Determination of slepton properties in scenarios with small mass differences

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Outline

Introduction

What can be done at ILC if SUSY exists, and is "next to LEP", and we use a real detector ? And if the LSP-NLSP difference is small ?

Look at the mSUGRA point SPS1a':

$M_{1/2} = 250$ GeV, $M_0 = 70$ GeV, $A_0 = -300$ GeV, $\tan\beta = 10, \mu > 0$
Just outside what is excluded by LEP and low-energy observations.
Compatible with WMAP, with $\tilde{\chi}^0_1$ Dark Matter.

- All sleptons available.
- No squarks.
- Lighter bosinos, up to $\tilde{\chi}^0_3$ (in $e^+e^- \rightarrow \tilde{\chi}^0_1\tilde{\chi}^0_3$)

and use:

- Full ILC simulation.
- Full background: SUSY, SM, machine.

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First of all

Many contributors, in many scenarios over many years. Here only ILD full-sim results from LOI and later will be mentioned. My apologises to all those that have contributed earlier analyses, from SiD, ...

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SPS1a' is excluded by LHC, but:

- LHC only excludes 1:st & 2:nd generation squarks. : not visible at ILC anyhow.
- The current LHC limits have no influence at all on the EW sector.
- “Easy” to find models with the same EW-sector, but heavier gen. 1&2 squarks.

Still a good show-case of ILC

- Full ILD simulation.
- Full background: SUSY, SM, machine.

SPS1a'

- In SPS1a', the $\tilde{\tau}_1$ is the NLSP.
- $M_{\tilde{\chi}_1^0}$ = 97.7 GeV/c^2, $M_{\tilde{\chi}_2^0}$ = $M_{\tilde{\chi}_1^\pm}$ = 184 GeV/c^2.
- $M_{\tilde{\tau}_1}$= 107.9 GeV: low ΔM. $M_{\tilde{e}_R}$= $M_{\tilde{\mu}_R}$=125.3 GeV
- $M_{\tilde{\tau}_2}$= 194.9 GeV, $M_{\tilde{e}_L}$= $M_{\tilde{\mu}_L}$= 189.9 GeV$>$ $M_{\tilde{\chi}_2^0}$ and $M_{\tilde{\chi}_1^\pm}$: cascades
- For $\tilde{\tau}_1$: $E_{\tau,min} = 2.6$ GeV, $E_{\tau,max} = 42.5$ GeV: $\gamma\gamma$ background.
- For $\tilde{\tau}_2$: $E_{\tau,min} = 35.0$ GeV, $E_{\tau,max} = 152.2$ GeV: $WW \rightarrow l\nu l\nu$ background.
- For $\tilde{e}_R$or $\tilde{\mu}_R$: $E_{l,min} = 6.6$ GeV, $E_{l,max} = 91.4$ GeV: Neither $\gamma\gamma$ nor $WW \rightarrow l\nu l\nu$ background severe.
- $\tilde{\tau}$ NLSP $\rightarrow$ τ:s in most SUSY decays $\rightarrow$ SUSY is background to SUSY.
- For pol=(-1,1): $\sigma(\tilde{\chi}_2^0\tilde{\chi}_2^0)$ and $\sigma(\tilde{\chi}_1^+\tilde{\chi}_1^-)$ = several hundred fb and BR(X$\rightarrow \tilde{\tau}$) $>$ 50 %. For pol=(1,-1): $\sigma(\tilde{\chi}_2^0\tilde{\chi}_2^0)$ and $\sigma(\tilde{\chi}_1^+\tilde{\chi}_1^-) \approx 0$.
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Extracting the $\tilde{\tau}$ properties

Use polarisation (0.8,-0.22) to reduce bosino background.

From decay kinematics:

- $M_{\tilde{\tau}}$ from end-point of spectrum = $E_{\tau,max}$.
- Other end-point hidden in $\gamma\gamma$ background: Must get $M_{\tilde{\chi}_1^0}$ from other sources. ($\tilde{\mu}$, $\tilde{e}$ ...)

From cross-section:

- $\sigma_{\tilde{\mathcal{T}}} = A(\theta_{\tilde{\mathcal{T}}}, \mathcal{P}_{beam}) \times \beta^3/s$, so
- $M_{\tilde{\tau}} = E_{beam}\sqrt{1-(\sigma s/A)^{2/3}}$: no $M_{\tilde{\chi}_1^0}$!

From decay spectra:

- $\mathcal{P}_\tau$ from exclusive τ decay-mode(s): handle on mixing angles $\theta_{\tilde{\mathcal{T}}}$ and $\theta_{\tilde{\chi}_1^0}$.

Topology selection

$\tilde{\tau}$ properties:

- Only two τ:s in the final state.
- Large missing energy and momentum.
- High Acolinearity, with little correlation to the energy of the τ decay-products.
- Central production.
- No forward-backward asymmetry.

Select this by:

- Exactly two jets.
- $N_{ch} < 10$
- Vanishing total charge.
- Charge of each jet = ± 1,
- $M_{jet} < 2.5 \text{ GeV}/c^2$,
- $E_{vis} < 300 \text{ GeV}$,
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+ anti $\gamma\gamma$ cuts (see backup)

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$\tilde{\tau}_1$ and $\tilde{\tau}_2$ further selections

- Channel specific anti $\gamma\gamma$
- $\tilde{\tau}_1$:
  - $(E_{jet1} + E_{jet2}) \sin\theta_{acop} <$ 30 GeV.
- $\tilde{\tau}_2$:
  - Other side jet not e or μ
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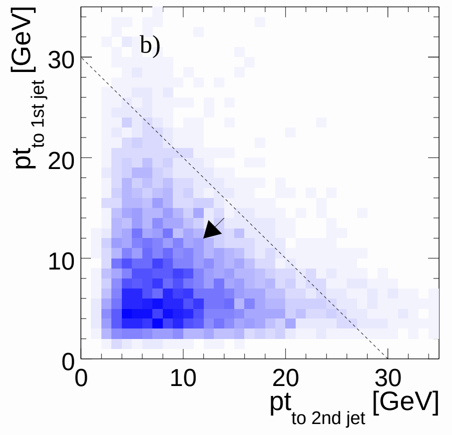
  - Cut on Signal-SM LR of $f(q_{jet1} cos\theta_{jet1}, q_{jet2} cos\theta_{jet2})$

