Constraining Dark Matter with cosmic ray data

IAP

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Collaborators

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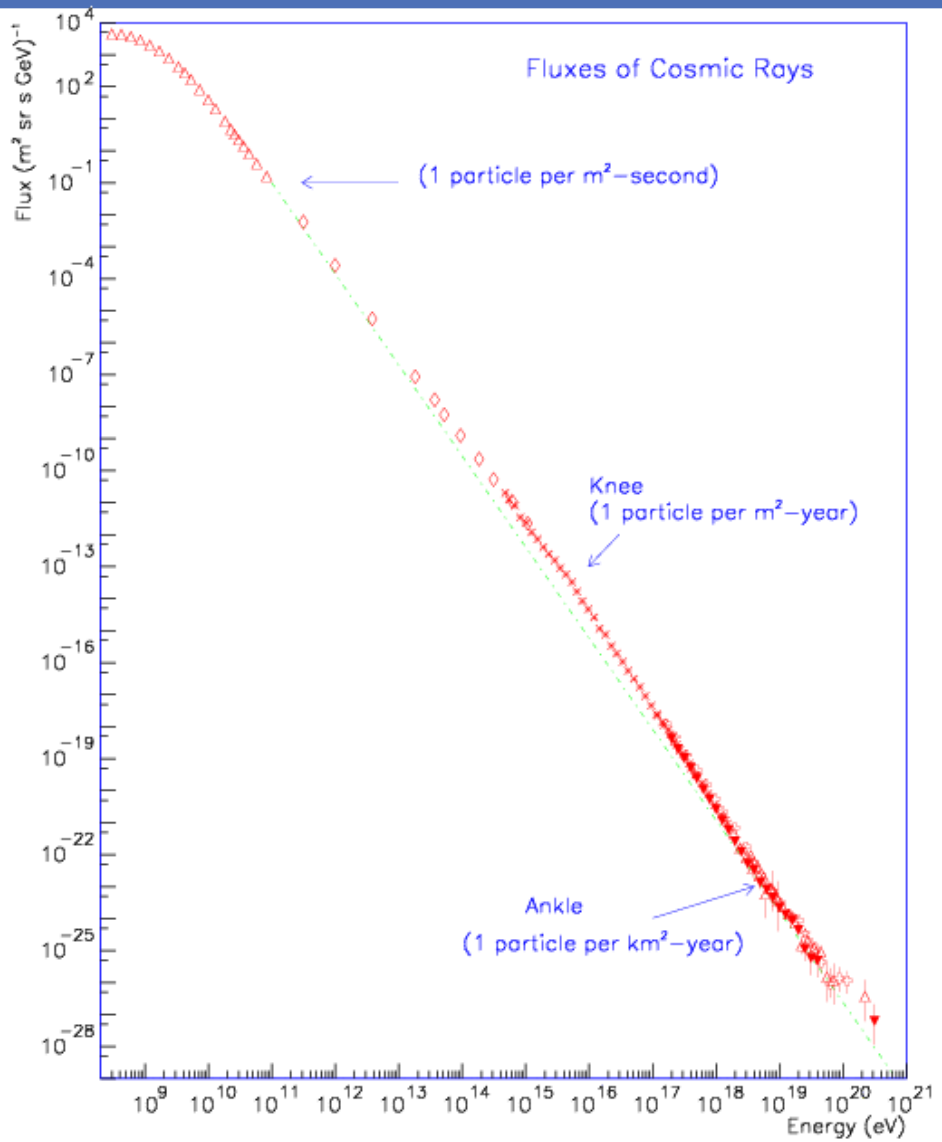
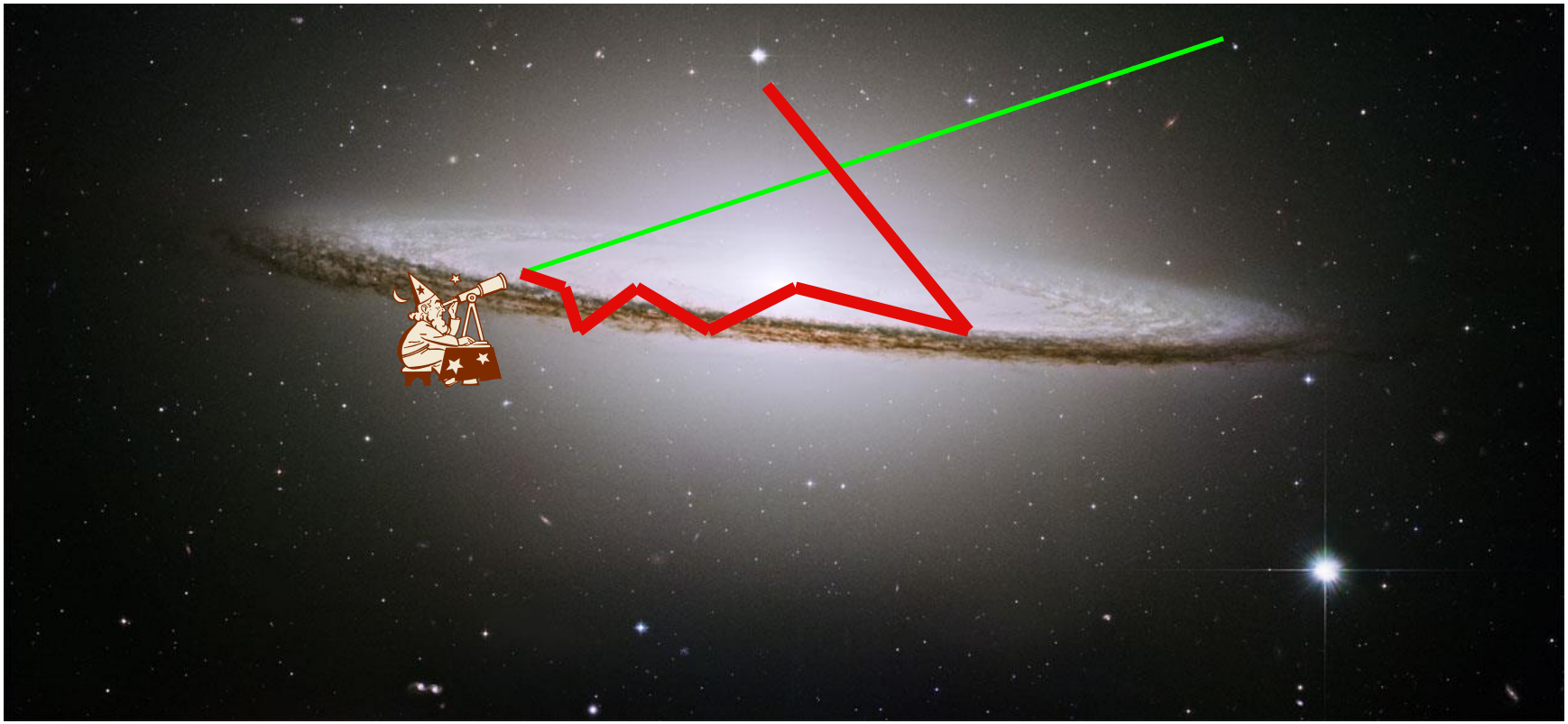
- Turin
  - Nicolao Fornengo
  - Fiorenza Donato
  - Julien Lavalle
  - Roberto Lineros
- Paris
  - Pierre Brun
  - David Maurin

Cosmic rays


Fluxes of Cosmic Rays
(1 particle per m²–second)
Knee
(1 particle per m²–year)
Ankle
(1 particle per km²–year)
Flux (m² sr s GeV)⁻¹
Energy (eV)

What is Dark Matter indirect detection?

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



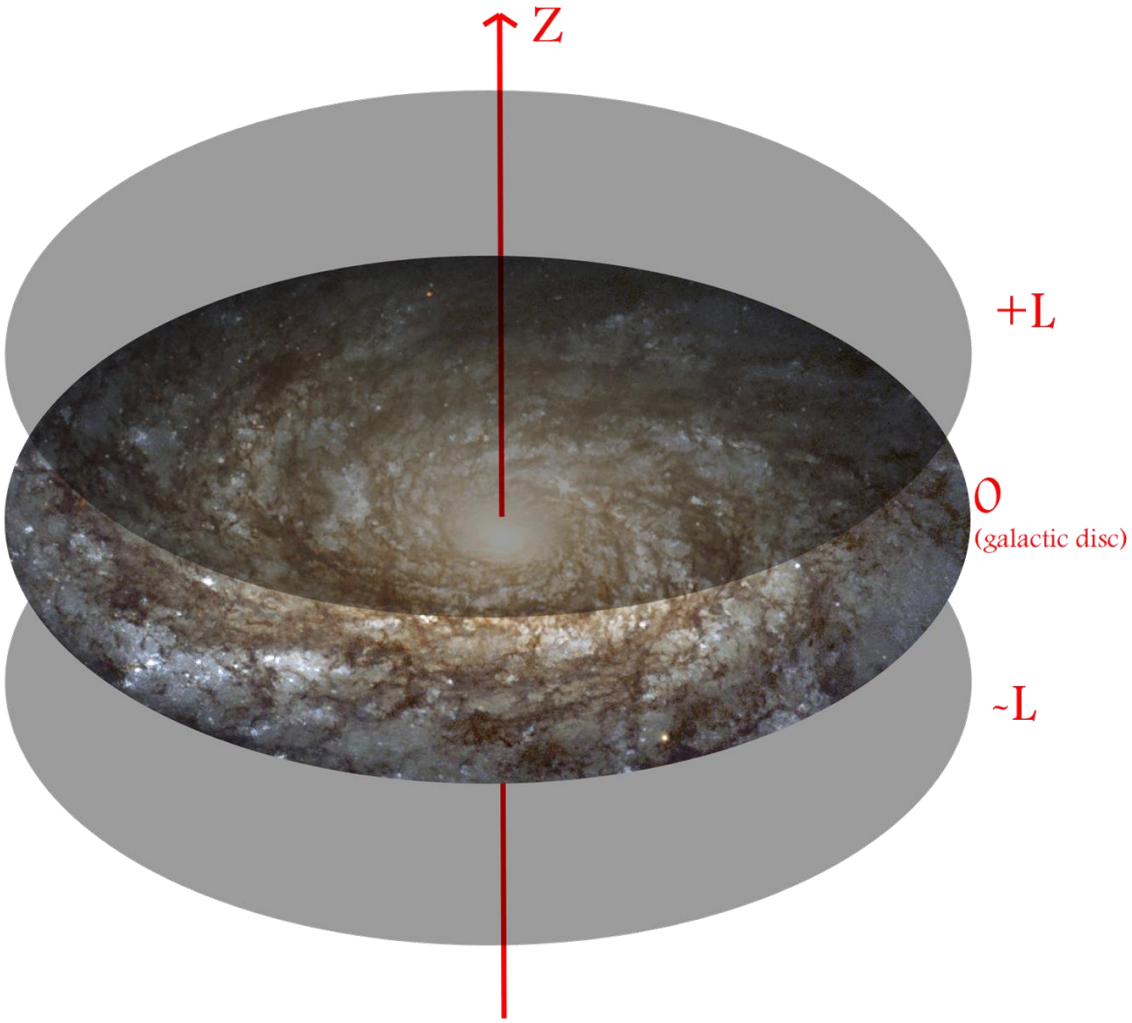
What is the background ?

$$p \text{ or } \alpha \text{ (CR)} \quad + \quad \text{ISM} \quad \rightarrow \quad \gamma, \bar{p}, \ \bar{D}, \ e^+ \ \& \ \nu' s$$

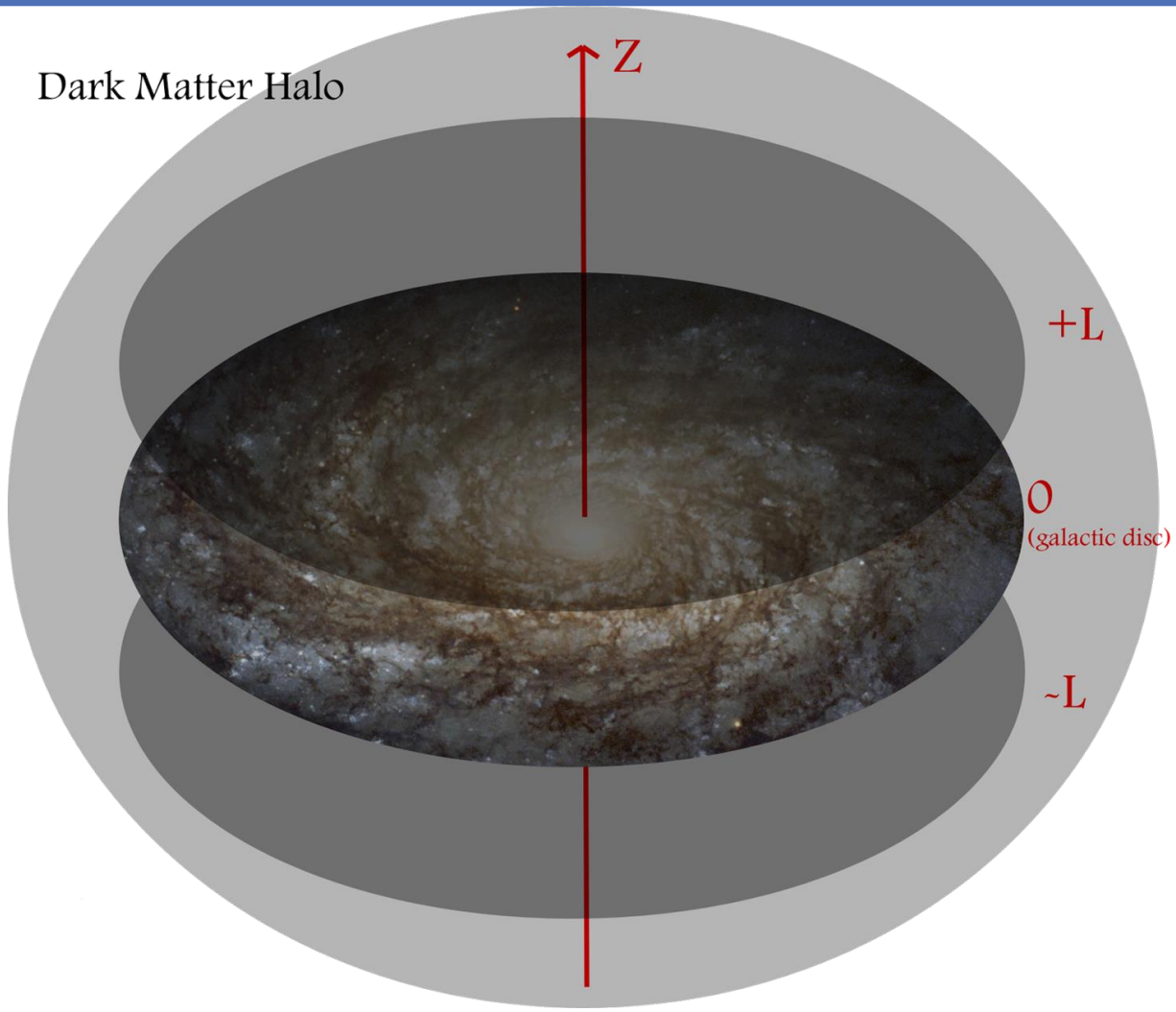
Charged Particles

- Creation
- Propagation

The propagation model



The propagation model



Diffusion equation

$$\nabla \cdot \left\{ - K_0 \, \epsilon^{\delta} \, \nabla N \, + \, \mathbf{V}_C(z) N \right\} \; + \\ + 2 \, h \, \delta(z) \frac{\partial}{\partial \epsilon} \left\{ b^{\mathrm{loss}}(\epsilon) \, N \; - \; K_{\epsilon\epsilon} \, \frac{\partial N}{\partial \epsilon} \right\} \; = \; q_{e^+}(\mathbf{x}, \epsilon)$$

