Large Neutralino-Nucleon Cross Section from Supergravity and Superstrings

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INTRODUCTION

♣ Recent intriguing experimental results might imply

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

♣ 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 $\tan\beta$

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

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_α

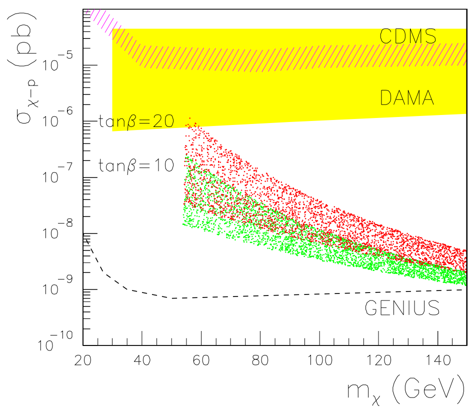
Bottino, Donato, Fornengo, Scopel
Accomando, Arnowitt, Dutta, Santoso
Gómez, Vergados

- Non-universal soft gaugino masses M_i

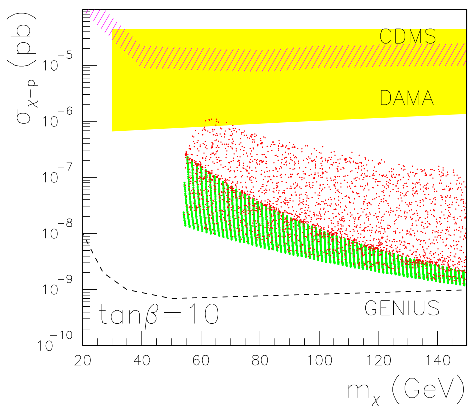
Corsetti, Nath
Cerdeño, Khalil, C.M.

- Focus point supersymmetry scenario

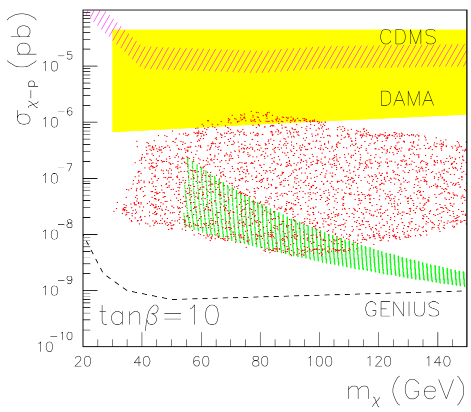
Feng, Matchev, Wilczek



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



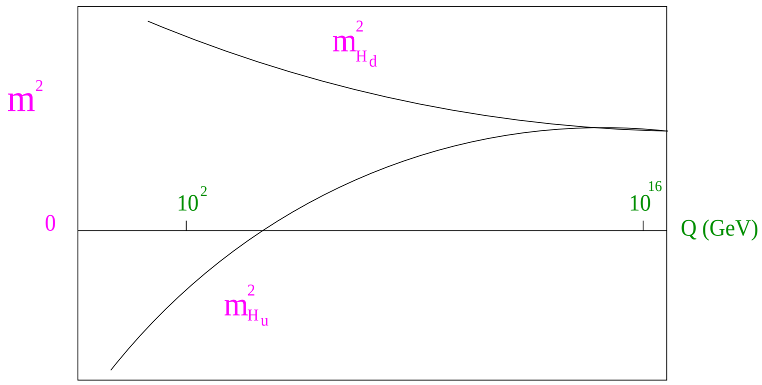
Using non-universal soft scalar masses: $m \leq m^2_{Hu} \leq 2m$, $0 \leq m^2_{H_d,Q_L,u_R} \leq m$



