Astroparticle physics view on supersymmetry
impact of cosmology and dark matter searches

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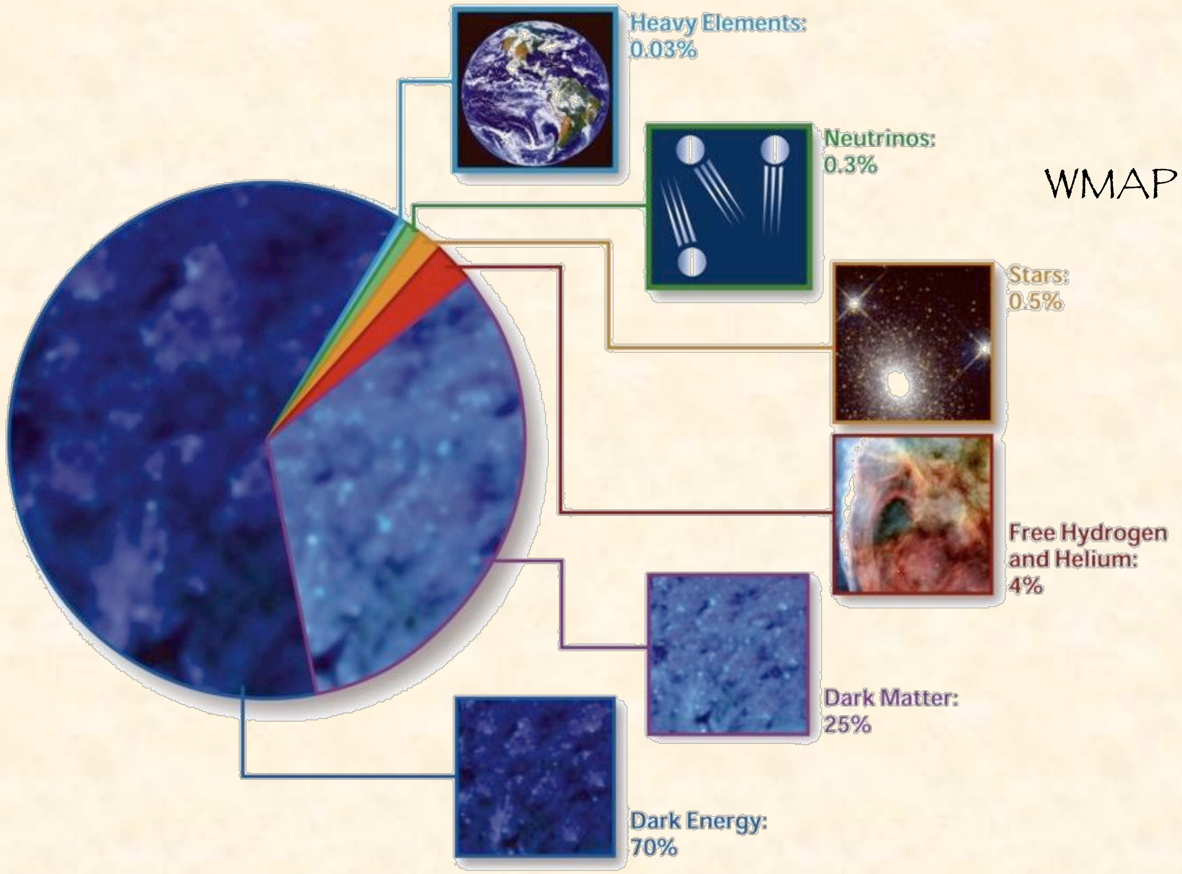
LC09: e+e- Physics at the TeV scale and the Dark Matter Connection
Perugia – 22.09.2009

The Dark Universe



WMAP + SN + BAO + galaxies distribution

Ω_{TOT}	1.0052 ± 0.0064
Ω_Λ	0.721 ± 0.015
Ω_M	0.233 ± 0.013
Ω_b	0.0462 ± 0.0015
h_0	0.701 ± 0.013
$\Omega_M h^2$	0.1369 ± 0.0037
$\Omega_b h^2$	0.02265 ± 0.00059
$\Omega_{DM} h^2$	0.1143 ± 0.0034

E. Komatsu et al., arXiv:0803.0547
J. Dunkley et al., arXiv:0803.0596
G. Hinshaw et al., arXiv:0803.0732

Ω_T CMB temperature anisotropies

Ω_Λ Luminosity distance of high-z SNIa

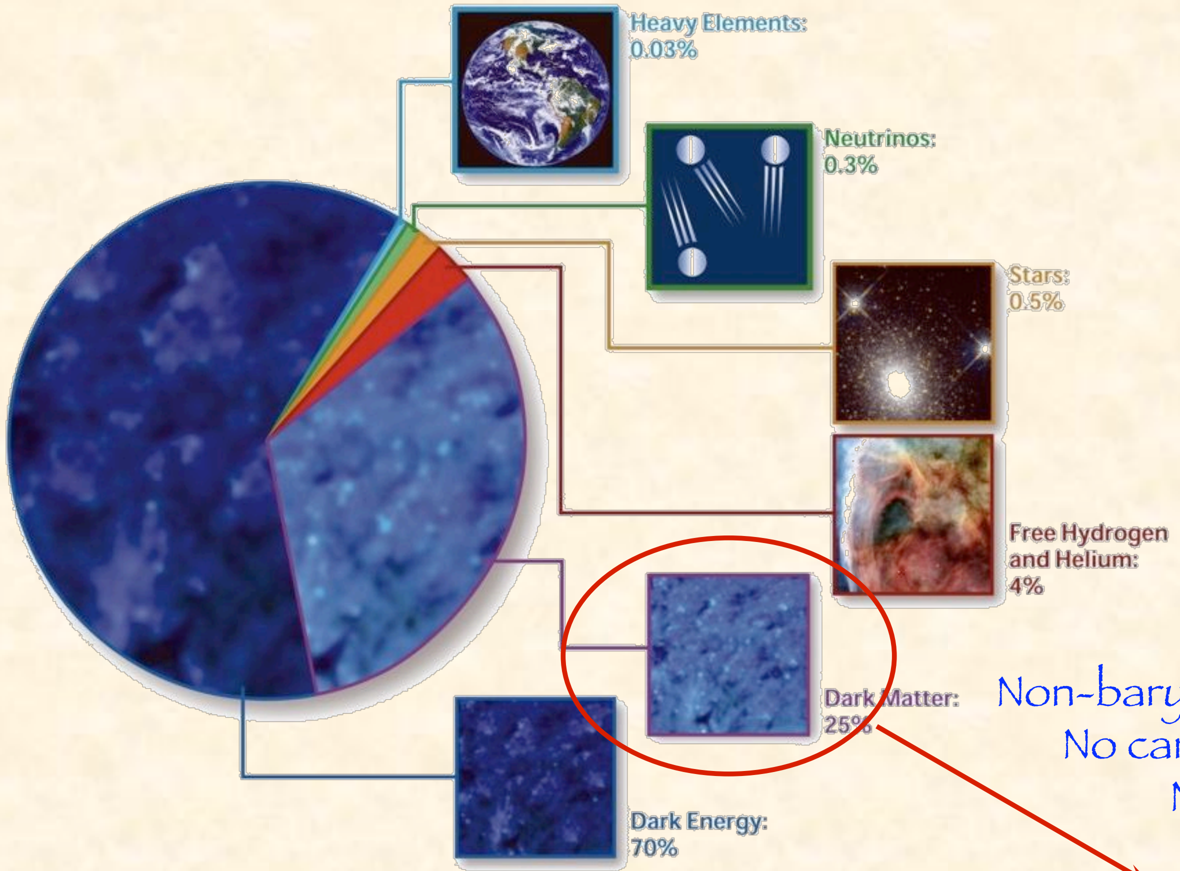
Ω_M Clustered mass abundance

Ω_B Primordial Nucleosynthesis
Amplitude of CMB temperature anisotropies

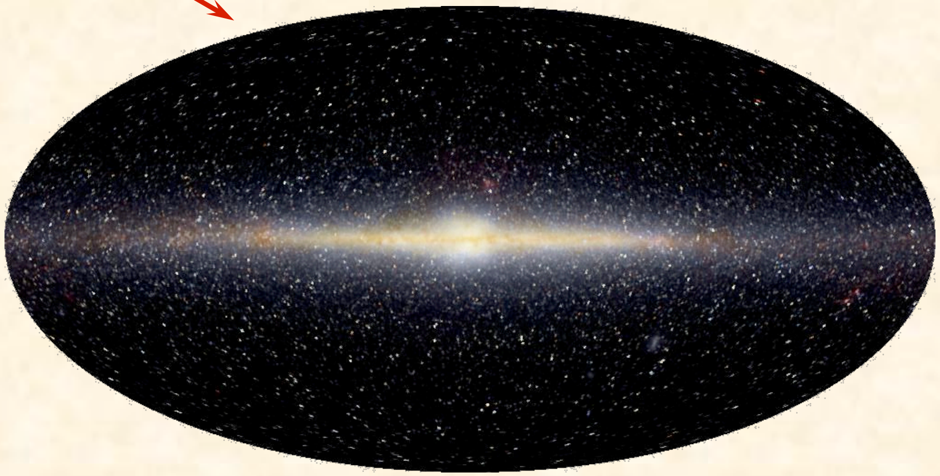
Geometry: the Universe is Flat
Dynamics: the Universe is expanding

- Decelerate for most of its history
- Accelerate since "recent" time and at very "old" times (inflation)

Dark Matter



Non-baryonic (cold) dark matter is needed
No candidate in the Standard Model
New fundamental Physics



- Dynamics of galaxy clusters
- Rotational curves of galaxies
- Weak lensing
- Structure formation from primordial density fluctuations
- Energy density budget

The Particle Dark Matter premise

- Particle candidate
- Cosmology of the particle candidate
- Astrophysical signals of the DM particle
- Accelerator physics searches for NP

Step 1

The Particle Physics Model

Non-baryonic DM candidates

- Non supersymmetric candidates
  - Neutrino: standard, RH MeV, (...)
  - "Minimal" candidates (e.g.: MDM)
  - Axion
  - Kaluza-Klein fields
  - Little Higgs models
  - Mirror baryons
  - (...)
- Supersymmetric candidates
  - Neutralino →
  - Sneutrino
  - Gravitino
  - Axino
  - Messenger fields
  - Stable non-topological solitons (Q-balls)
  - Heavy non-thermal relics
  - (...)

Neutralino:

- Low energy MSSM
  - Universal mass params
  - Light neutralinos
- Minimal SUGRA
- Non-minimal SUGRA
  - Higgs sector
  - Sfermion sector
  - Gaugino sector
- NMSSM
- Anomaly mediated ~~SUSY~~
- (...)

Non-baryonic DM candidates

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  (...)
- Supersymmetric candidates
  - Neutralino
  - Sneutrino →
  - Gravitino
  - Axino
  - Messenger fields
  - Stable non-topological solitons (Q-balls)
  - Heavy non-thermal relics

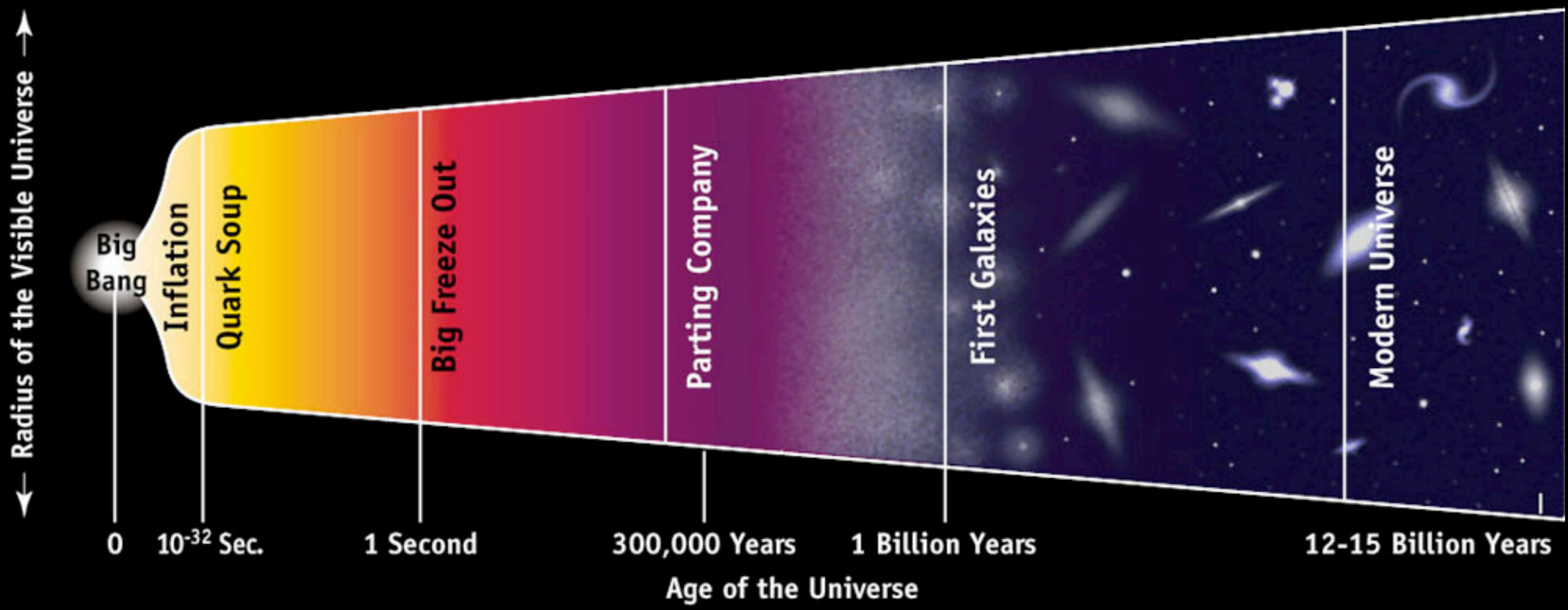
  (...)