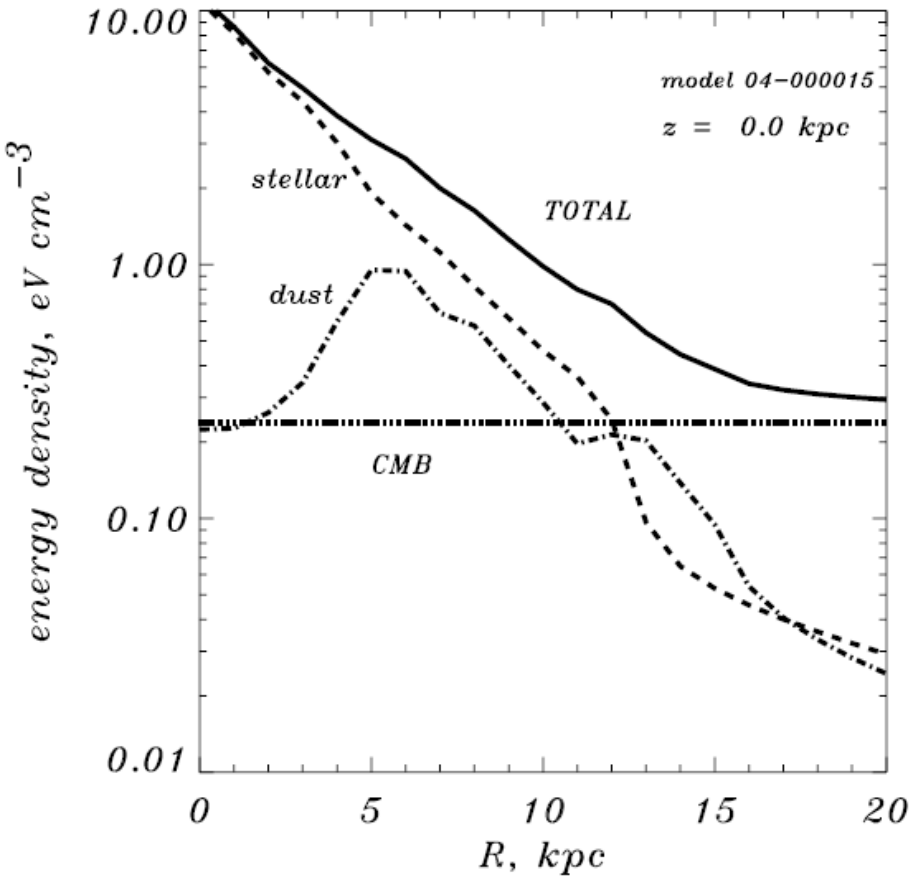
Energy losses

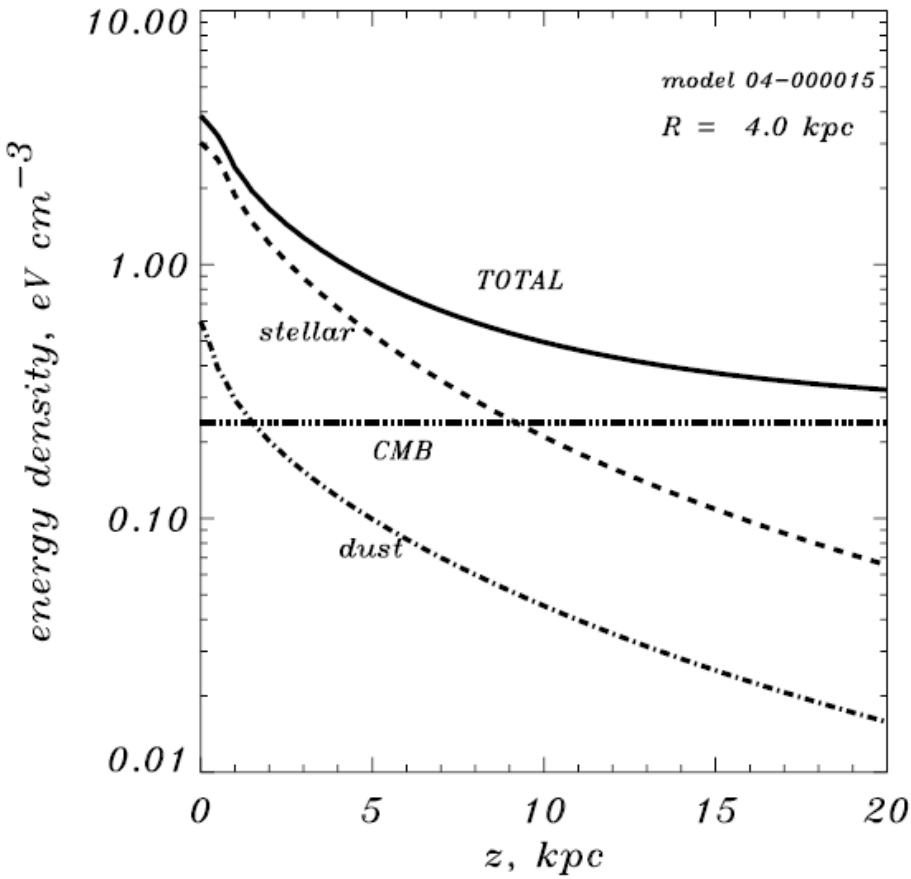
$$-b^{\mathrm{loss}}(\epsilon) = \begin{cases} \dfrac{\epsilon^2}{\tau_E} & \text{Inverse Compton and synchrotron} \\ +\nabla \cdot \mathbf{V}_C \, \dfrac{p^2}{6h\epsilon} & \text{Adiabatic losses} \\ +K_b \, n_H \, \epsilon & \text{Bremsstrahlung} \\ +K_i \, n_H \left\{ 3 \ln\left(\dfrac{E}{m_e}\right)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

Main losses

$$-b^{\mathrm{loss}}(\epsilon) = \frac{\epsilon^2}{\tau_E} = \frac{\epsilon^2}{\tau_{\mathrm{sync}}} + \frac{\epsilon^2}{\tau_*} + \frac{\epsilon^2}{\tau_{\mathrm{CMB}}}$$

