The MSSM invisible Higgs in the light of dark matter and $g - 2$.

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Abstract

Giving up the assumption of the gaugino mass unification at the GUT scale, the latest LEP and Tevatron data still allow the lightest supersymmetric Higgs to have a large branching fraction into invisible neutralinos. Such a Higgs may be difficult to discover at the LHC and is practically unreachable at the Tevatron. We argue that, for some of these models to be compatible with the relic density, light sleptons with masses not far above the current limits are needed. There are however models that allow for larger sleptons masses without being in conflict with the relic density constraint. This is possible because these neutralinos can annihilate efficiently through a Z-pole. We also find that many of these models can nicely account, at the 2σ level, for the discrepancy in the latest $g - 2$ measurement. However, requiring consistency with the $g - 2$ at the 1σ level, excludes models that lead to the largest Higgs branching fraction into LSP's. In all cases one expects that even though the Higgs might escape detection, one would have a rich SUSY phenomenology even at the Tevatron, through the production of charginos and neutralinos.

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1 Introduction

With the naturalness argument, the latest electroweak data that suggest a light Higgs make supersymmetry the most probable candidate for New Physics especially as it can also solve the dark matter problem. In most scenarios the lightest supersymmetric particle is a neutral, stable, weakly interacting particle: the neutralino LSP. Current limits[1] on both the Higgs and the neutralino in a general SUSY model are such that it is kinematically possible for the Higgs to decay into the lightest neutralino. If the decay rate is substantial the Higgs will be mainly invisible, while its usual branching ratios will be dramatically reduced preventing a detection in the much studied channels at the LHC and the Tevatron. Some theoretical studies[2, 3, 4, 5, 6] have addressed the issue of how to hunt an invisibly decaying Higgs at a hadronic machine, with optimistic conclusions especially in the case of the LHC. At the Tevatron[5] requiring a 5σ discovery of an invisible Higgs with as much as 100% branching into invisibles, $\mathrm{BR_{inv}}$, will need more than $30 fb^{-1}$ for a Higgs mass consistent with the direct limit from LEP. Therefore the prospect for the detection of an invisibly decaying Higgs at the Tevatron seems dim. As for the LHC it has been suggested to use WH/ZH production which could be efficient if $\mathrm{BR_{inv}} > 25\%$ with a luminosity of $100 fb^{-1}$[3], while $t\bar{t}h$[4] would require $\mathrm{BR_{inv}} > 60\%$. Both these studies should be updated and are in need of a full simulation. A recent suggestion[6] has been to exploit the W fusion process. The results for the latter are quite promising since for a luminosity of $100 fb^{-1}$ a branching ratio into invisibles as low as 5% is enough for Higgs discovery. It rests that a full simulation that should tackle the issue of trigger is needed, before one draws definite conclusions. The aim of the present study is to find out how large the branching ratio into neutralinos can be, taking into account the present data and also what accompanying SUSY phenomenology, if any, should we be prepared to look for in such eventuality. This letter is an update and an extension of a comprehensive study we have made recently[7]. Since we will be dealing with a rather light SUSY spectrum we will here also include a discussion about the latest limit on the muon $g-2$ from the E821 experiment[8] and whether the scenarios we are considering help account for the reported discrepancy with the $\mathcal{SM}$ value.

Our starting point is to find out under which conditions a large invisible width of the Higgs due to neutralinos is possible. The width of the lightest Higgs to the lightest neutralinos writes[9]

$$
\begin{aligned}
\Gamma(h \to \tilde{\chi}_1^0 \tilde{\chi}_1^0) &= \frac{G_F M_W m_h}{2\sqrt{2}\pi} \left(1 - 4m_{\tilde{\chi}_1^0}^2/m_h^2\right)^{3/2} |C_{h\tilde{\chi}_1^0\tilde{\chi}_1^0}|^2 \\
\text{where} \quad C_{h\tilde{\chi}_1^0\tilde{\chi}_1^0} &= (O_{12}^N - \tan\theta_W O_{11}^N)(\sin\alpha\, O_{13}^N + \cos\alpha\, O_{14}^N) \\
&\simeq (O_{12}^N - \tan\theta_W O_{11}^N)(\sin\beta\, O_{14}^N - \cos\beta\, O_{13}^N) \ \text{for} \ M_A \gg M_Z \quad (1)
\end{aligned}
$$

O_{ij}^N are the elements of the orthogonal (we assume $\mathcal{CP}$ conservation) matrix which diagonalizes the neutralino mass matrix (for convention and definition, see [7]) . α is the angle that enters the diagonalization of the $\mathcal{CP}$ -even neutral Higgses which in the decoupling limit (large M_A and ignoring radiative corrections) is trivially related to the angle β. $|O_{1j}^N|^2$ defines the composition of the lightest neutralino $\tilde{\chi}_1^0$. $j = 1$ defines the bino component, $j = 2$ the wino, while $j = 3, 4$ give the Higgsino component. It is clear then, apart from phase space, that the LSP has to be a mixture of gaugino and higgsino in order to have a large enough coupling to the Higgs. Since the lightest MSSM Higgs mass can not exceed 135GeV, one must require the LSP to be lighter than about 65GeV. This puts rather strict constraints on M_2 and μ, since these parameters also define the chargino masses whose limit is about 103GeV[1], almost independently of any other SUSY parameter. Thus one needs M_1 to be small enough so that it sets the mass of the neutralino which will then be, to a large degree, a bino. However one can not make μ too small either, otherwise one washes out any higgsino component which is essential to get enough mixing for the neutralino to couple to the Higgs. The fact that one tries to make μ as small as possible means that large mixings entail also light charginos and neutralinos NLSP not far above the present experimental limit. One also finds [7] that positive μ values are preferred. One would think that by taking larger values of $\tan\beta$ one would make the Higgs mass higher which will allow more phase space for the invisible decay. However, we find [7] that the LSP masses increase even faster and their coupling to the Higgs gets smaller with increasing $\tan\beta$. Therefore the largest effects for the invisible Higgs occur for moderate $\tan\beta$.