Efficiency 15 (22) %



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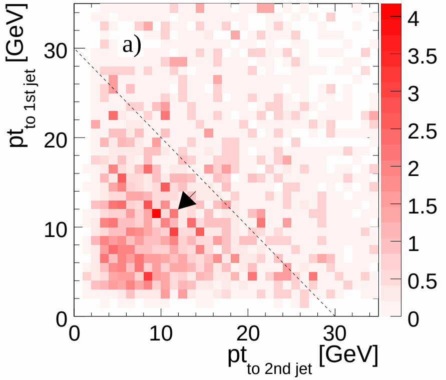

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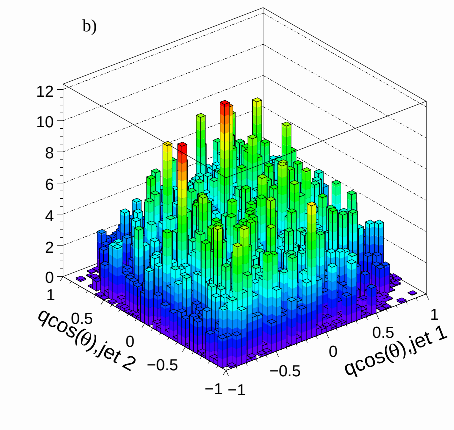

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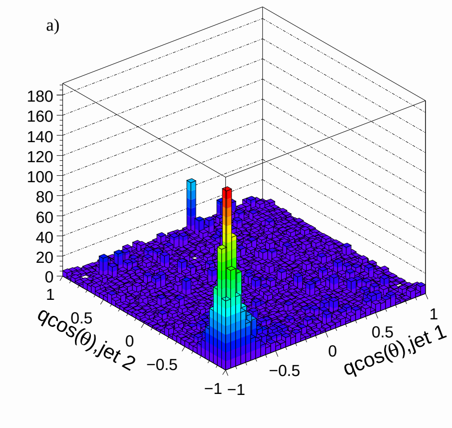

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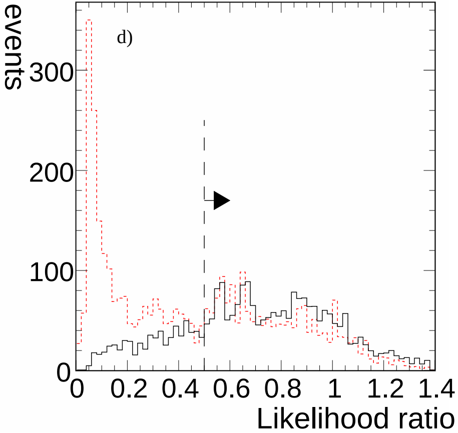

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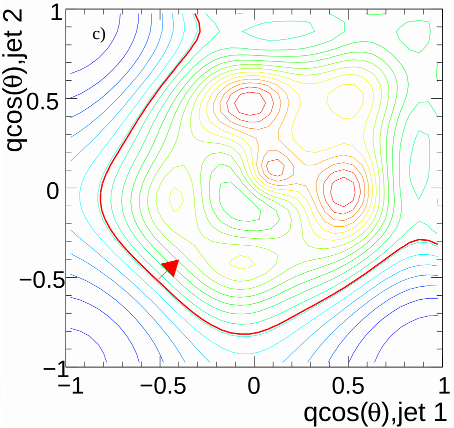

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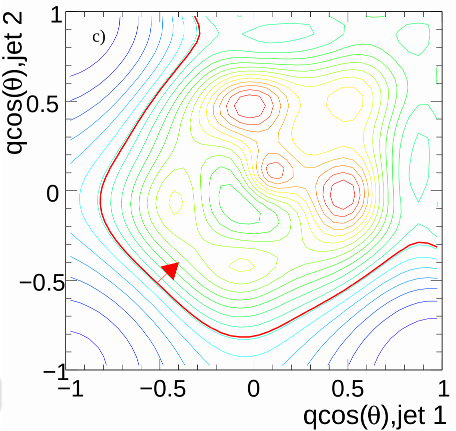

Fitting the $\tilde{\tau}$ mass

- Only the upper end-point is relevant.
- Background subtraction:
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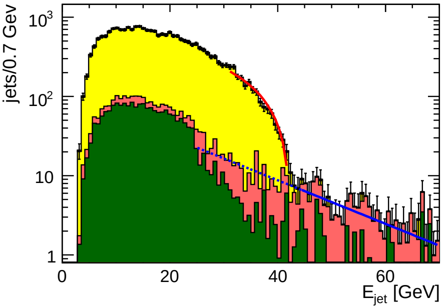

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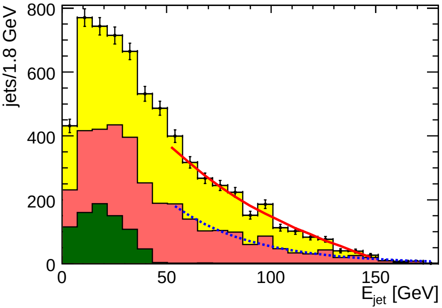

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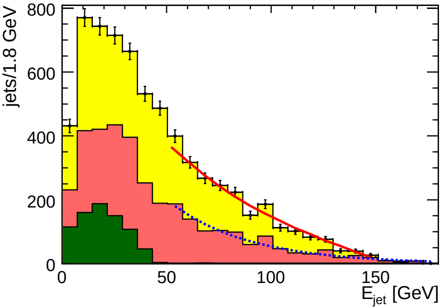

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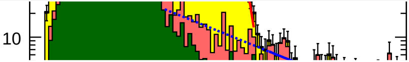
Results for $\tilde{\tau}_1$

$M_{\tilde{\tau}_1} = 107.73^{+0.03}_{-0.05}\ \mathrm{GeV}/c^2 \oplus 1.3\Delta(M_{\tilde{\chi}_1^0})$.
The error from $M_{\tilde{\chi}_1^0}$ largely dominates.

extrapolate.

- $\tilde{\tau}_2$: $\sim$ no SUSY background



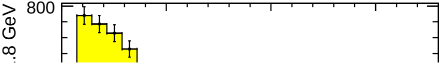
Results for $\tilde{\tau}_2$

$M_{\tilde{\tau}_2} = 183^{+11}_{-5}\ \mathrm{GeV}/c^2 \oplus 18\Delta(M_{\tilde{\chi}_1^0})$.
The error from the endpoint largely dominates.

- Fit line to (data-background fit).

