Title: The PAMELA excess int the light of cosmic ray propagation

Date: Jun 11, 2009 02:00 PM

URL: http://pirsa.org/09060037

Abstract: The positron excess measured by PAMELA may be the long waited hint of the presence of dark matter particles in the Milky Way halo. But before we rejoice, we need to examine the other Possible astrophysical explanations. Whatever the sources -- DM or conventional -- a crucial ingredient is the transport of cosmic rays in the magnetic fields of the Galaxy to which I will pay particular attention in this presentation.

The PAMELA excess & cosmic ray propagation

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

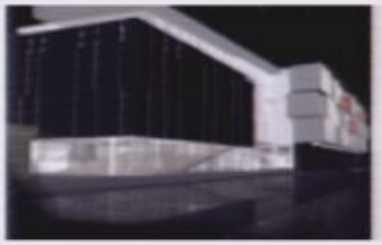
The Menu

1) Cosmic ray propagation in the Milky Way

2) Antiprotons or the revenge of orthodoxy

3) Secondary positron uncertainties

4) Astrophysical explanations of the PAMELA excess



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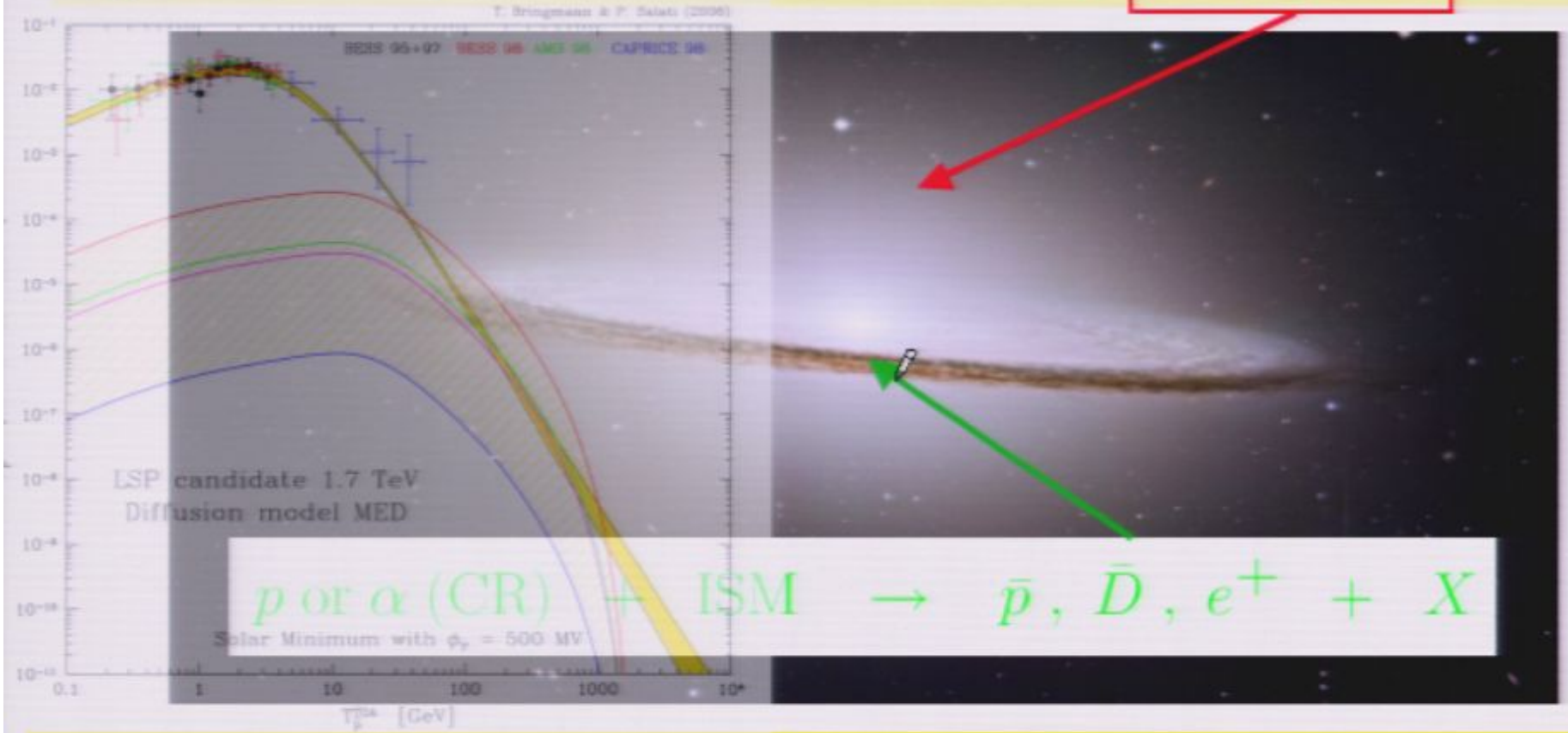
Indirect signatures of DM species

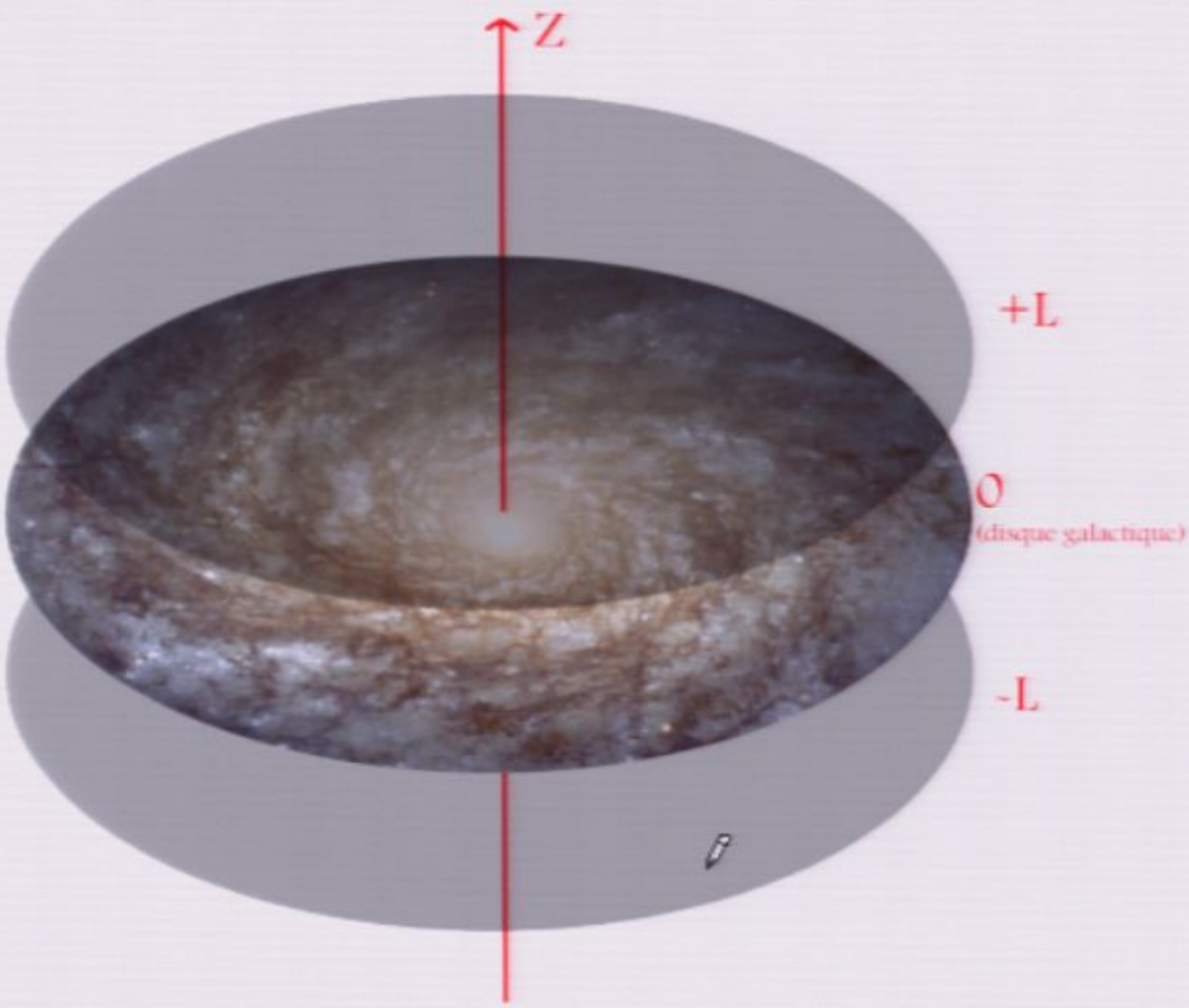
Weakly Interacting Massive particles – WIMPs – may be the major component of the haloes of galaxies. Their mutual annihilations would produce an indirect signature of high–energy cosmic rays :

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



Antimatter is already manufactured inside the galactic disk

1) Cosmic ray propagation in the Milky Way



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

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

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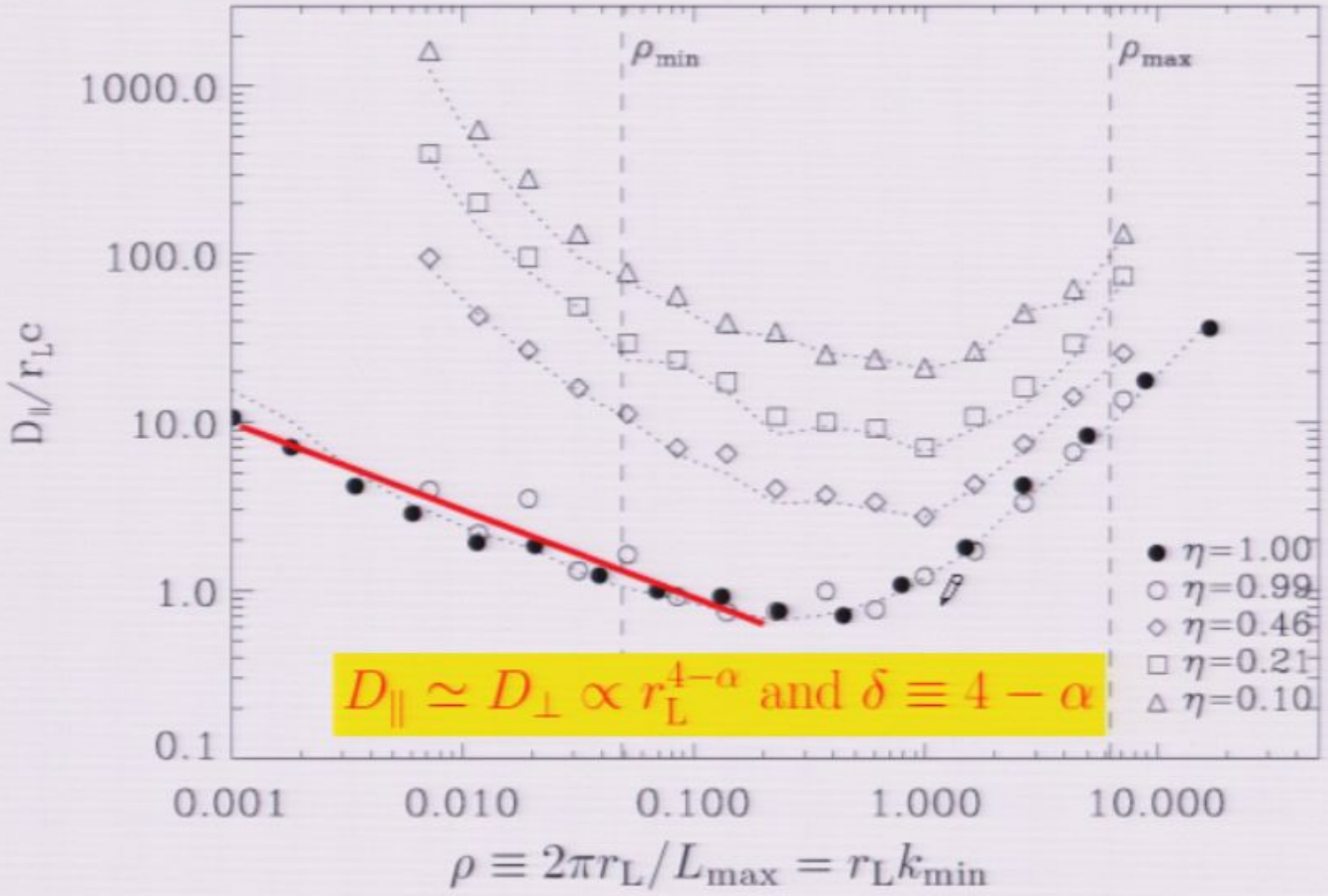

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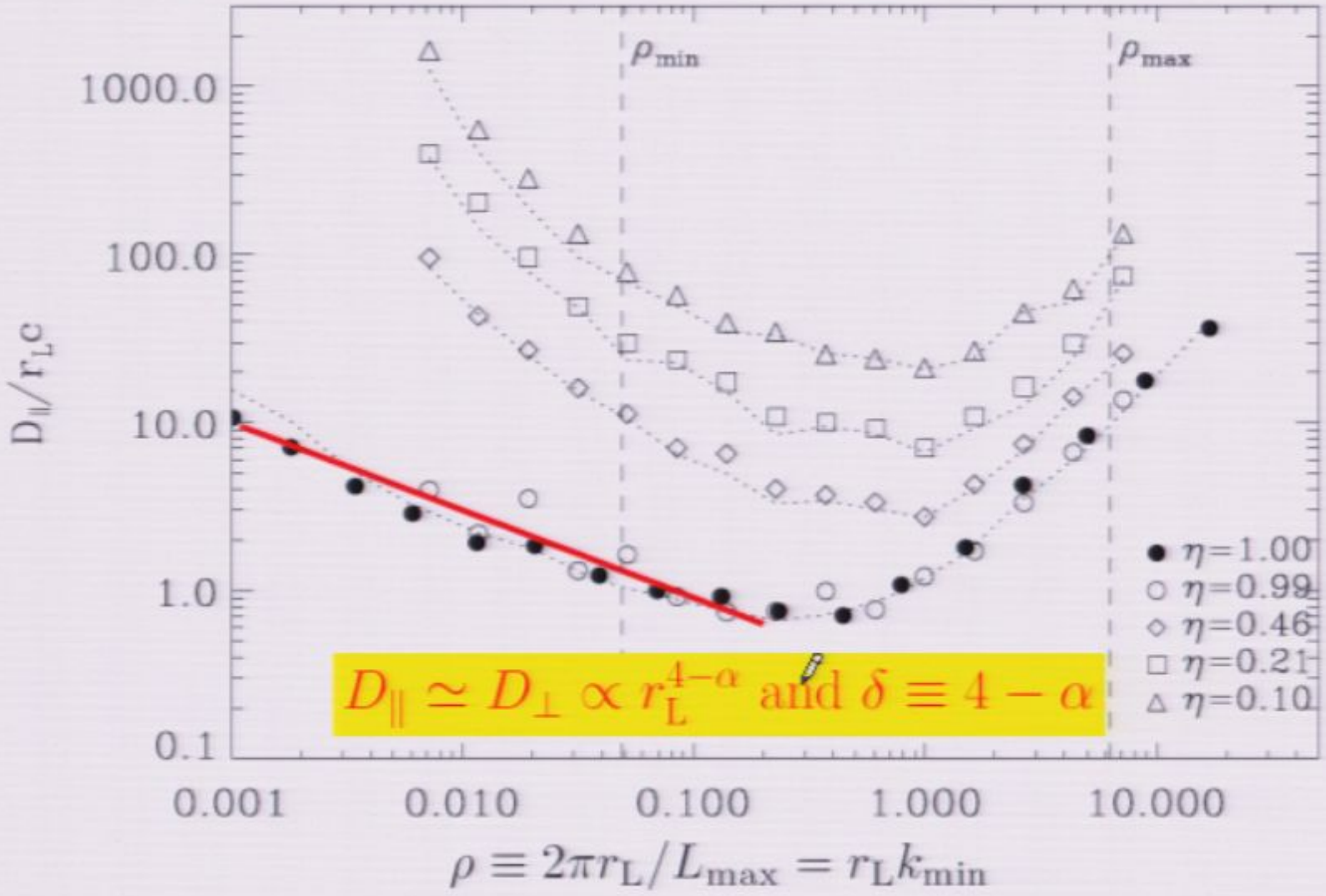

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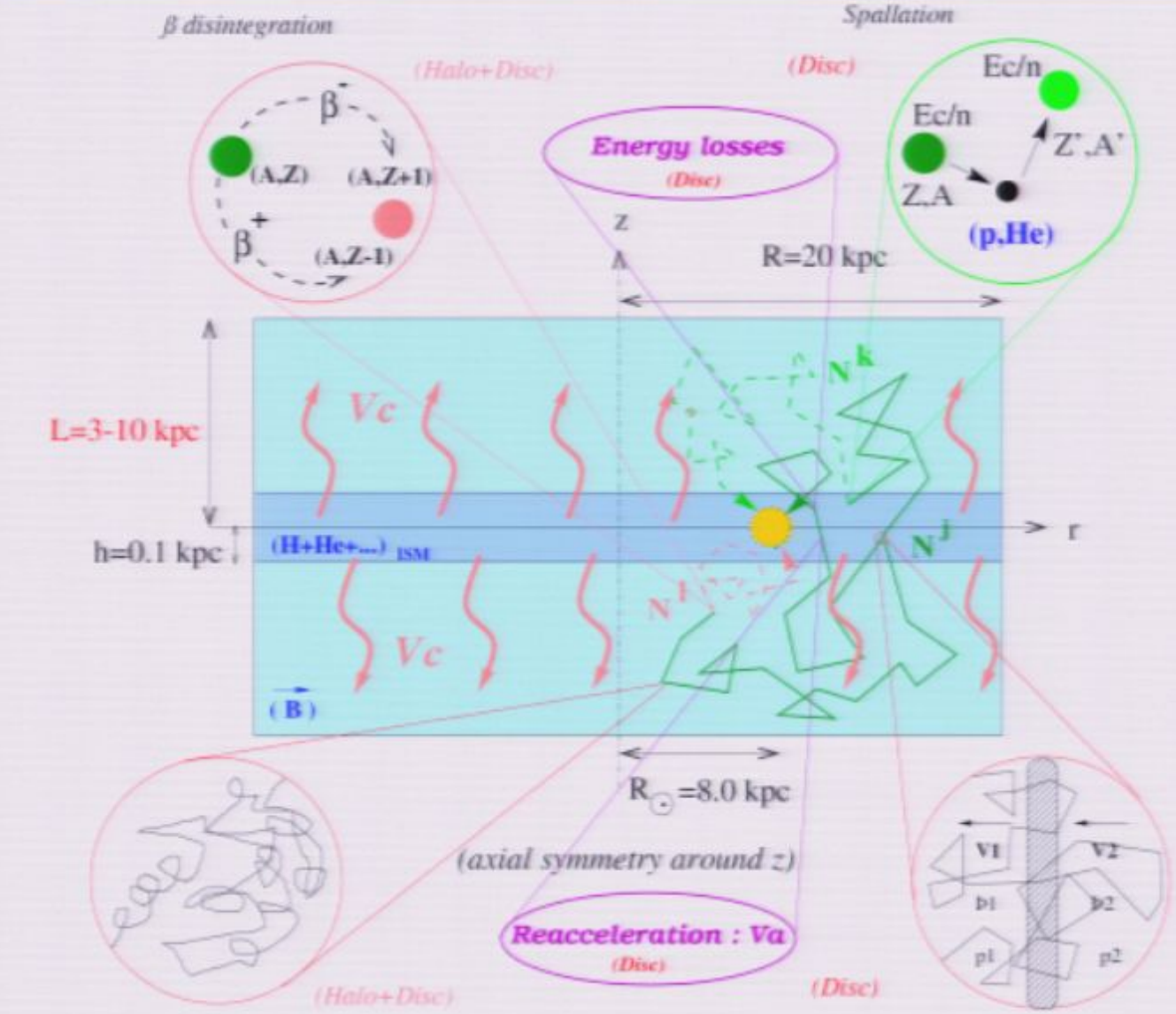
Milky–Way seen by a cosmic–ray physicist



D. Maurin, R. Taillet, F. Donato, P. Salati, A. Barrau and G. Boudoul, *Galactic cosmic ray nuclei as a*

Cosmic–rays diffuse in space and energy

The master equation for the CR density $\Psi(\vec{x}, E) = dn/dE$ is

$$\partial_{\mathrm{M}} J^{\mathrm{M}} = \partial_t \Psi + \vec{\nabla} \cdot \vec{J} + \partial_E J_E = Q$$

Cosmic–rays diffuse in space and energy

- Diffusion and convection in space

$$\vec{J} \;=\; -\,K\,\vec{\nabla}\Psi \;+\; \Psi\,\vec{V}_C$$

- Second order Fermi mechanism

$$J_E \;=\; b^{\rm loss}(E)\,\Psi \;-\; K_{EE}(E)\,\partial_E\Psi$$

- Steady state holds with $\partial_t\Psi = 0$

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$$V_C\,\partial_z\Psi \;-\; K\,\Delta\Psi \;+\; \partial_E\left\{b^{\rm loss}(E)\,\Psi \;-\; K_{EE}(E)\,\partial_E\Psi\right\} \;=\; Q$$

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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

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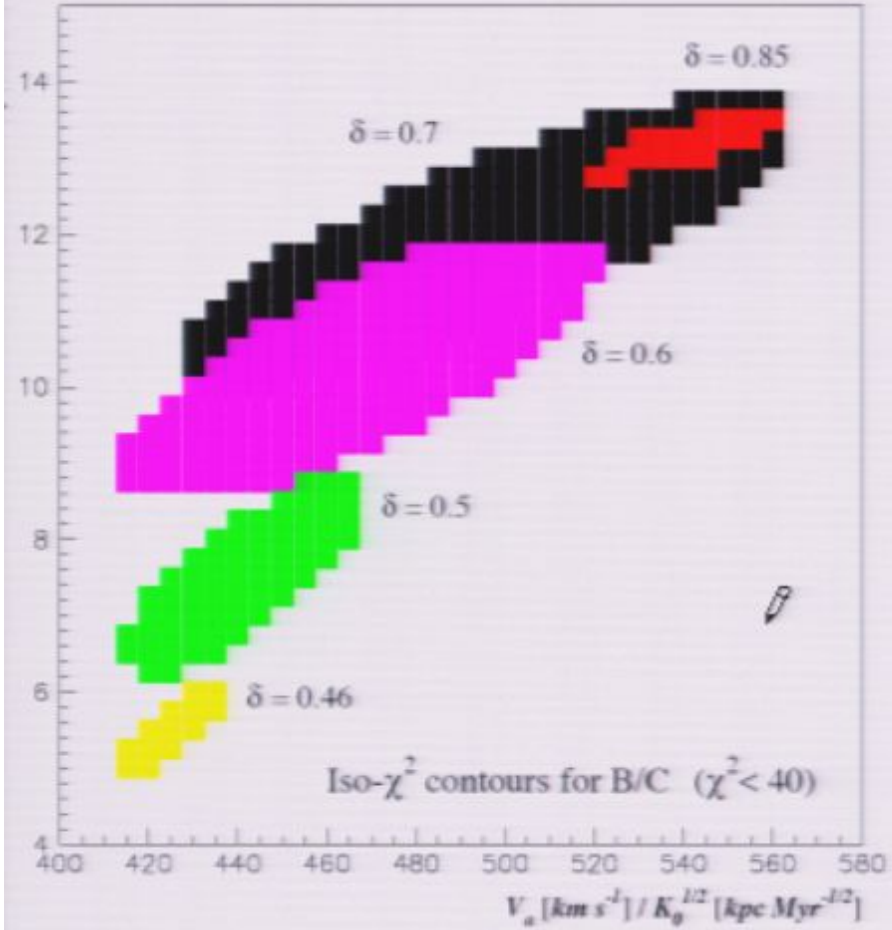
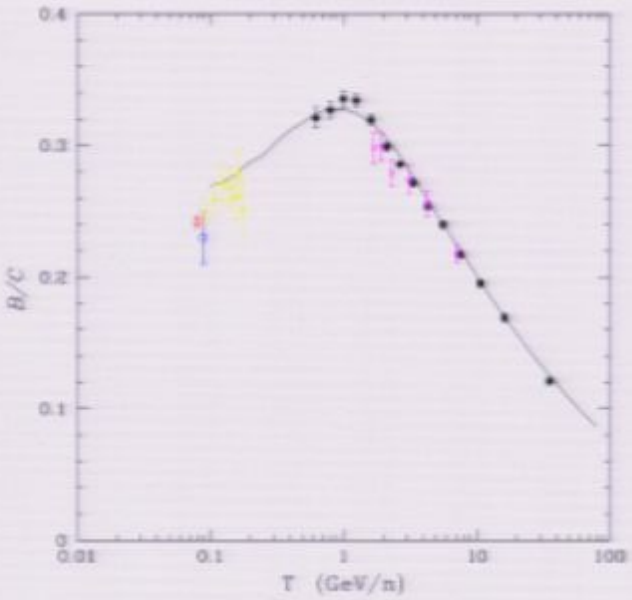
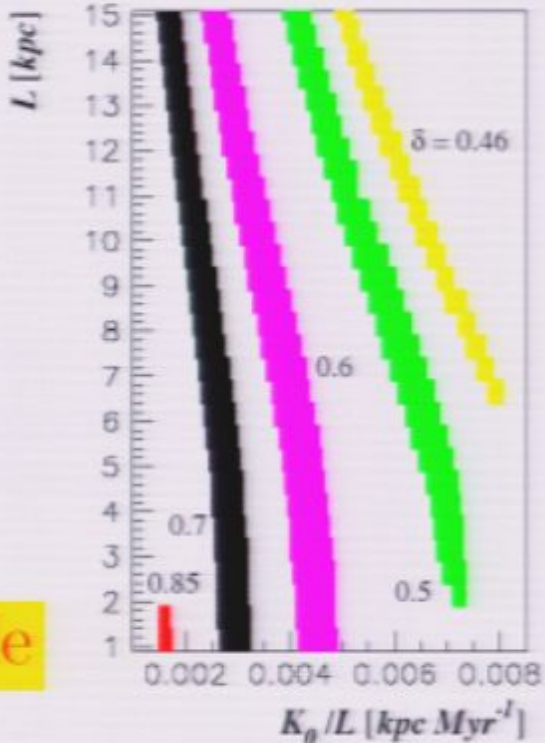
B/C ratio analysis – D. Maurin et al.

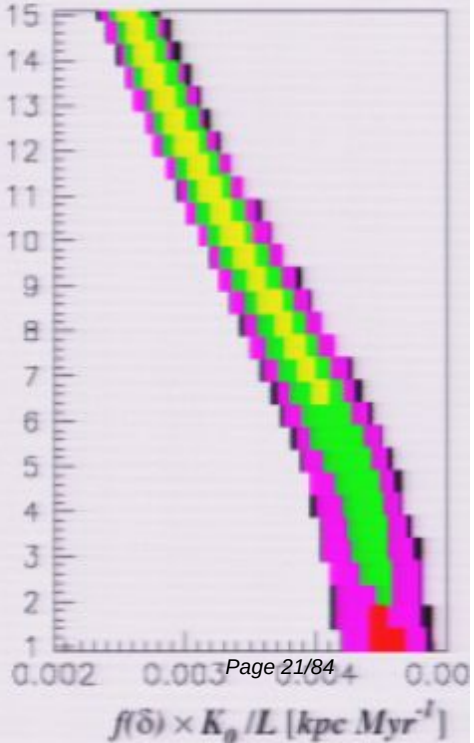
THE ASTROPHYSICAL JOURNAL, 555:585–596, 2001 July 10





Iso-χ^2 contours for B/C (χ^2< 40)





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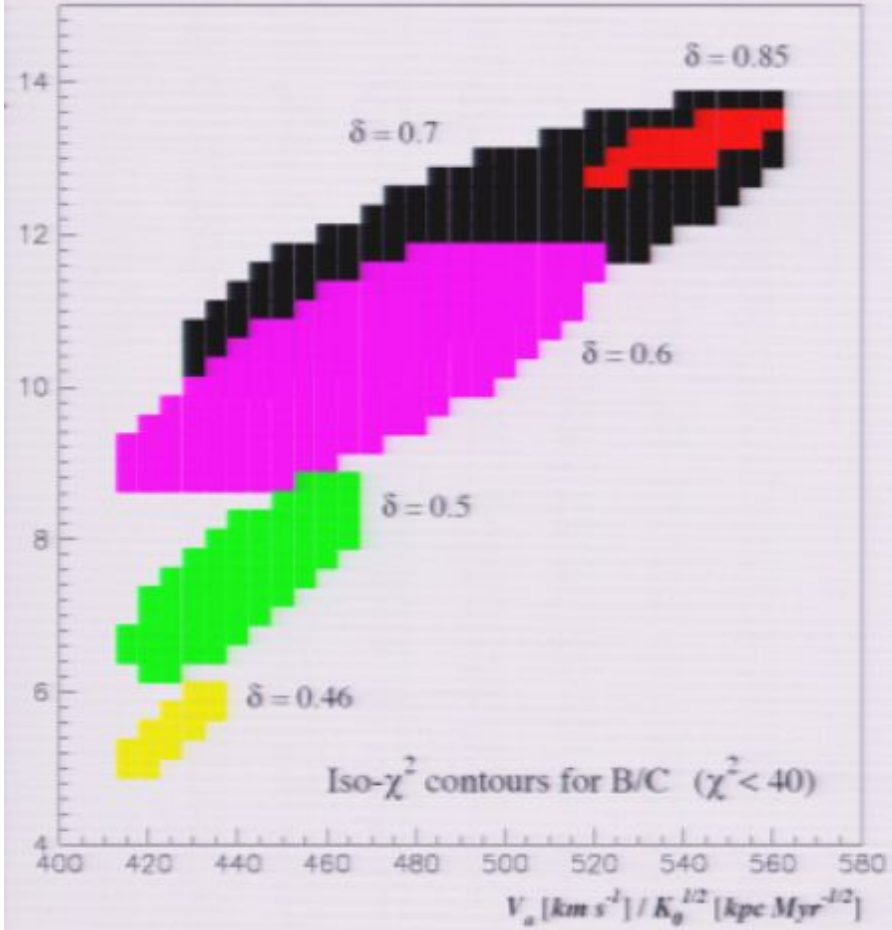

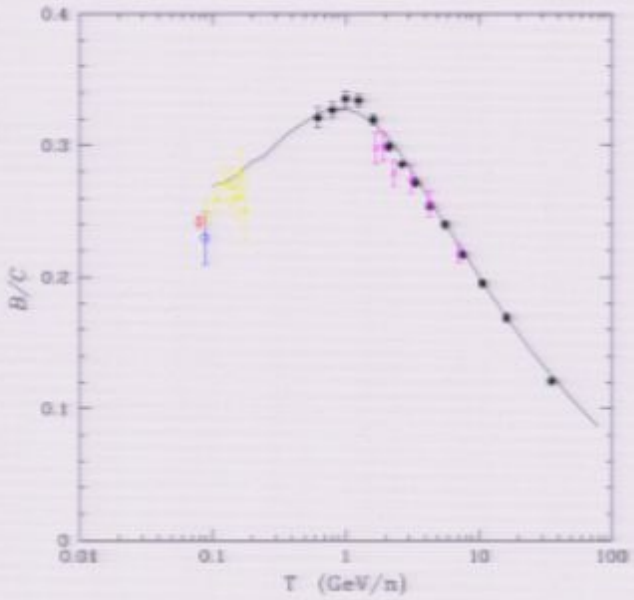

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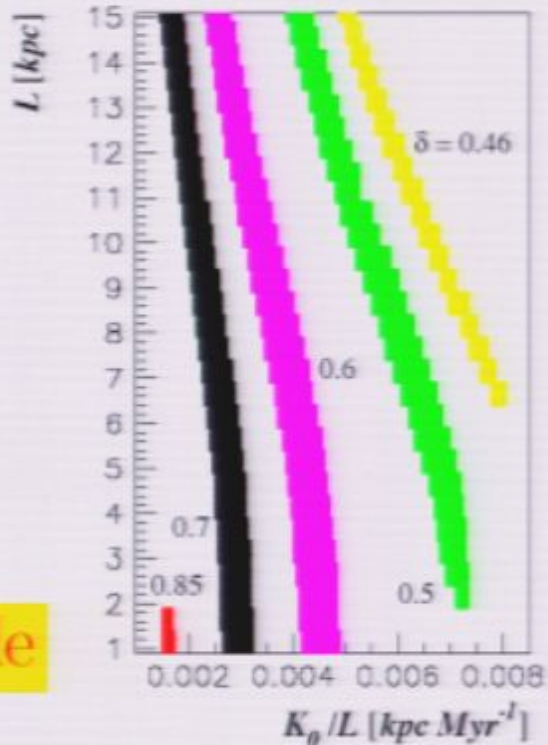

