Dark matter in split extended supersymmetry

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Plan:

- Some “trivia” about SUSY
- Split Extended-SUSY high energy setup
- Split Extended-SUSY “low” energy setup
- Dark matter and Split Extended SUSY
- Prospects for direct and indirect detection
- Conclusions

Some “trivia” about supersymmetry

- Historical motivation to introduce SUSY are:
  - Hierachy problem
  - Grand unification
  - Connection with string theory
- MSSM with R-parity provides a stable weakly interacting particle, a viable Dark Matter candidate
- New trend is to ignore the hierachy problem and “split” the SUSY spectrum (Harkani-Hamed and Dimopulos, Giudice and Romanino 2004)
- The Split-SUSY Dark Matter phenomenology well known (*e.g.* Masiero, Profumo and Ullio 2004)

Split Extended SUSY high energy setup

(Antoniadis et al. 2005)

- Intersencting 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 this scale is order 10^{13} GeV

Split Extended SUSY low energy setup: Higgs sector

- The lagrangian in terms of N=1 superfield reads:

$$\mathcal{L} = \mathcal{L}_{Kin.gaug} + \int d^4\theta (H_1^\dagger e^{-2gV} H_1 + H_2 e^{+2gV} H_2^\dagger) + \left(\int d^2\theta g\sqrt{2} H_2 \Phi H_1 + h.c.\right).$$

- After a straightforward computation the Higgs potential reads:

$$V = m_1^2|H_1|^2 + m_2^2|H_2| + m_3^2(H_2H_1 + h.c.) + \frac{g^2}{8}\left(H_1^\dagger\vec{\sigma}H_1 - H_2\vec{\sigma}H_2^\dagger\right)^2 + \frac{g'^2}{8}\left(|H_2|^2 - |H_1|^2\right)^2 + \frac{g'^2}{2}|H_2H_1|^2 + \frac{g^2}{2}|H_2\vec{\sigma}H_1|^2.$$

Split Extended SUSY low energy setup: Higgs sector

After the minimization mass eigenstates are:

- The unphysical would-be goldstone bosons

$$
\begin{aligned}
G^0 &= -\cos\beta\, Im[H_1^0] + \sin\beta\, Im[H_2^0] \\
G^+ &= -\cos\beta (H_1^-)^* + \sin\beta (H_2^+)
\end{aligned}
$$

- The CP-odd Higgs boson:

$$A^0 = \sin\beta\, Im[H_1^0] + \cos\beta\, Im[H_2^0]$$

with mass m_A

Split Extended SUSY low energy setup: Higgs sector

- The CP-even Higgs bosons:

$$\begin{aligned} H_2 &= \cos\beta\, Re[H_1^0 - v_1] + \sin\beta\, Re[H_2^0 - v_2] \\ H_1 &= \sin\beta\, Re[H_1^0 - v_1] - \cos\beta\, Re[H_2^0 - v_2] \end{aligned}$$

with mass:

$$\begin{aligned} m_{H_2} &= m_Z \\ m_{H_1} &= m_A \end{aligned}$$

- The charged Higgs boson:

$$H^+ = \sin\beta (H_1^-)^* + \cos\beta (H_2^+)$$

with mass: $m_{H^+}^2 = m_A^2 + m_W^2(2 - \tan^2\theta_W)$

Split Extended SUSY low energy setup: charginos and neutralinos

- There is only a chargino *i.e.* the Higgsino like one
- m_{LC}~μ
- The neutral extra fermions are the two Higgsino states and two bino states
- Neutralino mass matrix is:

$$\mathcal{M}_{\tilde{\chi}^0} = \begin{pmatrix} M & 0 & -m_Z s_W c_\beta & m_Z s_W s_\beta \\ 0 & M & m_Z s_W s_\beta & m_Z s_W c_\beta \\ -m_Z s_W c_\beta & m_Z s_W s_\beta & 0 & -\mu \\ m_Z s_W s_\beta & m_Z s_W c_\beta & -\mu & 0 \end{pmatrix}$$

Split Extended SUSY low energy setup: charginos and neutralinos

- There is only a chargino *i.e.* the Higgsino like one
- $m_{LC} \sim \mu$
- The neutral extra fermions are the two Higgsino states and two bino states

- Neutralino masses are in the form:

$$m_{\chi_i} = \frac{1}{2}\left[(M + \epsilon_1 \mu) - \epsilon_2 \sqrt{(M - \epsilon_1 \mu)^2 + 4 m_Z^2 \sin^2\theta_W}\right]$$

Neutralino masses are independent from tanβ!

