# Large Dark Matter Cross Section from Supergravity and Superstrings

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# INTRODUCTION

- Recent intriguing experimental results might imply

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

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

- Unfortunately, working in the SUGRA framework for the MSSM with universal soft terms ($m$, $M_{1/2}$, $A$), the LSP is mainly Bino and for low and moderate values of $\tan\beta$

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

Recently, several proposals have been made in order to modify this result:

- To work in the large $\tan\beta$ regime
- To work with non-universal soft scalar masses $m_\alpha$

  Bottino, Donato, Fornengo, Scopel
  Accomando, Arnowitt, Dutta, Santoso
  Gómez, Vergados

- Non-universal soft gaugino masses $M_i$

  Corsetti, Nath
  Cerdeño, Khalil, C.M.

- Focus point supersymmetry scenario

  Feng, Matchev, Wilczek

Analyses in the context of D-brane scenarios have also been carried out

Khalil, 98

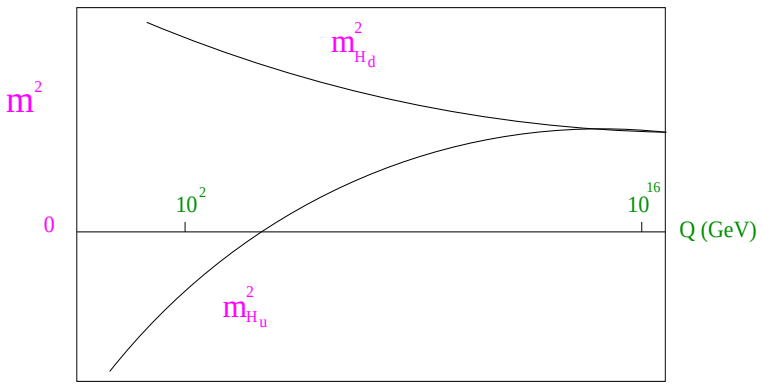
Corsetti, Nath, 00

Arnowitt, Dutta, Santoso, 00

Bailin, Kraniotis, Love, 00

# Initial scales and cross sections

We have pointed out that the analysis of $\sigma_{\tilde{\chi}_1^0-nucleon}$ is modified by taking a scale $M_I$ smaller than $M_{GUT} \approx 10^{16}$ GeV



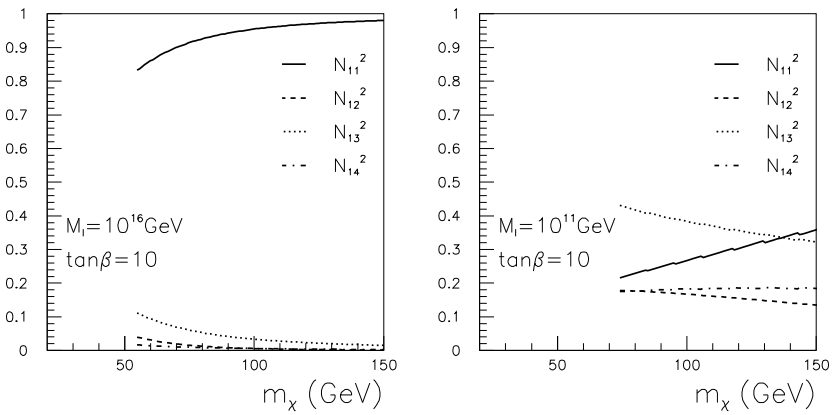

For $\tan\beta$ fixed, the smaller the initial scale for the running is, the smaller the value of $\mu$ becomes.

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

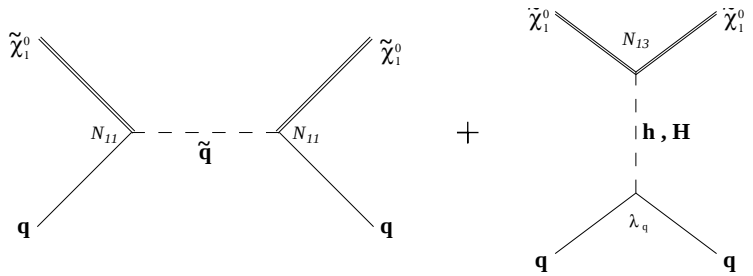
since $\mathcal{L} \sim \mu \tilde{H}_u^0 \tilde{H}_d^0 +$ h.c., the lightest neutralino $\tilde{\chi}_1^0$ will have an important Higgsino component