Fitting the $\tilde{\tau}$ mass

- Only the upper end-point is relevant.
- Background subtraction:
  - $\tilde{\tau}_1$: Substantial SUSY background but region



Results from cross-section for $\tilde{\tau}_1$

$\Delta(N_{signal})/N_{signal} = 3.1\% \rightarrow \Delta(M_{\tilde{\tau}_1}) = 3.2\ \mathrm{GeV}/c^2$

  - $\tilde{\tau}_2$: ... no SUSY background

Results from cross-section for $\tilde{\tau}_2$

$\Delta(N_{signal})/N_{signal} = 4.2\% \rightarrow \Delta(M_{\tilde{\tau}_2}) = 3.6\ \mathrm{GeV}/c^2$
End-point + Cross-section $\rightarrow \Delta(M_{\tilde{\chi}^0_1}) = 1.7\ \mathrm{GeV}/c^2$

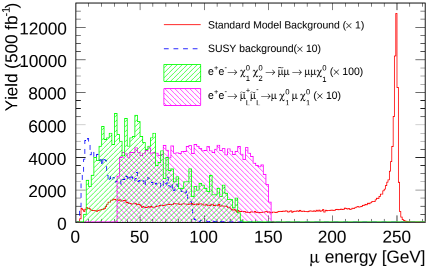
- Fit line to (data-background fit).

μ channels

Use “normal” polarisation (-0.8,0.22).

- $\tilde{\mu}_L\tilde{\mu}_L \to \mu\mu\tilde{\chi}^0_1\tilde{\chi}^0_1$
- $\tilde{\chi}^0_1\tilde{\chi}^0_2 \to \mu\tilde{\mu}_R\tilde{\chi}^0_1 \to \mu\mu\tilde{\chi}^0_1$

- Momentum of μ:s
- E_{miss}
- $M_{\mu\mu}$
- β of μ system.



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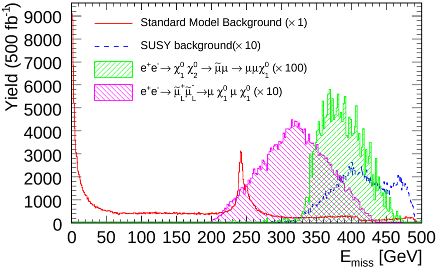

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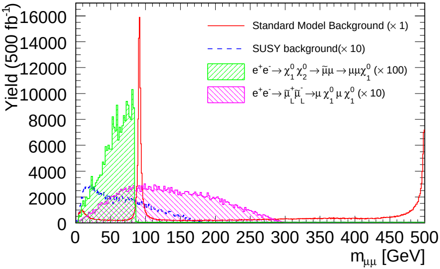

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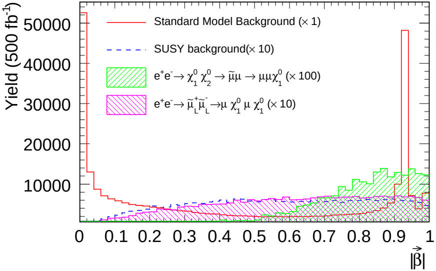
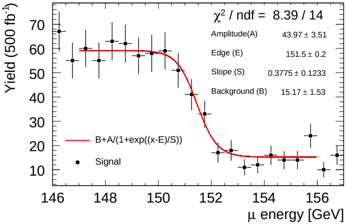


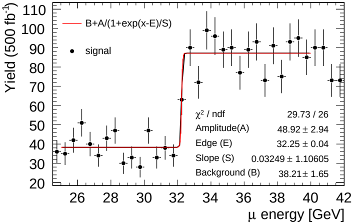
$\tilde{\mu}_L\tilde{\mu}_L$

Selections

- $\theta_{missing\ p} \in [0.1\pi, 0.9\pi]$
- $E_{miss} \in [200, 430]\mathrm{GeV}$
- $M_{\mu\mu} \notin [80, 100]\mathrm{GeV}$ and $> 30\mathrm{GeV}/c^2$

Masses from edges. Beam-energy spread dominates error.





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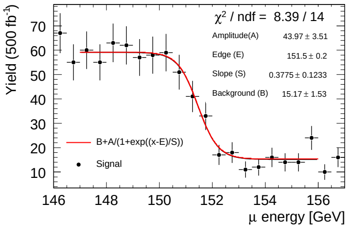
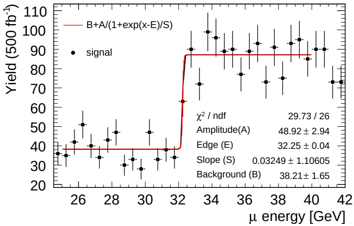
$$\Delta(M_{\tilde{\chi}_1^0}) = 920\mathrm{MeV}/c^2$$
$$\Delta(M_{\tilde{\mu}_L}) = 100\mathrm{MeV}/c^2$$





$\tilde{\chi}_1^0\tilde{\chi}_2^0$

Selections

- $\theta_{missing\ p} \in [0.2\pi, 0.8\pi]$
- $p_{Tmiss} > 40\mathrm{GeV}/c$
- β of μ system > 0.6.
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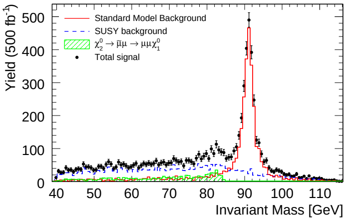
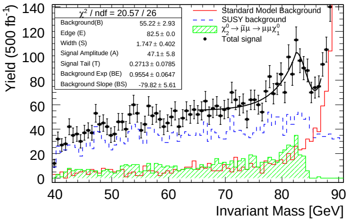
Mass from fit to invariant mass edge.





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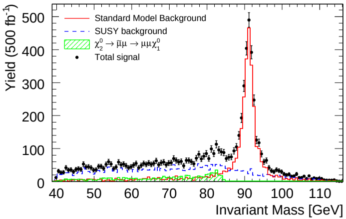
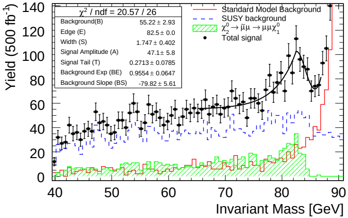
$$\Delta(M_{\tilde{\chi}_2^0}) = 1.38\mathrm{GeV}/c^2$$





The ẽ channel

$\sigma(\tilde{e}_R\tilde{e}_R)$ = 1.3 pb: Hundreds of thousands of almost background-free events expected.

Most of the reduction of the SM backround can be taken over from the $\tilde{\tau}$ analysis.

