Signatures of gaugino mass non-universality in cascade Higgs production at the LHC

Priyotosh Bandyopadhyay[1], AseshKrishna Datta[2]
and Biswarup Mukhopadhyaya[3]

Regional Centre for Accelerator-based Particle Physics
Harish-Chandra Research Institute
Chhatnag Road, Jhunsi, Allahabad, India 211019

Abstract

Supersymmetric cascades, involving charginos and neutralinos at various stages, contribute in a significant way to Higgs production at the LHC. We explore the nature of such cascades, completely relaxing the universality of the gaugino masses. It is found that the deviation from the scenario with universal gaugino masses would be reflected in the relative production rates for the lightest Higgs and the charged Higgses, two characteristic particles of an extended Higgs sector.

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[1]priyotosh@mri.ernet.in

[2]asesh@mri.ernet.in

[3]biswarup@mri.ernet.in

1 Introduction

Supersymmetry (SUSY) stands out as one of the most interesting alternatives beyond the Standard model (SM) of elementary particles. The Minimal Supersymmetric extension of the Standard Model (MSSM) necessarily contains two Higgs doublets, which, on electroweak symmetry breaking (EWSB), leads to 5 physical Higgs bosons, namely, two CP-even neutral scalars (h, H), one CP-odd Higgs (A) and two mutually conjugates charged scalars $(H^{\pm})$. In such a framework, the Higgs phenomenology is obviously richer than in the SM [1, 2]. With the Large Hadron Collider (LHC) all set to take off, the hunt for this yet undiscovered scalar sector has assumed a spacial significance, concurrently with the search for SUSY.

The phenomenology of the Higgs sector in the MSSM is considerably enriched by the interaction of the various scalar (Higgs) states with SUSY particles [3, 4, 5]. Notwithstanding the prevailing emphasis on Higgs production in processes driven by SM interactions, the prospect of extracting information from SUSY channels and cascades should therefore be always kept within sight. As for example, viable Higgs signals in associated production of superparticle have been suggested in recent studies, for cases where SM channels fail due to the effects of CP-violating phases [6]. In this paper, we suggest the utilisation of Higgs production in SUSY cascades in probing the chargino-neutralino sector of the MSSM. In particular, we show that the relative rates of h-and $H^{\pm}$-production in cascades can provide insight on whether M_1 and M_2, the $U(1)$ and $SU(2)$ gaugino masses, respectively, are related by a high-scale universality condition.

The significance of SUSY cascades as the source of the MSSM Higgs bosons has been discussed in detail in the recent past [7] within an MSSM framework, but keeping M_1 and M_2 constrained by universality. The central idea in such a study has been to exploit the huge production cross sections for the strongly interacting SUSY particles the squarks and the gluino at a hadron collider like the LHC. These sparticles, once produced, may undergo long cascade-decays that ultimately lead to stable SM particles (like leptons and quarks (jets)) along with the LSP's which escape detection if R-parity (defined as $R = (-)^{3B+L+2J}$) is conserved. It was pointed out in [7, 9]that one or more MSSM Higgs bosons can be produced at different stages of these cascades. It was also shown [8] that the suppressions resulting from different decay branching fractions under SUSY cascades are more than compensated for by the huge production cross-section of the strongly interacting particles. It is to be noted that such cascades, in order to be instrumental in Higgs production, necessarily require SUSY particles widely separated in mass. A high energy machine like LHC is an ideal hunting ground for MSSM Higgs bosons under such cascades.

As has been already pointed out in the earlier works [8], cascades can be very efficient sources of MSSM Higgs bosons in certain regions of MSSM parameter space

(viz., with intermediate $\tan \beta$ values) where usual modes cease to deliver. Here we make use of these sources, with the $M_1 - M_2$ universality conditions relaxed, and discover some rather spectacular consequences on the overall rates.

In canonical SUSY scenarios, the neutralinos and the charginos (which are the mass eigenstates and mixtures of electroweak gauginos and the higgsinos) can be much lighter compared to the strongly interacting sparticles like squarks and gluinos. Thus, charginos and neutralinos may take control of the proceedings at an early stage of the cascade. Further, their compositions (in terms of the gaugino and Higgsino contents), which play a crucial role. The compositions in turn are determined by the soft masses of the electroweak gauginos, namely, M_1 and M_2, μ, the so-called higgsino mass parameter, and $\tan \beta$, the ratio of the vacuum expectation values of the two Higgs doublets. In particular, the relative magnitudes of M_1, M_2 and μ largely determine their physical states.

There is no *a priori* justification as to why gaugino universality, albeit highly predictive and hence, popular, would necessarily hold at a high scale. In fact, it has its root in the trivial nature of the so-called gauge kinetic function from which the common gaugino mass arises at a high scale as SUSY breaks in the hidden sector. More specifically, such a universality arises when the gauge kinetic function involves a combination of the hidden sector fields which is singlet under the underlying gauge group of SUSY Grand Unified Theory(GUT). It has been shown [[10]-[18]] that involving higher GUT representations for the purpose would in general trigger nonuniversality among the gaugino soft masses at a high scale itself. Such a nonuniversality inevitably distorts the weak-scale gaugino spectrum thus modifying the compositions of the charginos and the neutralinos and their masses vis-a-vis the gluino mass. From a purely phenomenological point of view one can thus think of a completely uncorrelated gaugino sector at the weak scale. This can have profound implications in collider data [[19]-[25]]. It is interesting to note that imprints of such nonuniversality can be recognised even in SUSY-Higgs searches at the LHC. Also, unlike in earlier works [7, 8] we keep sleptons light enough so that they have a nontrivial role to play.

