Dark matter in split extended supersymmetry

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based on

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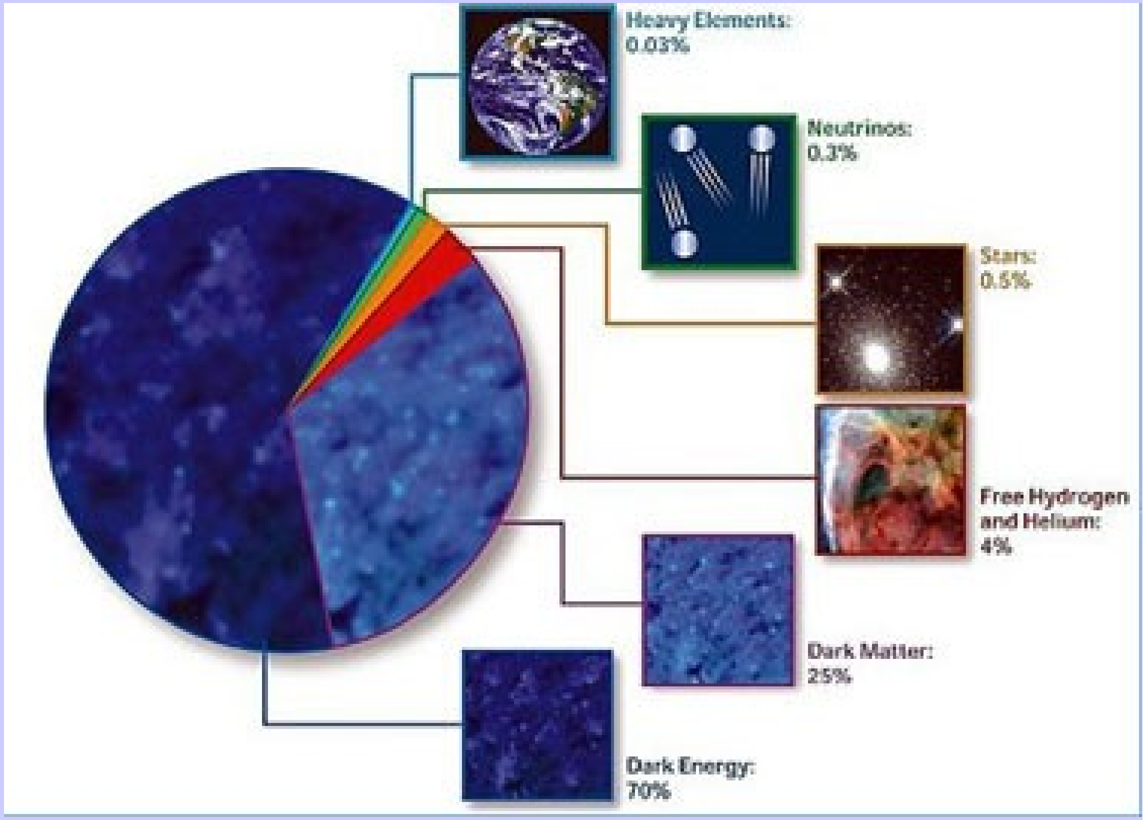
Dark matter: experimental clues

- Rotational curves of galaxies
- Velocity dispersion of galaxy in cluster (Historically the first Zwicky 1933)
- CMB data give the following values for the abundance of baryons and matter in the universe:



$$\Omega_{CDM} h^2 = 0.110 \pm 0.007$$
$$\Omega_b h^2 = 0.022 \pm 0.0006$$

with $\Omega_i \equiv \frac{\rho_i}{\rho_c}$ $\rho_c \equiv \frac{3H^2}{8\pi G_N}$ $h = H_0/100\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$

Relic density computation

We want to compute the relic density of the lightest SUSY particle (LSP) and compare it with $\Omega_{CDM} h^2$

Assuming :

1) Standard cosmology *i.e.* universe homogeneous and isotropic, no quintessence

2) All Dark Matter is made up by a single particle species

3) All Dark matter is thermally produced in the primordial plasma *i.e.* no late time entropy injection

We can solve the Boltzmann equation and compute the LSP relic density with public code on the "market" *e.g.* *DarkSusy*

Split Extended SUSY high energy setup

(Antoniadis et al. 2005)

- Intersecting branes
- Gauge bosons are in the N=2 SUSY representation
- Higgs sector is a N=2 hypermultiplet
- Matter fields are in a N=1 SUSY representation
- At one loop all the SUSY scalars and winos acquire soft masses
- Due to grand unification the scalar masses are order 10^{13} GeV (10^{9} GeV for Winos)

Split Extended SUSY low energy setup: Higgs sector

As in the MSSM the Higgs sector is made up by: a charged particle, two CP-even Higgs bosons and one CP odd Higgs boson

- The charged Higgs boson has mass: $m_{H^+}^2 = m_A^2 + 2m_W^2$,
- The CP-even states have masses : $m_H = m_A$, $m_h = m_Z$,
- Their mixing angle satisfies the sum rule: $\alpha = \beta - \pi/2$,
- The CP-odd Higgs boson has mass : m_A,

Split Extended SUSY low energy setup: charginos and neutralinos

- There is only the Higgsino like chargino with mass: $m_{\chi^+} = \mu.$
- The neutral extra fermions are the two Higgsino states and two Bino states,
- After the diagonalization of the neutralino mass matrix we learn:

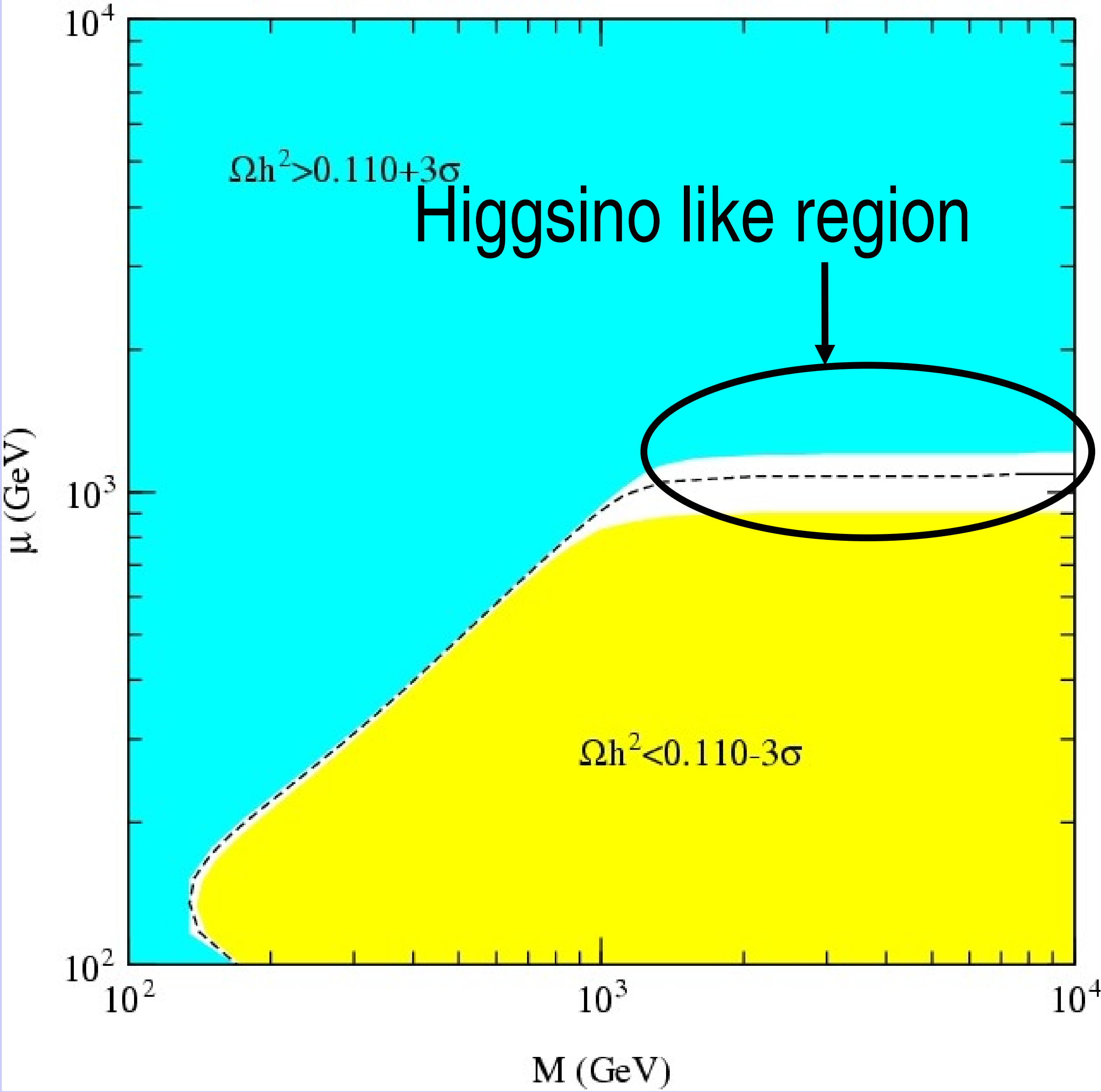
- The LSP is always the lightest neutralino,
- Neutralino masses are independent from tanβ,
- tanβ changes the relative weight of the two Bino states in the Lightest Neutralino composition,
- there is no coupling with the *Z* boson!

