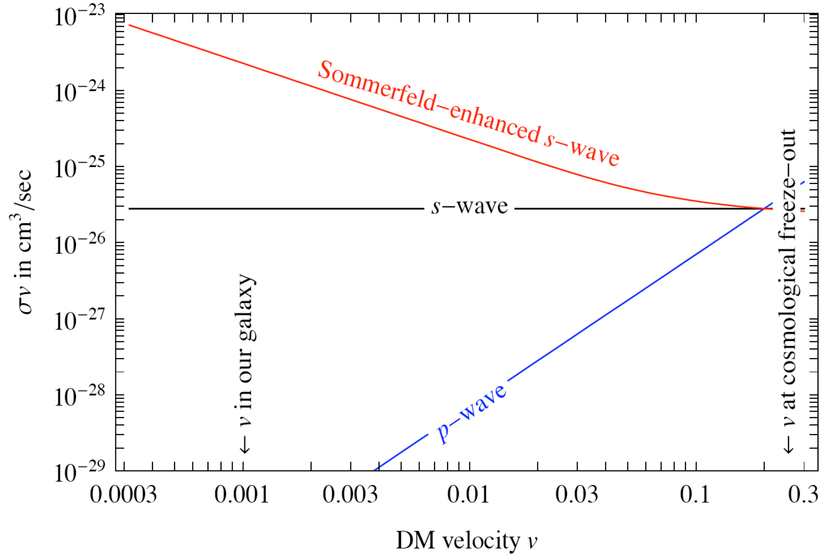
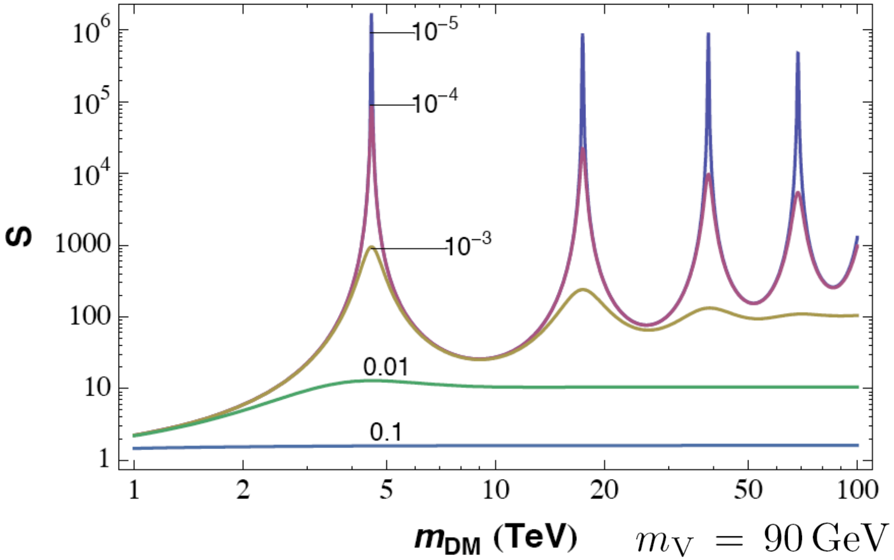


FIG. 3: The annihilation diagrams $\chi\chi \to \phi\phi$ both with (a) and without (b) the Sommerfeld enhancements.





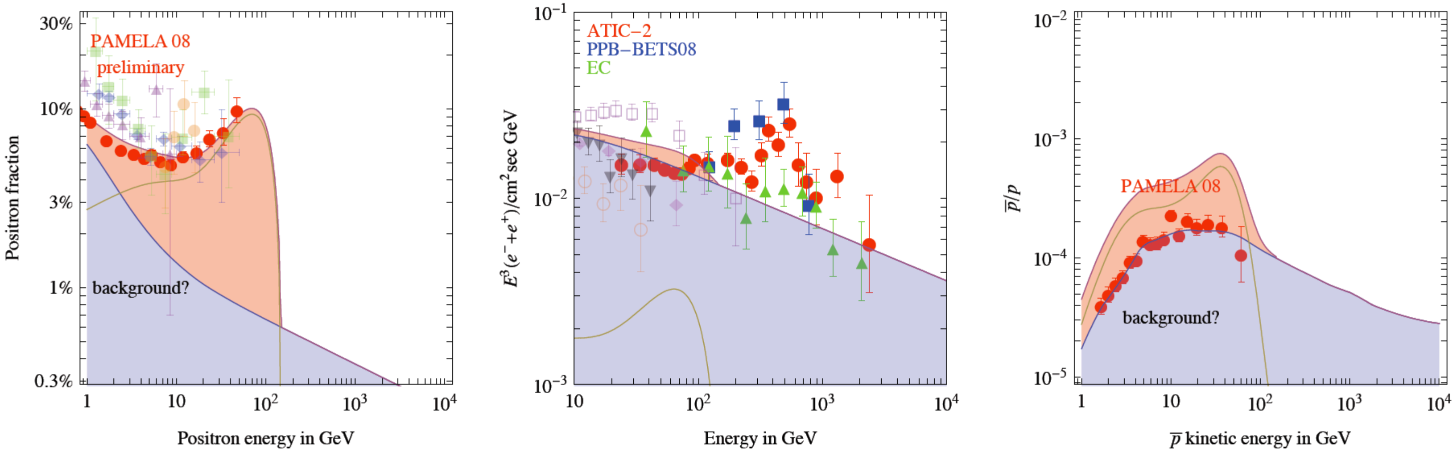
$$m_V = 90\,\text{GeV}$$
$$\alpha_2 \simeq 1/30$$

Other signals should not be overproduced

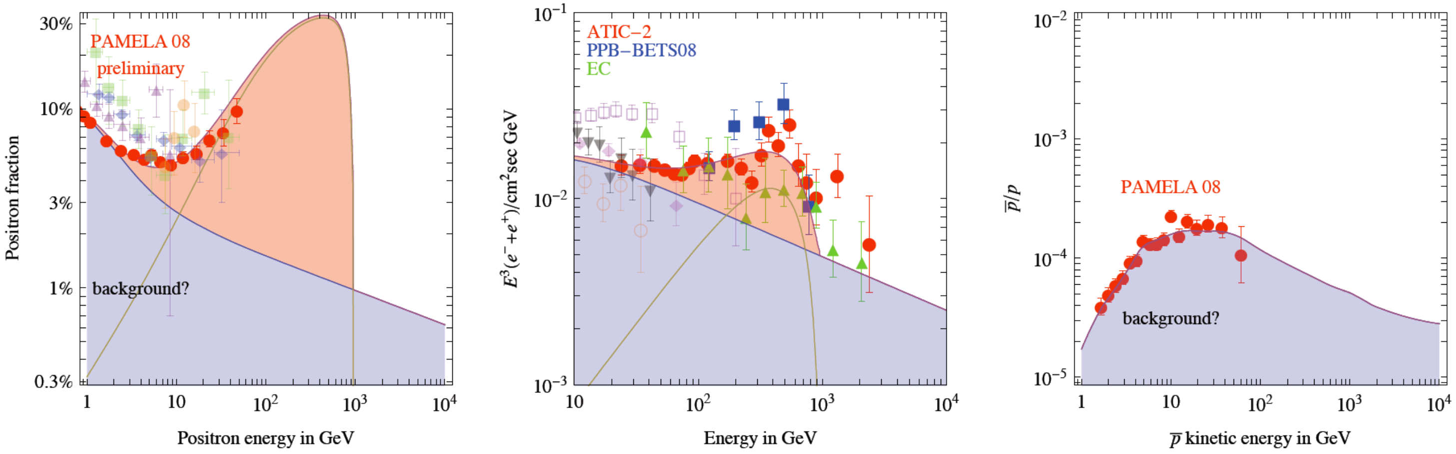
Quark channels are suppressed – purely leptophilic DM candidate

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**

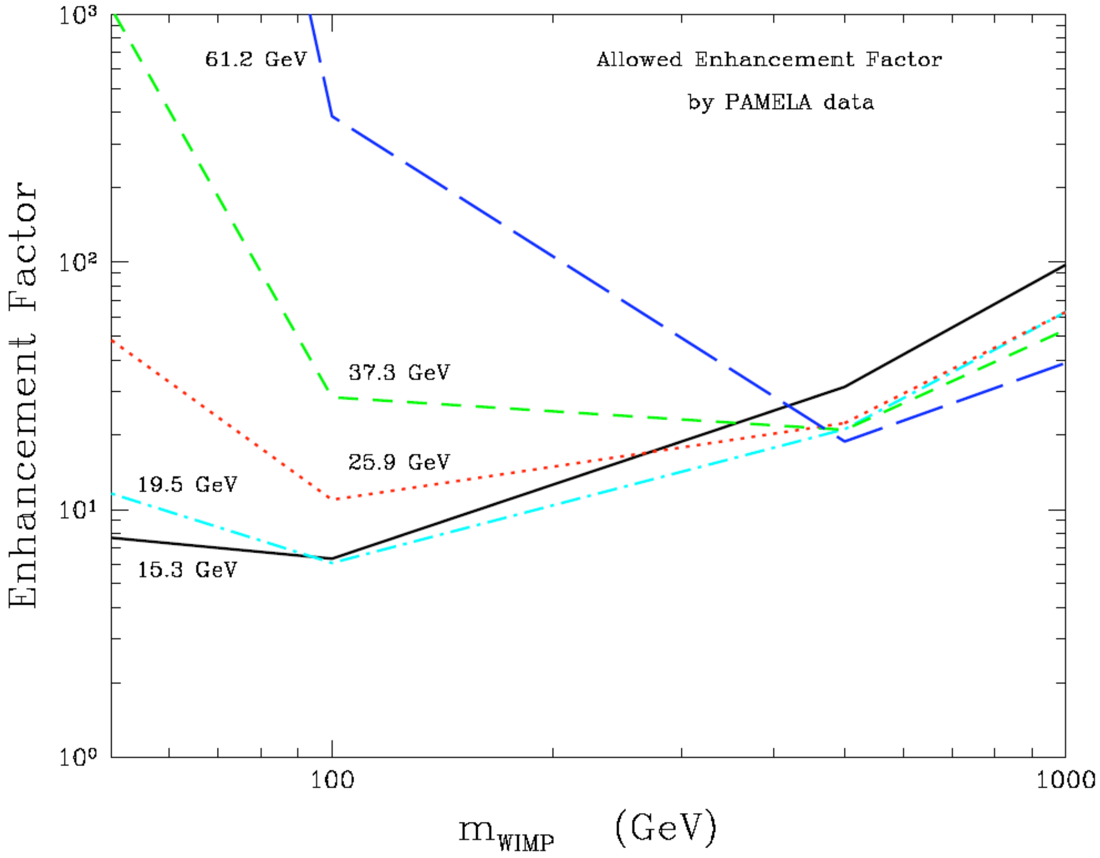


FIG. 2: Upper limits on the enhancement factor to the primary $\overline{p}$ flux as a function of the WIMP mass, derived from a comparison with PAMELA high energy data. Each curve is labelled according to the corresponding PAMELA energy bin.

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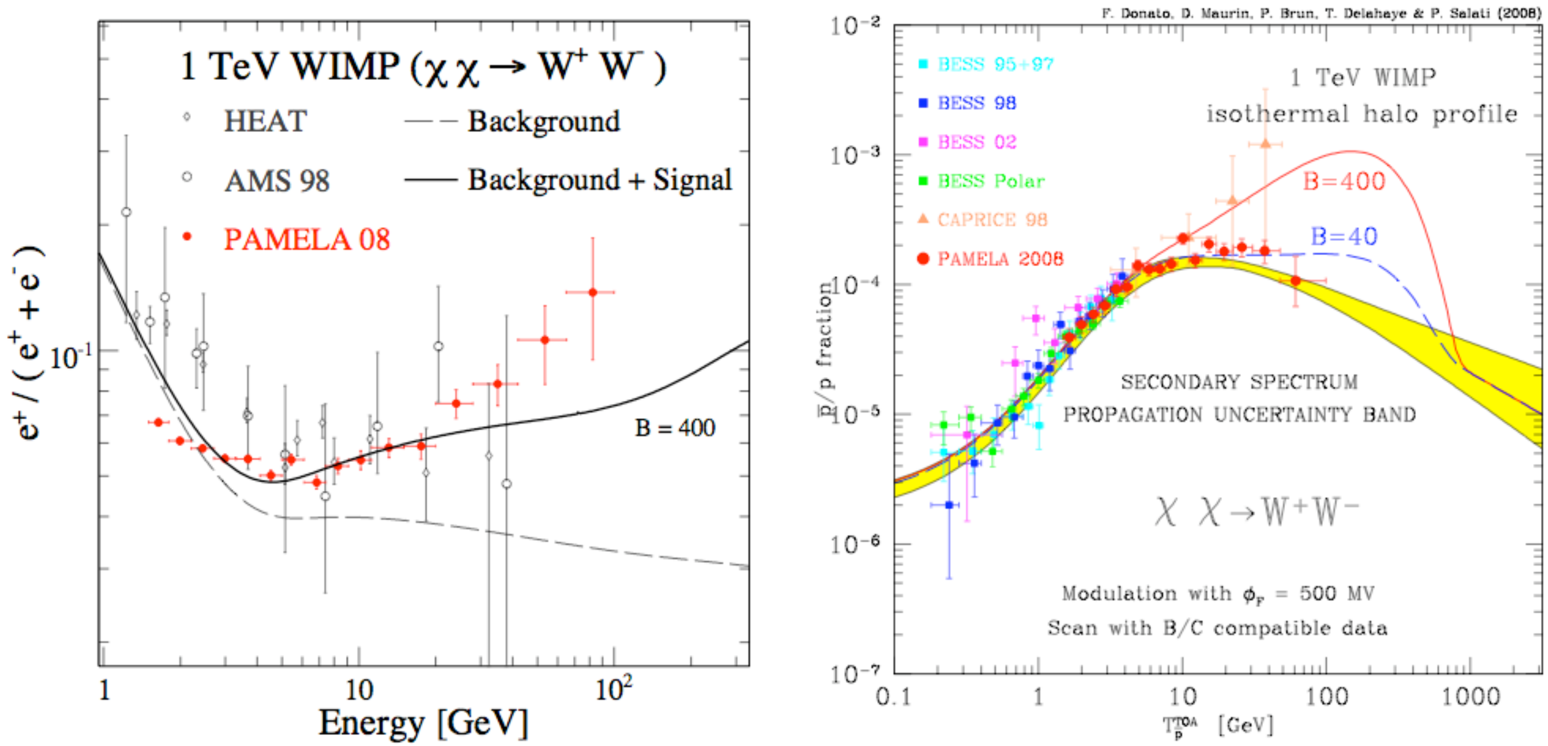


FIG. 3: The fiducial case of a 1 TeV LSP annihilating into a W^+W^- pair is featured. In the left panel, the positron signal which this DM species yields has been increased by a factor of 400, hence the solid curve and a marginal agreement with the PAMELA data. Positron fraction data are from HEAT [18], 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.