The main consequence of relaxing the universality condition on the $SU(3)$ gaugino mass (M_3) [7, 8] is that it gives a free hold to the gluino mass (and, in schemes of scalar mass evolution, the squark masses). This affects the rates of cascades through gluino and squark decay branching ratios only. By relaxing $M_1 - M_2$ universality, on the other hand, one opens up additional possibilities, as far as the cascade branching ratios of the charginos and neutralinos themselves are concerned. In addition, the lack of correlation between M_1 and M_2 affects the coupling strengths of a charged or neutral Higgs to a chargino-neutralino pair. Since such effects have not been studied systematically so far, we present an analysis here, in the context of the LHC.

In section 2 we outline the Higgs production process in cascades and the factors that control them. In section 3 we the production rates of the charged $H^\pm$ and the lightest

neutral Higgs (h) bosons and contrast them systematically. We demonstrate how such a knowledge could reflect on the nonuniversality of gaugino-masses We conlclude in section 4.

2 Higgs production in SUSY cascades

The squarks and the gluinos, once produced at LHC, would first undergo strong two-body decays like $\tilde{q} \to q\tilde{g}$ (for $m_{\tilde{q}} > m_{\tilde{g}}$) or $\tilde{g} \to q\tilde{q}$ (for $m_{\tilde{g}} > m_{\tilde{q}}$). Beyond this point, the cascade decays are electroweak in nature where Higgs bosons could appear [4].

Higgs production under such cascades mainly involves the charginos and neutralinos in the intermediate stages. With gluinos initiating a cascade, this is inevitable, since gluinos do not couple directly to the Higgs bosons at the tree level. For squarks, couplings to Higgs bosons are proportional to the corresponding quark masses, and are thus significant only for the squarks of the third family. Since the generic yield of such squarks is smaller in comparison to those of the first two families, most Higgs production processes in cascades involve the charginos and neutralinos in the intermediate stages.

Schematically, the chains of cascades leading to the Higgs bosons are as follows:

$$pp \to \tilde{g}\tilde{g},\ \tilde{q}\tilde{q},\ \tilde{q}\tilde{q}^*,\ \tilde{q}\tilde{g} \longrightarrow \chi_2^{\pm},\ \chi_3^0,\ \chi_4^0 + X \longrightarrow \chi_1^{\pm},\ \chi_2^0,\ \chi_1^0 + H^{\pm}, h, H, A + X \quad (1)$$

$$pp \to \tilde{g}\tilde{g},\ \tilde{q}\tilde{q},\ \tilde{q}\tilde{q}^*,\ \tilde{q}\tilde{g} \longrightarrow \chi_1^{\pm},\ \chi_2^0 + X \longrightarrow \chi_1^0, + H^{\pm}, h, H, A, H^{\pm} + X \quad (2)$$

The first decay chain above is a longer one as it involves direct decays of squark and gluinos to the heavier chargino/neuralinos followed by subsequent decays of the latter ones to lighter gauginos and the Higgs bosons. On the other hand, the second chain is shorter since it exploits direct decays of squarks and gluinos to the lighter chargino/neutralinos which then decay to Higgs bosons and the LSP. In the literature [8] the first scheme was called the 'big cascade' while the latter one was dubbed as the 'little cascade'. For convenience, we adopt the same terminology in this work.

It is thus expected that the final yield of Higgs bosons under such SUSY-cascades crucially depends upon the branching fractions of the relevant decay processes. Thus on a complicated, though comprehensible, interplay of different SUSY parameters in the form of various couplings and masses. Out of these, the couplings of the Higgs bosons with the charginos/neutralinos play the most important role. It is well known [5, 8] that the Higgs bosons couple favourably to charginos and neutralinos when the

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[4]A possible exception could be when all squarks except the ones from the third generation ($\tilde{t}_1$ or $\tilde{b}_1$) are heavier than the gluino. In such scenarios, a cascade of strong decays of squarks and gluinos might end up with $\tilde{t}_1$ or $\tilde{b}_1$ whose electroweak decays would lead to the Higgs bosons.

latter are mixtures of gauginos and Higgsinos while for gauge bosons the couplings are maximal when the charginos and the neutralinos are Higgsino-dominated.

Naturally, then, the compositions of the charginos and neutralinos would play a crucial role in our study [5]. Out of the determining parameters, the values of M_1, M_2 and μ have the most crucial bearings on the masses and the contents of the charginos and the neutralinos. For $\mu >> M_1, M_2$, one is in the so-called 'gaugino region' where the lighter neutralinos and chargino ($\chi_1^0, \chi_2^0, \chi_1^\pm$) are gaugino-dominated with $m_{\chi_1^0} \simeq min(M_1, M_2)$ and $m_{\chi_2^0}, m_{\chi_1^\pm} \simeq max(M_1, M_2)$ while the heavier ones ($\chi_3^0, \chi_4^0, \chi_2^\pm$) are mostly Higgsinos with $m_{\chi_3^0}, m_{\chi_4^0}, m_{\chi_2^\pm} \simeq \mu$. On the other hand, for $\mu << M_1, M_2$, we are in the 'Higgsino region' for which the lighter neutralinos and the chargino are predominantly Higgsinos with $m_{\chi_1^0}, m_{\chi_2^0}, m_{\chi_1^\pm} \simeq \mu$ while the heavier ones are dominated by gauginos with $\chi_3^0 \simeq min(M_1, M_2)$ and $\chi_4^0, m_{\chi_2^\pm} \simeq max(M_1, M_2)$. As expected, for different charginos and neutralinos, the masses and the contents have one-to-one correspondences in such 'pure' regions of the SUSY parameter space. For $M_1, M_2 \simeq \mu$, the charginos and the neutralinos become maximally mixed in gauginos and Higgsinos with their masses showing no particular pattern, albeit restricted within a range determined by the values of M_1, M_2 and μ.

