Antiprotons from Dark Matter: Constraints or Signal ???

Gaëlle Giesen, IPhT- CEA Saclay

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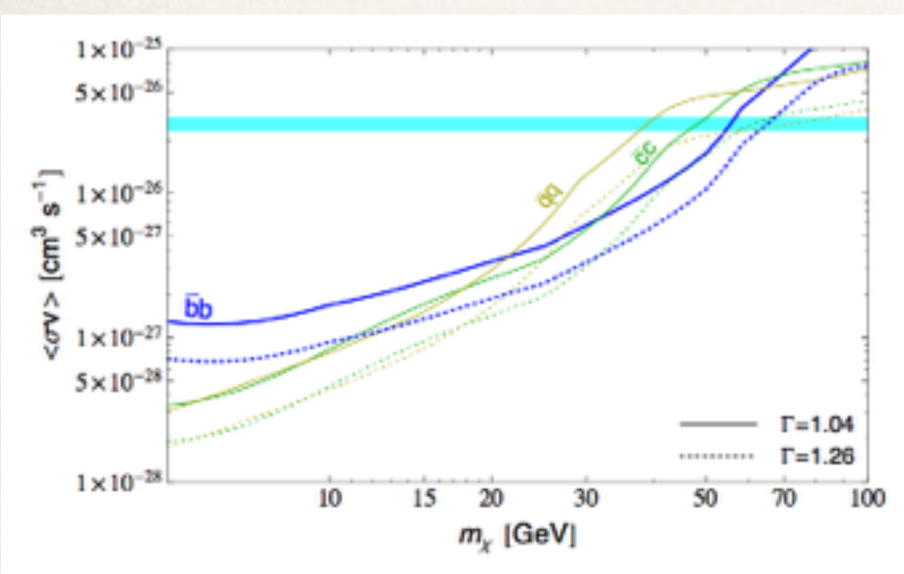
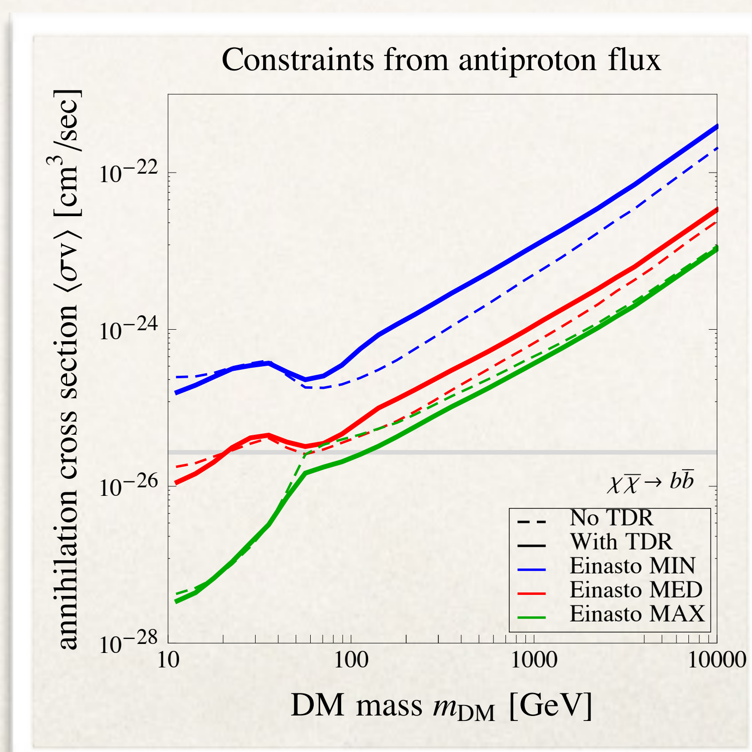
Introduction

How is it possible to get different results using the same data?
What are the differences?
Who's right who's wrong?

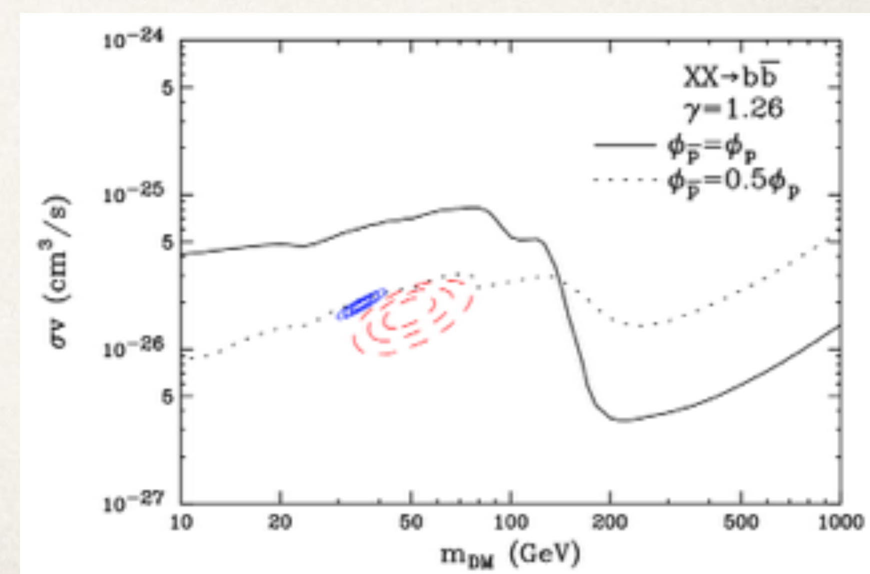
Bringmann, Vollmann, Weniger
1406.6027



Boudard, Cirelli, Giesen, Salati
1412.????



Hooper, Linden, Mertsch
1410.1527



Cosmic ray propagation

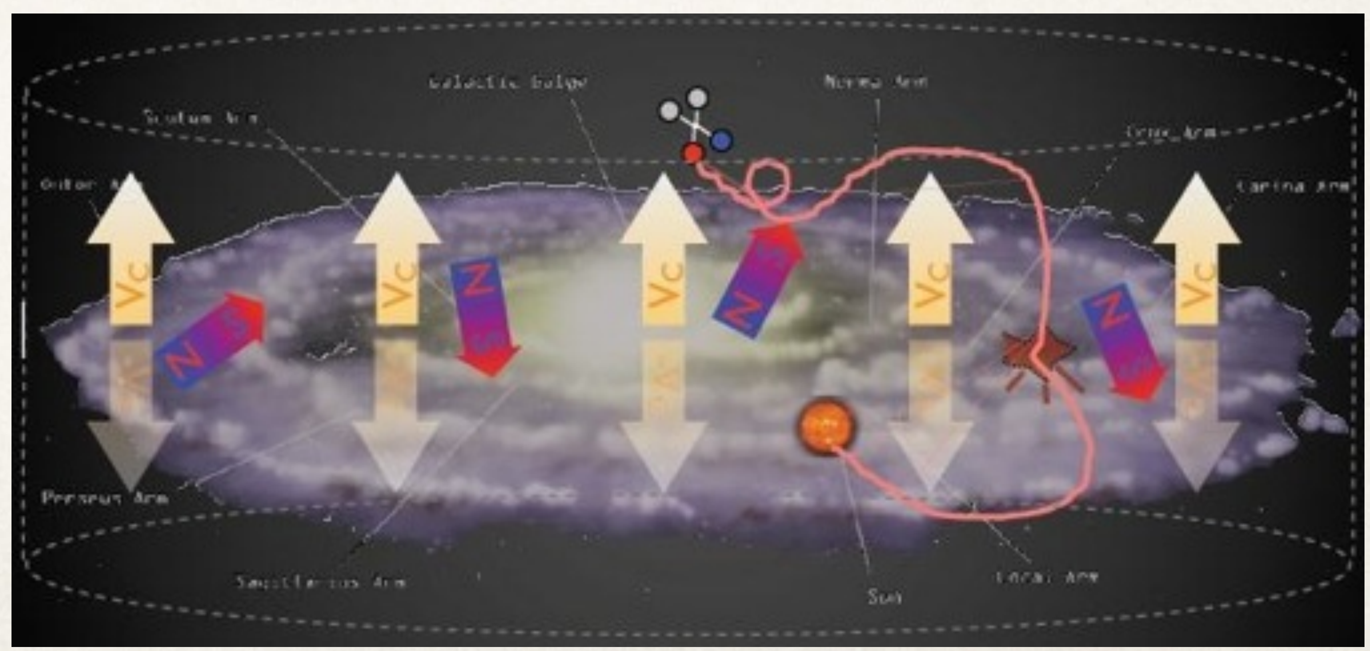
Master equation:

$$\frac{\partial N^i(r,z,p)}{\partial t} = \frac{\partial}{\partial x_i} D_{ij} \frac{\partial N^i}{\partial x_j} + v_c \cdot \nabla N^i - \frac{\partial}{\partial p}\left(\dot{p} - \frac{p}{3}\nabla \cdot v_c\right) N^i + \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p}\frac{N^i}{p^2} + Q(r,z,p)$$

