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Invisible Decays of the Supersymmetric Higgs and Dark Matter

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ABSTRACT

We discuss effects of the light sparticles on decays of the lightest Higgs in a supersymmetric model with nonuniversal gaugino masses at the high scale, focusing on the 'invisible' decays into neutralinos. These can impact significanlty the discovery possibilities of the lightest Higgs at the LHC. We show that due to these decays, there exist regions of the $M_2 - \mu$ space where the B.R. $(h \to \gamma\gamma)$ becomes dangerously low even after imposing the LEP constraints on the sparticle masses, implying a possible preclusion of its discovery in the $\gamma\gamma$ channel. We find that there exist regions in the parameter space with acceptable relic density and where the ratio $\frac{B.R.(h\to\gamma\gamma)_{SUSY}}{B.R.(h\to\gamma\gamma)_{SM}}$ falls below 0.6, implying loss of signal in the $\gamma\gamma$ channel. These regions correspond to $\tilde{\chi}_1^+, \tilde{\chi}_2^0$ masses which should be accessible already at the Tevatron. Further we find that considerations of relic density put lower limit on the $U(1)$ gaugino mass parameter M_1 independently of $\mu, \tan\beta$ and m_0.

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We discuss effects of the light sparticles on decays of the lightest Higgs in a supersymmetric model with nonuniversal gaugino masses at the high scale, focusing on the 'invisible' decays into neutralinos. These can impact significanlty the discovery possibilities of the lightest Higgs at the LHC. We show that due to these decays, there exist regions of the $M_2 - \mu$ space where the B.R. $(h \to \gamma\gamma)$ becomes dangerously low even after imposing the LEP constraints on the sparticle masses, implying a possible preclusion of its discovery in the $\gamma\gamma$ channel. We find that there exist regions in the parameter space with acceptable relic density and where the ratio $\frac{B.R.(h\to\gamma\gamma)_{SUSY}}{B.R.(h\to\gamma\gamma)_{SM}}$ falls below 0.6, implying loss of signal in the $\gamma\gamma$ channel. These regions correspond to $\tilde{\chi}_1^+, \tilde{\chi}_2^0$ masses which should be accessible already at the Tevatron. Further we find that considerations of relic density put lower limit on the $U(1)$ gaugino mass parameter M_1 independently of $\mu, \tan\beta$ and m_0.

1 Introduction

The importance of the search for the Higgs particle in the current and upcoming collider experiments, the TEV-II, LHC and possibly the next Linear Colliders, to confirm the crucial features of the Standard Model (SM) of the fundamental particles and interactions among them, can not be overemphasised[1]. Further, supersymmetry (SUSY) is one of the most attractive ways to go beyond the SM and provide a cure for one of its most serious theoretical ills *viz.* the hierarchy problem in the scalar sector[2]. Therefore, looking for the evidence of the extended Higgs sector of the supersymmetric model also forms a very important part of the planned research program of the current and future accelerator

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experiments. In this talk we discuss some aspects of the effect that the supersymmetric partners (the sparticles) can have on the decays of the lightest neutral scalar present in the Higgs sector of the supersymmetric theories, with special emphasis on those SUSY models where the gaugino masses are not unified at the high scale. The plan of this talk is as follows. We first summarise a few relevant facts about the expected Higgs spectrum in the supersymmetric models as well as a few details about the SM Higgs and the lightest neutral SUSY scalar, such as the theoretical as well as the current experimental bounds on its mass etc. We then discuss the effect of light superpartners on the couplings and the decay of the Higgs, notably the 'invisible' decay into a pair of neutralinos and its implications for the Higgs search at the LHC. We then examine the range of values predicted for B.R. ($h \to$ invisibles) once the current experimental constraints on the Dark Matter (DM) are implemented. We then end with a few remarks about probing at the Tevatron the region of the $M_2 - \mu$ parameter space, where the B.R. ($h \to$ invisibles) is substantial, yet the DM constraint is satisfied, as well as about looking for such an 'invisible' Higgs at the LHC through its associate production with a W/Z.

2 SM and MSSM Higgs: Masses and Couplings

The SM has precise predictions for the couplings of the h but can predict only limits on its mass. According to these limits given by the consideration of vacuum stability and triviality, using 2-loop RGE equations [3] the mass of the SM Higgs should lie in the range 160 ± 20 GeV if there is no new physics between the EW scale and the Planck scale. The high precision measurements of the Z-boson properties and those of M_W at LEP, of $\sin^2\theta_w$ at SLD, as well as the measurements of m_t, M_W at the Tevatron, all put together constrain the Higgs mass substantially and give an upper limit on its mass of 196 GeV at 95% c.l.[4]. Thus these indirect measurements of the Higgs mass prefer a light Higgs and the consistency of this indirect upper limit with the above mentioned range of 160 ± 20 GeV, is very tantalising. Very general theoretical arguments about the 'naturalness' requirements also indicate that the Higgs mass be small and of the order of the EW scale [5]. Furthermore, lack of any 'direct' experimental evidence for the Higgs in the process $e^+e^- \to Zh$ puts a limit [6] $m_h \gtrsim 113$ GeV, with a hint of a signal for a Higgs with mass close to this upper limit. Thus in the SM clearly a light Higgs is preferred, both experimentally and theoretically.

In the Supersymmetric theories the situation is not any different. These theories have to have two Higgs doublets for reasons of anomaly cancellations as well as to give mass to both the up and down-type fermions. Of the three neutral scalars h, H and A the first two are CP even and the last one is CP odd in the Minimal Supersymmetric Standard Model (MSSM). Supersymmetry keeps the mass of the lightest SUSY scalar m_h low 'naturally' for symmetry reasons. In these theories it is actually predicted in terms of M_Z, and the gauge coupling, being bounded from above by M_Z at the tree level. Large loop corrections due to the heavy top modify this upper limit to ~ 135 GeV [7] in the MSSM and to ~ 165 GeV in the NMSSM[8, 9, 10]. These upper limits are really quite robust and have very little dependence on most of the minimal SUSY model parameters, except on the trilinear parameter A_t, $\mu, \tan\beta$ through the $L-R$ mixing in the stop sector and the squark mass term for the top squarks. The direct experimental lower limits in the case of the MSSM, are 91.0 GeV [11] for the the CP even Higgs and 91.9 for the CP odd Higgs.