In a nutshell, the 'big cascades' are favoured in regions where, between ($\chi_2^\pm, \chi_3^0, \chi_4^0$) and ($\chi_1^\pm, \chi_1^0, \chi_2^0$), one set is gaugino-dominated, and the other, Higgsino-dominated. In situations where they are kinematically allowed, little cascades are on the hand possible when the members of the second set above comparable gaugino and Higgsino components.

We investigate charged as well as neutral Higgs production rates in cascades. For a ready comparison, we closely follow the earlier analyses [7, 8]. Explicit expressions for most cross-sections and decay widths of relevance are found in the above references.

3 The results of nonuniversality: numerical results

We are looking at 'effective cross-sections' of Higgs production of various kinds, which essentially means

$$pp \longrightarrow Higgs + X$$

where the cross-sections of all possible (from $2 \rightarrow 2$ strong productions) cascades are added up, so long as there is at least one Higgs of any kind in the final state. As cross-

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[5]In scenarios with a universal gaugino mass at a high scale (like the GUT scale), M_1 and M_2 gets related at the weak scale by the simple relation $M_2 \simeq 2M_1$. Thus, in that case, one only talks about 3 input parameters that govern the chargino-neutralino sector. In contrast, the present work addresses the issue of nonuniversality of gaugino masses in a particular context. Hence, M_1 and M_2 are taken to be two free parameters.

checks of the calculation, we have reproduced the results in [7, 8] in the appropriate limits. We have used PYTHIA [26] for our analysis and CTEQ3L [27] as parton distributions interfaced via LHAPDF [28]. The factorization/renormalization scale set at the average of the masses of the particles (squarks and/or gluinos) produced in the hard scattering. the analysis is based on leading order production only. Also, following [8], the set of relevant SM and SUSY inputs (at the weak scale) chosen for the analysis (unless otherwise specified) is:

$$m_{top} = 175 \text{ GeV} \quad \tan\beta = 10 \quad m_A = 162.1(237.5) \text{ GeV}$$

$$m_{\tilde{g}} = 900 \text{ GeV} \quad m_{\tilde{q}} = 800 \text{ GeV} \quad A_f = 0$$

This resulted in the following masses for the different Higgs bosons:

$$m_h = 109(110) \text{ GeV} \quad m_H = 164(238) \text{ GeV} \quad m_{H^\pm} = 180(250) \text{ GeV}$$

which are in close agreement with those used earlier in the literature [7, 8]. As for the sleptons, the only way they may signficantly contribute is by affecting the decay modes of the gauginos. As indicated in section 1, we demonstrated the role of light sleptons, taking them to be degenerate at 400 GeV [6].

The parameter-dependence of Higgs production rates under SUSY cascades is investigated in two ways: (i) variation with M_2 and (ii) variation with μ.
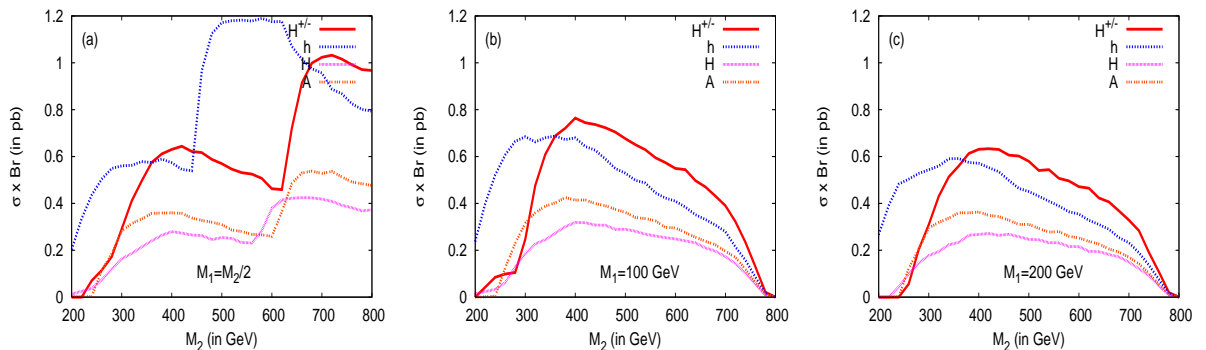
3.1 Variation with M_2

Figure 1: Effective cross-sections for universal ($M_1 = M_2/2$, (a)) and nonuniversal (with $M_1 = 100$ GeV, (b) and with $M_1 = 200$ GeV (c)) for $\mu = 150$ GeV and $m_{H^\pm} = 180$ GeV.

