The **Torino code** for Particle Dark Matter Phenomenology

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Tools08 MPI Munich, 3 – 07 - 2008

The Torino code for Particle Dark Matter Phenomenology

- Fortran Numerical Code for calculation of dark matter properties and signals (possible future release in the future)

- Began in the early 90s, it is a self-consistent *tool* for the **neutralino** dark matter calculations:

   1. Supersymmetric Models

   2. Relic Density

   3. Direct Detection

   4. Indirect Detection

Supersymmetric Models

- effMSSM – Effective Minimal Supersymmetric Standard Model at the EW scale
- effMSSM with non-universal gaugino masses (low-mass neutralinos)
- Minimal SUGRA
- SUGRA with non-universal scalar masses in Higgs sector

with the inclusion of:

- Experimental Limits on susy particles
- Experimental Limits on Higgs masses
- $a_\mu=(g_\mu-2)/2$
- B rare decays

Neutralino Relic Abundance

- Standard Cosmology
- Low-reheating cosmology - Alternative cosmologies

Direct detection

- Coherent cross sections
- Spin dependent cross sections

Galactic DM distribution functions:

- Isothermal sphere
- Axisymmetric and triaxial models
- Spherical models by Eddington theory (isotropic and non-isotropic)

Indirect detection

- Gamma rays
- Cosmic Antiprotons
- Cosmic Antideuterons
- Cosmic Positrons

} DM distribution functions:
- Cored isothermal sphere
- Profiles from numerical simulations (NFW, ..)

- Neutrinos from Earth and Sun → Inclusion of 3-families oscillation

Propagation of galactic cosmic rays treated with the numerical codes developed in collaboration with D. Maurin, P. Salati, R. Taillet

Effective MSSM scheme (effMSSM)

(Model parameters defined at the EW scale)

Independent parameters:

- M_1 U(1) gaugino soft breaking term
- M_2 SU(2) gaugino soft breaking term
- μ Higgs mixing mass parameter
- $\tan\beta$ ratio of two Higgs v.e.v.'s
- m_A mass of CP odd neutral Higgs boson
- m_q soft mass common to all squarks
- m_l soft mass common to all sleptons
- A trilinear parameter
- ($R \equiv M_1/M_2$ (=0.5 in GUT))

- Experimental Bounds

- Accelerator (LEP & Tevatron) data on Higgs and supersymmetric particle (negative) searches
- $b \rightarrow s\gamma$ $(2.89 \lesssim (B \rightarrow s+\gamma) \cdot 10^{-4} \lesssim 4.21)$
- $B_S \rightarrow \mu^+ \mu^-$ $(BR(B_S \rightarrow \mu^+ \mu^-) \lesssim 1.2 \times 10^{-7})$
- $a_\mu \equiv (g_\mu - 2)/2$ $(-98 \lesssim \Delta a_\mu \cdot 10^{11} \lesssim 565)$

- Requirements that neutralino is the LSP
- No a priori on the relic density $\Omega_\chi h^2$

Subdominant neutralinos, if detectable, could be very interesting for particle physics (new physics) and cosmology (mixture of candidates)

Direct detection rate

$$\frac{dR}{dE_R} = N_T A^2 \frac{\rho_{0,\chi}}{m_\chi} \frac{m_N}{2\mu^2} \xi \sigma_{nucleon}^{(scalar)} F^2(E_R) \int_{w \geq v_{\min}} d^3 w \frac{f(w)}{w}$$

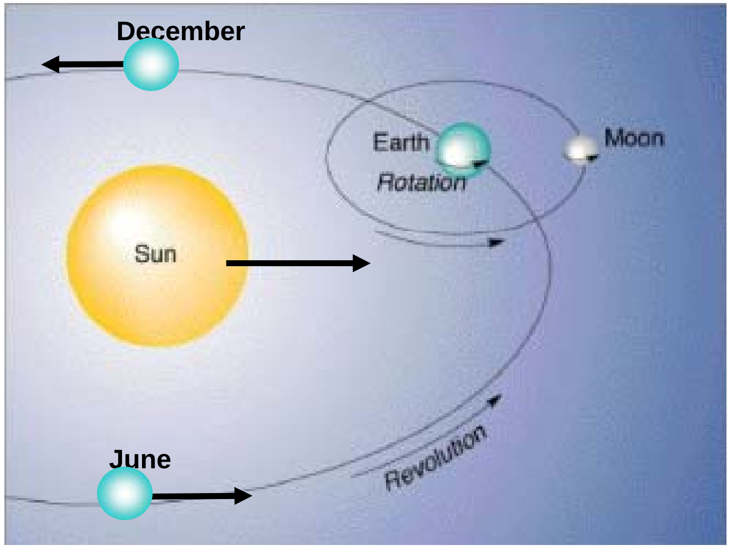
N_T, A, m_N: nucleus properties
μ: nucleus-neutralino reduced mass

1. $\rho_{0,\chi}$: local (solar neighborhood) CDM density
f(w): WIMP velocity distribution in the MW halo } *ASTROPHYSICS*