Therefore the search for a light SM Higgs and the lightest SUSY Higgs (*i.e.* $m_h < 2M_W$) deserves a special emphasis while assessing the capabilities of any collider, present or future. Although, it is true that a light Higgs, if found, can not be taken as a 'proof' of Supersymmetry, it is certain to boost our belief in weak scale SUSY. It is also clear that a discussion of the effect of sparticles on Higgs searches is also quite crucial. At the LHC the dominant mode of production of the Higgs is through its coupling to the gluons induced by the diagrams shown in the left panel of Fig.1. This coupling is dominated by

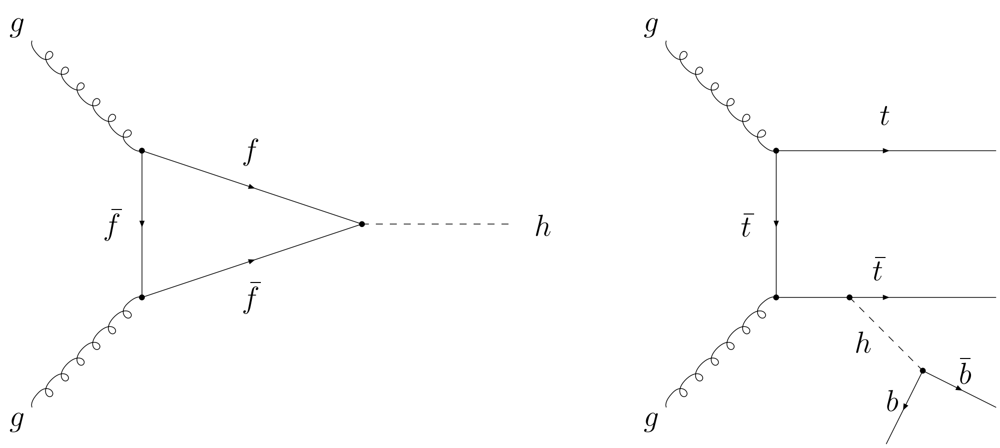

Figure 1: *Production processes for the SM Higgs in gg collisions*

the contribution of the t quarks in the loop. For the mass range $m_h < 2M_W$, the one we are interested in this discussion, the decay mode that can be used mostly for the search of the h in this inclusive production mode is $h \to \gamma\gamma$. This coupling is also loop induced and the corresponding diagrams in the SM are shown in Fig.2. This decay receives the dominant contribution from W loops. Thus for the inclusive production process shown in the left panel of Fig.1 we have,

$$\sigma(pp \to h) B.R.(h \to \gamma\gamma) \propto B.R.(h \to \gamma\gamma) \times B.R.(h \to gg). \quad (1)$$

Another good signal for the h at the LHC is via the associated $t\bar{t}h$ production depicted in the right panel of Fig.1. In this case due to the $t\bar{t}$ quarks present along with the h in the final state, one can use the dominant $h \to b\bar{b}$ decay mode for the search, the final state consisting of $t\bar{t}b\bar{b}$. In this case the search channel does not depend on the branching ratio of the h into the $\gamma\gamma$ or the gg channel but does depend on B.R. $(h \to b\bar{b})$. Thus the decays which play an important role in the determination of the search possibilities and reach for a light neutral scalar at the hadronic colliders are the tree level decay $h \to b\bar{b}$ and the loop induced one $h \to \gamma\gamma$.

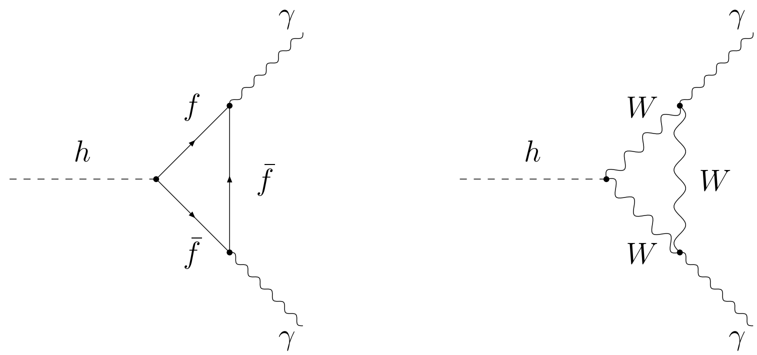

Figure 2: *Loop diagrams giving rise to the $h\gamma\gamma$ coupling in the SM.*

In case of the SUSY Higgs, its couplings depend on some of the parameters of the SUSY model *viz.* $m_A, \tan\beta$ and μ. For $m_A \gg M_Z$ the tree level couplings of the h to the SM fermions and the gauge bosons are very close to that in the SM, in this so called 'decoupling limit'. The loop induced gg and $\gamma\gamma$ couplings which affect the production through the gg mode and detection through the $\gamma\gamma$ mode respectively at the hadronic colliders, receive additional contributions from the loops containing the charged sparticles which have substantial coupling to the h, *viz.* the $\tilde{t}_1, \tilde{t}_2$, the charginos $\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^{\pm}$ and the charged Higgs $H^{\pm}$. These are shown in Figs. 3,4 respectively. For light sparticles,

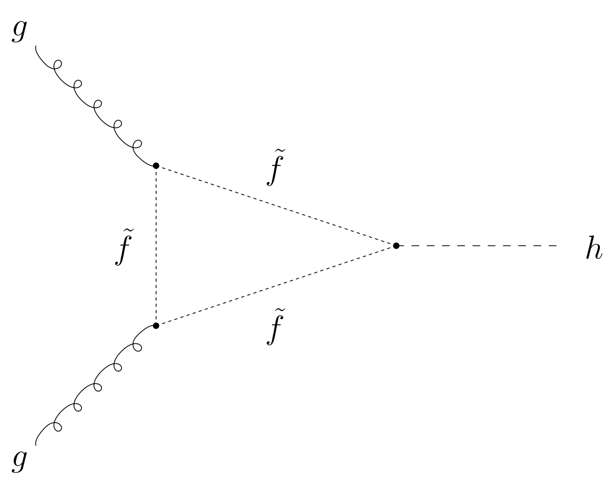

Figure 3: *Additional contributions to the ggh coupling for the SUSY Higgs h*

of course being consistent with the non observation at LEP, these effects can be large. Particularly strong is the effect of the light top squarks, $\tilde{t}_1, \tilde{t}_2$, on the ggh coupling. For comparable t and $\tilde{t}_i$ masses and large mixing between the left and right chiral top squarks, the f and $\tilde{f}$ contributions interfere destructively and can cause a decrease in the B.R.