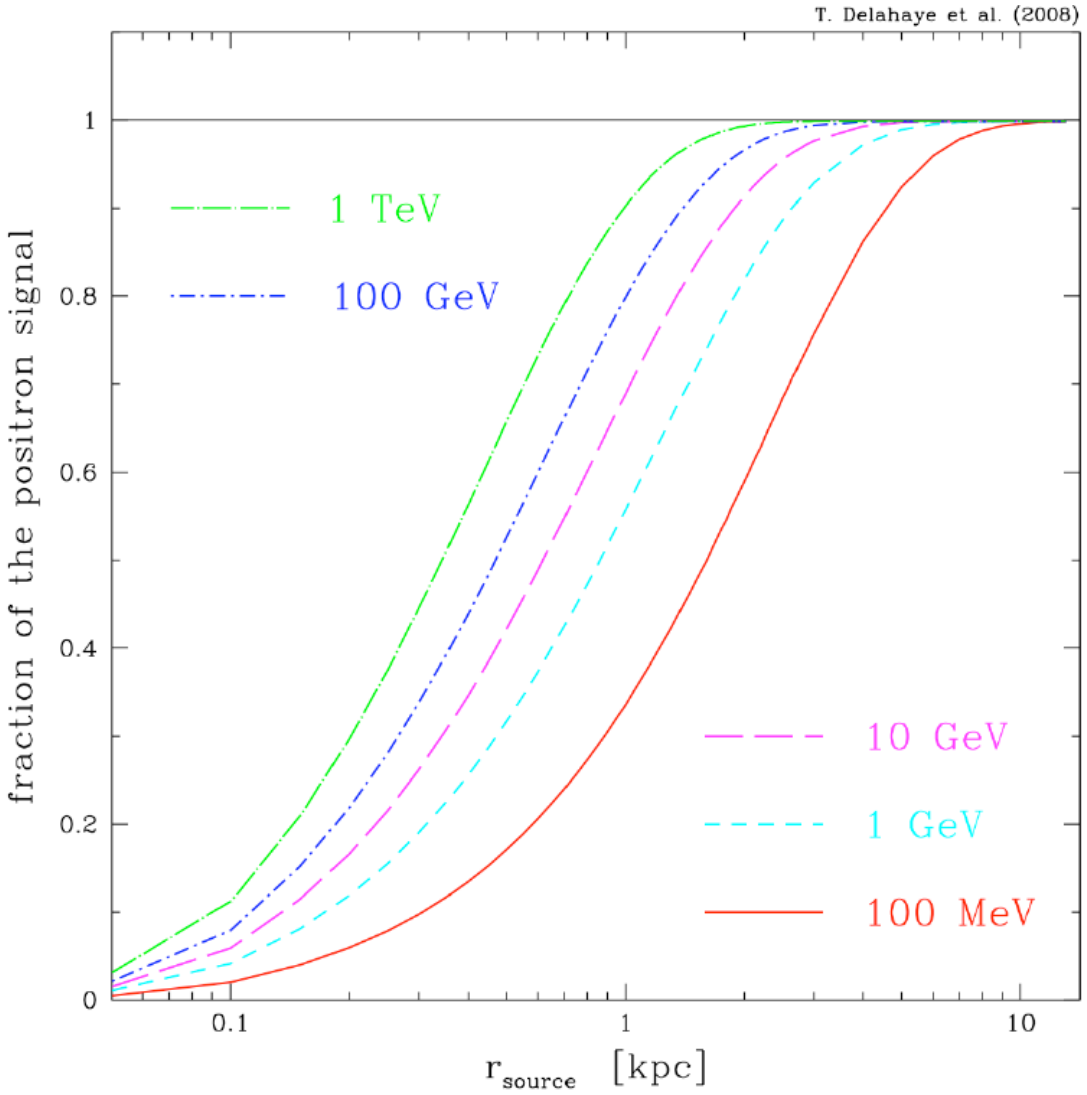
Inverse Compton





Stong, Moskalenko & Reimer APJ, 537,2, pp. 763-784

Positrons: Origin

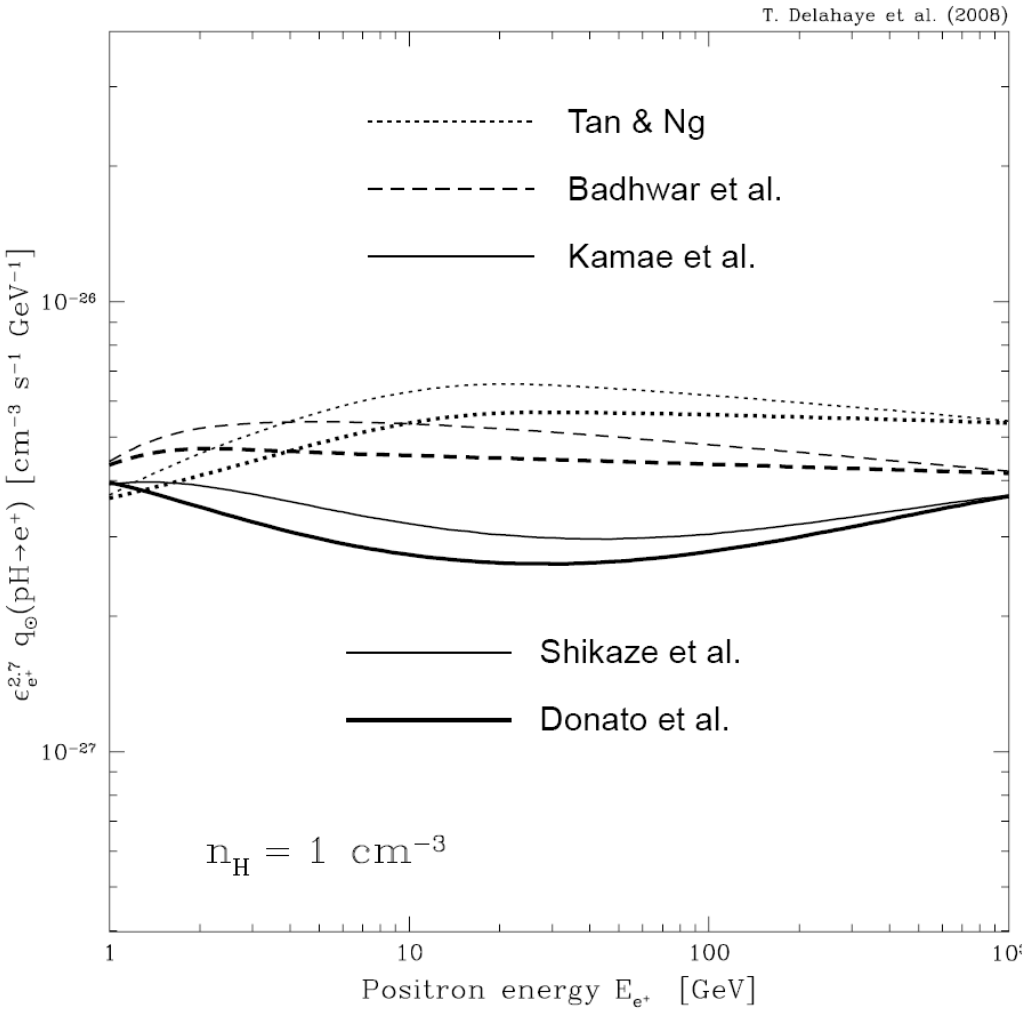


arXiv:0809.5268

Positrons: the uncertainties

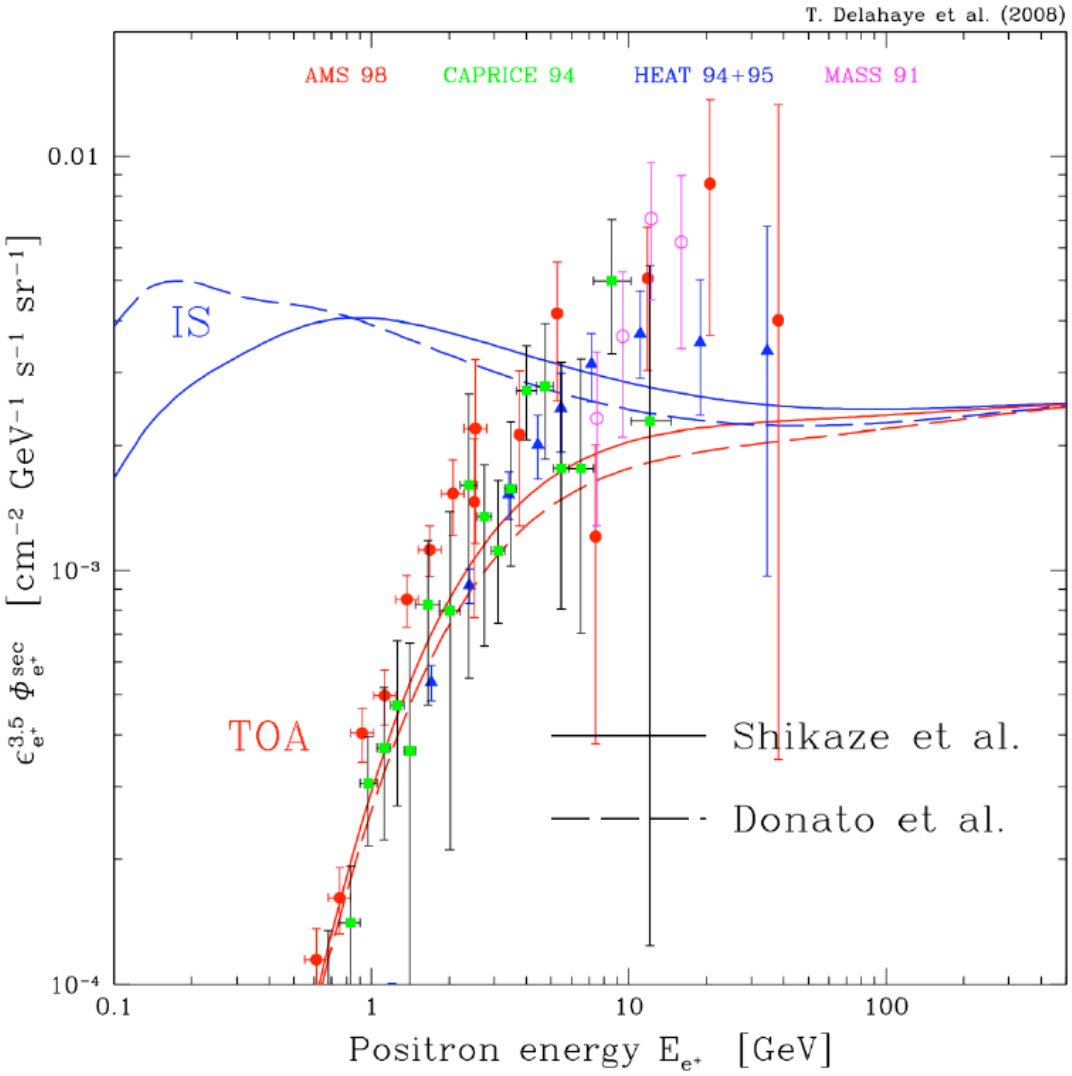
- Cross sections
  - Badhwar et alii 1977, Phys. Rev. D,15, 820
  - Tan & Ng 1983, Journal of Physics G Nuclear Physics,9, 1289
  - Kamae et alii 2006, ApJ, 647, 692
- Proton flux
  - Shikaze et alii 2007, Astroparticle Physics, 28,154
  - Donato et alii 2001, ApJ, 563, 172
- Propagation parameters
  - Boron/Carbon analysis: Maurin et alii 2001, ApJ, 555,585

Positrons: source

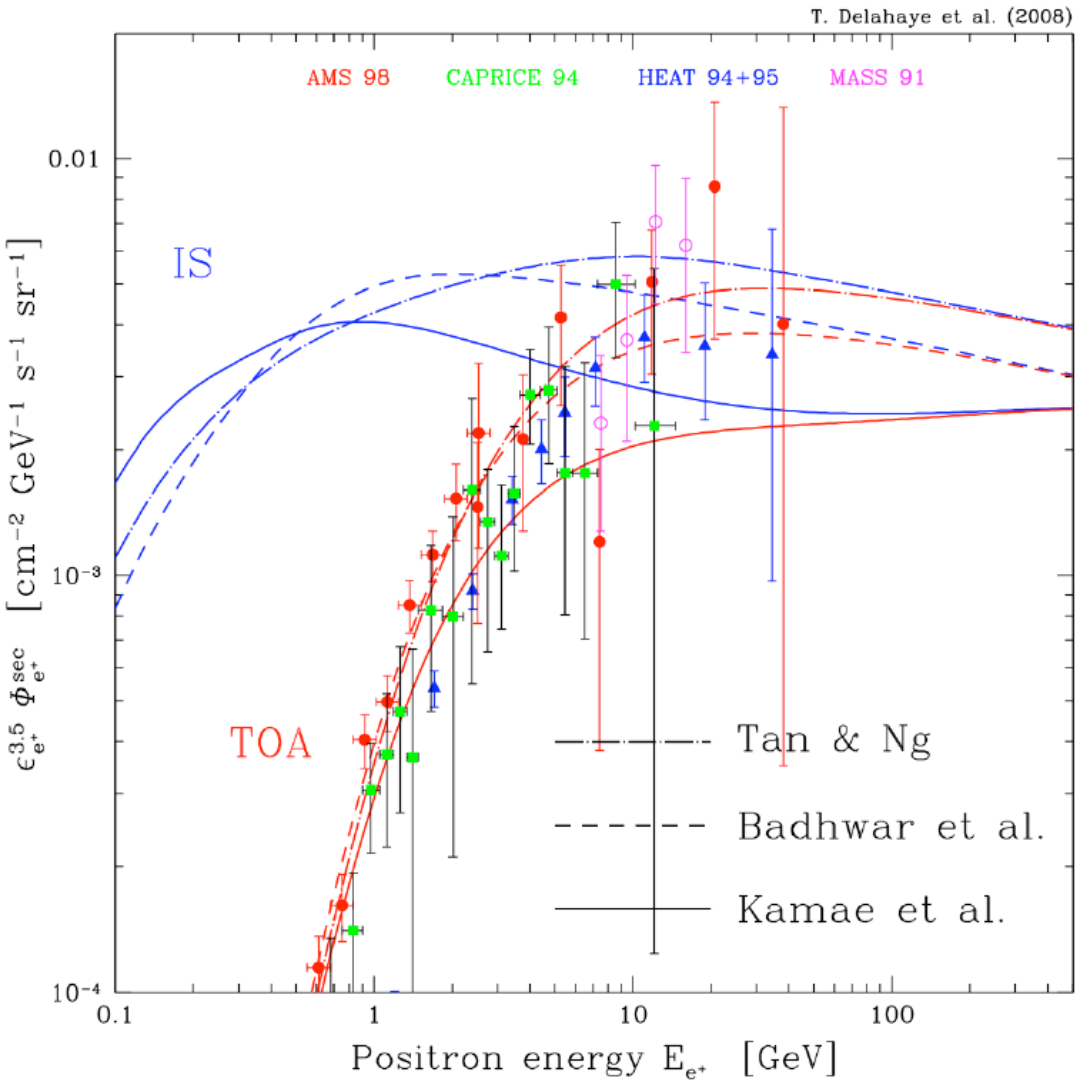


arXiv:0809.5268

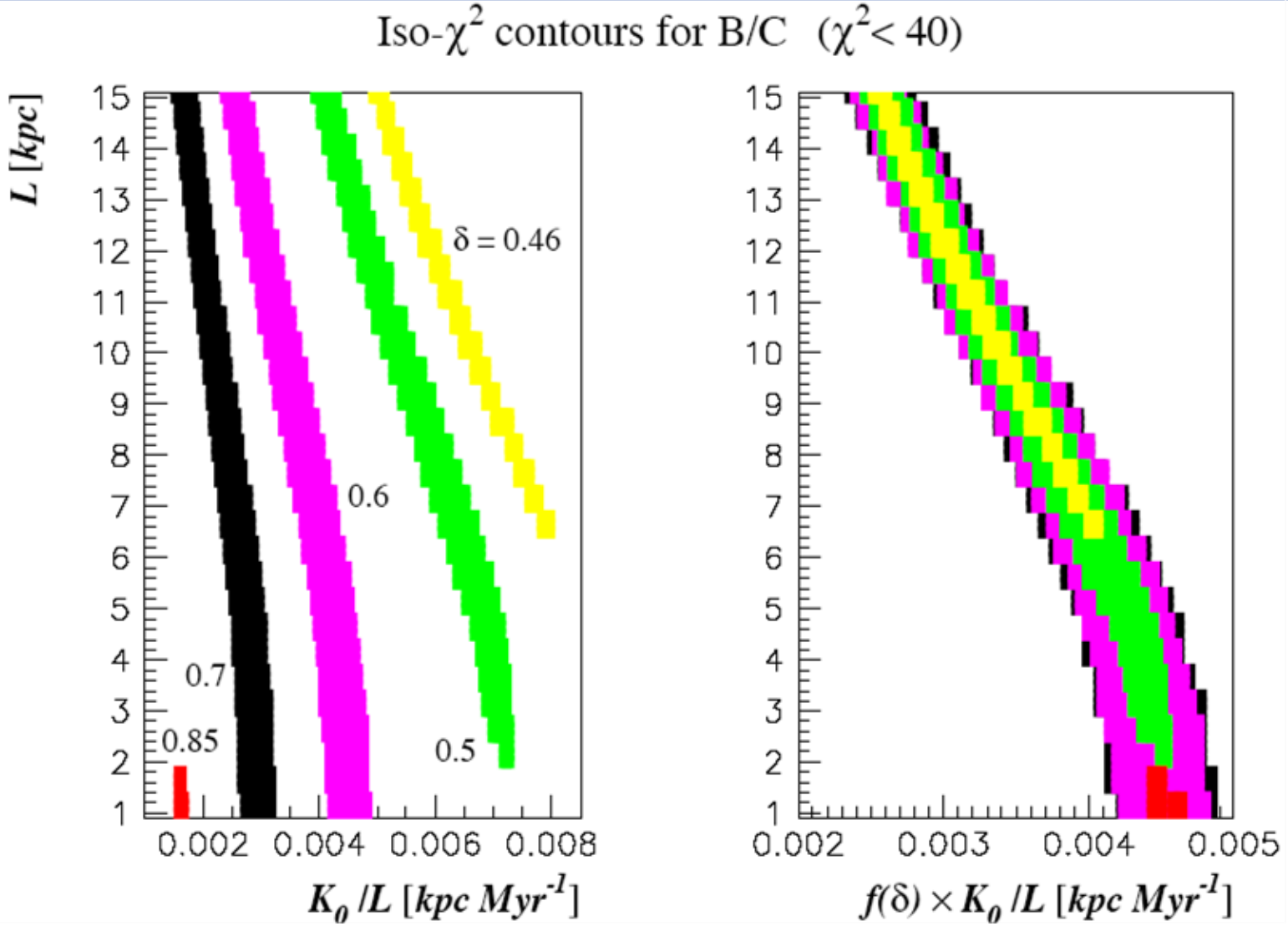
Proton influence



Cross-section influence



Diffusion parameters

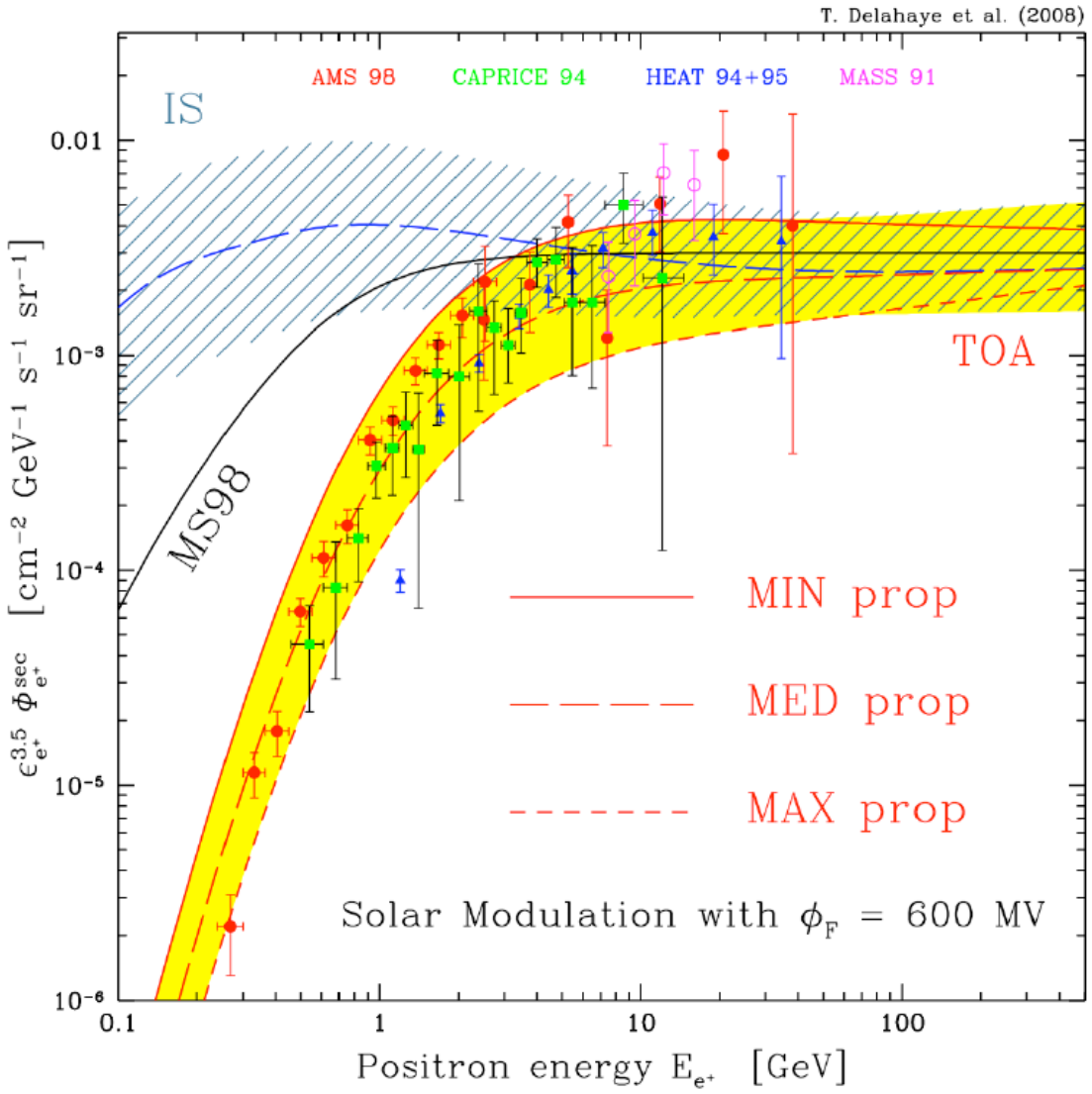


Diffusion equation

$$\nabla \cdot \left\{ - K_0 \, \epsilon^{\delta} \, \nabla N + \mathbf{V}_C(z) N \right\} +$$

