

A lower limit on the neutralino mass in the MSSM with non-universal gaugino masses.

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Abstract

We discuss constraints on SUSY models with non-unified gaugino masses. We concentrate on the slepton/gaugino sector and obtain a lower limit on the neutralino mass combining direct limits, indirect limits as well as relic density measurements.

1 Introduction

In the framework of the mSUGRA model which contains a rather limited number of parameters, many detailed analysis on the constraints from various collider experiments, high precision lower energies measurements as well as from the point of view of dark matter have been performed [1]-[4]. However it is interesting to relax some of the assumptions that go into mSUGRA and strive for a more model independent approach [5]-[7].

The main limits on the MSSM parameters come from LEP and Tevatron direct searches for SUSY particles and for the Higgs as well as from the muon anomalous moment $(g-2)_\mu$, the $b \rightarrow s\gamma$ process and the relic density of the lightest supersymmetric particle (LSP). The LEP limits, the $(g-2)_\mu$ limit as well as, to a large extend, the relic density, affect mainly the gaugino and slepton sector. On the other hand, the Tevatron is more sensitive to the coloured sector while the Higgs mass lower limit severely restricts the low $\tan\beta$ region and is much dependent on the squark sector (especially $m_{\tilde{t}}$ and A_t). The branching ratio for $b \rightarrow s\gamma$ also constrains the squark sector although it has some influence on the parameters of the gaugino/higgsino sector as it strongly favors $\mu > 0$.

A model independent approach with a manageable number of free parameters is then possible when one restricts oneself to the gaugino/sleptons sectors making only mild assumptions about the reminder of the MSSM parameters. Of particular interest is the lower limit on the neutralino mass that can be obtained in a general model. Indeed a light neutralino LSP opens the door for a sizeable branching fraction of the Higgs into invisible thus reducing universally the branching fractions into the usual discovery channels for a light Higgs, $h \rightarrow \gamma\gamma$ or $h \rightarrow b\bar{b}$ [8]. This possibility has triggered analyses by the LHC experiments to search for the Higgs with a sizeable branching fraction into invisible [9].

Here we concentrate solely on the lower limit on the neutralino mass in the general MSSM model. In particular we treat the case where the masses of $\tilde{l}_R$ and $\tilde{l}_L$ are not correlated. We also discuss the $\mu < 0$ as well as the large $\tan\beta$ cases even though they do not lead to the largest invisible Higgs width.

2 MSSM parameters

In the approach we are taking, the free parameters include the ones of the gaugino/higgsino sector as well as the parameters of the slepton sector. We consider two options, a model reminiscent of mSUGRA models featuring a common mass for the sleptons at the GUT scale (model M0) and a model where the slepton masses are not correlated (model LR). We impose universality among the generations. Altogether we allow 6(7) free parameters in model M0 (LR):

$$\tan \beta, M_1, M_2, \mu, A_l, m_0 \quad (m_{\tilde{e}_L}, m_{\tilde{e}_R}) \quad (1)$$

Using the renormalization group equations the masses at the weak scale can be related to the ones at the GUT scale, in model M0. For sleptons this can be done rather independently of the other MSSM parameters [8]. We assume that all the squarks are heavy and that the pseudoscalar mass M_A is large. We will only consider values of $\tan \beta > 5$ to make it easier to satisfy the direct limit $m_h > 114 \text{ GeV}$. To characterize the amount of non universality we define the parameter $r_{12} = \frac{M_1}{M_2}$. For scans over parameter space, unless otherwise specified, we will consider the range

$$5 < \tan \beta < 50, M_2 < 2 \text{ TeV}, .001 < r_{12} < .6, |\mu| < 1 \text{ TeV}, m_0(m_{\tilde{e}_L}, m_{\tilde{e}_R}) < 1 \text{ TeV} \quad (2)$$

We will usually fix $A_l = 0$ as most of the processes we will discuss are not very sensitive to the exact value of this parameter for the sleptons. For the squarks we take a value for A_t that gives a large enough Higgs mass.

