

New Higgs signals from vector boson fusion in R-parity violating supersymmetry

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Abstract

We investigate signals of the lightest neutral Higgs in an R-parity violating supersymmetric model through the vector boson fusion mechanism. Assuming that R-parity is violated through lepton number, and locating regions in the parameter space where decays of such a neutral scalar into a pair of lightest neutralinos can be significant, we proceed to calculate the event rates for final states arising from decays of the neutralinos through both λ - and λ' -type interactions. Regions of the parameter space where each of these types of interactions can lead to detectable events are identified. The possibilities where such signals can be faked by other superparticles (squarks, gluinos, charginos and neutralinos) are also investigated. It is found that over a sizable region, one can obtain distinguishable signals of an intermediate mass neutral scalar from a study of the suggested final states at the Large Hadron Collider.

1 Introduction

To a large extent, the notion of a supersymmetric nature owes itself to questions concerning the stability of the electroweak symmetry breaking sector. It is, therefore, of natural interest to look for some signature of supersymmetry (SUSY) [1] in the phenomenology of the (lightest) Higgs boson if and when it is discovered in collider experiments. In particular, if most of the SUSY particle spectrum is on the heavier side, then it is of considerable importance to study properties of the lightest neutral scalar and find out whether they correspond to a SUSY scenario, and if so, *what kind of a framework* it is.

Ironically, SUSY (at any rate in most of its incarnations) also dictates that the lightest neutral Higgs be within a mass range of about 140 *GeV* [2]. Since the lower two-thirds of this mass range

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is practically ruled out by data from the Large Electron Positron (LEP) collider [3], we are left with the so-called ‘intermediate mass range’ in which a SUSY Higgs should decidedly lie. The conventional method of producing such a neutral scalar via gluon fusion seems to suffer from an abundance of backgrounds for the dominant channels, and one has to depend only on decays like $H \rightarrow \gamma\gamma$ or $H \rightarrow VV^*$ (where $V = W, Z$) to uncover its presence [4]. Under the circumstances, a detailed investigation of the couplings and other properties of the Higgs becomes a rather difficult proposition.

A parallel channel explored for the discovery of a Higgs at a hadron collider (such as the upcoming Large Hadron Collider (LHC) at CERN) is the fusion of $W(Z)$ bosons emitted from quark pairs [5]. Though it was originally discussed in the context of a heavy Higgs [6], its usefulness in finding signals of an intermediate mass Higgs [7], too, has been established. Tagging of the energetic forward jets associated with such a process, together with the absence of hadronic activity in the large rapidity gap between them, [8] can considerably reduce backgrounds for final states ensuing from different Higgs decay channels. The process has been studied, both in the context of the standard model (SM) and the minimal SUSY standard model (MSSM), for channels such as $\tau\bar{\tau}$, $b\bar{b}$, $\gamma\gamma$ and for associated HW production processes [9], and the advantages compared to the gluon fusion mechanism have been reiterated. The observation of these various final states arising from the decay of neutral Higgs will undoubtedly go a long way in establishing the properties of the latter [10].

In this paper, we focus our attention on R-parity violating SUSY theories [11]. There is nothing that forbids the multiplicative quantum number R , defined as $R = (-)^{3B+L+2S}$, from being violated in SUSY so long as *one* of baryon (B) or lepton (L) number is conserved. On the other hand, the violation of R-parity makes the lightest SUSY particle (LSP) unstable, thereby altering many of the conventional signals of the MSSM [12]. Here we argue that if R-parity is violated, the small but non-negligible fraction of neutral scalars decaying into the $\chi_1^0\chi_1^0$ channel (where χ_1^0 is the lightest neutralino, the LSP in most cases), followed by decays of the χ_1^0 into three fermions, will lead to useful signals of the Higgs via the vector boson fusion (VBF) mechanism.

This channel has been discussed earlier in the context of MSSM as an invisible decay mode of the Higgs [13, 14]. As almost all of the parameter space that could make this the dominant decay mode has been ruled out by LEP data, its relevance in the context of R-conserving theories is perhaps not very high any more. However, we want to show that even a branching ratio of a few per cents (or less) for this channel can make it detectable if the VBF technique is employed. This not only gives us the source of a substantial signal for an intermediate mass Higgs, but also allows the measurement of the Higgs coupling with a neutralino pair if R-parity is violated.

The production of the neutral scalar via gluon fusion can also give rise to new signals if it decays into LSP pairs which in turn have three-body decays. However, in such cases it is very difficult to distinguish the Higgs signals against the backdrop of numerous superparticle cascades, most importantly those originating from squark or gluino pair production, all leading to the production

of LSP pairs. As we shall show here, the VBF signals give us tags with which we can eliminate the cascade ‘backgrounds’ quite effectively.

We confine ourselves to R-parity violation in terms of lepton number only. In section 2, we present an investigation of the SUSY parameter space and try to outline the region where the two-neutralino decay mode for the lightest Higgs can have any hope of detection. The signals corresponding to the so-called λ -and λ' -type couplings are discussed in sections 3 and 4. We have also looked into the possibilities of the Higgs signals being faked by strongly interacting superparticles (i.e. squarks and gluinos) as well as charginos or neutralinos. After a detailed estimate of such ‘backgrounds’, we identify in these two sections the regions in the parameter space where the corresponding signals have a strong chance of standing out. We summarise and conclude in section 5.

