Prospects for $\tilde{\tau}$ searches and measurements at the ILC

Teresa Núñez - DESY

- SUSY and SUSY searches
- Motivation of $\tilde{\tau}$ studies
- Limits at LHC and LEP
- $\tilde{\tau}$ searches at the ILC
- Prospects for $\tilde{\tau}$ measurements at the ILC
- Outlook and conclusions

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Physics at the Terascale, 23-11-21

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Supersymmetry

One of the promising candidates for new Physics

Symmetry of spacetime relating fermions and bosons

Considerable effort searching for SUSY at LHC and LEP

LHC

- Mainly sensitive to production of coloured particles, most probably the heaviest ones
- Limits only valid if many dependencies between the model parameters are full filled

- High sensitivity for production of colour-neutral states, but limited by the energy
- Limits are valid for any value of the model parameters not shown in the exclusion plots

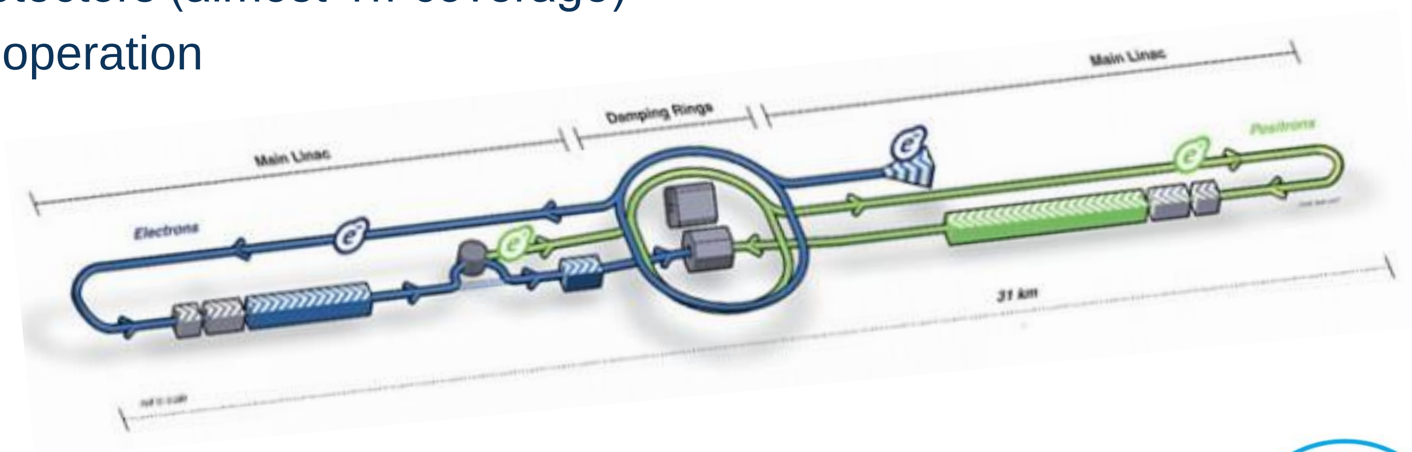
LEP

Not evidence of SUSY up to now, exclusion/discovery limits set

Supersymmetry at ILC

ILC ideal environment for SUSY studies

- Electron-Positron collider at $\sqrt{s}$ = 250-500 GeV with energy upgradability (1TeV)
- Electrons (+/- 80%) and positrons (+/- 30%) polarisations
- Well defined initial state: 4-Momentum and spin configuration
- Clean and reconstructable final state (near absence of pile-up)
- Hermetic detectors (almost 4π coverage)
- Triggerless operation



Triggerless operation -> huge advantage for precision measurements and unexpected signatures

Motivation for $\tilde{\tau}$ searches

Searching SUSY focused on best motivated NLSP candidates and most difficult scenarios

$\tilde{\tau}$ satisfies both conditions

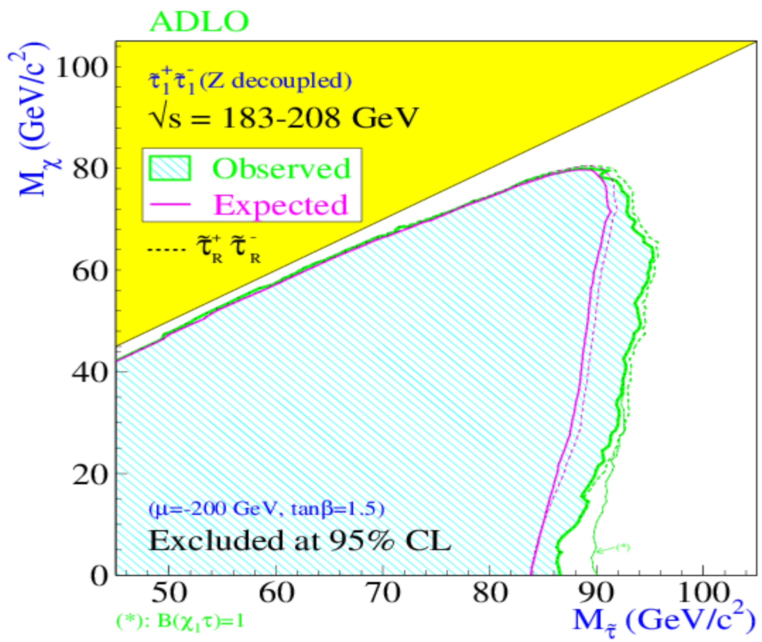
Scalar superpartner of τ-lepton

- Two weak hypercharge eigenstates ($\tilde{\tau}_R$, $\tilde{\tau}_L$) not mass degenerate
- Mixing yields to the physical states ($\tilde{\tau}_1$, $\tilde{\tau}_2$), the lightest one being with high probability the lightest sfermion (stronger trilinear couplings)
- With assumed R-parity conservation:
  - pair produced (s-channel via Z^0/γ exchange, lowest σ with no coupling to Z^0)
  - decay to LSP and τ, implying more difficult signal identification than the other sfermions

SUSY models with a light $\tilde{\tau}$ can accommodate the observed relic density ($\tilde{\tau}$ - neutralino coannihilation)

Limits at LHC and LEP

$\tilde{\tau}$ searches at LEP



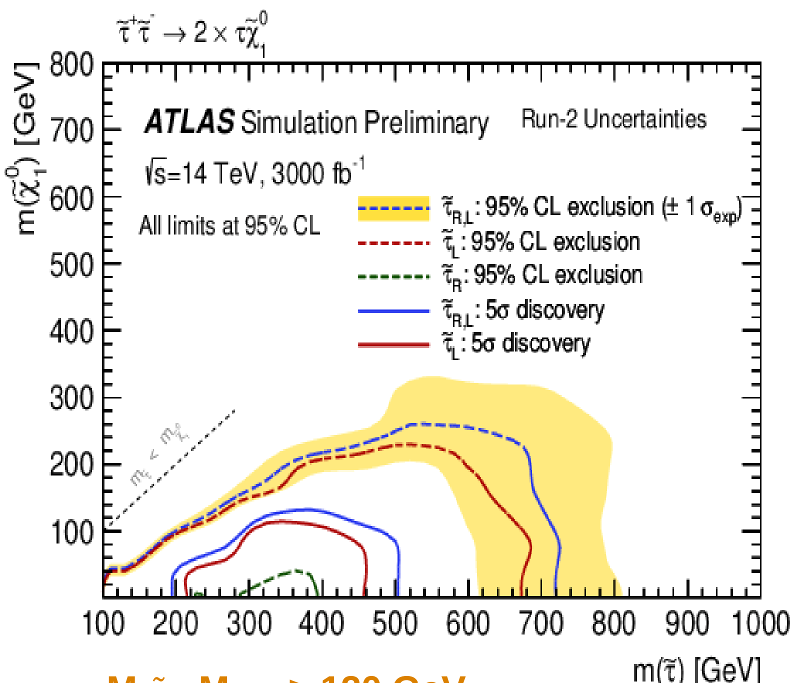
- $\sqrt{s}$ = 183-208 GeV
- Combined four LEP experiments data