Most collider constraints on the neutralino refer to the so-called gaugino unification condition $M_1 = \frac{5}{3}\tan^2\theta_W M_2 \simeq M_2/2$. In this case the limit on the lightest neutralino is set by the chargino which in turn leaves very little room for an appreciable Higgs decay into invisible neutralinos. In our previous paper[7] we found that, for such models, this branching is never above 20% and thus does not endanger the searches in the conventional channels. Previously we had concentrated on the case $M_1 = M_2/10$ valid at the electroweak scale and allowed M_2 and μ to vary. Though the value of M_1 with respect to μ was not optimised, substantial branching into invisible was found. In the present analysis we seek a larger higgsino-gaugino mixing and instead of $M_1 = M_2/10$ we also study $M_1 = M_2/5$, at the electroweak scale, in detail. We thus also allow for larger LSP masses which, as we will see, lead to some quite interesting novel features especially as concerns cosmological considerations. We will also investigate which range of M_1, independently of M_2 and μ, give the largest invisible branching ratio.

2   MSSM models for an invisible Higgs and constraints

Our scenario requires as large a Higgs mass as possible without making $\tan\beta$ too large. We will then only consider the MSSM in the decoupling limit with $M_A \sim 1\text{TeV}$ and choose large enough stop masses ($m_{\tilde{t}} = 1\text{TeV}$) and large mixing ($A_t = 2.4\text{TeV}$). With $\tan\beta > 5$, we could essentially consider the Higgs mass as a free parameter. We have imposed $m_h > 113\text{GeV}$ and with our parameters we have $m_h = 125\text{GeV}$ (128GeV) for $\tan\beta = 5(10)$.

The limits on M_1, M_2, μ, the key ingredients for this analysis, are set from the chargino mass limit at LEP2, $m_{\chi_1^\pm} > 103\text{GeV}$[1]. This bound can be slightly relaxed depending on $\tan\beta$ and the sneutrino mass, however we prefer to take the strongest constraint so that our results are more robust. The cross section into neutralinos at LEP2, $\sigma(e^+e^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_2^0 + \tilde{\chi}_1^0\tilde{\chi}_3^0)$ could in principle also help reduce the parameter space for these non-unified gaugino mass models. The neutralino cross section constraint, as opposed to the chargino mass limit, depends crucially on the higgsino content of the produced neutralinos, as well as on the mass of the selectron and the decay pattern. We impose $\sigma(e^+e^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_2^0 + \tilde{\chi}_1^0\tilde{\chi}_3^0 \rightarrow \not{E}\mu^+\mu^-) < .1pb$, for $\sqrt{s} = 208\text{GeV}$. Our formulae for the branching ratios of the heavier neutralinos include all two and three body decays. For the parameters we have studied we find, in fact, that this constraint does not overcome the chargino mass limit. We have also imposed the limits on the invisible width of the Z[10]:

$$\Gamma_{\text{inv}}^Z \equiv \Gamma(Z \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0) < 3MeV \tag{2}$$

We will also take $m_{\tilde{l}} > 96\text{GeV}$, for all sleptons $\tilde{l}$, even though the limit on the lightest stau is slightly lower[1].

Scenarios with low M_1 that have very light neutralino LSP into which the Higgs can decay, suppressing quite strongly its visible modes, can contribute quite substantially to the relic density Ωh^2, if all sfermions are heavy. Indeed, in the models we are considering the LSP is *mainly* (but not totally) a bino. Since it is rather light the annihilation channels are into the light fermions and therefore the largest contributions are from processes involving "right-handed" sleptons. This is because the latter have the largest hypercharge. In this case the relic density may be approximated as $\Omega h^2 \sim 10^{-3}m_{\tilde{l}_R}^4/m_{\tilde{\chi}_1^0}^2$ (all masses in GeV) which shows how the strong constraint on $m_{\tilde{l}_R}$ rapidly sets in. However this limit can become irrelevant in the models we consider. Interestingly, allowing larger neutralino masses than in our previous analysis[7], annihilation through the Z pole, $\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow Z$, can become very effective. The above formula for the relic density no longer holds then. We use a new code[11] for the calculation of the relic density that tackles all s-channels poles, threshold effects and includes all co-annihilations channels (including slepton, neutralino

