A Comparison Between Direct and Indirect Dark Matter Search

Carlos Muñoz

Universidad Autónoma de Madrid & Instituto de Física Teórica

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A good dark matter candidate must fulfil $\Omega\, h^2 \approx 0.1$

Recalling that $\Omega \propto \frac{1}{\sigma_{\text{annihilation}}}$

It is easy to check that a particle with weak scale interactions has the appropriate value of the annihilation cross section to obtain $\Omega\, h^2 \approx 0.1$

THUS AN INTERESTING CANDIDATE FOR DARK MATTER IS:

- a **Weakly Interacting Massive Particle with a mass** ~ $10^{2\text{-}3}$ GeV

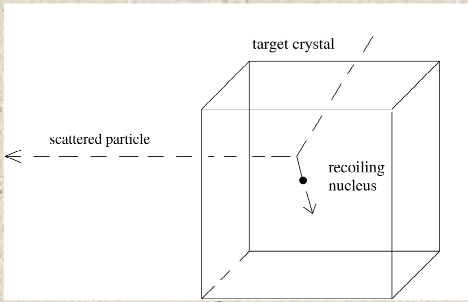
AND, AN INTERESTING CANDIDATE FOR **WIMP** IS: a **Neutralino**

- It has weak interactions and a mass ~ $10^{2\text{-}3}$ GeV
- It is stable, since it is the **LSP**
- It is a neutral particle

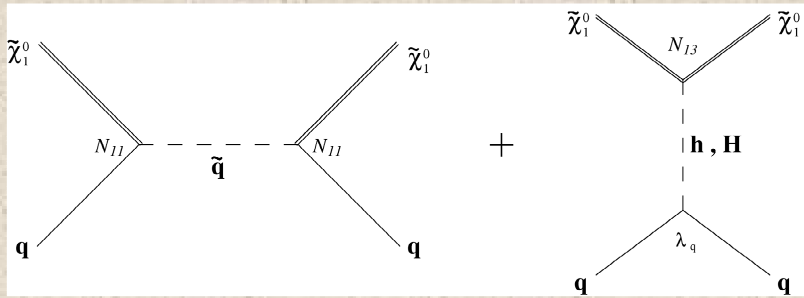
▪ We will analyze **The Neutralino** in the context of **Supergravity (SUGRA)**, and **Superstrings**

Which kind of experiments, direct or indirect detection, will be able to test larger regions of the parameter space of supersymmetric models ?

DIRECT DETECTION in SUGRA



Supersymmetry

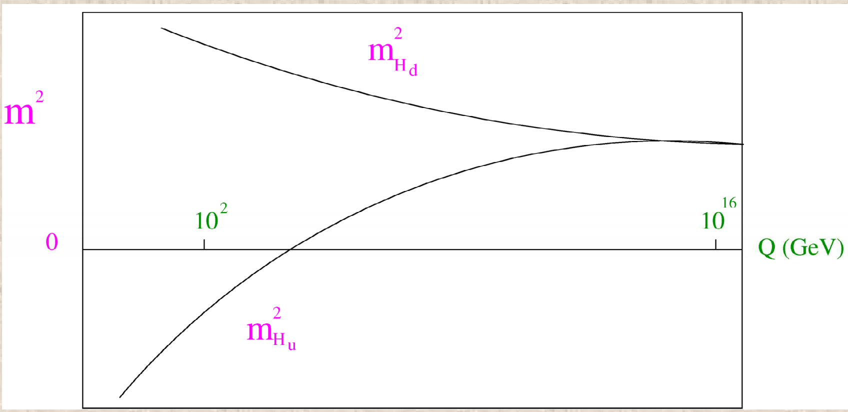


- Working in the framework of SUGRA, the masses, $\mathbf{M_a}$, $\mathbf{m_\alpha}$, are generated at high energy once SUSY is broken through gravitational interactions.

✓ The simplest possibility is to assume universality : $\mathbf{M_a = M}$, $\mathbf{m_\alpha = m}$

- The RGEs are used to derive the low-energy soft parameters

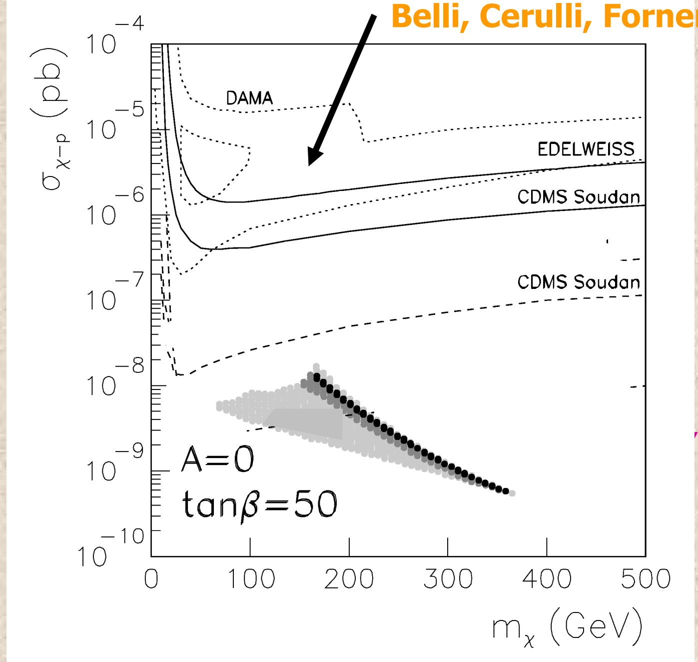
With $M_{GUT} \approx 2\times 10^{16}$ GeV, in the **MSSM** m^2_{Hu} evolves towards large and negative values



$\mu^2 \approx - m^2_{Hu} - (1/2)M^2_Z$ is large

$m^2_H \approx m_A \approx m^2_{Hd} - m^2_{Hu} - M^2_Z$ is large

Small cross section



$\sigma_{\chi_1^0}$**-n** $< 3\times10^{-8}$ pb

More sensitive detectors producing further data are needed e.g. 1 tonne detectors where

$\sigma_{\chi_1^0}$**-n** $\sim 10^{-10}$ pb

Experimental constraints:

-- masses of the Higgs and superpartners

-- low energy observables ($BR(b \longrightarrow s\gamma)$, $BR(B_s \longrightarrow \mu^+ \mu^-)$, g-2)

Astrophysical constraints:

--Relic density $0.1<\Omega_{DM}\, h^2<0.3$, WMAP range: $0.094<\Omega_{DM}\, h^2<0.129$

In addition, the parameter space may be limited by Charge and Colour Breaking constraints

Departures from universality can lead to an increase of the predictions for $\sigma_{\chi_1^0\text{-}n}$

- Working with non-universal scalar masses, m_α

Berezinsky, Bottino, Ellis, Fornengo, Mignola, Scopel, 95
Arnowitt, Nath, 97

...

