Indirect Dark Matter Detection

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NEUTRALINO INDIRECT SIGNALS

Annihilation inside celestial bodies:

- ν at ν telescopes as up-going μ's

$$\Phi_{\mu}^{Sun,Earth} \propto <\sigma_{ann} v> \frac{\rho_{\chi}}{m_{\chi}}$$

Annihilation in the galactic halo:

- γ-rays (diffuse, monochr.), radio
- $e^{+}, \ \overline{p}, \ \overline{D}$

$$\Phi^{\gamma,p,D,e^{+}} \propto <\sigma_{ann} v> \left(\frac{\rho_{\chi}}{m_{\chi}}\right)^{2}$$

ν and γ keep directionality

can be detected only if emitted from high χ density regions

Charged particles diffuse in the galactic halo

antimatter searched as rare components in cosmic rays (CRs)

ASTROPHYSICS OF COSMIC RAYS!

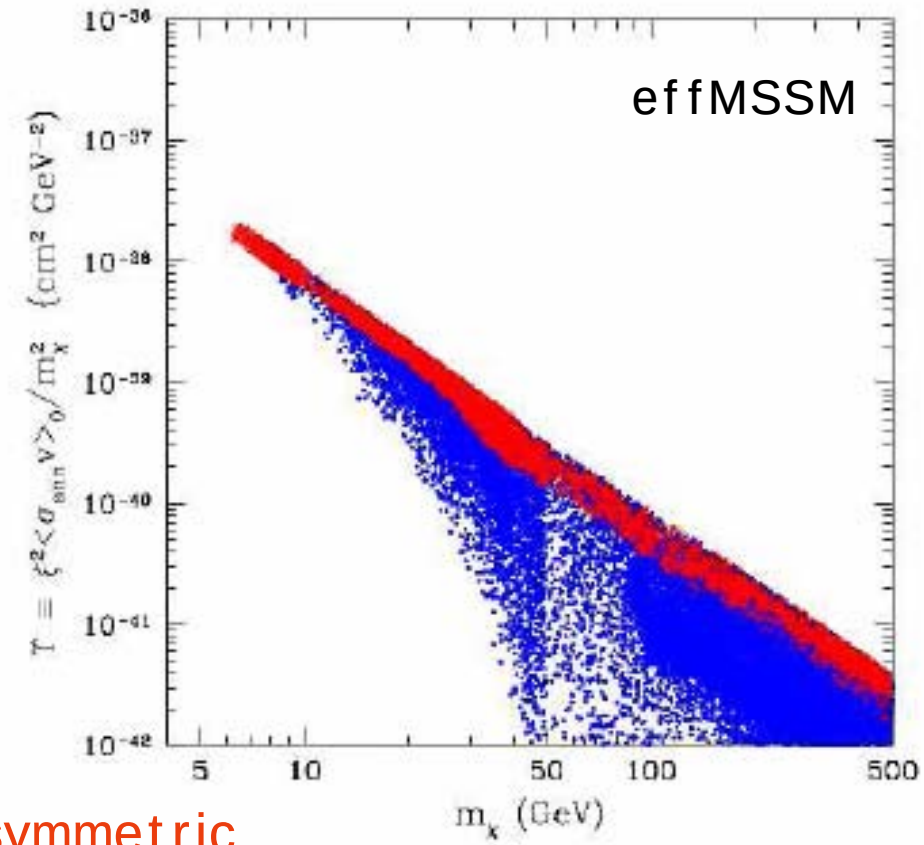
Supersymmetric term for fluxes originating from DM pair annihilation

$$Y = \frac{1}{2}\xi^2 \frac{(\sigma_{ann} v)_0}{m_\chi^2}$$

$\xi = \min(1, \Omega_\chi h^2 / (\Omega_{cdm} h^2))$

Depletion due to cosmological upper limit on $\Omega_{cdm} h^2$

Bottino, FD, Fornengo, Salati PRD 2005



Red dots: WMAP compatible
Blue dots: $\Omega_\chi h^2 \leq 0.095$

** Moreover, the supersymmetric model enters in the source spectrum (energy dependent → propagation for charged CR)

ANTIPROTONS from RELIC NEUTRALINOS

FD, Fornengo,Maurin,Salati,Taillet, PRD (2004), Bottino, FD, Fornengo, Salati PRD (1998,2005)
Bergström, Edsjö, Ullio ApJ (1999)

Source:

$$q_{\bar{p}}^{susy}(E_{\bar{p}}) = < \sigma_{ann} v > g(E_{\bar{p}}) \left\{ \frac{\rho_\chi(r,z)}{m_\chi} \right\}^2$$

