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Supersymmetry search via gauge boson fusion

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Abstract. We propose a novel method for the search of supersymmetry, especially for the electroweak gauginos at the large hadron collider (LHC). Gauge boson fusion technique was shown to be useful for heavy and intermediate mass Higgs bosons. In this article, we have shown that this method can also be applied to find the signals of EW gauginos in supersymmetric theories where the canonical search strategies for these particles fail.

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1. Introduction

Vector boson fusion (VBF) at hadronic colliders has been suggested as a useful channel for studying the signal of the Higgs boson. Characteristic features of this mechanism are two highly energetic quark-jets, produced in the forward direction in opposite hemispheres and carrying a large invariant mass. The absence of colour exchange between the forward jets ensures a suppression of hadronic activities in the central region [1]. Though it was originally proposed as a background-free signal of a heavy Higgs [2], the usefulness of the VBF channel in uncovering an intermediate mass Higgs has also been subsequently demonstrated [3].

Encouraged by the success of VBF technique in exploring the intermediate mass Higgs sector of standard model (SM) and minimal supersymmetric standard model (MSSM), one can ask whether this method can be used to explore other new physics scenarios. One of such candidates is of course the supersymmetry (SUSY). Different kinds of signals to unravel the mystery of SUSY in its minimal or in many non-minimal versions are already proposed in the context of present and future colliders. In the following, we will see how the VBF technique can be used very efficiently to explore the non-strongly interacting sector of the SUSY, not in all the cases, but certainly to the cases when canonical search strategies fail to produce any positive results.

In this article, we will concentrate only on the chargino–neutralino sector. Before delving into the details, let us discuss in brief, what is the commonly accepted search strategies for these particles and how at least in two cases these channels are not very useful.

When baryon and lepton numbers (or R-parity) are conserved, a conventional method of searching for charginos ($\chi^{\pm}$) and neutralinos (χ^0) at hadron colliders is their direct production. The most useful channel is $p\bar{p}/pp \rightarrow \chi_1^{\pm}\chi_2^0$ followed by the decays $\chi_1^{\pm} \rightarrow \chi_1^0 l^{\pm}\nu_l(\bar{\nu_l})$ and $\chi_2^0 \rightarrow \chi_1^0 l^+ l^-$, where χ_1^0 is the lightest SUSY particle (LSP) and hence is invisible. This gives rise to 'hadronically quiet' trilepton signals [4].

However, the leptonic decay channels might be relatively suppressed in certain cases. For example, as we shall see, χ_2^0 and $\chi_1^{\pm}$ may decay directly into leptons and jets in an R-parity violating scenario [5]. Under such circumstances, while the trilepton signals suffer from a suppression, the final states obtained from R-violating decays of charginos and neutralinos may be difficult to disentangle from the signals of gluinos and squarks. It is for such situations that we point out the usefulness of the VBF channel in isolating charginos and neutralinos through clearly identifiable and background-free events.

Another case which we will be going to investigate, is the following. In some currently popular SUSY models, the lighter chargino ($\chi_1^{\pm}$) and the lightest neutralino (χ_1^0) are closely degenerate in mass. Then the previously mentioned trilepton signal is no more detectable, since the chargino decays into either a soft pion (π) or very soft leptons/quarks together with the χ_1^0. This makes the chargino–neutralino pair essentially invisible. Under the circumstances, we find it useful to study the production of chargino–neutralino pairs in VBF. In such cases, two *forward jets* $+\not{E}_T$ can be treated as the generic signal of invisibly decaying charginos and neutralinos.

In the next section, we will consider these two cases one by one. We will show, in such cases, how chargino–neutralino production via VBF channel results in unambiguous signals of SUSY.

2. Signals of chargino–neutralino production via VBF

2.1 *Invisibly decaying charginos: Signals from AMSB ?*

In a SUSY theory with anomaly mediated supersymmetry breaking (AMSB), $\chi_1^{\pm}$ χ_1^0 are both wino-like and therefore very closely degenerate. We will not go into the detail description of AMSB, which along with possible search strategies for this model already exist in the literature [6–8].