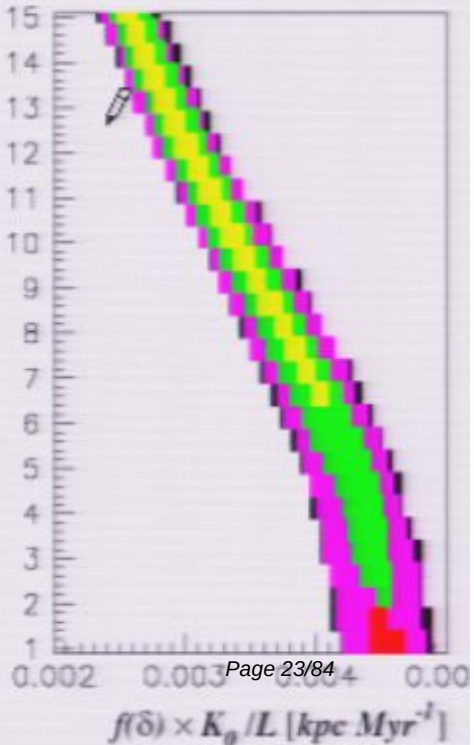

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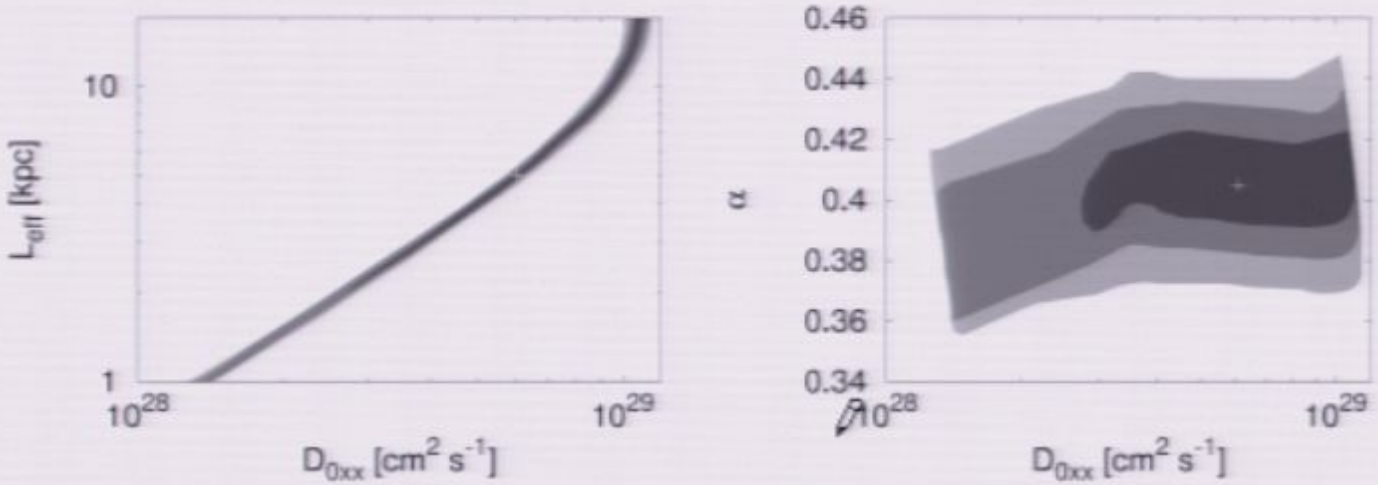
Melanie Simet[1] and Dan Hooper[1,2]

arXiv:0904.2398v1 [astro-ph.HE] 15 Apr 2009



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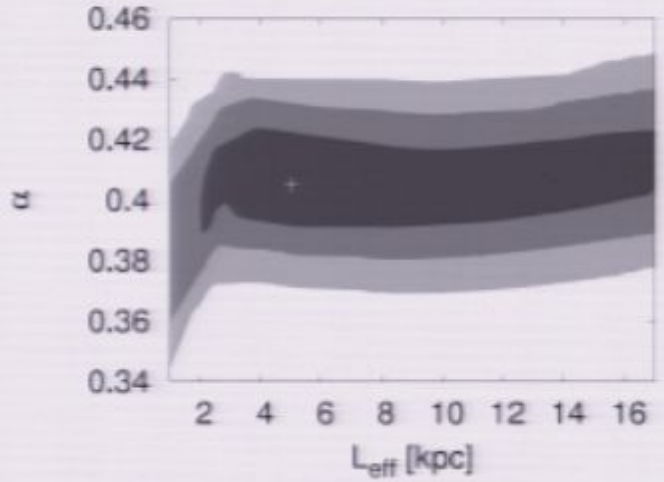

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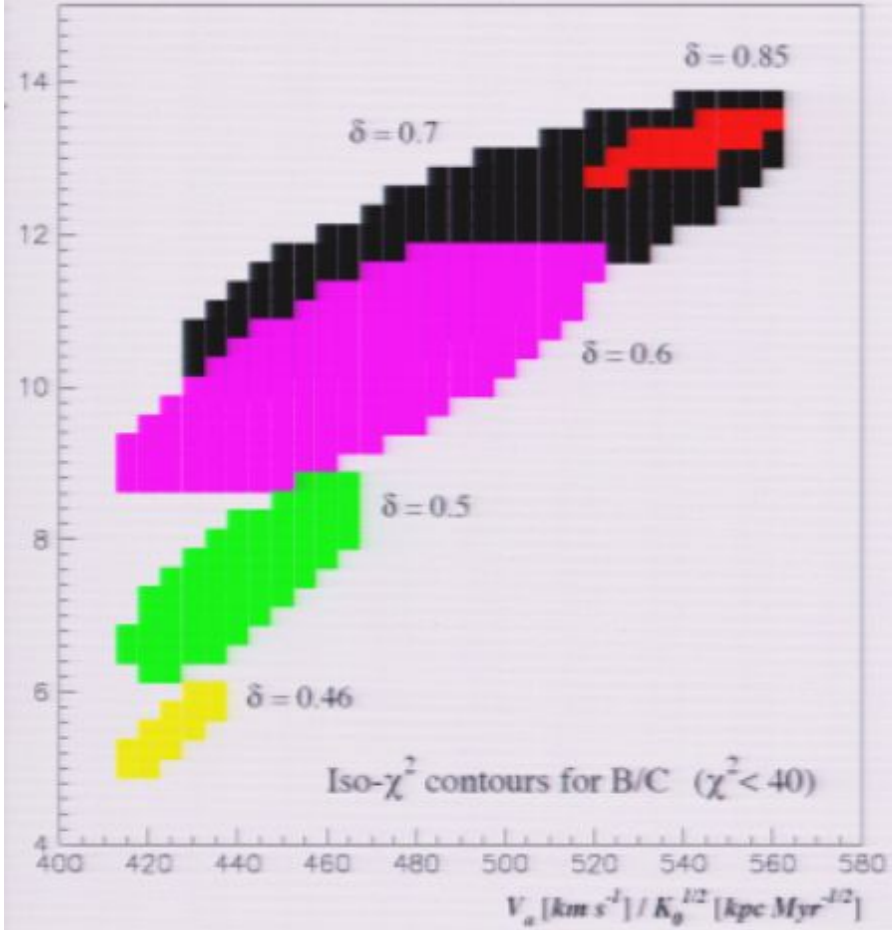

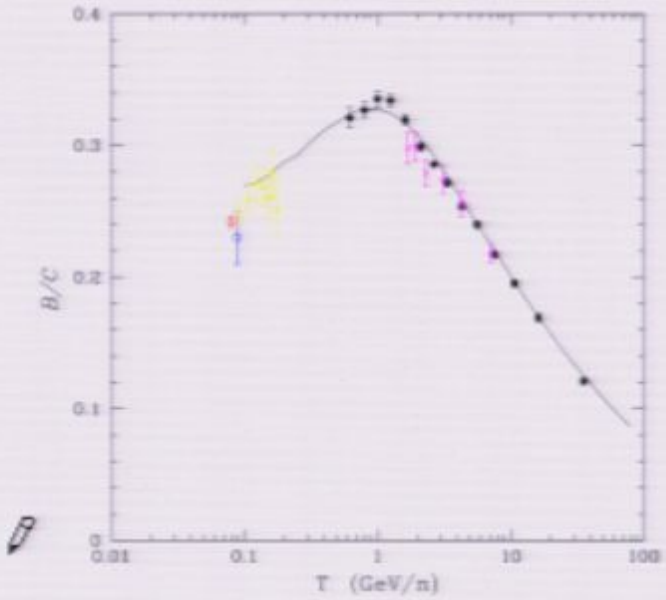

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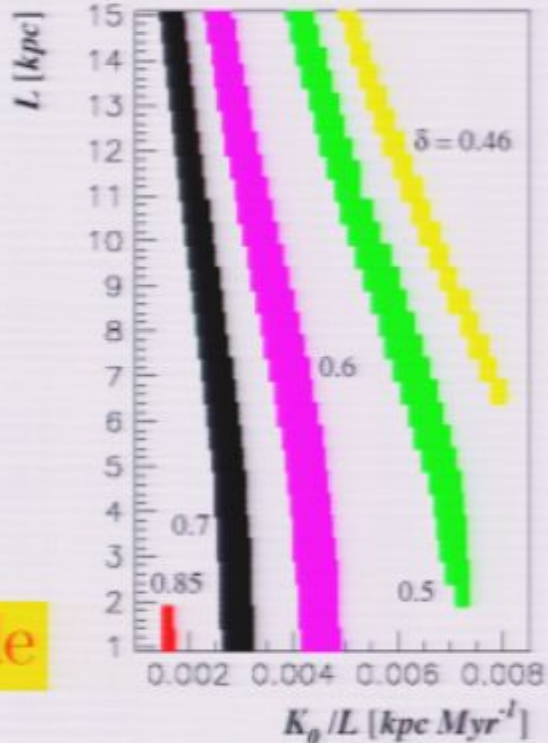

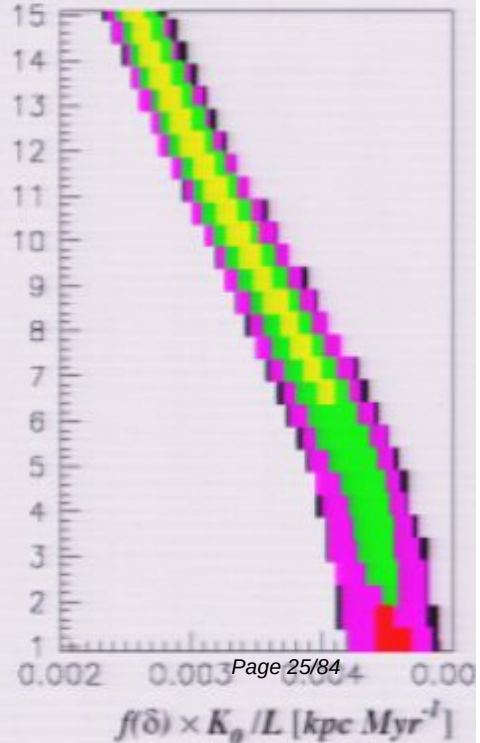

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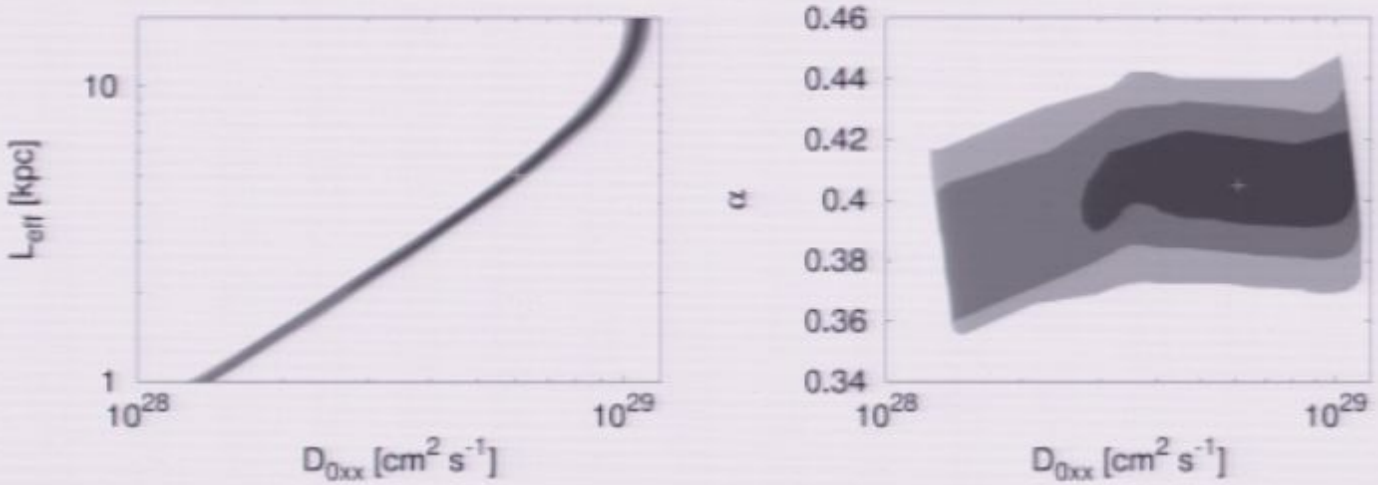

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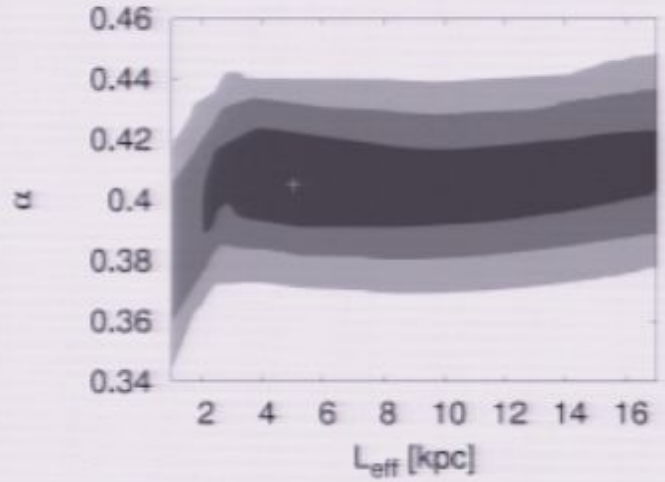

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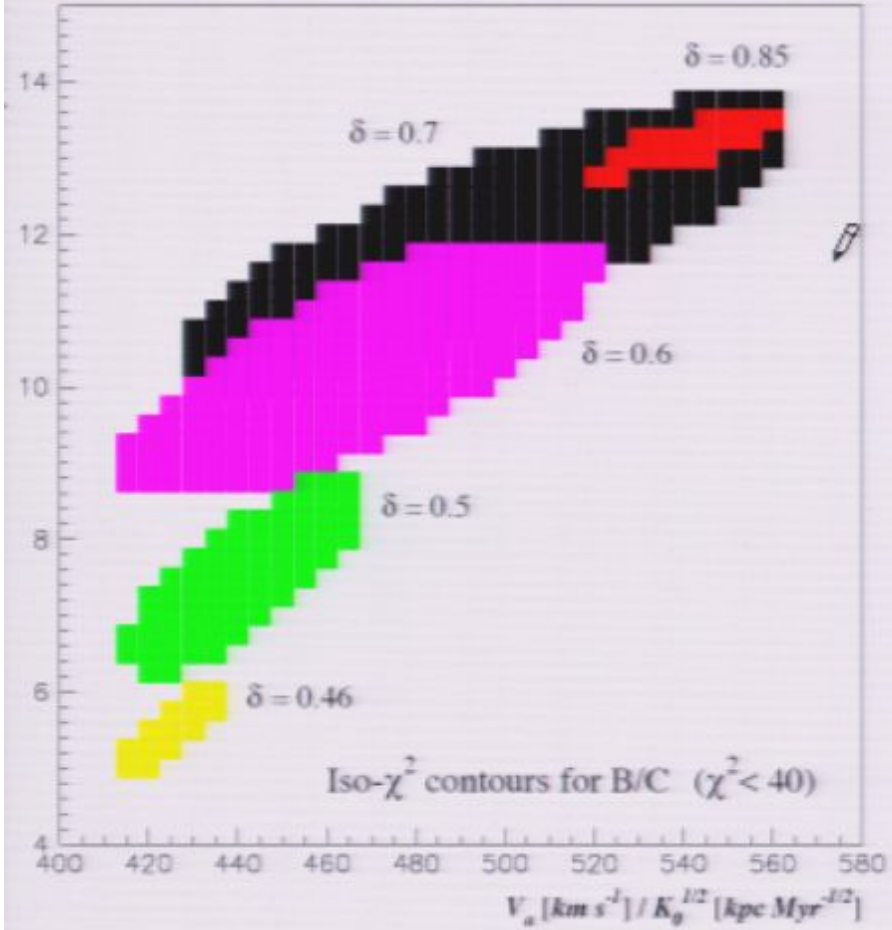

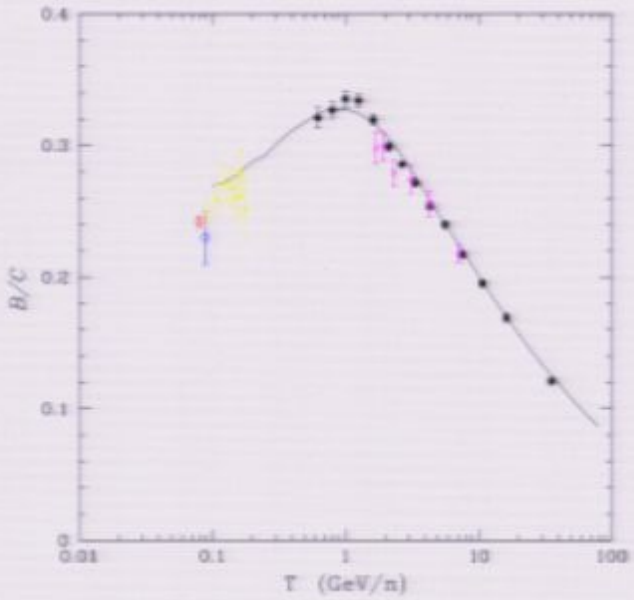

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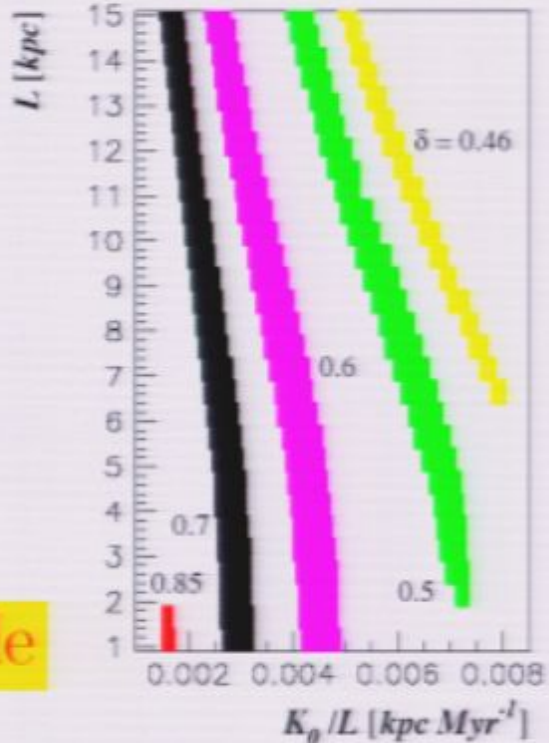

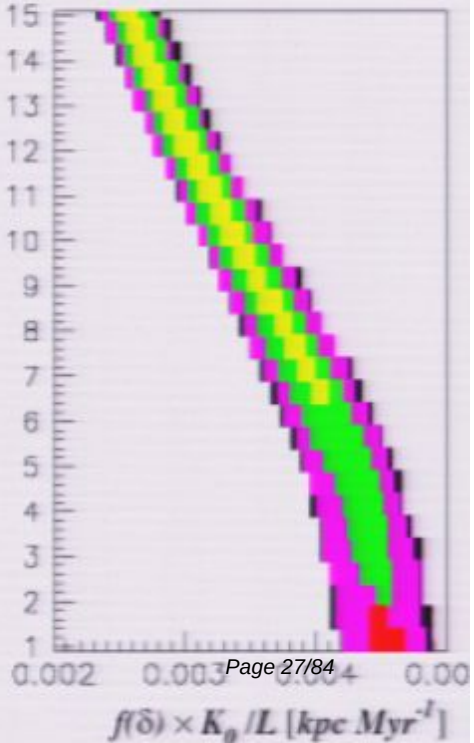

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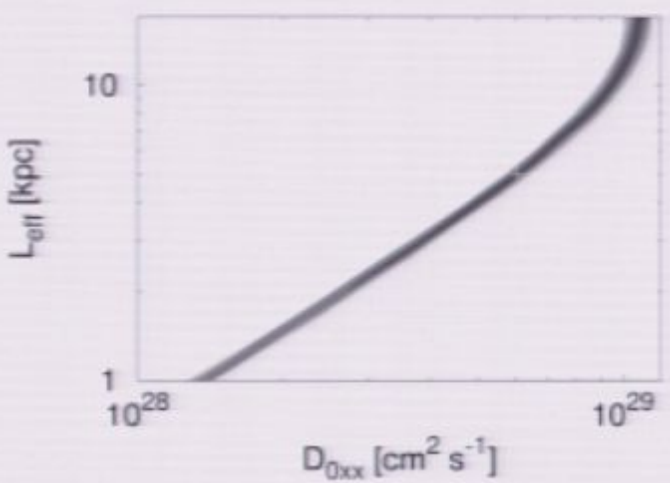

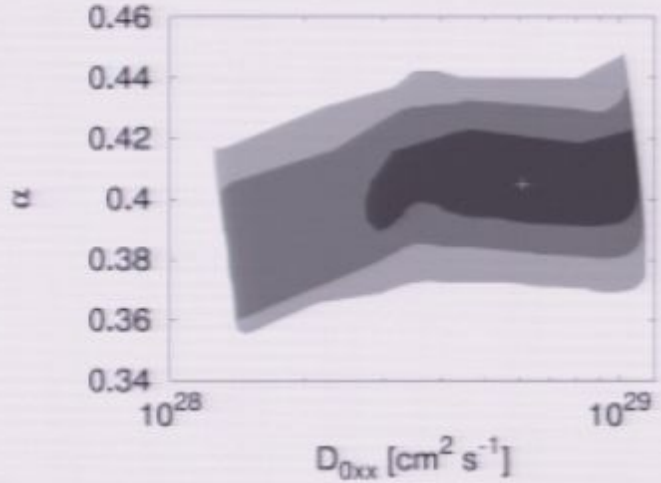

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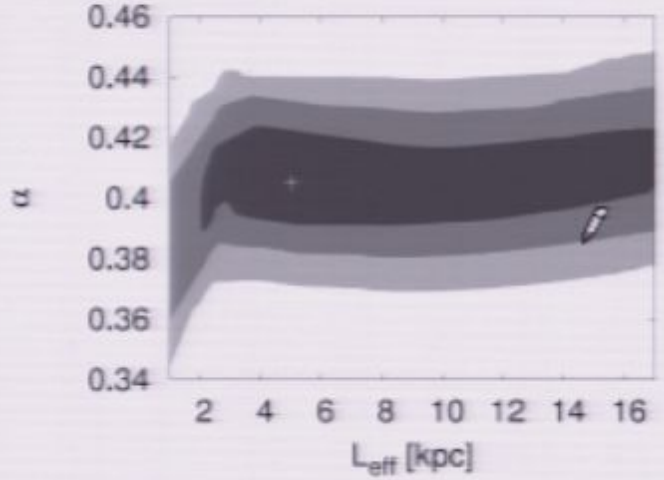

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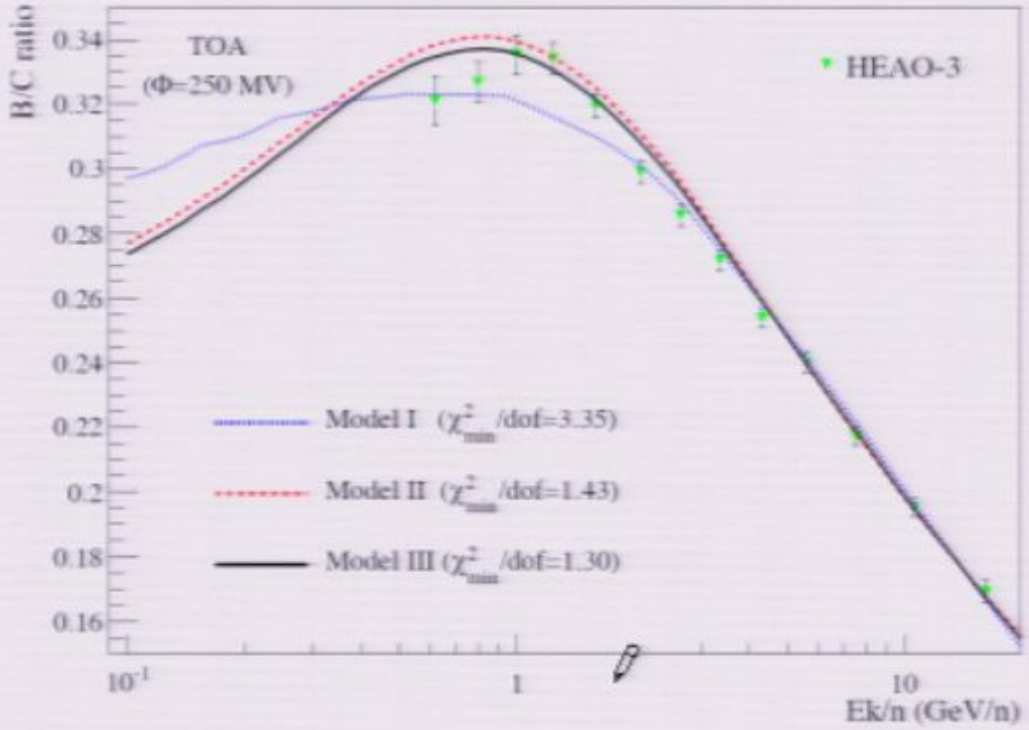
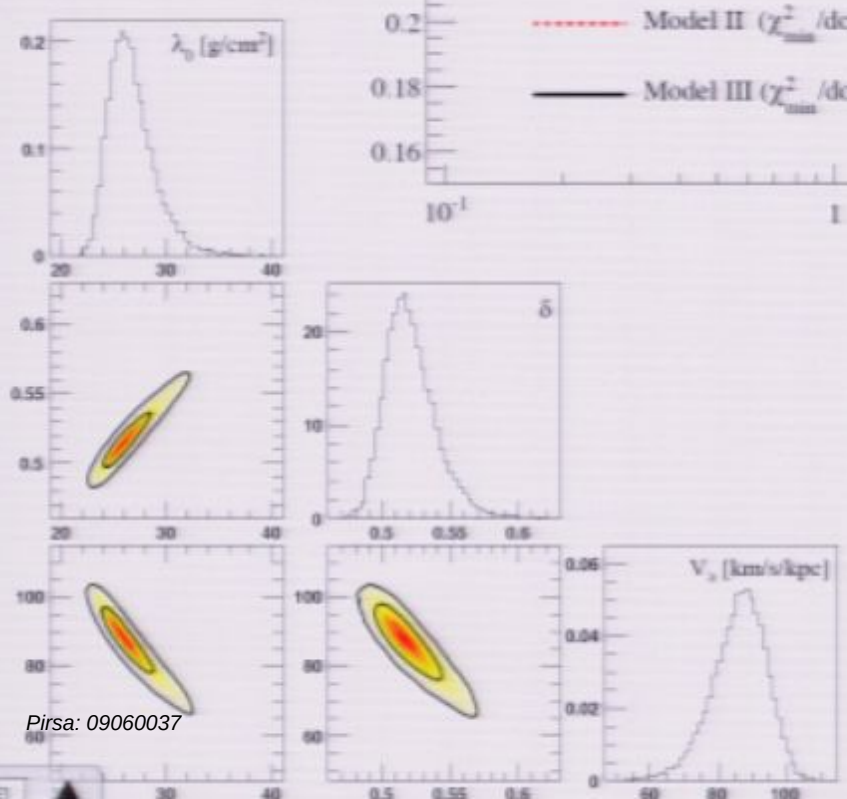
A Markov Chain Monte Carlo for Galactic Cosmic Ray physics

A. Putze[1], L. Derome[1], D. Maurin[2], L. Perotto[3], and R. Taillet[4,5]





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

Model	λ_0 g cm^{-2}	R_0 GV	δ	V_a km s^{-1}kpc^{-1}	$\chi^2_{\rm min}$/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 or the revenge of orthodoxy

Space diffusion dominates in the master equation

$$V_C\,\partial_z\Psi \;-\; K\,\Delta\Psi \;+\; \partial_E\left\{b^{\rm loss}(E)\,\Psi \;-\; K_{EE}(E)\,\partial_E\Psi\right\} \;=\; Q$$

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

$$\Downarrow$$

Long range with $G_{\bar{\rm p}}^{\rm 3D}(r) = \dfrac{Q}{4\pi K r}$

- 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

T. Bringmann & P. Salati (2006)

BESS 95+97 BESS 98 AMS 98 CAPRICE 98

$\delta = 0.46$ to 0.85

B/C measurements @ high E

A. Castellina & F. Donato, Astropart. Phys. **24** (2005) 146-159

SECONDARY SPECTRUM

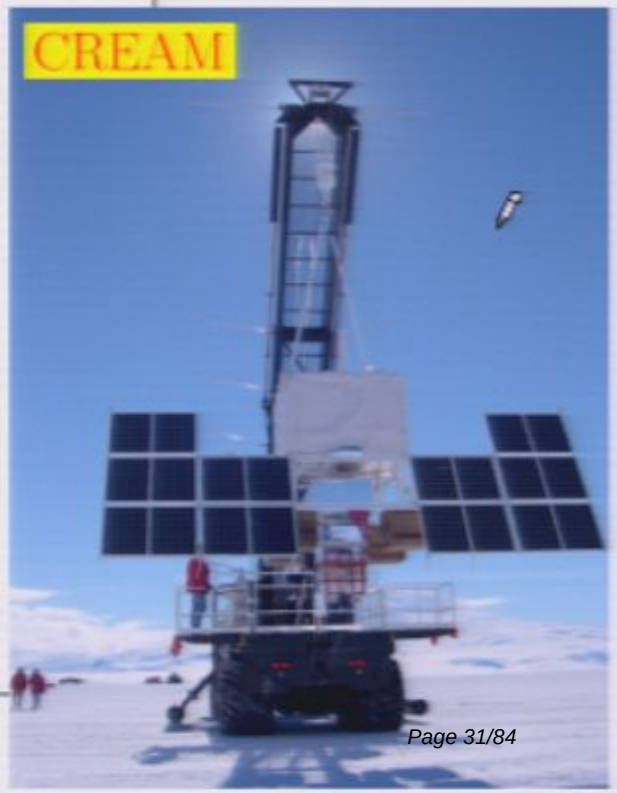
PROPAGATION UNCERTAINTY BAND

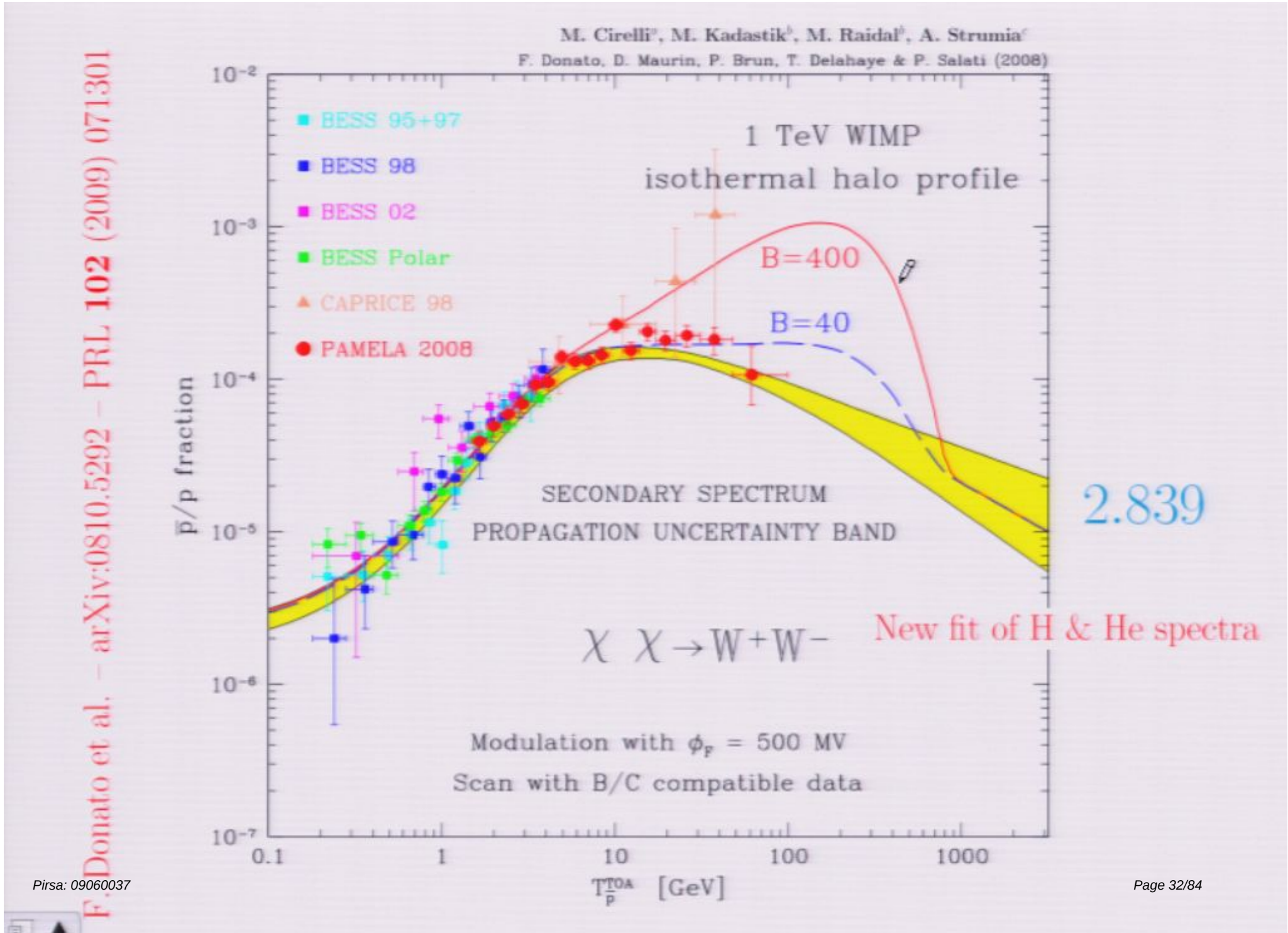
Solar Minimum with $\phi_F = 500$ MV

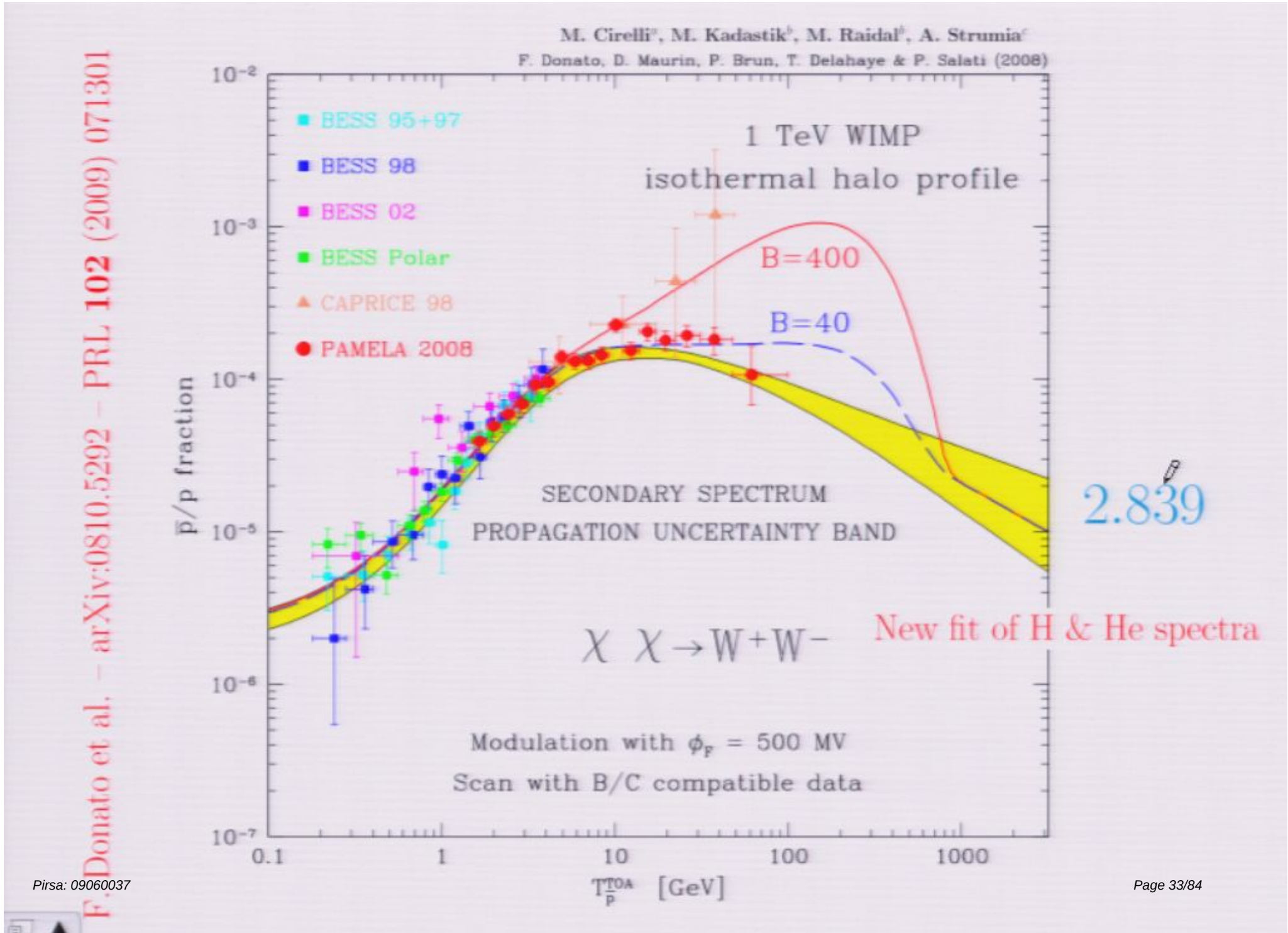
Scan with B/C compatible data **and ALL** δ