Split Extended SUSY low energy setup: summary of free parameters

- We are left with four free parameters: M, μ, m_A, $\tan\beta$.
- We will make the simplifying assumption $m_A \to \infty$
- In this limit the radiative corrections are the same for the split-susy scenario (Giudice and Romanino 2004). Since the scalar masses are $\sim\mathcal{O}(10^{13})$ GeV we expect to find m_h ~160 GeV
- In the end the free parameters are only 3!

Dark matter and Split Extended SUSY: relic abundance

- Neutralino thermal relic abundance is settled by annihilations in gauge bosons and coannihilation with Lightest Chargino



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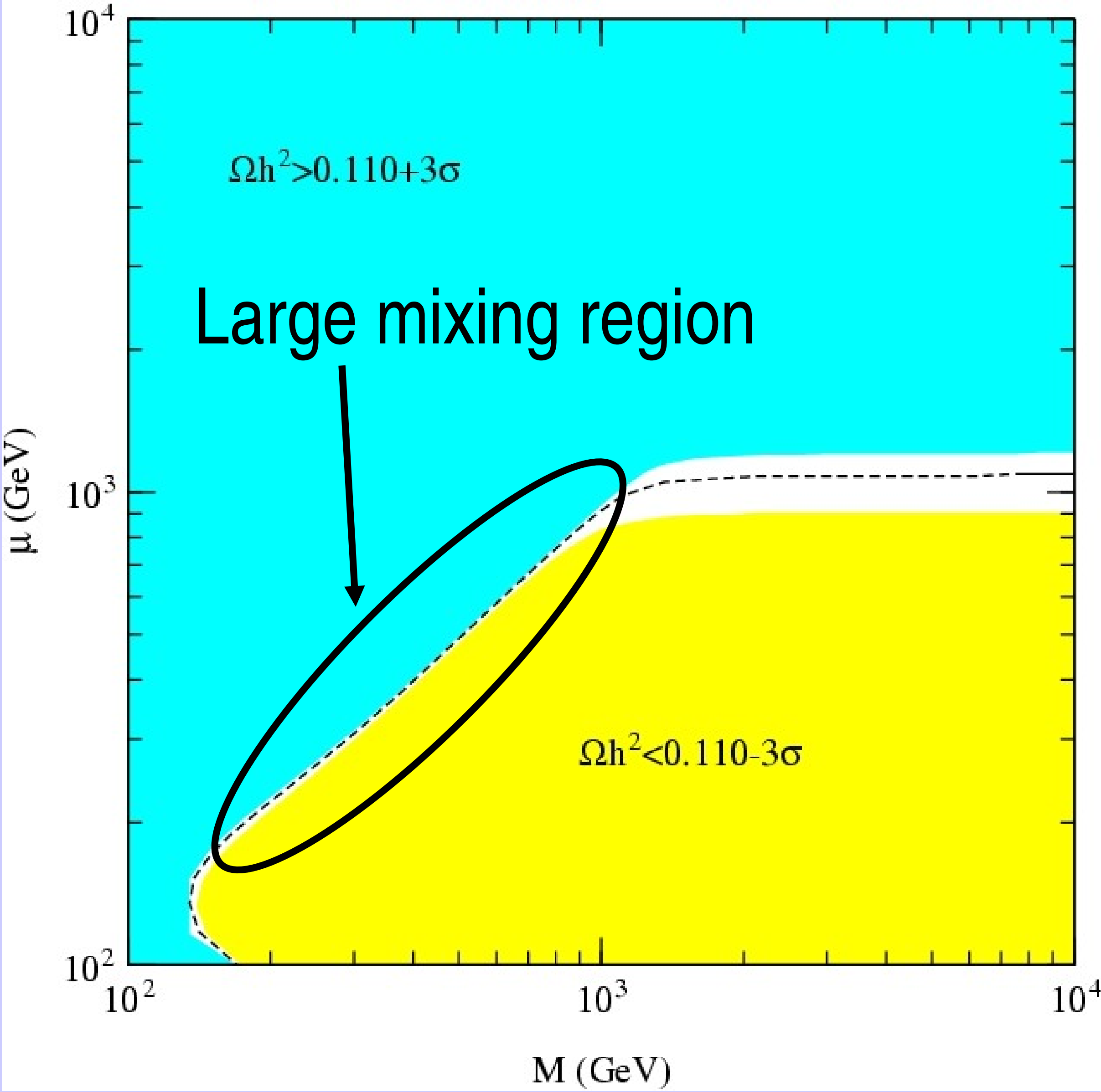
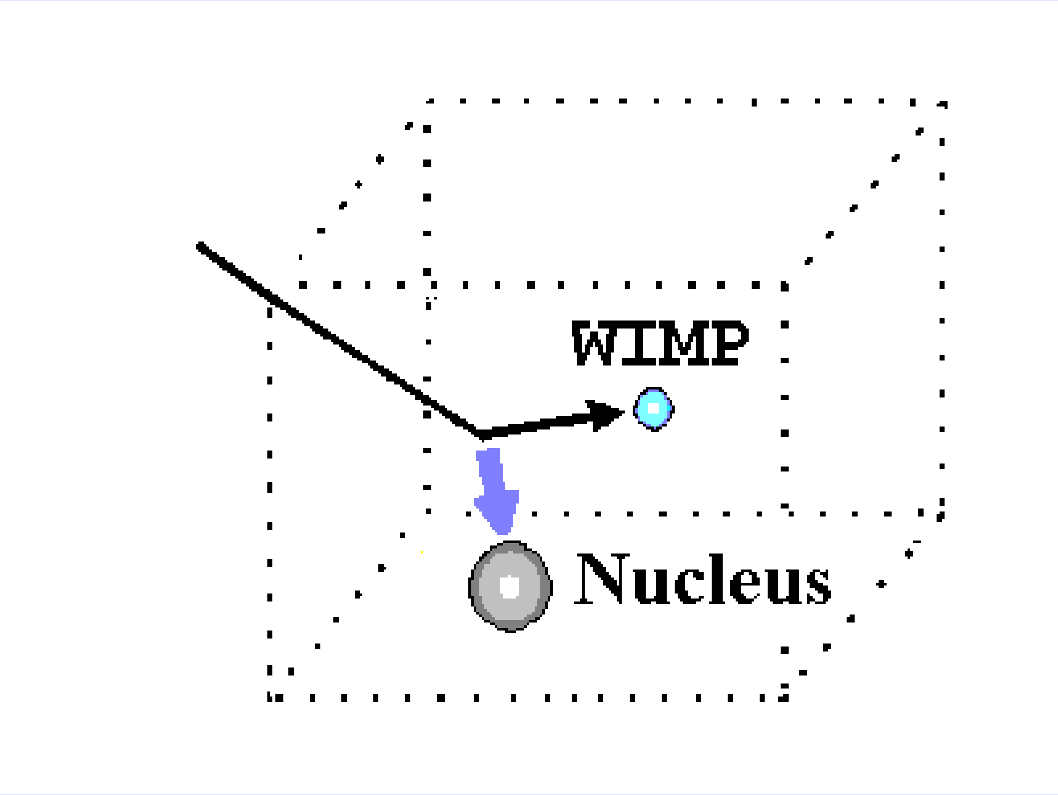


