Dark Matter in Cosmic Rays

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NEUTRALINO INDIRECT SIGNALS

Annihilation inside celestial bodies:

- Neutrinos (as up-going μ's)

Annihilation in the galactic halo:

- γ-rays (diffuse, monochr.), radio
- antimatter: antiprotons, <u>antideuterons, positrons</u>

ν and γ keep directionality

<u>can be detected only if emitted from high χ density regions</u>

Charged particles diffuse in the galactic halo

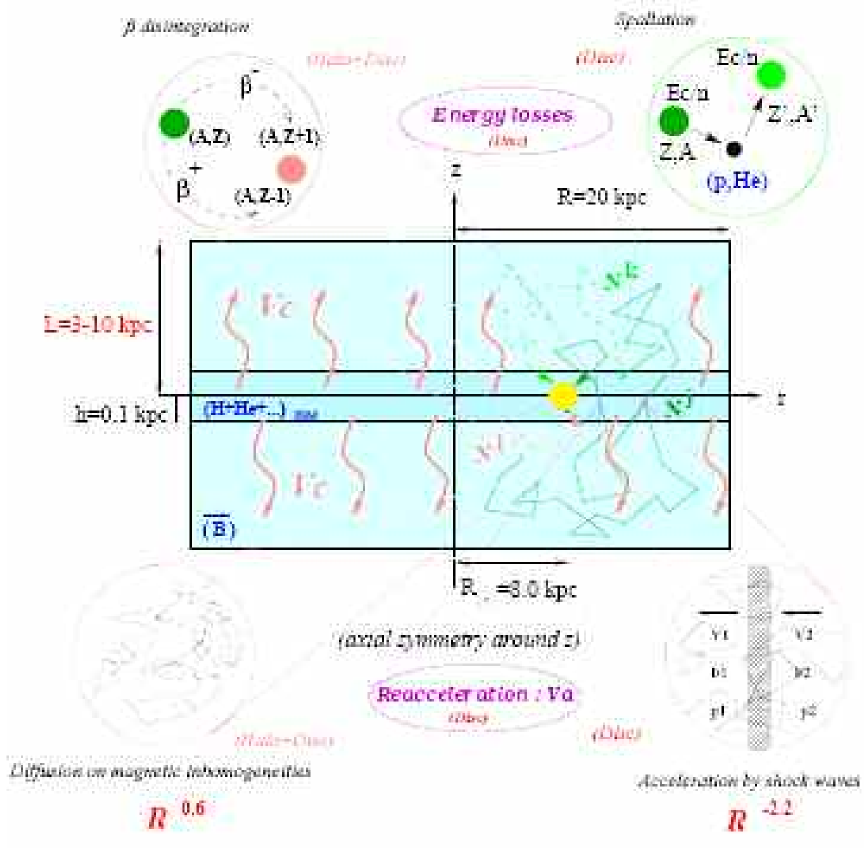
<u>antimatter searched as rare components in cosmic rays (CRs)</u>

⇒ ASTROPHYSICS OF COSMIC RAYS!

PROPAGATION OF CRs IN THE MW
2-zones DIFFUSION MODEL

Maurin, FD, Taillet, Salati ApJ 2000; Maurin, Taillet, FD A&A 2002

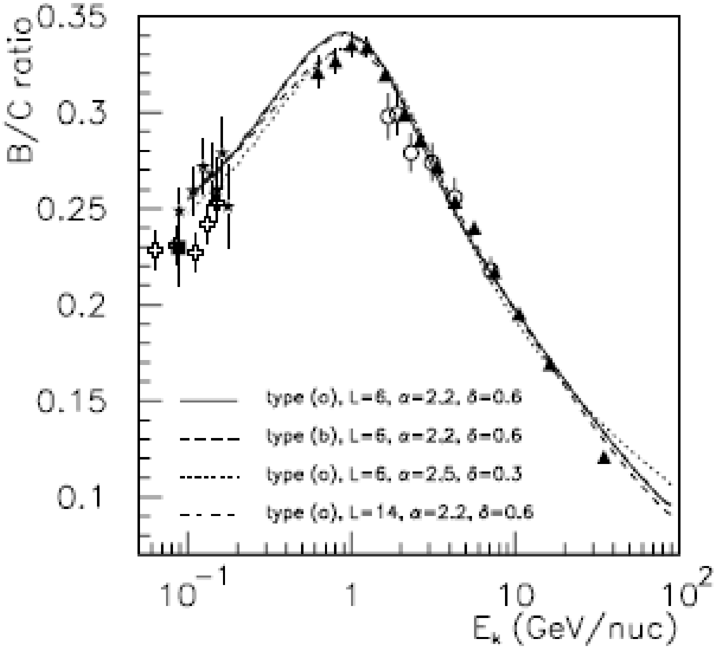
- Diffusion coefficient $K(R)=K_0\,\beta R^{\delta}$
- Constant convective wind V_c (km/sec)
- Reacceleration V_A (km/sec)
- Diffusive halo half-thickness L (kpc)