Constraints from γ–rays and radio

Lars Bergström[a], Gianfranco Bertone[b], Torsten Bringmann[a], Joakim Edsjö[a], and Marco Taoso[b,c]

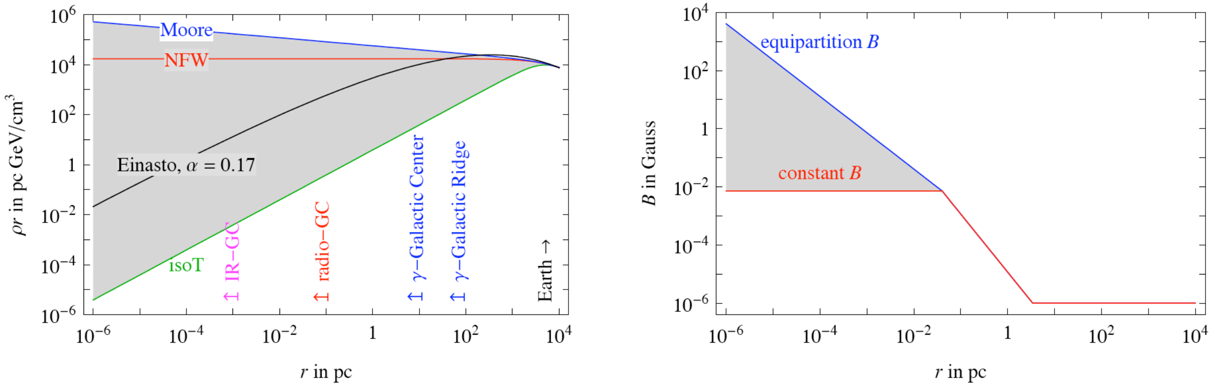
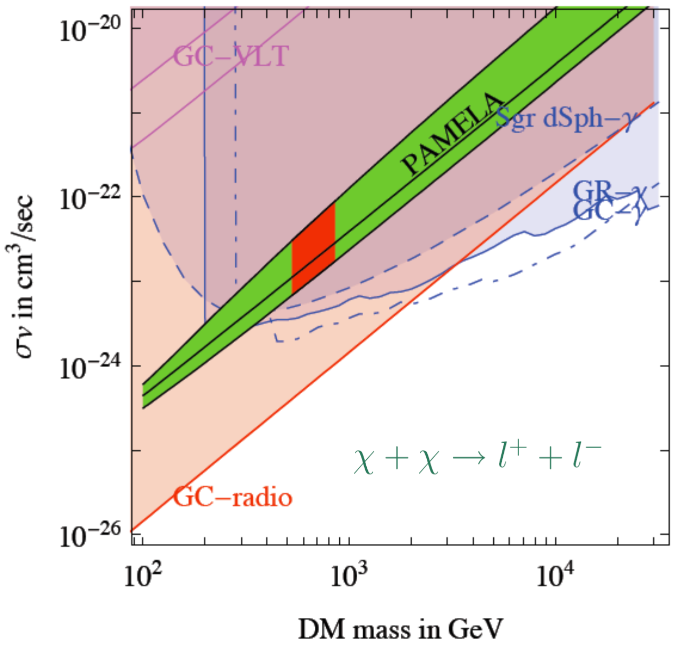
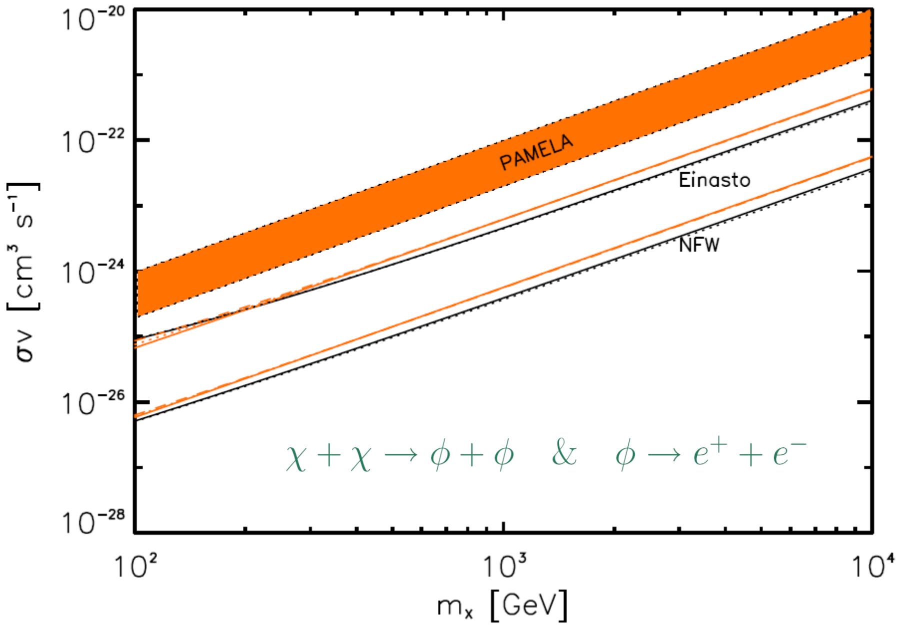


Figure 1: *Shape of DM density (left) and magnetic field (right) profiles discussed in the text, as a function of the galactocentric coordinate r.*

DM DM → e^+e^-, NFW profile





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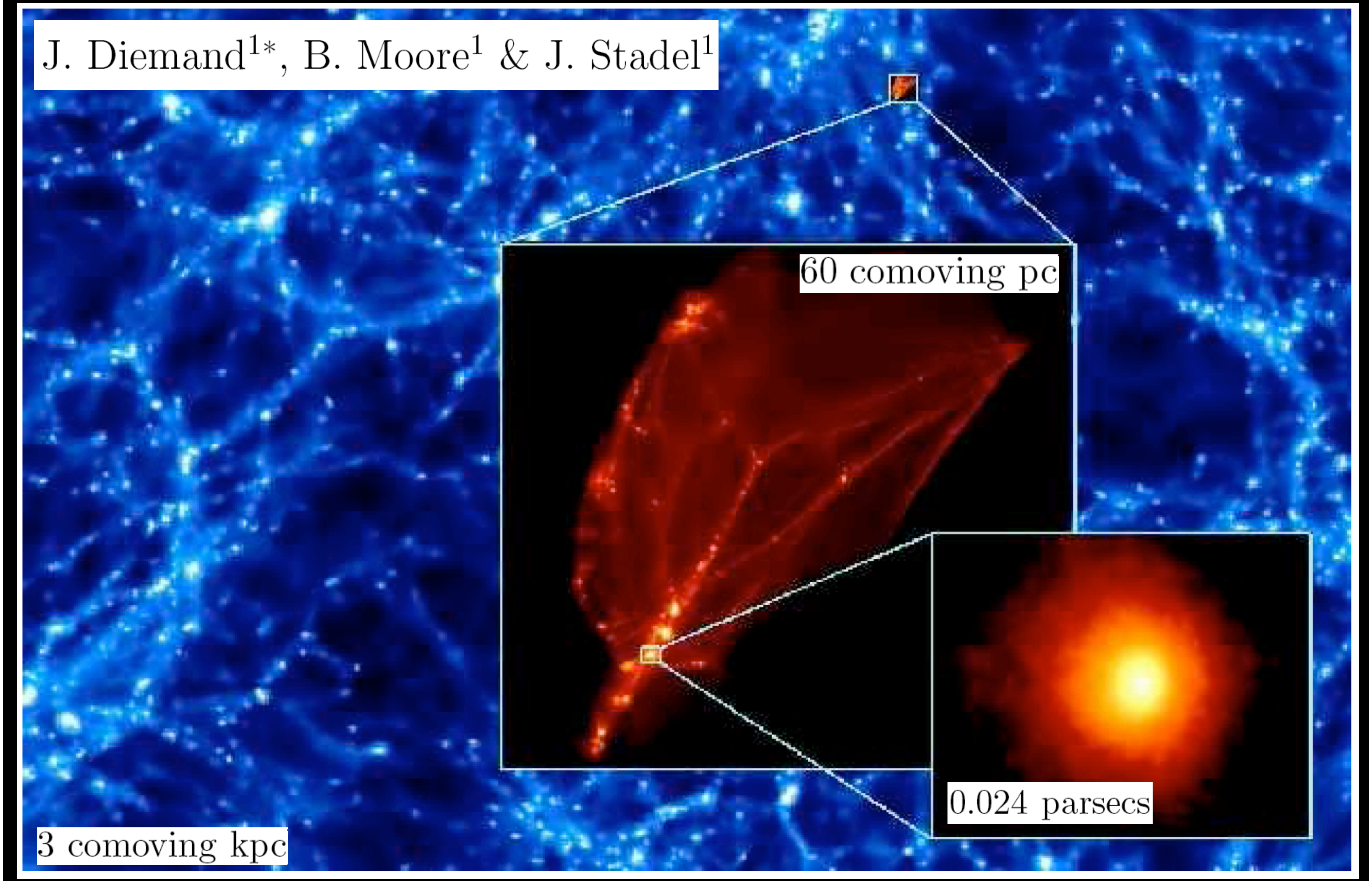

J. Diemand[1*], B. Moore[1] & J. Stadel[1]

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

Abandoning hope in clumpiness enhancement?

J. Lavalle[1], Q. Yuan[2], D. Maurin[3], and X.-J. Bi[2]

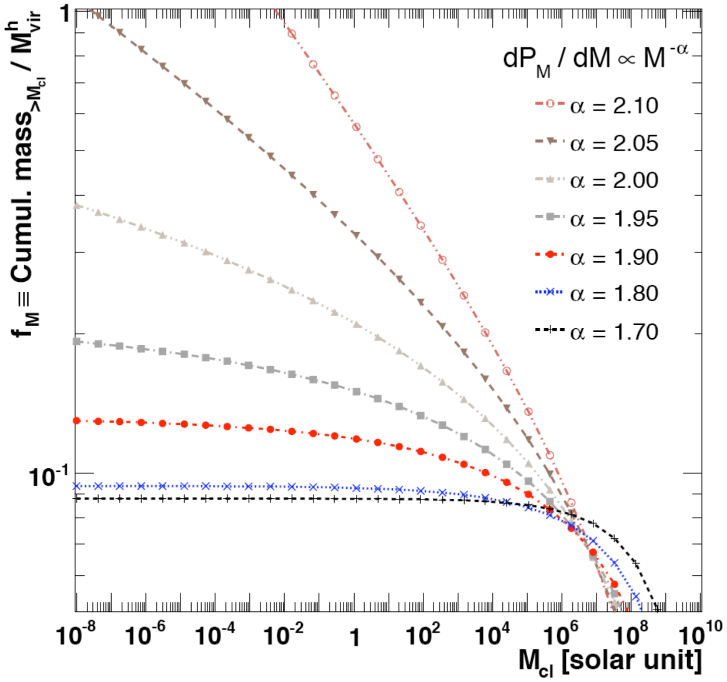


Fig. 1. The mass fraction f_M of DM in clumps is set once $M_{\rm min}$ and $\alpha_{\rm m}$ are chosen. This fraction can be directly read off the graph for various $\alpha_{\rm m}$ (from 2.1 down to 1.7—top to bottom curves) and various $M_{\rm min}$ (from $10^8 M_\odot$ down to $10^{-8} M_\odot$,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

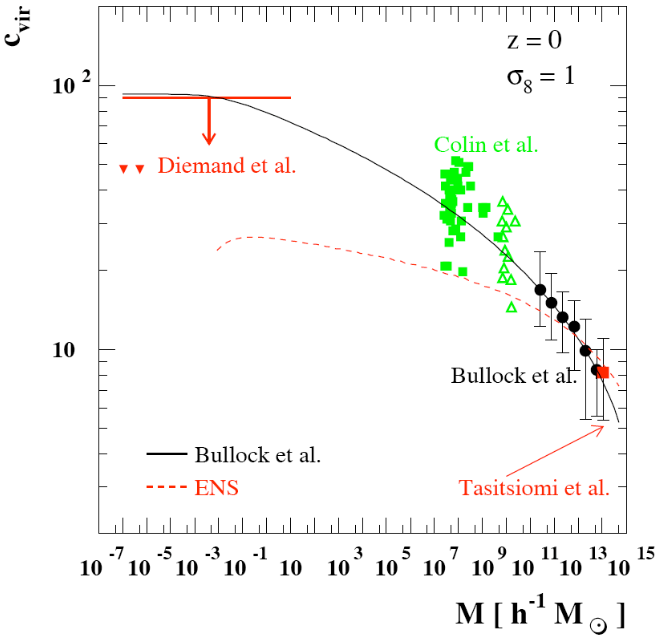


Fig. 1. The dependence of c_{vir} on the halo mass M, at $z = 0$, as in the Bullock et al. toy model (solid line) and in the ENS toy model (dashed line); predictions are compared to a few sets of simulation results in different mass ranges. A flat, vacuum-dominated cosmology with $\Omega_M = 0.3$, $\Omega_\Lambda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