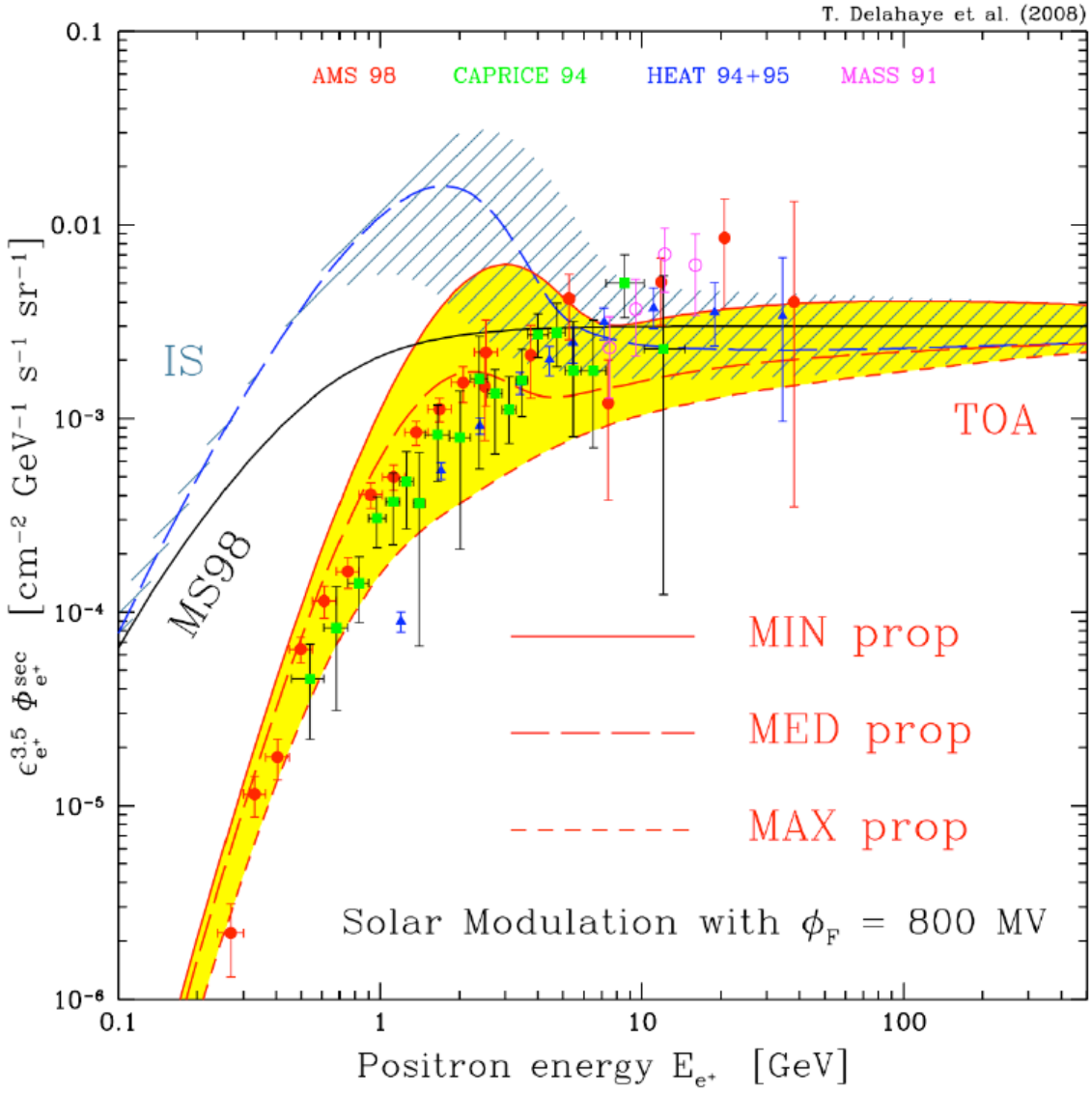
$$+ 2 \, h \, \delta(z) \frac{\partial}{\partial \epsilon} \left\{ b^{\mathrm{loss}}(\epsilon) \, N - K_{\epsilon\epsilon} \frac{\partial N}{\partial \epsilon} \right\} = q_{e^+}(\mathbf{x}, \epsilon)$$