- With R-handed (s)neutrino
- With Majorana mass terms
- In see-saw models
- NMSSM
- (...)

C. Arina, N. Fornengo, JHEP 0711 (2007) 029
C. Arina et al., PRL 101 (2008) 161802
D. Cerdeno et al., PRD 79 (2009) 023510
D. Cerdeno et al., arXiv:0903.4677 [hep-ph]
R. Allahverdi et al., PLB 677 (2009) 172
R. Allahverdi et al., arXiv:0907.1486
D. Demir et al., arXiv:0906.3540
(...)

Step 2

The Cosmological Context



Dark Matter formation

Particle DM formation

- Thermal relic

$$\Omega h^2 \sim \langle \sigma v \rangle_{\rm ann}^{-1} \longrightarrow \langle \sigma v \rangle_{\rm ann} = 3 \cdot 10^{-26} {\rm cm}^3 {\rm s}^{-1}$$

unless coannihilation occurs

- Thermal relic with non-standard cosmology

$$\Omega h^2 \sim \langle \sigma v \rangle_{\rm ann}^{-1} \quad \text{with} \quad \langle \sigma v \rangle_{\rm ann} \neq \langle \sigma v \rangle_{\rm ann}^{\rm GR}$$

- Non-thermal relic
  - In a low-reheating cosmology
  - From next-to-lightest particle decay

- (...)

Step 3

(Extra)Galactic Dark Matter Signals

Galactic Dark Matter

CDM in galaxies:

- DM as a non-baryonic particle
- Massive particle with weak-type interactions (WIMP)
- Distributed to form a halo
  - Thermal component
  - Substructures
  - Non-thermal component

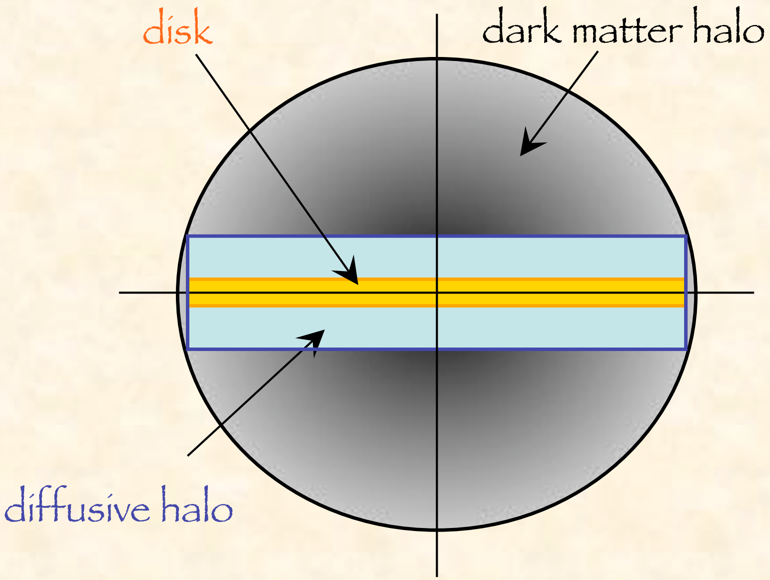
Galactic dark matter detection:

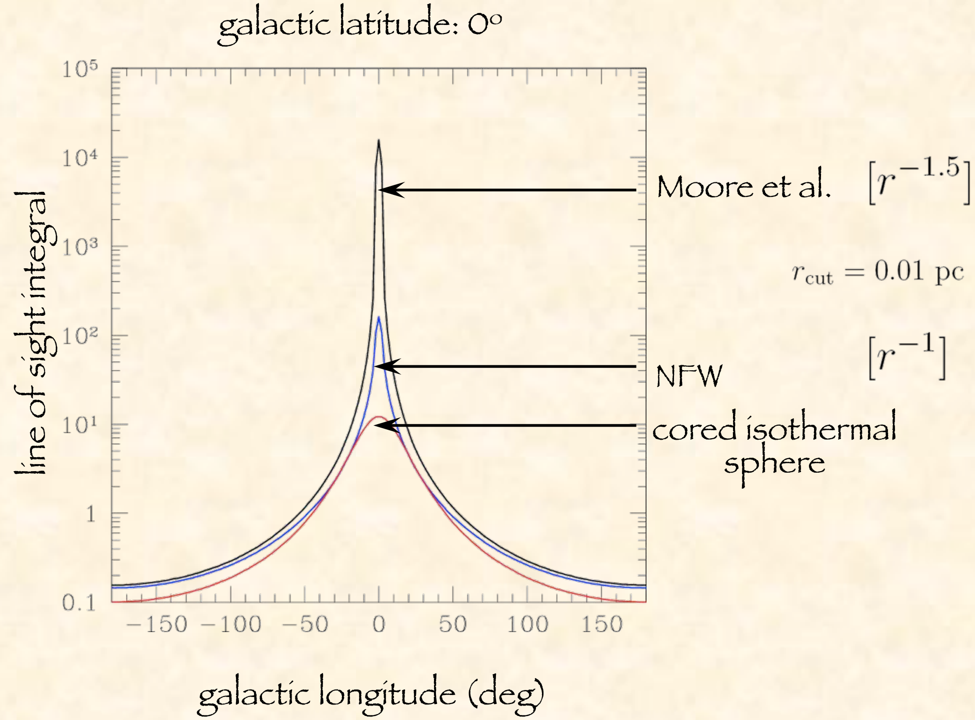
- Identify types of signals
- Exploit specific signatures
- Exploit (anti) correlations among signals
- Study relevant backgrounds
- Quantify uncertainties

MultiChannel search of dark matter

- Direct search: elastic scattering of χ off nuclei in a low background detector
  - → recoil energy of the nucleus
  - annual modulation of the rate
  - directionality of the recoil
- Indirect searches:
  - signals due to $\chi\chi$ annihilation taking place inside celestial bodies (Sun, Earth) where χ have been captured and accumulated
    - → Neutrino flux → up-going muons in a neutrino telescope
      source location/some spectral feature
  - signals due to $\chi\chi$ annihilation taking place in the galactic halo
    - → Neutrinos — source location/some spectral feature
    - → Photons
      - continuous gamma-ray flux — source location/some spectral feature
      - gamma-ray line — very good spectral feature
    - → Positrons — spectral feature
    - → Antiprotons — spectral feature
    - → Antideuterons — very good spectral feature
    - → Electrons/positrons → multiwavelength search (radio, X, gamma rays; SZ on CMB)

Gamma-rays





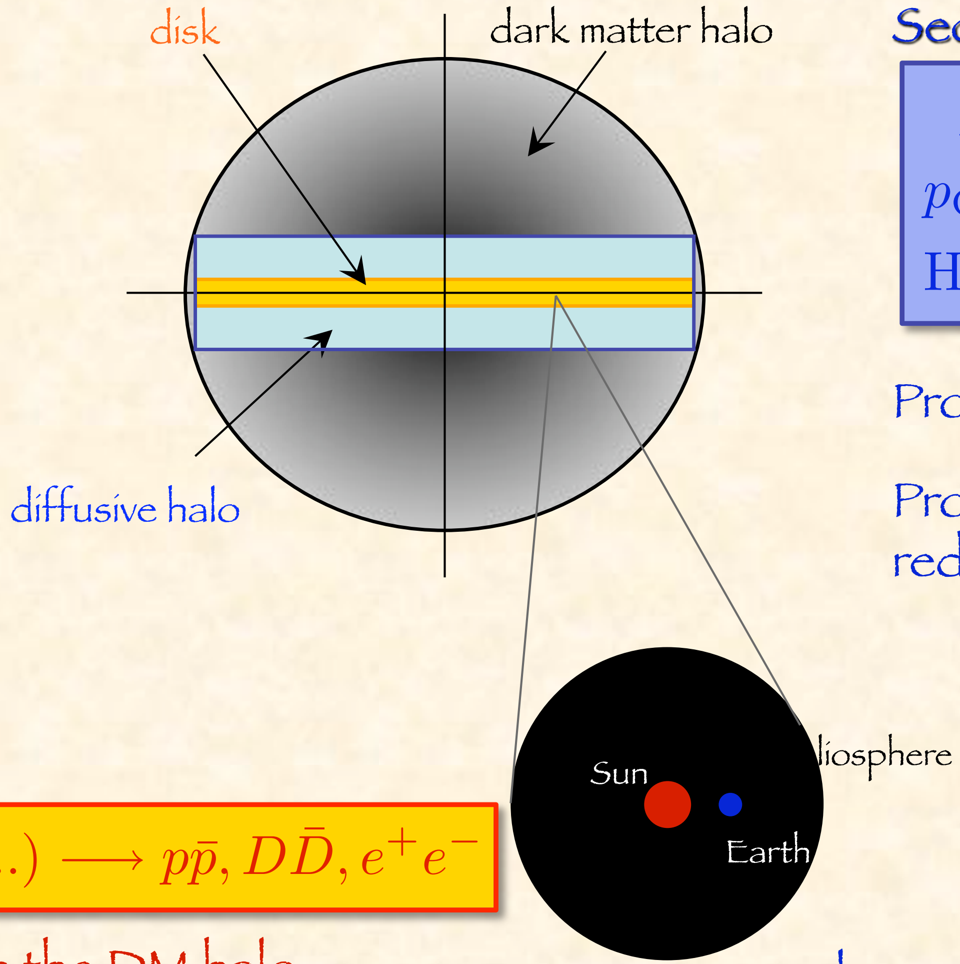
DM signal

$$\chi\chi \longrightarrow (.....) \longrightarrow \gamma \quad \text{diffuse}$$

$$\chi\chi \longrightarrow [1\ loop] \longrightarrow 2\gamma \quad \text{line}$$

The flux is sensitive to the DM density profile

Galactic antimatter



Secondaries

$$
\begin{aligned}
p_{\rm CR} + p_{\rm ISM} &\longrightarrow \bar{p}, \bar{D}, e^+ \\
p_{\rm CR} + {\rm He}_{\rm ISM} &\longrightarrow \bar{p}, \bar{D}, e^+ \\
{\rm He}_{\rm CR} + p_{\rm ISM} &\longrightarrow \bar{p}, \bar{D}, e^+
\end{aligned}
$$

Produced in the disk

Propagation and energy redistribution in the diffusive halo

solar modulation

DM signal

$$\chi\chi \longrightarrow (\ldots) \longrightarrow p\bar{p}, D\bar{D}, e^+e^-$$

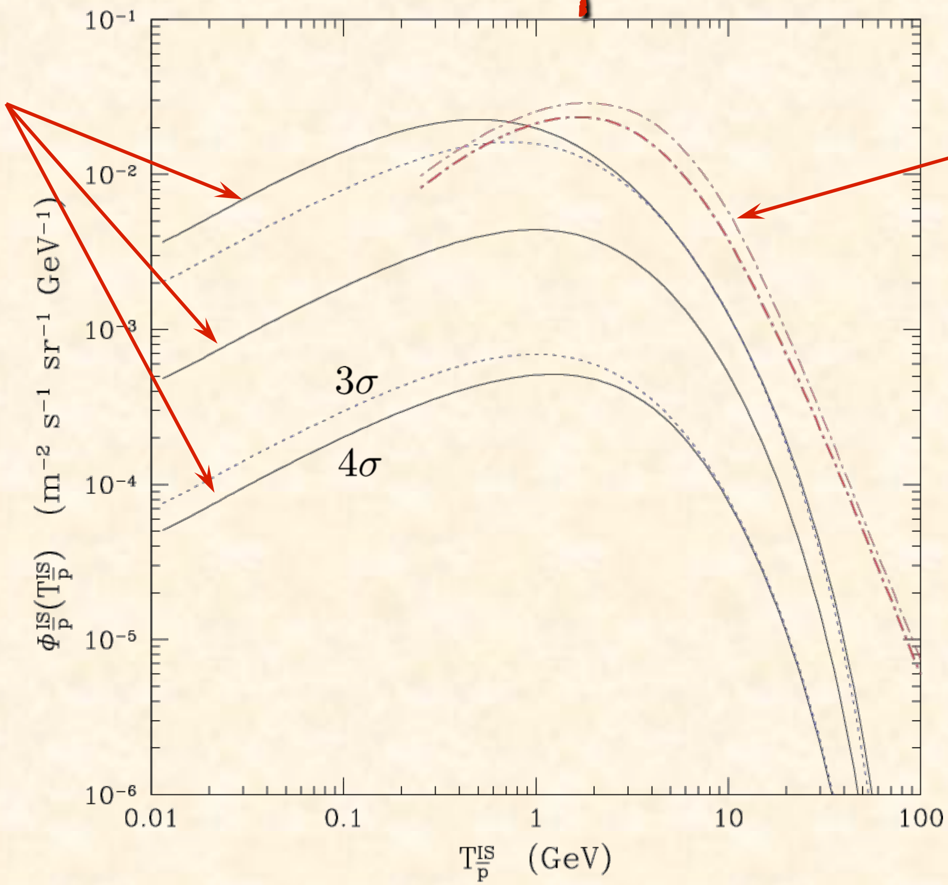
Produced in the DM halo

Propagation and energy redistribution in the diffusive halo

Interstellar antiproton fluxes

Primaries [1]
(DM signal)

$m_\chi = 100$ GeV



Secondaries [2]
(background)