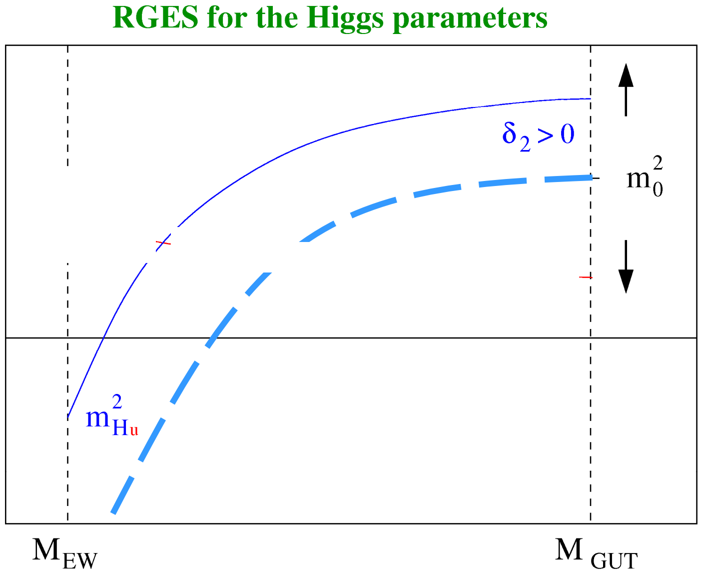
- Working with non-universal gaugino masses, M_a

Corsetti, Nath, 00
Cerdeño, Kahlil, C.M.,01

...

- Another approach is to use generic masses at the ew scale without using RGEs (**effMSSM)**

see e.g. Bottino, Donato, Fornengo, Scopel *e.g.:* $m^2_{Hu} = m^2\,(1+\delta_u)$ ✓ $\delta_u > 0$

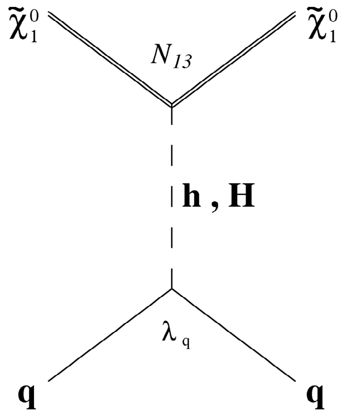


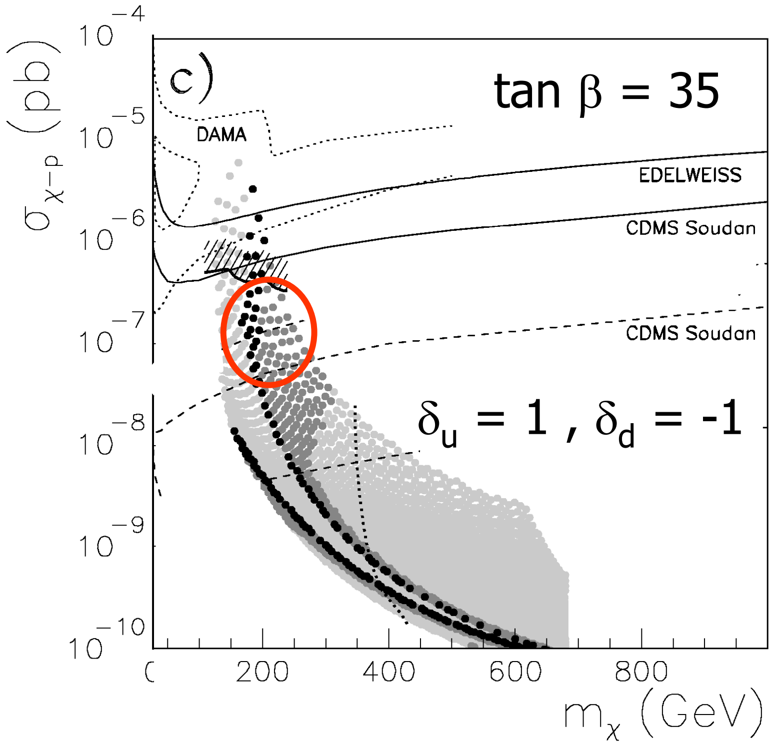
$\mu^2 \approx -m^2_{Hu} - (1/2)M^2_Z$

$m^2_H \approx m^2_A \approx m^2_{Hd} - m^2_{Hu} - M^2$

are smaller

Thus $\sigma_{\chi_1^0\text{-}n}$ is increased





Baek, Cerdeño, Y.G. Kim, Ko, C.M., 05

Summary

- Neutralinos with masses ≈ **(10-400) GeV** can be obtained within the reach of detectors

- CDMS Soudan, $\sigma_{\chi_1^0\text{-}n} \approx 10^{-7,-8}$ pb, will cover a small part of the parameter space

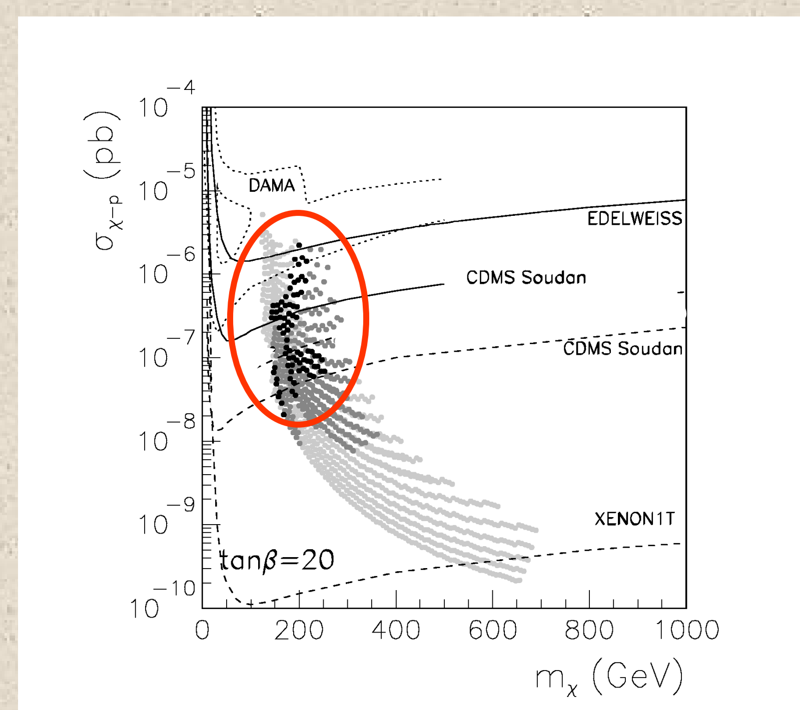
❖ Can non-universal masses arise from a more fundamental theory?