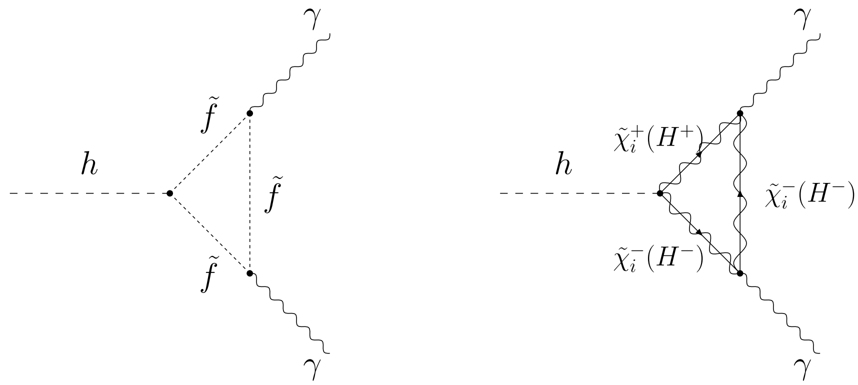

Figure 4: *Additional sparticle loop contributions to $h\gamma\gamma$ coupling for the SUSY Higgs*

($h \to gg$) lowering the production cross-section thereby. The decay $h \to \gamma\gamma$ also receives contribution from loops containing the charged particles and sparticles with only the EW couplings *viz.*, the $\tilde{\chi}_1^{\pm}$ and the W's, along with that from the top quarks/squarks. This actually increases the B.R. w.r.t. expectation in the SM, rising with increasing mixing in the $L-R$ sector for the $\tilde{t}$. Further the B.R. ($h \to \gamma\gamma$) and B.R. ($h \to gg$) are also affected by the decays of the Higgs h into final states containing sparticles. In view of the current LEP bounds the only possibility still allowed is the decay of h into a pair of neutralinos $\tilde{\chi}_l^0 \tilde{\chi}_m^0$ [12]. The decay $h \to \tilde{\chi}_1^0 \tilde{\chi}_1^0$ renders the Higgs invisible and in addition reduces the branching ratio of the h in both the $\gamma\gamma$ and the $b\bar{b}$ channel, relative to the values expected in the SM thereby reducing the significance of these useful channels.

3 Effect of light stops on h production/decay and the LHC observables

The figure of merit at the LHC for the search of a light Higgs h is the L.H.S. of Eq. 1 or the corresponding quantity for the $b\bar{b}$ final state with the $t\bar{t}h$ associate production. Hence the effect of sparticles on the light Higgs search at the LHC can be best assessed by studying the ratio

$$R_{gg\gamma\gamma} = \frac{\sigma(gg \to h) B.R.(h \to \gamma\gamma)_{SUSY}}{\sigma(gg \to h) B.R.(h \to \gamma\gamma)_{SM}}, \tag{2}$$

as well as similar ratios of branching ratios for the SUSY Higgs and the SM Higgs, $R_{\gamma\gamma}$ for B.R. ($h \to \gamma\gamma$) and $R_{b\bar{b}}$ for B.R. ($h \to b\bar{b}$). Effect of the light top squarks, on these ratios and hence on search of the SUSY Higgs at the LHC, with all the other sparticles being heavy [13, 14, 15] as well as that of the light $\tilde{\chi}_l^0, \tilde{\chi}_l^{\pm}$ [16] has been studied in detail. The analyses show that for $m_{\tilde{t}_1} \simeq m_t$ and large $L-R$ mixing, sensitivity to the light h at LHC

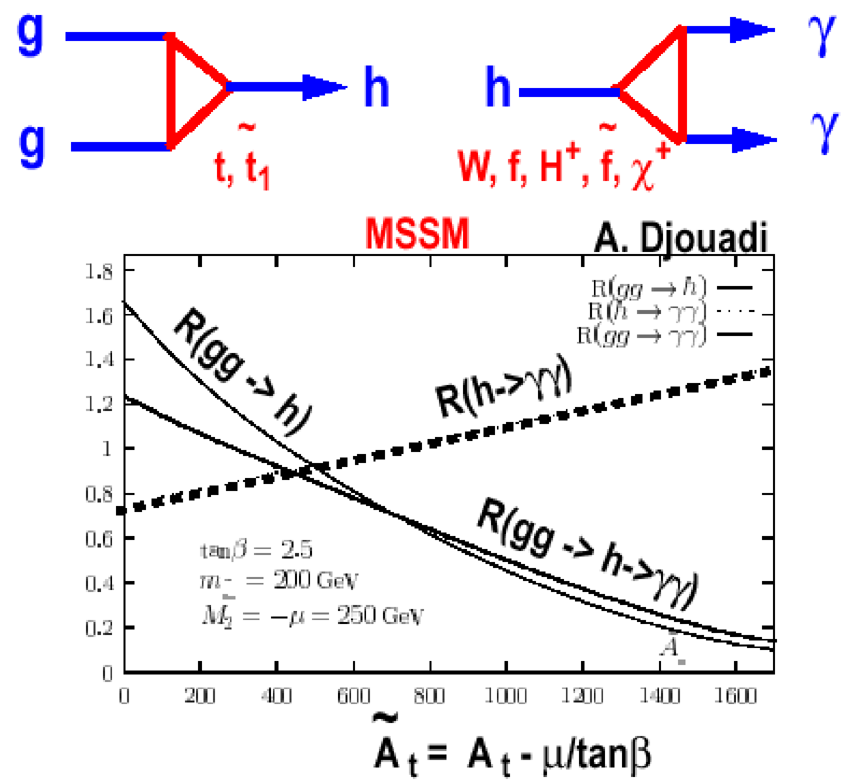

Figure 5: *The ratio $R_{gg\gamma\gamma}, R_{\gamma\gamma}$ and $R_{gg\to h}$ as a function of A_t, μ and* $\tan\beta$, *for light top squarks [13]*

can be completely lost. This is depicted in the Figs. 5 and 6 taken from Refs.[13] and [15] respectively. As one can see from these figures, for large stop mixing the ratio $R_{gg\gamma\gamma}$ falls below 0.6 thus losing the signal for the h in the inclusive $\gamma\gamma$ channel. The choice of 0.6 is arrived at by taking the possible level of significance somewhere between the ATLAS [17] and CMS simulations [18]. It was shown [15] that should the loss of signal be due to the light top squark, luckily a viable signal will still exist in the $\tilde{t}_1\tilde{t}_1^*h$ channel, along with the $t\bar{t}h$ channel mentioned above. It should be added here that analysis of optimisation of the search for the top squark in this mass range at the LHC is still not done.