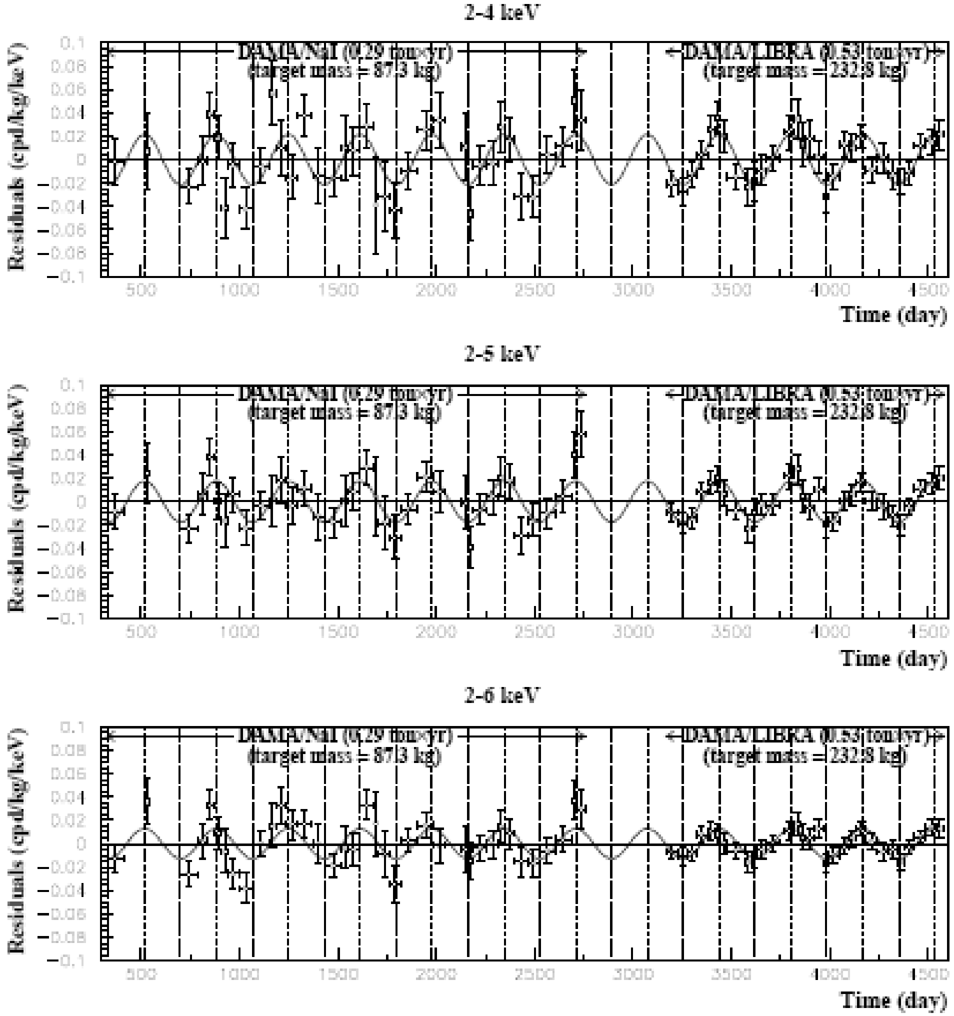
2. $\sigma_{nucleon}^{(scalar)}$ elastic cross-section
$\xi = \min(1, \Omega_\chi h^2/(\Omega_{CDM} h^2)$ } *PARTICLE PHYSICS*

3. $F(E_R)$ *NUCLEAR* form factor

The very DM signature: the annual modulation



Residual rate for single hit events



0.82 ton year total exposure
@ LN Gran Sasso (INFN)

Reported a positive evidence for a modulated signal 8.2σ C.L.

Bernabei et al. arXiv 0804.2738, 0804.2741

Bernabei et al. arXiv 0804.2741

Interpretation of direct detection results with the Torino code in effMSSM

(Bottino, FD, Fornengo, Scopel arXiv:0806.4099)

In addition: hadronic uncertainties on the WIMP-nucleon cross section

The neutralino-nucleon scalar cross section is mainly due to exchanges of the h and H Higgs (t-channel) and of the squarks (s- and u- channels):

Scalar cross section ∝ $I_{h,H} = k^{h,H}_{u-\rm type} g_u + k^{h,H}_{d-\rm type} g_d$:

$$\begin{aligned} g_u &\simeq m_l < N|\bar{l}l|N> + 2\, m_h < N|\bar{h}h|N> \\ &\simeq \frac{4}{27}(m_N + \frac{19}{8}\sigma_{\pi N} - \frac{1}{2} r(\sigma_{\pi N} - \sigma_0)), \end{aligned}$$

$$\begin{aligned} g_d &\simeq m_l < N|\bar{l}l|N> + m_s < N|\bar{s}s|N> + \\ &\quad + m_h < N|\bar{h}h|N> \\ &\simeq \frac{2}{27}(m_N + \frac{23}{4}\sigma_{\pi N} + \frac{25}{4} r(\sigma_{\pi N} - \sigma_0)); \end{aligned}$$

$$\sigma_{\pi N} = \frac{1}{2}(m_u + m_d) < N|\bar{u}u + \bar{d}d|N>$$

41 MeV ≤ $\sigma_{\pi N}$ ≤ 73 MeV REF: 56 MeV

$$\sigma_0 \equiv \frac{1}{2}(m_u + m_d) < N|\bar{u}u + \bar{d}d - 2\bar{s}s|N>$$