2 Analysis of the parameter space

Let us first take a close look at the parameter space of the theory and try to identify the regions where the $\chi_1^0\chi_1^0$ decay mode for the lighter neutral Higgs can have a branching ratio of one per cent or more. In doing so, we recall that in a general R-parity violating SUSY model, the following terms are added to the MSSM superpotential, written in terms of the quark, lepton and Higgs superfields [15]:

$$W_{\mathcal{R}} = \lambda_{ijk}\hat{L}_i\hat{L}_j\hat{E}_k^c + \lambda'_{ijk}\hat{L}_i\hat{Q}_j\hat{D}_k^c + \lambda''_{ijk}\hat{U}_i^c\hat{D}_j^c\hat{D}_k^c + \epsilon_i\hat{L}_i\hat{H}_2 \quad (1)$$

where the λ'' -term causes B-violation, and the remaining ones, L-violation. In order to suppress proton decay, it is customary to have one of the two types of nonconservation at a time. Here we will consider only lepton number violating effects. Furthermore, we simplify our analysis by keeping, in turn, only the λ -and λ' -type interactions. Experimental limits on the individual couplings can be found in the literature [16]. The presence of such interactions (which lead, among other things, to the instability of χ_1^0) affects the MSSM parameter space allowed by the LEP data, mainly through chargino search limits [17]. They, however, do not have any noticeable effect on the Higgs potential, and therefore the results of analyses corresponding to MSSM can be taken over directly for our purpose. It may be worthwhile to note here that when the bilinear terms $\epsilon_i\hat{L}_i\hat{H}_2$ are included [18], the presence of explicit Higgs-slepton mixing alters the character of the potential. Nonetheless, the conclusions reached by us are not drastically altered even upon the inclusion of such terms. We shall comment on this again in section 5.

We assume gaugino mass unification at a high energy scale, so that all masses and mixing angles in the chargino-neutralino sector are fixed when we specify the SU(2) gaugino mass M_2 , the Higgsino mass parameter μ , and $\tan\beta$, the ratio of the vacuum expectation values (vev) of the two Higgs doublets. No supergravity (SUGRA) framework has been postulated, so that the squark and slepton masses (and also μ) can be treated essentially as free parameters.

In the Higgs sector, the physical states are comprised of two neutral scalars (h , H), a neutral pseudoscalar (A) and two mutually conjugate charged scalars (H^\pm). At tree level, all these masses and also the neutral scalar mixing angle (α) get completely determined once the pseudoscalar mass (m_A) and $\tan\beta$ are specified. In addition, they are influenced by the top quark mass, the squark masses and the trilinear SUSY breaking parameter A_t when radiative corrections to the potential are taken into account. Here we have used the full one-loop corrected Higgs potential [19] to determine the various masses and the mixing angle α . Our results for different Higgs masses and corresponding branching ratios are consistent with those in [20].

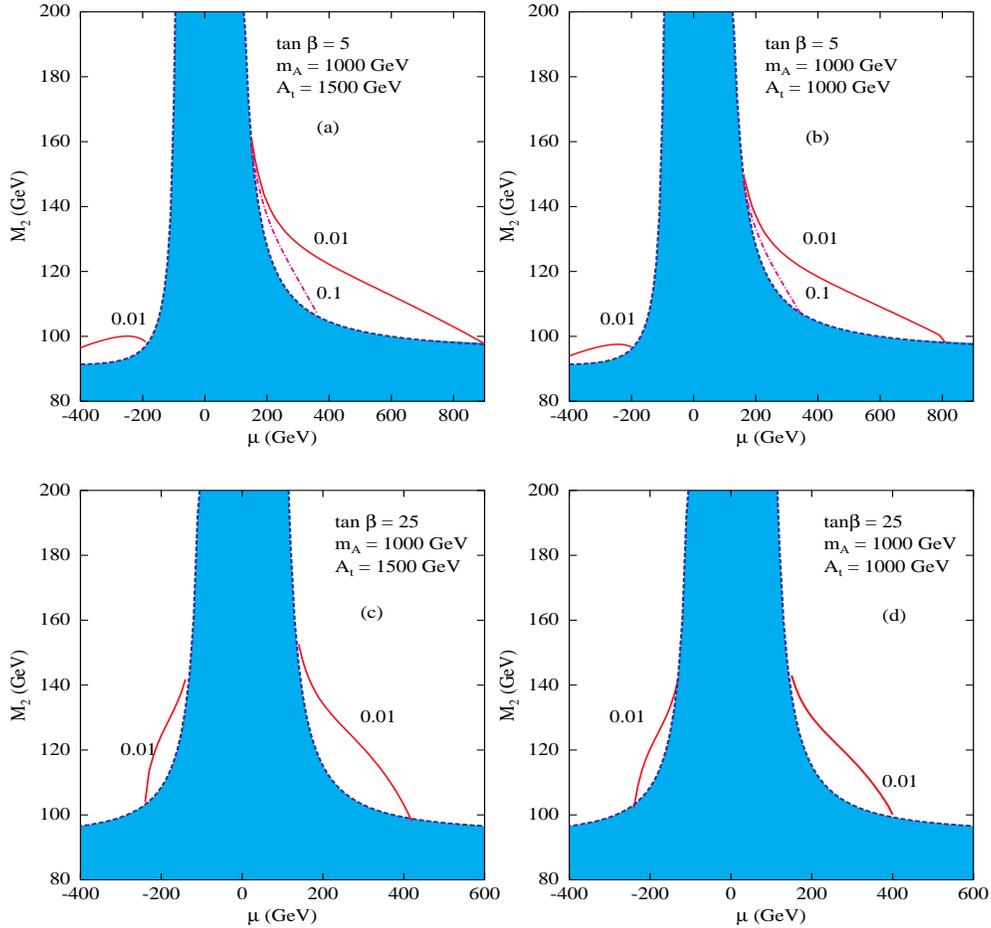


Figure 1: *Contours of constant branching ratio for $h \rightarrow \chi_1^0 \chi_1^0$ in the $\mu - M_2$ plane. The four panels are for different choices of A_t and $\tan\beta$.*

