SUSY Precision Spectroscopy at the ILC

Mikael Berggren[1]

[1]DESY, Hamburg

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Outline

SUSY

You've heard about the theoretical aspects of SUSY in Gudi's talk before the break. What are the experimental problems to face ?

Generically:

- $e^+e^- \rightarrow \tilde{X}\bar{\tilde{X}} \rightarrow X\bar{X}\tilde{Y}\bar{\tilde{Y}}$
- $\tilde{Y}$ might be stable, or further decay, $\tilde{Y} \rightarrow Y\tilde{U}$.
- Finally, one ends up with SM particles, and a lightest SUSY particle, the LSP.

- If R-parity (RP) is conserved, the LSP is stable. From cosmology and cosmic rays, this particle must be neutral and un-coloured.
- Ie.: Experimentally, it's like a heavy neutrino.

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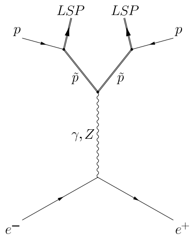

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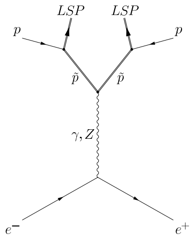

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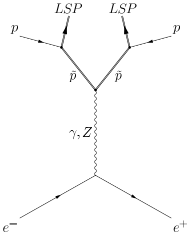

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SUSY signatures

Therefore:

- Conserved RP : Missing energy from the LSP, particle id of the SM products.
- Violated RP (RPV) : LSP *can* be charged and/or coloured, as the cosmological arguments evaporates. Odd signatures either a log-lived LSP, or an LSP that decays in the detector. *Won't talk about this*.

Furthermore:

- Amount of missing energy very important.
- Depends on the mass-difference between the last SUSY particle in the chain and the LSP.
- There is always an NLSP (Next to Lightest SUSY Particle), which is special:
    - It can only decay to it's SM partner and the LSP.
    - It can be pair-produced.

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SUSY signatures

So, what we look for and like to measure is:

- NLSP pairs $\Leftrightarrow$ Missing energy and momentum + pairs of the SM partner ($\tilde{\tau}_1$ gives τ, $\tilde{\mathrm{e}}$ gives e, $\tilde{\mathrm{t}}$ gives t gives jet, ...)
- Note:
  - Amount of missing stuff might span a wide range. Eg. small mass-difference between heavy sparticles gives large missing E, but little missing p.
  - If NLSP is a bosino, SM partner is a IVB, possibly far off-shell. At small mass differences, the set of SM particles might be non-obvious.
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- Real missing energy + pair of SM-particles = di-boson production, with neutrinos:
  - $WW \to \ell\nu\ell\nu$
  - $ZZ \to f\bar{f}\nu\nu$
- Fake missing energy + pair of SM-particles = $\gamma\gamma$ processes, ISR, single IVB.
  - $\mathrm{e^+e^-} \to e^+e^-\gamma\gamma \to e^+e^-f\bar{f}$, with both e^+e^- un-detected.
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IS there a signal for SUSY in the data?
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One needs to make a firm statement about this: Either that the signal is *excluded*, or *discovered*.

What exactly is in these two statements ?

Exclusion or Discovery ?

Two issues

1. What hypothesis H_0 is tested against what alternative H_1?
2. Which mistake is to be avoided?

- H_0: the signal is there, against H_1: only background.
- H_0: There is only background, against H_1: there is signal.

- Avoid rejecting H_0 if it is true (ie. avoid Type I error). P(Type I) = α, α is the *significance* of the test.
- Avoid not rejecting H_0 if it is false (ie. avoid Type II error). P(Type II) = 1 - β, β is the *power* of the test.

You want α to be small, and β to be large !

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Exclusion or Discovery ?

Which is which, and why ?

- For discovery, you want to take a very small risk to claim it, if it's not true.
- For exclusion, you want to take a moderately small risk both to claim that it is excluded, while it actually is there, and not to claim exclusion, if it is in fact not there.

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In both cases:

H_0 (the *null* hypothesis) should be what you *don't* hope to claim, ie. :

- Discovery: H_0 : there is no signal.
- Exclusion: H_0 : there is signal.

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Then choose α and construct your test, making sure that P(Type I error) = α. In the choice of α, don't bother about power in the discovery case, but keep it in mind for exclusion.

Exclusion

- H_0 : there is signal
- Under H_0, the number of selected events N $\in$ Po(S+B). Assume S+B large, so that N $\approx$ N(S+B,$\sqrt{S+B}$)
- Choose α such that P(Type I error) is low enough.
- Exclude H_0 if observed number of events $<$ c, where c is determined by α and the knowledge of the distribution of N.
- N $\in$ N(S+B,$\sqrt{S+B}$) $\Rightarrow$ c = S+B $-$ $\lambda_\alpha\sqrt{S+B}$. λ_α is the α-percentile of the Normal distribution.
- Power: P(Type II error) = 1-β = P(Background only > c). Background only $\in$ N(B,$\sqrt{B}$) $\Rightarrow$ $\beta = \Phi((c-B)/\sqrt{B})$
- So: Higher significance $\Rightarrow$ smaller α $\Rightarrow$ bigger λ_α $\Rightarrow$ smaller c $\Rightarrow$ smaller β $\Rightarrow$ lower power. Unavoidable dilemma !!!
- Compromise: Take moderately small α = 0.05 (CL = (1-α)100 % = 95 %). $\lambda_{5\%}$=1.64 (called "2σ" ...)
- Note that if S small, β small (=α if S = 0), If S big, β big. So, small signal $\Rightarrow$ low power, big signal $\Rightarrow$ high power.