and chargino co-annihilations). The program extracts all *exact* matrix elements (for about 500 processes) from `CompHEP`[12] and is linked to `HDECAY`[13] and `FeynHiggs`[14] for the Higgs sector. When possible, checks against `DarkSUSY`[15] have been performed. The agreement is generally quite good. In the last few years constraints on the cosmological parameters that enter the calculation of the relic density have improved substantially. Various observations[16] suggest to take as a benchmark $\Omega h^2 < .3$ where we identify Ω with the fraction of the critical energy density provided by neutralinos. h is the Hubble constant in units of 100 km sec^{-1} Mpc^{-1}. This constraint is consistent with limits on the age of the Universe[17], the measurements of the lower multipole moment power spectrum from CMB data and the determination of Ω_{matter} from rich clusters, see [16] for reviews. It also, *independently*, supports data from type Ia supernovae[18] indicative for a cosmological constant. Note that it is not essential to impose the lower bound $\Omega h^2 > .1$. A lower value of Ωh^2 would mean that one needs other form of dark matter than the SUSY models one is considering. Our bound $\Omega h^2 < .3$ can be considered as quite conservative in view of the latest CMB data from BOOMERANG[19], MAXIMA[20] and Dasi[21]. The latter extracts $\Omega h^2 = .14 \pm .04$ almost independently of the choice of a "prior" on h and thus the 2σ upper bound is .22. This is also consistent with the latest BOOMERANG data with a very weak "prior" on h, $.45 < h < .9$ and the requirement of an Universe older than 10Gyr[17]. Combining this with stronger priors including type Ia supernovae[18] and analysis of Large Scale Structure (LSS)[22] together with the theoretical bias $\Omega_{\text{tot}} = 1$, gives the rather precise constraint $\Omega h^2 = .13 \pm .01$, which at 2σ would only allow $\Omega h^2 < .15$ for any SUSY contribution. Although one should be cautious at this stage about using such a strict bound considering that some of the cosmological parameters are still subject to fluctuations, we will comment briefly on how our results change if one takes this strict constraint at face value.

For the calculation of the relic density one needs a model for the SUSY masses. We assumed all squarks to be heavy. In any case squarks compared to "right sleptons" do not contribute much to the annihilation cross section for a bino LSP. On the other hand heavy squarks, especially stops would be required in order to get a heavy enough light Higgs. A simple model would be to take a common scalar mass m_0 (defined at the GUT scale) for the SUSY breaking sfermion mass terms of both left and right sleptons of all three generations. As for the gaugino masses, to obtain $M_1 = rM_2$ at the electroweak scale one needs $\bar{M}_1 \simeq 2r\bar{M}_2$ at the GUT scale. $\bar{M}_2$ is the $SU(2)$ gaugino mass at the GUT scale which again relates to M_2 at the electroweak scale as $M_2 \sim 0.825\bar{M}_2$. For $r < 1/3$ or so, this scheme leads to almost no running of the right slepton mass, since the contribution from the running is of order M_1^2, while left sleptons have an added M_2^2 contribution and would then be "much heavier". Indeed, neglecting Yukawa couplings one may write, with

$M_1 = rM_2$ at the electroweak scale

$$
\begin{aligned}
m_{\tilde{e}_R}^2 &= m_0^2 \;+\; .88 \; r^2 M_2^2 \;-\; \sin^2 \theta_W D_z \\
m_{\tilde{e}_L}^2 &= m_0^2 \;+\; (0.72 + .22 \; r^2) M_2^2 \;-\; (.5 - \sin^2 \theta_W) D_z \\
m_{\tilde{\nu}_e}^2 &= m_0^2 \;+\; (0.72 + .22 \; r^2) M_2^2 \;+\; D_z/2 \quad \text{with} \\
D_z &= M_Z^2 \cos(2\beta)
\end{aligned}
\tag{3}
$$

Note that squarks can be made much heavier than the sleptons even by taking the same common scalar mass since they receive a large contribution from the SU(3) gaugino mass. Of course, to allow for a low μ in this scenario one needs to appropriately choose the soft SUSY Higgs scalar masses at high scale. It is important to stress that the kind of models we investigate in this letter are quite plausible. The GUT-scale relation which equates all the gaugino masses at high scale need not be valid in a more general scheme of SUSY breaking. In fact even within SUGRA this relation need not necessarily hold since it requires the kinetic terms for the gauge superfields to be the most simple and minimal possible (diagonal and equal). One can easily arrange for a departure from equality by allowing for more general forms for the kinetic terms[23]. Within $SU(5)$ this occurs when the auxiliary component of a superfield transforms as a **24** dimensional representation. In this case one gets $M_1 = M_2/6$, at the electroweak scale, but $M_3 = 2M_2$[24]. In superstring models, although dilaton dominated manifestations lead to universal gaugino masses, moduli-dominated or a mixture of moduli and dilaton fields lead also to non universality of the gaugino masses[25] and may or may not (multi-modulii[26]) lead to universal scalar masses. The so-called anomaly-mediated SUSY breaking mechanisms[27] are also characterised by non-universal gaugino masses, though most models in the literature lead rather to $r > 1$ which is irrelevant for the Higgs search.

Since the model requires light charginos and since dark matter argument may force us to also consider light sleptons one should inquire whether these scenarios may account for the latest $g - 2$ results[8] from the E821 experiment at Brookhaven. First, as stressed in our previous analyses[7] models that lead to the largest branching into invisibles have $\mu > 0$, which is preferred by $g - 2$. Though large $\tan \beta$ values do give a larger $g - 2$ they do not give as large branching into invisibles. Moderate $\tan \beta$ that give a large invisible Higgs decay should also have light sleptons to account for $g - 2$. We will discuss the situation by imposing the 2σ limit, $1.1 \; 10^{-9} < a_\mu^{\text{susy}} < 7.5 \; 10^{-9}$, on $g - 2$ as well as what remains when one does not take into account the observed discrepancy in the measurement of $g-2$. Our calculation of $g-2$, which we have checked against some of the computations in the extensive literature[28], includes also the effect of A_μ, the tri-linear soft-Susy breaking parameter in the smuon sector. However all of our discussion refers to

the situation with $A_\mu = 0$. We have checked that especially in the regions that lead to the largest branching into invisibles, the results are not much dependent on A_μ.

