Prospects for the study of $\tilde{\tau}$:s in SPS1a' in ILD

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Outline

Introduction

What can be done if SUSY exists, and is "next to LEP", and we use a real detector ?

- Study SPS1a'
- Weak-scale parameters with SPheno
- Whizard for event simulation (Produced at DESY)
- GuineaPig for beam-background
- DESY mass-production for both SUSY and SM:
  - Full simulation: ILD_00 in Mokka
  - Reconstruction using Marlin
- Study τ channels

People involved

- Olga Stempel, Peter Schade, J. List, P. Bechtle, M.B.

SPS1a'

Pure mSUGRA model:

$M_{1/2} = 250\ GeV, M_0 = 70\ GeV, A_0 = -300\ GeV,$
$\tan\beta = 10, sign(\mu) = +1$

Just outside what is excluded by LEP and low-energy observations.
Compatible with WMAP, with $\tilde{\chi}_1^0$ Dark Matter.
Close to "best fit" to present data.

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

Features of $\tilde{\tau}$:s in SPS1a'

- In SPS1a', the $\tilde{\tau}_1$ is the NLSP.
- $M_{\tilde{\tau}_1} = 107.9\ \mathrm{GeV}$, $M_{\tilde{\tau}_2} = 194.9\ \mathrm{GeV}$, $M_{\tilde{\chi}^0_1} = 97.7\ \mathrm{GeV}$
- $E_{\tilde{\tau}_1,min} = 2.6\ \mathrm{GeV}$, $E_{\tilde{\tau}_1,max} = 42.5\ \mathrm{GeV}$: $\gamma\gamma$ background.
- $E_{\tilde{\tau}_2,min} = 35.0\ \mathrm{GeV}$, $E_{\tilde{\tau}_2,max} = 152.2\ \mathrm{GeV}$: $WW \rightarrow l\nu l\nu$ background.
- Co-annihilation important for Dark Matter: $M_{\tilde{\tau}_1}$ important.
- The $\tilde{\tau}$ mass-eigen states $\neq$ chiral-eigen states: $\tilde{\tau}$-mixing
  - With $M_{\tilde{\mu}_L}$ and $M_{\tilde{\mu}_R}$, a measurement of θ_{mix} gives $A_{\tilde{\tau}} - \mu \tan\beta$.
  - Cross-section depends on θ_{mix} and beam-polarisation.
  - τ polarisation depends on θ_{mix} and on $\tilde{\chi}^0_1$-mixing.

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- $\tilde{\tau}$ NLSP $\rightarrow$ τ:s in most SUSY decays (BR(X$\rightarrow \tilde{\tau}$) $>$ 50 %) $\rightarrow$ SUSY is background to SUSY.
- Note:
  - For pol=(-1,1): $\sigma(\tilde{\chi}^0_2\tilde{\chi}^0_2)$ and $\sigma(\tilde{\chi}^+_1\tilde{\chi}^-_1)$ = several hundred fb.
  - For pol=(1,-1): $\sigma(\tilde{\chi}^0_2\tilde{\chi}^0_2)$ and $\sigma(\tilde{\chi}^+_1\tilde{\chi}^-_1) \approx 0$.
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Extracting the $\tilde{\tau}$ properties

Mass from decay kinematics:

- $M_{\tilde{\tau}}$ from $M_{\tilde{\chi}_1^0}$ and end-point of spectrum = $E_{\tau,max}$.
- Need to measure end-point of spectrum.
- In principle: $M_{\tilde{\chi}_1^0}$ turn-over of spectrum = $P_{\tau,min}$, but hidden in $\gamma\gamma$ background.
- Must get $M_{\tilde{\chi}_1^0}$ from other sources. ($\tilde{\mu}$, $\tilde{e}$, not yet done)

Mass from cross-section:

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

Polarisation from decay spectra:

- P from spectrum for exclusive decay-mode(s). Here: $\tau \rightarrow \pi^{+-}\nu_\tau$ and $\tau \rightarrow \rho^{+-}\nu_\tau \rightarrow \pi^{+-}\pi^0\nu_\tau$

Overview of Analysis

- Common to all aspects:
  - Reduce beam-beam background
  - Reduce $\gamma\gamma$ background
  - Find τ candidates
  - Select $\tilde{\tau}$-like topology
- Then specialise:
  - For mass: select events close to end point to reduce $\gamma\gamma$ background. Different for $\tilde{\tau}_1$ and $\tilde{\tau}_2$.
  - For polarisation: Select decay mode $\rightarrow$ PID.