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- N $\in$ N(B,$\sqrt{B}$) $\Rightarrow$ c = B + $\lambda_\alpha\sqrt{B}$. λ_α is the α-percentile of the Normal distribution.
- Power: P(Type II error) = 1 $-$ β = P(Signal+Background < c). Signal+Background $\in$ N(S+B,$\sqrt{S+B}$) $\Rightarrow$ $\beta = 1 - \Phi((c-(S+B))/\sqrt{S+B})$
- So: Higher significance $\Rightarrow$ smaller α $\Rightarrow$ bigger λ_α $\Rightarrow$ bigger c $\Rightarrow$ smaller β $\Rightarrow$ lower power. Unavoidable dilemma !!!
- But we don't care about power: Take very small α = 0.00005 (CL = (1-α)100 % = 99.99995 %). λ_α=5 ("5σ")

Exclusion or Discovery ?

Note the differences !!

Discovery	Exclusion
$\sigma = \sqrt{B}$	$\sigma = \sqrt{S+B}$
Critical region has upper limit.	Critical region has lower limit.
Critical region is average plus something.	Critical region is average minus something.
High confidence.	Modest confidence.

- If S is large: The (unlikely) outcome that the signal is *both* excluded and discovered is possible !
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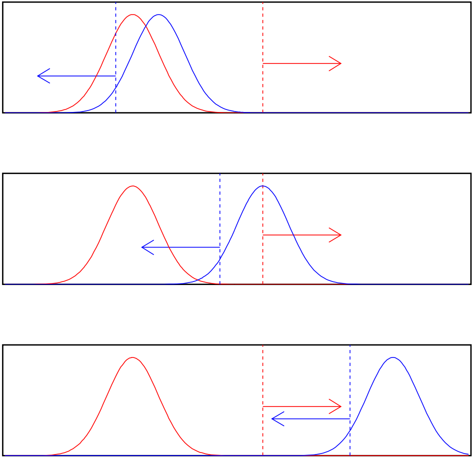
Exclusion or Discovery: Graphical summery

Red: Background only, Blue: Backgrond+Signal. Exclude if observed number in the “arrow” region !



Observables

So, supose we have observed SUSY. What kind of numbers can we extract from the data ?

- Two-body decays: spectra w/ end-points
  - Function of the masses and E_{CMS}.
- Cross-section in continuum
  - Function of mass of produced sparticle , it's mixing, and of E_{CMS} and beam polarisation.
- Angular distribution of seen stuff
  - Function of sparticle spin, mass, s vs. t-channel and E_{CMS}.
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Let's look in detail on pair-production of spartciles which then undergo two-body decays:

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    $\lambda(M_X^2, M_Y^2, M_U^2)/(2M_X)^2$ (λ=Källén function)
  - If M_Y small : $p_Y = (M_X^2 - M_U^2)/2M_X$

Observables: Pair-production, two-body decay

- Lorentz-transform from rest-frame to lab-frame (' system):
  - $E'_Y = \gamma E_Y + \gamma\beta p_{//}$
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  - Therefore: $f_V(v) = \frac{d}{dv}F_V(v) = \frac{d}{dv}(v-1)/2 = 1/2$, ie. a constant.
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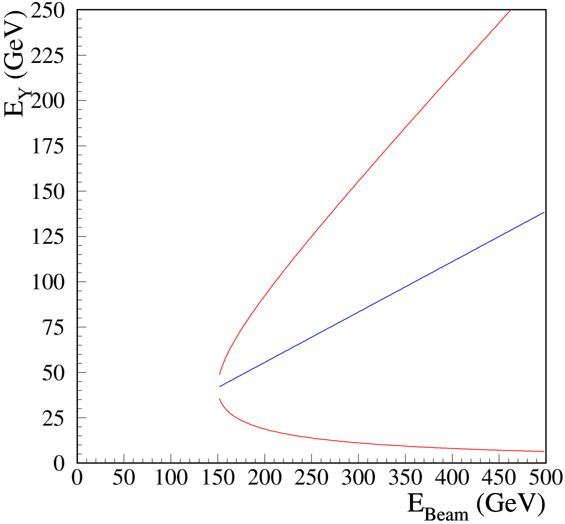
Graphically, for M_X = 150 GeV, M_U = 100 GeV.



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- So, there are two SUSY parameters, and two independent observables in the spectrum.
- Any pair of observables can be chosen, edges, average, standard deviation, width, ...
- Which choice is the best depends on the situation.
- Just a bit of algebra to extract the two SUSY masses.
- Note that if $E_{beam} >> M_X$, there is just one observable (low edge becomes 0, width becomes average/2), so one should not operate too far above threshold !
- Note that there are two decays in each event: two measurements per event.
- Also note that there are not enough measurements to make a constrained fit, even assuming that the two SUSY particles in the two decays are the same: (2×4 unknown components of 4-momentum (=8)) - (total E and p conservation (=4) + 2 equal-mass constraints) = 2 remaining unknowns.

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- If the masses are known from other measurements, there are enough constraints.
- Then the events can be completely reconstructed ...
- ... and the angular distributions both in production and decay can be measured.
- From this the spins can be determined, which is essential to determine that what we are seeing is SUSY.

