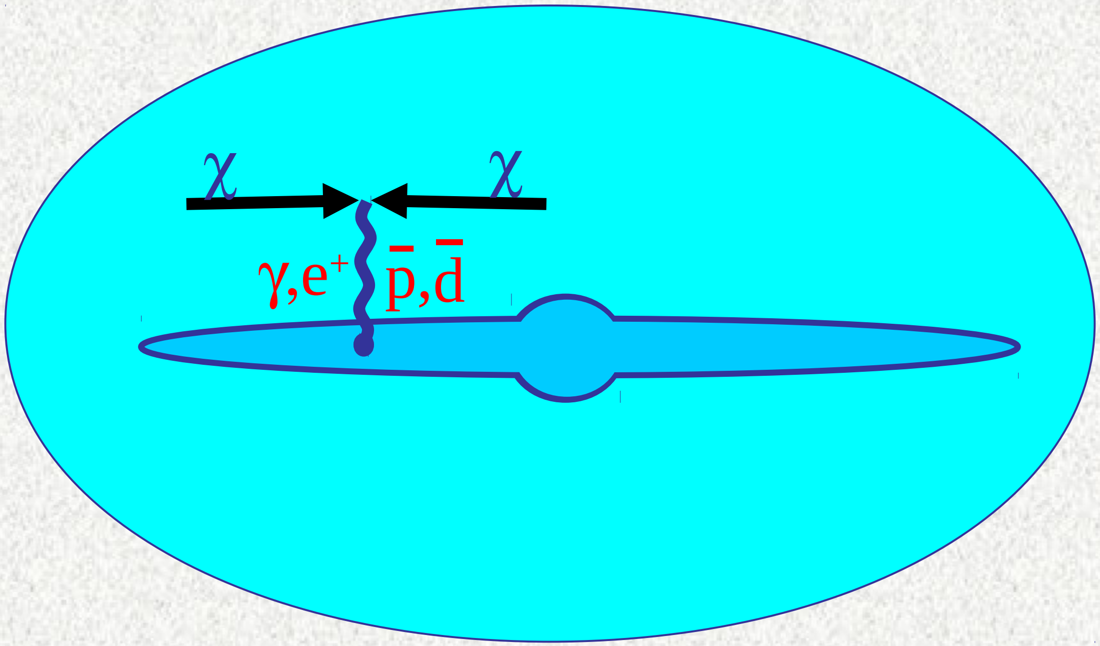
Dark Matter searches with antimatter

Fiorenza Donato
Department of Physics
Torino University & INFN, Italy

Workshop on the Future of Dark Matter Astro-Particle Physics: Insights and Perspectives

Trieste, ICTP – October 8, 2013

Dark Matter Indirect Detection



We look for an “exotic” contribution from

DARK MATTER PAIR ANNIHILATION

in a low astrophysics background of:

γ-rays:

Special ingredient is **DM space distribution ρ(r)**

Antiprotons, antideuterons, positrons:

special need is the **astrophysics of charged cosmic rays**

Antiproton, antideuteron, positron fluxes from DM:
Pair Annihilation in the Halo

- Mass and annihilation cross section: overall normalization
- Source term g(E): hadronization → MC (Pythia)
- Distribution of DM in the Galaxy (isoth., NFW, ...): $\rho(r,z)$
  flux depends on ρ^2, mostly relavant is ρ_{loc}^2
- For Dbar: nuclear fusion
- Propagation in the MW from source to the Earth:
  i.e. diffusion models
- Solar modulation: simplest model is effective force field approximation

Propagation with Diffusive Models

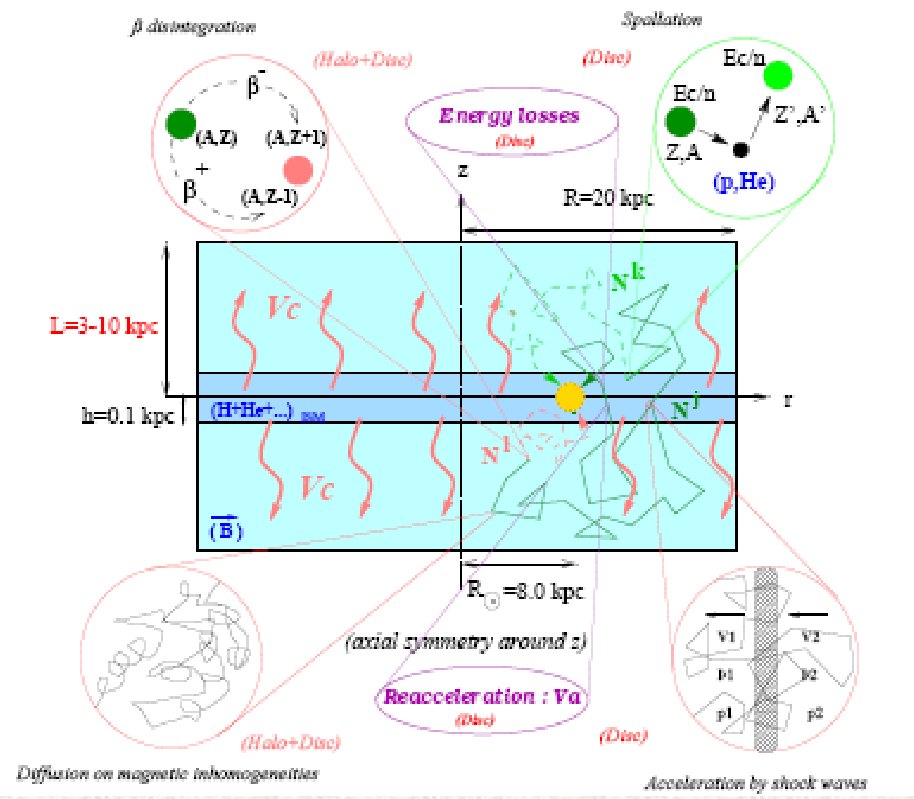
Maurin, Donato, Taillet, Salati ApJ 2001; Maurin, Taillet, Donato A&A 2002, …
Strong & Moskalenko ApJ 1998; Strong, Moskalenko, Ptuskin astro-ph/0701517, … (Galprop);
Evoli, Gaggero, Grasso, Maccione JCAP 2008; Di Bernardo et al. Astrop.Ph. 2010, … (Dragon)

+ Diffusion in the magnetic halo
  → HALO is clue for DM antimatter

+ Disc with sources and ISM

+ Convection, reacceleration

+ Local Bubble for radioactives



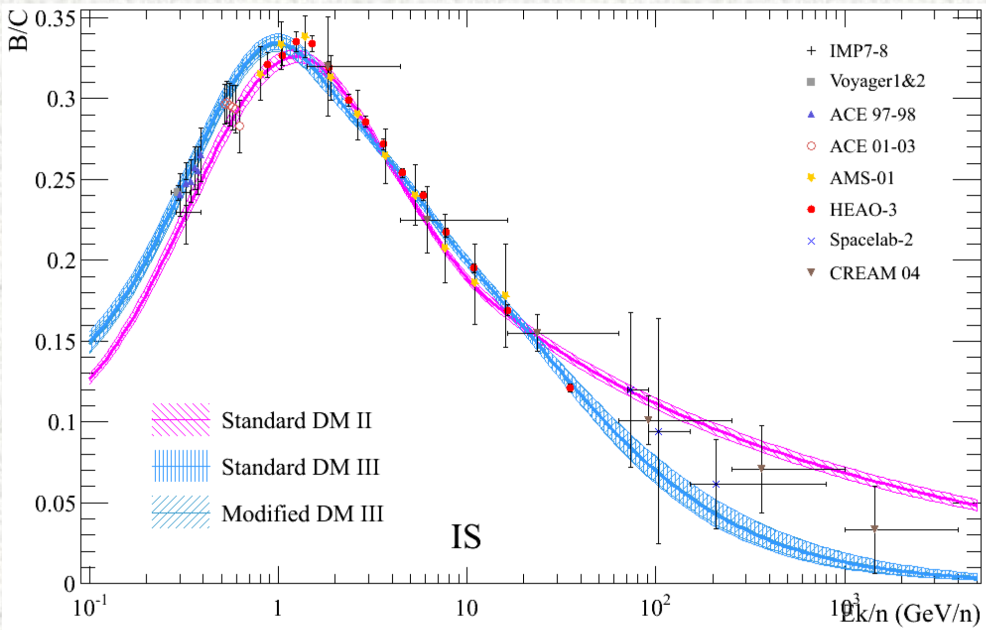
The goal is to shape **a unique galactic model** able to explain all the observables: nuclei, antinuclei, nuclear isotopes, leptons, in the O(10^2) MeV to TeV energies.

The same model(s!) should apply to multi-wavelength **photons** produced by CRs interactions (with ISM, magnetic fields,…)

See talks by P. Blasi, C. Evoli, A. Guess

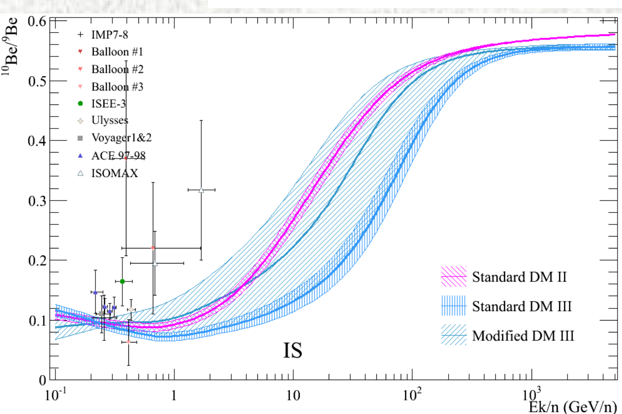
Propagation of CRs:
MCMC results on B/C AND radioactive isotopes