$$\Downarrow$$

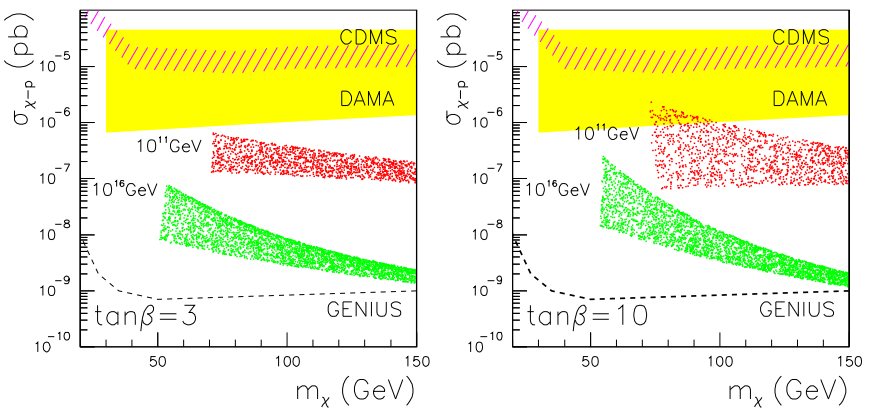
larger $\sigma_{\tilde{\chi}_1^0-nucleon}$




Gaugino-Higgsino components-squared of the lightest neutralino as a function of its mass




Feynman diagrams contributing to neutralino-nucleon cross section.




Scatter plot using universal soft terms with 30 GeV $\leq m \leq$ 550 GeV

# SUPERSTRINGS

It has been realized that the string scale may be anywhere between the weak scale and the Planck scale

Lykken, 96

Arkani-Hamed, Dimopoulos, Dvali,

Antoniadis, Bachas, Shiu, Tye, Kakushadze,...

For example, embedding the standard model inside D3-branes in type I strings,

$$M_I^4 = \frac{\alpha M_{\text{Planck}}}{\sqrt{2}} M_c^3$$

Thus one gets $M_I \approx 10^{10-12}$ GeV with $M_c \approx 10^{8-10}$ GeV

Phenomenologically, "intermediate" initial scales $M_I \approx 10^{10-14}$ GeV are specially attractive

Benakli, 99
Burgess, Ibañez, Quevedo, 99

- In order to explain experimental observations such as neutrino masses or the scale for axion physics
- In order to attack the hierarchy problem

$$m_{3/2} \approx \frac{F}{M_{Planck}} \approx \frac{M_I^2}{M_{Planck}} \approx \frac{\left(10^{10-12}\right)^2}{M_{Planck}} \approx M_W$$

- Might also explain the observed ultra-high energy cosmic rays as products of long-lived massive ($\approx 10^{12}$ GeV) string mode decays
- Inflation in models with large internal dimensions might favour also these initial scales

Kaloper, Linde, 99

- Charge and color breaking constraints become less strong

Abel, Allanach, Quevedo, Ibañez, Klein, 2000

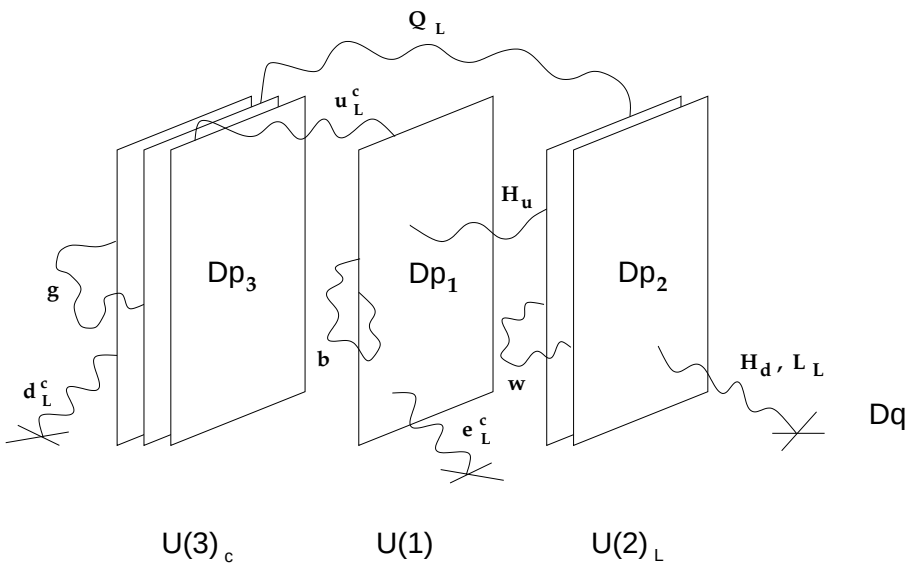
- Helpful concerning the muon anomalous magnetic moment recent experimental results