Annihilation cross section

Production spectrum

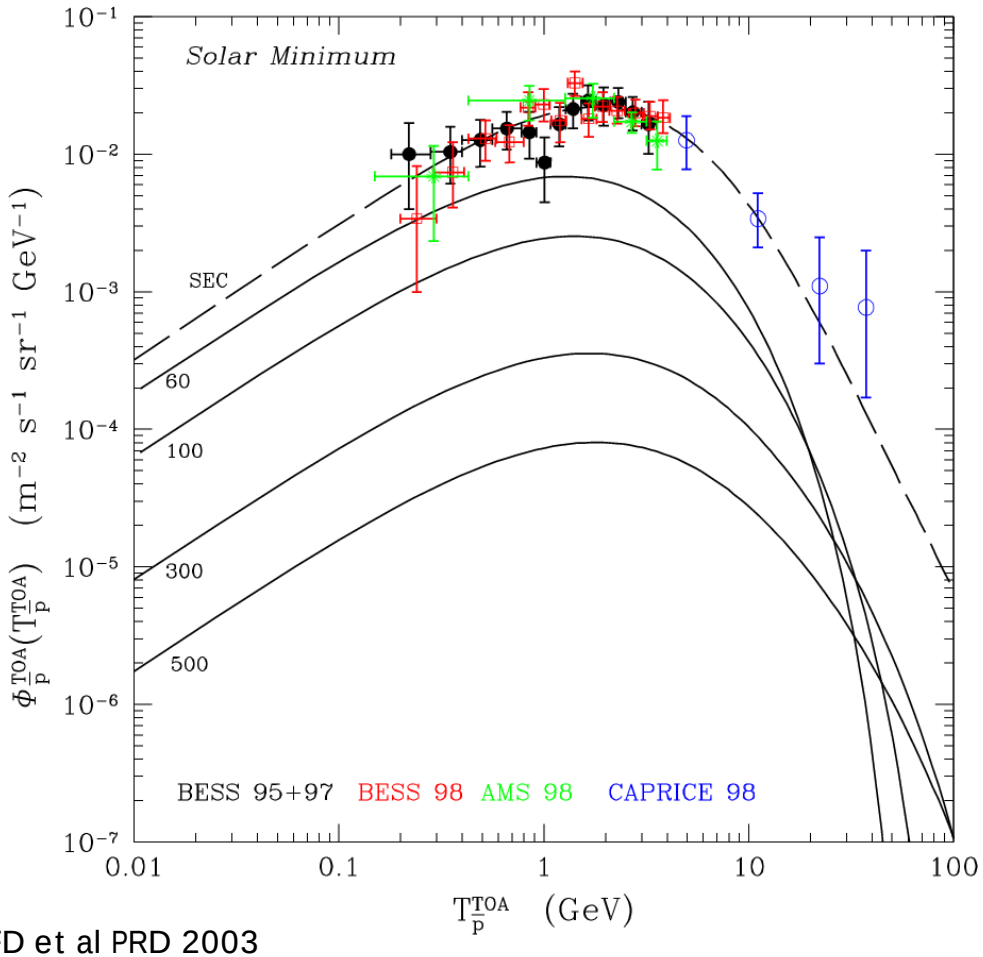
χ ***mass***

χ ***density***

Production takes place everywhere in the halo!!
Solutions different from secondaries

May we look for new physics?

ANTIPROTONS: PRIMARY, SECONDARY & DATA



FD et al PRD 2003

Propagation of CR:
2-zones diffusion model
with reacceleration,
convection,
halo size

(Maurin et al, ApJ 2001)

Secondaries alone fit quite well data

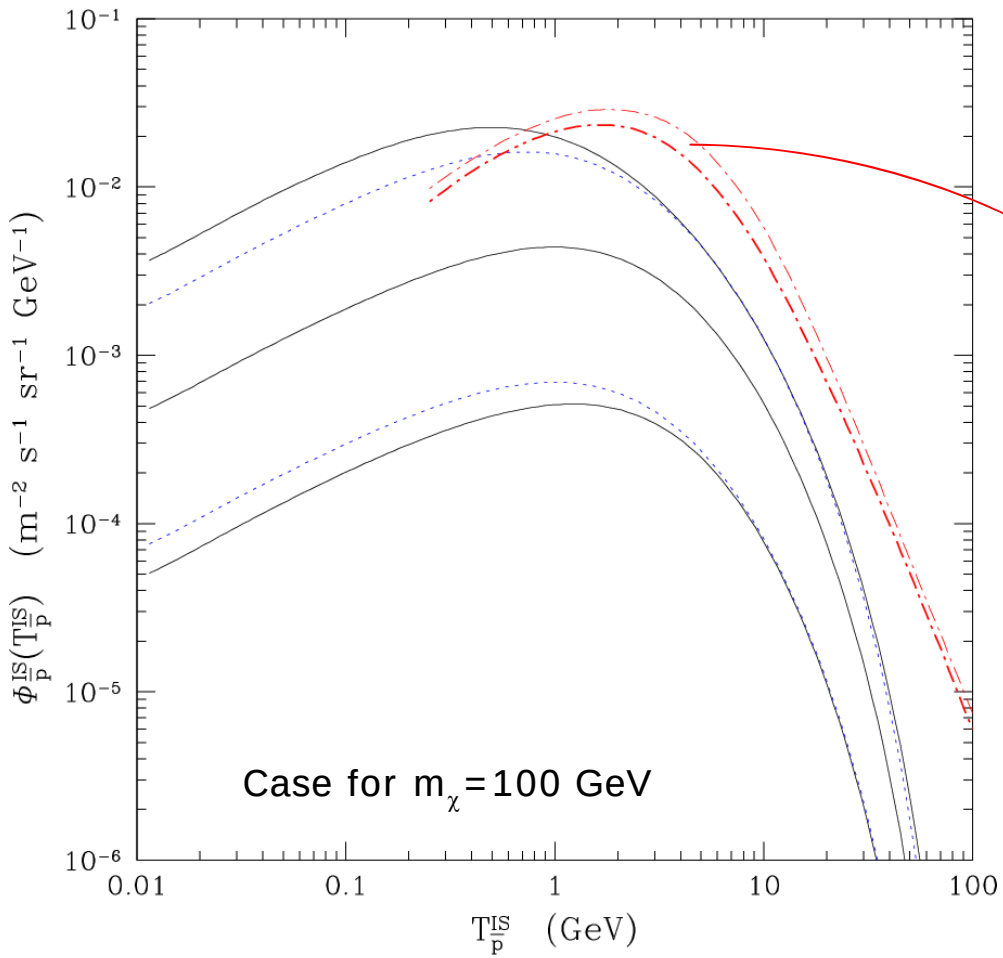
A primary component is not required to explain low-energy data