Split Extended SUSY low energy setup: charginos and neutralinos

- There is only a chargino *i.e.* the Higgsino like one
- $m_{LC} \sim \mu$
- The neutral extra fermions are the two Higgsino states and two bino states

- Lightest Neutralino eigenstate has the form:

$$N_{1,i} \alpha \left(-\frac{2 m_Z \sin\theta_W (c\beta + s\beta)}{M - \mu + \sqrt{(M-\mu)^2 + 4 m_Z^2 \sin^2\theta_W}}, \frac{2 m_Z \sin\theta_W (s\beta - c\beta)}{M - \mu + \sqrt{(M-\mu)^2 + 4 m_Z^2 \sin^2\theta_W}}, -1, 1 \right)$$

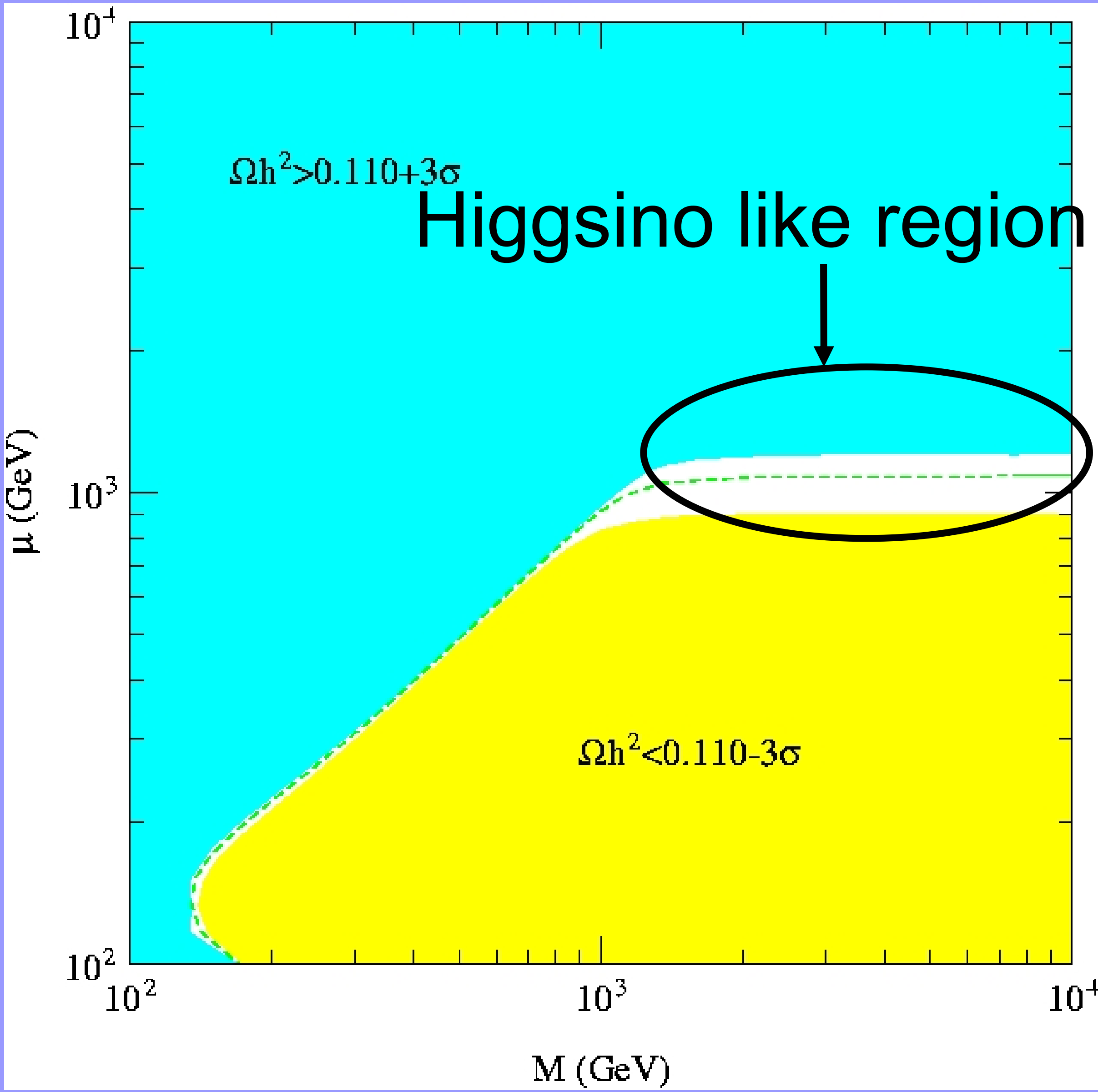
This means no coupling with the Z boson!

Split Extended SUSY low energy setup: summary of free parameters

- We are left with four free parameter: *M*, μ, m_A, *tan*β.
- We will make the simplifying assumption m_A ->◎
- In this limit the radiative corrections are the same for the split-susy scenario (Giudice and Romanino 2004). Having the GUT constraint set the scalar masses to be ~O(10^{13}) GeV we expect to find m_{H_2} ~170 GeV
- In the end the free parameter 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