Positrons: the background



arXiv:0809.5268

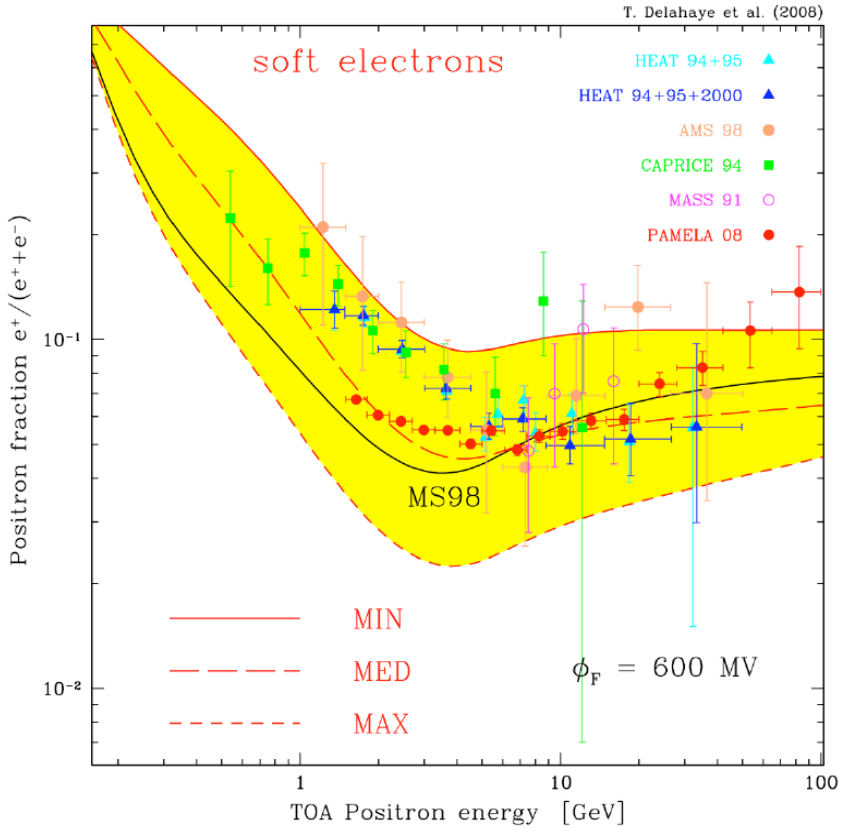
Positrons: the background

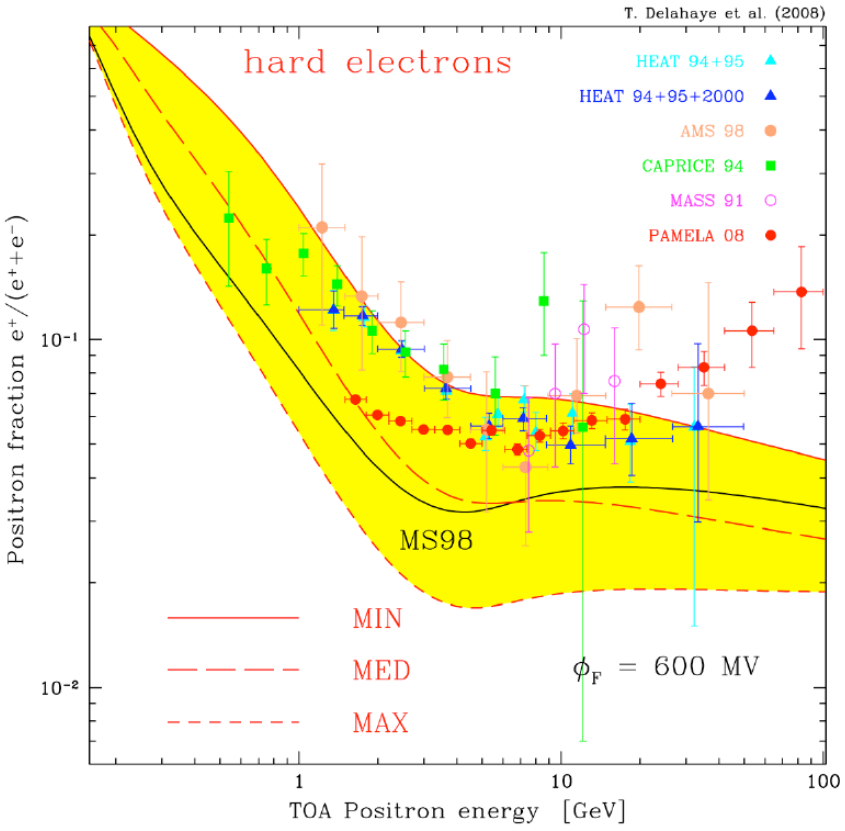


arXiv:0809.5268

PAMELA

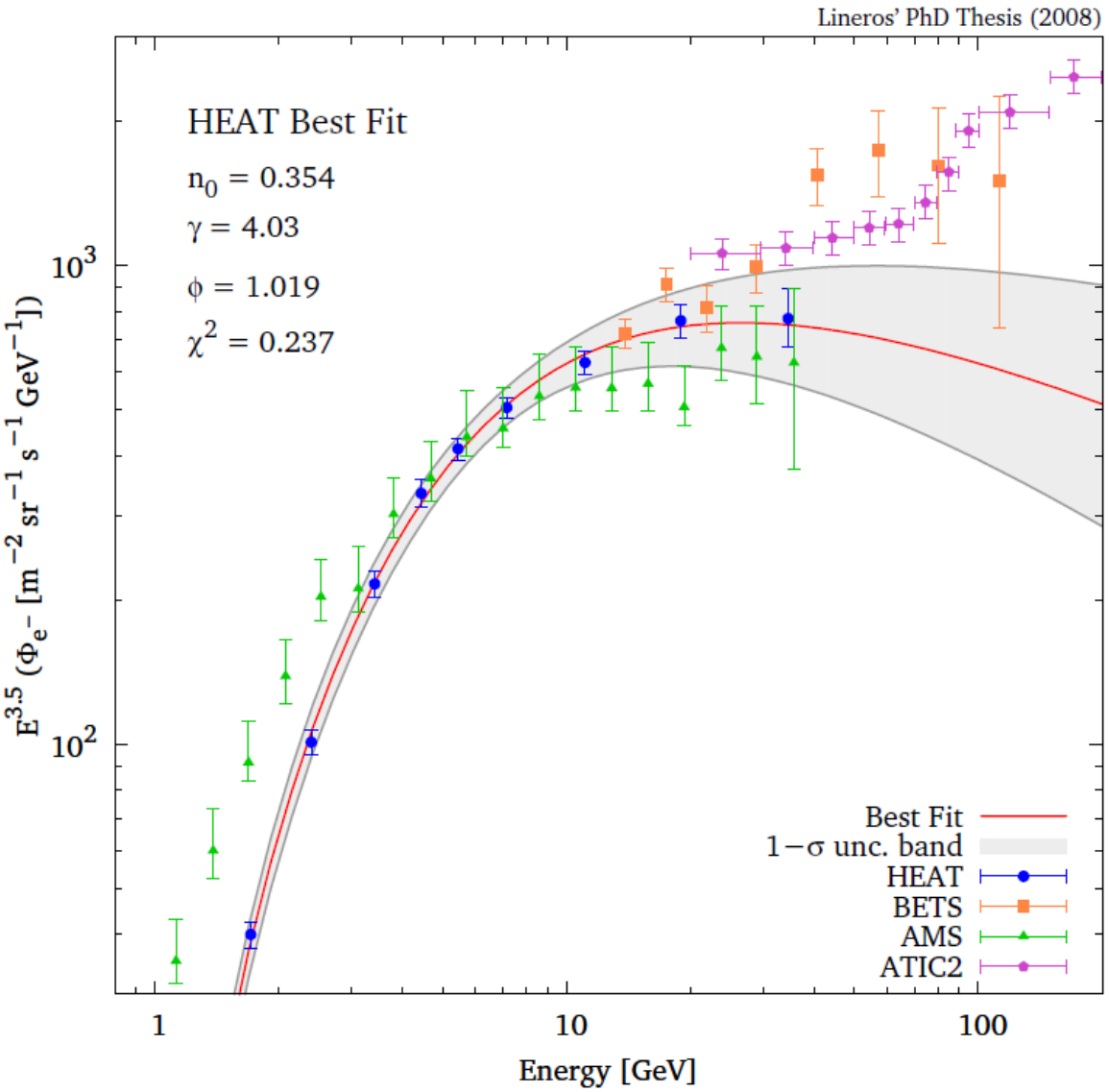
Positron fraction



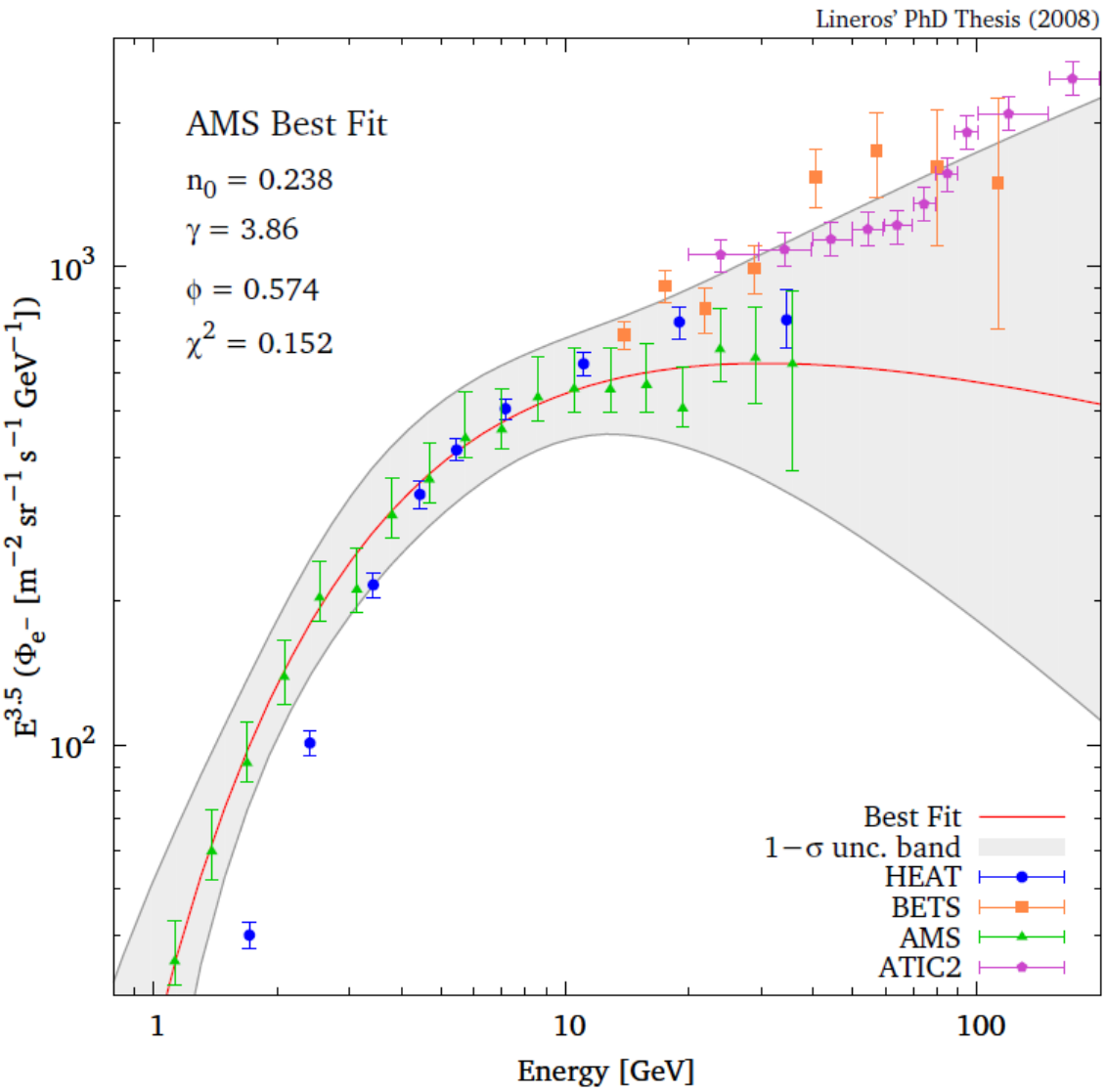


arXiv:0809.5268

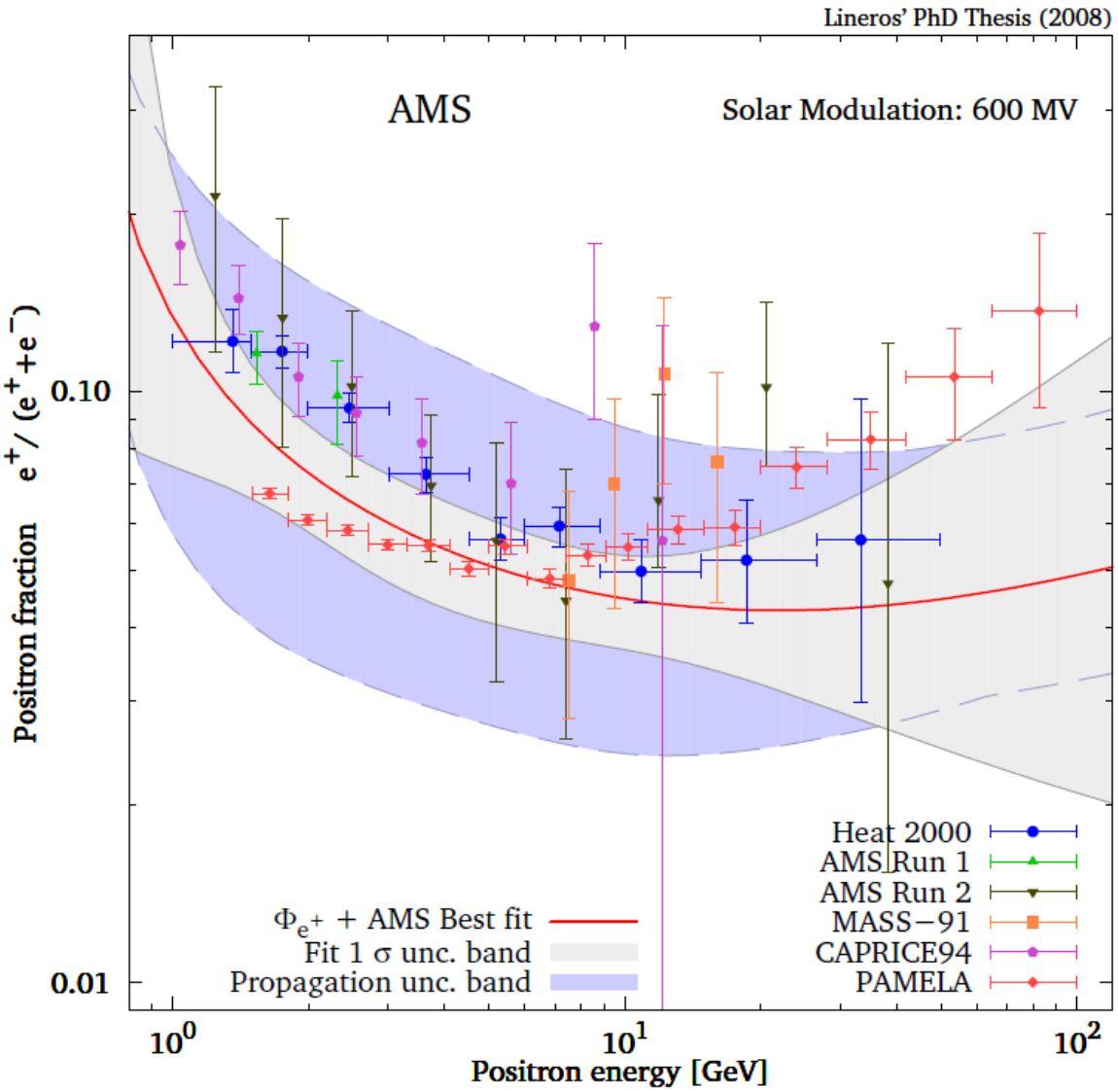
Electrons


Lineros' PhD Thesis (2008)
HEAT Best Fit
$n_0 = 0.354$
$\gamma = 4.03$
$\phi = 1.019$
$\chi^2 = 0.237$
$E^{3.5}\,(\Phi_{e^-}\,[m^{-2}\,sr^{-1}\,s^{-1}\,GeV^{-1}])$
10^3
10^2
1
10
100
Energy [GeV]
Best Fit
1−σ unc. band
HEAT
BETS
AMS
ATIC2

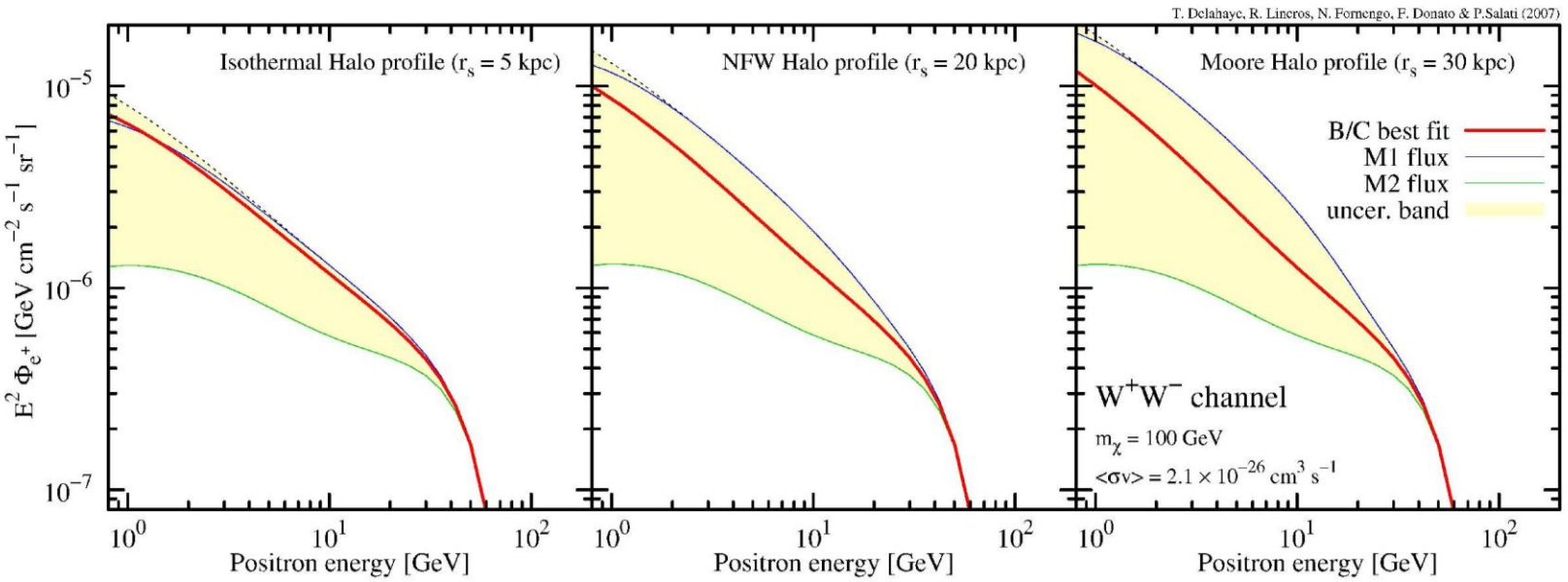
Electrons


Lineros' PhD Thesis (2008)
AMS Best Fit
$n_0 = 0.238$
$\gamma = 3.86$
$\phi = 0.574$
$\chi^2 = 0.152$
$E^{3.5}\,(\Phi_{e^-}\ [m^{-2}\,sr^{-1}\,s^{-1}\,GeV^{-1}])$
10^3
10^2
1
10
100
Energy [GeV]
Best Fit
1−σ unc. band
HEAT
BETS
AMS
ATIC2

