R-parity violation with jet signatures at the ATLAS detector

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Abstract. We demonstrate a recently proposed method for determining the mass of boosted neutralinos, in a hadronic detector environment, from their decays into three jets. The method exploits the substructure of the resulting single collimated jets using the $k_\perp$ algorithm. This is demonstrated on a straw R-parity violating supersymmetric model which is passed through full simulation of the ATLAS detector.

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INTRODUCTION

We take the explicit R-parity violating terms of the supersymmetric Lagrangian to be the following allowed in soft SUSY breaking:

$$W = \frac{1}{2}\lambda^{ijk} L_i L_j \bar{e}_k + \lambda'^{ijk} L_i Q_j \bar{d}_k + \mu'^i L_i H_u + \frac{1}{2}\lambda''^{ijk} \bar{u}_i \bar{d}_j \bar{d}_k \tag{1}$$

where all terms in the Lagrangian are defined in [1]. Models with non-zero λ'' are baryon number violating and allow the decay $\tilde{\chi}_1^0 \rightarrow qqq$. In a busy hadronic environment this decay will be difficult to extract from background events.

We test a method, recently proposed by J.M. Butterworth et al [2], for discovering these decays by looking at boosted neutralinos whose decay products have merged into single collimated jets. In a study performed without detector simulation they use the $k_\perp$ algorithm to reconstruct the neutralinos and exploit the substructure of the single jets to reduce the hadronic background. Using the same model we test their approach, using the full ATLAS detector simulation, for use at the LHC. The full results of this study are presented in [3]. Similar techniques have also been used to analyse WW scattering [4, 5].

METHOD

The $k_\perp$ algorithm runs over the collection of calorimeter clusters. For object k and pair of objects (k,l) the resolution variables given by Equations 2 and 3 are calculated.

$$d_{kB} = p_{Tk}^2 \tag{2}$$

$$d_{kl} = min(p_{Tk}^2, p_{Tl}^2)R_{kl}^2/R^2 \quad (3)$$

Here p_{Tk} is the transverse momentum of object k with respect to the beam axis and R_{kl}^2 the separation in $\eta - \phi$ space (Equation 4). The definitions of d_{kB}, d_{kl} and R_{kl}^2 control how the $k_\perp$ algorithm behaves in the soft and collinear limits. We use the ΔR angular scheme [6]. The algorithm finds the smallest of d_{kB} and d_{kl}. If d_{kl} is the smallest then k and l are combined into a single object with momentum p_{kl} (Equation 5). The process is repeated until all objects have been included as jets.

$$R_{kl}^2 = (\eta_k - \eta_l)^2 + (\phi_k - \phi_l)^2 \quad (4)$$

$$p_{kl} = p_k + p_l \quad (5)$$

The scale at which jets from two or more very collimated partons separate into their sub-jets is reflected by the values of d_{kl} calculated. The variable y, defined as $y = d_{kl}/m^2$ where m is the jet mass, can be used to isolate the signal from the background [2]. The sequence of y values records the distances between the merged jet constituents (y_1 is defined as the y value from the last merging and y_2 as that from the next-to-last merging). QCD jets are anticipated to have little structure, low jet masses and generally low y values, whereas $\tilde{\chi}_1^0 \rightarrow qqq$ decays should give jets with sizeable y_1 and y_2 splittings.

EVENT GENERATION

We use the mSUGRA bulk benchmark point SPS1a [7] which has a neutralino LSP of mass $m_{\tilde{\chi}_1^0} = 96.1$ GeV. R-Parity violation is added to the model by setting $\lambda''_{112} = 0.001$ as the only non-zero coupling. This model was chosen due to its reasonably high cross-section (17.4 pb at LO). The choice of λ'' ensures a final decay with no heavy flavours or displaced vertices to aid signal identification, we must rely on substructure.

The signal events were generated using the PYTHIA [8] Monte Carlo generator (using the old PYTHIA showering scheme) for 10 TeV proton-proton collisions. We consider dijets, W+jets, Z+jets and $t\bar{t}$ as the primary backgrounds. Dijets were generated using PYTHIA (with the standard showering scheme), the W+jets and Z+jets samples using ALPGEN [9] and $t\bar{t}$ generated using MC@NLO [10]. Events were passed through the complete ATLAS detector simulation and reconstruction. Locally-calibrated topoclusters (topological clusters [11]) were built from calorimeter cells which were then passed to the $k_\perp$ algorithm (with an R parameter of 0.7).

EVENT SELECTION

We make the following offline cuts:

1. at least four jets in the event, with the four highest p_T jets having $|\eta| < 2.5$
2. two jets with $p_T > 275$ GeV
3. for both of these jets $y_2 > -0.17y_1 + 0.08$

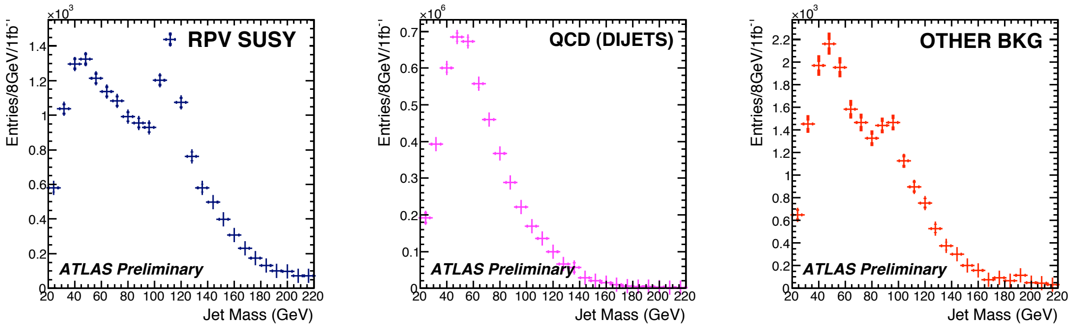

FIGURE 1. Jet mass for jets with $p_T > 275$ GeV in events with at least four jets with $|\eta| < 2.5$

