Cascade Decays, Shapes and Fittino

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PHYSICS AT THE TERA SCALE
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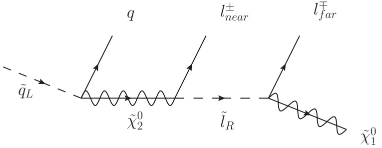
Outline

Cascade Decays

- Measurement of masses and spins possible using invariant mass distributions: m_{ll}, m_{qll}, $m_{ql_{near}}$, $m_{ql_{far}}$ and $m_{qll}(\theta > \pi/2)$.
- Standard cascade:



- l_{near} and l_{far} experimentally not distinguishable $\rightarrow$ $m_{ql}(high)$, $m_{ql}(low)$.
- Due to R-Parity conservation always two cascade decays per process.
- Light flavours degenerate. Distinction for third flavour necessary.

Edges

- Purely kinematics $\rightarrow$ "model independent". But: Need for certain hierarchy,
- Standard endpoints: m_{ll}^{max}, m_{qll}^{max}, $m_{ql}^{max}(high)$, $m_{ql}^{max}(low)$.
- Analytical inversion formulas available. May yield ambiguities between different phace space regions.
- Intensively studied (e.g. Miller et. al., 2005, hep-ph/0410303 & hep-ph/0510356).

Shapes

- Analytical formulas available including spin effects $\rightarrow$ model dependent.
- Shapes highly disturbed by BR, cuts, background, quasi-degenerate squarks, combinatorics etc.

Rates

- Ben talked about yesterday

Variation around mSUGRA SPS1a

We vary one mSUGRA paramter at a time around SPS1a within errors of Fittino (LE, LHC10 prospects as inputs)

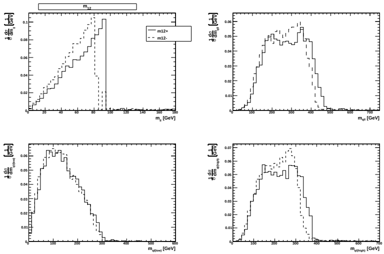
Parameter	Nom. Val.	Fit Val.		Error
M_0 [GeV]	100	96.74	$\pm$	4.17
$M_{1/2}$ [GeV]	250	248.8	$\pm$	3.5
$\tan\beta$	10	9.75	$\pm$	4.75
A_0 [GeV]	-100	-106.8	$\pm$	58.3

Parameter	$\sigma \times BR$[pb]
SPS1a	1.45
M_0+	1.47
M_0-	1.52
$M_{1/2}+$	1.24
$M_{1/2}-$	2.26
A_0+	2.21
A_0-	0.82
$\tan\beta+$	0.82
$\tan\beta-$	3.83

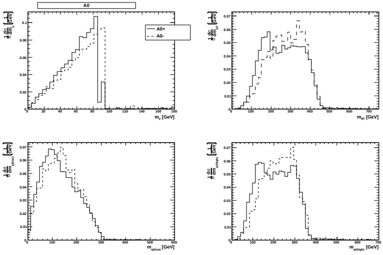
- M_0, $M_{1/2}$, A_0 are varied within 3σ. $\tan\beta$ is varied within 1σ.
- Variations in $\sigma \times BR$ mostly smaller than 50%. But much bigger effect possible (i.e. $\tan\beta-$).

Variation around mSUGRA SPS1a: Results

$m_{1/2} \pm 3\sigma$



$A_0 \pm 3\sigma$



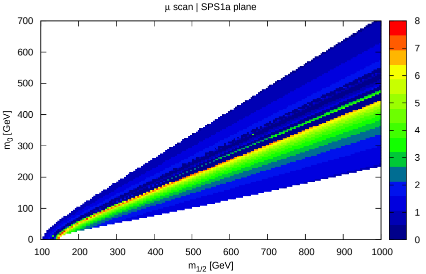
- Luminosity $\approx 15 - 20\ fb^{-1}$ @ 14 TeV.
- Shapes of invariant mass distributions seem to be quite robust under variation of SUSY paramters - at least in the SPS1a corner of parameter space.

Phase space ambiguities

- Using only m_{ll}^{max}, m_{qll}^{max}, $m_{ql}^{max}(high)$, $m_{ql}^{max}(low)$, there are *exact* mimic points all over the mSUGRA paramter space (only mass differences are properly constrained). These exact mimic points are not mSUGRA.
- Employing analytical shape formulas we perform a scan over the $m_0 - m_{1/2}$ SPS1a plane (s. hep-ph/0611259).
- We measures mass-differences (μ) and differences in shape (D).