Diffusion term: $D_{xx} = D_0 \beta^{(\eta)} \left(\frac{p}{p_0}\right)^{\delta}$

Reacceleration: $D_{pp} = \frac{4p^2 v_{alf}^2}{3\delta(4-\delta^2)(4-\delta)D_{xx}}$

Diffusion zone: L



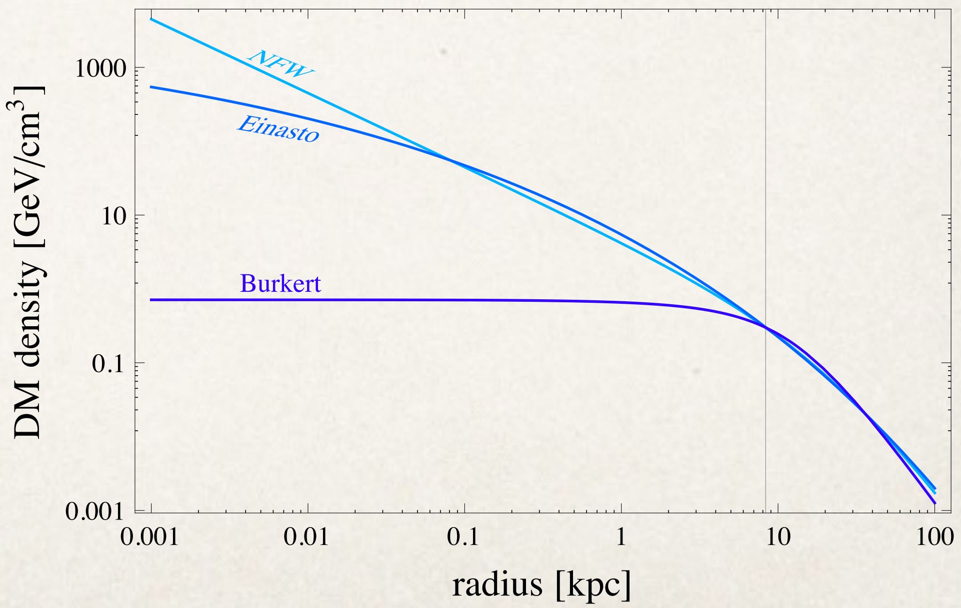
Main antiproton sources

- Secondaries: spallation of cosmic ray (CR) protons on the galactic disk

$$p_{CR} + H_{ISM} \rightarrow \bar{p} + X$$

- Primaries: DM annihilation in the halo

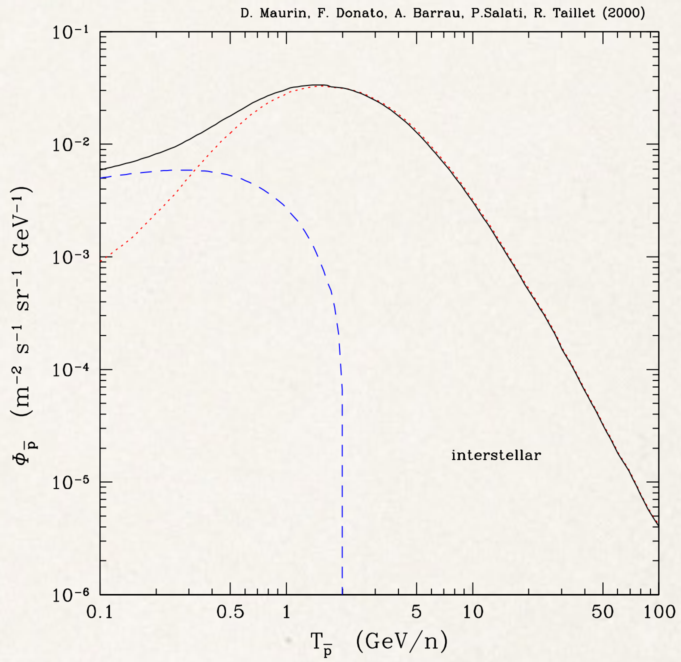
$$DM\ DM \rightarrow prim\ prim \rightarrow ... \rightarrow \bar{p}$$



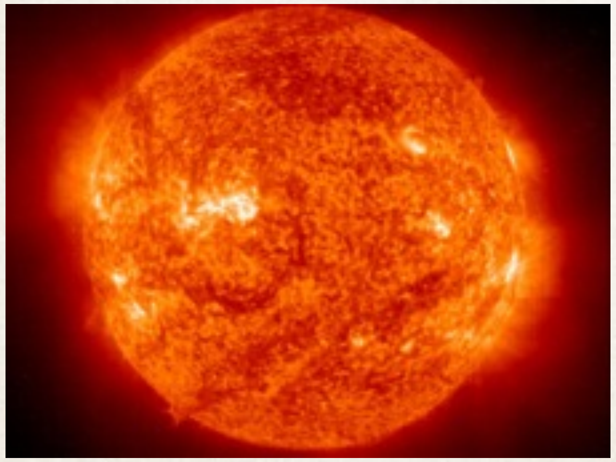
Low energy challenges (E< 10 GeV)

- Tertiaries: Inelastic (but non-annihilating) interactions of antiprotons on the interstellar hydrogen

$$\bar{p} + p_{ISM} \rightarrow \bar{p} + (\Delta + p + \pi)$$



- Solar modulation: force-field approximation



$$J_{\oplus}(K) = J_{\rm LIS}(K + \phi\frac{Z}{A})\frac{K(K+2\,m)}{(K+m+\phi\frac{Z}{A})^2 - m^2}$$

Propagation parameters

Bringmann, Vollmann, Weniger
1406.6027

KRA model:

$D_0 = 2.64 \times 10^{28}\ \mathrm{cm^2 s^{-1}}$

$\delta = 0.50$

$\eta = -0.39$

$v_a = 14.2\ \mathrm{km\ s^{-1}}$

$L = 4\ \mathrm{kpc}$

$\phi_{\bar{p}}$

Astro background:

$\alpha_{prop} \in [0; 1]$

$\alpha_{nuc} \in [0; 1]$

Boudard, Cirelli, Giesen, Salati
1412.????

MED model:

$D_0 = 0.338 \times 10^{28}\ \mathrm{cm^2 s^{-1}}$

$\delta = 0.70$

$v_a = 52.9\ \mathrm{km\ s^{-1}}$

$v_c = 12\ \mathrm{km\ s^{-1}}$

$L = 4\ \mathrm{kpc}$

$\phi_{\bar{p}} \in [0.1; 1.1]\ \mathrm{GV}$

Astro background:

$A \in [1; 1.25]$

Hooper, Linden, Mertsch
1410.1527

150 000 models:

$D_0 \in [5.45; 11.20] \times 10^{28}\ \mathrm{cm^2 s^{-1}}$

$\delta \in [0.26; 0.35]$

$v_a \in [34.2; 42.7]\ \mathrm{km\ s^{-1}}$

$L \in [3.2; 8.6]\ \mathrm{kpc}$

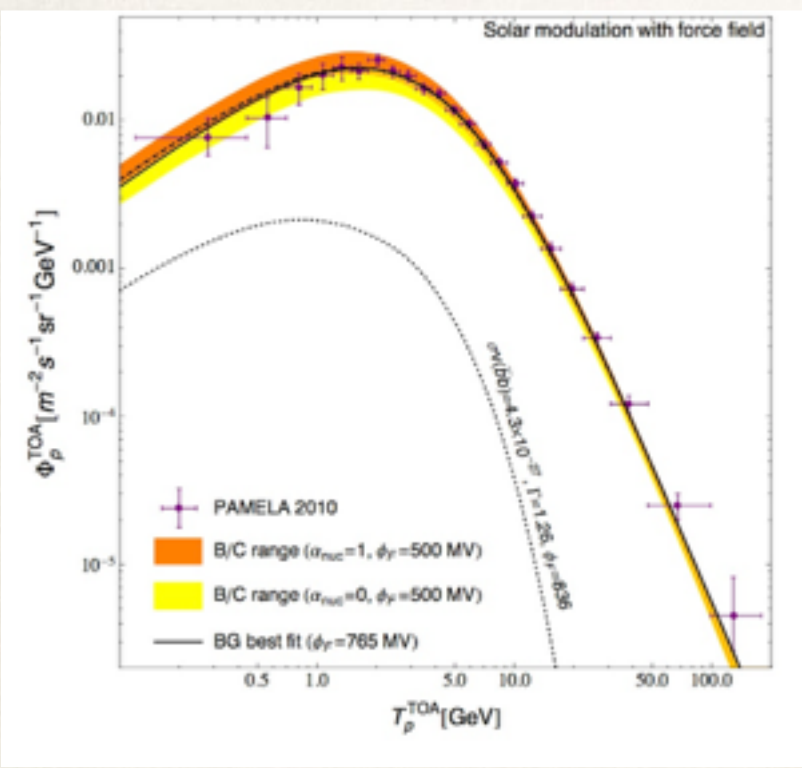
$\phi_{\bar{p}} = \phi_p \quad (\text{or } \phi_{\bar{p}} = \frac{1}{2}\phi_p)$