Since $m_{\tilde{\ell}}$ is taken to be 400 GeV, the sleptons have a significant role in the cascades. Thus, the natural expectation is that once these sleptonic decay modes of the

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[6]We have checked that the use of more recent parton distribution functions, the variations in rates with renormalization/factorization scale and the use of an updated top-quark mass do not alter the basic findings of the present work.
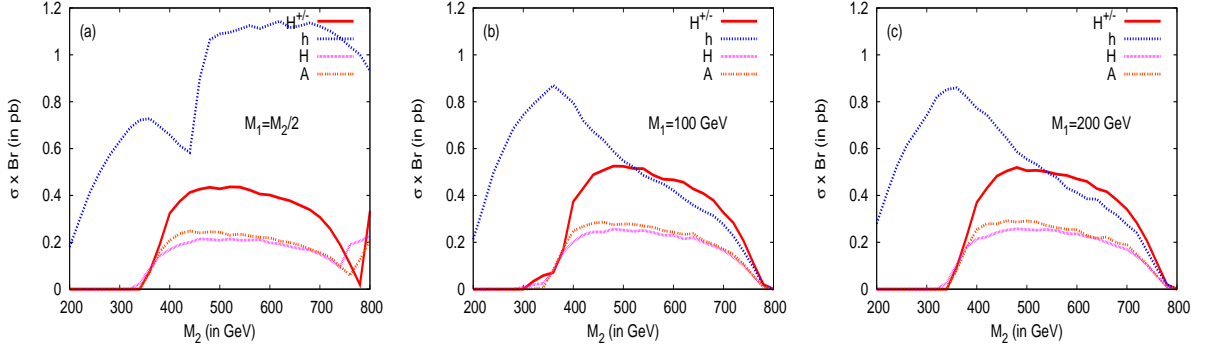
Figure 2: Effective cross-sections for universal ($M_1 = M_2/2$, (a)) and nonuniversal (with $M_1 = 100$ GeV, (b), with $M_1 = 200$ GeV (c)) for $\mu = 150$ GeV and $m_{H^\pm} = 250$ GeV.
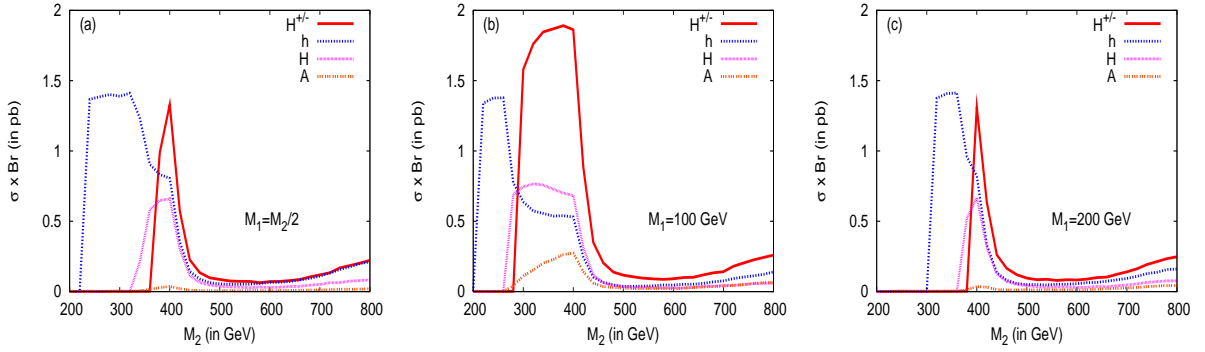

Figure 3: Effective cross-sections for universal ($M_1 = M_2/2$, (a)), nonuniversal (with $M_1 = 100$ GeV (b) and $M_1 = 200$ GeV (c)) for $\mu = 700$ GeV and $m_{H^\pm} = 180$ GeV.

charginos/neutralinos open up, cascades to Higgs would get suppressed. Hence the overall rates presented are of a conservative nature. This is clear from the set of Figures 1 to 4. We discuss below some generic features present in these figures and the information we get from them.

Plot (a)s depict the universal scenario while plot (b)s and plot (c)s are for the nonuniversal scenario. Figure 1 and Figure 2 are for $\mu = 150$ GeV while Figure 3 and Figure 4 are for $\mu = 700$ GeV. For $\mu = 150$ GeV the lighter gauginos are too closely degenerate (for both universal and nonuniversal scenarios) for the 'little cascades' to open up. Hence, the entire cascade contribution to Higgs production comes from the 'big cascade'. The sudden rises in some curves at specific M_2 values in the universal scenario indicate attaining the right mass-splitting between χ_3^0 and the LSP such that χ_3^0 decaying to the lightest neutral (charged) Higgs boson and the LSP (the lighter chargino) becomes possible. This feature is not there in the nonuniversal cases (where M_1 is set to 100 and 200 GeV respectively) as $m_{\chi_3^0} \sim \mu$.

One should note the different pattern of M_2-dependence of the rates for $\mu = 150$ GeV (Figures 1 & 2) and 700 GeV (Figures 3 & 4), respectively. This is because the
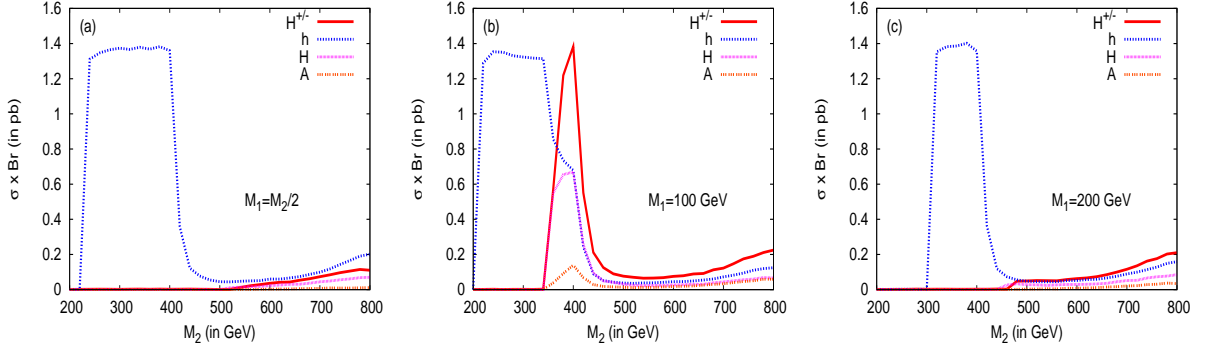
Figure 4: Effective cross-sections for universal ($M_1 = M_2/2$, (a)), nonuniversal (with $M_1 = 100$ GeV (b) and $M_1 = 200$ GeV (c)) for $\mu = 700$ GeV and $m_{H^\pm}$=250 GeV.