< 25% uncertainty

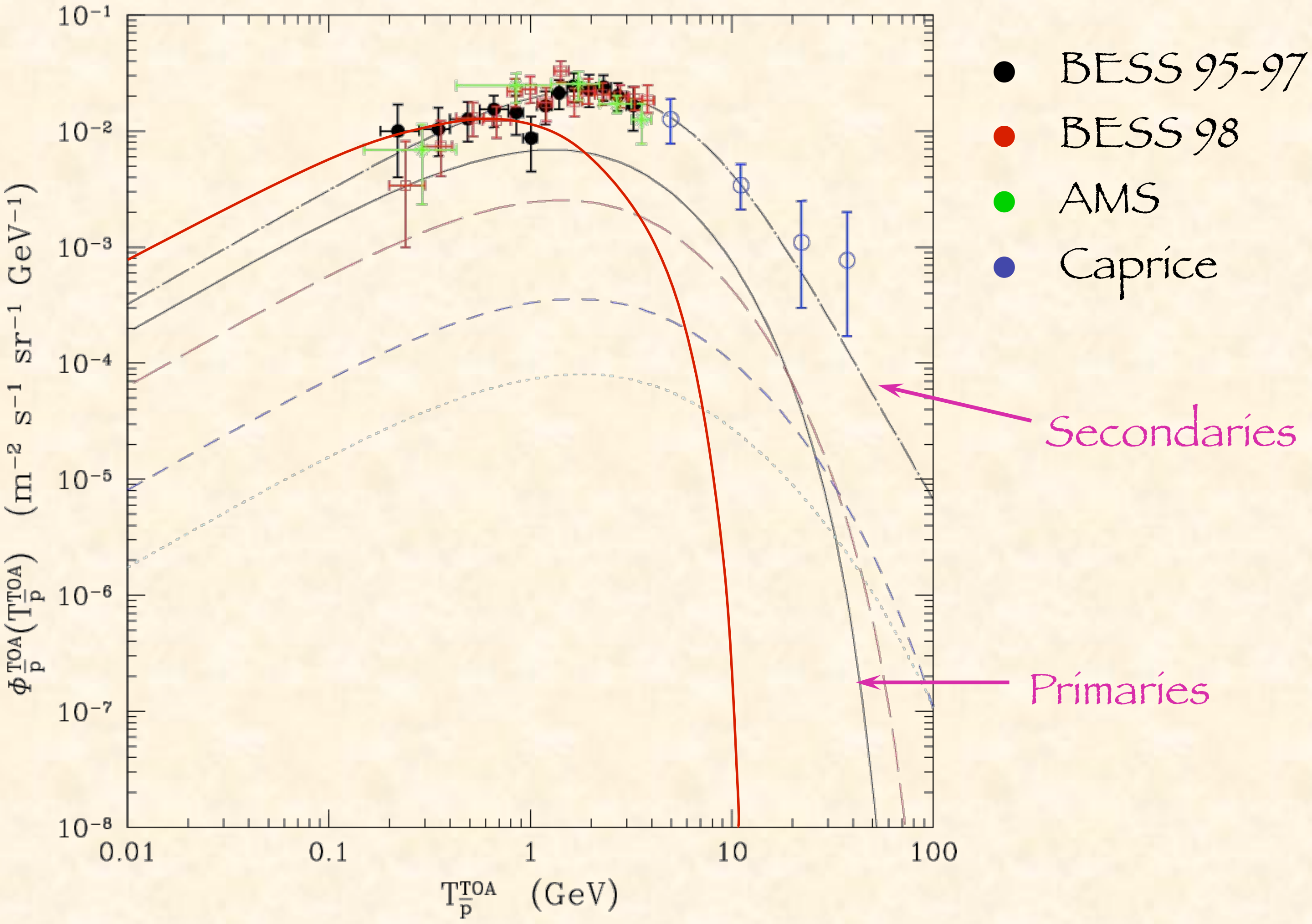
(1) F. Donato, N. Fornengo, D. Maurin, P. Salati, R. Taillet, PRD 69 (2004) 0603501

(2) D. Maurin et al. Astron. Astrophys. 381 (2002) 539

case	δ	K_0 (kpc^2/Myr)	L (kpc)	V_c (km/sec)	V_A (km/sec)	$\chi^2_{B/C}$
max	0.46	0.0765	15	5	117.6	39.98
med	0.70	0.0112	4	12	52.9	25.68
min	0.85	0.0016	1	13.5	22.4	39.02

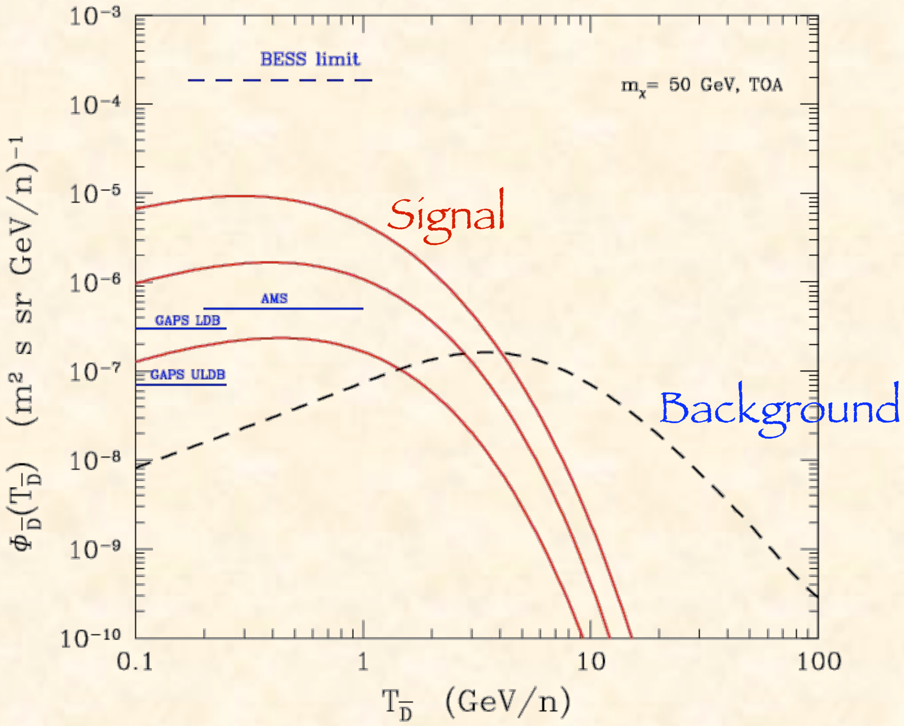
TOA fluxes and comparison with data

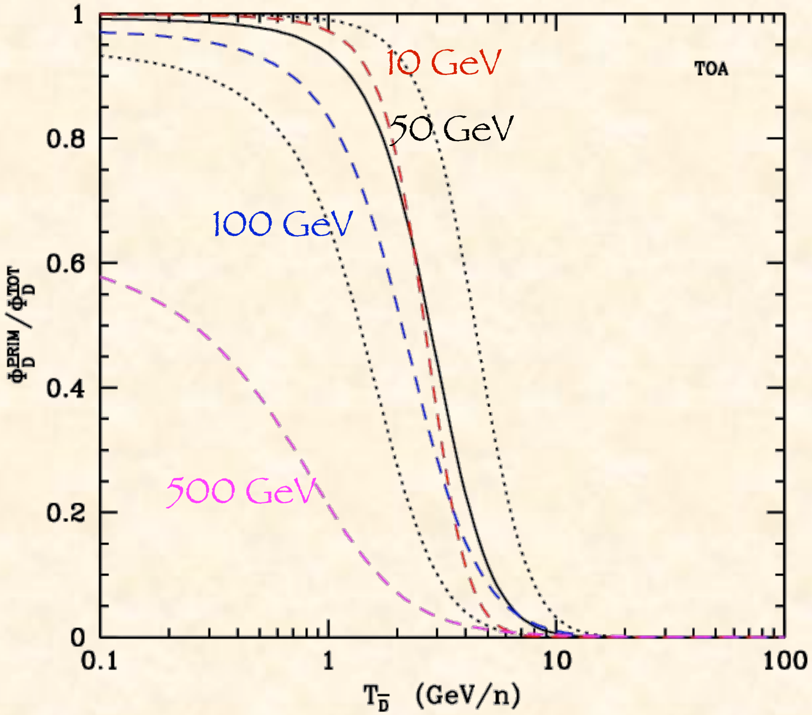
solar minimum



F. Donato, N.Fornengo, D. Maurin, P. Salati, R. Taillet, PRD 69 (2003) 063501

Cosmic Antideuterons





Signal with uncertainty band for:

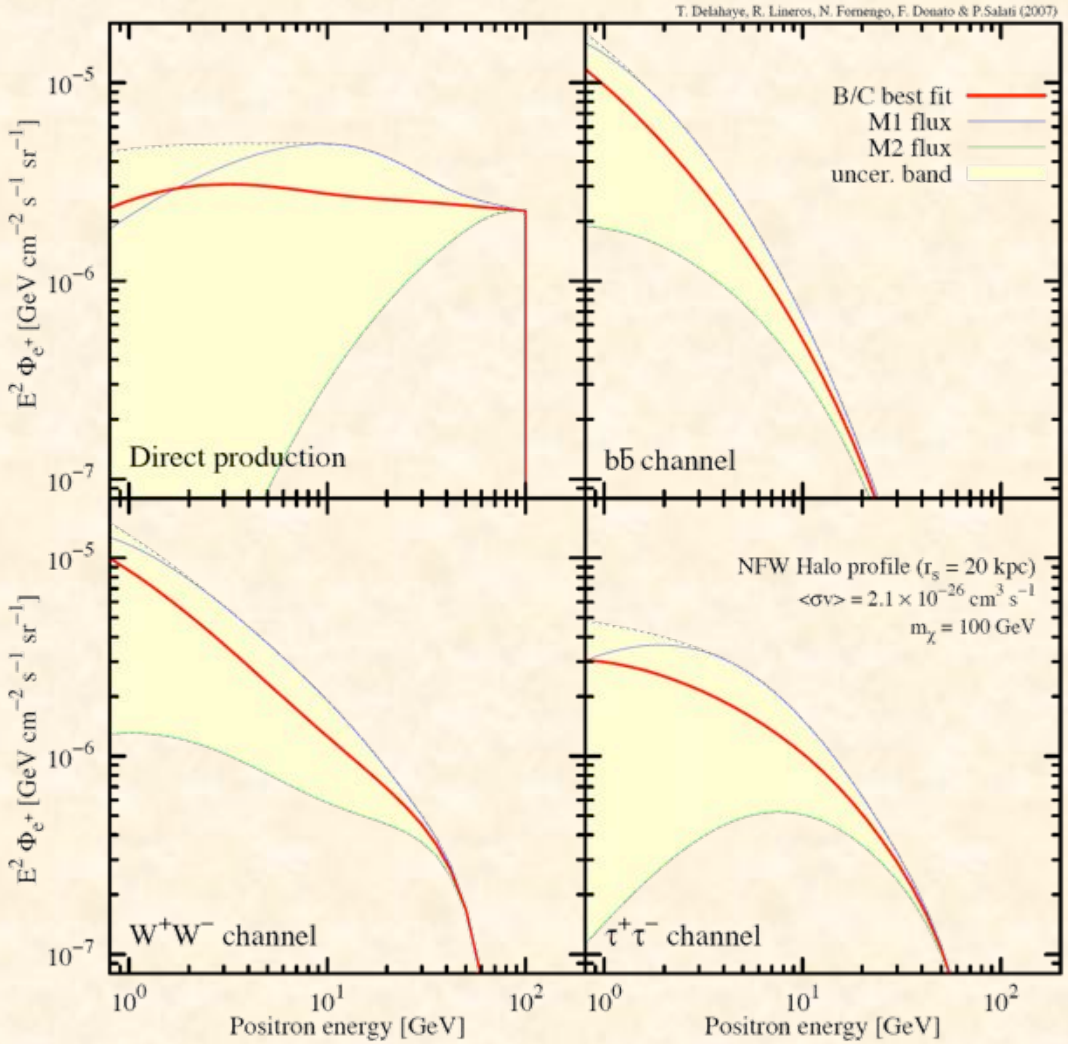
- 50 GeV WIMP mass
- WMAP relic abundance

Signal/(Back+Signal) ratio

F. Donato, N. Fornengo, D. Maurin, PRD 78 (2008) 043506

DM signal: astrophysical uncertainties

m_χ = 100 GeV



T. Delahaye, R. Lineros, F. Donato, N. Fornengo, P. Salati, Phys. Rev. D 77 (2008) 063527

Step 4

The Connection with Accelerator Physics

Particle DM

- Particle DM: can be searched at accelerators
  - Tevatron, LHC, B Factories, ILC

- This requires to specify the nature of the DM candidate and the underlying model of New Physics
  - Supersymmetry
  - GUT models
  - Additional symmetries
  - Extra-dimensions
  - Models of string theory or branes
  - (...)

- Information from cosmology and astrophysical searches can guide/complement accelerator searches for NP

What astrophysical signals probe?

- Direct detection:
  - (In)elastic scattering cross section on nuclei (non-relativistic)
  - Scattering cross section on electrons

- Indirect detection of antimatter, gamma rays, multi-λ photons
  - Annihilation cross section (non-relativistic)

- Indirect detection at neutrino telescopes:
  - Elastic scattering cross section on nuclei (or electrons)
  - BR of annihilation cross section

What accelerators probe?