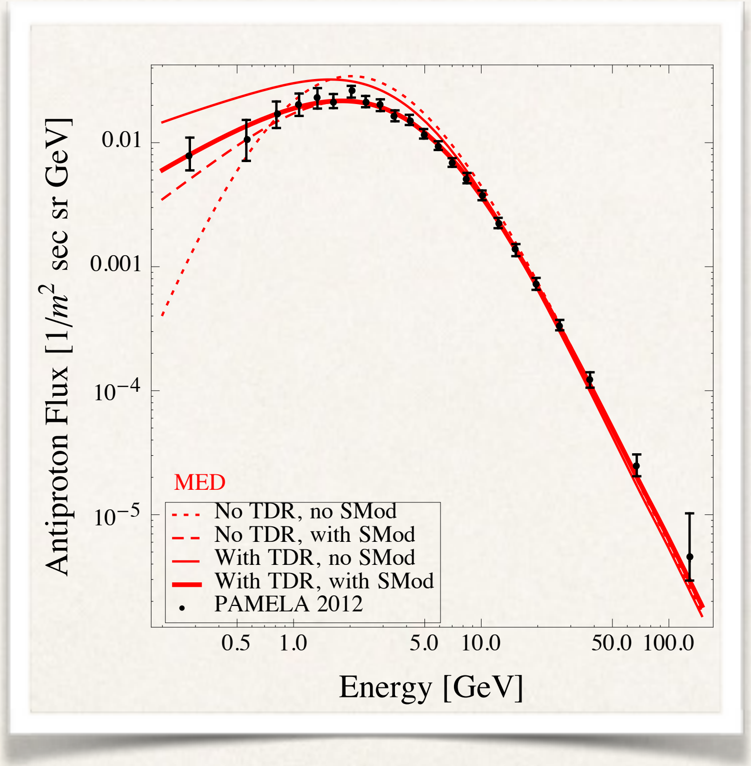
Astrophysical background

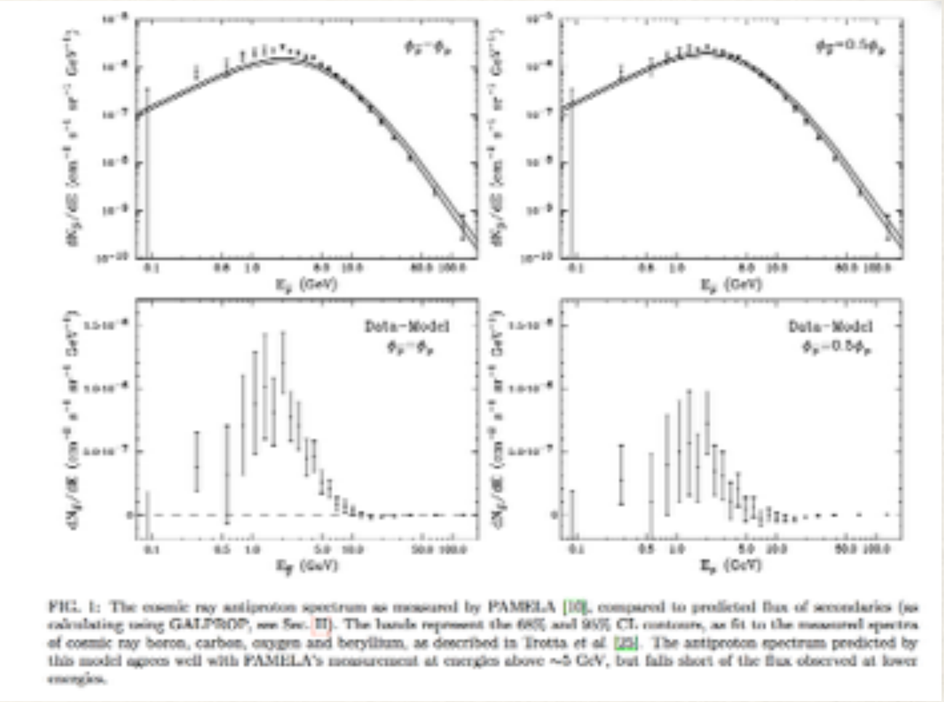
Bringmann, Vollmann, Weniger
1406.6027

Boudard, Cirelli, Giesen, Salati
1412.????

