Sparticle masses from hadronic decays

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Abstract. We present our work on reconstructing sparticle masses in purely hadronic decay chains, using the $k_T$ jet-algorithm on Monte Carlo simulated events at LHC energies.

1. Introduction

The production and detection of supersymmetric particles is one of the primary goals of the LHC experimental programs. As a proton-proton collider we expect the dominant production at the LHC to be coloured states: gluinos and squarks. Their decays through neutralinos and charginos into leptonic final states have been widely studied. However, much less work has been done on purely hadronic decay chains, and decays which produce massive bosons such as $W$, $Z$ or a Higgs. Moreover, large branching ratios for neutralinos and charginos into massive bosons have been shown to be a generic feature of models that relax the GUT universality assumptions on Higgs masses found in mSUGRA scenarios, and models that relax restrictions on parameter space due to the measured Dark Matter density by having a gravitino LSP [1].

In [2] we investigated the LHC potential for finding supersymmetry, and for setting bounds on sparticle masses, in decays of the type

\[ \tilde{q} \to q\tilde{\chi} \to qB\tilde{\chi}_1^0, \tag{1} \]

where $\tilde{\chi}$ is a neutralino/chargino intermediate and $B = \{W, Z, h\}$. The difficulty with the hadronic decay of $B$ is the large combinatorial background to the reconstruction - as a result of the high jet activity expected at the LHC, a single event typically has multiple boson candidates in the form of pairs of jets with the correct invariant mass. This is in particular a challenge for the measurement of sparticle masses through the invariant mass distributions of the final states in decay chains such as eq. (1). While a $Z$ can be reconstructed from decays into electrons or muons at the expense of statistics, the missing information from the neutrino in a leptonic $W$ decay was found to make mass determination very difficult. The same is true for a low mass Higgs decaying into taus.

To correctly identify massive bosons in decay chains such as eq. (1) we have followed an idea put forward in [3] for analysing $WW$ scattering, using the state-of-the-art $k_T$ jet-algorithm [4] for identifying a pair of collimated jets from the hadronic decay of a boosted, massive particle. Following a short summary of the method used, its successful application to a specific benchmark model and decay chain, presented in detail in [2], will be briefly discussed here.
2. Method

2.1. Monte Carlo event generation

In order to simulate sparticle production and top pair background at the LHC, we use PYTHIA 6.408 [5] with CTEQ 5L PDFs [6] interfaced to the HZTOOL framework [7], with some minor changes to allow for simulations of SUSY scenarios. Decay widths and branching ratios for the SUSY particles are calculated with SDECAY 1.1a [8]. The most important non-top Standard Model backgrounds consist of multiple gauge boson and/or multiple jet production that are generated using ALPGEN [9], HERWIG 6.510 [10] and JIMMY [11].

2.2. The \( k_T \) jet-algorithm

For each particle \( k \) and pair of particles \( (k, l) \), the \( k_T \) jet-algorithm calculates the quantities

\[
d_{kB} = p_{Tk}^2, \\
d_{dB} = p_{Tl}^2, \\
d_{kl} = \min(p_{Tk}^2, p_{Tl}^2)R_{kl}^2/R^2,
\]

where \( p_{Tk} \) is the transverse momentum of particle \( k \) with respect to the beam axis and

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

If \( d_{kB} \) or \( d_{dB} \) is the smallest, then particle \( k \) or \( l \) is labelled a jet and removed from the list. If \( d_{kl} \) is the smallest, particles \( k \) and \( l \) are merged by adding their four-momenta. The list is recalculated and the process is repeated until the list is empty\(^1\). The algorithm is infrared safe, and has the additional benefit that each particle is uniquely assigned to a single jet\(^2\).

2.3. Signal isolation and jet identification

To isolate the supersymmetry events from Standard Model background we apply cuts on missing energy \( E_T > 300 \) GeV, and require three jets with \( p_T > 200, 200, 150 \) GeV. To identify the massive boson in the signal decay chain, we first require \( p_T > 200 \) GeV for candidate jets to ensure they are energetic enough to contain a boosted massive particle. Then a cut is applied on the mass of the jet (calculated from the four-vectors of the constituents) to ensure that it is in a window around the nominal mass of the desired particle.

The final step is to decompose the jet into two sub-jets. The information gained from this is the \( y \) cut at which the sub-jets are defined: \( y \equiv d_{kl}/(p_T)^2 \), where \( p_T \) is the transverse momentum of the candidate jet containing the sub-jets \( k \) and \( l \). In the case of a genuine \( W, Z \) or \( h \) decay, the expectation for the scale at which the jet is resolved into sub-jets (i.e., \( yp_T^2 \)) is \( O(M^2) \), where \( M \) is the boson mass. For QCD jets initiated by a single quark or gluon, the scale of the splitting is expected to be substantially below \( p_T^2 \), i.e., \( y \ll 1 \), since in the region around the jet strongly-ordered QCD evolution dominates.

Although no detector simulation is employed in this analysis, the jet mass and sub-jet scale cuts has previously been shown to be robust against effects due to the calorimeter granularity and resolution [13, 14].

3. Results and conclusions

As an example of the method, we present in figure 1 the invariant mass distribution of two jets identified as coming from the squark and Higgs decays in the decay chain (1), for the SUSY

\(^1\) The parameter \( R \) plays a similar role to the adjustable cone radius in cone algorithms. In our study we have used \( R = 0.7 \), which is a compromise between reconstruction efficiency for the softest jets and mass resolution.

\(^2\) Recently, a fast implementation of the algorithm has been developed [12], which makes it practical for use even in the very high multiplicity events expected at the LHC.
benchmark scenario $\beta$, taken from [1]. See [2] for results with a $W$ or $Z$ in the cascade and for other benchmarks. The squark decay jet candidates are the jets in the event with $p_T > 200$ GeV that are not Higgs candidates, while the Higgs candidates are picked from $b$-tagged$^3$ jets only (left), with an additional jet mass cut of $110 < m_j < 140$ GeV (middle) and a sub-jet scale cut $1.8 < \log(p_T \sqrt{y}) < 2.1$ (right).

It is clear that the use of the jet mass and sub-jet scale cuts are central in picking out the signal above the SUSY background. With the application of the sub-jet scale cut, the expected edge in the invariant mass distribution can be seen in the right panel, which allows us to constrain the three sparticle masses involved in the decay chain using standard edge analysis techniques.

We conclude that the sophistication of the $k_T$ jet-algorithm, giving a jet mass with good resolution and the sub-jet scale of collimated jets, can be central in reconstructing SUSY decay chains at the LHC and in measuring or putting bounds on SUSY masses.

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$^3$ For details on the $b$-tagging procedure, see [2]