# Theoretical Predictions for the Direct Detection of Supersymmetric Dark Matter

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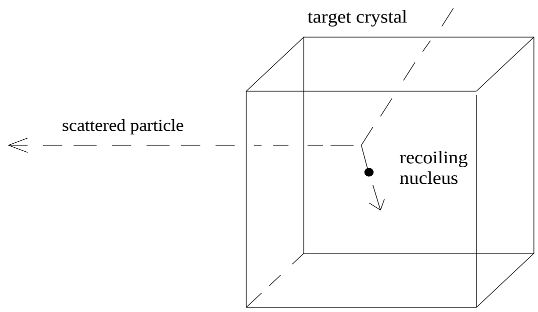
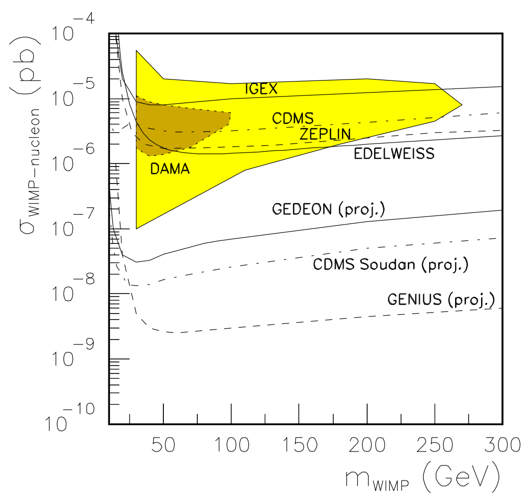
# INTRODUCTION

- Impressive experimental efforts have been carried out since 1987 for the detection of dark matter through elastic scattering with nuclei in a detector



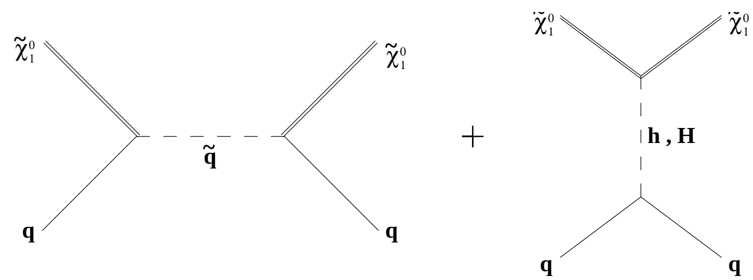

- Recent WIMP searches imply:




$$\sigma_{\text{WIMP-nucleon}} \lesssim 10^{-6} - 10^{-5}\ \text{pb}$$

New experimental projects: HDMS, GEDEON, DAMA/LIBRA, CDMS Soudan, CRESST, CUORE, GENIUS, MACHe3, PICASSO, ORPHEUS, DRIFT, ...

♣ It is then crucial to re-analyze the compatibility of the neutralino as a dark matter candidate, with the sensitivity of dark matter detectors




♣ Typically, one imposes the following constraints on the SUSY computation: Higgs mass, $b \to s\gamma$, $g_\mu$-2, relic density

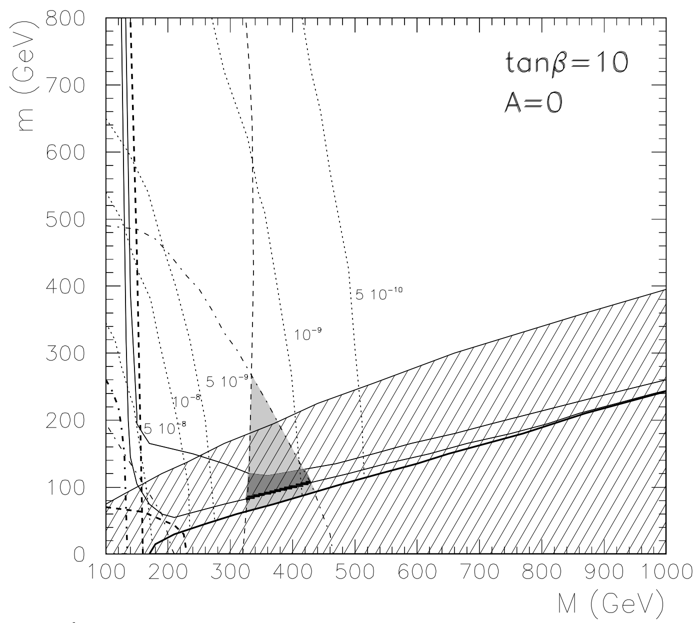
♢ We will include in the computation the constraints that arise from imposing the absence of dangerous charge and colour breaking minima

♢ We will discuss:

- Supergravity (with universal and non-universal soft terms, with GUT and intermediate scale)
- Superstrings (D-brane configurations from the type I superstring and orbifolds from the heterotic string)