former situation allows Higgs production mostly through 'big cascades'. The latter case, where larger separation amongst the low-lying states is possible, 'little cascade' more abundantly, thus making the variation of Higgs production rates with M_2 look different. In particular, slepton masses of the order of 400 GeV affect 'big cascades' less for larger value of M_2 throught the enhancement of the effective coupling for Higgs production. Little cascades are affected much more in such a case, thus causing difference in the way the rates fall with increasing M_2.

In Figure 2 we illustrate a case similar to Figure 1 except for $m_{H^\pm} = 250$ GeV. This needs a substantial increment in the mass of A as input and results in a larger H compared to those for Figure 1. Thus, in the universal case (Figure 2(a)) χ_3^0 needs to be heavier such that the heavier Higgs bosons may be produced in the decay of χ_3^0 along with χ_1^0 or $\chi_1^\pm$. Note that increasing $m_{H^\pm}$ does not affect the rate for the lightest higgs (h) significantly, when compared to the corresponding plot in Figure 1 since m_h remains almost unaffected by such an increase in $m_{H^\pm}$. Thus, for $m_{H^\pm} = 250$ GeV, there is no cross-over between the curves for h and $H^\pm$ in the universal case unlike $m_H^\pm$=180 GeV.

The general observation is that with increasing $m_{H^\pm}$ the threshold value of M_2 shifts naturally to the right leading to more massive heavier charginos and neutralinos such that the 'big cascades' may take place. This eventually pushes the cross-over point (of the rate-curves for the lightest and charged Higgs bosons) to larger values of M_2. Also, the rates for heavier Higgs bosons are smaller for $m_{H^\pm} = 250$ GeV as compared to $m_{H^\pm} = 180$ GeV. There are two reasons for this. First, the heavier Higgs bosons now become more massive whose rates suffer a phase-space suppression for similar chargino and neutralino masses. Second, the charginos and neutralinos whose decay results in the Higgs bosons (with increased masses) have to become heavier as well. Thus the production rates for the latter also get affected. Figures 2(b) and 2(c) illustrating the nonuniversal cases with $M_1 = 100$ GeV and 200 GeV are to be contrasted with the corresponding ones in Figure 1. They only differ by the generic features as described

above.

Figure 4 illustrates a situation similar to Figure 3 except for $m_{H^\pm} = 250$ GeV. In the universal case (Figure 4(a)), the peak in the $H^\pm$ rate disappears when compared to Figure 3(a). One should note that this peak is due predominantly to a 'little cascade' like $\chi_1^\pm \to \chi_1^0 H^\pm$. As indicated earlier, with growing $m_{H^\pm}$ the mass splitting between the gaugino states involved above are not enough to accommodate the above cascade. The situation could be a little different for a nonuniversal case with a lower value of M_1 (100 GeV) as shown in Figure 4(b). The smaller value of M_1 now ensures a lower mass for the χ_1^0 thus help regaining the required splitting when the peak in the $H^\pm$ is back (at around 400 GeV). In Figure 4(c), M_1 is 200 GeV and this again blocks the above decay mode at around 400 GeV. Of course, with increasing value of M_2 (≥ 500 GeV) the Higgs productions under such cascades open up again. But this time, $\mathrm{Br}[\chi_1^\pm \to \chi_1^0 H^\pm]$ starts getting suppressed as the two-body sleptonic decay modes of $\chi_1^\pm$ take off for our choice of slepton mass (400 GeV).
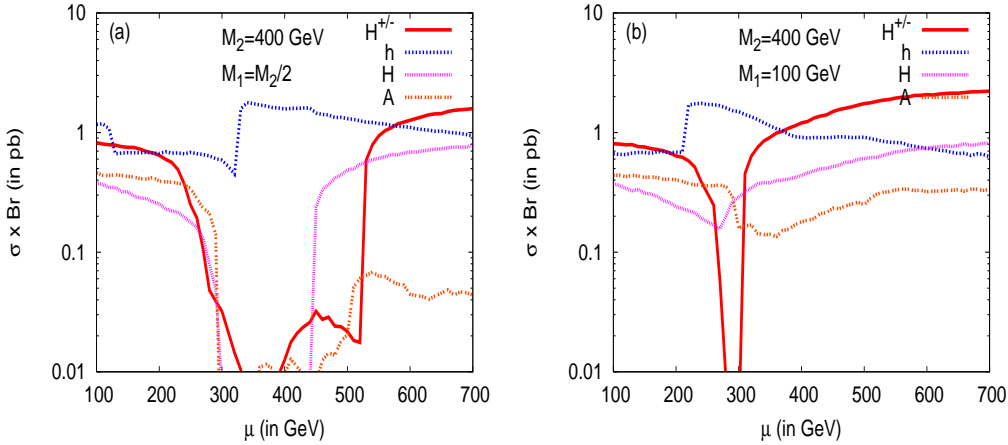
3.2 Variation with μ

Figure 5: Effective cross-section as a function of μ for universal (with $M_1 = M_2/2$, (a)) and nonuniversal (with $M_1 = 100$ GeV, (b)) scenarios with $M_2 = 400$ GeV and $m_{H^\pm} = 180$ GeV.

