Invariant Mass Distributions of SUSY Cascade Decays

Anders Kvellestad

University of Oslo

03.01.2012

Outline

Outline

Masses From Kinematic Endpoints

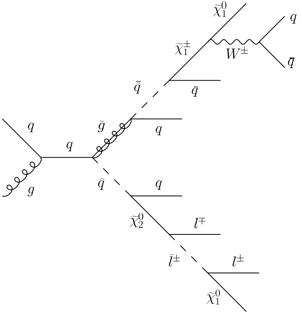
- If SUSY is discovered, theory parameters must be determined

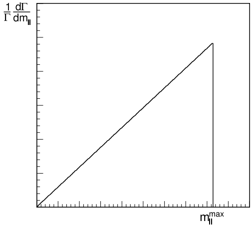
- Assume conserved R-parity
  - – cascade decays
  - – $\widetilde{\chi}_1^0$ LSP escapes detection
  - – inv. mass peaks not accessible

- Endpoints of inv. mass distributions can provide sparticle mass relations

- E.g. ‘dilepton cascade’:
  - – 4 masses: $m_{\tilde{q}}$, $m_{\widetilde{\chi}_2^0}$, $m_{\tilde{l}}$, $m_{\widetilde{\chi}_1^0}$
  - – 4 endpoints: m_{ll}, m_{ql_n}, m_{ql_f}, m_{qll}

$$m_{ll}^{\max} = \sqrt{\frac{\left(m^2_{\widetilde{\chi}_2^0} - m^2_{\tilde{l}}\right)\left(m^2_{\tilde{l}} - m^2_{\widetilde{\chi}_1^0}\right)}{m^2_{\tilde{l}}}}$$





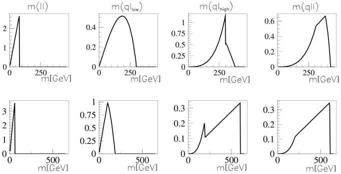
Complications

A few complicating aspects:

- Experimental 'near'/'far' ambiguity
  – must replace m_{ql_n}, m_{ql_f} by

$$m_{\text{high}} \equiv \max\{m_{ql_n}, m_{ql_f}\}$$
$$m_{\text{low}} \equiv \min\{m_{ql_n}, m_{ql_f}\}$$

- Shapes vary with sparticle masses
  – danger of 'feet' or 'drops'
- Multiple solutions
- Endpoints depend on mass *differences*
  – strong correlation in results
- Experimental limitations:
  combinatorics, statistics, backgrounds



[Gjelsten, Miller, Osland, hep-ph/0511008]

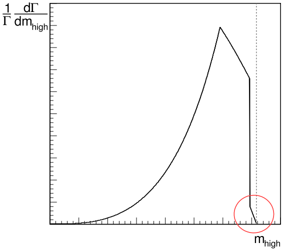
The Need for Analytical Shape Formulas

Analytical expressions might help:

- Shape formulas of the form

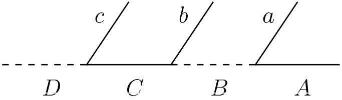
$$\frac{1}{\Gamma}\frac{d\Gamma}{dm} = f(m; \text{sparticle masses})$$

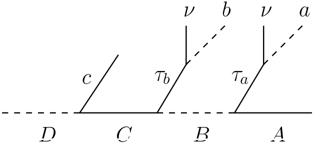
- Provides correct 'signal hypothesis' for endpoint fitting
- Predicts 'feet' and 'drops' for given mass sets
- Fits of *complete* distributions provide masses directly
  – may lift degeneracies
- Mass correlations still a problem
- Can be used to measure mixing parameters



Aim and Assumptions

- Shape formulas for the 'dilepton topology' have been derived $(l = e, \mu)$
  [Miller, Osland, Raklev], [Lester]
- **Aim:** Derive shape formulas for the 'ditau topology'
- More complicated topology due to in-detector τ decays
  – spin effects important
- Simplifying assumptions:
  – $m_a = m_b = m_c = 0$
  – massive particles on-shell