LEPSUSYWG/04-01.1

Valid for any mixing and any values of the not shown parameters

Limits at LHC and LEP

$\tilde{\tau}$ prospects at HL-LHC



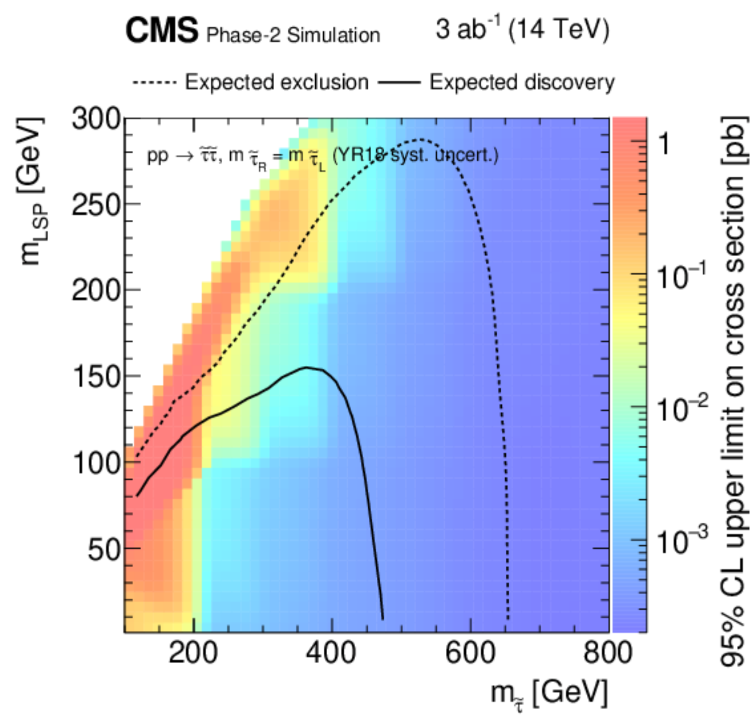
M $\tilde{\tau}$ - M_{LSP} > 120 GeV

ATL-PHYS-PUB-2018-048

Expected gain in sensitivity to direct $\tilde{\tau}$ production

- Two models: $\tilde{\tau}_R$ *and* $\tilde{\tau}_L$
- No mixing

- Two $\tilde{\tau}$ assumed to be mass-degenerate
- No mixing



No discovery potential for $\tilde{\tau}$ coannihilation scenarios or $\tilde{\tau}_R$ pair production

CMS PAS FTR-18-010

ILC Study: conditions and tools

$\tilde{\tau}$ searches in worst scenario using SGV fast simulation

- Mixing angle set to 53 degrees (lowest cross sections)
- Focused on small mass differences ($\Delta M < 11$ GeV)
- Cross-check larger mass differences

Previous preliminary study

ILC experimental conditions

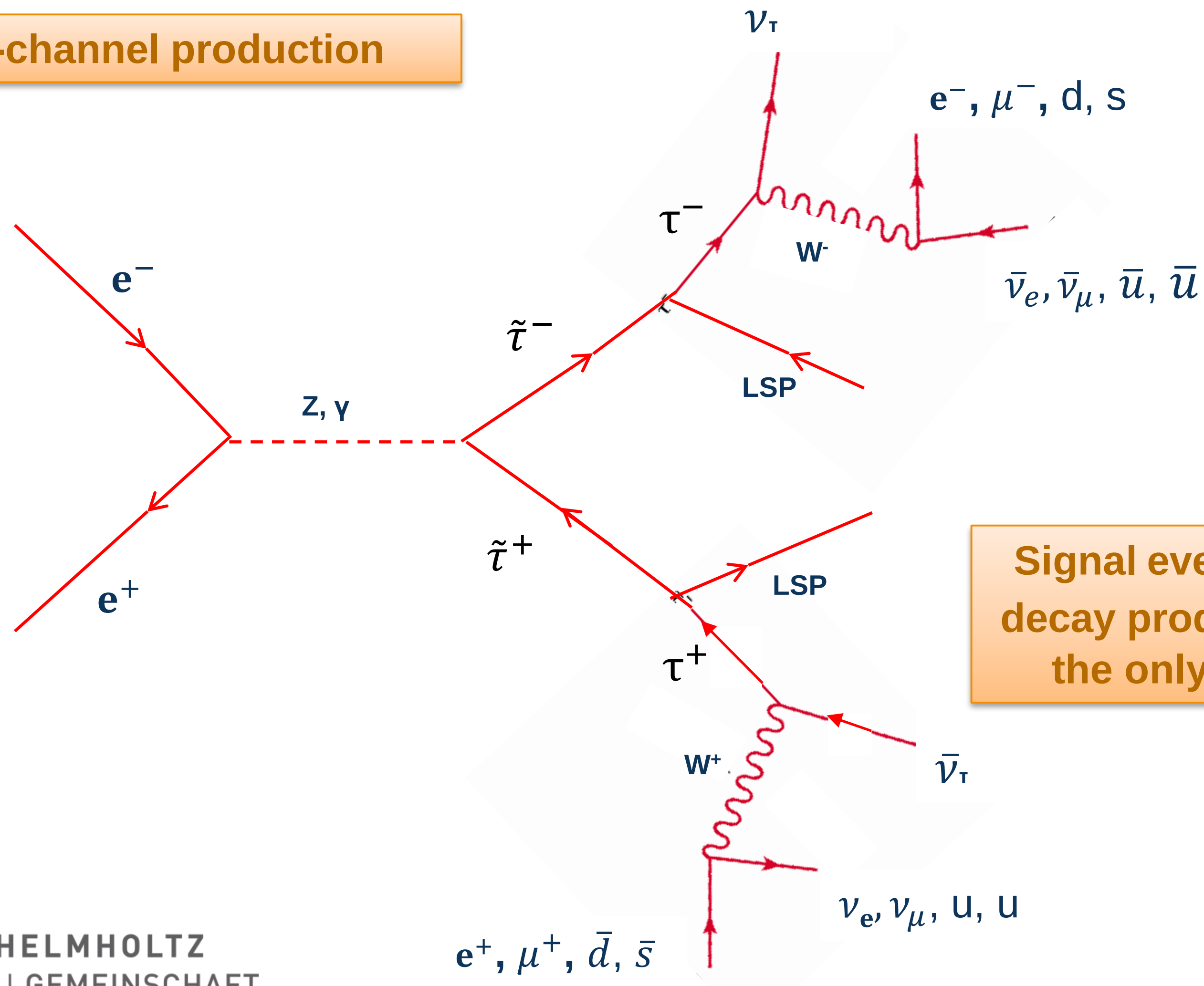
- Polarization $P(e^-,e^+)=(+80\%,-30\%)$
- $\sqrt{s}$ = 500 GeV with 1.6 ab^{-1} integrated luminosity (H-20, I-20 ILC500)

Event reconstruction using SGV adapted to the ILD detector concept at ILC

- Signal: Phytia 6.422
- Background: Whizard 1.95 (standard "DBD" background samples)
- No signal in the calorimeter closest to the beam pipe (the BeamCal)

Signal characterization

s-channel production



Signal events with the (visible) decay products of two τ's being the only detectable activity

Signal characterization (ctd.)

Signature:

- large missing energy and momentum
- high acollinearity, with little correlation to the energy of the decay products
- large fraction of detected activity in central detector (isotropic production of scalar particles)
- unbalanced transverse momentum
- no forward-backward asymmetry

Background

SM processes with real or fake missing energy

Irreducible

4-fermion production with two of the fermions being neutrinos and two leptons

- $ZZ \to \nu\nu\ \tau\tau$, $WW \to \nu\tau\ \nu\tau$

Almost irreducible

- $ee \to \tau\tau$, $ZZ \to \nu\nu\ ll$, $WW \to l\nu\ l\nu$ (l = e or μ)
- $ee \to \tau\tau$ + ISR, $ee \to \tau\tau\ ee$, $\gamma\gamma \to \tau\tau$

Mis-identification of τ´s or of missing momentum

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General cuts

Properties $\tilde{\tau}$ -events "must" have

Well known initial state
Hermeticity

- Missing energy (E_{miss}). $E_{miss} > 2 \times M_{LSP}$ GeV
- Visible mass (m_{vis}). $m_{vis} < 2 \times (M_{\tilde{\tau}} - M_{LSP})$ GeV
- Momentum of all jets (p_{jet}). $p_{jet} <$ 70% Beam Momentum (or $M_{\tilde{\tau}}/M_{LSP}$ dependent)

- Two well identified τ's and little other activity

Clean final state
('no' pile-up)

Above 95 % signal efficiency for each of these cuts
(excluding for the τ-identification)

- Maximum jet momentum:

$$P_{max} = \frac{\sqrt{s}}{4}\left(1 - (\mathrm{MLSP}/M_{\tilde{\tau}})^2\right)\left(1 + \sqrt{1 - \frac{4M_{\tilde{\tau}}^2}{s}}\right)$$

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General cuts (ctd.)