Fig. 1 shows the allowed parameter space in the M_2, μ plane with $\tan\beta = 5$ and $M_1 = M_2/5$ for four different values of m_0. To a good approximation m_0 can be identified with the "right slepton" mass. The chargino mass limit from LEP2 is delimited by a line. It does not depend on m_0. The direct LEP2 limits, expectedly, cut on the lowest μ, M_2 region. This is in contrast to the relic density requirement which depend sensitively on m_0. We delineate three regions set by the relic density:a) the overclosure region $\Omega h^2 > .3$ which we consider as being definitely ruled out, b) $.1 < \Omega h^2 < .3$ which is the preferred region and c) $\Omega h^2 < .1$ where there is simply not enough susy dark matter. As m_0 increases the allowed region for the relic density shrinks. These remaining allowed regions correspond essentially to the pole annihilation $\tilde\chi_1^0 \tilde\chi_1^0 \to Z$. Also shown is the line corresponding to the lower 2σ limit on the $g - 2$, which becomes also more constraining as m_0 increases. To compensate for the increase in m_0, smaller combinations of $\mu - M_2$ corresponding to lighter charginos in the loop are picked up. It is worth stressing that the $g - 2$ measurement constrains regions with large $\mu - M_2$ values especially for large m_0, but these regions as, we will see, do not correspond to the largest branching ratio into invisibles. Note that, especially for this somewhat low value of $\tan\beta$, we never find large contributions to $g - 2$. In fact if one slightly relaxes the $g - 2$ limit by requiring $a_\mu > 0$, one has for the parameters of interest no constraint from $g - 2$. On the other hand, had we imposed, for $\tan\beta = 5$, that the SUSY contribution be within 1σ we would not have found a solution, apart from a tiny "hole" at low $m_0 = 100$GeV. Finally, we note that $b \to s\gamma$ is irrelevant since the squarks and gluinos are assumed heavy and that we are choosing $\mu > 0$ anyway.

3 Results

The branching ratio into invisible due to neutralinos will be denoted by $B_{\chi\chi}$. The opening up of this channel will not have any effect on any of the Higgs production mechanisms. This is in contrast to other SUSY effects on the production and decay of the Higgs, like those due to a light stop, see for instance [29]. Thus the Higgs discovery significances of the different channels at the LHC (and the Tevatron) are only affected by the reduction in the branching ratio into $b\bar{b}$ and $\gamma\gamma$. We define R_{bb} as the reduction factor of the branching ratio of $h \to b\bar{b}$ due to invisible compared to the same branching ratio of a standard model Higgs with the same Higgs mass:

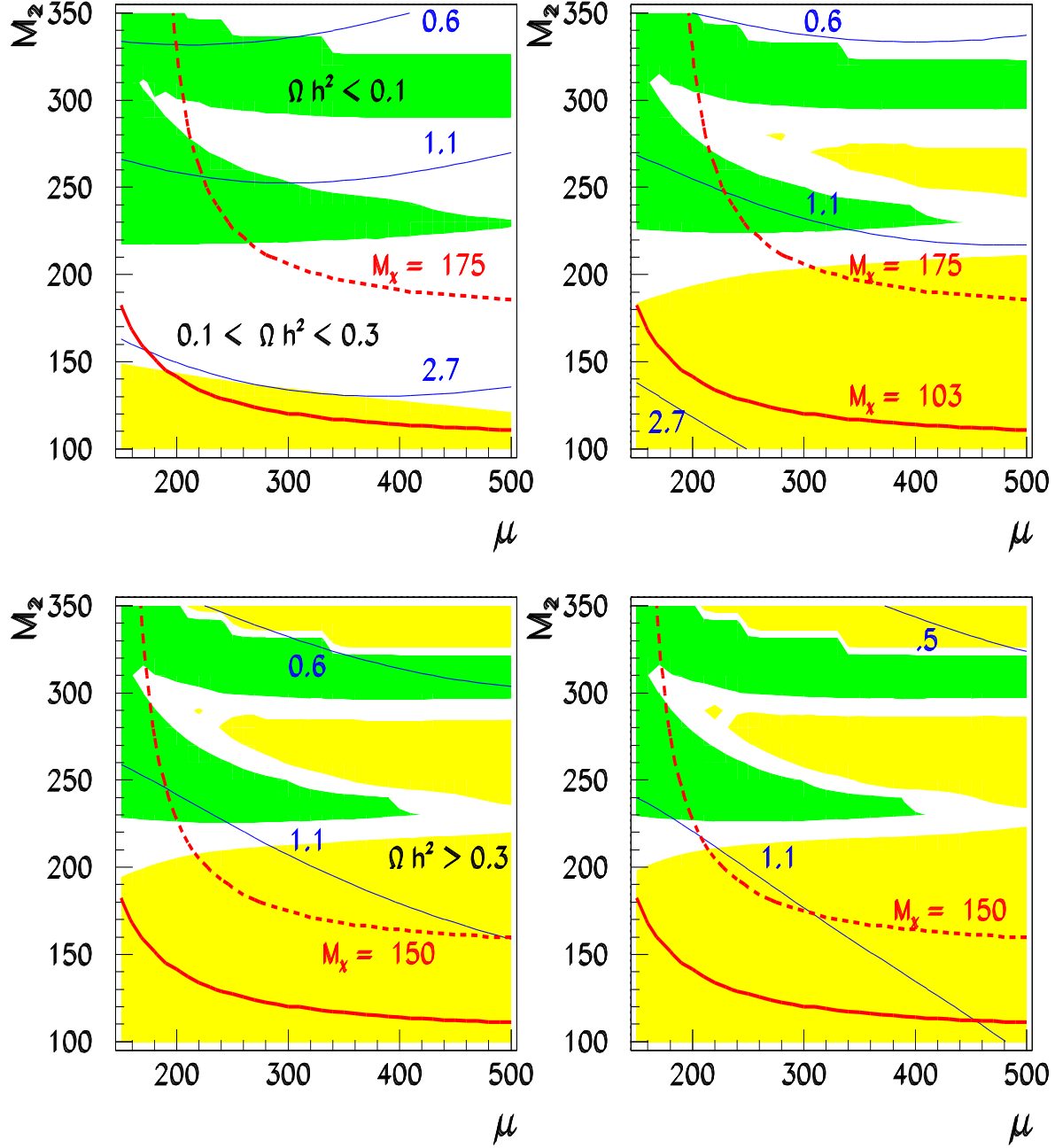$$R_{bb} = \frac{BR^{SUSY}(h \to b\bar{b})}{BR^{SM}(h \to b\bar{b})} \tag{4}$$