Hooper, Linden, Mertsch
1410.1527





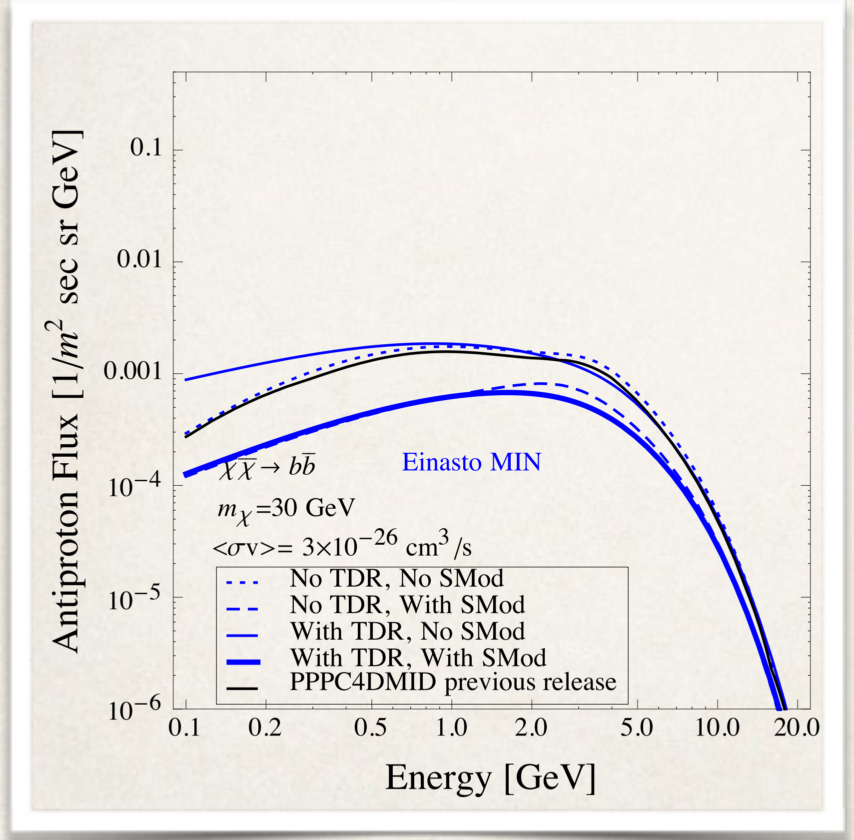


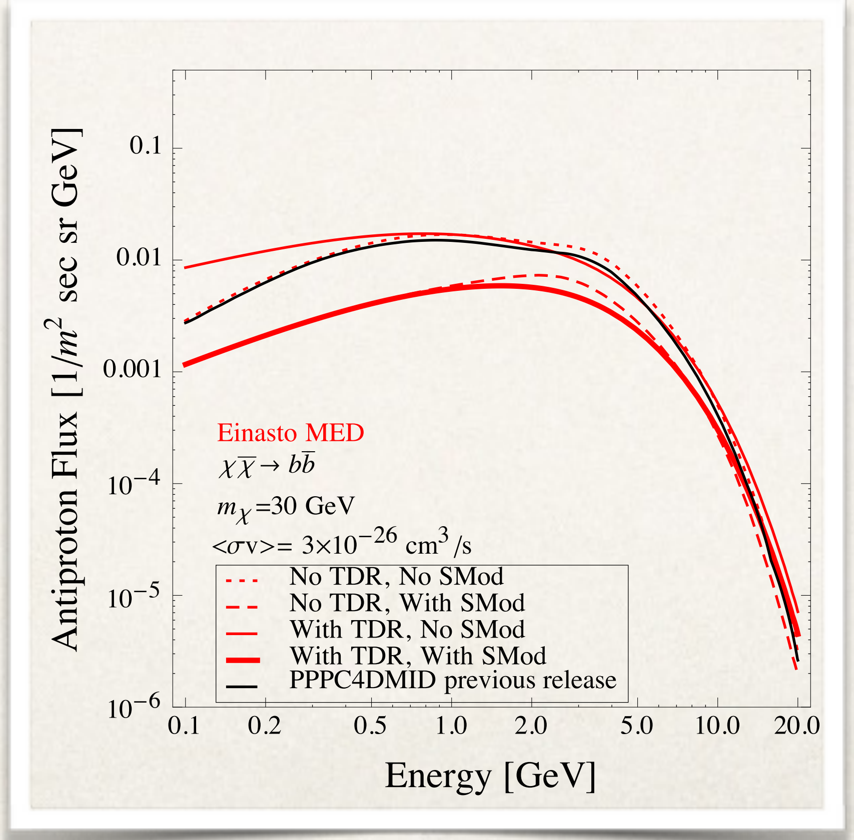
Dark Matter signal

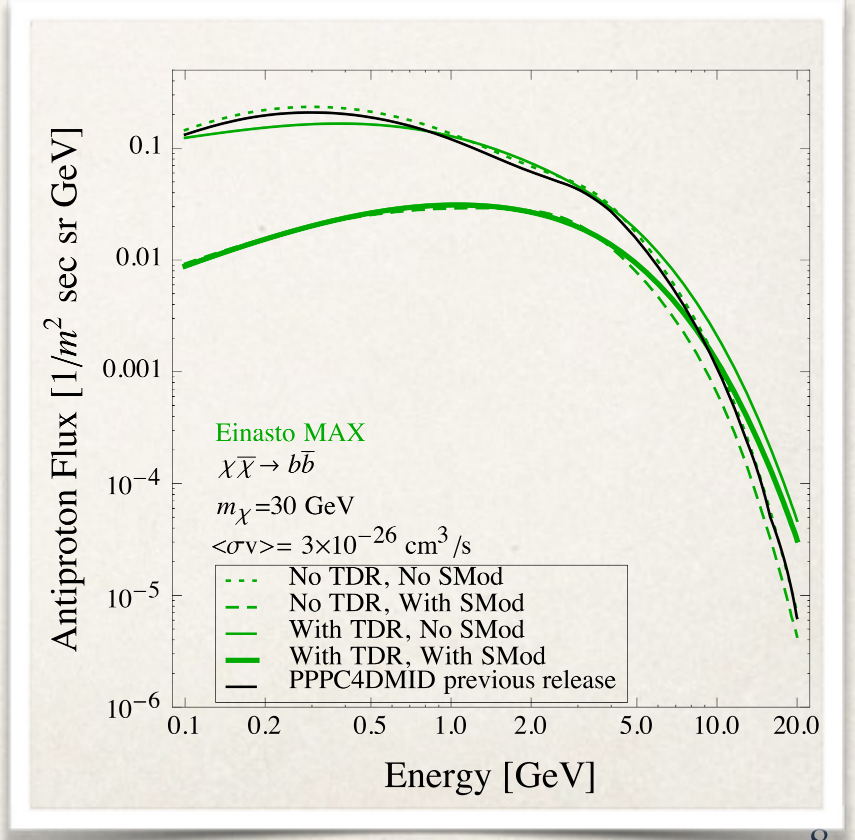
$$D_0 = 0.0482 \times 10^{28}\ \mathrm{cm}^2\mathrm{s}^{-1}$$
$$\delta = 0.85$$
$$v_a = 22.4\ \mathrm{km\ s}^{-1}$$
$$v_c = 13.5\mathrm{km\ s}^{-1}$$
$$L = 1\ \mathrm{kpc}$$

$$D_0 = 0.338 \times 10^{28}\ \mathrm{cm}^2\mathrm{s}^{-1}$$
$$\delta = 0.7$$
$$v_a = 52.9\ \mathrm{km\ s}^{-1}$$
$$v_c = 12\ \mathrm{km\ s}^{-1}$$
$$L = 4\ \mathrm{kpc}$$

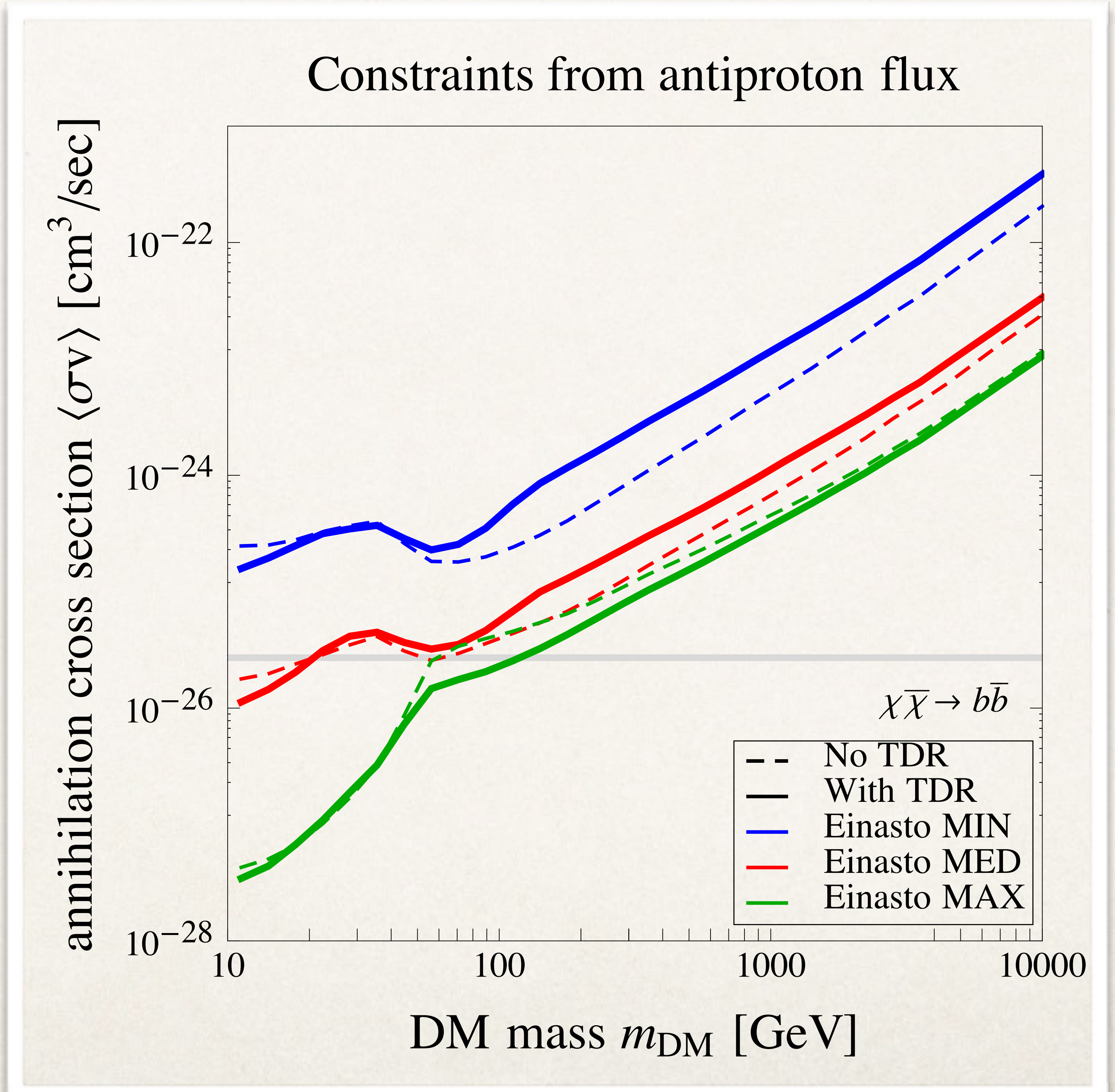
$$D_0 = 2.31 \times 10^{28}\ \mathrm{cm}^2\mathrm{s}^{-1}$$
$$\delta = 46$$
$$v_a = 117.6\ \mathrm{km\ s}^{-1}$$
$$v_c = 5\ \mathrm{km\ s}^{-1}$$
$$L = 15\ \mathrm{kpc}$$





