Reconstructing sleptons in cascade decays at the FLC

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Outline

- The kinematics of cascade decays.
- Reconstructing the sleptons.
- $\tilde{\mu}$ and $\tilde{\mathrm{e}}$ in SPS1a.
- Background, ISR, beam-strahlung, sensitivity to input assumptions.
- SPS3.
- Staus.
- A survey of SPS points.
- Conclusion.

The kinematics of cascade decays

Lets look at $\mathrm{e}^+\mathrm{e}^- \rightarrow \tilde{\chi}_2^0\tilde{\chi}_2^0$, with $\tilde{\chi}_2^0 \rightarrow l\tilde{l} \rightarrow ll\tilde{\chi}_1^0$ (or eg. $\mathrm{e}^+\mathrm{e}^- \rightarrow \tilde{\chi}_3^0\tilde{\chi}_3^0$, with $\tilde{\chi}_3^0 \rightarrow Z\tilde{\chi}_2^0 \rightarrow ZZ\tilde{\chi}_1^0$)

Assume $M_{\tilde{\chi}_i^0}$ are known to some extent. Count unknowns and equations:

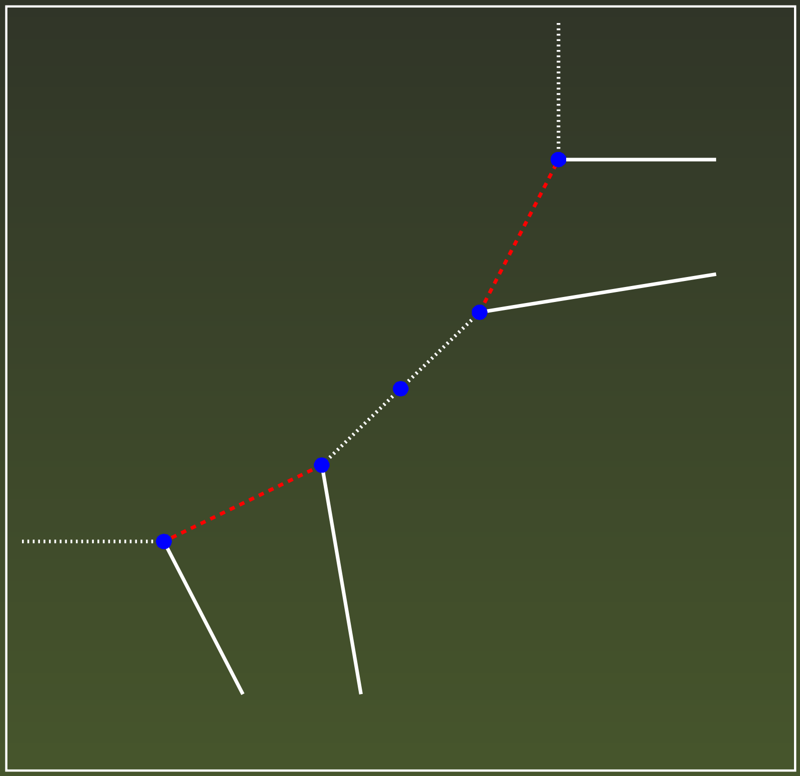
- Two $\tilde{\chi}_1^0$ four-momenta = 8 unknowns
- E & $\bar{p}$ conservation + four mass-relations = 8 constraints.

Hence, it should be possible to fully reconstruct the four-momenta, and since the SM particles are (Z, ℓ) are observed and measured in the detector the Four-momentum of the intermediate SUSY particle is measurable in each event There was no need to assume any value of the mass of this particle. The reconstruction is hence a direct measurement of the sparticle mass.

Note that this is no rare process: As soon as pair-production threshold of the NNLSP is passed, the NLSP can be reconstructed.

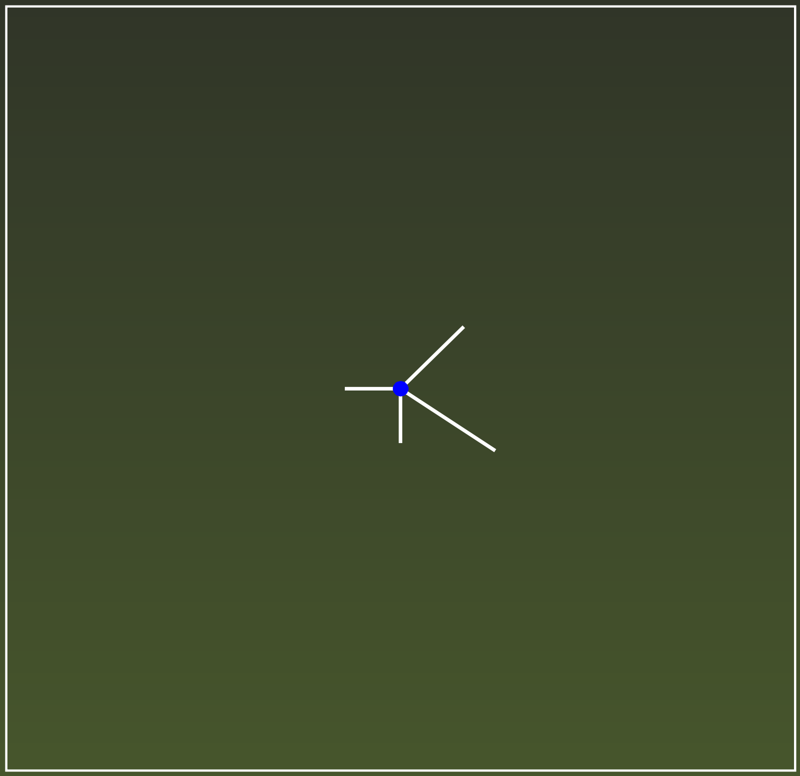
In eg, SPS1a, there are more $\tilde{\tau}$:s produced in $\tilde{\chi}_2^0\tilde{\chi}_2^0$ decays, than in direct $\tilde{\tau}$-pair production!

Reconstructing the sleptons



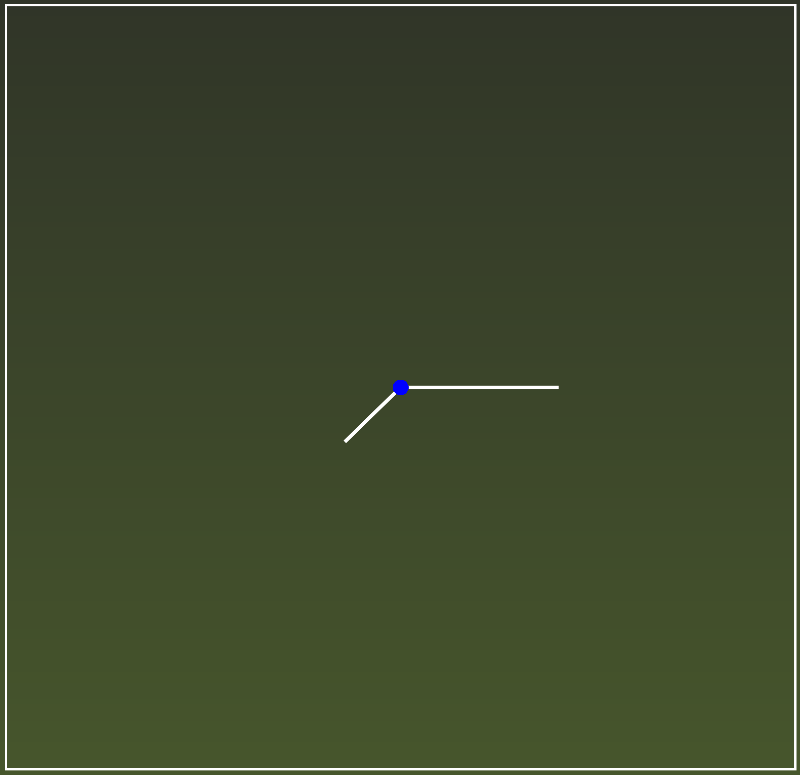
Schematic view of the event. It's the red particles we want to reconstruct.

Reconstructing the sleptons



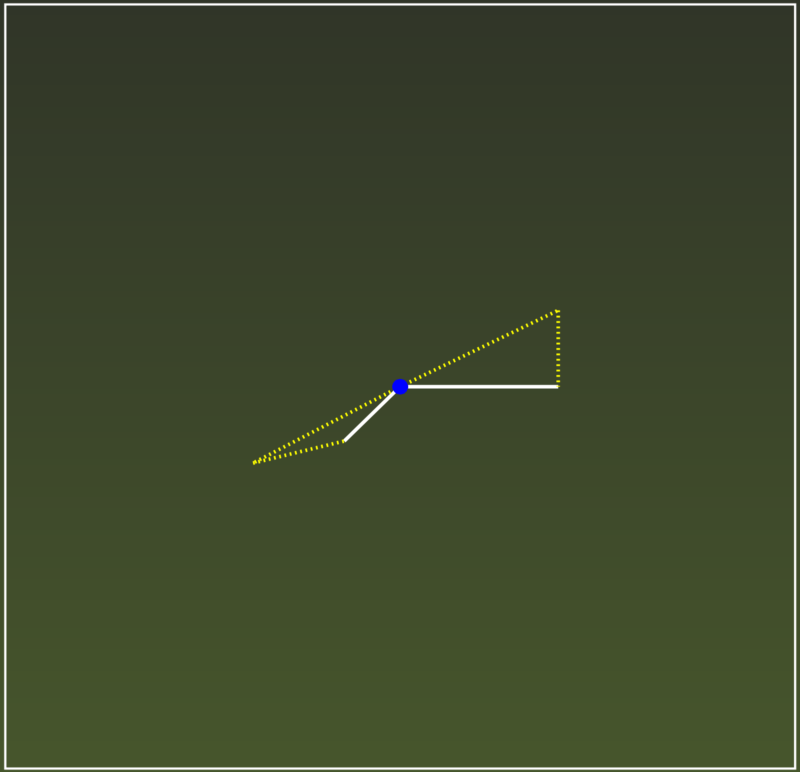
Actually, this is what the event looks like: Four leptons, missing energy and momentum, and nothing else.

Reconstructing the sleptons



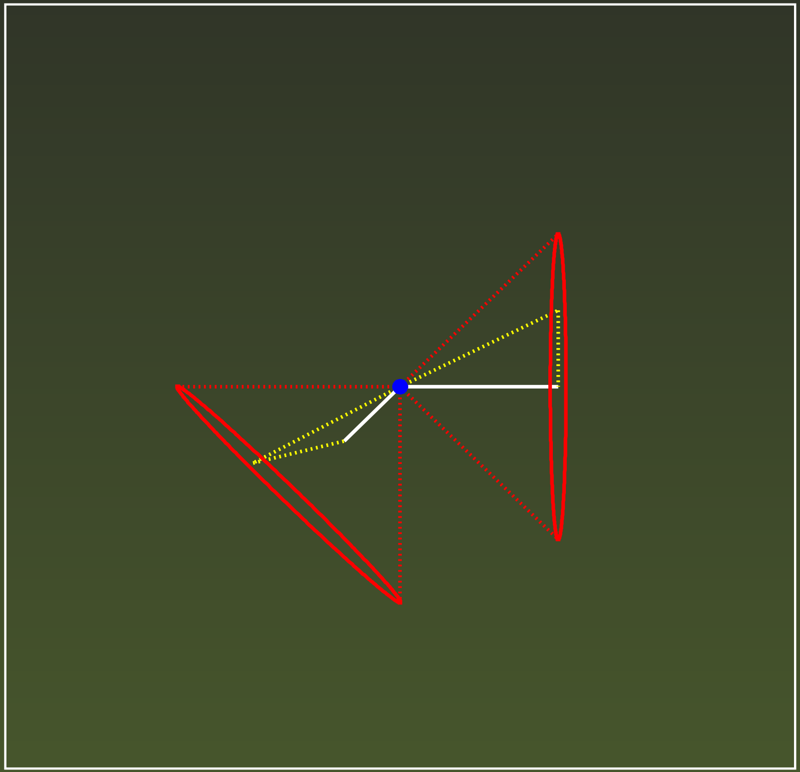
First, sum the opposite charged leptons.

Reconstructing the sleptons



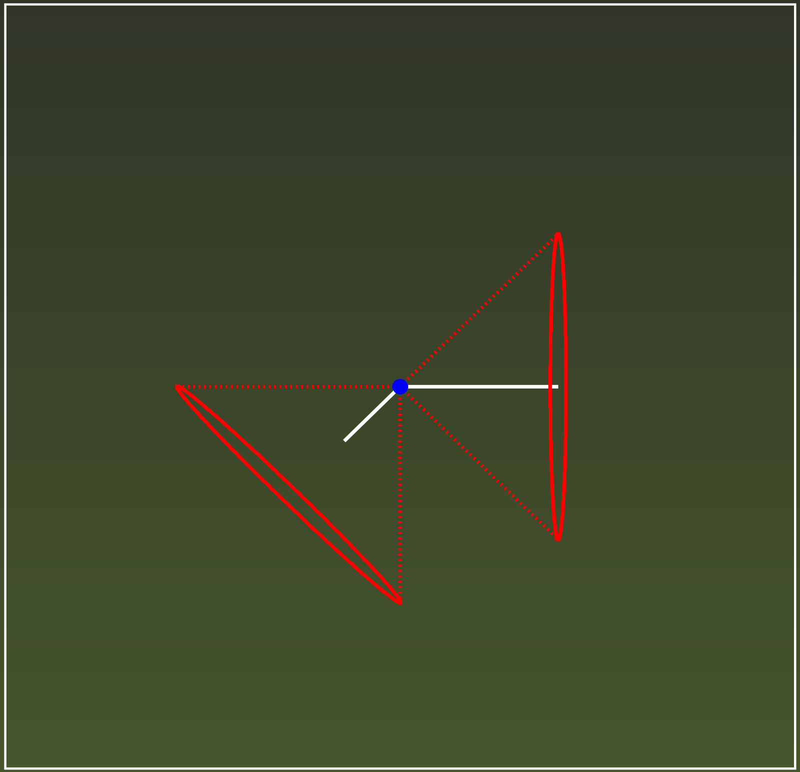
Because $M_{\tilde{\chi}_2^0}$ and $E_{be}{}^{am}$ are known, $|p_{\tilde{\chi}_2^0}|$ and $E_{\tilde{\chi}_2^0}$ are as well. $P_l{}^l$ is measured and $M_{\tilde{\chi}_1^0}$ is known, ie. also $|p_{\tilde{\chi}_1^0}|$ and $E_{\tilde{\chi}_1^0}$ are known.