In Figures 5 & 6, we illustrate the variation of the rates for Higgs production under SUSY cascades with μ. Plot (a)s represent the universal scenario while plot (b)s illustrate the same in a nonuniversal situation. In both cases, for small values of μ, the lighter charginos and neutralinos are Higgsino-like and their masses are of the order of $\sim \mu$ with a definite split from their heavier mates governed by the value of M_2 chosen. With increasing μ, the "mixed region" is approached and the mass-splittings among the heavier and lighter charginos decrease. This gradually eliminates the possible sources of the heavier Higgs bosons, especially those of $H^\pm$. Further, with increasing μ, channels like $\chi_2^\pm \to \chi_1^0 H^\pm$ again opens up followed by $\chi_1^\pm \to \chi_1^0 H^\pm$ at about $\mu = 525$ GeV in
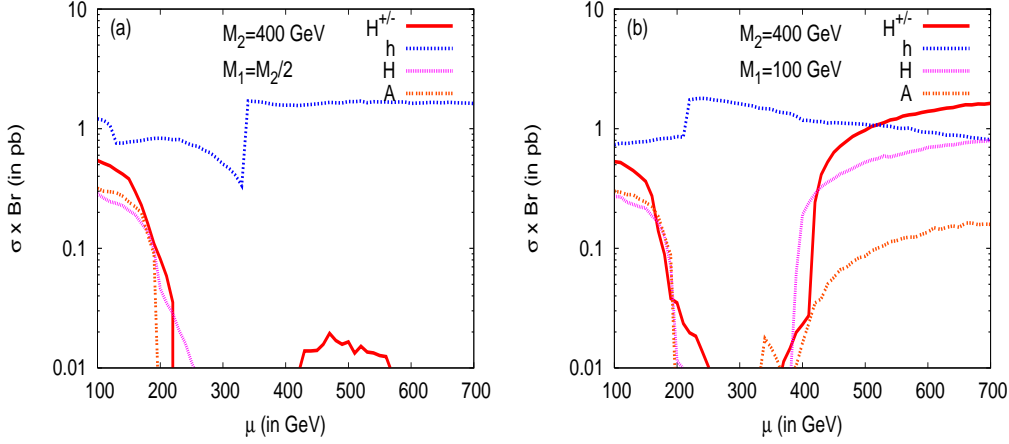
Figure 6: Effective cross-section as a function of μ for universal (with $M_1 = M_2/2$, (a)) and nonuniversal (with $M_1 = 100$ GeV, (b)) scenarios with $M_2 = 400$ GeV and $m_{H^\pm} = 250$ GeV.

the universal case. A further mild rise in the $H^\pm$-rate is observed at around $\mu = 550$ GeV when $\chi_3^0 \to \chi_1^\pm H^\pm$ opens up. However, in the nonuniversal case, due to a fixed low value of M_1 the LSP mass remains almost the same ($\sim M_1$). Hence channels like $\chi_1^\pm \to \chi_1^0 H^\pm$ opens up as early as $\mu = 300$ GeV. The features observed in these plots are generic as long as the relative splittings of gaugino masses and μ used here remain similar.

In Figure 6 we illustrate the case similar to Figure 5 except for $m_{H^\pm} = 250$ GeV. In the universal case, when compared to Figure 5, we find that the rise in the rate for $H^\pm$ at around $\mu = 500$ GeV is missing. This is because of the lack of enough splitting between the lighter chargino and the LSP masses that might lead to $H^\pm$ unlike what happened in the universal case when $m_{H^\pm} = 180$ GeV. For $M_1 = 100$ GeV, $\chi_1^\pm \to \chi_1^0 H^\pm$ opens up at a later stage compared to $m_H^\pm = 180$ GeV case. For higher neutral Higgses similar things happen.

3.3 Comparison between $H^\pm$ and h production rates

Figures 1, 3 and 5 ($m_{H^\pm} = 180$ GeV) along with the discussions in sections 3.1 and 3.2 reveal a rather complicated interplay of several masses and couplings. It is undoubtedly a difficult task to extract useful information from these processes in a systematic way. However, a closer look at these reveal that we have a somewhat clean feature in the variations of rates for $H^\pm$ and h which we can use to our benefit. These rates behave in a distinctly complementary fashion as functions of M_2 (Figures 1 and 3) and μ (Figure 5) and show up as multiple cross-over points. For universal and nonuniversal scenarios, these cross-overs take place at different values of M_2 and μ. This can be understood in a straight-forward manner following the discussions in sections 3.1 and 3.2.

The observations prompt us to look out for a suitable illustration of the situation. In Figure 7 we present the scattered plots of the two-rates compared in the $M_2 - \mu$ plane for both universal and nonuniversal cases. Over the grey regions the rates for

the charged Higgs bosons is greater than that for the lightest neutral Higgs boson and the reverse is the case over the darker regions. At suitable points on these plots, direct correspondences can be made with Figures 1, 3 and 5. There are quite a few distinctive patches on these two plots. If such relative rates can be known from the LHC experiments, these plots could be used to have a preliminary understanding of the gaugino mass pattern.

In Figure 8 we present a similar set of scattered plots but for $m_H^{\pm}$=250 GeV. In the universal case, all over the $M_2 - \mu$ space the rate for lightest Higgs is greater than that for the charged Higgses. For the nonuniversal case, with increasing M_1 the region where the rate for the charged Higgses is larger than that for the lightest Higgs gradually shrinks. Again, all these can be read off from the plots in Figures 1 to 6. Thus, we see that $m_{H^{\pm}}$ and M_1 play some significant roles in characterizing the $M_2 - \mu$ plane.