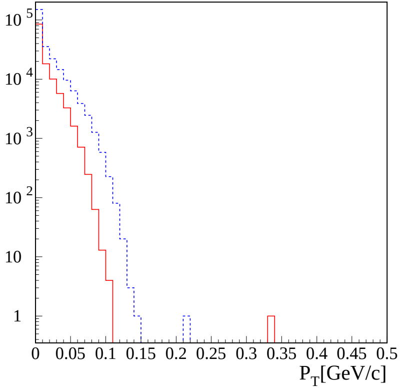
Beam-background

Simulation method

- Generate 1000 bunch-crossings with GuineaPig.
- Add simulated and reconstructed beam-background only events on beam-background free, fully simulated and reconstructed physics events → under-estimate pattern rec. problems.

Beam-background

- Most beam-background tracks seen in the tracker are low P_T
- .. or fakes.
- Reject by : $E > 500\mathrm{MeV}$
- ... and demand associated TPC hits for charged.



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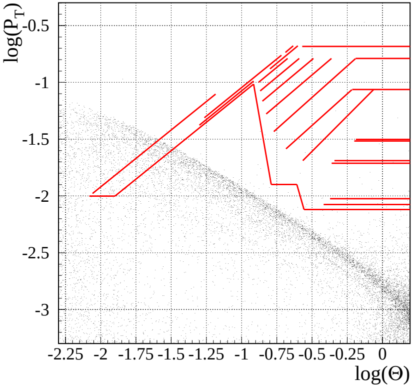

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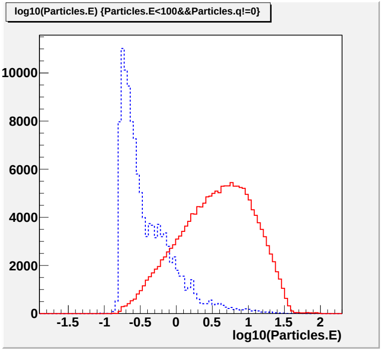

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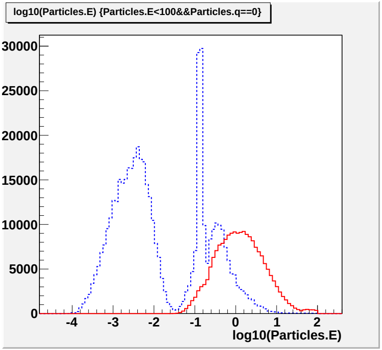

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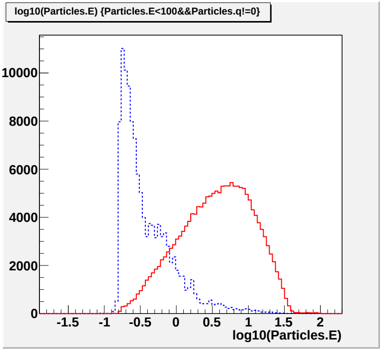

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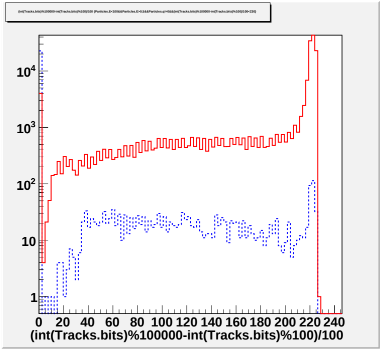

$\gamma\gamma$ suppression

Veto beam-remnant electrons:

- no significant activity in the BeamCal
- $\phi_{p\ miss}$ not in the direction of the incoming beam-pipe.

Visible system now almost back-to-back in transversal view

- Correlated cut in ρ and θ_{acop}: $\rho > 2.7 \sin\theta_{acop} + 1.8$.