Reconstructing the sleptons



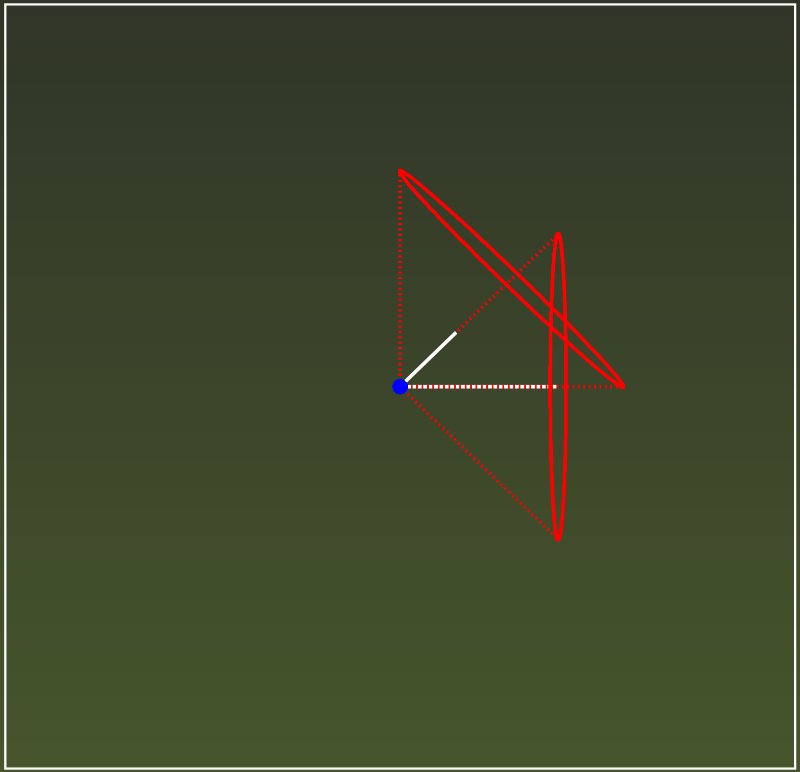
The azimuthal angle is not, so $\bar{p}_{\tilde{\chi}_2^0}$ is free to vary on cones around the lepton systems.

Reconstructing the sleptons



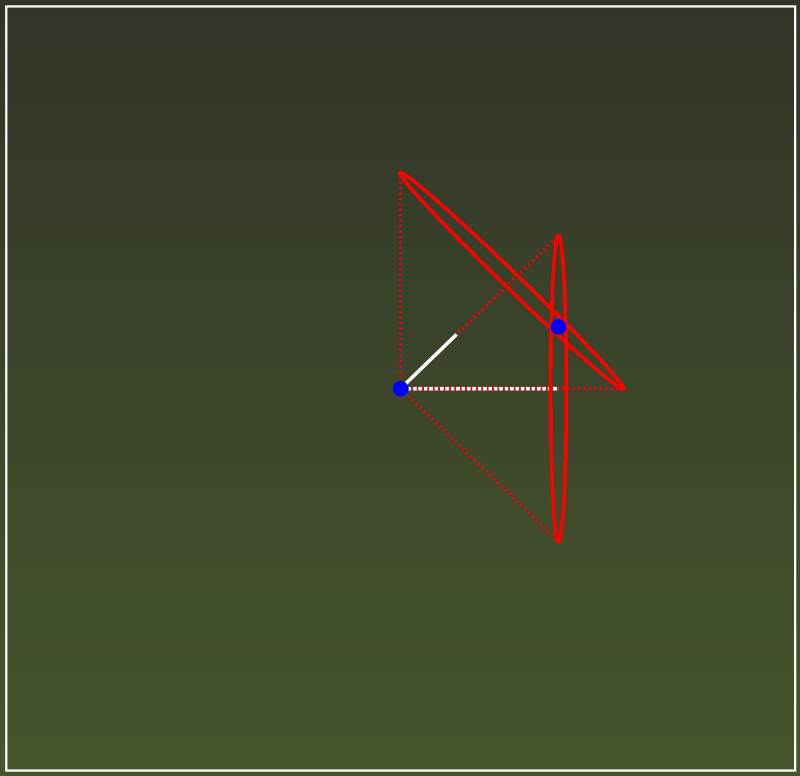
But: we do know the $\tilde{\chi}_2^0$:s are back-to-back.

Reconstructing the sleptons



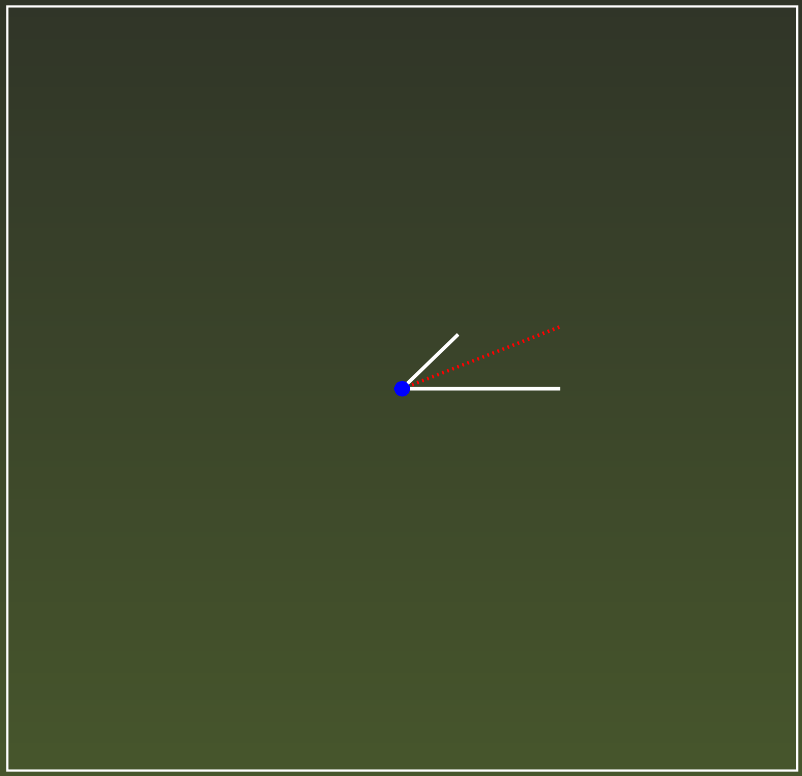
So, we flip one of the cones over...

Reconstructing the sleptons



... and find the intersection, to get $\bar{p}_{\tilde{\chi}_2^0}$.

Reconstructing the sleptons



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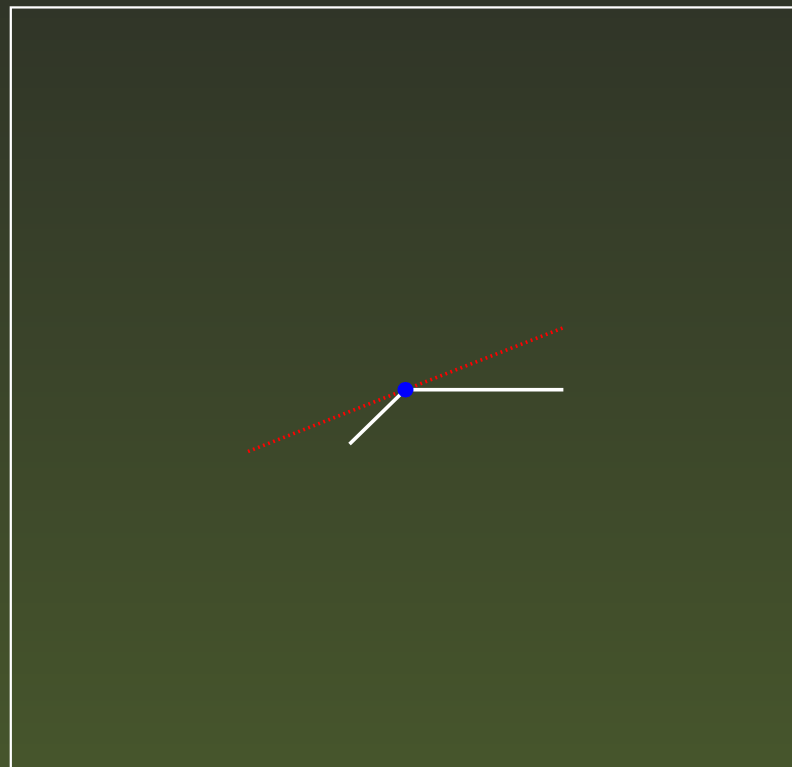
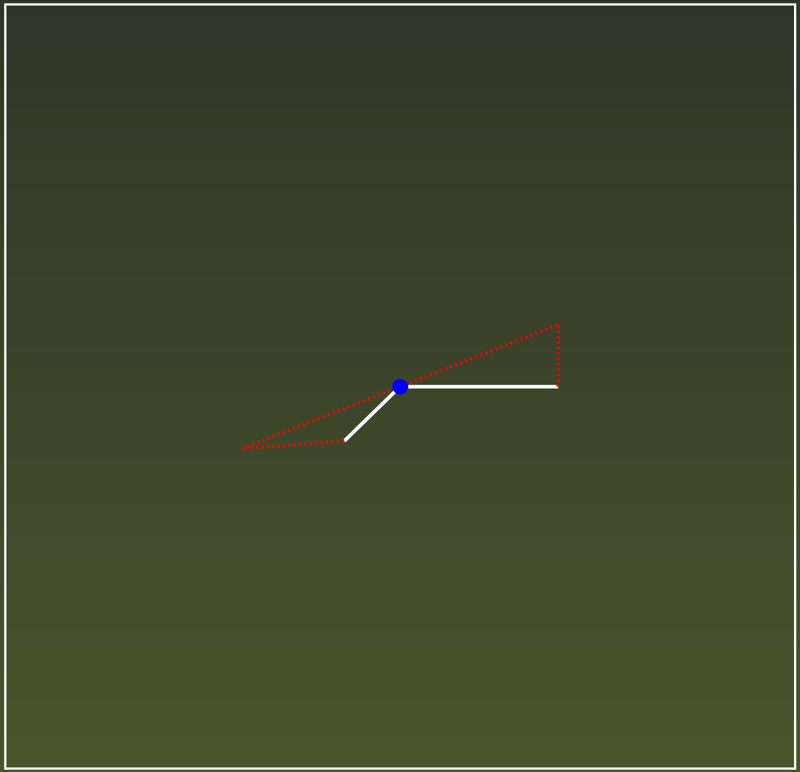


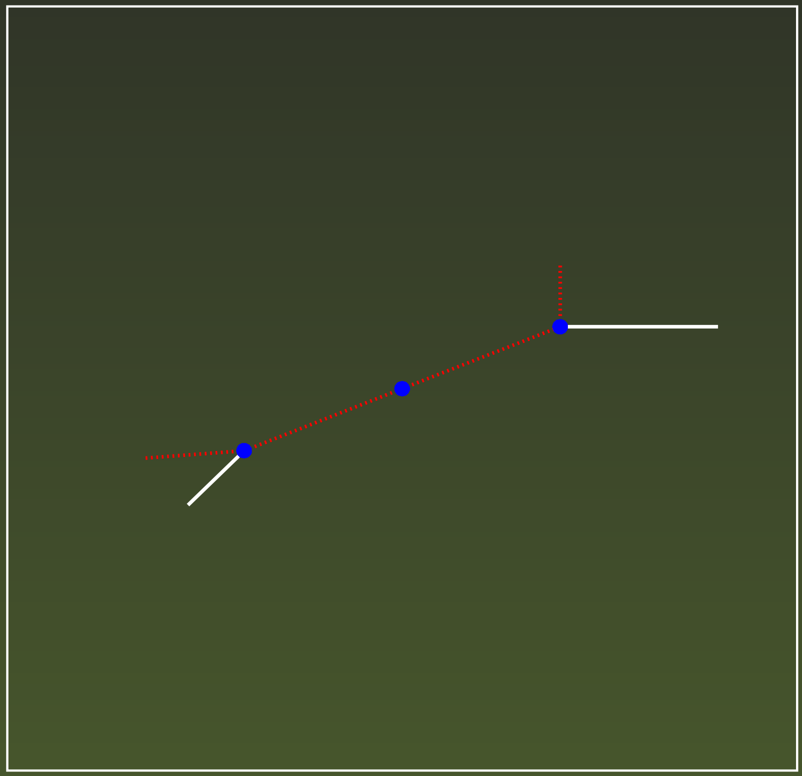
Flip back ...

Reconstructing the sleptons



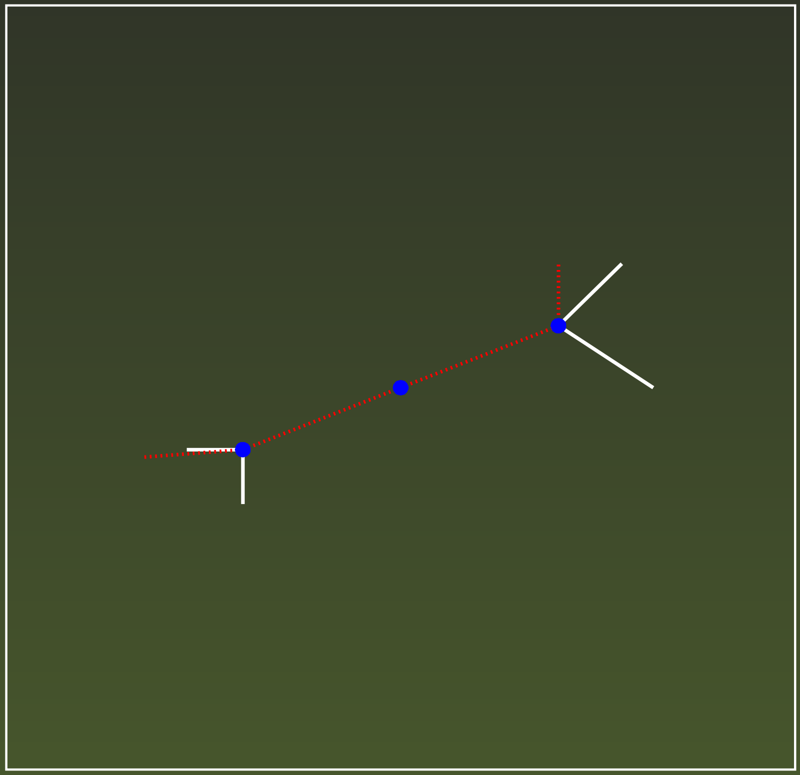
... and calculate $\bar{p}_{\tilde{\chi}_1^0}$.