We have checked that the results presented here are robust against wide variation of squark and gluino masses, even when their ordering is reversed. Increasing the slepton masses would only make life simpler in the sense that they get decoupled from the cascades and we checked that this does not bring out any new feature. We also checked that the effect of $\tan \beta$ is anything but significant. This validates one of the very basic expectations for studying the Higgs production under SUSY cascades and hence its power of probing the Higgs sector for intermediate values of $\tan \beta$.

It is useful to mention here that the confirmation of gaugino nonuniversality in Higgs production presupposes some knowledge of the SUSY spectrum, as obtained from the heaviness or missing-E_T distribution of the SUSY signals. As the scatter plots in figures 7 and 8 indicate, one is able to infer conclusively about universality (or the lack of it) from the relative magnitudes of the h- and $H^{\pm}$-production rates, provided that two quantities out of M_1, M_2 and μ are known. However, even that does not rob the present study of its merits, since any unambiguous conclusion about the particle spectrum of a new physics scenario requires a multichannel analysis. In that sense, the inclusive Higgs production processes provide a channel of supreme importance in understanding the electroweak gaugino-Higgsino sector.

4   Conclusions

We have investigated the rates for production of different physical Higgs states in SUSY cascades at the LHC. The new inputs are (a) relaxation of the universality condition relating electroweak gaugino masses and (b) allowing sleptons to be light enough to be produced on-shell in cascades. As we show through the dependence of production rates on various parameters, both these inputs can significantly affect the phenomenology at the LHC. The most important observation is that the presence or absence of gaugino
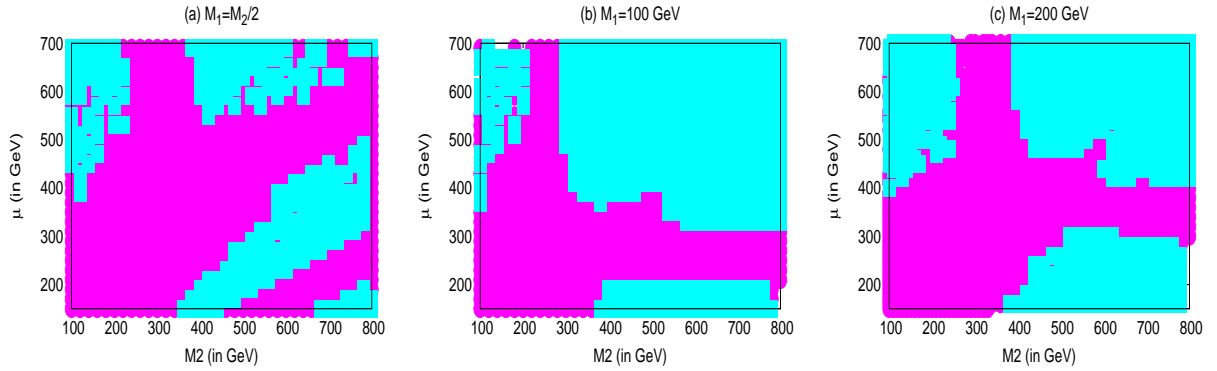
Figure 7: The pink (dark) region is the region where the rate for H$^{\pm}$ is less than that for h production, for the sky-blue region (grey) it is the opposite and white regions indicate zero production for both. We take $M_1 = M_2/2$ (a), $M_1 = 100$ GeV (b) and $M_1 = 200$ GeV (c). $m_{H^{\pm}}$ is set to 180 GeV.
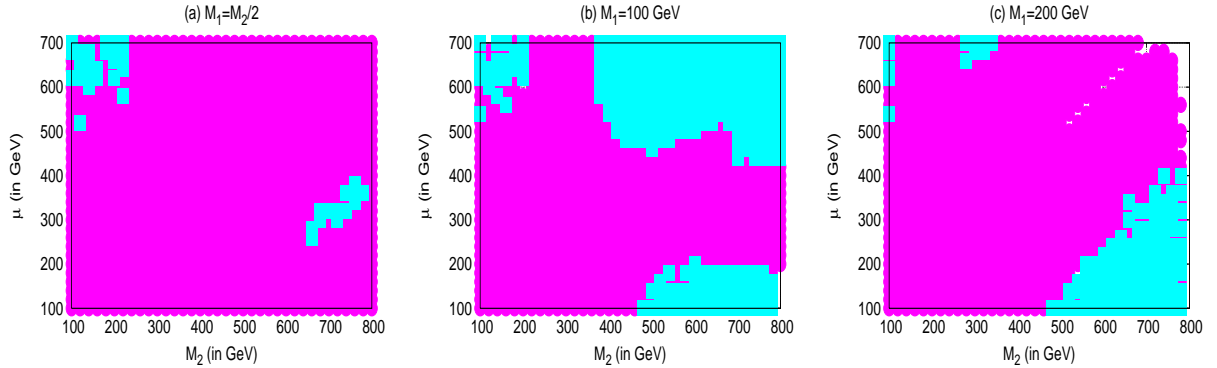

Figure 8: The pink (dark) region is the region where the rate for H$^{\pm}$ is less than that for h production, for the sky-blue region (grey) it is the opposite and white regions indicate zero production for both. We take $M_1 = M_2/2$ (a), $M_1 = 100$ GeV (b) and $M_1 = 200$ GeV (c). $m_{H^{\pm}}$ is set to 250 GeV.

universality is reflected in a rather interesting complementarity between the relative production rates of $H^{\pm}$ and h. Therefore, one should aim at a careful identification of charged as well as neutral Higgs signals in cascades to extract useful information about the underlying SUSY scenario. A detailed discussion of such signals *all* the physical Higgs states in SUSY and methods of suppressing their backgrounds will be presented in a separated study.