PRIMARY FLUXES and UNCERTAINTIES

Solid: $\chi^2_{B/C}<40$

Dotted: $\chi^2_{B/C}<30$

(22 DF)

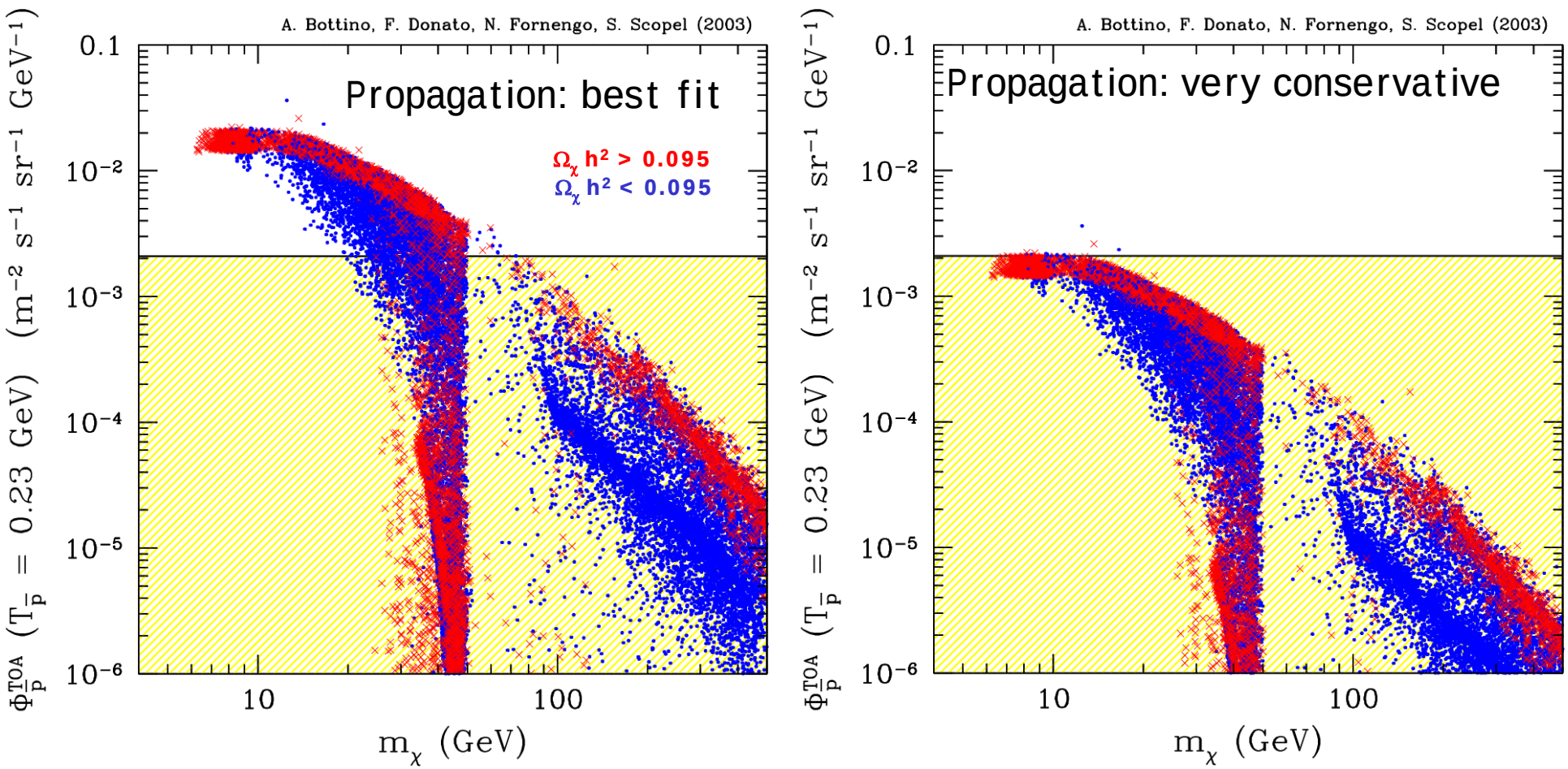


Secondary flux

Uncertainties from CR propagation in the Galaxy affect more seriously primary fluxes