Outline

1 SUSY Cascades and Mass Measurements

2 Results
- The m_{ab} Distribution
- The m_{high} Distribution

3 Conclusions and Outlook

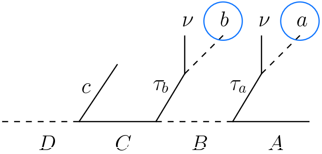
The m_{ab} Distribution

- The m_{ab} distribution

$$\frac{1}{\Gamma}\frac{d\Gamma}{dm_{ab}}$$

- Assume a, b are scalars (pions)

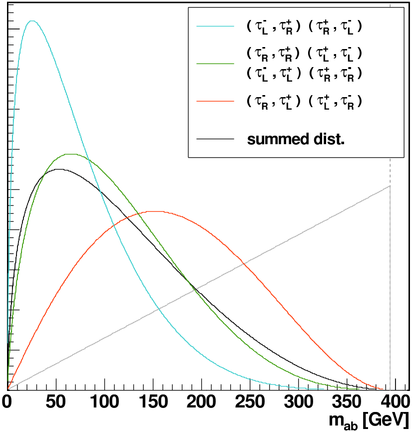
- Helicity states of τ_a, τ_b affect energies of a, b
  - if τ_b is τ_R^- or $\tau_L^+ \Rightarrow$ large E_b
  - if τ_b is τ_L^- or $\tau_R^+ \Rightarrow$ small E_b



The m_{ab} Distribution

$\mathbf{m_C}$	$\mathbf{m_B}$	$\mathbf{m_A}$
800	600	400

- Weighted towards low m_{ab} values due to escaping ν
- Shapes depend strongly on handedness – endpoints are unaffected
- Shapes are fixed as long as m_τ is negligible
- summed dist. = spin-0 dist.
- Spin shapes for $m_\tau = 0$ derived by Nattermann et al. (2009)



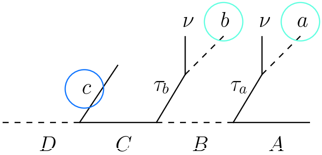
The m_{high} Distribution - No Spin

- The m_{high} distribution

$$\frac{1}{\Gamma}\frac{d\Gamma}{dm_{\text{high}}}$$

- No spin – only phase space
- Recall definition

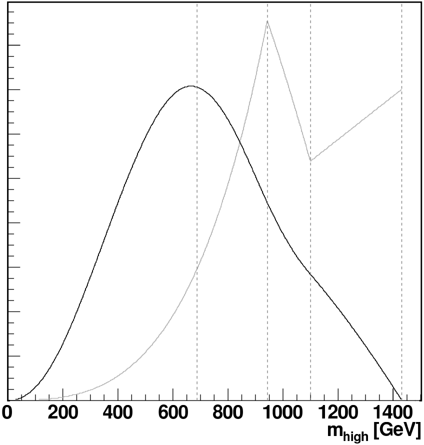
$$m_{\text{high}} \equiv \max\{m_{ac}, m_{bc}\}$$



The m_{high} Distribution - No Spin

$\mathbf{m_D}$	$\mathbf{m_C}$	$\mathbf{m_B}$	$\mathbf{m_A}$
2000	800	500	400

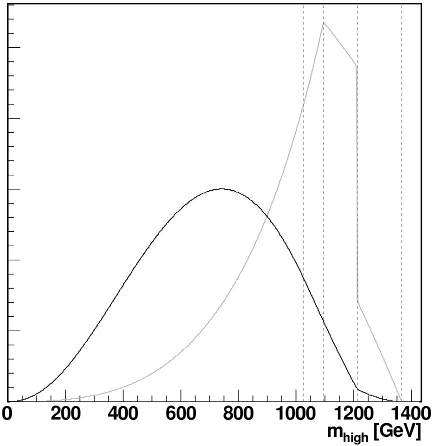
- Strong shape dependence on $(m_C - m_B)$ and $(m_B - m_A)$
  – m_D only sets scale
- Rich structure due to composite nature of m_{high}
  – note endpoint 'foot'
- m_τ negligible unless m_A, m_B m_C are close to degenerate