# SUGRA predictions

## mSUGRA scenario with a GUT scale




* $m_h \gtrsim 114$ GeV (region to the right of the near-vertical dashed line)
* $2 \times 10^{-4} \leq BR(b \to s\gamma) \leq 4.1 \times 10^{-4}$ (right of the double dot-dashed line)
* $11.3 \times 10^{-10} \leq a_\mu \leq 56.1 \times 10^{-10}$ (region bounded by dot-dashed lines)
* $\tilde{\chi}_1^0$ is the LSP (region above the double solid line)

The light shaded area, with $\sigma_{\tilde{\chi}_1^0 - n} \approx 10^{-9}$ pb, is favoured by all the phenomenological constraints, while the dark one fulfills in addition: $0.1 \lesssim \Omega_{\mathrm{DM}} h^2 \lesssim 0.3$. The black region on top of this indicates the WMAP range: $0.094 \lesssim \Omega_{\mathrm{DM}} h^2 \lesssim 0.129$

The ruled region bounded by the upper solid line is excluded because of the UFB-3 constraint

$$V_{\mathrm{UFB-3}} \approx (m_{H_u}^2 + m_{L_i}^2)|H_u|^2 + \frac{|\mu|}{\lambda_{e_j}}(m_{L_j}^2 + m_{e_j}^2 + m_{L_i}^2)|H_u|$$

$\tan\beta \lesssim 20$ is excluded for any $A$. Larger values can also be forbidden depending on $A$

several mechanisms were proposed in the past to increase the cross section:

- to work in the large $\tan\beta$ regime

- to work with non-universal soft scalar masses $m_\alpha$

Bottino, Donato, Fornengo, Scopel, 99

Arnowitt, Nath, 99

Accomando, Arnowitt, Dutta, Santoso, 00

- to work with non-universal gaugino masses

Corsetti, Nath, 00

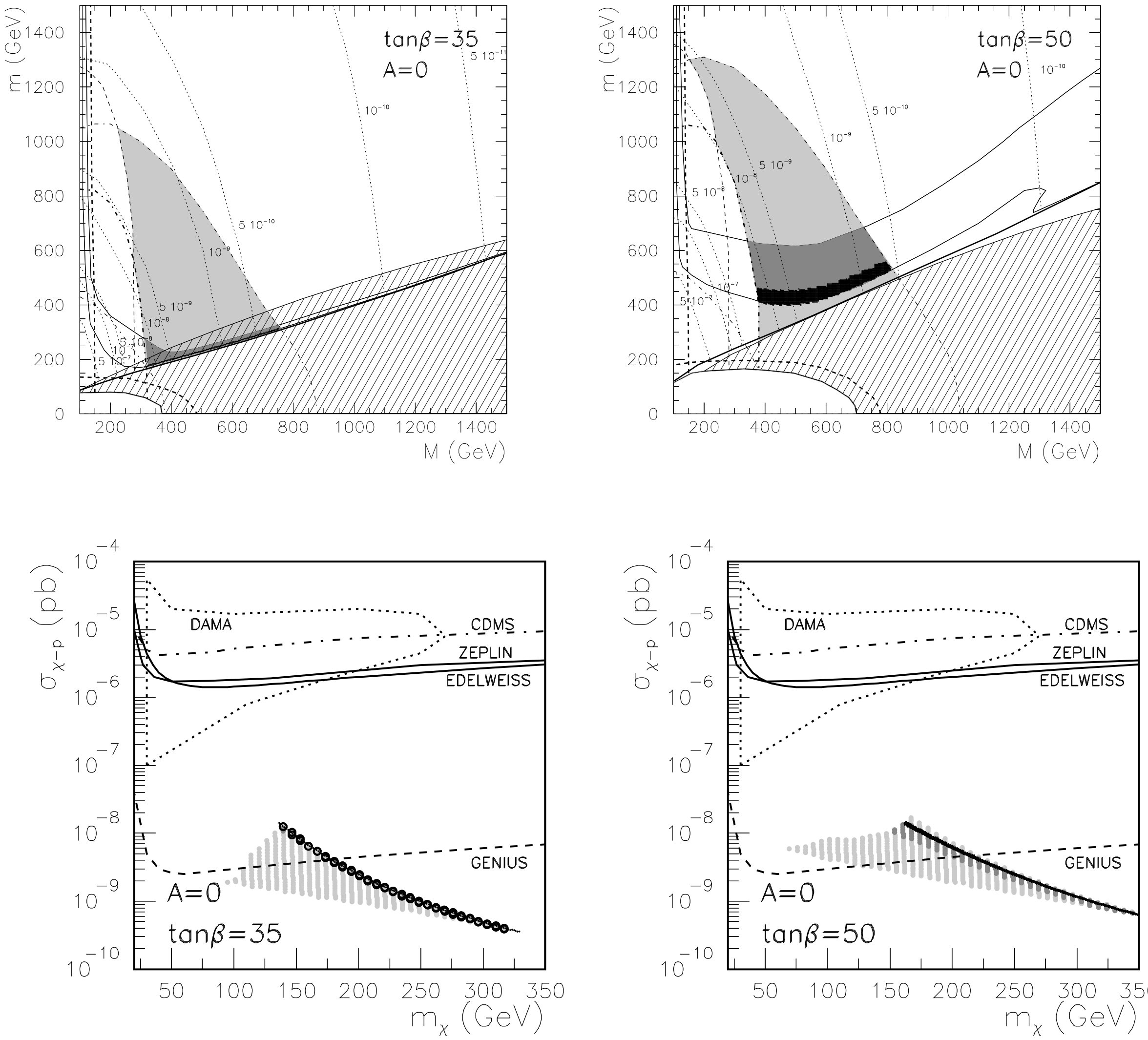
Cerdeño, Khalil, C.M., 01

- Focus point supersymmetry scenario

Feng, Matchev, Wilczek, 00

- to work with an intermediate scale

Gabrielli, Khalil, C.M., Torrente-Lujan, 00



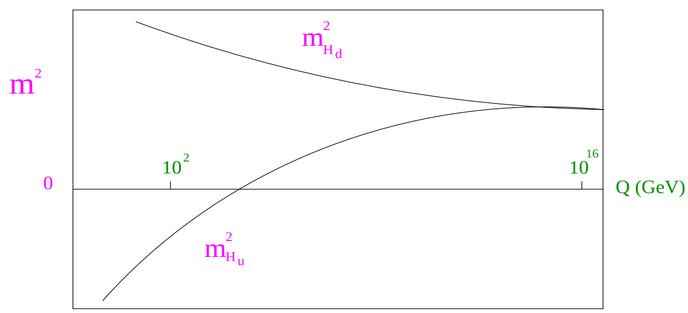

For example, for $\tan\beta = 35$ and $A = M$ essentially the whole dark shaded area is allowed by UFB-3 constraint, whereas for $A = -M, -2M$ this is forbidden

$$\sigma_{\tilde{\chi}_1^0 - n} \lesssim 3 \times 10^{-8} \text{ pb}$$

## mSUGRA scenario with an intermediate scale

There are several interesting phenomenological arguments in favour of SUGRA scenarios with scales $M_I \approx 10^{10-14}$ GeV. In addition, the string scale may be anywhere between the weak and the Planck scale.

The analysis of $\sigma_{\tilde{\chi}_1^0-n}$ is modified by taking a scale $M_I$ smaller than $M_{GUT} \approx 10^{16}$ GeV




because $\mu^2 = \frac{m^2_{H_d^0} - m^2_{H_u^0} \tan^2\beta}{\tan^2\beta - 1} - \frac{1}{2}M_Z^2$ will decrease

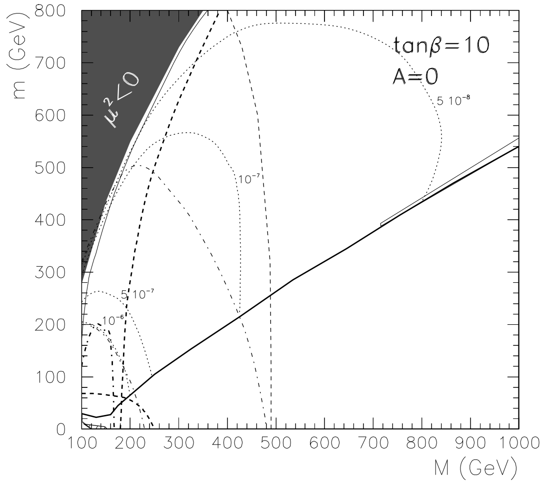
since $\mathcal{L} \sim \mu \tilde{H}_u^0 \tilde{H}_d^0$ + h.c., the lightest neutralino $\tilde{\chi}_1^0$ will have an important Higgsino component