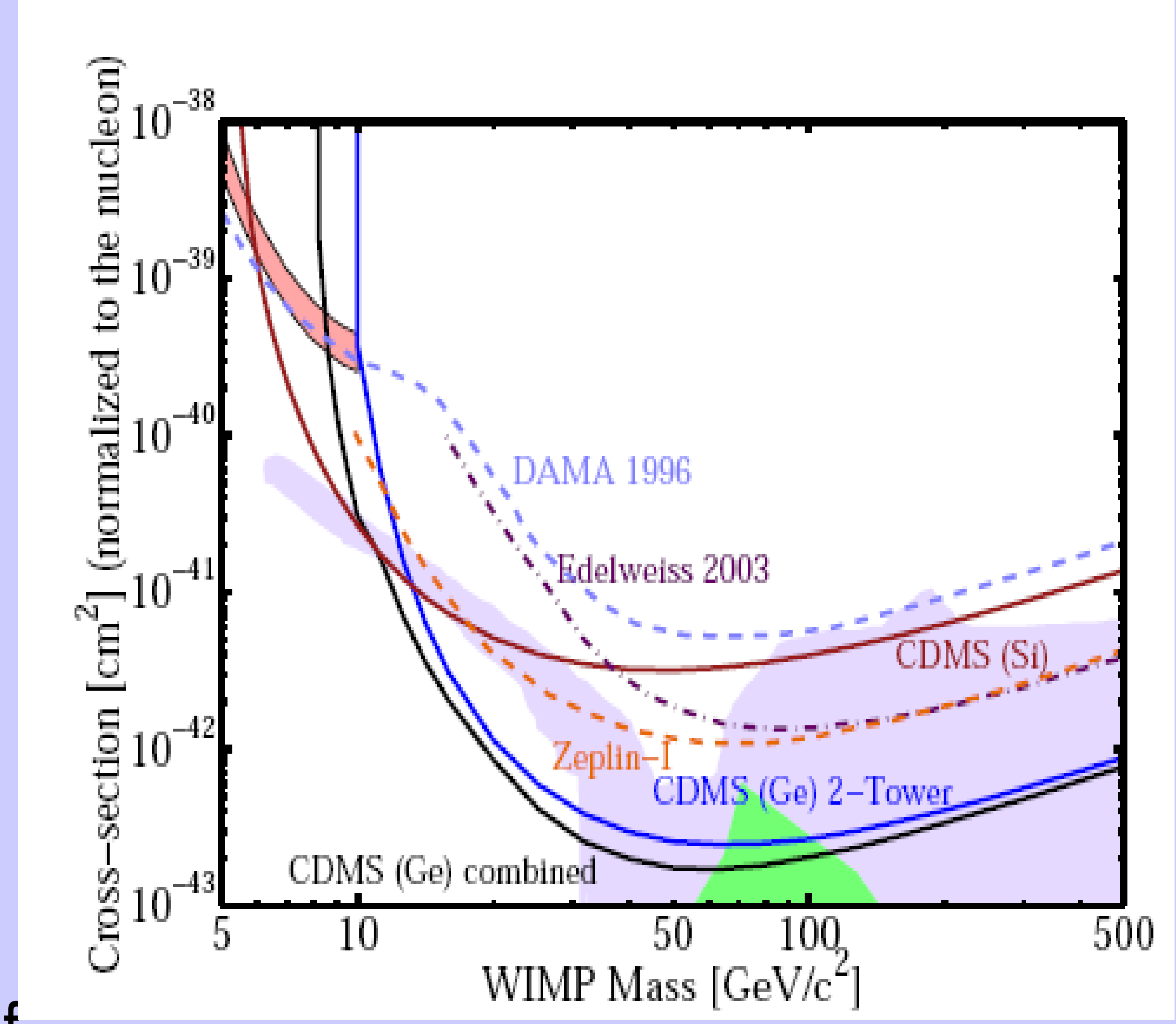
Dark matter: direct detection

- The goal is to measure the energy deposited in elastic scatterings on target nuclei by dark matter
- We have to distinguish between spin-independent coupling (mainly diagrams with Higgs bosons in t-channel) and spin-dependent coupling (mainly Z boson exchange in t-channel)



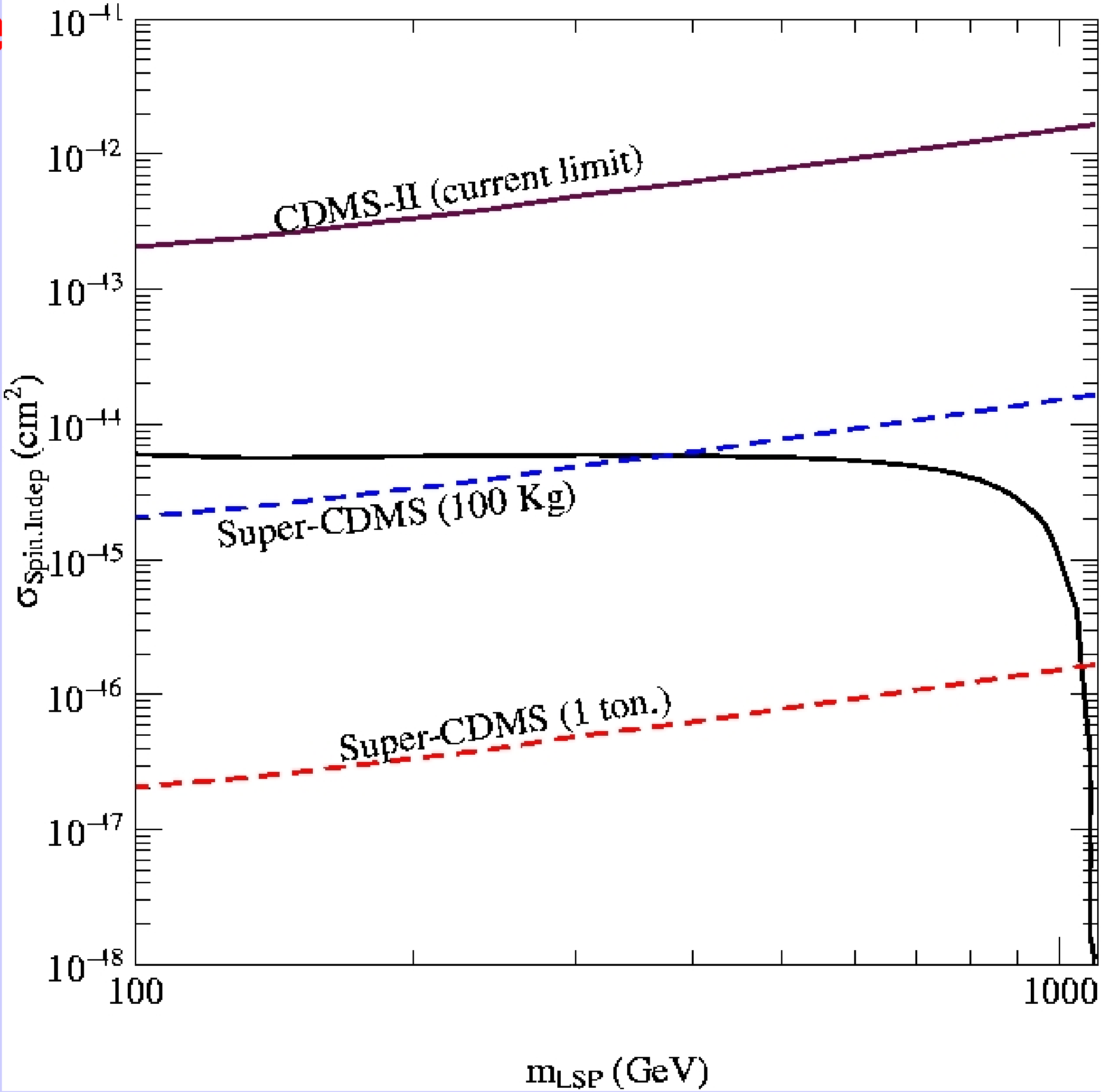
Dark matter: direct detection

- The spin-independent cross section is coherent: it then increases with the atomic number
- The spin-independent cross section dominates over the spin-dependent cross section in the current experiments
- Rates are proportional to the Detector Mass
- 1 ton. size detector will improve bounds by 3 order of magnitude

