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

Teresa Núñez - DESY

On behalf of the ILD concept group

- 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

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

LEP

- 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

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

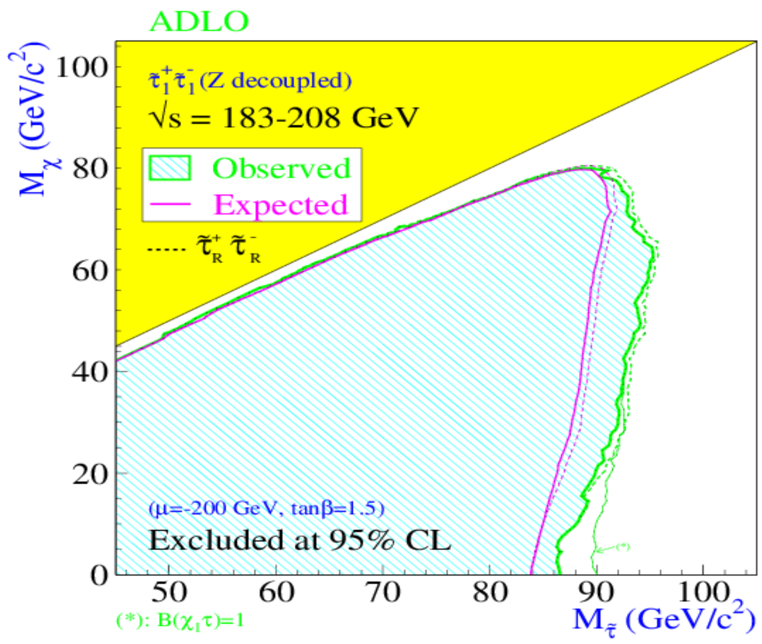
Scalar superpartner of τ-lepton

- 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

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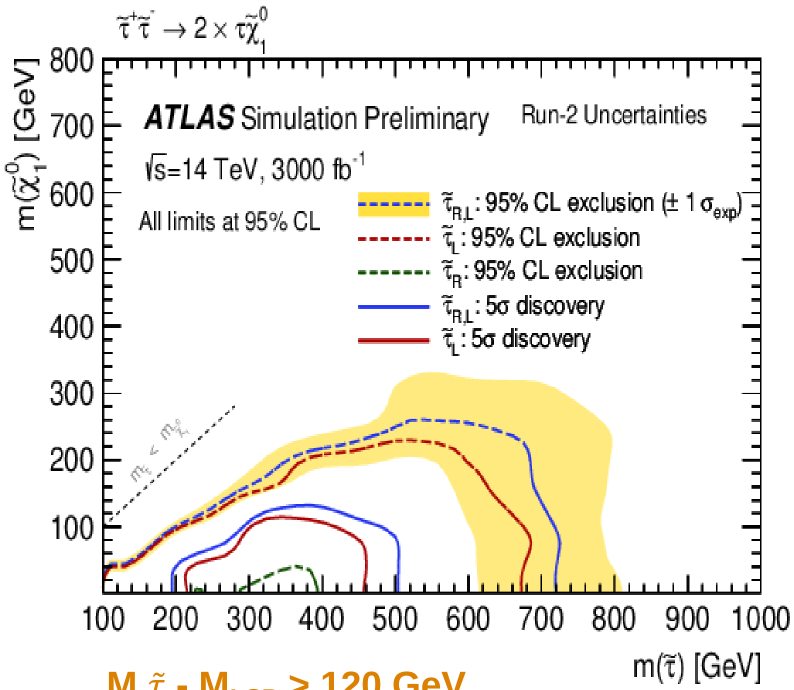
Limits at LHC and LEP