Furthermore:

- Looking at more complicated decays, such as cascade decays, there are enough constraints if some (but not all) masses are known.
- Allows to reconstruct eg. the slepton mass in $\tilde{\chi}_2^0 \to \tilde{\ell}\ell \to \ell\ell\tilde{\chi}_1^0$ if chargino and LSP masses are known.
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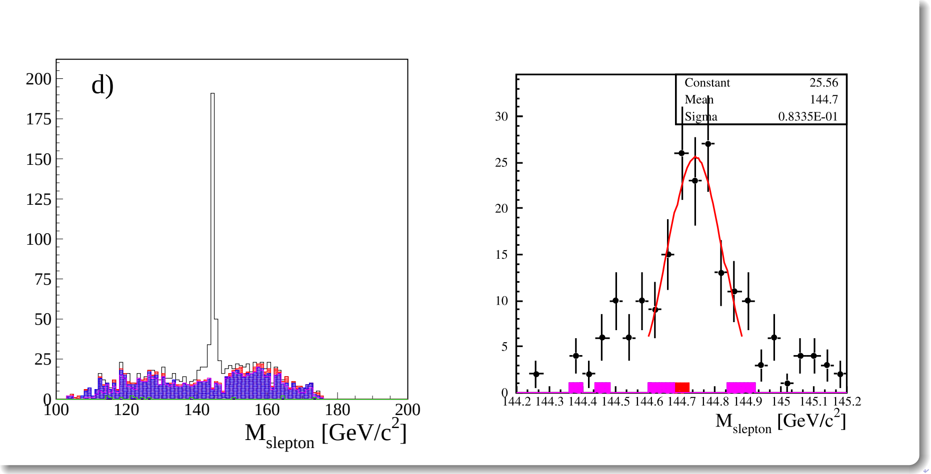

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But this is not all !

- The cross-section in $\mathrm{e}^+\mathrm{e}^- \rightarrow XX$ close to threshold depends both on coupling and kinematics.
- Kinematics means β, and β is $\sqrt{1-\left(\frac{M_X}{E_{Beam}}\right)^2}$, ie. depends on M_X, but not on what X decays to, ie not on M_Y or M_U.
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- Therefore, the cross-section also depends on the mixing between L and R components. $\tilde{\tau}$, $\tilde{\mathrm{t}}$ and $\tilde{\mathrm{b}}$ are likely to be mixed, the bosinos almost certainly are.
- For a given state the cross-section is different for different beam-polarisations.
- So checking how much the cross-section changes when switching beam-polarisations measures mixing.

Furthermore:

- If one can measure the helicity of the SM particle, one gets a handle of the properties of the particles in the decay, ie. in addition to the produced X, also the invisible U.
- In one case this is possible: In $\tilde{\tau} \to \tau\tilde{\chi}_1^0 \to X\nu_\tau\tilde{\chi}_1^0$, the spectrum of X gives information of the spin of the τ (since there is no such thing as a right-handed ν_τ).

Observables: Summary

For masses:

- Measure energy and directions of SM particles.
- Might mean leptons or jets or specific hadrons or IVB (on- or off-shell). Separate W and Z!
- Need to know E_{CMS}
- Try to keep spectrum shape under control. Both for end-points and position.
- Don't be too far from threshold.
- Specific problem: Low edge hidden in background ?

For cross-section:

- Need to know overall efficiency
- ... and background.

For mixing:

- Need to know beam-polarisation.
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Measurement requirements

- Precision: Measurement errors, Initial conditions uncertainty, Background part of observables.
- Accuracy: Systematic effects in method and conditions.
- Usually too many unknowns for kinematic constraints $\Rightarrow$ For leptons or far off-shell W or Z , uncertainty from beam-spectrum larger than measurement errors.
- NB: special cases (cascades with sleptons). Here momentum measurement might be an issue (momentum resolution).
- For fully hadronic W or Z, jet energy resolution is important.
- To fight fake missing E and P from $\gamma\gamma$ and single IVB:s, hermeticity is extremely important. Not only for $e^{\pm}$ and γ:s, but also muons and hadrons.
- For model testing, theoretical uncertainties important - not the topic in this lecture!

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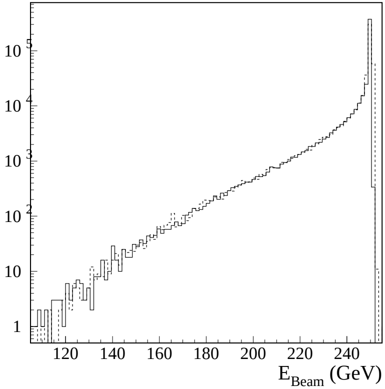
Machine issues

Cf. Nick's talk this morning !

- Beam-spectrum for e^+ beam (solid) and e^- beam (dashed).
- e^- beam is wider due to ondulator.
- Beam-strahlung: Strong EM fields of one beam acting on the other one:
  - Syncrotron radiation.
  - Can back-scatter $\Rightarrow \gamma$ component of beam.
  - Or pair-create $\Rightarrow$: pairs-background.
  - Particles with "wrong" charge gets kicked out of the beam, and hits the forward instrumentation.



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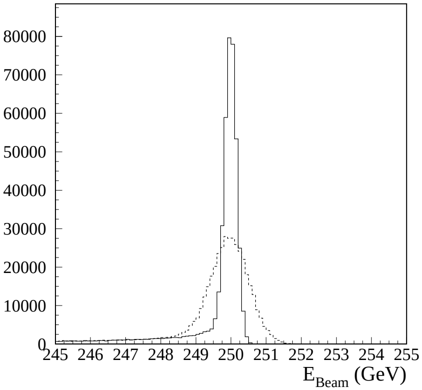

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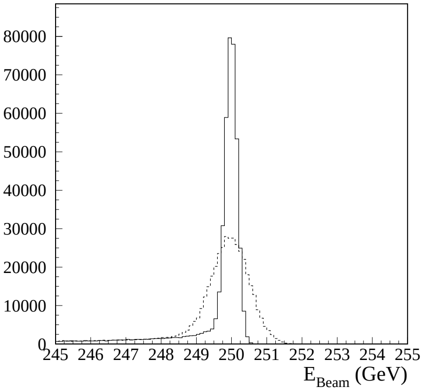

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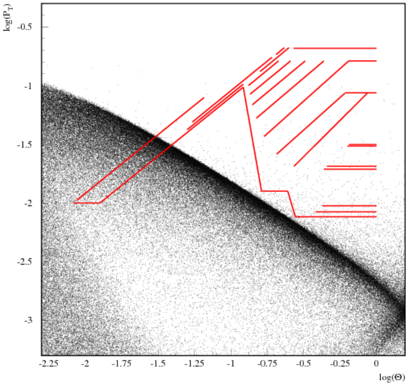