Some changes needed:

- $E_{vis} < 170$ GeV (rather than 120).
- $(E_{jet1} + E_{jet2}) \sin\theta_{acop} \in [21, 105]$ GeV. (rather than $\in [0, 30]$ GeV)
- $|\cos\theta_{missing\ momentum}| < 0.95$ (rather than 0.8).
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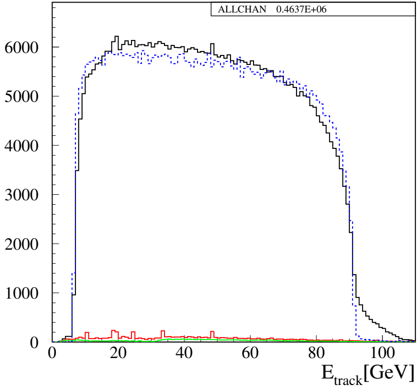
$\tilde{e}_R$ spectrum

- Signal: 227750 events (solid: fullsim, dashed: generator)
- Background: SUSY 1560 events, SM 2219 events.
- Efficiency: 67.8 %.
- Masses:
  - From average and RMS (true: 125.3 & 97.7): $M_{\tilde{e}_R} = 126.5 \pm 0.5\ \mathrm{GeV}/c^2$ and $M_{\tilde{\chi}^0_1} = 99.6 \pm 0.4\ \mathrm{GeV}/c^2$
  - From $E_{vis} \in [40, 150]$ GeV: $M_{\tilde{e}_R} = 124.6 \pm 0.5\ \mathrm{GeV}/c^2$ and $M_{\tilde{\chi}^0_1} = 98.3 \pm 0.4\ \mathrm{GeV}/c^2$ (potentionally: $\pm 0.21\ \mathrm{GeV}/c^2$ and $\pm 0.17\ \mathrm{GeV}/c^2$)



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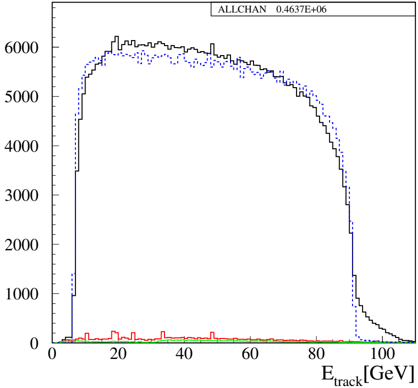

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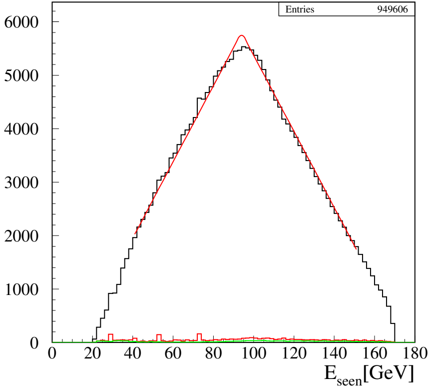

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Comming:

Integration over beam-spectrum and folding in detector-effects.

$M_{\tilde{\chi}^0_1} = 99.6 \pm 0.4$ GeV$/c^2$

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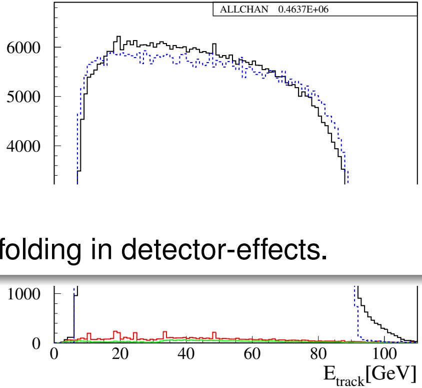
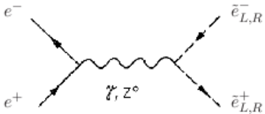


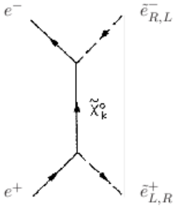
Near Degenerate ẽ and polarisation

(Preliminary work by M.B., G. Moortgat-Pick)

SUSY associates scalars to chiral (anti)fermions

$$e^-_{\mathrm{L,R}} \leftrightarrow \tilde{e}^-_{\mathrm{L,R}} \quad \text{and} \quad e^+_{\mathrm{L,R}} \leftrightarrow \tilde{e}^+_{\mathrm{R,L}}. \tag{1}$$





ẽ:s with same chirality

Chirality for $\tilde{e}^\pm$ same as $e^\pm$

What if $M_{\tilde{e}_L} \approx M_{\tilde{e}_R}$, so that thresholds can't separate $e^+e^- \rightarrow \tilde{e}_L\tilde{e}_L, \tilde{e}_R\tilde{e}_R$ and $\tilde{e}_R\tilde{e}_L$?

Near Degenerate $\tilde{e}$ and polarisation

Model: SPS1a' like, but:

$M_{\tilde{e}_L}$ = 200 GeVand $M_{\tilde{e}_R}$ = 195 GeV. Both decay 100 % to $\tilde{\chi}_1^0$ e.

Background and efficiency from Full-sim SPS1a' sample, kinematics from Whizard simulation of the model.

Even with $P_{e^-} \geq +90\%$: No separation of $\tilde{e}_L^+ \tilde{e}_R^-$ and $\tilde{e}_R^+ \tilde{e}_R^-$: Ratio of the cross sections $\approx$ constant.

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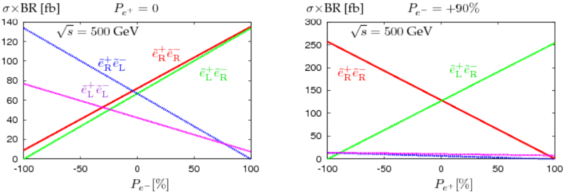

Near Degenerate ẽ and polarisation

The handle:
Opposite polarisation beams produces ẽ:s in both s- and t-channel.
Same polarisation produces ẽ:s in t-channel only ⇒

Modification of Θ distribution with changed positron polarisation

However, the effect is small since t-channel always dominates !
ẽ:s are heavy (and are scalars) ⇒ t- and s- channel kinematic distributions of the electrons are not very different.

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Analyse assuming 100 fb^{-1} for each of the polarisations configurations.
Reconstruct $\Theta_{\tilde{e}}$ event-by-event assuming $M_{\tilde{e}}$ and $M_{\tilde{\chi}_1^0}$ know.