4 Effect of light chargino/neutralinos on the SUSY Higgs production and decay.

In view of the LEP bounds [19] ($m_{\tilde{\chi}_1^+} > 103$ GeV), the only effect that the $\tilde{\chi}_1^+$ can have on the Higgs widths and the couplings is through the loop effects on $h\gamma\gamma$ coupling. On the other hand the light neutralinos open up a new channel for the h decay and thus can affect the branching ratios into the $\gamma\gamma$ and $b\bar{b}$ channel. Since for the mass range of the h

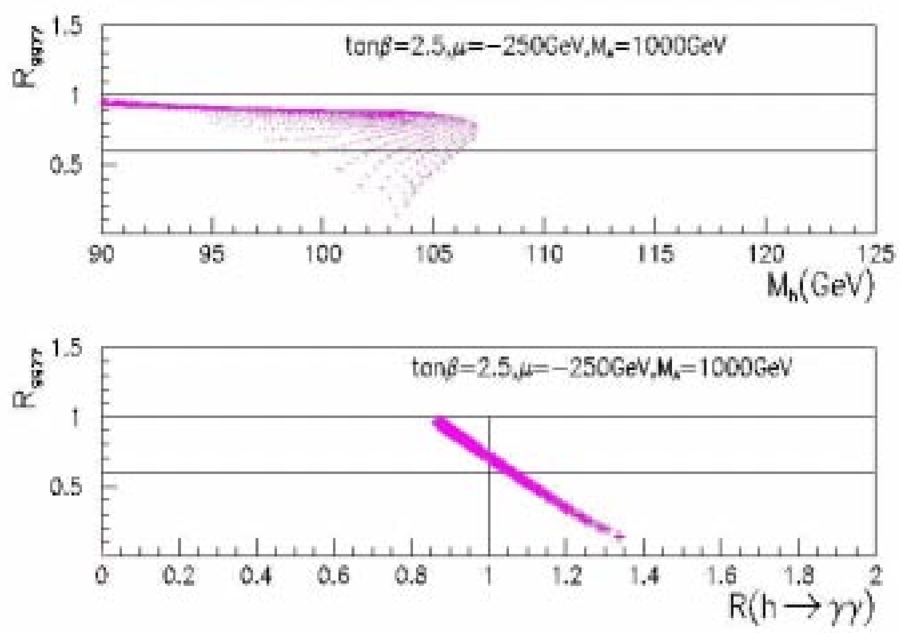

Figure 6: *Ratio $R_{gg\gamma\gamma}$ as a function of $R_{\gamma\gamma}$ and m_h [15]. The values of various parameters are indicated in the figure.*

we are interested in, $h \to b\bar{b}$ is the only dominant decay mode, we have

$$R_{\gamma\gamma} \simeq R_{b\bar{b}} \simeq 1 - B.R.(H \to \tilde{\chi}_1^0\tilde{\chi}_1^0) \qquad (3)$$

An increasing branching ratio for the channel $h \to \tilde{\chi}_1^0\tilde{\chi}_1^0$ thus causes a depletion into the $\gamma\gamma$ and $b\bar{b}$ channel, with respect to the SM values. Since we consider the case of heavy squarks, the production rate of the h in the inclusive channel $p\bar{p} \to ggX \to hX$ is not affected. Since the chargino/neutralino sector is completely defined in terms of the SUSY breaking $SU(2)$ and $U(1)$ gaugino masses M_1, M_2 in addition to $\tan\beta$ and μ, one can study these effects as a function of these parameters. The Higgs mass m_h depends on A_t, m_A in addition. Of course, under the assumption of unified gaugino masses at high scale, $M_1 \simeq 0.5 M_2$ at the EW scale and thus the number of independent parameters is reduced by one. For our studies [16] we chose moderate $\tan\beta$ and large A_t, to maximise m_h and $\tilde{\chi}_1^0\tilde{\chi}_1^0 h$ coupling and still have light enough $\tilde{\chi}_1^0$, thus enhancing the possibility of direct decays of the h into a neutralino pair. Further, if one also assumes unification of the gaugino masses at high scale, then the observed experimental limits on the $m_{\tilde{\chi}_1^\pm}$ of ~ 103 GeV implies a limit on the $m_{\tilde{\chi}_1^0}$ of about 60 GeV reducing the phase space for the 'invisible' h decay into a neutralino pair. The current LEP bounds on the masses of all other sfermions make the decays of h into a $\tilde{f}\tilde{f}^*$ pair impossible. Fig.7 shows first our results where we assume the gaugino mass unification at high scale. Panel (a) shows the region in the $M_2 - \mu$ plane which is allowed by the experimental limit on the $\tilde{\chi}_1^+$ mass along with contours of B.R. $(h \to \tilde{\chi}_1^0\tilde{\chi}_1^0)$. We see that largish values for this branching ratio are allowed only close to the edge of the allowed region in the $M_2 - \mu$ plane, consistent with the general argument presented above. The remaining panels show correlation of