The decay width of the lightest neutral scalar h into two lightest neutralinos is given by [13].

$$\Gamma(h \rightarrow \chi_1^0 \chi_1^0) = \frac{G_F m_W^2 m_h}{2\sqrt{2}\pi} |\Delta_{11}|^2 (1 - 4m_{\chi_1^0}^2/m_h^2)^3 \quad (2)$$

where

$$\Delta_{11} = (N_{12} - N_{11} \tan\theta_W)(N_{13} \sin\alpha + N_{14} \cos\alpha) \quad (3)$$

N being the neutralino mixing matrix in the basis $(\tilde{B}, \tilde{W}_3, \tilde{H}_1, \tilde{H}_2)$. As is evident from the expression, the decay requires contributions from the gaugino components of one neutralino and Higgsino components of the other. Thus the branching ratio is expected to go down when either of M_2 and μ becomes large compared to the other, so that either the gaugino or the Higgsino components may fall appreciably.

In figures 1(a-d), we show contours of different branching ratios in the μ - M_2 plane. The region disallowed by LEP data (upto the 202 GeV run) has been shaded out in each graph. Clearly, even within the LEP-allowed regions, a branching ratio of the order of 1% and ranging up to 10% are possible. There is a predictable decrease in the branching ratio as one moves outwards in each case, since, in addition to the reason given in the previous paragraph, the χ_1^0 mass rises when both M_2 and μ are increased.

A comparison between 1(a) and 1(c) (as also between 1(b) and 1(d)) shows that larger values of $\tan\beta$ tend to suppress the branching ratio for the $\chi_1^0\chi_1^0$ channel, an effect resulting mainly from the enhancement of the $b\bar{b}$ coupling of h .

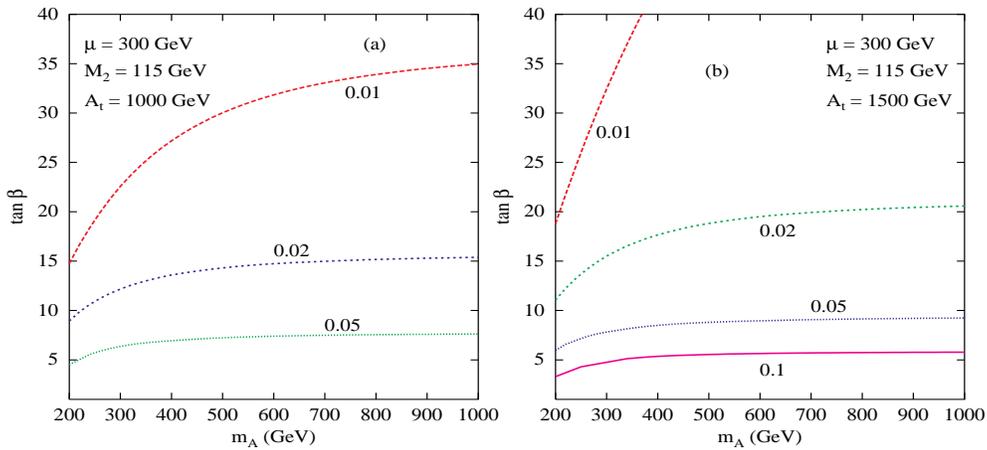


Figure 2: *Contours of constant branching ratio for $h \rightarrow \chi_1^0\chi_1^0$ in the $m_A - \tan\beta$ plane.*

On the other hand, the decay of our interest is seen to be boosted if one has a larger value of the trilinear SUSY breaking parameter A_t . As has already been mentioned, the latter has a crucial influence on the one-loop corrections to the scalar potential, thereby affecting not only the neutral scalar mass but also the mixing angle α . However, A_t is also constrained from considerations such as the absence of flavor-changing neutral currents, and more stringently, from the requirement to prevent charge and color breaking as well as instability of the scalar potential [21]. Keeping all these constraints in view, the value of A_t can be as high as 1 TeV and can even go up to 1.5 TeV, but with a simultaneous increase in the sfermion masses. Thus higher branching ratios for $h \rightarrow \chi_1^0\chi_1^0$, triggered by A_t , seem to be more likely when the squarks and sleptons are close to 1 TeV.

In figures 2, we show the branching ratio contours in the $\tan\beta - m_A$ plane. Together with A_t , these two variables fix the mass of the decaying h . The figures show that there is a marginal

increase in the branching ratio as one increases m_A . This effect is more pronounced for higher values of $\tan\beta$. The reason behind this is the fact that in the region of our interest, the decay width in equation (2) is controlled by the terms proportional to $\cos\alpha$ which, as can be easily checked, increases slowly with m_A . However, the same terms are also proportional to the quantity N_{14} which is larger for large $\tan\beta$, thereby leading to the features observed in the figures.

The above analysis thus leads us to the conclusion that over a sizable region of the parameter space, the two-neutralino decay mode of an intermediate mass Higgs can have a branching ratio ranging from 1 to 10 per cent and can occasionally go up to 20 per cent as well. As we shall see in the following sections, such values can yield detectable and background-free events at the LHC when the lightest neutralino is unstable.

3 Signals with λ -type interactions

Since there are thirty-six independent λ - and λ' -type couplings which are *a priori* unrelated, a transparent analysis is possible when only some of them are considered at a time. Here we assume the presence of just *one* λ -type interaction (say, λ_{212}) which can lead to the decay $\chi_1^0 \rightarrow \bar{l}'\nu$ for the lightest neutralino, with $l, l' = e, \mu$.