Reconstructing the sleptons



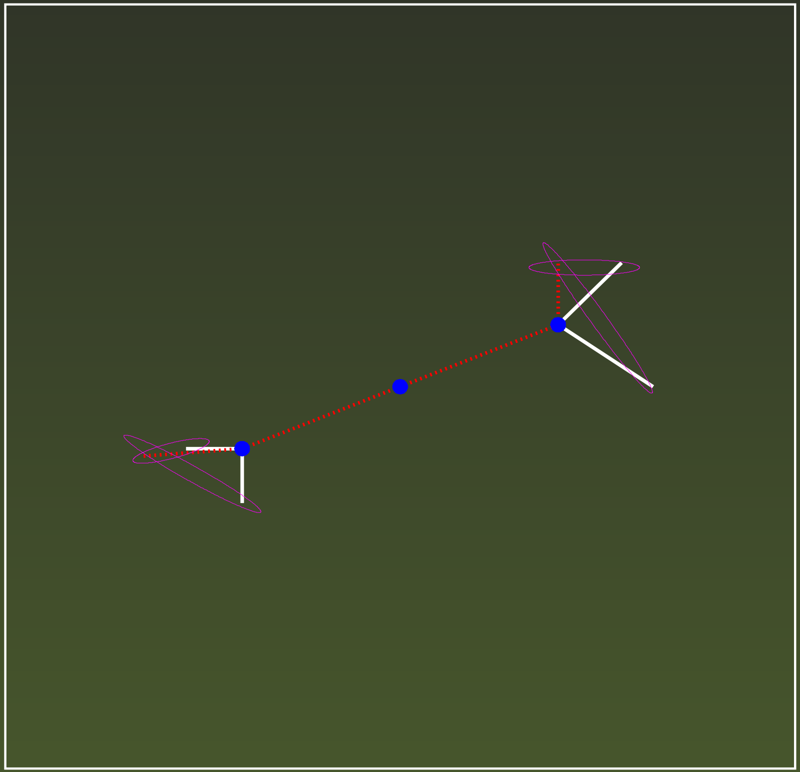
Translate the vectors ....

Reconstructing the sleptons



... and expand the lepton systems.

Reconstructing the sleptons



Finally: Add P_l to $P_{\tilde{\chi}_2^0}$ to get $P_{\tilde{\ell}}$.

Programs used

In the plots following, these programs have been used to generate signal and background, simulate the detector, and to analyse the generated sample.

SUSY spectrum: SUSPECT.

Generators: SUSYGEN 3.0 and PYTHIA 6.205

ISR: PHOTOS

Beam-strahlung: CIRCE

τ-decays: TAUOLA

Detector simulation: SGV 2.32β, which includes full covariance matrix, brems and γ-conversions, shower/track confusion.

Analysis: SGV native and TSTTAU (the DELPHI τ-finder for SUSY searches)

Reconstructing the sleptons

Problems:

Reconstructing the sleptons

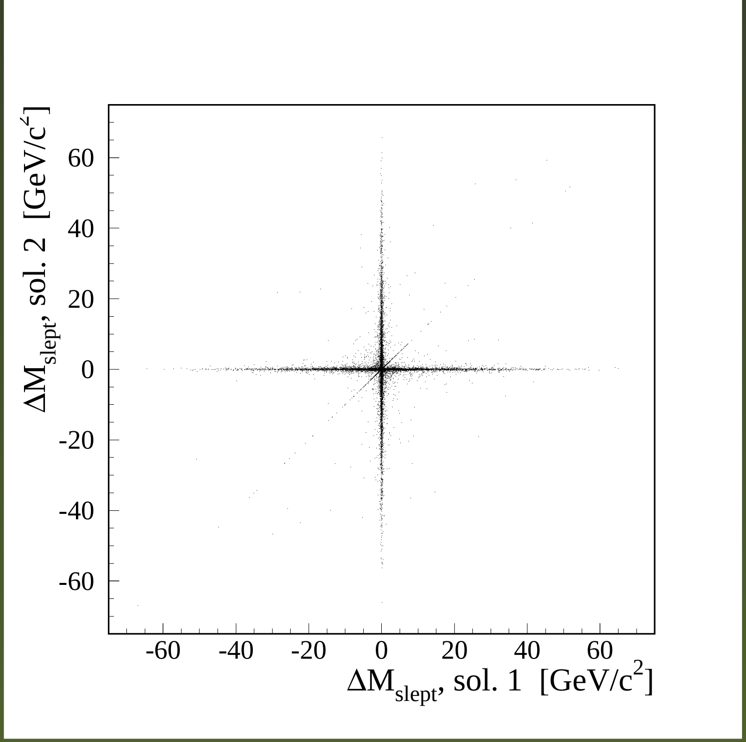
Problems:

- Two solutions

Reconstructing the sleptons

Problems:

- Two solutions ... but two sleptons
  $\rightarrow$ choose solution which gives
  the same result.



Reconstructing the sleptons

Problems:

- Two solutions ... but two sleptons
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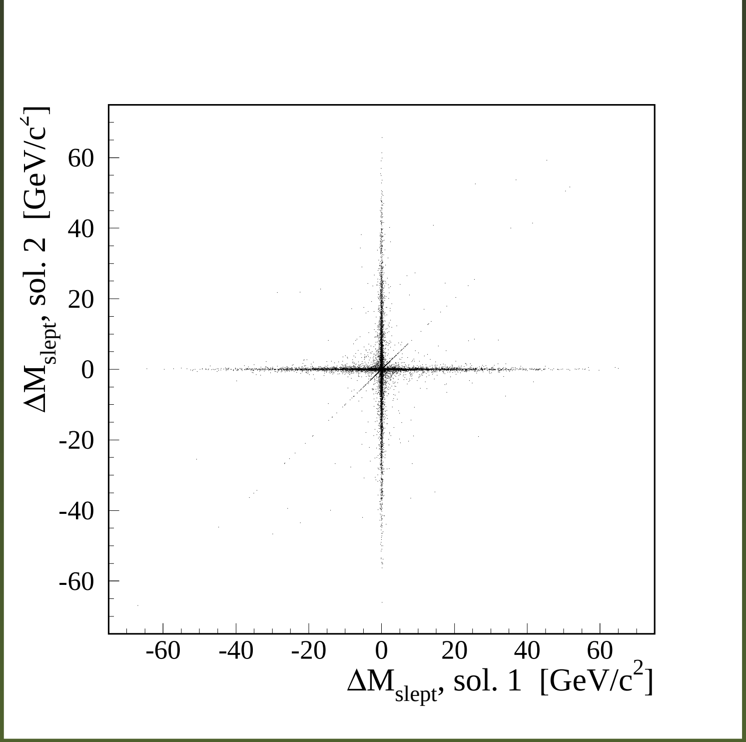
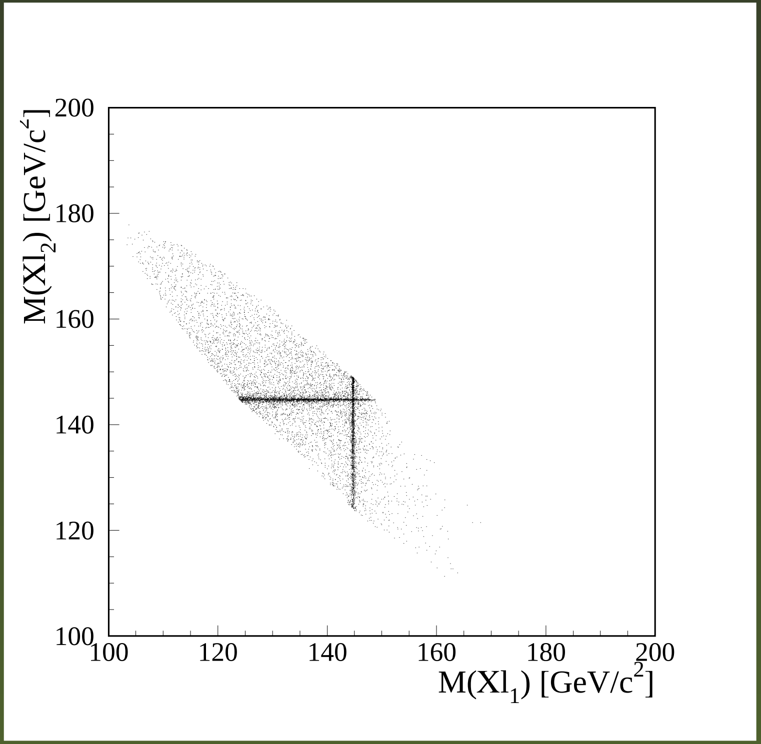
- Two leptons



Reconstructing the sleptons

Problems:

- Two solutions ... but two sleptons $\rightarrow$ choose solution which gives the same result.
- Two leptons ... but usually a ordering in momentum singles out the right one. Three-body decay $\rightarrow$ Dalitz plot. Expect bands for right choice, flat for wrong.



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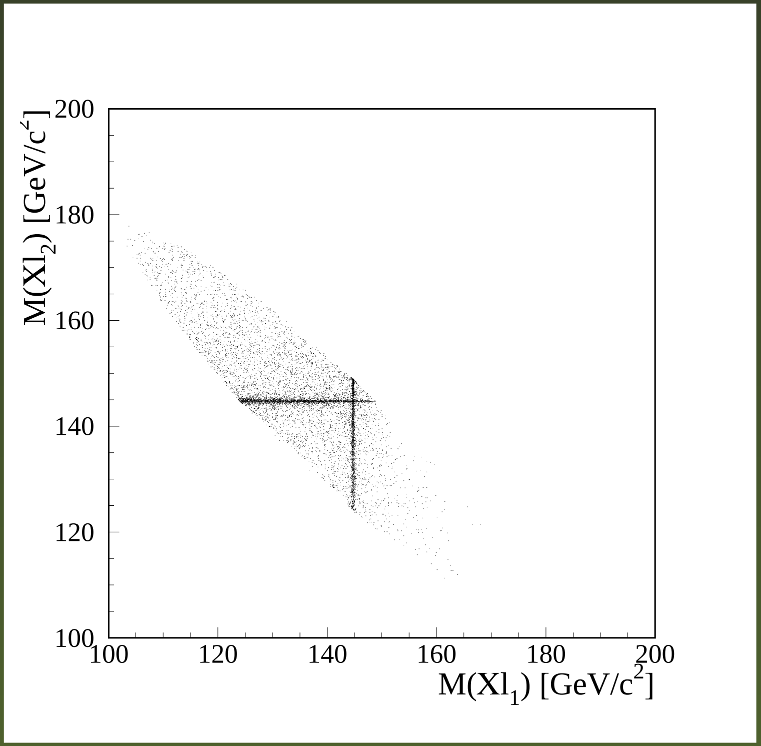
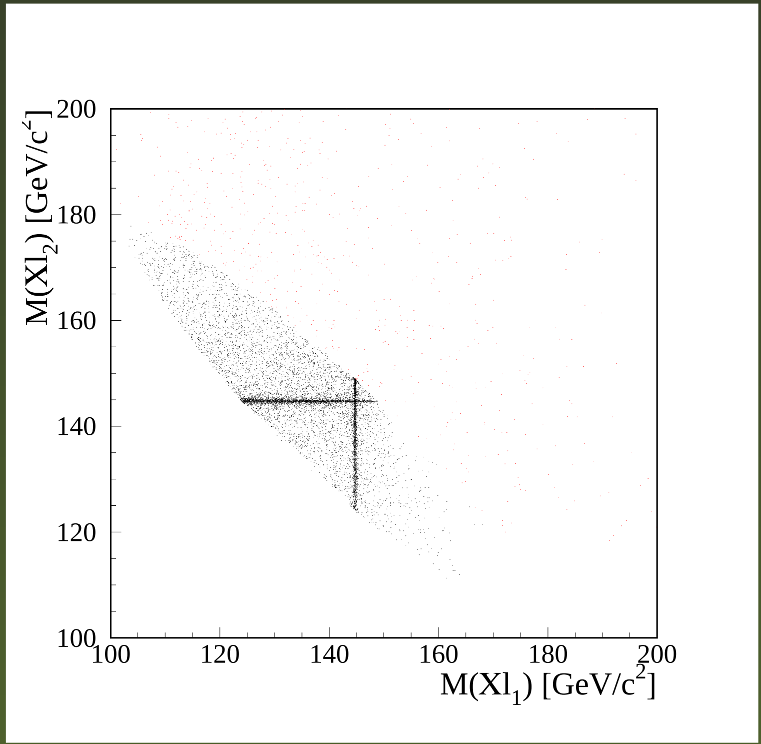
- Two leptons ... but usually a ordering in momentum singles out the right one. Three-body decay $\rightarrow$ Dalitz plot. Expect bands for right choice, flat for wrong.
- Two sides



Reconstructing the sleptons

Problems:

- Two solutions ... but two sleptons $\rightarrow$ choose solution which gives the same result.
- Two leptons ... but usually a ordering in momentum singles out the right one. Three-body decay $\rightarrow$ Dalitz plot. Expect bands for right choice, flat for wrong.
- Two sides ... no problem if one side has a $\tilde{\mu}$, the other a $\tilde{e}$. If all are the same: No reason that a combination with a lepton from the wrong $\tilde{\chi}_2^0$-decay should fall in the Dalitz-triangle.