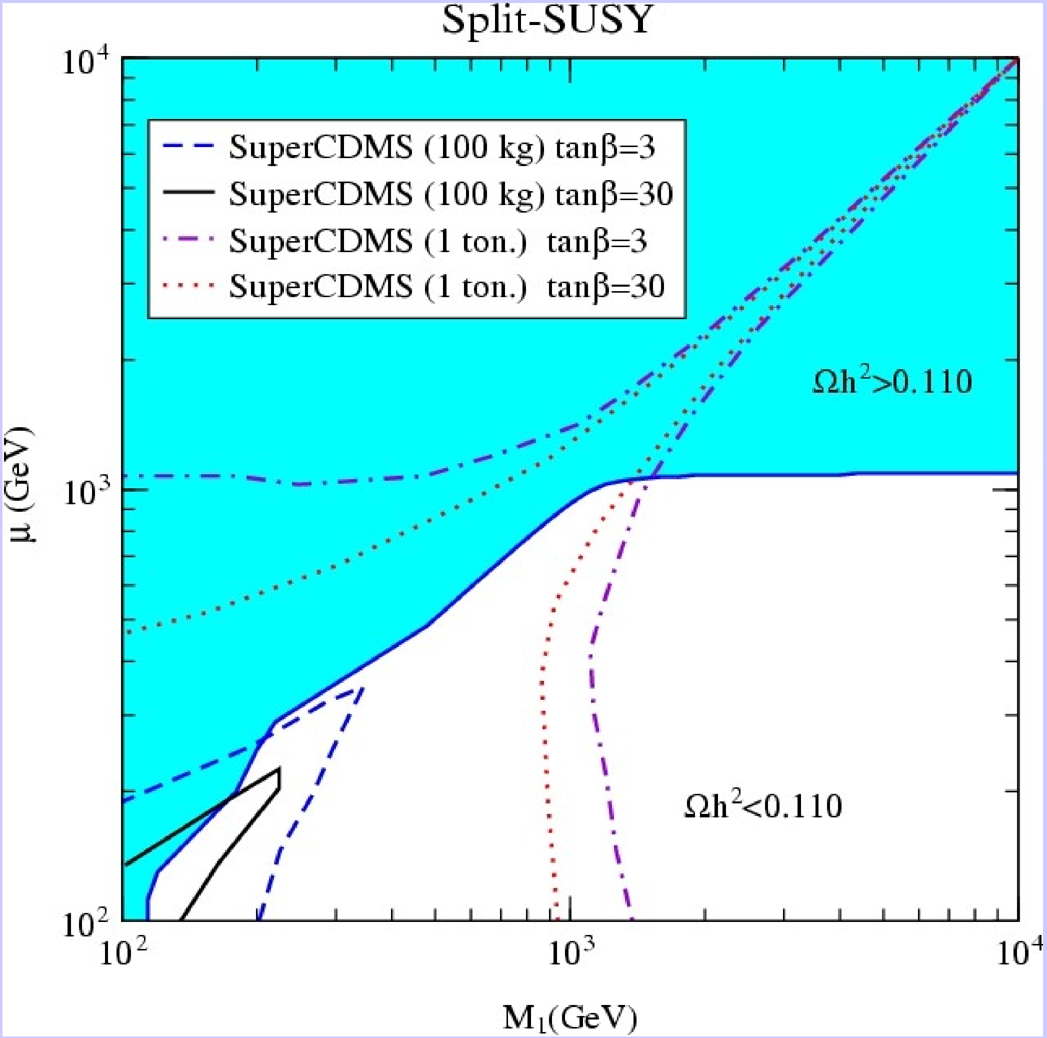


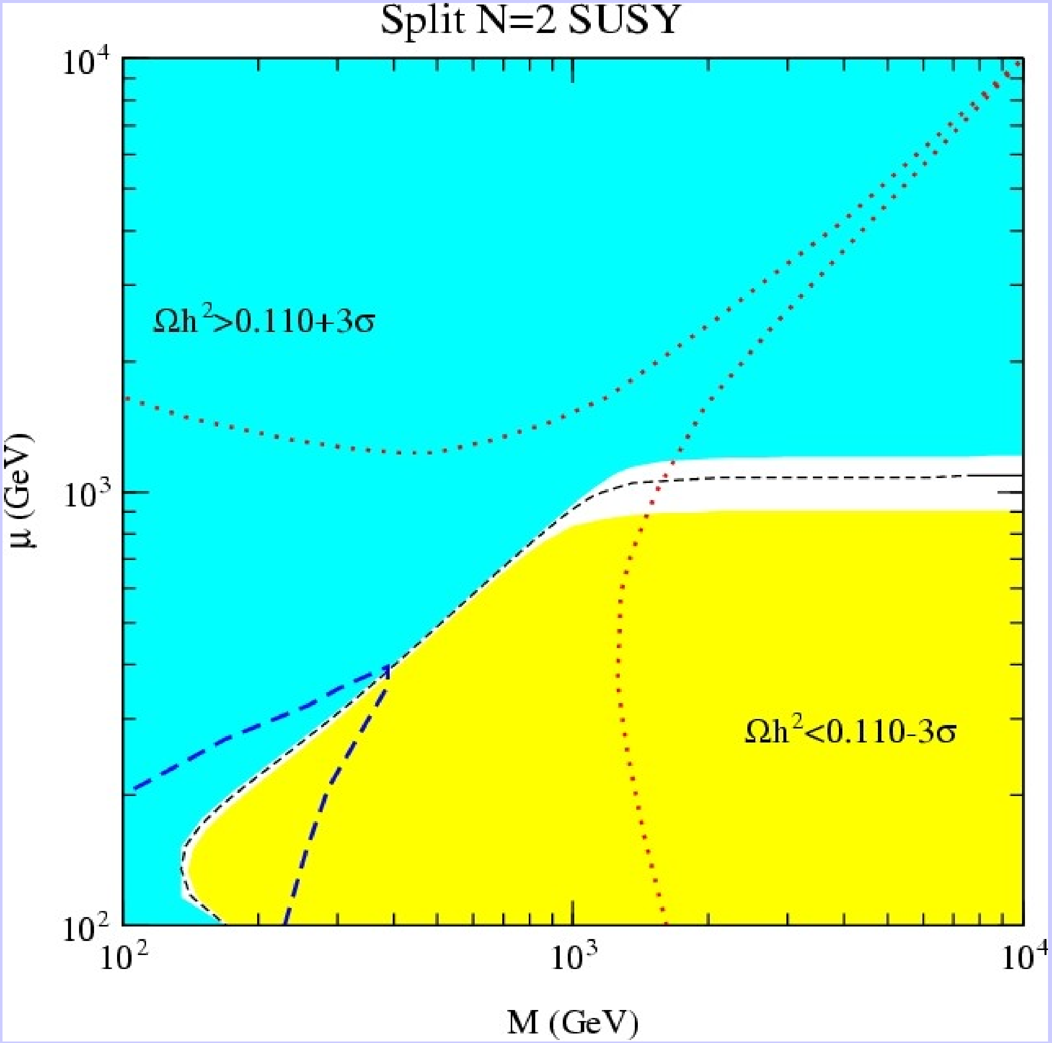
Dark matter and Split Extended SUSY: direct detection

- Direct detection will scan a large portion of the WMAP central value isolevel curve
- The spin-independent coupling is proportional to the Bino-Higgsino mixing; then it is small in the high mass region of the isolevel curve
- Since two binos are present the plot is *tanβ* independent