The experimental limits on the interactions of the above kind can be found, for example, in reference [16]. However, our predicted number of events will be independent on the actual value of the coupling so long as there is just one coupling driving the decay of χ_1^0 (and we impose identical event selection criteria for both electrons and muons).

Thus the type of events we are predicting here can be described as

$$qq \rightarrow qqh \rightarrow qq\chi_1^0\chi_1^0 \rightarrow qq + 4l + \cancel{E}_T \quad (4)$$

the missing transverse energy coming from the neutrinos produced in three-body decays of the neutralino. The absence of color exchange between the quarks leads to a suppression of hadron production in the central region, so that a ‘central jet veto’ (whose efficacy in eliminating backgrounds can be established by looking into the VBF process along with one-parton emission) can be applied for final states like the ones under consideration here. The two quark jets are highly energetic and in high-rapidity regions, with a large rapidity gap in between, where the four leptons resulting from Higgs decay are expected to lie. It is by tagging these forward jets that one can trace the origin of the neutralino decay products to the neutral scalar h , thereby distinguishing them from conventional superparticle cascades started by the production of squarks or gluinos through strong interactions.

Our calculation is based on a parton level Monte Carlo for pp collisions with $\sqrt{s} = 14 \text{ TeV}$. Here as well as in the next section, we have set a degenerate squark mass of 300 GeV and a degenerate slepton mass of 200 GeV . We have used the CTEQ4L [22] parton distribution functions. The lowest order tree-level matrix elements for both WW and ZZ fusion processes have been used.

We have not included QCD corrections which are usually rather modest [23]. The jet and lepton energies have been further smeared using Gaussian functions, with half-widths (ΔE) given by [24]

$$\Delta E = 0.15\sqrt{E} + 0.01E \quad (5)$$

for leptons, and

$$\Delta E = 0.4\sqrt{E} + 0.02E \quad (6)$$

for jets.

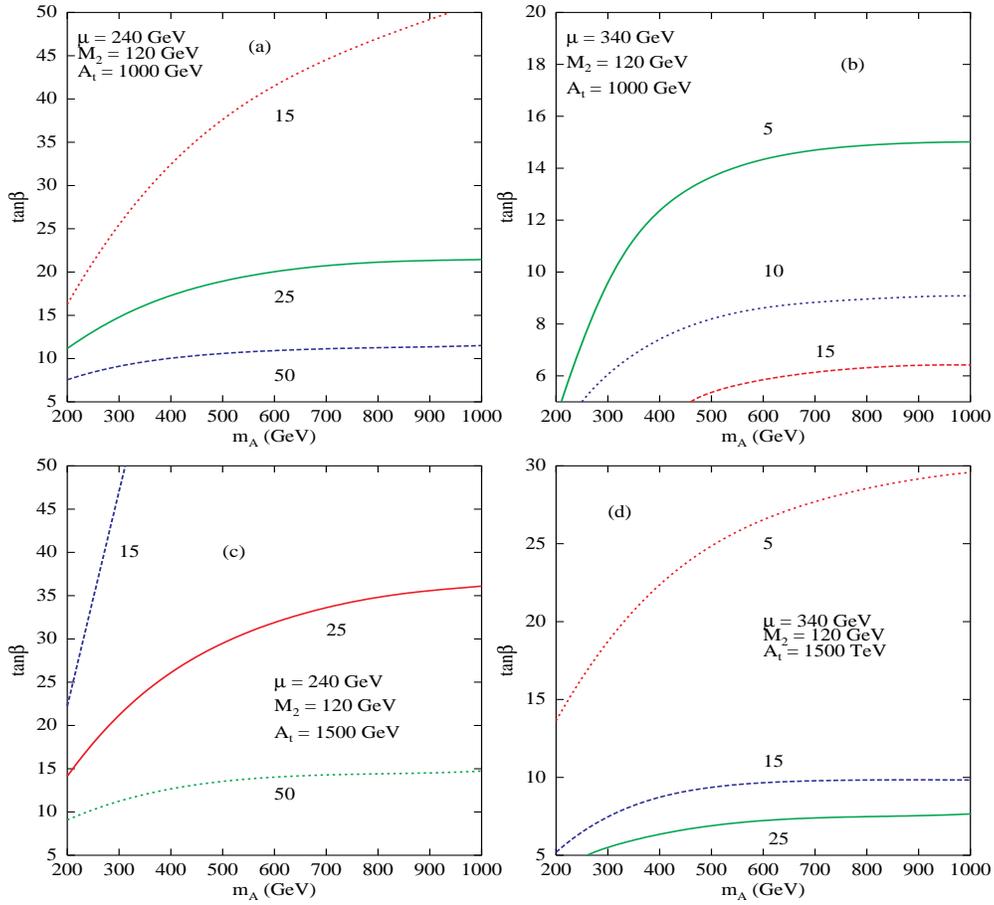


Figure 3: Contours of $2j + 4l$ events from χ_1^0 pair decay via λ -coupling in the $m_A - \tan\beta$ plane. Four panels are for different choices of μ and A_t .

The $2j + 4l + \cancel{E}_T$ events are subjected to the following event selection criteria [25]:

- **Rapidity of jets:** for each jet, $2.5 \leq |\eta| \leq 5.0$. The upper limit is there to ensure detectability in the hadronic calorimeter. Also, the existence of two jets in opposite hemispheres is ensured by demanding that $\eta_{j_1}\eta_{j_2}$ be negative.