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

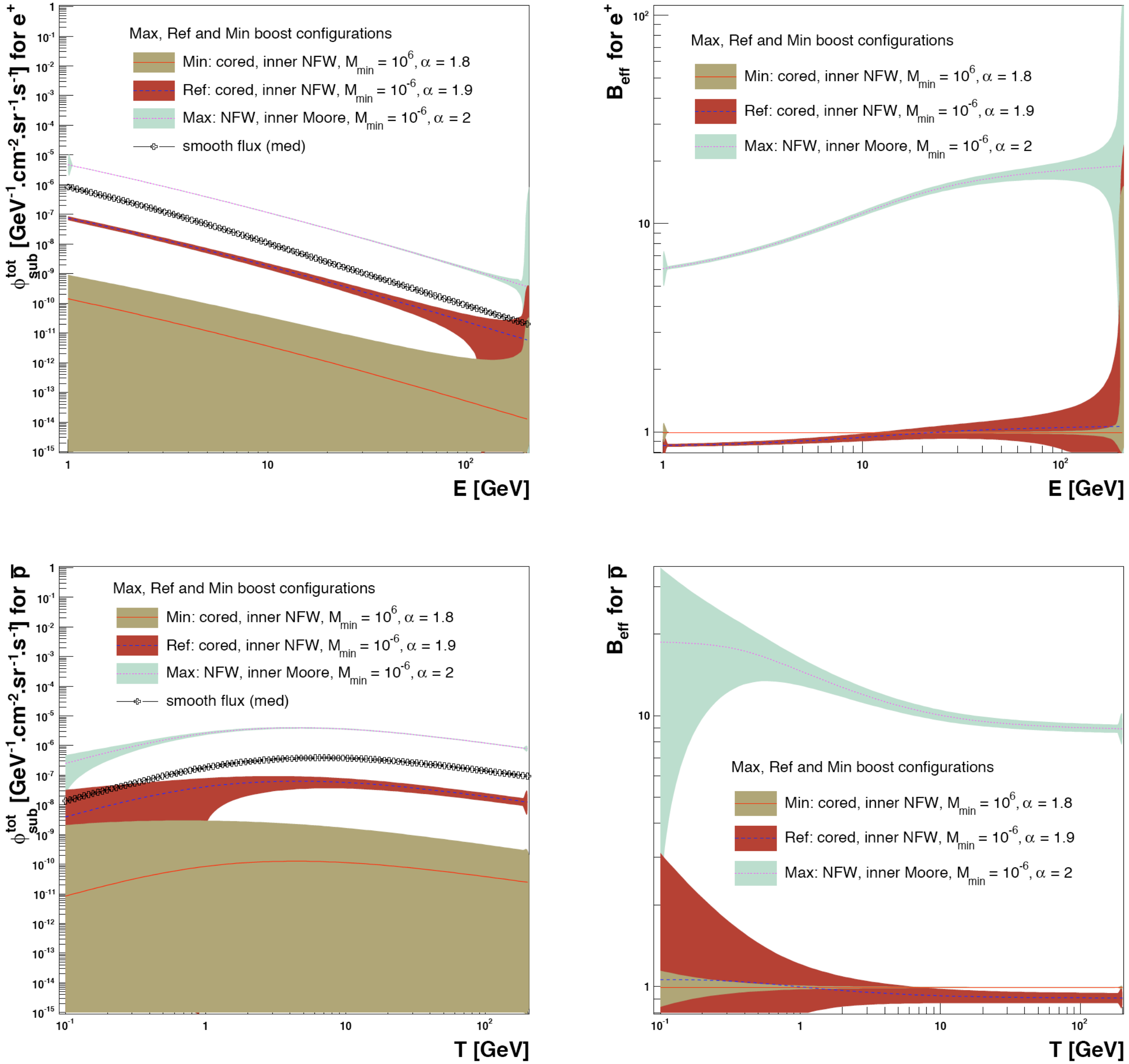
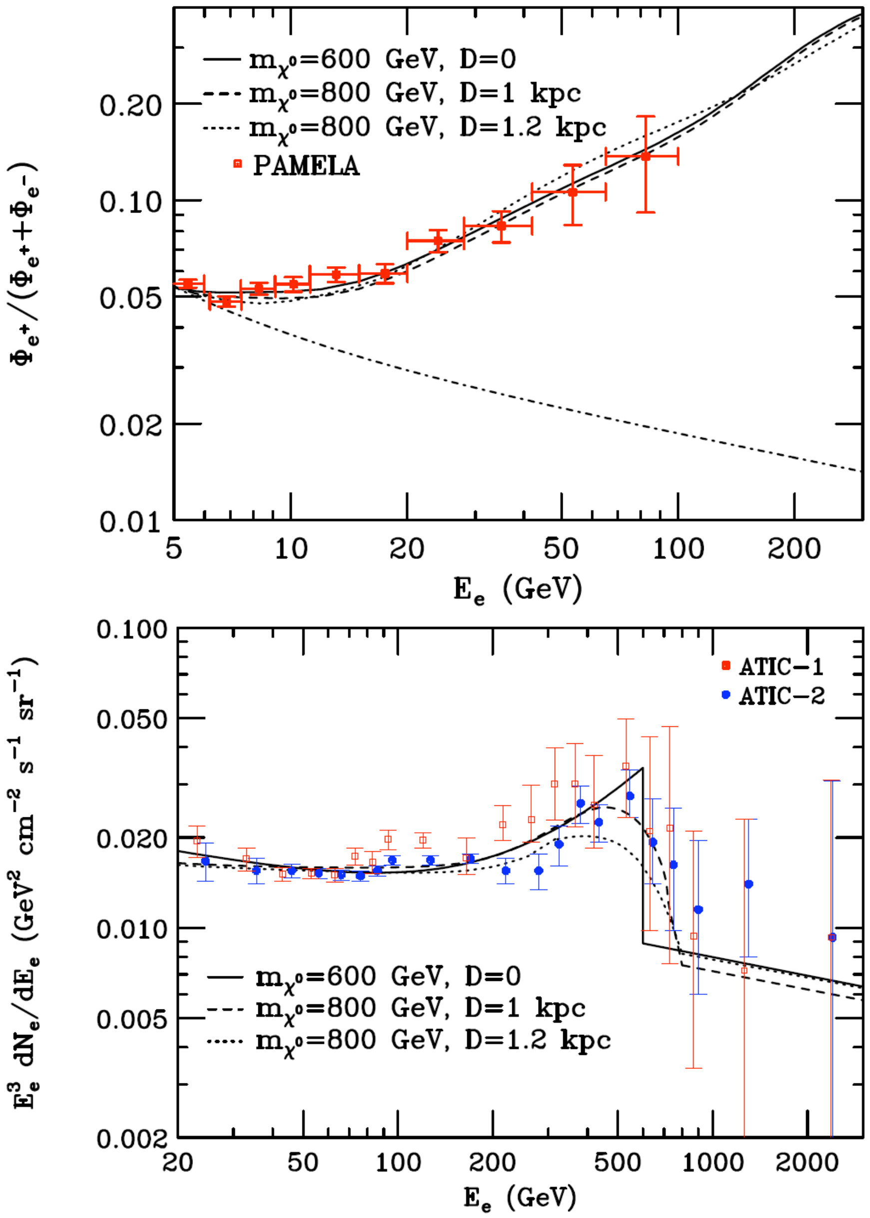


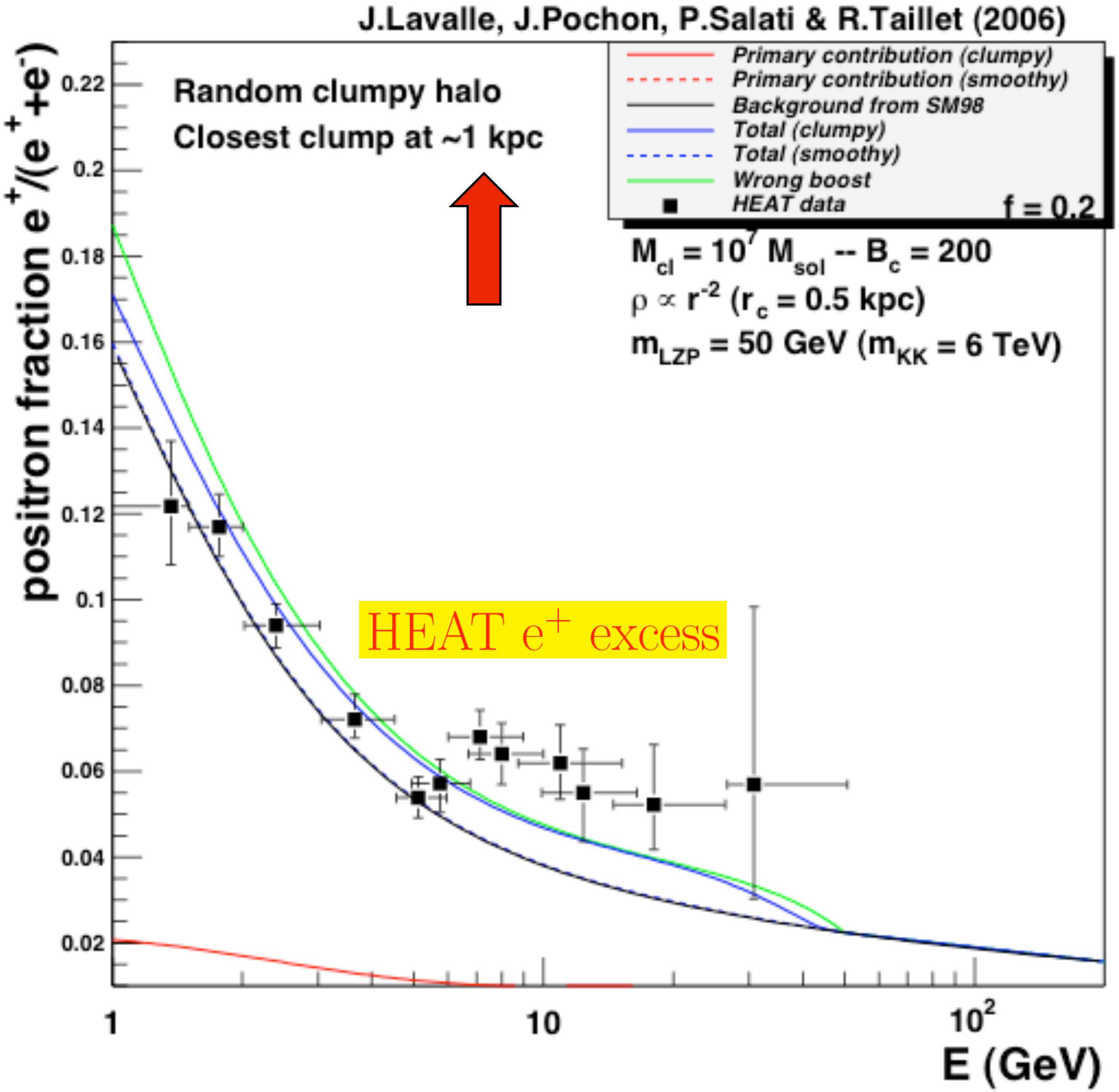
Fig. 6. *Extreme cases for the DM configurations: sub-halo antimatter fluxes associated with the maximal, reference and minimal DM configurations (medium set of propagation parameters). Left/right: fluxes/boosts and corresponding* $1-\sigma$ *contours. Top/bottom: positrons/anti-protons. See details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

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

Dan Hooper[1,2], Albert Stebbins[1], and Kathryn M. Zurek[1]