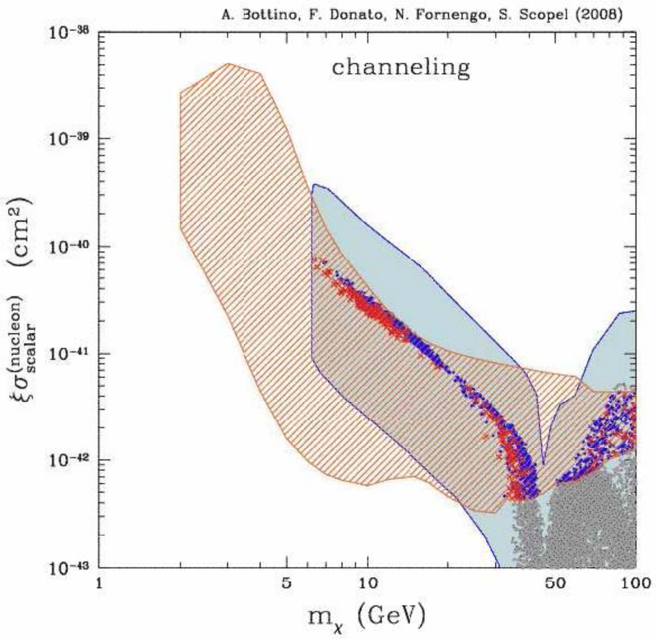
σ_0 = 30÷40 MeV

$$r = 2m_s/(m_u + m_d)$$

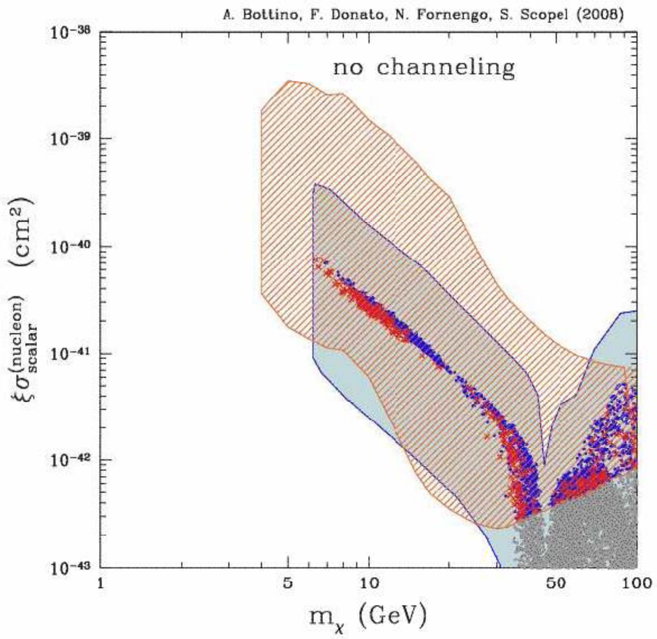
r = 25

Interpretation of direct detection results with the Torino code in effMSSM

No-channeling



Channeling

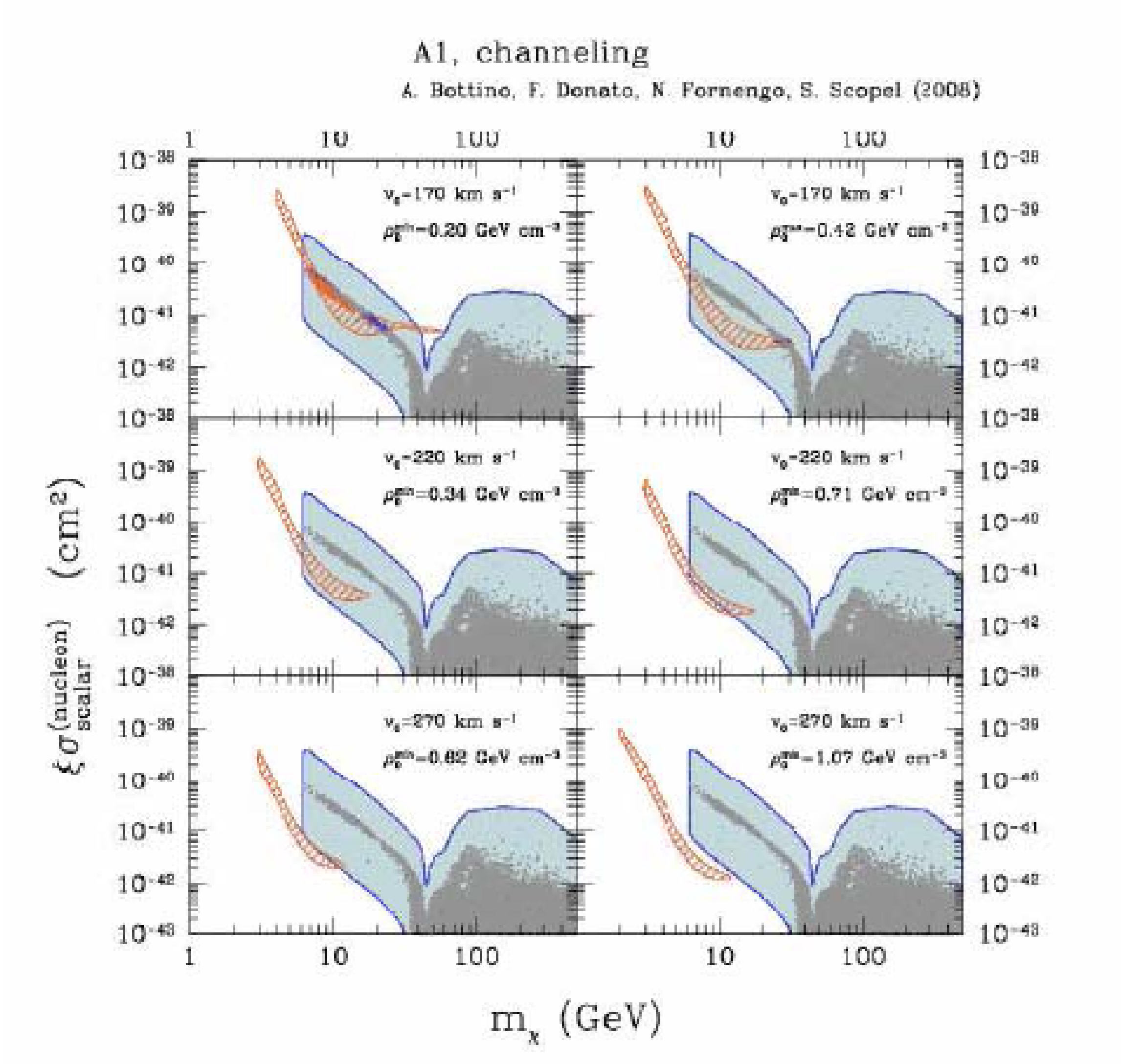


Red region: DAMA annual modulation (with astroph. uncert.)