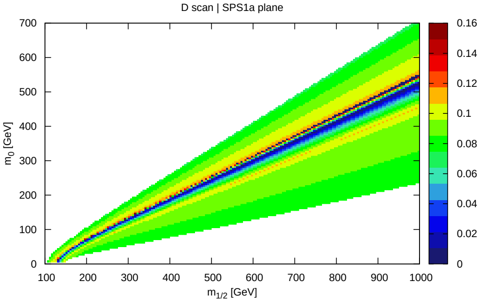
$$\mu = \frac{\sum_i |m_i^{false} - m_i^{true}|}{m_i^{true}}$$

- There are ambiguities almost all over the considered parameter space.
- In general fairly small mass-differences between degenerate solutions.
- Along wedge in the plane mass differences are bigger.
- Scenarios with very different masses might be distinguishable by comparesion of cross sections.



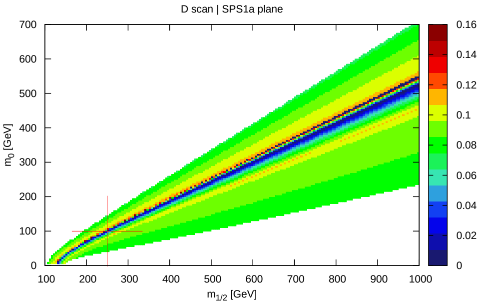
Solving ambiguities using shapes

$$D = \frac{1}{2N} \sum_{i=1}^{N} \int_{0}^{m_i^{max}} |f_i(m) - g_i(m)| dm$$



- Fairly constant around $D \approx 0.08$.
- Along wedge in the plane distributions change rapidly between different phase space regions/analytical forms.
- Wedge in μ scan does not correspond this region.
- There might be regions with small mass differences but big differences in shape.

Solving ambiguities using shapes

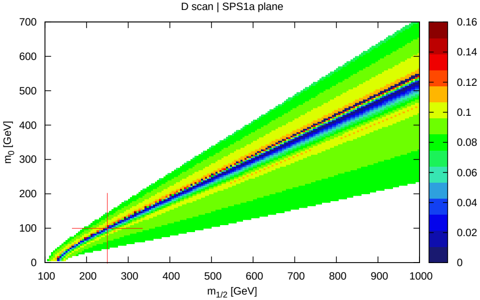


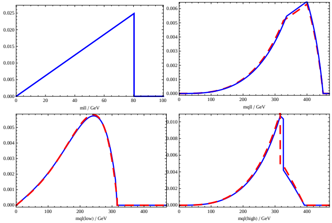
For SPS1a:

- $\mu \approx 0.41$ (low).
- $D \approx 0.024$ (low).
- SPS1a and its mimic not distinguishable by shapes.
- Stable in variations and concerning mimic points.
- Analytical shapes?

masses / GeV	$m_{\tilde{\chi}_1^0}$	$m_{\tilde{l}_R}$	$m_{\tilde{\chi}_2^0}$	$m_{\tilde{q}_L}$
real	97.23	142.81	180.10	564.52
mimic	112.88	160.80	196.46	584.29
edges / GeV	m_{ll}^{max}	m_{qll}^{max}	$m_{ql}^{max}(high)$	$m_{ql}^{max}(low)$
	80.38	450.37	391.89	316.15

Solving ambiguities using shapes





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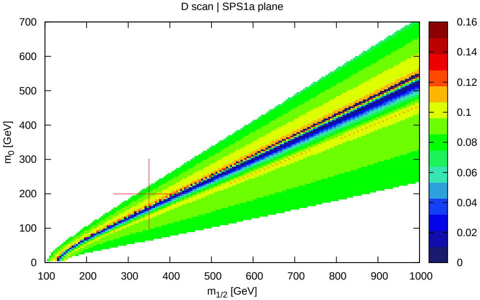
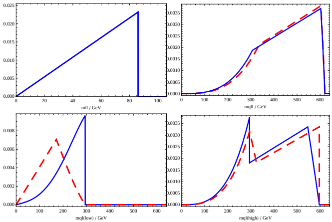


Consider point p1:
$m_0 = 200, \; m_{1/2} = 350$

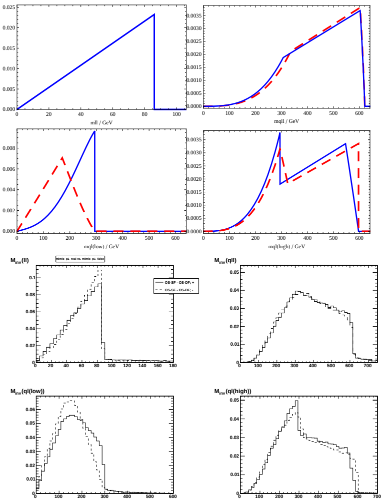
- $\mu \approx 1.0$ (still low).
- $D \approx 0.089$ (average).