Properties $\tilde{\tau}$ -events "might" have, but background "rarely" has

- Missing transverse momentum
- Large acoplanarity
- Large transverse momentum wrt. thrust-axis
- High angles to beam

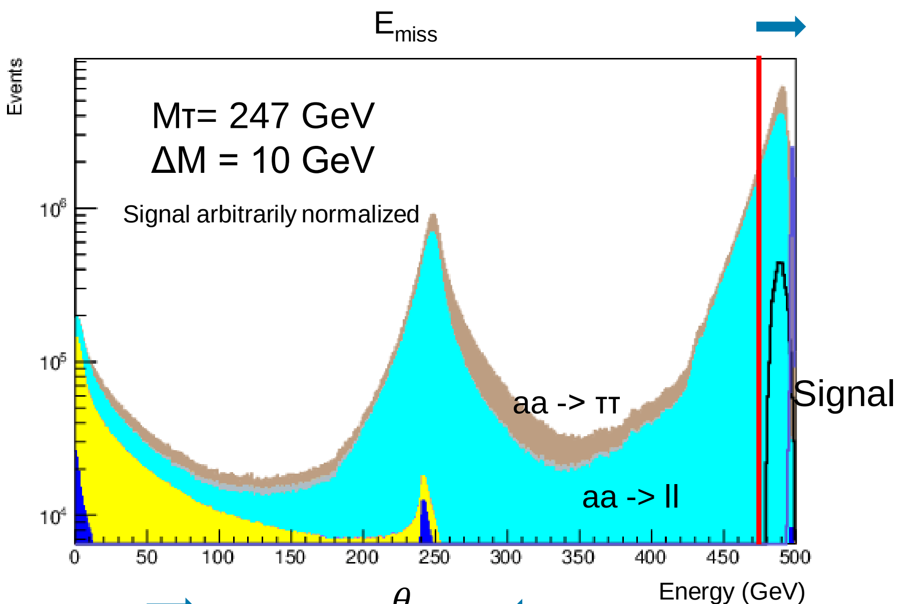
Cuts against properties of irreducible sources of background

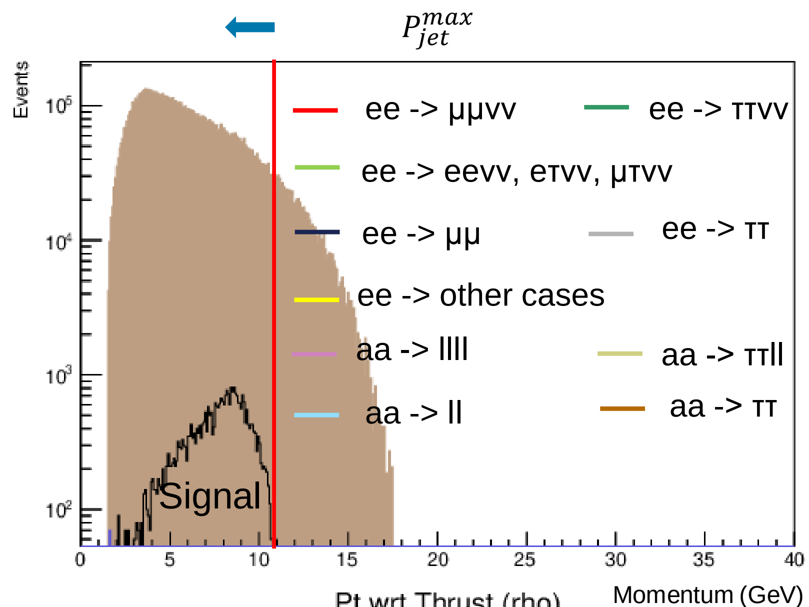
- Charge asymmetry ($\Sigma charge * \cos(polar\_angle)$)
- Difference between visible mass and Z mass

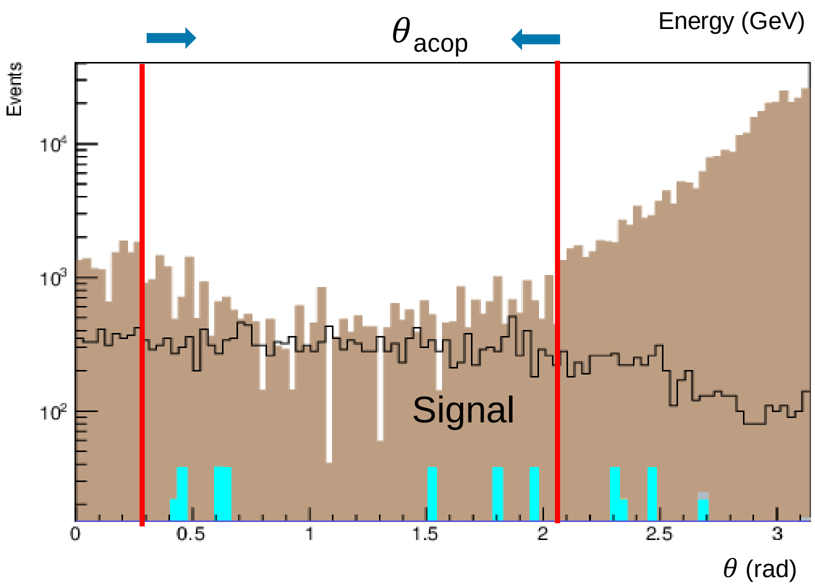
Properties that the background often "does not" have

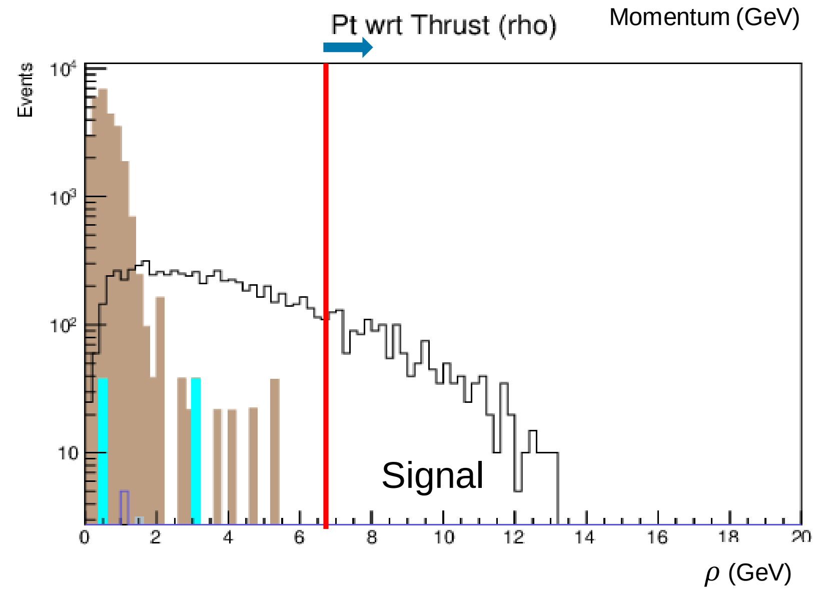
- Low energy in small angles
- Low energy of isolated neutral clusters

General cuts (ctd.)