Positron fraction

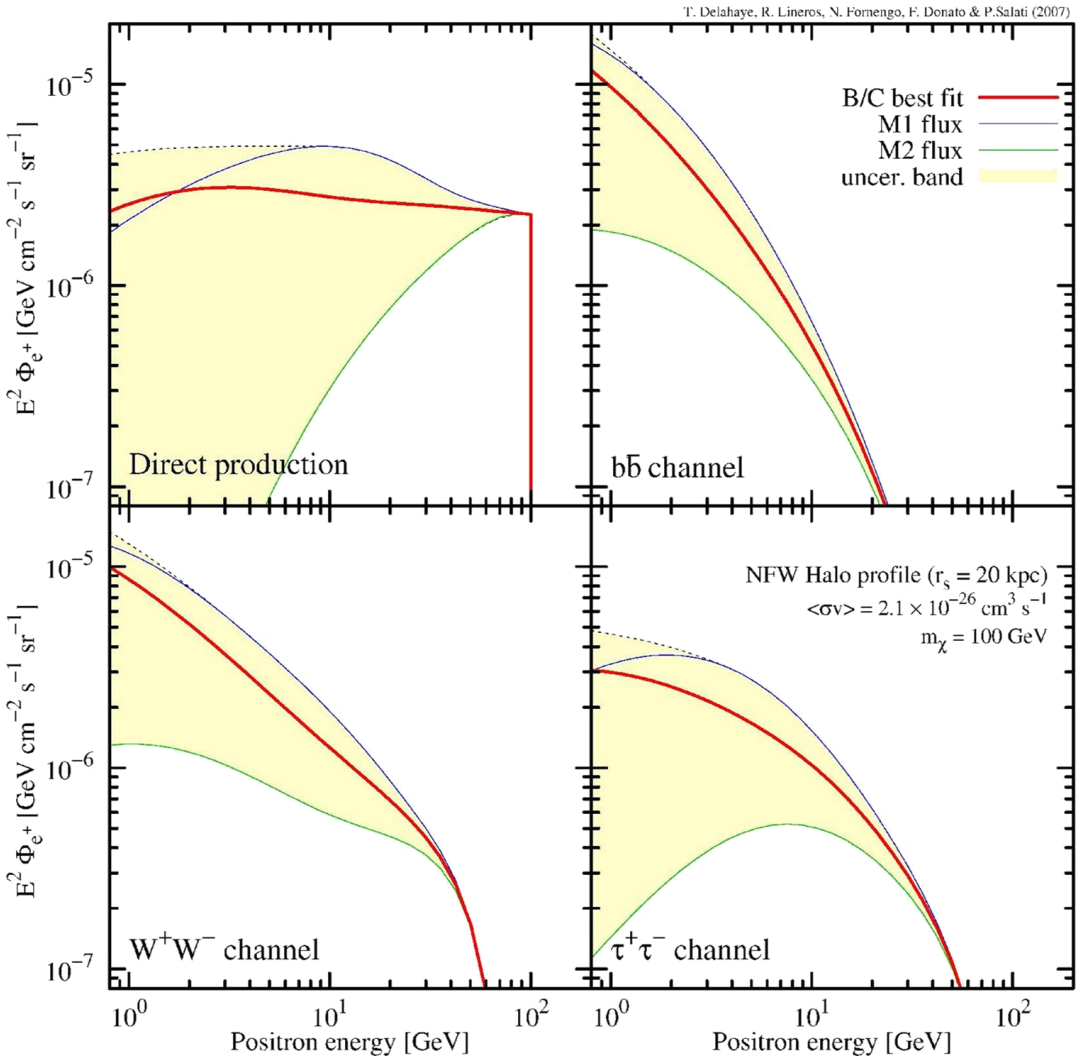


Influence of the halo profile



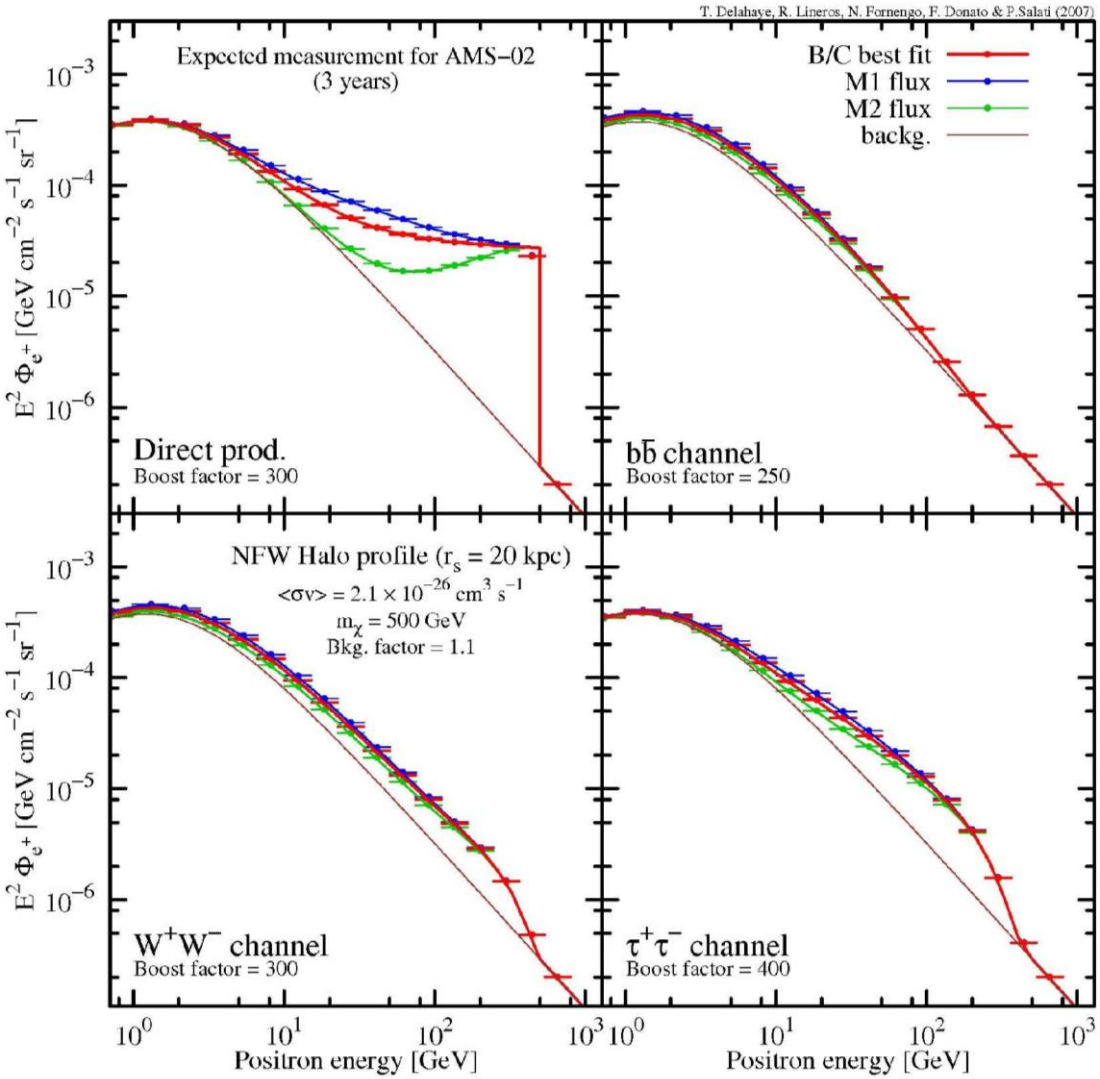
PRD77 (2008) 063527

Influence of the channel



PRD77 (2008) 063527

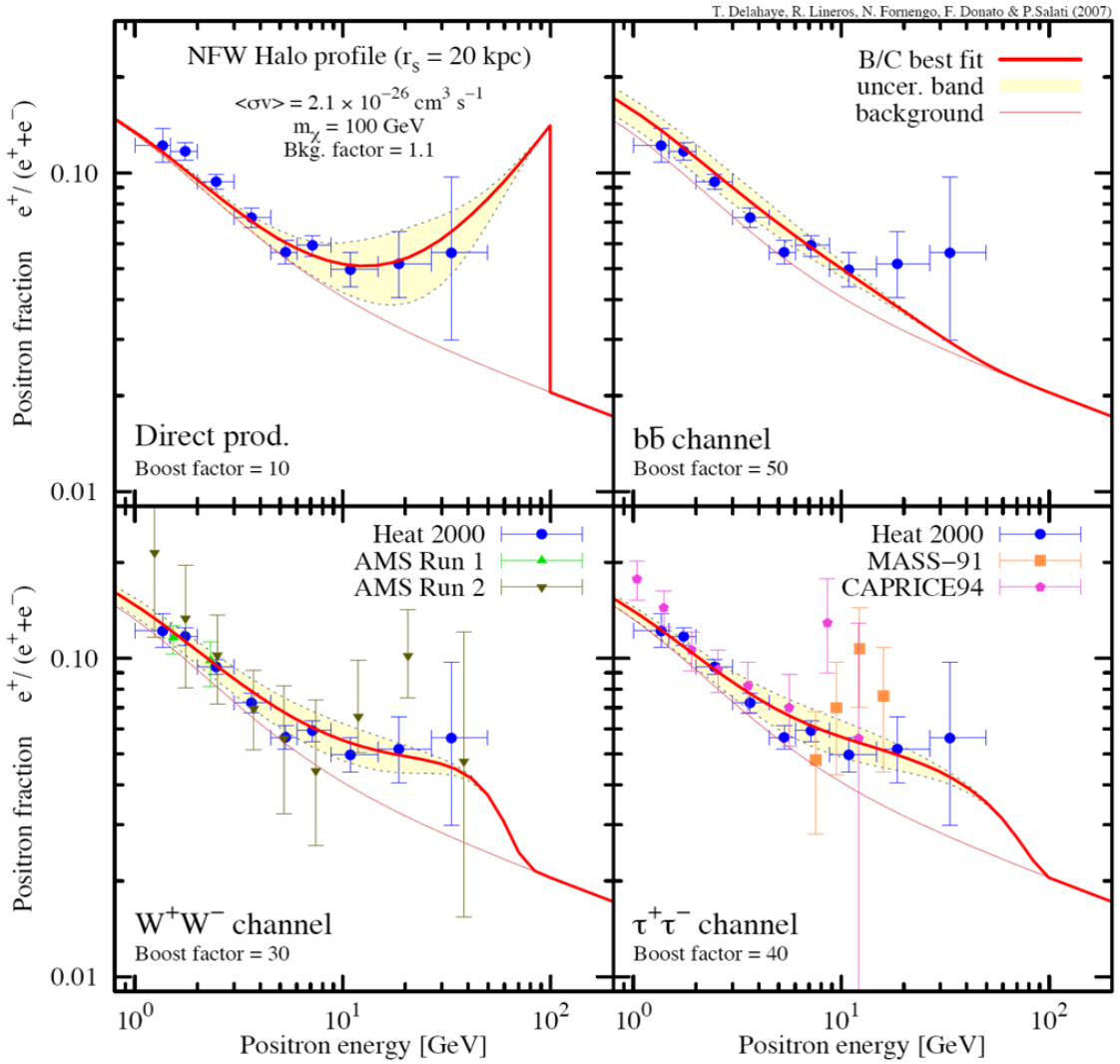
Total flux



GALPROP APJ 493 (1998) 694

PRD77 (2008) 063527

Dark Matter ?



GALPROP APJ 493 (1998) 694

PRD77 (2008) 063527

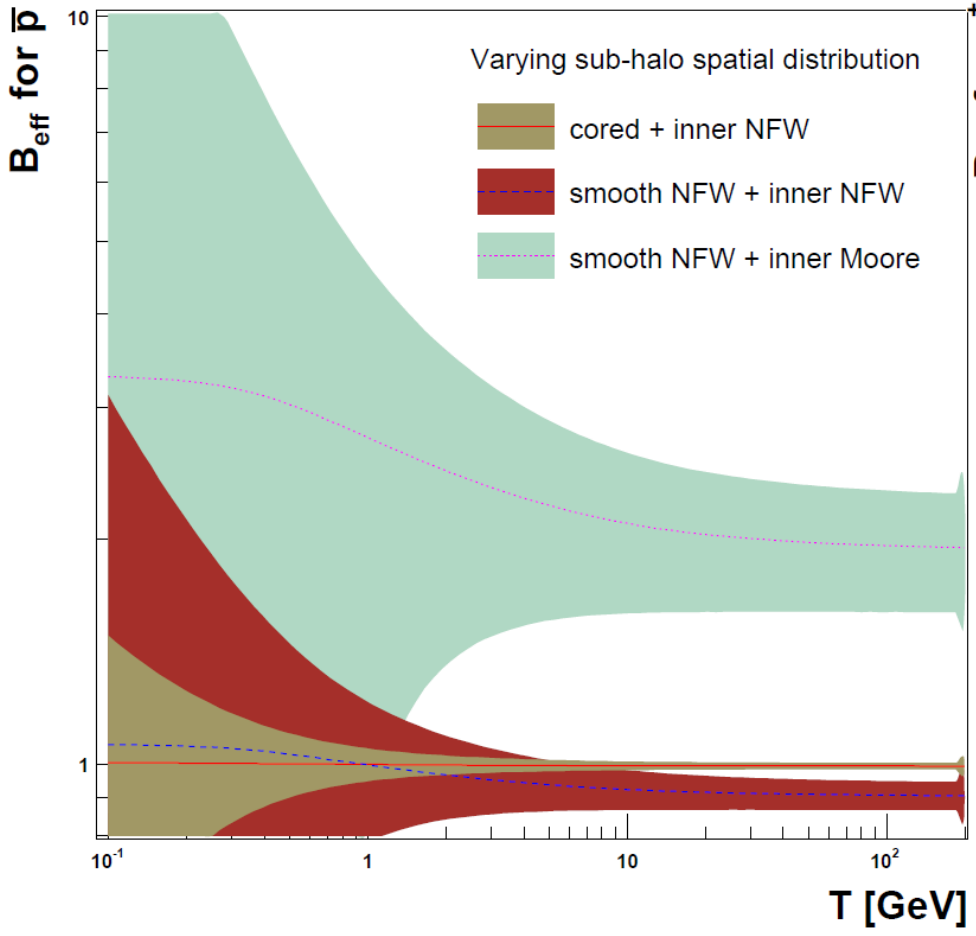
Boost Factor(s)

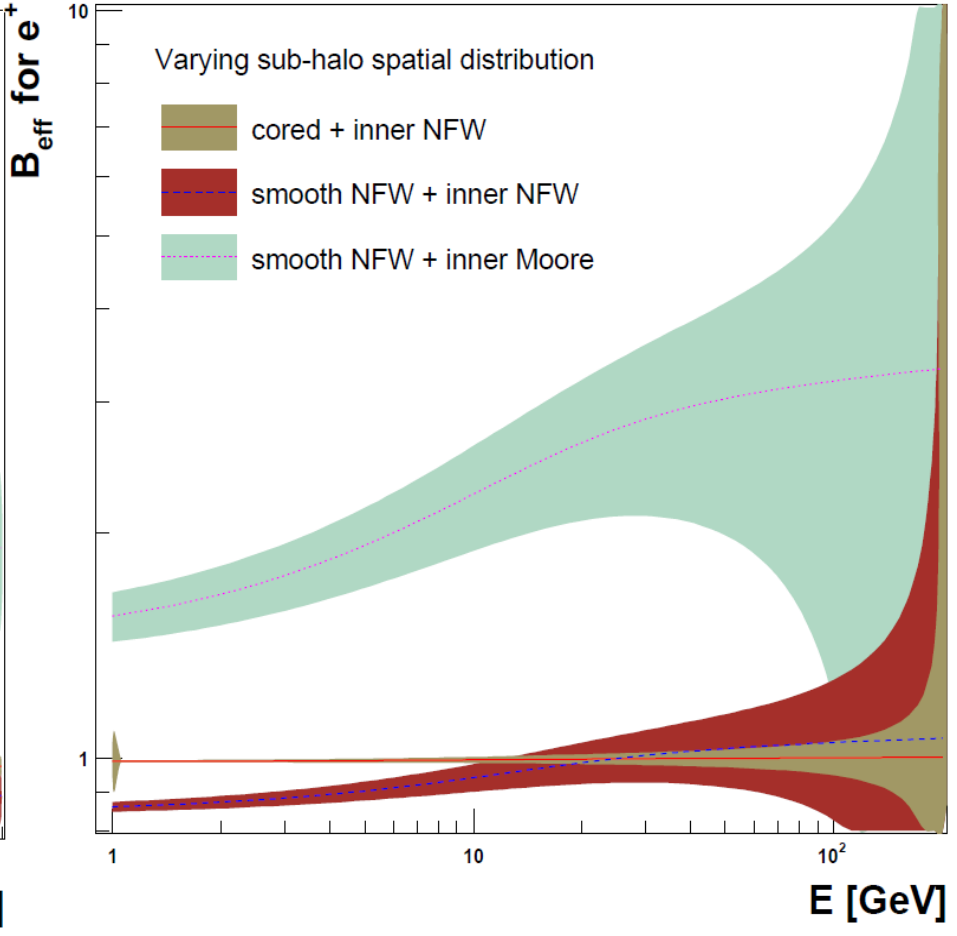
- Particle Physics:
  - Sommerfeld Effect
  - Resonances
  - Exciting Dark Matter
  - …

Boost Factor(s)

- Astrophysics: Clumps
  - Limited value: Lavalle et alii A&A 479, 427-452 (2008)
  - Different for positrons and anti-protons