- **Rapidity gap and isolation between jets:** $\Delta\eta_{j_1j_2} \geq 3.0$, $\Delta R_{j_1j_2} \geq 0.7$, where $\Delta R^2 = \Delta\eta^2 + \Delta\phi^2$, $\Delta\phi$ being the angular separation in the azimuthal plane. This retains a large part of the signal, since the signal rapidity interval tends to peak between 4 and 5.
- **Jet transverse energy:** for each forward jet, $E_T \geq 20 \text{ GeV}$.
- **Central jet veto:** no jet in the large rapidity interval.
- **Absence of b-jets:** no b-induced jet identified. Does not affect the signal at all.
- **Jet invariant mass:** $M_{j_1j_2} \geq 650 \text{ GeV}$. Kills an enormous amount of QCD background, and, as we shall see, helps in distinguishing the signal from other SUSY cascades.
- **Lepton location:** all four leptons to lie in the rapidity interval between the forward-tagged jets, with $\Delta R_{lj} \geq 0.4$.
- **Lepton transverse momentum(energy):** For each muon(electron), $p_T(E_T) \geq 20 \text{ GeV}$. Together with the isolation cut on leptons, this hardness cuts should eliminate of all SM backgrounds.
- **Missing transverse energy:** $\cancel{E}_T \geq 15 \text{ GeV}$ is required.

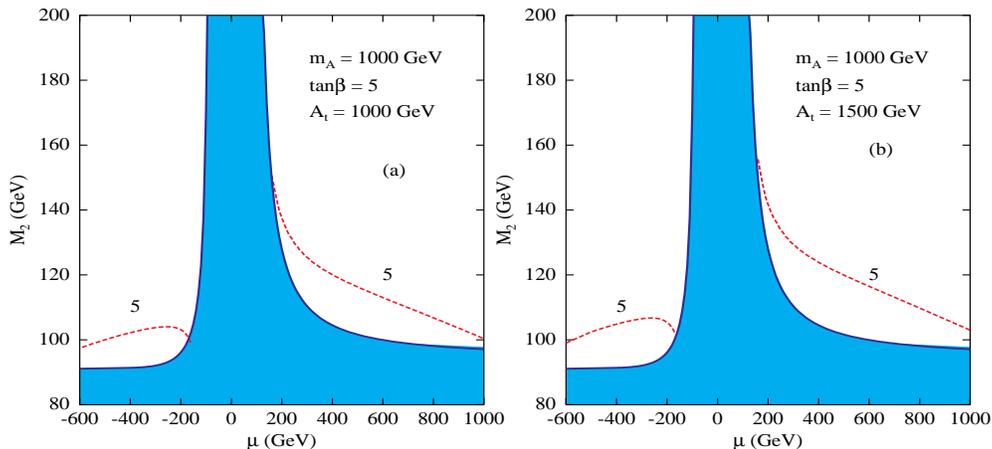


Figure 4: Contours of 5 events ($2j + 4l$) in the $\mu - M_2$ plane coming from χ_1^0 -pair decay via λ -coupling for a) $A_t = 1 \text{ TeV}$ and b) $A_t = 1.5 \text{ TeV}$. The shaded region is disallowed from chargino search at LEP. In the region bounded by the 5-event contour and LEP-bound contour number of events is greater than 5.

In figures 3(a-d) we show contours in the $m_A - \tan\beta$ plane for different numbers of events, predicted for an integrated luminosity of 100 fb^{-1} . As can be seen from the figures, up to about 50 events are predicted over a rather large region of the parameter space. If the lepton $p_T(E_T)$ cut

is further relaxed to 15 GeV (something that is feasible at the LHC) [26], the event rates are even higher. As expected from the discussion in the previous section, the event rate tends to decrease with a rise in $\tan\beta$, and increase with m_A . Also, higher values of the soft breaking parameter A_t seems to favour high event rates. Side by side, a look at figures 4(a-b) tells us how much of the LEP-allowed region in the chargino-neutralino parameter space can be explored through this channel. Judging by the fact that the signals are practically free from standard model backgrounds, event rates of such magnitude should be detectable. It is also interesting to note, by comparison with figure 1, that even a small branching ratio for $h \rightarrow \chi_1^0 \chi_1^0$ can lead to useful signals at the LHC.

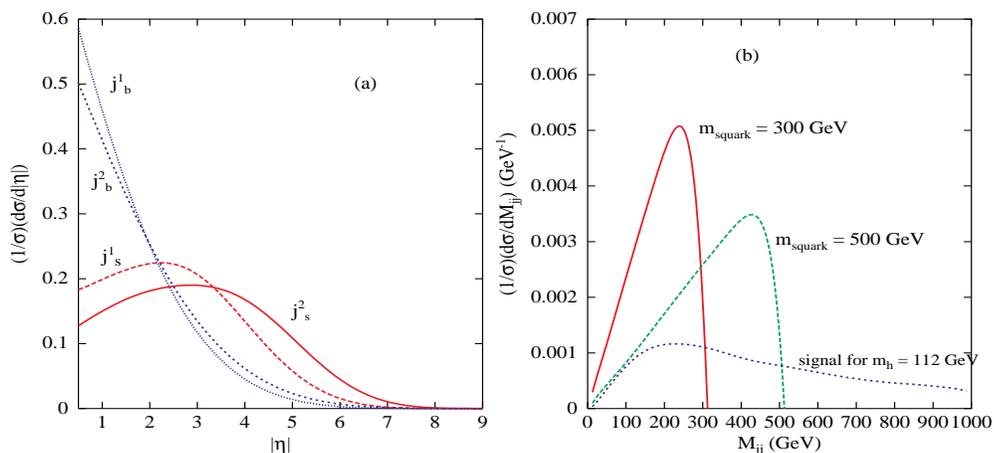


Figure 5: *a) Normalised rapidity distributions of the jets from signal (j_s^1, j_s^2) and “background” (j_b^1, j_b^2) due to squark pair production and decay. b) Normalised invariant mass (of two jets) distribution of the signal and “background” from squark production. Two different values of squark masses are chosen for the purpose of illustration.*

