Large dark matter cross sections from supergravity and superstrings

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We study the direct detection of supersymmetric dark matter in the light of recent experimental results. In particular, we show that regions in the parameter space of several scenarios with a neutralino-nucleon cross section of the order of 10^{-6} pb, i.e., where current dark matter detectors are sensitive, can be obtained. These are supergravity scenarios with intermediate unification scale, and superstring scenarios with D-branes.

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1 Introduction

One of the most interesting candidates for dark matter is a long-lived or stable weakly-interacting massive particle (WIMP). WIMPs can remain from the earliest moments of the Universe in sufficient number to account for a significant fraction of relic density. These particles would form not only a background density in the Universe, but also would cluster gravitationally with ordinary stars in the galactic halos.

This raises the hope of detecting relic WIMPs directly, by observing their elastic scattering on target nuclei through nuclear recoils. Since WIMPs interact with ordinary matter with very roughly weak strength, and assuming that their masses are of the order of weak scale (i.e., between 10 GeV and a few TeV), it is natural to expect a WIMP-nucleus cross section of the same order as that of a weak process, which is around 1 pb. This would imply a WIMP-nucleon cross section around 10^{-8} pb, too low to be detected by current dark matter experiments, which are sensitive to a cross section around 10^{-6} pb. Surprisingly, the DAMA collaboration reported recently [1] data favouring the existence of a WIMP signal in their search for annual modulation. When uncertainties as e.g. the WIMP velocity or possible bulk halo rotation, are included, it was claimed that the preferred range of parameters is (at 4σ C.L.) 10^{-6} pb $\lesssim \sigma \lesssim 10^{-5}$ pb for a WIMP mass 30 GeV $\lesssim m \lesssim 200$ GeV. However, unlike this spectacular result, the CDMS collaboration claims to have excluded [2] regions of the DAMA parameter space.

Given these intriguing experimental results, it is then crucial to re-analyze the compatibility of WIMPs as dark matter candidates, with the sensitivity of current dark matter detectors. To carry this analysis out we have to assume a particular candidate for WIMP. The leading candidate in this class is the lightest neutralino [3], a particle predicted by the supersymmetric (SUSY) extension of the standard model.

In particular, in the minimal supersymmetric standard model (MSSM) there are four neutralinos, $\tilde{\chi}_i^0$ ($i = 1, 2, 3, 4$), since they are the physical superpositions of the fermionic partners of the neutral electroweak gauge bosons, called bino ($\tilde{B}^0$) and wino ($\tilde{W}_3^0$), and of the fermionic partners of the neutral Higgs bosons, called Higgsinos ($\tilde{H}_u^0$, $\tilde{H}_d^0$). Therefore the lightest neutralino, $\tilde{\chi}_1^0$, will be the dark matter candidate. We parameterize the gaugino and Higgsino content of the lightest neutralino according to

$$\tilde{\chi}_1^0 = N_{11}\tilde{B}^0 + N_{12}\tilde{W}_3^0 + N_{13}\tilde{H}_d^0 + N_{14}\tilde{H}_u^0 \ . \tag{1}$$

It is commonly defined that $\tilde{\chi}_1^0$ is mostly gaugino-like if $P \equiv |N_{11}|^2 + |N_{12}|^2 > 0.9$, Higgsino-like if $P < 0.1$, and mixed otherwise.

The cross section for the elastic scattering of relic neutralinos on protons and neutrons has been examined exhaustively in the literature [4]. This is for example the case in the framework of minimal supergravity (mSUGRA). Let us recall that in this framework one makes several assumptions. In particular, the scalar mass parameters, the gaugino mass parameters, and the trilinear couplings, which are generated once SUSY is broken through gravitational interactions, are universal at the grand unification scale, $M_{GUT} \approx 2 \times 10^{16}$

GeV. They are denoted by m_0, $M_{1/2}$, and A_0 respectively. Likewise, radiative electroweak symmetry breaking is imposed, i.e., the Higgsino mass parameter μ is determined by the minimization of the Higgs effective potential. This implies

$$\mu^2 = \frac{m_{H_d}^2 - m_{H_u}^2 \tan^2 \beta}{\tan^2 \beta - 1} - \frac{1}{2} M_Z^2 \;, \tag{2}$$

where $\tan \beta = \langle H_u^0 \rangle / \langle H_d^0 \rangle$ is the ratio of Higgs vacuum expectation values. With these assumptions, the mSUGRA framework allows four free parameters: m_0, $M_{1/2}$, A_0, and $\tan \beta$. In addition, the sign of μ remains also undetermined.