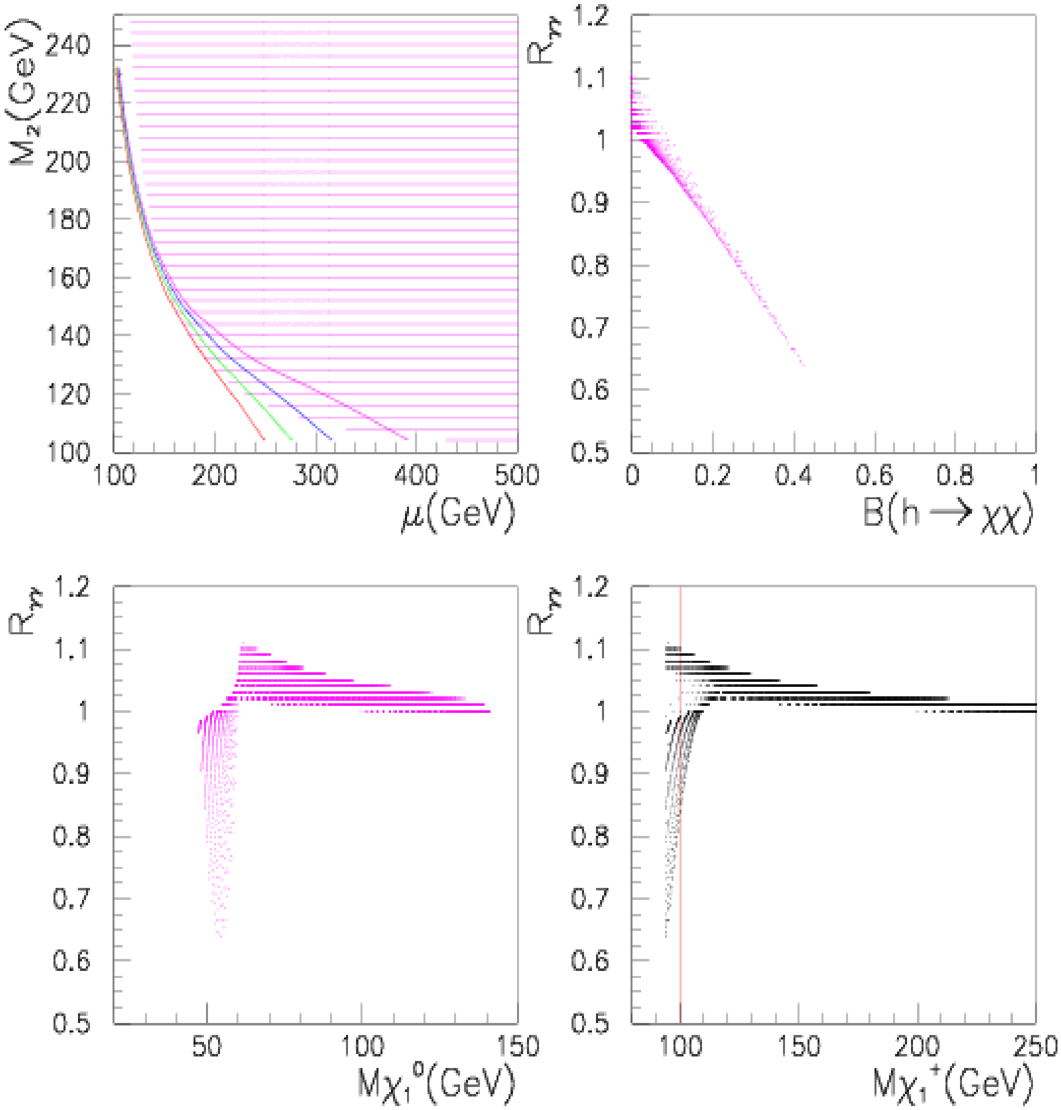

Figure 7: *a) Contour plot of* $Br(h \to \tilde{\chi}_1^0\tilde{\chi}_1^0) = 0.1, 0.2, 0.3, 0.4$ *(from right to left respectively) in the* $M_2 - \mu$ *plane. The shaded area is the allowed region.b) Correlation between* $R_{\gamma\gamma}$*and* $Br(h \to \tilde{\chi}_1^0\tilde{\chi}_1^0)$ *c) Variation of* $R_{\gamma\gamma}$ *with the mass of the LSP* $M_{\tilde{\chi}_1^0}$ *and d) mass of the chargino* $m_{\tilde{\chi}_1^+}$*. The vertical line corresponds to* $m_{\tilde{\chi}_1^+} = 100 GeV$*. All plots are for* $\tan\beta = 5$*,* $M_2 = 50 - 300 GeV$*,* $\mu = 100 - 500 GeV$ *and* $A_t = 2.4 TeV$ *.*

$R_{\gamma\gamma}$ with B.R. ($h \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0$), the mass of the chargino and the LSP. We see clearly that for the case of the light $\tilde{\chi}_1^\pm, \tilde{\chi}_1^0$, the dominant effect on $R_{\gamma\gamma}$ is through the 'invisible' decays of the h once the LEP constraints on the $m_{\tilde{\chi}_1^+}$ are imposed. The reduction is close to the dangerous value of 0.6 - 0.7 over a very small region of the $M_2 - \mu$ space in this case. This can be easily understood by looking at the conditions that maximise the B.R. ($h \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0$). Recall, $\tilde{\chi}_1^0$ is a mixture of gaugino/higgsino given by $\tilde{\chi}_1^0 = N_{11}\tilde{B} + N_{12}\tilde{W}_3 + N_{14}\tilde{H}_1^0 + N_{13}\tilde{H}_2^0$ and the $h\tilde{\chi}_1^0\tilde{\chi}_1^0$ coupling $C_{h\tilde{\chi}_1^0\tilde{\chi}_1^0} \propto (N_{12} - \tan\theta_w N_{11}) \times (N_{14}\sin\beta - N_{13}\cos\beta)$. To maximise this coupling the $\tilde{\chi}_1^0$ needs to have both the Higgsino and the Gaugino components at a sizable level. For a light LSP and hence a small M_1 this requires small μ. For $h \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0$ to be possible, we need further $m_{\tilde{\chi}_1^0} \lesssim 65$ GeV. Since we also have to impose, $m_{\tilde{\chi}_1^+} > 103$ GeV, the values of μ are bounded from below. Hence, the region where these conditions are satisfied is rather small. Thus, apart from the degenerate case where $m_{\tilde{\chi}_1^+} \simeq m_{\tilde{\nu}}$ and hence the LEP constraints on the chargino mass are not applicable, for the case with unified gaugino masses at the high scale the 'invisible' Higgs decays can not cause a big reduction in $R_{\gamma\gamma}$ and hence does not pose a big danger to the h search.