Finally, let us verify that the event selection procedure adopted here enables us to differentiate the Higgs signals from remnants of superparticle cascades. We demonstrate this by considering χ_1^0 's, together with quark jets, coming from pair-produced squarks. Although the uncut cross-section for this process is considerably larger than that for our signal, the forward-tagged jets cause the latter to stand out. In figure 5a we show the rapidity distributions for the signal jets as well as for those arising from squark decays. The latter exhibits a strong central peaking, and is largely removed by a rapidity cut of 2.5. In addition, if we look at the invariant mass distribution of the jet pair in figure 5b, one can see that all such squark decay ‘backgrounds’ can be completely eliminated just with the invariant mass cut of 650 GeV , while a substantial fraction of the signal survives. This is true unless the squark mass is above 650 GeV . For a squark mass of, say, 700 GeV , the uncut cross-section for χ_1^0 -pair production through squark decay cascades is about $2\text{-}3 \text{ pb}$. However, as figure 5a tells us, the overwhelming majority of the resulting jets lie in low-rapidity

regions. Subjected to the rapidity, E_T and invariant mass cuts of the suggested magnitudes, they get reduced to a level well below the threshold of detectability. The same argument applies to cascade decays of gluino pairs, where there is usually a greater multiplicity of quark jets, and the probability of their merger into just two jets, satisfying all the cuts, is extremely low.

μ (GeV)	M_2 (GeV)	Number of Events	
		MSSM	\mathcal{R}_p
200	137.6	0.037	0.55
400	120.02	0.039	0.44
600	113.03	0.066	0.45
800	106.79	0.081	0.36
1000	100.34	0.084	0.6
-200	103.5	0.003	0.32
-400	102.18	0.101	0.3
-600	97.44	0.142	0.35

Table 1 The number of ‘4l + forward jets’ events coming from neutralino pairs both for MSSM and with R-parity violation, for different values of μ and M_2 , with $\tan\beta = 5$, $m_{\tilde{q}} = 300$ GeV and $m_{\tilde{l}} = 200$ GeV.

Similar final states can also in principle be faked by direct production of neutralino pairs via VBF. There are two possibilities: (a) in an MSSM scenario, the pair-production of the second lightest neutralino, and their subsequent decays in the channel $\chi_2^0 \rightarrow \chi_1^0 \tilde{l} \bar{l}$ can lead to signals of our type; and (b) the production of $\chi_1^0 \chi_1^0$, $\chi_1^0 \chi_2^0$ or $\chi_2^0 \chi_2^0$ and their subsequent decays (through λ -type couplings) including the possibility of R-parity violation can be the sources of similar signals. In table 1 we have shown the results of our estimate of such ‘fake’ signals, obtained at such points of the parameter space where the Higgs signals are at their weakest (i.e. at about 5 events level). In the R-parity violating case, one λ -type coupling has been assumed, and has been kept at the highest value compatible with phenomenological bounds. The forward jets and leptons in between them have been subjected to the same cuts as the ones employed for our Higgs signals. The table shows that after all cuts, the number of such ‘backgrounds’ get extremely suppressed, so that even as low 5 as events for the Higgs signal should be quite conspicuous compared to them.

4 Signals with λ' -type interactions

In presence of the λ' -type interactions (again, taken in isolation), the lightest neutralino decays in the channel $\chi_1^0 \rightarrow q\bar{q}l$ or $\chi_1^0 \rightarrow q\bar{q}\nu_l$. Of these, we use only the former channels where the decay products are all visible. The signal will then consist of two forward jets together with four central jets and two leptons, all in the rapidity interval between the former. Obviously, the central

jet veto is not going to be effective here. However, a compensating feature here is the visibility of all the particles in the final state. Thus two bunches of particles, each consisting of two jets and one lepton, can be identified with the same invariant mass (equal to $m_{\chi_1^0}$), and the whole bunch of particles in between the forward-tagged jets can be reconstructed to an invariant mass peak equal to the mass of the lighter neutral scalar h .

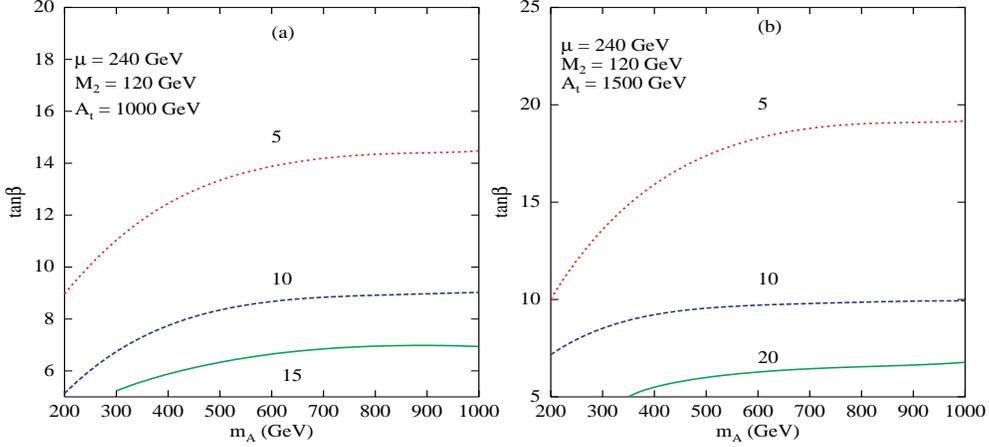


Figure 6: *Contours of $(jj)_f + \text{central jets} + 2l$ events (from χ_1^0 pair decay via λ' -coupling) in the $m_A - \tan \beta$ plane, for two different choices of A_t .*

The signal here thus corresponds to the process

$$qq \longrightarrow qqh \longrightarrow qq\chi_1^0\chi_1^0 \longrightarrow qq + (4q) + 2l \quad (7)$$

leading to two forward-tagged jets with two, three or four jets (due to possible jet merger) together with two leptons in the rapidity interval between the former.