After compactification of the Heterotic Superstring on a 6-dimensional orbifold, the resulting 4D SUGRA is described by:

$$m_\alpha^2 = m_{3/2}^2 \left\{ 1 + \underbrace{n_\alpha \cos^2\theta + \frac{q_\alpha^A}{q_C^A}\left[(6-n_C)\cos^2\theta - 5\right]}_{\delta} \right\}$$

These soft terms are generically **non-universal**

Few free parameters: **$m_{3/2}$** , θ



Cerdeño, Kobayashi, C.M., 07

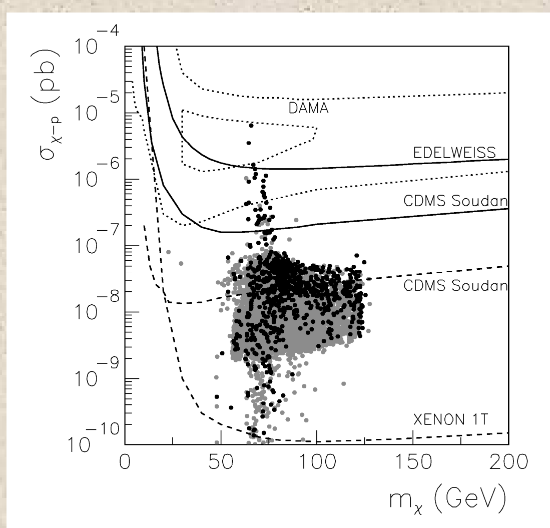
$$\delta_{H_u} = 10 - 17\cos^2\theta, \qquad \delta_{H_d} = -\frac{5}{2} + \cos^2\theta,$$

NMSSM

$\mu H_1 H_2 \longrightarrow \lambda S H_1 H_2 \Rightarrow \mu_{eff} = \lambda \langle S \rangle$

- NMSSM has a richer and more complex phenomenology:

2 extra Higgses
1 additional neutralino



A light Higgs is experimentally viable: Implications for $\sigma_{\chi\text{-}n}$

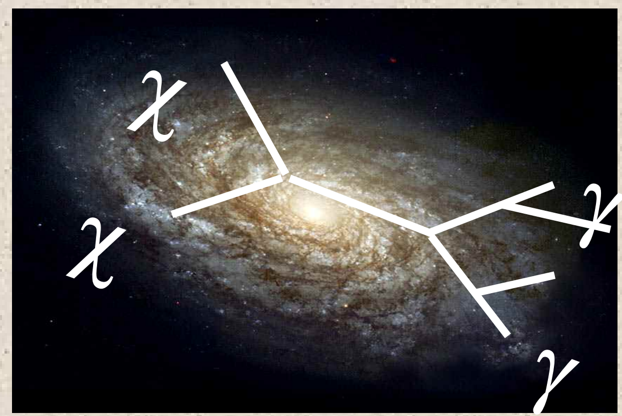
Cerdeño, Gabrielli, Lopez-Fogliani, C.M., Teixeira, 07

Large values of $\sigma\chi_1^0$**-n** , within the reach of detectors, can be obtained:

- Very light, singlet-like Higgses $m_h \geq 15$ GeV

INDIRECT DETECTION in the MSSM

- Annihilation of neutralinos in the galactic center will produce gamma rays, and these can be measured, e.g., in space –based detectors

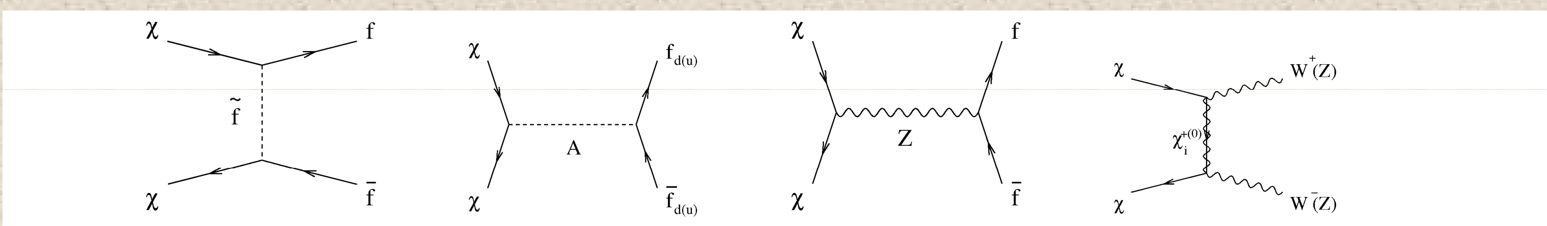


Starting this year, the GLAST satellite will be able to detect a flux of gamma rays, as small as 10^{-11} cm^{-2} s^{-1}

$$\phi \sim \left(\int_{\text{line of sight}} \rho^2\, dr\right) \sigma_{ann} v / m^2$$

Astrophysics

Particle physics

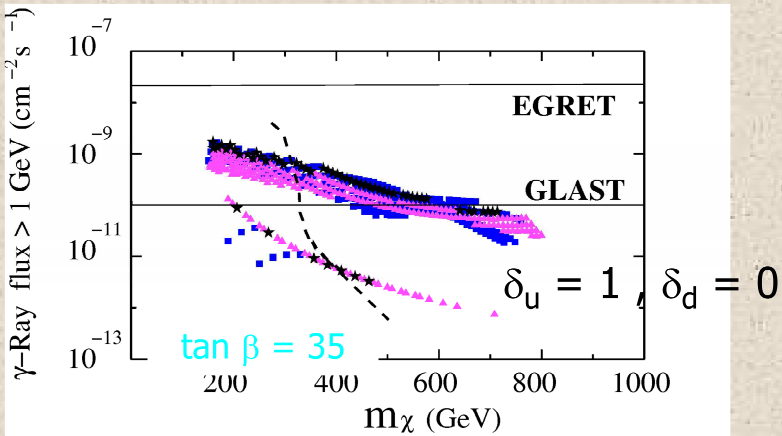


Particle physics: $\propto \frac{m_\chi m_f}{m_{\tilde f}^2} Z_{11}^2 \quad \propto \frac{m_\chi^2}{m_A^2}\frac{Z_{11}Z_{13,14}}{m_W} m_{f_d} \tan\beta\left(\frac{m_{f_u}}{\tan\beta}\right) \quad \propto \frac{m_f m_\chi}{m_Z^2} Z_{13,14}^2 \quad \propto \frac{[-Z_{14}V_{21}^* + \sqrt{2} Z_{12} V_{11}^*]^2 (-Z_{13}N_{31}^* + Z_{14}N_{41}^*)^2}{1 + m^2_{\chi_i^{+(0)}}/m_\chi^2 - m^2_{W(Z)}/m_\chi^2}$

Since the diagrams are related, we can use the same arguments as for direct detection

Astrophysics: e.g. a **NFW profile** for our galaxy, has for small distances from the galactic center $\rho(r) \sim \rho_0 / r$

The combination of both effects implies that GLAST will be able to test some regions