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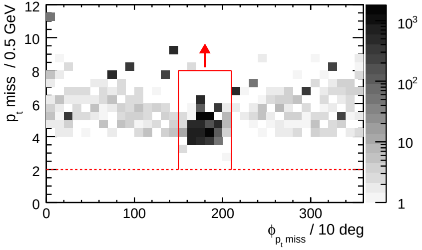

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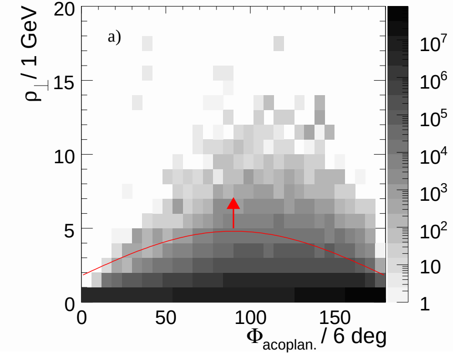

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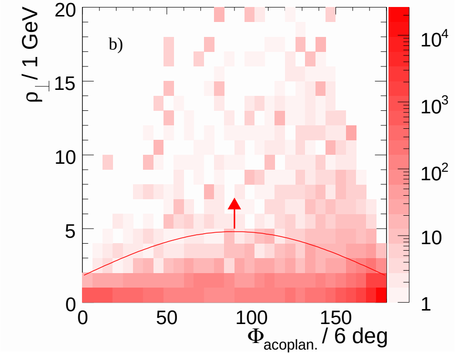

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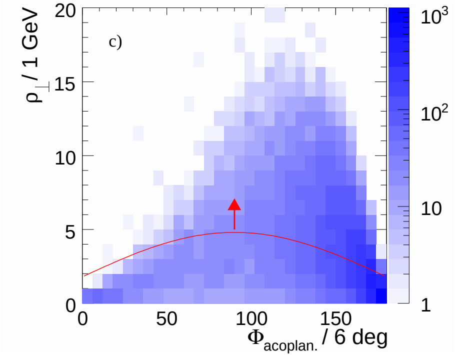

Finding τ:s

In particular in the presence of beam-background, general jet-finders perform poorly when used to find τ:s

Use the DELPHI τ-finder:

1. Test all possible ways to group the charged tracks in the event in collections with $M < 2\ \mathrm{GeV}/c^2$.
2. Prefer the grouping giving the lowest number of groups.
3. If more than one possible, use the one with lowest ΣM.
4. End when no smaller number of groups possible.
5. Then add any neutrals to the groups, always selecting the situation giving the lowest mass
6. If the lowest mass is $> 2\ \mathrm{GeV}/c^2$, leave the neutral to the "Rest-of-event" group

Additional options not yet exploited: Special treatment of leptons, neutral hadrons.

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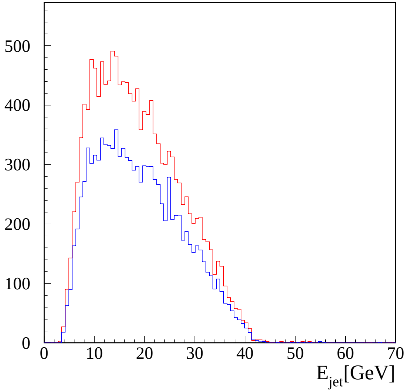
Performs better than Durham forced to two jets already without background:



BLUE: Durham, RED: DELPHI

Topology selection

$\tilde{\tau}$ properties:

- Only two τ:s in the final state.
- Large missing energy and momentum.
- High acollinearity, with modest 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,
- $M_{jet} < 2.5\ \mathrm{GeV}/c^2$,
- $E_{vis} < 300\ \mathrm{GeV}$,
- $M_{miss} > 250\ \mathrm{GeV}/c^2$,
- No particle with momentum above $180\ \mathrm{GeV}/c$ in the event.

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End-point and cross-section

Additional cuts against $\gamma\gamma$:

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

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

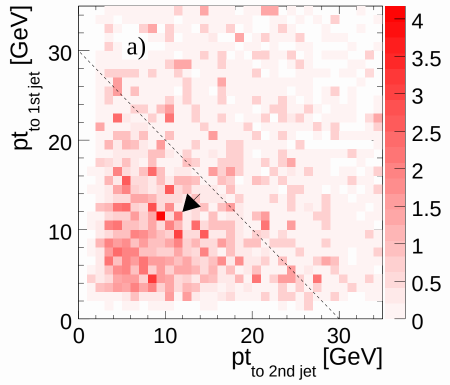
$\tilde{\tau}_1$ End-point and cross-section

Against $\gamma\gamma$:

- $E_{vis} < 120$ GeV,
- $|\cos\theta_{jet}| < 0.9$ for both jets,
- $\theta_{acop} > 85°$,
- $M_{vis} > 20$ GeV$/c^2$.