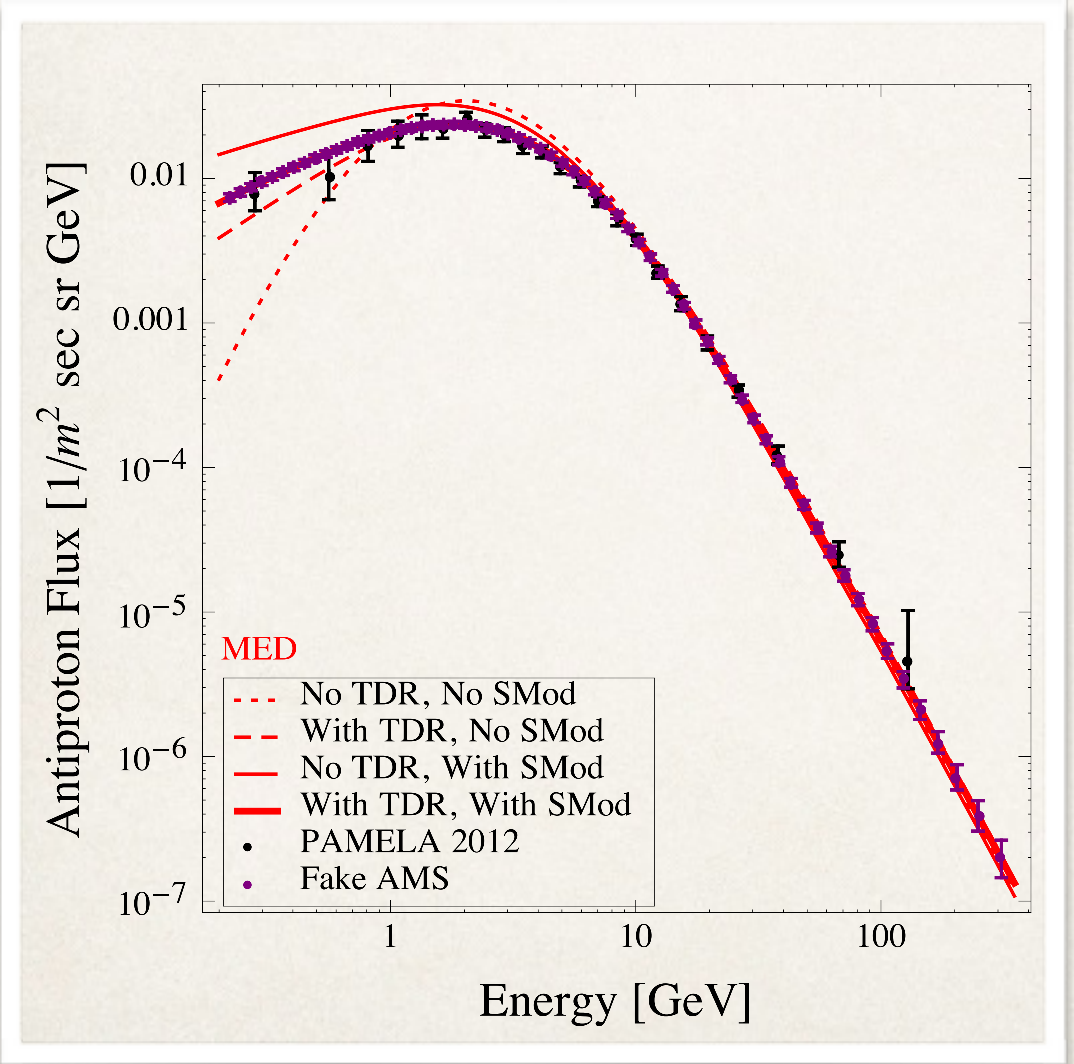


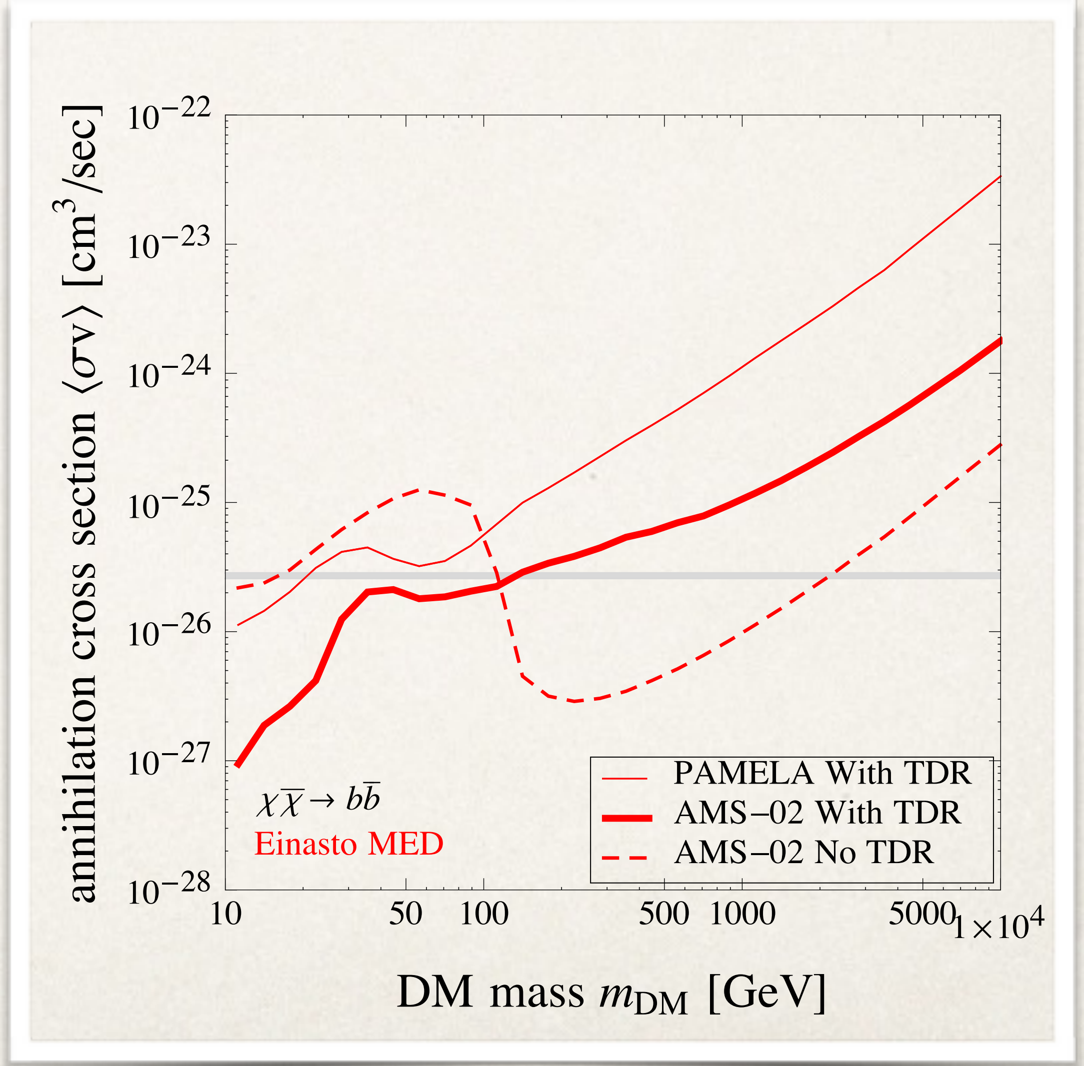
Constraints on DM



In the future…

Fake Data (65 points): $A = 1.24 \quad \phi = 0.6$





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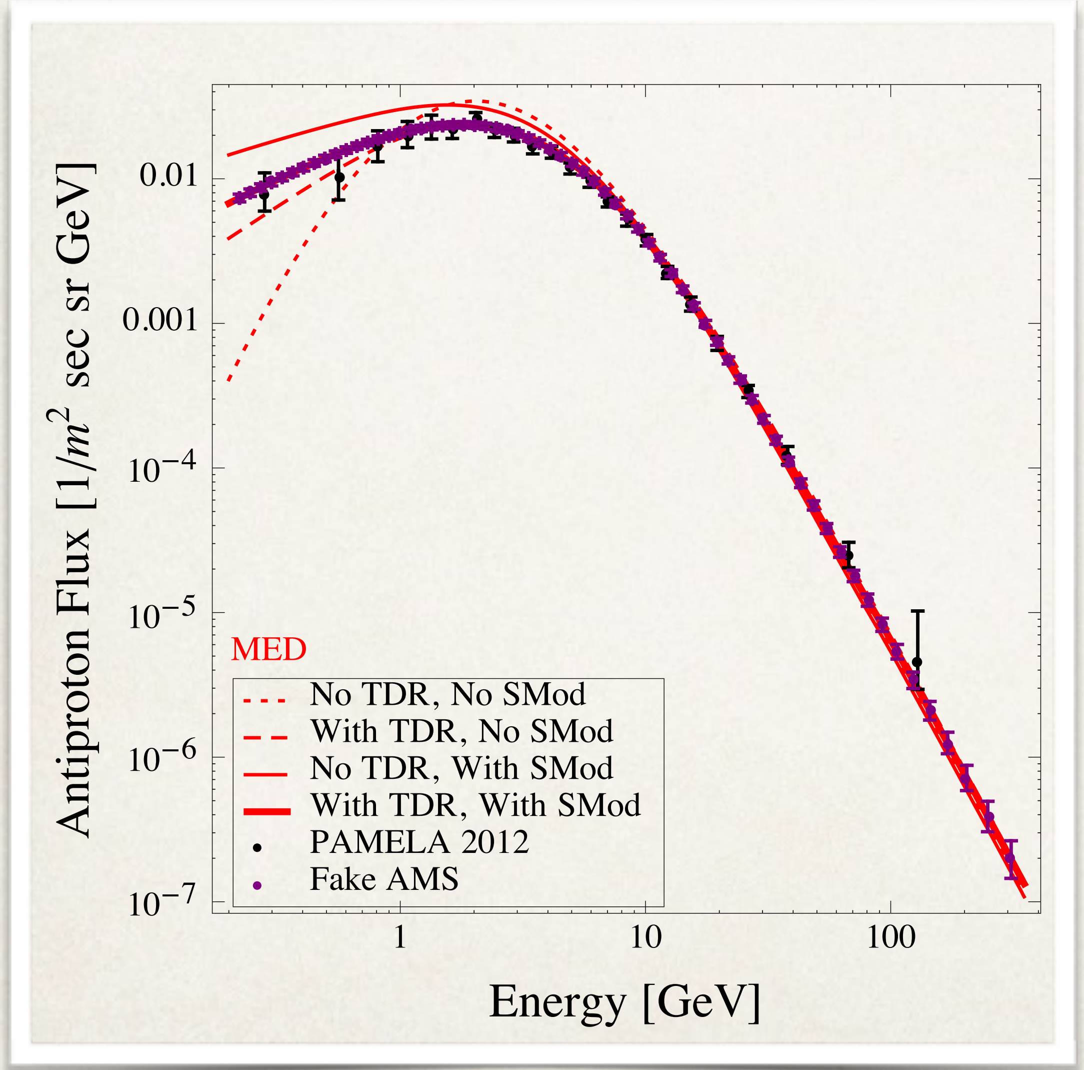