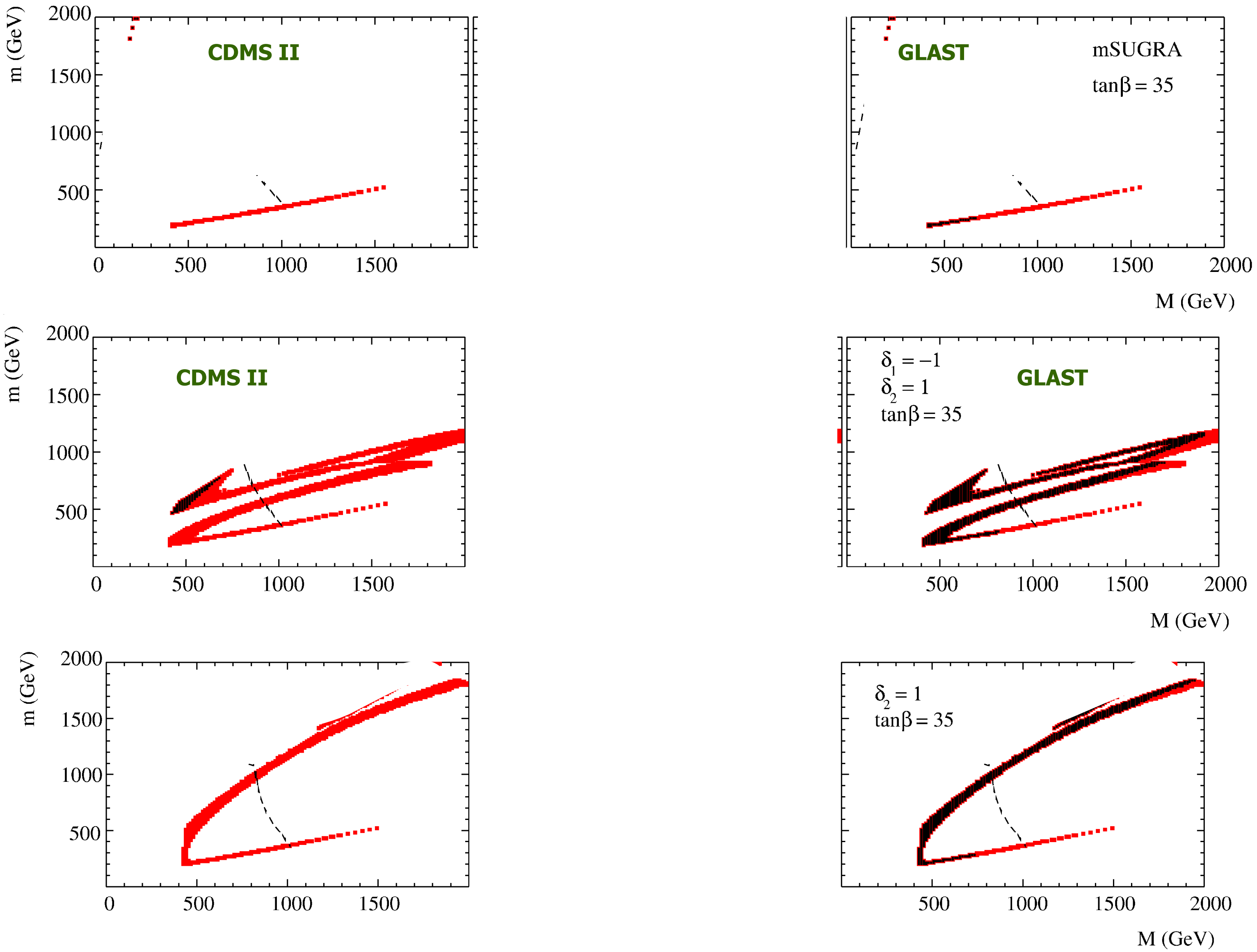


Mambrini, C.M., 04

DIRECT versus INDIRECT detection

Which kind of experiments, direct or indirect detection, will be able to test larger regions of the parameter space of supersymmetric models ?

Mambrini, C.M., 04



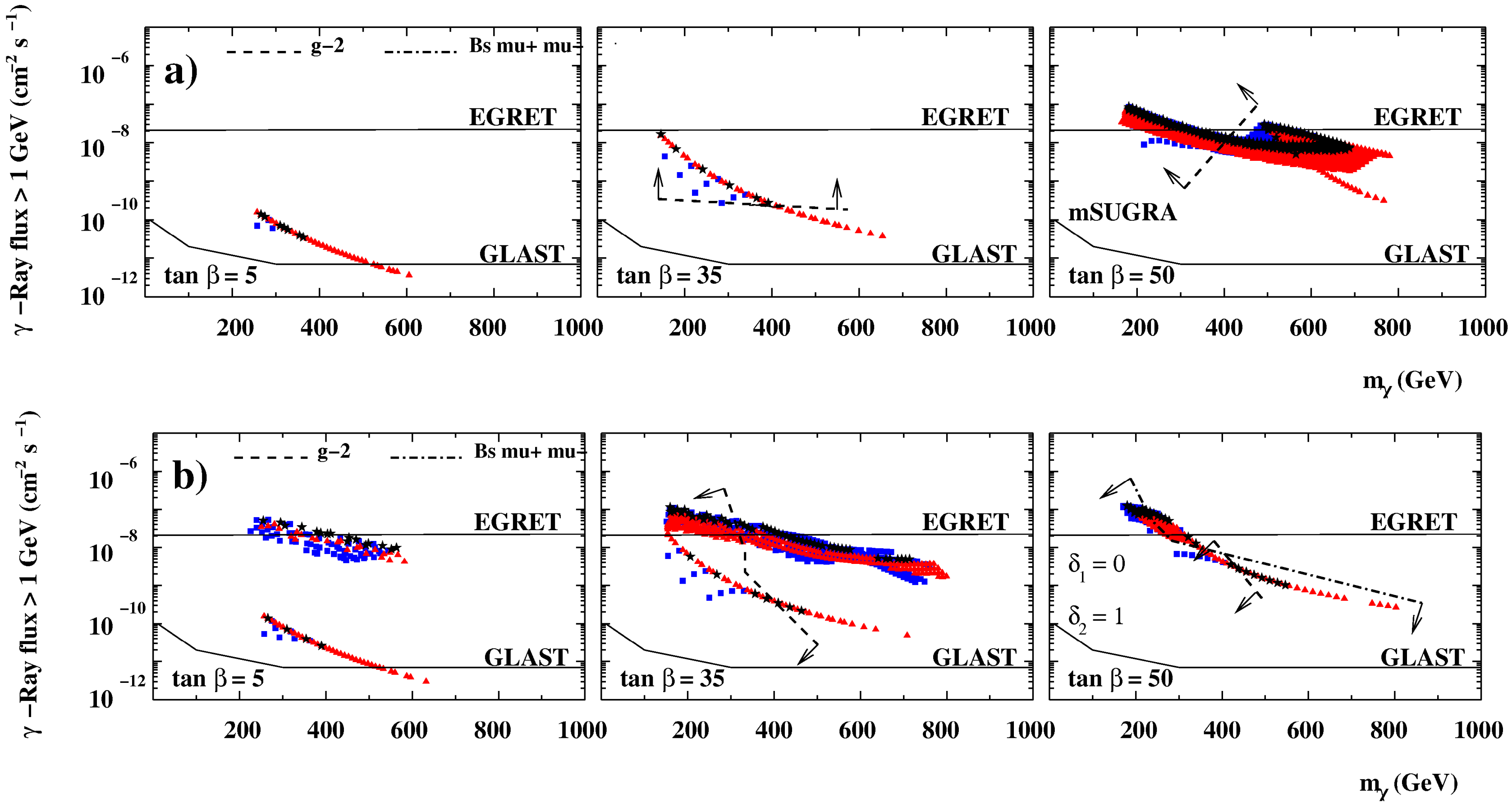
✘ The previous situation occurs for simulations of halos without baryons. When baryons are taken into account a larger $\rho(r)$ is obtain, producing a larger ϕ