- P(e^-)= +80 % and ..
- P(e^+) = ± 22 % ...
- P(e^+) = ± 30 % ...
- P(e^+) = ± 60 % ...
- ... and for P(e^-)= ± 80 %
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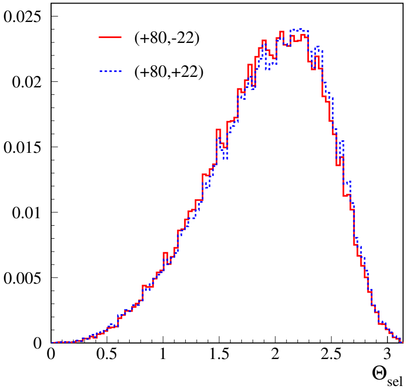

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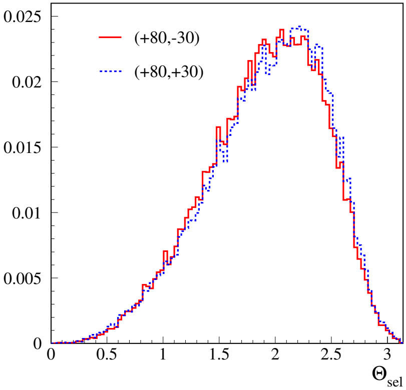

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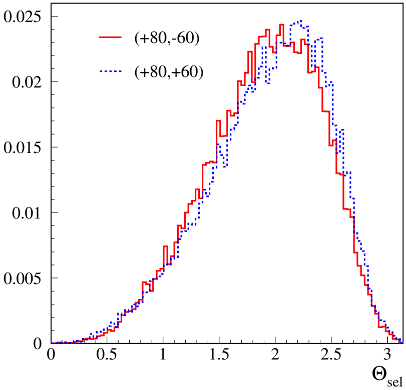

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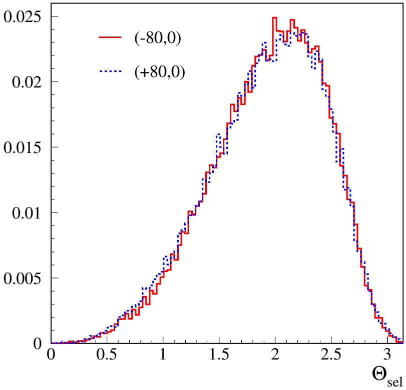

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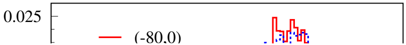
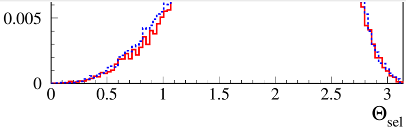


$\lvert P(e^+)\rvert$ (%)	significance of shift (σ)	Title of paper
22	2.4	"Limit on ..."
30	3.5	"Evidence for ..."
60	6.6	"Observation of ..."



Summary

Full simulation of $\tilde{e}$, $\tilde{\mu}$ and $\tilde{\tau}$ production in SPS1a' in the ILD detector at ILC was presented

- All background - SUSY and SM - included. .
- Beam-background included.
- After 4 ILC years:
  - $\Delta(M_{\tilde{\tau}_1}) = 80\ \mathrm{MeV}/c^2 \oplus 1.3\Delta(M_{\tilde{\chi}^0_1})$.
    $\Delta(M_{\tilde{\tau}_2}) = 8\ \mathrm{GeV}/c^2 \oplus 18\Delta(M_{\tilde{\chi}^0_1})$.
  - $\Delta(\mathcal{P}_\tau) \approx 6$ % (see backup).
  - For $e^+e^- \rightarrow \tilde{\mu}_L \tilde{\mu}_L$, we find: $\Delta(M_{\tilde{\chi}^0_1}) = 920\mathrm{MeV}/c^2$
    $\Delta(M_{\tilde{\mu}_L}) = 100\mathrm{MeV}/c^2$,
  - For $\tilde{\chi}^0_1 \tilde{\chi}^0_2 \rightarrow \mu \tilde{\mu}_R \tilde{\chi}^0_1 \rightarrow \mu\mu \tilde{\chi}^0_1 \tilde{\chi}^0_1$, we find $\Delta(M_{\tilde{\chi}^0_2}) = 1.38\mathrm{GeV}/c^2$
  - $\Delta(M_{\tilde{\chi}^0_1}) = 400\ \mathrm{MeV}/c^2$ (prospect: $170\ \mathrm{MeV}/c^2$)
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Summary

Full simulation of $\tilde{\mathrm{e}}$, $\tilde{\mu}$ and $\tilde{\tau}$ production in SPS1a' in the ILD detector at ILC was presented

- All background - SUSY and SM - included. .
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Outlook

At SPS1a' there are

- 10 masses
- Cross-sections for 13 channels
- >100 branching ratios
- Several mixing angles

to measure at a 500 GeVILC.

We intend to define a similar point not excluded by LHC and systematically study it

- At different E_{CMS}
- With different beam-polarisations
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THANK YOU !

Backup

BACKUP SLIDES

$\gamma\gamma$ suppression

$\Delta(M) = 10.2\ \mathrm{GeV}/c^2 \rightarrow \gamma\gamma$ background ...

- Correlated cut in ρ and θ_{acop}: $\rho > 2.7\sin\theta_{acop} + 1.8$. ($\rho$ = P_T of jets wrt. thrust axis, in x-y projection.)
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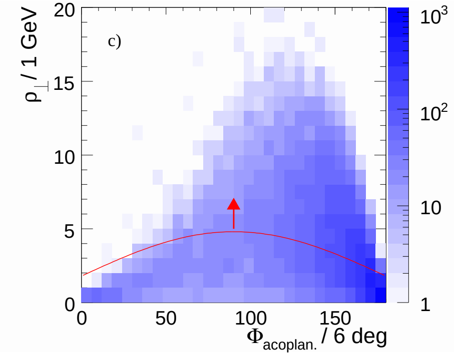

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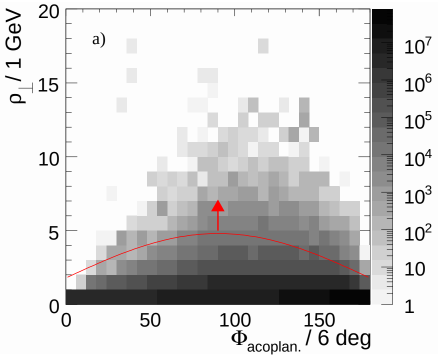

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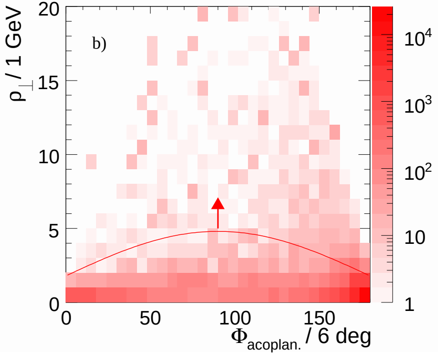

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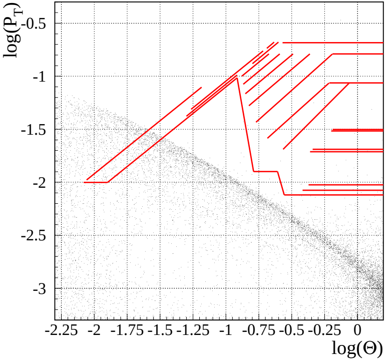

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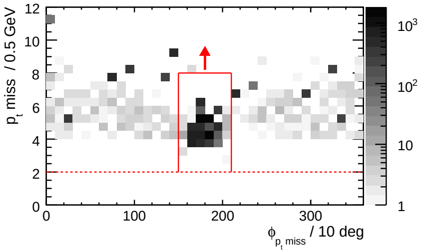

End-point and cross-section

Additional cuts against $\gamma\gamma$ (not needed for polarisation, due to PID requirements):

- $|\cos\theta_{missing\ momentum}| < 0.8$
- Low fraction of “Rest-of-Event” energy at low angles.