However, even for mSUGRA the unification of gaugino masses at high scale is true only for the case where the kinetic term for the gauge superfields is minimal [20]. Non-universal gaugino masses are expected also in models with Anomaly mediated SUSY breaking (AMSB) [21] or moduli dominated SUSY breaking [22]. In general therefore, we can expect $M_1 = rM_2$ with $r \neq 0.5$ at the EW scale. We therefore study the effect of relaxing the assumption of universal gaugino masses on the 'invisible' decays of the h. A ratio r between the two gaugino masses at the EW scale needs,

$$M_1 = 2rM_2, \tag{4}$$

at the GUT scale. Since we want to explore regions of parameter space which maximise the B.R. ($h \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0$), we necessarily need $\tilde{\chi}_1^0$ lighter than the ones allowed in the case of universal gaugino masses and hence $r < 1$. One should note here that most of the models mentioned above give $r > 1$. So our choice of $r < 1$ is to be treated as completely phenomenological. Fig. 8 shows B.R. ($h \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0$) as a function of M_2 and μ as well as correlations between $R_{\gamma\gamma}$with $\mu, m_{\tilde{\chi}_1^+}, M_2$ and B.R. ($h \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0$) for $r = 0.1$. Note that one needs to reinterpret the LEP allowed regions in the $M_2 - \mu$ plane for our chosen value of $r = 0.1$. For these plots we have taken the selectrons to be heavy just like the squarks. We see, indeed that there exist now large regions at low μ where $R_{\gamma\gamma}$ dips below the dangerous limit of 0.6. The plots also clearly show that the dip in $R_{\gamma\gamma}$ comes essentially from the opening up of the decay channel $h \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0$. The last panel ($f$) in the figure also shows that the same of course causes a depletion in $R_{b\bar{b}}$ and further $R_{b\bar{b}} \simeq R_{\gamma\gamma} = 1 - B.R.(h \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0)$. Thus the significance of the reach at the LHC in the inclusive channel as well as the $t\bar{t}h$ channel is affected by the 'invisible' decays of the h quite substantially over a large region in the $M_2 - \mu$ space once we allow $r \neq 1$. The effects are more modest for larger values of $\tan\beta$ as the rise in the $\tilde{\chi}_1^0$ mass with $\tan\beta$ is much more than the inrease in the value of m_h.

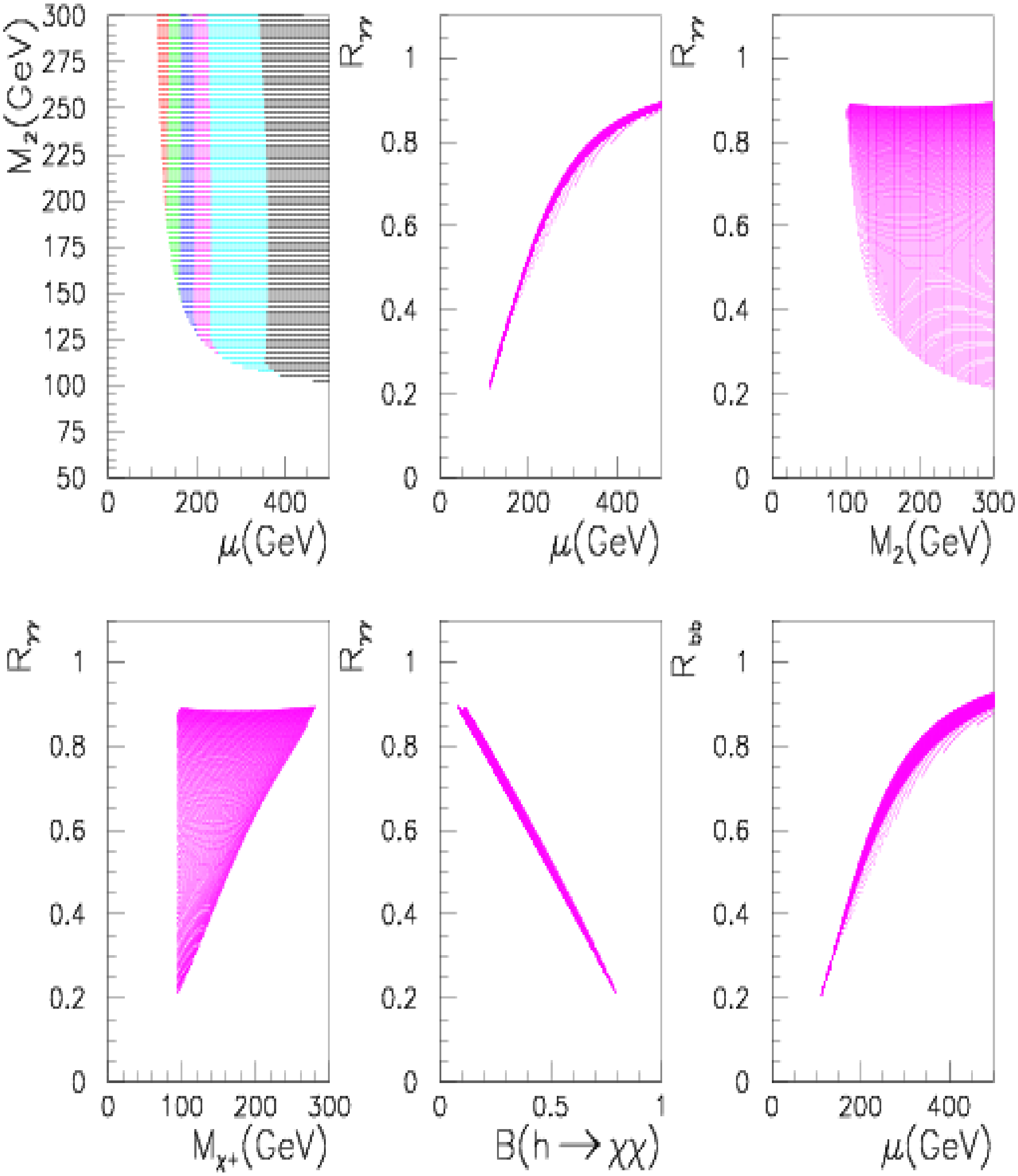

Figure 8: *Effects of neutralinos from* $M_1 = M_2/10$ *with* $\tan\beta = 5$ *and* $A_t = 0$ *with heavy selectrons. In all the plots, scans are over* $M_2 = 50 - 300\,GeV$, $\mu = 100 - 500\,GeV$. *From left to right and top to bottom a) Density plot for* $R_{\gamma\gamma}$ *in the allowed* $M_2 - \mu$ *plane. The different shadings correspond to* $.3 < R_{\gamma\gamma} < .4$ *(left band) to* $.8 < R_{\gamma\gamma} < .9$ *(right band). b) Variation of* $R_{\gamma\gamma}$ *with* μ *c) with* M_2 *d) with the mass of the chargino* $m_{\chi_1^+}$. *e) Correlation between* $R_{\gamma\gamma}$ *and the branching into LSP. f) Variation of* $R_{b\bar{b}}$ *with* μ.