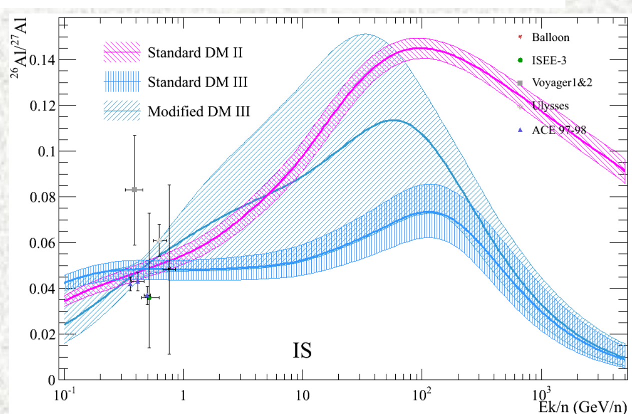
Putze, Derome, Maurin A&A 2010

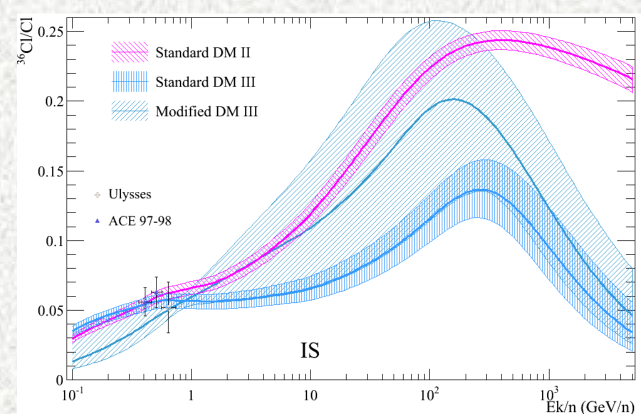


B/C: high degeneracies
in the propagation models

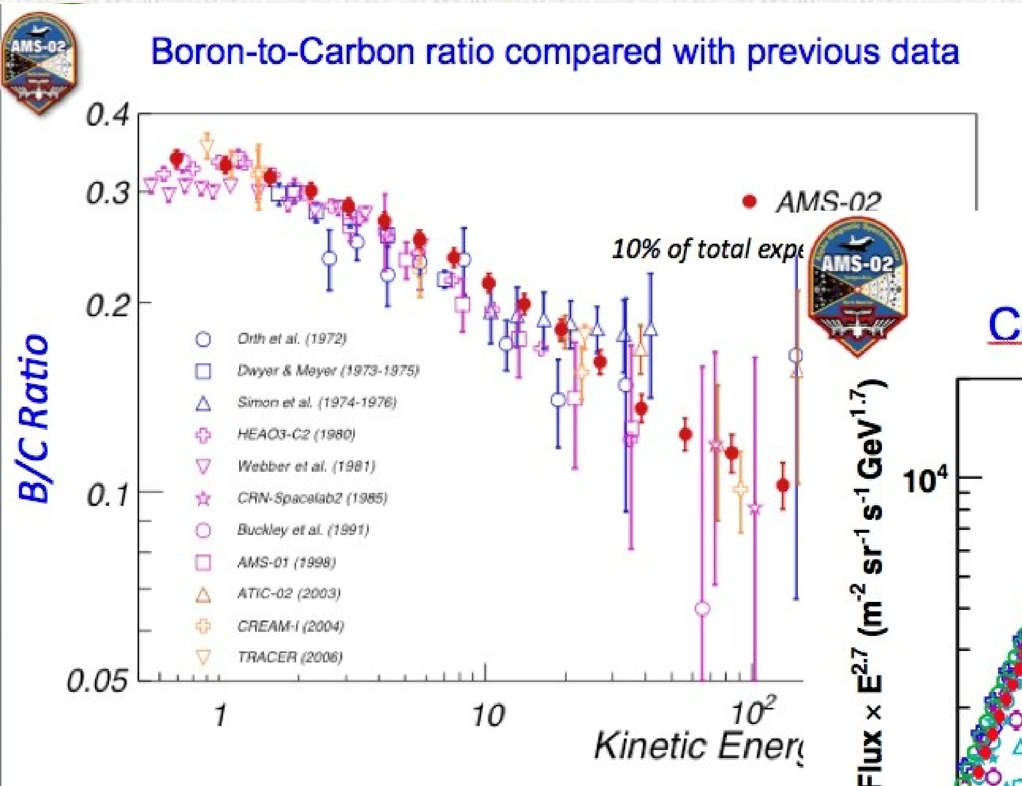
<u>(pre-AMS-02 data)</u>



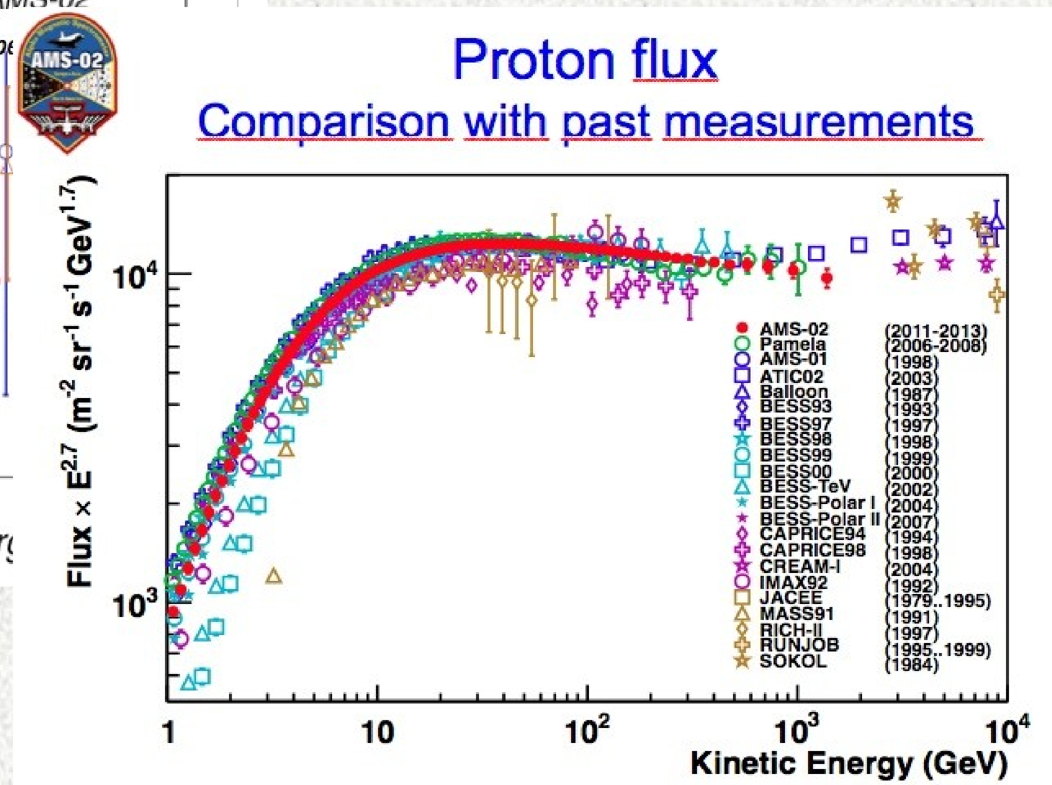




Nuclear AMS-02 data (ICRC july 2013)



No structure in
proton data (similar for He)



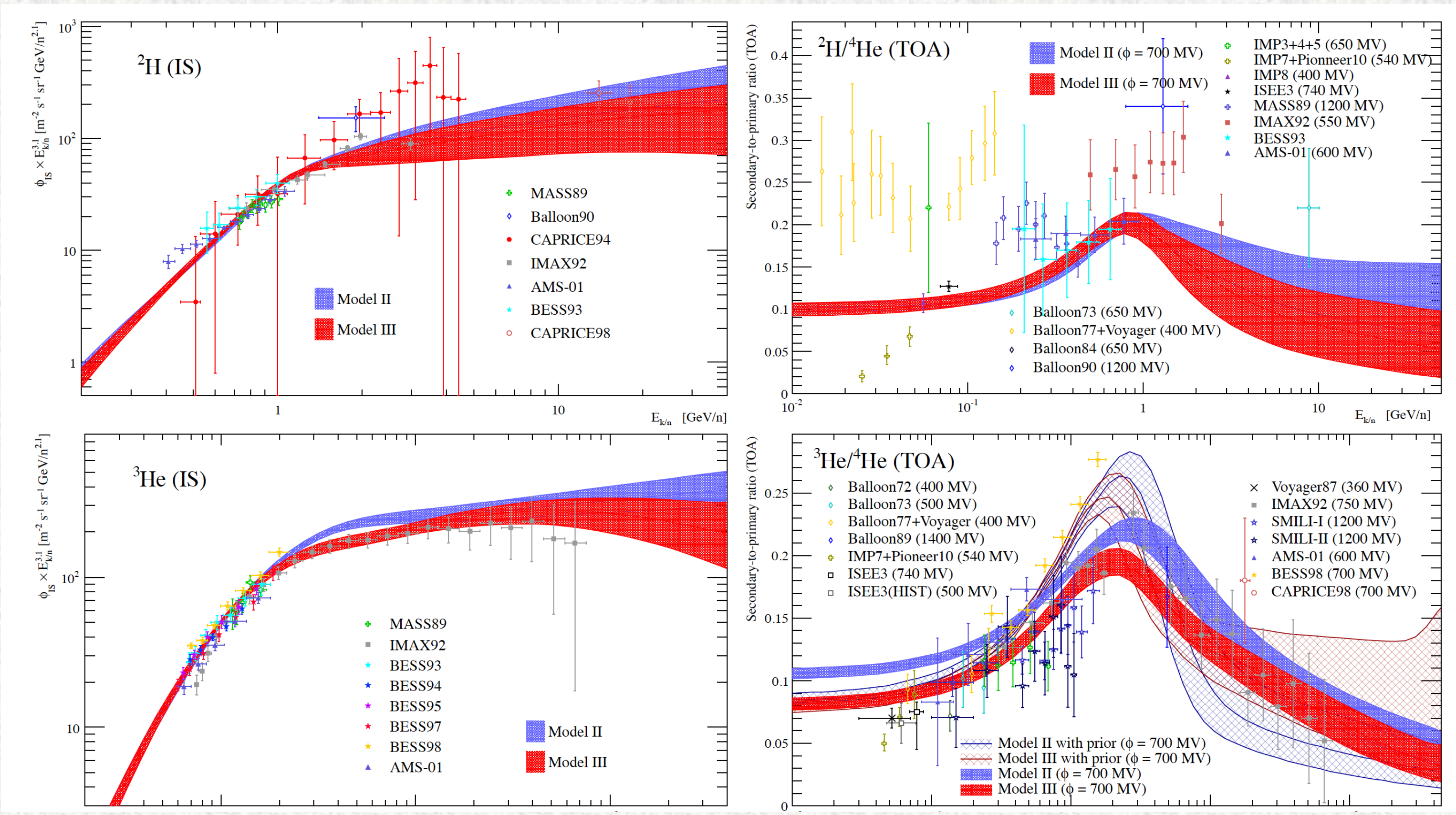
B/C: HEAO3 peak at 1 GeV/n is confirmed
HE trend is similar (slightly softer? Trend changes at ~ 30 GeV/n?)

Possible improvements:
analysis of AMS-02 nuclear data can reduce uncertainties in the antimatter spectra induced by DM

Analysis with Z<=2 Nuclei

Coste, Derome, Maurin, Putze A&A 2012

^{1}H, ^{2}H, ^{3}He, ^{4}He almost as powerful as B/C
Noticeable effort on reliable cross sections

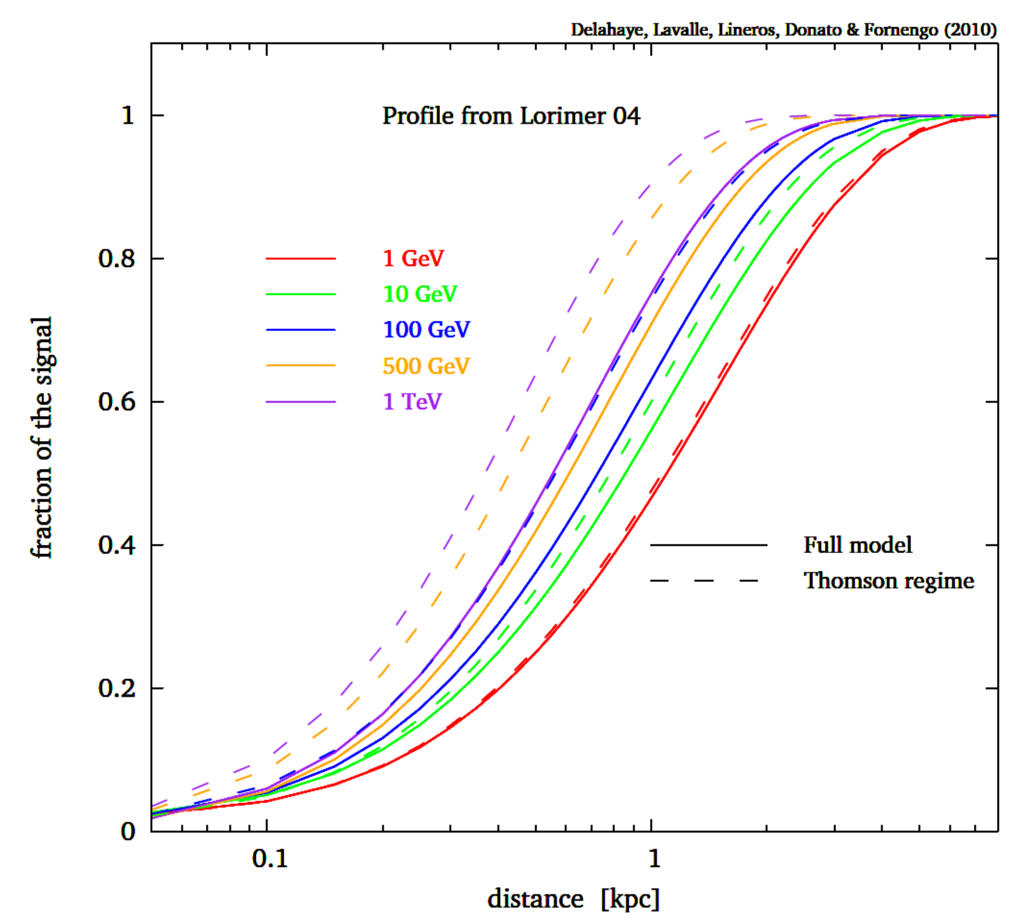


Possible improvements:
New data from Pamela:1304.5420

Positrons in cosmic rays

Propagation of e^+ & e^-

Delahaye, Lavalle, Lineros, FD, Fornengo, Salati, Taillet A&A 2009



Diffusive semi-analytical model:
Thin disk and confinement halo
Free parameters fixed by B/C

Above few GeV: only spatial diffusion and energy losses

Energetic positrons & electron are quite local

Relativistic (KN) energy losses induce a longer propagation scale

95%(80%) for 2kpc and E>100(10) GeV

Sources of positrons in the Milky Way

Generically, we can list the following sources of e^+ and e^- in the Galaxy:

1. Secondary e^+e^-: spallation of cosmic p and He on the ISM (H, He)
   * $p+H \rightarrow p+\Delta^+ \rightarrow p+\pi^0$ & $n+\pi^+$ (mainly below 3 GeV)
   * $p+H \rightarrow p+n+\pi^+$
   * $p+H \rightarrow X + K^\pm$

2. Primary e- from SNR: 1° type Fermi acceleration mechanism

3. Primary e- and e+ from Pulsars:
   pair production in the strong PULSAR magnetoshpere

4. Primary e^+e^- from exotic sources (i.e. Dark Matter)

* Pamela data triggered an enormous theoretical and phenomenological activity in order to explain the positron fraction raising at high energies*