In addition, $m_A^2 = m^2_{H_d} + m^2_{H_u} + 2\mu^2$ also decreases

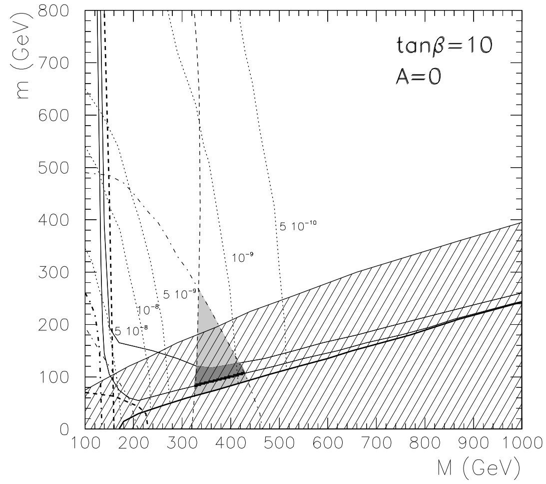
$\Downarrow$

larger $\sigma_{\tilde{\chi}_1^0-n}$

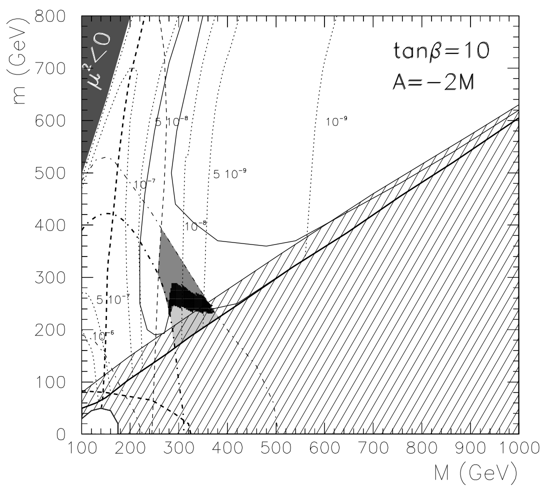
$M_I = 10^{11}$ GeV

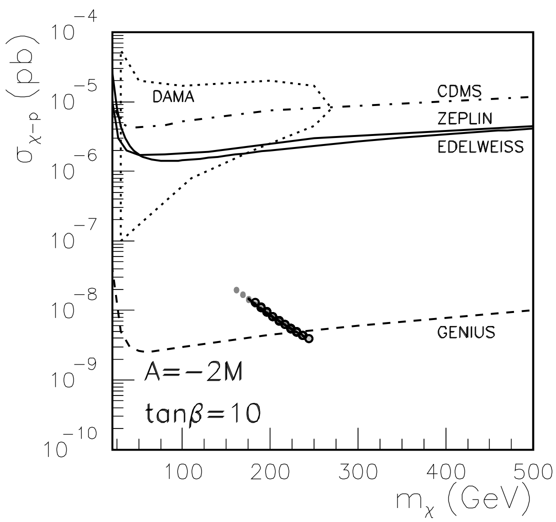



$M_{GUT}$




$M_I = 10^{11}$ GeV




Regions excluded by the UFB-3 constraint are much smaller than in those cases where the initial scale is the GUT one, since $m^2_{H_u}$ is less negative. Recall that

$$V_{\rm UFB-3} \approx (m^2_{H_u} + m^2_{L_i})|H_u|^2 + \frac{|\mu|}{\lambda_{e_j}}(m^2_{L_j} + m^2_{e_j} + m^2_{L_i})|H_u|$$

$$\sigma_{\tilde{\chi}^0_1 - n} \lesssim 10^{-7} \text{ pb}$$

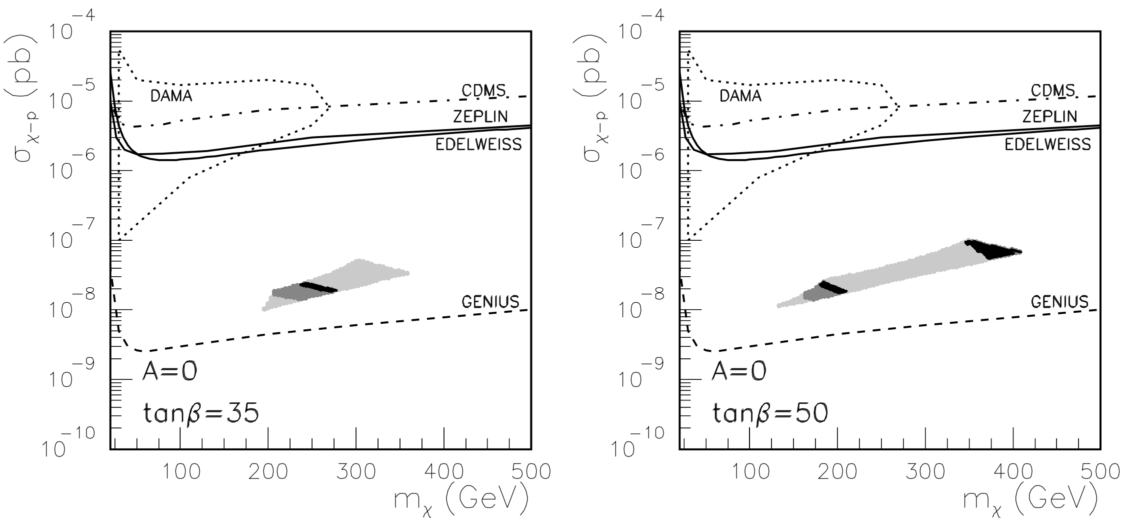
## SUGRA scenario with non-universal gaugino masses

$$M_1 = M(1+\delta_1),\ M_2 = M(1+\delta_2),\ M_3 = M(1+\delta_3)$$

For example, if $M_3$ is small, $m^2_{H_u}$ at low energy will be less negative, and then $\mu^2$ will become smaller $\Rightarrow$ larger cross section