From now on: Different cuts for $\tilde{\tau}_1$ ($\gamma\gamma$ background), and $\tilde{\tau}_2$ (*WW* background).

Fitting the $\tilde{\tau}$ mass: Cross-section

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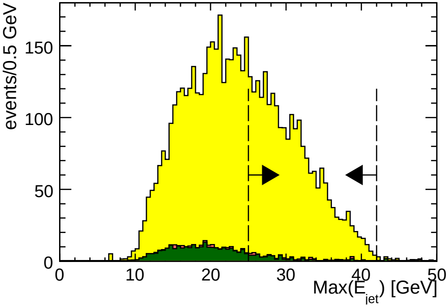

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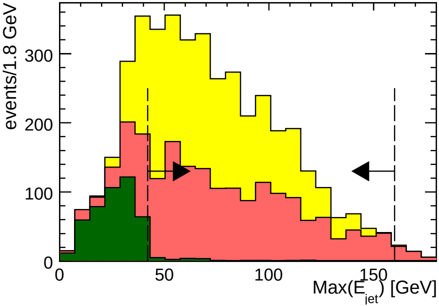

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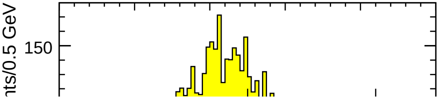

Results for $\tilde{\tau}_1$

$\Delta(N_{signal})/N_{signal} = 3.1\%$
$\Delta(M_{\tilde{\tau}_1})/M_{\tilde{\tau}_1} = (\Delta(\sigma)/\sigma)(\beta^2)/3(1-\beta^2)$= 2.1 %, ie.
$\Delta(M_{\tilde{\tau}_1}) = 3.2\ \mathrm{GeV}/c^2$

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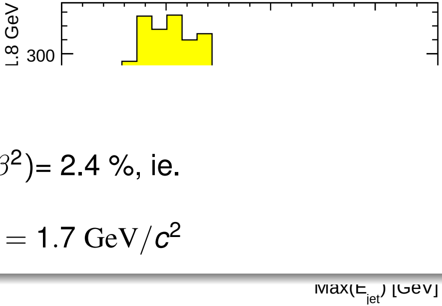

Results for $\tilde{\tau}_2$

$\Delta(N_{signal})/N_{signal} = 4.2\%$

$\Delta(M_{\tilde{\tau}_2})/M_{\tilde{\tau}_2} = (\Delta(\sigma)/\sigma)(\beta^2)/3(1-\beta^2)$= 2.4 %, ie.

$\Delta(M_{\tilde{\tau}_2}) = 3.6\ \mathrm{GeV}/c^2$

End-point + Cros-section $\rightarrow \Delta(M_{\tilde{\chi}_1^0}) = 1.7\ \mathrm{GeV}/c^2$

$\tilde{\tau}_1$ End-point and cross-section

- $E_{vis} < 120\ \mathrm{GeV}$,
- $|\cos\theta_{jet}| < 0.9$ for both jets,
- $\theta_{acop} > 85^\circ$,
- $(E_{jet1} + E_{jet2})\sin\theta_{acop} < 30\ \mathrm{GeV}$.
- $M_{vis} > 20\ \mathrm{GeV}/c^2$.

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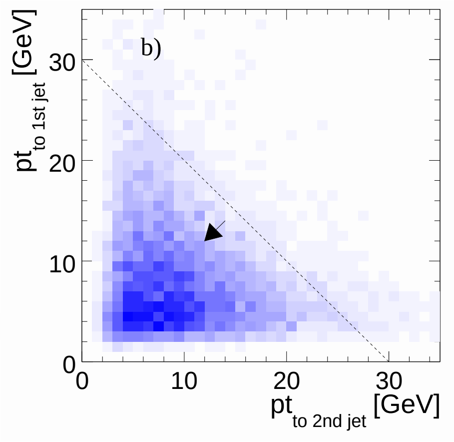

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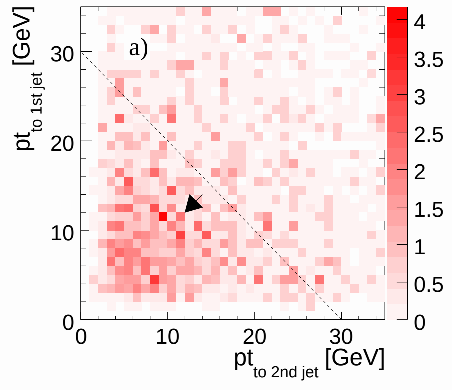

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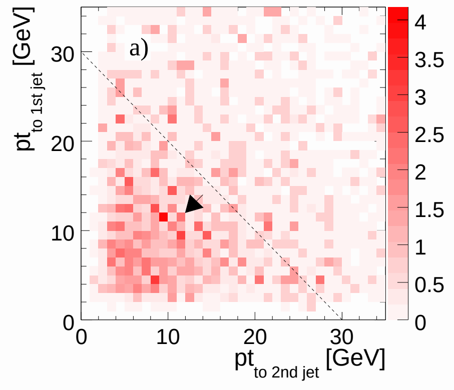
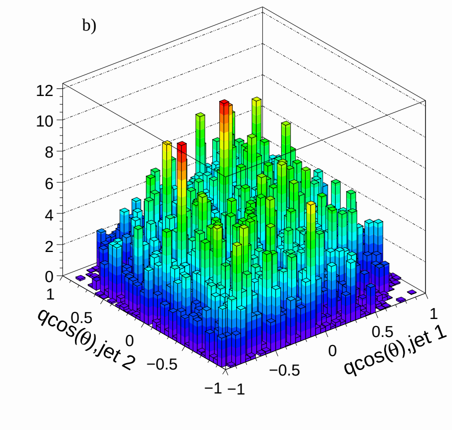