Against other, heavier, SUSY particles:

- $(E_{jet1} + E_{jet2}) \sin\theta_{acop} <$ 30 GeV.



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$N_{bck,SM}$= 390 , $N_{bck,SUSY}$ = 1020.

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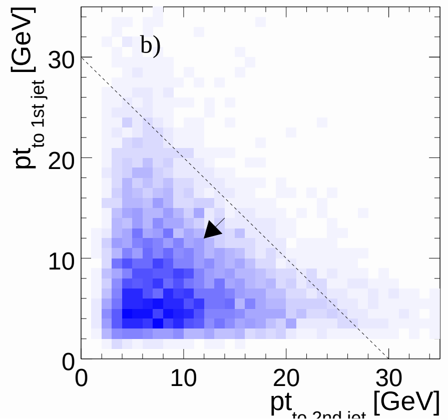

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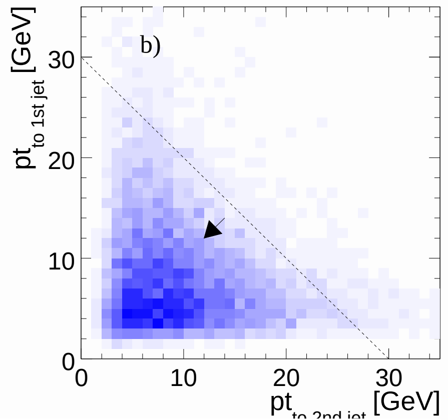

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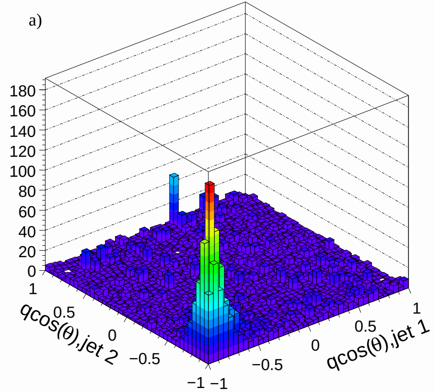
- $E_{vis} > 50$ GeV.
- $M_{vis} > 20$ GeV$/c^2$.
- $\theta_{acop} < 155°$.

Against $WW \to l\nu l\nu$:

- Other side jet not e or μ
- Most energetic jet not e or μ
- Cut on Signal-SM LR of f($q_{jet1} cos\theta_{jet1}$,$q_{jet2} cos\theta_{jet2}$)



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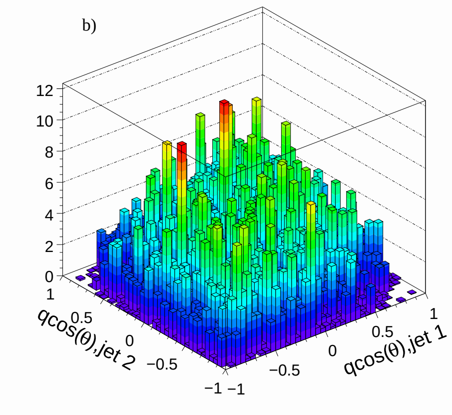

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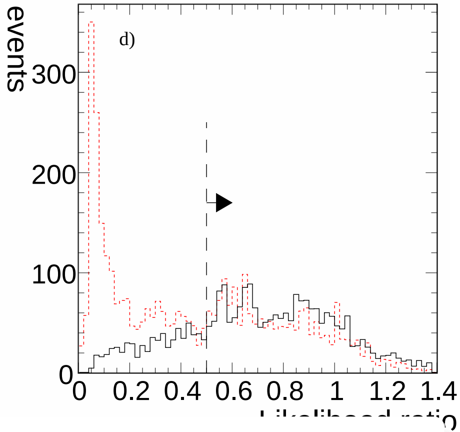