$T_{\bar{p}}^3 \, \phi_{\bar{p}}^{TOA}$ [m^{-2} s^{-1} sr^{-1} GeV^2]

$T_{\bar{p}}^{TOA}$ [GeV]




M. Cirelli, M. Kadastik, M. Raidal, A. Strumia
F. Donato, D. Maurin, P. Brun, T. Delahaye & P. Salati (2008)
F.Donato et al. – arXiv:0810.5292 – PRL 102 (2009) 071301
BESS 95+97
BESS 98
BESS 02
BESS Polar
CAPRICE 98
PAMELA 2008
1 TeV WIMP
isothermal halo profile
B=400
B=40
SECONDARY SPECTRUM
PROPAGATION UNCERTAINTY BAND
2.839
New fit of H & He spectra
χ χ → W+W−
Modulation with φF = 500 MV
Scan with B/C compatible data
p̄/p fraction
T_p̄^TOA [GeV]
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
0.1
1
10
100
1000


M. Cirelli, M. Kadastik, M. Raidal, A. Strumia
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T_p̄^TOA [GeV]
10^-2
10^-3
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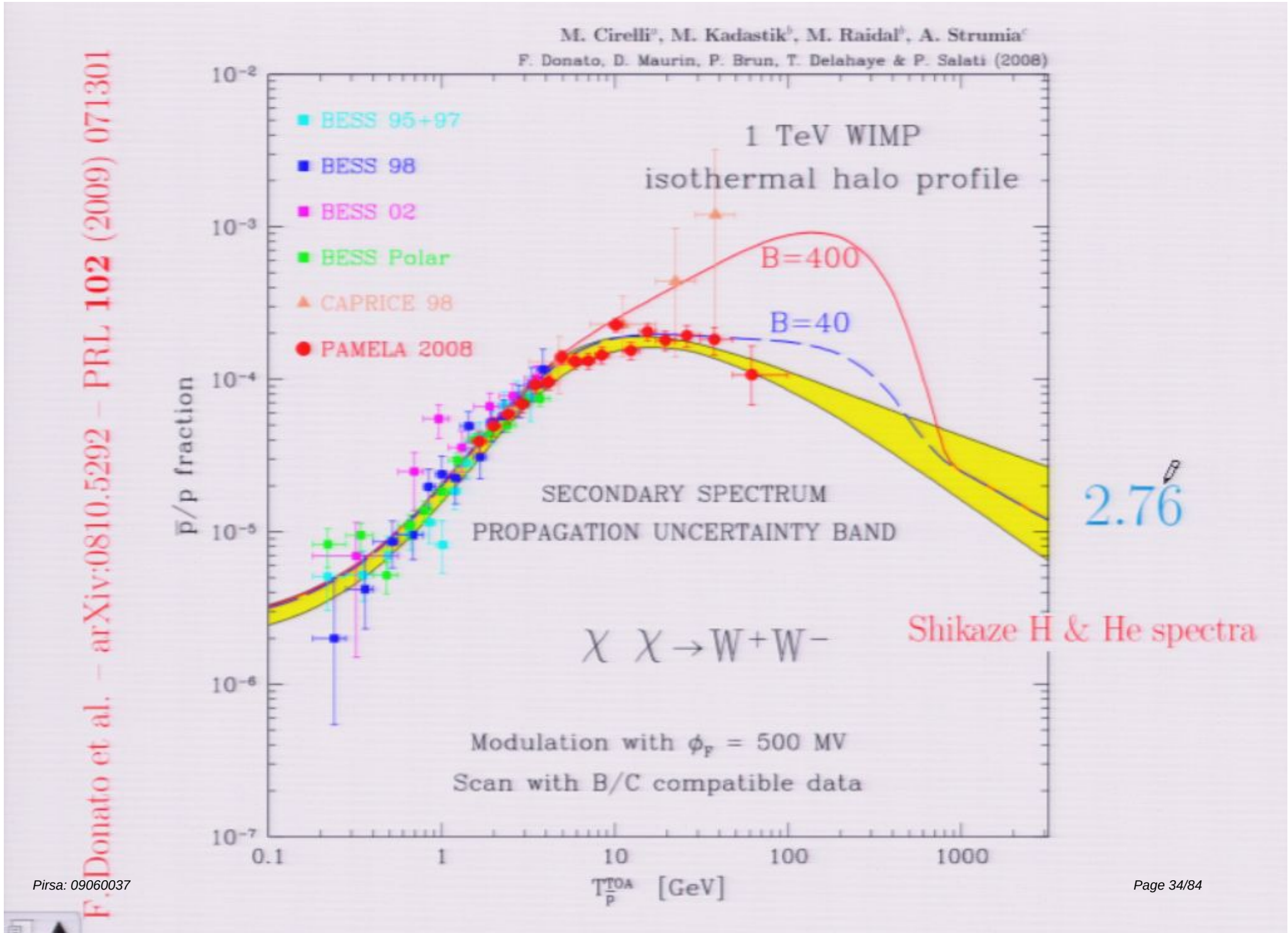
10^-5
10^-6
10^-7
0.1
1
10
100
1000


M. Cirelli[a], M. Kadastik[b], M. Raidal[b], A. Strumia[c]
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BESS 95+97
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isothermal halo profile
B=400
B=40
SECONDARY SPECTRUM
PROPAGATION UNCERTAINTY BAND
2.76
Shikaze H & He spectra
χ χ→W+W−
Modulation with φF = 500 MV
Scan with B/C compatible data
p̄/p fraction
10−2
10−3
10−4
10−5
10−6
10−7
0.1
1
10
100
1000
T p̄TOA [GeV]

3) Secondary positron uncertainties

Mostly sensitive to the local region

Energy losses dominate

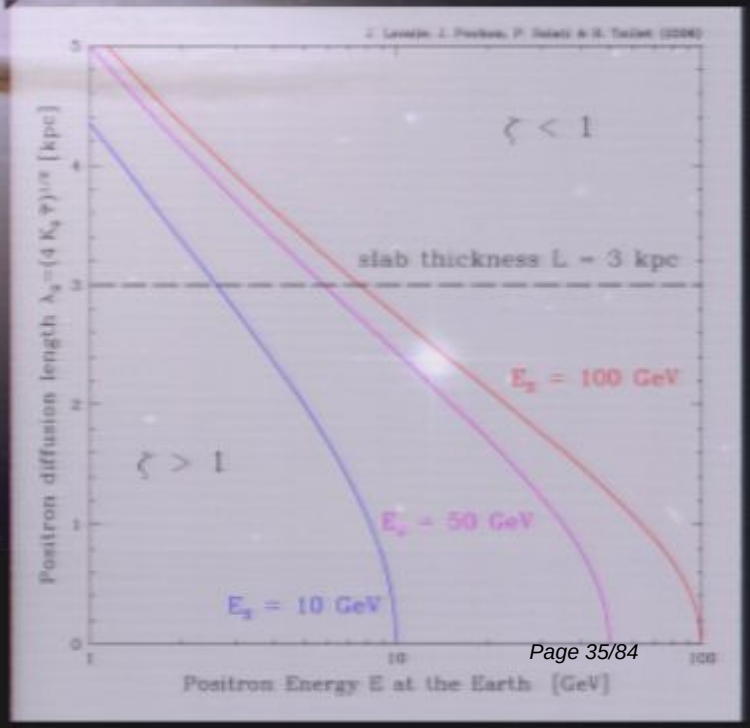
IC on stellar light and CMB – synchrotron

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

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

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

$$V_S = \left(\sqrt{2\pi}\,\lambda_{\rm D}\right)^3$$



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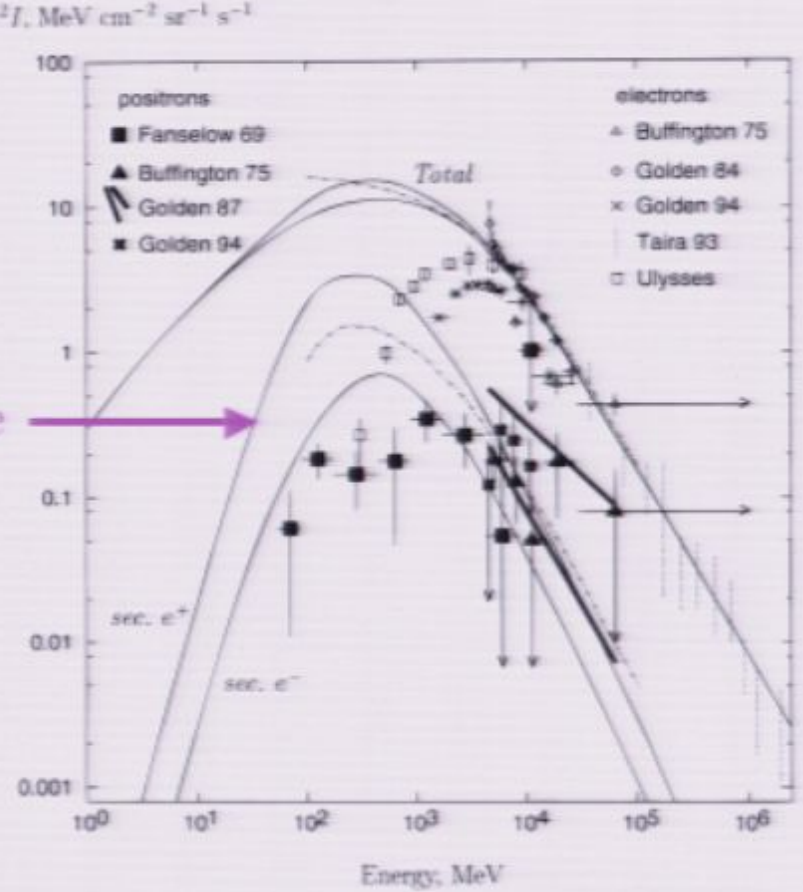
I. V. Moskalenko and A. W. Strong, *Production and propagation of cosmic ray positrons and electrons*, *Astrophys. J.* **493** (1998) 694 [astro-ph/9710124].

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

e^+ spectral reference

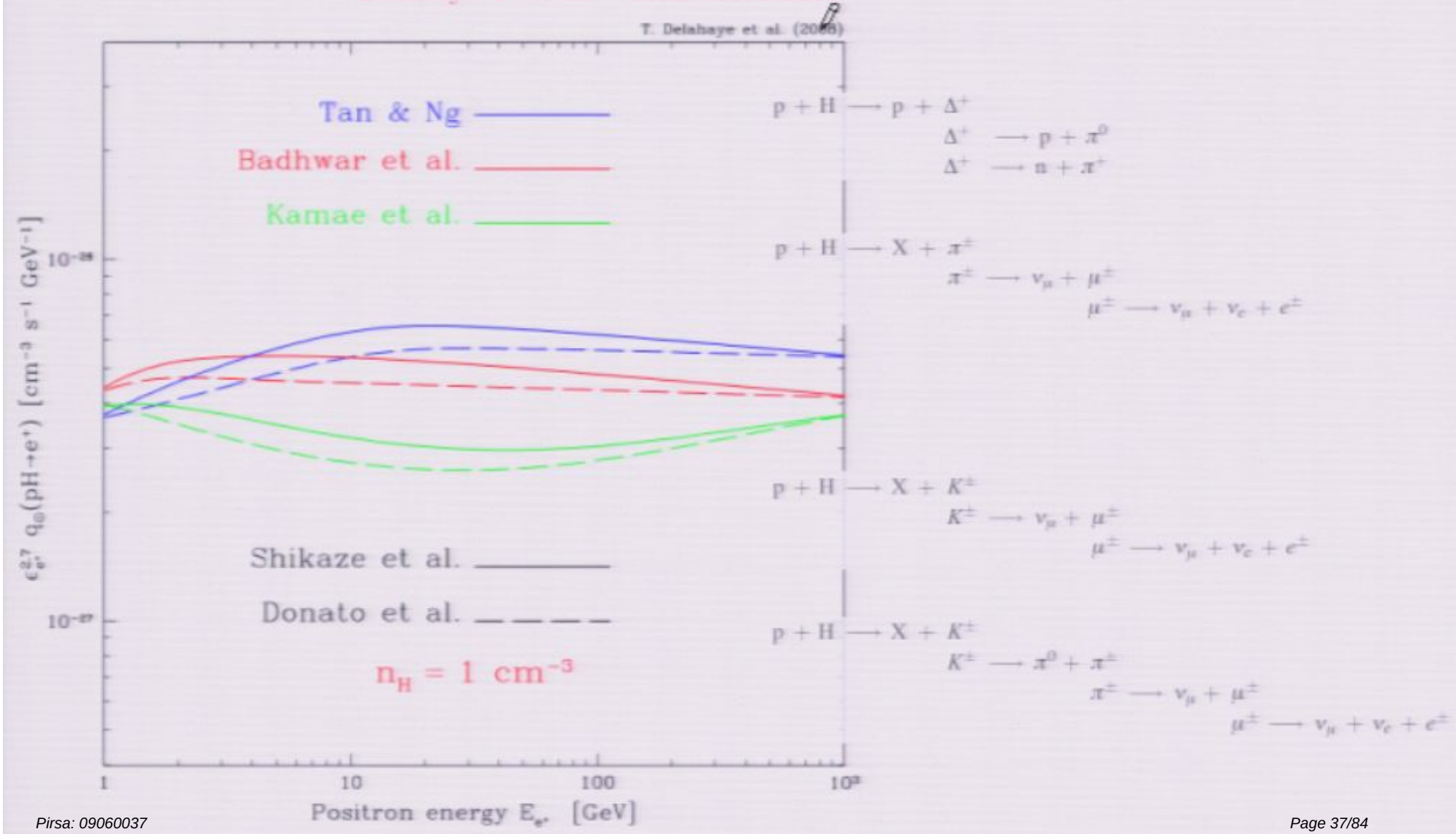


PARAMETERS OF MODELS

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^*	Protons I_0^*	Helium γ	Helium p_0^*	Helium I_0^*
08-005	3	2.0×10^{28}	3.0×10^3	0.60	0	2.15	10^4	3×10^{-4}	2.35	4×10^4	4×10^{-5}
08-006	3	4.2×10^{28}	3.0×10^3	0.33	20	2.25	10^4	3×10^{-4}	2.45	4×10^4	4×10^{-5}
08-009	3	2.0×10^{28}	3.0×10^3	0.60	0	2.00	10^4	3×10^{-4}	2.00	4×10^4	4×10^{-5}

Positron source term

Delahaye T. et al. – arXiv:0809.5268



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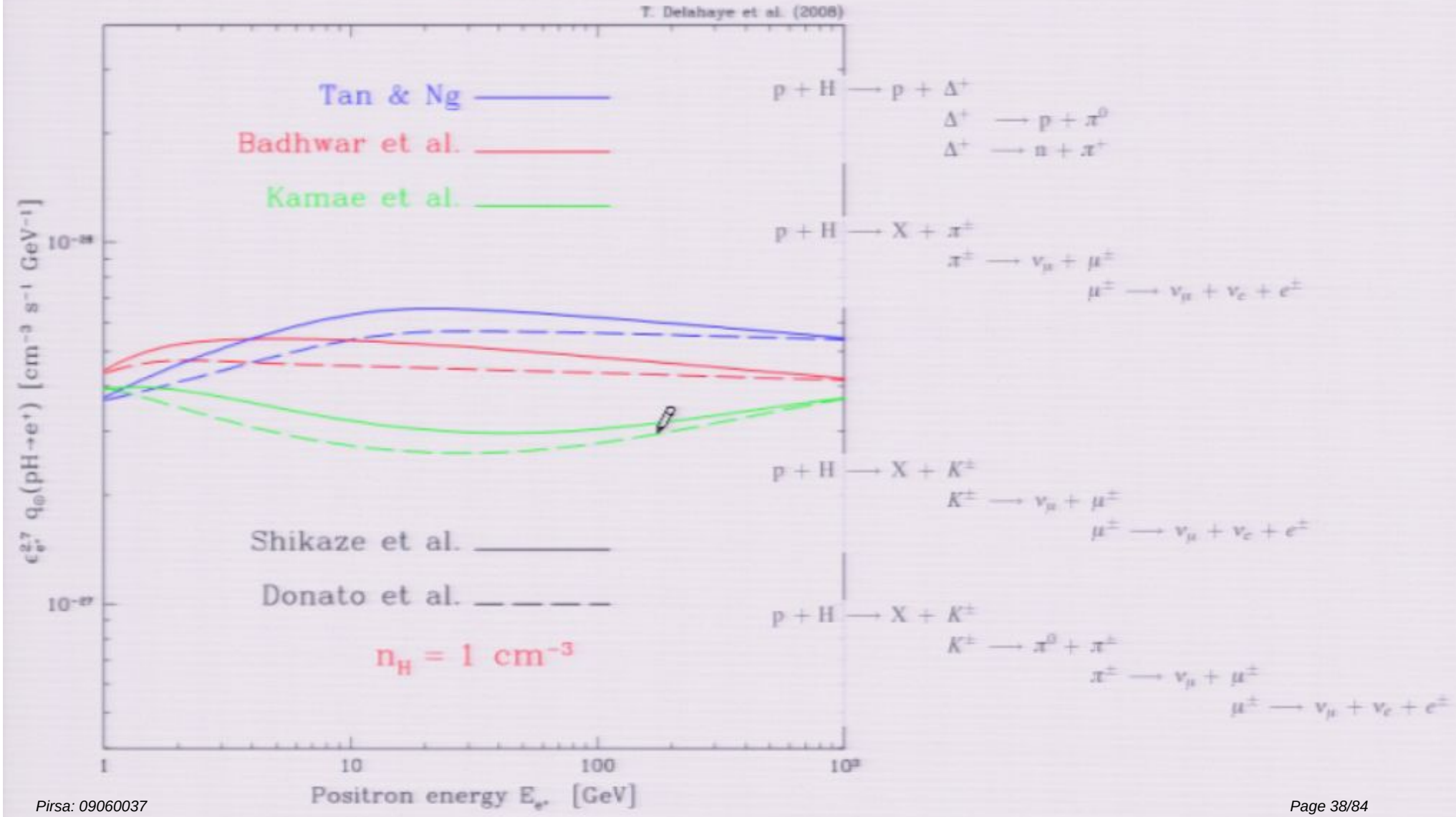
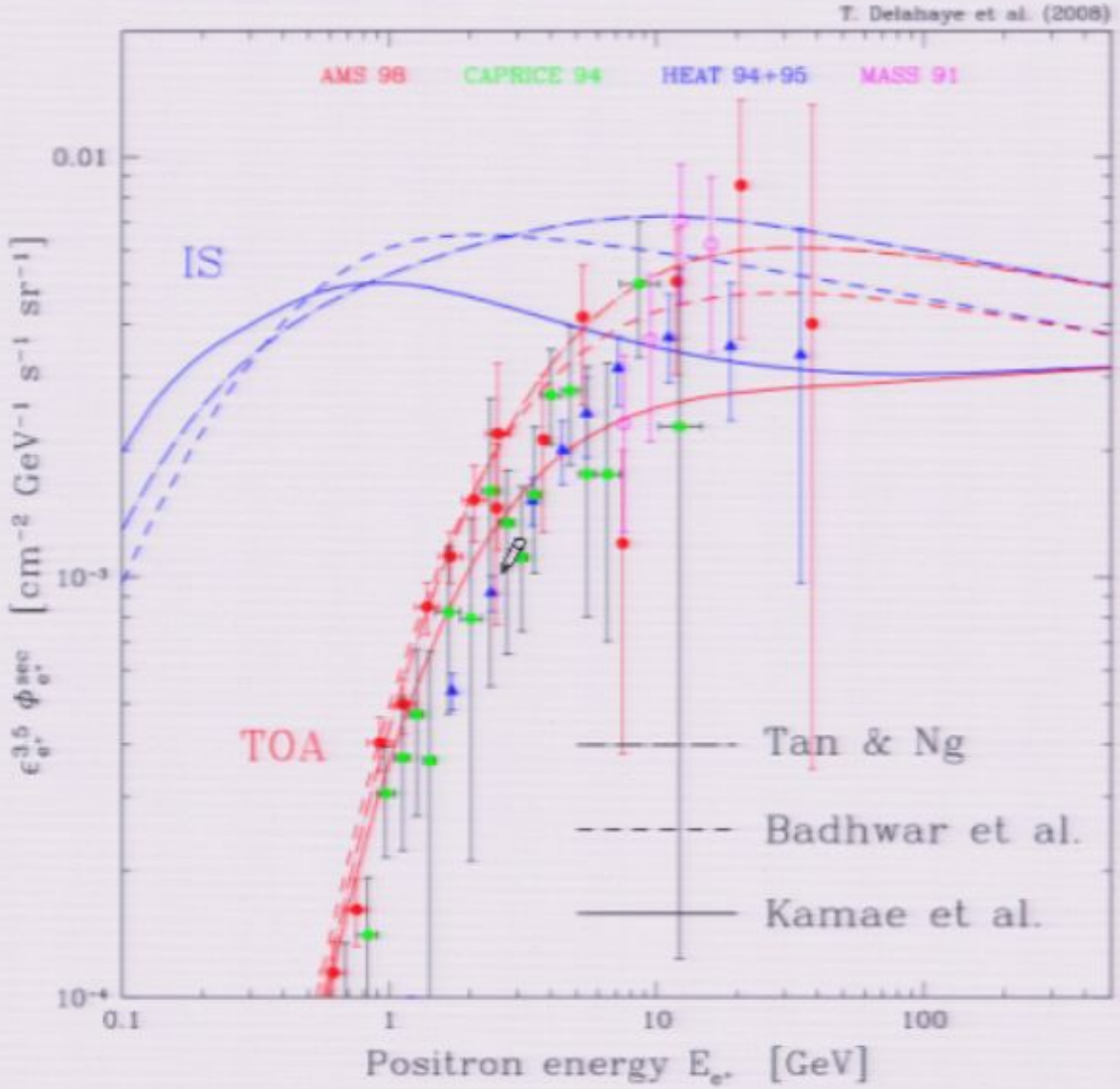


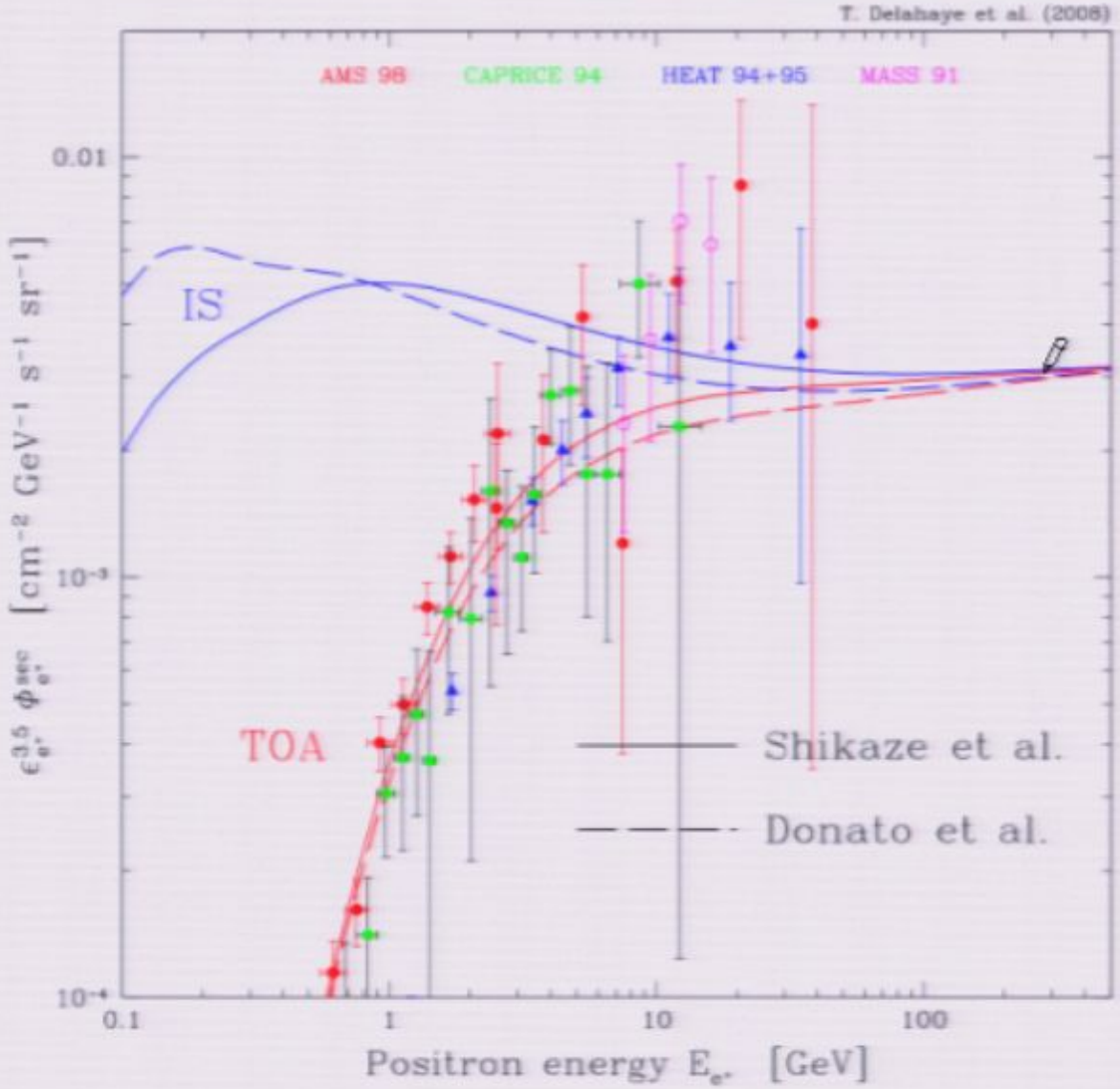
Cross sections

Delahaye T. et al. – arXiv:0809.5268



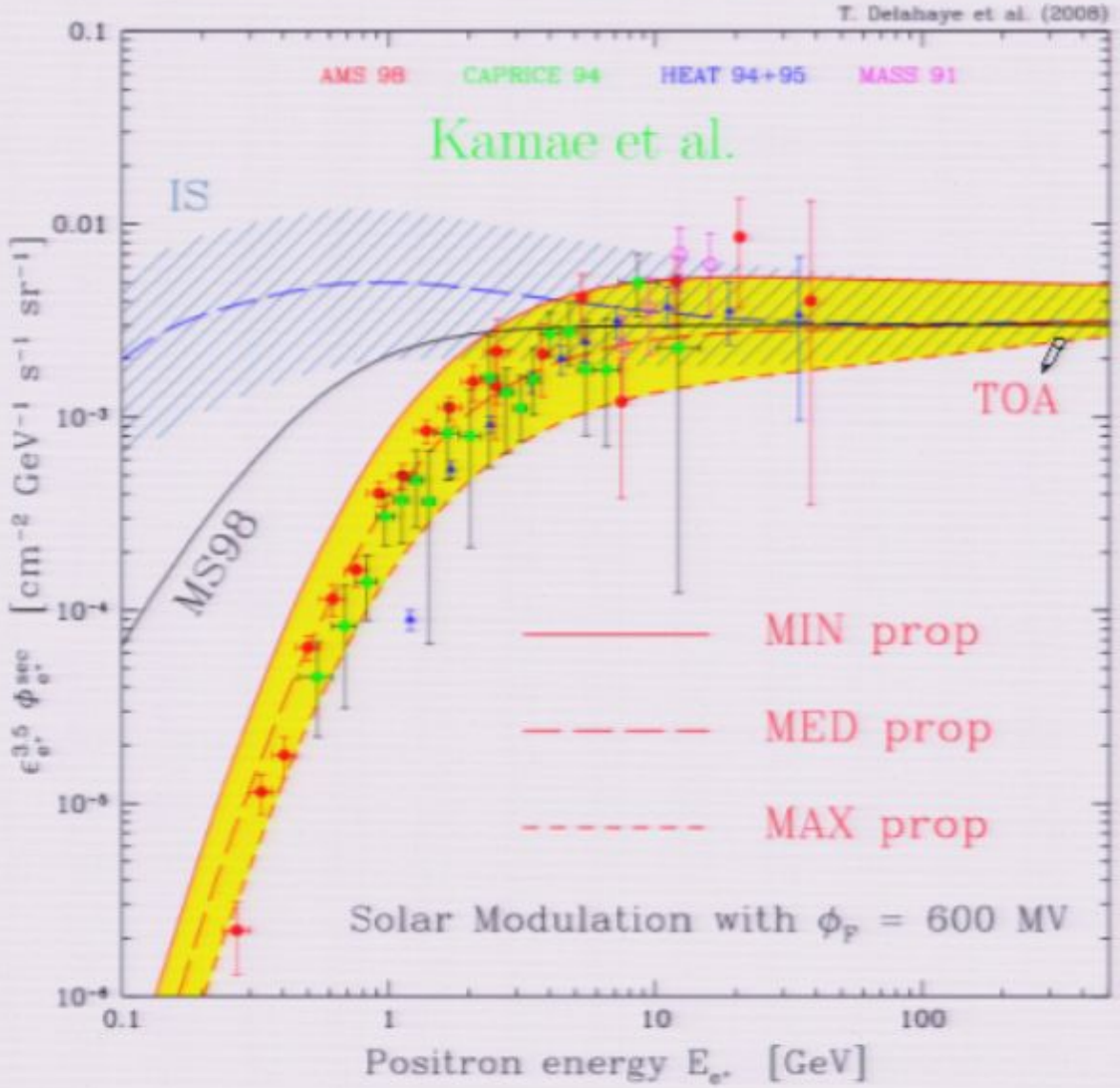
Proton & Helium fluxes

Delahaye T. et al. – arXiv:0809.5268



Galactic CR propagation

Delahaye T. et al. – arXiv:0809.5268



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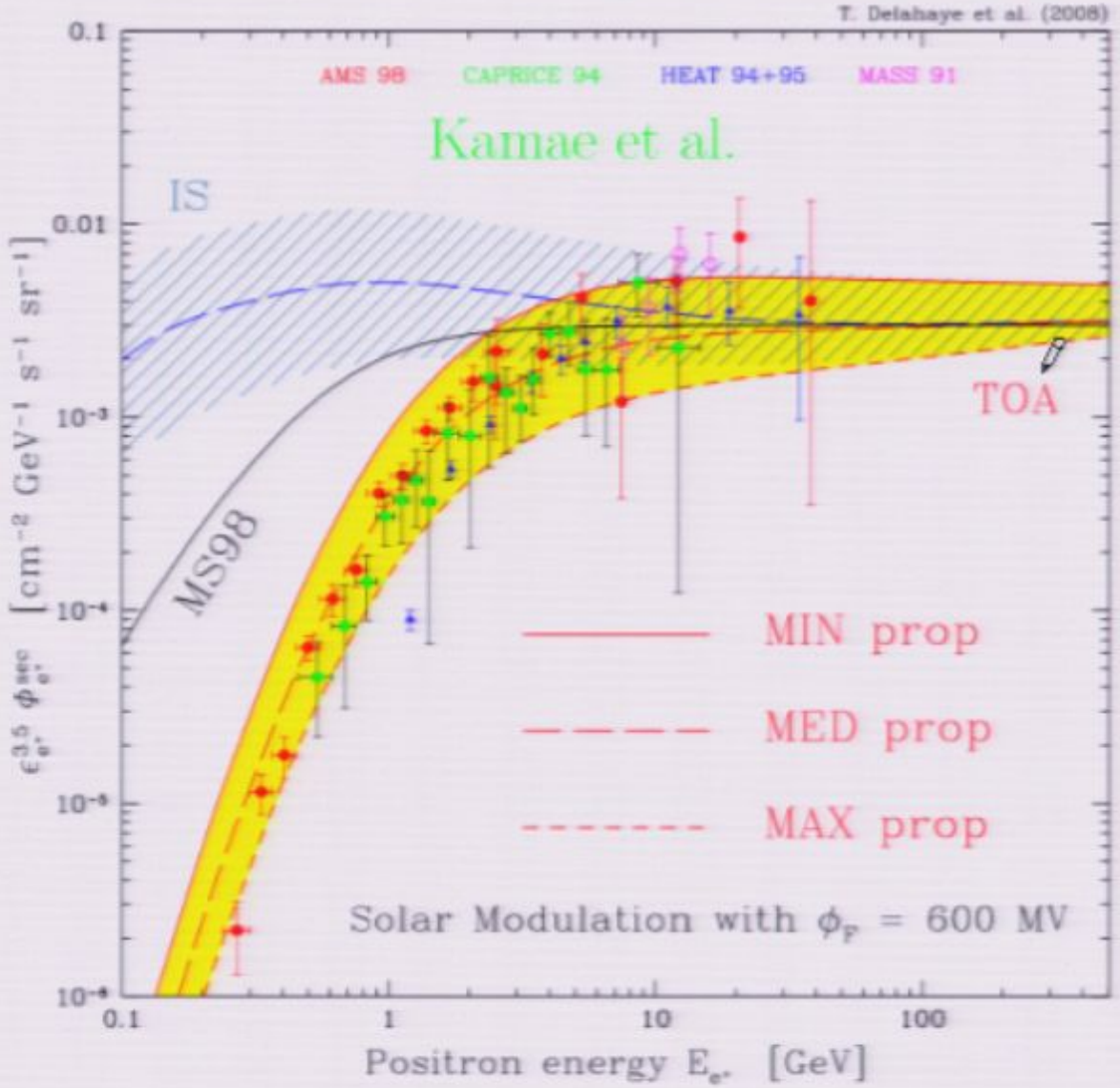