Dark matter and Split Extended SUSY: relic abundance

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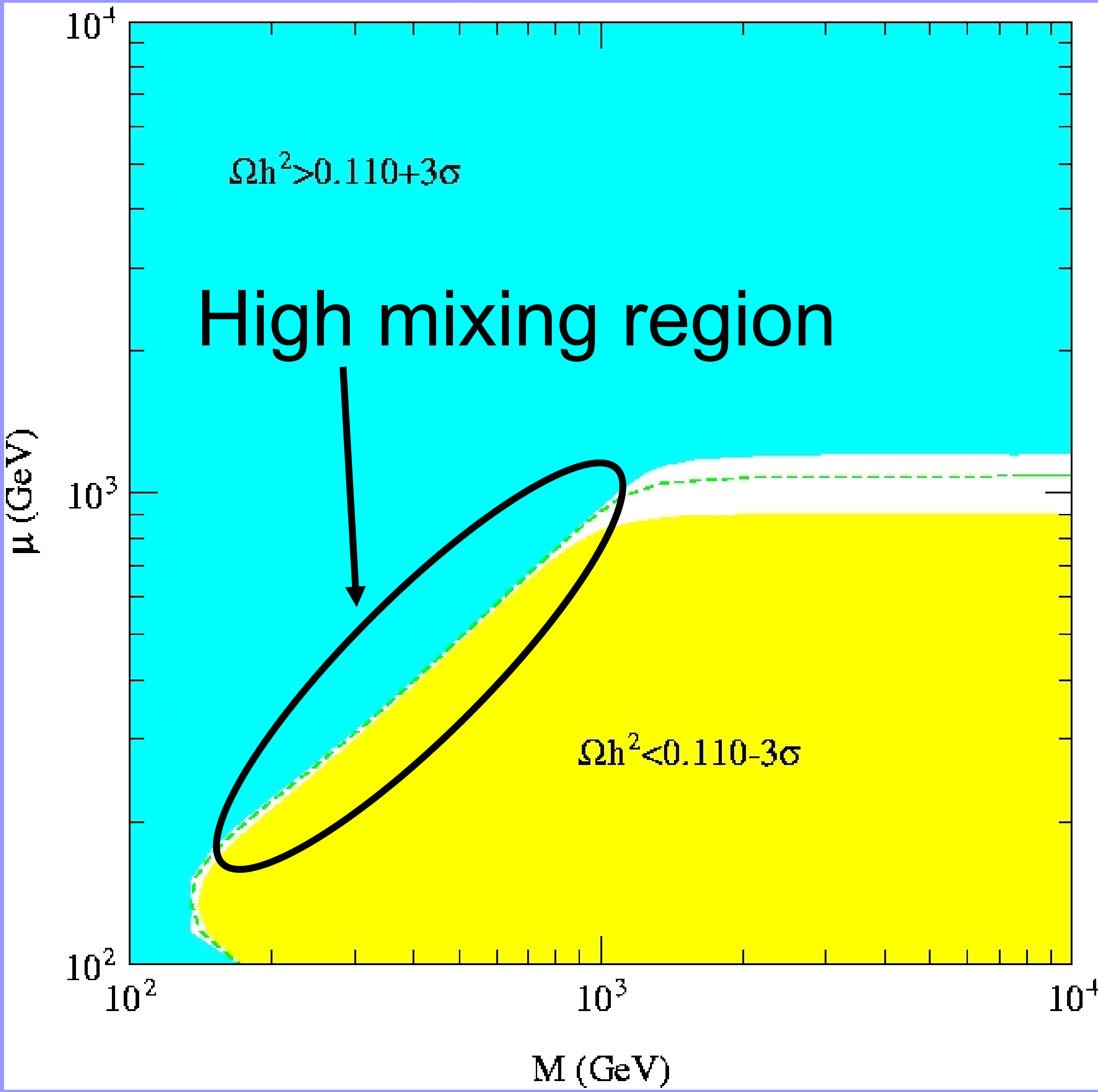