It was observed (for a recent re-evaluation see ref.[5]) that for low and moderate values of $\tan \beta$ the lightest neutralino is mainly bino, and therefore the predicted scalar neutralino-proton cross sections are well below the accessible experimental regions. In particular, $\sigma_{\tilde{\chi}_1^0 - p} \lesssim 10^{-7}$ pb, and therefore we would have to wait in principle for projected detectors, as e.g. GENIUS [6], to be able to test the neutralino as a dark-matter candidate.

Recently, several proposals have been made in order to modify this result, enhancing the neutralino-nucleon cross section. This is the case of scenarios with large $\tan \beta$ [7]-[9], with non-universal soft SUSY-breaking terms [7, 8, 10], with multi-TeV masses for scalar superpartners known as 'focus point' supersymmetry [11], with intermediate unification scale [12], and finally superstring scenarios with D-branes [13, 10, 14, 15, 16]. In these proceedings we will concentrate only on the last two. A recent review where all the above mentioned scenarios are critically reappraised can be found in ref.[17].

2 Scenarios with intermediate unification scale

The analyses of the neutralino-nucleon cross section in mSUGRA, mentioned above, were performed assuming the unification scale $M_{GUT} \approx 10^{16}$ GeV, as is usually done in the SUSY literature. However, it was recently pointed out [12] that this cross section $\sigma_{\tilde{\chi}_1^0 - p}$ is very sensitive to the variation of the initial scale for the running of the soft terms. In particular, intermediate unification scales were considered. For instance, by taking $M_I = 10^{10-12}$ GeV rather than M_{GUT}, regions in the parameter space of mSUGRA have been found where $\sigma_{\tilde{\chi}_1^0 - p}$ is in the expected range of sensitivity of present detectors, and this even for moderate values of $\tan \beta$ ($\tan \beta \gtrsim 3$). This analysis was performed in the universal scenario for the soft terms. In contrast, in the usual case with initial scale at M_{GUT}, this large cross section is achieved only for $\tan \beta \gtrsim 20$.

The fact that smaller initial scales imply a larger neutralino-proton cross section can be understood from the variation in the value of μ with M_I. One observes that, for $\tan \beta$ fixed, the smaller the initial scale for the running is, the smaller the numerator in the first piece of eq.(2) becomes. This can be understood qualitatively from Fig. 1, where the well known evolution of $m_{H_d}^2$ and $m_{H_u}^2$ with the scale is schematically shown. Clearly, the smaller the initial scale is, the shorter the running becomes. As a consequence, also
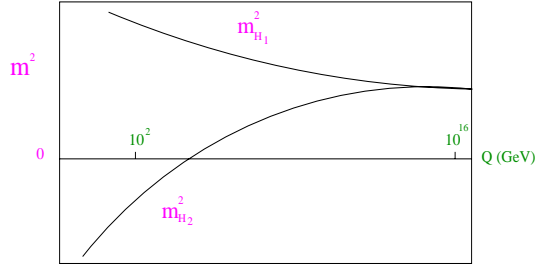
Figure 1: Running of the soft Higgs masses-squared with energy Q.

the less important the positive(negative) contribution $m_{H_d}^2(m_{H_u}^2)$ to μ in eq.(2) becomes. Thus $|\mu|$ decreases.