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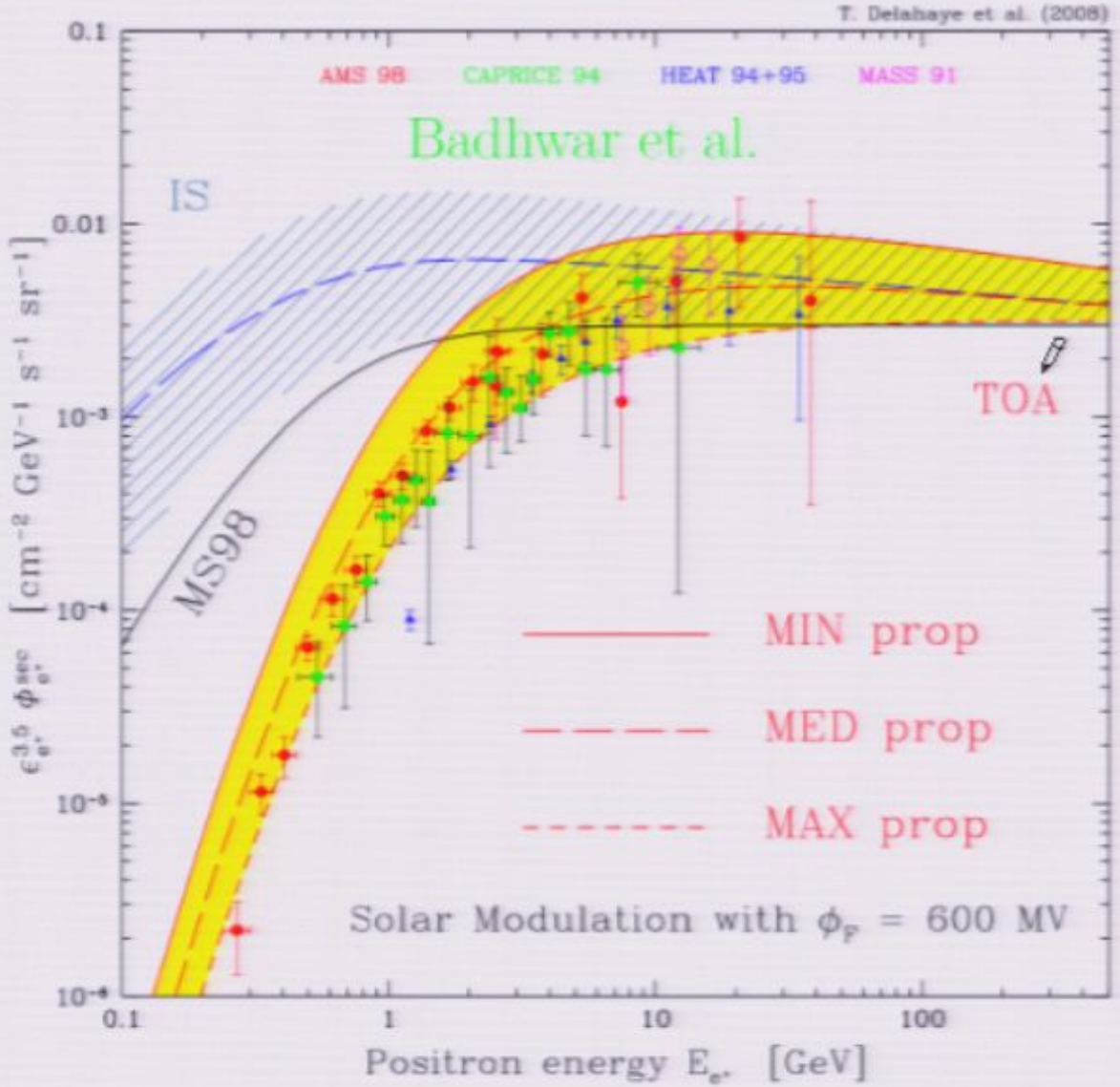

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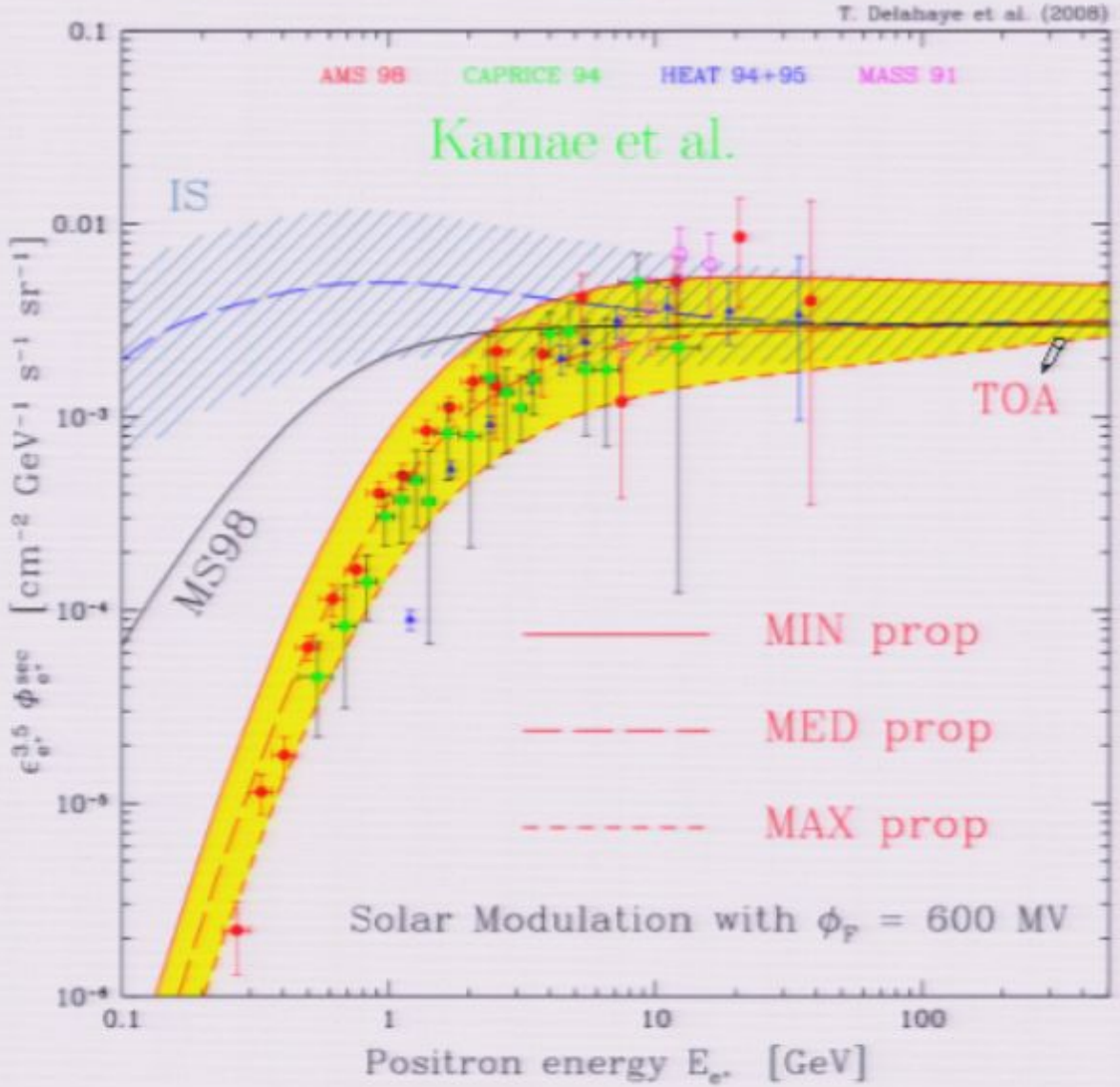

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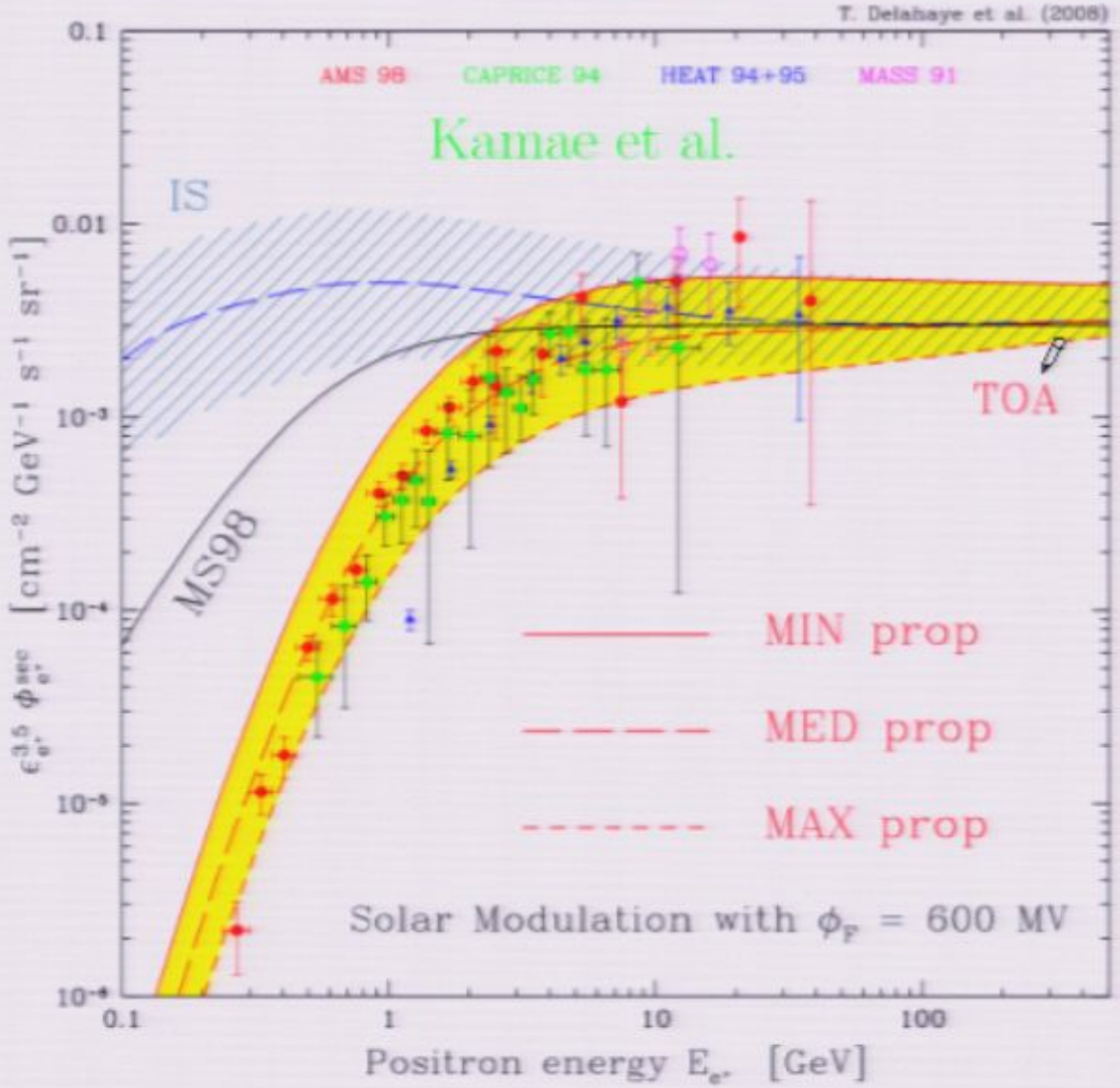

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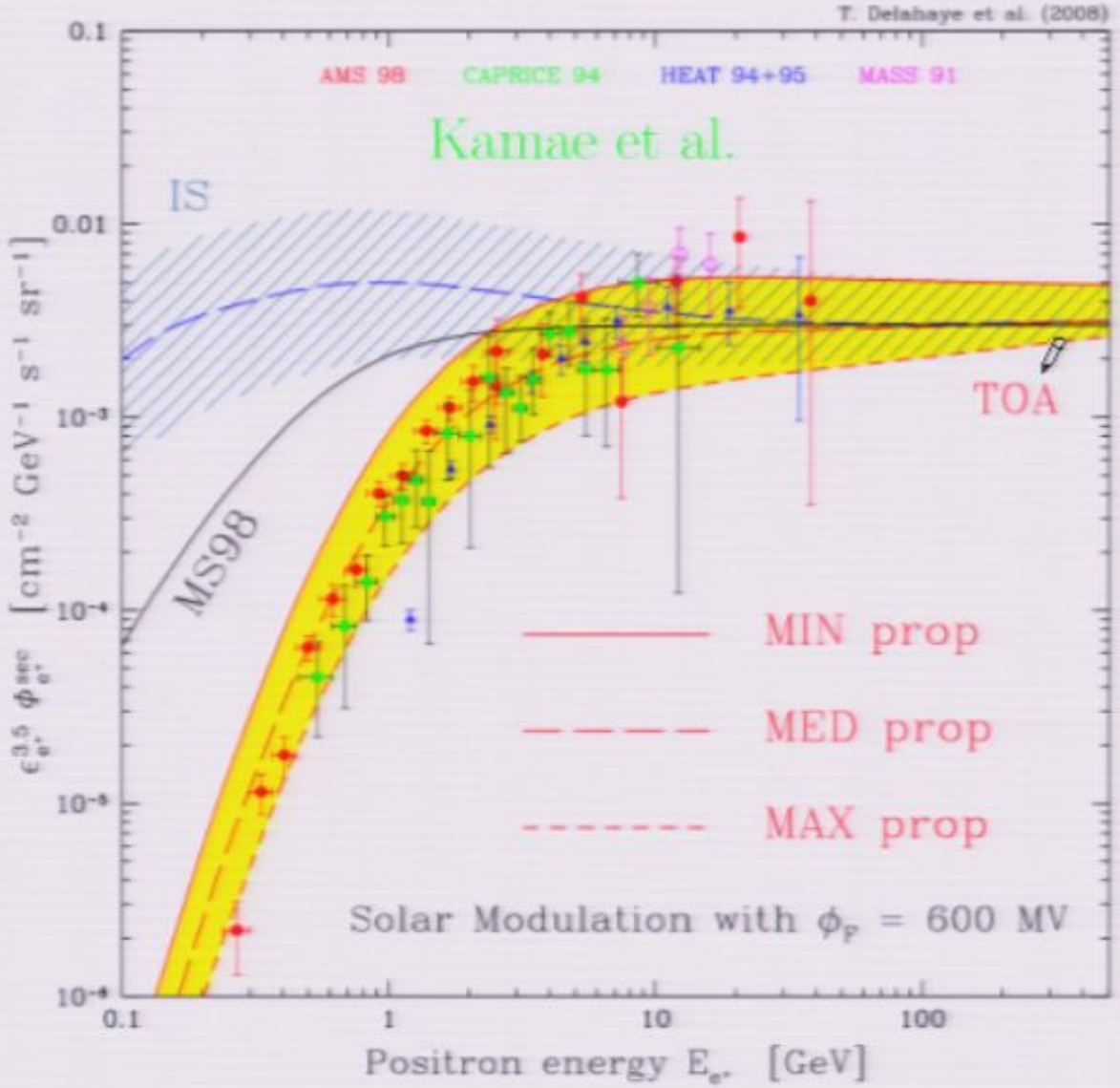

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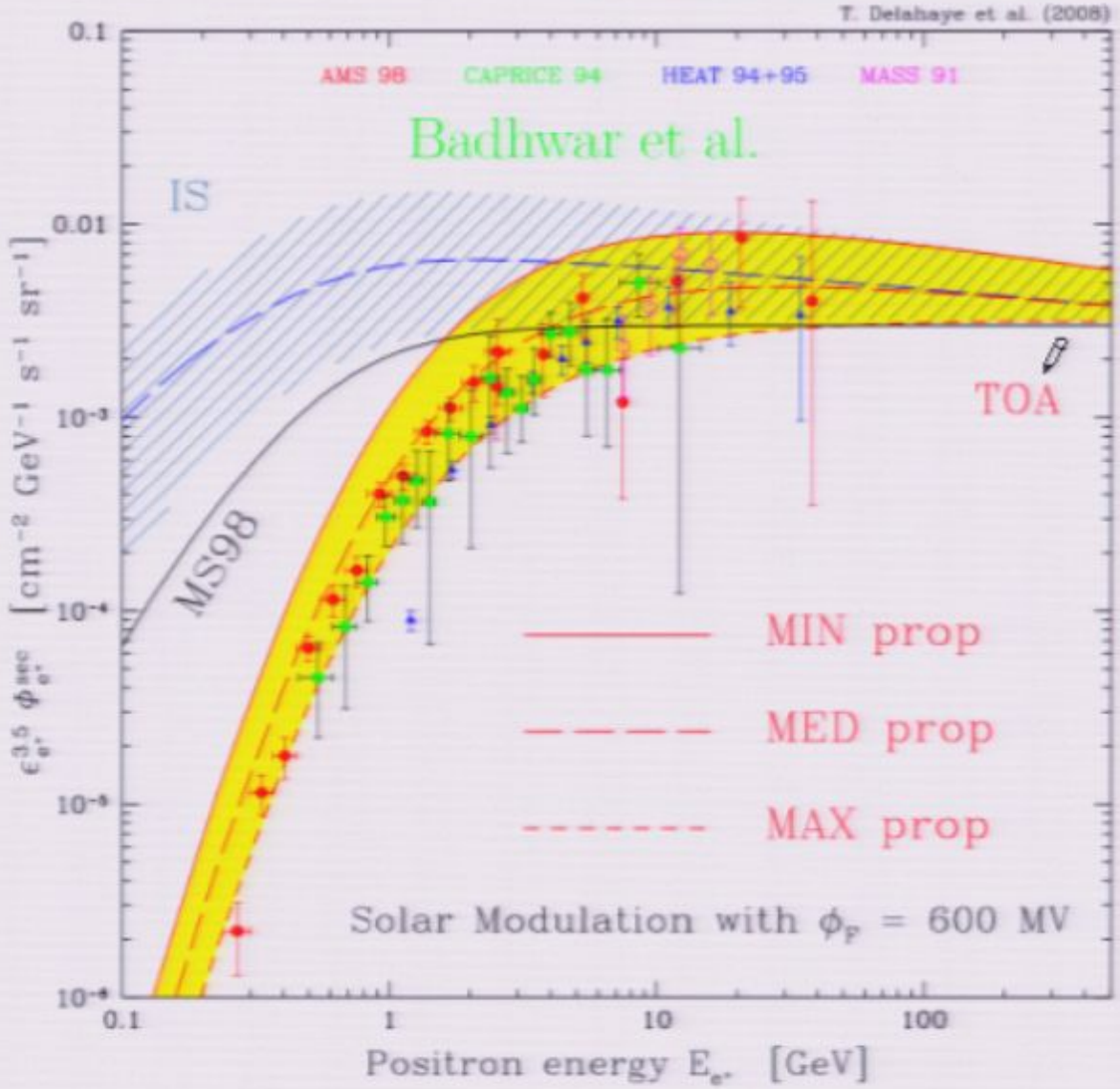

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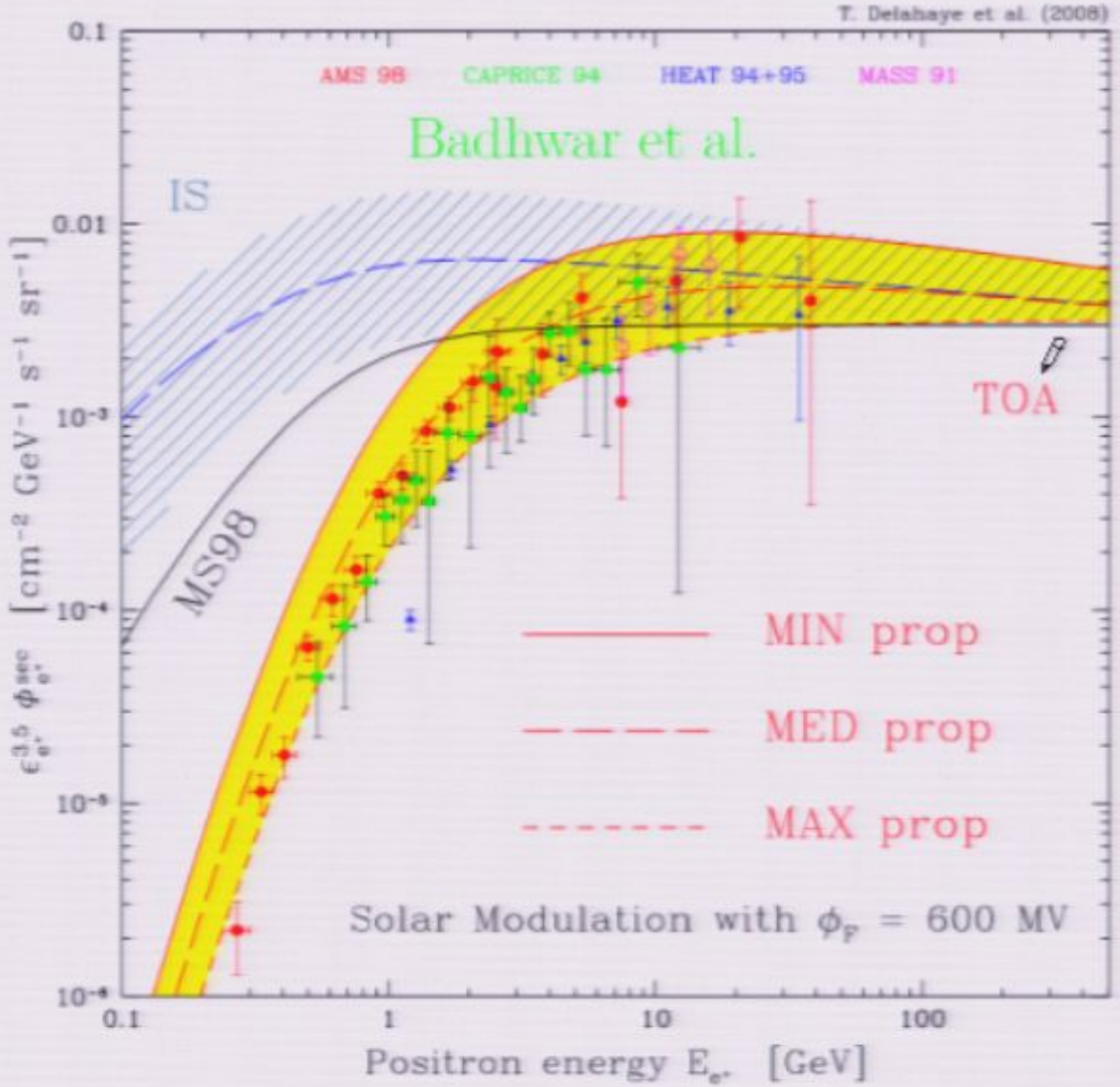

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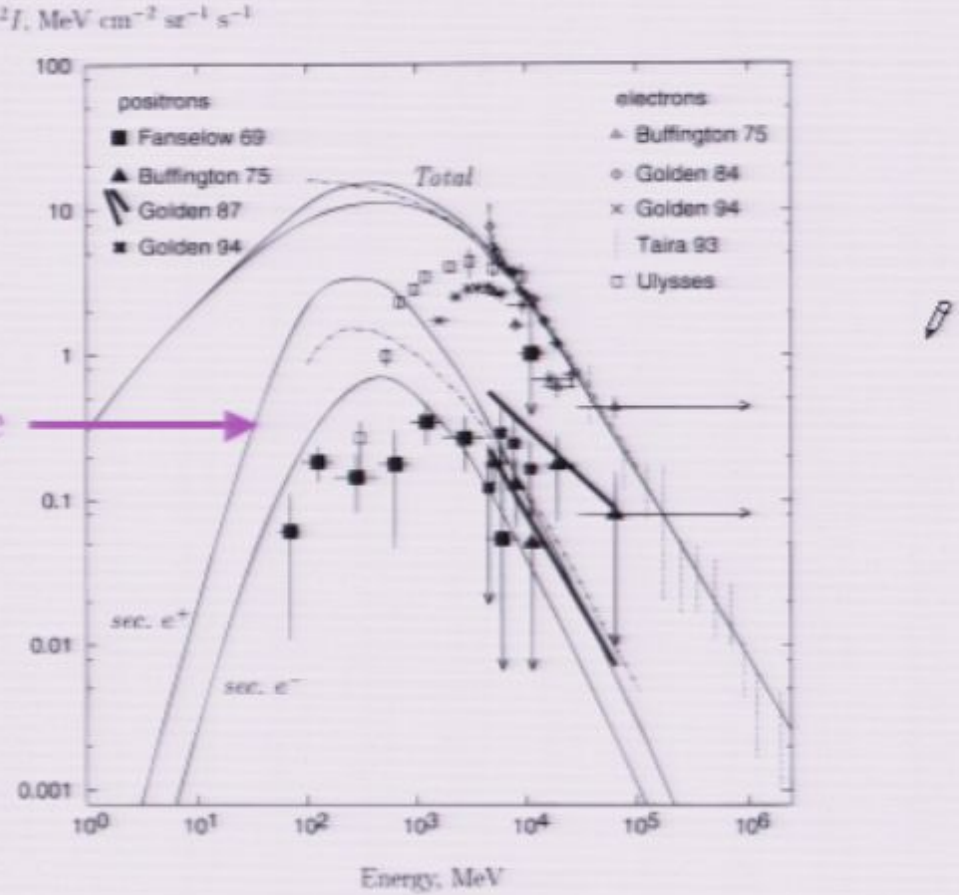
no diffusive reacceleration

e^+ spectral reference



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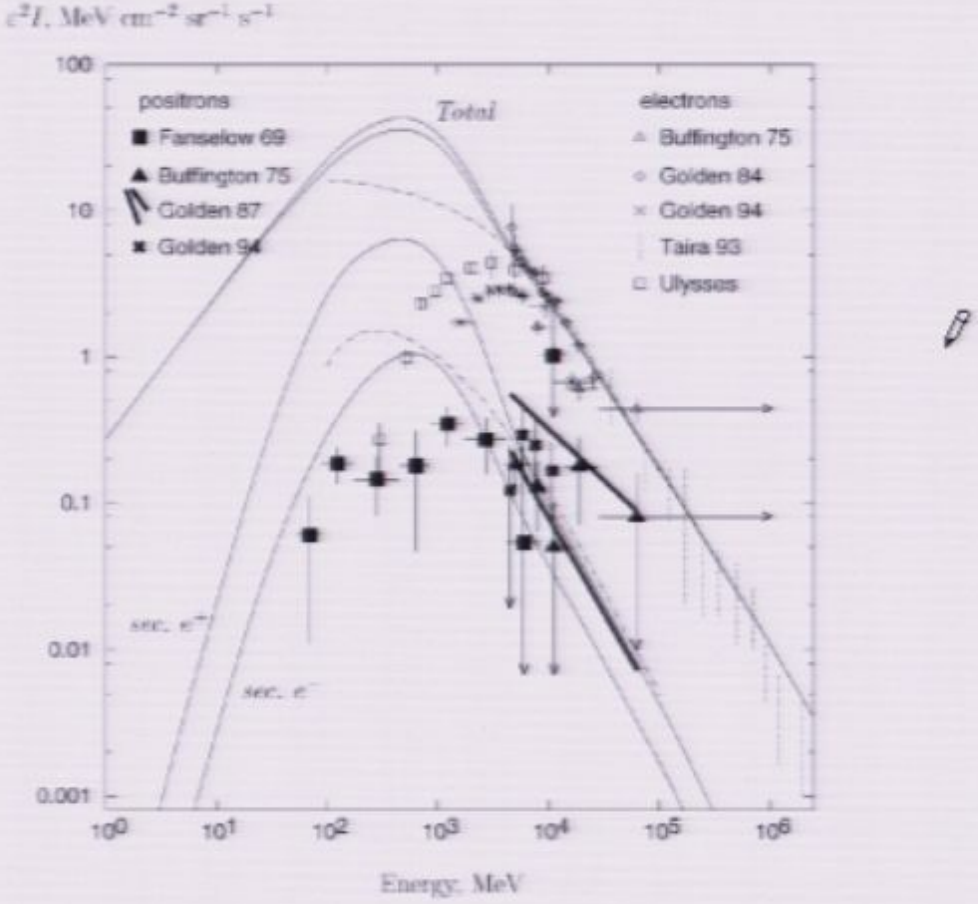
diffusive reacceleration