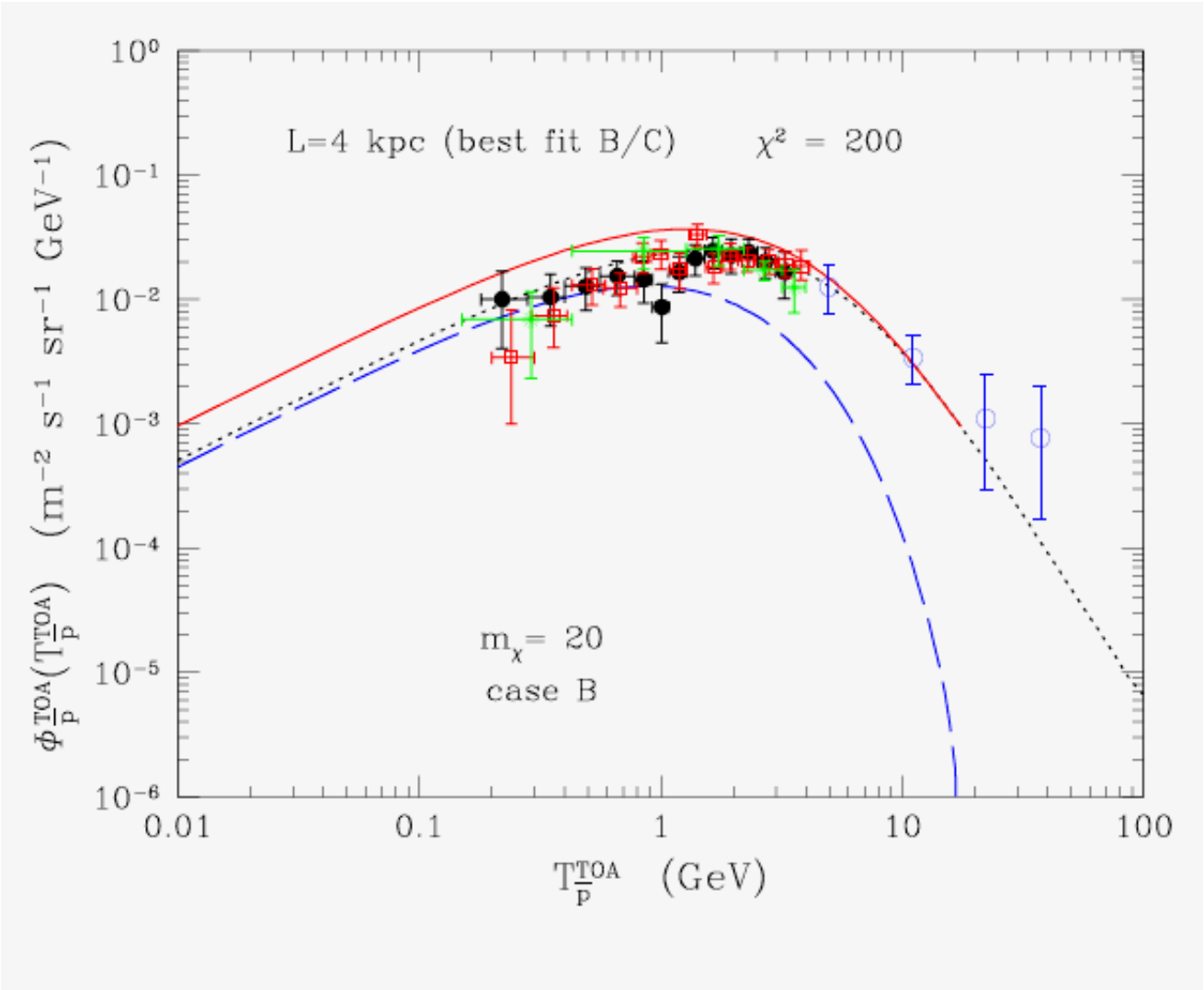
CONSTRAINTS from Antiproton Data on SUSY Models

(Bottino, FD, Fornengo, Scopel PRD 2004)



Antiprotons in CRs might constrain the lightest neutralino masses

Antiproton flux from low-mass neutralinos



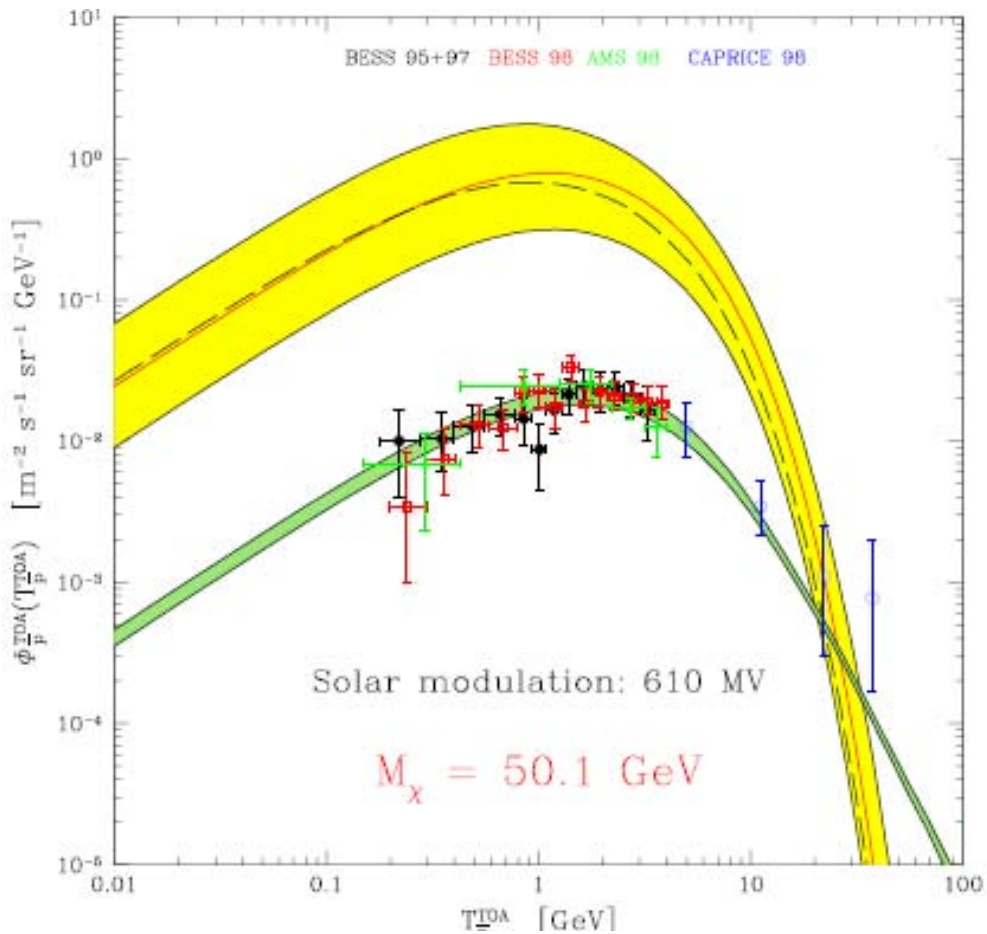
CONSTRAINTS from Antiproton Data on Astrophysical Models