Cerdeño, Gabrielli, Khalil, C.M., Torrente-Lujan, 2001

D-brane scenarios 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

Due to these results, large cross sections, even in the small $\tan\beta$ regime, can be obtained




$$U(3)_c \times U(2)_L \times U(1) \rightarrow (SU(3)_c \times U(1)_3) \times \left(SU(2)_L \times U(1)_2\right) \times U(1)_1$$

$\alpha_3$ $\alpha_2$ $\alpha_1$

$$\Rightarrow Y = -\frac{1}{3}\, Q_3 - \frac{1}{2}\, Q_2 + Q_1$$

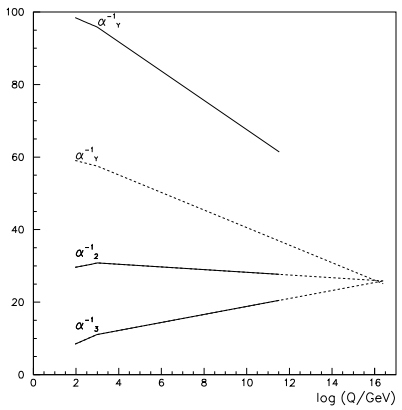
$$\frac{1}{\alpha_Y(M_I)} = \frac{2}{\alpha_1(M_I)} + \frac{1}{\alpha_2(M_I)} + \frac{2}{3\alpha_3(M_I)}$$

$$\Downarrow$$

$$\ln \frac{M_I}{M_Z} = \frac{2\pi\left(\frac{1}{\alpha_Y(M_Z)} - \frac{2}{\alpha_1(M_I)} - \frac{1}{\alpha_2(M_Z)} - \frac{2}{3\alpha_3(M_Z)}\right)}{\left(\frac{2}{3}b_3 + b_2 - b_Y\right)}$$

$$\Downarrow$$

$M_I$ is fixed to intermediate values




Running of the gauge couplings of the MSSM with energy $Q$ embedding the gauge groups within different sets of D$p$-branes (solid lines). For comparison the running of the MSSM couplings with the usual normalization factor for the hypercharge, $3/5$, is also shown with dashed lines.

## **Soft terms** using the parameterization

$$F^S = \sqrt{3}(S+S^*)m_{3/2}\sin\theta$$
$$F^i = \sqrt{3}(T_i+T_i^*)m_{3/2}\cos\theta\,\Theta_i$$

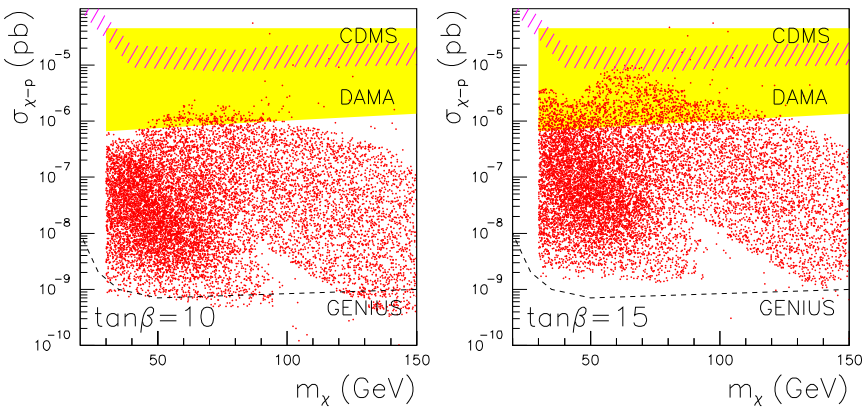
$$M_3 = \sqrt{3}m_{3/2}\sin\theta$$
$$M_2 = \sqrt{3}m_{3/2}\,\Theta_1\cos\theta$$
$$M_Y = \sqrt{3}m_{3/2}\,\alpha_Y(M_I)\left(\frac{2\,\Theta_3\cos\theta}{\alpha_1(M_I)}+\frac{\Theta_1\cos\theta}{\alpha_2(M_I)}+\frac{2\,\sin\theta}{3\alpha_3(M_I)}\right)$$