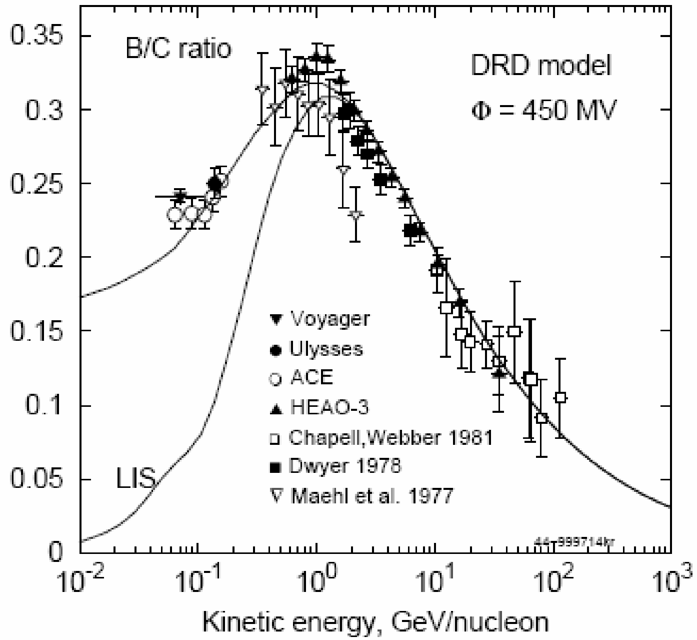
Models reproduce B/C, antiprotons (see **P. Salati's talk**), radiactive nuclei, C, O

Secondary/primary nuclei: B/C & sub-Fe/Fe

Maurin, Taillet, FD A&A 2002



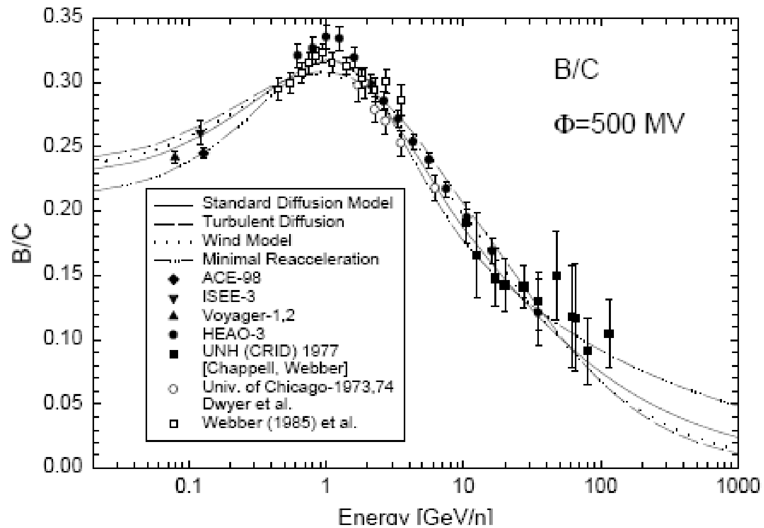
Moskalenko&Strong 2004



No definite propagation model comes out

High degeneracy of models

Need more data around 1 GeV/n and at >20-30 GeV/n



Jones, et al. ApJ (2001)

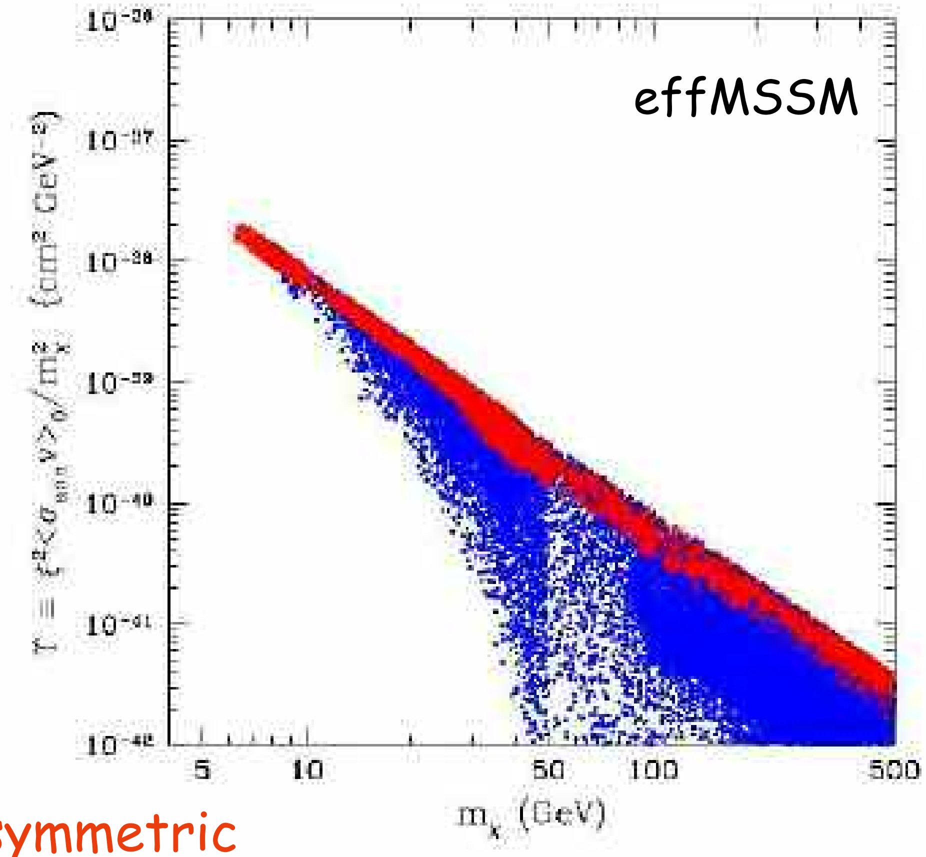
Supersymmetric term for fluxes originating from DM pair annihilation