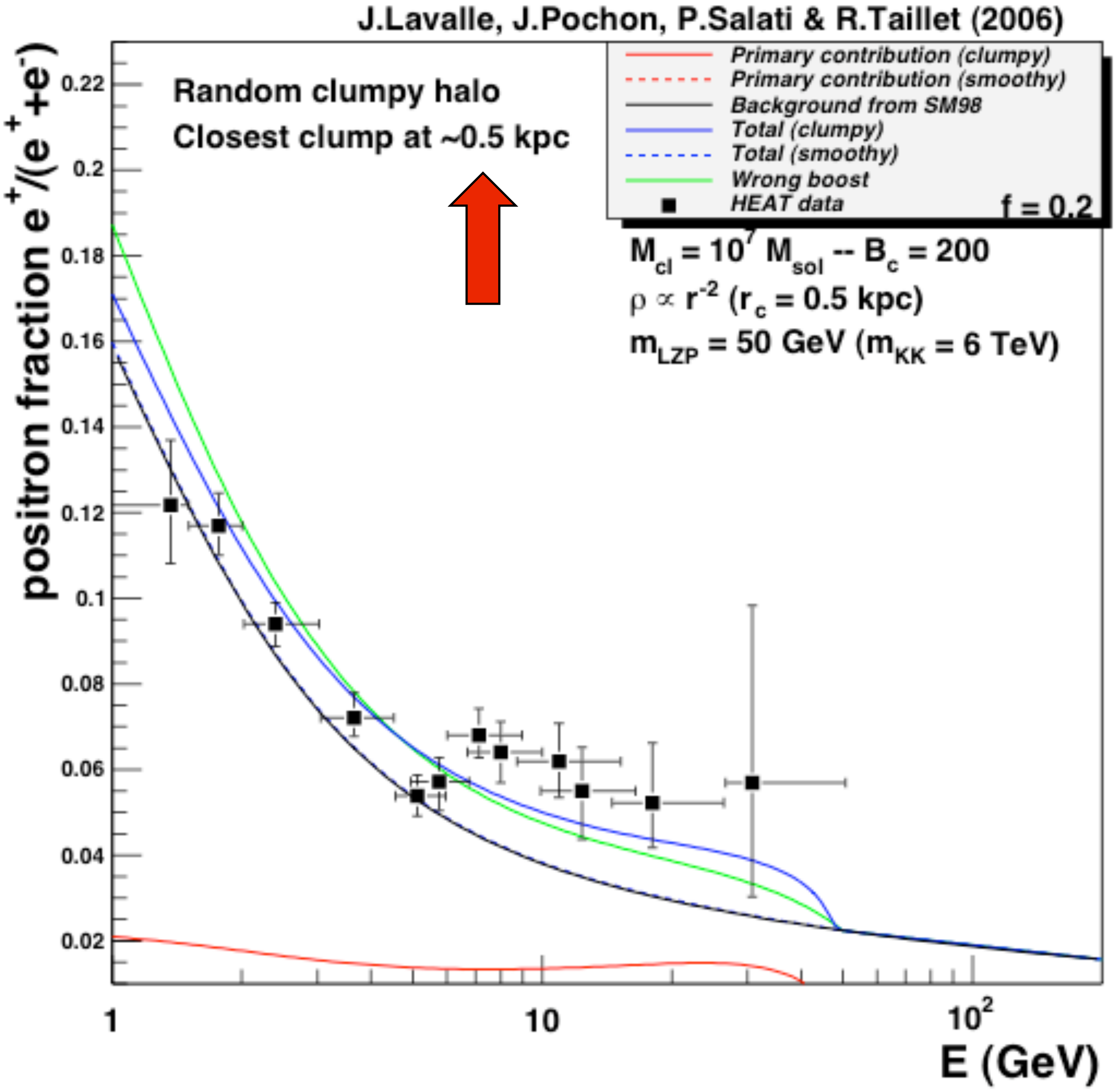


J. Lavalle, J. Pochon, **P.S.** & R. Taillet, A&A 462 (2007) 827

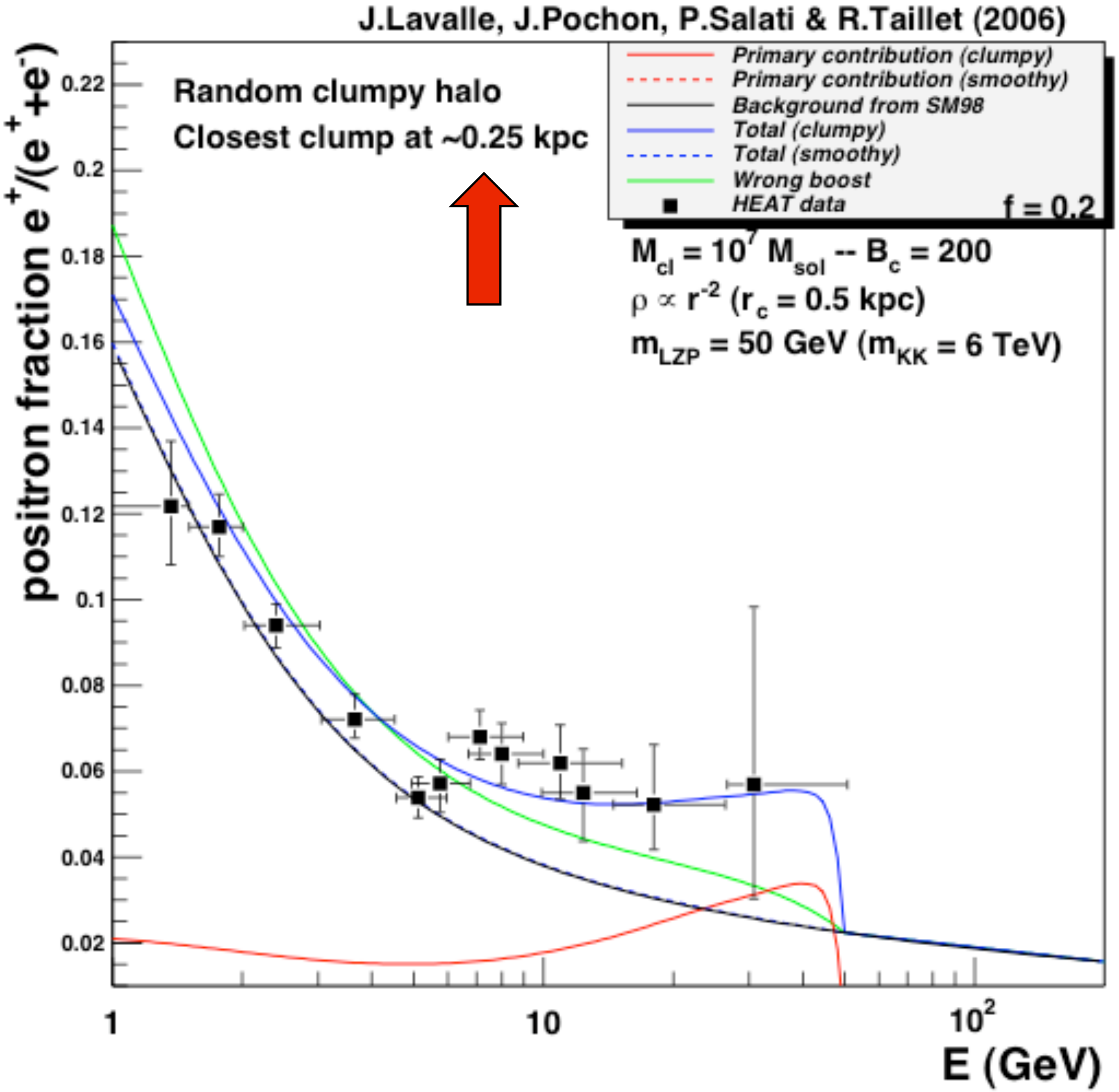


HEAT e^+ excess

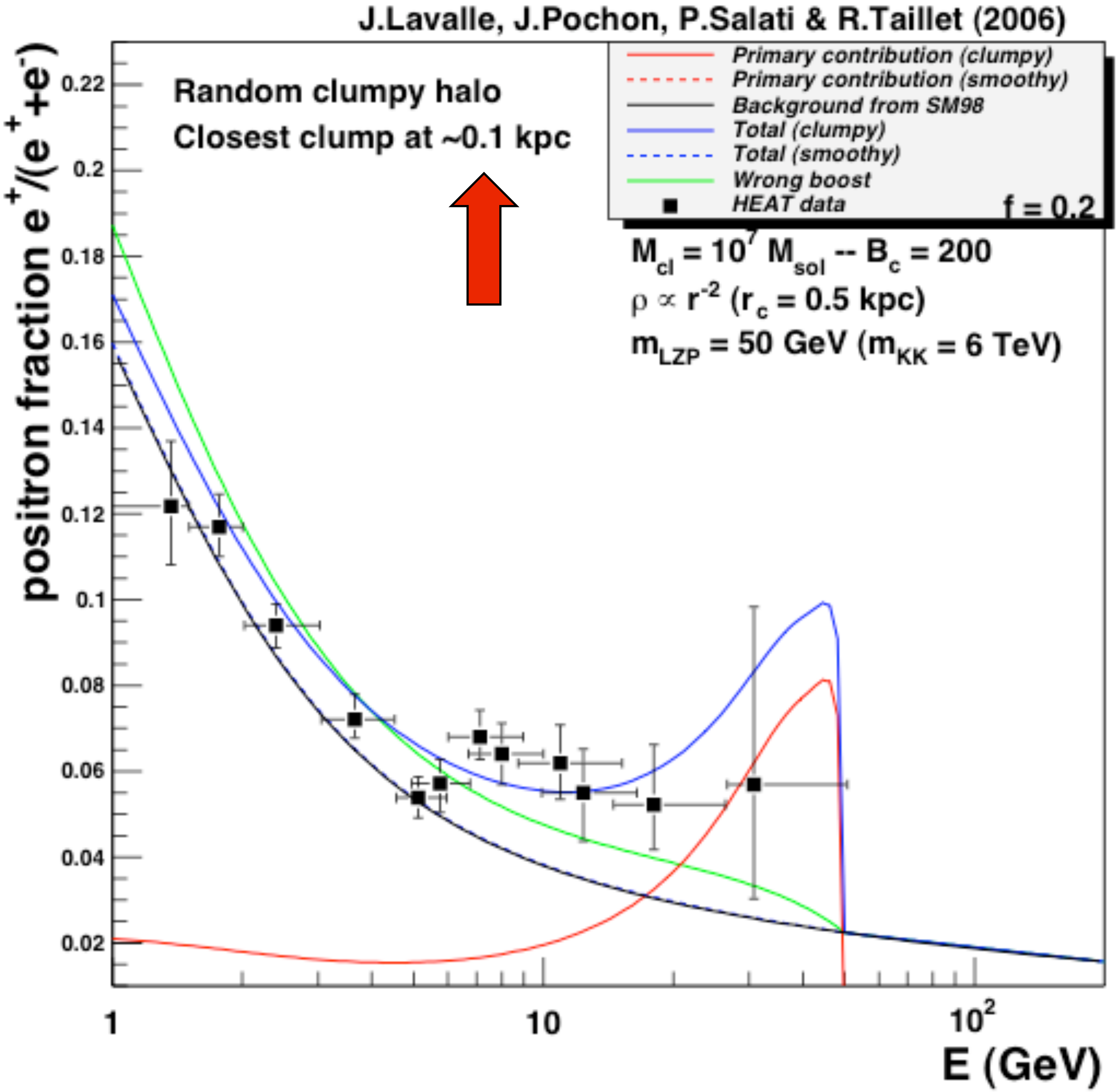
J. Lavalle, J. Pochon, **P.S.** & R. Taillet, A&A 462 (2007) 827



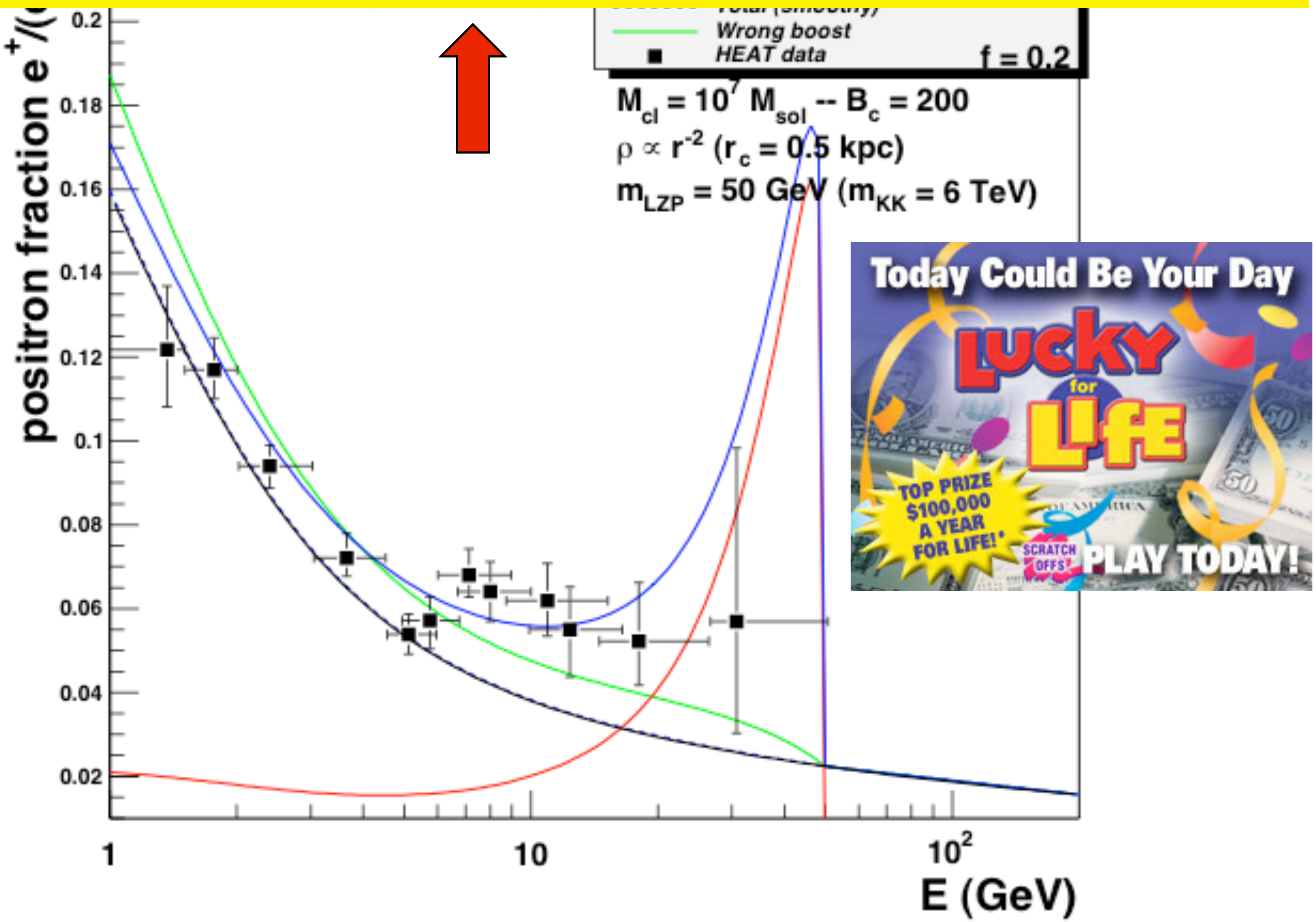
J. Lavalle, J. Pochon, **P.S.** & R. Taillet, A&A 462 (2007) 827



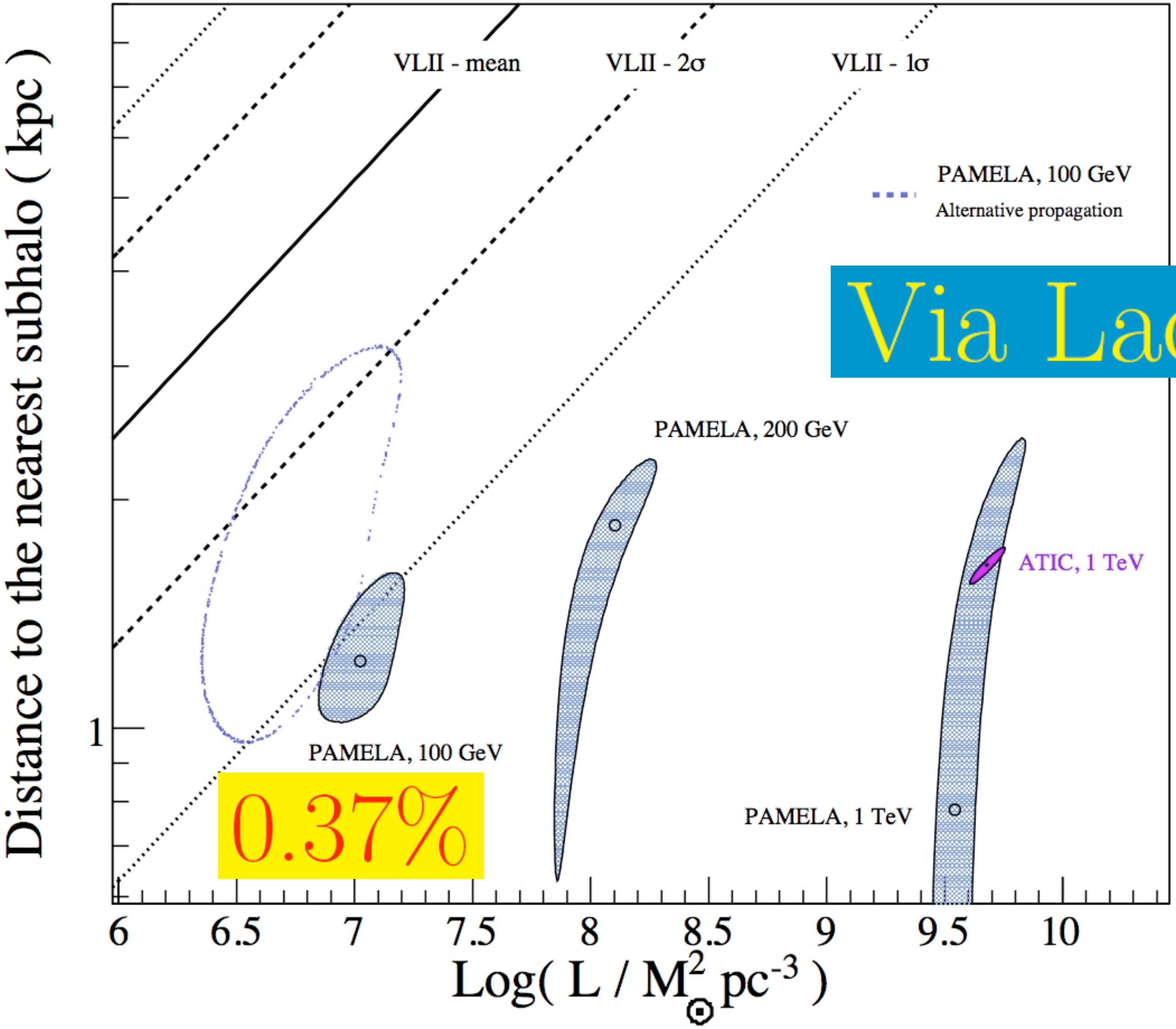
J. Lavalle, J. Pochon, **P.S.** & R. Taillet, A&A 462 (2007) 827



How probable is that ?