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- Tracking: VXD, SIT, TPC, VFT.
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  - Good enough for SUSY.
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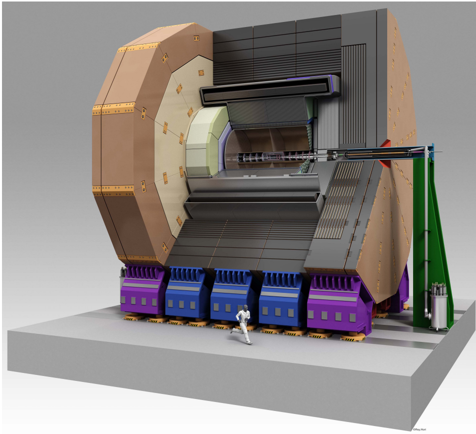

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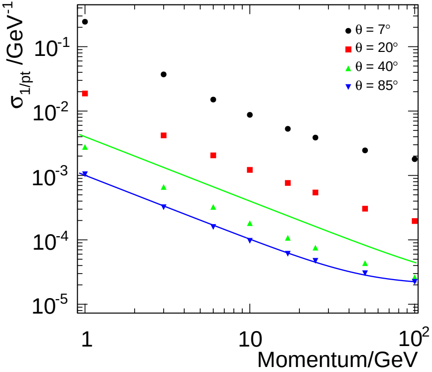

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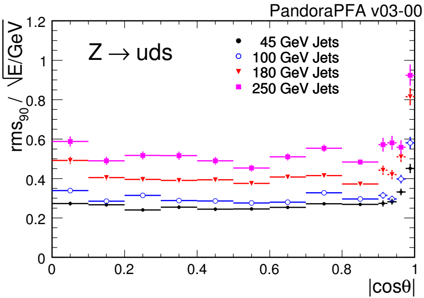

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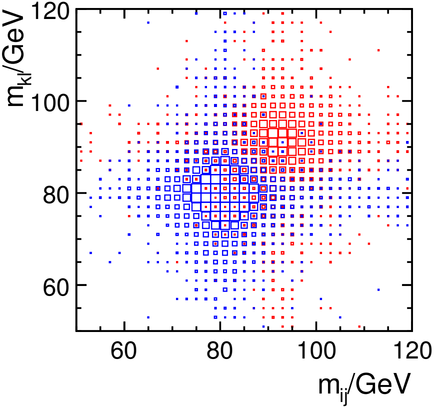

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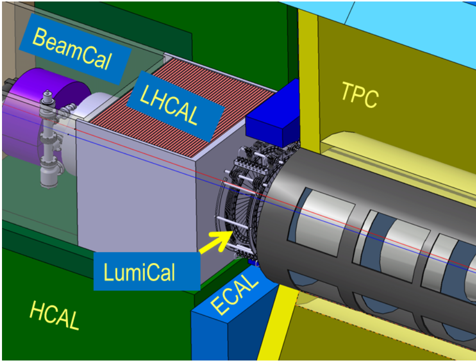

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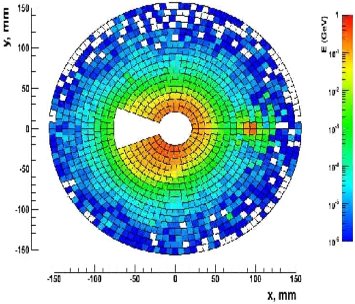

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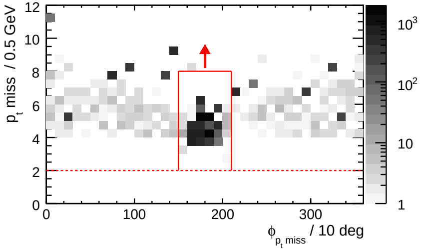


Example: SPS1a'/STC4

STC4-8

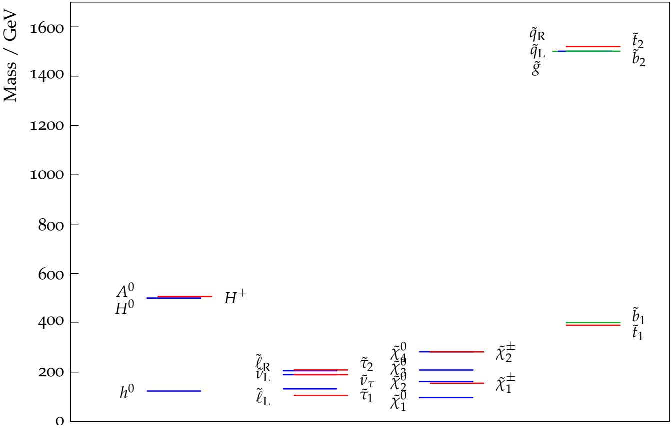
- 11 parameters.
- Separate gluino
- Higgs, un-coloured, and coloured scalar parameters separate

Parameters chosen to deliver all constraints (LHC, LEP, cosmology, low energy).
At E_{CMS} = 500 GeV:

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

(For SPS1a', see J. List, P. Bechtle, P. Schade, M.B., PRD 82,no5 (2010), arXiv:0908.0876)