- DM candidate
  - Contributes to missing momenta (since neutral and massive)

- New Physics (NP) spectrum
  - Masses and couplings (partly)

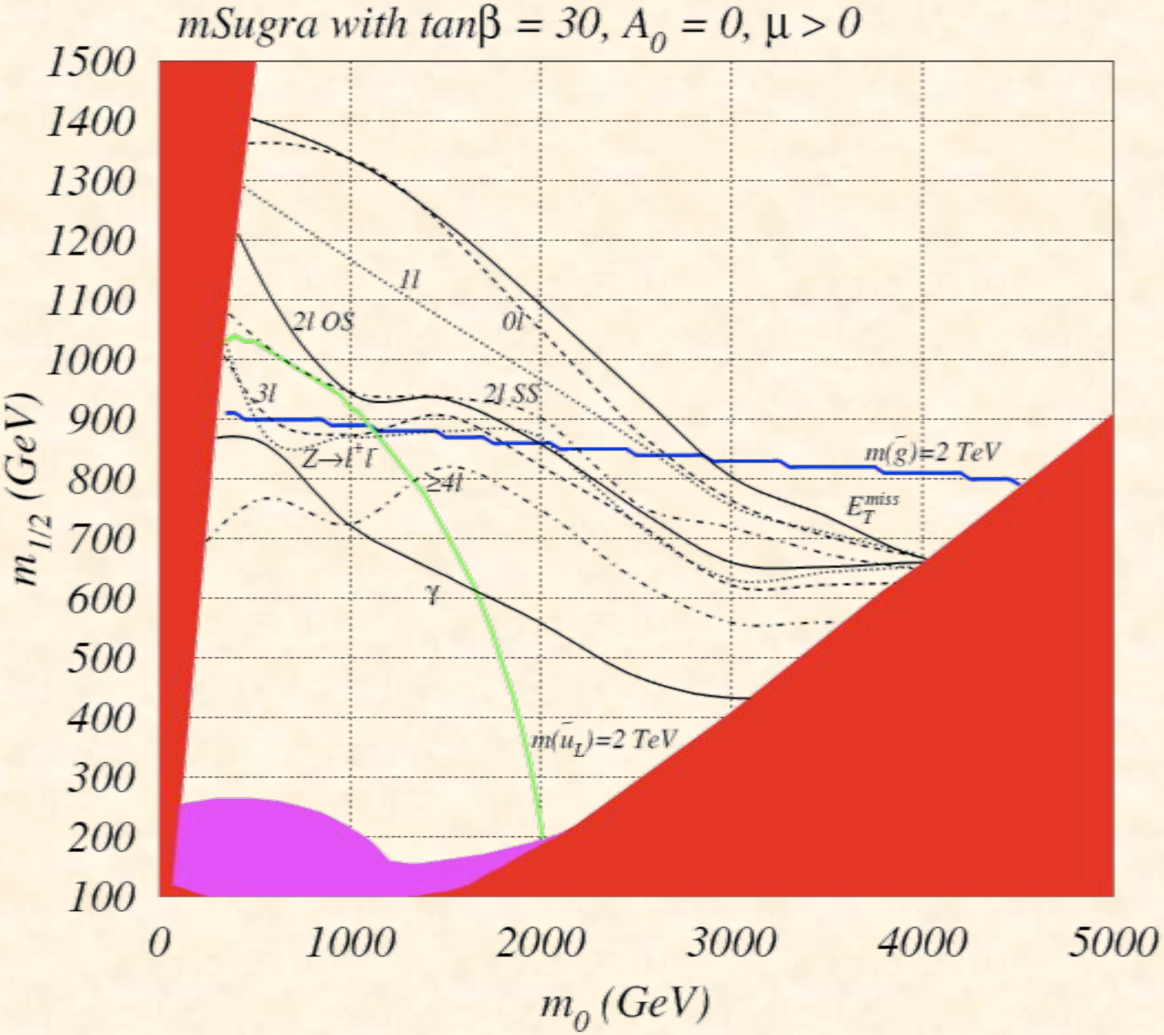
- The mechanism of production at accelerators relies on processes different from the those producing the astrophysical signals

- Accelerator physics and astrophysical signals may either probe the same or different sectors of the NP parameter space