Smuons and selectrons in SPS1a

In SPS1a:

- $M_{\tilde{\chi}_2^0}$ is 183 GeV/c^2
- $M_{\tilde{\mu}}$= $M_{\tilde{\mathrm{e}}}$= 144.73 GeV/c^2

SUSPECT gives

- $\sigma(\mathrm{e}^+\mathrm{e}^- \rightarrow \tilde{\chi}_2^0\tilde{\chi}_2^0)$ = 82 fb.
- $BR(\tilde{\chi}_2^0 \rightarrow \tilde{\ell}\ell)$= 14 % $(\tilde{\ell} \neq \tilde{\tau})$
- No other cascades open at 500 GeV

$\rightarrow$ 41000 $\tilde{\chi}_2^0\tilde{\chi}_2^0$ events for $\mathcal{L}$ = 500 fb^{-1}, 800 with both $\tilde{\chi}_2^0$ to $\tilde{\ell}\ell$.

The total SUSY cross-section is 2015 fb, ie. 1 007 500 events. This was the size of the sample generated

Smuons and selectrons in SPS1a

Select events by

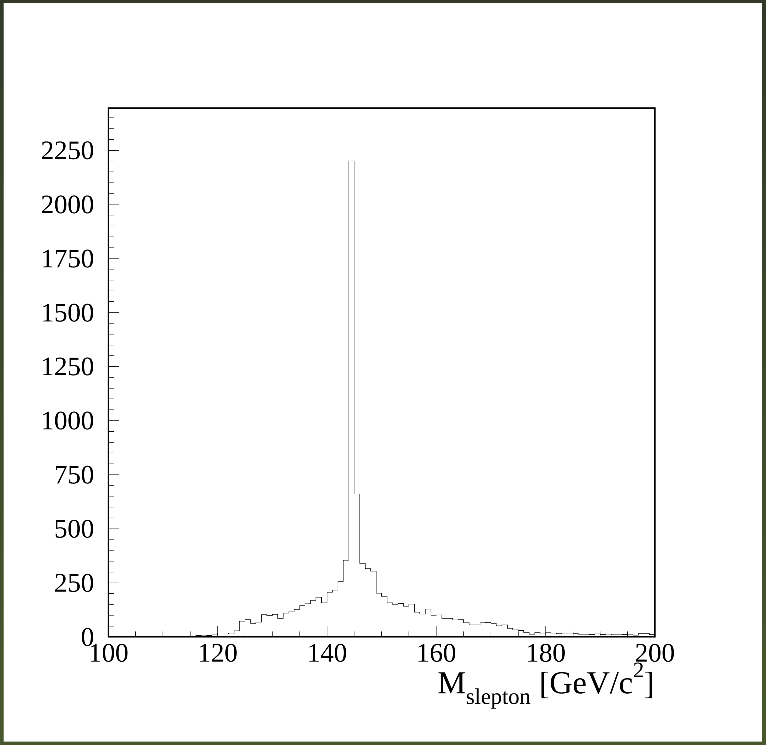
- Four charged leptons as only seen charged tracks.
- $\not{p}_t > 10\ \mathrm{GeV}/c$
- Visible mass between 100 and 300 GeV/c^2.
- Seen energy $< 300\ \mathrm{GeV}$.
- Seen neutral energy $< 150\ \mathrm{GeV}$.
- Thrust axis above 0.3 Rad.
- Calorimetric energy below 30$\mathrm{deg} < 150\ \mathrm{GeV}$.

$\approx$ NO Standard Model background !

Smuons and selectrons in SPS1a

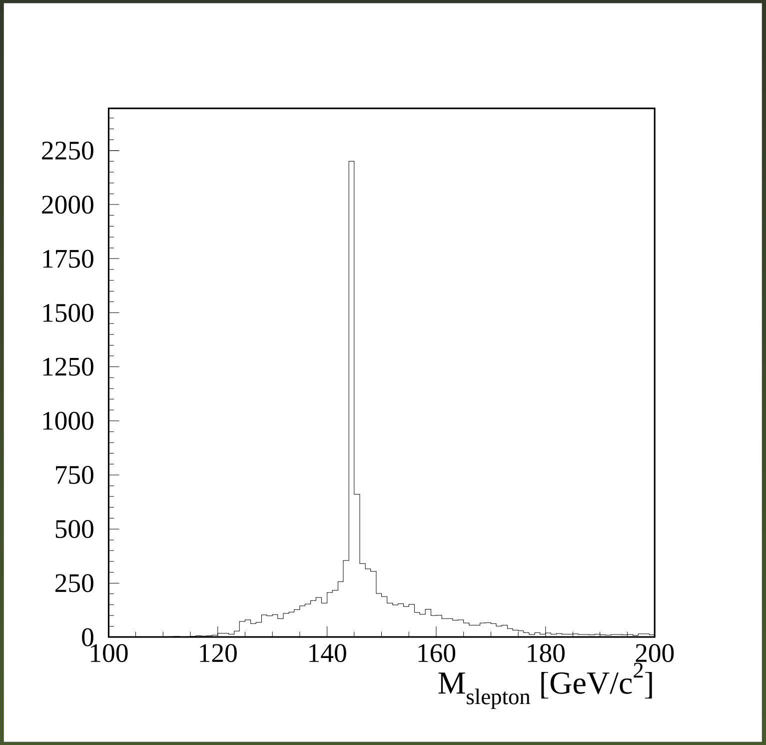
Smuons and selectrons in SPS1a

- Reconstruct events. 8 solutions...



Smuons and selectrons in SPS1a

- Reconstruct events. 8 solutions...
- Select only events in the Dalitz-triangle and ...



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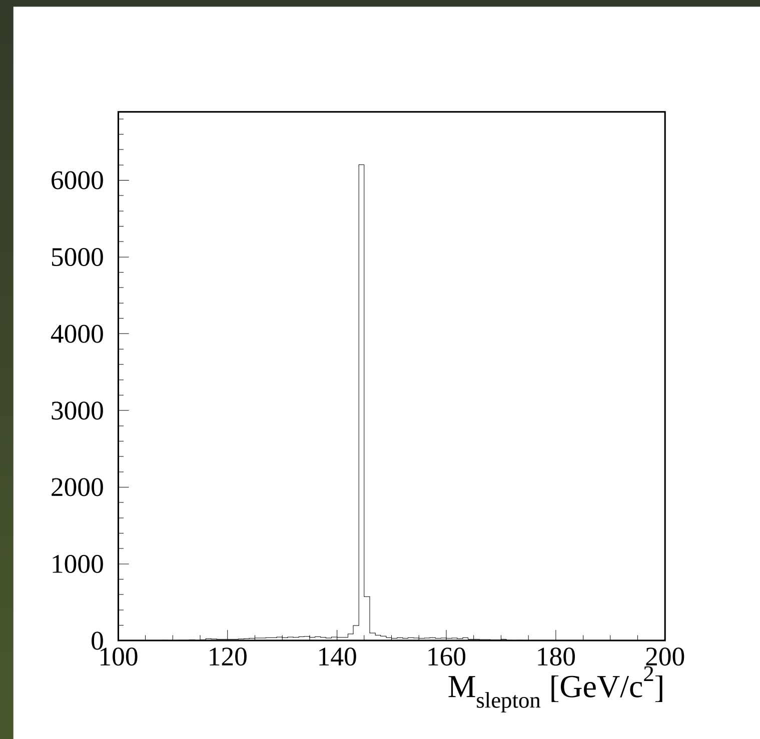
- Plot the average of the two closest slepton-masses.



Smuons and selectrons in SPS1a

- Reconstruct events. 8 solutions...
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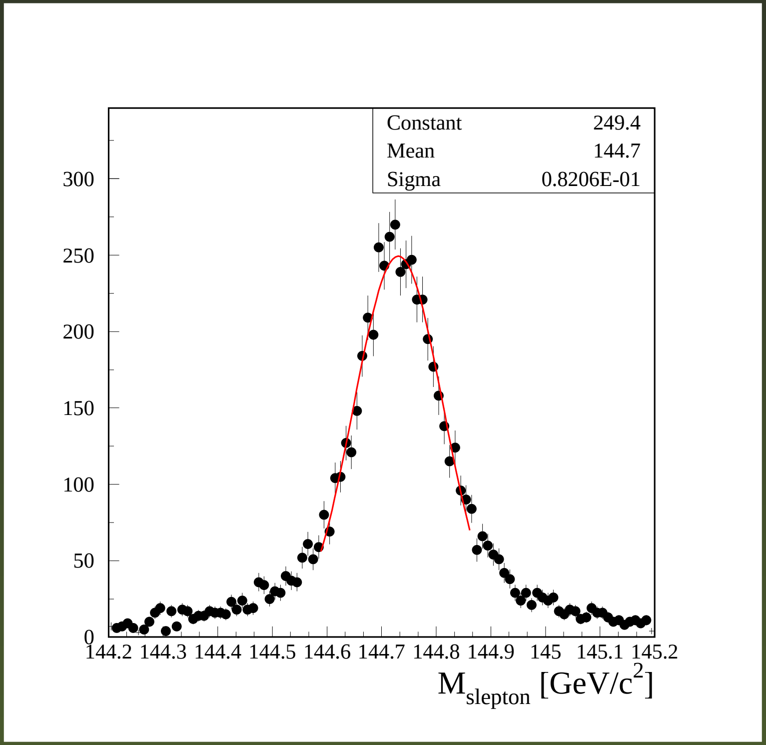
$\sigma = 82 \text{ MeV}/c^2$

Efficiency = 33 %.



Background, ISR, beam-strahlung, sensitivity to input assumptions

One might suspect that a number of things might cause problems:

- Beam-strahlung
- ISR
- Input assumptions on $M_{\tilde{\chi}_i^0}$
- Background

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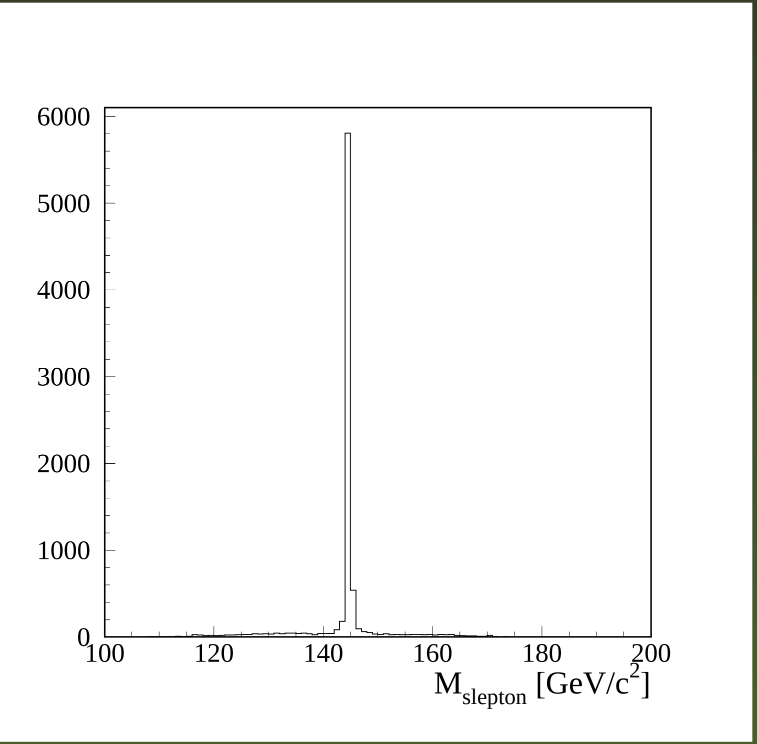

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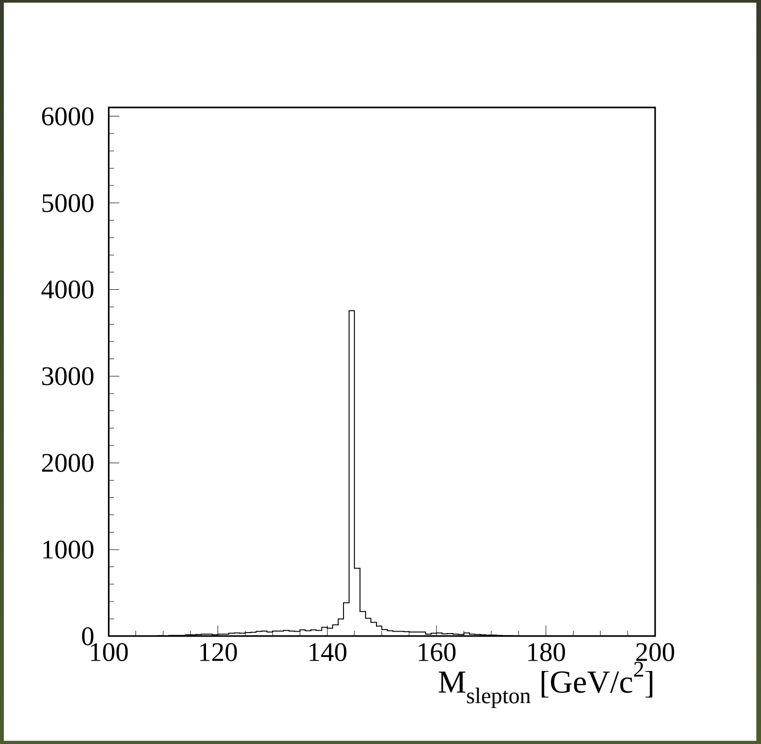

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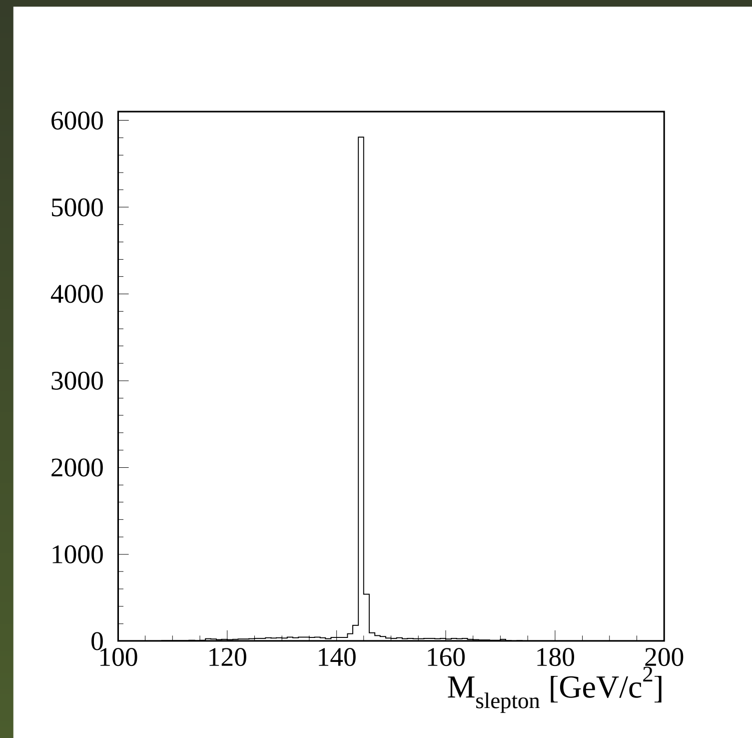