The AMSB particle spectrum implies that the dominant decay mode for the lighter chargino is $\chi_1^{\pm} \longrightarrow \pi^{\pm}\chi_1^0$. The pion in such cases is too soft to be detected, making the chargino essentially invisible. We exploit the invisibility of the lighter chargino and tagging of the forward jets in the VBF channel to explore or exclude this kind of a theory at the large hadron collider (LHC). Our analysis is based on the processes $pp \longrightarrow \chi_1^{\pm}\chi_1^0\ jj$, $pp \longrightarrow \chi_1^+\chi_1^-\ jj$ and $pp \longrightarrow \chi_1^0\chi_1^0\ jj$, driven by the fusion of gauge bosons, which give rise to just two visible forward jets with missing transverse energy. Similar final states may also arise from $\chi_1^{\pm}\chi_2^0$ production, but the contribution to the events of our interest is small, since (a) the bino-dominated character of χ_2^0 makes the production rate low and (b) the invisible final states can only arise from $\chi_2^0 \longrightarrow \nu\bar{\nu}\chi_1^0$ where a further suppression by the branching fraction takes place.

The signals, however, are not background-free. As has been already discussed in ref. [9], such events can be faked by the pair-production of neutrinos along with two forward jets. In addition, two forward jets together with a soft lepton and missing $\not{E}_T$ (due to a neutrino) can also fake the signal. Such final states can arise in the standard model from real emission corrections to the Drell–Yan process as well as from electroweak W and Z production along

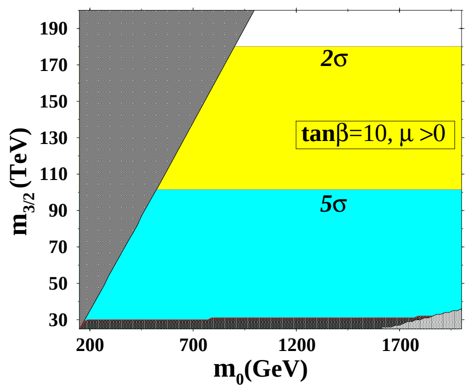

Figure 1. 5σ and 2σ discovery regions in the m_0–$m_{3/2}$ plane for $\mu > 0$ and $\tan\beta = 10$ in an AMSB scenario. The upper-left shaded region is excluded to prevent the lighter $\tilde{\tau}$ becoming first the LSP and then tachyonic. The dark shaded region parallel to the m_0 axis in low $m_{3/2}$ is disallowed from LEP data. The light shaded portion in the lower-right corner is excluded to ensure electroweak symmetry breaking.

with two jets. We will not discuss in detail the kinematic cuts which reduce the background rate. These can be obtained from our earlier paper [10]. We must mention here one crucial point about background estimation. The dominant contribution to the background comes from the processes of the order $\alpha_s^2 \alpha_{EW}^2$. As our estimate of the background processes are at the LO, there is a large uncertainty associated with the estimate as LO cross-sections are very much scale dependent. While estimating the background we thus set the scale of α_s and parton distribution functions at the minimum scale (p_T of the softer jet) available to make our estimate conservative.

Figure 1 shows the regions in the m_0–$m_{3/2}$ plane corresponding to 2σ and 5σ detectability of the signal against the backgrounds estimated above. An integrated luminosity of 100 fb^{-1} has been assumed. The signal event rates are independent of m_0 and highly insensitive to $\tan\beta$.

We have also considered the situation when, gaugino masses are large compared to the μ-parameter in a SUSY grand unification theory (GUT). Treating μ as a free parameter, one can have as small a separation as about 5 GeV between $\chi_1^\pm$ and χ_1^0 in such cases, while χ_2^0 can be within about 15 GeV of $\chi_1^\pm$, so long as one is within the region allowed by the LEP data. Invisibility of the chargino mostly hinges on the ensuing leptons and quarks produced in three-body decays being sufficiently soft. Very similar considerations apply to the decay of the χ_2^0 as well. A very small region (at very high M_2) of μ–M_2 plane can be excluded at 95% CL [10] via this channel.

2.2 *New signals for R-parity violating SUSY*

We have argued earlier that conventional tri-lepton signal of charginos and neutralinos may be suppressed due to the opening up of new decay channels for these particles. In this sub-section, we will consider how the lepton number violating interactions present in su-