Using non-universal soft gaugino masses

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



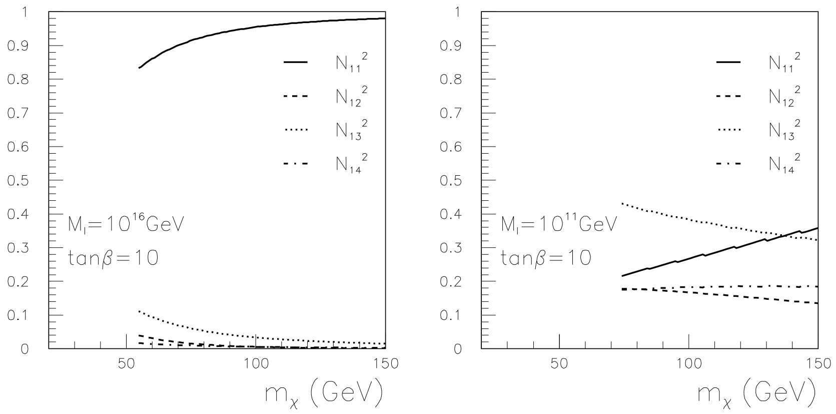
For $\tan\beta$ fixed, the smaller the initial scale for the running is, the smaller the value of μ becomes.

$$\mu^2 = \frac{m^2_{H^0_d} - m^2_{H^0_u}\tan^2\beta}{\tan^2\beta - 1} - \frac{1}{2}M_Z^2$$

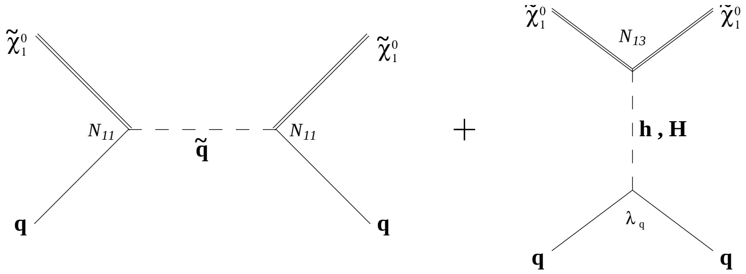
since $\mathcal{L} \sim \mu \tilde{H}^0_u \tilde{H}^0_d$ + h.c., the lightest neutralino $\tilde{\chi}^0_1$ will have an important Higgsino component

$$\Downarrow$$

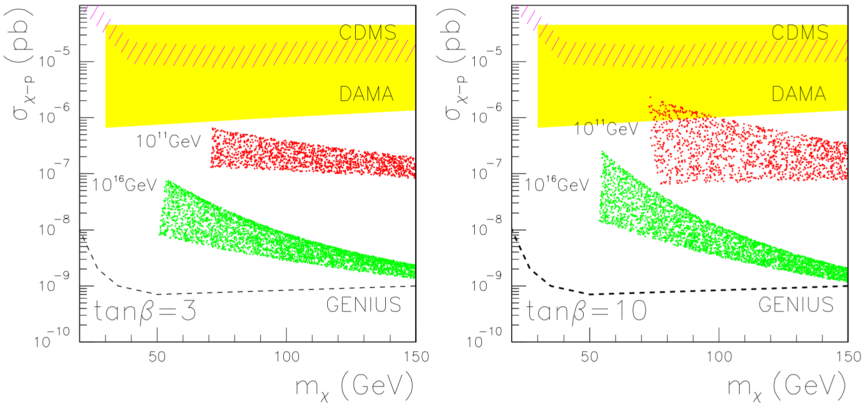
larger $\sigma_{\tilde{\chi}_1^0-nucleon}$