P. Brun, T. Delahaye, J. Diemand, S. Profumo & P. Salati, in progress



Via Lactea II

0.37%

T. Bringmann, J. Lavalle & P. Salati, arXiv:0902.3665

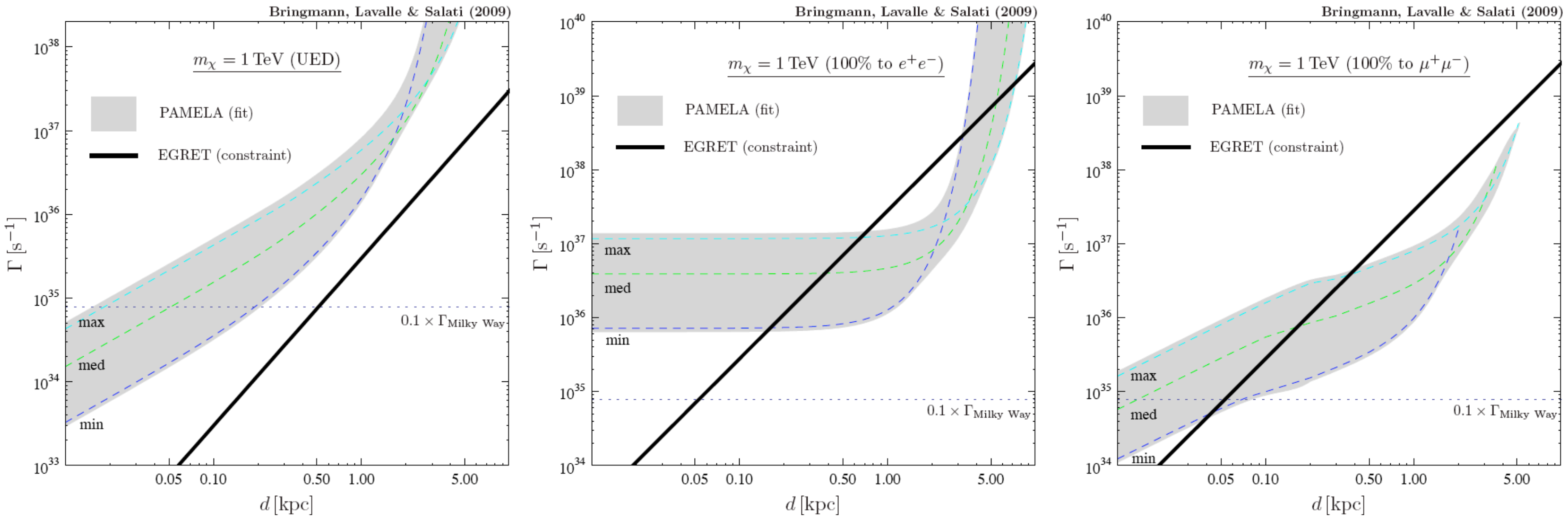
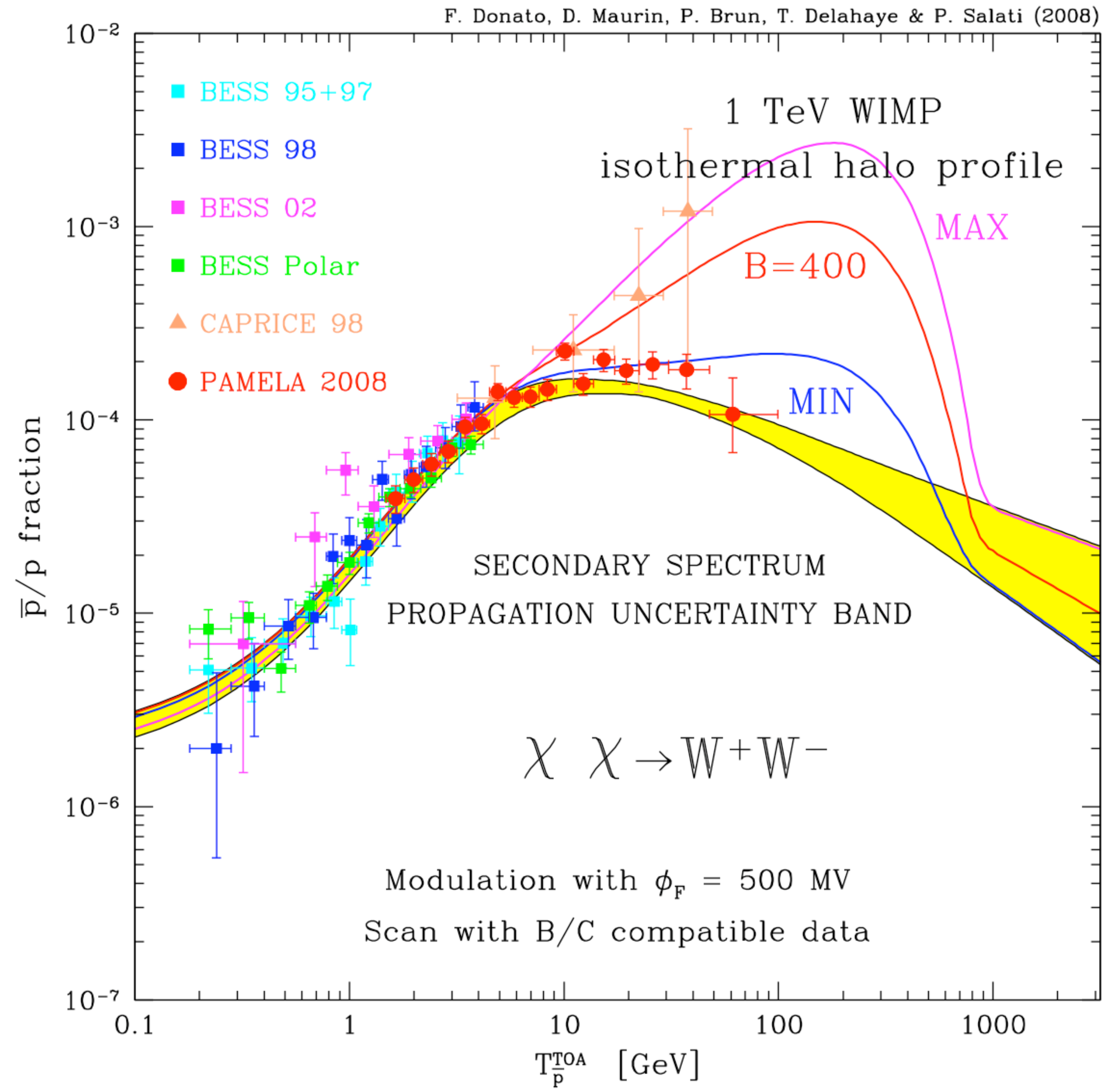


FIG. 3: The solid lines give the constraints on the DM annihilation rate $\Gamma = \frac{1}{2}\sigma v\,(\rho_0/m_\chi)^2\,\xi$ of a nearby DM overdensity at a distance d from the Earth; from left to right, we show the case of KK DM and a fiducial DM candidate annihilating to e^+e^- and $\mu^+\mu^-$, respectively. The dashed lines show the Γ needed to fit the PAMELA data, for sets of propagation parameters as defined in [19]. For comparison, the dotted line indicates 10% of Γ for the *whole Milky Way*, assuming $\langle\sigma v\rangle \sim 3\cdot 10^{-26}\mathrm{cm}^{-3}\mathrm{s}^{-1}$.

	PAMELA		ATIC
m_χ (GeV)	100	1 000	1 000
$\mathrm{e}^+/\mathrm{e}^-$	$(1.22; 1.07\cdot 10^7)$	$(0.78; 3.56\cdot 10^9)$	$(1.64; 4.81\cdot 10^9)$
$\mathrm{e}^\pm + \mu^\pm + \tau^\pm$	$(0.44; 2.51\cdot 10^7)$	$(0.27; 9.84\cdot 10^9)$	$(1.45; 9.44\cdot 10^9)$

TABLE I: Best fit values of the $(D; L)$ couple in units of $(\mathrm{kpc}; \mathrm{M}_\odot^2\,\mathrm{pc}^{-3})$ for various DM particle masses and annihilation channels.

F. Donato et al. – arXiv:0810.5292 – soon in PRL


F. Donato, D. Maurin, P. Brun, T. Delahaye & P. Salati (2008)

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

Jeter Hall[1,*] and Dan Hooper[2,3,†]

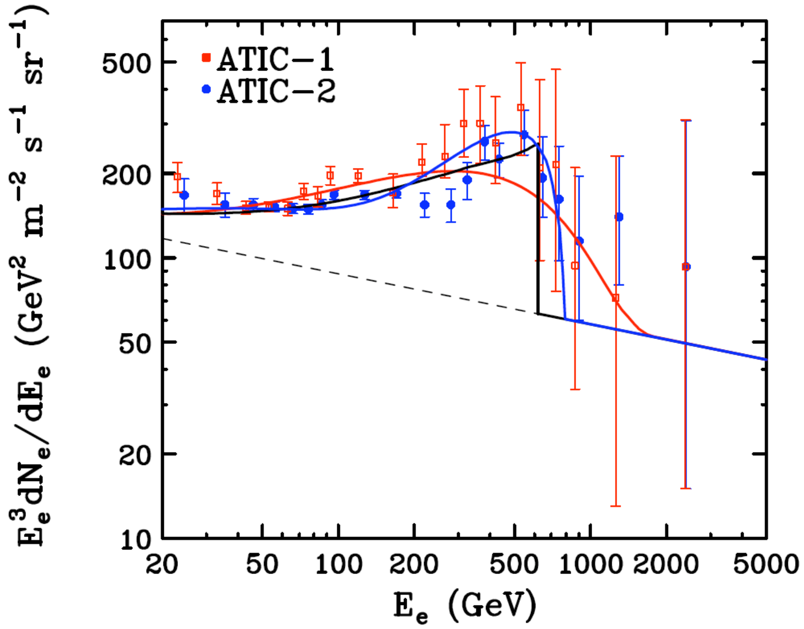
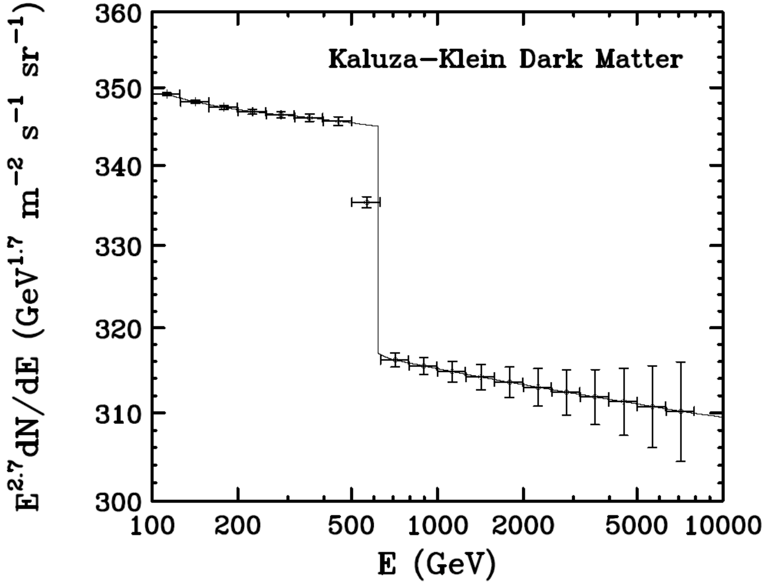
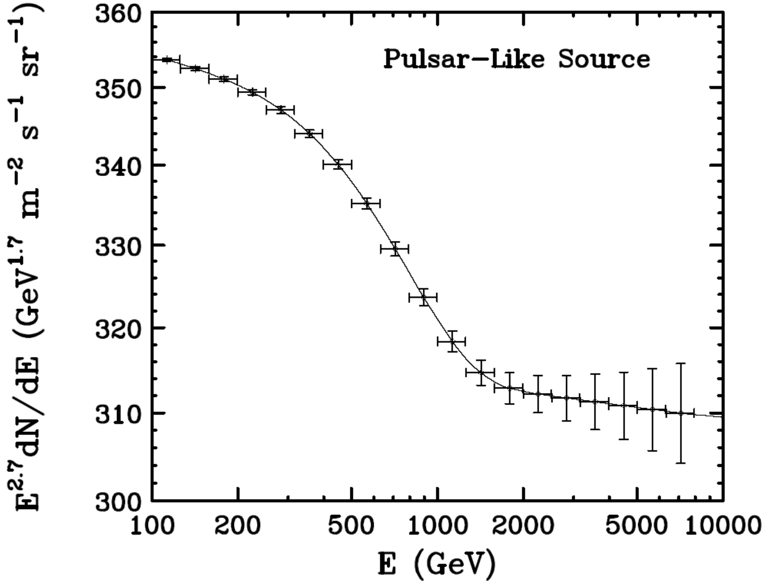
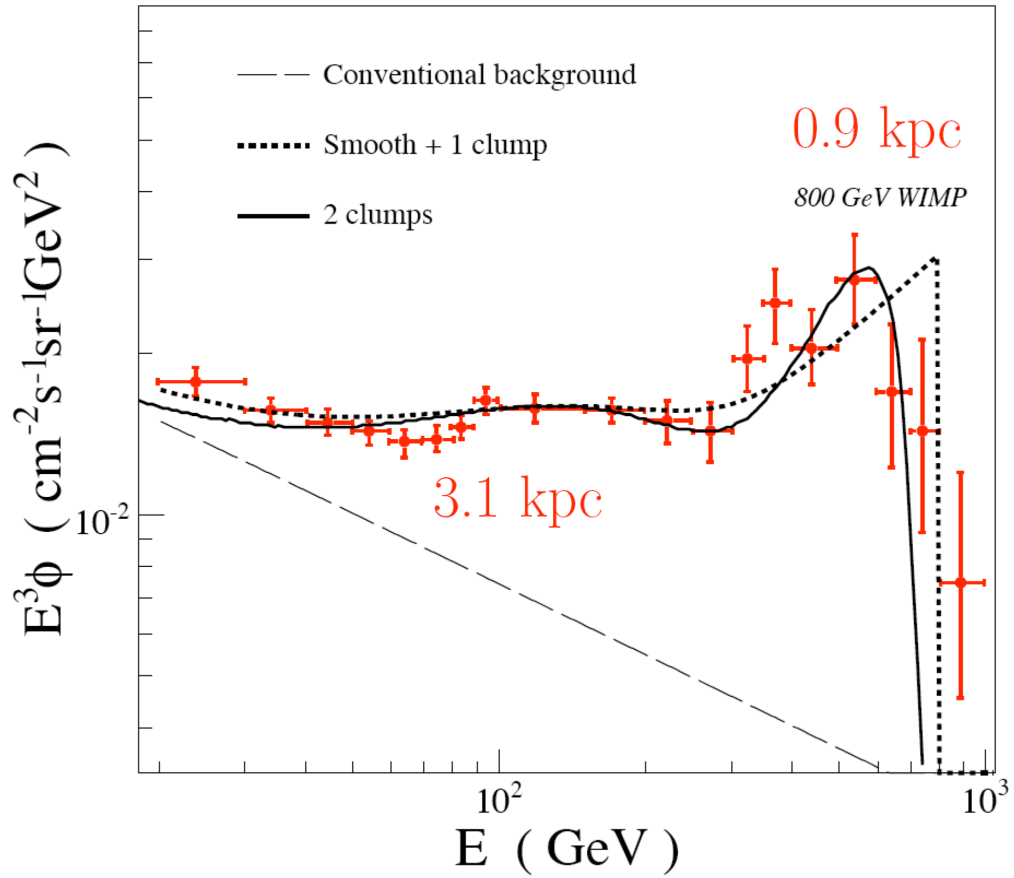