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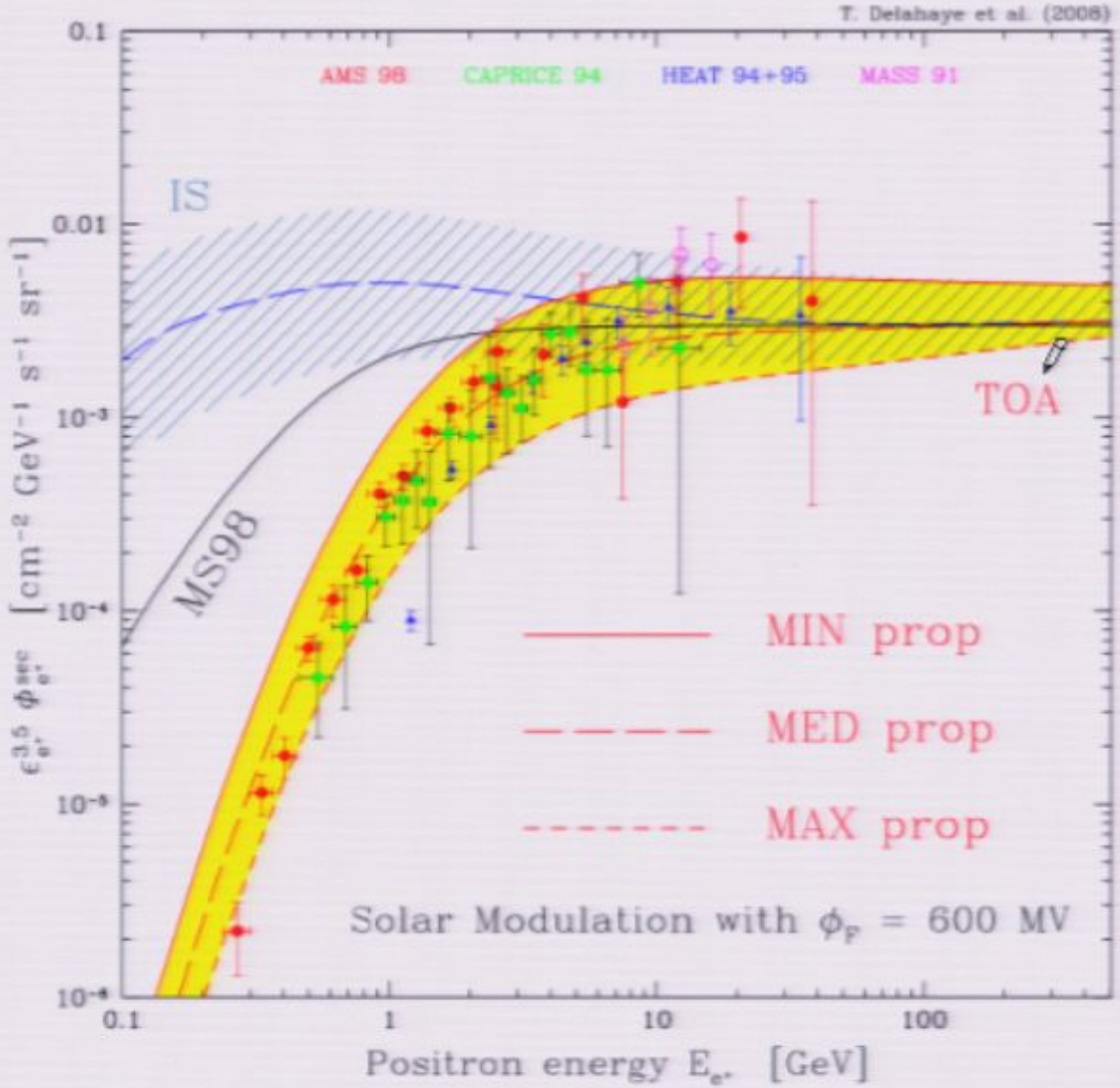
Absolute e^+ flux

no diffusive reacceleration

Delahaye T. et al. – arXiv:0809.5268



Absolute e^+ flux

diffusive reacceleration

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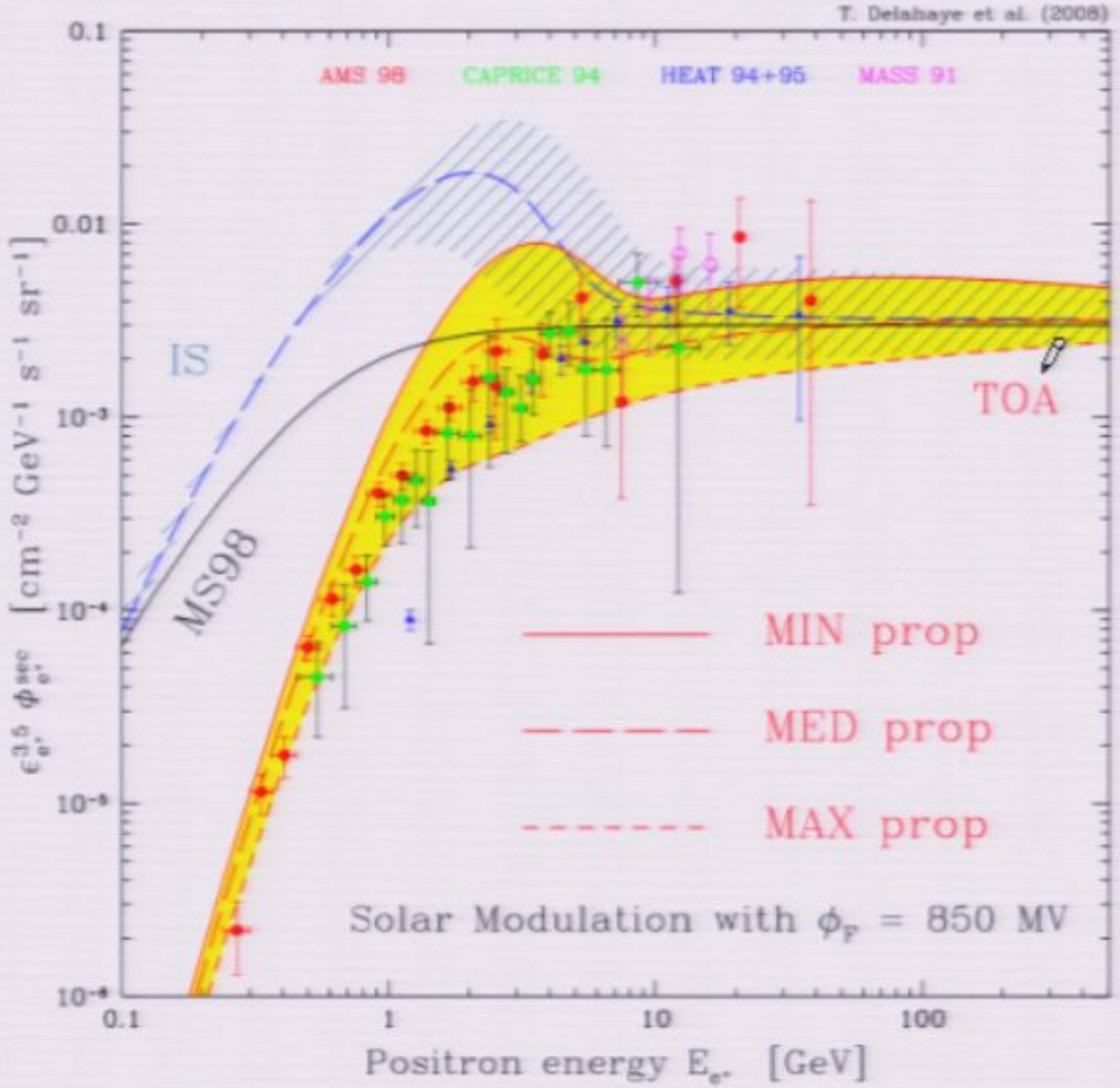

Absolute e^+ flux

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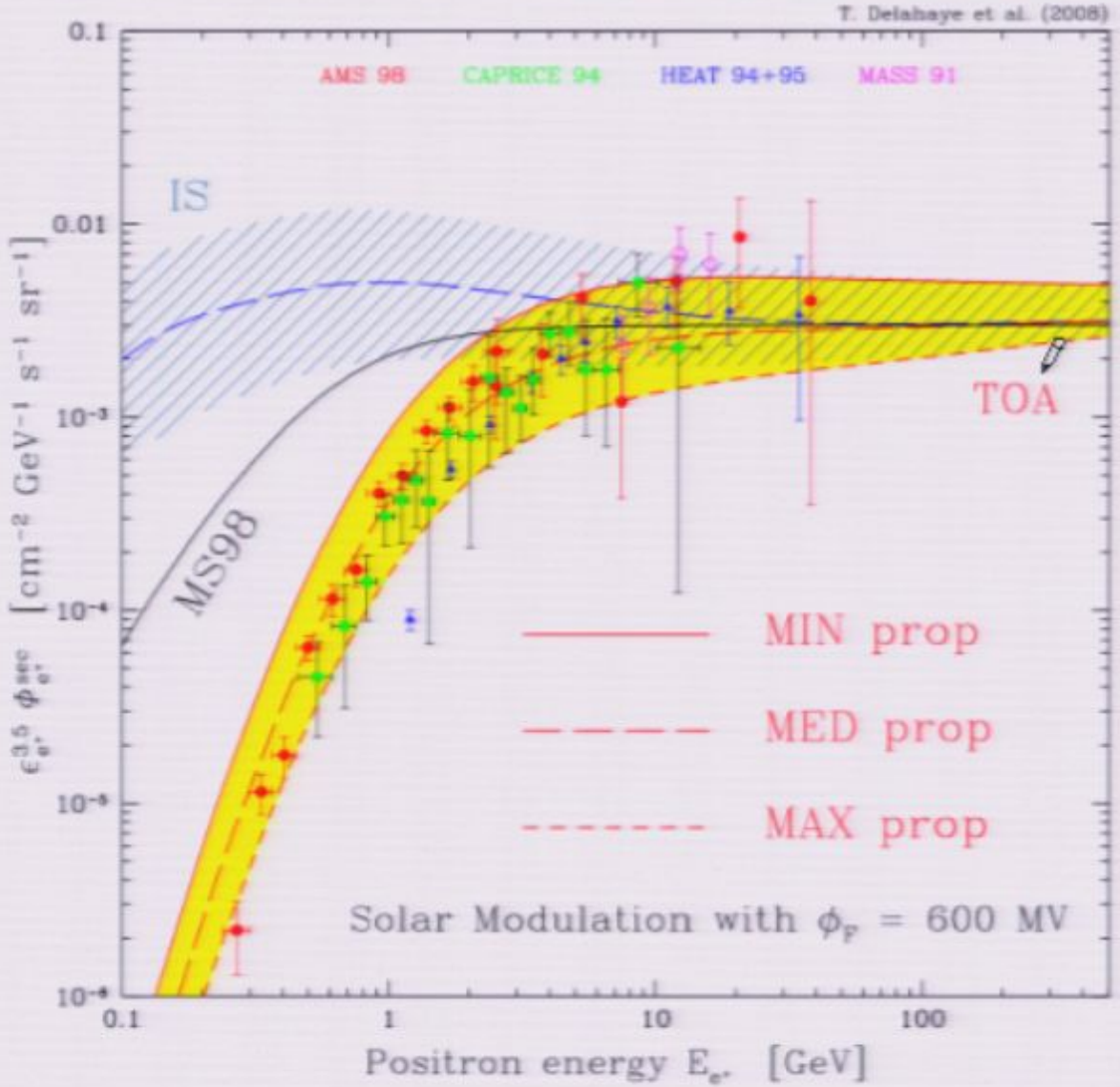

Absolute e^+ flux

diffusive reacceleration

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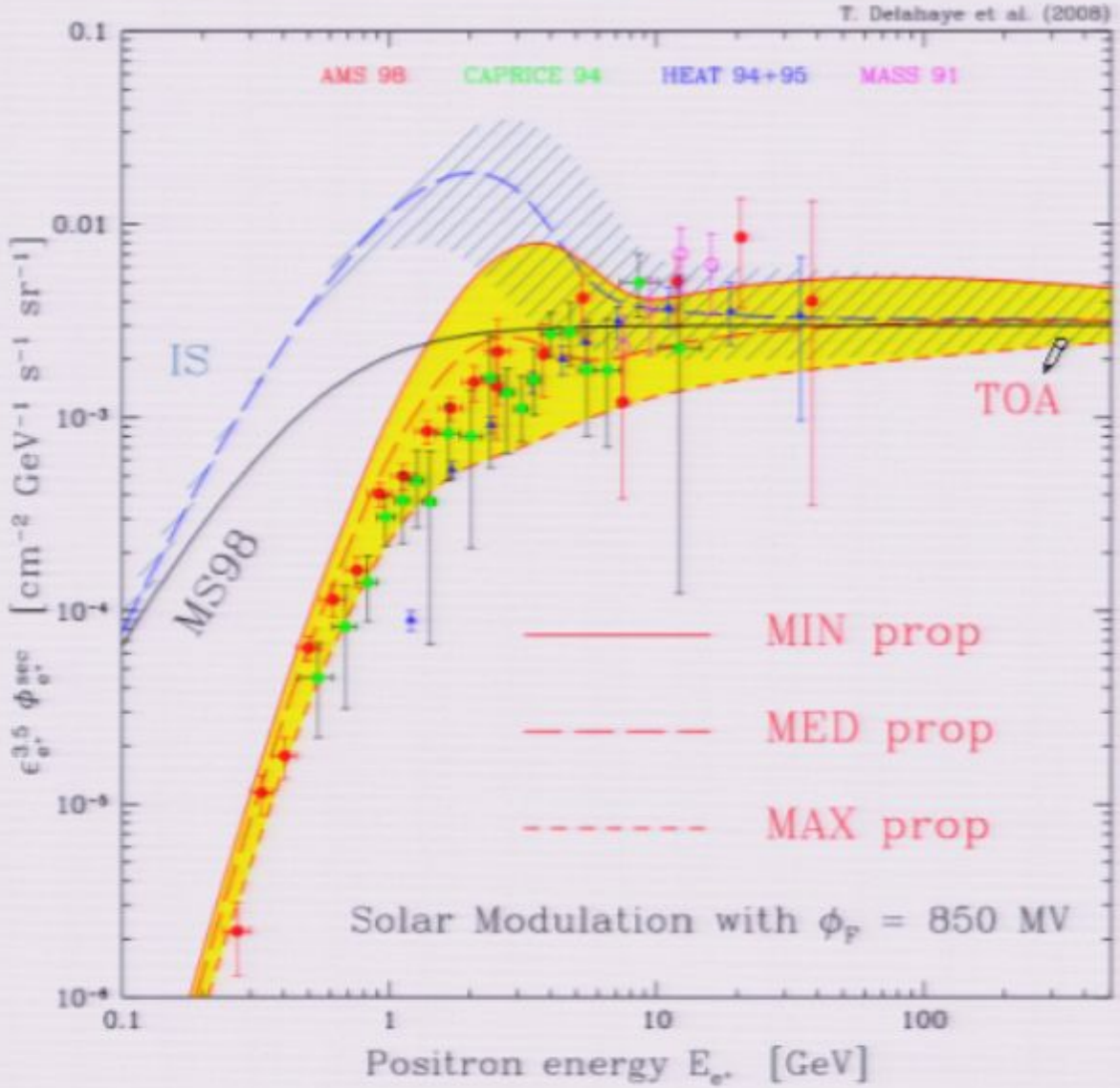

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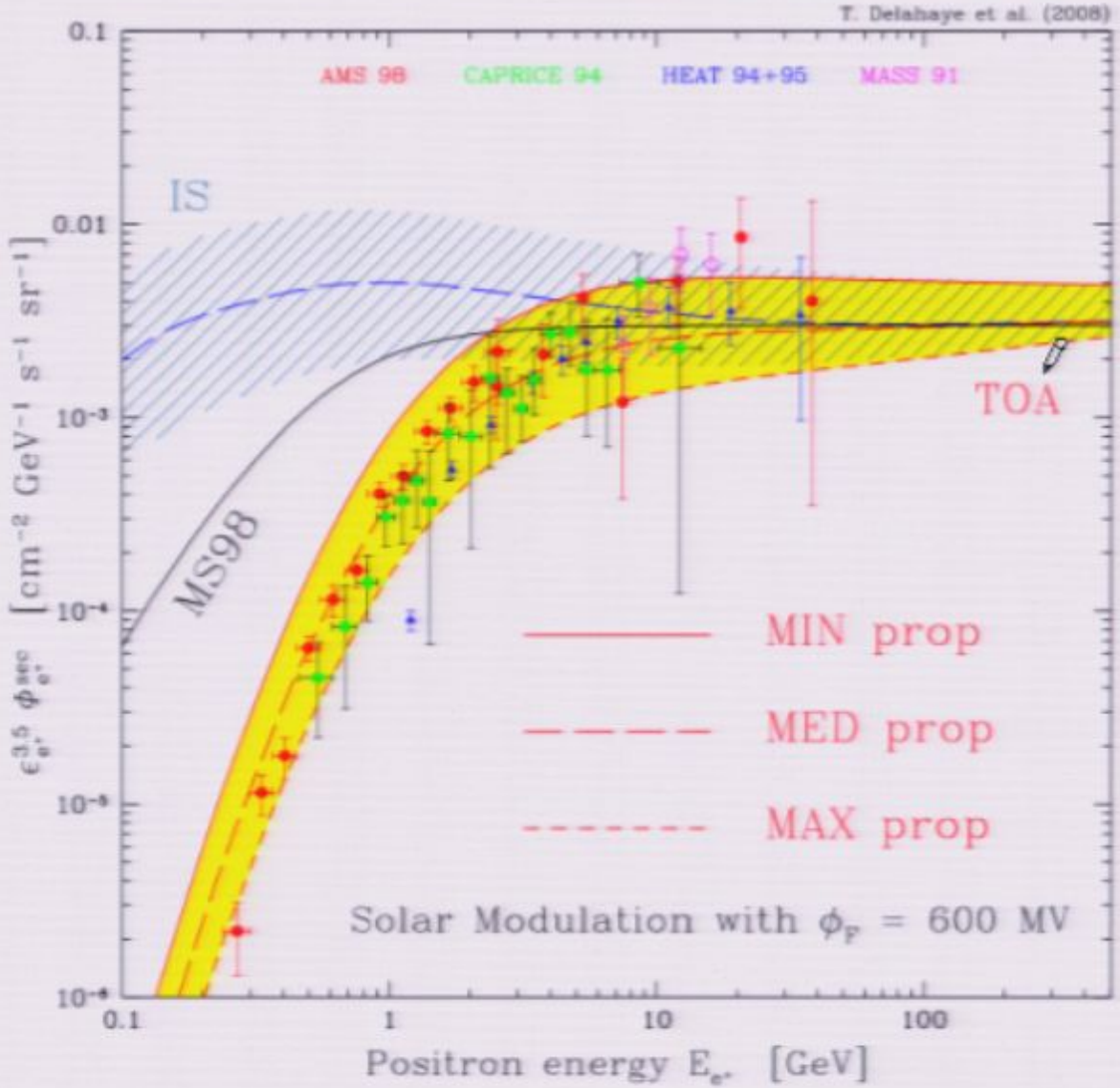

Absolute e^+ flux

diffusive reacceleration

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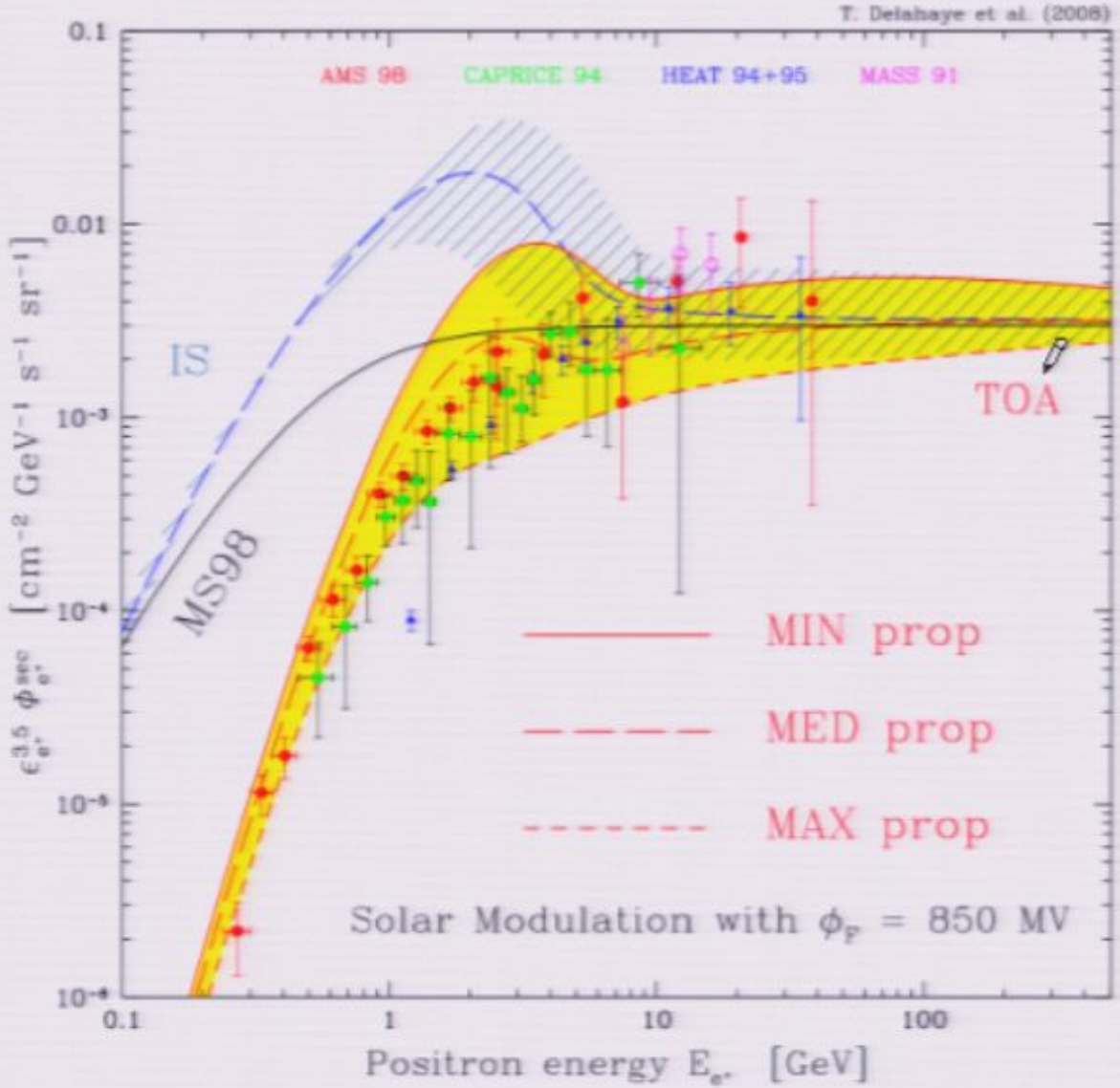

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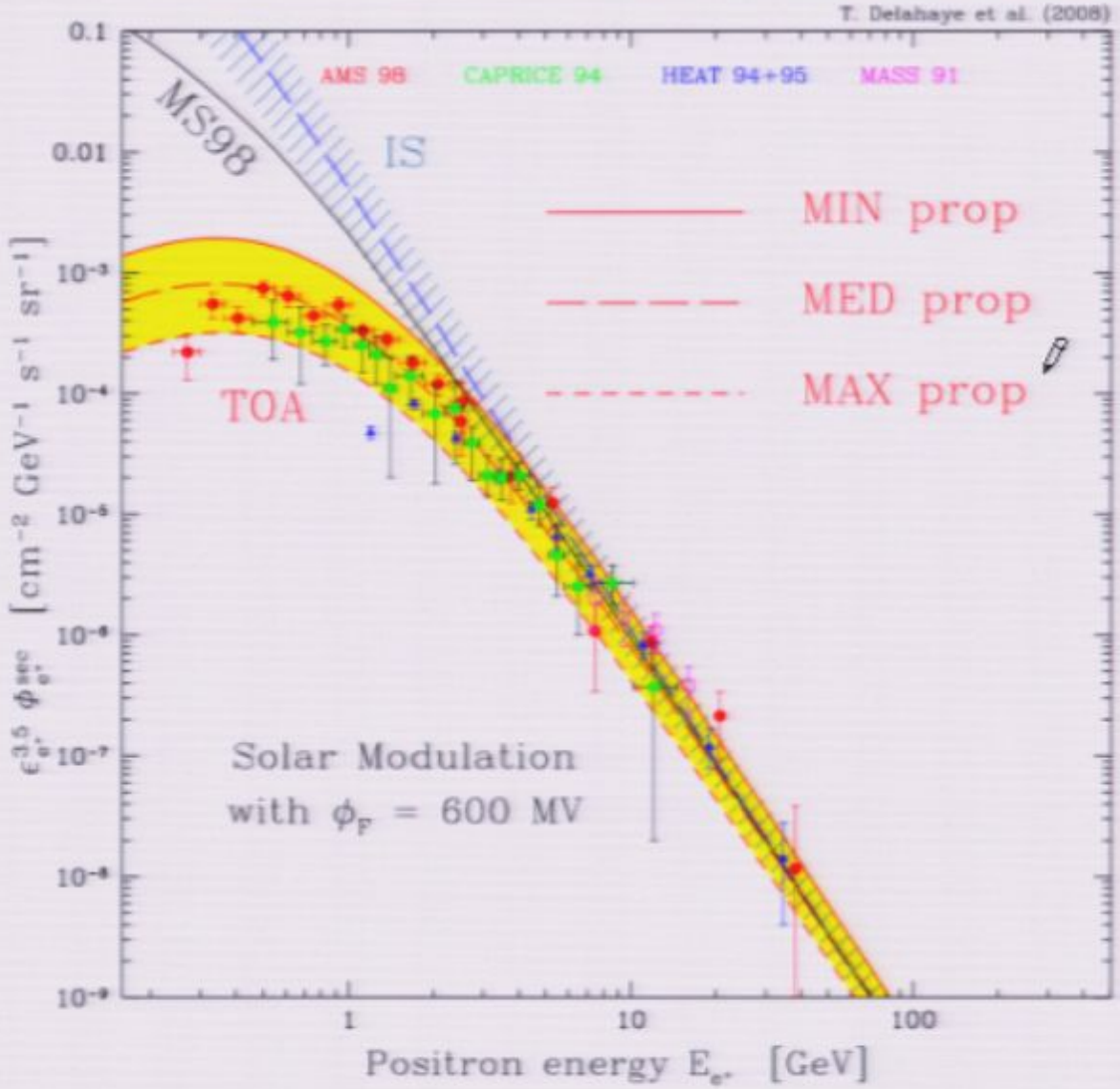

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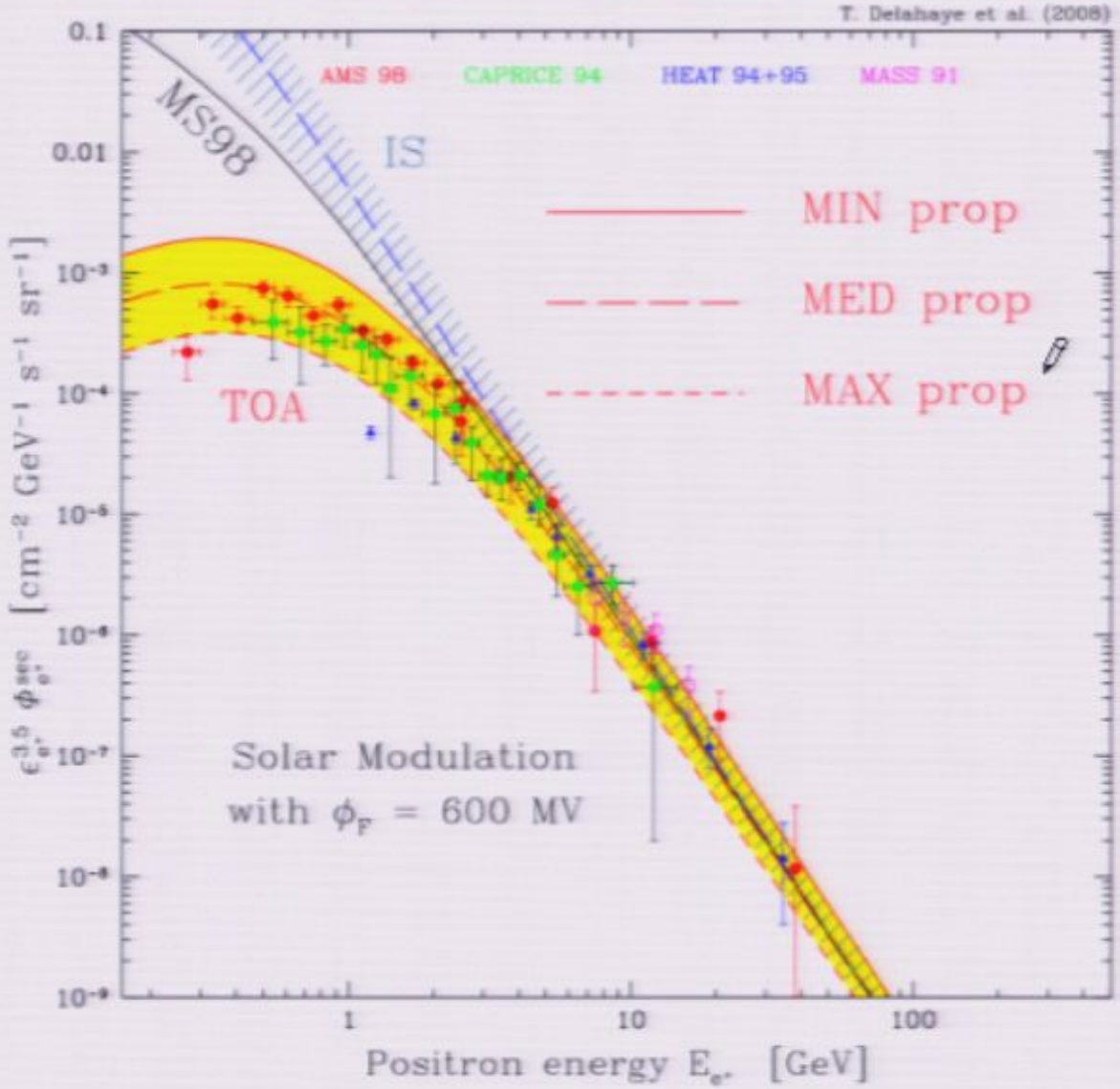

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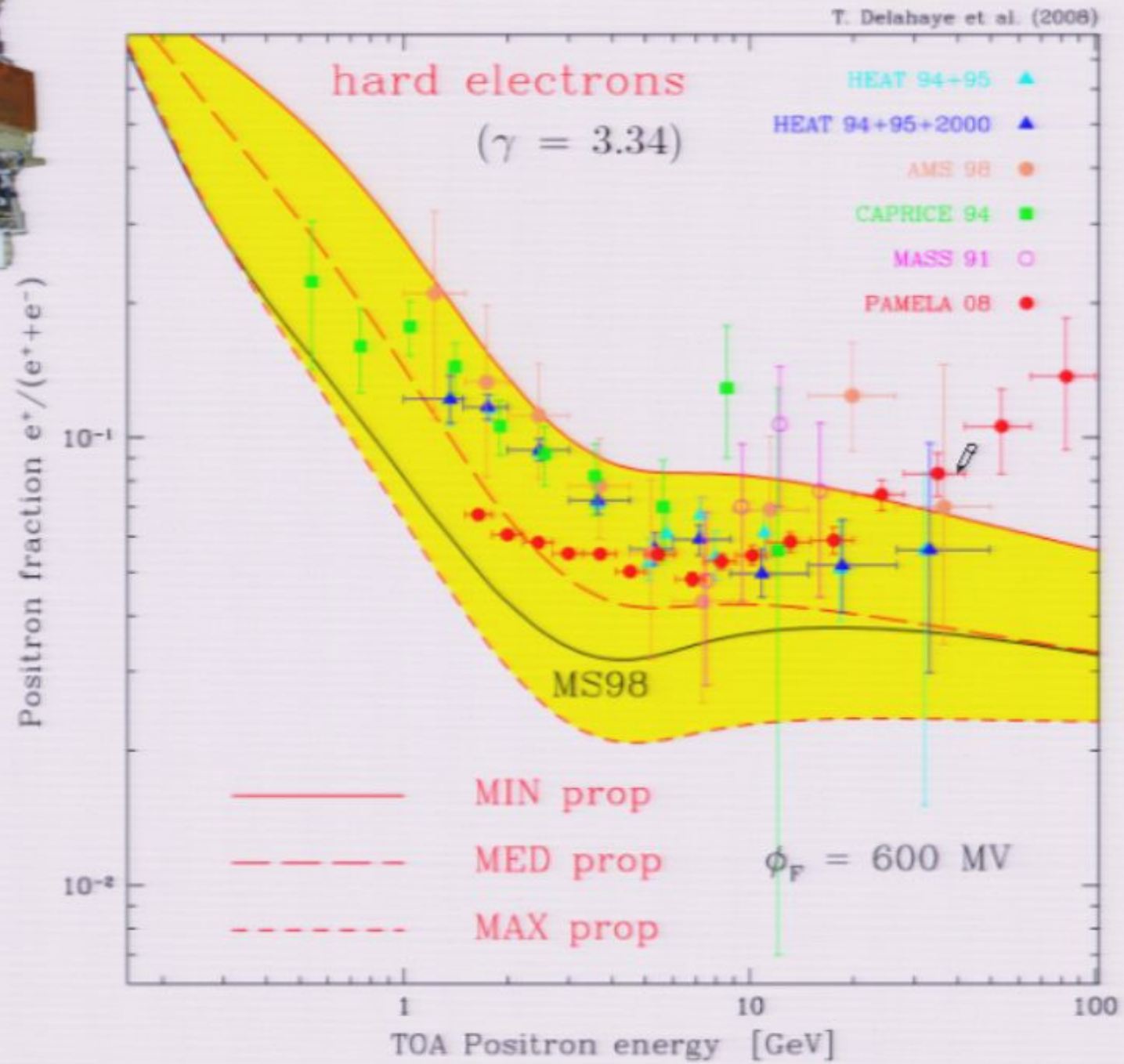