- Comparisons have to be performed in specific models of NP

Reach of LHC in mSUGRA

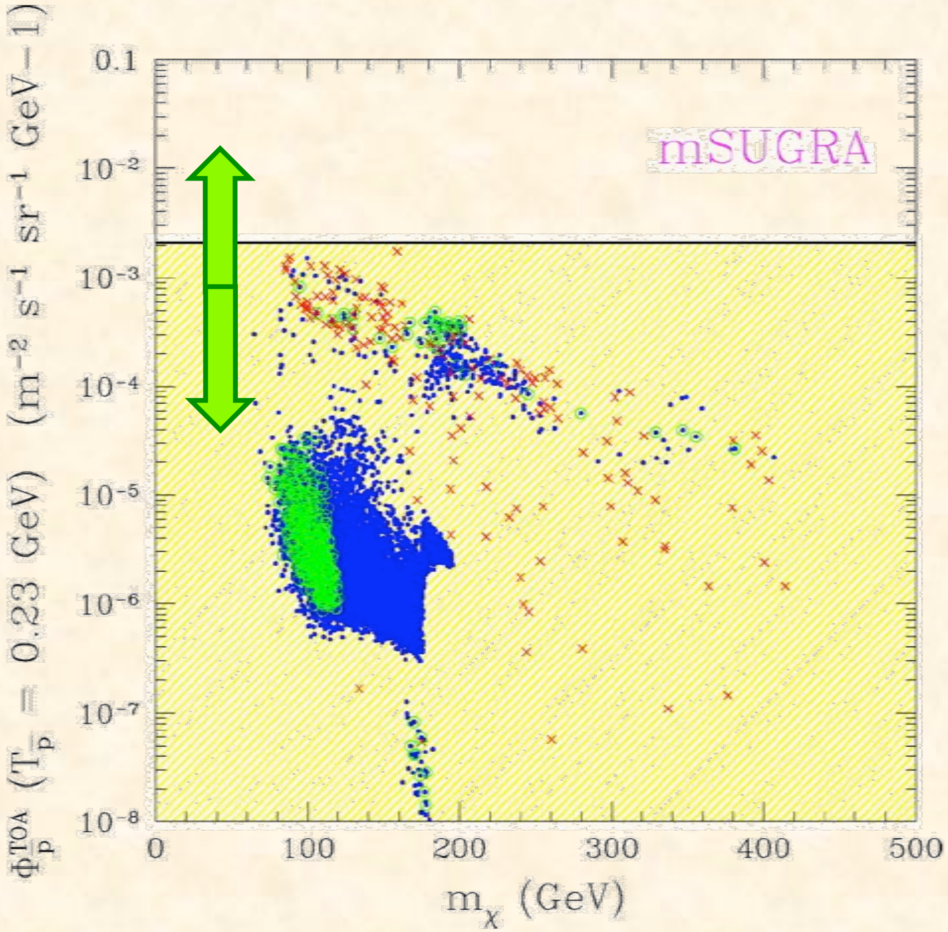
100 fb^{-1}



H. Baer, 0901.4732 [hep-ph]

Cosmic antiprotons

SUGRA

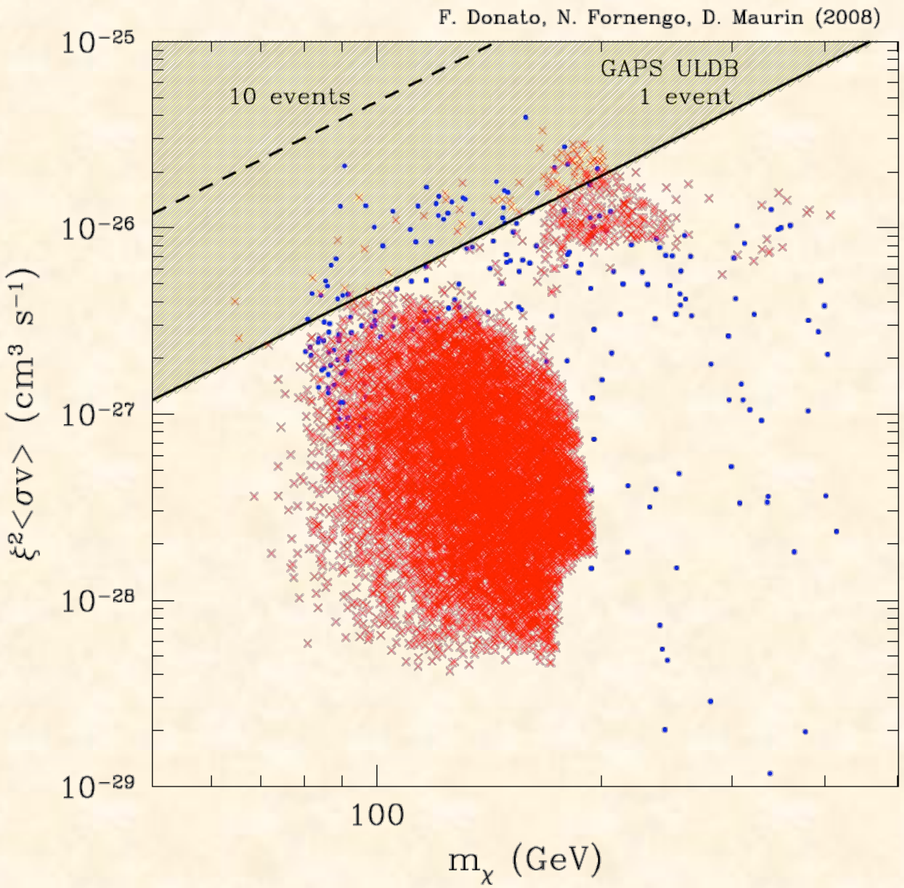


Best-fit astro params

F. Donato, N.Fornengo, D. Mauron, P. Salati, R. Taillet, PRD 69 (2004) 063501

Cosmic antideuterons

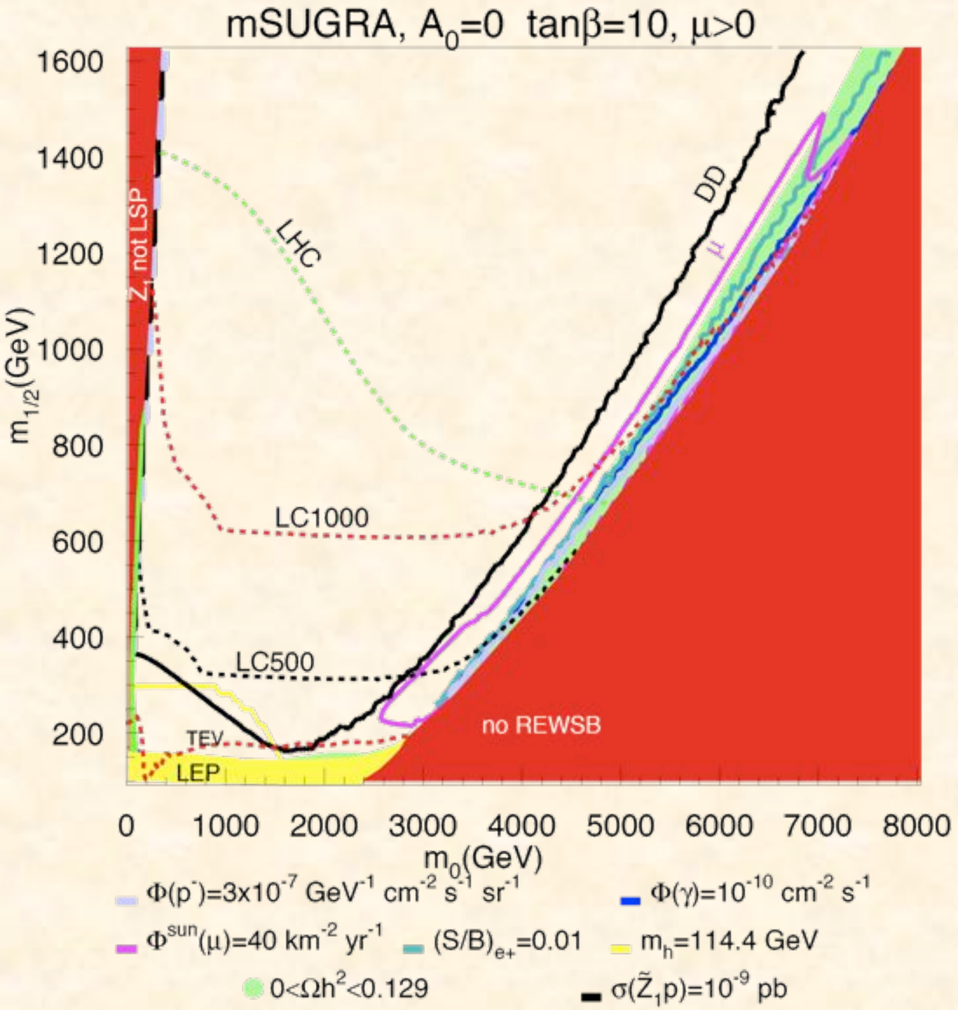
SUGRA



Best-fit astro params

F. Donato, N. Fornengo, D. Maurin, PRD 78 (2008) 043506

Accelerators and cosmo/astro DM interplay



H. Baer, 0901.4732 [hep-ph]

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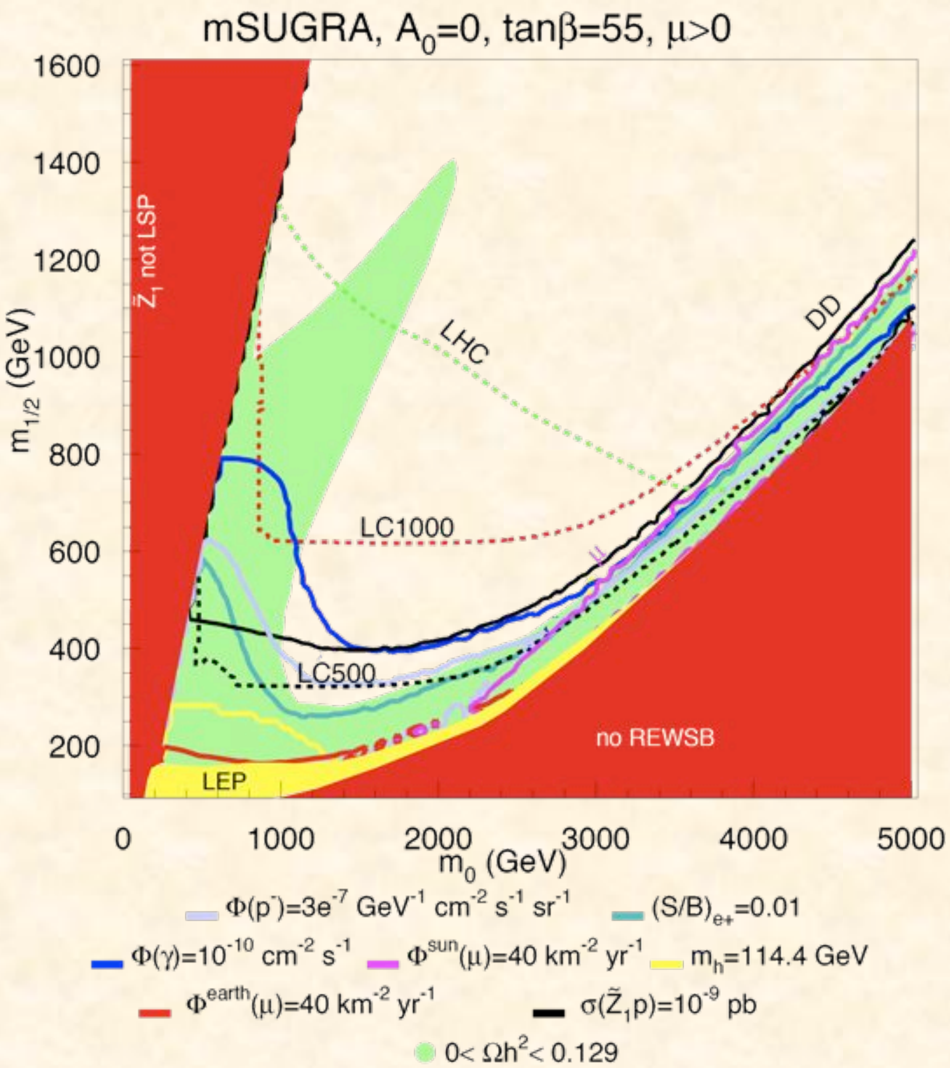
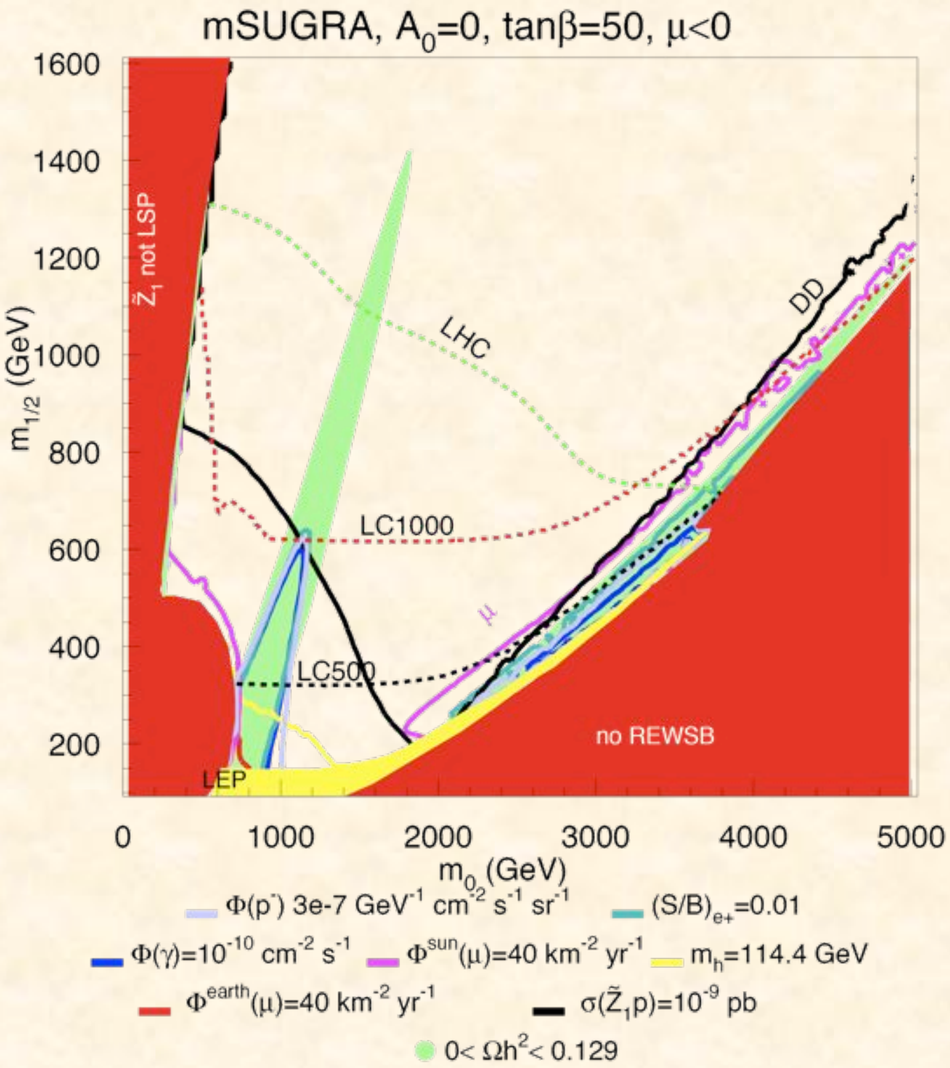


H. Baer, 0901.4732 [hep-ph]

Accelerators and cosmo/astro DM interplay



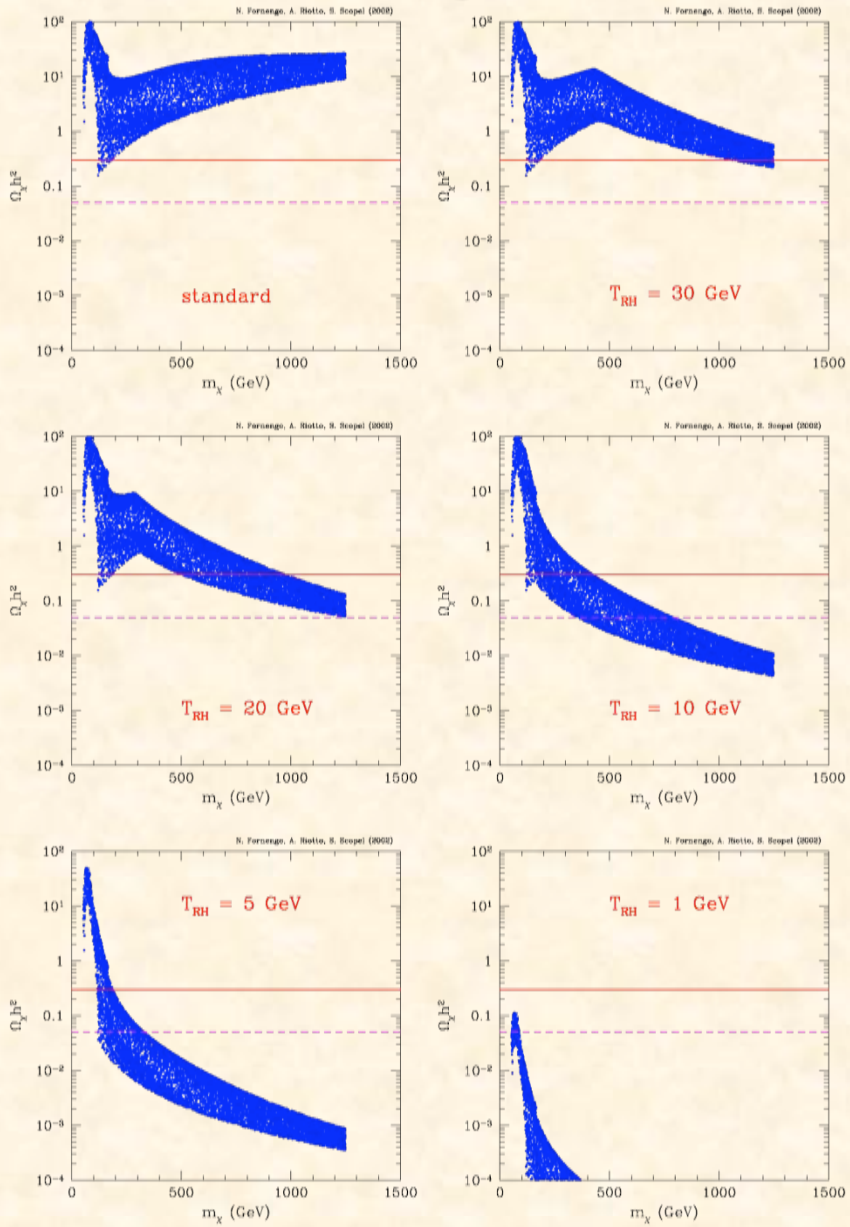
H. Baer, 0901.4732 [hep-ph]

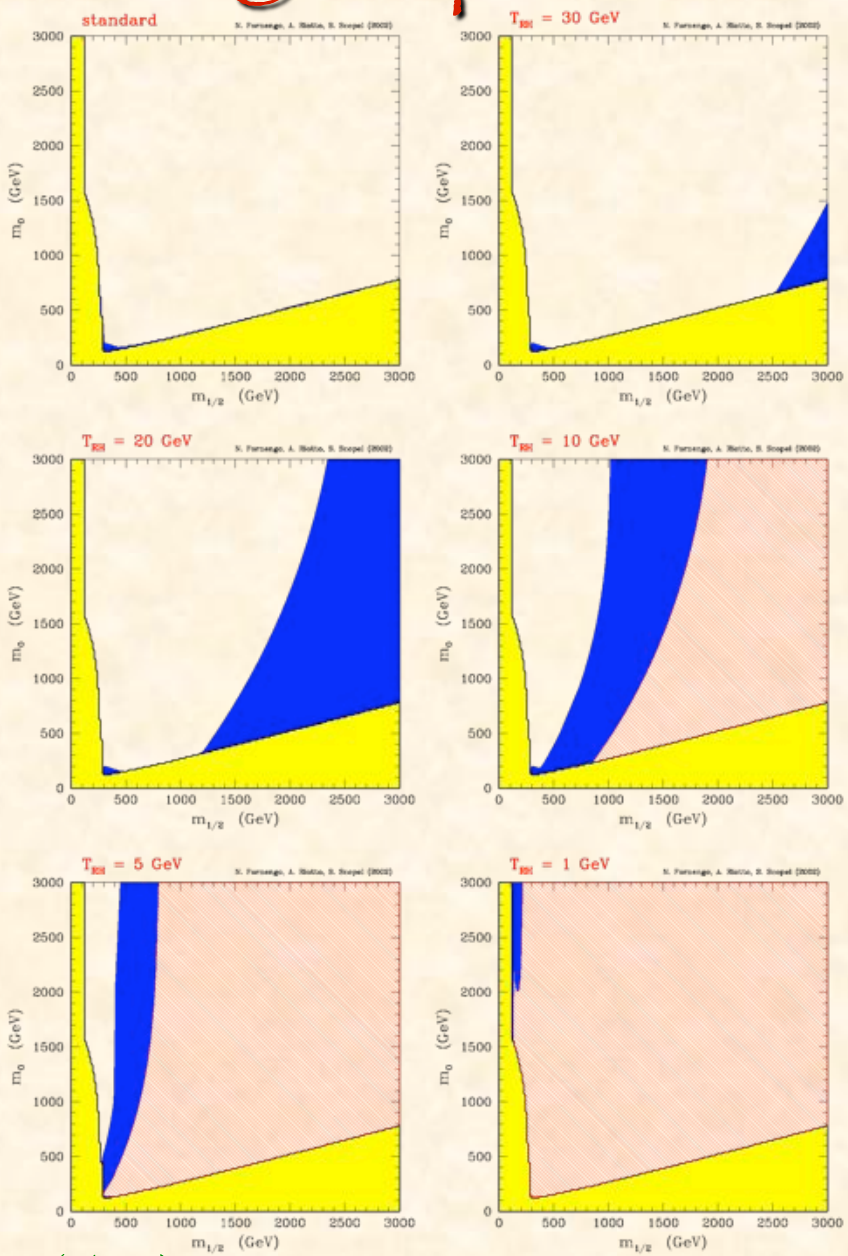
Cosmology may play a role!