5 Light $\tilde{\chi}_1^0$ and the cosmological relic density

Thus we see that models with nonuniversal gaugino masses can allow 'invisible' decays of the h into a pair of LSP's, at a level which can bring down the branching ratio of the h into the discovery channels of $\gamma\gamma$ and $b\bar{b}$ to low enough values threatening to preclude its discovery at the LHC. We also saw that this basically needs a light $\tilde{\chi}_1^0$. However, such a stable, light $\tilde{\chi}_1^0$ has also cosmological implications. Such a WIMP $\tilde{\chi}_1^0$, is an ideal Dark Matter (DM) candidate. The relic density of the DM is decided by the annihilation cross-sections $\sigma(\tilde{\chi}_1^0\tilde{\chi}_1^0 \to f^+f^-)$. Some of the diagrams contributing to these are shown in Fig. 9. A light $\tilde{\chi}_1^0$ such as the one we are looking at which is mostly a Bino, gets

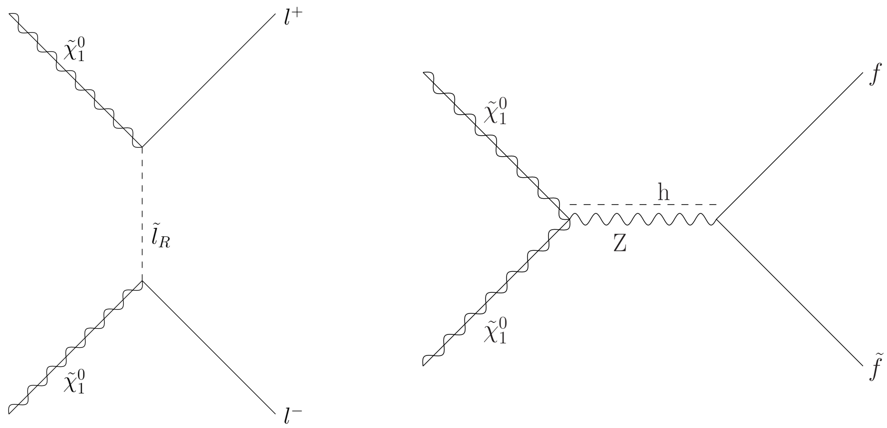

Figure 9: *Annihilation of a $\tilde{\chi}_1^0\tilde{\chi}_1^0$ pair via a $\tilde{l}_R, Z$ or h.*

largest contributions to the annihilation cross-sections via diagrams involving a light $\tilde{l}_R$. For somewhat heavier $\tilde{\chi}_1^0$ which can annihilate through a h/Z the relic density is reduced very effectively when the exchanged h/Z is on mass shell. A code [23] which includes all the coannihilation channels as well as tackles all the $s-$ channel poles and threshold effects is used to calculate the relic density for the sparticle mass spectrum obtained with $r = 0.1, 0.2$ and with a common scalar mass (defined at the GUT scale) for all the three generations of the light and left chiral sleptons and taking all the squarks to be heavy. The squarks can be much heavier with the same common scalar mass at the GUT scale due to much larger $SU(3)$ contributions that the squark masses receive. Various observations [24] suggest that $0.1 < \Omega h^2 < 0.3$, where Ω is the fraction of the critical energy density provided by the neutralinos and h is the Hubble constant in units of 100 km s^{-1}Mpc^{-1}. Our choice of the upper limit is indeed very conservative in view of the recent measurements[25]. Note also that the upper limit is the only relevant one because if Ωh^2 from neutralinos is less than 0.1 we can always imagine some other source of the DM. Fig. 10 shows in the right (left) panel contours for B.R. $(h \to \tilde{\chi}_1^0\tilde{\chi}_1^0)$ corresponding to 0.2 to 0.6 (0.65), for $r = 0.1$ $(r = 0.2)$, along with regions of different expected values of Ωh^2. In this figure we have used a value of $m_0 = 94(100)$ GeV corresponding to light sleptons and $\tan\beta = 5$. Due to the efficient annihilation via the Z/h pole one can get