The m_{high} Distribution - No Spin

$\mathbf{m_D}$	$\mathbf{m_C}$	$\mathbf{m_B}$	$\mathbf{m_A}$
2000	800	600	400

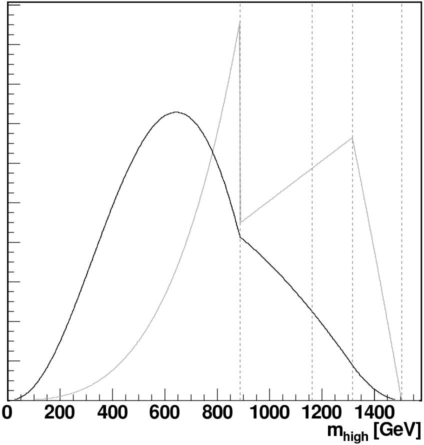
- Strong shape dependence on $(m_C - m_B)$ and $(m_B - m_A)$
  – m_D only sets scale
- Rich structure due to composite nature of m_{high}
  – note endpoint 'foot'
- m_τ negligible unless m_A, m_B m_C are close to degenerate



The m_{high} Distribution - No Spin

$\mathbf{m_D}$	$\mathbf{m_C}$	$\mathbf{m_B}$	$\mathbf{m_A}$
2000	800	700	400

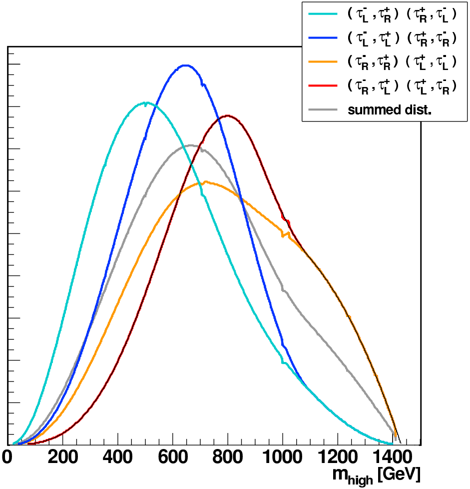
- Strong shape dependence on $(m_C - m_B)$ and $(m_B - m_A)$
  – m_D only sets scale
- Rich structure due to composite nature of m_{high}
  – note endpoint 'foot'
- m_τ negligible unless m_A, m_B m_C are close to degenerate



The m_{high} Distribution

$\mathbf{m_D}$	$\mathbf{m_C}$	$\mathbf{m_B}$	$\mathbf{m_A}$
2000	800	500	400

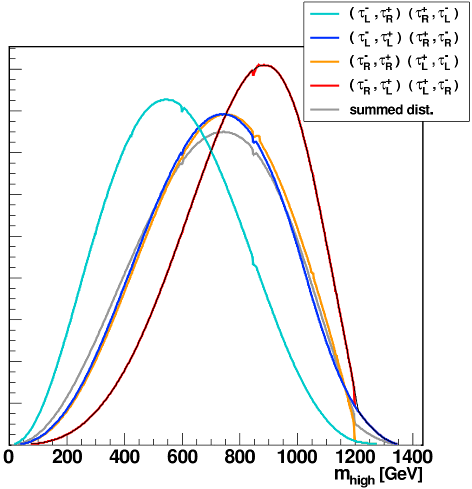
- …and including spin (work in progress):
- Splits into four distinct distributions
- One complete analytical result so far (thin black dist.)



The m_{high} Distribution

$\mathbf{m_D}$	$\mathbf{m_C}$	$\mathbf{m_B}$	$\mathbf{m_A}$
2000	800	600	400

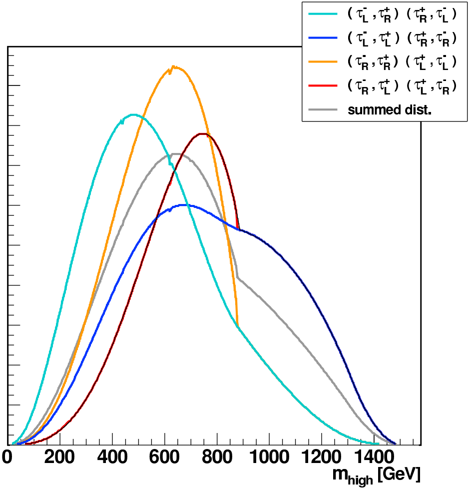
- . . . and including spin (work in progress):
- Splits into four distinct distributions
- One complete analytical result so far (thin black dist.)