- Cosmologically allowed regions depend on the mechanism of DM formation in the early Universe (pre-BBN era)

- The thermal history of the Universe before or around the time of decoupling may drastically change the current value of the relic abundance for a given candidate

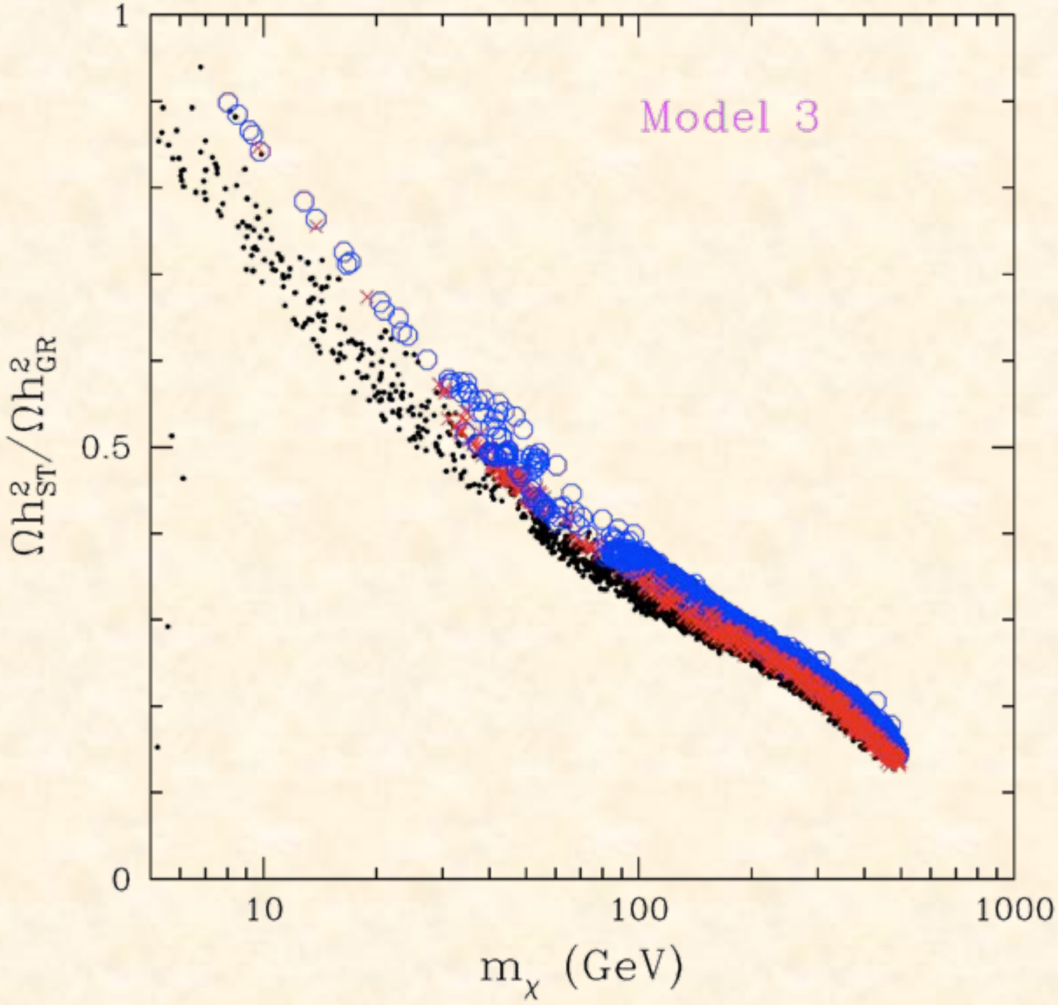
Cosmology with a low-reheating temperature





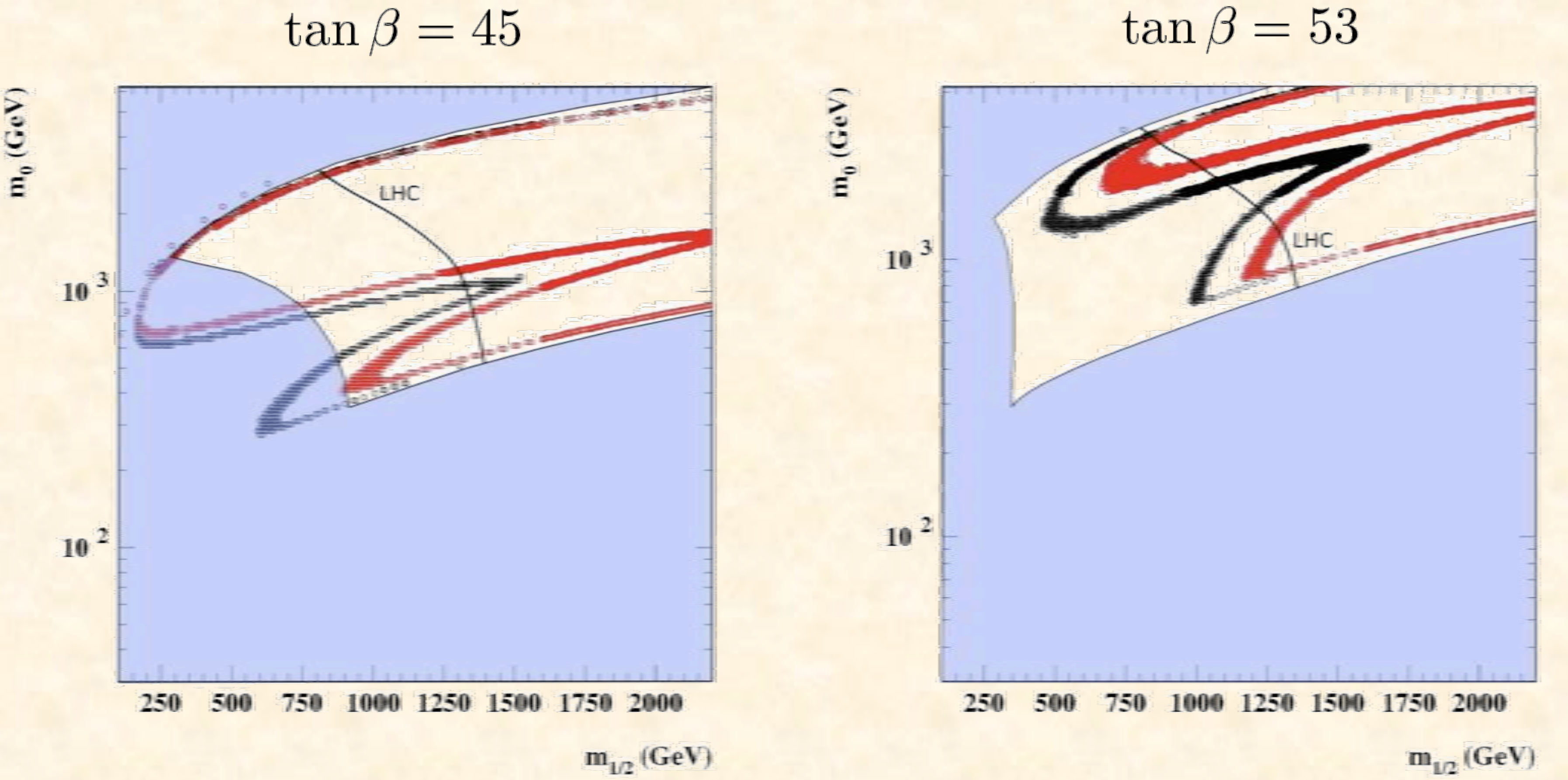
N. Fornengo, A. Riotto, S. Scopel, PRD 67 (2003) 023514