FIG. 1: The cosmic ray electron spectrum as measured by ATIC [1] compared to the spectrum predicted from three possible sources: a nearby pulsar (red), annihilation of 800 GeV dark matter annihilating to W^+W^- (blue), and annihilation of 620 GeV Kaluza-Klein dark matter (which annihilates to e^+e^-, $\mu^+\mu^-$, 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).





P. Brun, T. Delahaye, J. Diemand, S. Profumo & P. Salati, in progress



Non–linear effect of the positron horizon

The pieces of the puzzle

(4) DM particles – halo clumpiness.

- Substructures are characterized by $\langle \rho^2 \rangle \geq \langle \rho \rangle^2$.

But $B_{\text{Milky Way}} \lesssim 10$

- A single nearby clump – how probable is it ?
- A mixture between Sommerfeld and clumpiness ?
- Could two to two be revived ?
  - ✓ Antiproton and positron Green functions are different.
  - ✓ CR propagation parameters could suppress antiprotons.

Still open problem

Smoking gun signatures for the various options ?

Transport of Cosmic Rays in Chaotic Magnetic Fields

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

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

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

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

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

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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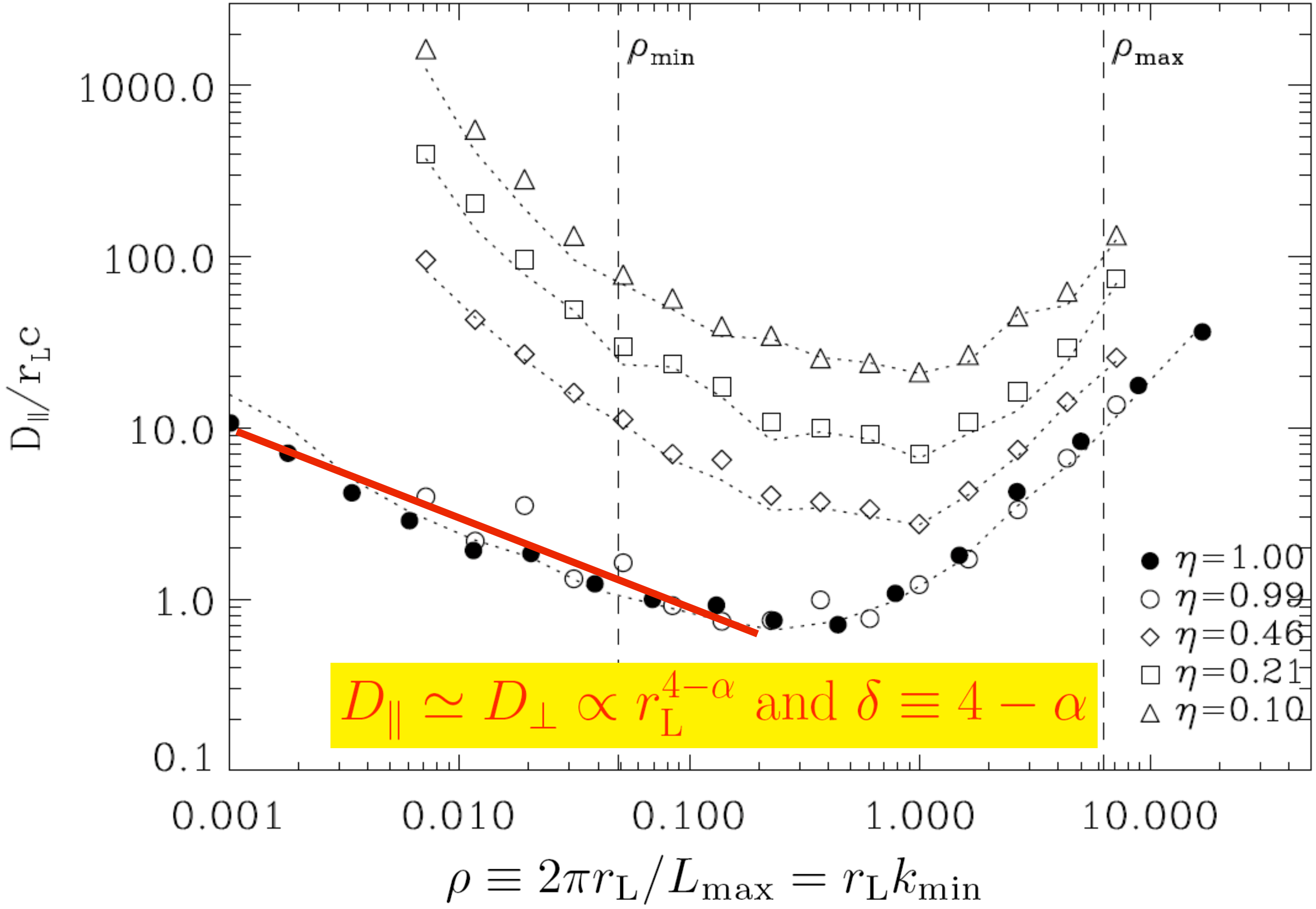


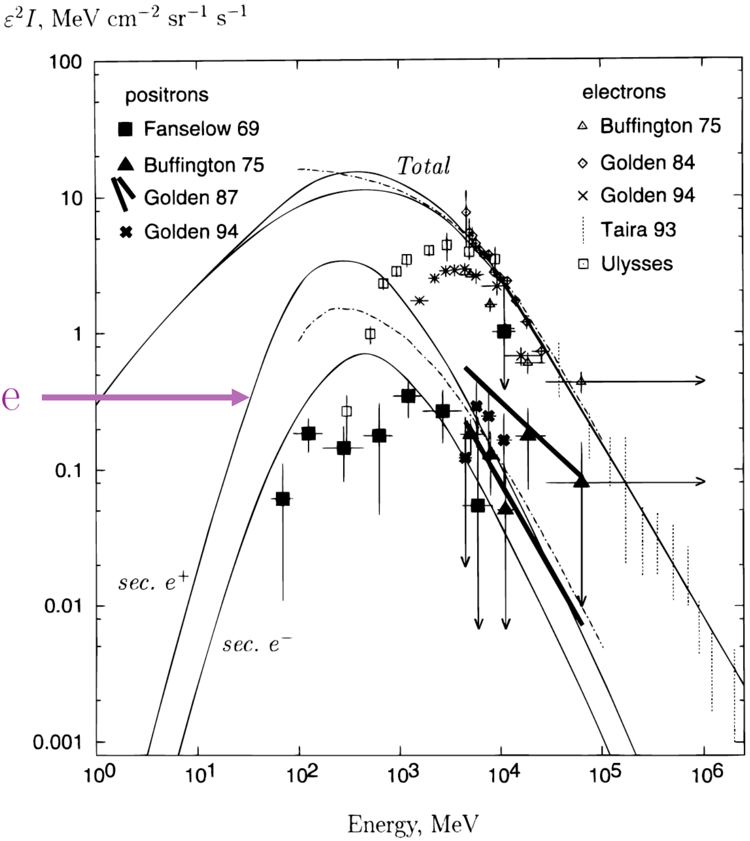
$D_\parallel \simeq D_\perp \propto r_L^{4-\alpha}$ and $\delta \equiv 4-\alpha$

$\delta = 1/3$ (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



e^+ spectral reference

Parameters of Models

Model	z_h (kpc)	D_0 (cm^2 s^{-1})	ρ_0 (MV/c)	δ	v_A (km s^{-1})	Protons γ	Protons p_0[a]	Protons I_0[b]	Helium γ	Helium p_0[a]	Helium 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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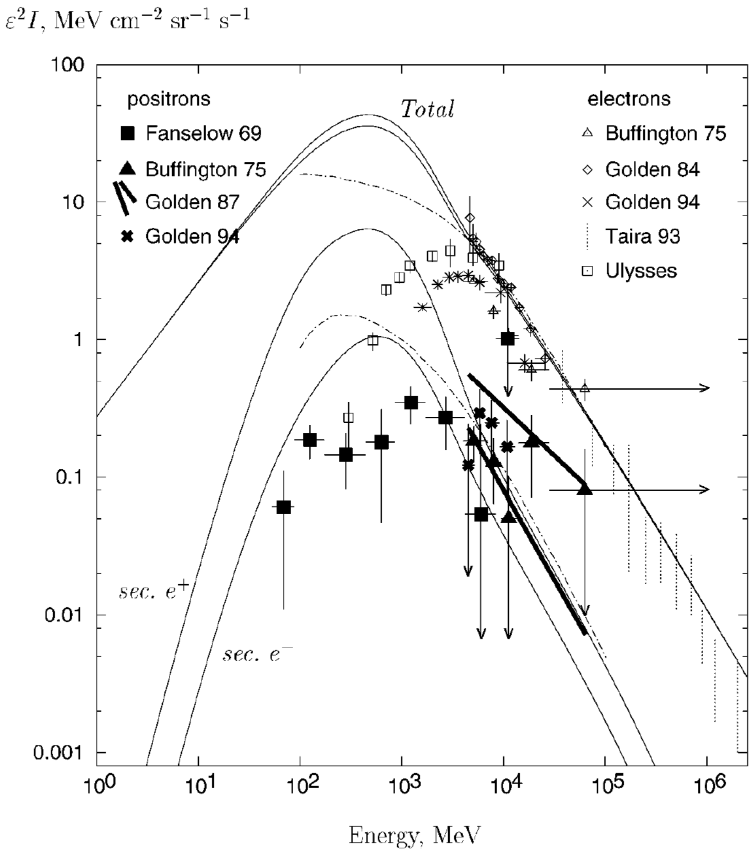
diffusive reacceleration