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

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

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)

Cosmic Antideuterons

- Galactic production from cosmic rays on the interstellar medium
  (FD, Fornengo, Salati PRD 2000; Duperray et al. PRD 2005)
- Atmospheric production from galactic cosmic rays (Duperray et al. PRD 2005)

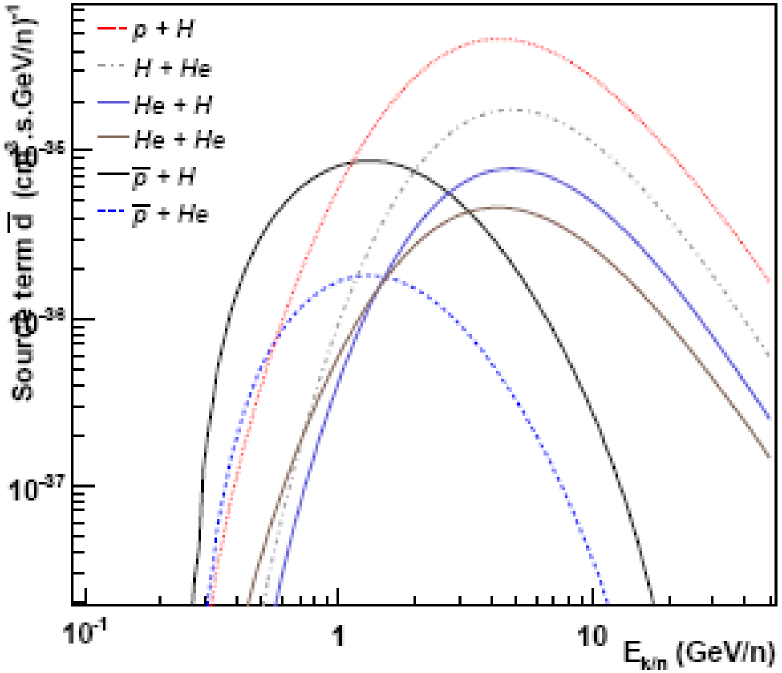
- Primary production from:
  - Dark Matter annihilation in the galactic halo (FD, Fornengo, Salati PRD 2000)
  - Evaporation of Primordial Black Holes (Barrau et al., A&A 2003)

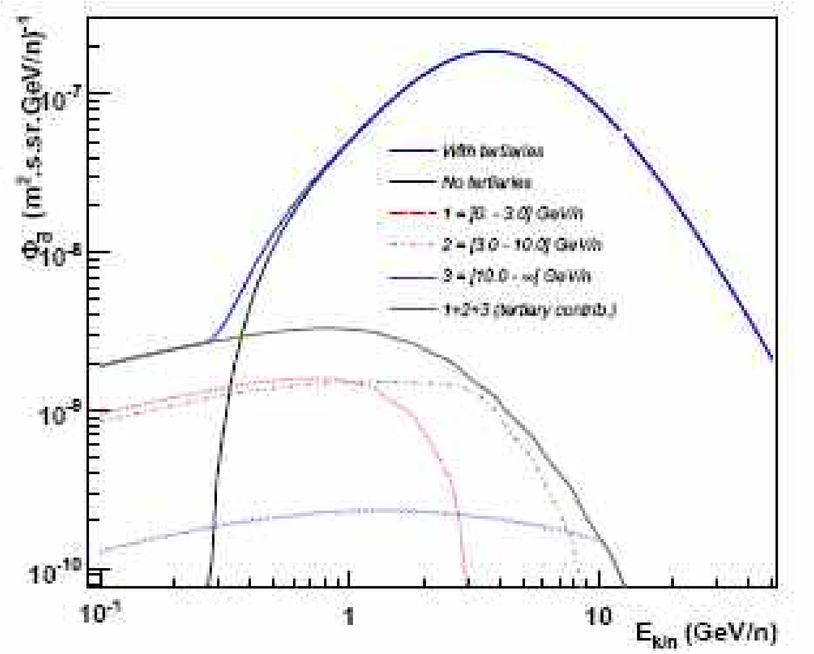
No antideuteron has been detected so far
(10^{-4} less abundant than antiprotons)

Low-energy (< 1 GeV/nucleon) antideuterons may be the indirect probe of the existence of a WIMP dark matter galactic halo