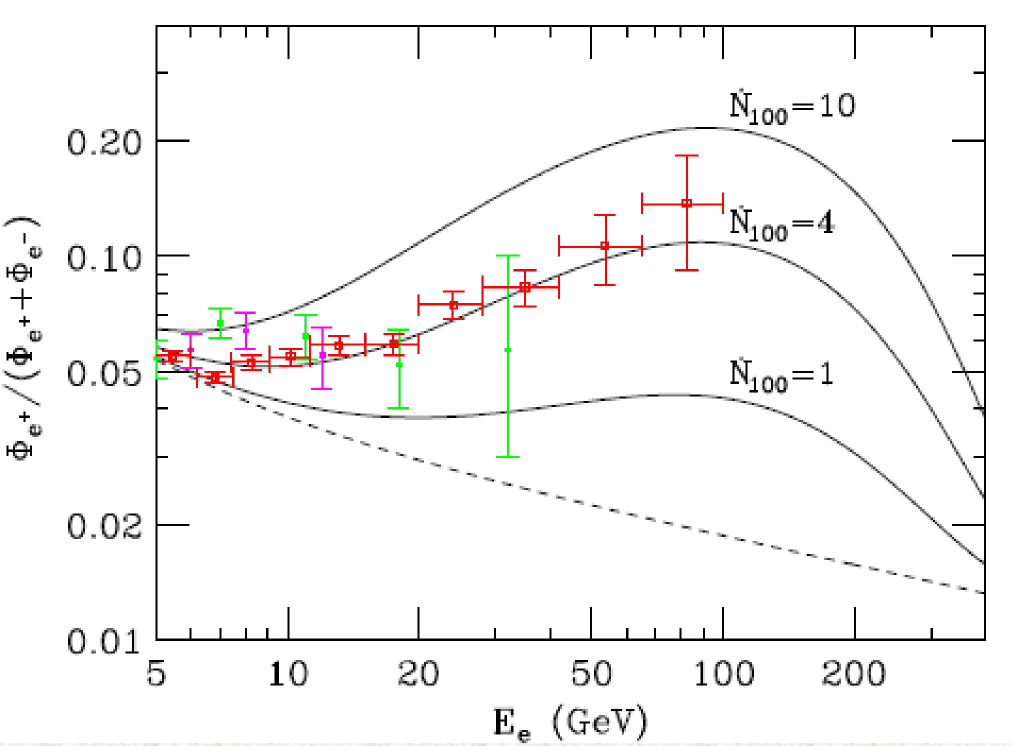
Primary positrons and electrons from pulsars

Pulsars can be the sources of energetic e^+ and e^-:

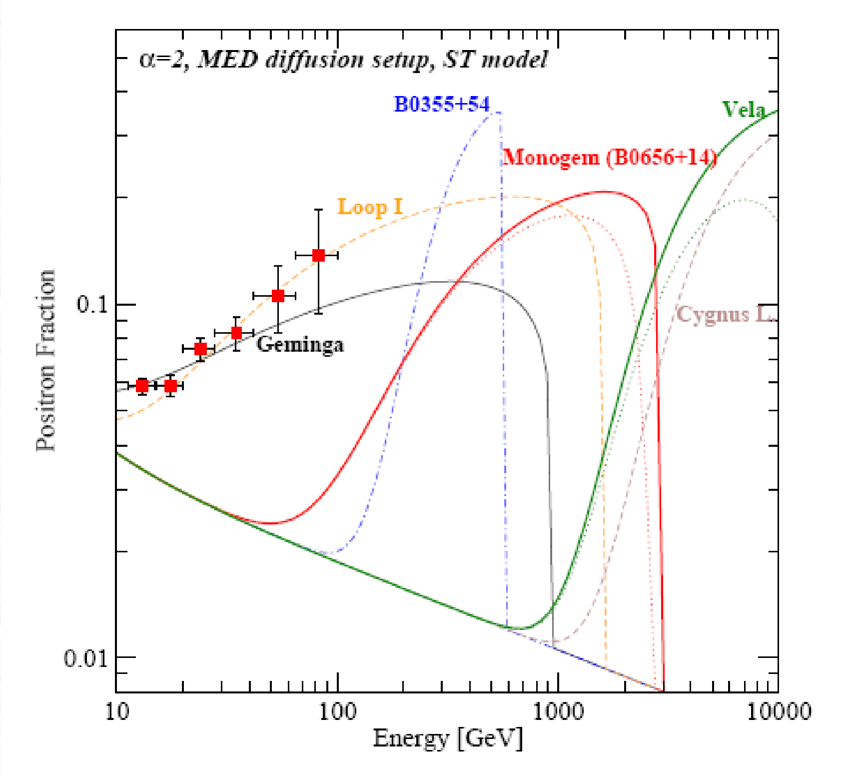
pair production in the strong pulsar magnetoshpere

can explain Pamela data

Hooper, Blasi, Serpico, JCAP 2009

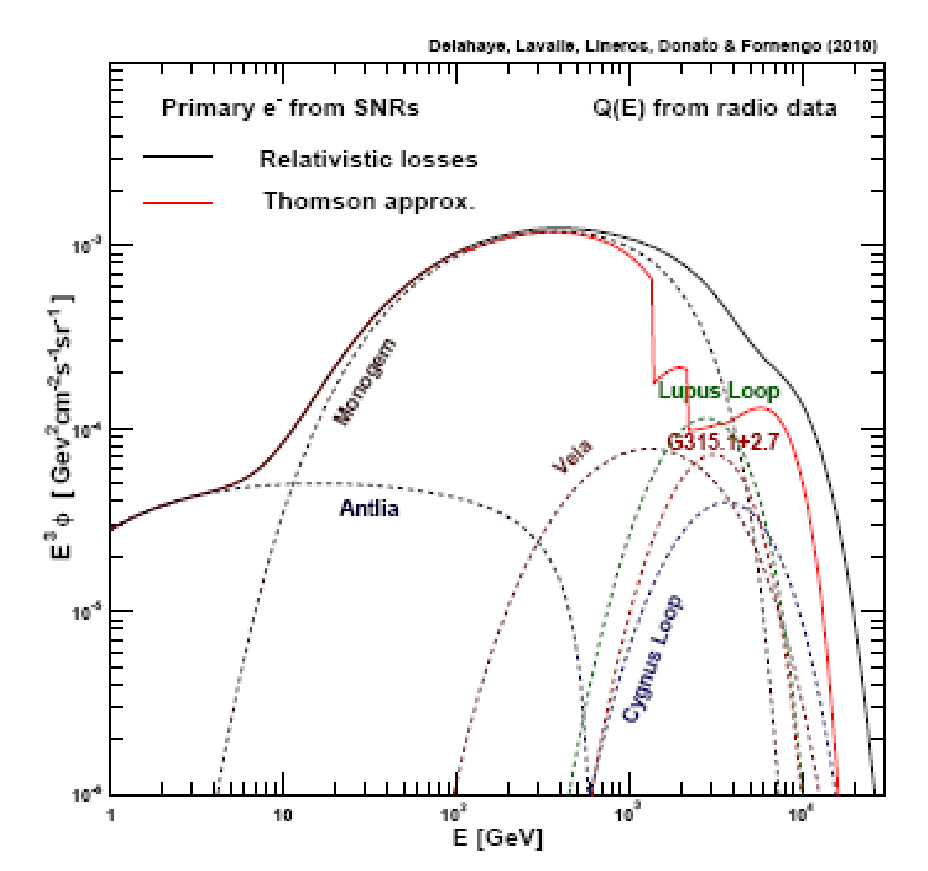


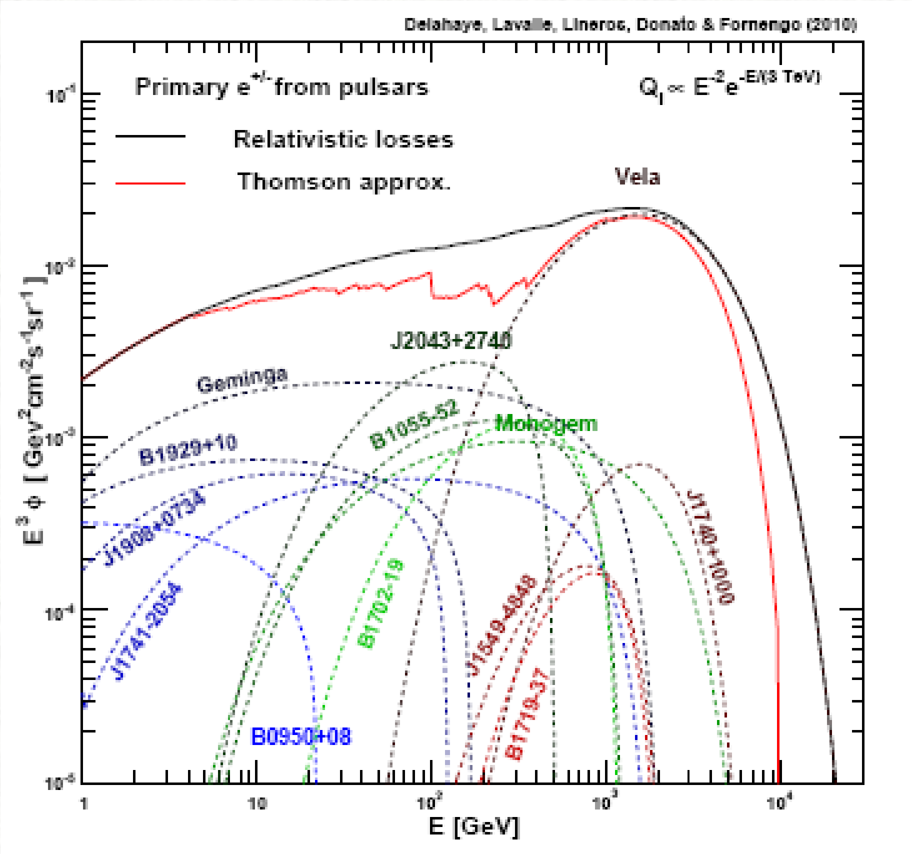
Profumo arxiv:0812.4457



Primary e+ & e- from pulsars and SNR

Delahaye, Lavalle, Lineros, FD, Fornengo A&A 2010



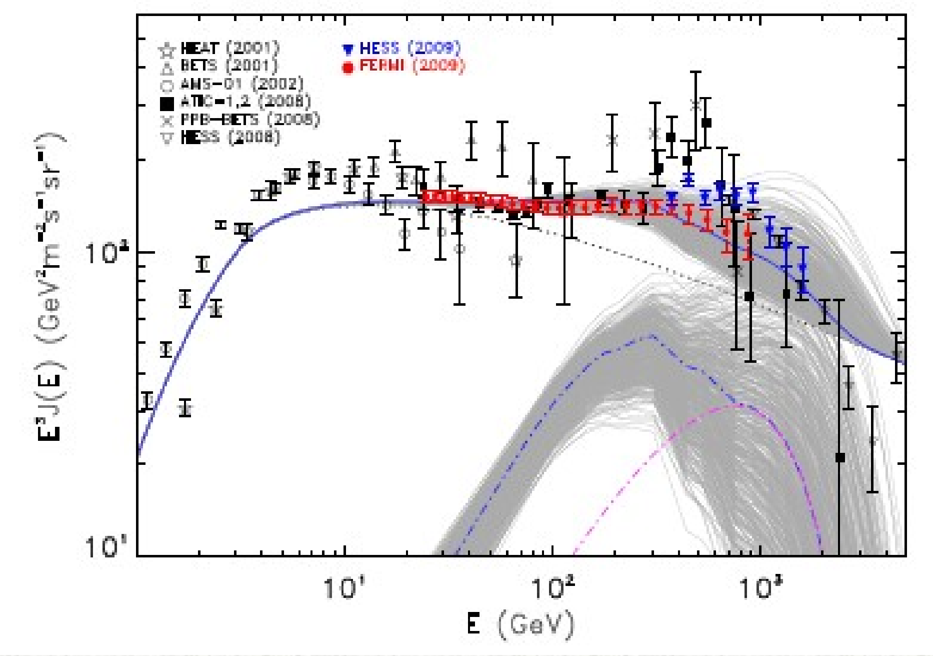


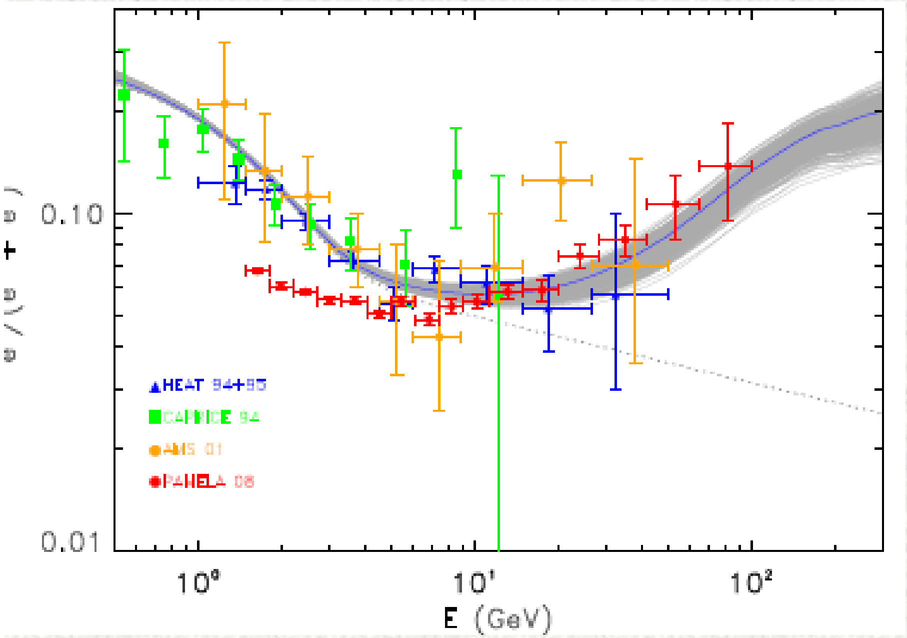
SNR

Pulsars

FERMI electrons and PAMELA positron fraction: contribution from local pulsars (d<3 kpc)