Now, since $\mathcal{L} \sim \mu \tilde{H}_u^0 \tilde{H}_d^0 + $ h.c., the Higgsino components of the lightest neutralino, N_{13} and N_{14} in eq.(1), increase. In Fig. 2, for $\tan\beta = 10$ and $m_0 = 150$ GeV, we exhibit the gaugino-Higgsino components-squared N_{1i}^2 of the lightest neutralino as a function of its mass $m_{\tilde{\chi}_1^0}$ for two different values of the initial scale, $M_I = 10^{16}$ GeV $\approx M_{GUT}$ and $M_I = 10^{11}$ GeV. Clearly, the smaller the scale is, the larger the Higgsino components become. For $M_I = 10^{11}$ GeV, e.g. the Higgsino contribution N_{13} becomes important and even dominant for $m_{\tilde{\chi}_1^0} \lesssim 140$ GeV. Then, the scattering channels through Higgs exchange shown in Fig. 3 are important, and therefore the cross section may be large.
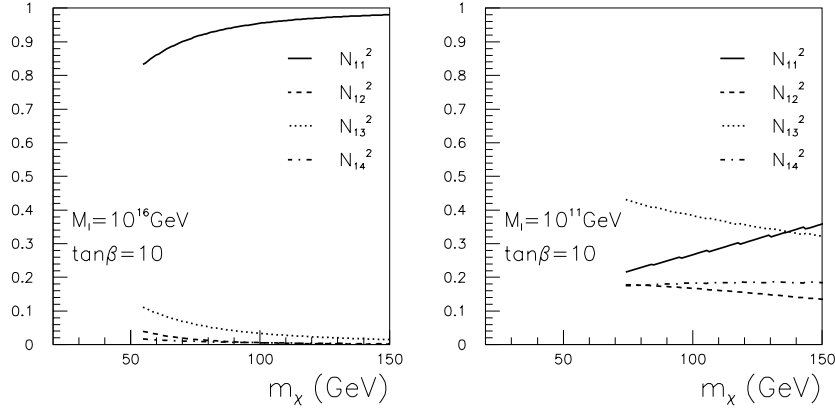

Figure 2: Gaugino-Higgsino components-squared of the lightest neutralino as a function of its mass for the unification scale, $M_I = 10^{16}$ GeV, and for the intermediate scale, $M_I = 10^{11}$ GeV.
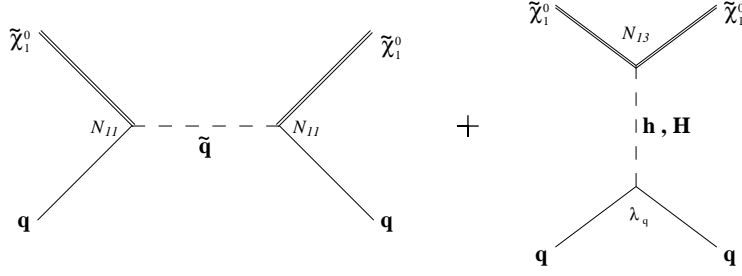
Figure 3: Feynman diagrams contributing to neutralino-nucleon cross section.

This is shown in Fig. 4, where the cross section as a function of the lightest neutralino mass $m_{\tilde\chi_1^0}$ is plotted. In particular we are comparing the result for the scale $M_I = M_{GUT}$ with the result for the intermediate scale $M_I = 10^{11}$ GeV. For instance, when $m_{\tilde\chi_1^0} = 100$ GeV, $\sigma_{\tilde\chi_1^0-p}$ for $M_I = 10^{11}$ GeV is two orders of magnitude larger than for M_{GUT}. In particular, for $\tan\beta = 3$, one finds $\sigma_{\tilde\chi_1^0-p} \lesssim 10^{-7}$ pb if the initial scale is $M_I = 10^{16}$ GeV. However $\sigma_{\tilde\chi_1^0-p} \lesssim 10^{-6}$ GeV is possible if M_I decreases.