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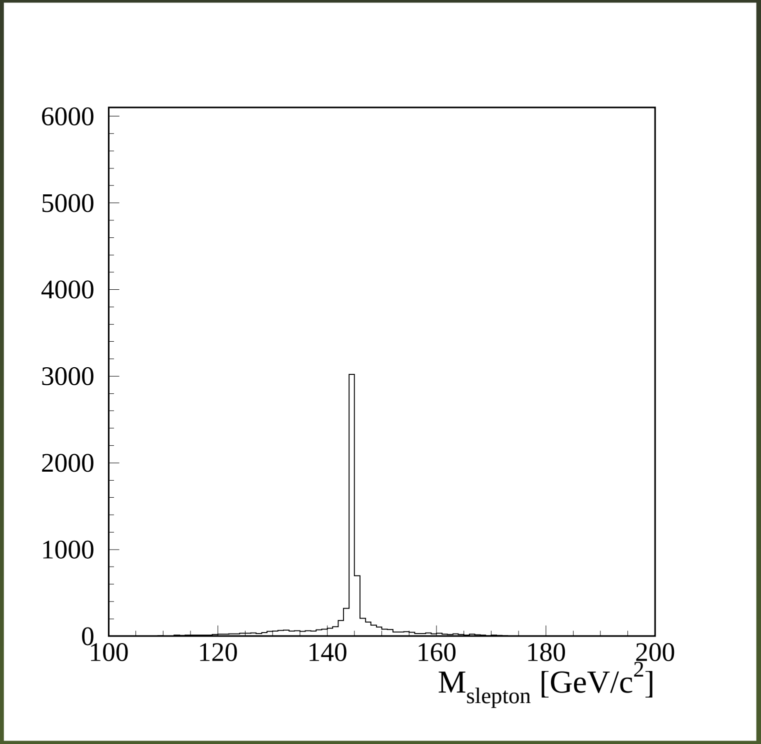

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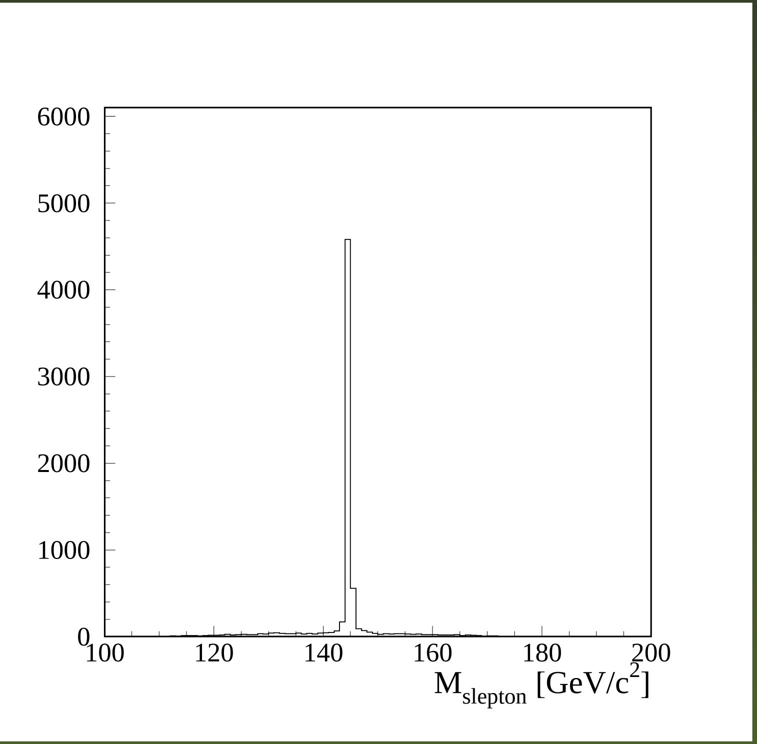

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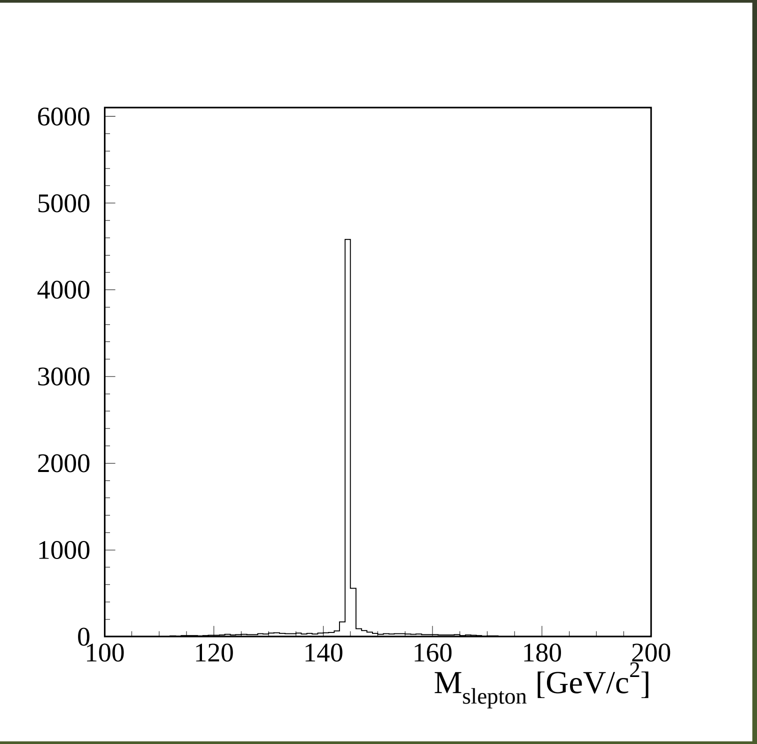

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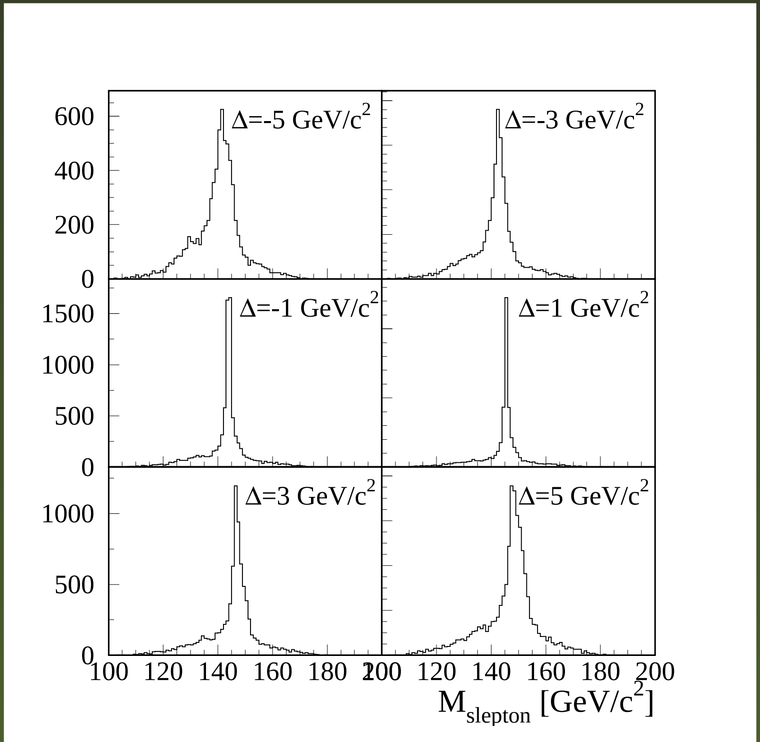

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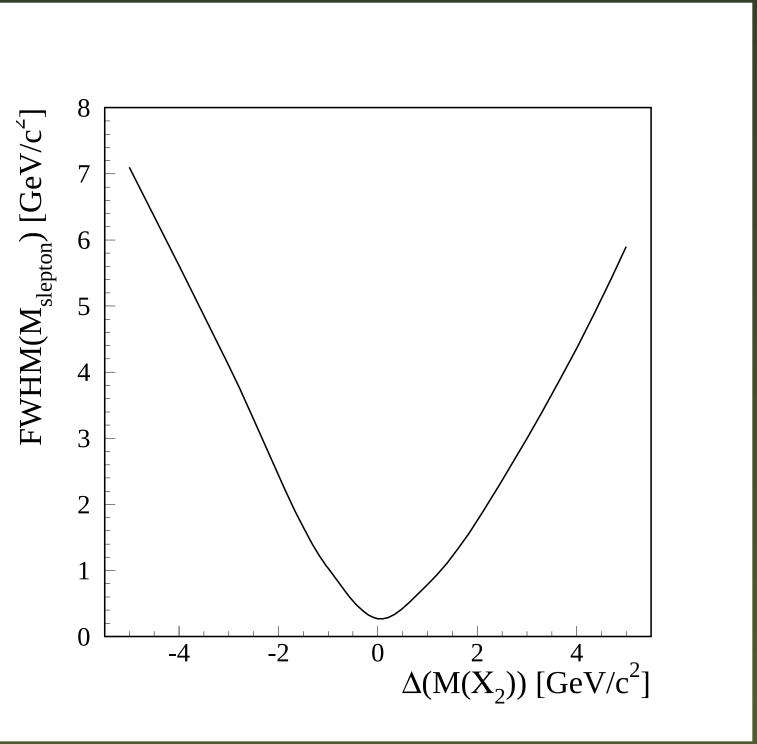

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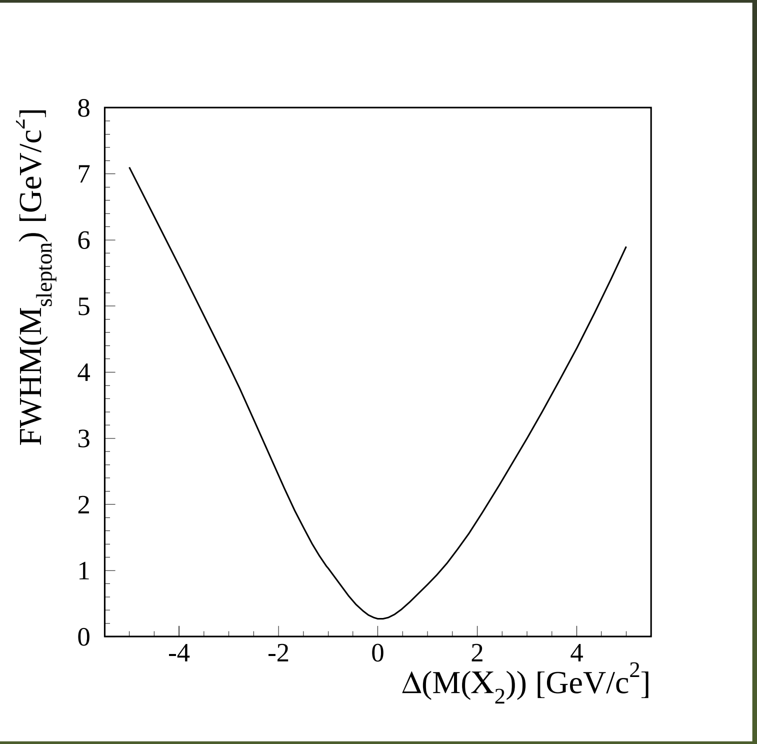

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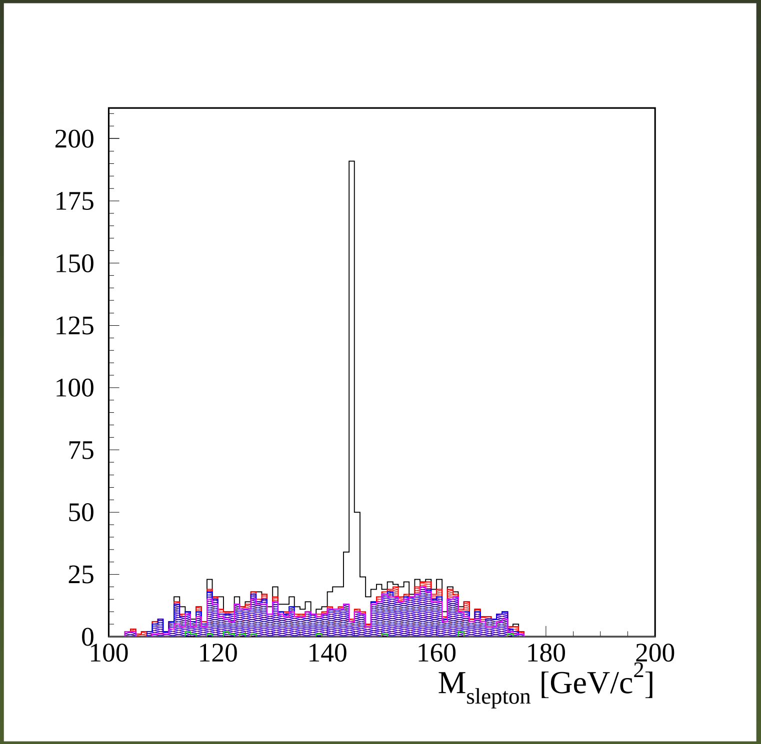

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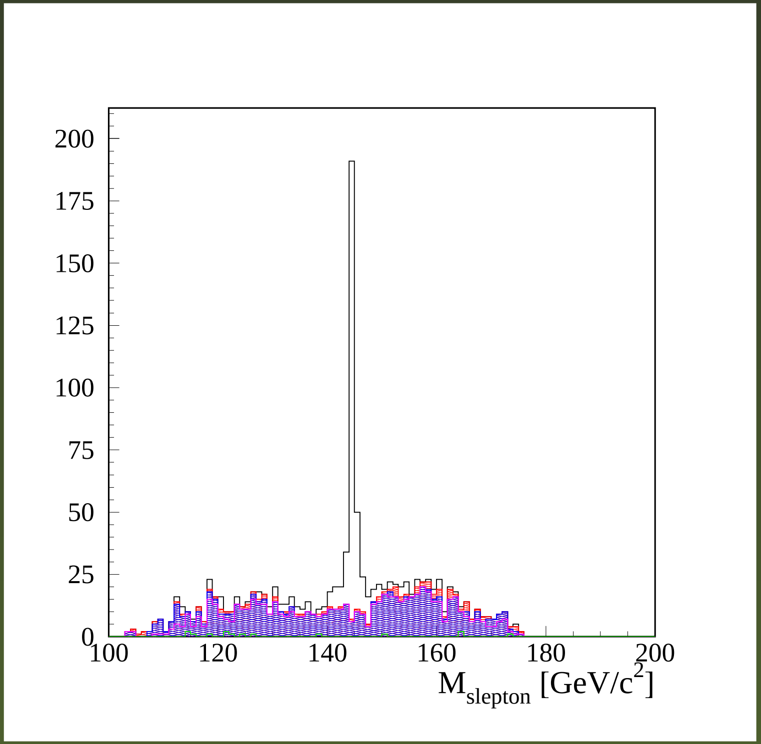
- Input assumptions on $M_{\tilde{\chi}^0_i}$ NO
- Background NO

The main background is $\tilde{\mathrm{e}}_\mathrm{L}\tilde{\mathrm{e}}_\mathrm{R}$, with $\tilde{\mathrm{e}}_\mathrm{L} \rightarrow \tilde{\chi}^0_2 e \rightarrow \tilde{\ell}\,\ell$.