Scatter plot: reference effMSSM (red: WMAP ok)

Shaded blue: effMSSM with hadronic uncertainties

Modulation regions & effMSSM

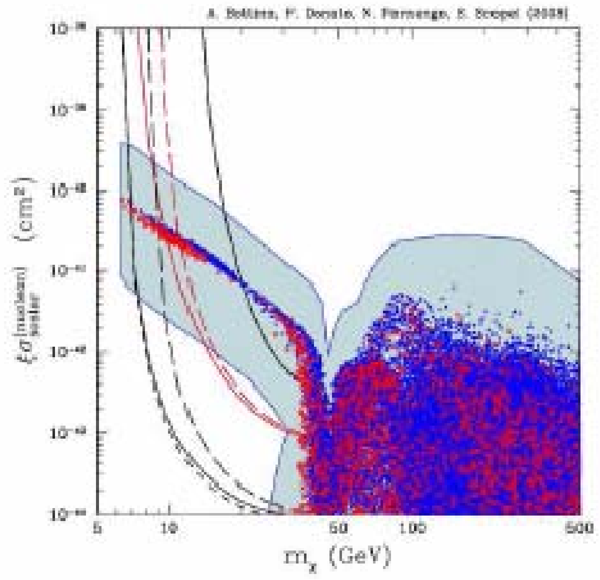


Cored isothermal sphere DF
Different rotational velocities
and local DM densities

Relic neutralinos fit the data:

- $m_\chi \sim$ 7-30 GeV
- $v_0 \sim$ 170-220 km/sec
- $\rho_0 \sim$ 0.3-0.4 GeV cm^{-3}

Upper bounds on the WIMP-nucleon scalar cross section



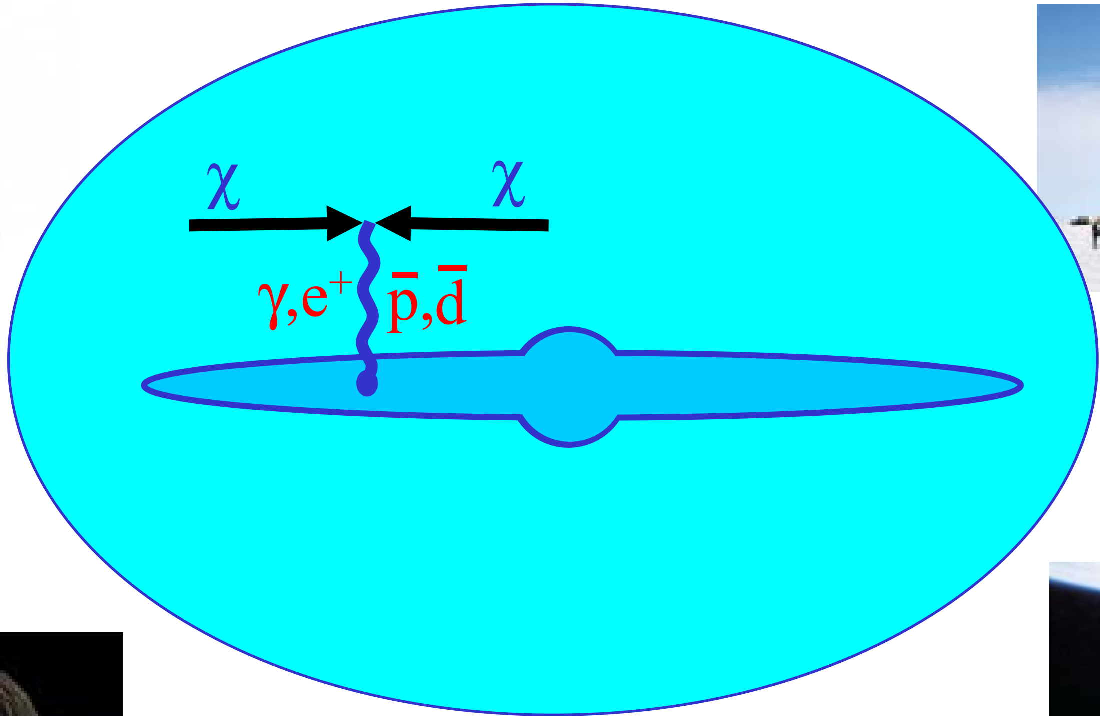
Other exps (e.g. CDMS, Xenon, Edelweiss, Cresst, Coupp…) for direct detection put upper bounds on the expected signal.

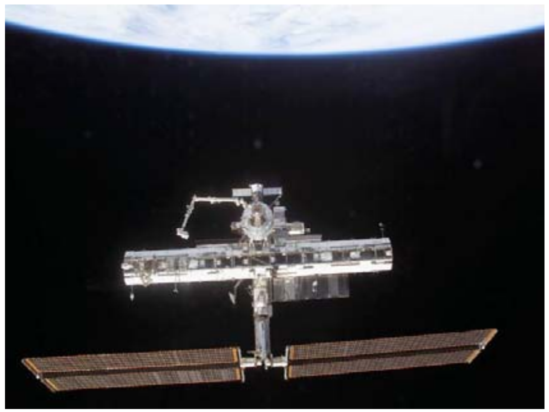
They cannot measure the annual modulation.

effMSSM & upper bounds from CDMS data for various velocity DFs
red: standard cored isothermal spherical DF (V_0= 220 km/s, ρ_0 = 0.3 GeV/cm^3)

The conservative upper bound does not exclude any configuration (when hadronic unc. taken into account). Other DFs (isoth., i.e.) would reduce susy population.