It is also worth noticing that, for any fixed value of M_I, the larger $\tan\beta$ is, the larger the Higgsino contributions become, and therefore the cross section increases. For $\tan\beta = 10$ we see in Fig. 4 that the range 70 GeV $\lesssim m_{\tilde\chi_1^0} \lesssim$ 100 GeV is now consistent with DAMA limits.
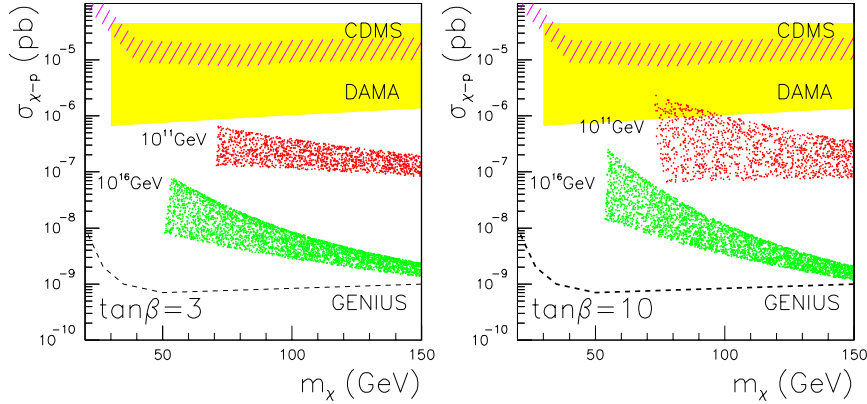

Figure 4: Scatter plot of the neutralino-proton cross section as a function of the neutralino mass for two values of the initial scale, $M_I = 10^{16}$ GeV and 10^{11} GeV, and for $\tan\beta = 3$ and 10. DAMA and CDMS current experimental limits and projected GENIUS limits are shown.

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Let us remark that these figures have been obtained [12] taking $30 \lesssim m_0 \lesssim 550$ GeV and $A_0 = M_{1/2}$. In any case, the cross section is not very sensitive to the specific values of A_0. In particular it was checked that this is so for $\mid A_0/M_{1/2} \mid \lesssim 1$.

Let us finally recall that non universality of the soft terms in addition to intermediate scales may introduce more flexibility in the computation. In particular, decreasing $|\mu|$ in order to obtain regions in the parameter space giving rise to cross sections compatible with the sensitivity of current detectors, may be easier.

3   Superstring scenarios

In the above section the analyses were performed assuming intermediate unification scales. In fact, this situation can be inspired by superstring theories, since it was recently realized that the string scale may be anywhere between the weak and the Plank scale [18]-[24]. For example, embedding the standard model inside D3-branes in type I strings, the string scale is given by:

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

where α is the gauge coupling and M_c is the compactification scale. Thus one gets $M_I \approx 10^{10-12}$ GeV with $M_c \approx 10^{8-10}$ GeV.

Then, to use the value of the initial scale, say M_I, as a free parameter for the running of the soft terms is particularly interesting. In addition, there are several arguments in favour of SUSY scenarios with scales $M_I \approx 10^{10-14}$ GeV. These scales were suggested [21, 22] to explain many experimental observations as neutrino masses or the scale for axion physics. With the string scale of the order of 10^{10-12} GeV one is also able to attack the hierarchy problem of unified theories without invoking any hierarchically suppressed non-perturbative effect [21, 22]. In supergravity models supersymmetry can be spontaneously broken in a hidden sector of the theory and the gravitino mass, which sets the overall scale of the soft terms, is given by $m_{3/2} \approx \frac{F}{M_{Planck}}$, where F is the auxiliary field whose vacuum expectation value breaks supersymmetry. Since in supergravity one would expect $F \approx M_{Planck}^2$, one obtains $m_{3/2} \approx M_{Planck}$ and therefore the hierarchy problem solved in principle by supersymmetry would be re-introduced. However, if the scale of the fundamental theory is $M_I \approx 10^{10-12}$ GeV instead of M_{Planck}, then $F \approx M_I^2$ and one gets $m_{3/2} \approx M_W$ in a natural way.