Secondary antideuterons flux

FD, Fornengo, Maurin ICRC 2007
Duperray et al. PRD 2005





Source terms:

P(He)+H(He) → $\bar{d}$

$\bar{p}$ + H(He) → $\bar{d}$

Secondary flux
with/without tertiaries

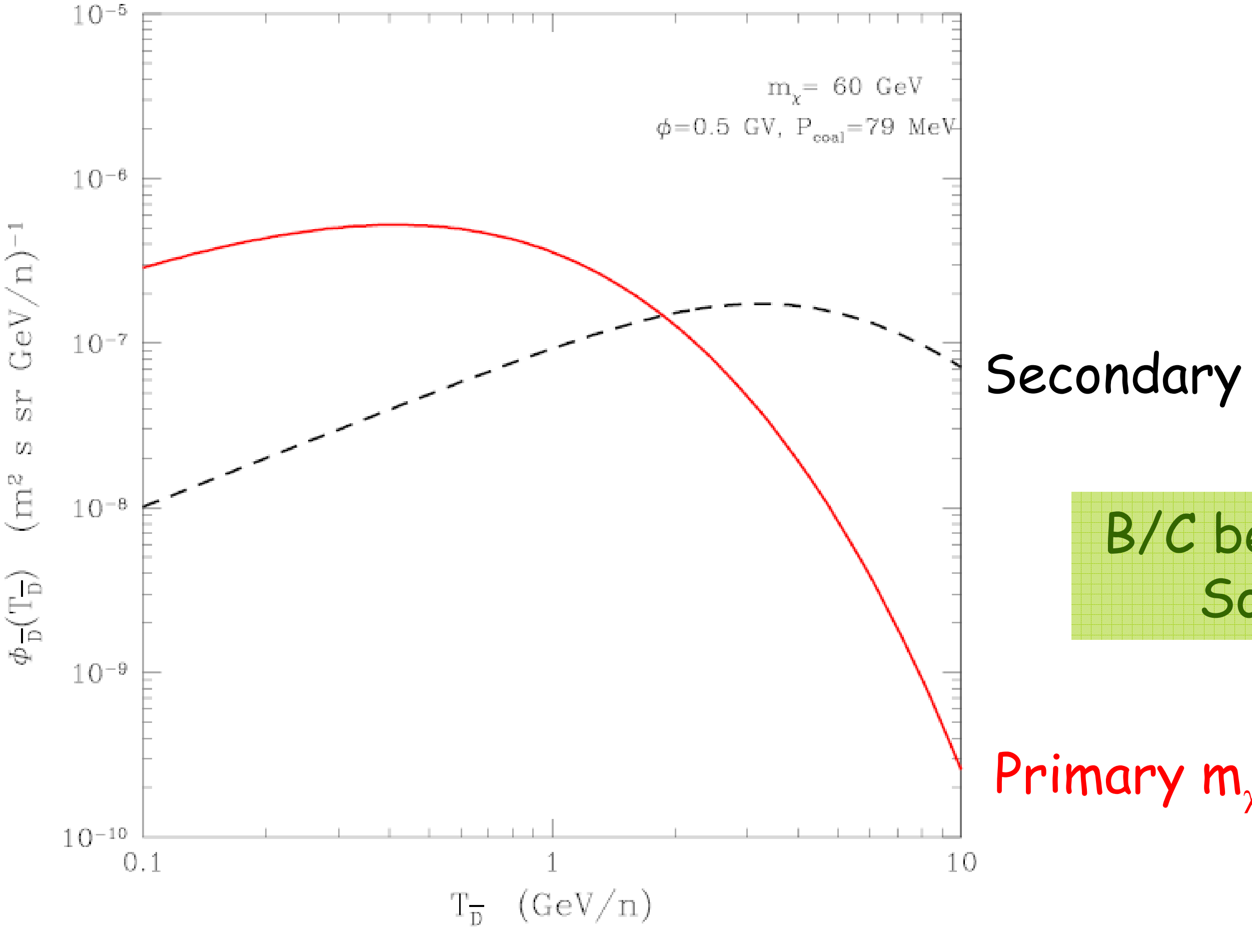
Antideuteron flux from neutralino DM pair annihilation in the halo

- Distribution of DM in the Galaxy (isoth., NFW, ...): $\rho(r,z)$
  flux depends on ρ^2
- Mass and annihilation cross section: effMSSM
  overall normalization
- Source term g(E): hadronization →antiproton, antineutron
  Pythia MC
- Nuclear fusion: coalescence model, one parameter P_{coal} = 79 MeV
  the flux depends on $(P_{coal})^3$
- Propagation in the MW from source to the Earth:
  2-zones semi-analytic diffusion model
- Solar modulation: force field approximation
  ϕ= 0.5 MV for solar minimum

PRIMARY & SECONDARY ANTIDEUTERONS
in a 2-zones diffusion model
with convection, reaccelaration, tertiaries, halo effect ….