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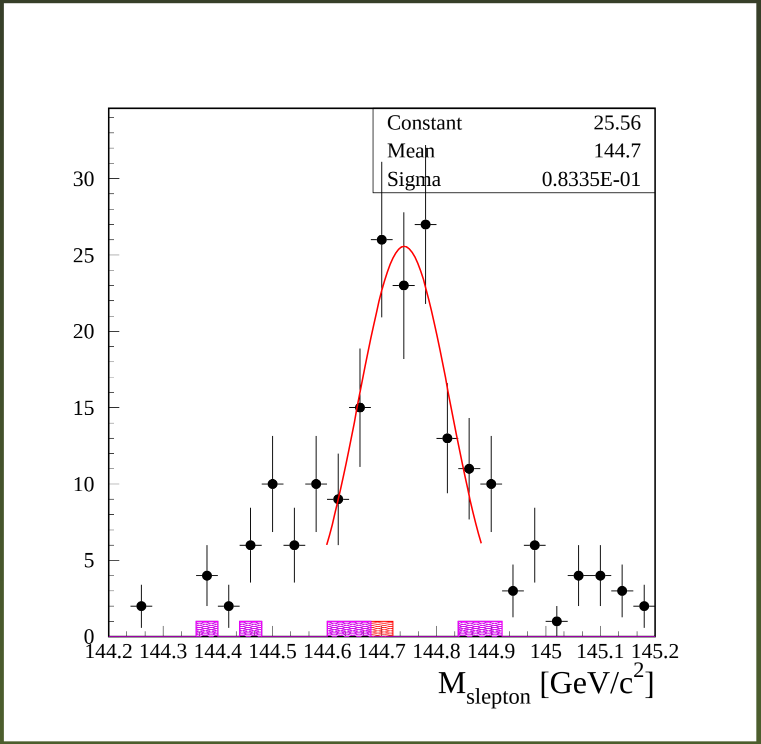
The main background is $\tilde{\mathrm{e}}_\mathrm{L}\tilde{\mathrm{e}}_\mathrm{R}$, with $\tilde{\mathrm{e}}_\mathrm{L} \rightarrow \tilde{\chi}_2^0 e \rightarrow \tilde{\ell}\,\ell$.

$\sigma = 83\ \mathrm{MeV}/c^2$

90 events in the peak (11 % efficiency).

$\rightarrow \delta(M_{\tilde{\ell}}) = \frac{\sigma}{\sqrt{N}} = 8.7\ \mathrm{MeV}/c^2$.

Fitted mass = $174.74\ \mathrm{GeV}/c^2$ (input was $174.73\ \mathrm{GeV}/c^2$).



SPS3 : More than one cascade

In SPS 3

- $M_{\tilde{\chi}_2^0}$ is 308 GeV$/c^2$
- $M_{\tilde{\mu}\,L} = M_{\tilde{\mathrm{e}}\,L}$ = 289.96 GeV$/c^2$
- $M_{\tilde{\mu}\,R} = M_{\tilde{\mathrm{e}}\,R}$ = 181.83 GeV$/c^2$

SUSPECT gives

- $\sigma(\,\mathrm{e}^+\mathrm{e}^- \rightarrow \tilde{\chi}_2^0\tilde{\chi}_2^0)$ = 21 fb.
- $BR(\tilde{\chi}_2^0 \rightarrow \tilde{\ell}_L\ell)$= 16 % $(\tilde{\ell} \neq \tilde{\tau})$
- $BR(\tilde{\chi}_2^0 \rightarrow \tilde{\ell}_R\ell)$= 2 % $(\tilde{\ell} \neq \tilde{\tau})$
- No other cascades open at 800 GeV

$\rightarrow$ 10500 $\tilde{\chi}_2^0\tilde{\chi}_2^0$ events for $\mathcal{L}$ = 500 fb^{-1}, 340 with both $\tilde{\chi}_2^0$ to $\tilde{\ell}\;\ell$.

The total SUSY cross-section is 593 fb, ie. 269 500 events, which was generated.

SPS3 : More than one cascade

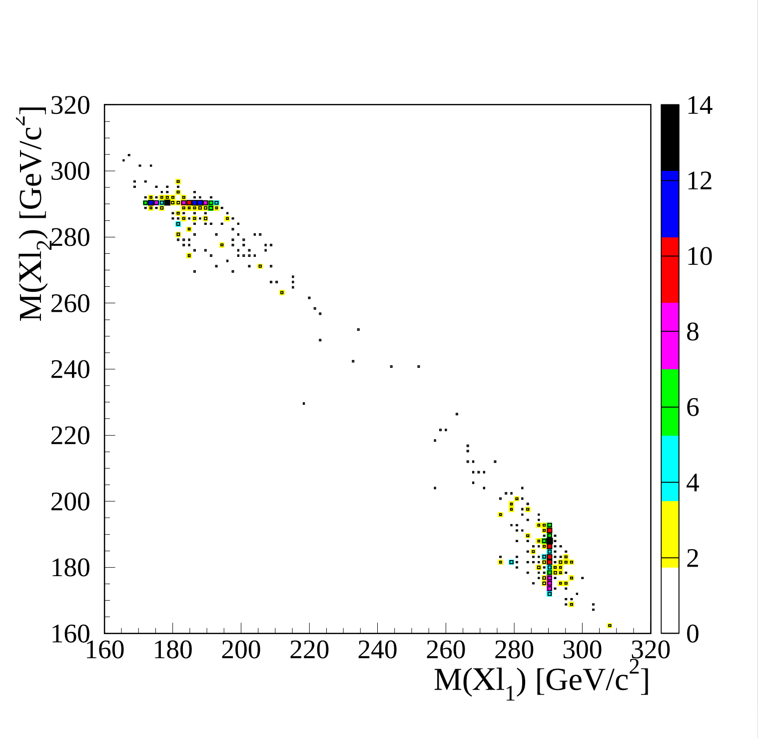
- Selection: as SPS1a, with rescaling for the higher machine energy

SPS3 : More than one cascade

- Selection: as SPS1a, with rescaling for the higher machine energy
- Reconstruct events.

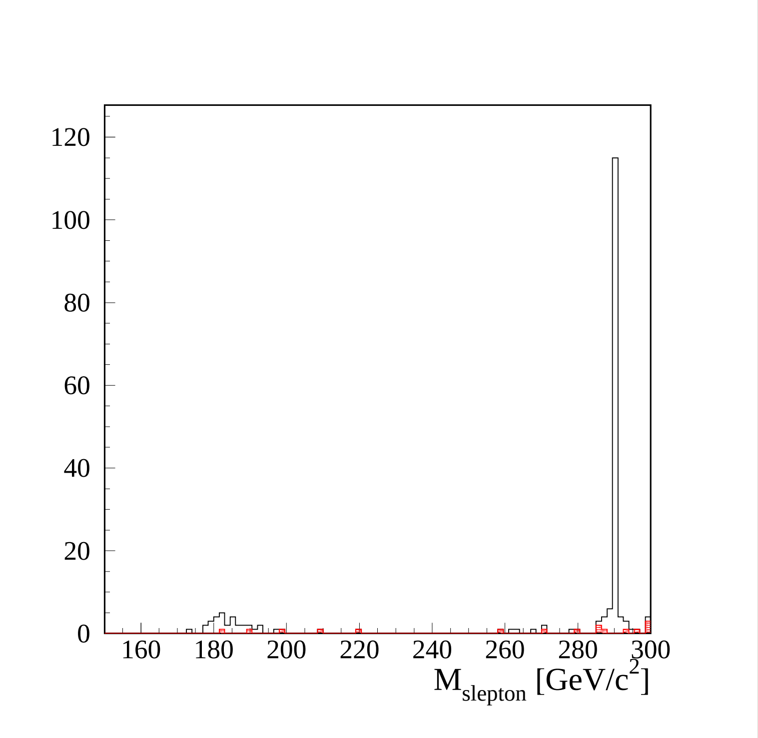
SPS3 : More than one cascade

- Selection: as SPS1a, with rescaling for the higher machine energy
- Reconstruct events.
- Select only events in the Dalitz-triangle. Note overlap: the right pairing in one case ≈ the wrong pairing in the *other* case.



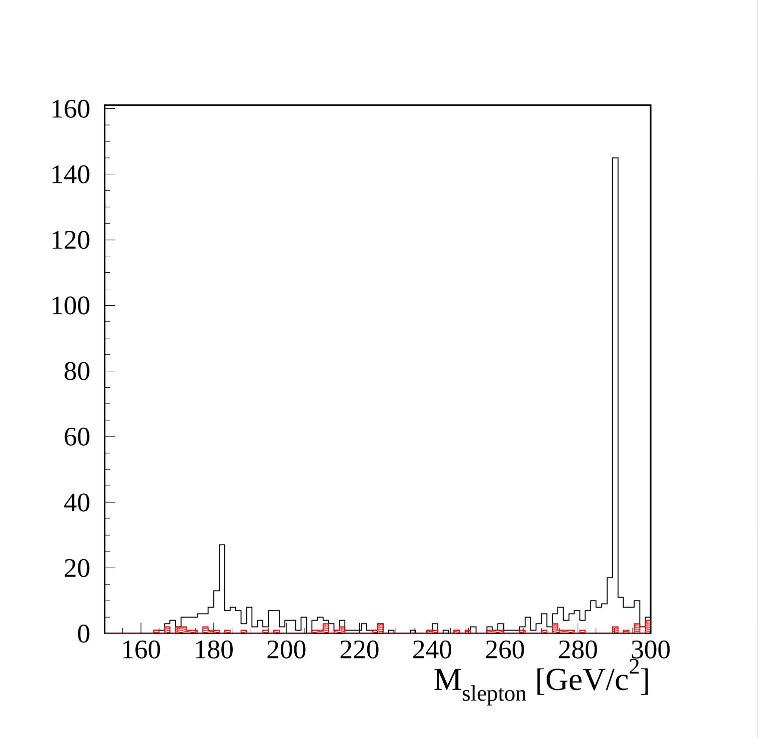
SPS3 : More than one cascade

- The average of the two closest masses gives a peak for the one with the larger BR - $\tilde{\ell}_L$ - but not for the other: it is hidden in wrong-pairing blob from the $\tilde{\ell}_L$.



SPS3 : More than one cascade

- The average of the two closest masses gives a peak for the one with the larger BR - $\tilde{\ell}_L$ - but not for the other: it is hidden in wrong-pairing blob from the $\tilde{\ell}_L$.
- Plot one pairing, cut out events where the *other* pairing is close to $M_{\tilde{\ell}_L}$, find the peak, and adjust the cut.