Figure 1: *Constraints on the parameter space for* $\tan\beta = 5$ *and* $M_1 = M_2/5$, *for four values of the slepton mass* $m_0 = 100, 140, 180, 220\,GeV$ *from left to right and top to bottom. Slepton masses are defined via* m_0 *according to Eq. 3. The thick (red) line defines the chargino mass constraint* $m_{\chi^+} > 103\,GeV$ *(the area below the line is excluded). The dashed (red) line corresponds to* $m_{\chi^+} > 175\,GeV$ *for* $m_0 = 100, 140\,GeV$ *and* $m_{\chi^+} > 150\,GeV$ *for* $m_0 = 180, 220\,GeV$ *which we estimate (conservatively) as being the Tevatron RunII reach. The light grey (yellow) area has* $\Omega h^2 > .3$ *and is therefore excluded. The dark grey area (green) has* $\Omega h^2 < .1$. *The white area is the cosmologically preferred scenario with* $.1 < \Omega h^2 < .3$. *The thin (blue) lines are constant* a_μ *lines in units of* 10^{-9} *so that 1.1 (2.7) corresponds to the* 2σ (1σ) *present lower bound.*

Likewise we define $R_{\gamma\gamma}$ for the branching ratio into $\gamma\gamma$. Since in the absence of light neutralinos the width of the Higgs is dominated by that into $b\bar{b}$, one has roughly

$$R_{bb} \sim R_{\gamma\gamma} \sim 1 - B_{\chi\chi} \tag{5}$$

This is well supported by our full analysis and therefore we will refrain from showing simultaneously the behaviour of all these three observables .

We take a scenario with $\tan\beta = 5$ and $M_1 = M_2/5$ and scan over μ, M_2, m_0 (defined in Eq. 3) with $70 < m_0 < 300\text{GeV}$, $100 < M_2 < 350\text{GeV}$ and $150 < \mu < 500\text{GeV}$. We see, in Fig. 2, that indeed the largest drop in $R_{\gamma\gamma}$ is for the lowest allowed value of μ, which as argued earlier maximises the higgsino component. The second panel of the figure shows that even after putting the $g - 2$ constraint, a large fraction of the parameter space is compatible with the relic density constraint, many models giving even just the needed amount of dark matter, $.1 - .3$. One also sees that large values of slepton masses are still compatible with dark matter and lead to large drops in the channels with visible signatures. As the figure clearly shows this is due to the efficient annihilation at the Z pole. We also show (second panel), that imposing the strict bound suggested by BOOMERANG, $\Omega h^2 < .15$, still allows values of $B_{\chi\chi}$ as large as about 70%. Fig. 3 shows the different contours in the $M_2 - \mu$ plane of $B_{\chi\chi}$ together with the constraint from the relic density and $g - 2$. We see that, even after taking all these constraints, we still find large branching ratio of the lightest SUSY Higgs into neutralinos and we confirm that the largest branchings correspond to the smallest μ values which are not terribly constrained by dark matter and $g - 2$. Insisting on explaining the $g - 2$ value at 1σ for $m_0 = 100\text{GeV}$ selects a tiny region corresponding to $B_{\chi\chi}$ in the range $.4 - .6$. It is also worth stressing that even in these general models, the branching ratio into invisible is never larger than 70%.

For completeness we have also redone the same analysis but with $\tan\beta = 10$. As expected the largest $B_{\chi\chi}$ is more modest than for a lower $\tan\beta$ and is found to be 45% at most, as shown in Fig. 4. This corresponds to $R_{\gamma\gamma} > .5$, which means that with enough luminosity, $300fb^{-1}$ at the LHC, one should see the 2γ signal.