Astro background:

With TDR: $\chi^2 = 0 \; A = 1.24 \; \phi = 0.6$

No TDR: $\chi^2 = 465 \; A = 1.24 \; \phi = 0.74$

DM contribution (NO TDR):

$m_{DM} = 10$ GeV

$\langle \sigma v \rangle = 5 \times 10^{-27}\ \mathrm{cm^3 s^{-1}}$

$A = 1.14$

$\phi_F = 0.74$ GV

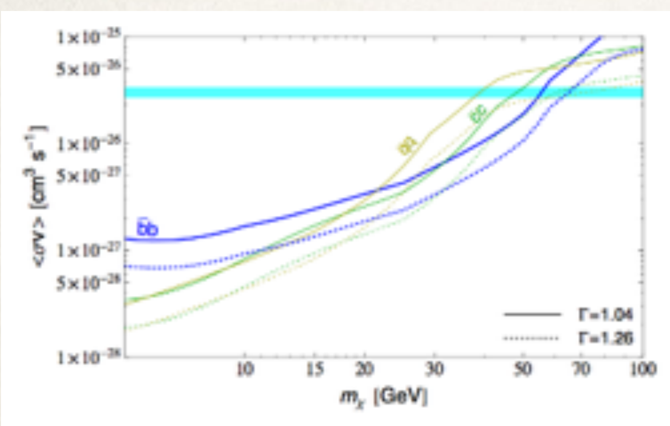
$\Rightarrow$

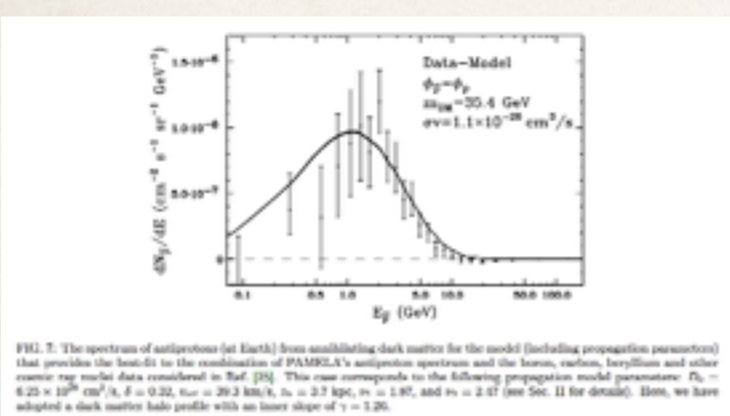
$\Delta\chi^2 = -452$

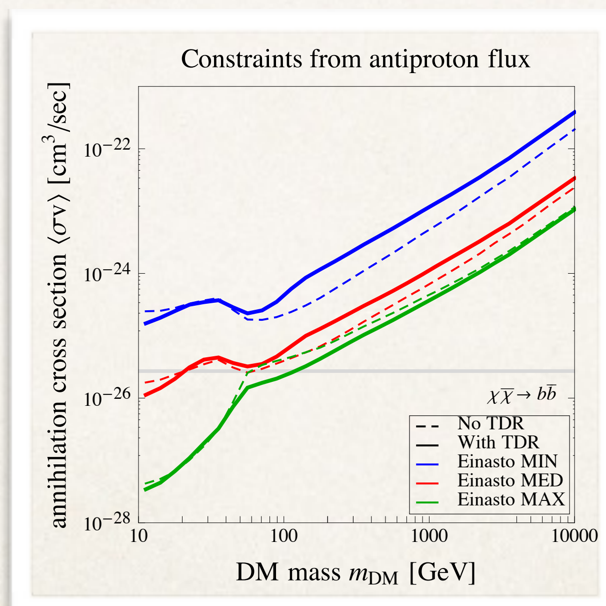
$\chi^2/d.o.f. = 12/63$

Conclusion

- Importance of the tertiary component (PPPC4DMID)
- Signal or constraints ???