In figures 6 and 7 we present some event contours, of the same style as those applied earlier. The two forward jets are subjected to the same cuts as those applied earlier. The rapidity interval demanded of the leptons and the central jets are also the same. The jets arising from neutralino decays are also required to have a minimum isolation of $\Delta R = 0.6$ with respect to the forward jets, and a minimum transverse energy of 20 GeV . The minimum $p_T(E_T)$ required of each lepton is 15 GeV . In addition, the invariant mass of the lepton pair is made to lie outside an interval of $\pm 10 \text{ GeV}$ of the Z -boson mass. Also, we demand that there should be no missing energy ($\leq 10 \text{ GeV}$), something that enables us to distinguish the events from cases of undetected jets. These cuts are found to be sufficient to eliminate standard model background, including arising from Drell-Yan process and $t\bar{t}$ production. Moreover, as figure 8 indicates, the distribution in the azimuthal angle between the two leptons in the transverse plane peaks at a very low value. Since dileptons from Drell-Yan process tend to be aligned back-to-back, one kills all backgrounds without affecting the signal strength by requiring this angle to be less than 120 degrees.

Clearly, we have fewer events predicted in this case than in the one with the λ -type interactions.

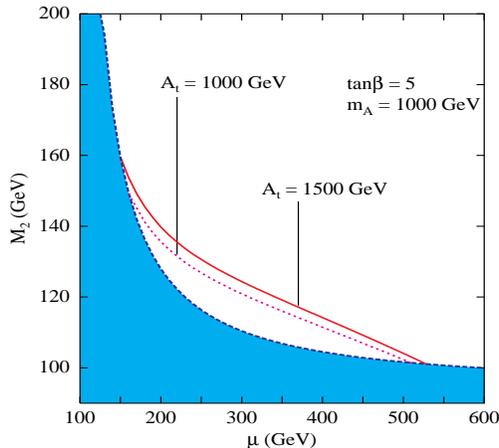


Figure 7: *Contours of 5 events ($((jj)_f + \text{central jets} + 2l)$) in the $\mu - M_2$ plane coming from χ_1^0 -pair decay via λ' -coupling for $A_t = 1 \text{ TeV}$ and $A_t = 1.5 \text{ TeV}$. The shaded region is disallowed from chargino search at LEP. In the region bounded by the 5-event contour and LEP-bound contour, number of events is greater than 5.*

This is primarily due to the stringent cuts on the jets, in terms of both hardness and isolation from the forward-tagged ones. Nonetheless, contours of 5 to 20 events span a substantial part of the parameter space. Considering the absence of SM backgrounds, these events should enable us to identify the Higgs in the corresponding regions. The observed dependence on other parameters such as A_t and μ is similar to that noted in the previous section.

Again, it is necessary to address the question of possible faking of the signal through charginos and neutralinos. It is found that the strongest candidates in this are $\chi_1^+ \chi_1^-$ and $\chi_2^0 \chi_2^0$, when their subsequent R-parity violating decays through λ' -type interactions are allowed. On the face of it, such decays can have large branching ratios (of the order of 30-40%) and the *forward jets + 2l + jets* events can have high survival probability on imposing the aforementioned cuts. However, it should be borne in mind that we are discussing a Higgs boson of mass well below 135 *GeV* or so. Thus the invariant mass of the visible particles in between the forward-tagged jets should peak at that value. On the other hand, simple kinematics tells us that the combined invariant mass of the products of χ_1^\pm or χ_2^0 -pair decays peaks at much higher values for chargino and neutralino masses currently allowed by the LEP data. As an example, we show in figure 9 the invariant mass distribution for a case where the chargino mass is at the lowest limit. In spite of that, the number of surviving events drop from about 85 to 0.01 once an invariant mass less than 140 *GeV* is demanded from the decay products. Thus such backgrounds, too, do not pose any hindrance to unmasking the Higgs via the λ' -type interactions in the VBF channel.

Clearly, it requires considerable care to reconstruct the neutralinos individually. In order to do that, one has to select only those events where none of the two jets from one neutralino merges

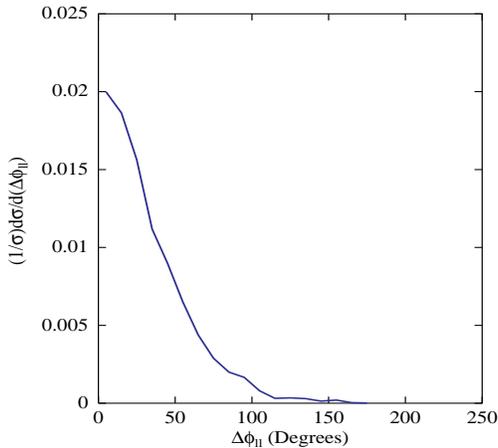


Figure 8: Normalised $\Delta\phi$ (angle between the leptons in the transverse plane) distribution of jets + $2l$ events coming from χ_1^0 pair decay.