Blumenthal, Faber, Flores, Primack, 86; Prada, Klypin, Flix, Martinez, Simonneau, 04; Bertone, Merrit, 05; Athanassoula, Ling, Nezri, 05

a NFW profile including baryons has $\rho(r) \sim \rho_0/r^{1.45}$, producing ϕ **x 100**

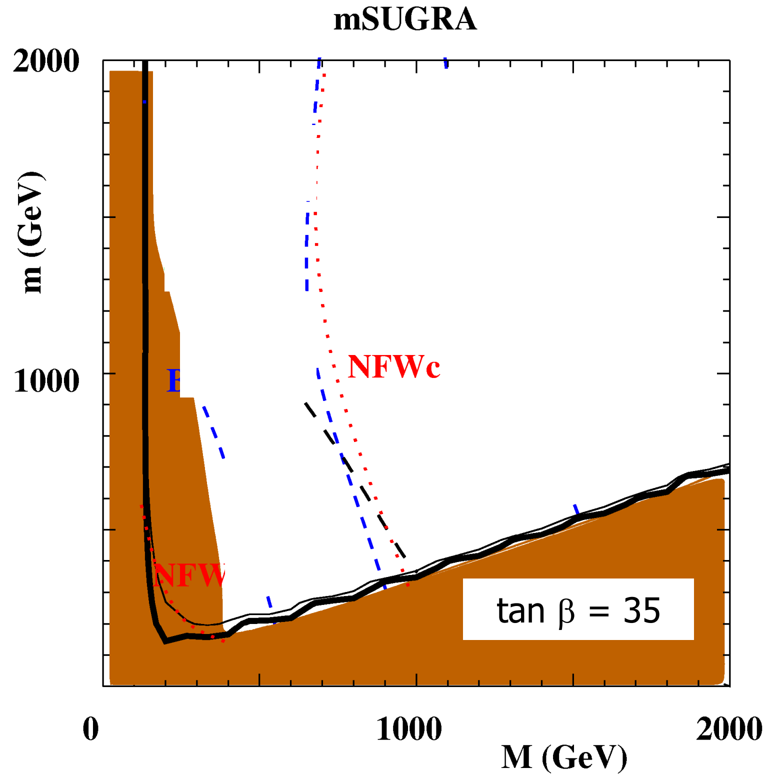
Equivalent to Moore et al. profile without baryons

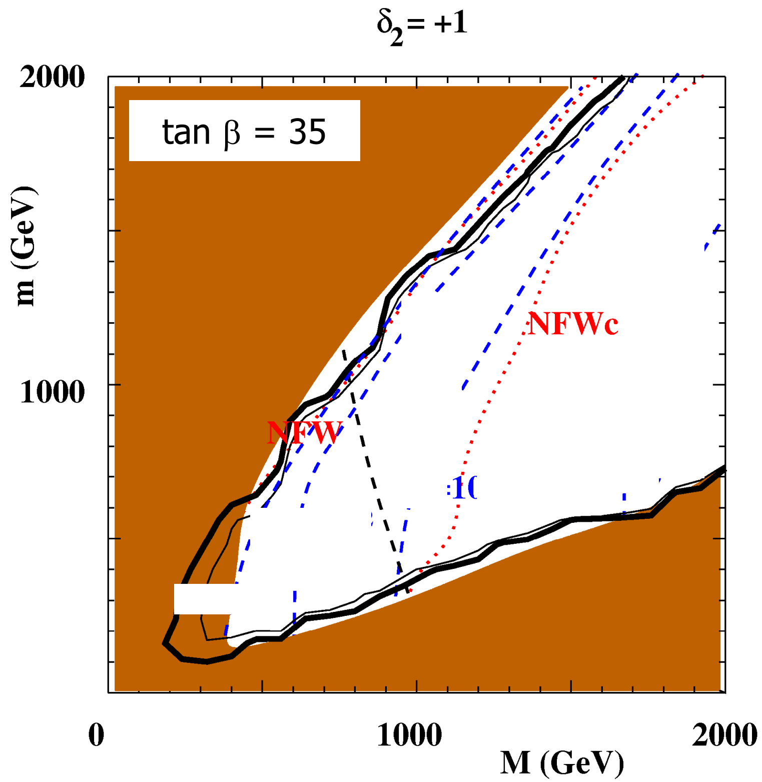
Mambrini, C.M., Nezri, Prada, 05

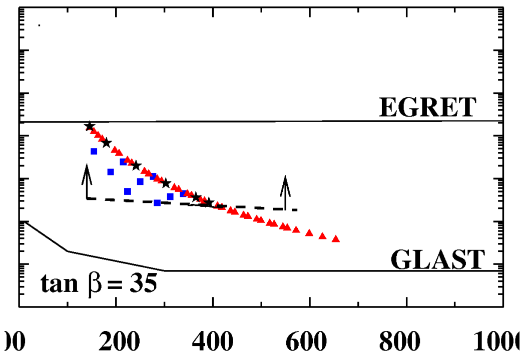


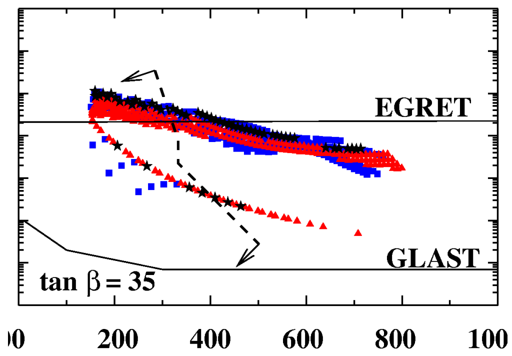
Carrying out a more sophisticated analysis, e.g. considering the HESS data as the gamma ray background, as suggested by Zaharijas, Hooper, 06, the previous optimistic results are ameliorated

