R-Parity violation with jet signatures at the ATLAS Detector

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Introduction (1)

- J.M. Butterworth et al. have recently proposed a method for discovering heavy particles ...

by considering jet substructure - looking at very boosted particles and trying to spot the single jets which are made out of collimated subjets...

[see J. Butterworth, J. Ellis, A. Raklev and G. Salam, Discovering baryon-number violating neutralino decays at the LHC, arXiv:0906.0728 and also J. Butterworth, J. Ellis and A. Raklev, hep-ph/0702150]

- This method looks for massive particles with a boost decaying to three semi-collimated light jets
- They use the k_T algorithm to look at jet substructure and demonstrate the method by searching for neutralino decays in baryon-number violating SUSY
- We test their approach for use at ATLAS by also considering hadronic neutralino decays...

Introduction (2)

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

$$W = \frac{1}{2}\lambda^{ijk}L_iL_j\bar{e}_k + \lambda'^{ijk}L_iQ_j\bar{d}_k + \mu'^iL_iH_u + \frac{1}{2}\lambda''^{ijk}\bar{u}_i\bar{d}_j\bar{d}_k$$

- Non zero values of any of these couplings give us very different phenomenologies to the RPC MSSM**
- We consider **non-zero λ'' which is the dominant parameter in baryon number violating models**
- It will give us the decay:

$$\tilde{\chi}_1^0 \rightarrow qqq$$

- In this new method we **do not need to use a lepton requirement** to separate these decays from a highly hadronic background **as has previously been the case...**

[see: B.C. Allanach et al, Measuring Supersymmetric Particle Masses at the LHC in Scenarios with Baryon-Number R-Parity Violating Couplings, hep-ph/0102173]

Method (1)

- In this method the primary tool for classifying jet substructure is the k_T algorithm

- Takes a pair of calorimeter clusters (k,l) and **calculates two resolution** variables:

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

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

- If it finds that d_{kl} is smallest k and l will be combined to make a single object with momentum p_{kl}

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

$$p_{kl} = p_k + p_l$$

- The **scale at which jets from two or more collimated partons separate into their subjects is reflected by the values of d_{kl} calculated** in this jet-finding algorithm
- The variable y is then introduced:

$$y = d_{kl} / m^2$$

Method (2)

- If the heavy particles, in our case neutralinos, are sufficiently boosted the three jets from the decay will collimate...
- **Look at the true circumcircle radius (or half the maximum ΔR when this is smallest) of the three jets as a function of particle p_T**
- **This gives some indication of an appropriate R parameter**

higher R worsens jet reconstruction but improves signal efficiency

- Jet mass defined as the invariant mass of the final objects

Method (3)

- Choose **R parameter of 0.7**
- y_1 and y_2** are the **y-values** from the last and next to last merging of the subjects
- Triggers:**
 - signal events have multiple high p_T jets
 - high trigger efficiency for many un-prescaled triggers e.g. 4 jets with $p_T > 125$ GeV trigger
- Make the following **offline selection cuts**:
 - at least four jets in the event, with the four highest p_T jets having $|\eta| < 2.5$
 - two jets with $p_T > 275$ GeV
 - for both of these jets $y_2 > -0.17y_1 + 0.08$
 - two further jets both with $p_T > 135$ GeV

	Cut 1	Cuts 1 & 2	Cuts 1,2 & 3	Cuts 1,2,3 & 4
SUSY	14577	5849	792	347
$t\bar{t}$	2.3×10^5	2,000	200	1
dijets	3.2×10^9	1.1×10^6	1.8×10^4	1100
W +jets	1500	20	20	0
Z +jets	1.9×10^4	210	2	1

The Model

- Take the **SPS1a** SUSY Point as our straw model to test the method and set $\lambda''_{112}=0.001$ **giving a final decay with no heavy flavours or displaced vertices to aid identification**
- Consider 1fb^{-1} of integrated luminosity at 10TeV
- **Signal Model:** $\lambda''_{112}=0.001$, $\sigma=17\text{pb}$ (at LO), $m_{\text{neutralino}}=96.1\text{GeV}$, $m_0=100\text{GeV}$, $\tan\beta=10$, $A_0=-100$, $m_{1/2}=250\text{GeV}$, $\text{sign}(\mu)>0$

(NB: ruled out by current experimental limits, but this analysis should be model independent and apply to other λ''_{ijk} with $i,j,k=1,2$)

- **Backgrounds:** **W+jets, Z+jets, dijets and ttbar**
- Signal events were generated using Pythia
- Both signal and background were then passed through full simulation of the ATLAS detector
- The k_T algorithm was used on locally calibrated topological clusters built from calorimeter cells

The ATLAS Detector

Results (1)

- The signal p_T vs. mass distribution shows a stripe at a mass of $\sim 100\text{GeV}$ (background distribution shows no such structure) which validates the strategy of **selecting neutralino jets using a high p_T cut**

- The mass distribution of jets with $p_T > 275\text{GeV}$ shows that we must reduce QCD background by several orders of magnitude in order to see the signal neutralino peak

Results (2)

- A plot of y_2 vs y_1 shows that a cut on these two variables will reduce the dijet background significantly (events above the drawn cut line are accepted)

- Requiring 3rd and 4th jets with $p_T > 135\text{GeV}$ helps remove even more background without reducing signal (40% of neutralinos produced by squark decay - expect another jet, or even a jet from higher up a decay chain)
- The mass distribution of jets with $p_T > 275\text{GeV}$ and $y_2 > -0.17y_1 + 0.08$ after making all event selection cuts shows that QCD has been reduced by 10^3 across the jet mass range

Results (3)

- Comparable numbers of signal and background events remaining
- Remains a clear peak in the signal distribution at the mass of the neutralino
- Cut on y-values has significantly reduced the dijet background
- QCD mass distribution suffers from low statistics, due to limited Monte Carlo, and so the events are highly weighted
 - In real data this will not be a problem
 - The smaller error bars (poisson) give the size of the errors expected for 1fb⁻¹ of data, these are much more manageable
- **Success or failure of this method depends on the amount of background underneath the signal and on the degree to which we can estimate or measure its size and shape**
- We might be able to model this background by loosening cuts and letting in more background to make background enriched samples – allowing us to ascertain the true shape and smoothness (or otherwise) of the underlying background

Conclusions & Outlook

- We have successfully taken a recently proposed method and demonstrated that, albeit with a few additional background removing cuts, **ATLAS has the potential to detect highly boosted neutralinos by looking at the substructure of the resulting single collimated jets**
 - **We could extend this to consider other jet algorithms**
 - **We have simulated and studied an R-Parity violating supersymmetric point but we have avoided making the analysis depend strongly on this choice... but it is 'aided' by:**
 - Supersymmetric pair production providing a natural source of neutralino pairs (allowing us to ask for two high p_T candidates)
 - Long decay chains providing source of boosts and additional jets (3rd and 4th)
- We have therefore **only tested the applicability of this method to models with pair production of the decaying state and models where we have an equivalent means of providing the part of the background rejection provided by the 3rd and 4th jet cuts**
- These **cuts have not been fully optimised** but **serve to demonstrate the suitability of the method for investigating baryon number violating SUSY models in ATLAS**