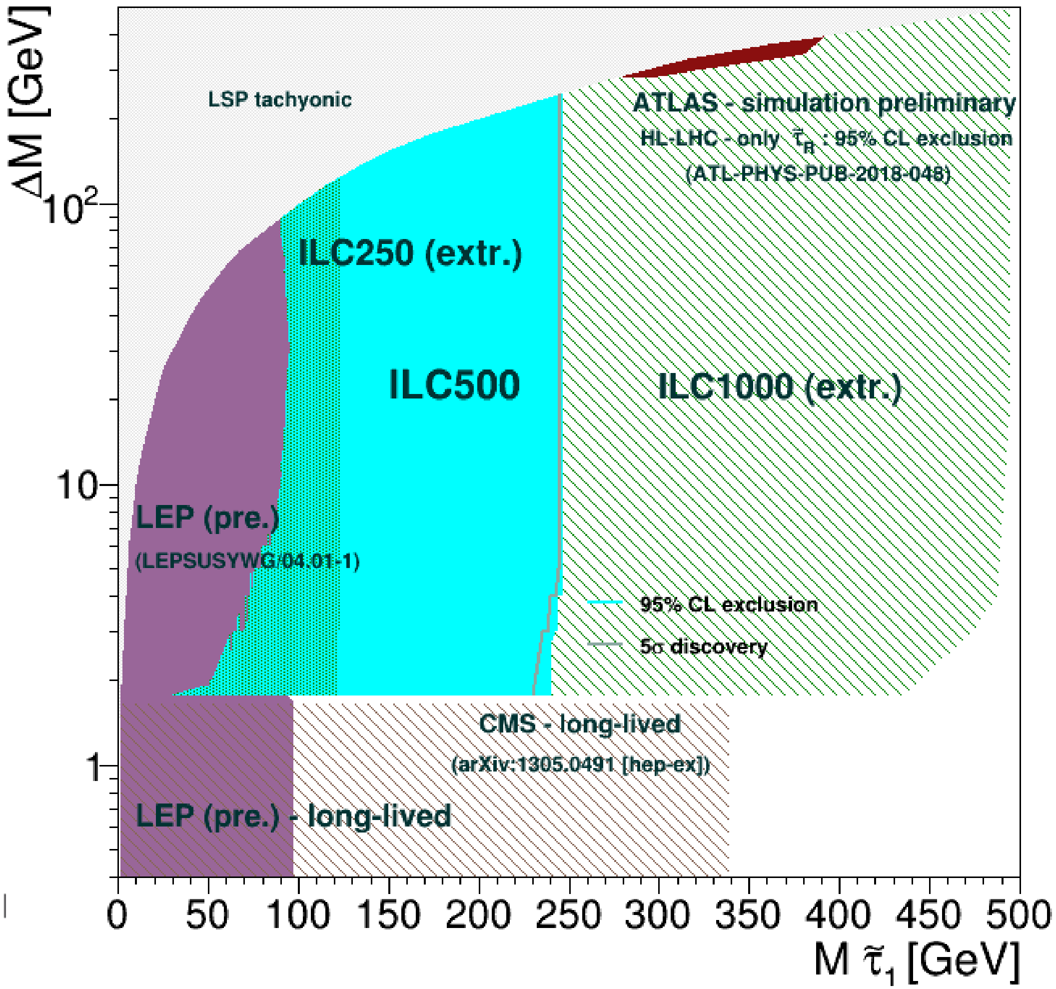








ILC expected limits



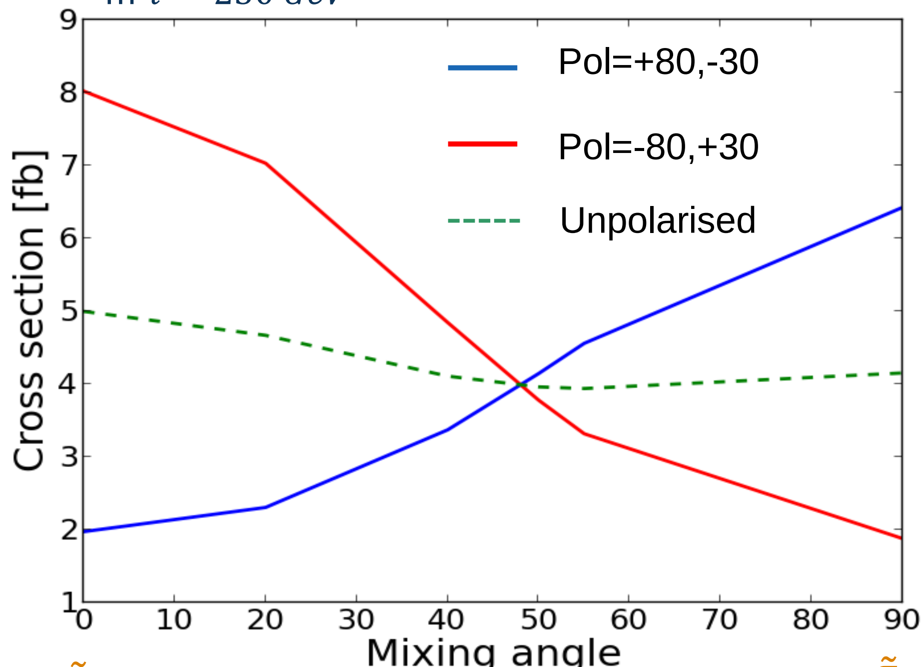
At ILC discovery and exclusion are almost the same

Analysis of worst scenario

Search for "worst" mixing angle

53 degrees $\tilde{\tau}$ mixing angle corresponds to the worst case for (unpolarized) LEP conditions

m $\tilde{\tau} = 230\ GeV$



$\tilde{\tau}_L$ $\tilde{\tau}_R$

Use ILC conditions weighting contribution of both polarisations

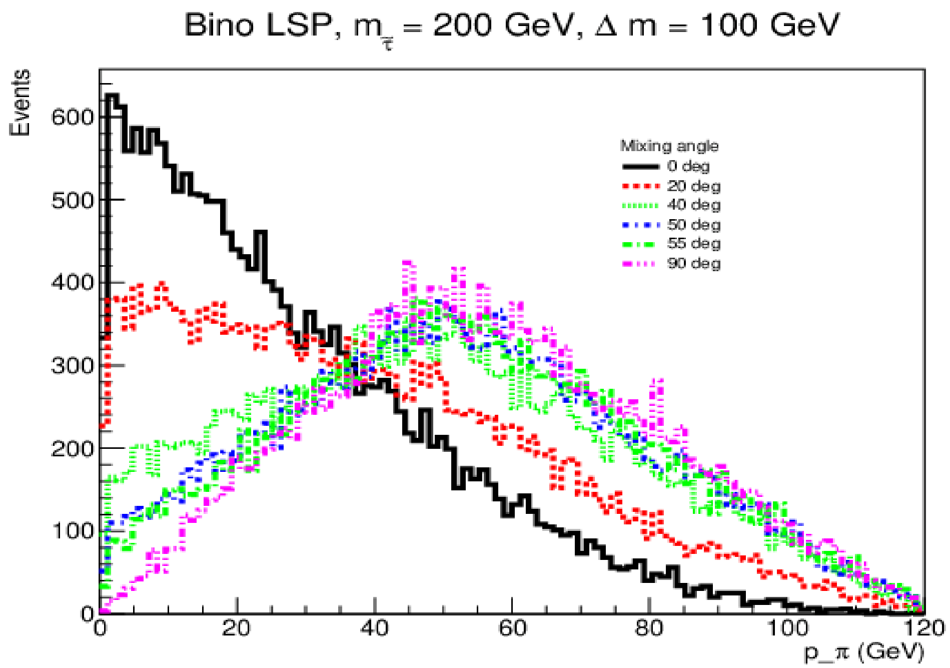
Take into account effect of mixing in cross-section and signal efficiency

- Signal: Whizard + Tauola
- Background: Whizard 1.95 (standard "DBD" background samples)

Event reconstruction using SGV adapted to the ILD detector concept at ILC

Analysis of worst scenario

Dependence of signal efficiency on $\tilde{\tau}$ mixing



- Signal efficiency depends on spectrum of detectable τ decays
- Spectrum of τ decay products depends on τ polarisation
- τ polarisation depends on $\tilde{\tau}$ and LSP mixing angles

Higgsino changes chirality but Bino does not

$\tilde{\tau}_L$ + Bino LSP ($\tilde{\tau}_R$ + Higgsino LSP) softer visible decay products