There are other arguments in favour of scenarios with initial scales M_I smaller than M_{GUT}. For example, charge and color breaking constraints, which are very strong with the usual scale M_{GUT} [25], become less important [26]. These scales might also explain the observed ultra-high energy ($\approx 10^{20}$ eV) cosmic rays as products of long-lived massive string mode decays. [21, 22] (see ref.[27] for more details about this possibility). Besides, several models of chaotic inflation favour also these scales [28].
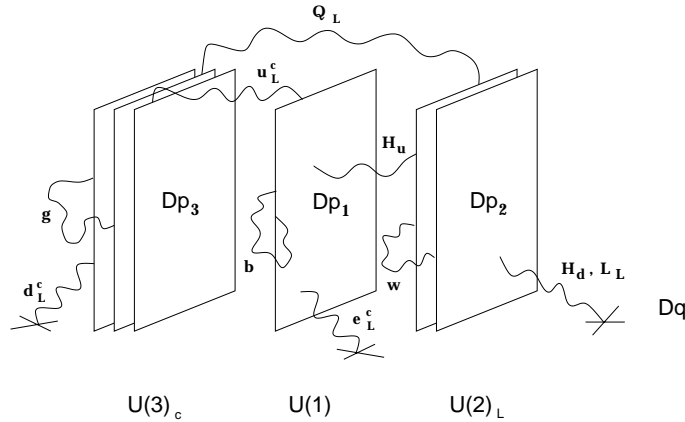
Figure 5: A generic D-brane scenario giving rise to the gauge bosons and matter of the standard model. It contains three Dp_3-branes, two Dp_2-branes and one Dp_1-brane, where p_N may be either 9 and 5_i or 3 and 7_i. The presence of extra D-branes, say Dq-branes, is also necessary. For each set the Dp_N-branes are in fact on the top of each other.

D-brane constructions are explicit scenarios where the two situations mentioned above, namely, non-universality and intermediate scales, may occur. Let us then analyse this possibility.

3.1 D-branes

The first attempts to study dark matter within these constructions were carried out in scenarios with the unification scale $M_{GUT} \approx 10^{16}$ GeV as the initial scale [13, 10, 14] and dilaton-dominated SUSY-breaking scenarios with an intermediate scale as the initial scale [15]. However, the important issue of the D-brane origin of the $U(1)_Y$ gauge group as a combination of other $U(1)$'s and its influence on the matter distribution in these scenarios was not included in the above analyses. When this is taken into account, interesting results are obtained [16]. In particular, 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 in the small $\tan \beta$ regime can be obtained.

Let us consider for example a type I string scenario [16] where the gauge group $U(3) \times U(2) \times U(1)$, giving rise to $SU(3) \times SU(2) \times U(1)^3$, arises from three different types of D-branes, as shown schematically in Fig. 5. For the sake of visualization each set is depicted at parallel locations, but in fact they are intersecting each other. Other examples with the standard model gauge group embedded in D-branes in a different way can be found in ref.[16]. Here $U(1)_Y$ is a linear combination of the three $U(1)$ gauge groups arising from
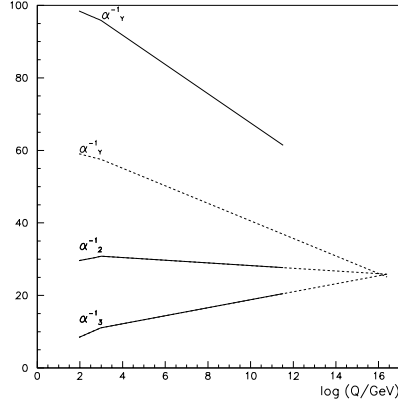
Figure 6: Running of the gauge couplings of the MSSM with energy Q embedding the gauge groups within different sets of Dp-branes (solid lines). Due to the D-brane origin of the $U(1)$ gauge groups, relation (5) must be fulfilled. For comparison the running of the MSSM couplings with the usual normalization factor for the hypercharge, $3/5$, is also shown with dashed lines.

$U(3)$, $U(2)$ and $U(1)$ within the three different D-branes. This implies

$$Y = -\frac{1}{3}Q_3 - \frac{1}{2}Q_2 + Q_1 \ , \tag{4}$$

and therefore,

$$\frac{1}{\alpha_Y(M_I)} = \frac{2}{\alpha_1(M_I)} + \frac{1}{\alpha_2(M_I)} + \frac{2}{3\alpha_3(M_I)} \ , \tag{5}$$

where α_k correspond to the gauge couplings of the $U(k)$ branes. Let us remark that since the D-branes are of different types, the gauge couplings are non-universal. Now, using the RGEs for gauge couplings one obtains