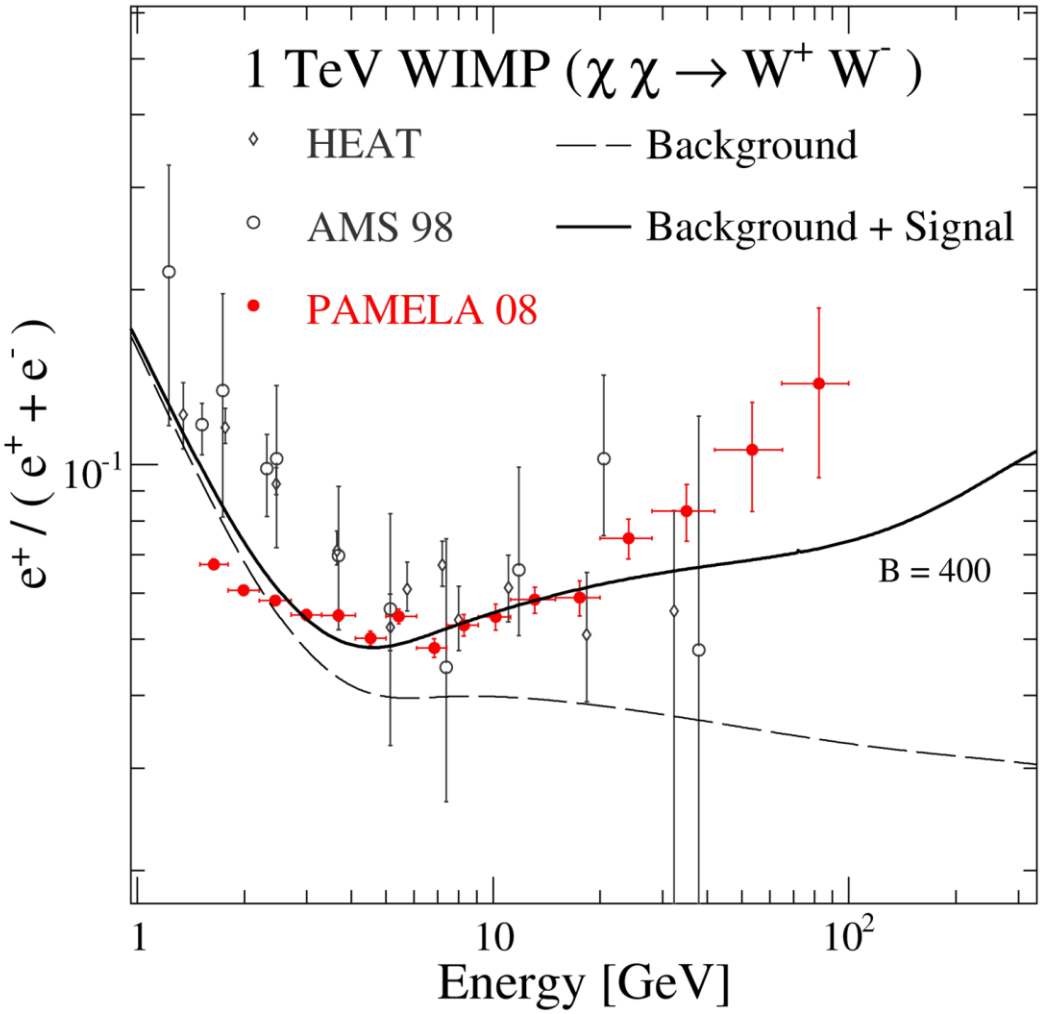
Astrophysical boost factor





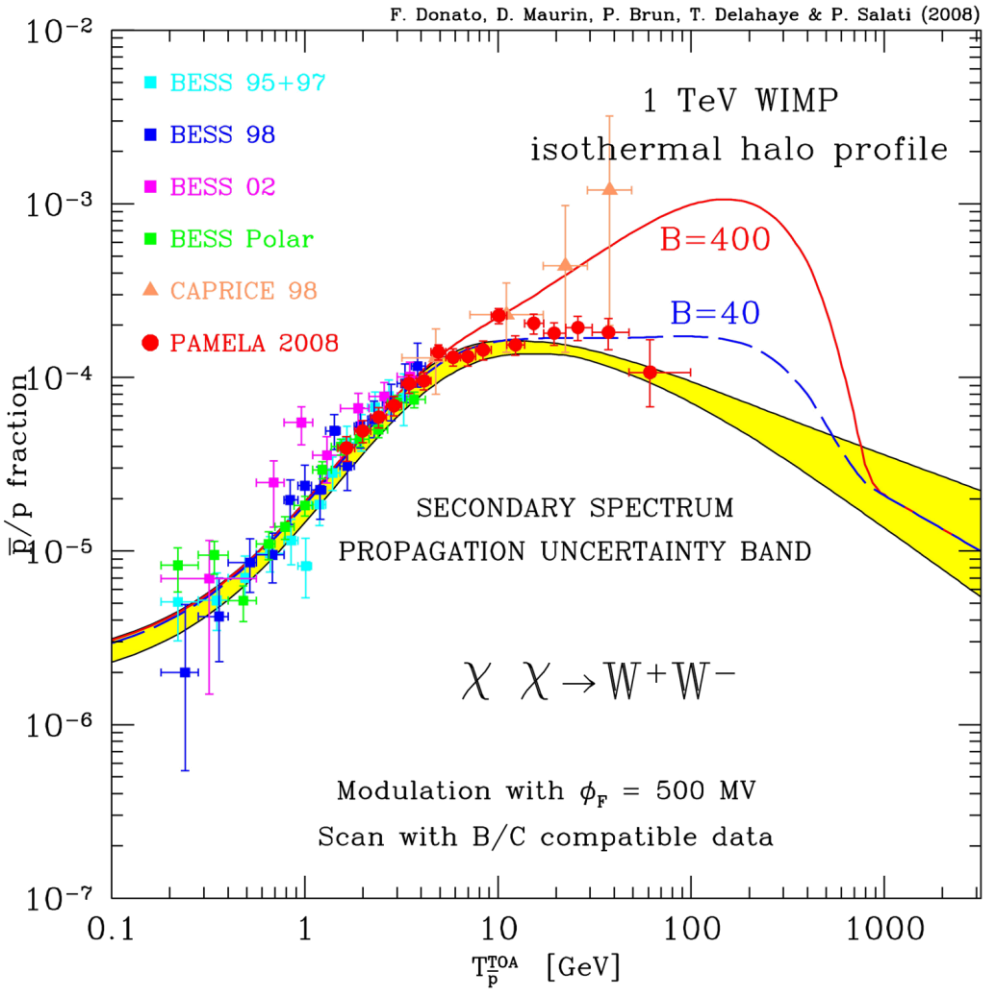
Lavalle et alii A&A 479, 427-452 (2008)

Positrons: Dark Matter ?



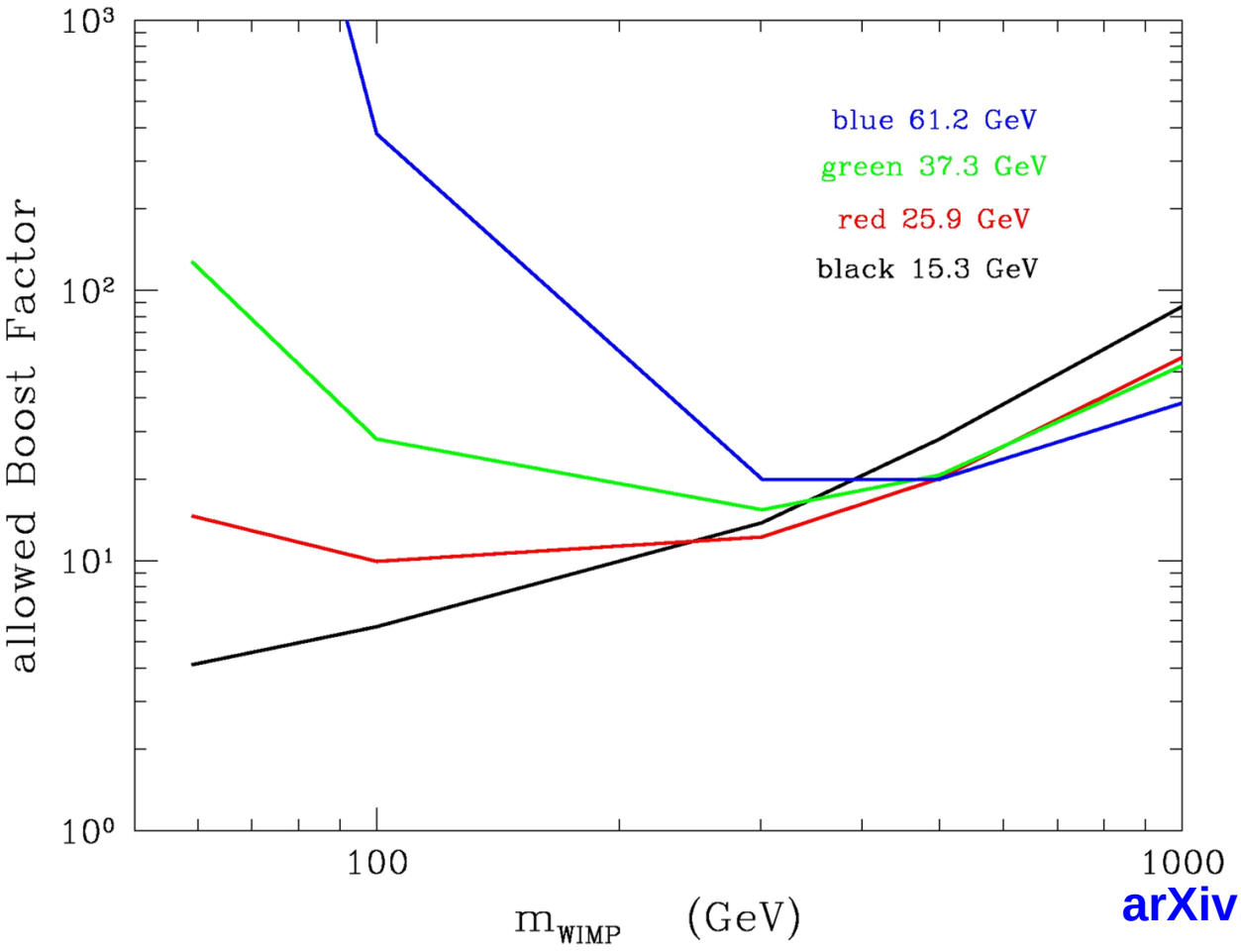
arXiv:0810.5292

Anti-protons



arXiv:0810.5292

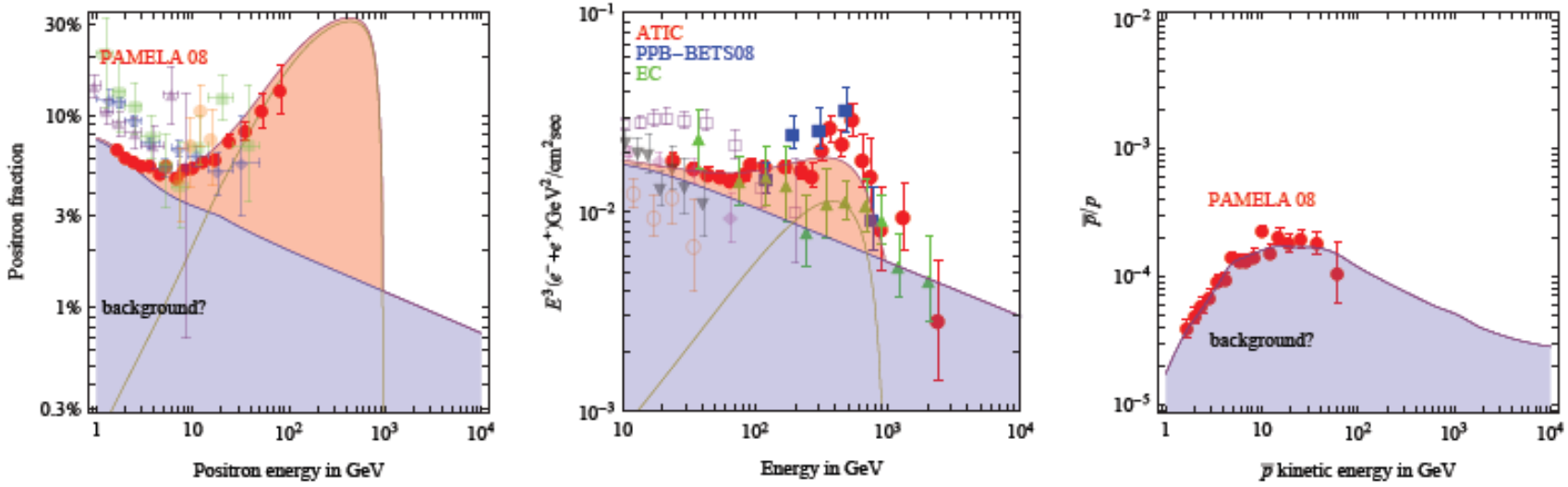
Anti-protons: constraints



arXiv:0810.5292

Leptonic Dark Matter ?

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



M. Cirelli, M. Kadastik, M. Raidal & A. Strumia
arXiv:0809.2409

Astrophysical objects

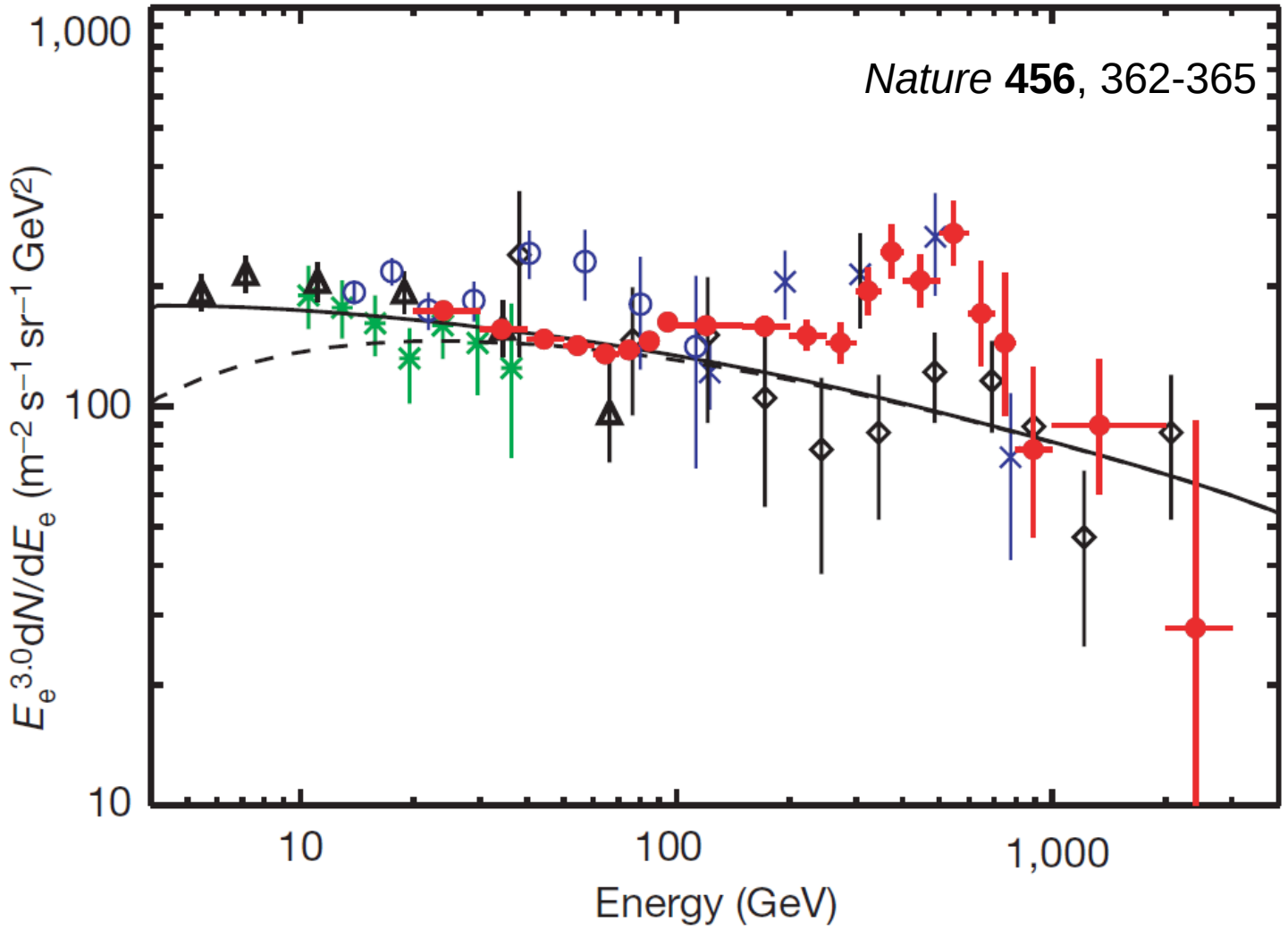
- Pulsar
  - Hall & Hooper arXiv:0811.3362
  - Yüksel, Kistler & Stanev arXiv:0810.2784
- Super Nova remnants
  - Hu et alii arXiv:0901.1520

What else do we need ?