Maurin, FD, Taillet, Salati ApJ 2000
Maurin, Taillet, FD A&A 2002

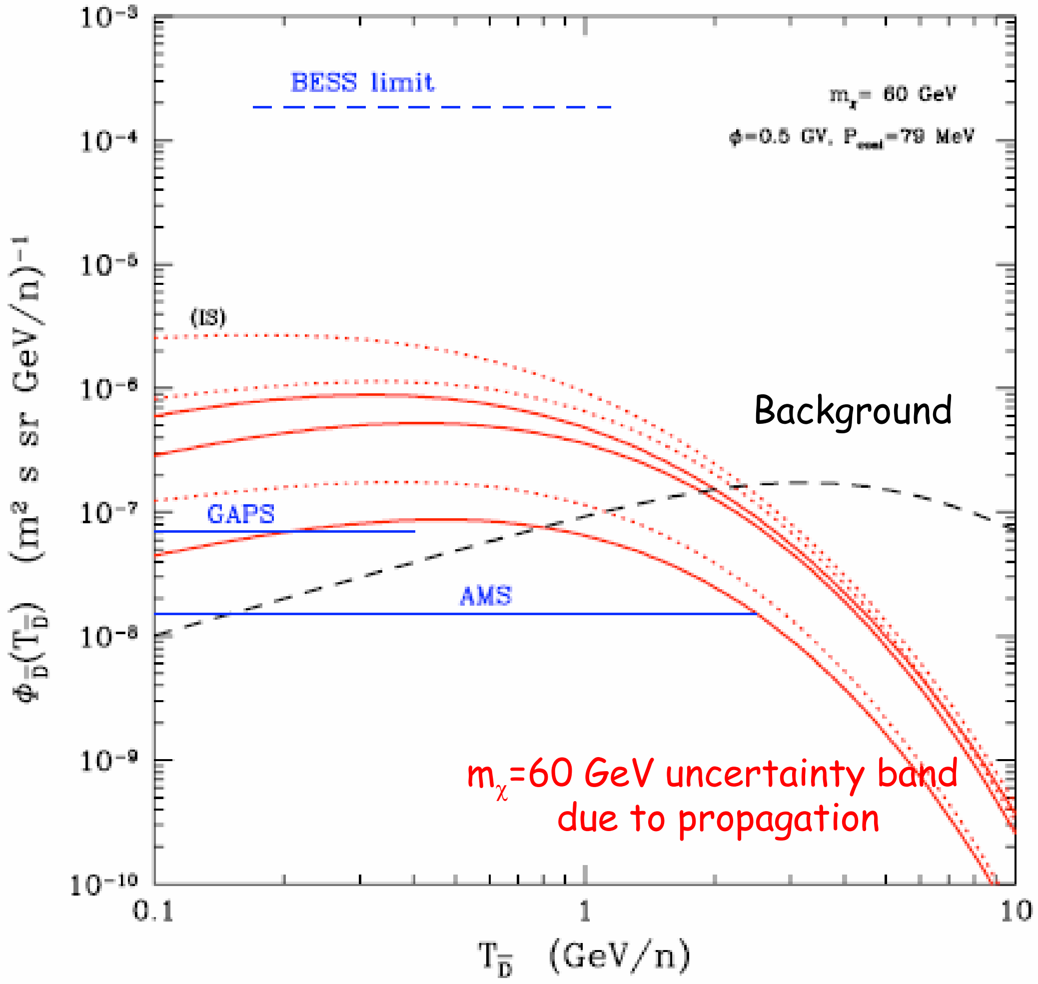
FD, Fornengo, Maurin ICRC 2007



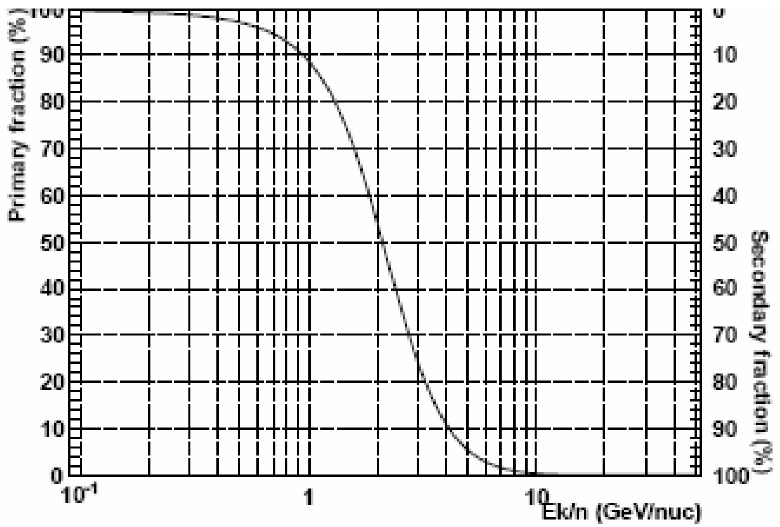
B/C best fit (L=4 kpc)
Solar minimum

PRIMARY & SECONDARY ANTIDEUTERONS in a 2-zones diffusion model

Results for the BEST FIT (with convection & reaccelaration)