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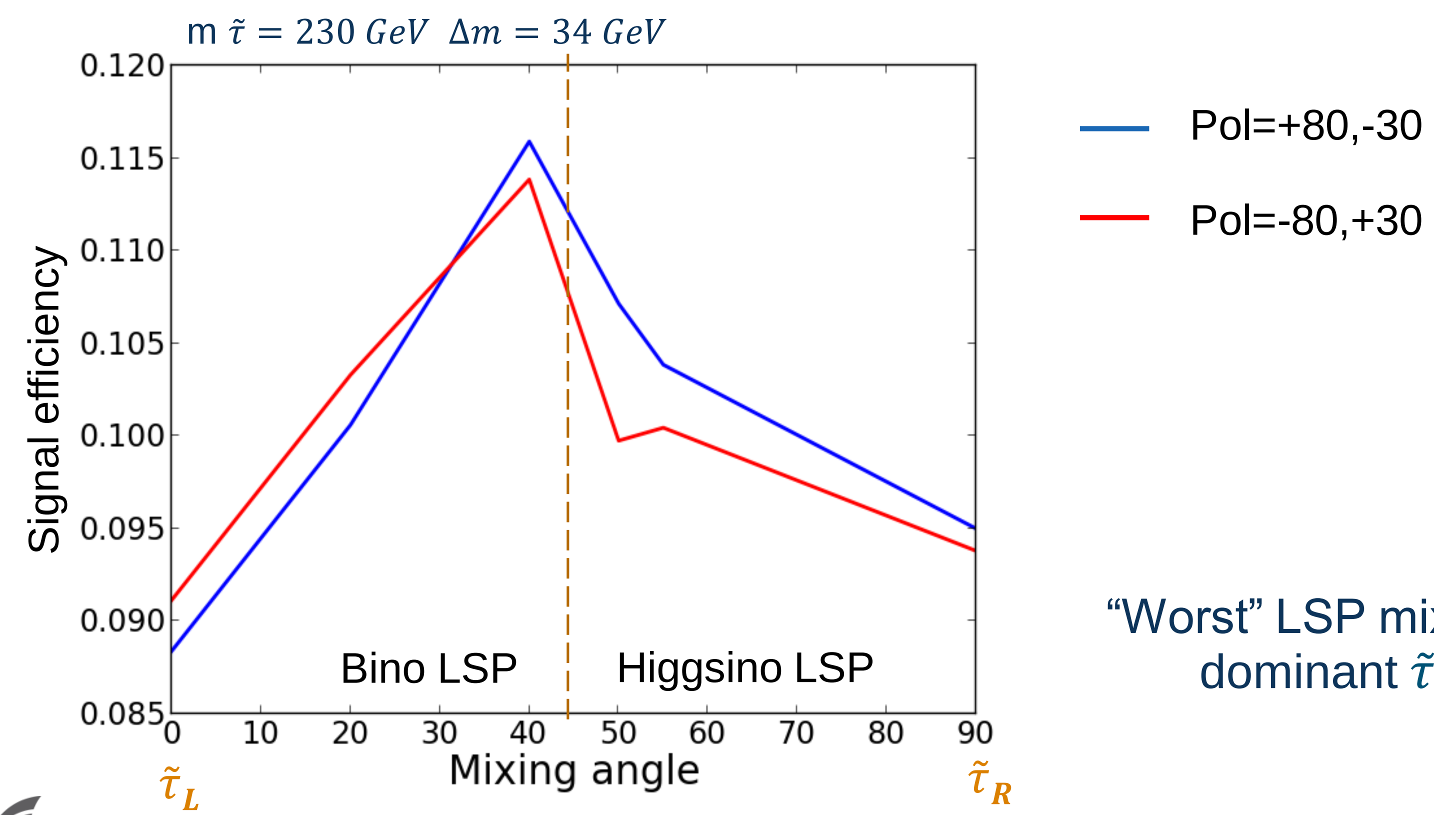
Analysis of worst scenario

Dependence of signal efficiency on $\tilde{\tau}$ mixing



"Worst" LSP mixing depends on dominant $\tilde{\tau}$ component

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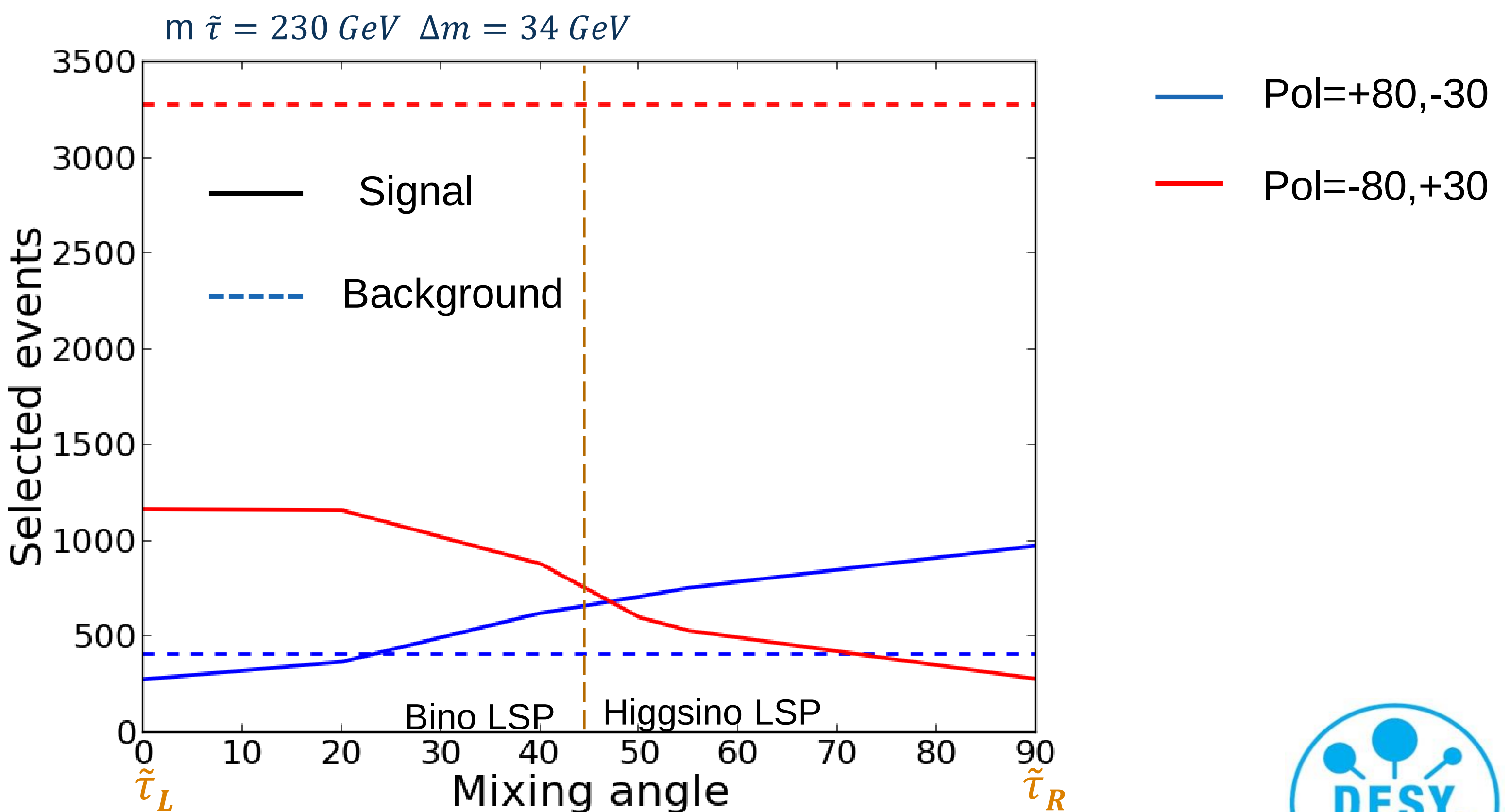
Analysis of worst scenario