4. two further jets both with $p_T > 135$ GeV

The first high p_T jet cut (275 GeV) is used to select the highly boosted candidates. The $y_{1,2}$ cut then eliminates a significant proportion of the background by exploiting the substructure of the boosted jets which are formed by the merging of the three sub-jets. The rejection achieved using these hard p_T cuts and structure cuts is not sufficient to obtain a significant signal. In order to achieve higher background rejection we make an additional cut, which requires two jets with $p_T > 135$ GeV, to exploit the properties of the rest of the SUSY decay chain. This is not especially model dependent, since we expect coloured SUSY particle production to dominate. The ATLAS trigger system has several unprescaled jet triggers that will pass signal events with very high efficiency, guaranteeing that signal events will not be lost from the events recorded.

RESULTS

In Figure 1 we plot the masses of all jets with $p_T > 275$ GeV. The peak from the neutralino can be seen clearly in the signal events. Jets from the decay of highly-boosted W bosons and top quarks cause noticeable peaks near their respective masses. The dominant contribution to our background is from QCD jets which must be reduced by several orders of magnitude before these mass peaks can become experimentally detectable.

Figure 2 shows the y value distribution for these jets ($p_T > 275$ GeV), along with our proposed y cut (only 2% of the dijet events pass the y cut, compared with 14% of the SUSY events). After applying this cut, we re-plot the mass distributions (Figure 3) and the resultant numbers of signal and background events are comparable. Near the peak, dijet background has been reduced by $\sim 10^3$ and the signal by a much smaller factor.

A clear peak remains in the signal distribution at the mass of the neutralino. The QCD mass distribution suffers from low statistics, due to the limited Monte Carlo, giving highly weighted events (with large errors). This will not be a problem with real data. This analysis looks for a peak on a smooth controlled background. The key to its success or failure depends on the amount of background underneath the signal and on the degree to which we can measure or estimate its size and shape.

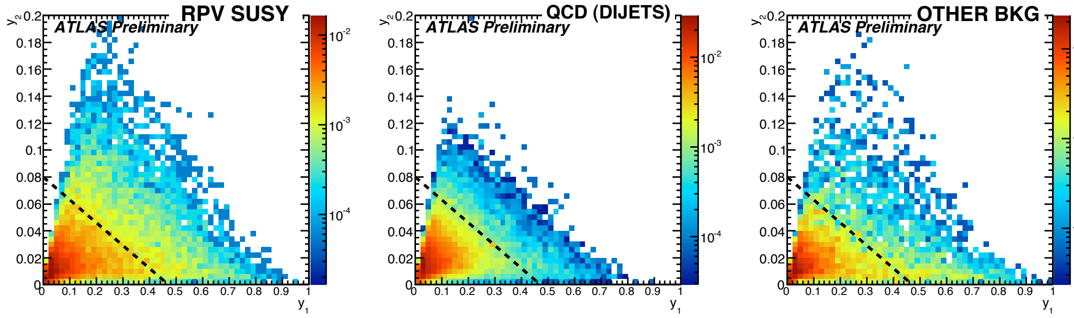

FIGURE 2. y_2 vs. y_1 for jets with $p_T > 275$ GeV in events with at least four jets with $|\eta| < 2.5$ (distributions normalised to unity). Jets above the cut-line will be accepted.

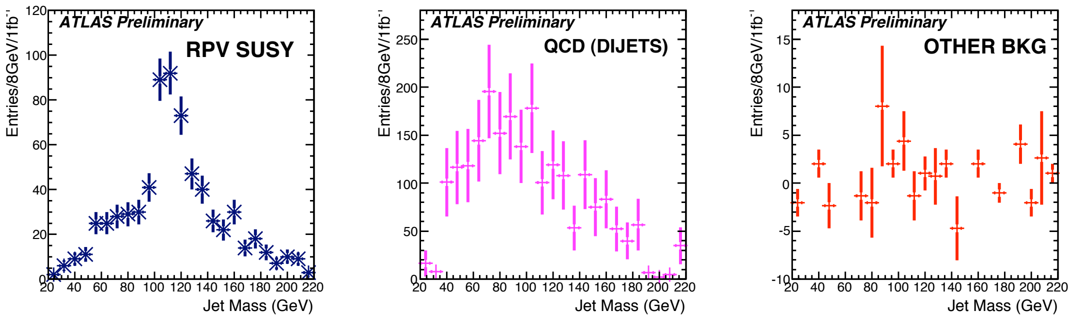

FIGURE 3. Jet mass for jets with $p_T > 275$ GeV and $y_2 > -0.17y_1 + 0.08$ in events passing all event selection cuts

CONCLUSIONS

We have demonstrated that the recently proposed method for reconstructing neutralinos from their decays into three collimated jets [2] has the potential to work at ATLAS. By exploiting the substructure of single jets from highly boosted neutralinos we can reduce hadronic background to manageable levels.

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