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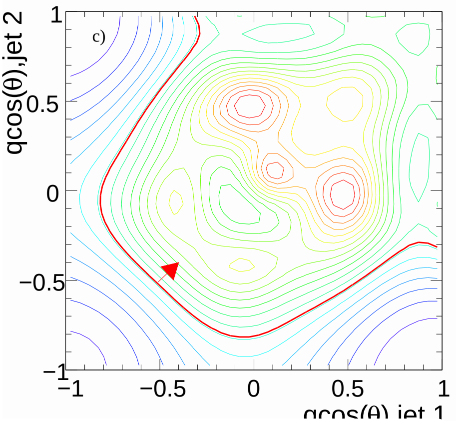

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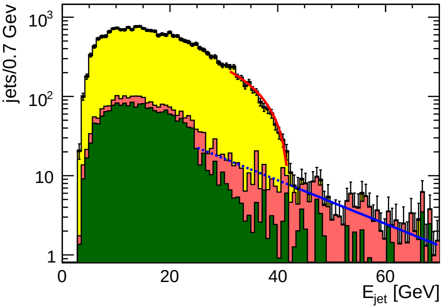
Fitting the $\tilde{\tau}_1$ mass: Endpoint

- Only the upper end-point is relevant.
- Region above 45 GeV is signal free. Fit exponential.
- Fit line to (data-background fit extrapolation):
  - MINUIT, ML fit, with MINOS+HESSE.



$E_{\tau,max} = 41.96^{+0.15}_{-0.13}$ GeV (true value 42.54 GeV)
$M_{\tilde{\tau}_1} = 107.69^{+0.03}_{-0.06}$ GeV.

NB: $dM_{\tilde{\tau}}/dM_{\tilde{\chi}^0_1} \approx 1.1$: Even if $\Delta(M_{\tilde{\chi}^0_1}) \approx 100$ MeV the error from $M_{\tilde{\chi}^0_1}$ largely dominates.

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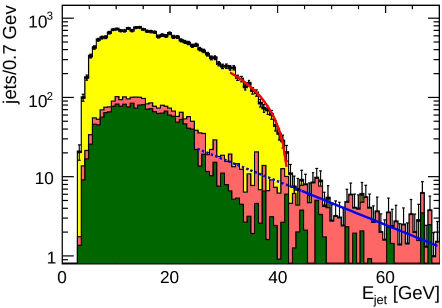
- Only the upper end-point is relevant.
- Region above 45 GeV is signal free. Fit exponential.
- Fit line to (data-background fit extrapolation):
  - MINUIT, ML fit, with MINOS+HESSE.

$E_{\tau,max} = 41.96^{+0.15}_{-0.13}$ GeV (true value 42.54 GeV)
$M_{\tilde{\tau}_1} = 107.69^{+0.03}_{-0.06}$ GeV.



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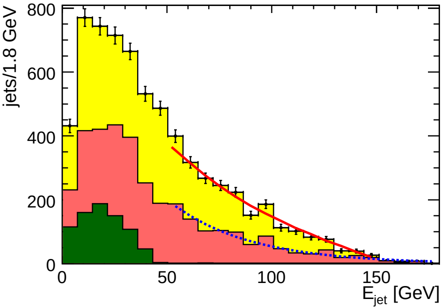

$E_{\tau,max} = 151.2^{+1.9}_{-1.6}$ GeV (true value 152.2 GeV)
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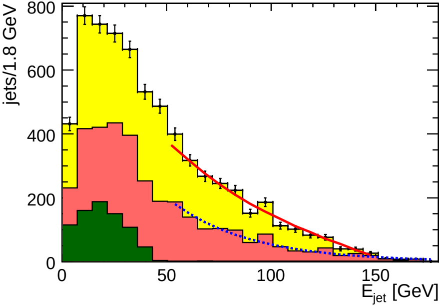

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Fitting the $\tilde{\tau}_1$ mass: Cross-section

- Main background is SM: well known.
- Some SUSY background: poorly known.
- Select region where SUSY bck is as low as possible.

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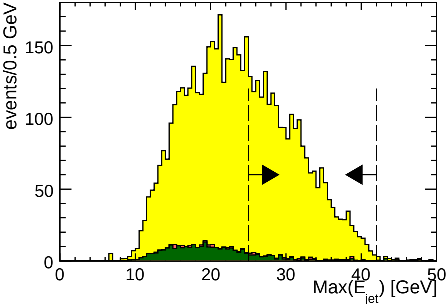

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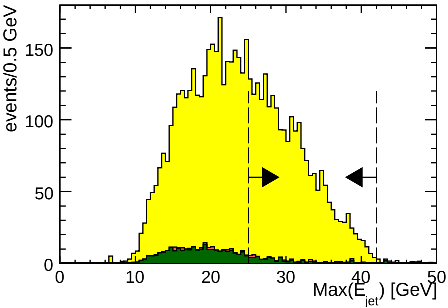

Fitting the $\tilde{\tau}_2$ mass: Cross-section

- Main background is SM: well known.
- Hardly any SUSY background beyond $\tilde{\tau}_1$ endpoint.
- Select this region.