$\tilde{\tau}_2$ End-point and cross-section

- $E_{vis} > 50$ GeV.
- $\theta_{acop} < 155°$.
- Other side jet not e or μ
- Most energetic jet not e or μ
- Cut on Signal-SM LR of $f(q_{jet1} cos\theta_{jet1}, q_{jet2} cos\theta_{jet2})$

Efficiency 22.3 %



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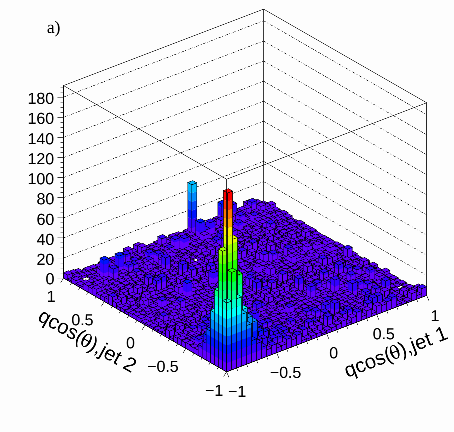

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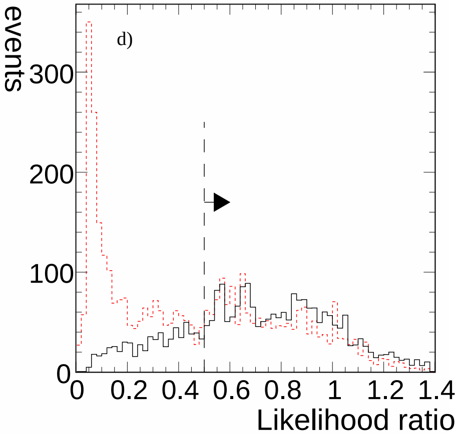

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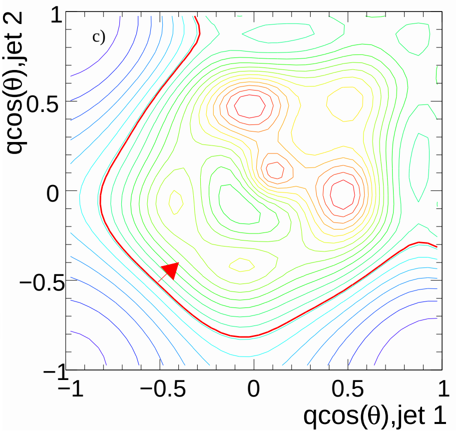

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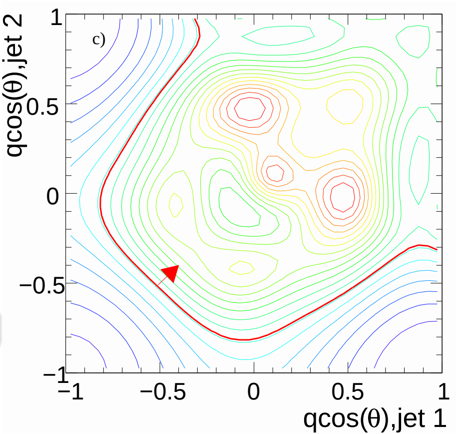

τ Polarisation: formulae and corrections

Spectrum of π:s in $\tau \to \pi^{+-}\nu_\tau$:

$$\frac{1}{\sigma}\frac{d\sigma}{dy_\pi} \sim \begin{cases} (1-P_\tau)\log\frac{P_{\tilde{\mathcal{T}},max}}{P_{\tilde{\mathcal{T}},min}} + 2P_\tau y_\pi\left(\frac{1}{P_{\tilde{\mathcal{T}},min}} - \frac{1}{P_{\tilde{\mathcal{T}},max}}\right) & \text{for } y_\pi < P_{\tilde{\mathcal{T}},min} \\ (1-P_\tau)\log\frac{P_{\tilde{\mathcal{T}},max}}{y_\pi} + 2P_\tau\left(1-\frac{y_\pi}{P_{\tilde{\mathcal{T}},max}}\right) & \text{for } Y_\pi > P_{\tilde{\mathcal{T}},min} \end{cases}$$

Analysers:

- π-cannel: P_π
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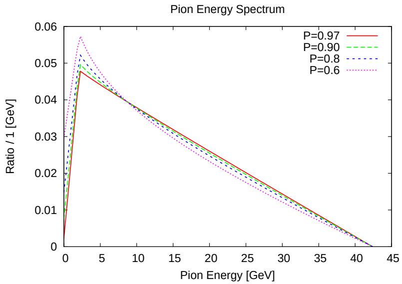

τ Polarisation from π: background and signal fit

Method to extract the polarisation:

- Fit background MC.
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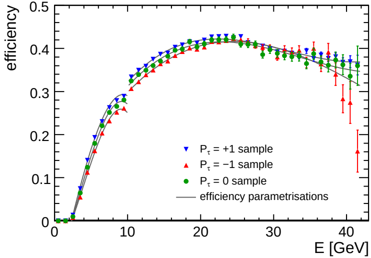

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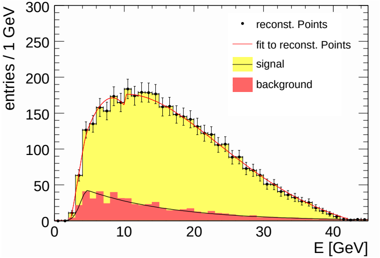

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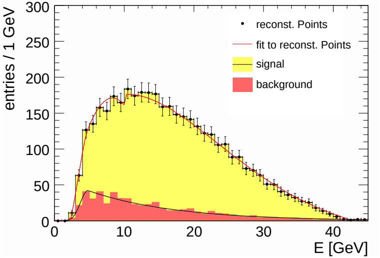

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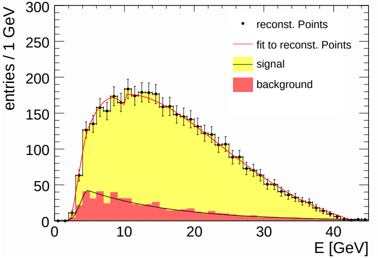

$\mathcal{P}_\tau = 93 \pm 6 \pm 5(\text{bkg}) \pm 3(\text{SUSY masses})\%$

τ Polarisation from ρ: background and signal fit

Method to extract the polarisation:

- Fit background MC.
- Subtract this background estimate.
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- Fit for $\mathcal{P}_\tau$ for $0.1 < R < 0.85$