Selected background and signal events



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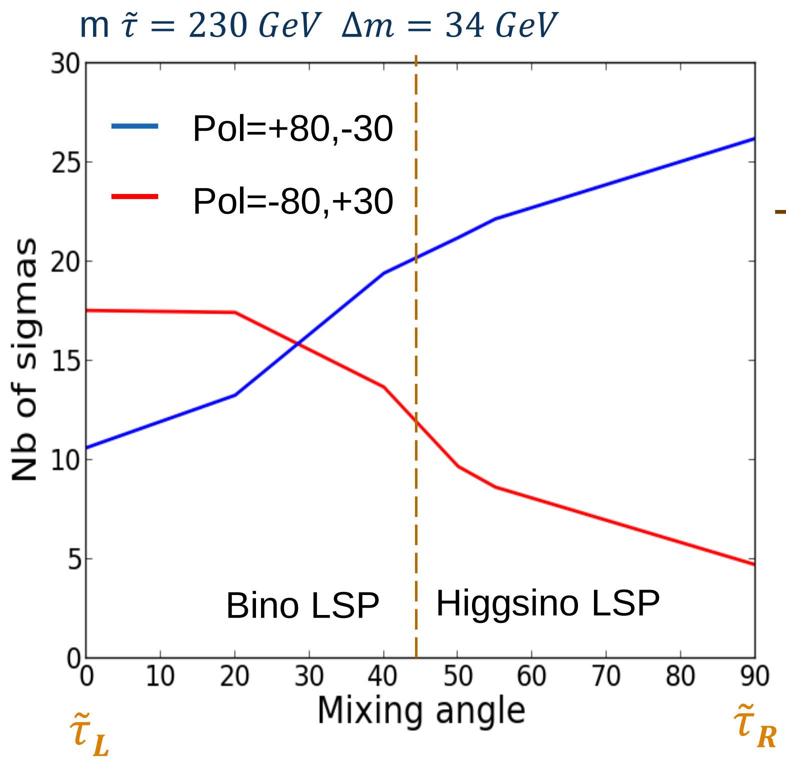
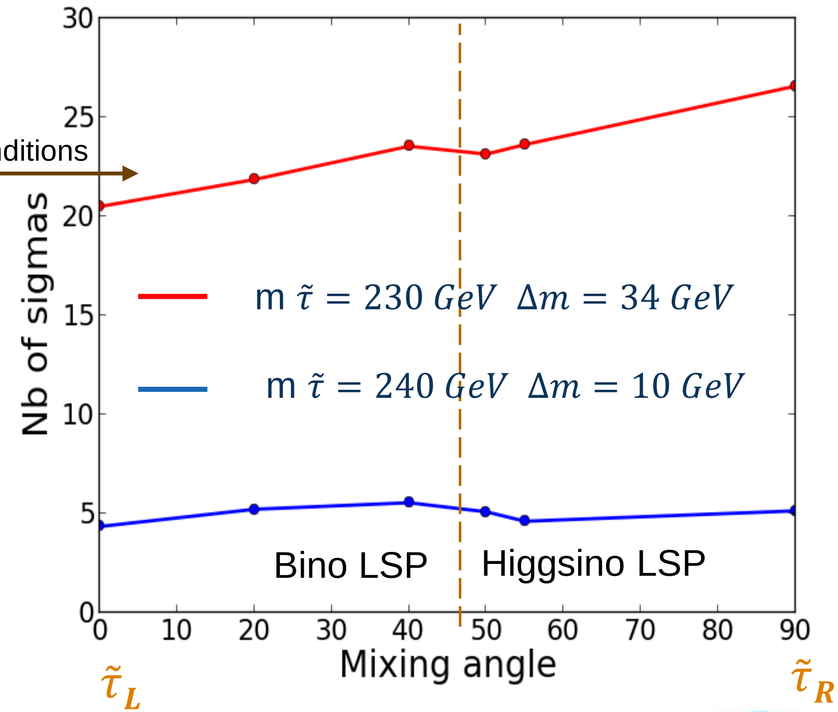
Analysis of worst scenario

Likelihood-ratio statistic used to weight both polarisations



H20 conditions



Equal sharing of P(+80,-30) and P(-80,+30) forseen in H20 ensures an uniform sensitivity to all mixing angles

Prospects for $\tilde{\tau}$ measurements at the ILC

Evaluate precision on $\tilde{\tau}$ properties measurements

EPJC, 76(4),1 (2016)

Phys Rev, D82,055016 (2010)

- Two specific models, STCx and SPS1a, evaluated:
  - $\tilde{\tau}_1$ NLSP, with $\Delta M < 10$ GeV
  - $\tilde{\tau}_1$ and $\tilde{\tau}_2$, as well as other sfermions and lighter bosinos, can be produced at 500 GeV
  - excluded by LHC but not due to the $\tilde{\tau}$ sector
- Beam energy 500 GeV and integrated luminosity of 500 fb^{-1} per beam polarization (expected one 1600 fb^{-1})

- $\tilde{\tau}_1$ and $\tilde{\tau}_2$ masses from spectrum end-points and cross sections
- Cross sections
- τ polarisation and $\tilde{\tau}$ mixing angle

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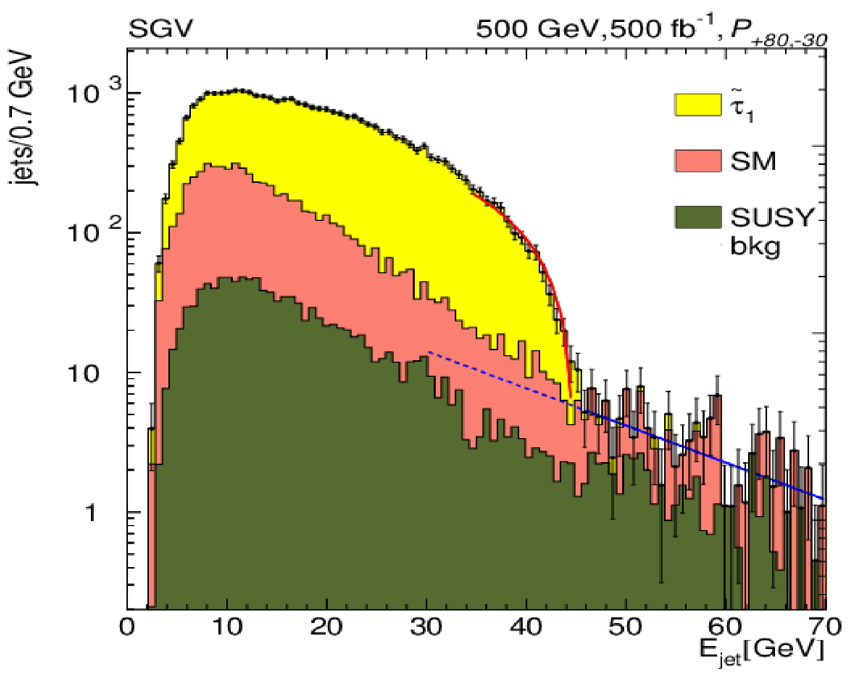
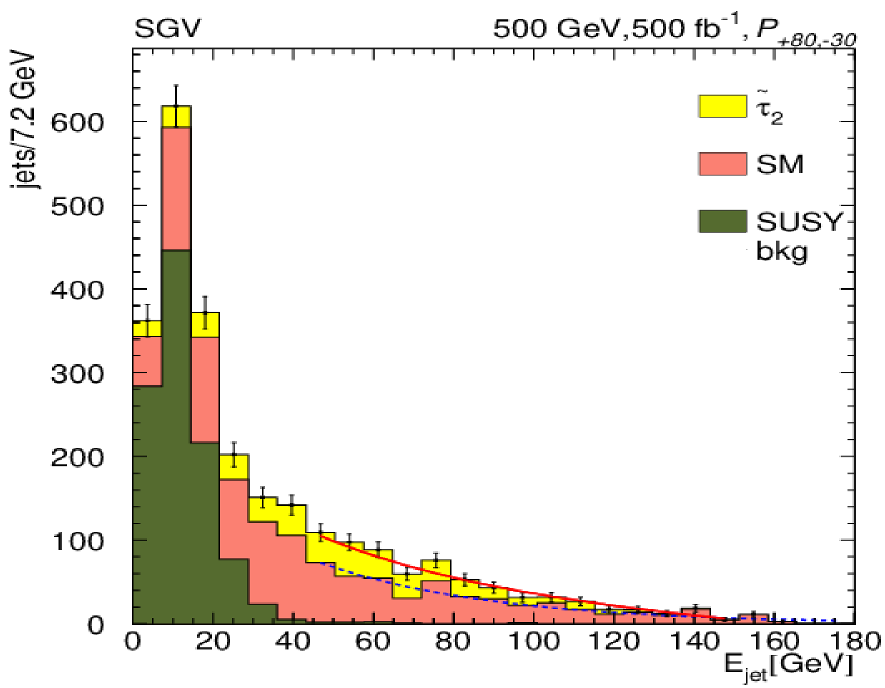
$\tilde{\tau}$ masses fitting end-points