PARAMETERS OF MODELS

MODEL	z_h (kpc)	D_0 (cm^2 s^{-1})	ρ_0 (MV/c)	δ	v_A (km s^{-1})	PROTONS γ	PROTONS p_0[a]	PROTONS I_0[b]	HELIUM γ	HELIUM p_0[a]	HELIUM I_0[b]
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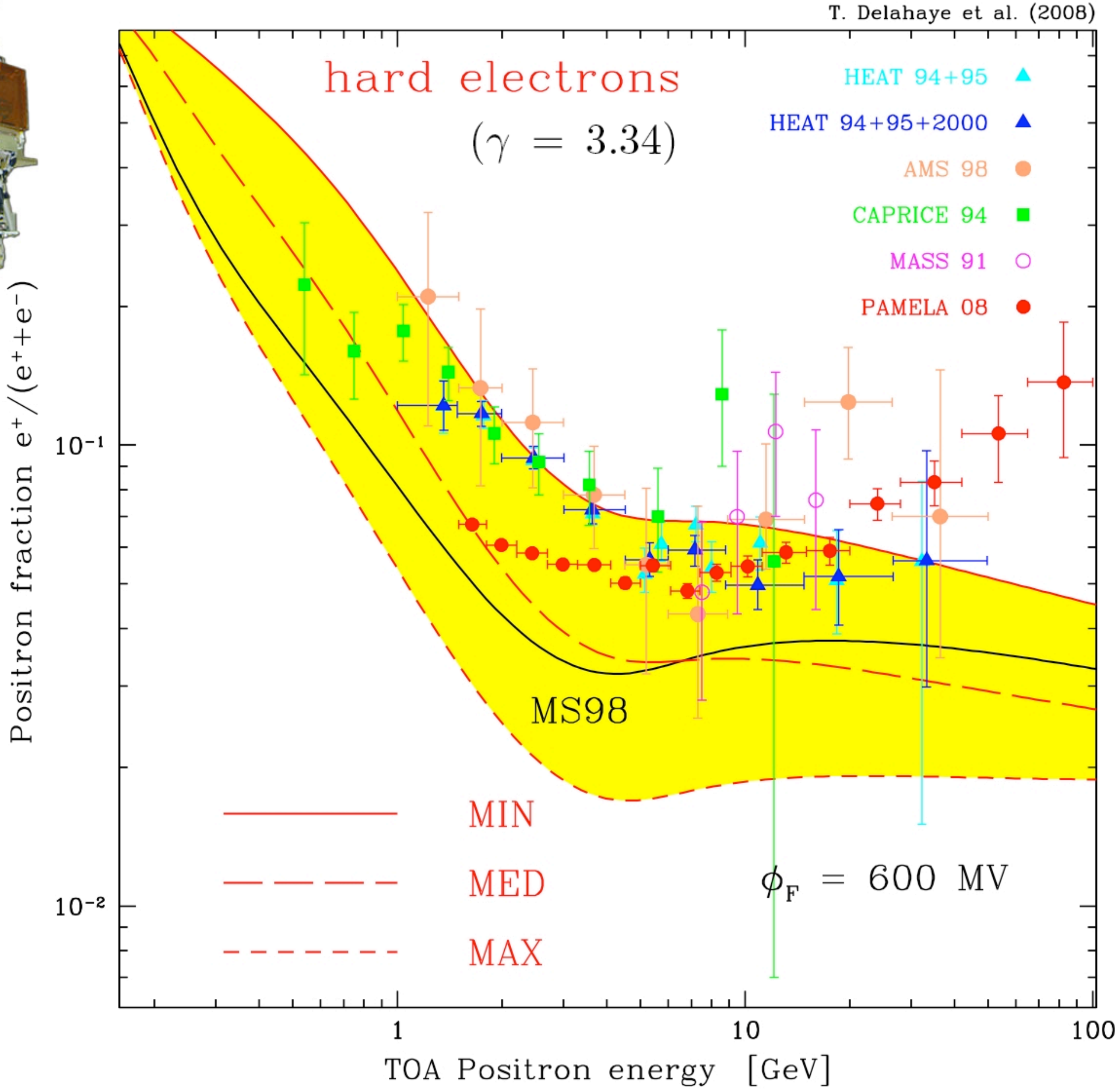
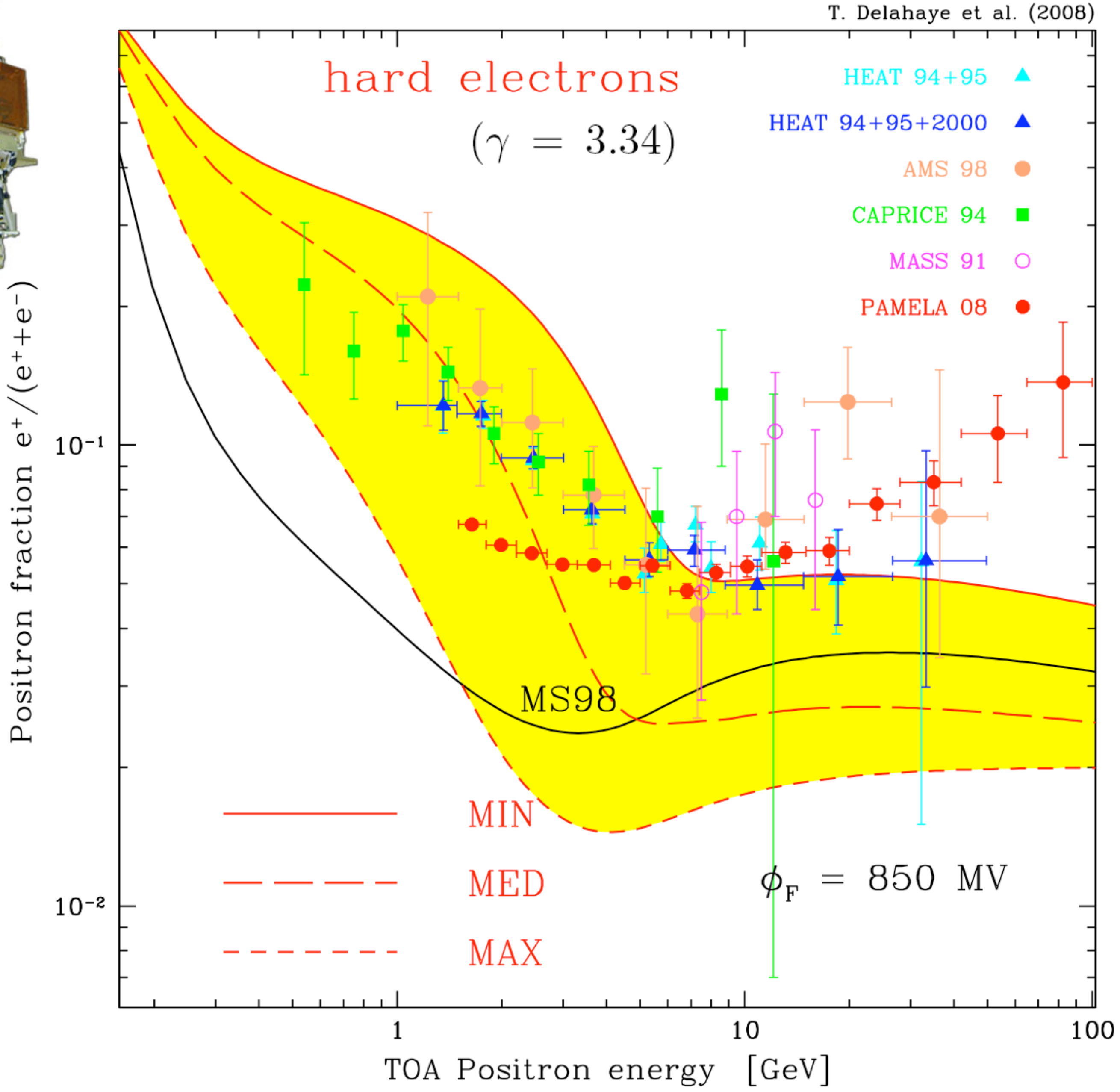
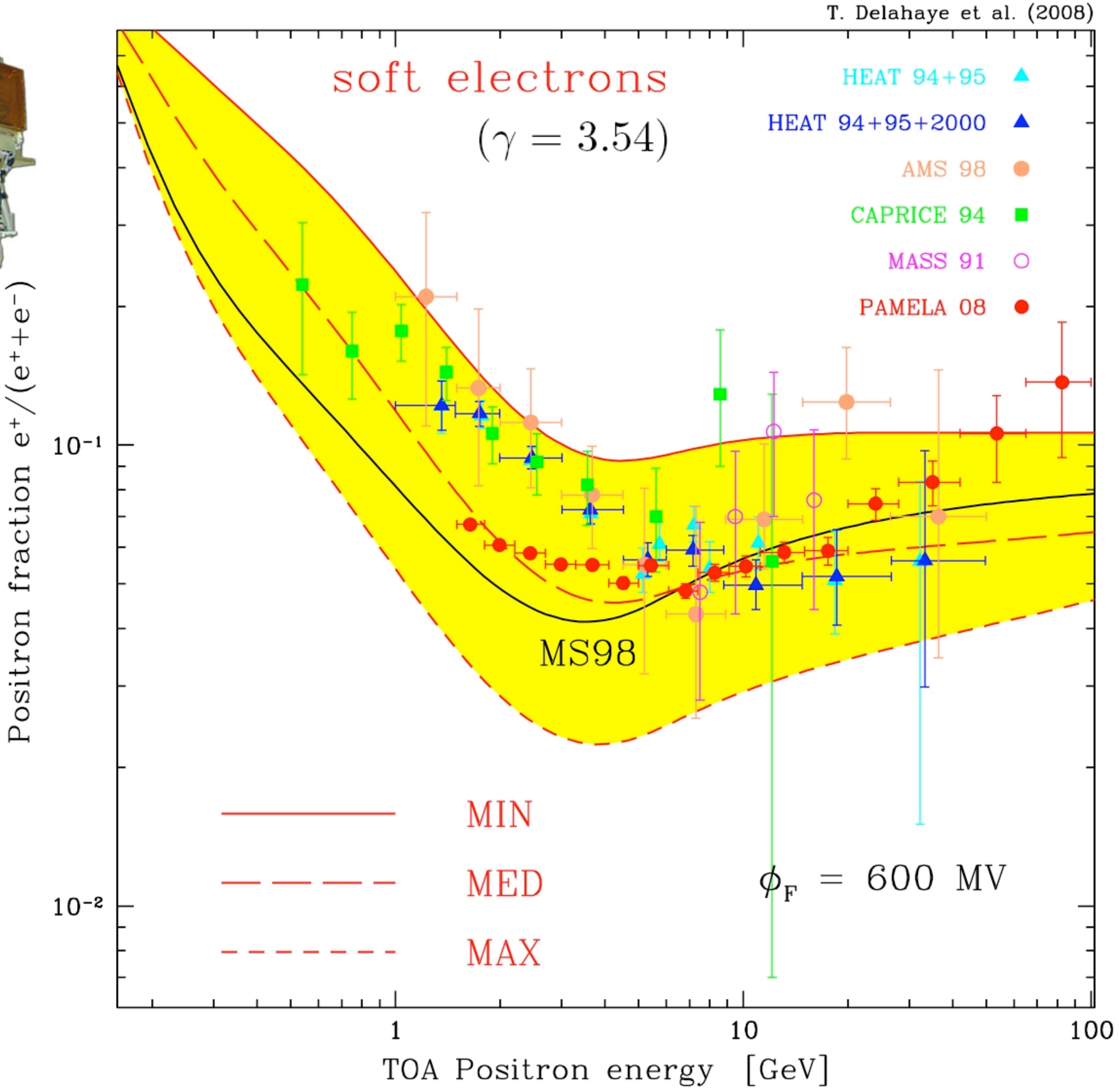
Delahaye T. et al. – arXiv:0809.5268