$$\ln \frac{M_I}{M_s} = \frac{2\pi \left(\frac{1}{\alpha_Y(M_Z)} - \frac{2}{\alpha_1(M_I)} - \frac{1}{\alpha_2(M_Z)} - \frac{2}{3\alpha_3(M_Z)} \right) + \left(b_Y^{ns} - b_2^{ns} - \frac{2}{3}b_3^{ns} \right) \ln \frac{M_s}{M_Z}}{\left(\frac{2}{3}b_3^s + b_2^s - b_Y^s \right)} \ , \tag{6}$$

where b_j^s (b_j^{ns}) with $j = 2, 3, Y$ are the coefficients of the supersymmetric (non-supersymmetric) β-functions, and the scale M_s corresponds to the supersymmetric threshold, 200 GeV $\lesssim M_s \lesssim$ 1000 GeV. For example, choosing the value of the coupling associated to the Dp_1-brane in the range $0.07 \lesssim \alpha_1(M_I) \lesssim 0.1$, and the experimental values for $\alpha_{3,2,Y}$, one obtains $M_I \approx 10^{10-12}$ GeV. This scenario is shown in Fig. 6 for $\alpha_1(M_I) = 0.1$ and $M_s = 1$ TeV. Let us remark that the extra $U(1)$'s are anomalous and therefore the associated gauge bosons have masses of the order of M_I.

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The analysis of the soft terms has been done under the assumption that only the dilaton (S) and moduli (T_i) fields contribute to SUSY breaking and it has been found that these soft terms are generically non-universal. Using the standard parameterization [29]

$$F^S = \sqrt{3}(S + S^*)m_{3/2} \sin\theta \ ,$$
$$F^i = \sqrt{3}(T_i + T_i^*)m_{3/2} \cos\theta \ \Theta_i \ , \tag{7}$$

where $i = 1, 2, 3$ labels the three complex compact dimensions, and the angle θ and the Θ_i with $\sum_i |\Theta_i|^2 = 1$, just parameterize the direction of the goldstino in the S, T_i field space, one is able to obtain the following soft terms [16]. The gaugino masses associated to the three gauge groups of the standard model are given by

$$\begin{aligned}
M_3 &= \sqrt{3}m_{3/2} \sin\theta \ , \\
M_2 &= \sqrt{3}m_{3/2} \ \Theta_1 \cos\theta \ , \\
M_Y &= \sqrt{3}m_{3/2} \ \alpha_Y(M_I) \left(\frac{2 \ \Theta_3 \cos\theta}{\alpha_1(M_I)} + \frac{\Theta_1 \cos\theta}{\alpha_2(M_I)} + \frac{2 \ \sin\theta}{3\alpha_3(M_I)} \right) \ .
\end{aligned} \tag{8}$$

The soft scalar masses of the three families are given by

$$\begin{aligned}
m_{Q_L}^2 &= m_{3/2}^2 \left[1 - \frac{3}{2} \left(1 - \Theta_1^2 \right) \cos^2\theta \right] \ , \\
m_{d_R}^2 &= m_{3/2}^2 \left[1 - \frac{3}{2} \left(1 - \Theta_2^2 \right) \cos^2\theta \right] \ , \\
m_{u_R}^2 &= m_{3/2}^2 \left[1 - \frac{3}{2} \left(1 - \Theta_3^2 \right) \cos^2\theta \right] \ , \\
m_{e_R}^2 &= m_{3/2}^2 \left[1 - \frac{3}{2} \left(\sin^2\theta + \Theta_1^2 \cos^2\theta \right) \right] \ , \\
m_{L_L}^2 &= m_{3/2}^2 \left[1 - \frac{3}{2} \left(\sin^2\theta + \Theta_3^2 \cos^2\theta \right) \right] \ , \\
m_{H_u}^2 &= m_{3/2}^2 \left[1 - \frac{3}{2} \left(\sin^2\theta + \Theta_2^2 \cos^2\theta \right) \right] \ , \\
m_{H_d}^2 &= m_{L_L}^2 \ ,
\end{aligned} \tag{9}$$