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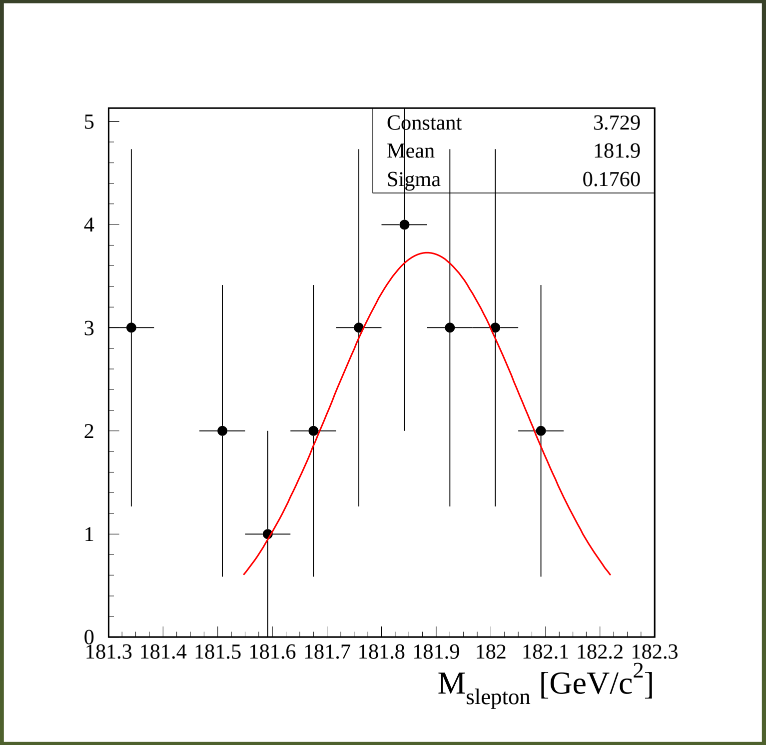
- Plot one pairing, cut out events where the *other* pairing is close to $M_{\tilde{\ell}_L}$, find the peak, and adjust the cut.
- Zoom in



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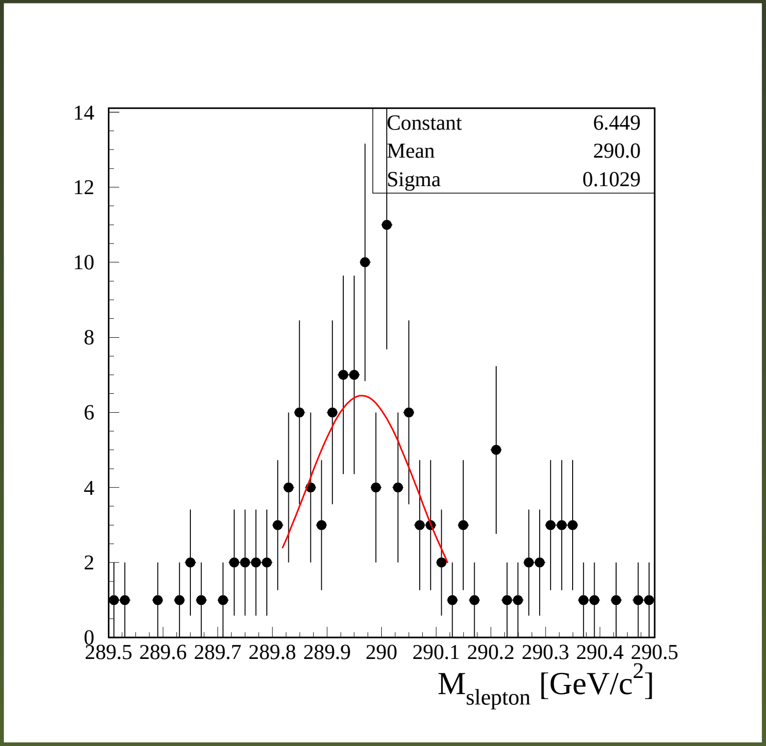
- Plot one pairing, cut out events where the *other* pairing is close to $M_{\tilde{\ell}_L}$, find the peak, and adjust the cut.
- Zoom in



$\sigma_{L(R)} = 103$ (176)MeV$/c^2$
50 (18) events in the peak
$\rightarrow \delta(M_{\tilde{\ell}LR}) = 14.5$ (41.5) MeV$/c^2$.
Fitted mass = 290.0 (181.9) GeV$/c^2$ (input was 289.96 (181.83)GeV$/c^2$).

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- Constrain the non-$\tilde{\tau}$ decay to give the right $M_{\tilde{\mu}}$(or $M_{\tilde{\mathrm{e}}}$) $\to$ 1 unknown!

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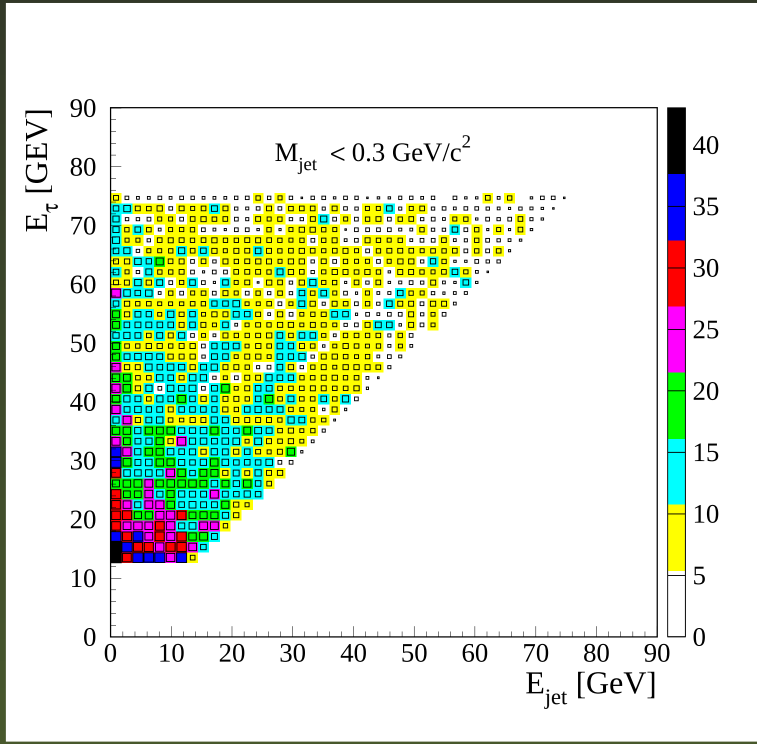

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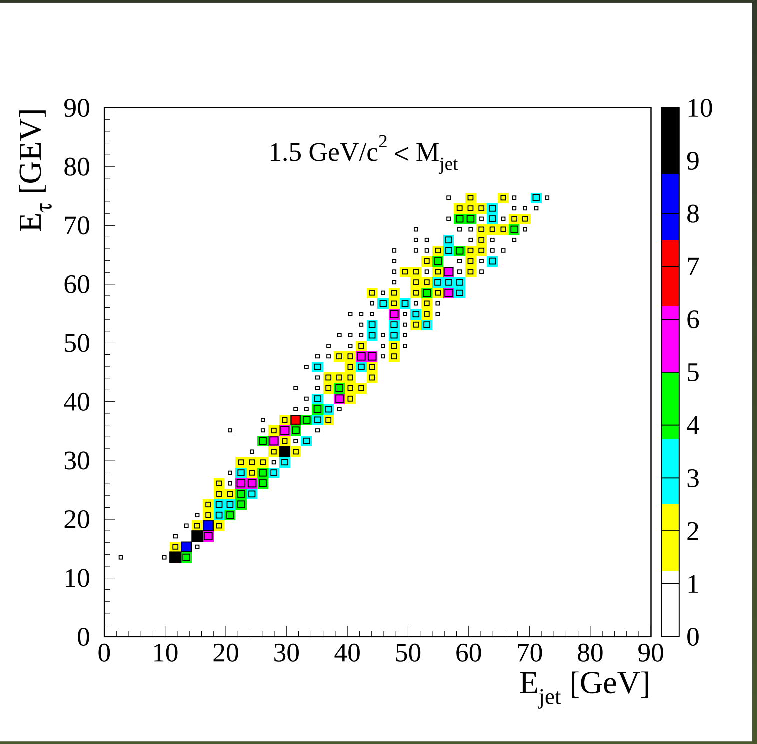

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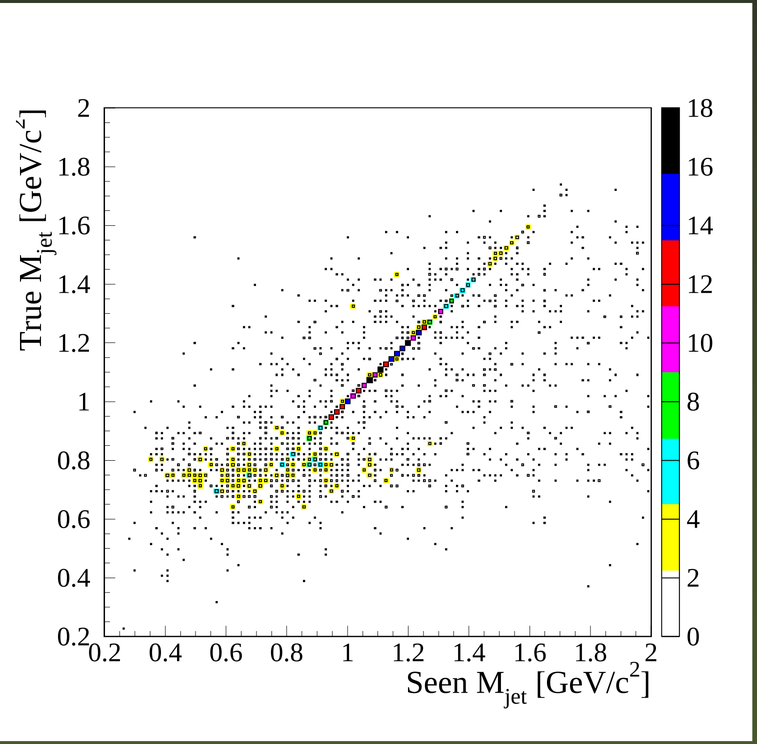

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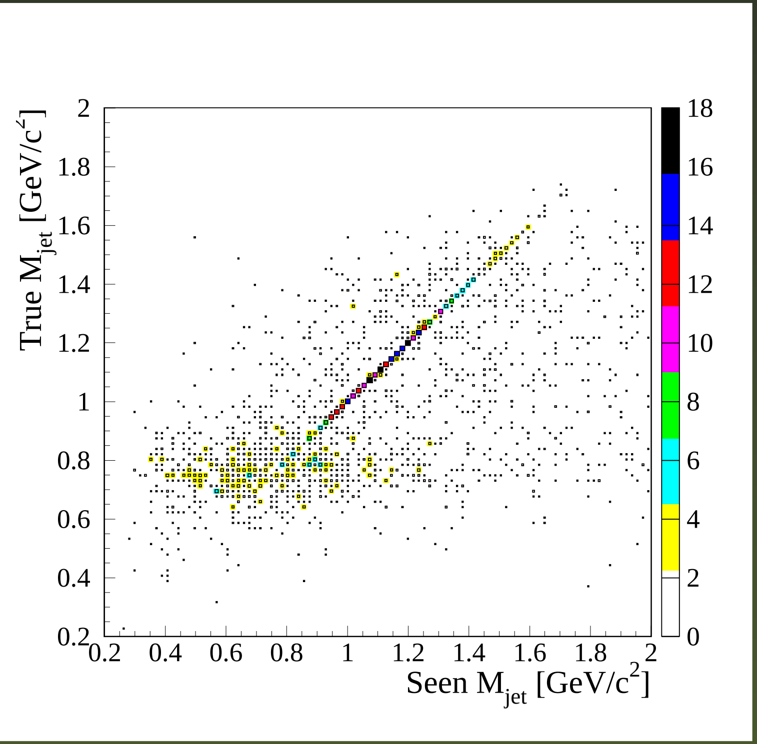
- Verify the angles, the quality of the guess *a posteriori*.



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Same cuts as for $\tilde{\mathrm{e}}$ and $\tilde{\mu}$ except that four τ:s (DELPHI τ-algorithm), rather than four light leptons was requested.

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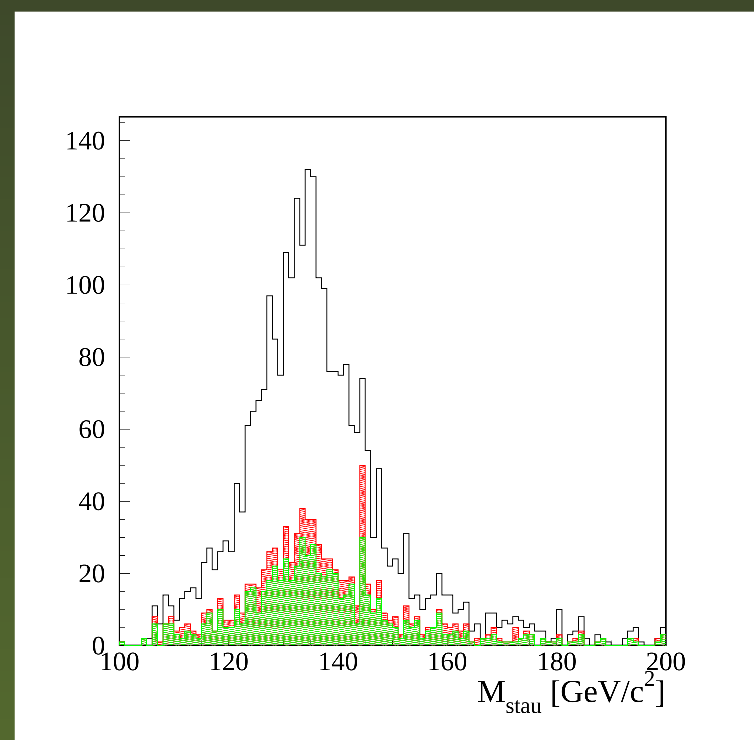

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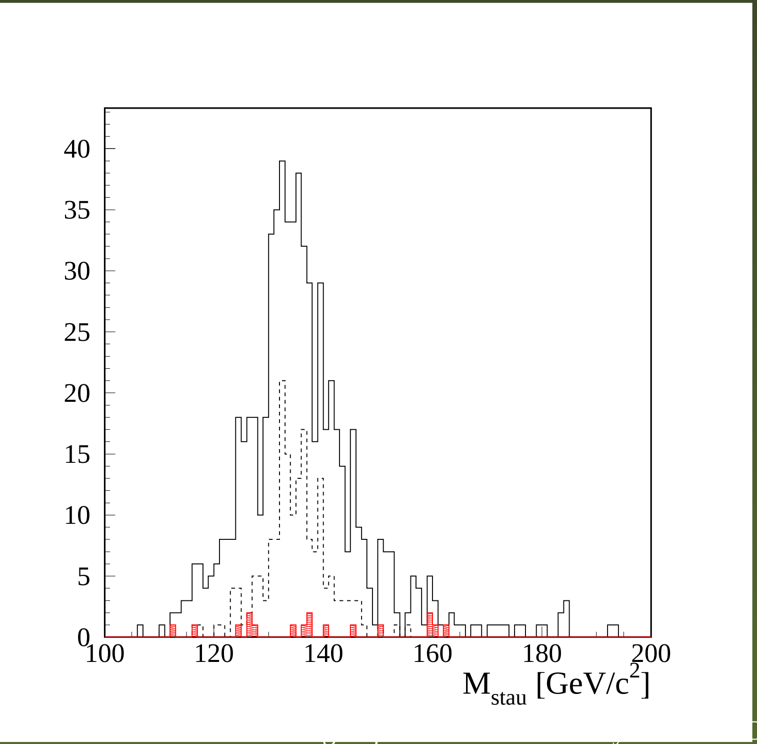