$\Delta(N_{signal})/N_{signal} = 4.2\%$
$\Delta(M_{\tilde{\tau}_2})/M_{\tilde{\tau}_2} = (\Delta(\sigma)/\sigma)(\beta^2)/3(1-\beta^2)$= 2.4 %, ie. $\Delta(M_{\tilde{\tau}_2}) = 3.6\ \mathrm{GeV}/c^2$
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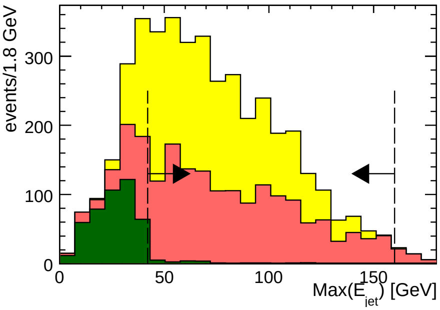

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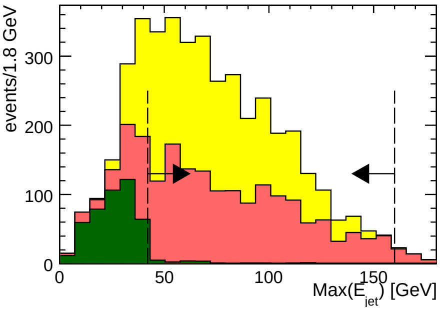

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- $\tilde{\tau}$ L-R mix $\otimes$ $\tilde{\chi}^0_1$ gaugino-higgsino mix $\rightarrow$ τ Polarisation
- Due to non-existance of ν_R, τ polarisation reflects in τ decay-product spectrum.

If $\tau \rightarrow \nu$+(pseudo)scalar:

- ν mostly backward/forward for τ_R/τ_L
- $\rightarrow$ Hard visible spectum: τ_R, Soft visible spectum: τ_L.
- *Absoulte* energy counts: Need to correct for ISR and beam-strahlung!

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- The events should pass the topology selection and anti-$\gamma\gamma$ cut.
- $E_{vis} < 90$ GeV.
- No jet with $E > 60$ GeV(43 GeV for ρ channel)

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

- At least one jets should contain a single particle.
- The particle should have a π-id (both calorimetric and dE/dx).
- Also kills remaining $\gamma\gamma$

Extract the $\tau \to \rho^{+-}\nu_\tau$ signal.

- At least one jets should contain one charged particle, and at least two neutrals.
- The charged particle should have a π-id (dE/dx only).
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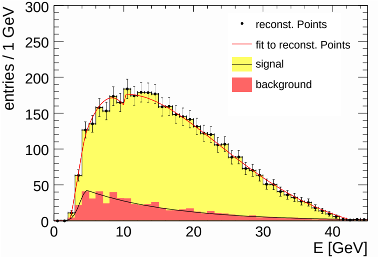
Bacground estimate

- SUSY dominates
- Assume $\Delta_{theor} = \Delta_{exp}$, with ILC as only relevant input.
- Δ_{exp} from signal-depleted control sample.
- Due to lack of statistics in the SM $\gamma\gamma$-sample, no serious estimate of uncertainty due to background can be done in the ρ-channel!