STC4 mass-spectrum



Features of SPS1a'/STC4

- In SPS1a' and the STC points, the $\tilde{\tau}_1$ is the NLSP.
- For $\tilde{\tau}_1$: $E_{\tau,min} = 2.6\,\mathrm{GeV}$, $E_{\tau,max} = 42.5\,\mathrm{GeV}$:
  $\gamma\gamma - background \Leftrightarrow pairs - background$.
- For $\tilde{\tau}_2$: :$E_{\tau,min} = 35.0\,\mathrm{GeV}$, $E_{\tau,max} = 152.2\,\mathrm{GeV}$:
  $WW \rightarrow l\nu l\nu - background \Leftrightarrow Polarisation$.
- $\tilde{\tau}$ NLSP $\rightarrow$ τ:s in most SUSY decays $\rightarrow$ SUSY is background to SUSY.
- For pol=(-1,1): $\sigma(\tilde{\chi}^0_2\tilde{\chi}^0_2)$ and $\sigma(\tilde{\chi}^+_1\tilde{\chi}^-_1)$ = several hundred fb and BR(X$\rightarrow \tilde{\tau}$) $>$ 50 %. For pol=(1,-1): $\sigma(\tilde{\chi}^0_2\tilde{\chi}^0_2)$ and $\sigma(\tilde{\chi}^+_1\tilde{\chi}^-_1) \approx 0$.
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- For $\tilde{\mathrm{e}}_\mathrm{R}$or $\tilde{\mu}_\mathrm{R}$: :$E_{l,min} = 6.6\,\mathrm{GeV}$, $E_{l,max} = 91.4\,\mathrm{GeV}$: Neither $\gamma\gamma$ nor $WW \rightarrow l\nu l\nu$ background severe.

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Extracting the $\tilde{\tau}$ properties

See Phys.Rev.D82:055016,2010

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

From decay kinematics:

- $M_{\tilde{\tau}}$ from $M_{\tilde{\chi}_1^0}$ and 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. ($\tilde{\mu}$, $\tilde{\mathrm{e}}$, ...)

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 $M_{\tilde{\chi}_1^0}$!

From decay spectra:

- $\mathcal{P}_\tau$ from exclusive decay-mode(s): handle on mixing angles $\theta_{\tilde{\tau}}$ 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 = $\pm$ 1,
- $M_{jet} < 2.5\ \mathrm{GeV}/c^2$,
- $E_{vis} < 300\ \mathrm{GeV}$,
- $M_{miss} > 250\ \mathrm{GeV}c^2$,
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$\tilde{\tau}_1$ and $\tilde{\tau}_2$ further selections

- $\tilde{\tau}_1$:
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- $\tilde{\tau}_2$:
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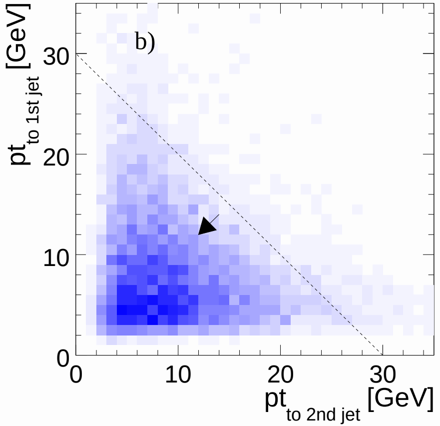
  - Cut on Signal-SM LR of $f(q_{jet1}\cos\theta_{jet1}, q_{jet2}\cos\theta_{jet2})$

Efficiency 15 (22) %



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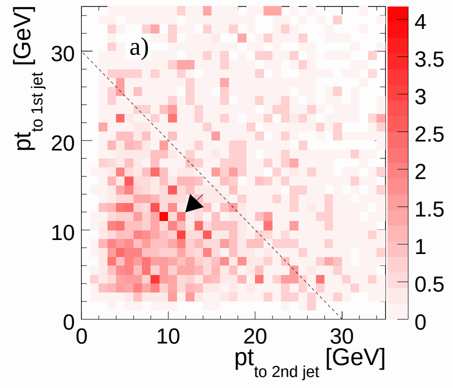

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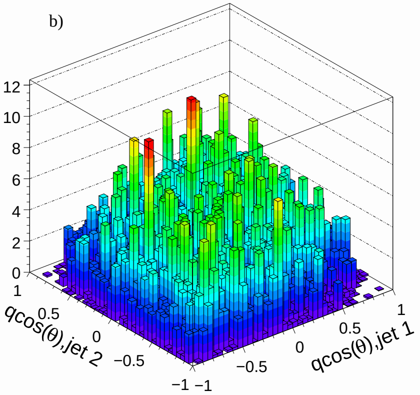

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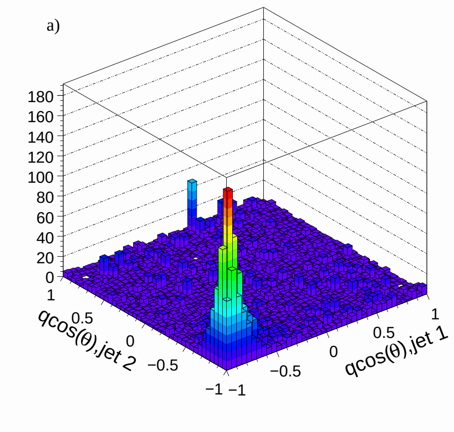
  - Cut on Signal-SM LR of f$(q_{jet1} \cos\theta_{jet1}, q_{jet2} \cos\theta_{jet2})$

Efficiency 15 (22) %



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

- $\tilde{\tau}_1$:
  - $(E_{jet1} + E_{jet2}) \sin\theta_{acop} < 30$ GeV.
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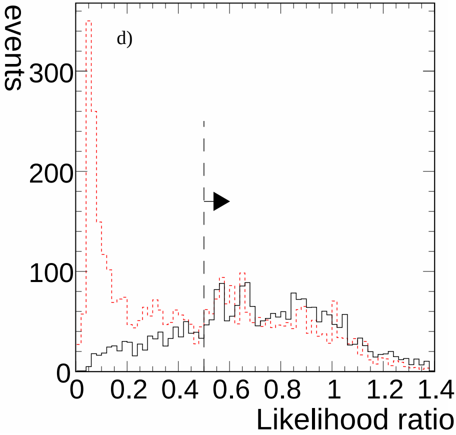