However, small values of $M_3$ also lead to an important decrease in the Higgs mass

For instance, using $\delta_{1,2} = 0, \delta_3 = -0.5$:




Regions excluded by the UFB-3 constraint are not very relevant

$$\sigma_{\tilde{\chi}^0_1-n} \lesssim 10^{-7}\ \text{pb}$$

$$m^2_{H_d} = m^2(1+\delta_d) \ , \quad m^2_{H_u} = m^2(1+\delta_u)$$

One can increase the cross section:

♣ reducing $\mu$ through $\delta_u > 0$

♣ decreasing $m_A^2$ through $\delta_d < 0$

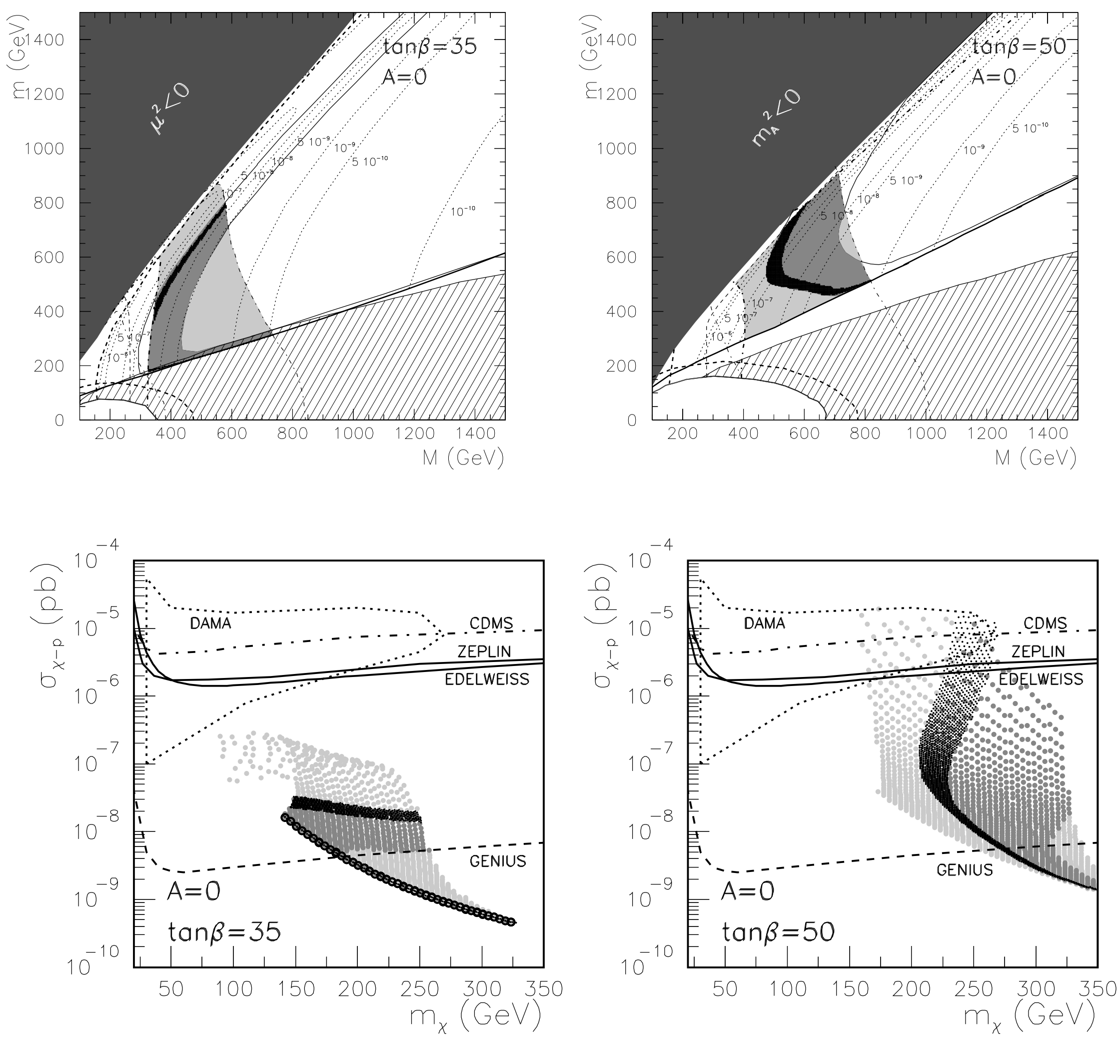
Three representative cases:

a) $\delta_d = 0 \ , \delta_u = 1$

b) $\delta_d = -1 \ , \delta_u = 0$

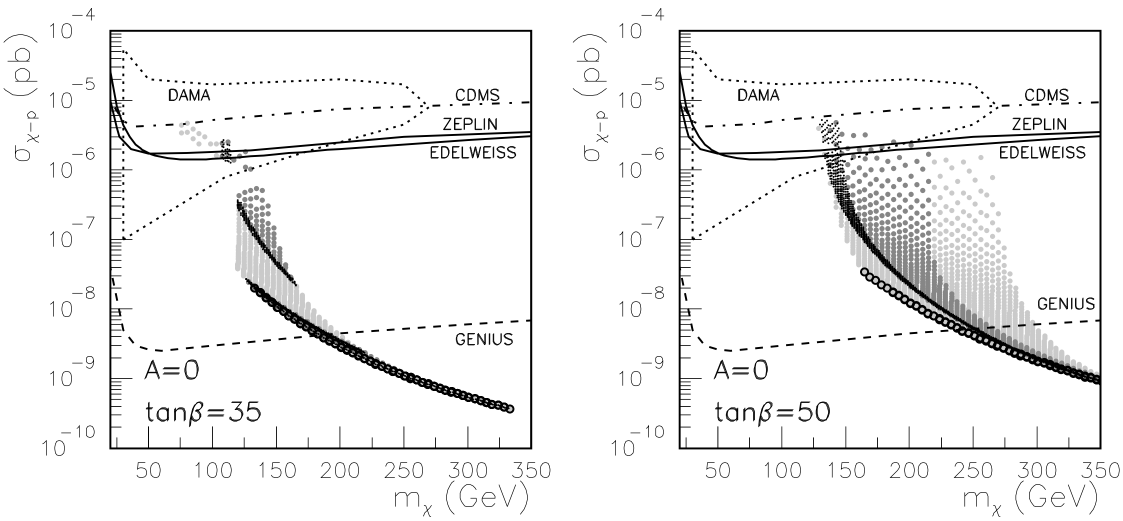
c) $\delta_d = -1 \ , \delta_u = 1$

Case a)



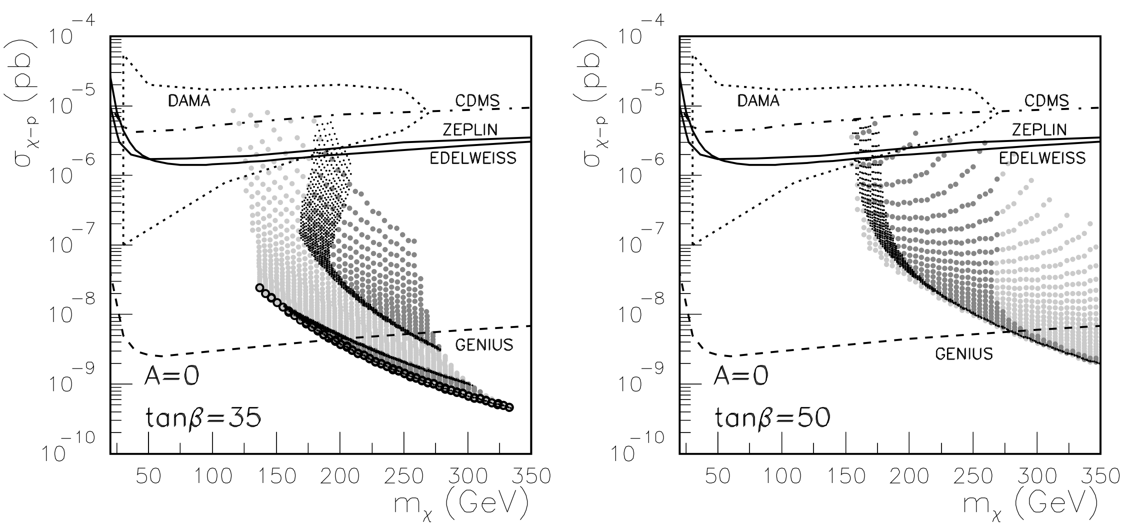

$\delta_u > 0.85$ is sufficient to enter in DAMA fulfilling all constraints

Case b) $\delta_d = -1$ , $\delta_u = 0$




For $\tan\beta = 50$, $\delta_d \lesssim -0.4$ is sufficient to enter in DAMA fulfilling all constraints