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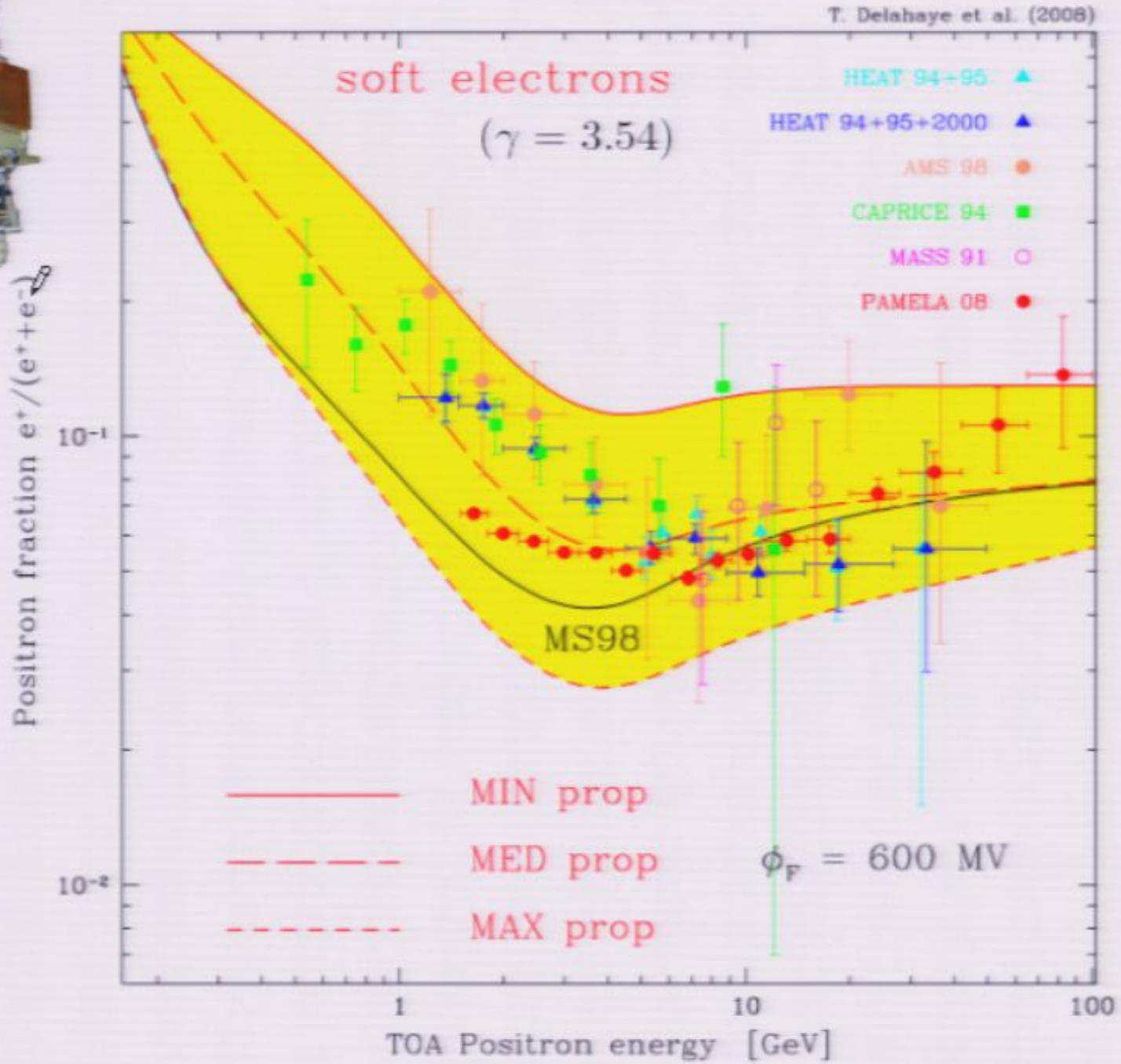

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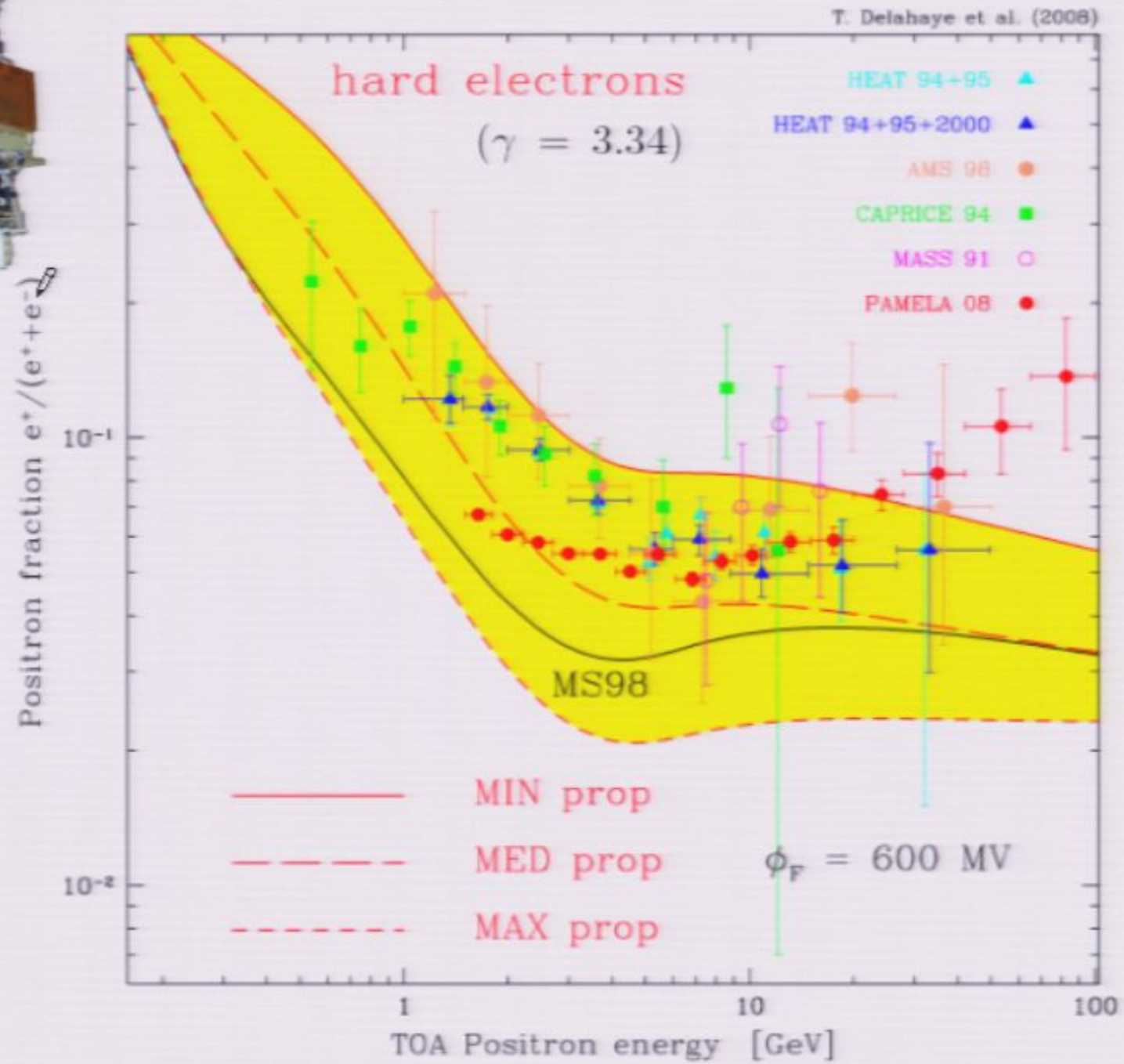

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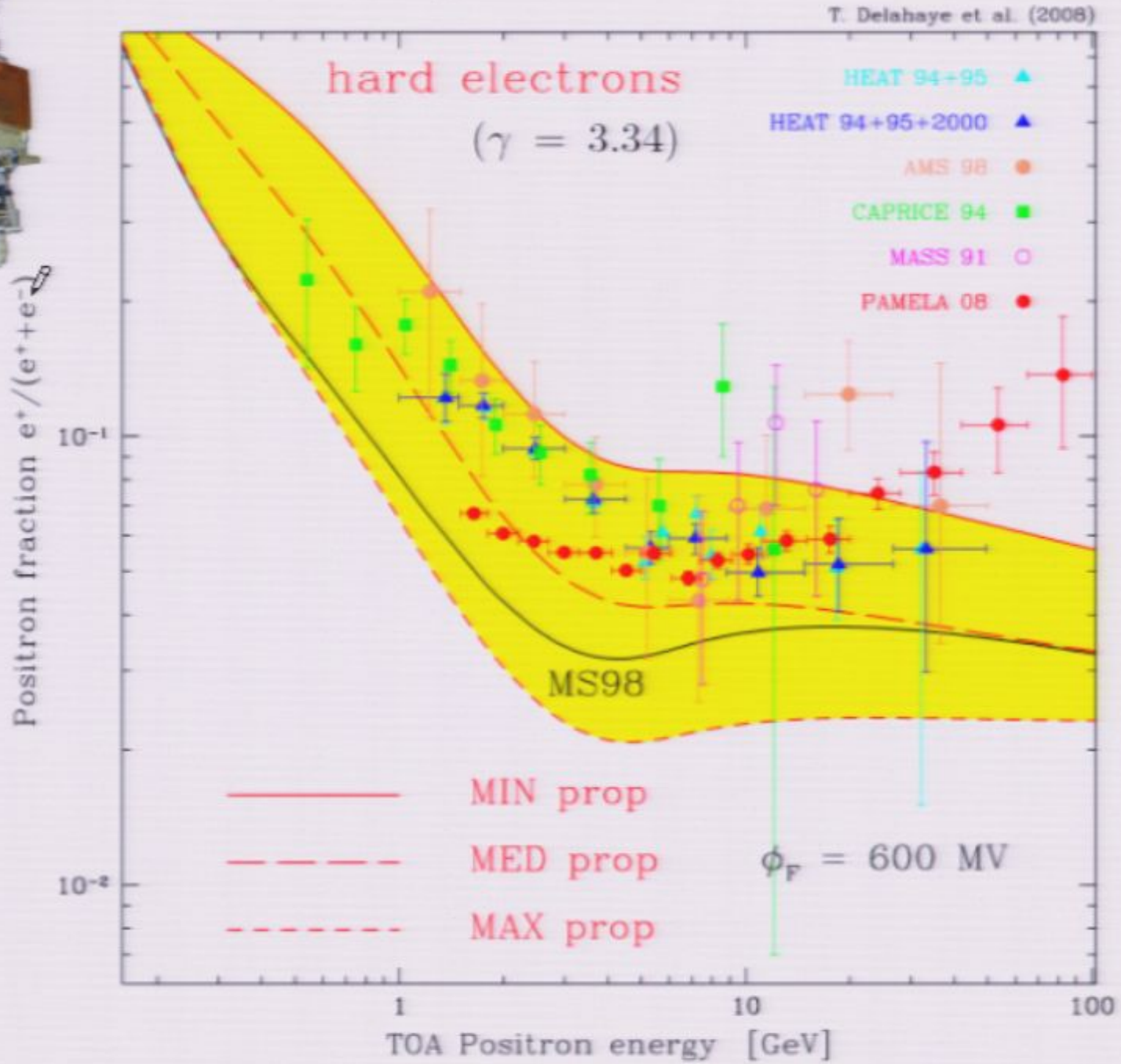
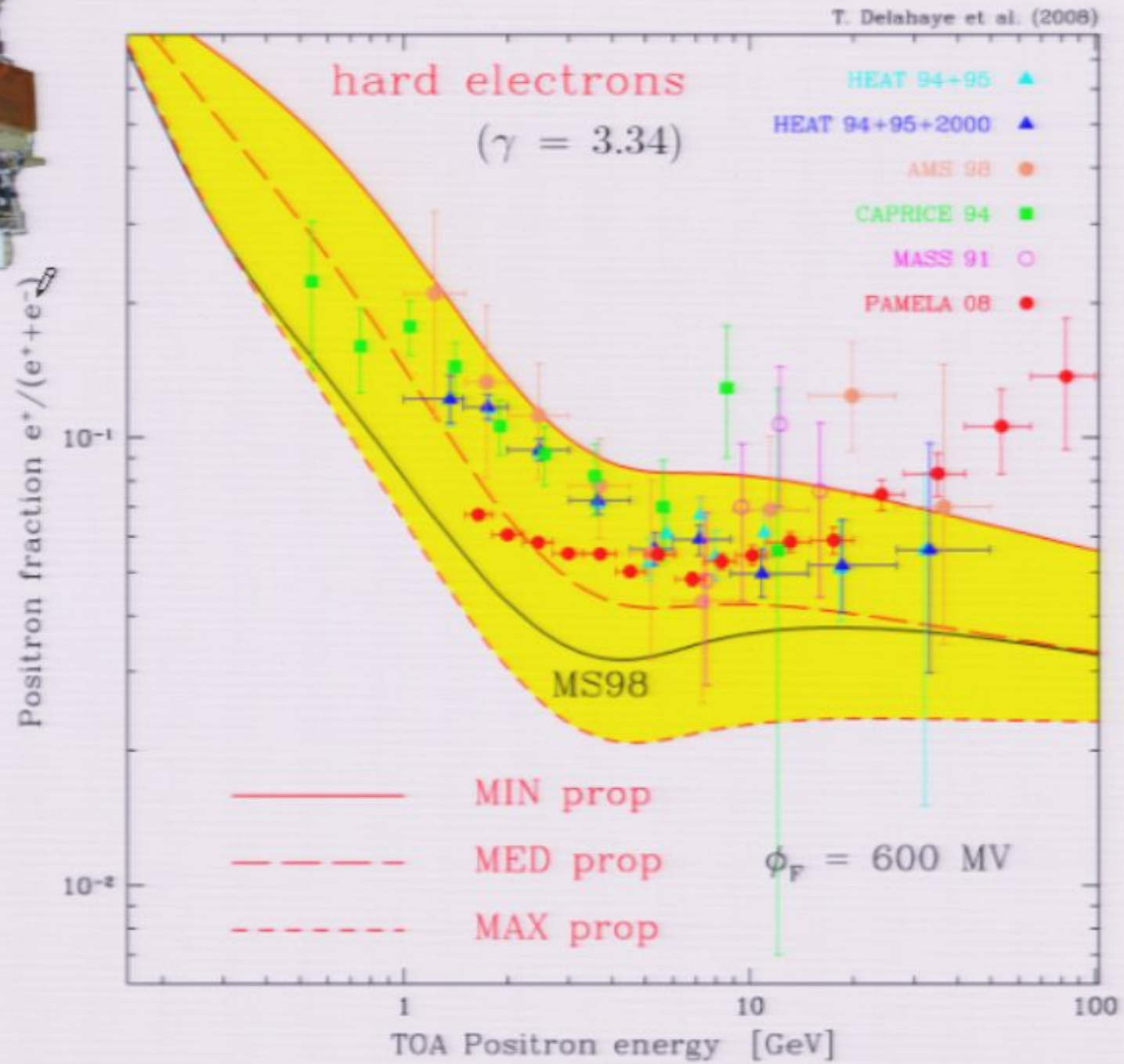


Delahaye T. et al. – arXiv:0809.5268



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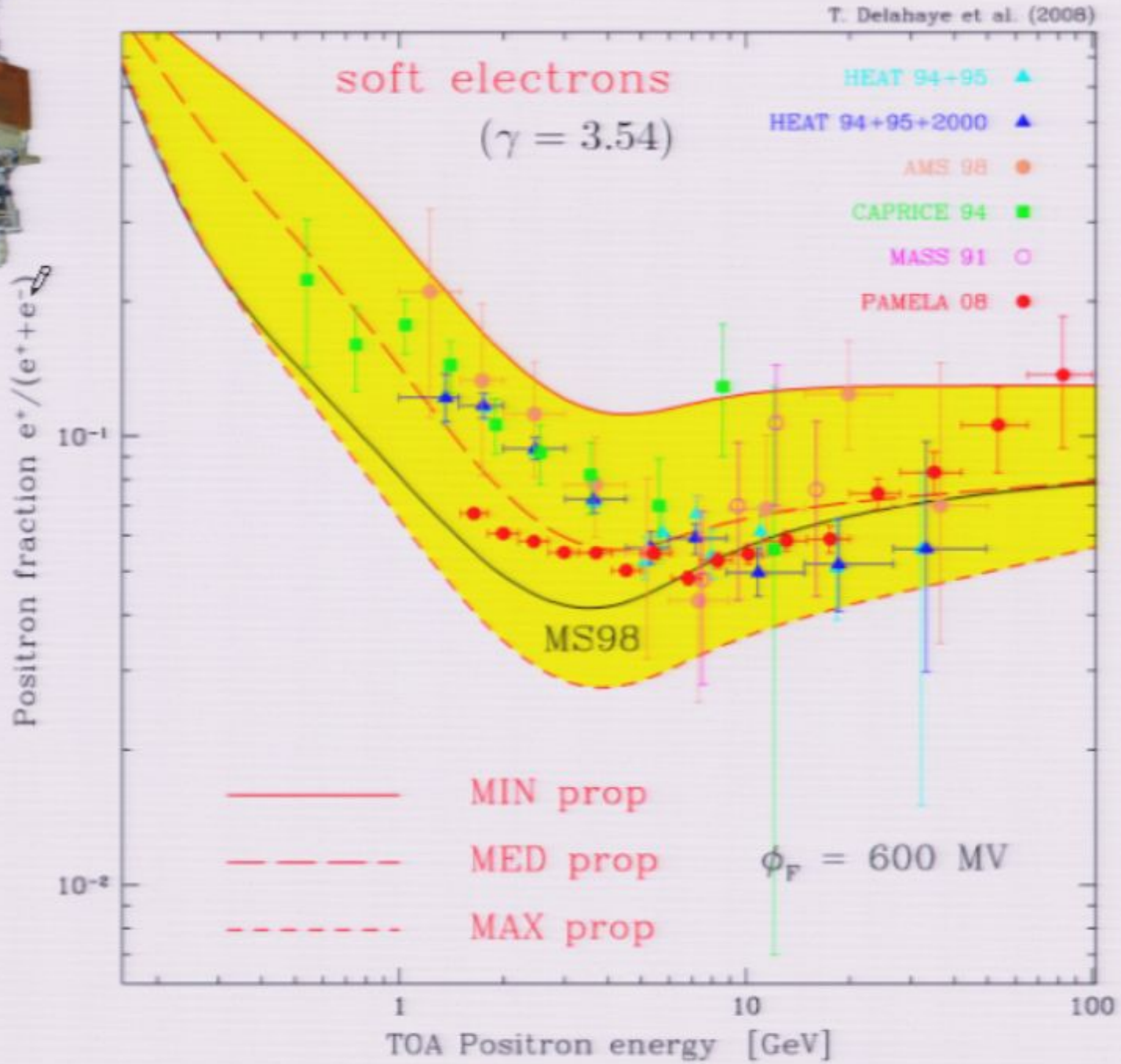
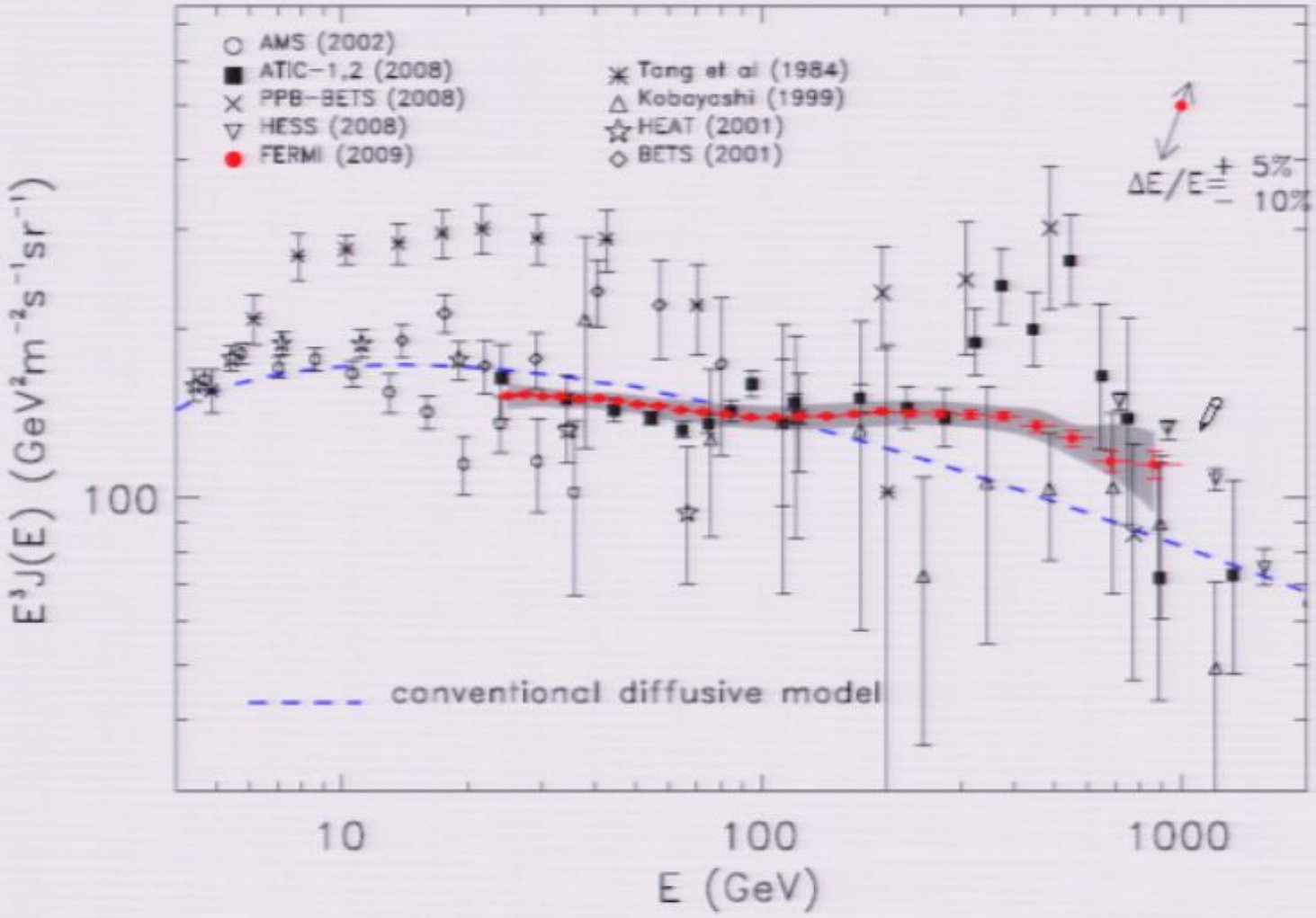


Measurement of the Cosmic Ray $e^+ + e^-$ spectrum from 20 GeV to 1 TeV with the Fermi Large Area Telescope

arXiv:0905.0025v1 [astro-ph.HE] 30 Apr 2009



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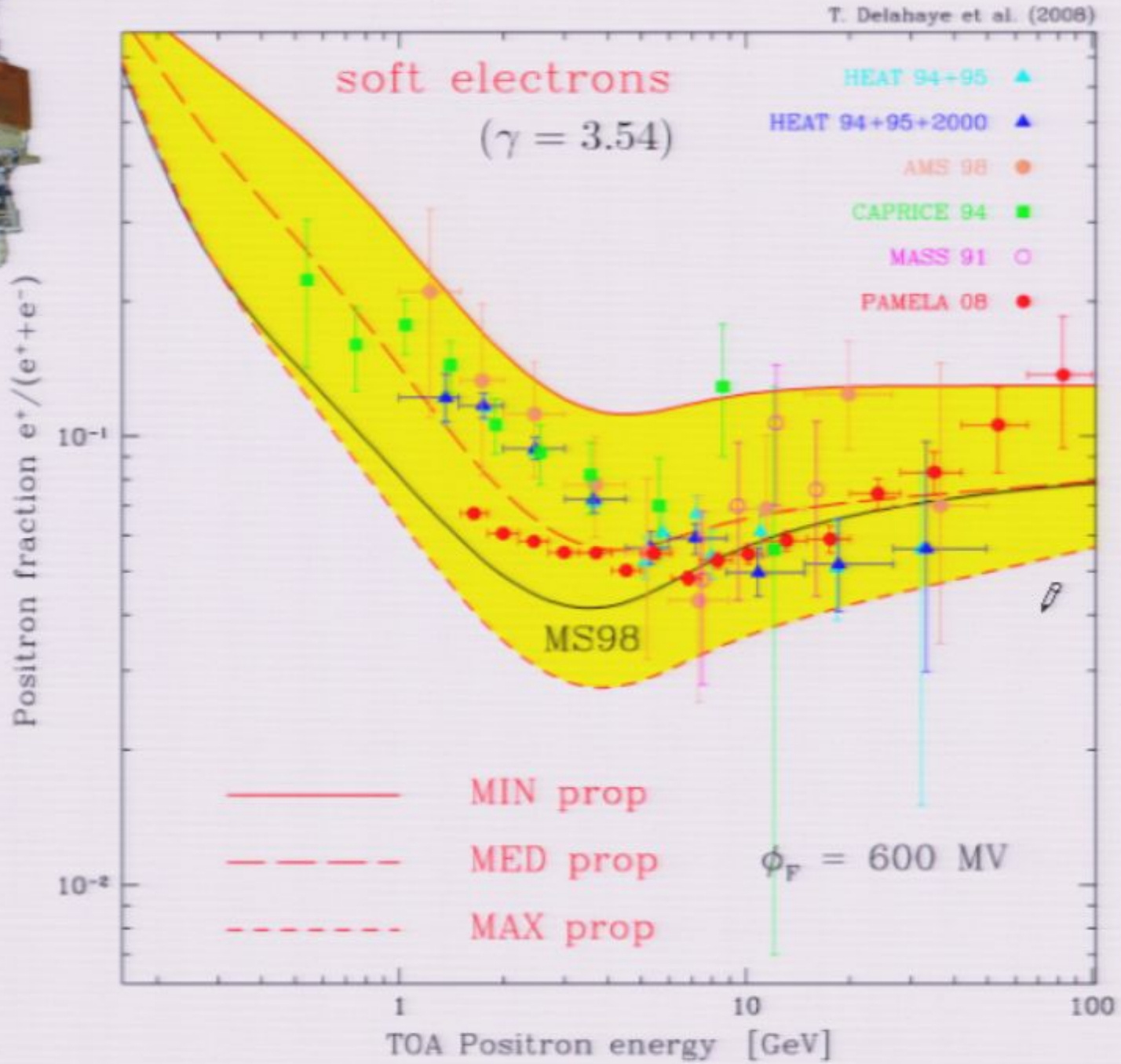

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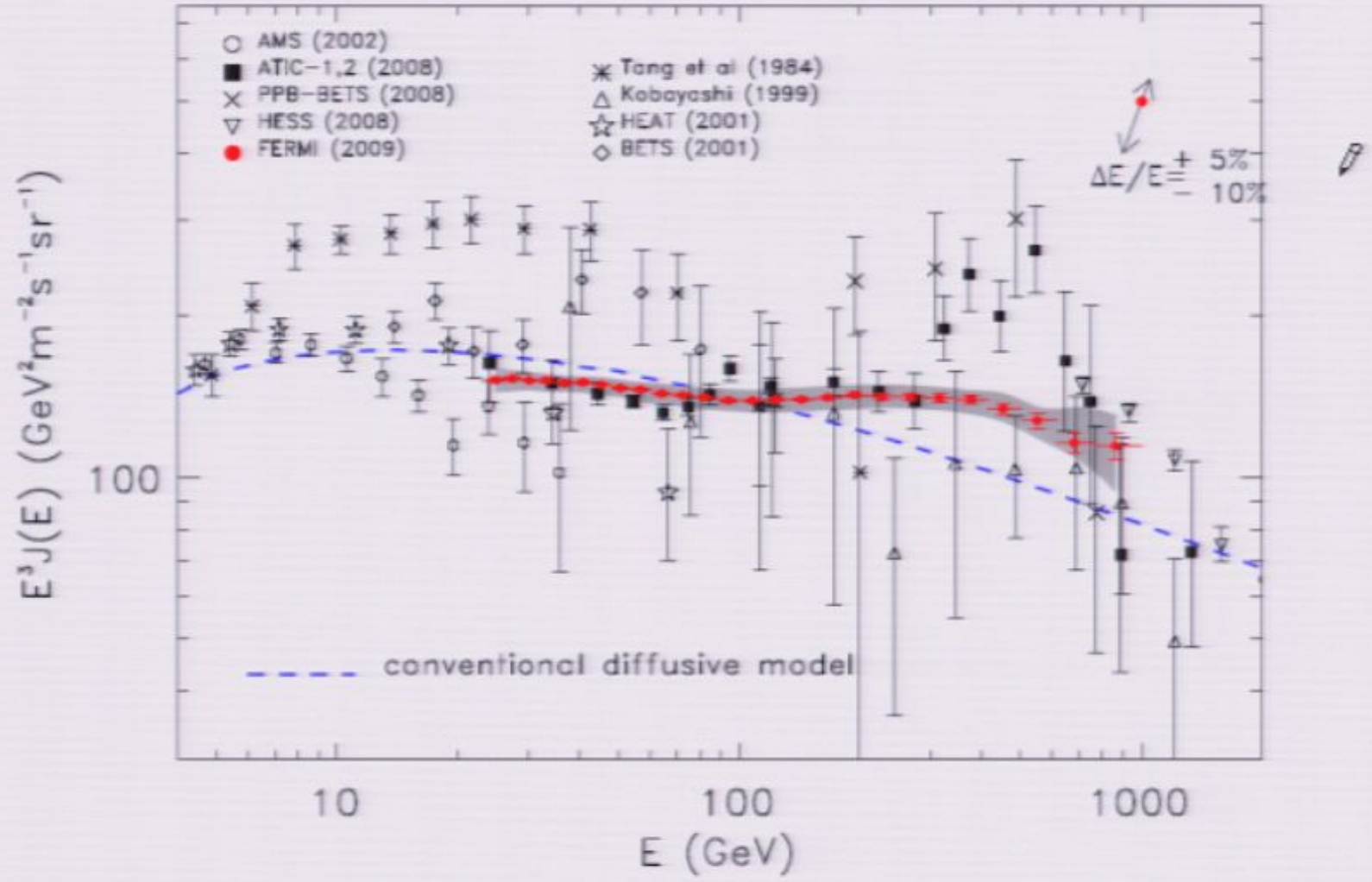