References

[1] A. Djouadi, Phys. Rept. **457** (2008) 1 [arXiv:hep-ph/0503172]; A. Djouadi, Phys. Rept. **459** (2008) 1 [arXiv:hep-ph/0503173].

[2] J. A. Aguilar-Saavedra *et al.*, Eur. Phys. J. C **46** (2006) 43 [arXiv:hep-ph/0511344].

[3] H. E. Haber and G. L. Kane, Phys. Rept. **117** (1985) 75.

[4] For a review on the Higgs sector of the MSSM, see J.F. Gunion, H.E. Haber, G.L. Kane and S. Dawson, "The Higgs Hunter's Guide", Addison–Wesley, Reading 1990.

[5] J. F. Gunion and H. E. Haber, Nucl. Phys. B **272** (1986) 1 [Erratum-ibid. B **402** (1993) 567]; A. Djouadi, P. Ohmann, P. M. Zerwas and J. Kalinowski, arXiv:hep-ph/9605437.

[6] P. Bandyopadhyay, Asesh K. Datta, A. Datta and B. Mukhopadhyaya, arXiv:0710.3016 [hep-ph].

[7] Asesh K. Datta, A. Djouadi, M. Guchait and F. Moortgat, Nucl. Phys. B **681** (2004) 31 [arXiv:hep-ph/0303095].

[8] Asesh K. Datta, A. Djouadi, M. Guchait and Y. Mambrini, Phys. Rev. D **65** (2002) 015007 [arXiv:hep-ph/0107271].

[9] H. Baer, M. Bisset, X. Tata and J. Woodside, Phys. Rev. D **46** (1992) 303.

[10] S. P. Martin, arXiv: hep-ph/9709356.

[11] A. V. Gladyshev and D. I. Kazakov, arXiv: hep-ph/0606288.

[12] Asesh K. Datta, G. L. Kane and M. Toharia, arXiv:hep-ph/0510204.

[13] J. R. Ellis, C. Kounnas and D. V. Nanopoulos, Nucl. Phys. B **247** (1984) 373 ; J. R. Ellis, K. Enqvist, D. V. Nanopoulos and K. Tamvakis, Phys. Lett. B **155** (1985) 381.

[14] M. Drees, Phys. Lett. B **158**(1985) 409.

[15] N. Chamoun, C. S. Huang, C. Liu and X. H. Wu, Nucl. Phys. B **624** (2002) 81. [arXiv:hep-ph/0110332].

[16] A. Corsetti and P. Nath, Phys. Rev. D **64** (2001) 125010. [arXiv:hep-ph/0003186].

[17] B. Ananthanarayan and P. N. Pandita, Int. J. Mod. Phys. A **22** (2007) 3229 [arXiv:0706.2560 [hep-ph]].

[18] E. Cremmer, B. Julia, J. Scherk, P. van Nieuwenhuizen, S. Ferrara and L. Girardello, Phys. Lett. B **79**(1978) 231 (1978) ; E. Cremmer, B. Julia, J. Scherk, S. Ferrara, L. Girardello and P. van Nieuwenhuizen, Nucl. Phys. B **147** (1979) 105.

[19] S. I. Bityukov and N. V. Krasnikov, Phys. Atom. Nucl. **65**(2002) 1341 [Yad. Fiz. **65** (2002) 1374] [arXiv:hep-ph/0102179].

[20] S. I. Bityukov and N. V. Krasnikov, arXiv:hep-ph/0210269 ; S. I. Bityukov and N. V. Krasnikov, Nuovo Cim. A **112** (1999) 913 [arXiv:hep-ph/9903519] ; S. I. Bityukov and N. V. Krasnikov, Phys. Lett. B **469** (1999) 149 [Phys. Atom. Nucl. **64** (2001) 1315 (YAFIA,64,1391-1398.2001)] [arXiv:hep-ph/9907257].

[21] S. Bhattacharya, Asesh K. Datta and B. Mukhopadhyaya, JHEP **0710** (2007) 080 [arXiv:0708.2427 [hep-ph]].

[22] H. Baer, A. Mustafayev, E. K. Park and X. Tata, JHEP **0805** (2008) 058 [arXiv:0802.3384 [hep-ph]]; H. Baer, A. Mustafayev, H. Summy and X. Tata, JHEP **0710** (2007) 088 [arXiv:0708.4003 [hep-ph]]; H. Baer, A. Mustafayev, E. K. Park, S. Profumo and X. Tata, JHEP **0604** (2006) 041 [arXiv:hep-ph/0603197]; H. Baer, A. Mustafayev, S. Profumo, A. Belyaev and X. Tata, JHEP **0507** (2005) 065 [arXiv:hep-ph/0504001].

[23] A. Belyaev, S. Dar, I. Gogoladze, A. Mustafayev and Q. Shafi, arXiv:0712.1049 [hep-ph].

[24] K. Huitu, J. Laamanen, P. N. Pandita and S. Roy, Phys. Rev. D **72** (2005) 055013 [arXiv:hep-ph/0502100].

[25] K. Huitu, J. Laamanen and S. Roy, arXiv:0710.2058 [hep-ph].

[26] T. Sjostrand, S. Mrenna and P. Skands, JHEP **0605** (2006) 026 [arXiv:hep-ph/0603175].

[27] CTEQ Collaboration (H.L. Lai et al.), Phys. Rev.D55 (1997) 1280;

[28] see 'http://projects.hepforge.org/lhapdf/'