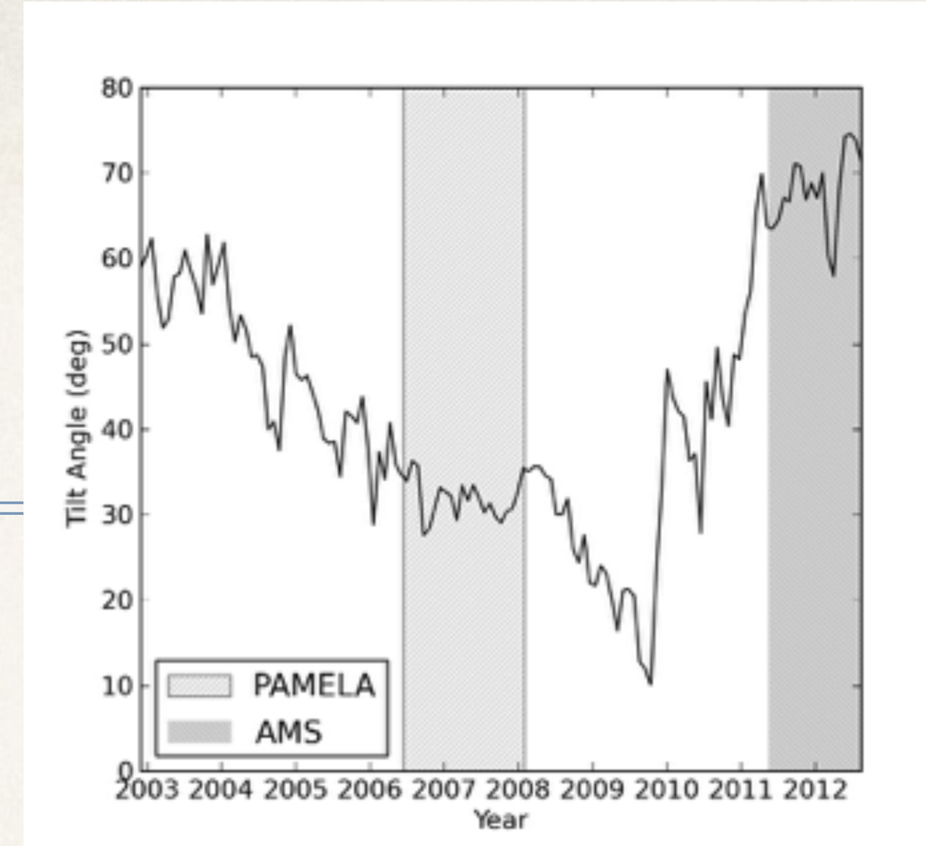


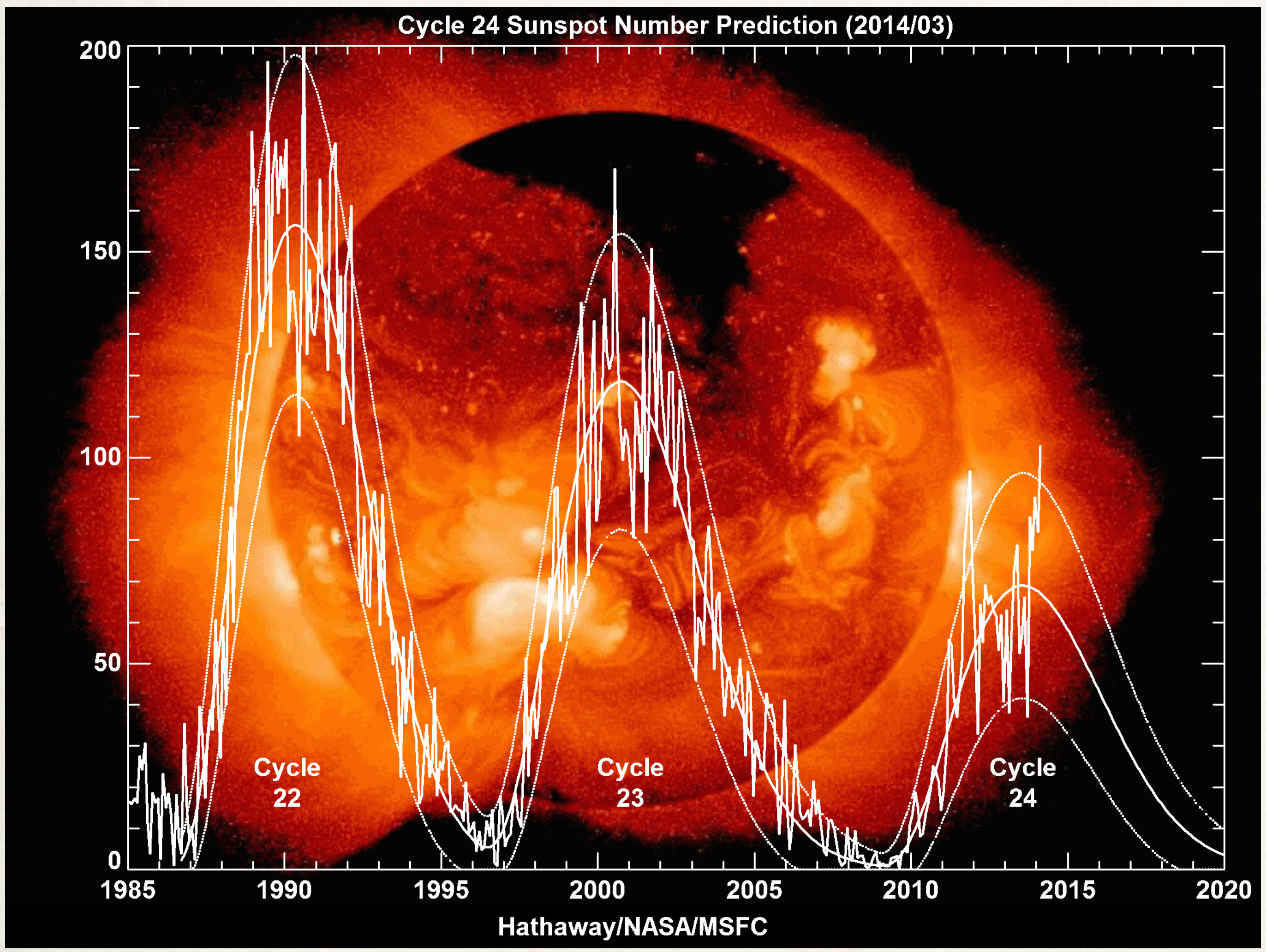




Thank You !!!

Solar Modulation

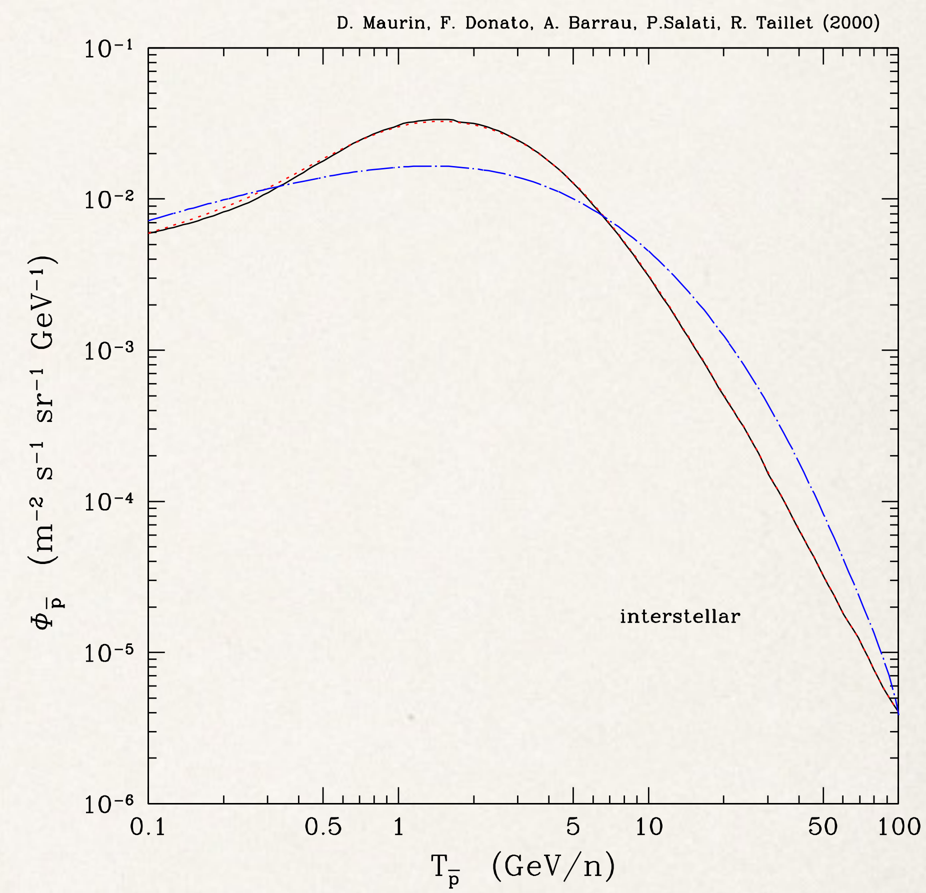




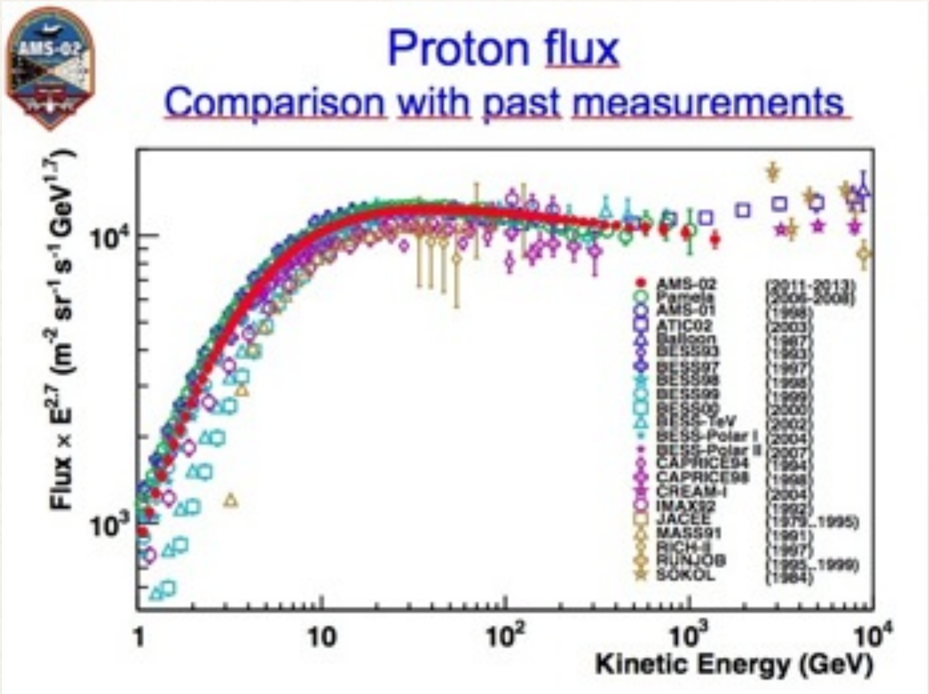
polarity	tilt angle	m.f.p. (AU)	δ	ϕ_p	$\phi_{\bar{p}}$	rel. diff.
-1.00	10.00	0.05	0.30	1.18	1.18	0.00%
-1.00	10.00	0.05	0.50	1.18	1.18	0.00%
-1.00	10.00	0.05	1.00	1.12	1.12	0.00%
-1.00	10.00	0.10	0.30	1.06	1.10	3.77%
-1.00	10.00	0.10	0.50	1.02	1.10	7.84%
-1.00	10.00	0.10	1.00	1.02	1.10	7.84%
-1.00	10.00	0.20	0.30	0.78	0.96	23.08%
-1.00	10.00	0.20	0.50	0.74	0.90	21.62%
-1.00	10.00	0.20	1.00	0.60	0.74	23.33%
-1.00	10.00	0.30	0.30	0.60	0.82	36.67%
-1.00	10.00	0.30	0.50	0.54	0.76	40.74%
-1.00	10.00	0.30	1.00	0.46	0.58	26.09%
-1.00	10.00	0.40	0.30	0.36	0.46	27.78%
-1.00	10.00	0.40	1.00	0.48	0.72	50.00%
-1.00	20.00	0.05	0.30	1.46	1.18	-19.18%
-1.00	20.00	0.05	1.00	1.28	1.12	-12.50%
-1.00	20.00	0.40	0.30	0.48	0.72	50.00%
-1.00	20.00	0.40	1.00	0.36	0.46	27.78%
-1.00	40.00	0.05	0.30	1.56	1.18	-24.36%
-1.00	40.00	0.40	0.30	0.50	0.70	40.00%
-1.00	40.00	0.40	1.00	0.38	0.44	15.79%
-1.00	60.00	0.05	0.30	1.50	1.86	24.00%
-1.00	60.00	0.05	1.00	1.18	1.34	13.56%
-1.00	60.00	0.40	0.30	0.50	0.66	32.00%
-1.00	60.00	0.40	1.00	0.40	0.42	5.00%