Scalar-tensor gravity with 2 scalar fields



R. Catena, N. Fornengo, A. Masiero, M. Pietroni, M. Schelke, JHEP 0810 (2008) 003

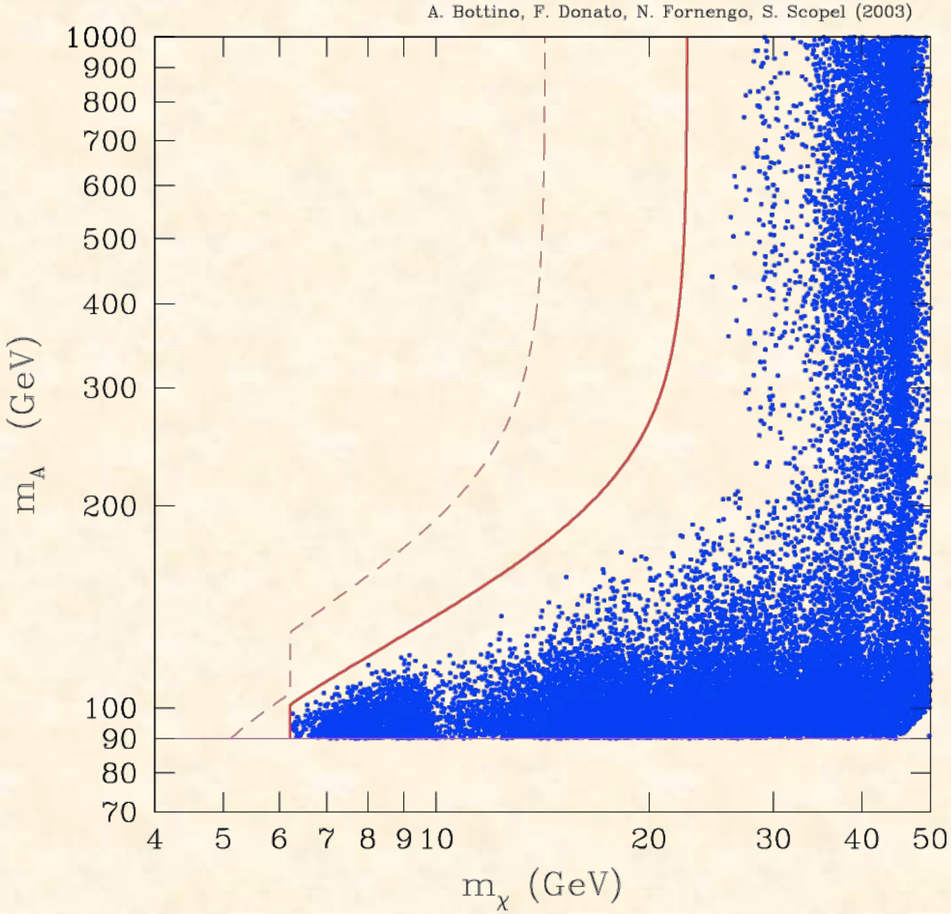
Impact on mSUGRA

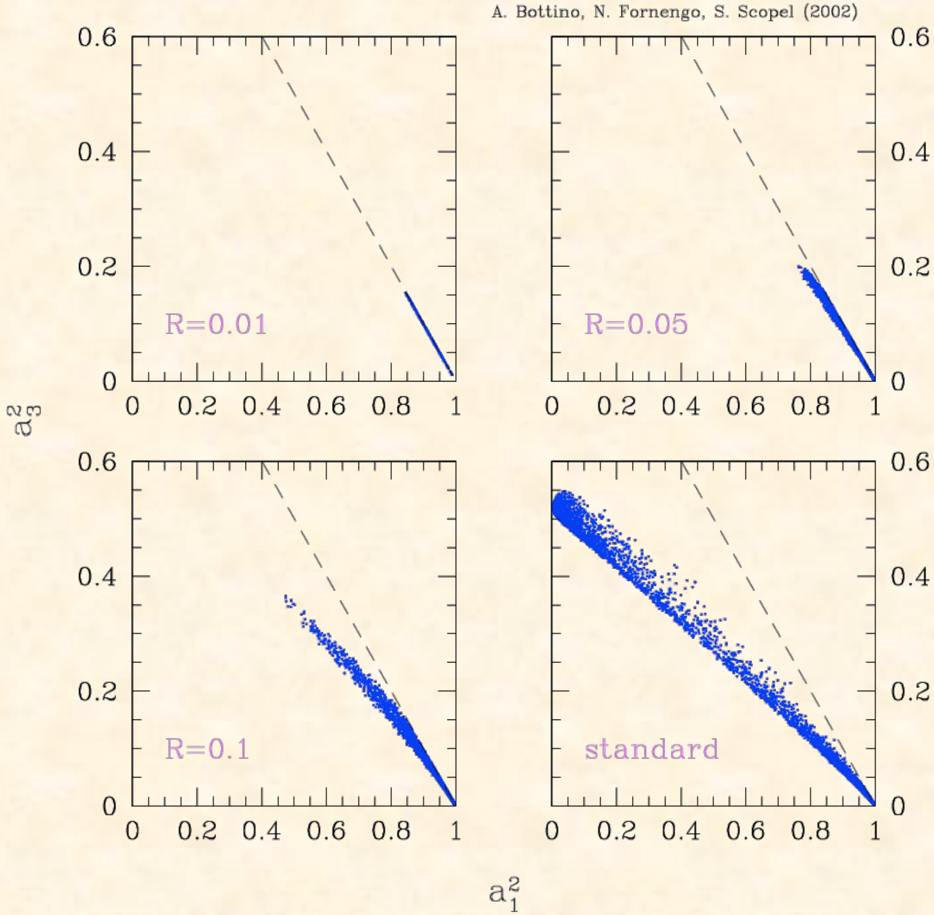


R. Catena, N. Fornengo, A. Masiero, M. Pietroni, M. Schelke, JHEP 0810 (2008) 003

MSSM + Gaugino non-universality

$$M_1(M_{EW}) \equiv R\ M_2(M_{EW})$$



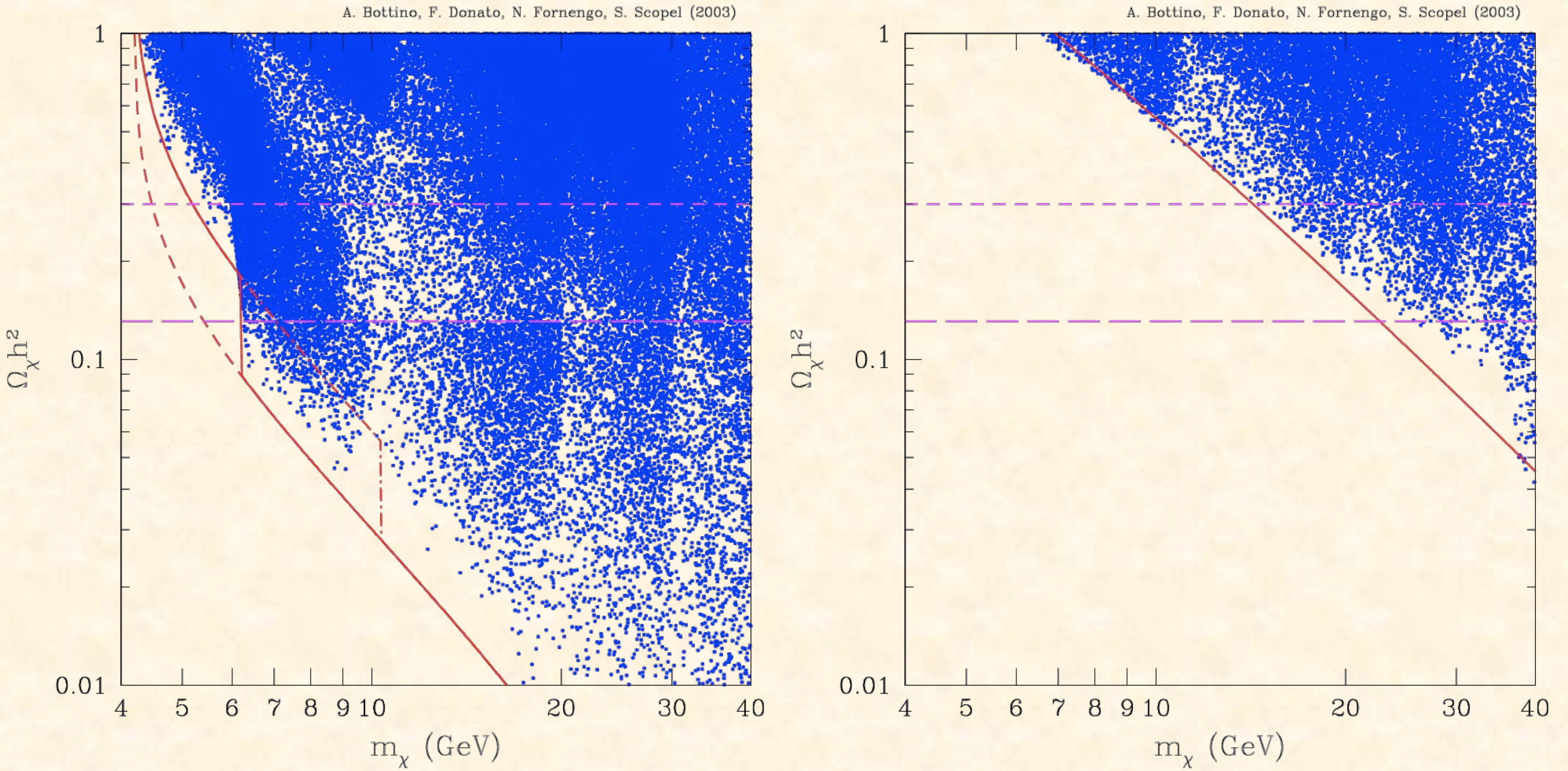


Light Neutralino LSP: almost pure bino + fraction of higgsino

A. Bottino, F. Donato, N. Fornengo, S. Scopel, PRD 68 (2008) 043506

Cosmological lower bound on mass

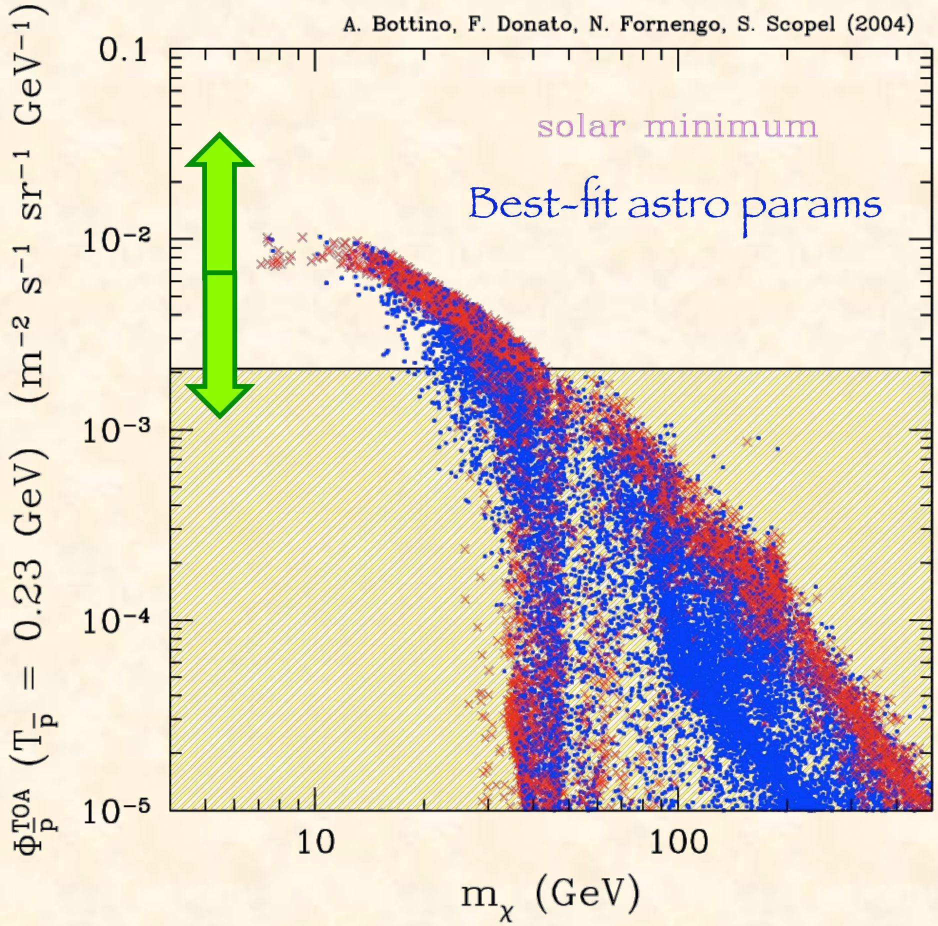
with: $m_A > 90$ GeV | with: $m_A \longrightarrow \infty$



A. Bottino, F. Donato, N. Fornengo, S. Scopel, PRD 68 (2008) 043506

Cosmic antiprotons

MSSM + gaugino non universal



A. Bottino, F. Donato, N.Fornengo, S. Scopel, PRD 70 (2004) 015005

Cosmic antideuterons

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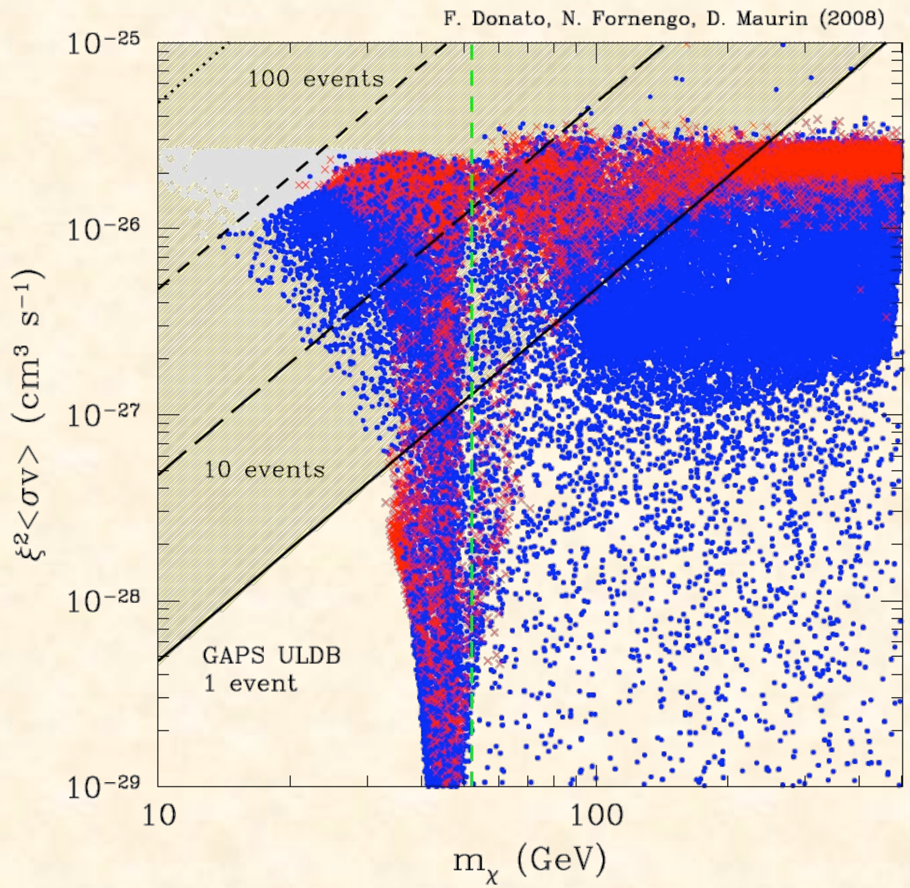
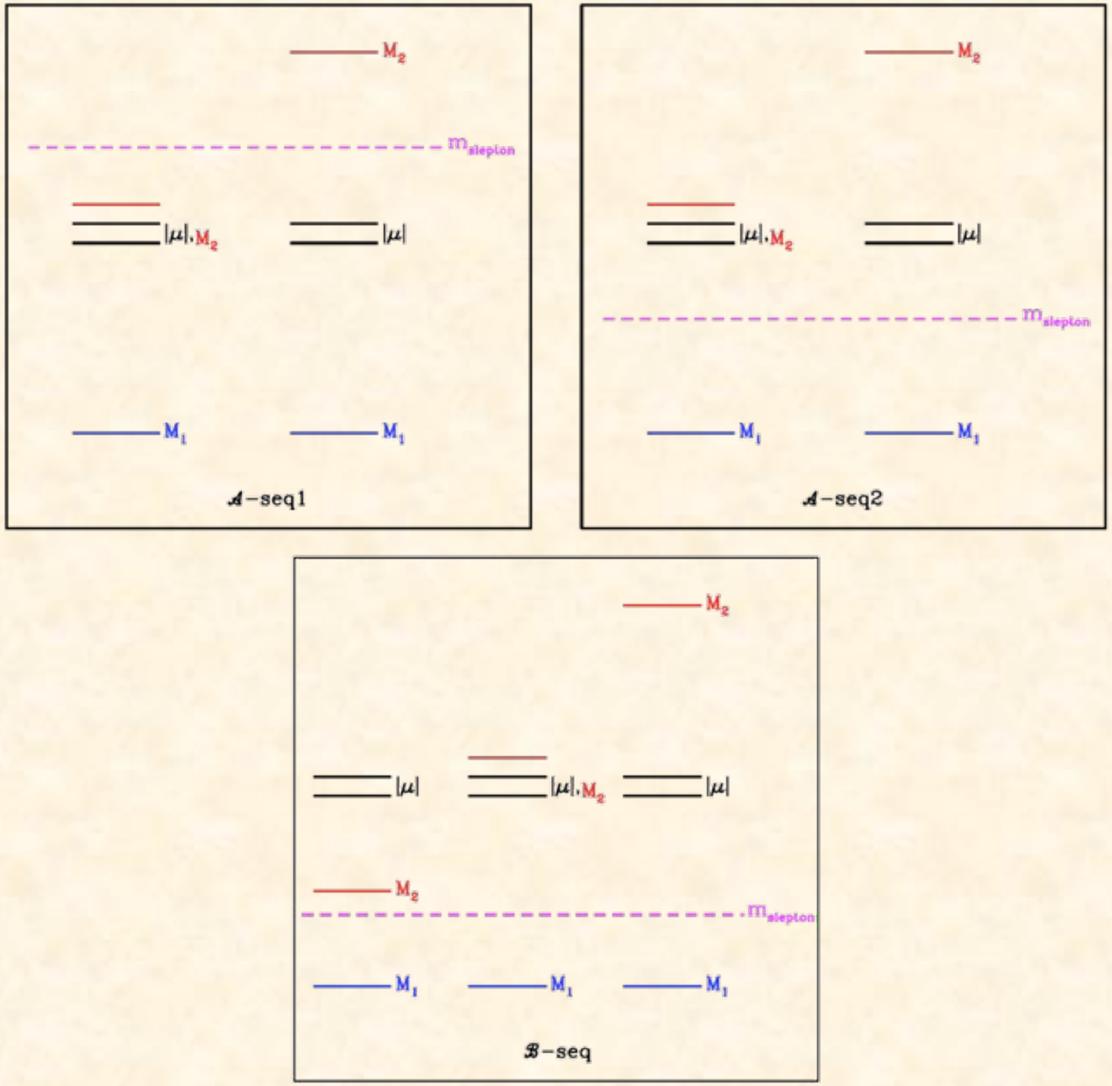


Best-fit astro params

F. Donato, N. Fornengo, D. Maurin, PRD 78 (2008) 043506

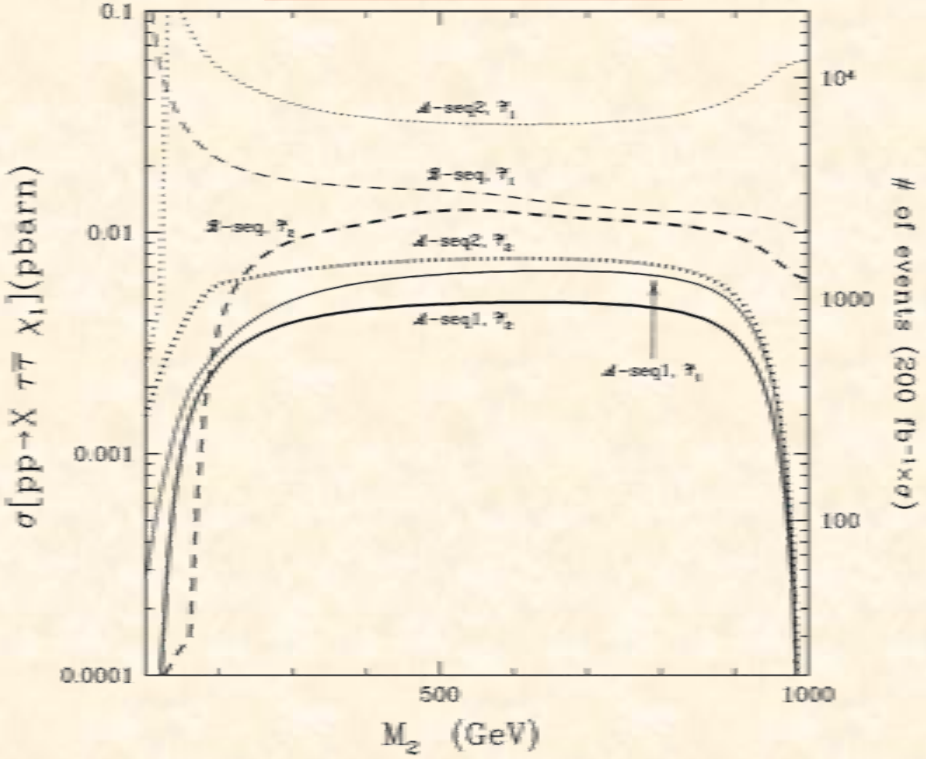
Light neutralinos at LHC: sequential chain



