Sparticle spins from cascade decays

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Introduction

When SUSY is discovered at the LHC via large missing $P_T$ it will be important to:

- Measure the mass spectrum
  - Pin down the mechanism of SUSY breaking
  - Make a first step towards a GUT theory
  - See Børge’s talk
- Make sure it is SUSY!
  - Measure the sparticle coupling and compare with SM couplings
  - Measure the sparticle spins

*Endpoint method*  

*Shapes*  
The Cascade Decay

Most analyses of sparticle spins to date have investigated some part of this susy cascade:

or the analogous case in other models (e.g. UED)


L.T. Wang, I. Yavin, arXiv:hep-ph/0605296  \[\tilde{u} \rightarrow \chi_1^+ d \rightarrow W^+ \chi_1^0 d\]

via charginos, e.g.
In principle, can measure the spins of sparticles from the invariant mass shapes for this cascade.

e.g. use the q\text{I} invariant mass


2 problems:

How can we distinguish the ‘near’ lepton from the ‘far’ lepton?

How can we tell $l^+ q$ from $l^+ \bar{q}$?

Since $\tilde{\chi}^0_2$ is a Majorana particle it can decay to $l^+ \tilde{l}^*_R$ or to $l^- \tilde{l}^*_R$
Barr solves this by constructing an asymmetry:

\[ A = \frac{s^+ - s^-}{s^+ + s^-} \quad \text{with} \quad s^{\pm} = \frac{d\sigma}{dm_{l^{\pm}q}} \]

If we had the same number of quarks as anti-quarks this would give zero,

but since the LHC is a pp collider we have many more quarks than anti-quarks.

The Asymmetry is polluted by the anti-quarks but not enough to destroy the asymmetry:

![Graph showing A vs. m_{lq} with \( \int Ldt = 150 \text{ fb}^{-1} \)]

- \( m_0 = 100 \text{ GeV} \)
- \( m_{1/2} = 300 \text{ GeV} \)
- \( A_0 = 300 \text{ GeV} \)
- \( \tan \beta = 2.1 \)
- \( \mu > 0 \)
Realistically, we still expect angular momentum to be conserved.

The SUSY decay chain is

\[ \text{scalar } (\tilde{q}) \longrightarrow \text{fermion } (\tilde{\chi}_2^0) \longrightarrow \text{scalar } (\tilde{l}_R) \longrightarrow \text{fermion } (\tilde{\chi}_1^0) \]

This can’t suddenly become a scalar without anything else changing!

It makes more sense to compare with other types of chain, e.g. in UED

\[ \text{fermion } \longrightarrow \text{vector } \longrightarrow \text{fermion } \longrightarrow \text{vector} \]


parton level,
SPS 1a mass spectrum
Another trick has been suggested by A. Alves, O. Eboli, T. Plehn, arXiv:hepph/0605067 to distinguish $q$ from $\bar{q}$.

Use b-quarks only: to tag a b-quark needs a lepton in the jet

\[ \text{use the lepton charge to distinguish } b \text{ from } \bar{b} \]

They use this to measure the spin of the gluino

\[ \text{for more details see Tilman’s talk} \]
Reconstructing the LSP

We will take a different approach and look at individual decays in the cascade by **reconstructing all the momenta**.

We do this by using a method from:

M.M. Nojiri, G. Polesello and D.R. Tovey, arXiv:hep-ph/0312317

Once the masses of the sparticles are known we have extra constraints on the system

Since SUSY states are quite narrow (their decays are restricted by $P_R$ conservation) they will be approximately on-shell.

We have 4 mass-shell conditions

) solve for the 4 LSP momentum components

See Børge’s talk
\[ \vec{E}_A^2 = \vec{p}_A^2 + m_A^2 \]
\[ p_A \cdot p_1 = (m_B^2 - m_A^2)/2 \]
\[ p_A \cdot p_2 = (m_C^2 - m_B^2 - m_{12}^2)/2 \]
\[ p_A \cdot p_3 = (m_D^2 - m_C^2 - m_{123}^2 + m_{12}^2)/2 \]

write \[ \vec{p}_A = \alpha_i \vec{p}_i \]

\[ E_A^2 = \alpha_i \alpha_j \vec{p}_i \cdot \vec{p}_j + m_A^2 \]
\[ E_A E_1 - \alpha_i \vec{p}_i \cdot \vec{p}_1 = (m_B^2 - m_A^2)/2 \]
\[ E_A E_2 - \alpha_i \vec{p}_i \cdot \vec{p}_2 = (m_C^2 - m_B^2 - m_{12}^2)/2 \]
\[ E_A E_3 - \alpha_i \vec{p}_i \cdot \vec{p}_3 = (m_D^2 - m_C^2 - m_{123}^2 + m_{12}^2)/2. \]