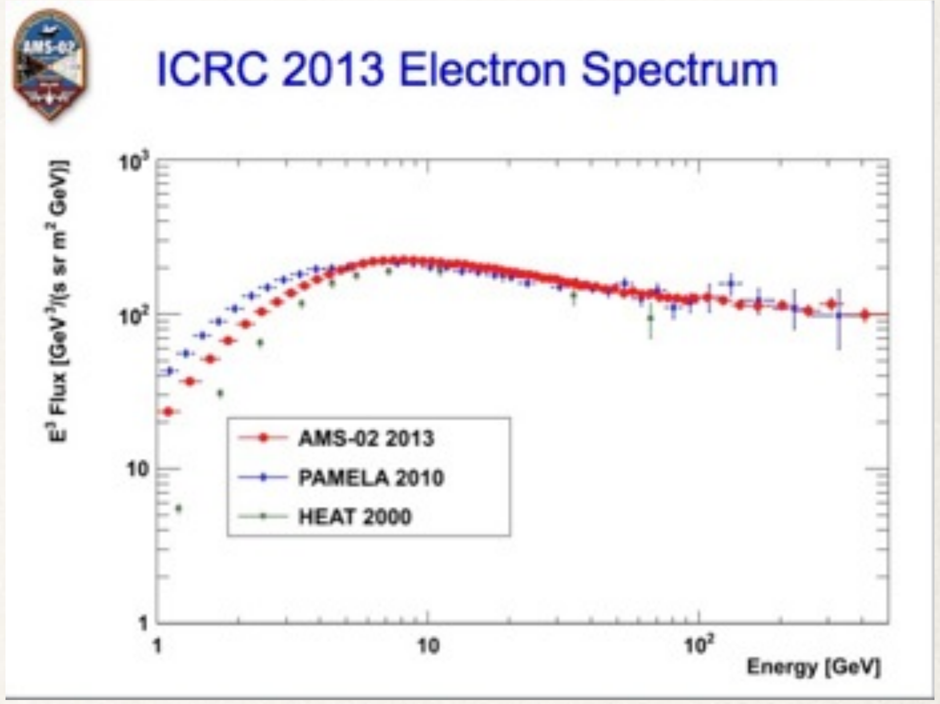
Diffusive reacceleration

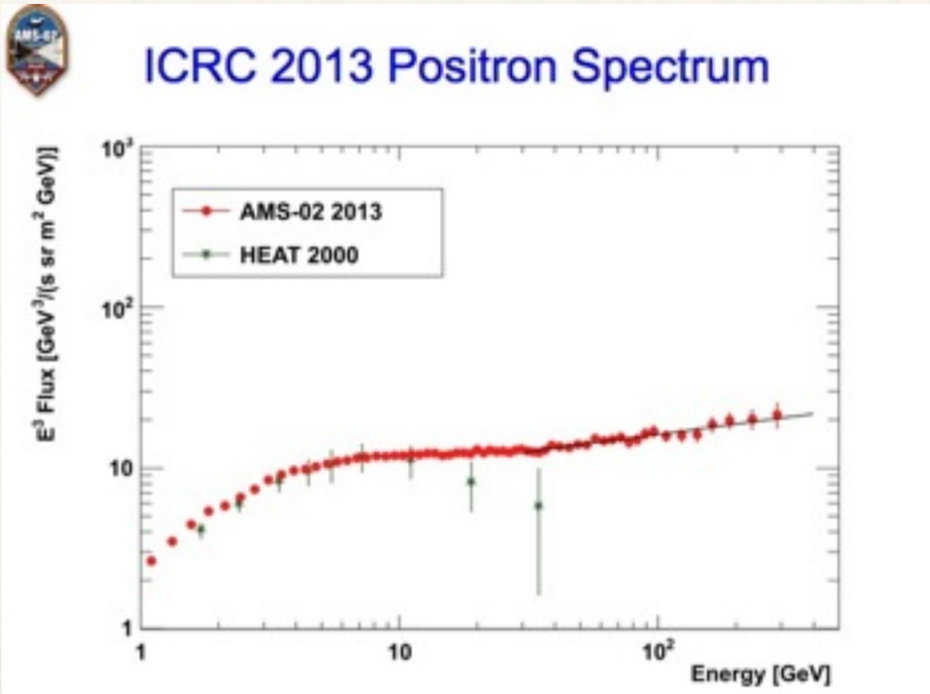
- Interaction of antiprotons with turbulent magnetic fields, gain in energy to a stochastic second-order Fermi type of acceleration



AMS-02 Data


Proton flux
Comparison with past measurements
Flux × E^2.7 (m^-2 sr^-1 s^-1 GeV^1.7)
Kinetic Energy (GeV)
AMS-02
Pamela
AMS-01
ATIC02
Balloon
BESS93
BESS97
BESS98
BESS99
BESS00
BESS-TeV
BESS-Polar I
BESS-Polar II
CAPRICE94
CAPRICE98
CREAM-I
IMAX92
JACEE
MASS91
RICH-II
RUNJOB
SOKOL


ICRC 2013 Electron Spectrum
E^3 Flux [GeV^3/(s sr m^2 GeV)]
Energy [GeV]
AMS-02 2013
PAMELA 2010
HEAT 2000

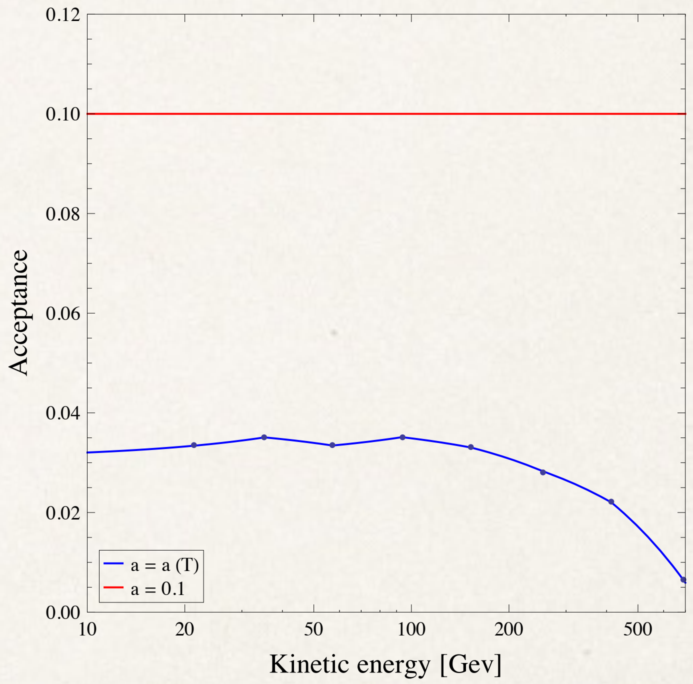

ICRC 2013 Positron Spectrum
E^3 Flux [GeV^3/(s sr m^2 GeV)]
Energy [GeV]
AMS-02 2013
HEAT 2000

Fake AMS-02 Data

Linear approximation of the rigidity resolution: $r(T) = \frac{\Delta T}{T} = 0.0042 \cdot T + 0.1$

The number of collected and reconstructed antiprotons a bin i centered around a kinetic energy T_i :

$$N_i = \epsilon a(T_i)\phi(T_i)\Delta T_i \Delta t$$



ϵ	efficiency
a	geometrical acceptance
ϕ	antiproton flux
ΔT	width of the kinetic energy bin
Δt	exposure time

Statistical error: $\Delta N = \sqrt{N} \Rightarrow \Delta\phi_i\,|_{stat} = \sqrt{\frac{\phi(T_i)}{\epsilon a(T_i)\Delta T_i \Delta t}}$

Systematical error: $\Delta\phi_i\,|_{syst} = 0.05 \cdot \phi_i(T_i)$