Bergstrom, Edsji, Gustafsson & Salati JCAP 2006

Antiprotons calculated in 2-zones diffusion models with all effects

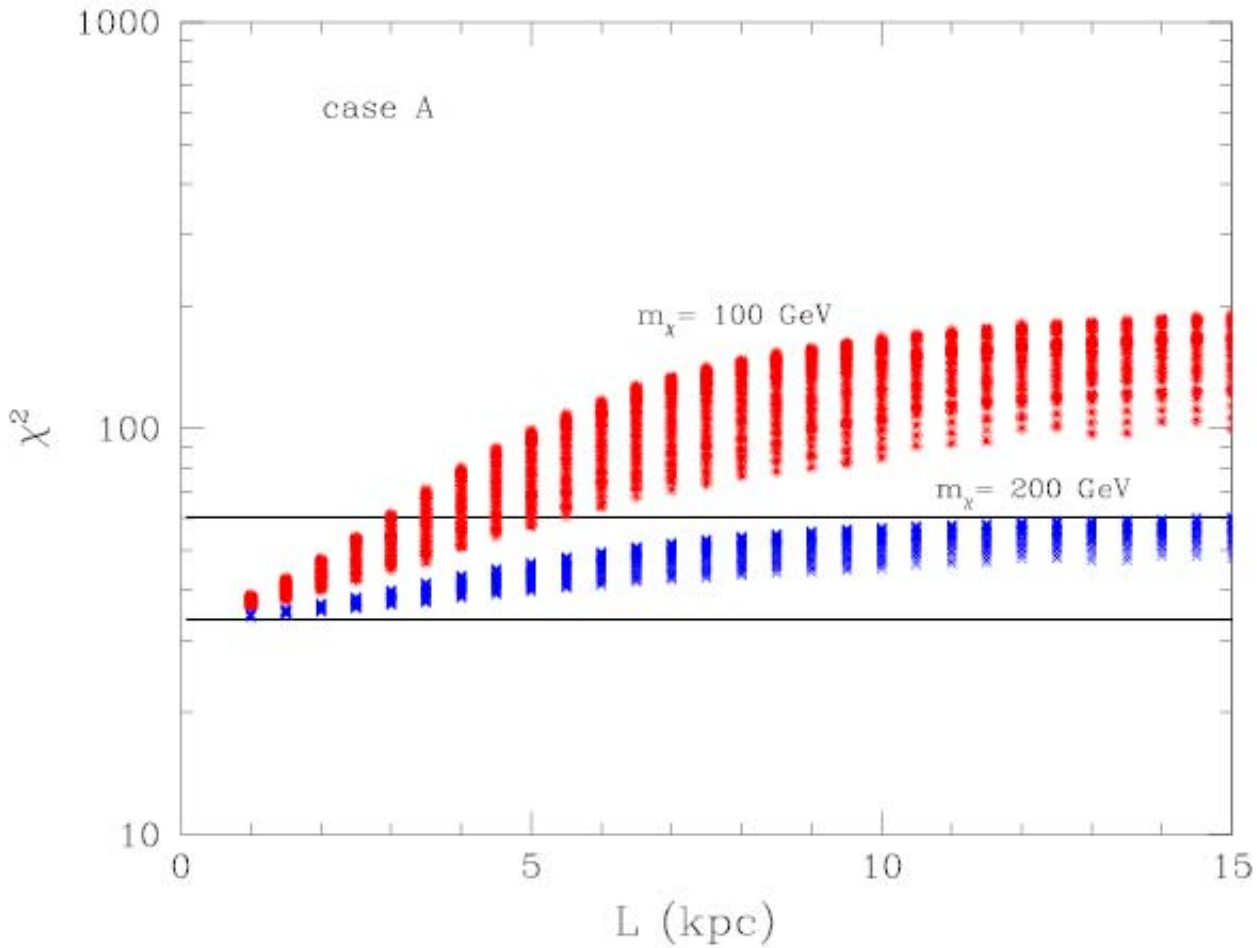
All uncertainties in Propagation models included

Fit to EGRET
Same boost factor as for γ



Halo model proposed by de Boer et al. excluded by a wide margin from the measured flux of antiprotons

DIFFUSIVE HALO EFFECT ON ANTIPROTON SEARCHES



Higher haloes give higer fluxes

For m_χ > 300 GeV antiprotons fluxes are too low to modify fit with bkd

ANTIDEUTERONS from RELIC NEUTRALINOS

FD, Fornengo, Salati PRD 2000
FD, Fornengo, Maurin in preparation (DFTT6/2007)

Kinematics of spallation reactions prevents the formation of very low antiprotons (antineutrons).
At variance, neutralinos annihilate almost at rest