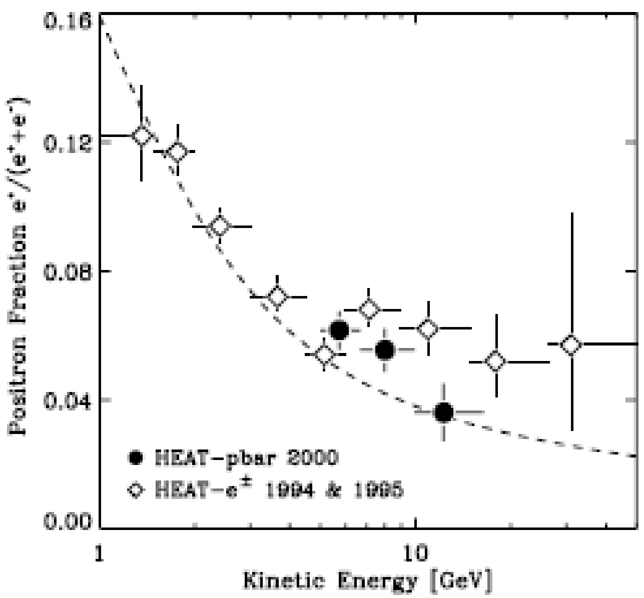


Fraction of primary/secondary for best fit propagation & m_χ=60 GeV



Cosmic Positrons

- Galactic production from cosmic rays on the interstellar medium (Moskalenko & Strong ApJ 1998)
- Dark Matter annihilation in the galactic halo
  - SUSY DM (Baltz&Edsjo PRD 1999, Hooper&Silk PRD 2005, Lavalle et al. A&A 2007)
  - Kaluza-Klein DM (Hooper&Kribs, PRD 2004)



Data from HEAT (PRL 2004) indicate a small component of non-standard origin positrons

Secondary component derived in a diffusive halo model (here: no reacceleration, L_z=3 kpc)
Harder IS nucleon spectrum would fit better the data
<u>No estimation of uncertainties due to propagation</u>

Positron flux from relic neutralinos

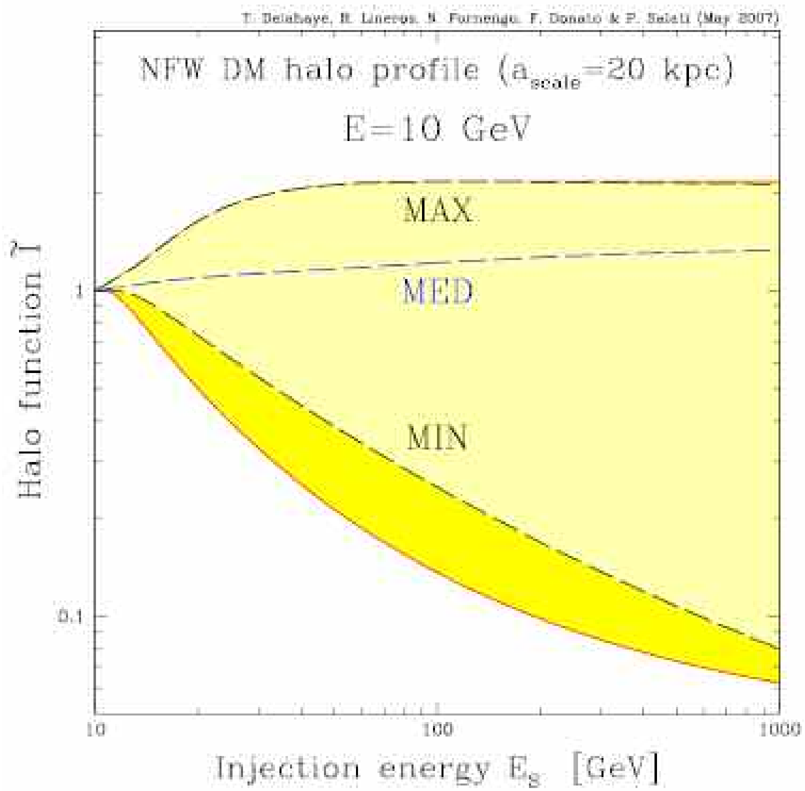
- Distribution of DM in the Galaxy (isoth., NFW, ...): $\rho(r,z)$
  flux depends on ρ^2
  Clumpiness?
- Mass and annihilation cross section: effMSSM
  overall normalization
- Source term g(E): direct production or from secondary decays (from
  bb,WW,$\tau\tau$, ...) → Pythia MC
- Propagation in the MW from source to the Earth:
  2-zones semi-analytic diffusion model
- Solar modulation: force field approximation
  ϕ= 0.5 MV for solar minimum