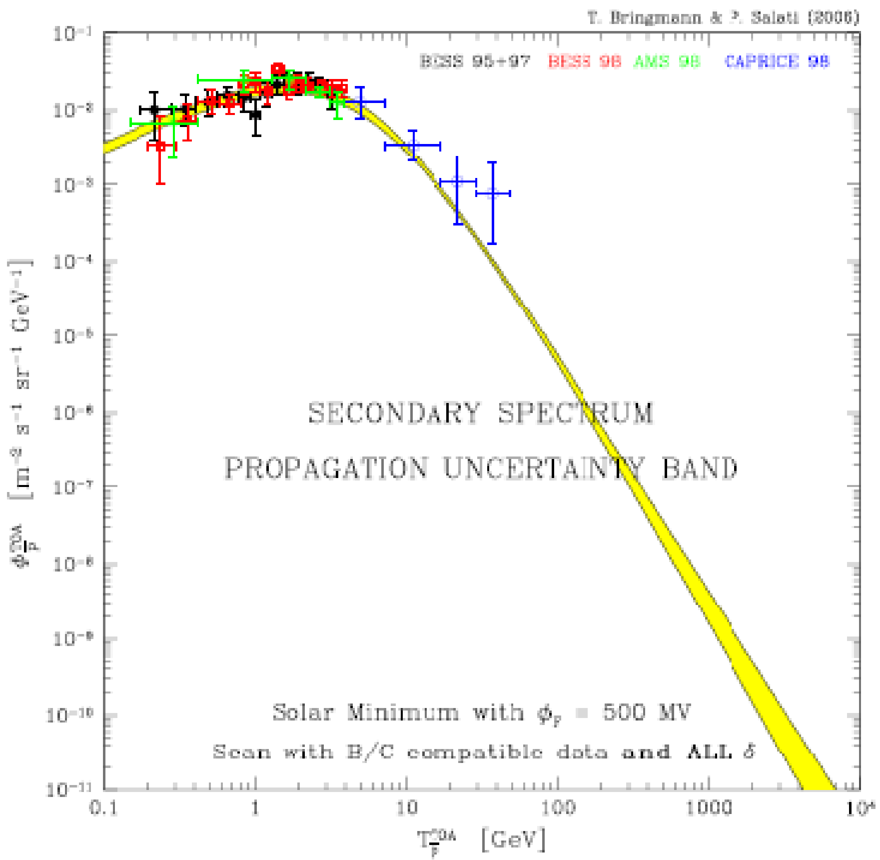
The study of cosmic **antiprotons**
as a **tool** to put constraints on
supersymmetric and/or astrophysical models

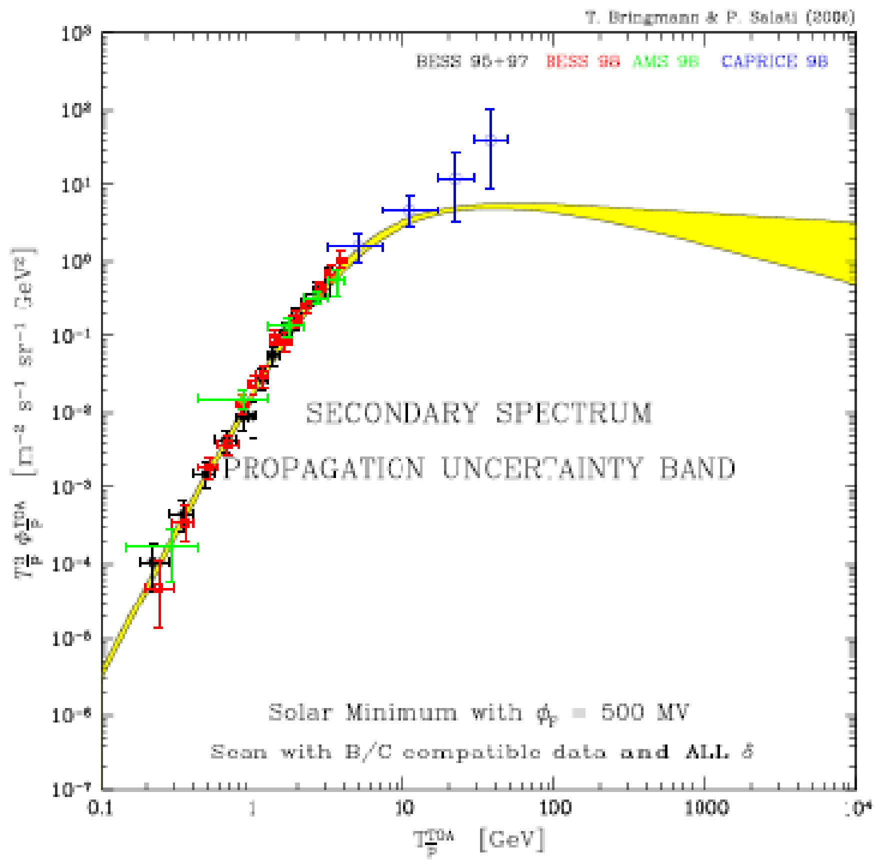




Uncertainties on the Secondary Antiproton Flux

Bringmann & Salati 2006; FD et al. APj 2001)



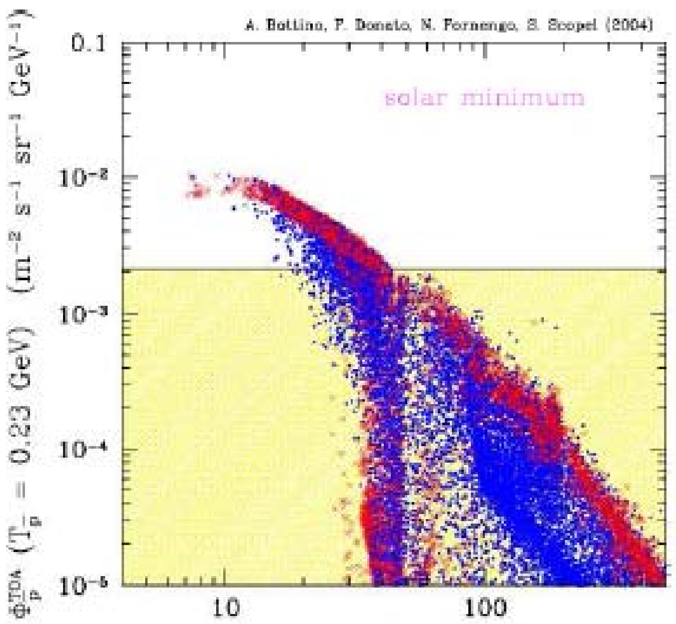


AMS & Pamela will explore the range less affected by propagation (astrophysical and nuclear) uncertainties (<2)