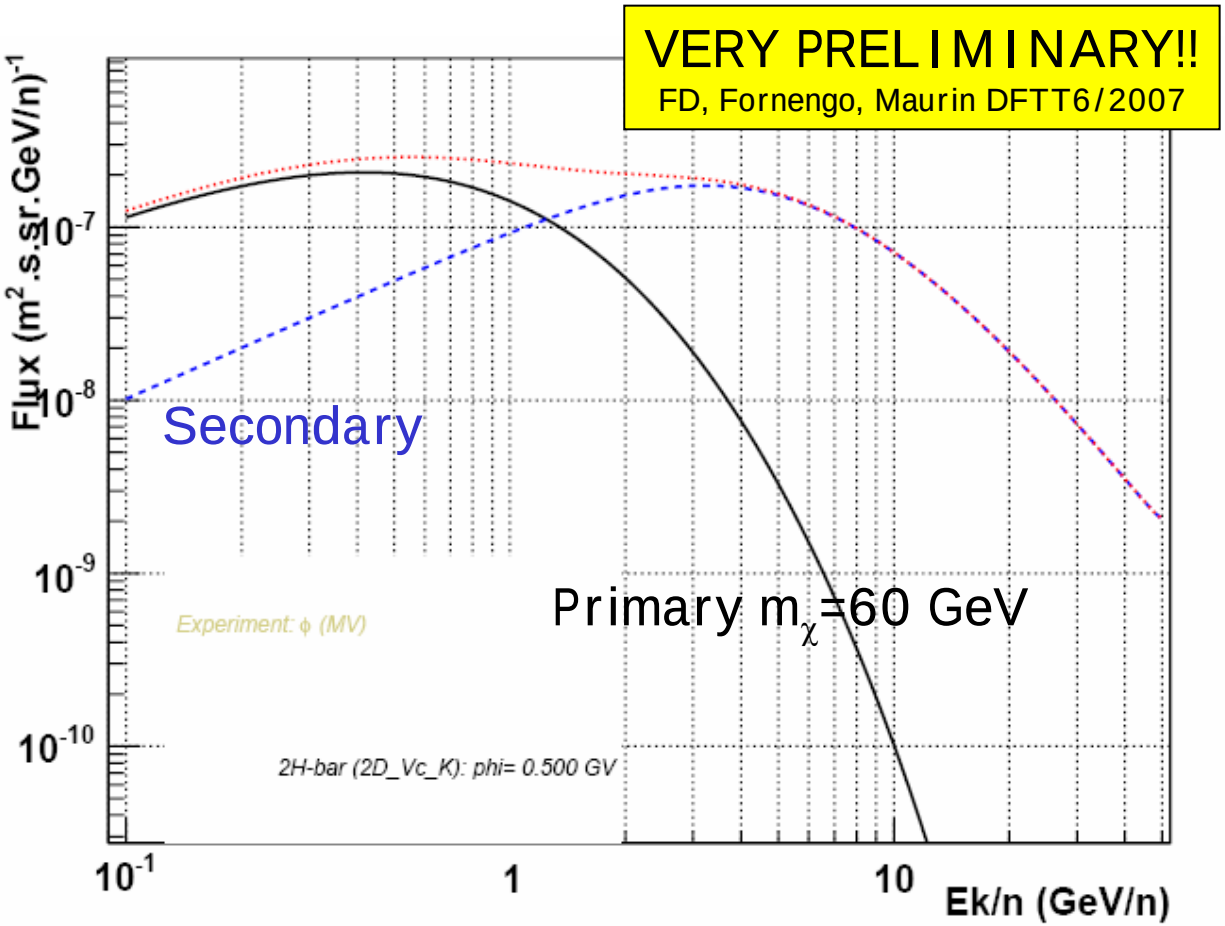
$$\frac{dN_{\bar{D}}}{dE_{\bar{D}}} = \left(\frac{4\,P_{coal}{}^3}{3\,k_{\bar{D}}}\right)\left(\frac{m_{\bar{D}}}{m_{\bar{p}}\,m_{\bar{n}}}\right)\sum_{F,h} B^{(F)}_{\chi h}\left\{\frac{dN^h_{\bar{p}}}{dE_{\bar{p}}}\left(E_{\bar{p}} = \frac{E_{\bar{D}}}{2}\right)\right\}^2$$

P_{coal} : the simplest parameterization for nuclear fusion

N.B: Up to now, NO ANTIDEUTERON has been detected yet.
Several expreriments are planned: AMS/ISS, BESS-Polar, GAPS …

PRIMARY & SECONDARY ANTIDEUTERONS in a 2-zones diffusion model

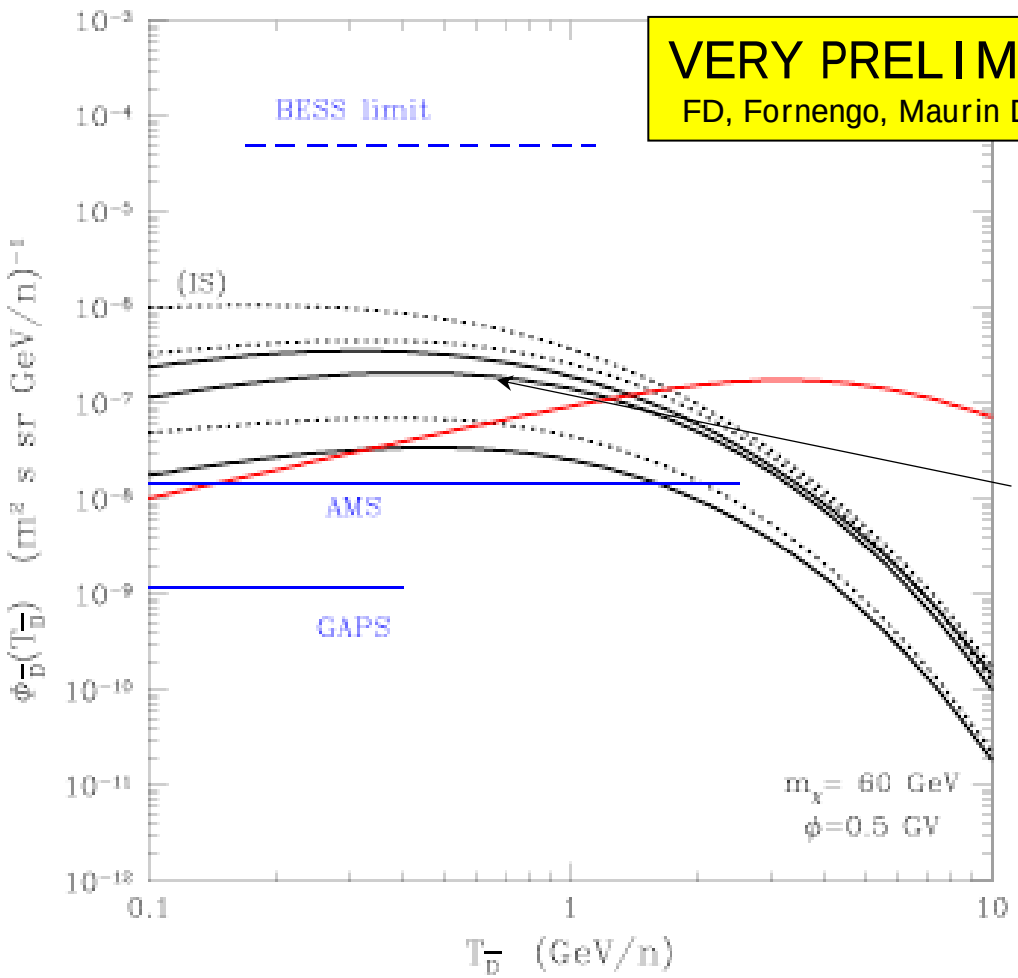
with convection, reaccelaration, tertiaries, halo effect ....