(Grasso et. al 0905.0636)



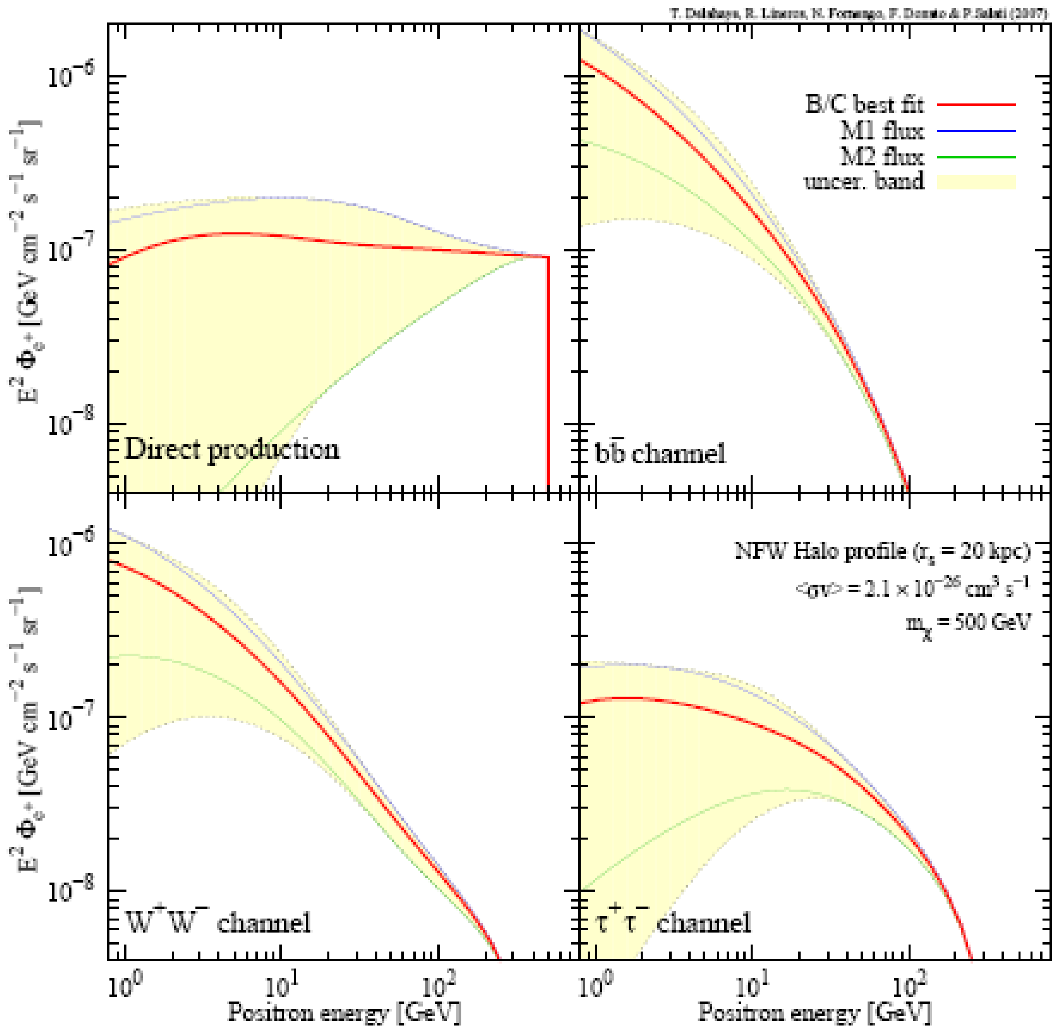


Good description of both e^- and $e^+/(e^+e^-)$

If it were Dark Matter?

Positron from DM: shape from annihilation channels

Delahaye et al. PRD 2008



m=500 GeV

Direct annnihilation in e, or in tau, are **harder** than bb or gauge boson

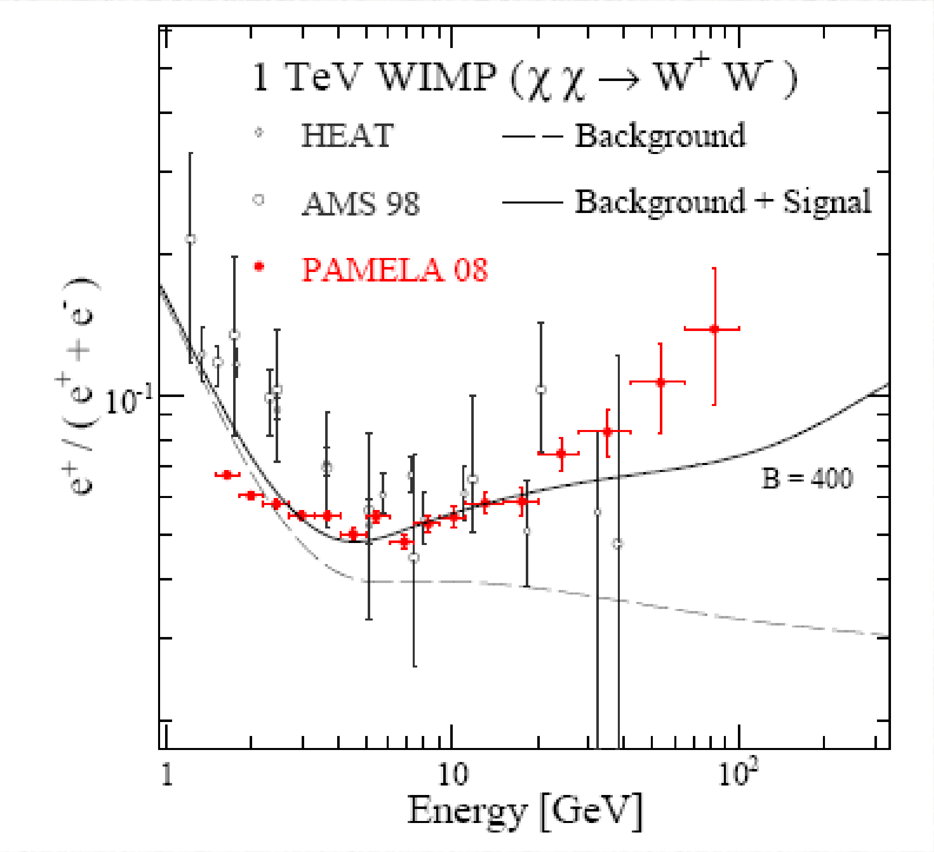
In typical SUSY models annihilation in leptons is helicity **suppressed** wrt quark production

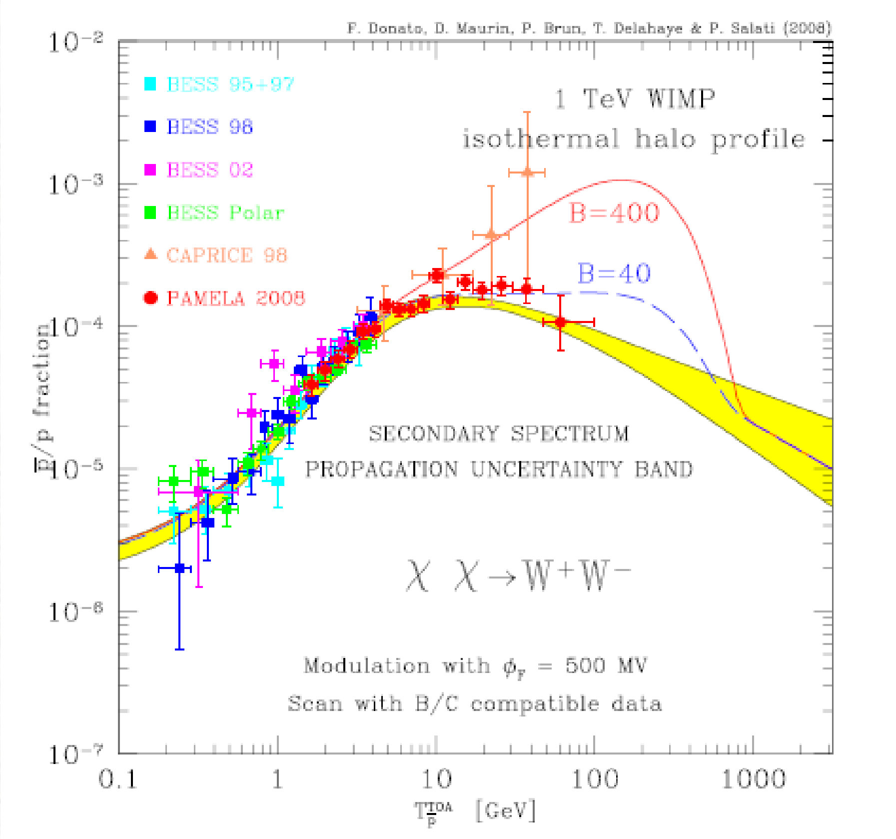
Uncertainties on primaries is 3-5, depending on:

- Energy
- Annihilation channel
- DM distribution

DM Constraints to PAMELA positron/electron data from antiprotons flux

Donato et al. PRL 2009



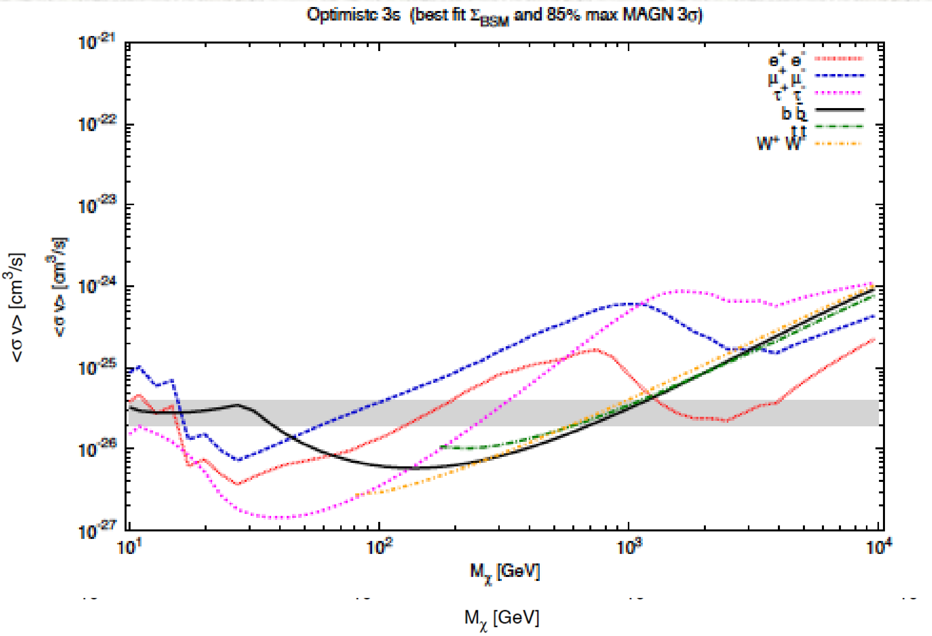


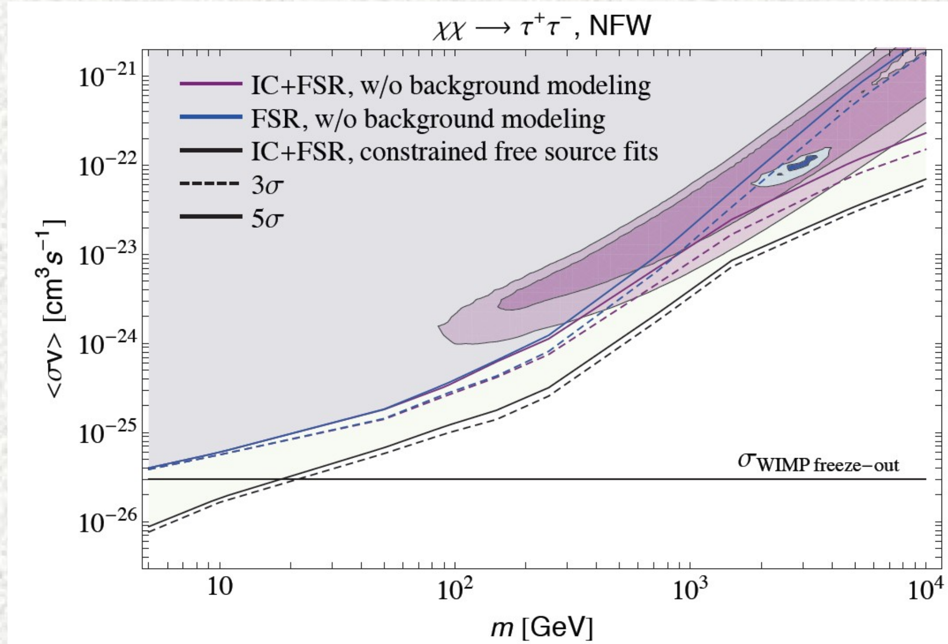
The same example: 1 TeV DM candidate

B=400 largely excluded by Pamela!