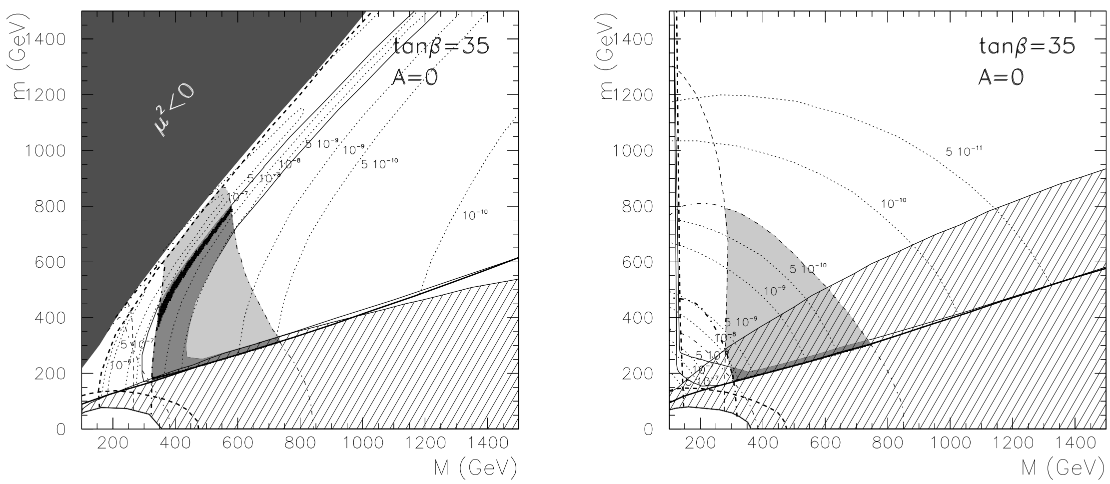
Case c) $\delta_d = -1$ , $\delta_u = 1$




Large regions accesible for experiments are present

Concerning the restrictions coming from the UFB-3 constraint, these are slightly less important than in the universal scenario

This is not a general result, and different choices of the $\delta$'s can modify the situation. For example, for the same case as before, a) $\delta_d = 0 \, , \delta_u = 1$, but using the opposite choice for the sign of the $\delta$ parameters, not only the cross section is smaller, $\sigma_{\tilde{\chi}_1^0 - n} < 10^{-8}$ pb, but also the UFB-3 constraint is very restrictive, forbidding all points which are allowed by the experimental and astrophysical constraints.




a) $\delta_d = 0 \, , \delta_u = 1$ $\qquad$ $\delta_d = 0 \, , \delta_u = -1$

$$m_{H_u}^2 = m^2(1 + \delta_u)$$

$$V_{\rm UFB-3} \approx (m_{H_u}^2 + m_{L_i}^2)|H_u|^2 + \frac{|\mu|}{\lambda_{e_j}}(m_{L_j}^2 + m_{e_j}^2 + m_{L_i}^2)|H_u|$$

# Superstring scenarios

D-brane scenarios from the Type I String with the gauge group and particle content of the SUSY standard model lead naturally to intermediate values for the string scale, in order to reproduce the value of gauge couplings deduced from experiments

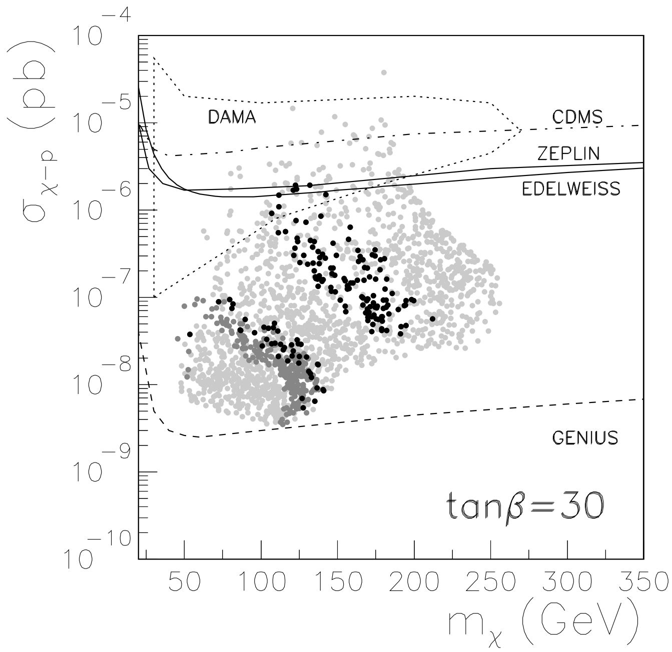
In addition, the soft terms turn out to be generically non universal

$$M_3 = \sqrt{3} m_{3/2} \sin\theta$$
$$M_2 = \sqrt{3} m_{3/2}\, \Theta_1 \cos\theta$$
$$M_Y = \sqrt{3} m_{3/2}\, \alpha_Y(M_I) \left( \frac{2\, \Theta_3 \cos\theta}{\alpha_1(M_I)} + \frac{\Theta_1 \cos\theta}{\alpha_2(M_I)} + \frac{2\ \sin\theta}{3\alpha_3(M_I)} \right)$$