Solve for \( \alpha_i \) (invert a 3\times3 matrix) and \( E_A \)

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full reconstruction of the LSP 4-momentum
Full reconstruction of LSP momentum → reconstruction of all momenta in the chain

use more traditional methods of determining spin via angular distributions

Signal chains: use SPS 1a for our analysis and PYTHIA + AcerDET

opposite sign same flavour leptons (OSSF)

(on the other side)

BR = 98.6%

We use Barr’s trick (more quarks than anti-quarks in the proton) to ‘identify’ the quark. This is actually unfortunate because we lose all squarks coming from a gluino:

inclusive \( \sigma(\bar{q}_R\bar{q}_L) = 13.3 \text{ pb} \) vs. direct \( \sigma(q_Rq_L) = 4.8 \text{ pb} \)
But
  • which is the jet from $\tilde{q}_L$?
  • which is the near lepton and which is the far lepton?

Can we distinguish them from their $p_T$ spectra?

Jets from a gluino decay are easily distinguished, but it is impossible to tell those from $\tilde{q}_L$ and those from $\tilde{q}_R$ apart.
Leptons are similarly difficult.

This is particularly bad for SPS 1a because the mass spectrum similar $p_T$ for near and far leptons.
Instead, take all possibilities for particle identification

For each, check to see if this choice has a solution to the LSP reconstruction

- If it doesn’t, throw it away.
- If it is, construct the invariant masses and compare with the predicted shapes. Throw away if it doesn’t conform with predicted shapes.

Still need to make a choice

Use the spin-0 shapes to choose most probable identification of particles (i.e. next-neighbour triangular shape)

This will bias our sample, but the bias is **towards** spin-0, so finding a non-zero spin for the neutralino is still valid. (We would need to do something different for the slepton though.)
Plot the distance from lepton/jet candidate and true lepton/jet:

For **leptons**, we get the right lepton approximately 60% of the time.

(If we had just guessed we would have got it right 50% of the time, so this isn’t a huge improvement.)

For jets, we get the jets right approximately 80% of the time.
Once we are (think) we have the right particle assignments, we can \textbf{reconstruct} the LSP and all the particle in the chain.

\[ \cos(\theta) \]

know the angle between the near lepton and the quark in the \( \tilde{\chi}_2^0 \) rest frame.

The two possible processes give different shapes (as predicted).

A scalar parent would give flat distributions.

\[ \int Ldt = 70 \text{ fb}^{-1} \]

\[ q\ell^- l^+ \text{ or } \bar{q}\ell^+ l^- \]

\[ q\ell^+ l^- \text{ or } \bar{q}\ell^- l^+ \]
Alternatively we could define an asymmetry

\[ A = \frac{N_+ - N_-}{N_+ + N_-} \]

\[ \chi^2 / \text{ndf} \quad 15.6 / 9 \]

Slope \quad 0.59 \pm 0.17

For a scalar parent, this line would be flat.

\[ \text{slope} = 0.59 \pm 0.17 \]

This is > 3\sigma so is 'evidence' of (non-zero) neutralino spin.

This should improve with more statistics.
Conclusions and Summary

- When SUSY is discovered we need to
  - measure mass spectrum
  - measure couplings
  - measure spins

- Analyses already exist looking for spin correlations in cascade decays

- We tried to reconstruct the LSP momentum using
  M.M. Nojiri, G. Polesello and D.R. Tovey, arXiv:hep-ph/0312317

- Then plot angular distribution of particle’s decay products

- Looks promising that we can show $\tilde{\chi}_2^0$ is not a scalar, though higher statistics would be useful