Dark matter and Split Extended SUSY: direct detection



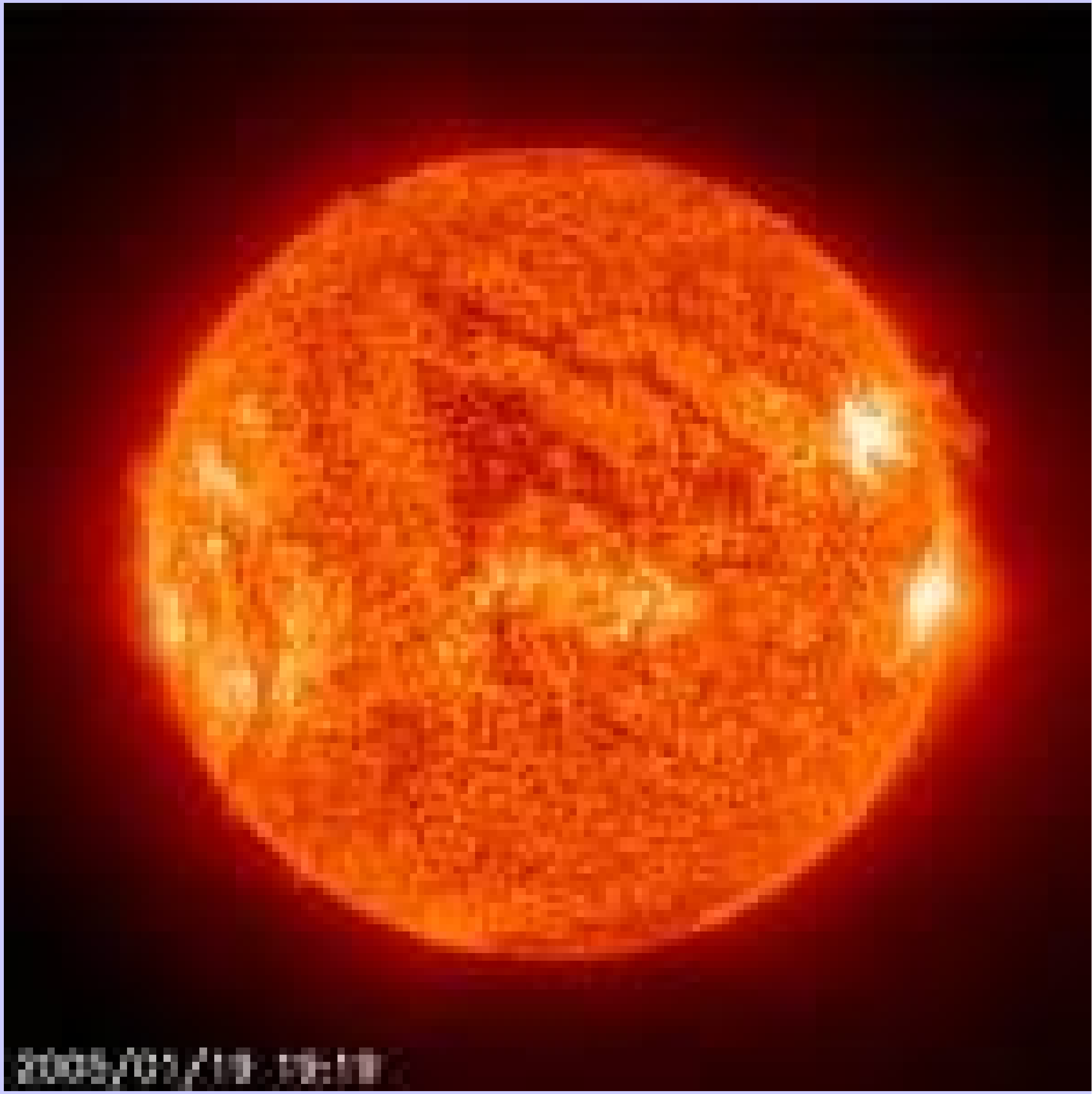


Dark Matter indirect searches

- The goal is to observe stable neutralino annihilation products *i.e.* neutrinos, positrons, antiprotons, antidiuterons and gamma rays.
- Where do we have to look?
- Neutral particles: we expect point like sources where the DM density increases *i.e.* Galactic center or other astrophysical objects
- Charged particles: more tricky; we have to take into account that they diffuse in the magnetic field present in the Galaxy

Dark Matter indirect searches: neutrinos

- The Sun is the best "astrophysical amplifier" for neutrinos flux
- Capture rate is driven by the spin-dependent cross section
- A neutrino flux is established when there is equilibrium between the annihilation rate and the capture rate
- In our model the neutrinos flux is negligible



Dark Matter indirect searches: gamma rays

- The best "astrophysical amplifier" for gamma rays produced in neutralinos annihilations is the Galactic center
- The gamma rays flux is given by:

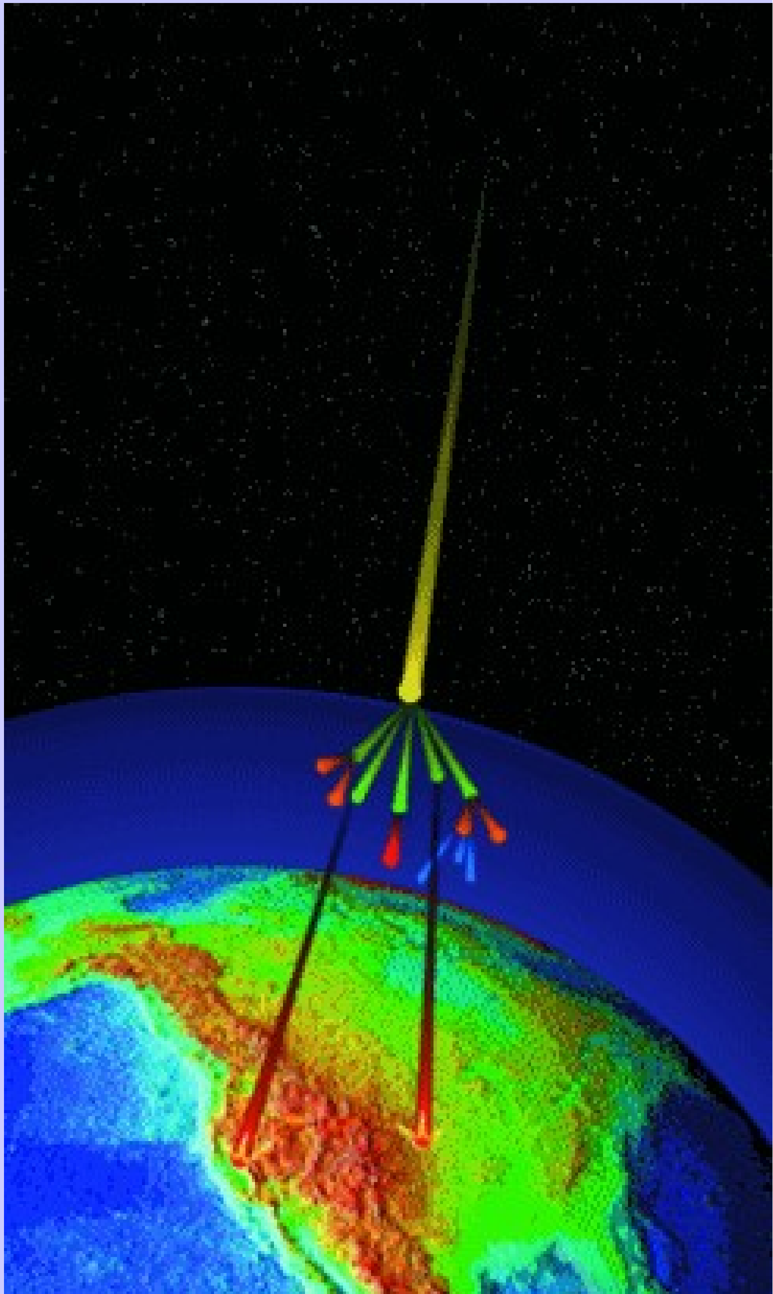
$$\phi^{E_\gamma} \equiv \frac{N_\gamma \langle \sigma v \rangle}{4\pi m_{\rm DM}^2} J_{\Delta\Omega}$$

where

$$J_{\Delta\Omega} \equiv \frac{1}{\Delta\Omega} \int_{\Delta\Omega} \int_{\rm l.o.s.} \rho_{\rm DM}^2 [r(s)] {\rm d}s$$