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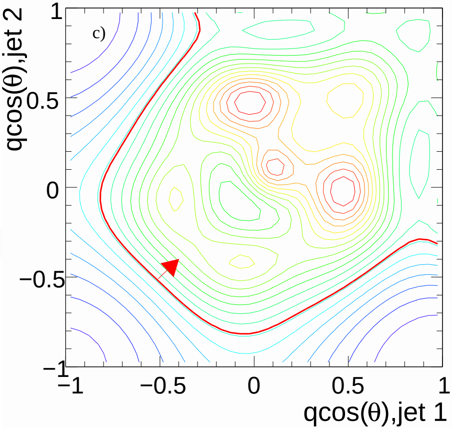

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Fitting the $\tilde{\tau}$ mass

- Only the upper end-point is relevant.
- Background subtraction:
  - $\tilde{\tau}_1$: Important SUSY background,but region above 45 GeV is signal free. Fit exponential and extrapolate.
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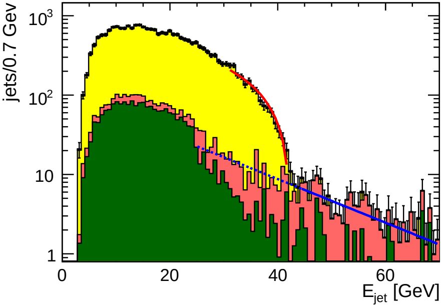

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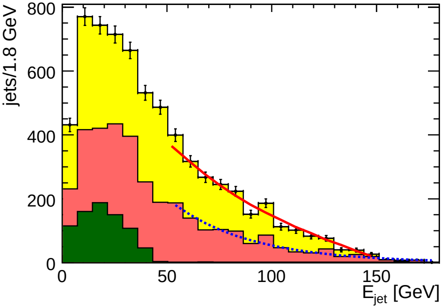

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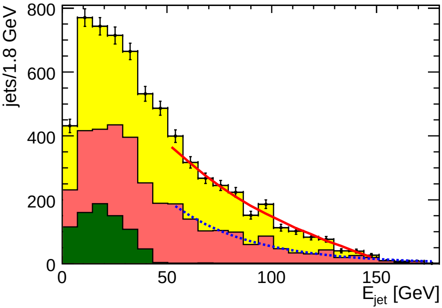

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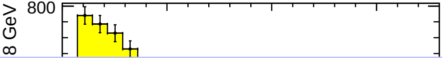

Results for $\tilde{\tau}_1$

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

Results for $\tilde{\tau}_2$

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

- Fit line to (data-background fit).

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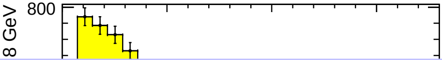
  - $\tilde{\tau}_2$: no SUSY background



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

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

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 $\rightarrow \Delta(M_{\tilde{\chi}^0_1}) = 1.7\mathrm{GeV}/c^2$

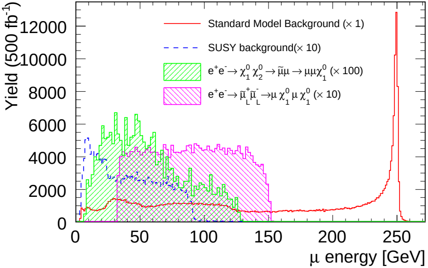
- Fit line to (data-background fit).

$\tilde{\mu}$ channels

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

- $\tilde{\mu}_{\mathrm{L}}\tilde{\mu}_{\mathrm{L}} \rightarrow \mu\mu\tilde{\chi}^0_1\tilde{\chi}^0_1$
- $\tilde{\chi}^0_1\tilde{\chi}^0_2 \rightarrow \mu\tilde{\mu}_{\mathrm{R}}\tilde{\chi}^0_1 \rightarrow \mu\mu\tilde{\chi}^0_1\tilde{\chi}^0_1$

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



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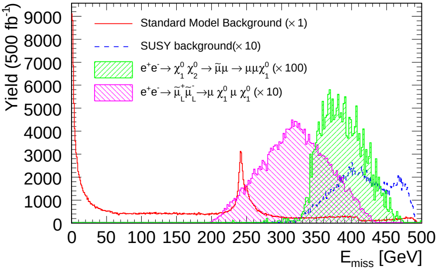

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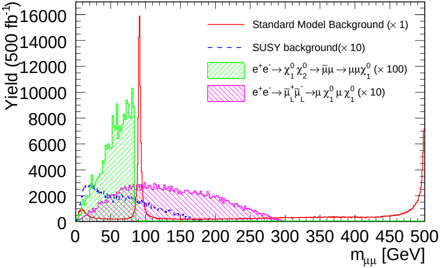
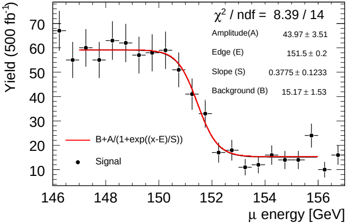


$\tilde{\mu}_L\tilde{\mu}_L$

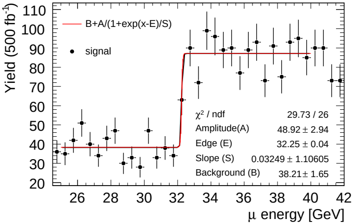
Selections

- $\theta_{missingp} \in [0.1\pi; 0.9\pi]$
- $E_{miss} \in [200, 430]\mathrm{GeV}$
- $M_{\mu\mu} \notin [80.100]\mathrm{GeV}$ and > 30 GeV/c^2

Masses from edges. Beam-energy spread dominates error.