Antiprotons are a very effective **tool** in setting limits to

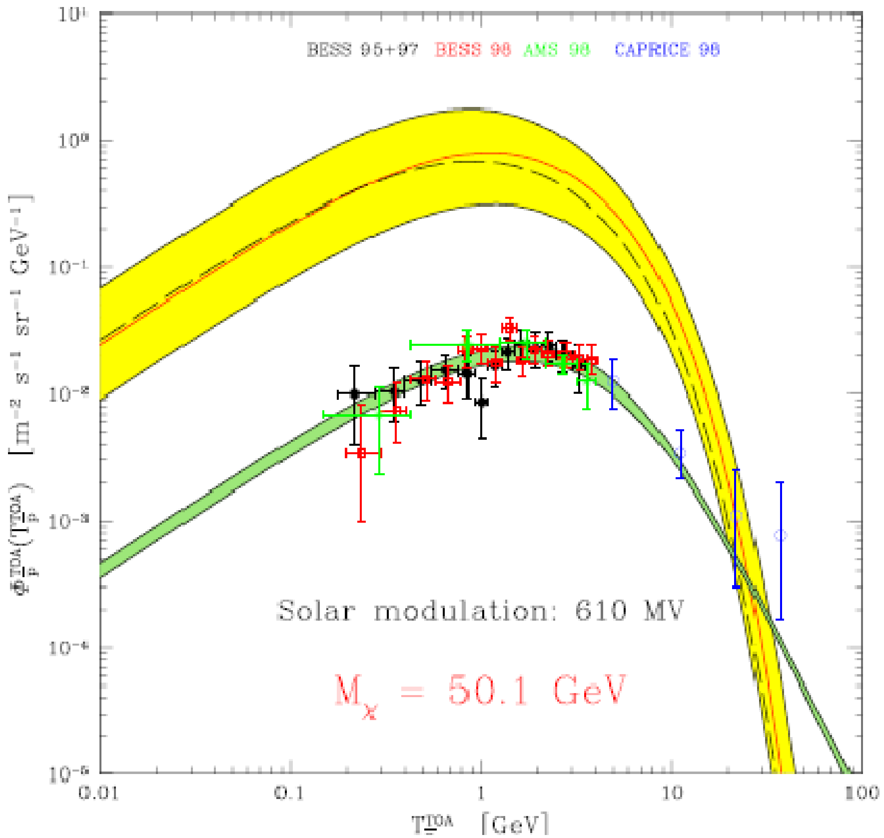
Cosmic antiprotons as a tool to constraint new models (susy, astro)

Bottino, FD, Fornengo, Scopel PRD 2004



effMSSM: Light masses & Bess DATA
Best fit propagation parameters

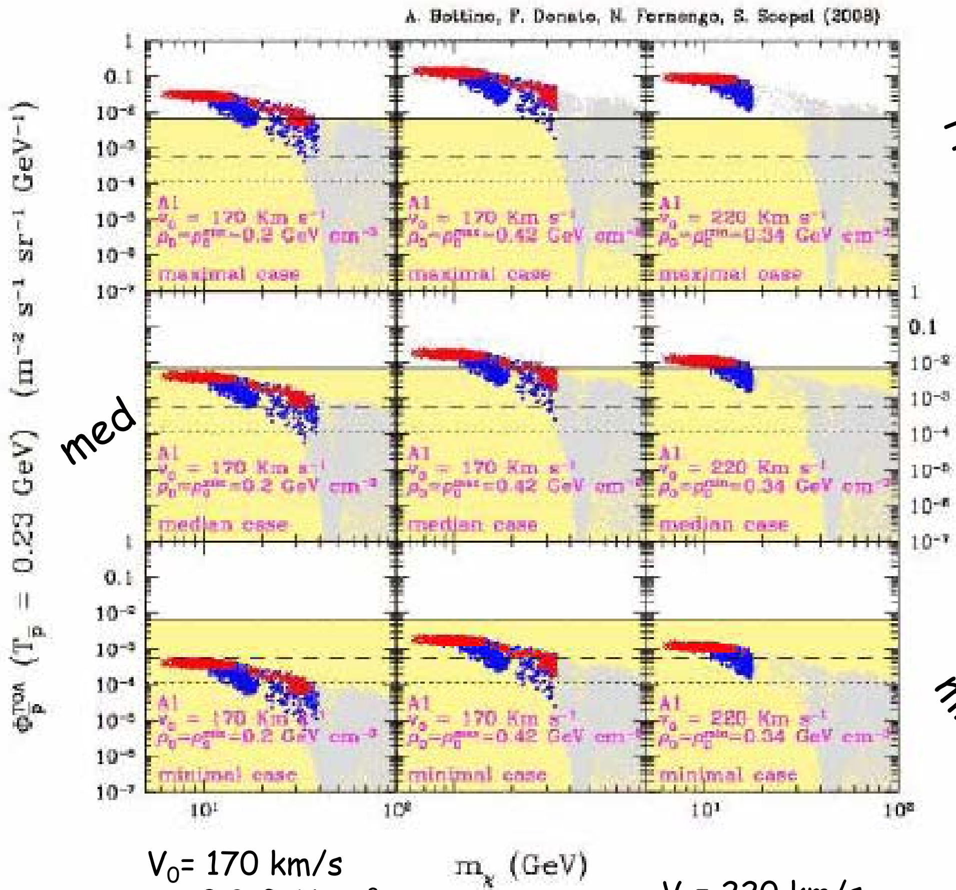
Bergström, Edsjo, Gustaffson, Salati astro-ph/0602632



With astro models from
De Boer et al. A&A2005

Antiprotons in cosmic rays as a **tool** for constraining supersymmetric models

Antiproton flux in effMSSM @ 240 MeV & Dama allowed region



Prop.:max

med

min

V_0= 170 km/s
ρ = 0.2 GeVcm^{-3}

V_0= 170 km/s
ρ = 0.42 GeVcm^{-3}

V_0= 220 km/s
ρ = 0.34 GeVcm^{-3}

red: WMAP
blue: subdominant, rescaled

Yellow band: compatible with Antiproton data (Bess exp.)