Mambrini, C.M., Nezri, 06





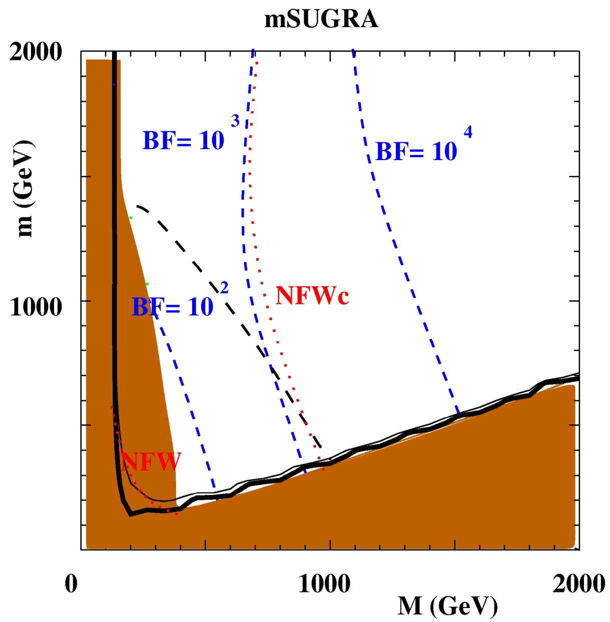


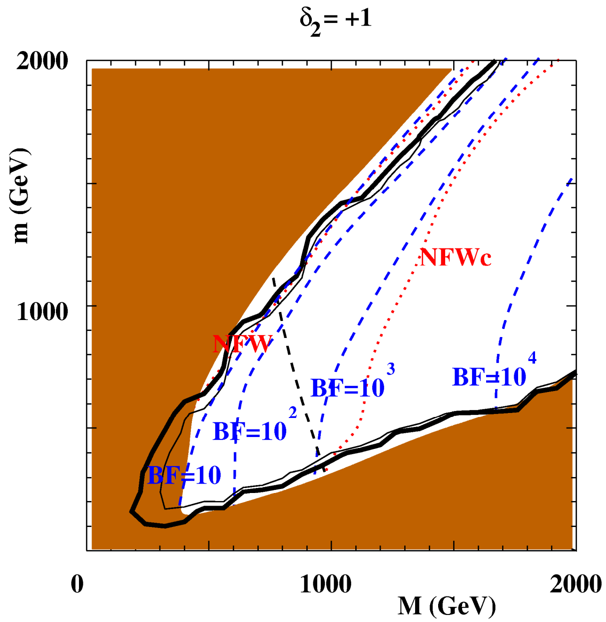


GLAST versus PAMELA

To simplify the analysis we consider,
PAMELA: we use a constant boost factor to parameterise possible clumps in the halo
(see Lavalle, Pochon, Salati, Taillet, 06 for a more sophisticated analysis of the clumps)

GLAST: we neglect the efect of clumpliness
(see Bergstrom, Edsjo, Gondolo, Ullio, 98 where an enhacement due to clumps is obtained)
our predictions for GLAST are therefore conservative.





Mambrini, C.M., Nezri, 06

PAMELA will be competitive with GLAST, for typical NFW profiles,
if the boost factor is about 10

CONCLUSIONS

Direct Detection

- $\sigma_{\chi_1^0\text{-nucleon}}$ in supergravity, with universal soft terms, is too small
- Larger $\sigma_{\chi_1^0\text{-nucleon}}$ can be obtained with non-universal masses

Regions accesible for experiments are present

- Neutralinos with masses $\approx$ **(10-500) GeV** can be obtained within the reach of dark matter detectors in the **MSSM**

- Similarly in the **NMSSM (50-100) GeV** and **orbifolds (200-400) GeV**

CDMS Soudan, $\sigma_{\chi_1^0}$**-n** $\approx 10^{-7,-8}$ pb, will cover a small part of the parameter space

Indirect

- ϕ_γ $(\chi_1^0\text{-}\chi_1^0)$ in Supergravity with universality is in general small

- Larger ϕ can be obtained with non-universality. Actually, using a NFW profile, more regions will be accesible than in direct detection

Including baryons, GLAST will cover important regions of the parameter space

PAMELA will be competitive with GLAST, for typical NFW profiles, if the boost factor is about 10

THE END

Backup Slides

Baryons

✗ The previous situation occurs for simulations of halos without baryons. When baryons are taken into account a larger $\rho(r)$ is obtain, producing a larger ϕ

Blumenthal, Faber, Flores, Primack, 86
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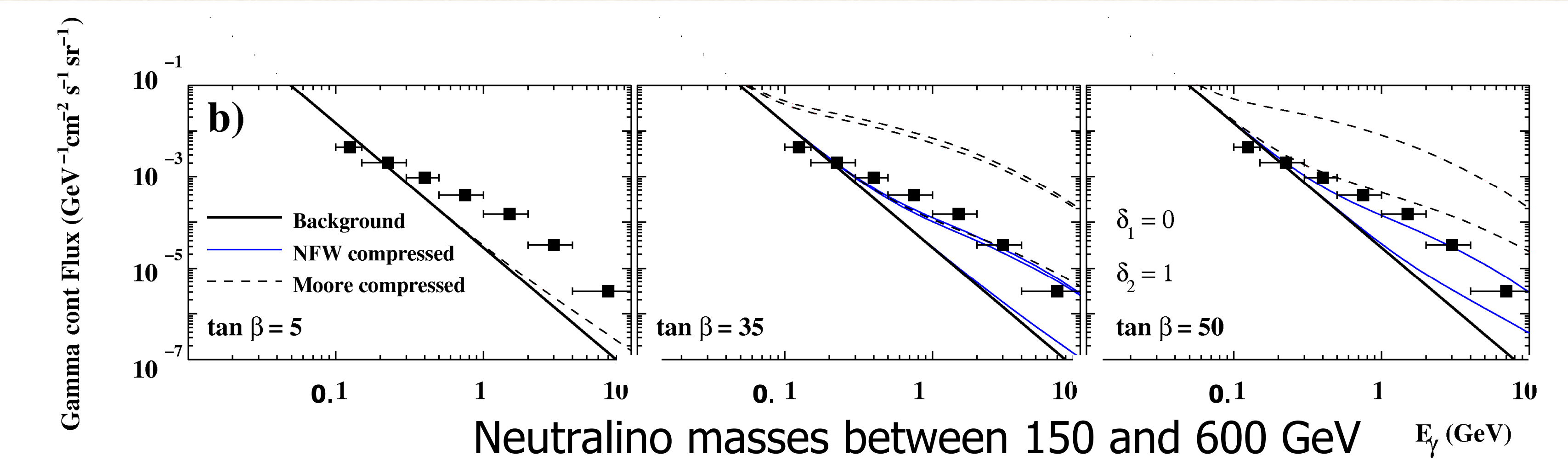
Mambrini, C.M., Nezri, Prada, 05

- The combination of both effects, non-universality + baryons, may even allow to reproduce the observations of **EGRET**



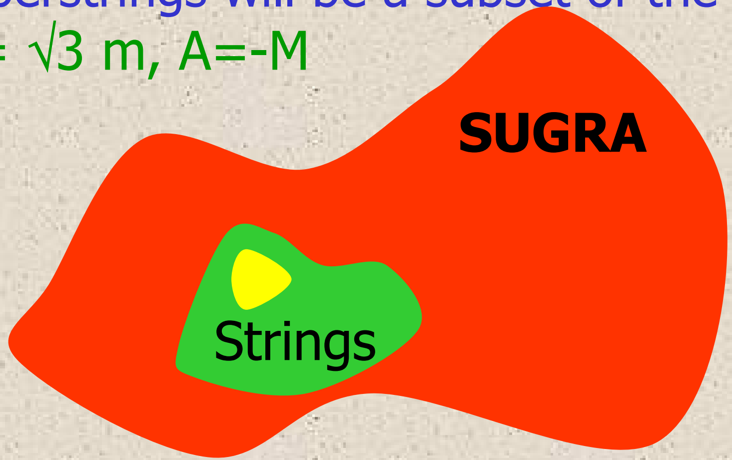
Neutralino masses between 150 and 600 GeV