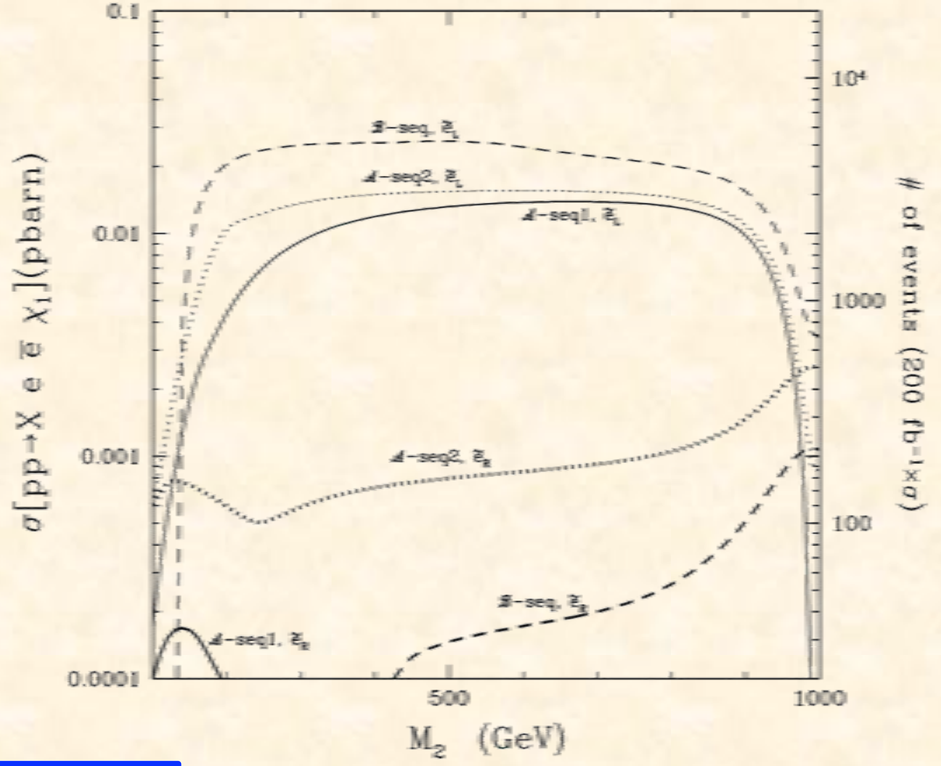
$$\tilde{q} \rightarrow q\chi_i \rightarrow q\tilde{f}f \rightarrow q\bar{f}f\chi_1$$

Sequential chain

$pp \to X\tau\bar{\tau}\chi_1$



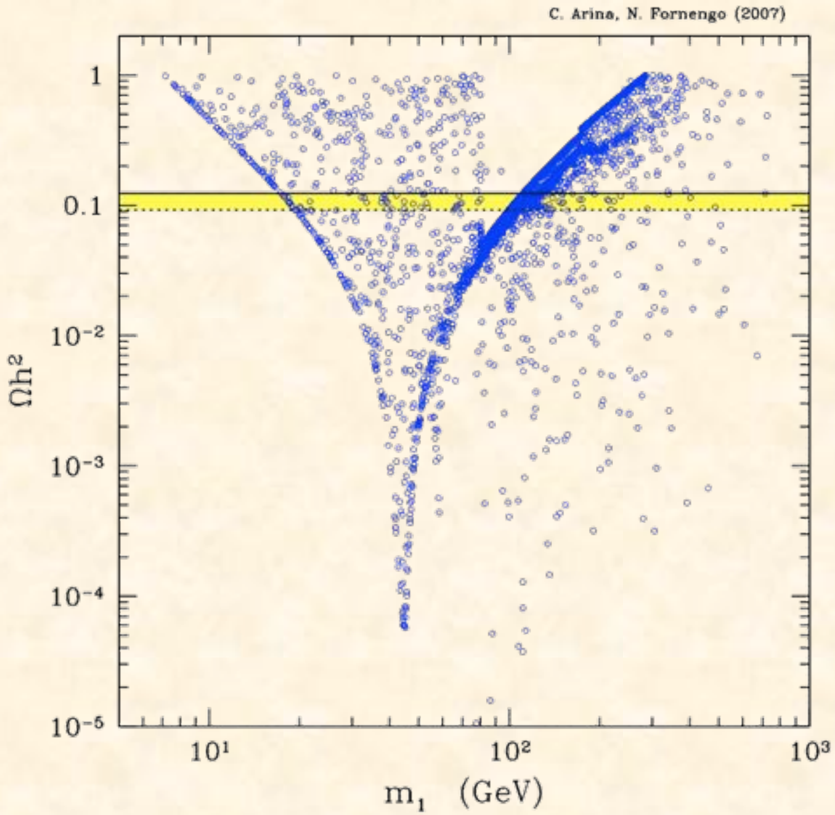
$pp \to Xe\bar{e}\chi_1$



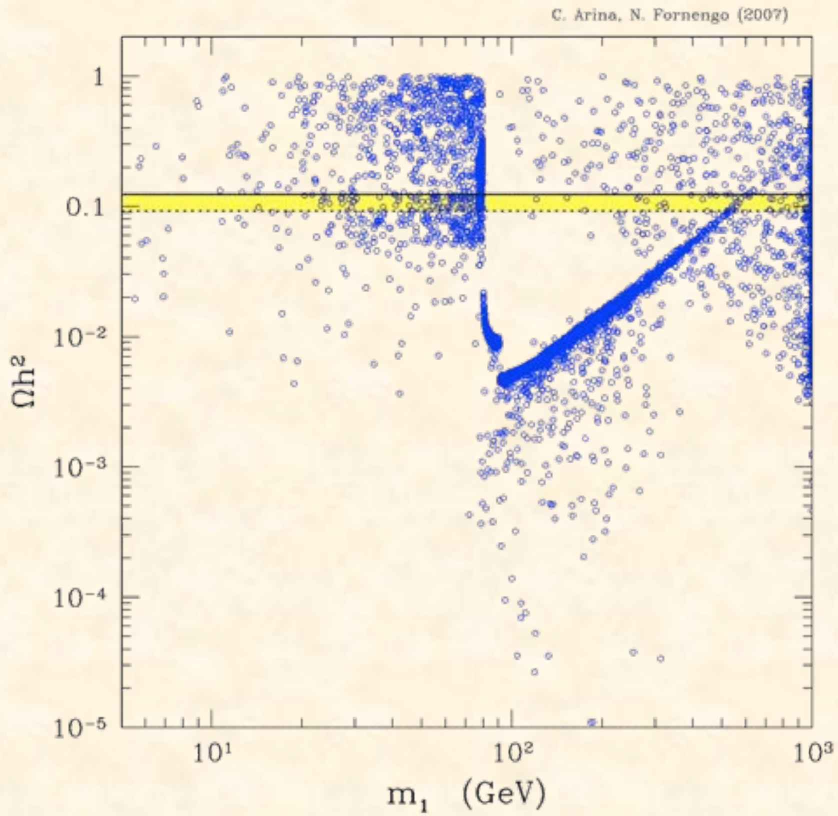
$\sqrt{s} = 14$ TeV

A. Bottino, N.Fornengo, G. Polesello, S. Scopel, PRD 77 (2008) 115026

Sneutrino relic abundance



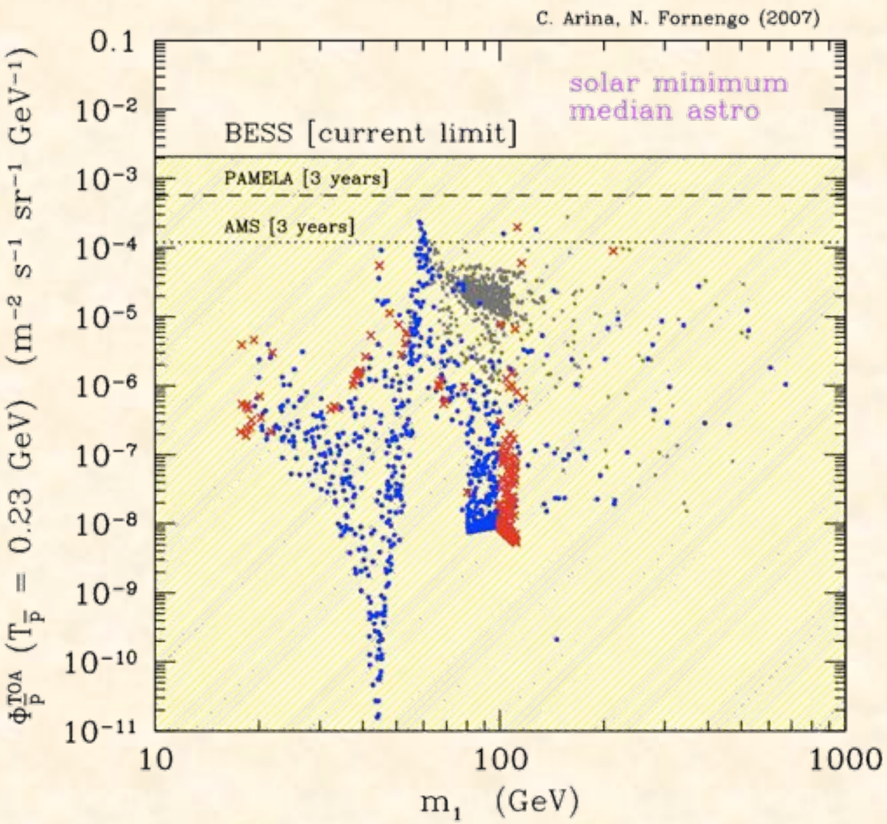
Left-right models



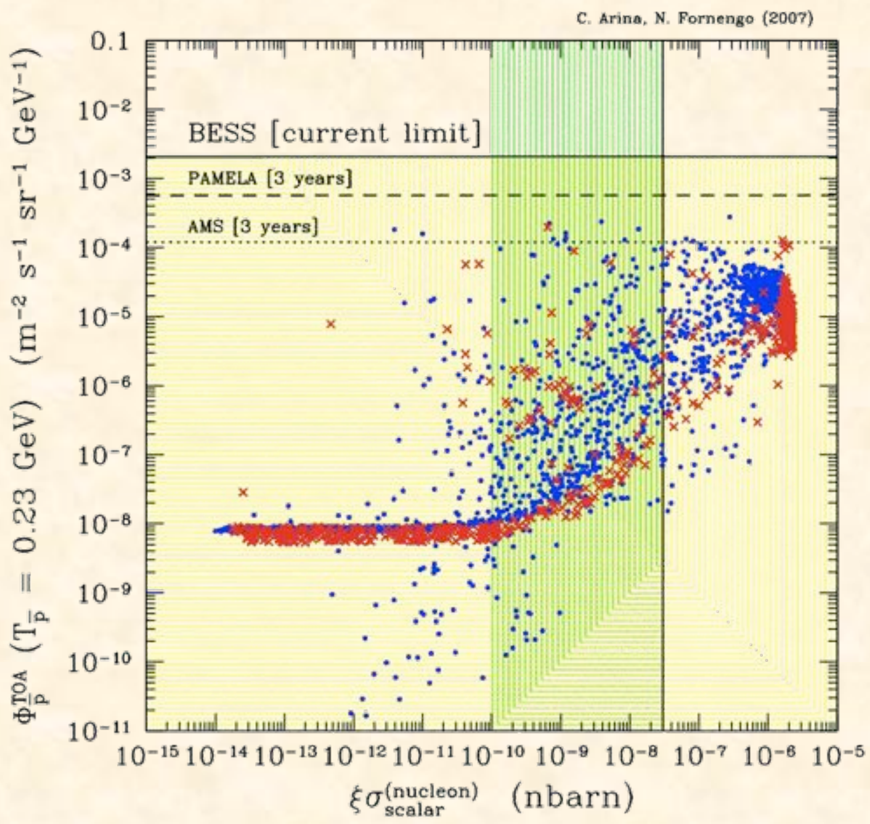
“Majorana” models

C. Arina, N. Fornengo, JHEP 0711 (2007) 029

Sneutrino Dark Matter in Left-Right models



antiprotons vs. mass



antiprotons vs. direct detection

Conclusions

- Astropysical searches may be proficiently be used to set constraints on the properties of particle DM
- If a signal is detected, it will guide us toward the properties of the DM candidate (and to some extent of the underlying NP model)
- The large number of current and foreseen data will allow a deep study of the particle DM hypothesis
- This requires good knowledge of the sources of backgrounds and of the astrophysical uncertainties (still large)

Conclusions

- Cosmological properties and astrophysical signals of particle DM candidates can either guide or complement accelerator physics searches
- Viceversa, accelerators, with their capability of identifying (at least part of the) BSM particles and their properties, will allow to shape out the predictions for DM signals
- The two approaches are therefore both fundamental in the study of the DM hypothesis
  - Accelerators: prove the existence of Physics BSM and directly discover the new physical states
  - DM searches: prove the new physical states explain the DM puzzle and explicitely dentify the DM presence in the astrophysical environment
- The interplay between the two approaches may also tell something on the cosmological evolution of the early Universe