where e.g. u_R denotes the three family squarks $\tilde{u}_R$, $\tilde{c}_R$, $\tilde{t}_R$. Finally the trilinear parameters of the three families are

$$\begin{aligned}
A_u &= \frac{\sqrt{3}}{2}m_{3/2} \left[(\Theta_2 - \Theta_1 - \Theta_3) \cos\theta - \sin\theta \right] \ , \\
A_d &= \frac{\sqrt{3}}{2}m_{3/2} \left[(\Theta_3 - \Theta_1 - \Theta_2) \cos\theta - \sin\theta \right] \ , \\
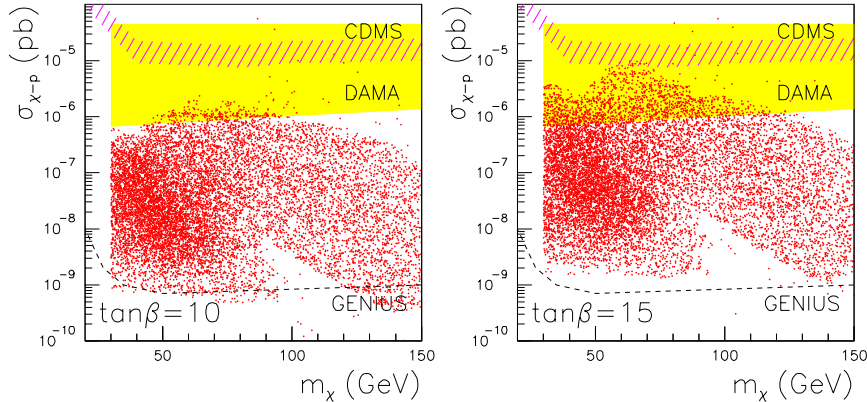A_e &= 0 \ .
\end{aligned} \tag{10}$$

Figure 7: The same as in Fig. 4 but for the D-brane scenario with the string scale $M_I = 10^{12}$ GeV discussed in the text, and for $\tan\beta = 10$ and 15.

Although these formulas for the soft terms imply that one has in principle five free parameters, $m_{3/2}$, θ and Θ_i with $i = 1, 2, 3$, due to relation $\sum_i |\Theta_i|^2 = 1$ only four of them are independent. 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. Concerning Yukawa couplings, their values are fixed imposing the correct fermion mass spectrum at low energies, i.e., one is assuming that Yukawa structures of D-brane scenarios give rise to those values.

Fig. 7 displays a scatter plot of $\sigma_{\tilde\chi_1^0-p}$ as a function of the neutralino mass $m_{\tilde\chi_1^0}$ for a scanning of the parameter space discussed above. Two different values of $\tan\beta$, 10 and 15, are shown. It is worth noticing that for $\tan\beta = 10$ there are regions of the parameter space consistent with DAMA limits. In fact, one can check that $\tan\beta > 5$ is enough to obtain compatibility with DAMA. Since the larger $\tan\beta$ is, the larger the cross section becomes, for $\tan\beta = 15$ these regions increase.

4 Relic neutralino density versus cross section

As discussed in the Introduction, current dark matter detectors are sensitive to a neutralino-proton cross section around 10^{-6} pb. This value is obtained taking into account, basically, that the density of dark matter in our Galaxy, which follows from the observed rotation curves, is $\rho_{DM} \approx 0.3$ GeV/cm^3. Thus in this work we were mainly interested in reviewing the possibility of obtaining such large cross sections in the context of mSUGRA and superstring scenarios. In order to compute the cross section only simple field theory techniques are needed, no cosmological assumptions about the early Universe need to be used.

On the other hand, such cosmological assumptions indeed must be taken into account

when computing the amount of relic neutralino density arising from the above scenarios. Generically, through thermal production of neutralinos, one obtains [4]

$$\Omega_{\tilde{\chi}_1^0} h^2 \simeq \frac{C}{< \sigma_{\tilde{\chi}_1^0}^{ann} . v >} \ , \tag{11}$$

where $\sigma_{\tilde{\chi}_1^0}^{ann}$ is the cross section for annihilation of a pair of neutralinos into standard model particles, v is the relative velocity between the two neutralinos, and $< .. >$ denotes thermal averaging. The constant C involves factors of Newton's constant, the temperature of the cosmic background radiation, etc. Then one may compare this result with dark matter observations in the Universe. Let us then discuss briefly the effect of relic neutralino density bounds on cross sections.