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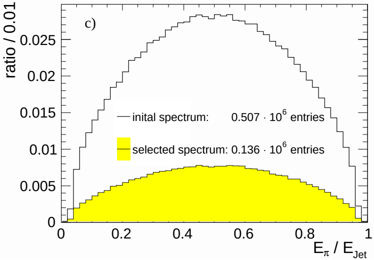

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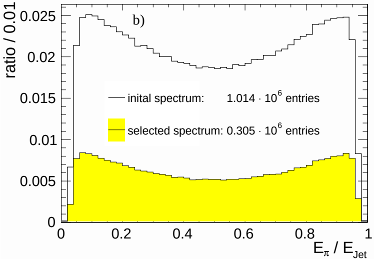

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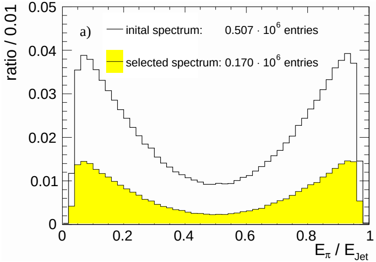

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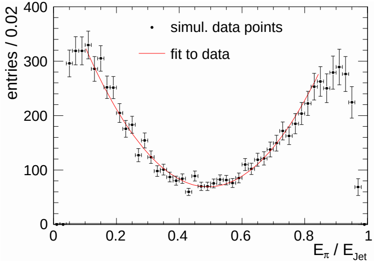

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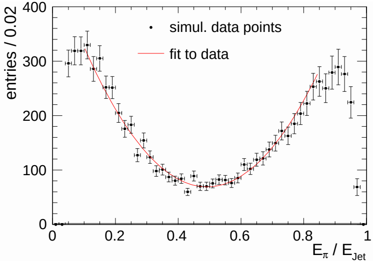

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τ Polarisation from π: formulae and corrections

Correct for the spread in E_{beam}:

- Plot spectrum (at generator level), with and without beam-strahlung and ISR shows difference.
- Parametrise actual spectrum for $\mathcal{P}_\tau = \pm 1$ ($= F(E, \pm 1)$)
- True spectrum will be $F(E, \mathcal{P}_\tau) = \frac{1+\mathcal{P}_\tau}{2} F(E, +1) + \frac{1-\mathcal{P}_\tau}{2} F(E, -1)$

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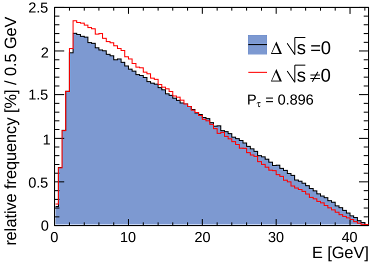

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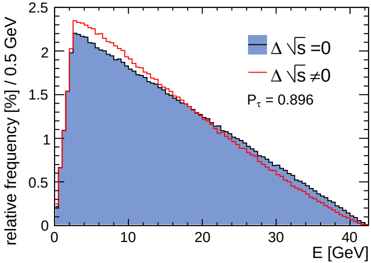

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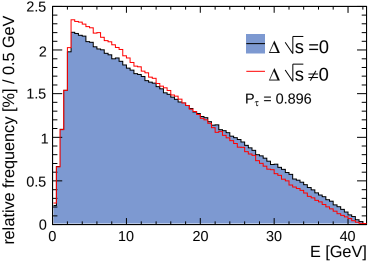

τ Polarisation from π: Select the signal process

Extract the $\tau \rightarrow \pi^{+-}\nu_\tau$ signal.

- The events should pass the anti-$\gamma\gamma$ cut.
- $E_{vis} < 90\ \mathrm{GeV}$.
- No jet with $E > 60\ \mathrm{GeV}$
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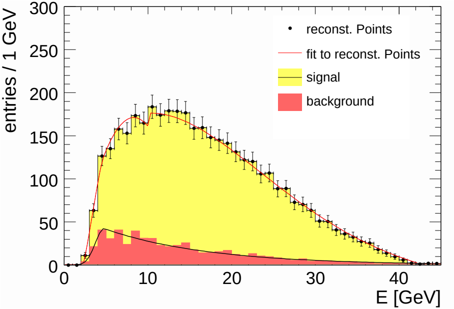

τ Polarisation from ρ: Select the signal process

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- $E_{vis} < 90$ GeV.
- No jet with $E > 43$ GeV
- Tighter ρ cut:$\rho > 3.5 \sin\theta_{acop} + 2$.
- At least one jets should contain one charged particle, and at least two neutrals.
- The single particle should have a π-id (dE/dx only).
- Mass of this jet close to M_ρ:$M_{jet} \in [0.4, 1.1]\mathrm{GeV}/c^2$.

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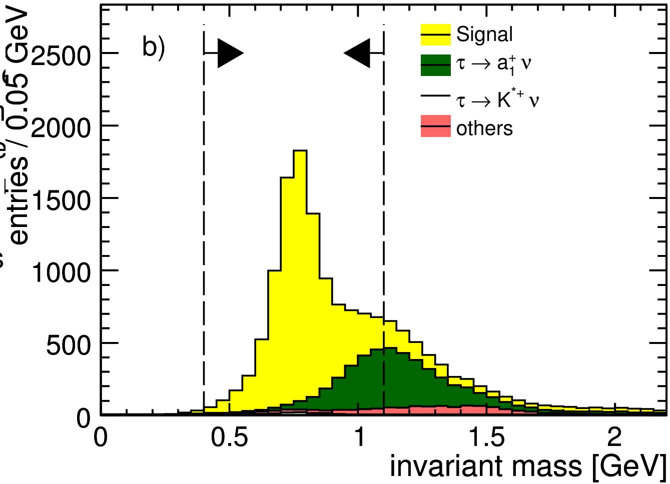

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Background and efficiency from Full-sim SPS1a' sample, kinematics from Whizard simulation of the model.

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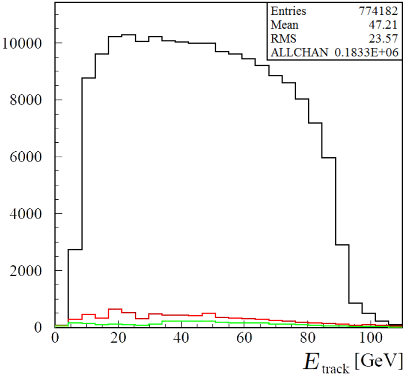

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For the signal:

- Generate (with Whizard 1.95) the modified model.
- Apply the kinematic cuts used for the full simulation analysis.
- Scale down the over-all event-weight so that the efficiency agrees with the full simulation.