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

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

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

These soft terms are generically **non-universal**. For example in the overall modulus limit ($\Theta_{1,2,3} = 1/\sqrt{3}$) universality cannot be obtained. The dilaton limit ($\sin^2\theta = 1$) would give rise to tachyonic states $e_R$ and $L_L$.




D-brane scenario with the string scale $M_I = 10^{12}$ GeV

e.g. $\tan\beta > 5$ is enough to obtain compatibility with DAMA

In the analysis the parameters $\theta$ and $\Theta_i$ are varied in the whole allowed range, $0 \leq \theta \leq 2\pi$, $-1 \leq \Theta_i \leq 1$. For the gravitino mass, $m_{3/2} \leq 300$ GeV is taken

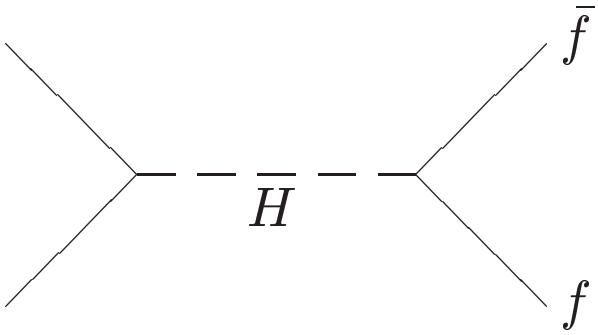
## RELIC DENSITY

Current detectors are sensitive to $\sigma_{\tilde{\chi}_1^0 - nucleon} \approx 10^{-6}$ pb. This value is obtained, basically, from the observational result $\rho_{DM} \approx 0.3$ GeV/cm$^3$.

We were interested in the possibility of obtaining such large $\sigma$'s in the context of intermediate-scale scenarios. In order to compute $\sigma$ only field theory techniques are needed. *No cosmological assumptions about the early Universe need to be used.*

Such cosmological assumptions indeed must be taken into account when computing the amount of relic neutralino density arising from those scenarios. Dark matter observations in the Universe imply that one should obtain $0.01 \lesssim \Omega_{\tilde{\chi}_1^0} h^2 \lesssim 0.3$

- Thermal relic density implies $\Omega\, h^2 \propto 1/\sigma_{\text{annihilation}}$




thus it is expected that high $\sigma_{\tilde{\chi}_1^0 - nucleon}$ will correspond to low $\Omega_{\tilde{\chi}_1^0}$

Likewise there will be a steady increase in the value of the relic density when we move from $M_I \approx 10^{11}$ GeV to $M_I \approx 10^{16}$ GeV

- Moduli decays can produce neutralinos

The decay width $\Gamma_\phi \sim \frac{m_\phi^3}{M}$ would imply $T_R \gtrsim 1$ MeV if $M = M_I$

This is the case of $M_\alpha$ fields in type I strings

$n/s \propto 1/T$ and since $T_R << T_f \approx m_\chi/20$ the relic neutralino density might be larger

# 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

  - We have noted that $\sigma_{\tilde{\chi}_1^0-nucleon}$ in the MSSM is quite sensitive to the value of the initial scale

  - Taking $M_I \approx 10^{10-12}$ GeV rather than $M_{GUT} \approx 10^{16}$ GeV we find in the universal case that $\sigma$ is compatible with current experiments for $\tan\beta > 3$. For larger values, as e.g. $M_I = 10^{14}$ GeV, the compatibility is obtained for $\tan\beta \gtrsim 10$

  - D-brane constructions are explicit scenarios where intermediate scales arise naturally, due to the origin of the $U(1)_Y$ gauge group as a combination of other U(1)'s. In addition, they have in general non-universal soft terms due to the particular matter distribution $\Rightarrow$ Large regions compatible with current experiments