$$m^2_{Q_L} = m^2_{3/2} \left[1 - \tfrac{3}{2}\left(1 - \Theta_1^2\right)\cos^2\theta\right]$$
$$m^2_{d_R} = m^2_{3/2} \left[1 - \tfrac{3}{2}\left(1 - \Theta_2^2\right)\cos^2\theta\right]$$
$$m^2_{u_R} = m^2_{3/2} \left[1 - \tfrac{3}{2}\left(1 - \Theta_3^2\right)\cos^2\theta\right]$$
$$m^2_{e_R} = m^2_{3/2} \left[1 - \tfrac{3}{2}\left(\sin^2\theta + \Theta_1^2\cos^2\theta\right)\right]$$
$$m^2_{L_L} = m^2_{3/2} \left[1 - \tfrac{3}{2}\left(\sin^2\theta + \Theta_3^2\cos^2\theta\right)\right]$$
$$m^2_{H_u} = m^2_{3/2} \left[1 - \tfrac{3}{2}\left(\sin^2\theta + \Theta_3^2\cos^2\theta\right)\right]$$
$$m^2_{H_d} = m^2_{3/2} \left[1 - \tfrac{3}{2}\left(\sin^2\theta + \Theta_2^2\cos^2\theta\right)\right]$$

$$A_u = \frac{\sqrt{3}}{2} m_{3/2} \left[(\Theta_2 - \Theta_1 - \Theta_3)\cos\theta - \sin\theta\right]$$
$$A_d = \frac{\sqrt{3}}{2} m_{3/2} \left[(\Theta_3 - \Theta_1 - \Theta_2)\cos\theta - \sin\theta\right]$$
$$A_e = 0$$

4 free parameters, $m_{3/2}$, $\theta$ and two $\Theta_i$'s since $\sum_{i=1,2,3} |\Theta_i|^2 = 1$



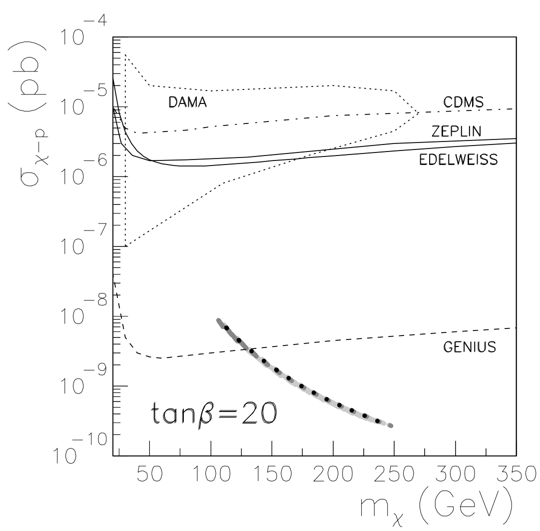

Cerdeño, C.M., in preparation

Orbifold scenarios of the Heterotic String have generically non-universal soft terms

In order to reproduce the value of gauge couplings deduced from experiments, they have

$$M^2 \approx 3m_{3/2}^2\left(1-\cos^2\theta\right)$$
$$m_{Q_L}^2, m_{d_R}^2 = m_{3/2}^2\left(1-\cos^2\theta\right)$$
$$m_{u_R}^2 = m_{3/2}^2\left(1-2\cos^2\theta\right)$$
$$m_{L_L}^2, m_{e_R}^2 = m_{3/2}^2\left(1-3\cos^2\theta\right)$$
$$m_{H_u}^2 = m_{3/2}^2\left(1-\cos^2\theta\right)$$
$$m_{H_d}^2 = m_{3/2}^2\left(1-4\cos^2\theta\right)$$

$M > m$ produces:




Cerdeño, C.M., in preparation

In addition, the UFB-3 constraint excludes all these points

# CONCLUSIONS

♣ Impressive experimental efforts in order to obtain a direct detection of WIMPs ...Heidelberg-Moscow, IGEX, UKDMC, DAMA, CDMS, upgraded IGEX, HDMS, DAMA 250 kg, CDMS Soudan, CRESST, CUORE, GENIUS, EDELWEISS, MACHe3, PICASSO, ORPHEUS, ZEPLIN, DRIFT,...

♣ From the theoretical point of view, there are also efforts analyzing the compatibility of different models with the sensitivity of experiments

- The absence of dangerous charge and colour breaking minima imposes interesting constraints on the computation of $\sigma_{\tilde{\chi}_1^0 - nucleon}$
- $\sigma_{\tilde{\chi}_1^0 - nucleon}$ in mSUGRA is not compatible with present experiments
- Larger $\sigma_{\tilde{\chi}_1^0 - nucleon}$ can be obtained with non-universal scalar masses $\rightarrow$ Large regions accesible for experiments are present
- D-brane constructions are explicit scenarios where intermediate scales and non-universal soft terms arise naturally $\rightarrow$ Regions compatible with current experiments