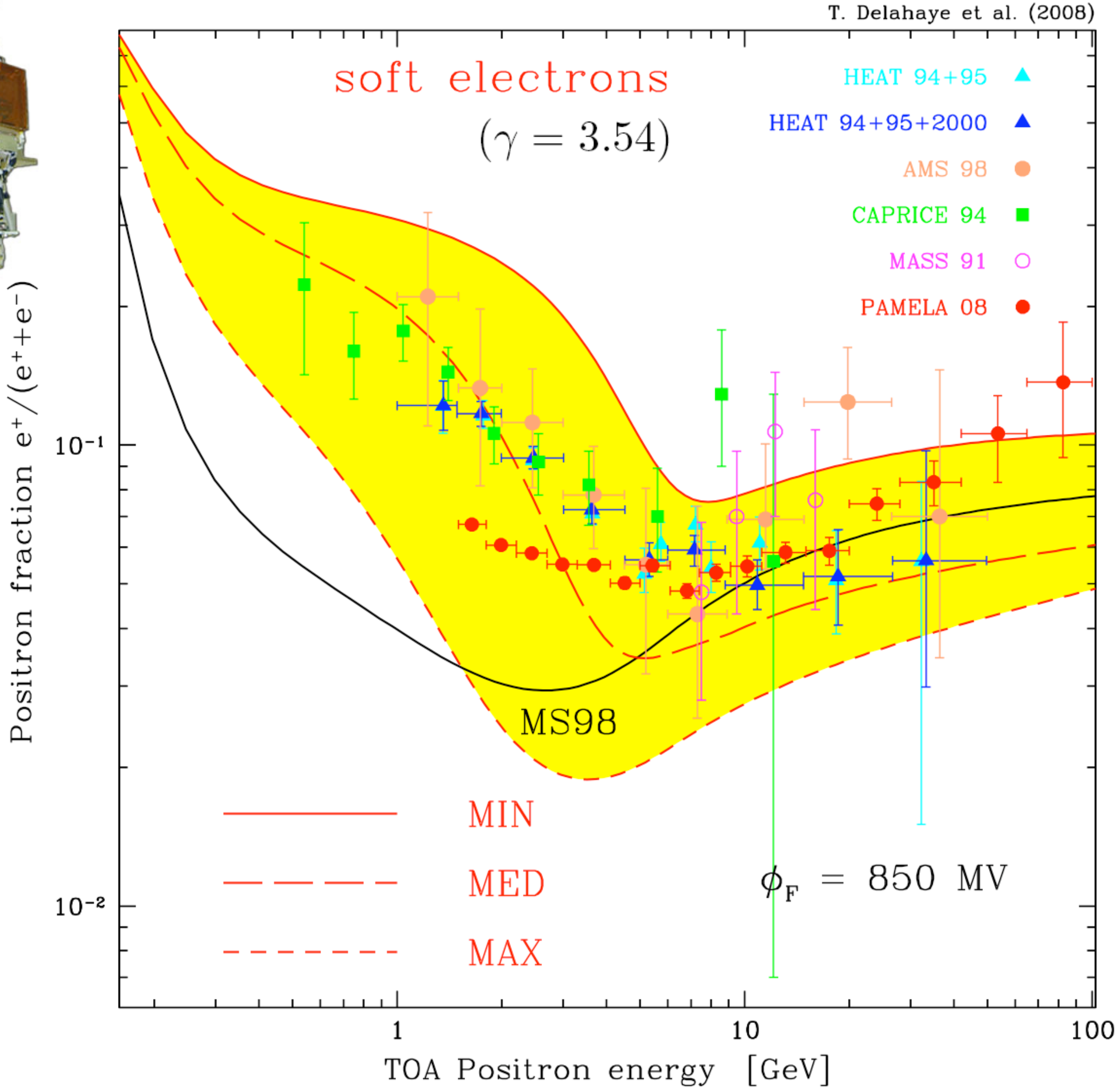
Delahaye T. et al. – arXiv:0809.5268



Delahaye T. et al. – arXiv:0809.5268

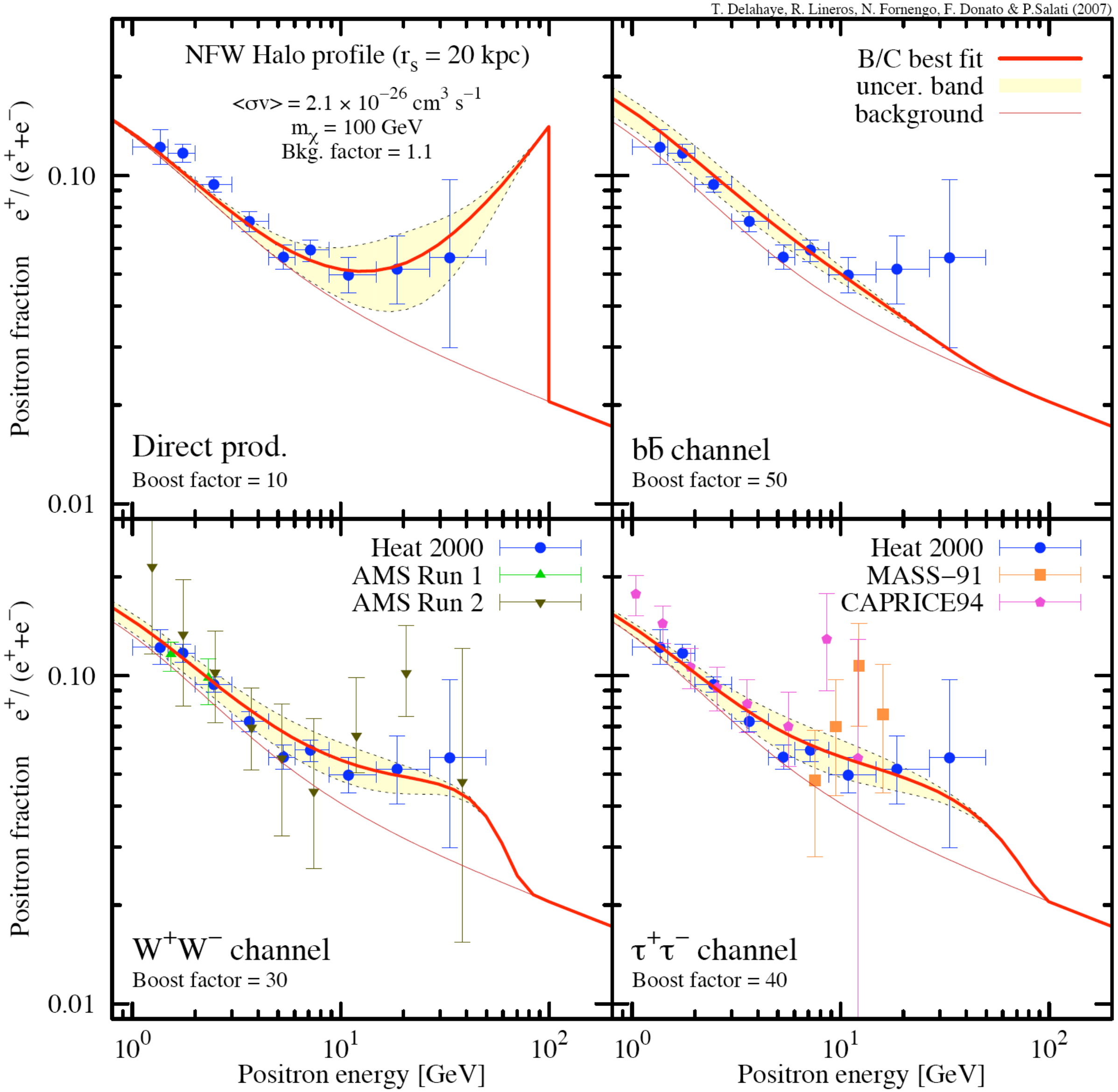


Delahaye T. et al. – arXiv:0809.5268

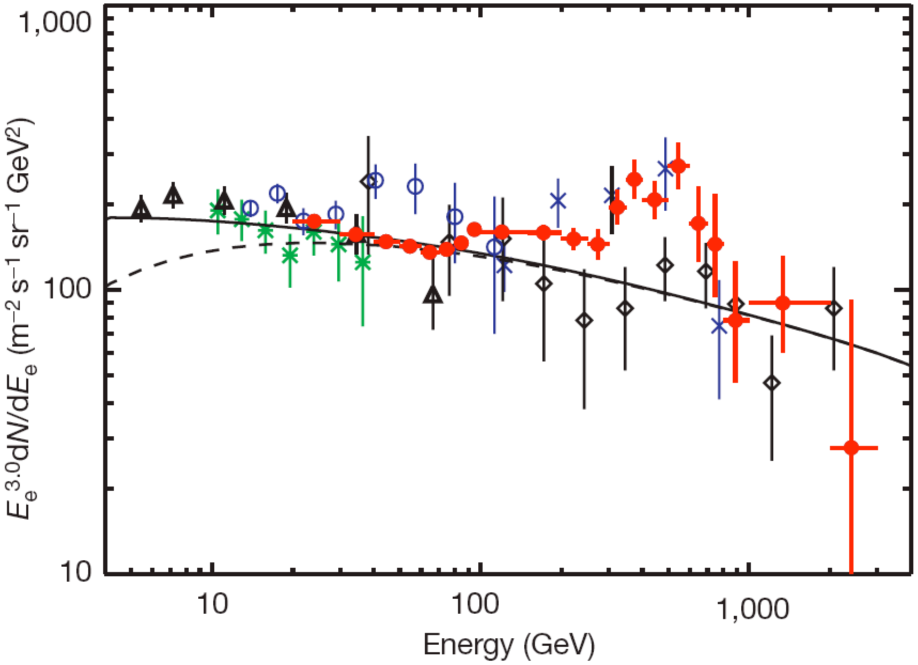


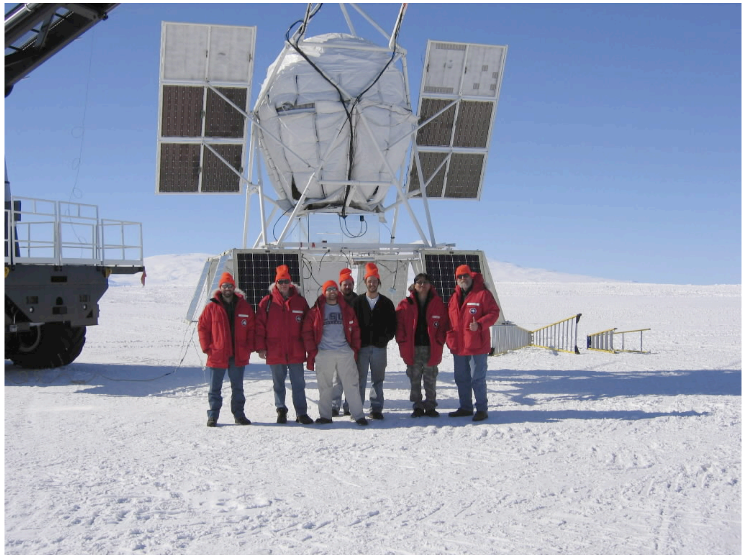
The secondary e^+ spectrum so far used has been computed in 1998

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

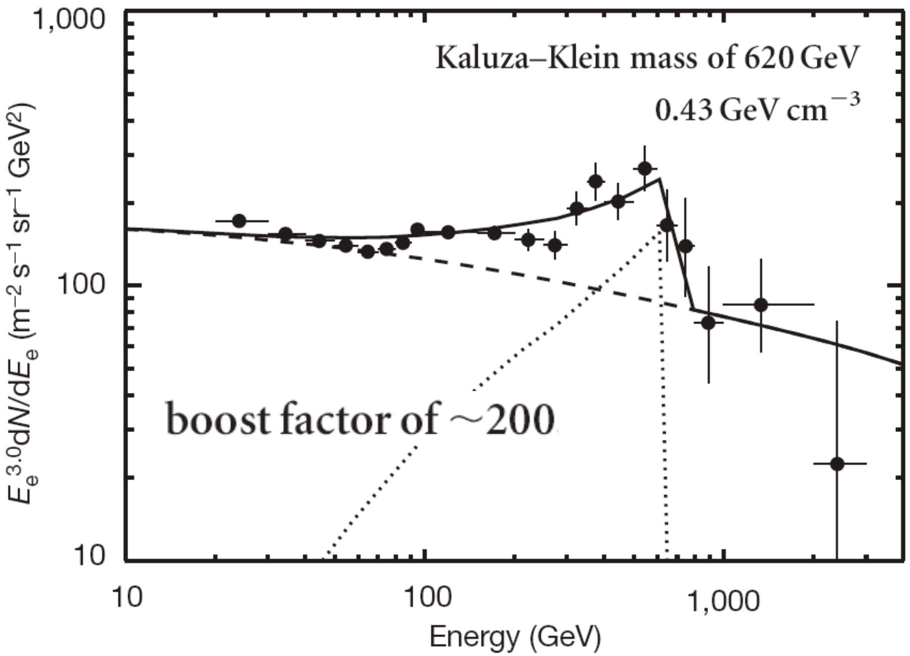


An excess of cosmic ray electrons at energies of 300–800 GeV



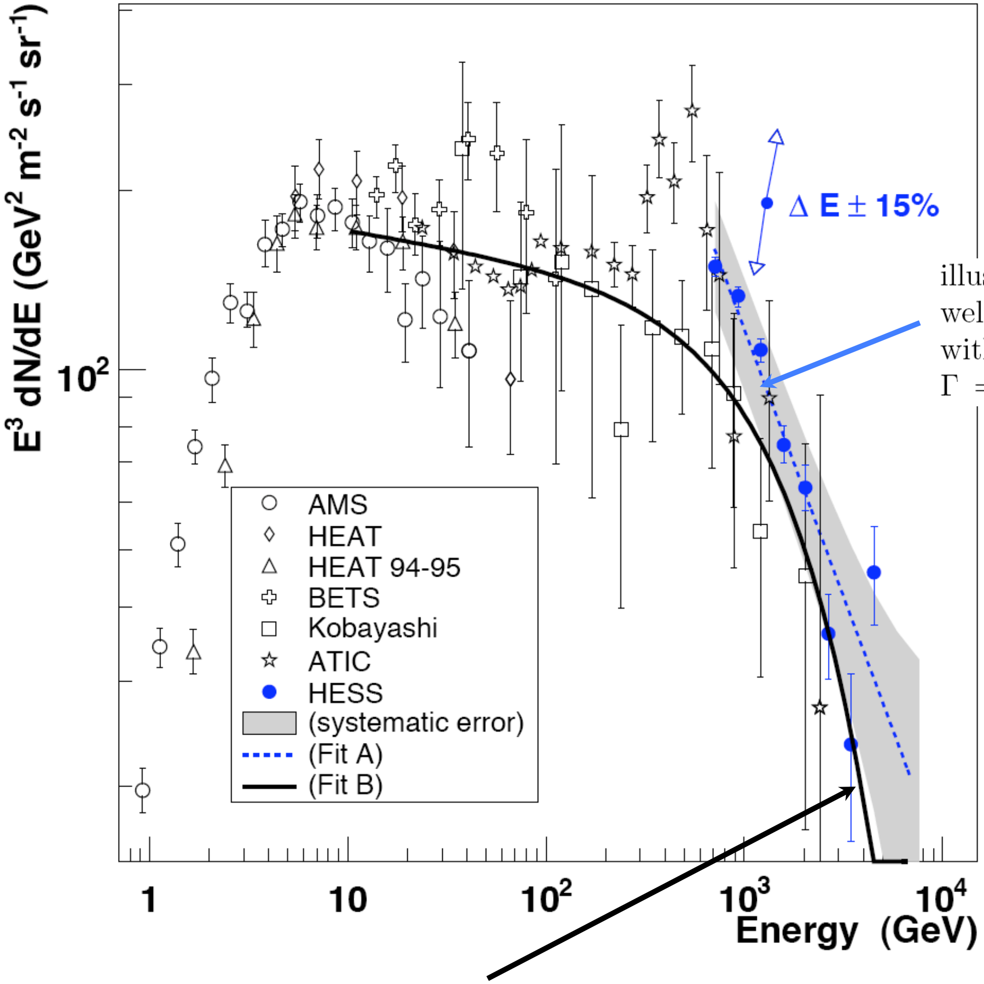


Vol 456|20 November 2008|**doi:10.1038/nature07477**



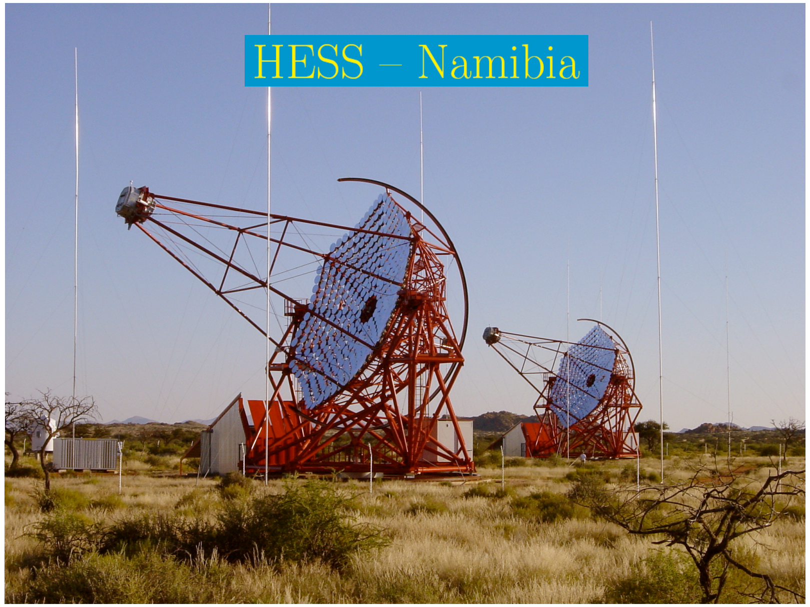
HESS measurement of the high–energy $e^{\pm}$ spectrum

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



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

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



HESS – Namibia