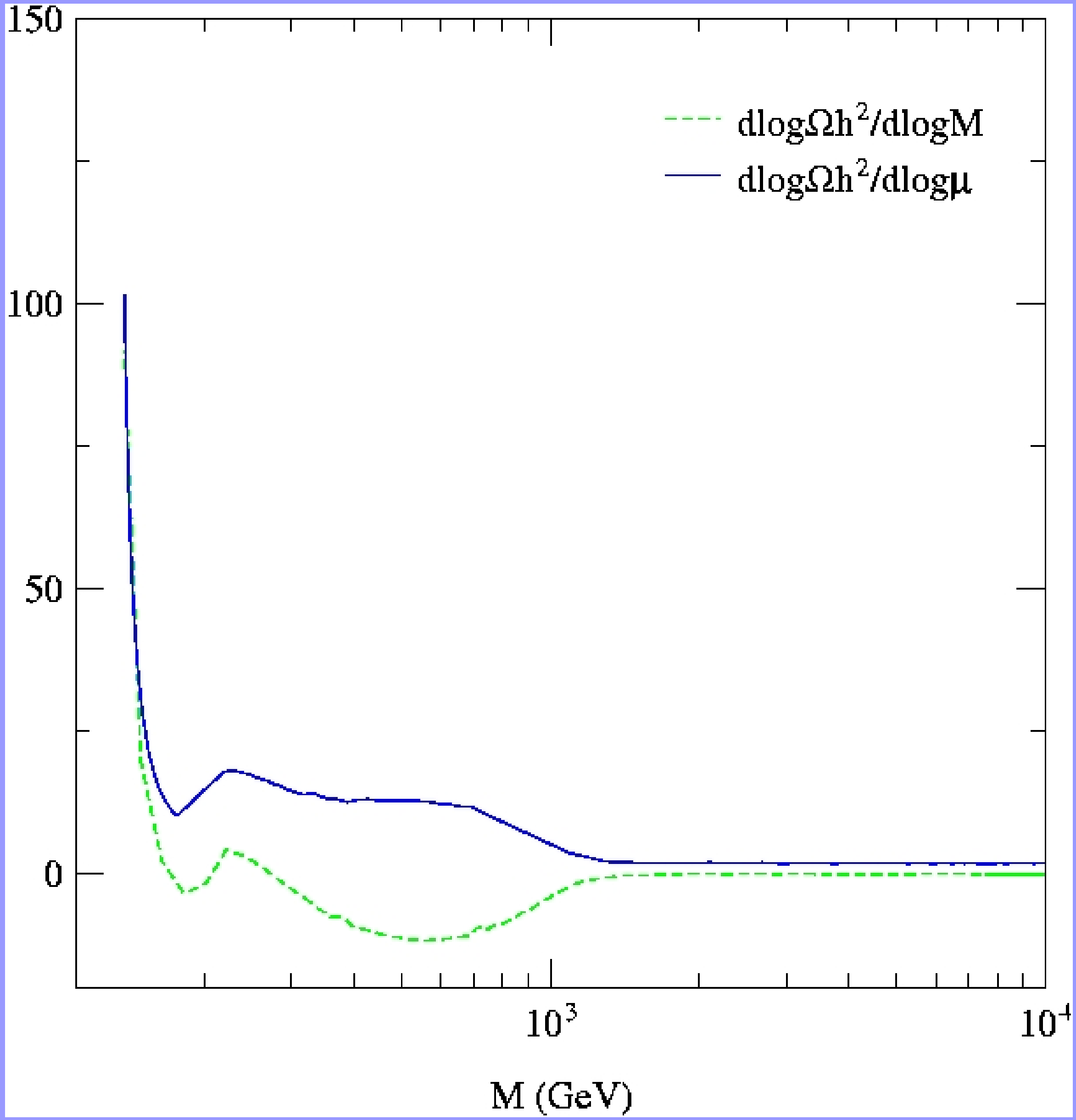
Dark matter and Split Extended SUSY: relic abundance

- We introduce the finetuning indices:

$$\frac{d\log\Omega h^2}{d\log\mu},$$

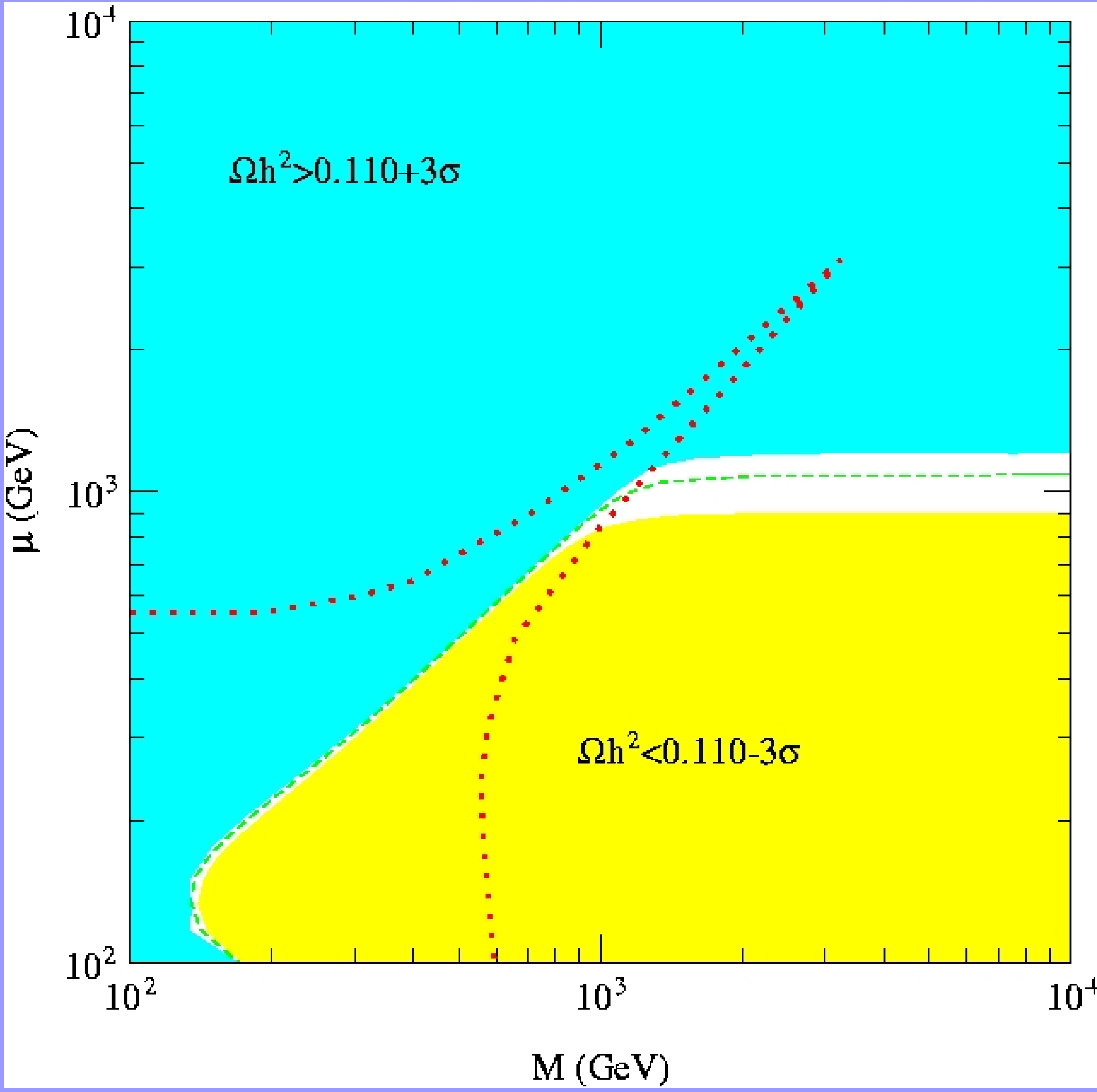
$$\frac{d\log\Omega h^2}{d\log M}$$

- We have a huge finetuning in the High-Mixing region

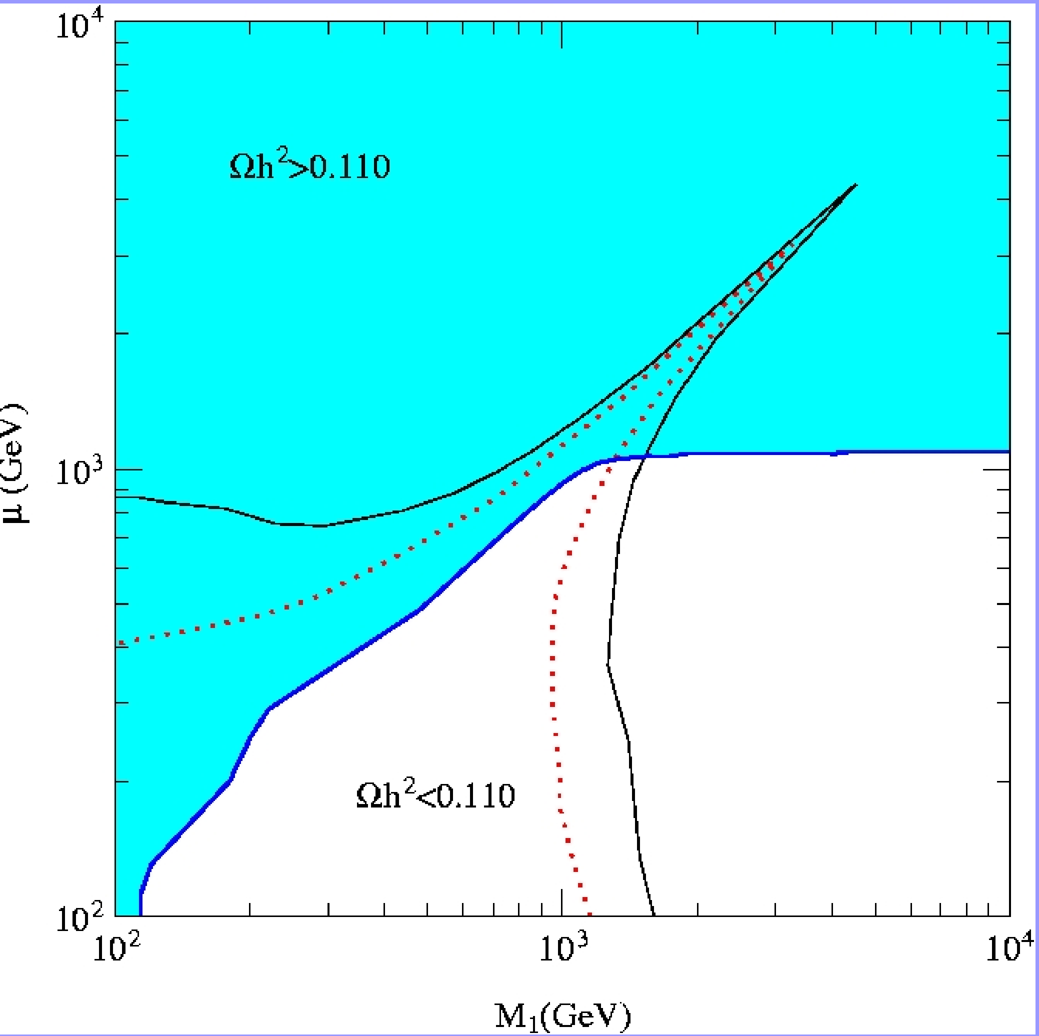


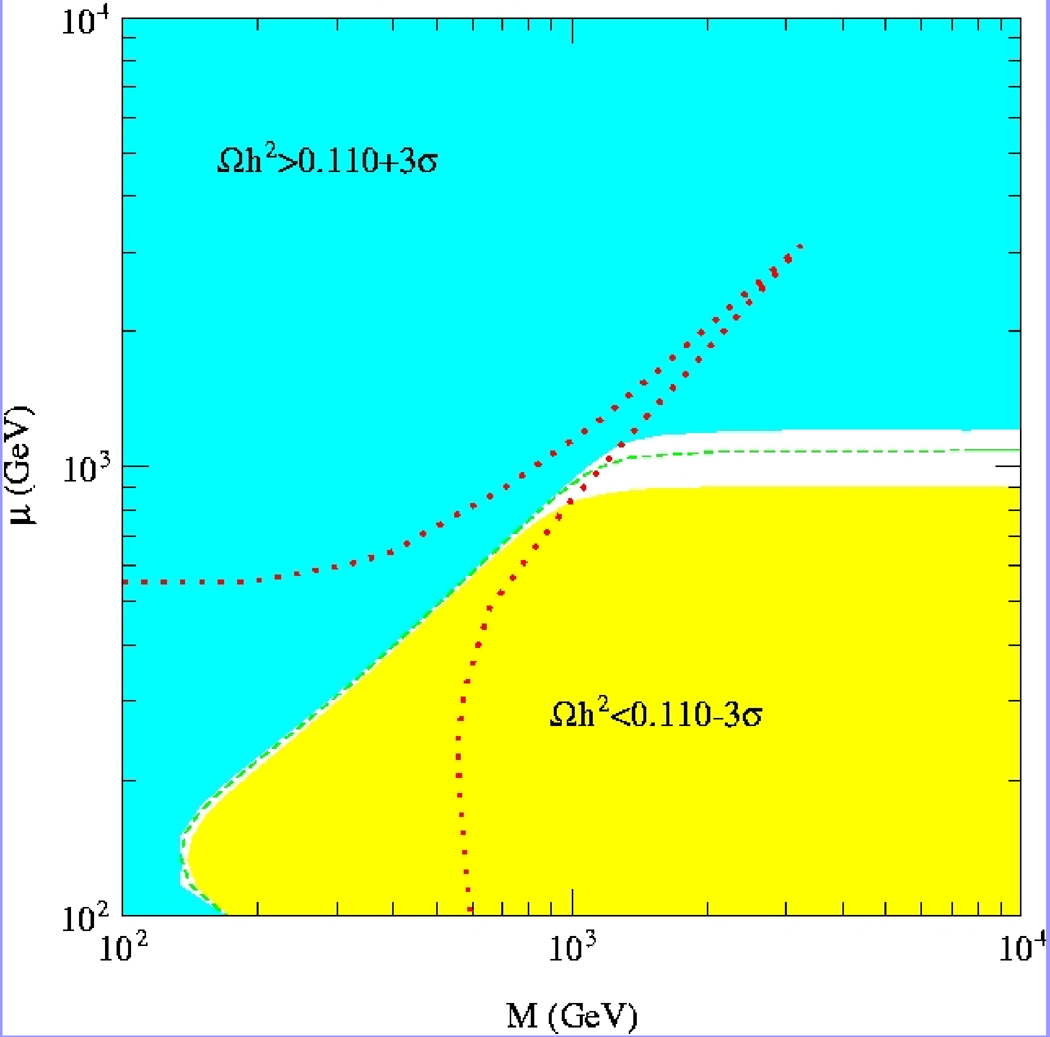
Dark matter and Split Extended SUSY: direct detection

- The goal is to to measure the energy deposited in elastic scatterings on target nuclei by dark matter
- Only the diagram with Higgs boson exchange is present then we can scan only the high mixing region
- Since two binos are present the plot is *tanβ* independent



Dark matter and Split Extended SUSY: direct detection





Dark matter and Split Extended SUSY: indirect detection

- The goal is observe neutralino annihilation product

- To predict antimatter fluxes from annihilation in the Dark Matter Galactic halo we need the local CDM distribution.
We will refer to a "Burkert" halo profile (cored)