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



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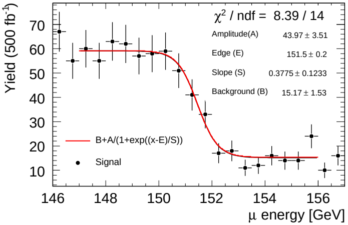

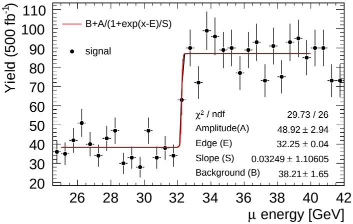

$\tilde{\chi}_1^0\ \tilde{\chi}_2^0$

Selections

- $\theta_{missingp} \in [0.2\pi; 0.8\pi]$
- $p_{Tmiss} > 40\mathrm{GeV}/c$
- β of μ system > 0.6.
- $E_{miss} \in [355, 395]\mathrm{GeV}$

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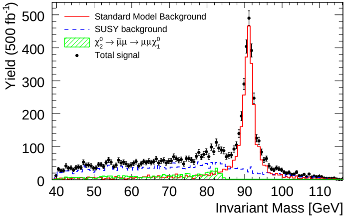
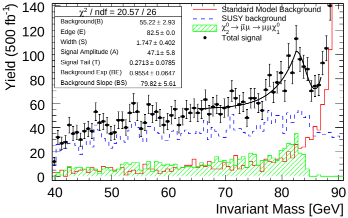
$\Delta(M_{\tilde{\chi}_2^0}) = 1.38\mathrm{GeV}/c^2$





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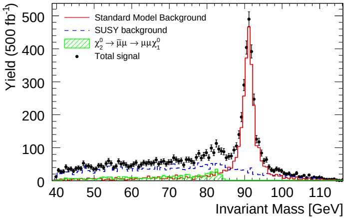

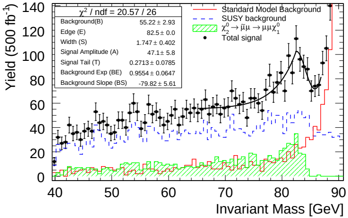

$\tilde{\mu}_{\mathrm{R}}$ threshold scan

From these spectra, we can estimate $M_{\tilde{\mathrm{e}}_{\mathrm{R}}}$, $M_{\tilde{\mu}_{\mathrm{R}}}$ and $M_{\tilde{\chi}^0_1}$ to < 1 GeV.

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So: Next step is $M_{\tilde{\mu}_{\mathrm{R}}}$ from threshold:

- 10 points, 10 fb^{-1}/point.
- Luminousity $\propto E_{CMS}$, so this is $\Leftrightarrow$ 170 fb^{-1} @ E_{CMS}=500 GeV.

Error on $M_{\tilde{\mu}_{\mathrm{R}}}$ = 197 Mev

$\tilde{\mu}_R$ threshold scan

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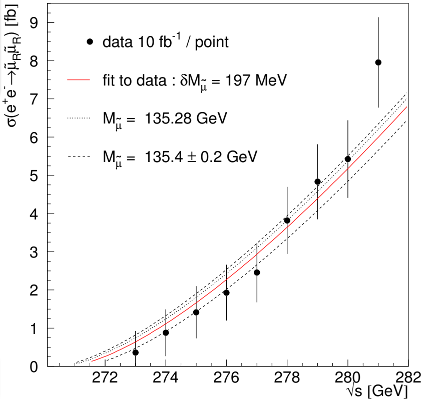

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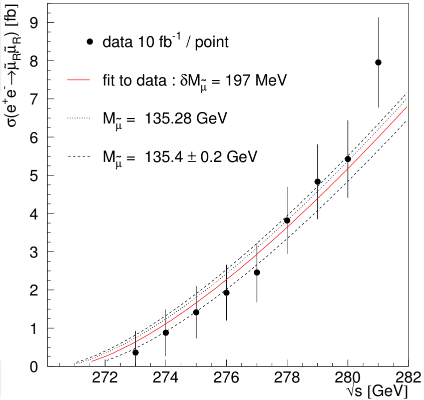
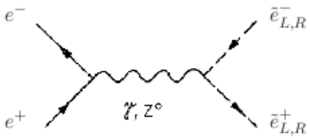
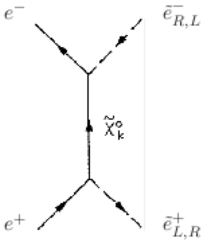


Polarisation and Near Degenerate ẽ

Super-symmetry associates scalars to chiral (anti)fermions

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





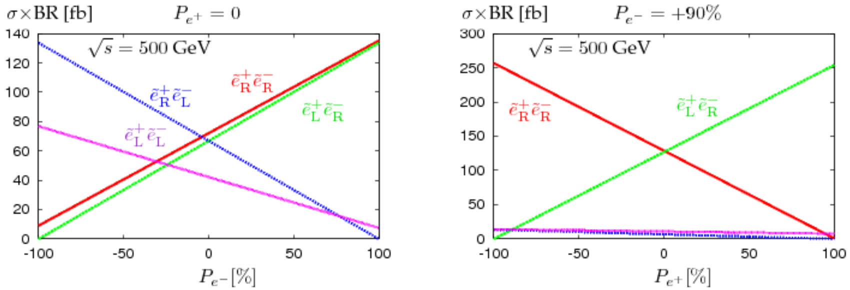
What if $M_{\tilde{e}_L} \approx M_{\tilde{e}_R}$, so that thresholds can't separate $e^+e^- \to \tilde{e}_L\tilde{e}_L, \tilde{e}_R\tilde{e}_R$ and $\tilde{e}_R\tilde{e}_L$?