Many configurations are compatible with Dama & Bess

Exclusion of effMSSM parameters depends on propagation models.....

Antideuteron flux from neutralino DM pair annihilation in the halo

- Mass and annihilation cross section: effMSSM
  overall normalization

- Source term g(E): hadronization →antiproton, antineutron
  Pythia MC

- Distribution of DM in the Galaxy (isoth., NFW, ...): $\rho(r,z)$
  flux depends on ρ^2

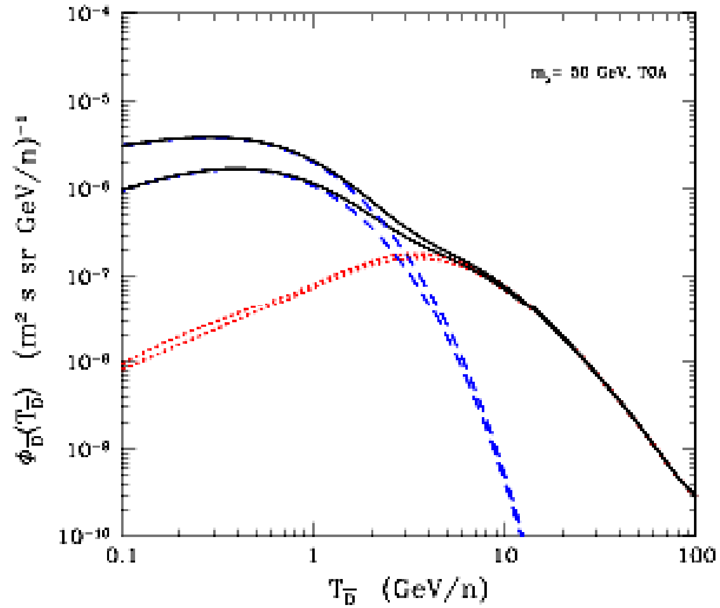
- Nuclear fusion: coalescence model, one parameter P_{coal} = 79 MeV
  the flux depends on $(P_{coal})^3$

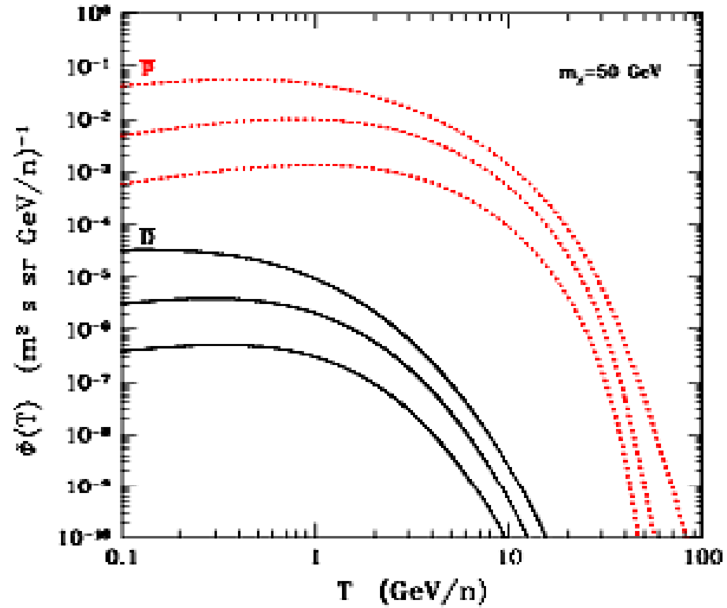
- Propagation in the MW from source to the Earth:
  2-zones semi-analytic diffusion model

- Solar modulation: force field approximation
  ϕ= 0.5 MV for solar minimum

PRIMARY & SECONDARY ANTIDEUTERONS
in a 2-zones diffusion model

(FD, Fornengo, Maurin, arXiv:0803.2460)