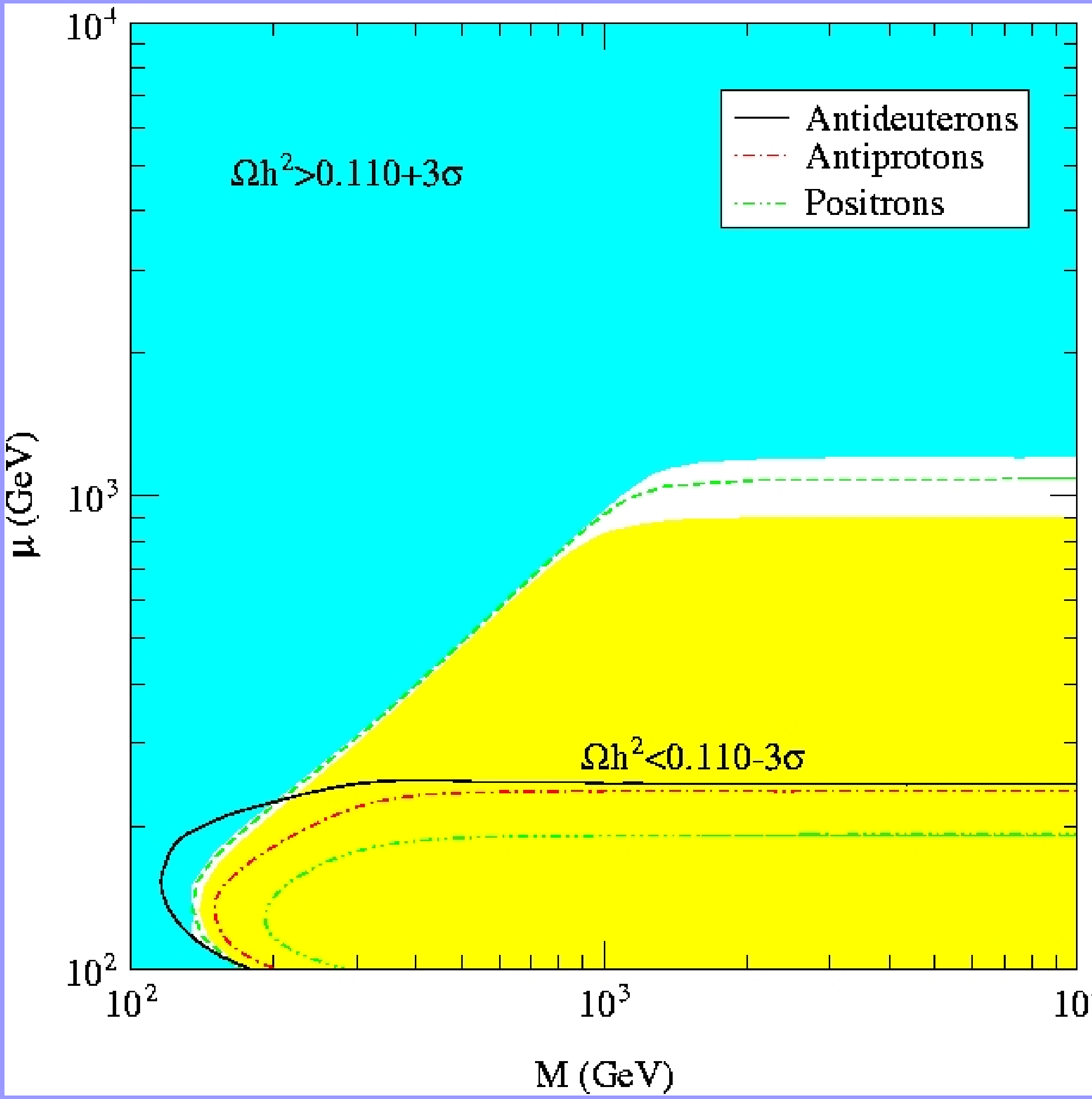
- To understand the discovery potential of positron and antiproton flux measurements, an useful quantity is :

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

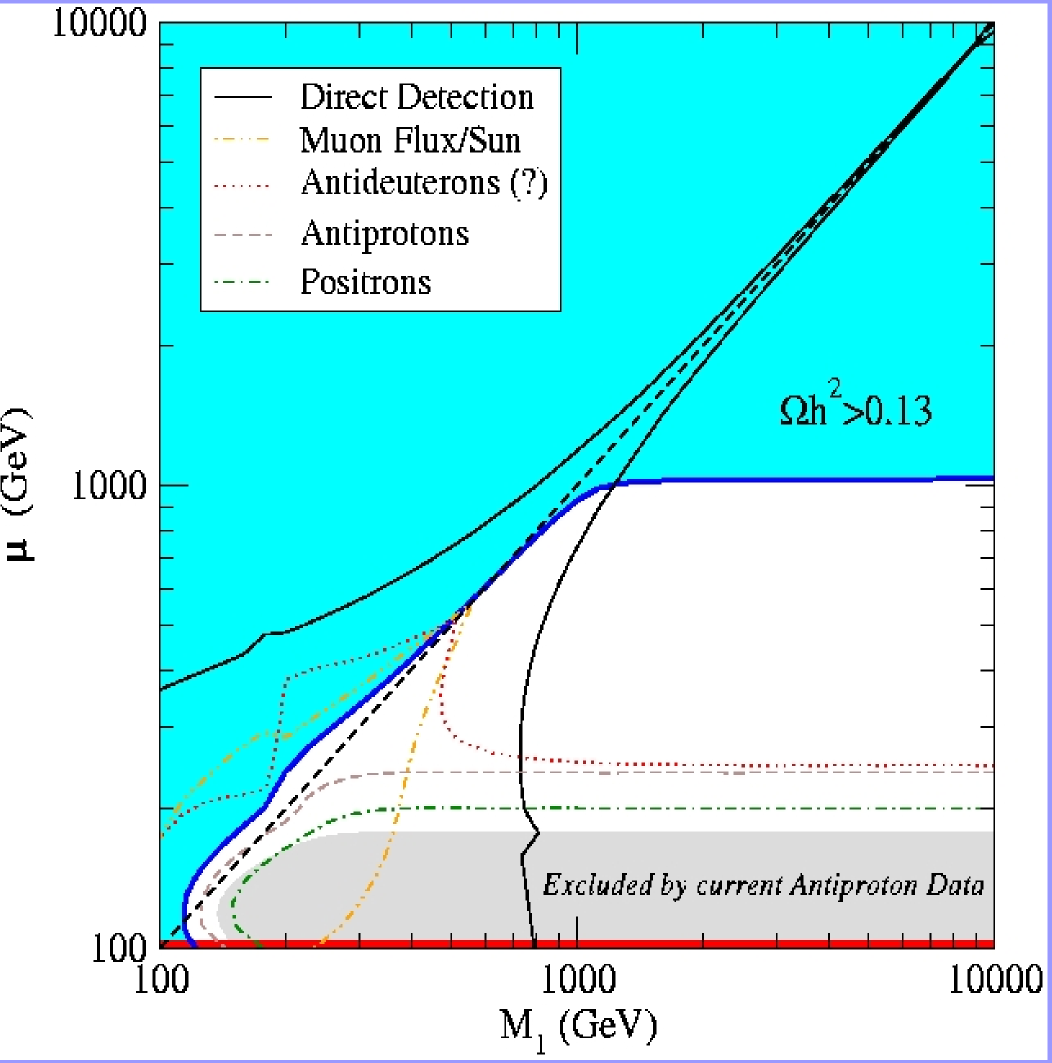
- We will refer to PAMELA experiment for antiprotons and positrons searches and to GAPS experiment for antidiuterons search