3 Direct limits from LEP

The direct limits from LEP on gauginos as well as on sleptons are relevant to obtain a lower bound on the lightest neutralino as the sleptons play an important role in the relic density calculation. The LEP experiments obtain a lower limit on the neutralino mass while assuming unified gaugino masses at the GUT scale. The constraint on the neutralino mass is basically derived from the lower limit on the chargino mass obtained in the pair production process. The lower bound on the chargino rests near the kinematic limit, $m_{\chi^\pm}^+ > 103.5 \text{ GeV}$ when sneutrinos are heavy, and drops to $m_{\chi^\pm}^+ > 73 \text{ GeV}$ when $75 < m_{\tilde{\nu}} < 85 \text{ GeV}$ due to the destructive interference between the t- and s-channel contributions. In a general MSSM, the charginos and neutralino masses are uncorrelated and the lower limit on the neutralino mass weakens when $r_{12} < .5$. The production of $\chi_1^0 \chi_2^0 (\chi_3^0)$ can be used to somewhat constrain the parameter space. In our scans we implemented the upper limit from the L3 experiment on these cross-sections [10]. For selectrons, a limit of 99.5 GeV can be set on both $\tilde{e}_L$ as well as $\tilde{e}_R$ in the case of a light neutralino, whereas basically model independent limits of $m_{\tilde{\mu}} > 96 \text{ GeV}$ and $m_{\tilde{\tau}} > 86 \text{ GeV}$ can be reached [11].

The radiative processes where a photon is emitted in addition to a pair of invisibly decaying supersymmetric particles will contribute to the process $e^+e^- \rightarrow \gamma + \text{invisible}$ which has been searched for by the LEP2 experiments. Such processes can be used to

search for the lightest neutralino [12] or sneutrinos decaying to $\tilde{\nu} \rightarrow \chi^0 \nu$. The radiative processes can also help closing some loopholes in the LEP analyses in the case of charged sparticles that decay invisibly when they are nearly degenerate in mass with the LSP. Using calcHEP [13] we have computed all radiative processes involving sleptons and gauginos.

For the lightest neutralino, after scanning over a wide range of parameters in the MSSM, we found that the cross-section could reach $\sigma = 50\text{fb}$ for $m_0 = 100\text{GeV}$. This is below the value reached by LEP, approximately $\sigma < 0.2(.1)\text{pb}$ for one(four) experiment(s). However, for sneutrinos, the cross-section for the radiative process often exceeds these limits. For sleptons nearly degenerate with the LSP, we found lower limits on the neutralino even more stringent than in the case without mass degeneracy, for example, $m_{\tilde{e}_R} \approx m_{\tilde{\chi}_1^0} > 56\text{GeV}$ for $\tan\beta = 10, \mu > 0$ in model M0.

4 Indirect limits : relic density, $(g - 2)_\mu$, $b \rightarrow s\gamma$

A MSSM model with a light neutralino must be consistent at least with the upper limit on the amount of cold dark matter ($\Omega h^2 < .3$). Our calculations of the relic density is based on micrOMEGAs, a program that calculates the relic density in the MSSM including all possible coannihilation channels [14]. For the light neutralino masses under consideration, it is the main annihilation channels that are most relevant, in particular annihilation into a pair of light fermions. Basically two diagrams contribute, s-channel Z (or Higgs) and t-channel sfermion exchange. A light neutralino that is mainly a Bino couples preferentially to right-handed sleptons, the ones that have the largest hypercharge. To have a large enough annihilation rate (in order to bring down the relic density below the upper limit allowed) one needs either a light slepton or a mass close to $M_Z/2$. In the former case, the constraint from LEP plays an important role. In the heavy slepton case, the coupling of the Z should be substantial, which requires that the neutralino should have a certain Higgsino component. This means μ small, but still consistent with the chargino constraint.

Both the theoretical predictions and experimental results on the muon anomalous magnetic moment have been refined on several occasions in the last year. At this conference, we presented results obtained using the bound

$$\delta a_\mu = (23 \pm 15_{|\text{exp.}} \pm 14_{|\text{theo.}}) \times 10^{-10}. \quad (3)$$

Adding linearly the theoretical error to a 2σ experimental error, this translates into

$$-21 < \delta a_\mu \times 10^{10} < 67. \quad (4)$$

Here, the hadronic vacuum polarisation is extracted after averaging the e^+e^- and τ data [15]. This value has been updated in the last few weeks with a more precise experimental result [16] as well as new estimates of the hadronic vacuum polarisation [17]. The allowed 2σ range (using e^+e^- data alone) becomes

$$-3 < \delta a_\mu \times 10^{10} < 67 \quad (5)$$

To be very conservative and since many issues need to be clarified in particular concerning the estimation of the hadronic polarisation, we will still discuss the limits presented in

Eq. 4. Note that in this case, the lower bound corresponds roughly to the 5σ limit based on the most recent results using only e^+e^- data [18]. In that scenario, the values $\mu < 0$, although severely constrained at large $\tan\beta$ are not completely ruled out. Note that in general the sign of μ is strongly correlated to the one of δa_μ , however cancellations between the chargino and the neutralino diagrams can change the relative sign of δa_μ and μ . When $\mu > 0$, only scenarios with large $\tan\beta$, small m_0 and light neutralinos/charginos are expected to exceed the upper limit.