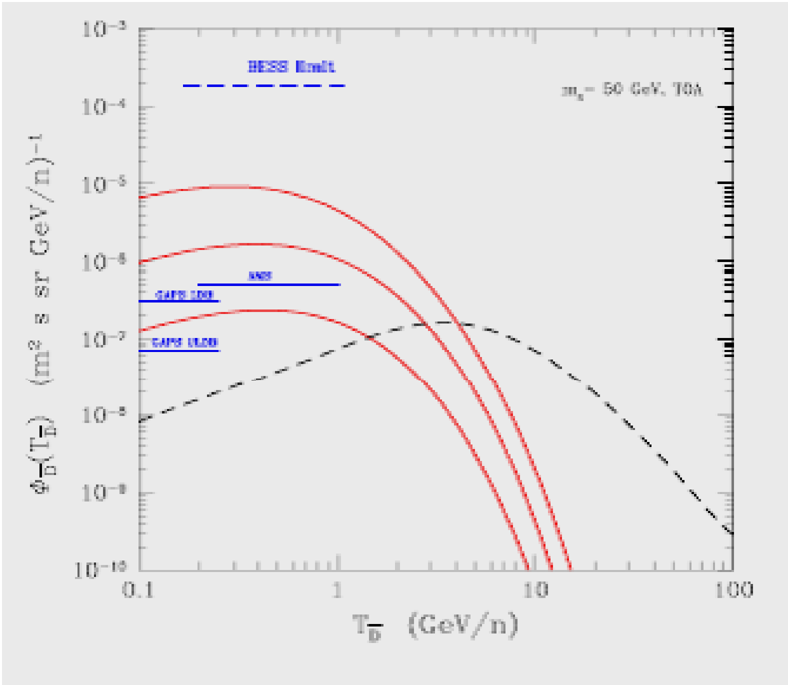
Secondary Primary Total

B/C best fit (L=4 kpc)
InterStellar (upper) &
solar minimum

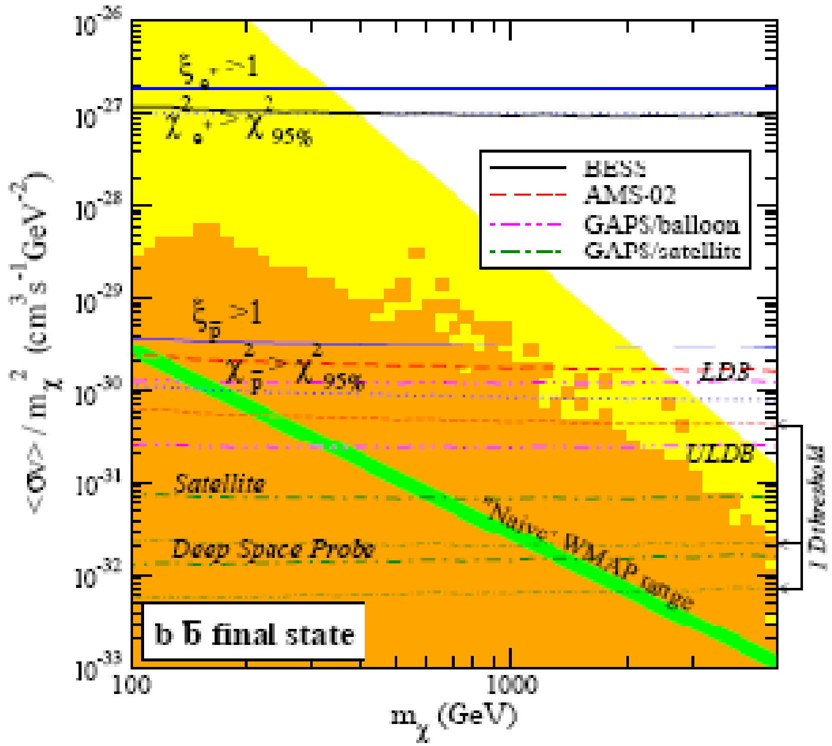
Antiprotons & Antideuterons
Propagation Uncertainties

ANTIDEUTERONS & future experiments

FD, Fornengo, Maurin PRD 2008



Baer & Profumo, JCAP 2005



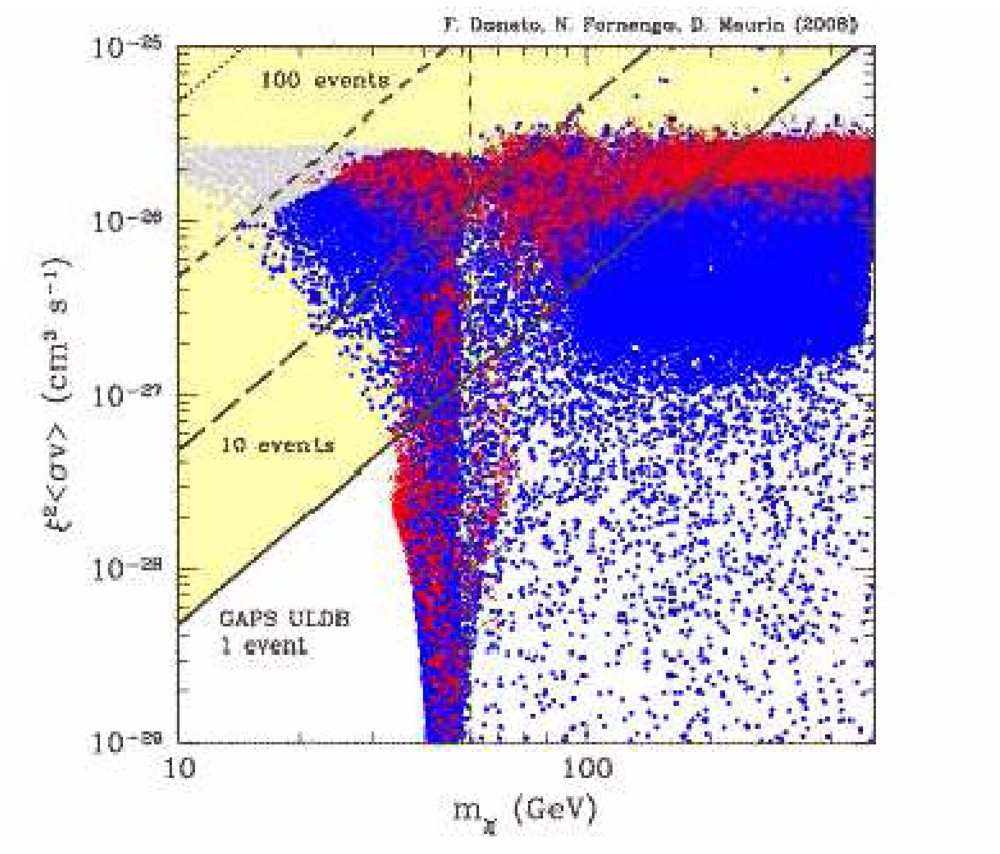
effMSSM neutralino dark matter can be detected by means of next generation space instruments measuring antideuterons in CRs

effMSSM Inspections with Antideuterons

Median (B/C best fit)
propagation parameters

Red: dominant neutralinos
Blue: subdominant neutralinos

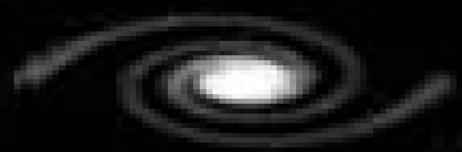
GAPS ULDB reach



The Torino code for DM phenomenology can compute (in different BSM schemes):

- relic density
- direct detection and
- indirect detection signals (gamma, positrons, antiprotons and antideuterons in CRs)

Recent results on the interplay between direct and indirect detection (antiproton) results → effMSSM



The next future deserves many results in all the above-mentionned field (underground labs, Antarctica balloons, ISS, satellites) … and the LHC, of course!

Positrons in CRs

R. Sparvoli for Pamela Coll. June 2008