B=40 marginally allowed

DM constraints from diffuse γ-ray emission





High latitude data: |b|>10:

Bringmann, Calore, Di Mauro, FD 2013

-<u>Negligible</u> the choice for ρ(r)
-<u>crucial </u>the backgrounds from extra-galactic unresolved sources

Halo 5<|b|<15,|l|<80:

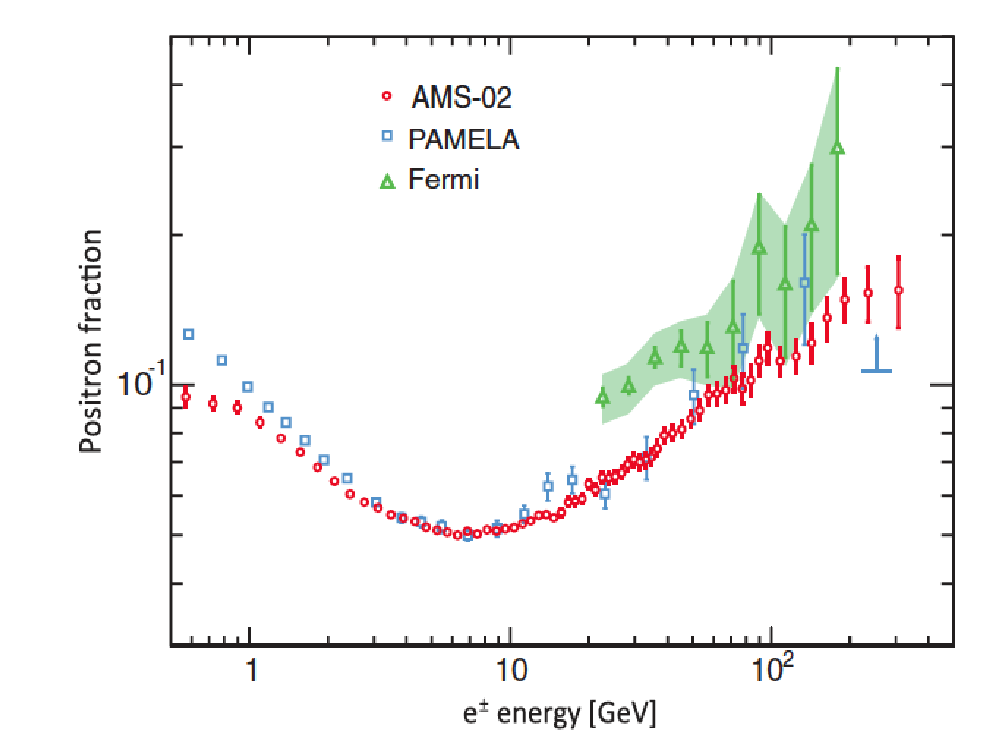
Fermi-LAT Coll. 1204.6474

-Models for the diffuse galactic emission <u>improve</u> the limits
-<u>Important</u> the choice for ρ(r)

And also Cirelli, Panci, Serpico NPB2010 for IC

Positron Fraction: new data from AMS-02

AMS Coll. PRL 2013 & Talk by R. Battiston



AMS-02 data confirm Pamela measurements, with higher precision and larger energies

$$\Phi_{e^+} = C_{e^+} E^{-\gamma_{e^+}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

Excellent fit with diffuse-like spectra and a common, generic, cut-off source

AMS-02 data on leptons

Data interpretation with pure astrophysical models

M. Di Mauro, FD, N. Fornengo, R. Lineros, A. Vittino, in preparation

Our model includes:

SOURCES:

- e^- from SNRs (near & far sources)
- e^+ from spallations of CRs on ISM
- $e^+ e^-$ from PSRs

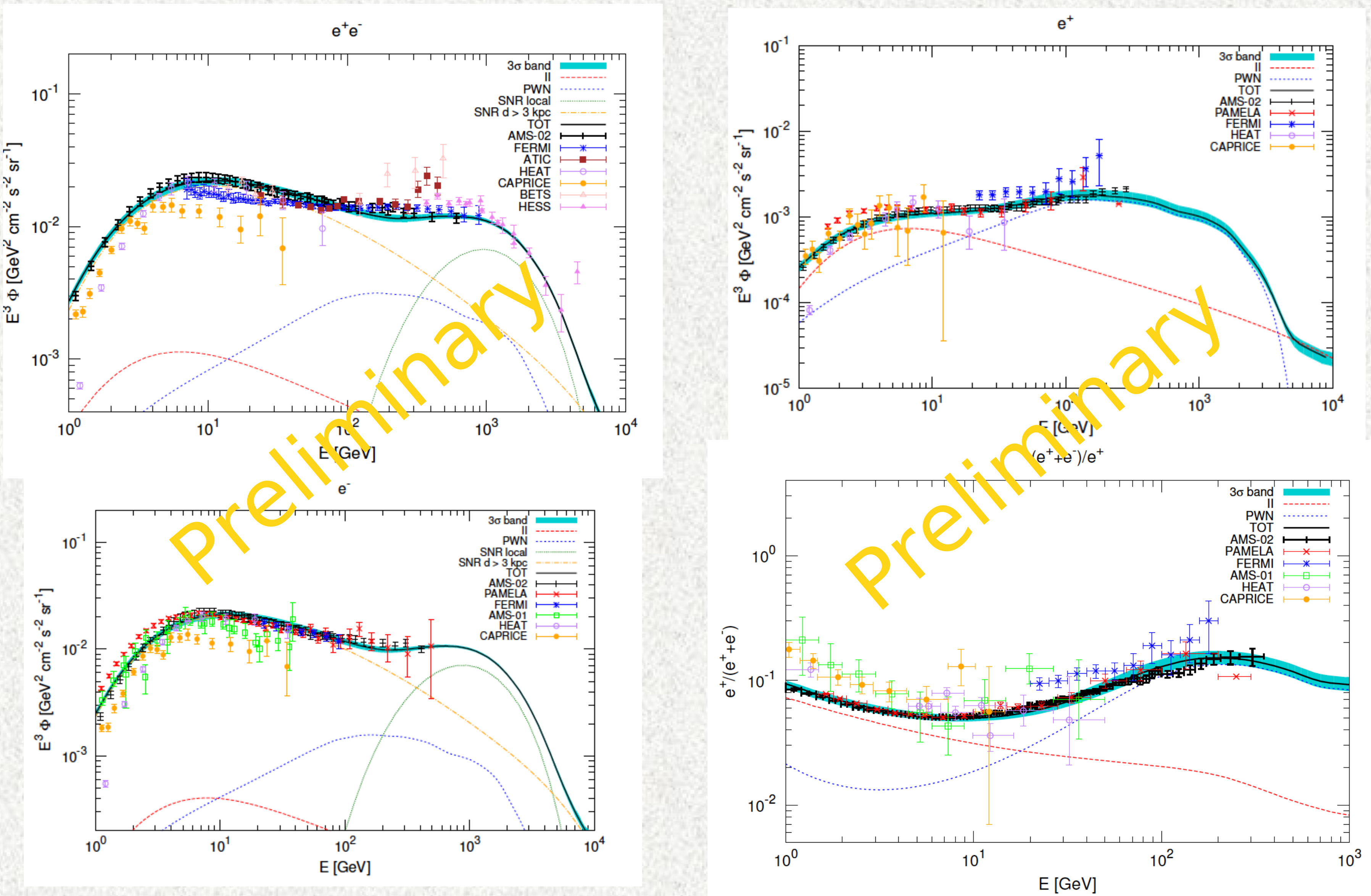
PROPAGATION IN THE MW:

- Diffusion
- Full energy losses

- FITS to ICRC2013 AMS-02 data on e^-, e^+, e^-+e^+, $e^+/(e^-+e^+)$

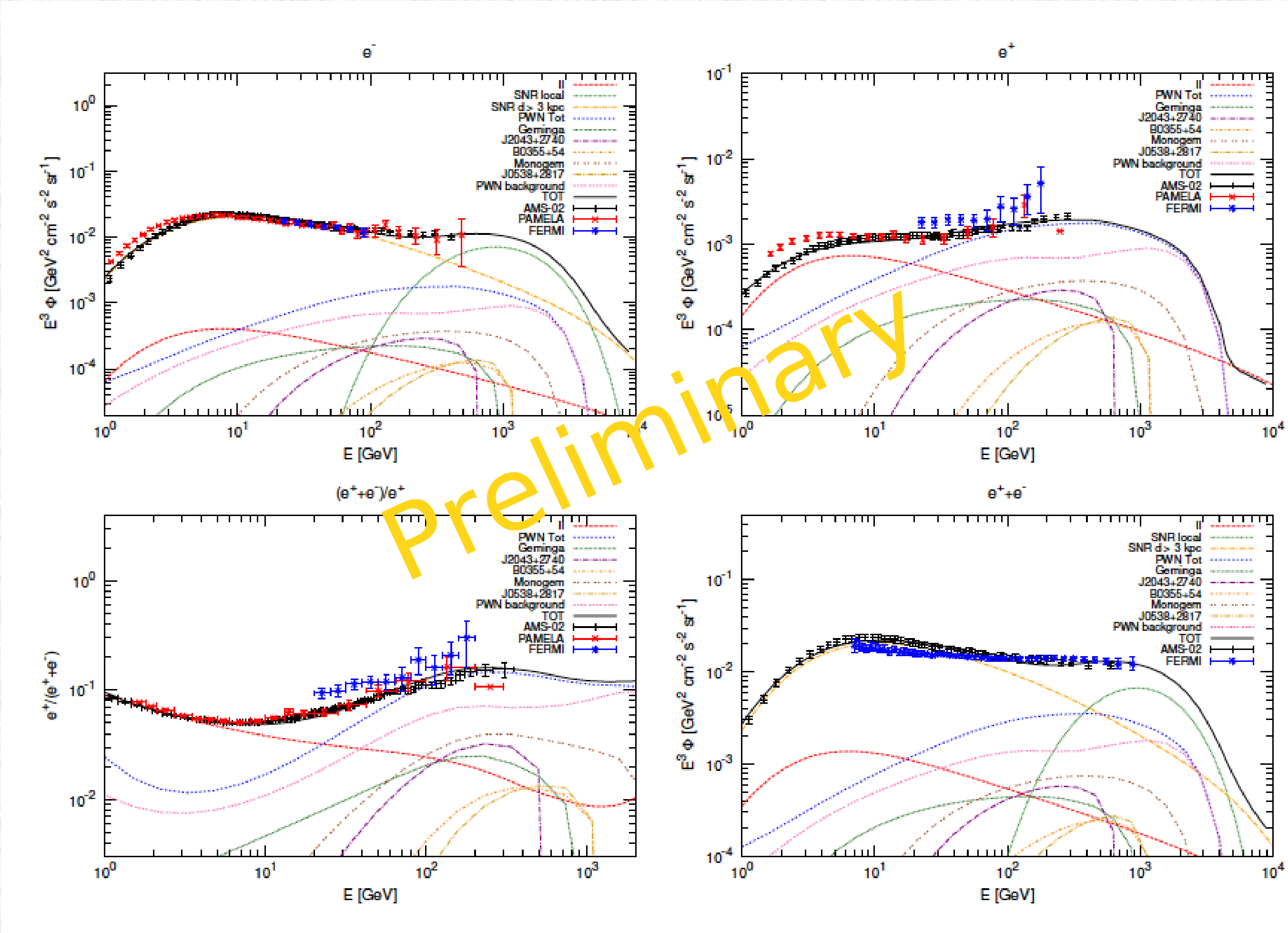
Fit to the AMS-02 data

Di Mauro, FD, Fornengo, Lineros, Vittino, in preparation



Fit to the AMS-02 data: a unique model

Di Mauro, FD, Fornengo, Lineros, Vittino, in preparation



A unique astrophysical model with few local sources may explain all the leptonic AMS-02 data at all energies

Fit to the AMS-02 data: a unique astrophisical model

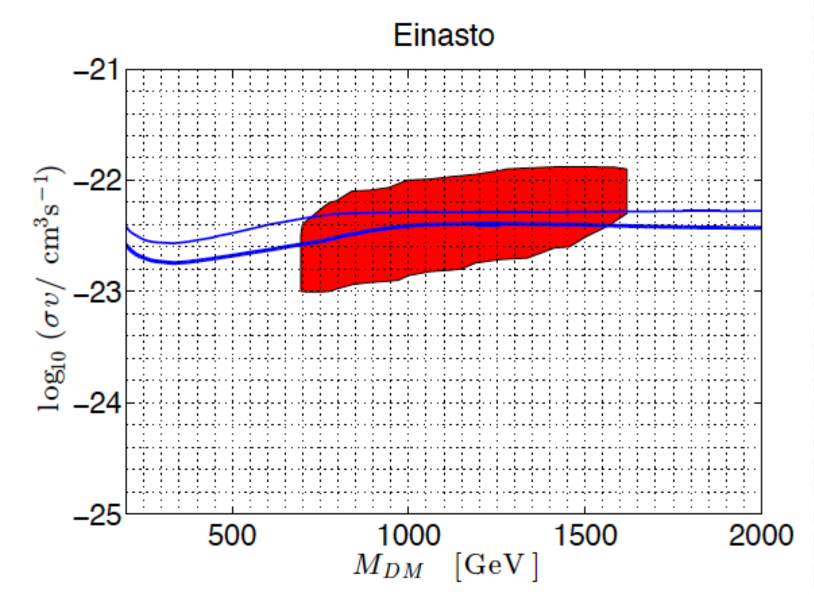
Di Mauro, FD, Fornengo, Lineros, Vittino, in preparation