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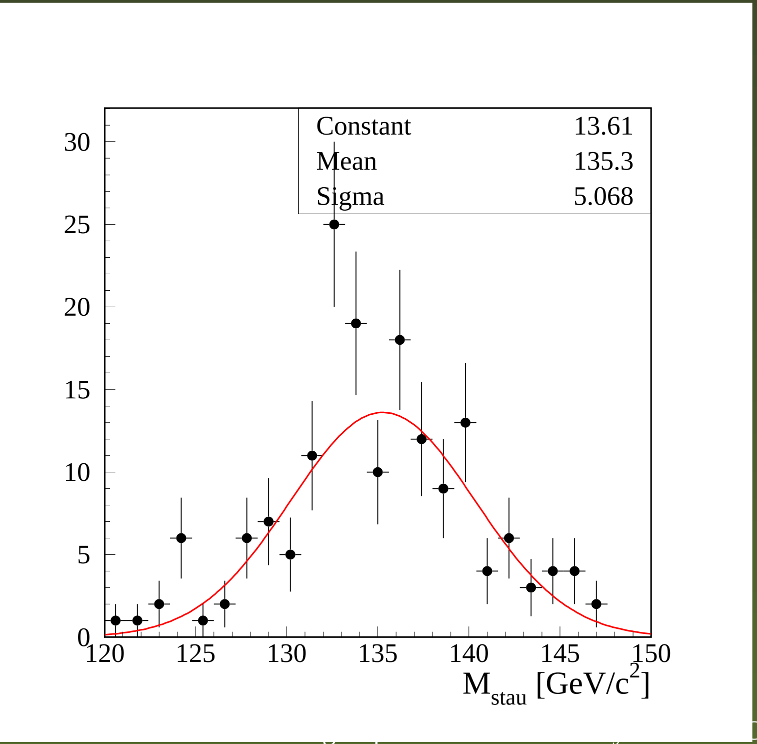

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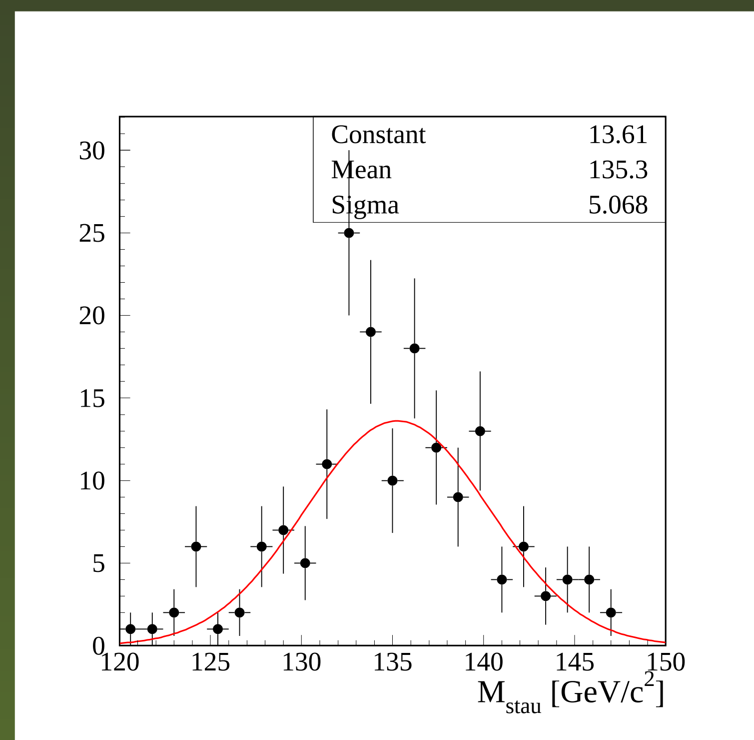
σ = 5.07 GeV$/c^2$

176 events in the peak (7 % efficiency).

$\to \delta(M_{\tilde{\tau}}) = \frac{\sigma}{\sqrt{N}} =$ 380 MeV$/c^2$.

Fitted mass = 135.3 GeV$/c^2$ (input was 135.4 GeV$/c^2$).



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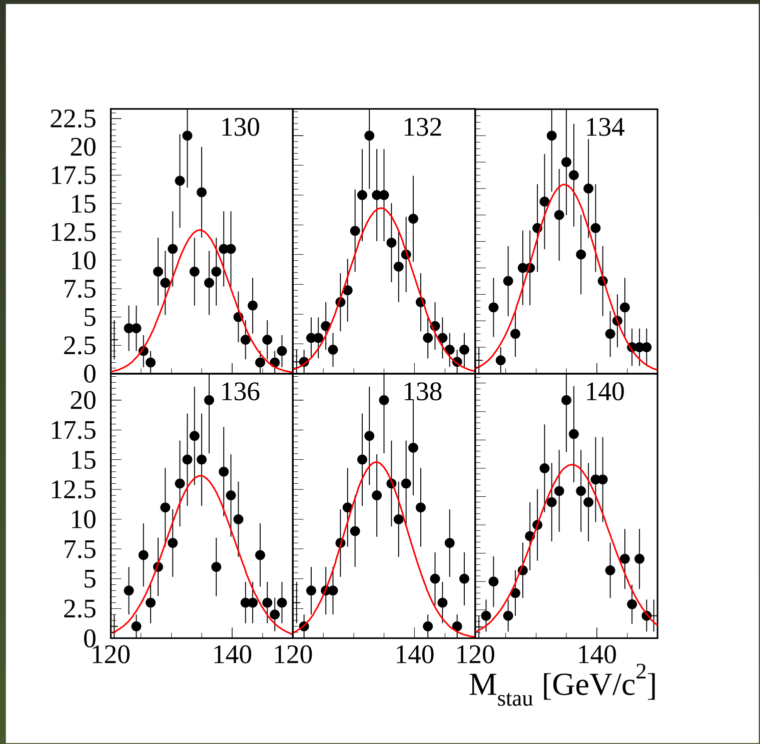

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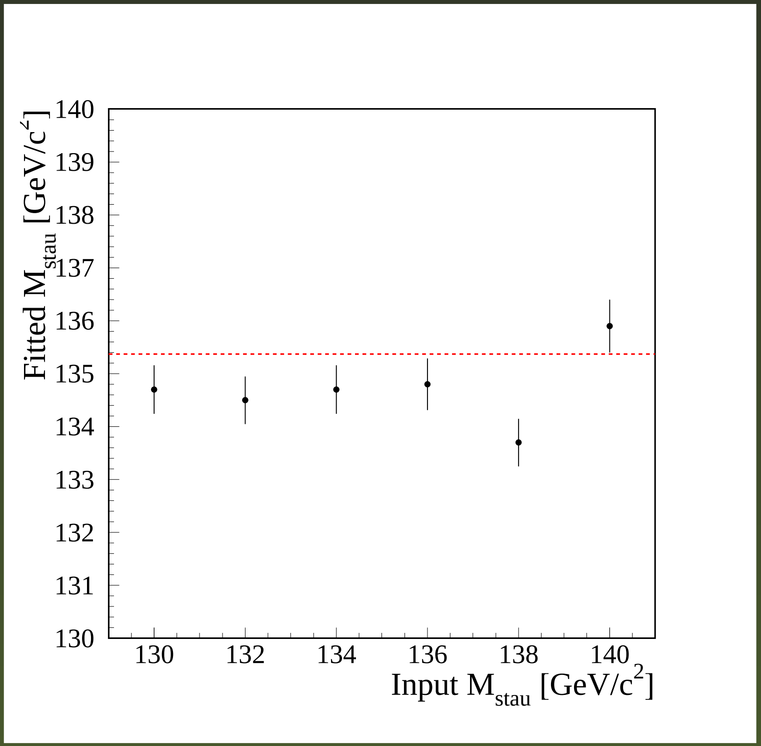

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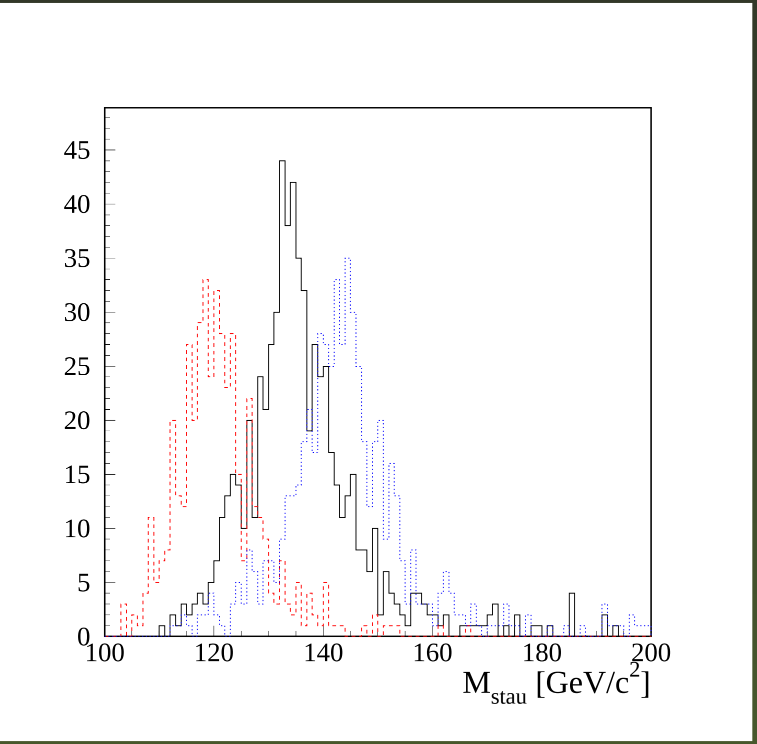

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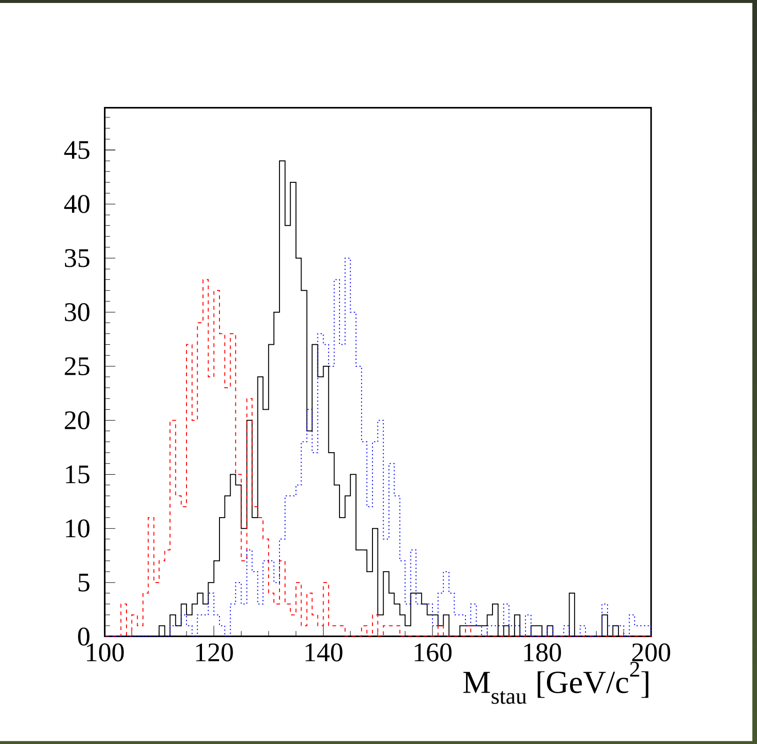

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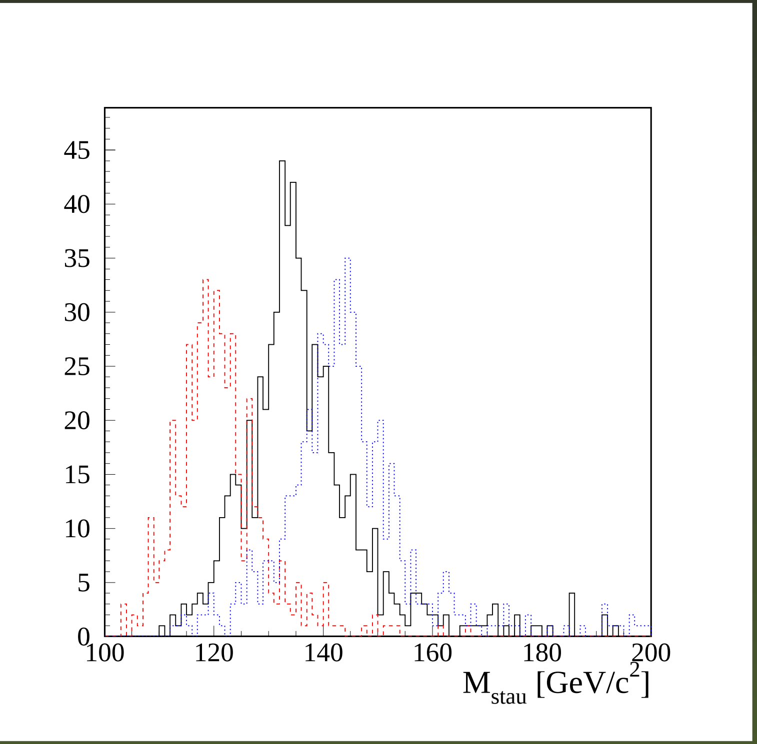

A Survey

In which of the SPS mSUGRA points are there cascades accessible for a sub-TeV LC ?

	E_{cms}					
	500		800		1000	
SPS point	$\tilde{\ell}$	$\tilde{\chi}_i^0$	$\tilde{\ell}$	$\tilde{\chi}_i^0$	$\tilde{\ell}$	$\tilde{\chi}_i^0$
1a	Y'	N	Y'	Y	Y'	Y
2	N	Y	N	Y	N	Y
3	N	N	Y'	N	Y'	N
4	N	N	Y	Y	Y	Y
5	Y'	N	Y'	N	Y'	N
6	N	N	N	Y	N	Y

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  These numbers can be ameliorated with more sophisticated analysis.
- The result takes background, ISR, beam-strahlung, τ decays, detector effects, and realistic solutions for ambiguities into account.

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