$M_{\tilde{\tau}}$ from M_{LSP} and end-point of spectrum



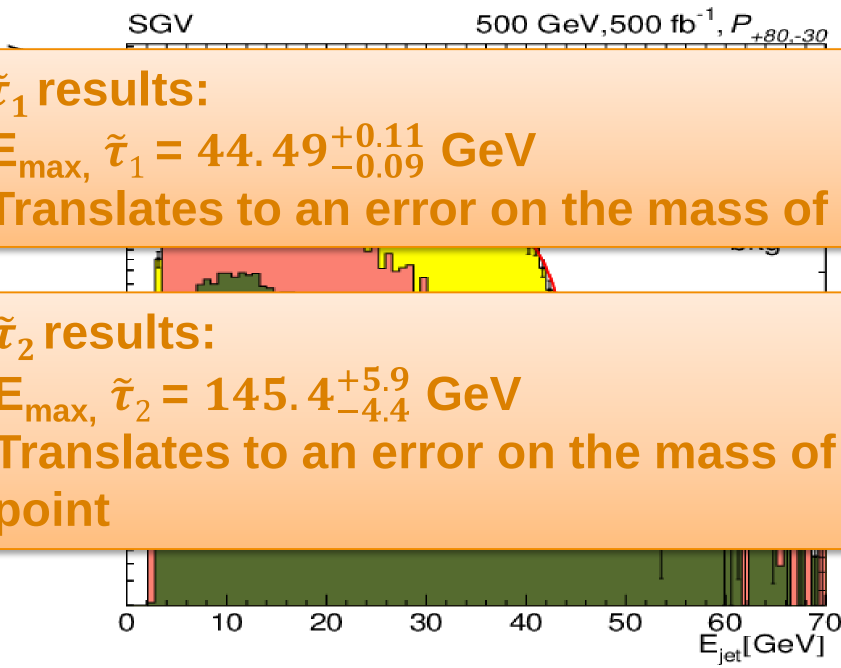


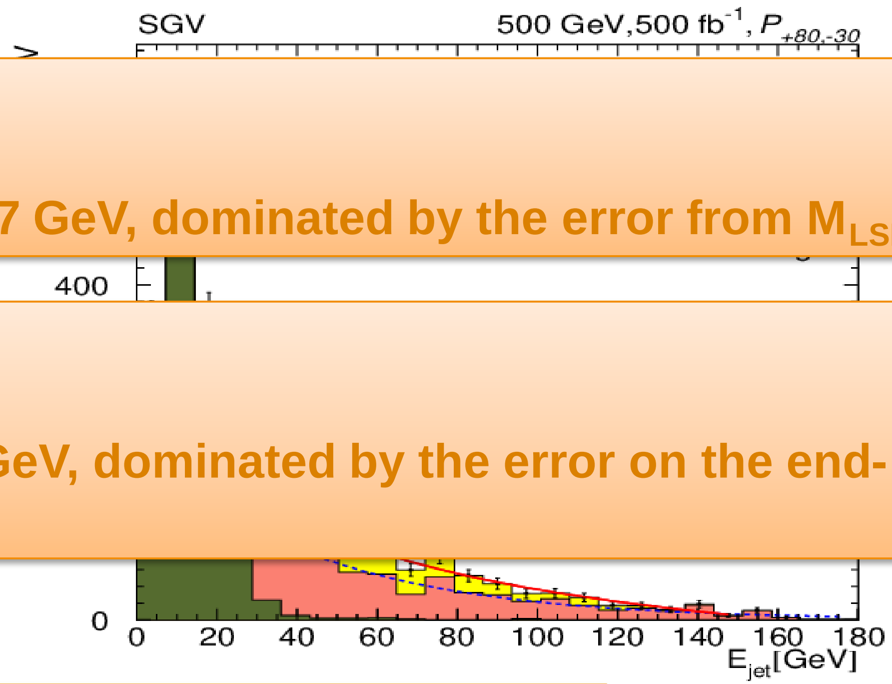
Only upper-end is relevant

Must get M_{LSP} from other sources (ex. smuon, selectron end-points)

$\tilde{\tau}$ masses fitting end-points

$M_{\tilde{\tau}}$ from M_{LSP} and end-point of spectrum





$\tilde{\tau}_1$ results:

$E_{max,}$ $\tilde{\tau}_1$ = $44.49^{+0.11}_{-0.09}$ GeV

Translates to an error on the mass of 0.27 GeV, dominated by the error from M_{LSP}

$\tilde{\tau}_2$ results:

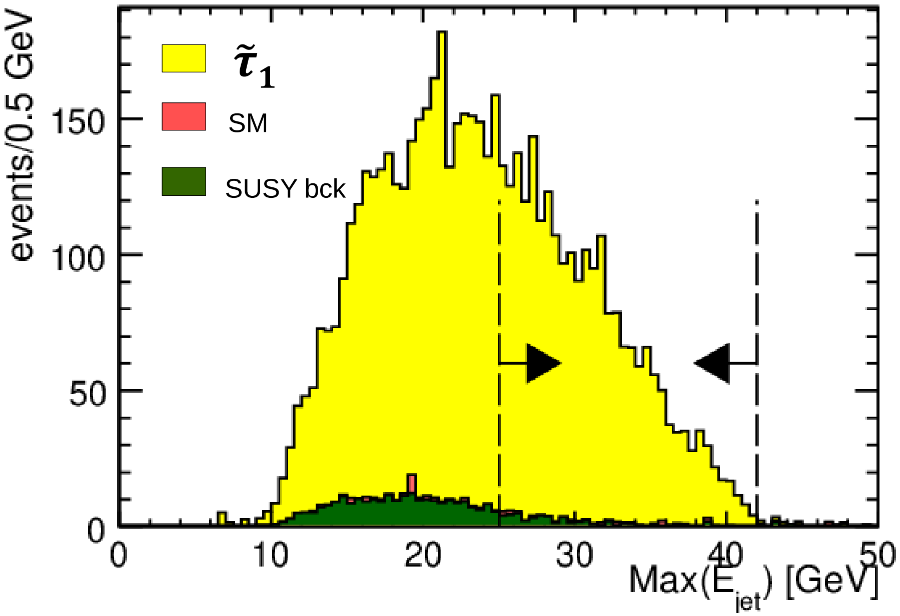
$E_{max,}$ $\tilde{\tau}_2$ = $145.4^{+5.9}_{-4.4}$ GeV

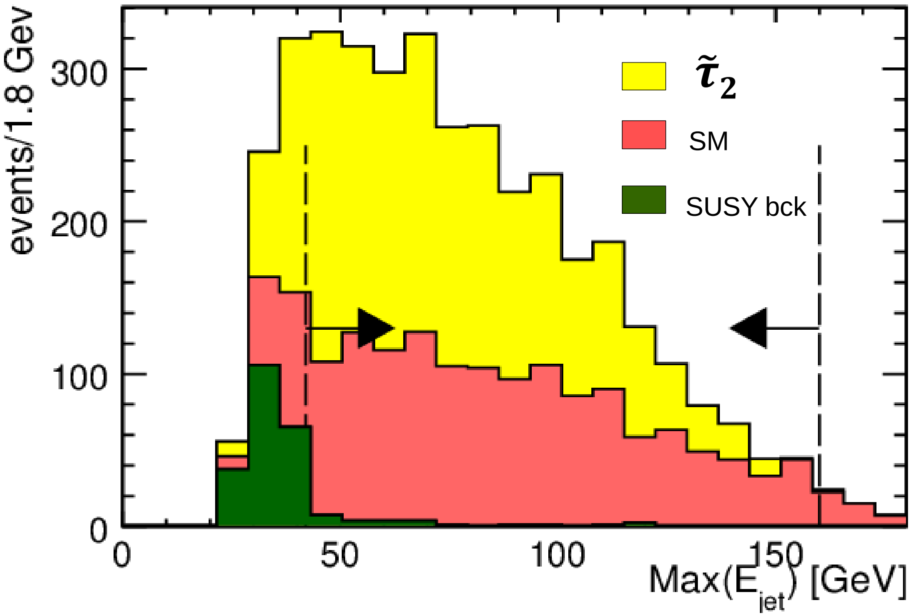
Translates to an error on the mass of 5 GeV, dominated by the error on the end-point