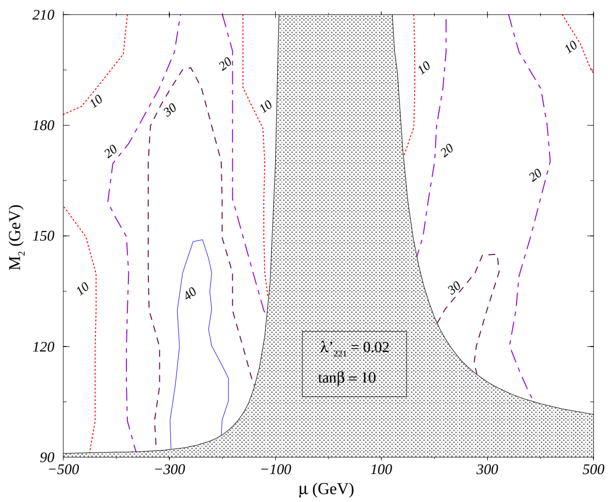

Figure 2. Event contours for like-sign dilepton (LSD) production in M_2–μ plane, with $\lambda'_{221} = 0.02$ and $\tan\beta = 10$. The central shaded region is disallowed from the (negative) LEP results on chargino search.

perpotential ($W_{\not{L}} = \lambda'_{ijk}\hat{L}_i\hat{Q}_j\hat{D}^c_k$) can reduce the leptonic branching ratios of neutralinos and charginos and how chargino–neutralino production via gauge boson fusion can produce almost background free signals of these particles in such circumstances. In the presence of a λ'-type term in the superpotential, the following additional decay modes become available to neutralinos and charginos: ($\chi^0 \longrightarrow l^{\pm}q\overline{q'}; \chi^{\pm} \longrightarrow l^{\pm}q\overline{q}$), the branching ratios depending on the strength of the lepton number violating interaction. In addition, of course, final states with neutrinos replacing leptons are also possible.

Our numerical estimates are done by assuming λ'_{221} to be the only non-zero L-violating coupling. Throughout this study, we have fixed slepton and squark masses at 200 and 300 GeV respectively. For such a squark mass, the maximum allowed value for λ'_{221} is 0.54 [11]. We use values well within this limit to compute the branching ratios for the decays mentioned above and finally to calculate the event rates. Depending on the other parameters of the theory, branching ratio to these new channels may be as large as 50% for the charginos and 30% for the neutralinos. In cases like the above, it is hardly necessary to emphasize the importance of new production channels in unraveling the non-strongly interacting sector of SUSY. We take this up in the following. If neutralinos and charginos are produced via VBF, and consequently, decay to R-parity violating channels, the centrally produced charginos and neutralinos should give rise to events of the type

$$\text{Like- or Unlike-Sign Dileptons} + \geq 2 \text{ Jets}$$

in the rapidity interval between the two high invariant mass forward jets. With our particular choice of the λ'-coupling, the leptons actually turn out to be muons. Such events are largely free from standard model backgrounds, too, especially after applying the kinematic cuts as discussed in ref. [12]. Signals of the above type can be obtained from $\chi_i^0\chi_j^0$, $\chi_i^{\pm}\chi_j^{\pm}$, $\chi_i^+\chi_j^-$ as well as $\chi_i^0\chi_j^{\pm}$. Of these, the largest contributions come from $\chi_1^+\chi_1^-$ and $\chi_2^0\chi_1^{\pm}$, so long as one adheres to a gaugino mass unification scheme.

Similar kind of signals could arise from the processes like $t\bar{t}$ production and charged Higgs pair production (along with two forward jets). But if we demand the absence of any missing energy in the signal, all these backgrounds can be successfully killed and the signal become background free. These issues are discussed in detail in an earlier work [12].

We have presented our results (for like sign dilepton events) in the μ–M_2 plane in figure 2. From the figure, it is evident that even for $\lambda'_{221} = 0.02$, one can have 20 signal events, for values of M_2 up to about 200 GeV. In terms of neutralino–chargino masses, this means that we can probe up to a lighter chargino and second lightest neutralino mass up to about 200 GeV. The lightest chargino mass reach is nearly half of the above value. This is indicative of how much improvement over the LEP results is possible through the VBF technique in probing the chargino–neutrino sector of an R-parity violating scenario.

3. Conclusion

In summary, we discussed how vector boson fusion channel can play useful role in getting characteristic signal for some popular SUSY models. For example, we have shown in R-parity violating SUSY and in anomaly mediated SUSY breaking theories, when canonical search strategies for neutralinos and charginos fail, VBF channel can be used very efficiently. It is worthwhile to mention that this channel is the only way to produce like-sign charginos. The effectiveness of VBF method is also evident when a Higgs boson in R-parity violating model decays into a pair of neutralinos, and neutralinos subsequently decay to jets and leptons, thus producing a multi-jet multi-lepton final state [13].

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