The $b \rightarrow s\gamma$ depends mostly on the squark and gaugino sector. We find that for a given value of $\tan\beta$ it is always possible to find some values of A_t that brings the branching ratio in the allowed range,

$$2.04 \times 10^{-4} < Br(b \rightarrow s\gamma) < 4.42 \times 10^{-4} \quad (6)$$

over the full set of parameter space and that is also consistent with the Higgs mass.

5 Results

1) Heavy sleptons, $m_0 = 500\text{GeV}$.

In the case of heavy sleptons, the main constraint on the neutralino arises from the relic density. The contribution from sfermion exchange to neutralino annihilation should be negligible. Then in order to have a sufficient annihilation rate, which means sufficient coupling to the Z, a certain amount of Higgsino component is necessary. We scanned over the parameters $r_{12}, M_2, \mu, \tan\beta$ as specified in Eq.2. The minimum value for the mass is $m_{\tilde{\chi}_1^0} > 27\text{GeV}$ and occurs for $r_{12} < .2$. This lower bound is more or less independent of $\tan\beta$ and occurs for $|\mu| \approx 100\text{GeV}$. Improving the upper bound on the relic density would strengthen the lower limit on $m_{\tilde{\chi}_1^0}$ by a few GeV's. However one cannot do much better than $\approx 35\text{GeV}$. Indeed, when $m_{\tilde{\chi}_1^0}$ approaches $M_Z/2$, the effect of the Z peak becomes so important that the relic density constraint is easily satisfied. As r_{12} increases, the direct limit from the chargino mass dominates.

2) Light sleptons, $\mu > 0$

One expects the contribution from t-channel sfermions to weaken the constraint from the relic density. Here the constraints on the mass of sfermions from LEP must be taken into account. We show in Fig.1 the lower limit on the neutralino mass as a function of r_{12} after scanning over M_2, μ and m_0 . The lower bound on the neutralino mass rests at 18GeV for $\tan\beta = 10$ and $r_{12} < .2$. This lower bound increases with r_{12} and follows the limit from the chargino mass. At larger values of $\tan\beta$, the relic density constraint is more severe except for $r_{12} < .1$. Furthermore one starts to marginally see the impact of the $(g-2)_\mu$.

3) Light sleptons, $\mu < 0$.

The main difference with the case discussed above is that here the $(g-2)_\mu$ constraint plays an important role. To get some insight on the effect of combining various constraints we first consider the special case, $\mu < 0, r_{12} = .1$. The free parameters are M_2, m_0, μ . As already mentioned it is in the small m_0 region that one finds the lightest neutralino. However, it is precisely in that region of the $m_0 - M_1$ plane that one gets too large a

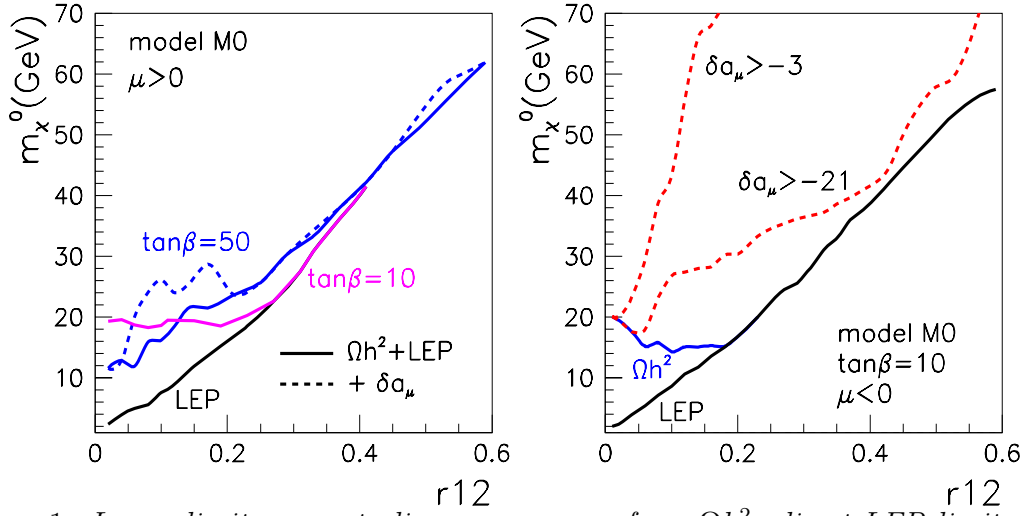


Figure 1: Lower limit on neutralino mass vs r_{12} from Ωh^2 , direct LEP limits as well as $\delta a_\mu > -21(-3) \times 10^{-10}$ for a) $\tan\beta = 10, 50$ and $\mu > 0$ b) $\tan\beta = 10, \mu < 0$.