Dark matter indirect detection: antimatter background

- Interactions between cosmic rays and atmosphere leads to the formation of antimatter
- Positrons and antiprotons spectrum is known (HEAT '95, CAPRICE '98, BESS 2000) and in agreement with theoretical predictions (a part the so called HEAT excess)
- There is an upper limit on antidiuterons (BESS 2000)

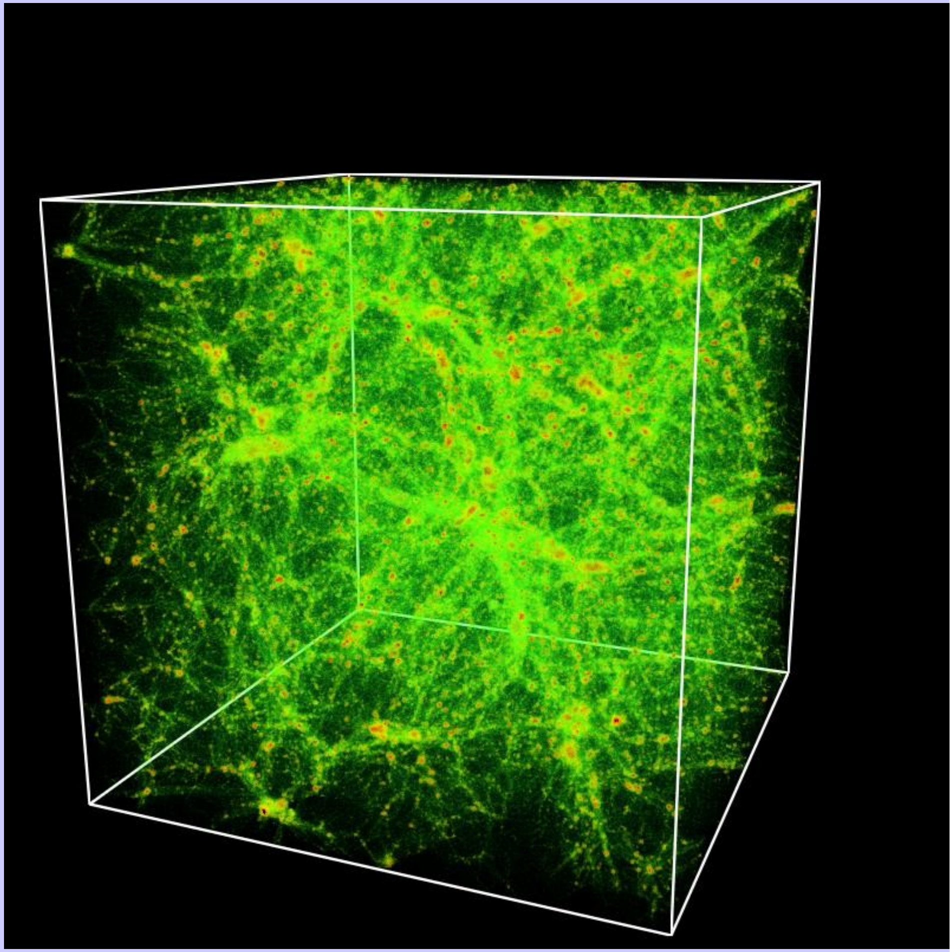


Dark matter indirect detection: how to build the signal

- The recipe to construct the antimatter fingerprint of a dark matter candidate is the following:

1) Compute the annihilation cross sections and the branching ratios for various channels
2) Run a montecarlo program (*e.g.* Phytia) to estimate the yield of stable antimatter species from the product at 1)
3) Give the local dark matter density
4) Model the propagation of such particles in the intergalactic magnetic field and against the solar wind in the solar system (*e.g.* using the GALPROP code)

Dark matter indirect search: halo choice

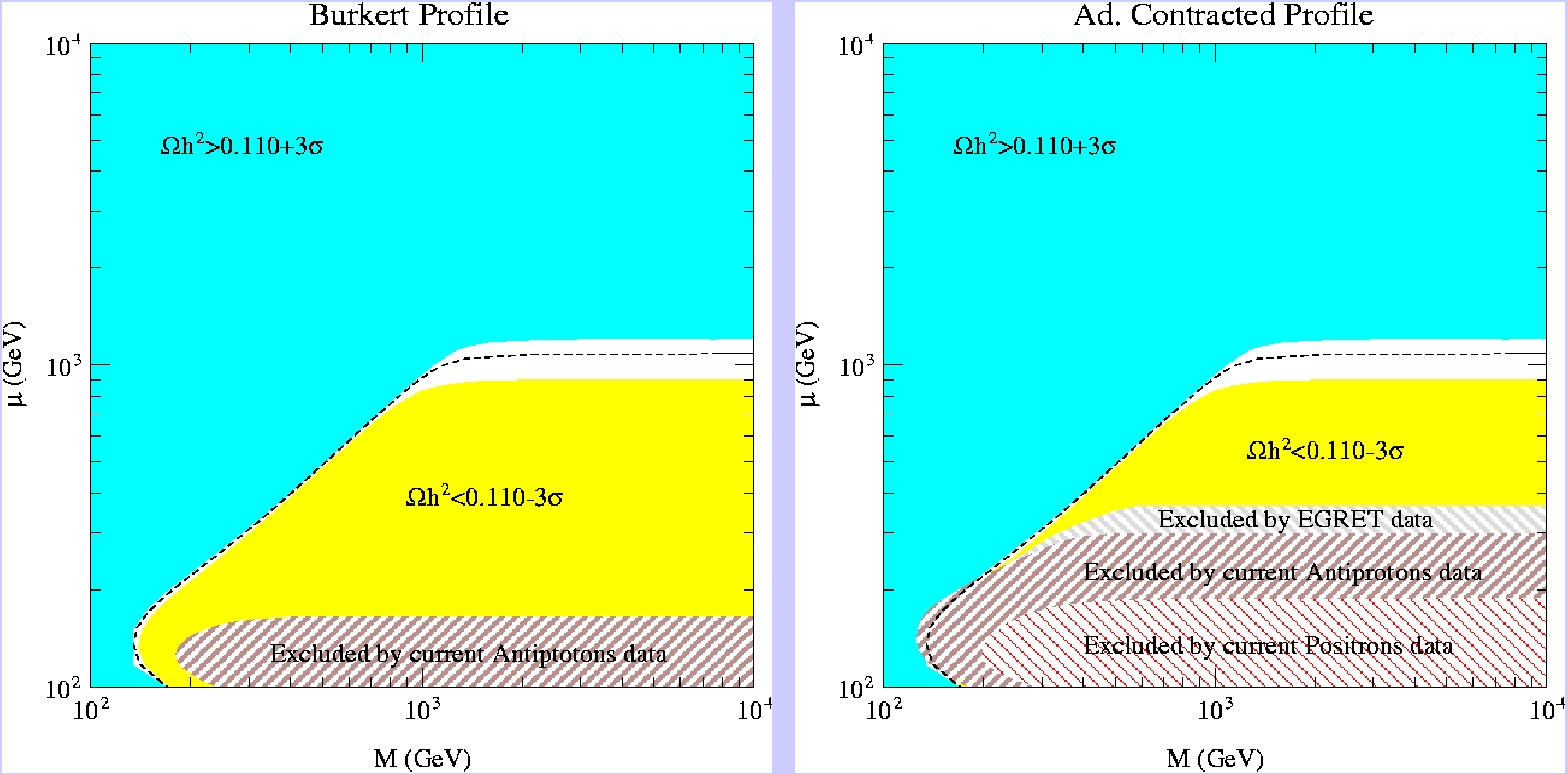


- To predict antimatter fluxes from annihilation in the Dark Matter Galactic halo we need the local CDM distribution.
- N-body simulation fitted with galaxy rotational curves
- Spherical distribution (no clumps)
- We will refer to:

  1) The "Burkert" halo profile (cored) obtained assuming a large angular momentum redistribution

  2) The "Adiabatically contracted" halo (cuspy) obtained assuming no angular momentum redistribution between its components

Dark matter indirect detection: current constraints



Dark matter indirect detection: positrons and antiprotons

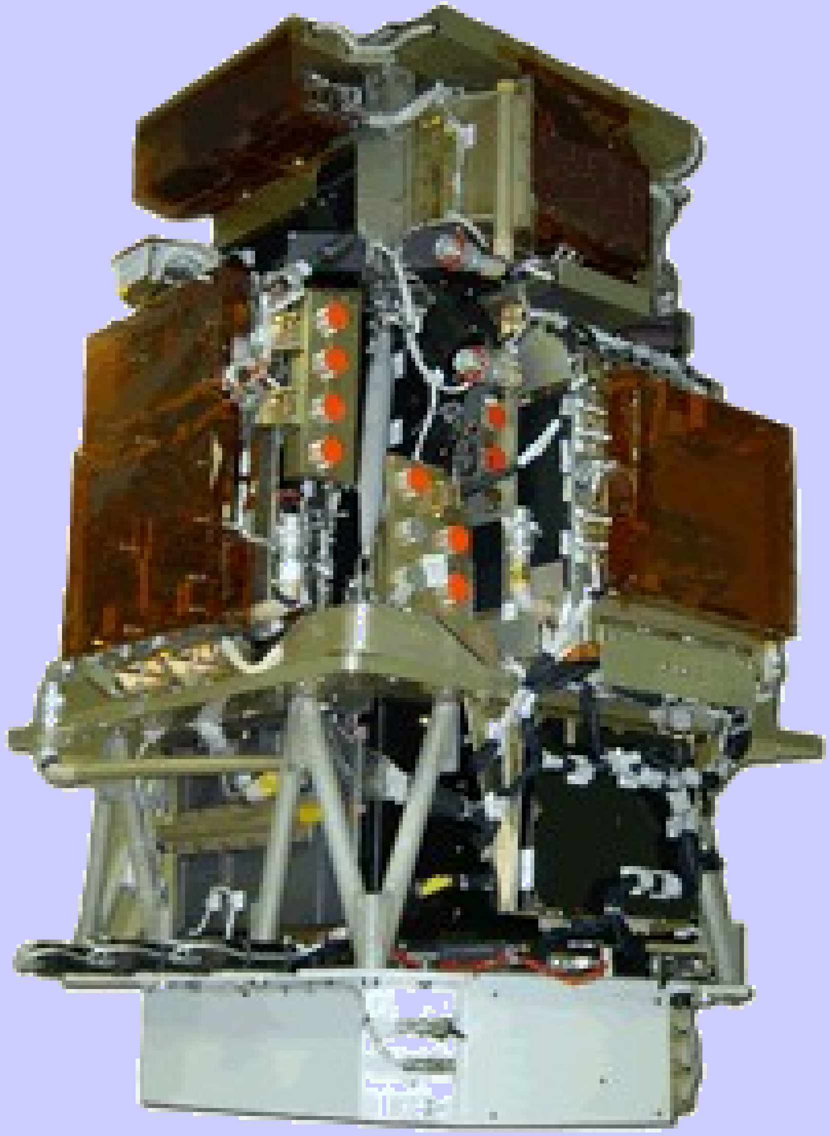
- PAMELA satellite launched on 15 July 2006 is now taking data
- The goal is to measure the positron spectrum in the range 50 Mev-270 GeV (present limit 400 Mev-30 GeV) and antiproton spectrum in the range 80 Mev-190 GeV (present limit 200 Mev-50 GeV)
- To understand the discovery potential of positron and antiproton flux measurements, an useful quantity is :

$$I_\Phi \equiv \int_{E_{min}}^{E_{max}} dE \, \frac{[\Phi_s(E)]^2}{\Phi_b(E)}$$

Dark matter indirect detection: antimatter

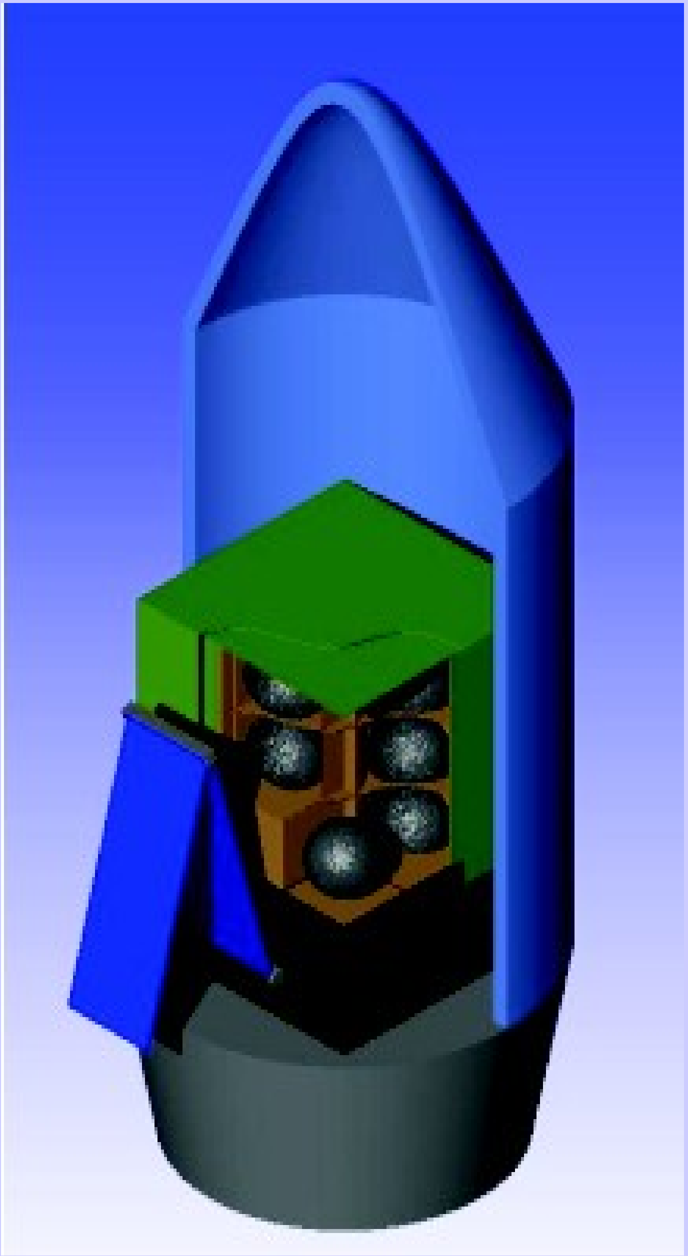
- PAMELA satellite launched on 15 July 2006 is now taking data
- The goal is to measure the positron spectrum in the range 50 Mev-270 GeV (present limit 400 Mev-30 GeV) and antiproton spectrum in the range 80 Mev-190 GeV (present limit 200 Mev-50 GeV)
- Regions are detectable where:

$$I_{\Phi} \geqslant 3.2 \times 10^{-8} cm^{-2}\, sr^{-1}\, s^{-1}$$



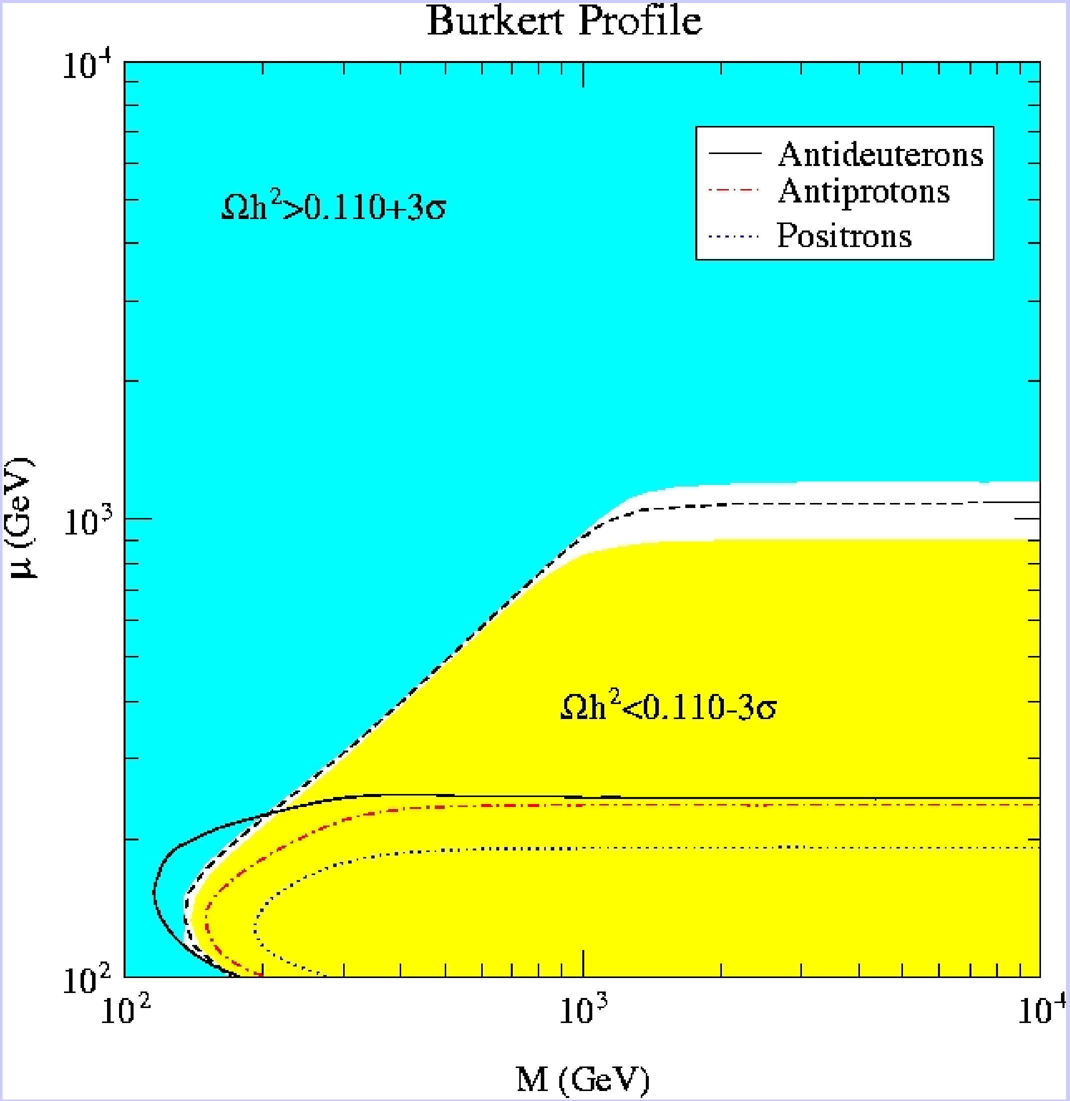
Dark Matter indirect detection: antidiuterons

- GAPS experiment   to launch on balloon from Australia in 2011
- Designed to search for antiduterons in with energy 0.1-0.4 GeV/nucleon n.b. the background is negligible
- To understand the discovery potential of the GAPS experiment we use the ratio expected flux vs. sensitivity



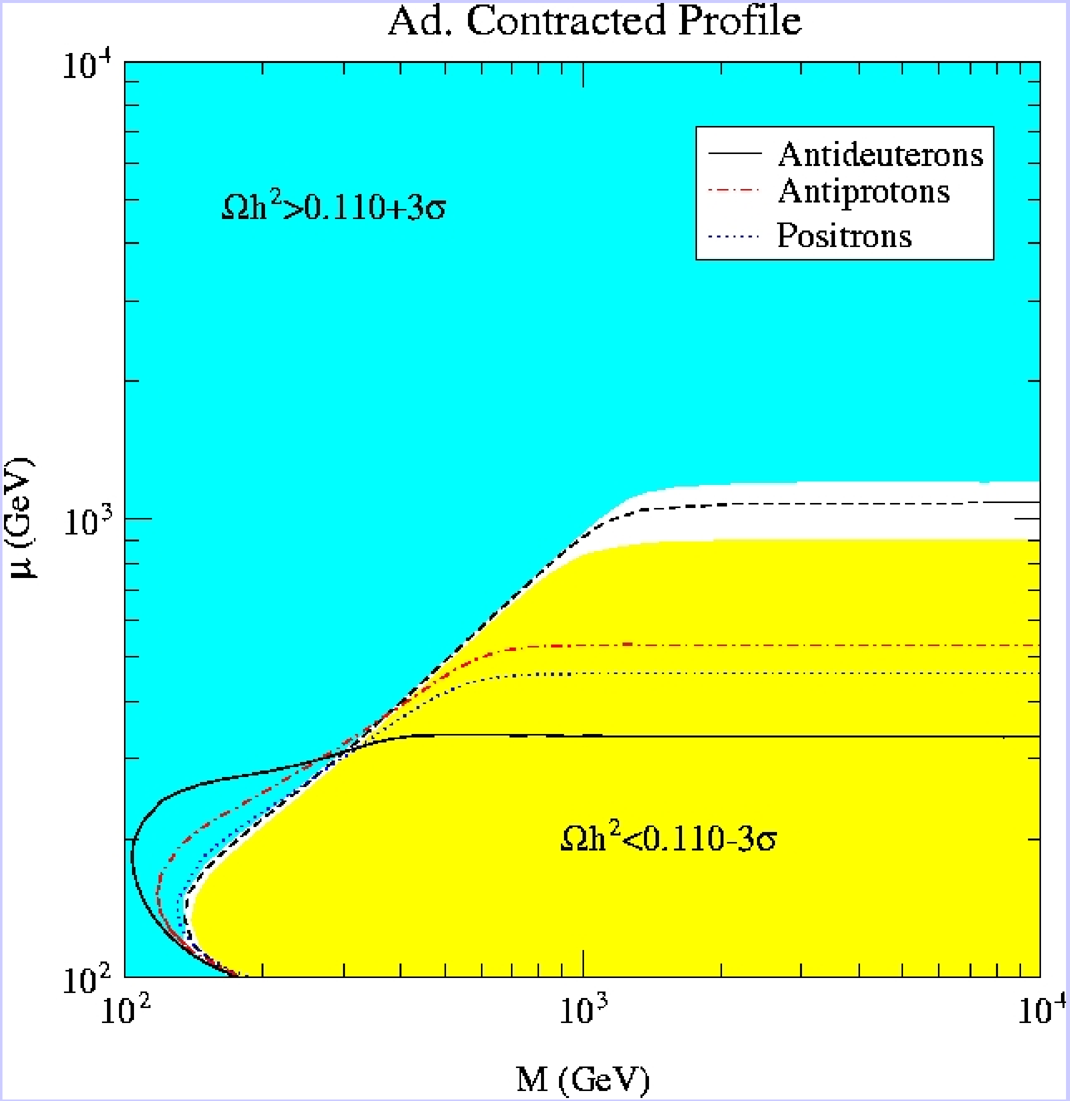
Dark matter and Split Extended SUSY: indirect detection

- We refer to the "pessimistic" choice of the Burkert profile
- Only a portion of the large mixing region can be scanned with these techniques



Dark matter and Split Extended SUSY: indirect detection

- We refer to the "optimistic" choice of the Adiabatically contracted halo profile
- A significant portion of the pure Higgsino region can be scanned



Conclusions

- We showed that astroparticle physics can put severe constraints on the parameter space of the split extended SUSY model
- We found some regions in the parameter space where the thermal relic abundance of the Lightest Neutralino is in the WMAP range
- Current antimatter and gamma rays data already exclude a portion of the parameter space
- Direct Detection is a very promising technique covering a significantly larger region than the standard case