B/C best fit (L=4 kpc)
Solar minimum

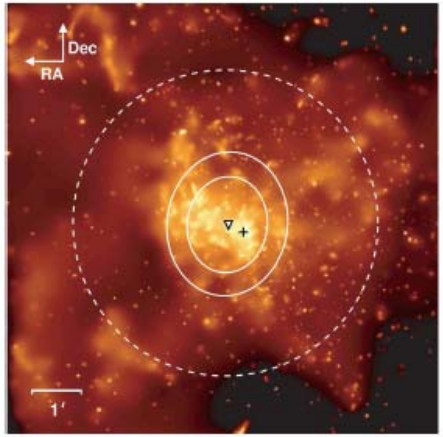
PRIMARY & SECONDARY ANTIDEUTERONS in a 2-zones diffusion model

with convection, reaccelaration, tertiaries, halo effect ....



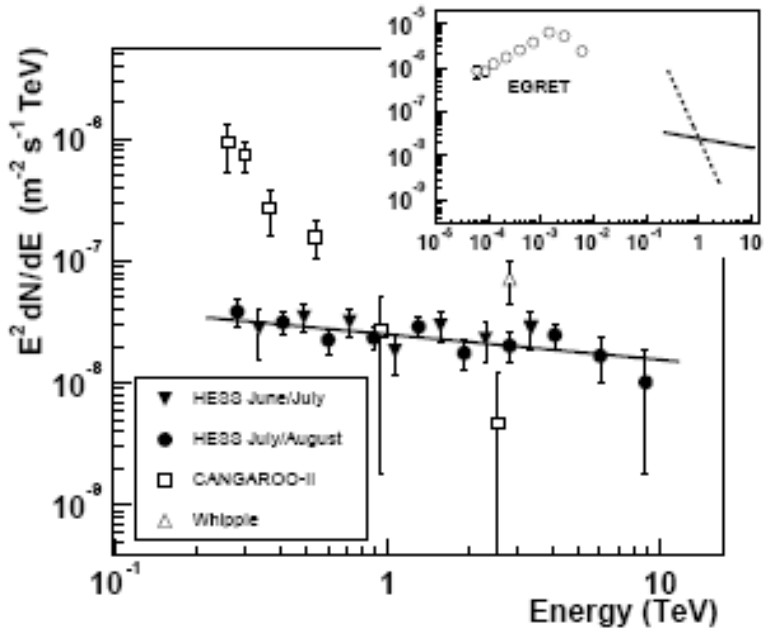
Background at best fit, solar modulated

60 GeV neutralino at best fit, solar modulated



γ-rays from the GC

HESS view of
the GC at TeV energies



HESS 2004 (Aharonian et al. A&A)

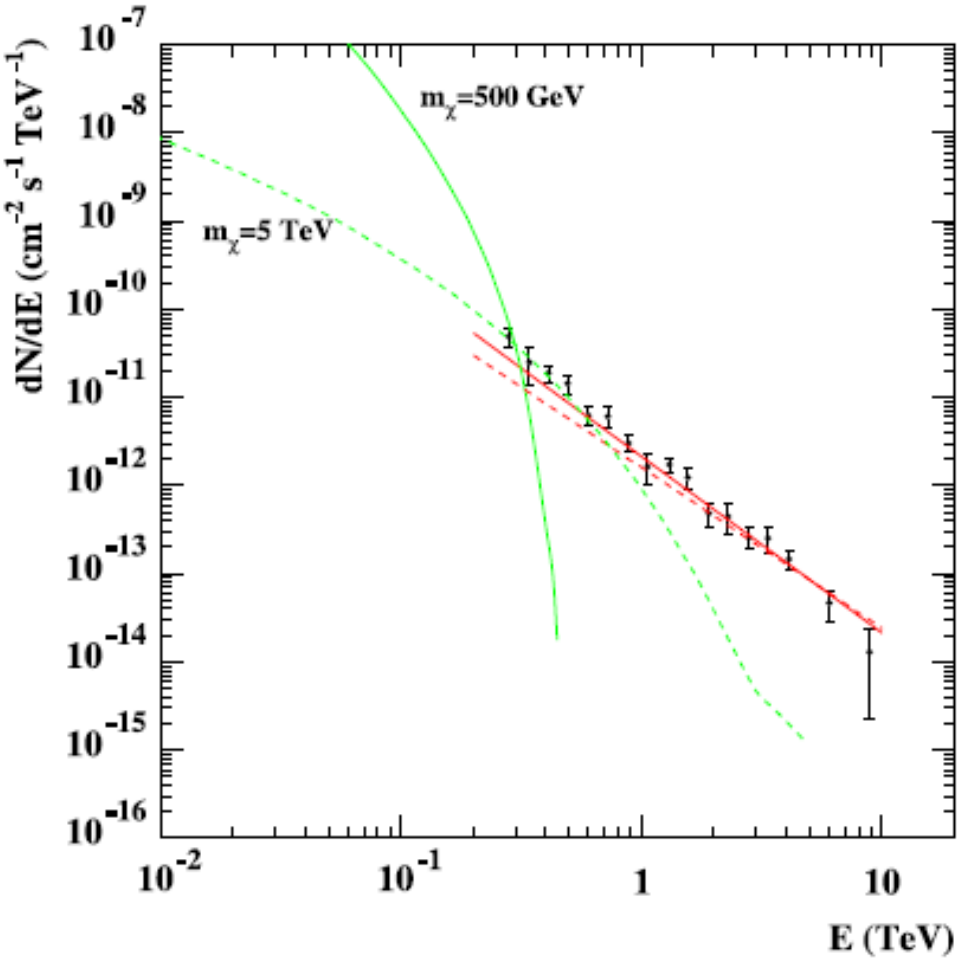
- Data fit by hard spectrum $E^{-2.2}$
- Astrophysical background