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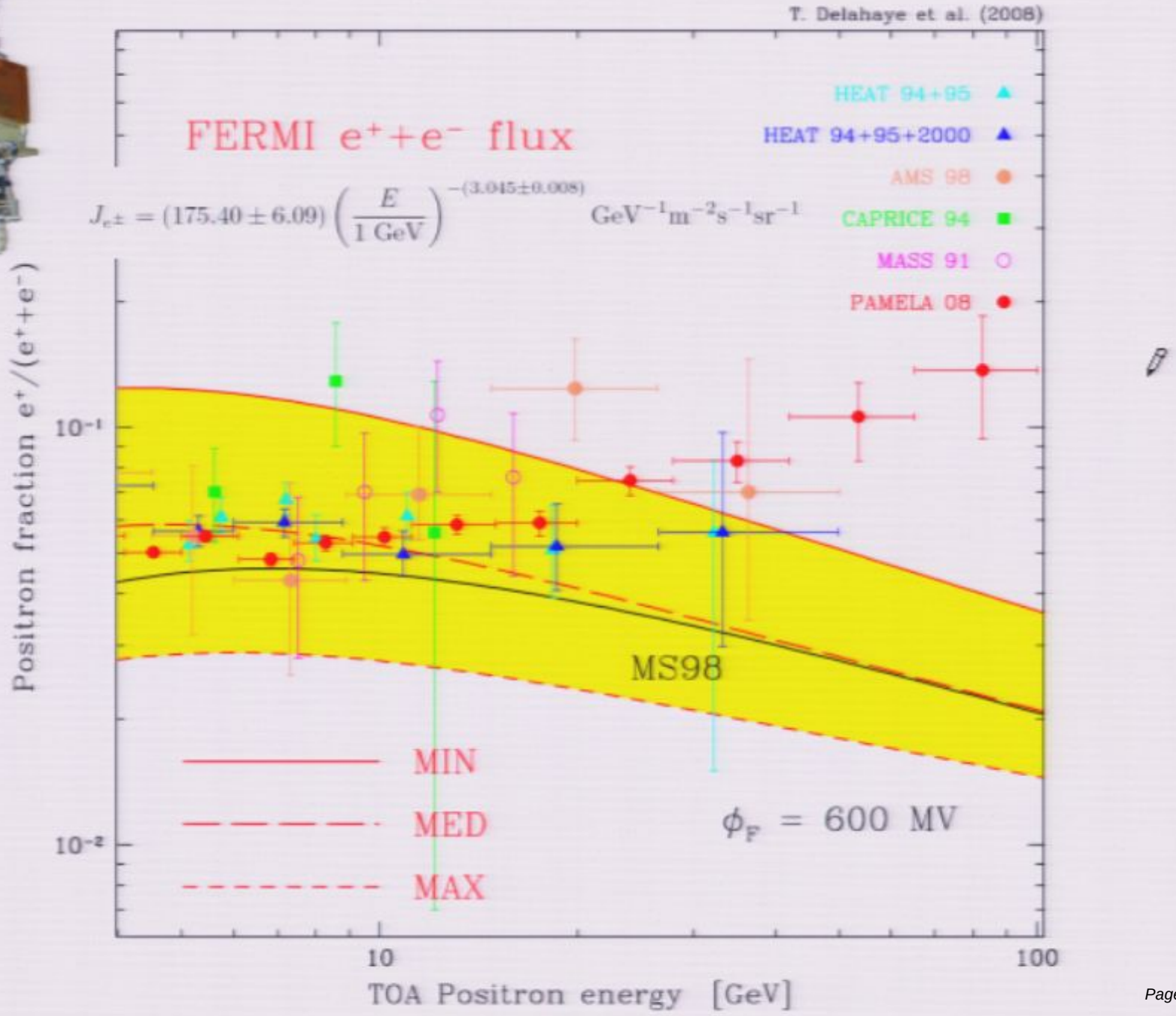
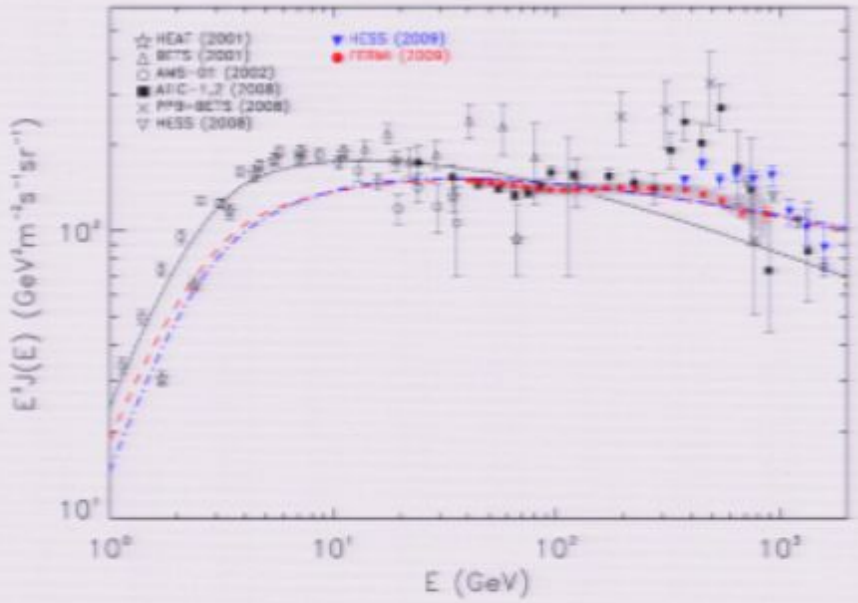
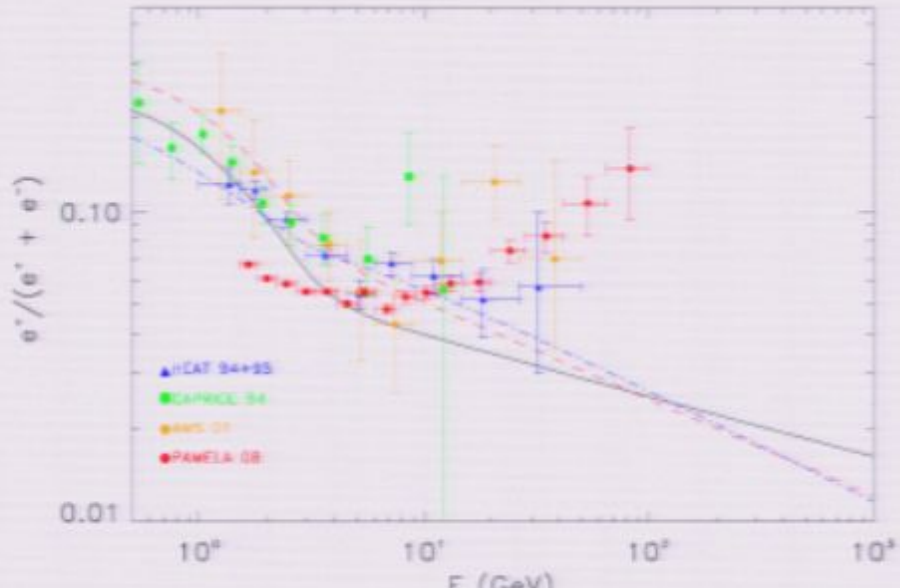


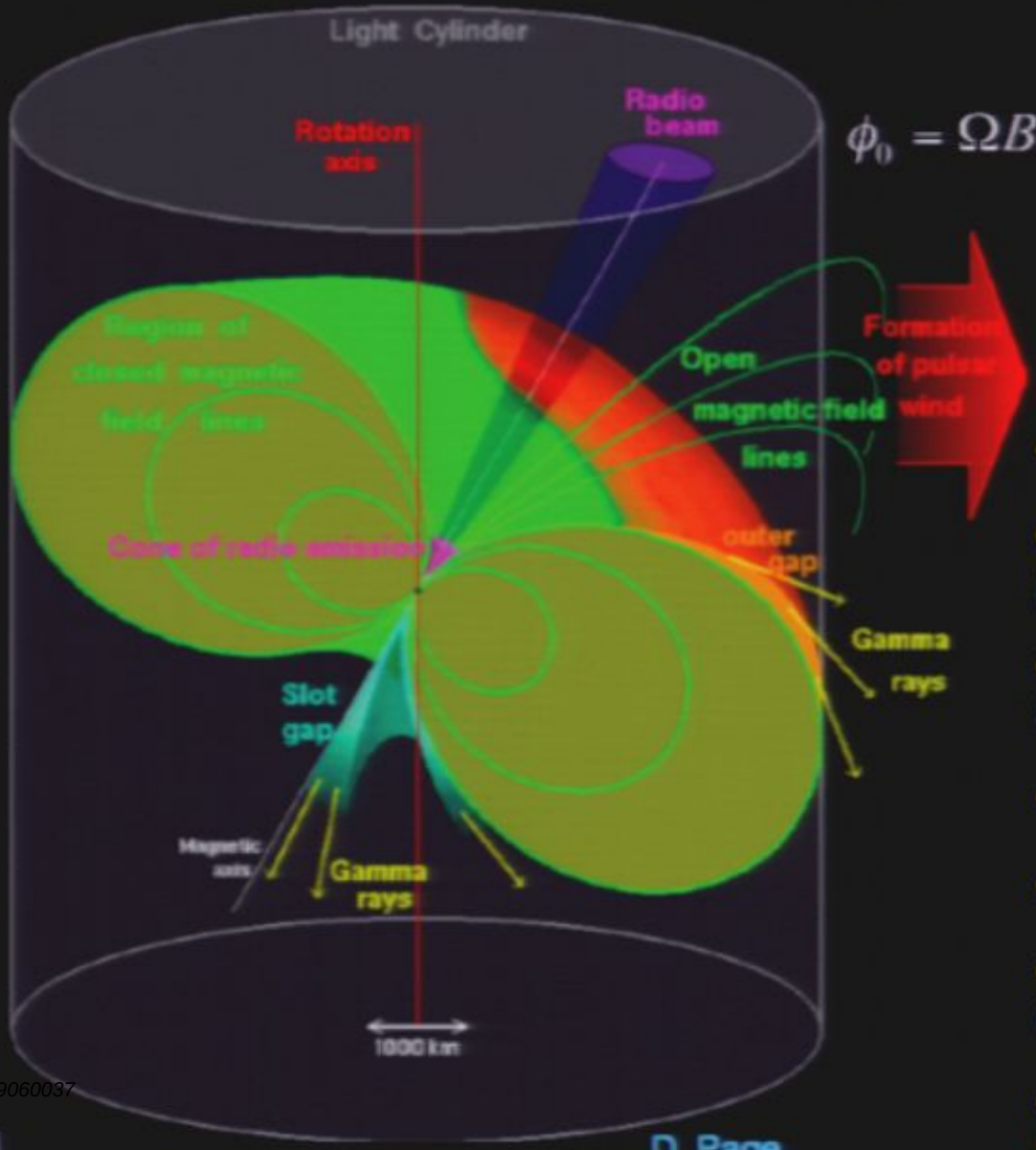
Model #	D_0 $(cm^2 s^{-1})$	δ	z_h (kpc)	γ_0	N_{e^-} $(m^{-2} s^{-1} sr^{-1} GeV^{-1})$	γ_0^p
0	3.6×10^{28}	0.33	4	2.54	1.3×10^{-4}	2.42
1	3.6×10^{28}	0.33	4	2.42	1.3×10^{-4}	2.42
2	1.3×10^{28}	0.60	4	2.33	1.3×10^{-4}	2.1



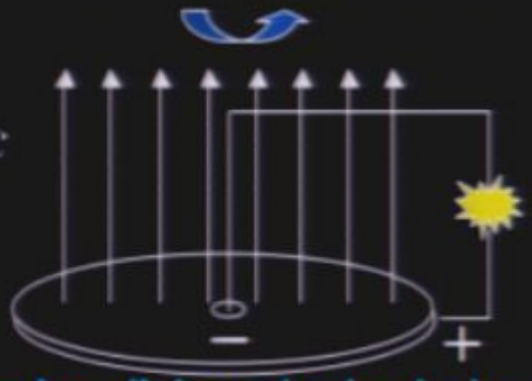


4) Astrophysical explanations of the PAMELA excess

Courtesy of Anatoly Spitkovsky – Princeton



$$\phi_0 = \Omega B a^2 / c$$



Faraday disk: unipolar induction

- but pulsars are not in vacuum!
- Equator-pole potential difference (10^{15}V for Crab)
- Charge extraction from the surface (E field >> gravity)
- Currents, strong magnetization
- Corotating zone; Light cylinder
- Throwing away toroidal field – energy loss (Poynting flux)
- Plasma currents modify field. How can we model this?

D. Page

Galactic and local pulsars

D. Hooper, P. Blasi & P. D. Serpico, **arXiv:0810.1527** S. Profumo, **arXiv:0812.4457**

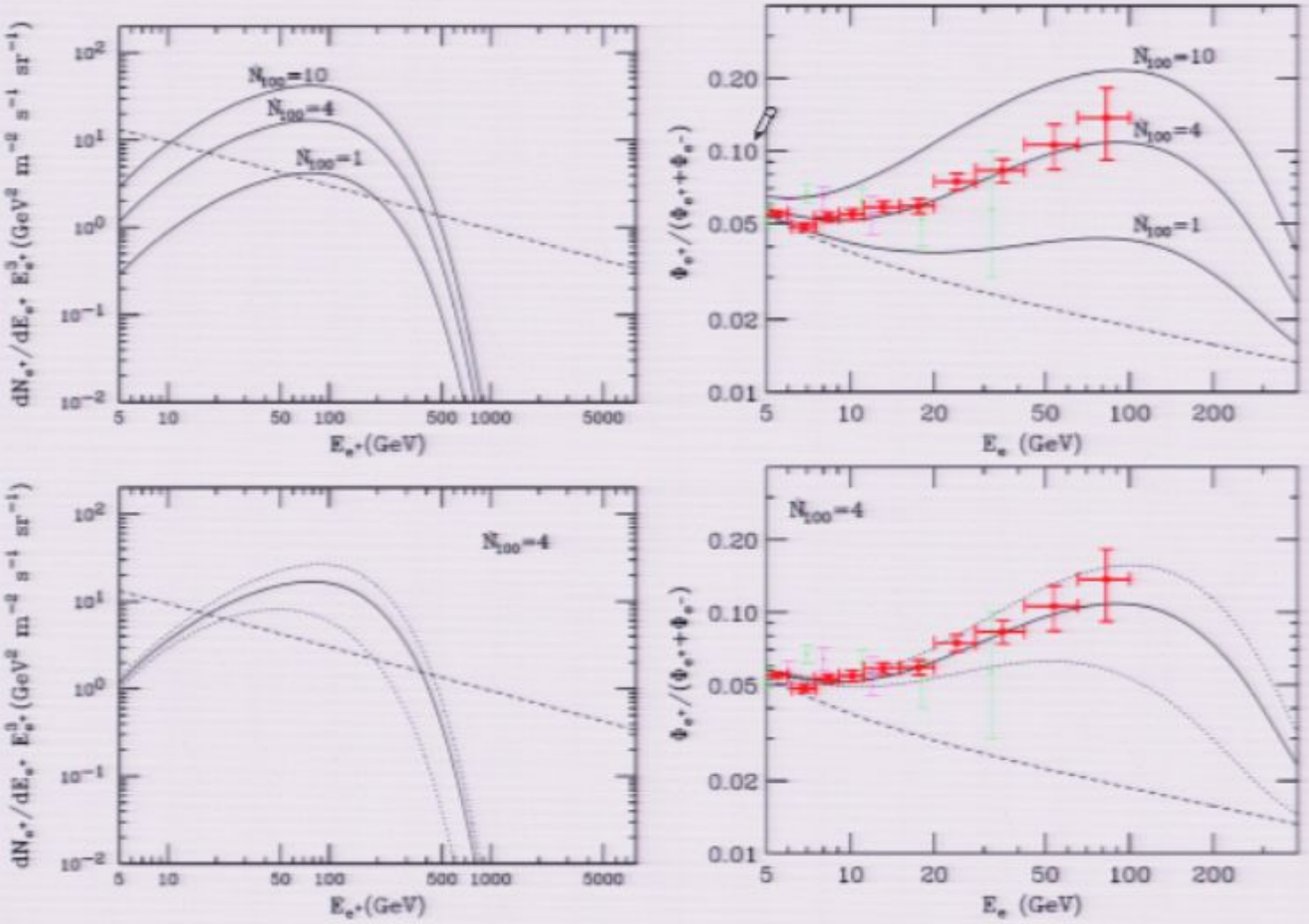


FIG. 1: The spectrum of cosmic ray positrons (left) and the positron fraction (right) resulting from the sum of all pulsars throughout the Milky Way. Also shown as a dashed line is the prediction for secondary positrons (and primary and secondary electrons in the right frames) as calculated in Ref. [27].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

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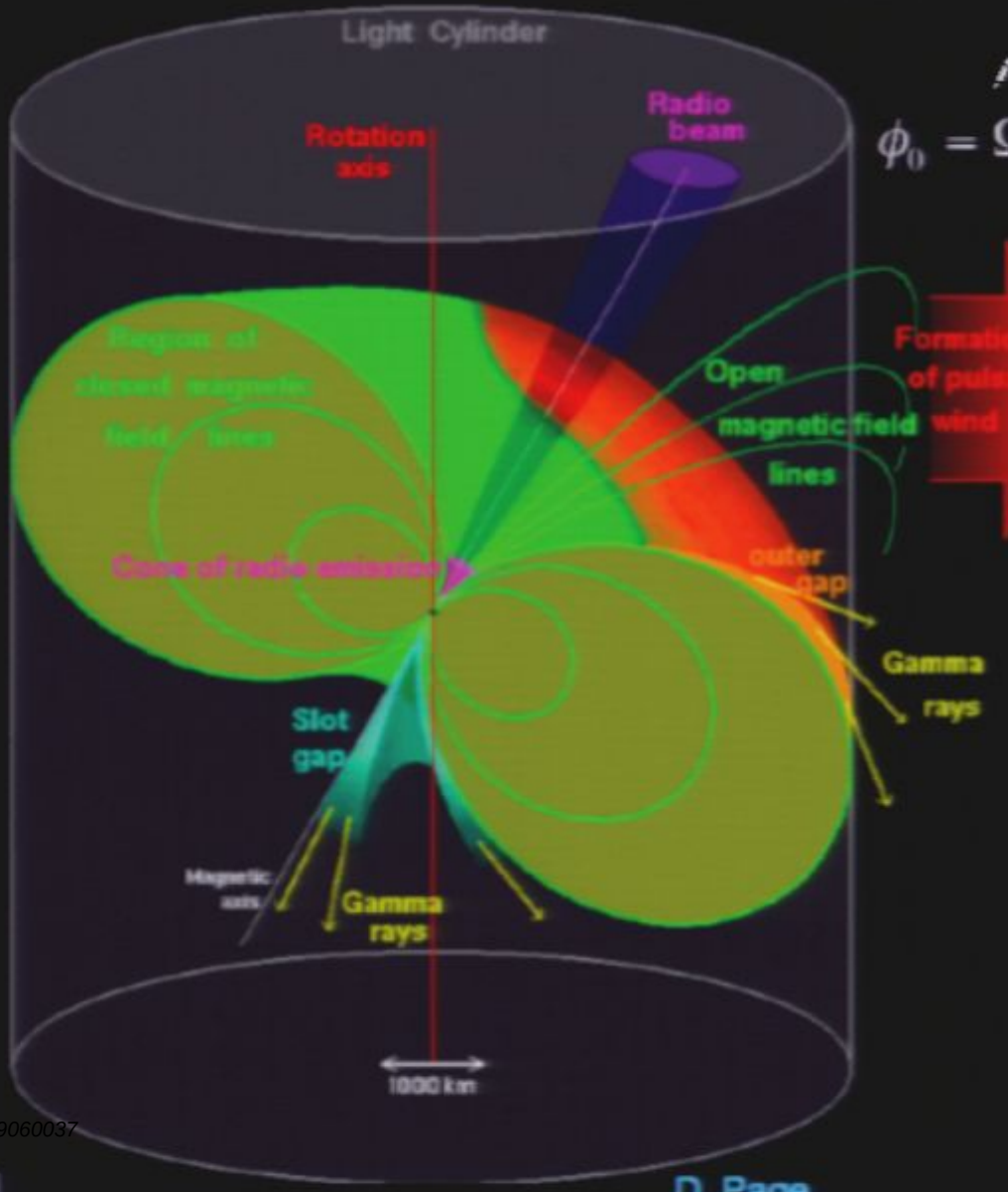

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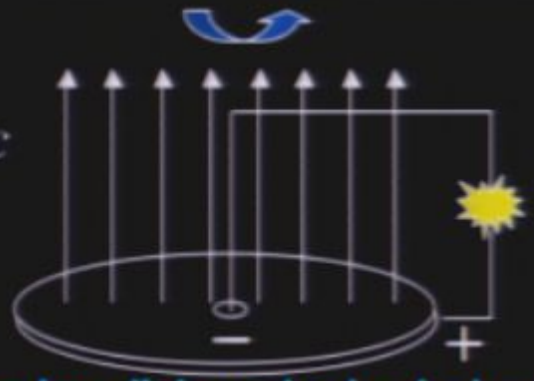

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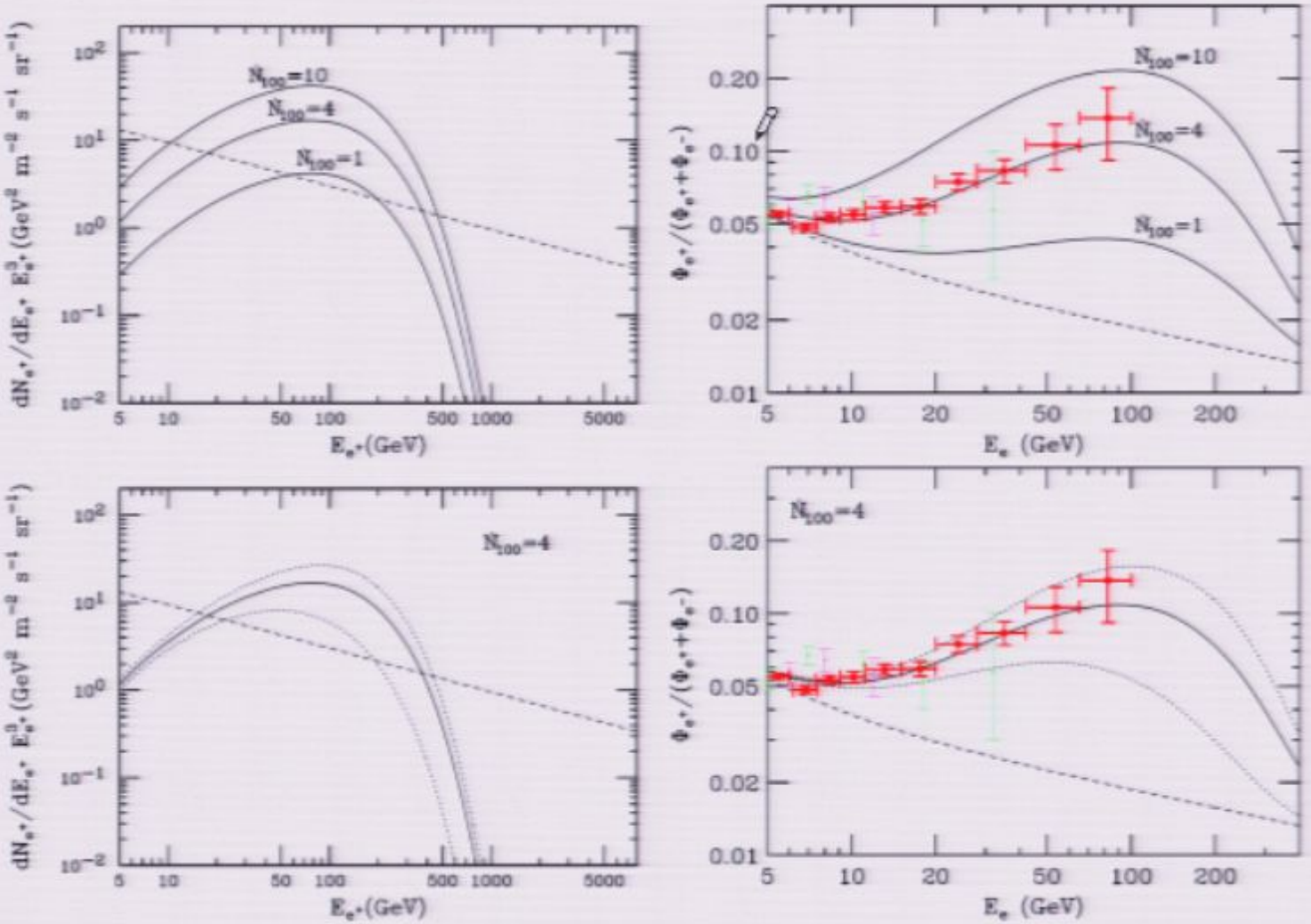

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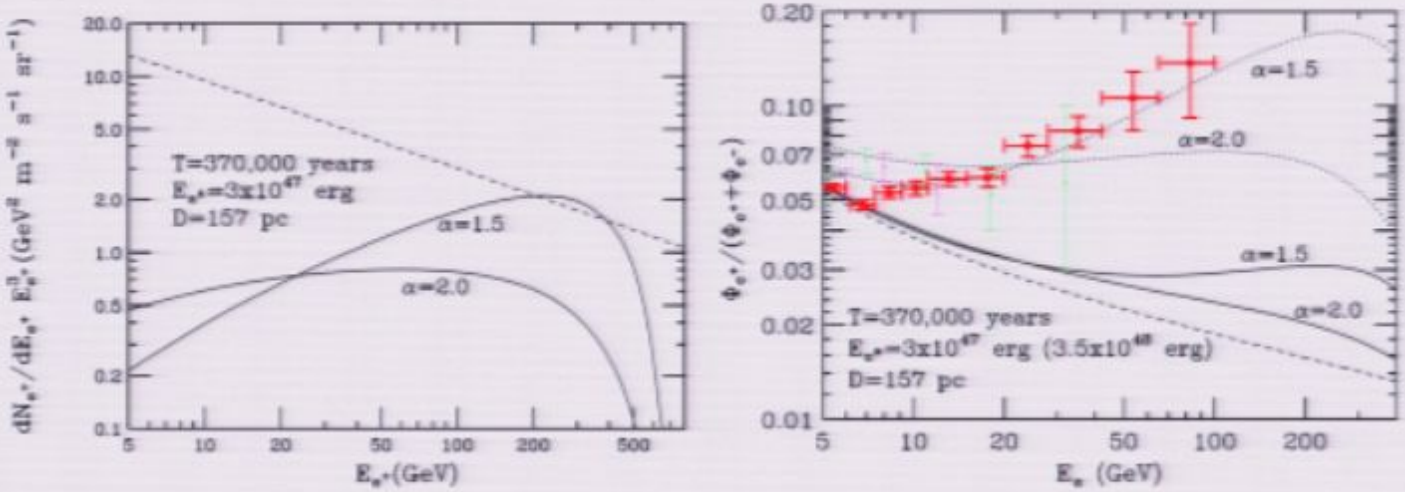

FIG. 2: The spectrum of positrons (left) and ratio of positrons to electrons plus positrons (right) from the pulsar Geminga, with the dashed lines as in Fig. 1. In the right frames, the measurements of HEAT [3] (light green and magenta) and measurements of PAMELA [2] (dark red) are also shown. Here we 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.

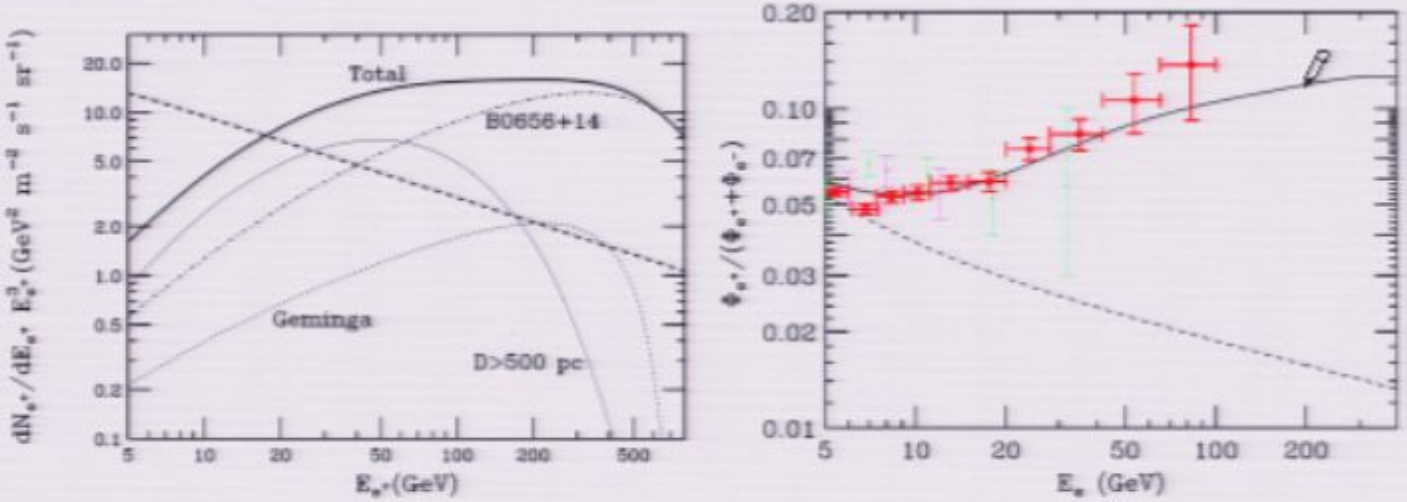

FIG. 4: The positron spectrum and positron fraction from the sum of contributions from B0656+14, Geminga, and all pulsars farther than 500 parsecs from the Solar System.

Galactic and local pulsars

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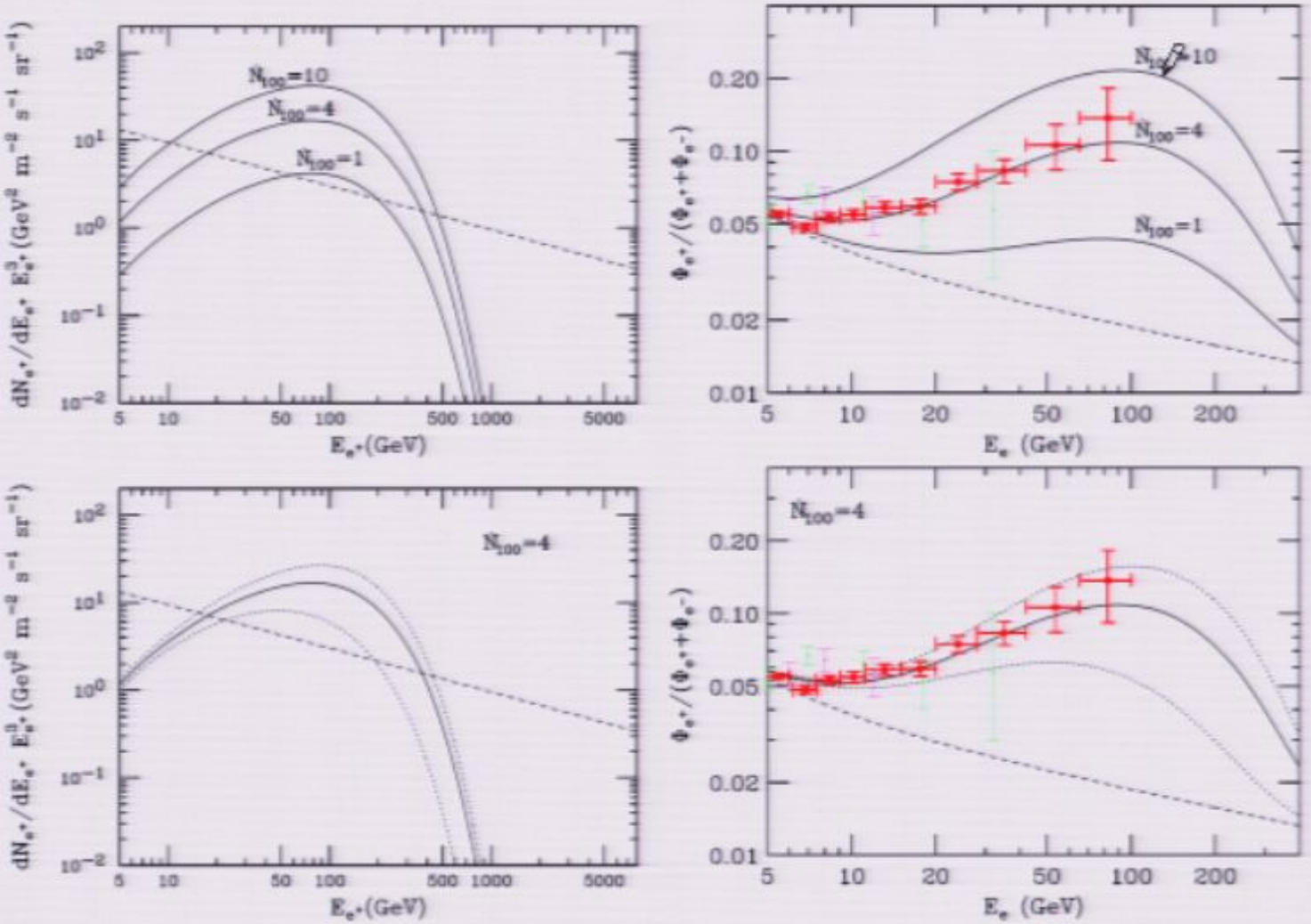

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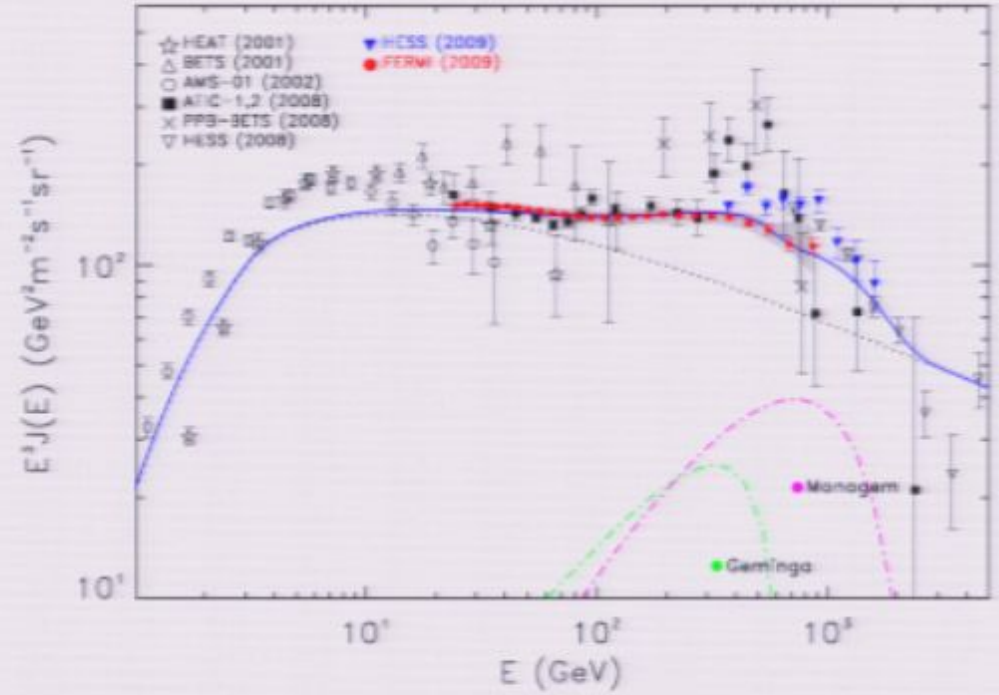