Per mil-level mass-measurements will be possible at the ILC

Must get M_{LSP} from other sources (ex. smuon, selectron end-points)

$\tilde{\tau}$ masses from cross-sections

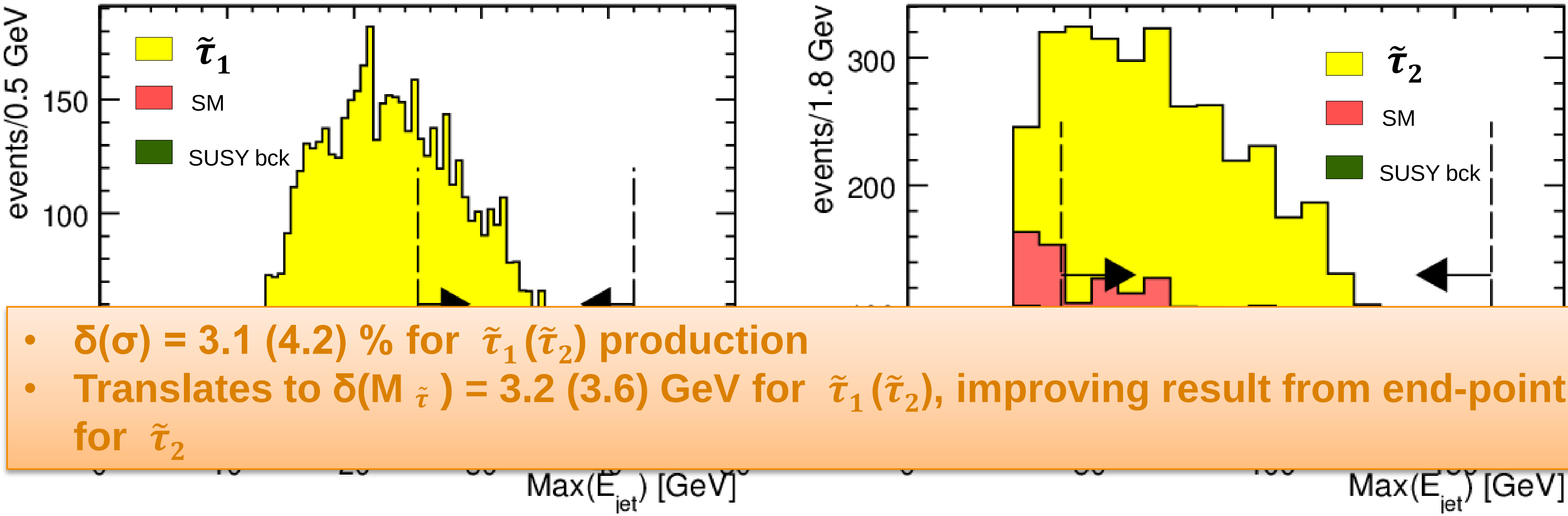




Evaluate cross-sections from regions with lower SUSY background (unknown)

No dependence on M_{LSP}

$\tilde{\tau}$ masses from cross-sections



- **δ(σ) = 3.1 (4.2) % for $\tilde{\tau}_1$ ($\tilde{\tau}_2$) production**
- **Translates to δ(M $_{\tilde{\tau}}$) = 3.2 (3.6) GeV for $\tilde{\tau}_1$ ($\tilde{\tau}_2$), improving result from end-point for $\tilde{\tau}_2$**

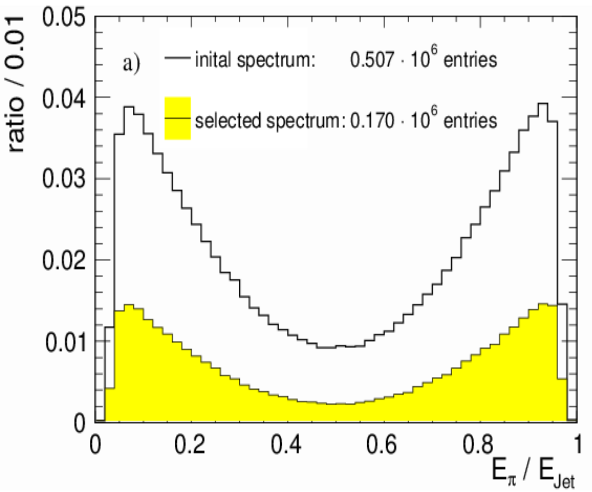
Evaluate cross-sections from regions with lower SUSY background (unknown)

No dependence on M_{LSP}

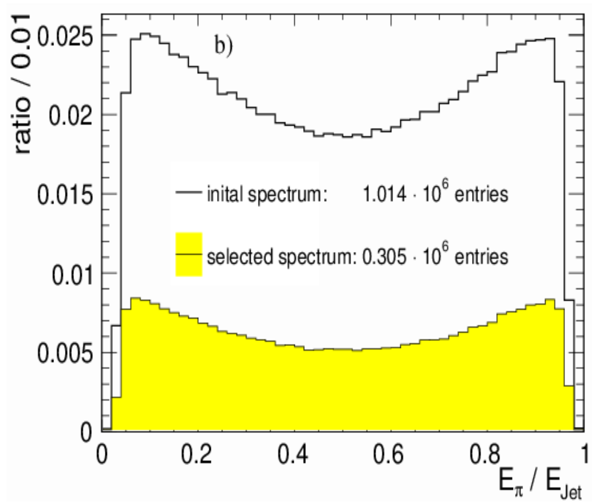
τ polarisation measurements

τ polarisation depends on $\tilde{\tau}$ and LSP mixing angles

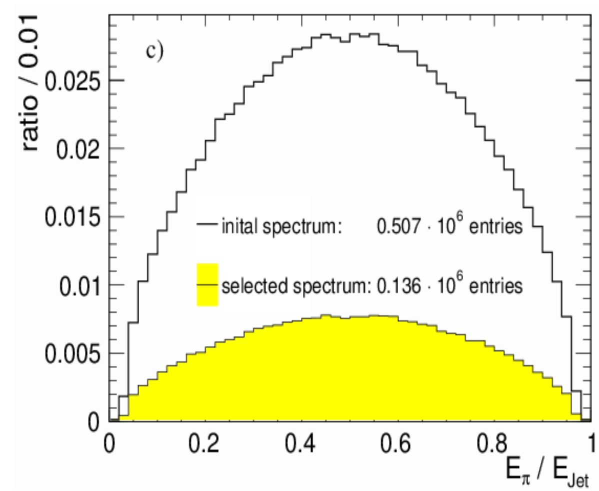
τ leptons right-handed



τ leptons opposite helicity



τ leptons left-handed



Study spectrum of $\tau \rightarrow \pi\nu$ and $\tau \rightarrow \nu\rho$ for P=1, 0 or -1

Per cent-level polarisation-measurements will be possible at the ILC

$\tilde{\tau}$ mixing angle measurements

Cross-section depends on $\tilde{\tau}$ mixing angle and mass

$$\sigma_{\tilde{\tau}} = A(\theta\tilde{\tau}, P_{\mathrm{beam}}) \times \beta^3 / s$$

$$\beta^3 = (1 - 4M\tilde{\tau}^2)^{3/2}$$

- With known $M\tilde{\tau}$, only dependence on $\theta\tilde{\tau}$
- Cross-section difference for RL and LR beams

Per cent-level measurement is likely possible at the ILC

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Outlook/Conclusions

- Exclusion and discovery limits for $\tilde{\tau}$ pair production at the ILC have been computed
- No dependence on hidden SUSY parameters have been imposed for the validity of the limits
- ILC will discover/exclude $\tilde{\tau}$'s for any $\tilde{\tau}$-LSP mass difference and any $\tilde{\tau}$-mixing nearly up to the kinematic limit
- Even after HL-LHC, large parts of the $\tilde{\tau}$-LSP mass plane will remain unexplored
- Worst scenario for $\tilde{\tau}$ production at the ILC was reviewed taking into account ILC beam polarisation conditions
- If $\tilde{\tau}$´s exist in the kinematic range of the ILC, precision measurements of $\tilde{\tau}$ properties are possible at few percent level

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