contribution to δa_μ as displayed in Fig.2 for $\tan\beta = 10$. Coupling the limit from δa_μ with the one from the relic density then considerably strengthens the lower limit on the neutralino mass, $m_{\tilde{\chi}_1^0} > 27\text{GeV}$. Furthermore one finds that the lightest neutralino allowed are necessarily accompanied by light charginos. For larger values of $\tan\beta$, it becomes increasingly difficult to accommodate light neutralinos due to the constraint from δa_μ .

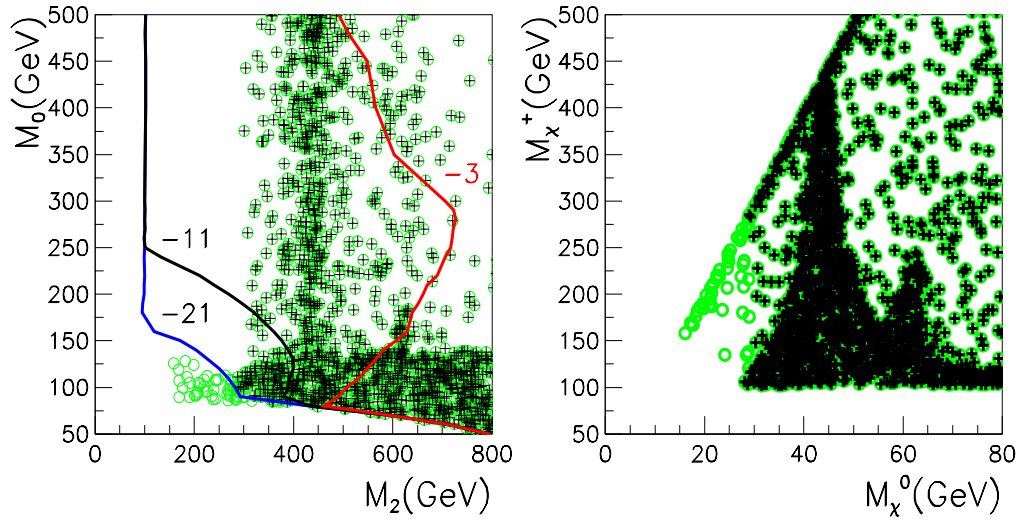


Figure 2: Impact of the $\delta a_\mu = -21 \times 10^{-10}$ constraint (crosses, dark grey) on the allowed region (circles, light grey) in the a) $M_0 - M_2$ plane b) $m_{\tilde{\chi}^+} - m_{\tilde{\chi}_1^0}$ plane for $\mu < 0, r_{12} = .1, \tan\beta = 10$. Contours for $\delta a_\mu = -21, -11, -3 \times 10^{-10}$ are displayed.

From a full scan over the parameter space for $\mu < 0$ we find that combining the three constraints increases the lower bound on the neutralino especially in the $r_{12} \approx .1 - .4$ region (Fig.1). When $M_1 \ll M_2$ cancellations between the neutralino and chargino contributions to δa_μ can occur thus making it possible to have $m_{\tilde{\chi}_1^0} \approx 20\text{GeV}$. The impact

of the $(g-2)_\mu$ is more drastic for very large $\tan\beta$. These results hold for the model M0.

For model LR, allowing light $\tilde{e}_L$ has no significant impact on the relic density contribution which is dominated by $\tilde{e}_R$. However the $(g-2)_\mu$ is much relaxed and basically one recovers more or less the results obtained without the constraint from $(g-2)_\mu$.

6 Conclusion

Combining the upper limit from the relic density of neutralinos with direct limits from LEP on gauginos and sleptons constrains the MSSM with non universal gaugino masses. In particular a lower limit on the neutralino mass is obtained, $m_{\tilde{\chi}_1^0} > 12 - 18\text{GeV}$ for $M_1 \ll M_2$, leaving ample room for an invisibly decaying Higgs boson. The implication of such models at linear colliders are discussed in Ref.[19].

Acknowledgments

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