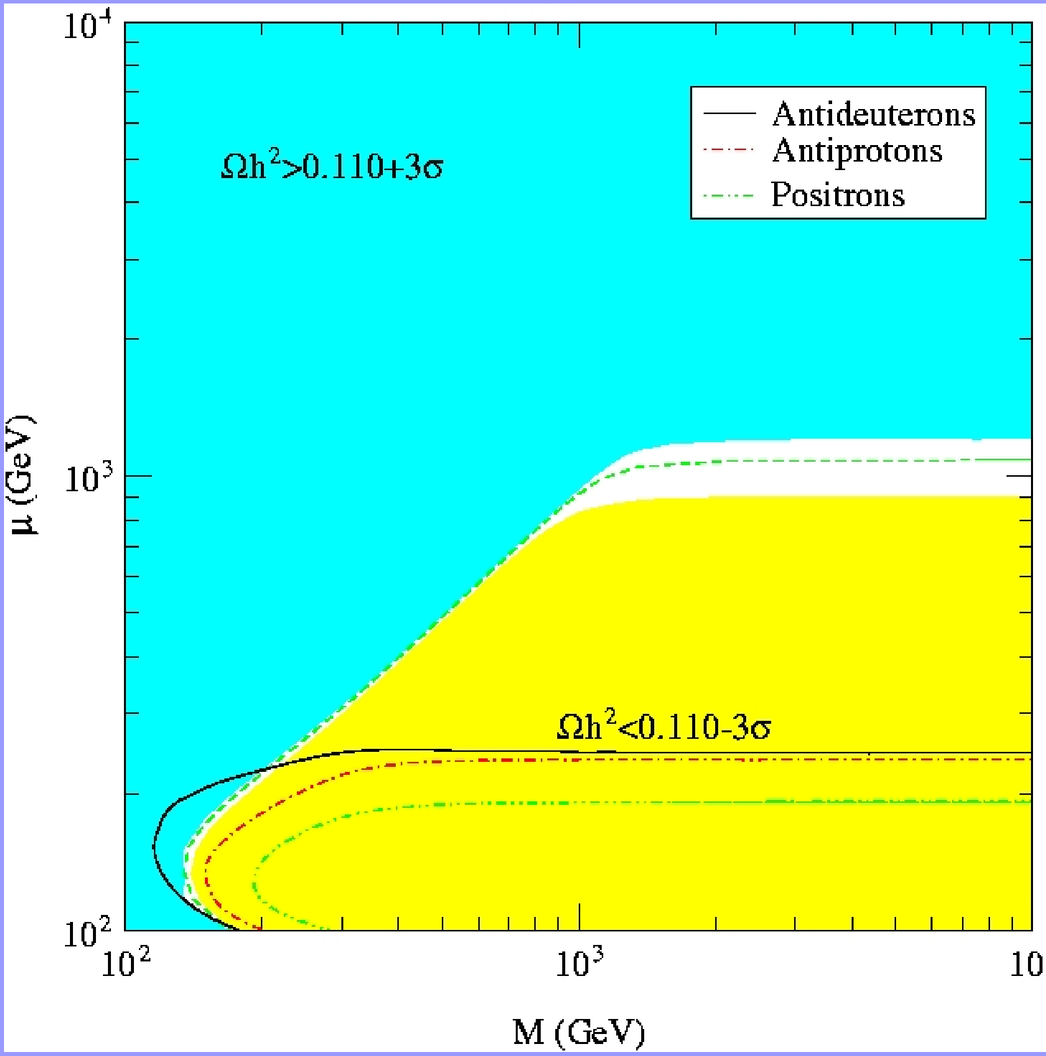
Dark matter and Split Extended SUSY: indirect detection

- Due to the absence of a spin-dependent coupling neutrino flux is negligible
- Only a portion of the High mixing of the WMAP allowed region can be scanned with this techniques
- The situation is better with less conservatives DM halos



Dark matter and Split Extended SUSY: indirect detection





Conclusions

- We find some regions in the parameter space where the thermal relic abundance of the Lightest Neutralino is in the WMAP range
- Only a portion of this area can be scanned at future experiments
- Complementarity between different experiments is crucial to distinguish this model from split-SUSY