The m_{high} Distribution

$\mathbf{m_D}$	$\mathbf{m_C}$	$\mathbf{m_B}$	$\mathbf{m_A}$
2000	800	700	400

- …and including spin (work in progress):
- Splits into four distinct distributions
- One complete analytical result so far (thin black dist.)



Outline

Conclusions and Outlook

- Main result: The actual analytical expressions
  (not shown explicitly here due to complicated form)
- Distribution shapes depend strongly on tau handedness
  (stau and neutralino mixing)
- Strong dependence on mass scenario for m_{high}
  – promising for complete shape fit
- Further work:
  - Derive remaining shape formulas
  - Compare shapes to simulated data
  - Investigate deviations due to cuts, detector effects, etc

Thank you

Backup slides

General Method

- Method developed in
  [Miller, Osland, Raklev, hep-ph/0510356]
  – adapted for the 'ditau topology'
- Start from variables with known distributions

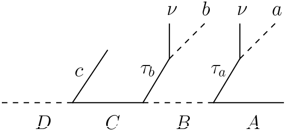
$$\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}u\,\mathrm{d}v\,\mathrm{d}w} = g(u,v,w)$$

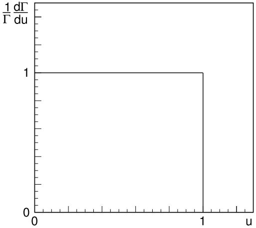
- Kinematics

$$m^2 = h(u,v,w\,;\text{sparticle masses})$$

- Variable changes and integrations

$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma}{\mathrm{d}m^2} = \iint \left|\frac{\partial(u,v,w)}{\partial(u,v,m^2)}\right| \frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}u\,\mathrm{d}v\,\mathrm{d}w}\,\mathrm{d}u\,\mathrm{d}v$$



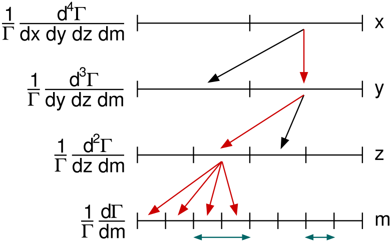


$$u = \frac{1}{2}\left(1 - \cos\theta^B_{\tau\tau}\right)$$

Main Difficulty

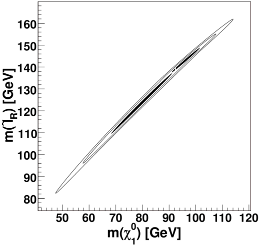
Main difficulty of the derivations:

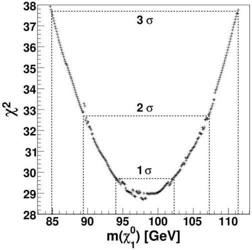
- All possible integration regions must be covered
- 2- or 3-dimensional regions with complicated structure
- Expressions 'fraction' for each integration
- Order of final m regions shift with sparticle mass scenarios
- In sum: lots of bookkeeping!



Multiple Solutions

- One set of endpoints may be consistent with several sets of sparticle masses
- In some scenarios, endpoints are linearly dependent
- Need extra information
- Fits of analytical shape formulas can provide this information

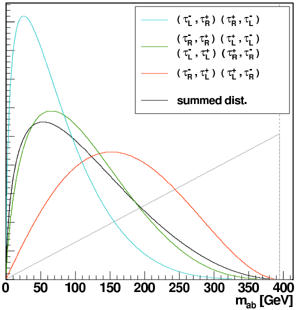


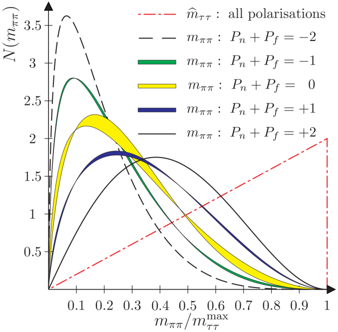


[Gjelsten, Miller, Osland, Raklev, hep-ph/0611259]