We have also searched, by making a large scan over M_1, M_2, μ and m_0, but for fixed $\tan\beta = 5$, which minimum value of M_1 one can entertain given our assumption for the slepton spectrum. Here M_1 was varied in the range $10 < M_1 < 100\text{GeV}$. We find that, in order not to have too large a relic density, one can not have values of M_1 below 20GeV independently of M_2 and μ, as seen in Fig. 5. This is not a value that gives the largest branching into invisibles since considering the limit on μ, the mixing is not as strong as with a value of M_1 around $40 - 50\text{GeV}$. Higher values of M_1 ($M_1 > 65\text{GeV}$) are safe
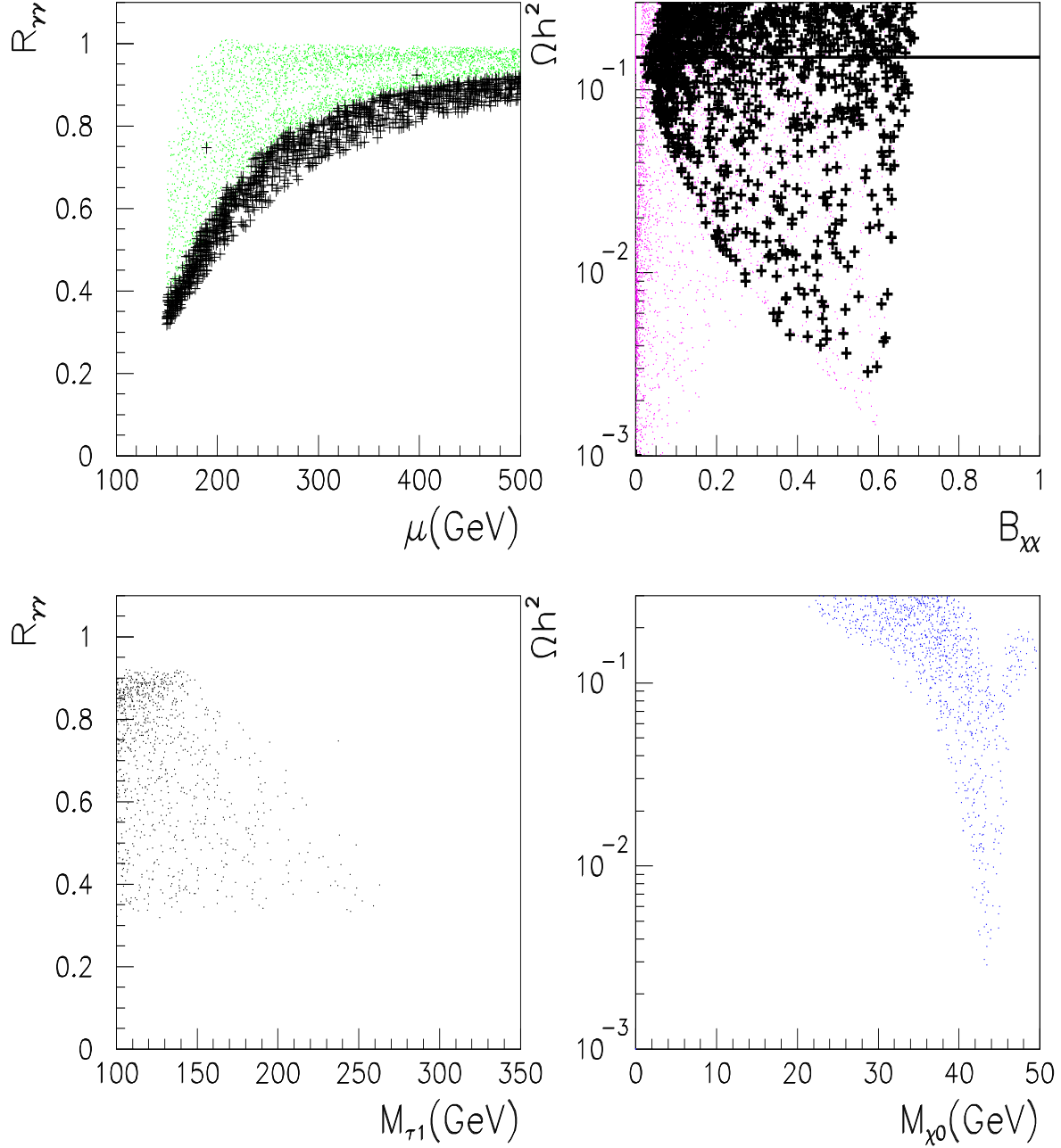
Figure 2: *Results for* $\tan\beta = 5$ *and* $M_1 = M_2/5$, *scanning over* M_2, μ *and* m_0. *The first panel shows* $R_{\gamma\gamma}$ *vs.* μ. *The area with the crosses has* $g-2$ *imposed at* 2σ *while the additional light shaded (green) region does not have this constraint. The second panel gives the branching ratio into invisibles vs the relic density with* $\Omega h^2 < .3$. *In the region with crosses the* 2σ $g-2$ *constraint