SUGRA from SUPERSTRINGS

Since the low-energy limit of superstring theory is 4-dimensional SUGRA, the neutralino is also a candidate for dark matter in superstring constructions

Taking into account that the soft terms can in principle be computed in these constructions, once can study the associated χ_1^0-nucleon cross section

Of course, the results in superstrings will be a subset of the ones studied in SUGRA e.g. in the dilaton limit $M= \sqrt{3}\ m$, $A=-M$



M_a, m_α, $A_{\alpha\beta\gamma}$

The previous general analysis of soft terms in SUGRA, and the strategy to obtain a large cross section, is very useful for the study of these more specific cases

Orbifold Scenarios

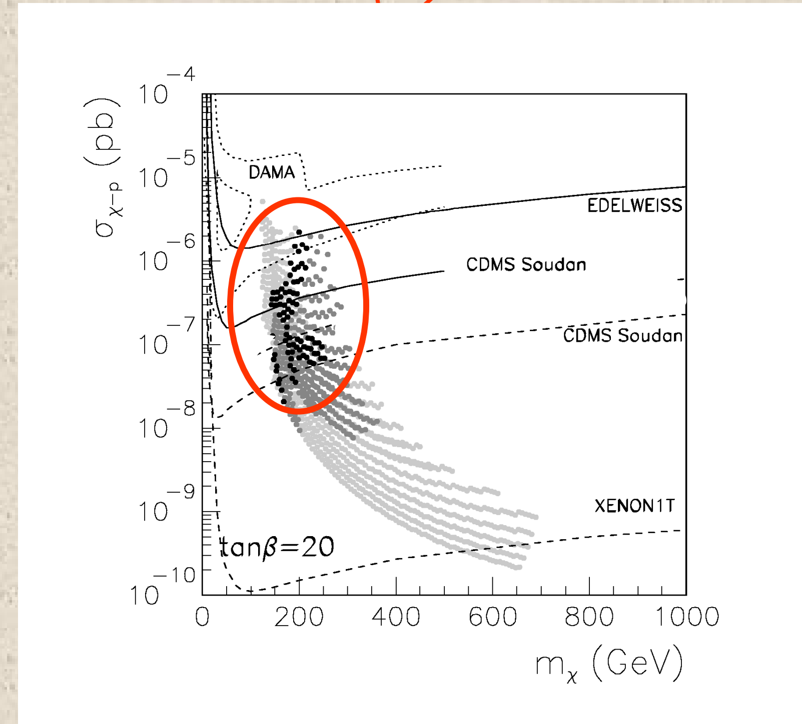
After compactification of the Heterotic Superstring on a 6-dimensional orbifold, the resulting 4D SUGRA is described by:

$$m_\alpha^2 = m_{3/2}^2 \left\{ 1 + n_\alpha \cos^2\theta + \frac{q_\alpha^A}{q_C^A}\left[(6 - n_C)\cos^2\theta - 5 \right] \right\}$$

These soft terms are generically **non-universal**

δ

Few free parameters: $\mathbf{m_{3/2}}$, θ



Cerdeño, Kobayashi, C.M., 07

$$\delta_{H_u} = 10 - 17\cos^2\theta, \qquad \delta_{H_d} = -\frac{5}{2} + \cos^2\theta,$$

NMSSM

- Going beyond the MSSM: adding singlet superfield S – the NMSSM
  - Elegant solution to the μ-problem of the MSSM

$$\mu H_1 H_2 \longrightarrow \lambda S H_1 H_2 \Rightarrow \mu_{eff} = \lambda \langle S \rangle$$

- NMSSM has a richer and more complex phenomenology:
  - 2 extra Higgses
  - 1 additional neutralino
  - A light Higgs is experimentally viable: Implications for $\sigma_{\chi\text{-}n}$

- Parameter space of the NMSSM:

$$\lambda\,, \quad \kappa\,, \quad \mu(=\lambda s)\,, \quad \tan\beta\,, \quad A_\lambda\,, \quad A_\kappa\,, \quad M_1\,, \quad M_2$$

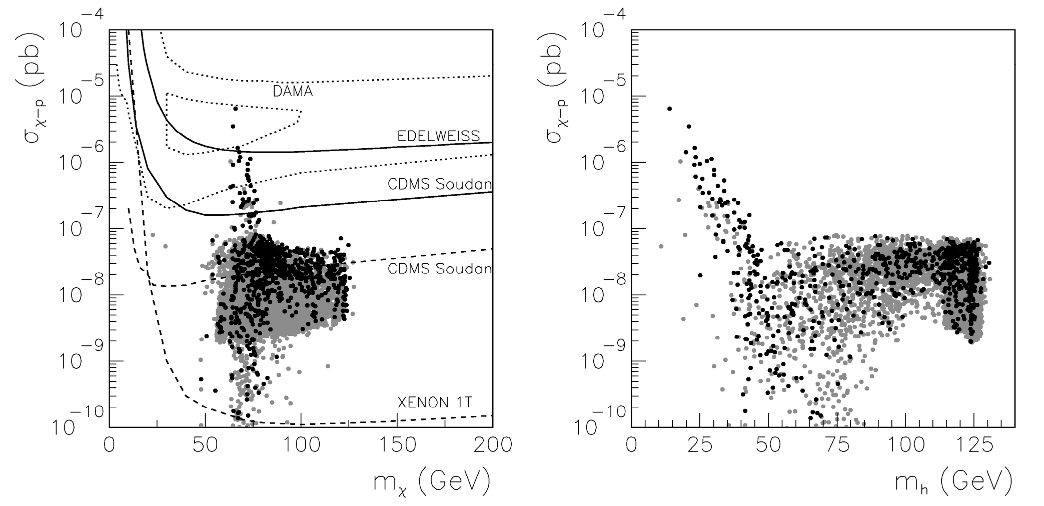


Figure 11: Scatter plot of the neutralino-nucleon cross section as a function of the neutralino mass (left) and as a function of the lightest CP-even Higgs mass (right) for an example with $\tan\beta = 5$, and the remaining parameters in the ranges $0.01 \leq \lambda, \kappa \leq 0.7$, $110\ \text{GeV} \lesssim M_2 \lesssim 430\ \text{GeV}$, $-300\ \text{GeV} \lesssim A_\kappa \lesssim 300\ \text{GeV}$, $-800\ \text{GeV} \lesssim A_\lambda \lesssim 800\ \text{GeV}$, and $110\ \text{GeV} < \mu < 300\ \text{GeV}$. All the points represented are in agreement with LEP/Tevatron, a_μ^{SUSY}, and BR($b \to s\,\gamma$) constraints, and have a relic density in agreement with the astrophysical bound (grey dots) or the WMAP constraint (black dots).