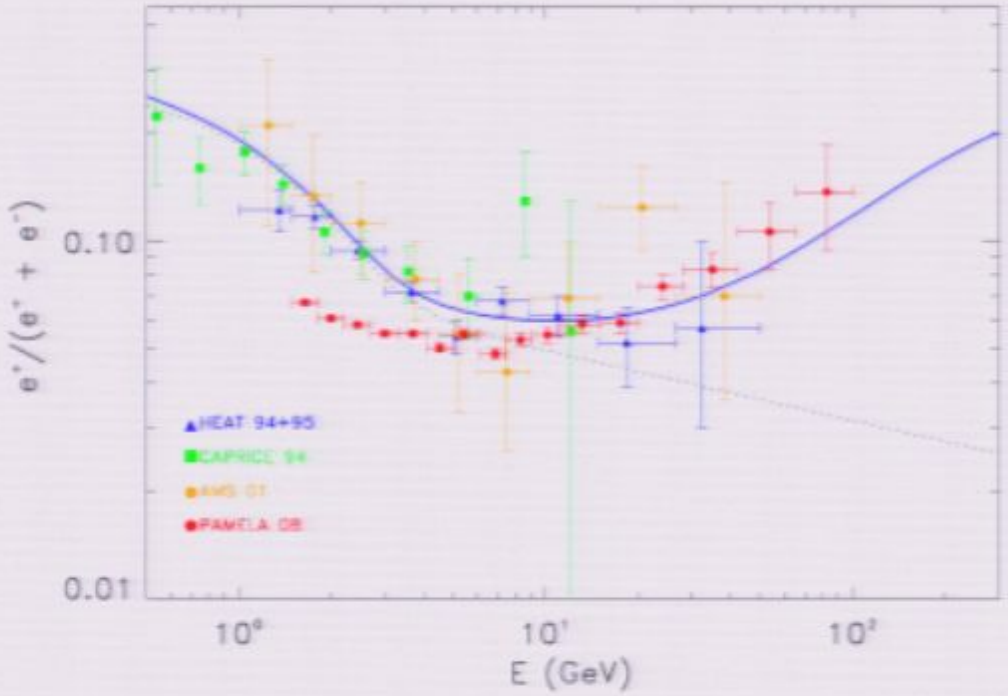

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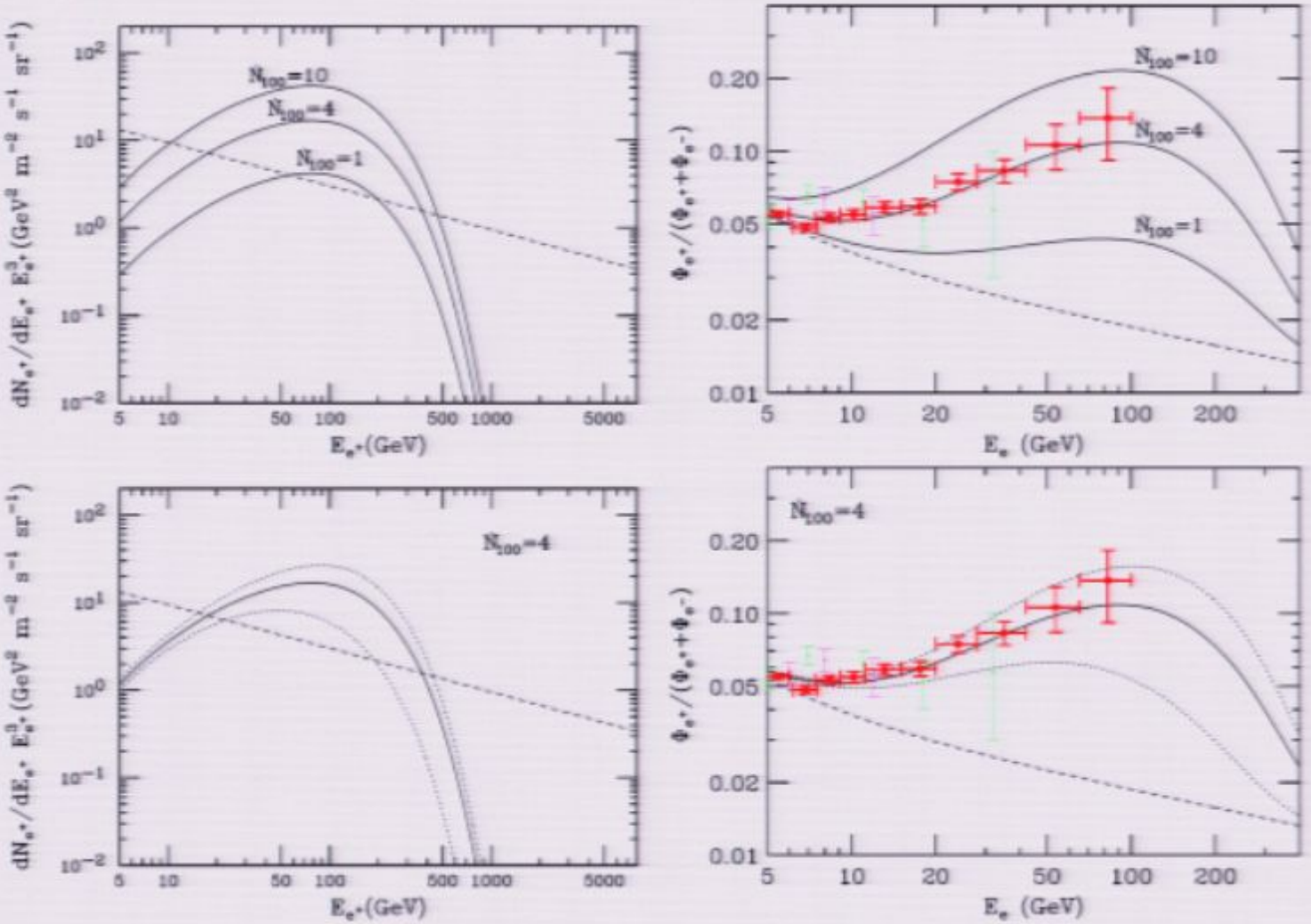

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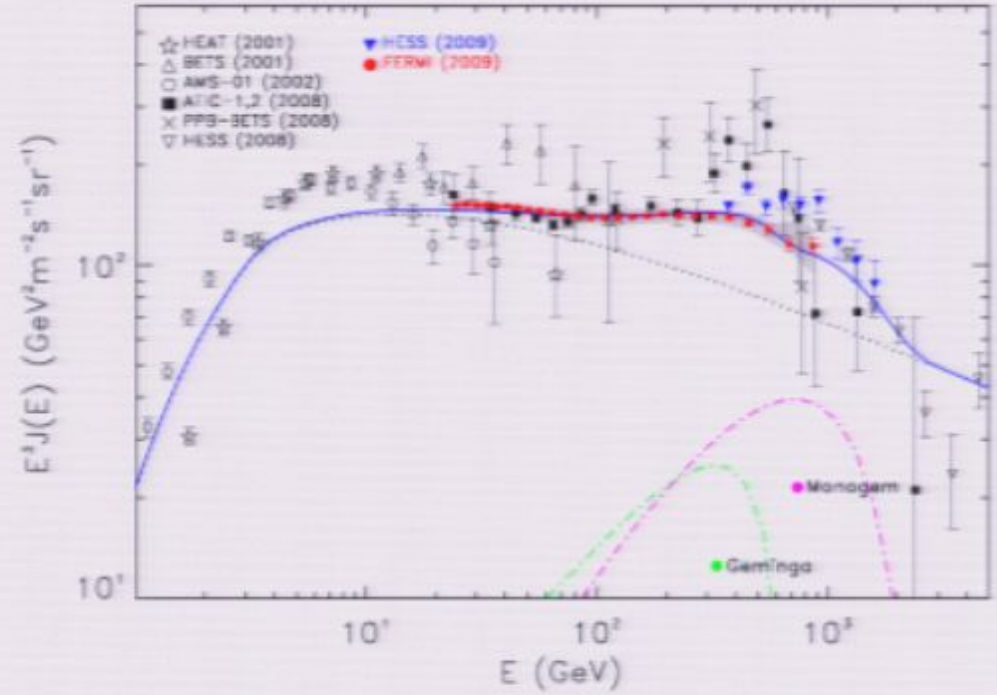
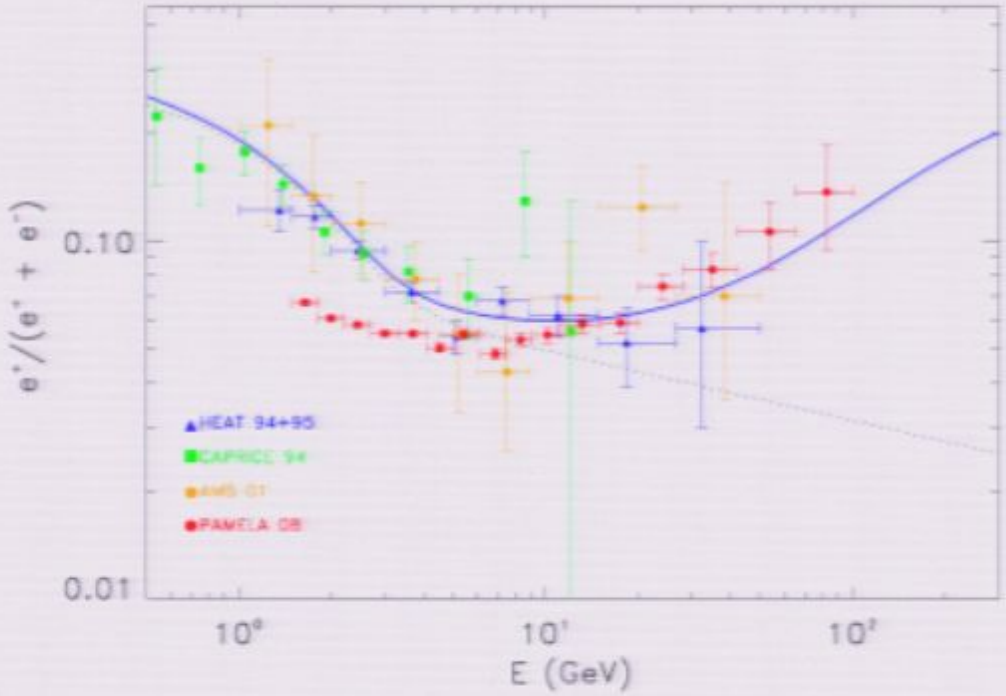
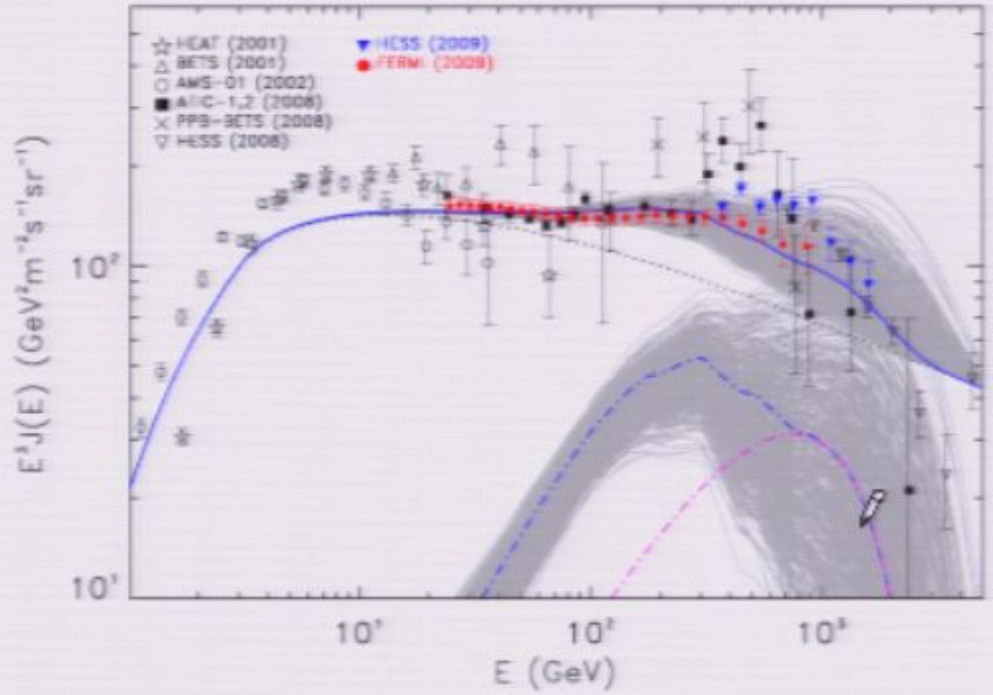
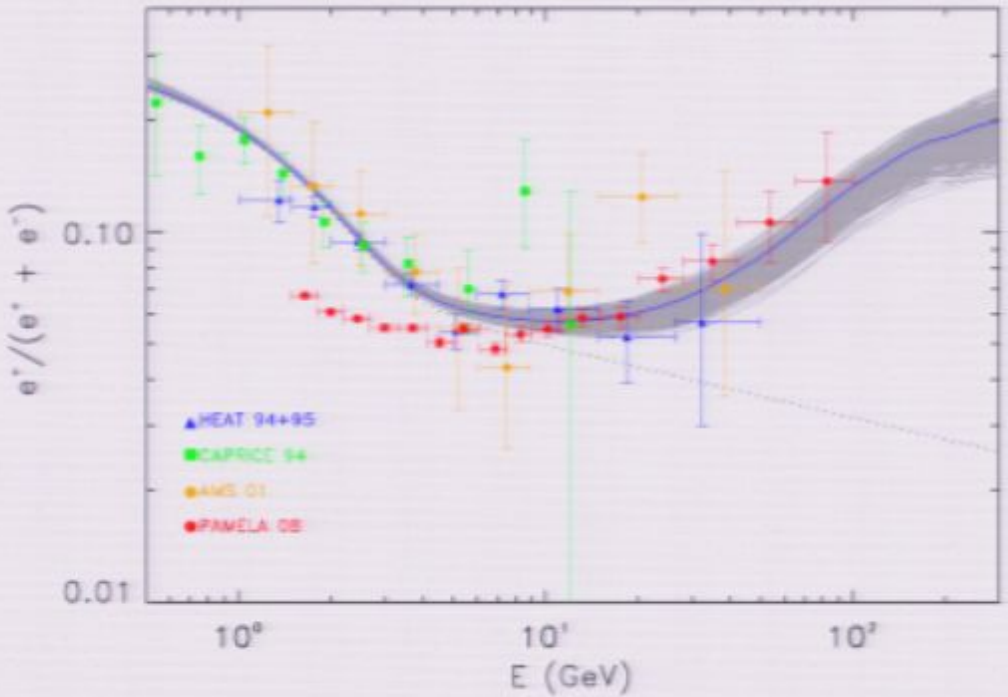




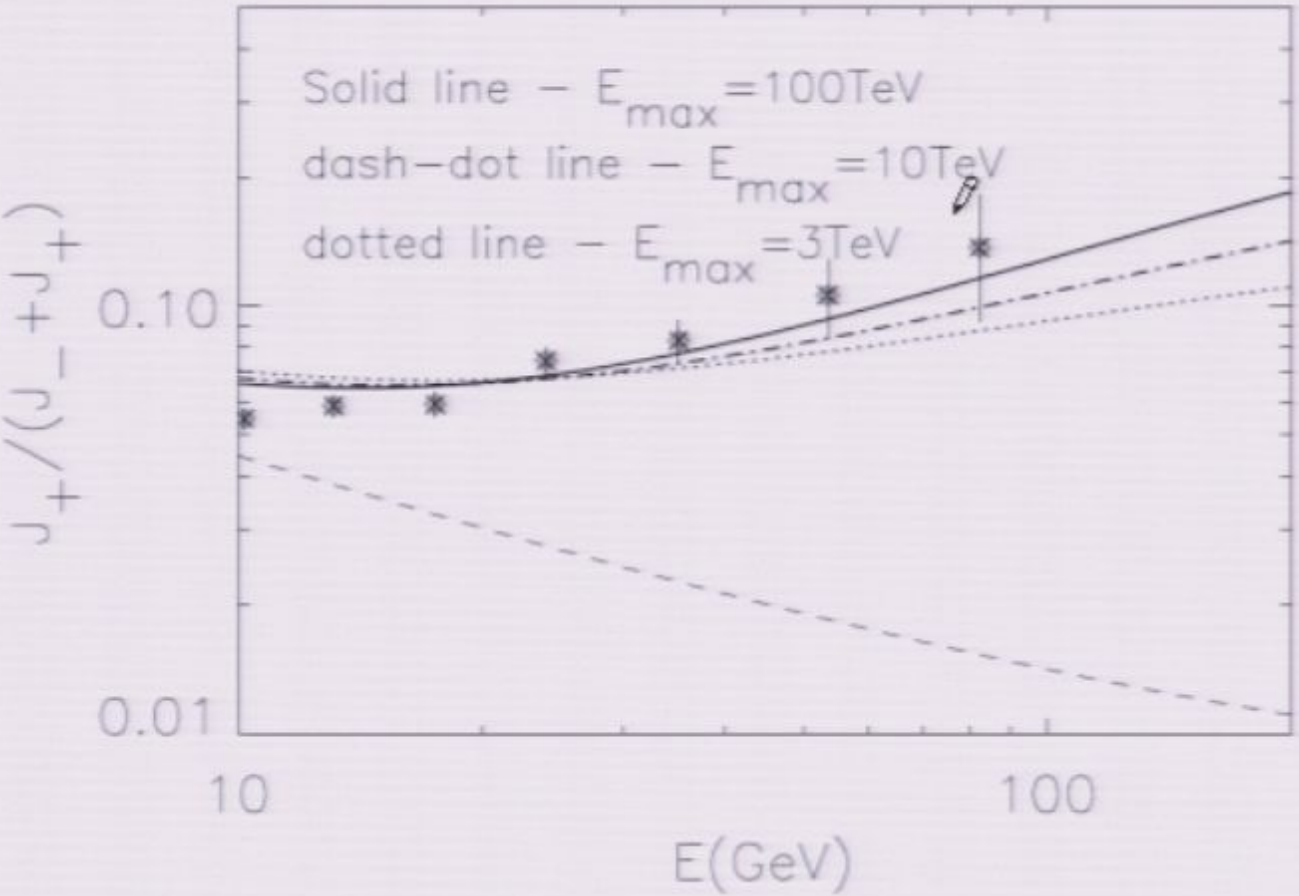




The origin of the positron excess in cosmic rays

Pasquale Blasi

Acceleration **and** spallation in SN shock waves



B/C and $\bar{p}/p$ should increase at high E

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

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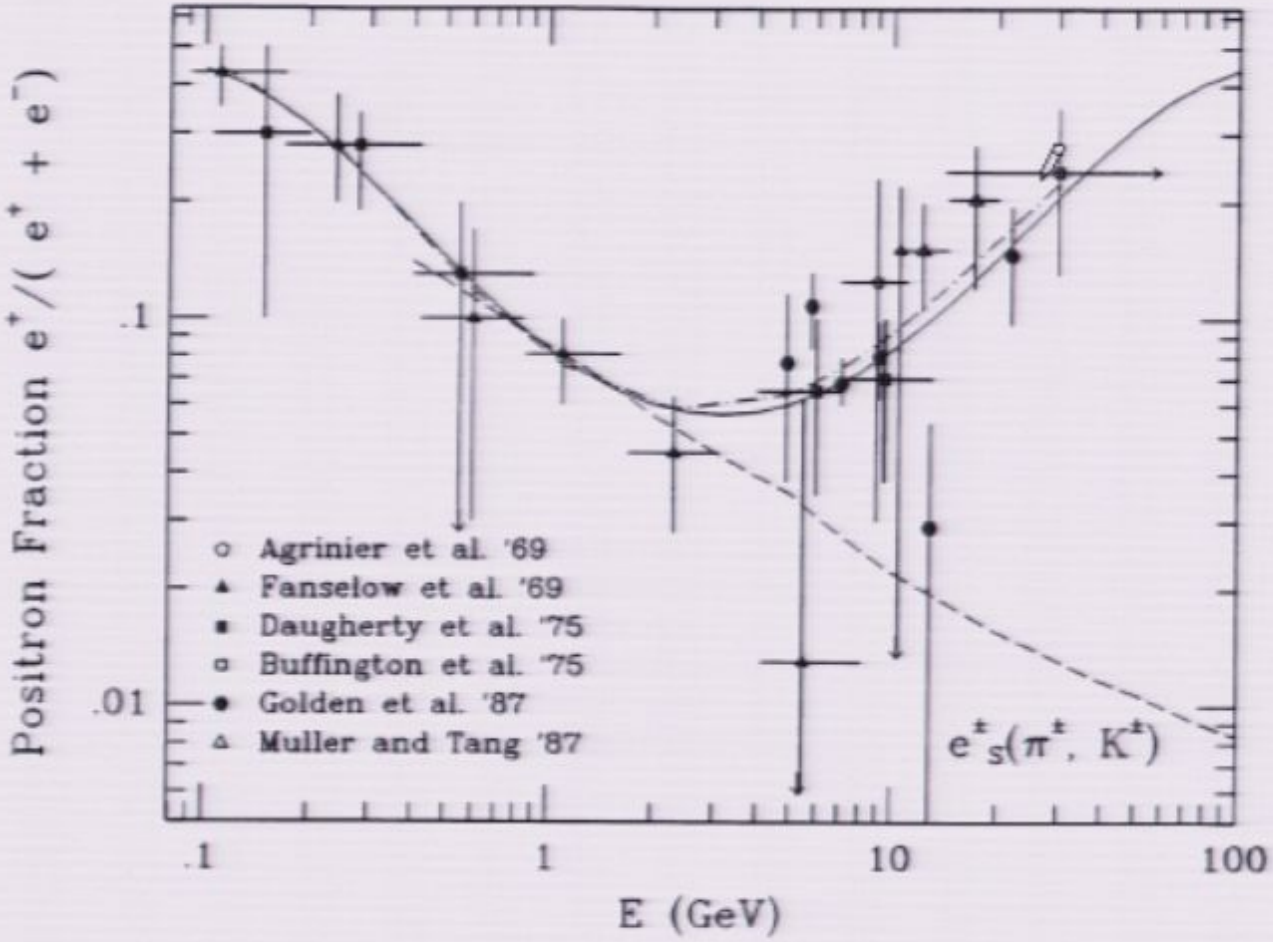

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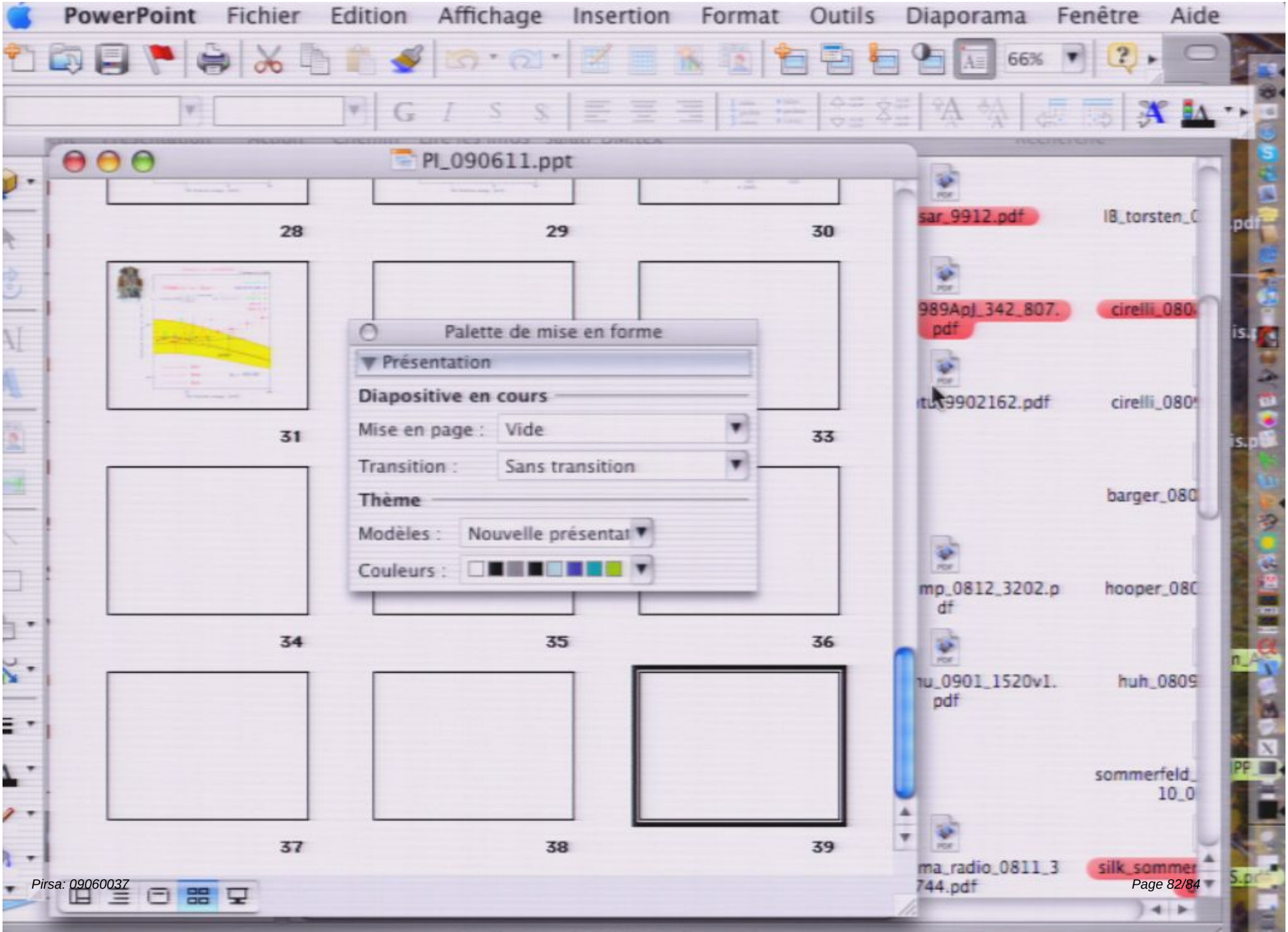
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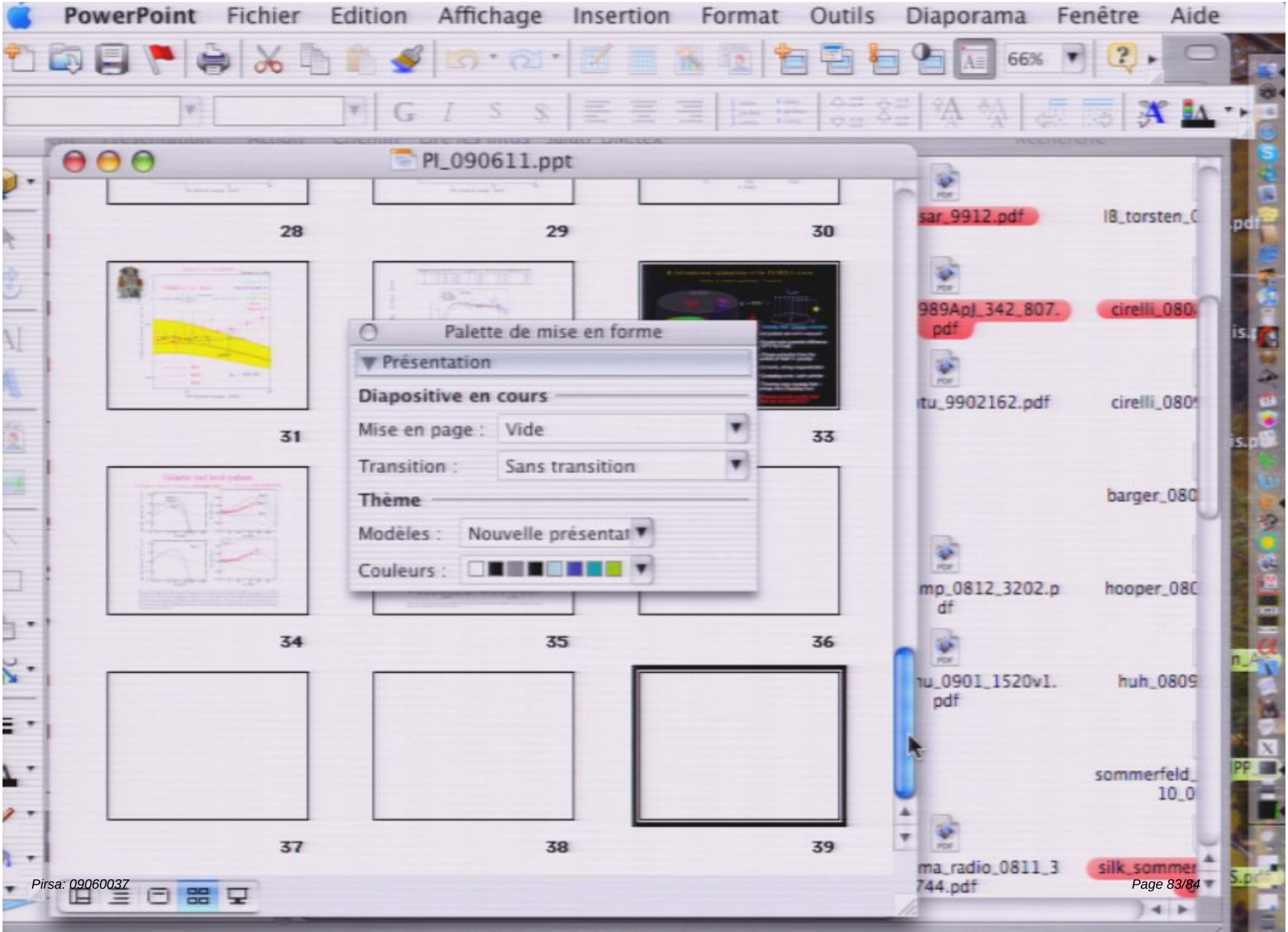
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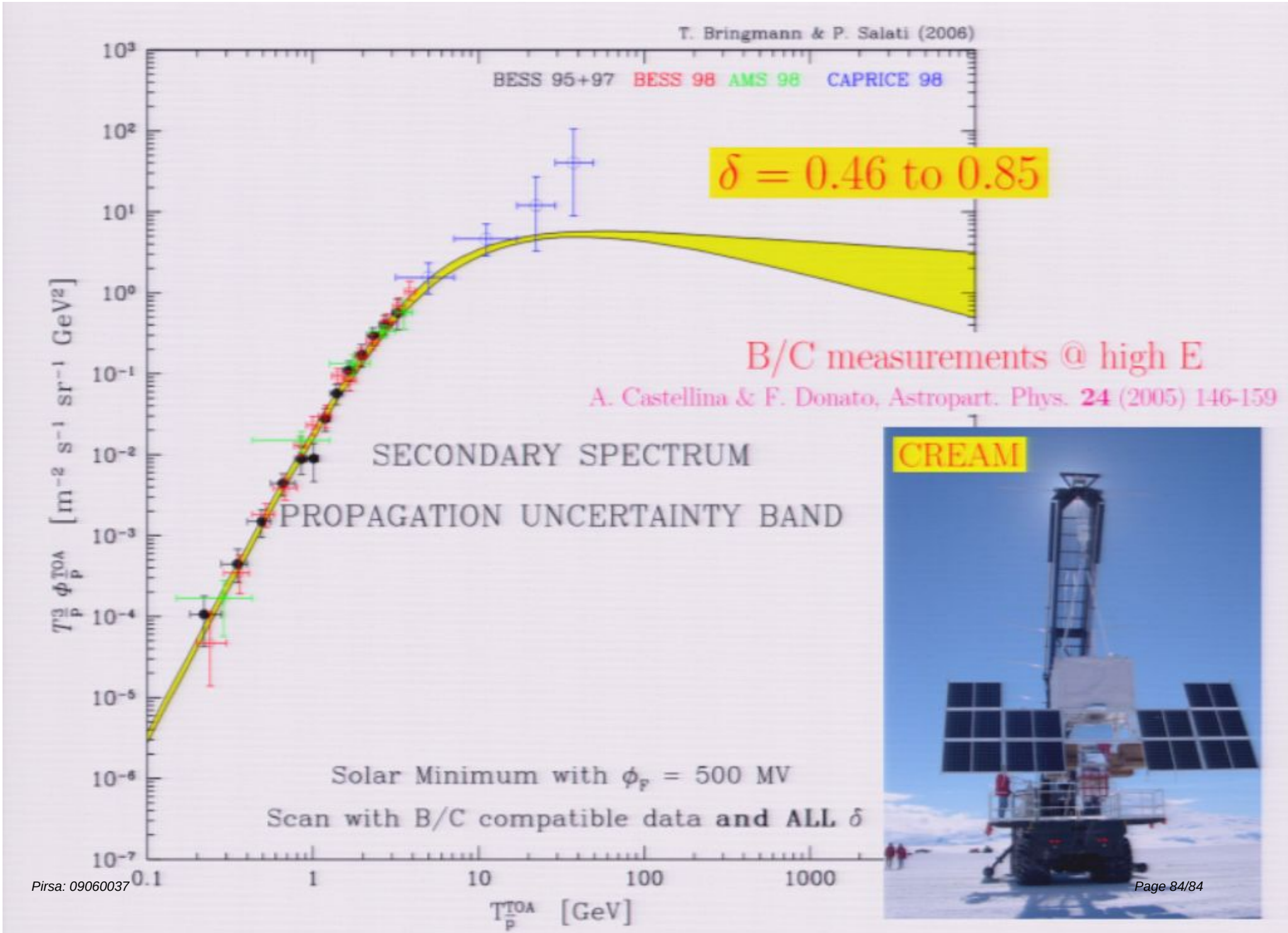
T. Bringmann & P. Salati (2006)
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BESS 98
AMS 98
CAPRICE 98
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B/C measurements @ high E
A. Castellina & F. Donato, Astropart. Phys. 24 (2005) 146-159
SECONDARY SPECTRUM
PROPAGATION UNCERTAINTY BAND
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