The most robust evidence for the existence of dark matter comes from relatively small scales, in particular, from the flat rotation curves of spiral Galaxies. On the opposite side, observations at large scales, have also provided estimates of Ω_{DM}. Taking both kind of observations one is able to obtain a favoured range [3] $0.1 \lesssim \Omega_{DM} h^2 \lesssim 0.3$, where h is the reduced Hubble constant. It is worth noticing, however, that more conservative lower limits have also been quoted in the literature (a brief discussion can be found in ref.[17] and references therein).

As is well known, for $\sigma_{\tilde{\chi}_1^0}^{ann}$ of the order of a weak-process cross section, $\Omega_{\tilde{\chi}_1^0}$ obtained from eq.(11) is within the favoured range discussed above [4]. This is precisely the generic case when the lightest neutralino is mainly bino. Then, the neutralino-nucleus cross section is of the order of 1 pb, i.e. $\sigma_{\tilde{\chi}_1^0-p} \approx 10^{-8}$ pb, and therefore it is natural to obtain that neutralinos annihilate with very roughly the weak interaction strength. In fact, for these cross sections, there is always a set of parameters which yield $0.1 < \Omega_{\tilde{\chi}_1^0} h^2 < 0.3$. This analysis, including a complete treatment of coannihilations was carried out in refs.[5, 30].

On the other hand, in these proceedings we were interested in larger neutralino-nucleon cross sections in order to be in the range of sensitivity of current dark matter detectors. It is then expected that such high neutralino-proton cross sections $\sigma_{\tilde{\chi}_1^0-p} \approx 10^{-6}$ pb, as those presented in Sections 2 and 3, will correspond to relatively low relic neutralino densities. This is in fact the general situation [12, 15, 16].

Let us remark, however, that thermal production of neutralinos is not the only possibility, moduli decays can also produce neutralinos. Since the decay width of the moduli is $\Gamma_\phi \sim \frac{m_\phi^3}{M^2}$, scenarios with intermediate scales might give rise to cosmological results different from the usual ones summarized in eq.(11). Note that if $M = M_I$ the usual moduli problem may be avoided since a reheating temperature T_{RH} small but larger than 1 MeV can be obtained. This is e.g. the case of the twisted moduli fields M_α in type I strings. Recall that $n/s \propto 1/T$ and since we can have a situation with $T_{RH} << T_f \approx m_\chi/20 \sim \mathcal{O}(1$ GeV), the relic neutralino density might be larger than in the usual case of thermal production. As a consequence, $\Omega_{\tilde{\chi}_1^0} h^2 > 0.1$ may be obtained [31].

5   Final comments and outlook

In the present proceedings we have studied the direct detection of supersymmetric dark matter in the light of recent experimental efforts. In particular, DAMA collaboration using a NaI detector has reported recently data favouring the existence of a WIMP signal in their search for annual modulation. They require a large cross section of the order of 10^{-6} pb. We have observed that there are regions in the parameter space of mSUGRA scenarios with intermediate scales and superstring scenarios with D-branes where such a value can be obtained, although it is fair to say that smaller values can also be obtained and even more easily. The latter result may be important since CDMS collaboration using a germanium detector has reported a null result for part of the region explored by DAMA. Clearly, more sensitive detectors producing further data are needed to solve this contradiction. Fortunately, many dark matter detectors are being projected. This is the case e.g. of DAMA 250 kg., CDMS Soudan, GENIUS, etc. where values of the cross section as low as 10^{-9} pb will be accesible.

In summary, underground physics as the one discussed here in order to detect dark matter is crucial. Even if neutralinos are discovered at future particle accelerators such as LHC, only their direct detection due to their presence in our galactic halo will confirm that they are the sought-after dark matter of the Universe.

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