with any jet arising from the decay of the other. Using a jet merger criterion of $\Delta R \leq 0.6$, we find that the event rates get drastically reduced. One way to salvage them is to relax the $p_T(E_T)$ cut on the leptons. In figure 10 we show how the rates are enhanced when a separation of jets is demanded and for leptons the minimum $p_T(E_T)$ required is 10 GeV , with all other parameters affecting the results in the same way as before. Here one has two, three or four-jet and dilepton events plus the forward-tagged jets. In addition, the invariant mass of one lepton with one or two jets should equal that of the remaining particles in the central region. This kind of intertwining of leptons and jets in the invariant mass peaks makes the signals almost completely free of SM backgrounds. In this way, the lightest neutralino is also fully reconstructed. Since one can aspire to see other signatures of such a neutralino at the LHC as well, the reconstruction from the Higgs decay events with the neutralino mass peaks at the right place serves in a big way to establish the *locus standi* of the process under investigation here, to remove combinatoric backgrounds, and to improve measurements of the Higgs-neutralino coupling. Therefore, if the detector sensitivity permits one to use these somewhat relaxed cuts, then one has one of the cleanest signals of an intermediate mass Higgs in an R-parity violating scenario, at least in the identified regions of the parameter space.

5 Summary and conclusions

We have considered signals of the lightest neutral Higgs at the LHC in a SUSY scenario where R-parity is violated through lepton number in trilinear interactions. Regions have been identified in the parameter space where the Higgs, lying in the intermediate mass range, has a perceptible decay width into a pair of lightest neutralinos. Then we have considered the production of such a Higgs by the vector boson fusion mechanism, and looked at the decay products of the two lightest

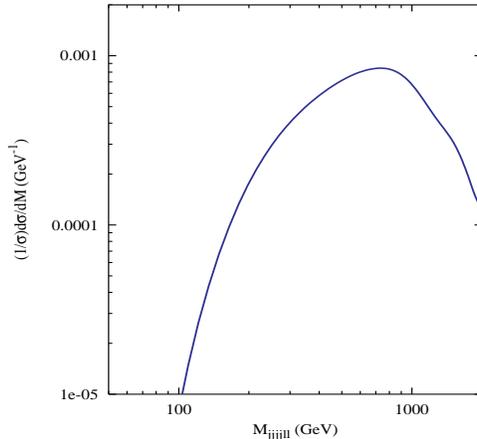


Figure 9: *Normalised invariant mass distribution of the visible products in between the forward tagged jets, from the decays of charginos and neutralinos, for $\mu = 500$ GeV, $M_2 = 100$ GeV, $\tan \beta = 5$, $m_{\tilde{q}} = 300$ GeV and $m_{\tilde{l}} = 200$ GeV.*

neutralinos, noting that the forward-tagged jets and the associated event selection strategies remove interference from cascades arising out of strongly interacting superparticles.

We have presented an analysis based on only the lepton number violating trilinear interactions. Inclusion of the bilinear terms $\epsilon_i L_i H_2$ in the superpotential will open additional decay channels of the lightest neutralino like $\chi_1^0 \rightarrow lW$ and $\chi_1^0 \rightarrow \nu Z$ through neutralino-neutrino and charged lepton-chargino mixing [27]. However, since we are concerned here with a parameter region where the decay of χ_1^0 can lead only to virtual W and Z , the final products will still consist of three fermions. In this case, events of both the types discussed in sections 3 and 4 will be always present. Another consequence of the bilinear terms is mixing between the neutral Higgs and sneutrinos in the scalar potential. Such mixing may somewhat alter the parameter space discussed in section 2, but no qualitative difference is expected, given the phenomenological constraints on models of this type [28]. Therefore, the existence of bilinear R-violating interactions are expected to result in signals of the same kind as those investigated here.

We observe that while the signals obtained from the λ -type interactions are more copious and cover a larger area of the parameter space, the λ' -type interactions provide a way of reconstructing the Higgs completely, though they lead to smaller event rates after applying the cuts. The complete reconstruction of the events including the lightest neutralinos, however, require cuts that tend to reduce the event rates. It is by being able to identify leptons with transverse energies down to 10 GeV that one can reconstruct both the Higgs and the neutralinos which act as intermediaries in the signals of our interest. Therefore, if optimal detection efficiencies of the various final states discussed here can be achieved at the LHC, it will be of great help in identifying an intermediate mass Higgs in an R-parity violating supersymmetric theory. In addition, by looking for signals of this kind, we can obtain useful information on the different couplings of an intermediate Higgs

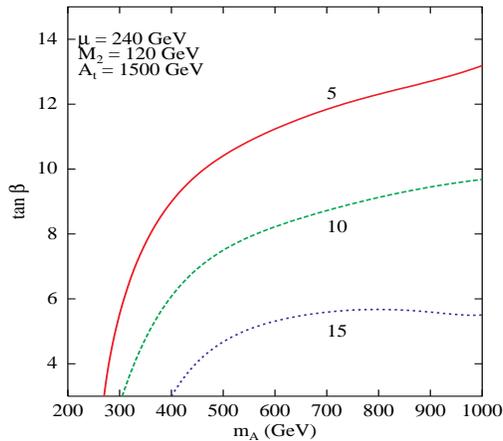


Figure 10: Contours of $(jj)_f + \text{central jets} + 2l$ events (from χ_1^0 pair decay via λ' -coupling) in the $m_A - \tan\beta$ plane. Here we demand that the jets are well separated in the central region and the p_T -cut on the leptons is reduced to 10 GeV.

boson when it is discovered, so as to be enlightened on what kind of an electroweak symmetry breaking scenario it represents.

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