has been imposed while in the additional area (pink) this constraint was removed. Also shown in this panel by the (horizontal) line is the strict bound from BOOMERANG with priors* $\Omega h^2 < .15$. *The third panel (bottom left) shows the correlation between the lightest slepton mass* $(\tilde{\tau}_1)$ *and the drop in the two photon rate. The last panel exhibits the annihilation through the* Z *pole by showing the behaviour of the relic density vs the mass of the neutralino LSP.*
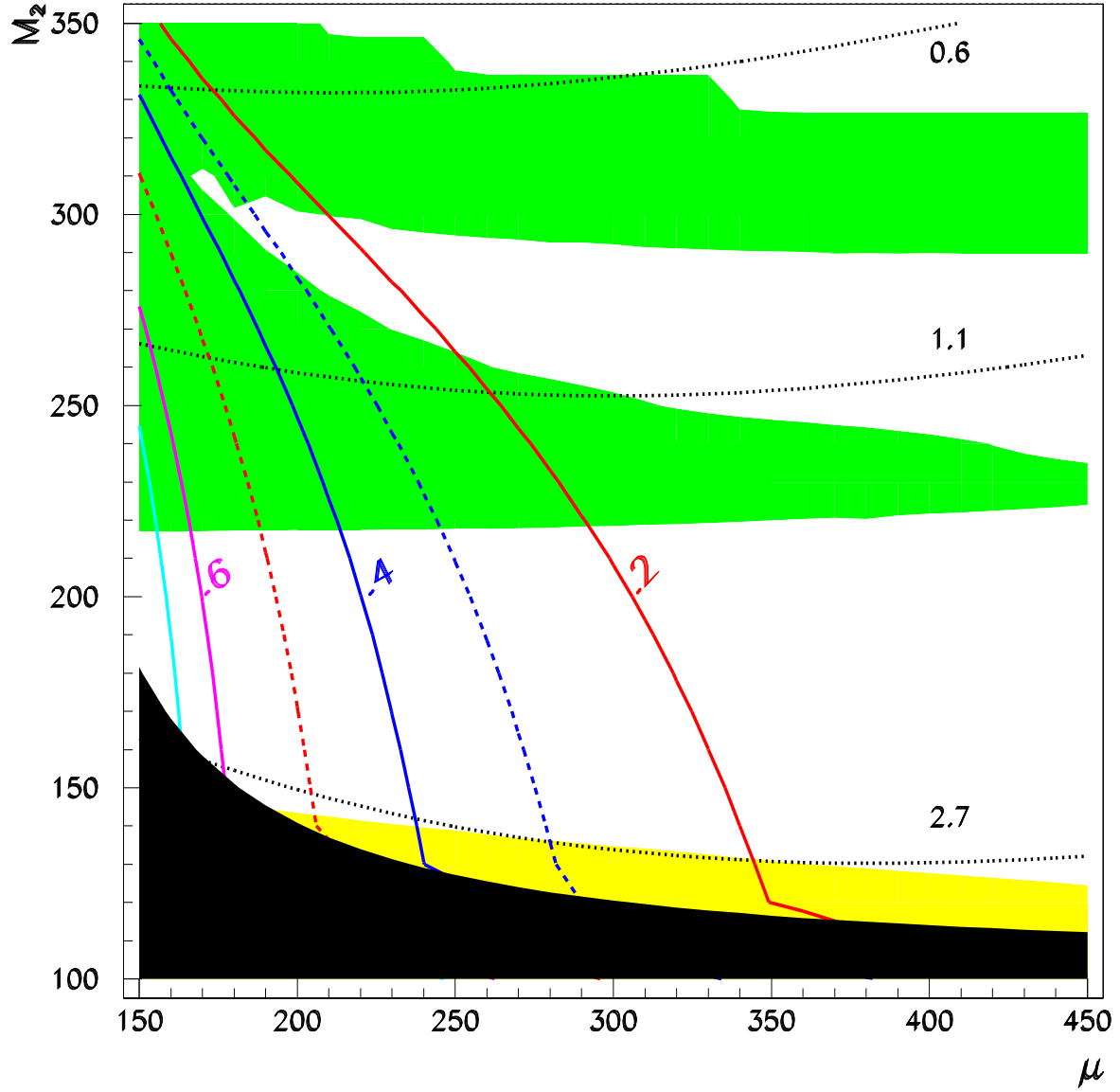
Figure 3: *With the parameters as in the previous figure, contours of constant $Br_{\chi\chi}$ from .2 (far right) to .65 (far left). We have also superimposed the various constraints, choosing $m_0 = 100\,GeV$, which correspond to the first panel of Fig. 1. The black area is excluded by the chargino mass at LEP. The other shadings refer to the relic density (as in Fig. 1). The dotted lines are constant a_μ lines in units of 10^{-9}.*
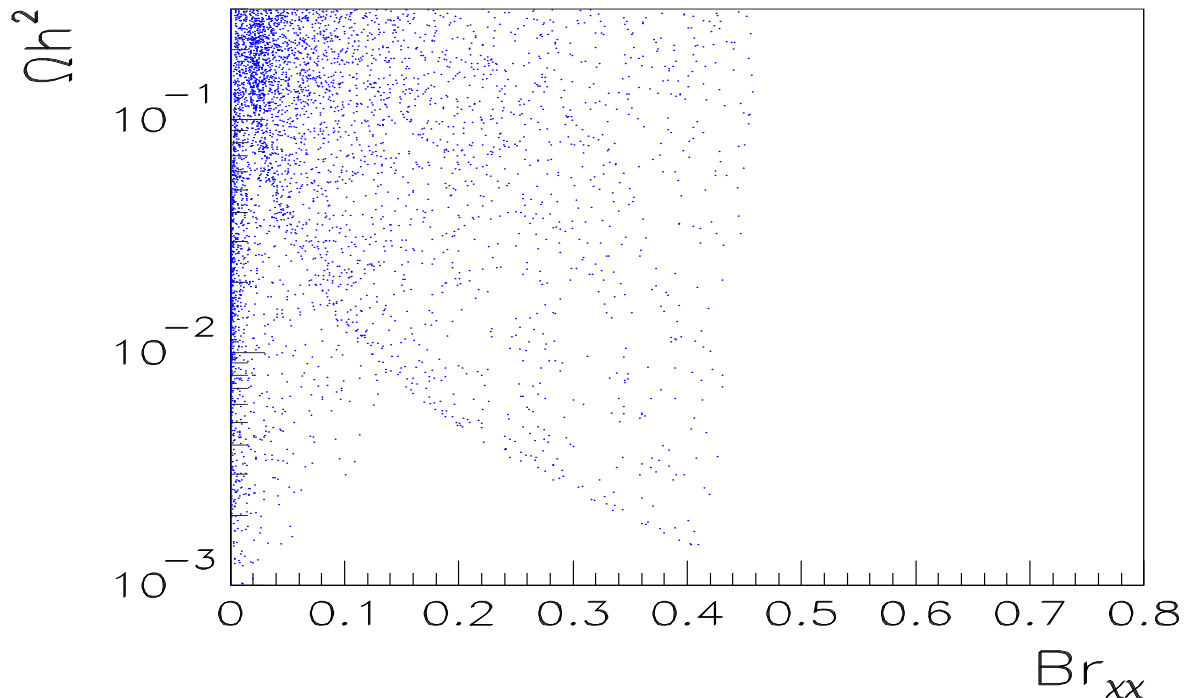
Figure 4: Ωh^2 vs $B_{\chi\chi}$ for $\tan\beta = 10$ and $M_1 = M_2/5$, scanning over M_2, μ and m_0. .