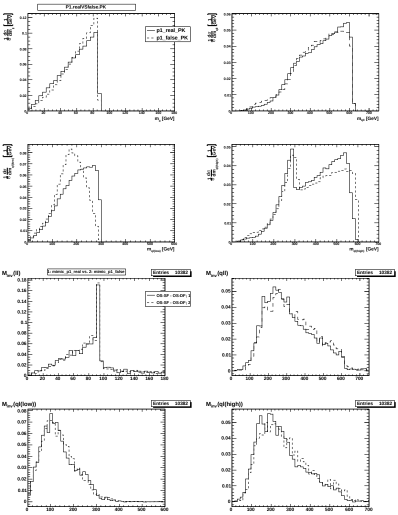


- MC shapes?

masses / GeV	$m_{\tilde{\chi}_1^0}$	$m_{\tilde{l}_R}$	$m_{\tilde{\chi}_2^0}$	$m_{\tilde{q}_L}$
real	140.598	241.576	263.725	779.589
mimic	103.051	116.138	219.745	736.296
edges / GeV	m_{ll}^{max}	m_{qll}^{max}	$m_{ql}^{max}(high)$	$m_{ql}^{max}(low)$
	86.03	620.68	596.57	294.29

Solving ambiguities using shapes?





Solving ambiguities using different endpoints?

- Piecewise endpoint definitions due to near-far lepton ambiguity.
- Goal: Construct new inv. mass distribution exhibiting symmetry $m_{j\ell_{near}} \leftrightarrow m_{j\ell_{far}}$
- New invariant mass distributions:

$$\begin{aligned}
m_{\ell\ell} &\rightarrow (m_{\ell\ell}^{max})^2 = m_D^2\, R_{CD}\,(1-R_{BC})\,(1-R_{AB}) \\
m_{j\ell_n}^2 \cup m_{j\ell_f}^2 &\rightarrow \left(M_{jl(u)}^{max}\right)^2,\ \ \left(m_{jl(u)}^{max}\right)^2 \\
m_{j\ell_n}^2 + m_{j\ell_f}^2 &\rightarrow \left(m_{j\ell(s)}^{max}\right)^2 \equiv m_D^2(1-R_{CD})(1-R_{AC}) \\
|m_{j\ell_n}^2 - m_{j\ell_f}^2| &\rightarrow \left(m_{j\ell(d)}^{max}\right)^2 \equiv \left(M_{jl(u)}^{max}\right)^2
\end{aligned}$$

- Endpoints lineraly independent in all parameter space.
- Inverted mass relations pose only a two-fold ambiguity $\rightarrow$ Easy to solve (different methods).
- Set of new invariant mass distributions introduced by Matchev et. al. (0906.2417).

Numerical example: SPS1a

	SPS1a	mimic
$m_{\tilde{\chi}_1^0}$	97.2	112.9
$m_{\tilde{l}_r}$	142.2	160.8
$m_{\tilde{\chi}_2}$	180.1	196.5
$m_{\tilde{q}_l}$	564.5	584.3
m_{ll}^{max}	80.4	80.4
$m_{jl(high)}^{max}$	391.9	391.9
$m_{jl(low)}^{max}$	316.1	316.1
m_{jll}^{max}	450.4	450.4
$m_{jll(\theta>\frac{\pi}{2})}^{min}$	216.0	210.3
$m_{jl(u)}^{max}$	326.0	316.1
$M_{jl(u)}^{max}$	391.9	391.9
$m_{jl(s)}^{max}$	450.4	450.3
$m_{jl(d)}^{max}$	391.9	391.9
$m_{jl(p)}^{max}$	318.3	318.4

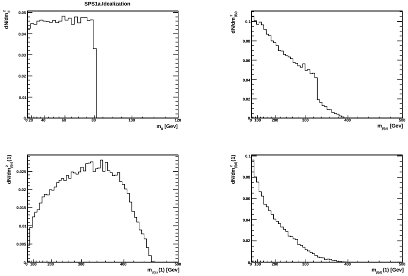


Figure: m_{ll},$m_{jl(u)}$,$m_{jl(s)}$ and $m_{jl(d)}$ for SPS1a. purely exclusive + full event reconstruction.

Numerical example: SPS1a

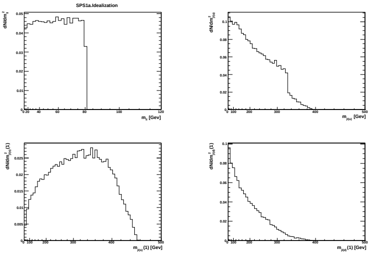


Figure: SPS1a. purely exclusive + full event reconstruction.

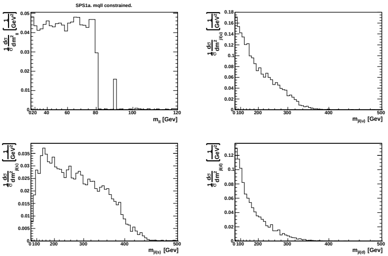


Figure: SPS1a. full sample + ordinary combinatorics.

Conclusion

Shapes

- Shapes of invariant mass distributions seem to be quite robust under variation of SUSY paramters - at least in the SPS1a corner of parameter space.
- There are exact mass mimic points all over the parameter space.
- Mimic Points hard to distinguished by invariant mass distribution shapes or additional endpoints.
- Solve jet combinatorics?