Preliminary results from our analysis:

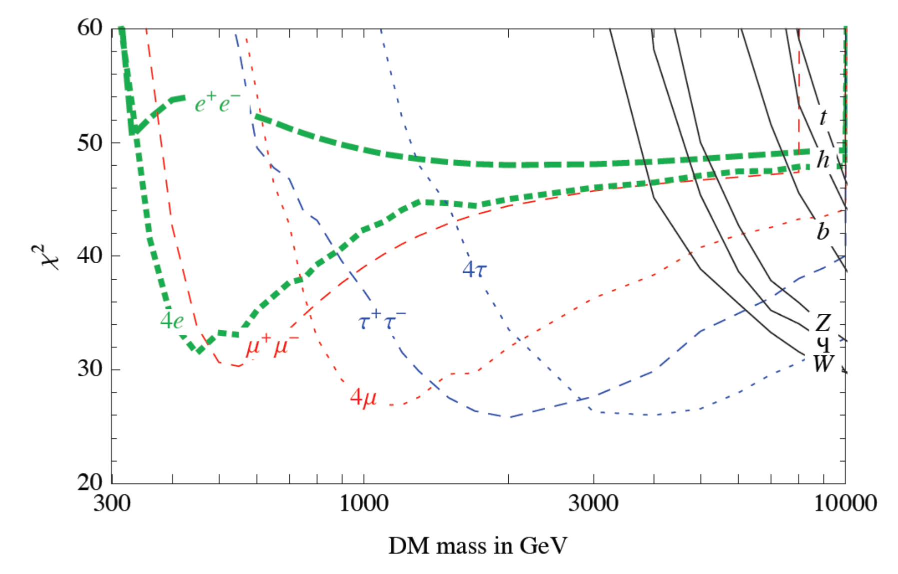
- A unique astrophysical model with few local sources may explain all the leptonic AMS-02 data at all energies
- The parameters describing the single sources have been constrained by multi-wavelength (when available) data
- There is no need for a dark matter component in order

AMS-02 data: DM interpretation

De Simone, Riotto, Xue JCAP2013



Cirelli et al. NPB 2009;+2013

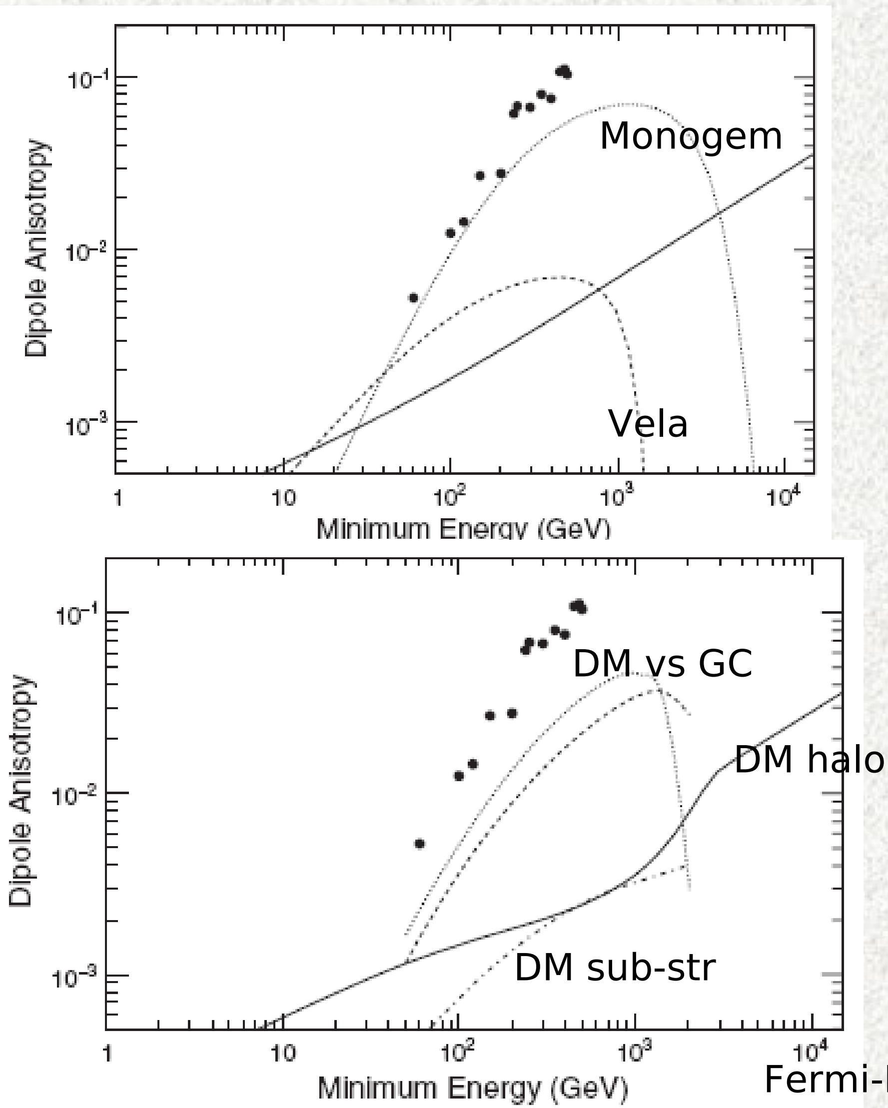


Best fit with: $\tau^+\tau^-$, m_{DM}~1 TeV

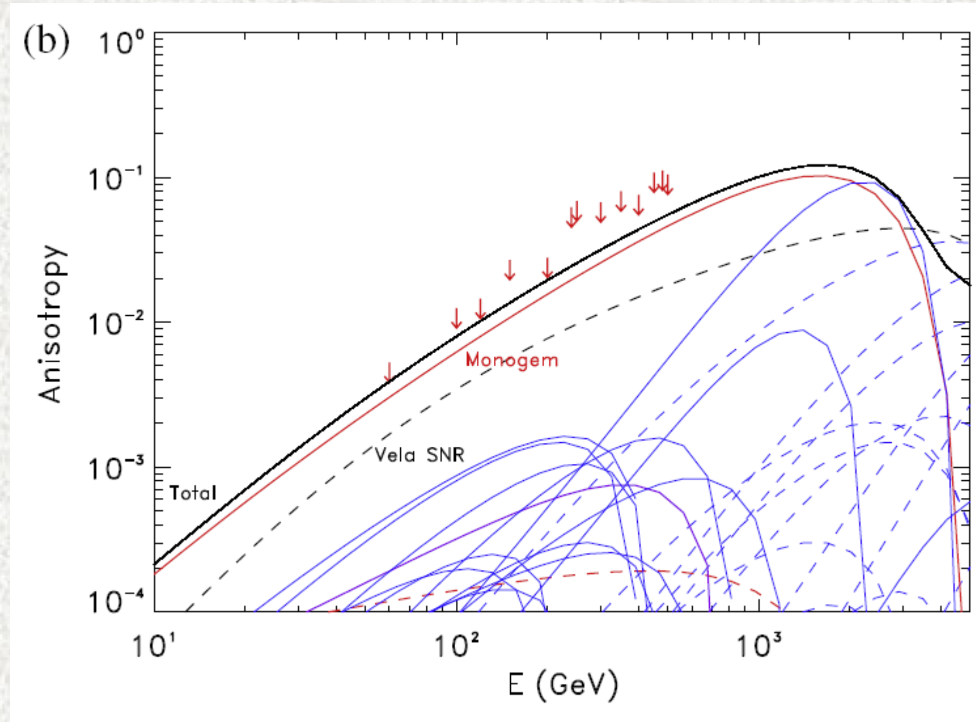
- Leptonic channels already constrained by γ-rays (see before)
- Tension with antiprotons (Donato et al PRL2009;)
- AMS-02 data suggests (Cirelli et al. NPB 2009;+2013):
  - leptonic channels strictly required (WW not compatible)
  - m_{DM} <~1 TeV required by the hinted flattening of the data

Anisotropy in CR electrons

Being quite local (1-2 kpc), e^- observed flux can be the overlap anysotropic nearby sources: pulsars, SNR; DM



Fermi-LAT PRD 2010



Di Bernardo et al., Astrop. Ph. 2011

Fermi/LAT upper limits

DM models tuned to Pamela data

Antiprotons

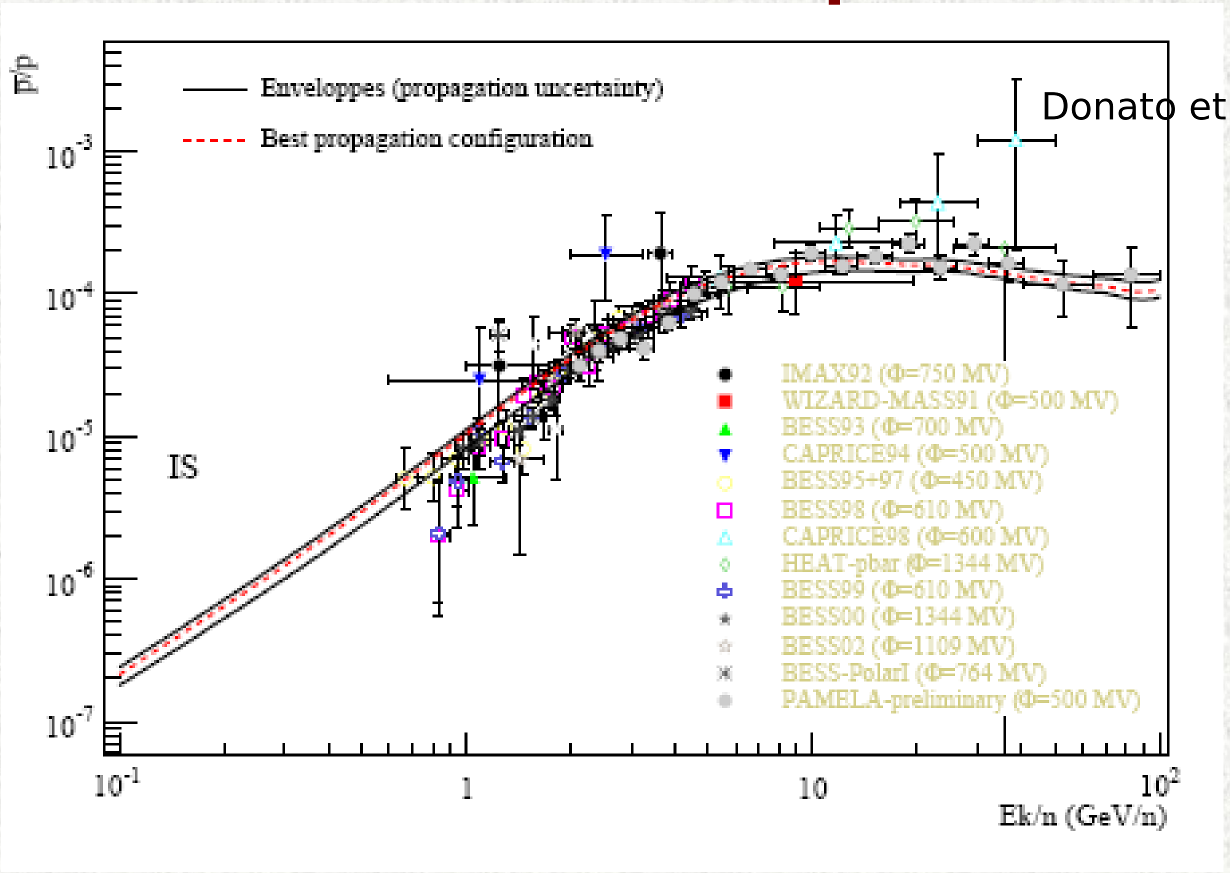
Antiproton in CRs: data and models

Theoretical calculations with the semi-analytical DM, compatible with stable and radioactive nuclei

NO need for new phenomena (astrophysical / particle physics)