- Absolute fluxes
  - Positrons
  - Protons
  - Anti-protons
- Other data
  - Boron/Carbon
  - Anisotropy

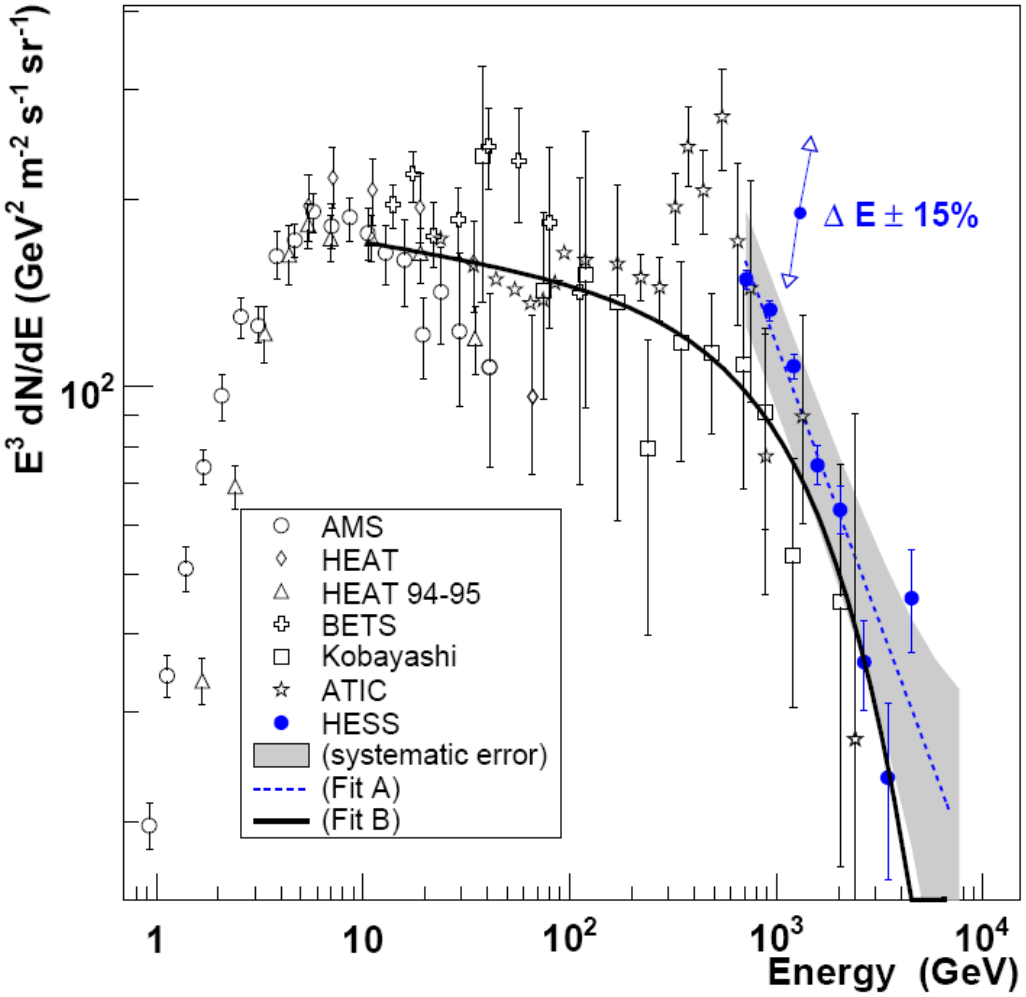
ATIC

Une ère ATIC ?


Nature **456**, 362-365
1,000
100
10
10
100
1,000
Energy (GeV)
$E_e^{3.0} dN/dE_e$ ($m^{-2}\,s^{-1}\,sr^{-1}\,GeV^2$)

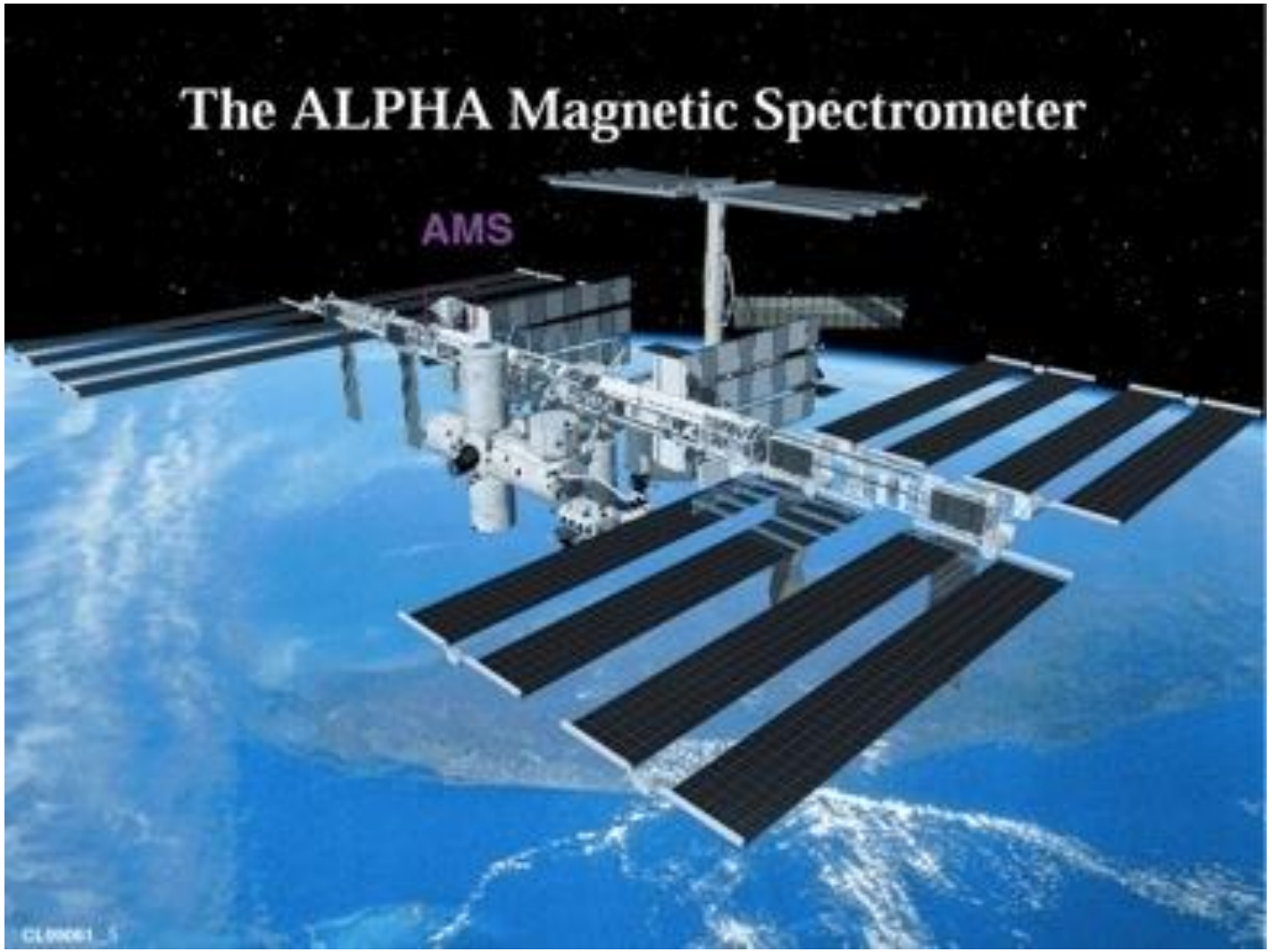
HESS

HESS



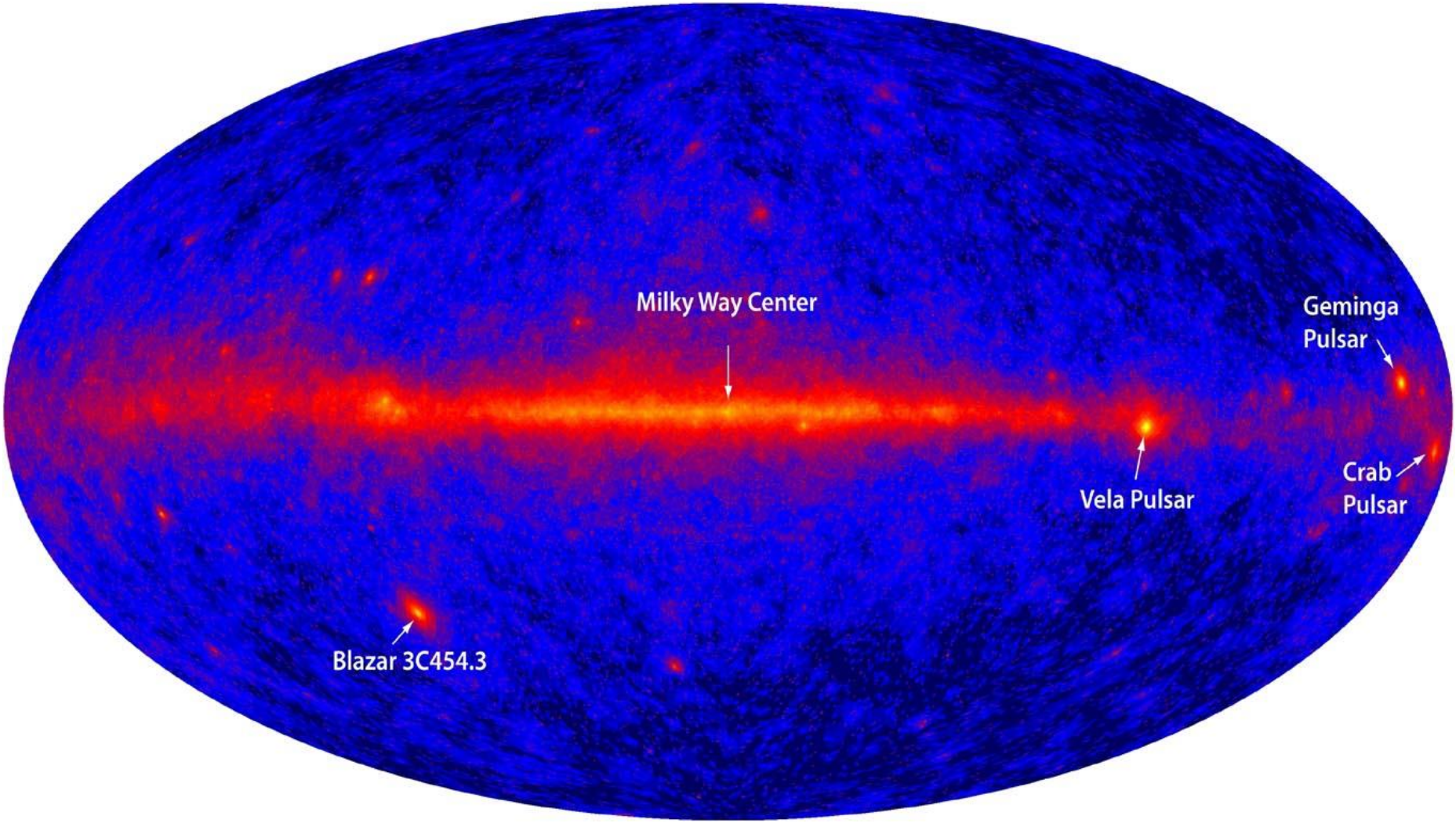
arXiv:0811.3894

AMS ?



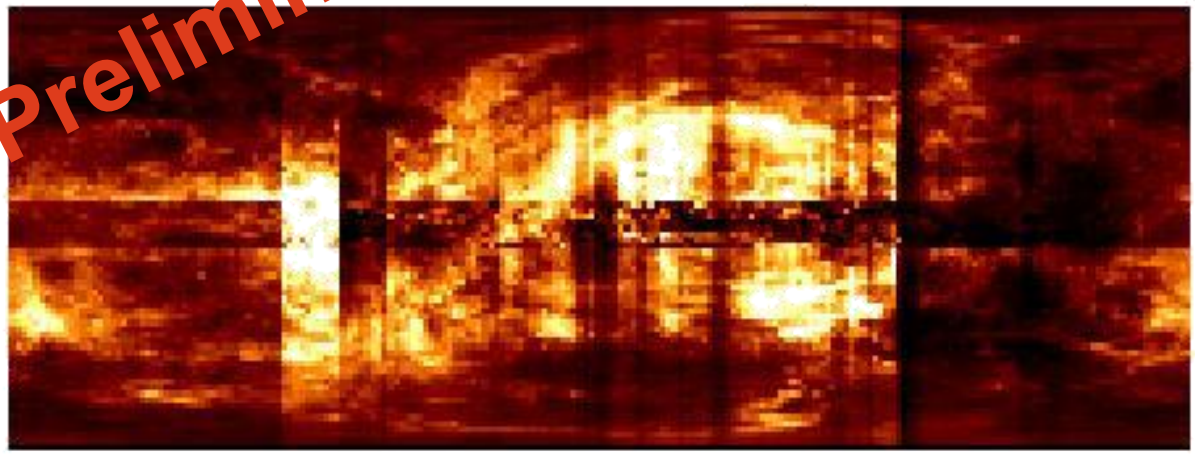
What about Gamma rays ?

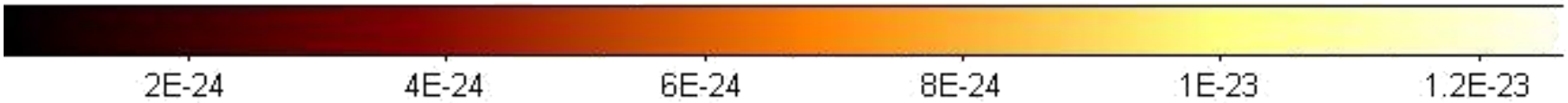
First light


Milky Way Center
Geminga Pulsar
Vela Pulsar
Crab Pulsar
Blazar 3C454.3

Diffuse emission

Very Preliminary !





Conclusion

- The method
  - Reduce uncertainties on the background
  - Model independant fits
  - Multi-channel analysis
  - Proper use of boost factors
- The aim
  - Discovery in collider

Next ?

- Astrophysical boost factors
- Gamma ray background
- Comparision with LHC data (no hurry!)

Questions