Polarisation and Near Degenerate $\tilde{e}$

Model: SPS1a' like, but:

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

Even with $P_{e^-} \geq +90\%$, one can't disentangle the pairs $\tilde{e}_L^+ \tilde{e}_R^-$ and $\tilde{e}_R^+ \tilde{e}_R^-$': Ratio of the cross sections $\approx$ constant.



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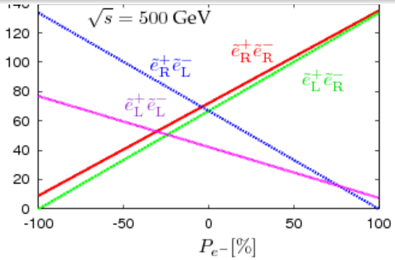
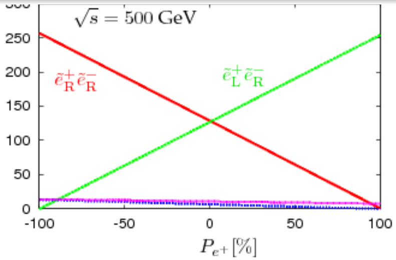
Polarised positrons a must !





Polarisation and Near Degenerate $\tilde{e}$

The handle:
Opposite polarisation beams produces $\tilde{e}$:s in both s- and t-channel.
Same polarisation produces $\tilde{e}$:s in t-channel only $\Rightarrow$

Modification of Θ distribution with changed positron polarisation

However, the effect is small since t-channel always dominates ! $\tilde{e}$:s are heavy (and are scalars) $\Rightarrow$ t- and s- channel kinematic distributions of the electrons are not very different.
Need to reconstruct the $\tilde{e}$ direction:

- 8 Unknown $\tilde{\chi}_1^0$ momentum components
- Assume $M_{\tilde{e}}$ and $M_{\tilde{\chi}_1^0}$ known $\rightarrow$
- 8 constraints (E and p conservation, 4 mass-relations)

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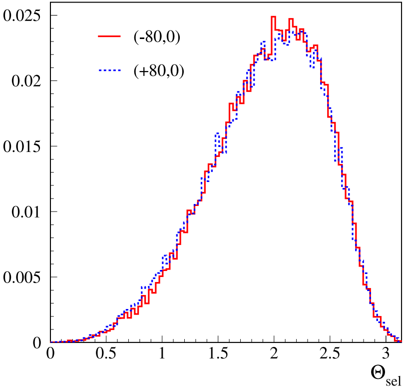
Analyse assuming 100 fb^{-1} for each of the polarisations configurations.

- For $P(e^-) = \pm 80$ % $P(e^+) = 0$ and then ..
- ... for $P(e^-) = +80$ % and $P(e^+) = \pm 22$ % or ...
- $P(e^+) = \pm 30$ % or ...
- $P(e^+) = \pm 60$ % .



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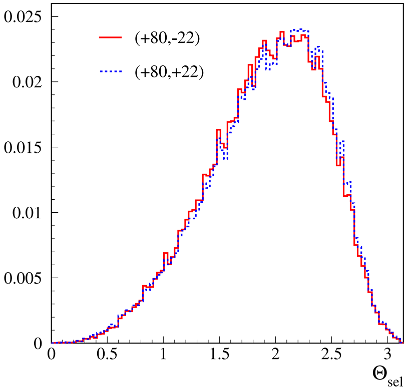

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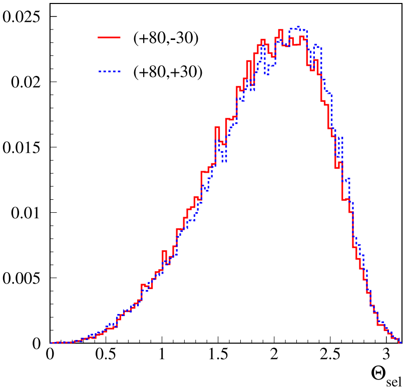

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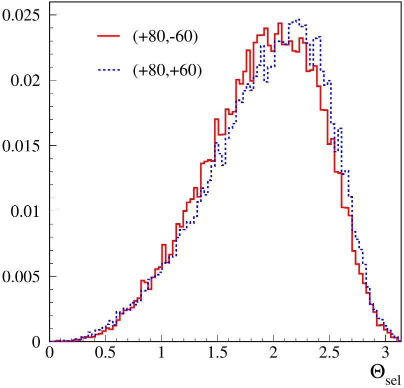
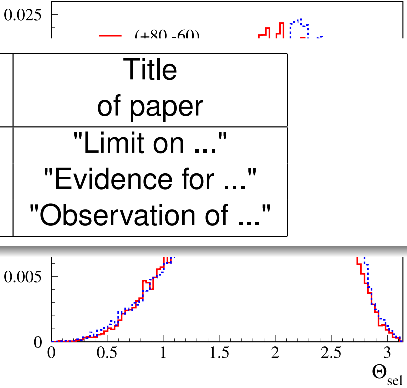


Polarisation and Near Degenerate $\tilde{e}$

Analyse assuming 100 fb^{-1} for each of the polarisations configurations.

- For $P(e^-) = \pm$ 80 % $P(e^+) = 0$



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

Conclusions

If indeed SUSY is kinematically accessible, the ILC is the ideal place to study it.

- Lepton-collider: Initial state is known.
- Production is EW $\Rightarrow$
  - Small theoretical uncertainties.
  - No “underpaying event”.
  - Low cross-sections also for background.
  - Trigger-less operation, so that even very soft stuff will be on tape.
- Many observables accessible: Spectra, angular distributions, total and differential cross-sections, branching ratios, ...
- Often measurable to permil level.
- I’ve shown as an example what can be measured in the STC4 bench-mark. Please check out other cases presented this week:
  - Hale Sert (Thursday 16:30): Very low $\Delta(M)$ higgsino production.
  - Madalina Chera (Friday 11:30): Bosinos decaying to on-shell IVB.

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