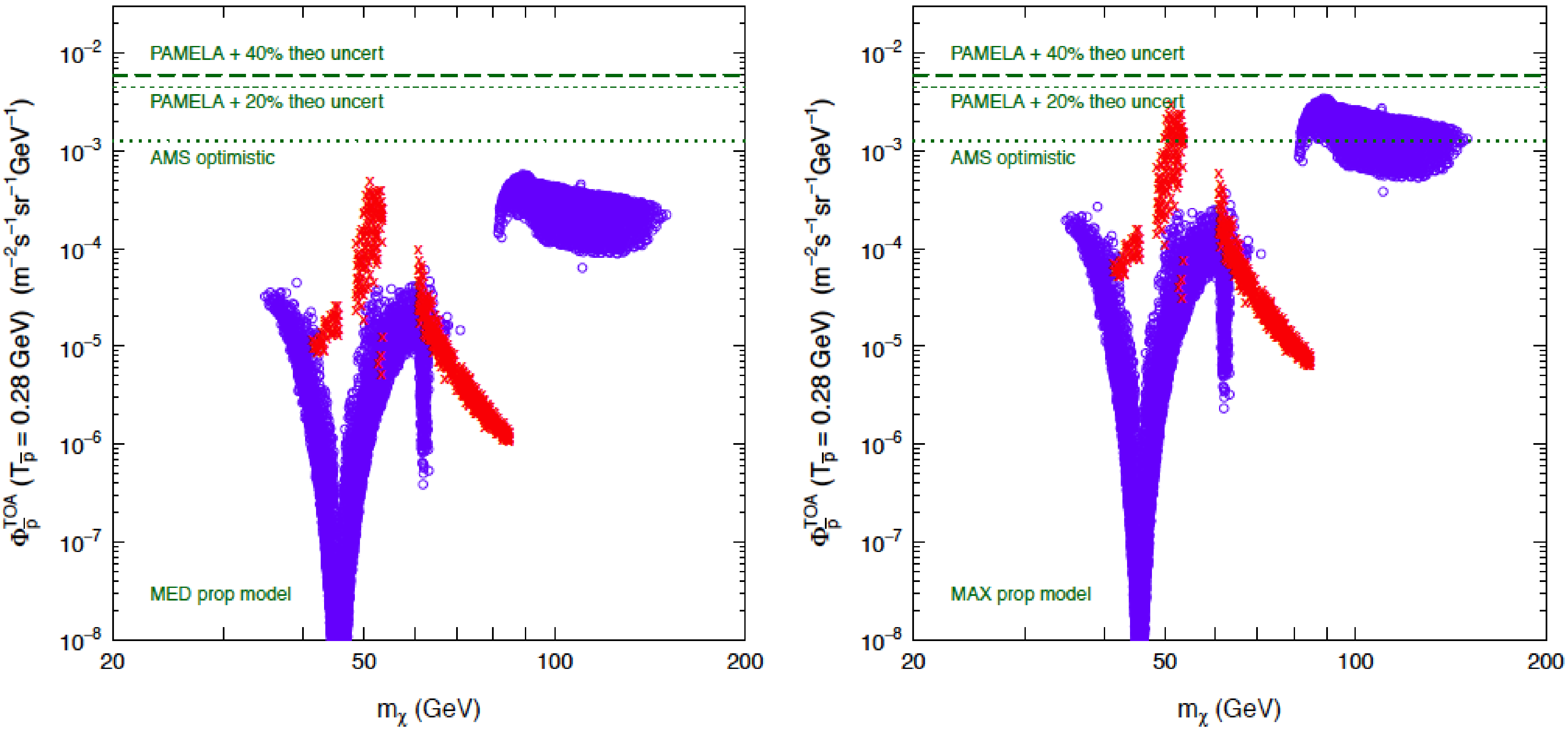
_→ Bounds to models

AMS-02 data expected ☺



Donato et al. PRL 2009

Antiprotons: constraining tool, with caveats



effMSSM models surviving LHC constraints and two Higgs scenarios for the scalar at 126 GeV (h or H)

Scopel, Fornengo, Bottino 1304.5353

Secondary antiprotons in cosmic rays (CR) are produced by spallation reactions on the interstellar medium (ISM)

$p_{CR} + H_{ISM}$
$p_{CR} + He_{ISM}$
$p_{CR} + H_{ISM}$
$He_{CR} + He_{ISM}$

} $\bar{p}$ + X

$\bar{p}$

The only measured cross section is pp → + X

ALL CROSS SECTIONS INVOLVING He (projectile or target) ARE DERIVED FROM OTHER DATA

- p+p: $\sigma_{p+p \rightarrow \text{antiprotons}}$ analytical expression

  (Tan & Ng, PRD26 (1982) 1179; J.Phys.G:NuclPhys 9 (1983) 227)

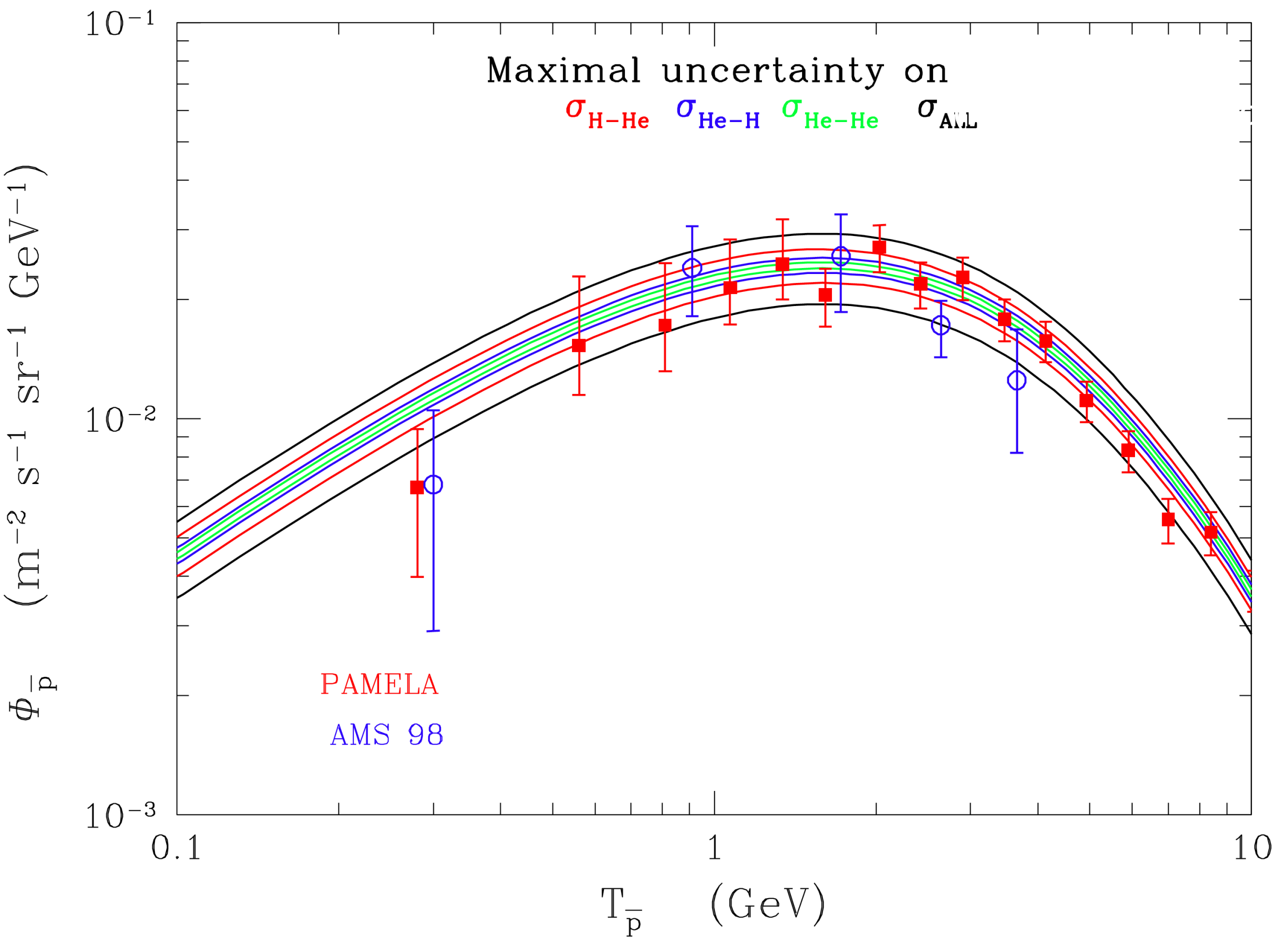
  Possible improvements (we're working on): data from NA49

  (Eur.Phys.J. C65 (2010) 9)

- p+ He, He+p, He+He: $\sigma_{(He)+(p,He) \rightarrow \text{antiprotons}}$ derived from MonteCarlo

Uncertainties on antiproton flux from nuclear cross sections

Model from Donato et al. ApJ 2001, PRL 2009

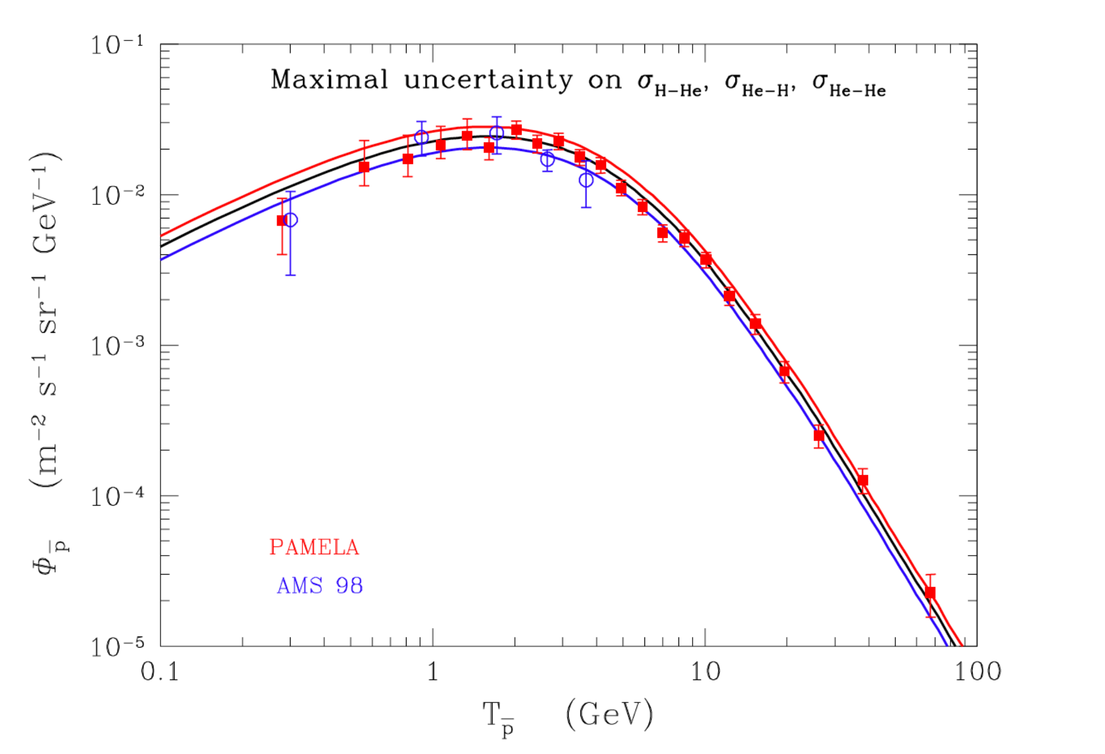


- pp: Tan& Ng
- H-He, He-H, He-He: DTUNUC MC

Maximal uncertainty from H-He: 20-25%

Functional form for the cross section derived from other reactions

The caveat:
antiproton data will likely be more precise than theoretical predictions



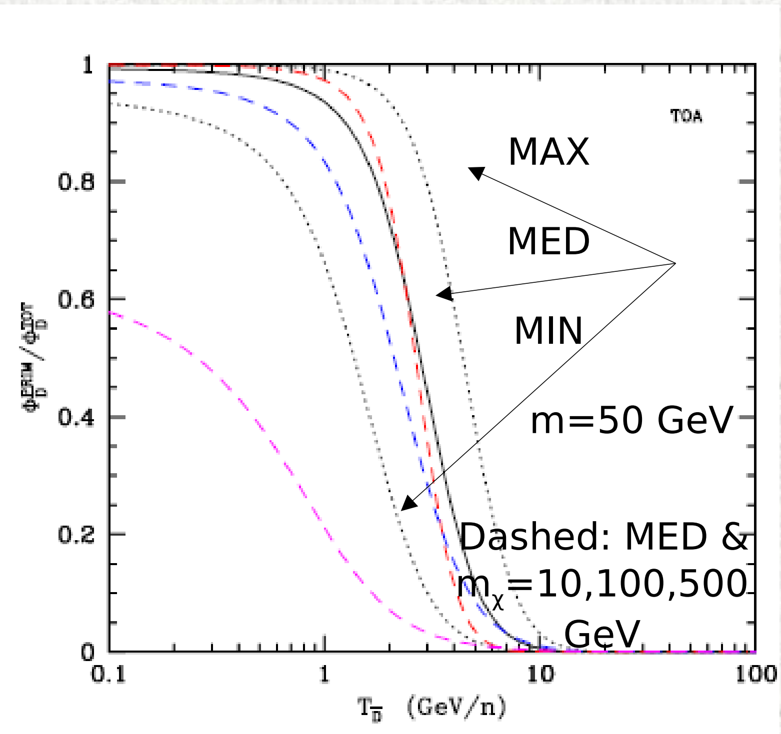
The major problem is nuclear physics!!
Lack of data for cross sections on (with) Helium