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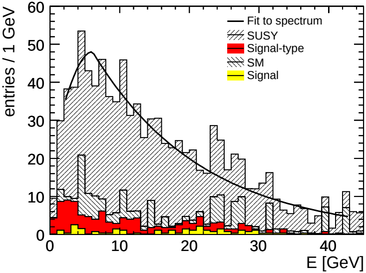

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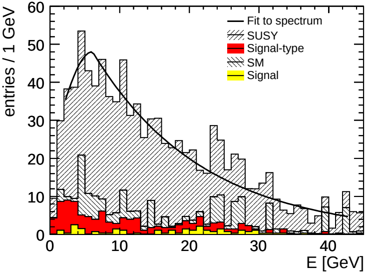

τ Polarisation

Efficency and spectrum correction:

- Select events.
- Fit background MC.
- Subtract this background estimate.
- Calculate efficiency correction:
  - $\epsilon(-1, E), \epsilon(0, E), \epsilon(+1, E)$ from fastsim.
- Spectrum (π channel only!)
  - 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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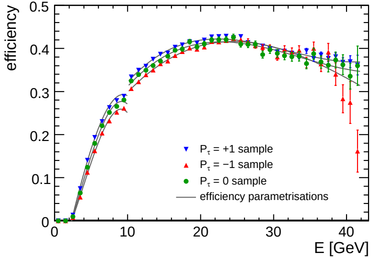

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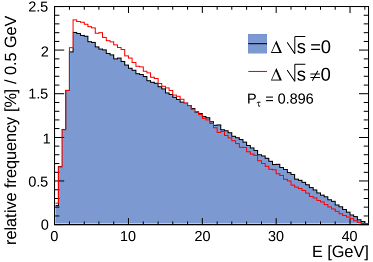

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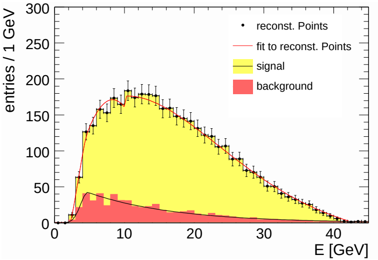

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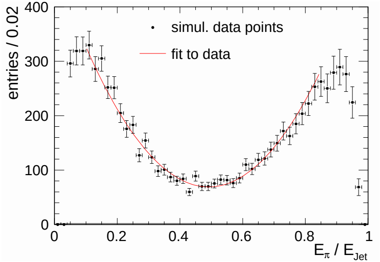

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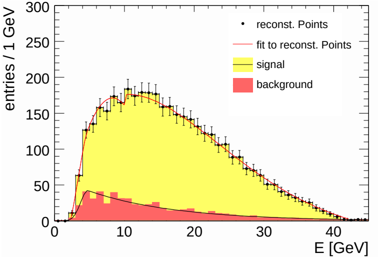

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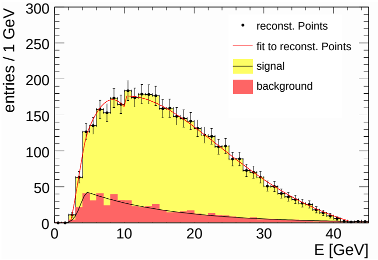

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Detector, machine, and simulation

- Detector requirements:
  - Low angle coverage.
  - PID
  - Resolution more than enough
- Machine
  - Can cope with background in RDR nominal.
  - Low P: Probably no issue for tracking.
  - But: more pairs at higher angles in BeamCal: worse low angle coverage (?)
  - And: less lumi in the peak(?). Of-peak lumi is *useless* for end point.
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Full simulation of $\tilde{\tau}$ production in SPS1a' in the ILD detector was presented

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- Beam-background included: decreases signal by %5, but also decreases (physics) background by 15 %.
- $E_{\tau,max} = 41.96^{+0.15}_{-0.13}$ GeV, $M_{\tilde{\tau}_1} = 107.69^{+0.03}_{-0.06} \oplus 1.1\Delta(M_{\tilde{\chi}^0_1})$ GeV
- $E_{\tau,max} = 151.2^{+1.9}_{-1.6}$ GeV , $M_{\tilde{\tau}_2} = 183^{+11}_{-5}$ GeV $\oplus 18\Delta(M_{\tilde{\chi}^0_1})$.
- $\Delta(\sigma_{\tilde{\tau}_1)=}$ 3.1 %, $\Delta(\sigma_{\tilde{\tau}_2)=}$ 4.2 %.
- $\mathcal{P}_\tau = 93 \pm 6 \pm 5\ (\mathrm{bgd}) \pm 3\ (\mathrm{SUSY masses})\%\ (\mathcal{P}_\tau = 87.0 \pm 3.4\%)$
- No mayor detector issues
- Need more channels, at different E_{cms} and polarisation.

Full account: arXiv:0908.0876 [hep-ex]/DESY 09-125 (submitted to Phys. Rev. D)

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