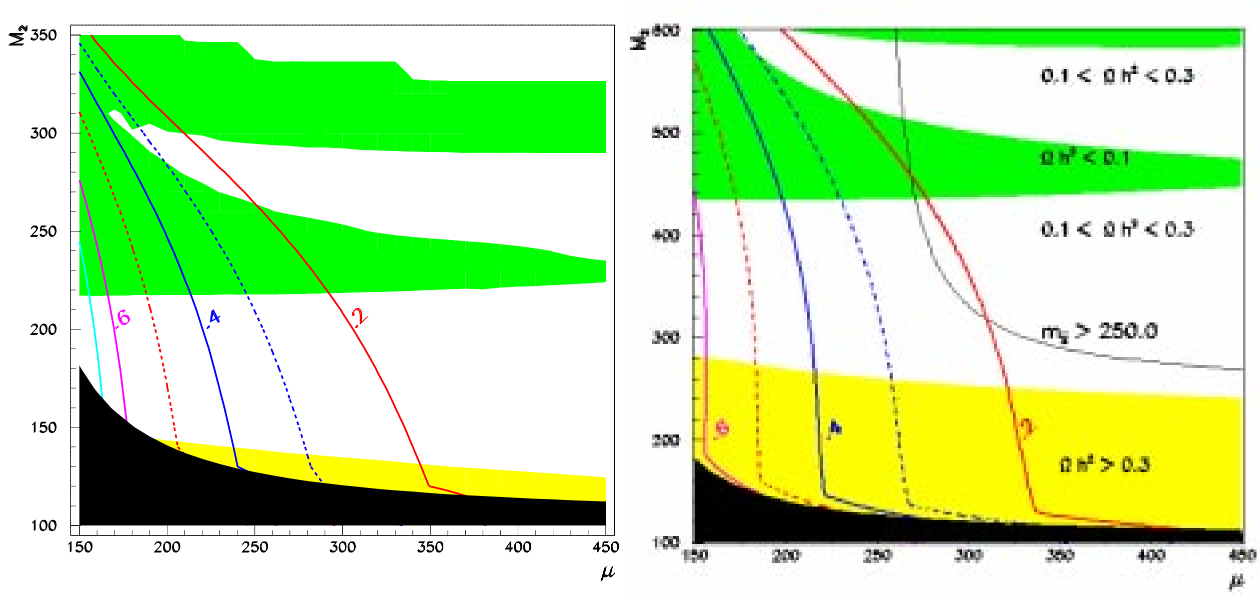

Figure 10: *Contours of constant* $B.R.(h \to \tilde{\chi}_1^0\tilde{\chi}_1^0) = .2, .3, .4, .5, .6, (.65)$ *for* $r = .1(.2)$ *in the right (left) panel, along with the DM as well as LEP constraints on the* $M_2 - \mu$ *parameter space. The white region is the cosmologically preferred area with* $.1 < \Omega h^2 < 0.3$, *for* $m_0 = 94(100)$ *GeV. This corresponds to* $\tan\beta = 5$ *and* $m_h = 125$ *GeV. The black region corresponds to the area excluded by the chargino searches at LEP. The lightly (heavily) shaded region corresponds to* $\Omega h^2 > 0.3 (< 0.1)$.

regions with acceptable relic densities even for heavier slepton masses[26]. The panel on the right shows contour for $m_{\tilde{\chi}_1^+} = 250$ GeV which indicate the extreme values that could be probed at the Tevatron Run-II. Since in these models the $\tilde{\chi}_1^0$ is lighter than in the ones with universal gaugino masses, the decay products of the $\tilde{\chi}_1^\pm$ should have higher energy. It is obvious

1. There exist regions in the $M_2 - \mu$ parameter space where the $B.R.(h \to \tilde{\chi}_1^0\tilde{\chi}_1^0)$ can be dangerously high to threaten loss of discovery in both the $\gamma\gamma$ as well as the $b\bar{b}$ channels and which give rise to acceptable relic density,

2. These regions correspond to chargino masses which can be explored at the Tevatron.

We also looked, by keeping $\tan\beta$ fixed at 5 and scanning over a wide range of M_2, M_1 and m_0 values, for the minimum value of M_1 that one can entertain and have acceptable relic density. The results are shown in Fig. 11. One sees from this figure that values of M_1 smaller than 20 GeV will lead to an unacceptably high relic density, independently of μ, M_2 and m_0. This plot is obtained by a scan over M_2, μ and m_0 values in the range $150 < \mu < 500$ GeV, $100 < M_2 < 350$ GeV, $70 < m_0 < 300$ GeV and M_1 was varied between 10 and 100 GeV. The result is also stable with respect to the variations in $\tan\beta$.

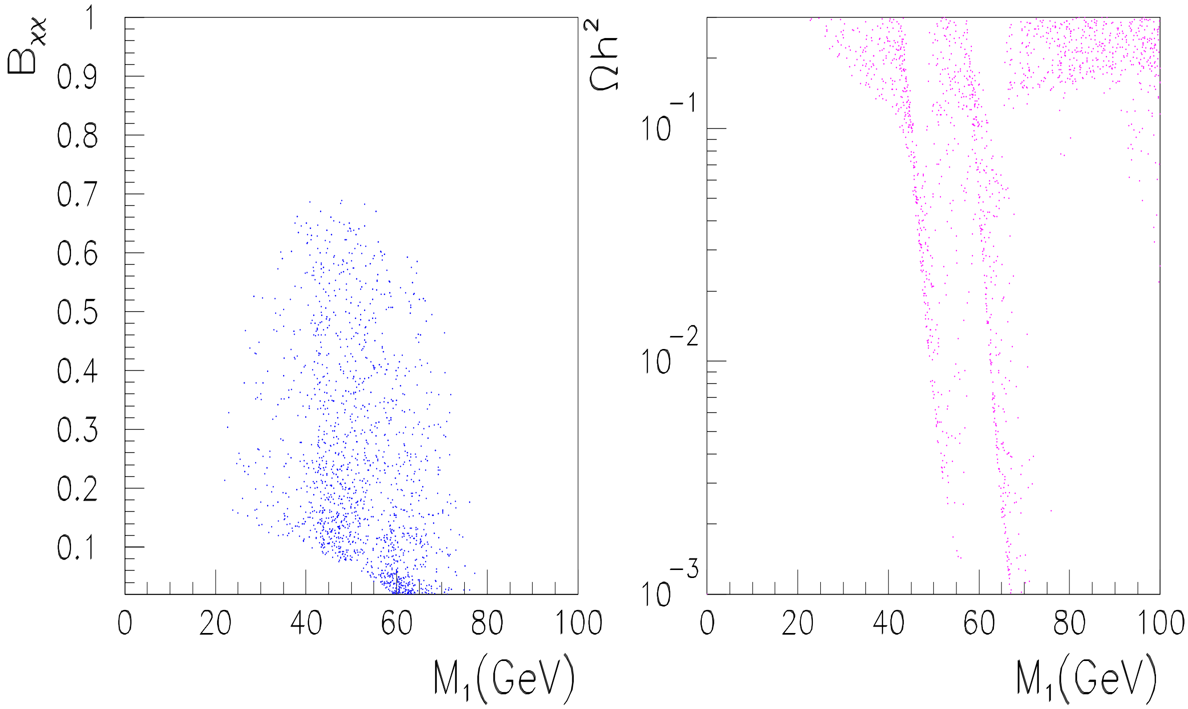

Figure 11: *Large scan over* M_1, M_2, μ, m_0 *for* $\tan\beta = 5$. *The left panel shows the branching ratio into invisibles vs* M_1. *The right panel shows the relic density as a function of* M_1. *Note that one hits both the* Z *pole and the Higgs pole. However for the latter configurations* $B_{\chi\chi}$ *is negligible.*

6 conclusion

Thus in conclusion we can say the following. It is possible to find substantial regions in the parameter space where the 'invisible' decay of the lightest Higgs h into $\tilde{\chi}_1^0$ pairs can dominate in scenarios with nonuniversal gaugino masses at the high scale. Further we find that these scenarios do not necessarily require a light slepton as they give rise to an acceptable relic density due to efficient annihilation at the Z pole. The depletion into the $\gamma\gamma$ or $b\bar{b}$ channel can be as low as 0.4 compared to the SM. Such scenarios, do necessarily imply light enough $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ which can be produced at the Tevatron Run-II. However, this also shows the need of sharpening up the strategies of looking for such an intermediate mass, 'invisibly' decaying Higgs [27, 28, 29, 30, 31].

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