since the LSP mass turns out to be too large for the Higgs to decay invisibly. Note that values of $M_1 \sim 40-50\text{GeV}$ within the gaugino masses unification assumption correspond to $M_2 \sim 100\text{GeV}$. As we can see from the first panel of Fig. 1, such "low" M_2 values can only be compatible with the LEP2 limit on the chargino mass for a large μ around $400-500\text{GeV}$. For such high μ there is not enough higgsino component in the LSP. Lower μ values require $M_2 > 180\text{GeV}$, $(M_1 > 90\text{GeV})$ leaving no phase space for the invisible decay of the Higgs. We thus see how useful it is once again to disconnect M_1 from M_2.

To conclude we have found that there are still regions of parameter space that give a substantial branching fraction of the lightest SUSY Higgs into invisibles that can account both for the discrepancy in the $g-2$ value and for the dark matter in the universe. We also find that these scenarios do not always require a very light slepton since we can obtain an acceptable amount of LSP relic density through an efficient annihilation at the Z pole. However scenarios with the largest branching ratio into LSP do entail that the lightest chargino and at the least the next LSP are light enough that they could be produced at the Tevatron. The phenomenology at the Tevatron should somehow be similar to the Sugra $SU(5)$ based "24-model" mentioned above and which was studied in [24]. Among other things, due to the fact that one has a larger splitting between the LSP and the NLSP, as compared to the usual unified scenario, one expects an excess of events containing
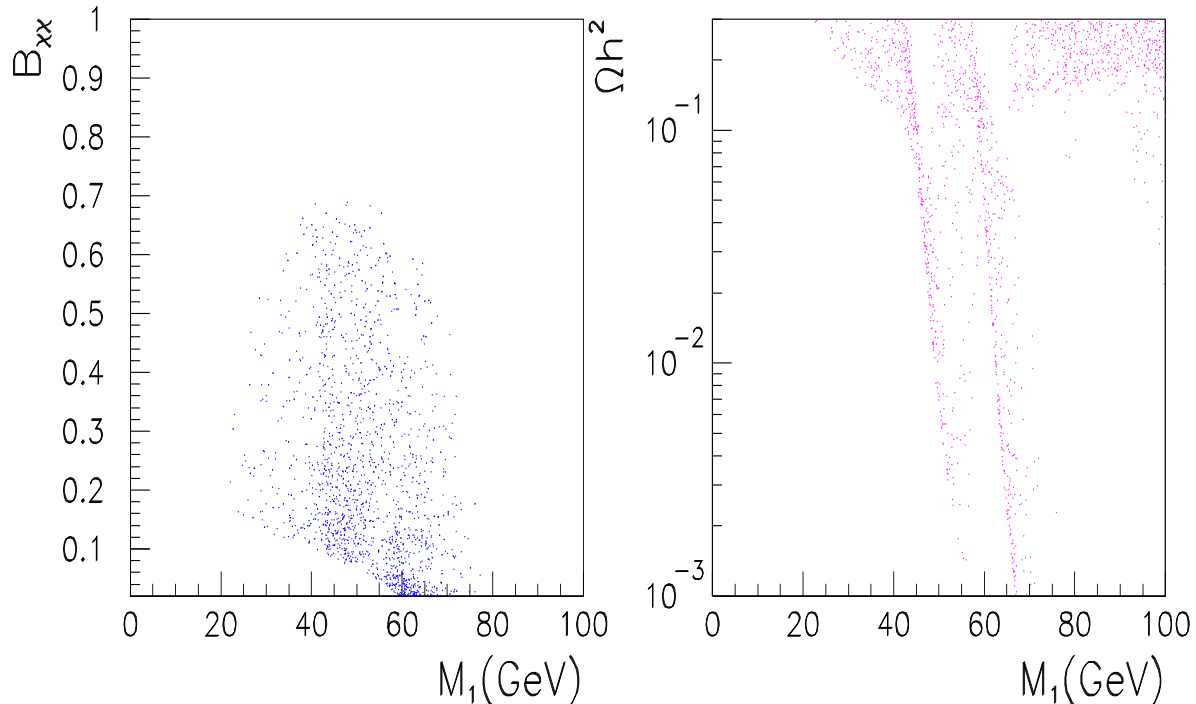
Figure 5: *Large scan over M_1, M_2, μ, m_0 for $\tan\beta = 5$. The first panel shows the branching ratio into invisibles vs M_1. The second panel shows the relic density as a function of M_1. Note that one hits both the Z pole and the Higgs pole. However for the latter configurations $B_{\chi\chi}$ is negligible.*

many isolated leptons originating, for example, from a real Z coming from the decay of the NLSP. However to make definite statements about observability of these states at the Tevatron requires a thorough simulation. Recently it has also been pointed out[30] that models with light sleptons and charginos of a mixed nature (as are required in our analysis to obtain a large branching into invisibles) apart from helping give a "good" $g - 2$ at not so large $\tan\beta$ can also help improve the χ^2 fits of the electroweak data. It is therefore important to study in detail phenomenological models out of the mSUGRA paradigm.

Acknowledgments

Physics.

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