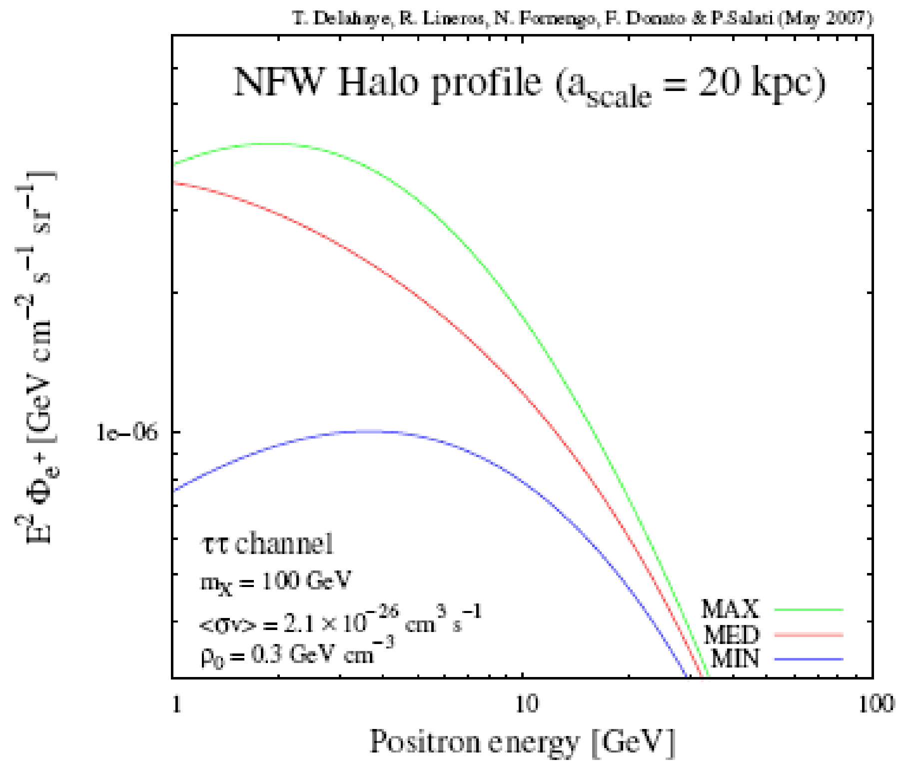
NB The positron flux is more local than antiprotons or antideuterons depending on the propagation model: $r_{e+}/r_{p+,D+} \approx 0.1$ (Maurin&Taillet A&A 2003)

Propagation of positron sources

$$\Phi(E) = k_{susy} \frac{\tau_E}{E_0 \varepsilon^2} \int_E^\infty dE_S \, f(E_S) \tilde{I}(\lambda_D)$$