The m_{ab} Distribution

$\mathbf{m_C}$	$\mathbf{m_B}$	$\mathbf{m_A}$
800	600	400



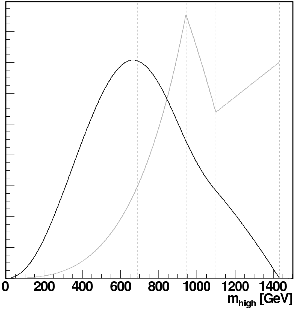


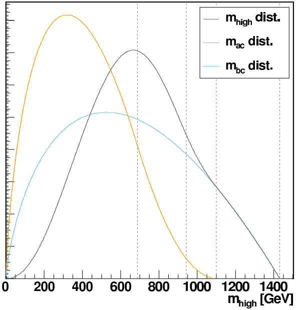
[Nattermann et al., arXiv:0903.0714]

- Weighted towards low m_{ab} values due to escaping ν
- Shapes depend strongly on chirality – endpoints are unaffected
- Shapes are fixed as long as m_τ is negligible
- summed dist. = spin-0 dist.
- Spin shapes for $m_\tau = 0$ derived by Nattermann et al. (2009)

The m_{high} Distribution - No Spin

$\mathbf{m_D}$	$\mathbf{m_C}$	$\mathbf{m_B}$	$\mathbf{m_A}$
2000	800	500	400

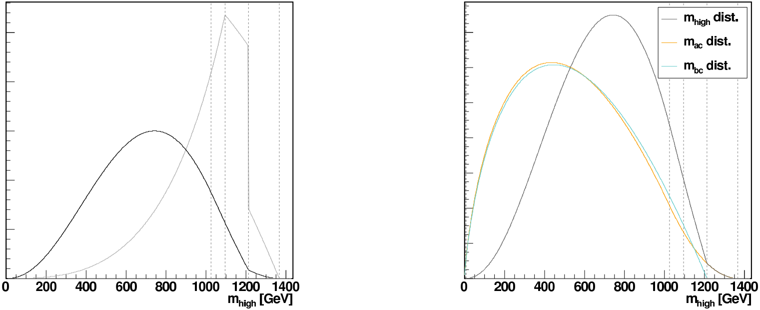




- Strong shape dependence on $(m_C - m_B)$ and $(m_B - m_A)$
  – m_D only sets scale
- Rich structure due to composite nature of m_{high}
  – note endpoint 'foot'
- m_τ negligible unless m_A, m_B m_C are close to degenerate

The m_{high} Distribution - No Spin

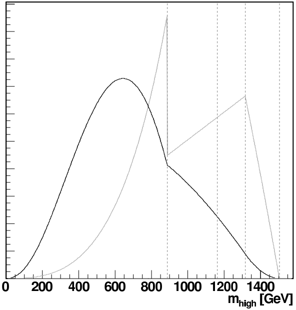
$\mathbf{m_D}$	$\mathbf{m_C}$	$\mathbf{m_B}$	$\mathbf{m_A}$
2000	800	600	400

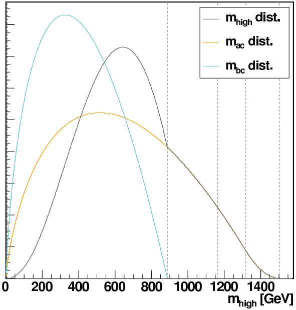


- Strong shape dependence on $(m_C - m_B)$ and $(m_B - m_A)$
  – m_D only sets scale
- Rich structure due to composite nature of m_{high}
  – note endpoint 'foot'
- m_τ negligible unless m_A, m_B m_C are close to degenerate

The m_{high} Distribution - No Spin

$\mathbf{m_D}$	$\mathbf{m_C}$	$\mathbf{m_B}$	$\mathbf{m_A}$
2000	800	700	400





- Strong shape dependence on $(m_C - m_B)$ and $(m_B - m_A)$
  – m_D only sets scale
- Rich structure due to composite nature of m_{high}
  – note endpoint ‘foot’
- m_τ negligible unless m_A, m_B m_C are close to degenerate