Cerdeño, Gabrielli, Lopez-Fogliani, C.M., Teixeira, 07

Large values of $\sigma\chi_1^0$**-n** , within the reach of detectors, can be obtained:

- Very light, singlet-like Higgses $m_h \geq 15$ GeV
- Lightest neutralino is a mixed Higgsino-singlino state
- In those regions the neutralino mass is in the range 50-100 GeV

In addition, the parameter space is very limited by experimental, astrophysical, and CCB constraints

Experimental constraints:

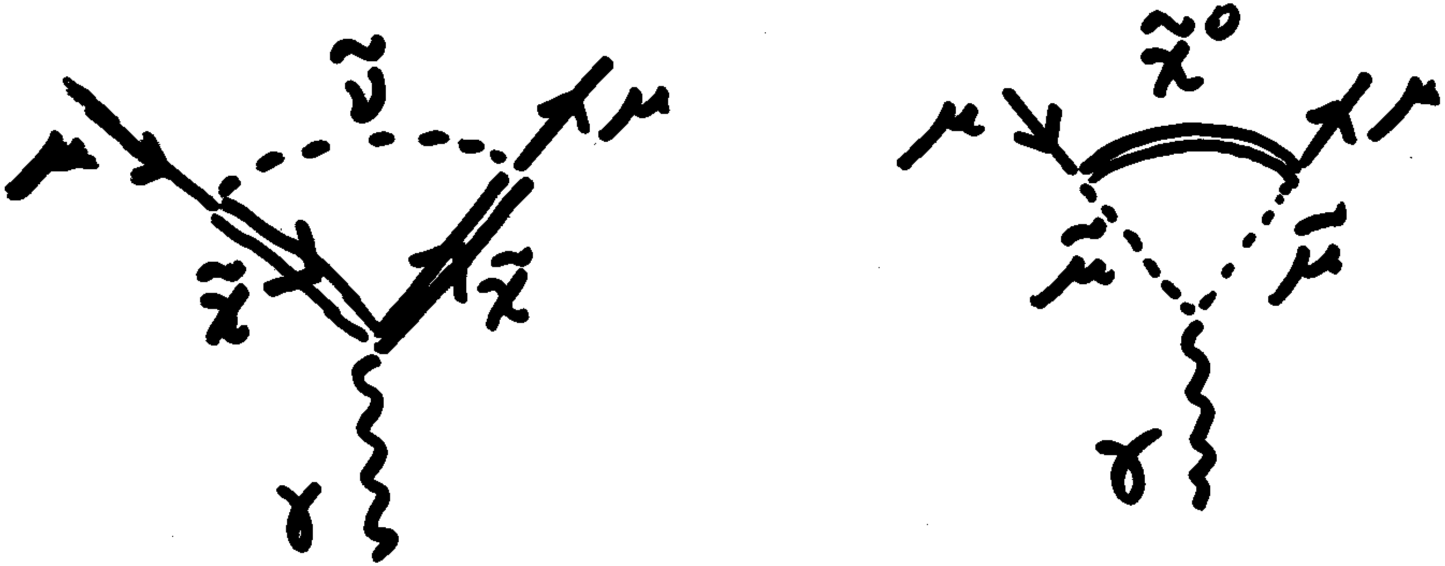
- Supersymmetric spectrum: $m_{\tilde{\chi}_1^\pm} > 103$ GeV, . . .
- Higgs Mass: $m_h > 114.1$ GeV
  (dependent on $\sin^2(\alpha - \beta)$)
- $7.1 \times 10^{-10} < a_\mu^{SUSY} < 47.1 \times 10^{-10}$
- $2 \times 10^{-4} < BR(b \to s\gamma) < 4.1 \times 10^{-4}$

Astrophysical constraints:

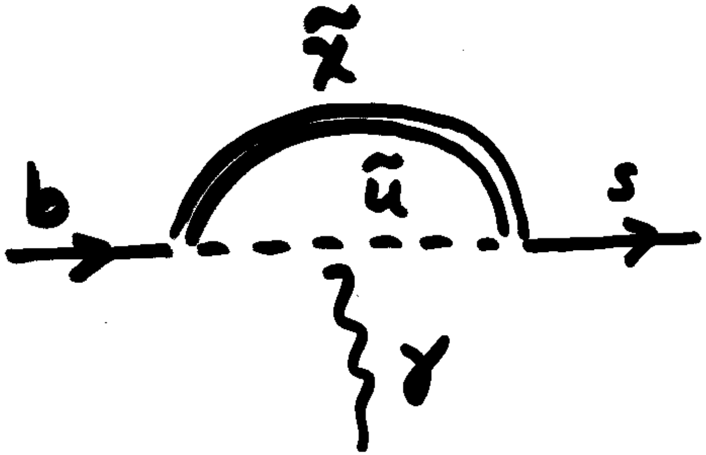
- Relic density: $0.1 \lesssim \Omega_{\tilde{\chi}_1^0} h^2 \lesssim 0.3$

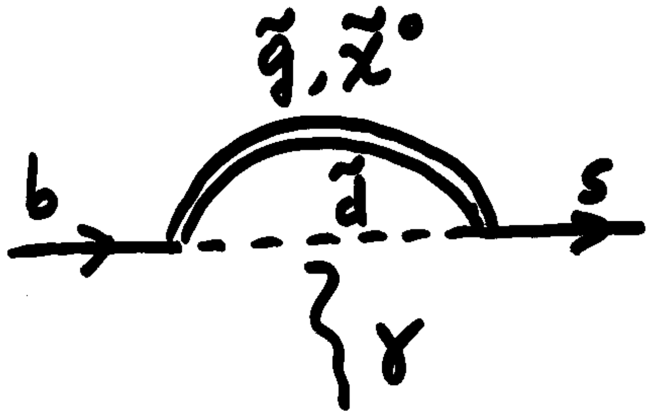
WMAP: $0.094 \lesssim \Omega_{\tilde{\chi}_1^0} h^2 \lesssim 0.129$

g-2



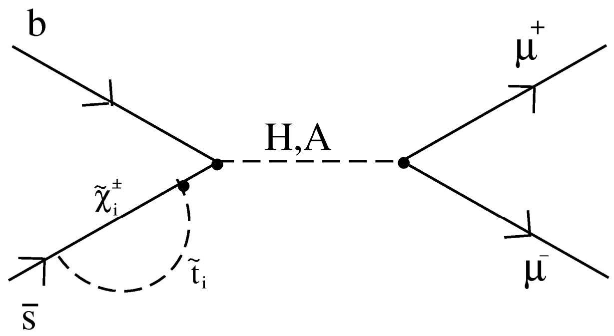
$b \to s + \gamma$





$B_s \longrightarrow \mu^+ \mu^-$

The decay $B_s \longrightarrow \mu^+ \mu^-$ is very sensitive to large values of **tan β** **and small values of Higgs masses ,** in particular $\propto \tan^6\beta / m_H^4$



Thus the current upper limit
$B (B_s \text{ to } \mu^+ \mu^-) < 2.9 \times 10^{-7}$
may exclude regions of the parameter space with large $\sigma_{\chi_1^0\text{-}n}$

Baek, Y.G. Kim, Ko, 04