Antideuterons

Antideuterons in Cosmic Rays

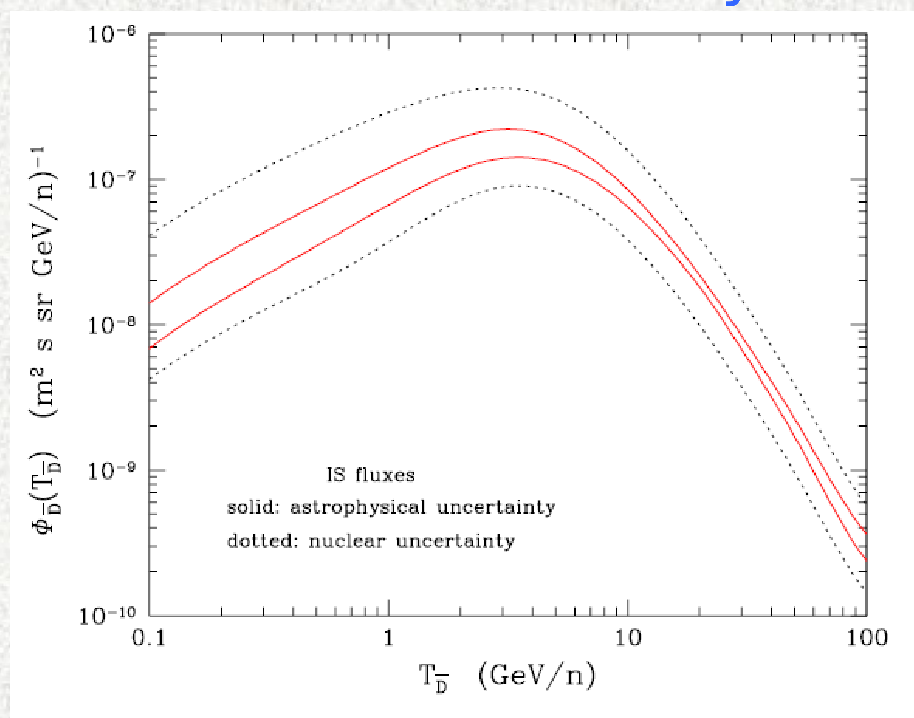
FD, Fornengo, Salati PRD 2000; FD, Fornengo, Maurin PRD 2008

Antideuterons may form by the fusion of an antiproton and an antineutron



Low energy antideuterons have a <u>high discrimination power</u>

Secondary antideuterons are predicted with sizeable nuclear uncertainty



Antideuterons: detection perspectives

AMS is in space
and performing very well!

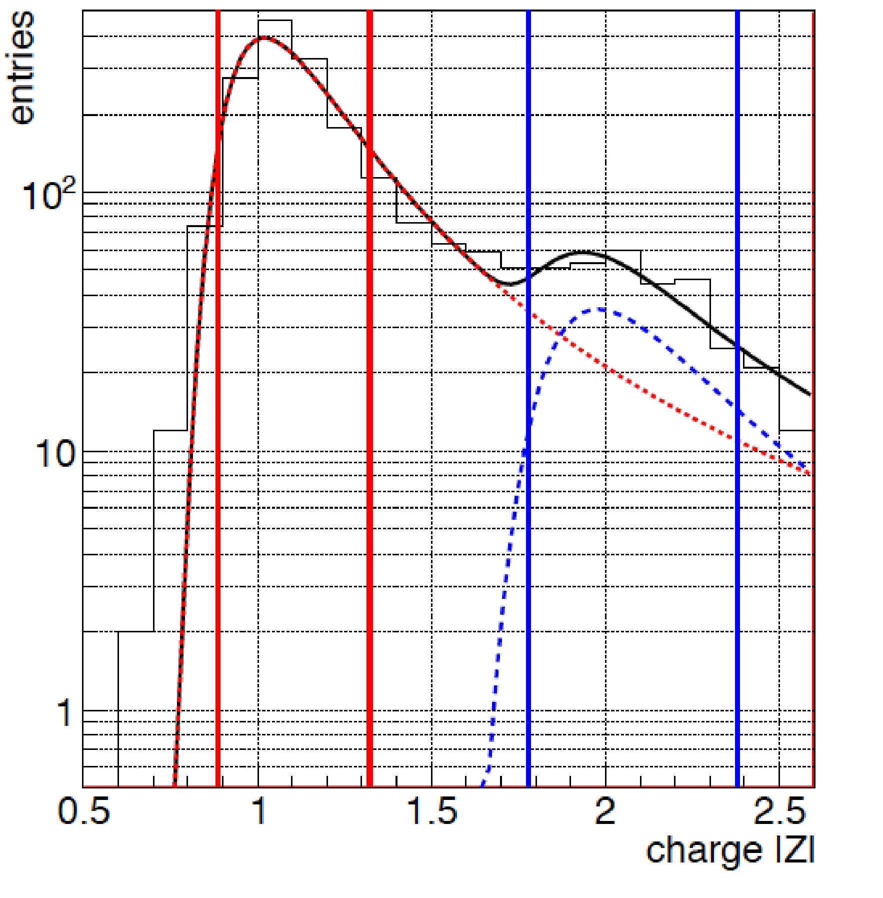
(see talk by Roberto Battiston)

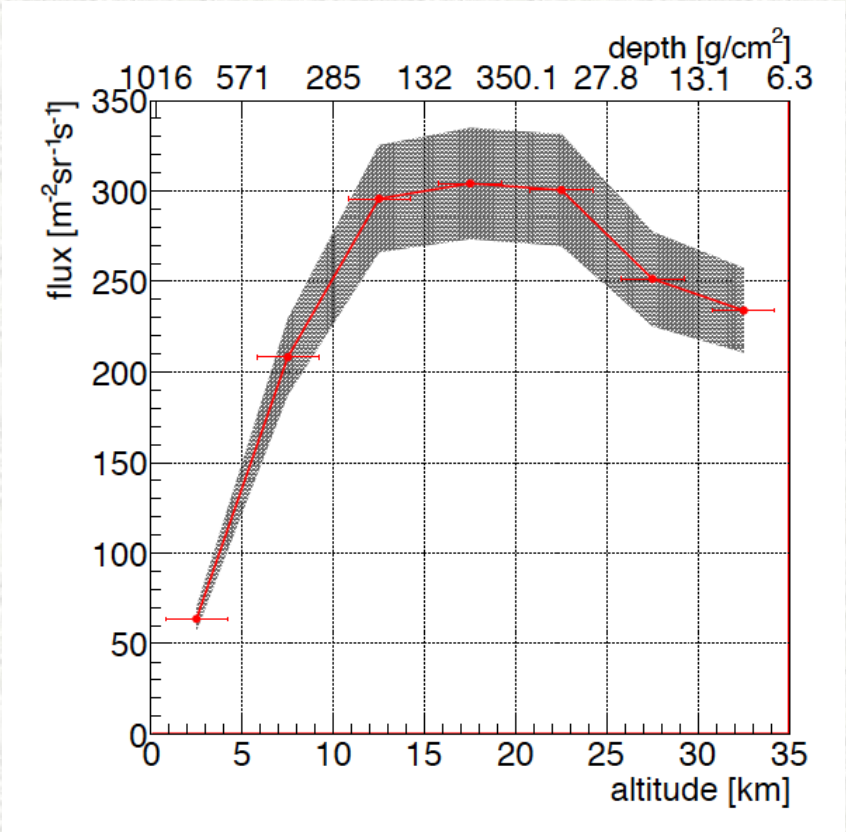
GAPS is a dedicated balloon experiment

Prototype flight 06.2012!
(1307.3538)

GAPS prototype flight

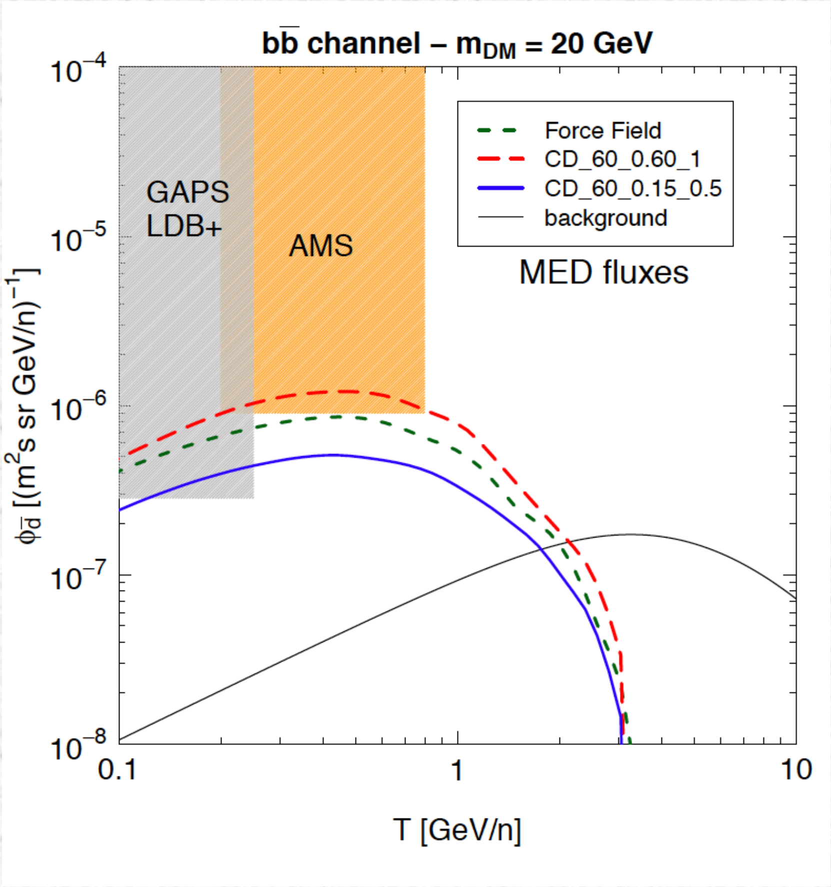
P. von Doetinchem et al. 1307.3538

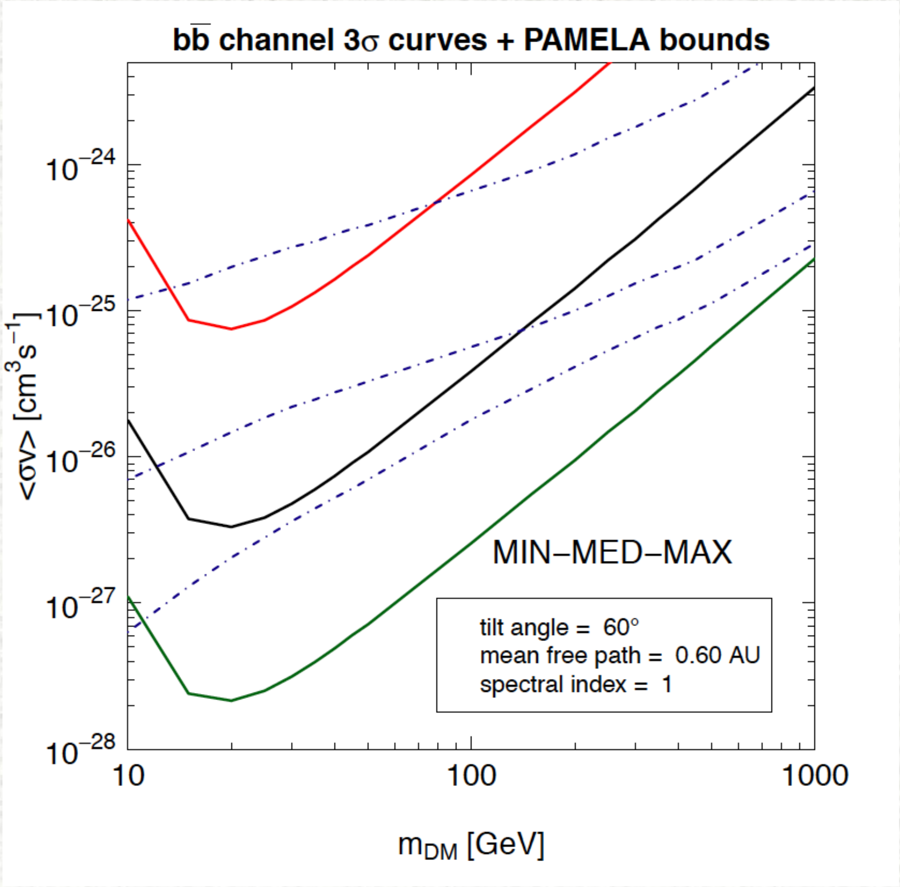




Antideuterons: detection perspectives

Fornengo, Maccione, Vittino 1306.4171





3σ expected sensitivities

Prospects for 3σ detection of antideuteron with GAPS (dotted lines are Pamela bounds from antiprotons)

Conclusions and outlooks

- Indirect dark matter detection has entered a **precision** era, most recently thanks to Fermi-LAT and AMS-02

- A striking DM signal in antimatter seems now unexpected: we have to search **tiny effects** in important astrophysical contributions. Anisotropy may be a useful tool

- Major effort is needed in the understanding astrophysical **backgrounds**: a tough astrophysical work is needed

- A **multi-wavelength** and multi-channel approach - mandatory for backgrounds understanding – looks powerful for DM searches as well

Indirect DM searches cannot proceed alone but are complemented by direct DM searches and new particle production at colliders