For TeV region: Aharonian & Neronov 2006

For GeV region: Hunter et al. ApJ 1997, Mori ApJ 1997, Strong et al. ApJ 2000, Aharonian & Atonyan A&A 2000, Busching et al. A&A 2001, Erlykin & Wolfendale JPG 2002, ...

HESS constraint on pre-BBN expansion

FD, Fornengo, Schelke, JCAP 2007



HESS data from the GC
(Aharonian et al. A&A 2004)

Maximum allowable DM contribution

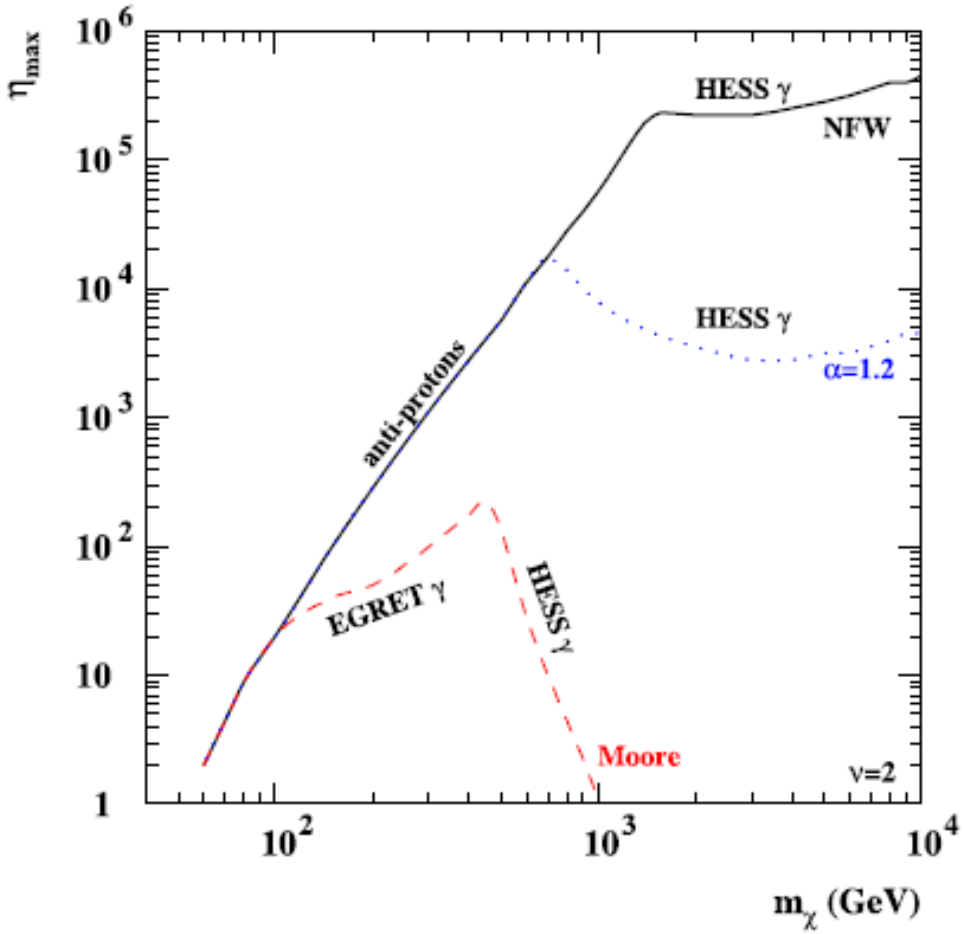
Free Background (kE^{Γ})

NFW profile

Compatibility with EGRET

Upper bound on the Hubble enhancement rate

FD, Fornengo, Schelke, JCAP 2007



Enhanced Hubble expansion causes an enhanced WIMP DM relic density

In order to have $(\Omega_\chi h^2)_{WMAP}$ higher cross sections are tolerated

HESS γ-ray data from the GC constrain cosmological models for higher WIMP masses, depending on the DM profile

Lower masses are constrained by antiprotons
(Schelke et al. PRD 2006)

Summary

- Existing data on cosmic antiprotons are a powerful means for the study of low-mass DM particles or boosted DM haloes

- Antideuterons are probably the clearest indirect signature

- Gamma-rays may already constraint cosmology

- Exciting perspectives from indirect DM searches!

  Many data are expected for all the channels (positrons, antiprotons, antideuterons, gamma-rays)

  PAMELA, AGILE, GAPS, GLAST, AMS, ...

THEIR COMBINED ANALYSIS COULD UNRAVEL DM PRESENCE IN THE MILKY WAY !!