E_0=1 GeV
ε=E/ E_0
τ=10^{16} s



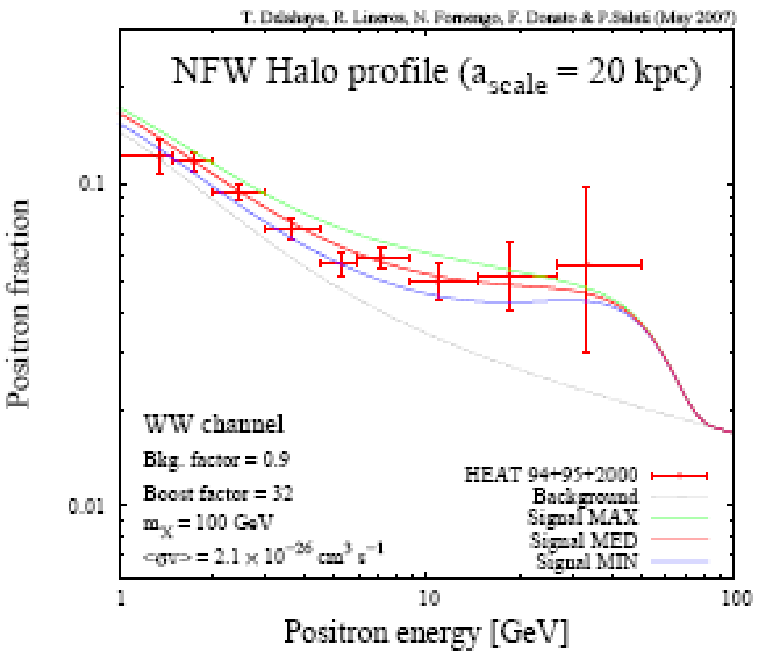


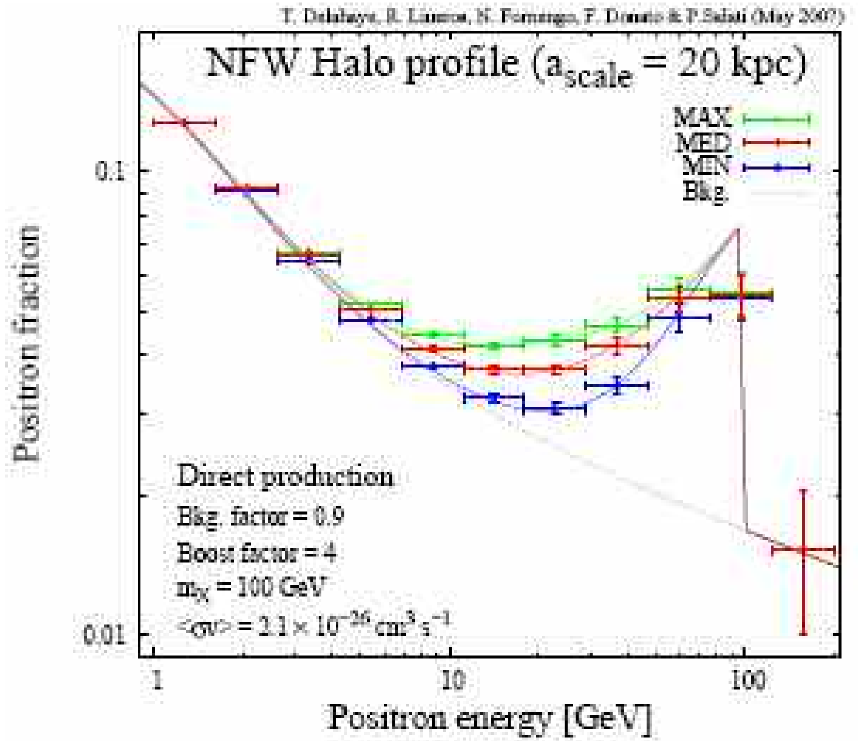
Propagation models allowed by B/C

Delahaye, Lineros, Fornengo, FD, Salati ICRC 2007

Propagation effects on primary positrons

Maximal-Median-Minimal Propagation models





Uncertainty on the primary flux: 2÷5
on the total flux: 20-30%

Prediction for PAMELA

Delahaye, Lineros, Fornengo, FD, Salati ICRC 2007

Effect of a clumpy halo

(Lavalle, Pochon, Salati & Taillet A&A 2007)

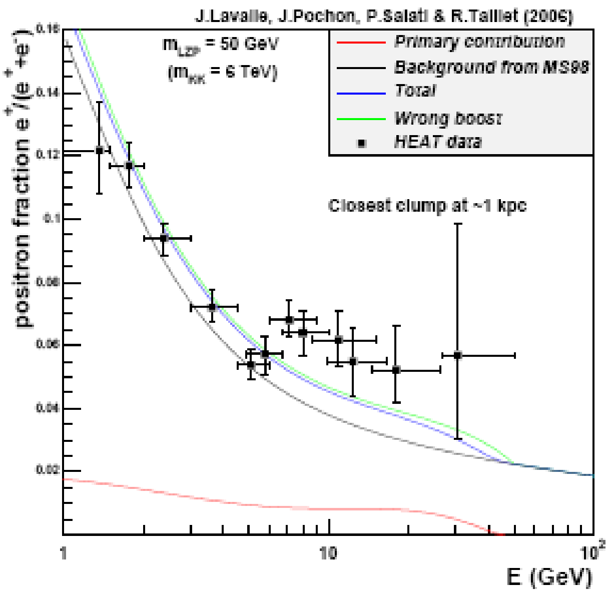
Diemand, Kuhlen & Madau, astro-ph/0611370

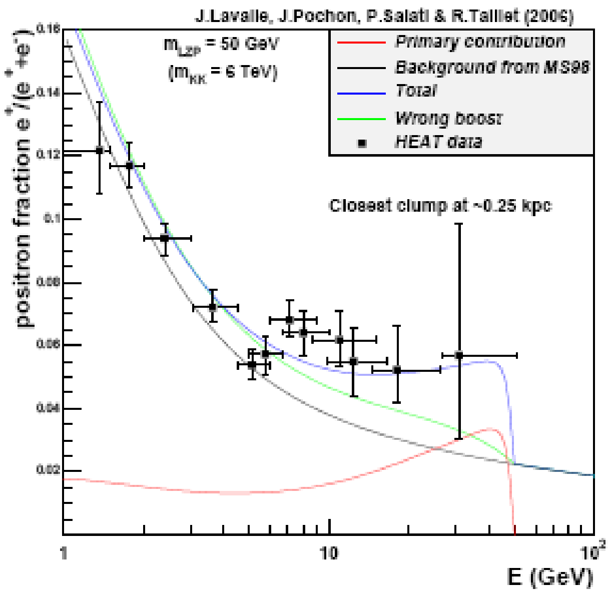
For γ-rays the total DM ann. luminosity is increased by a factor 2

For charged antimatter:

- boost factor due to clumps in the dark halo is ENERGY DEPENDENT

- may differ for positrons, antiprotons, antideuterons





Conclusions

- The antideuteron flux from neutralino annihilation and the astrophysical background have been calculated in a full diffusion model
- Propagation affects the supersymmetric flux by a factor O(10)
- A DM halo of 50-100 GeV neutralinos would provide an amount of antideuterons detectable by the next generation of experiments (GAPS, AMS), depending on the σv
- For a 100 GeV DM particle uncertaintis are 10-30 for few GeV e^+ and 2-5 above 10 GeV detected e^+
- Uncertainty band depends on: DM halo models, energy (source & detection)

Perspectives

- A DM halo of 50-100 GeV neutralinos would provide an amount of antideuterons detectable by the next generation of experiments (GAPS, AMS), depending on the σv
- Future experiments such as PAMELA could confirm the possible HEAT excess with no limitations from propagation uncertainties and shed light also on astrophysical models