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

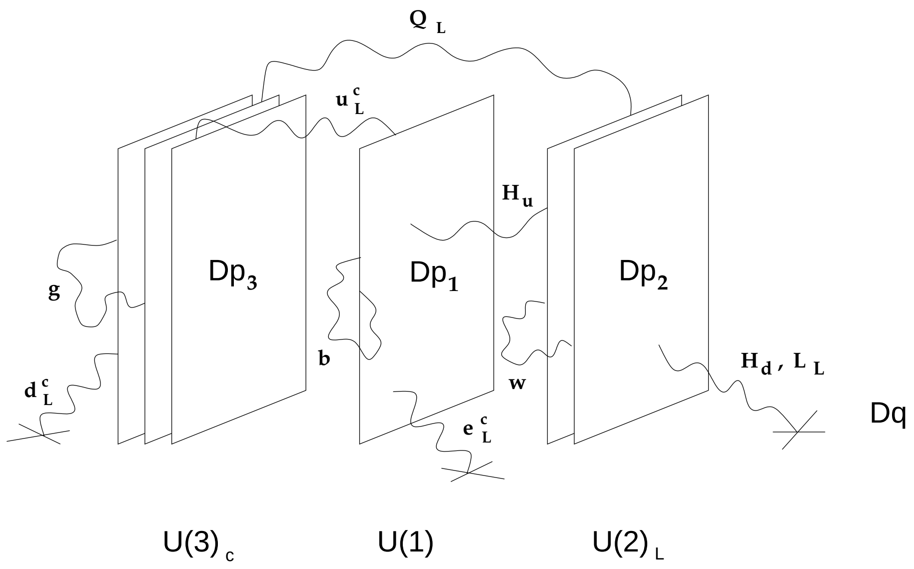
- Helpful concerning the muon anomalous magnetic moment recent experimental results

  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



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

α_3 α_2 α_1

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

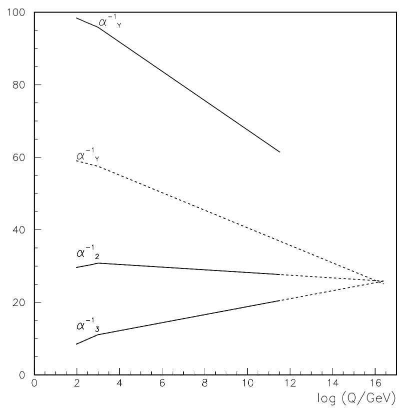
$$\frac{1}{\alpha_Y(M_I)} = \frac{2}{\alpha_1(M_I)} + \frac{1}{\alpha_2(M_I)} + \frac{2}{3\alpha_3(M_I)}$$

$$\Downarrow$$

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

$$\Downarrow$$

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 Dp-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

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

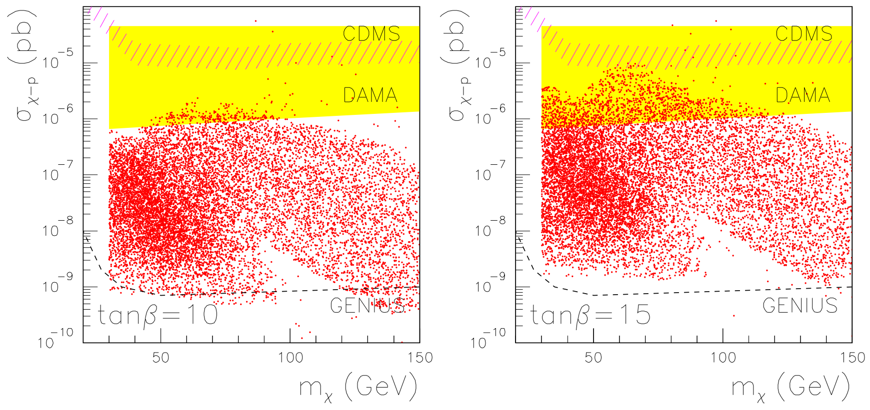
$$M_3 = \sqrt{3} m_{3/2} \sin\theta$$
$$M_2 = \sqrt{3} m_{3/2}\, \Theta_1 \cos\theta$$
$$M_Y = \sqrt{3} m_{3/2}\, \alpha_Y(M_I) \left(\frac{2\ \Theta_3 \cos\theta}{\alpha_1(M_I)} + \frac{\Theta_1 \cos\theta}{\alpha_2(M_I)} + \frac{2\ \sin\theta}{3\alpha_3(M_I)} \right)$$

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

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

4 free parameters, $m_{3/2}$, θ and two Θ_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 θ and Θ_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

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 σ 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