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



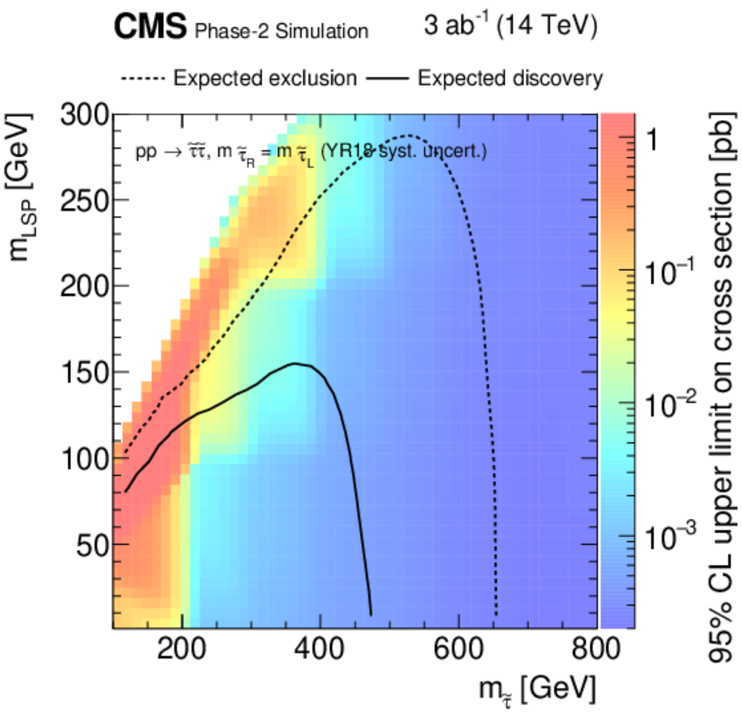
M $\tilde{\tau}$ - M_{LSP} > 120 GeV

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

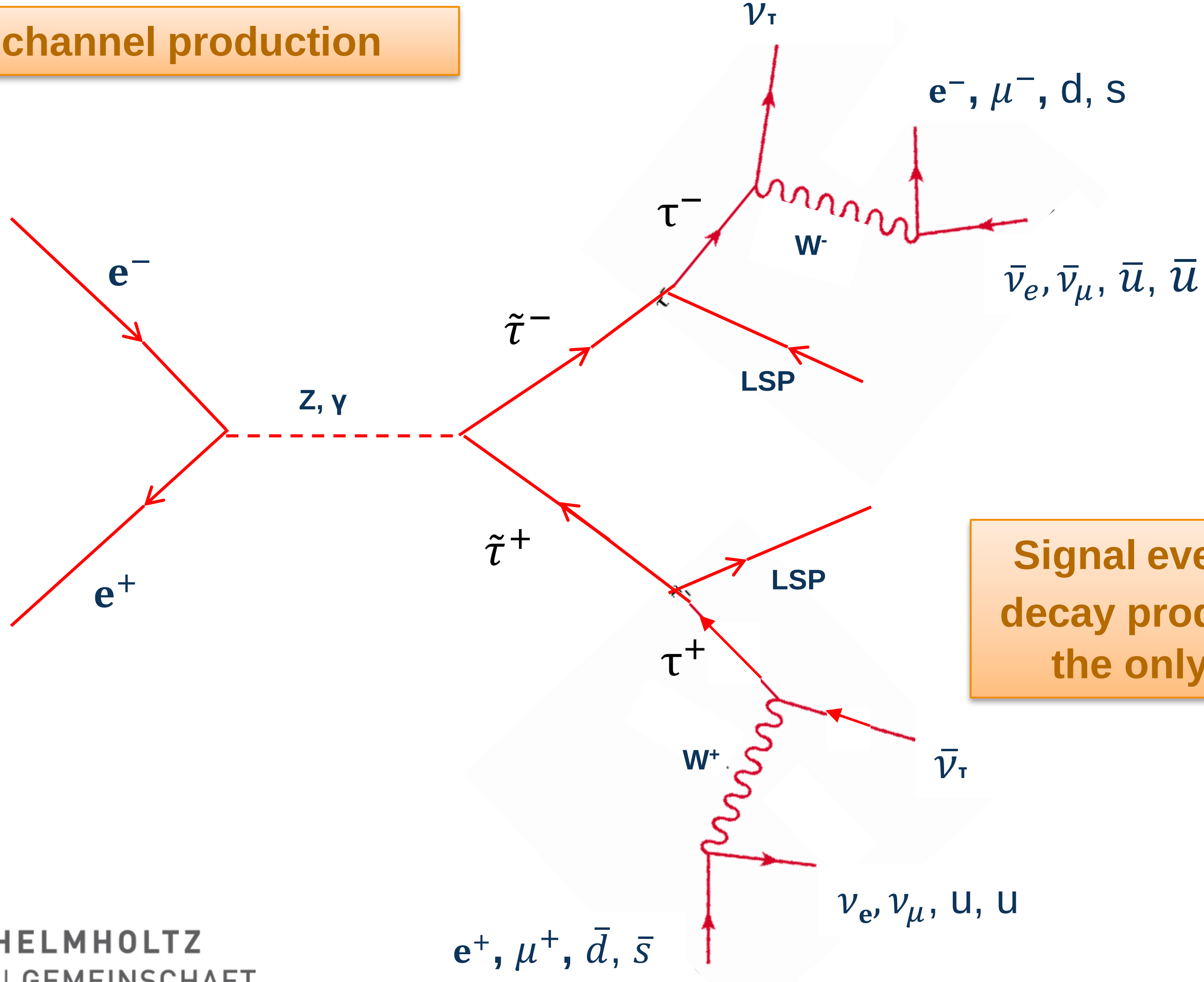
- Polarization $P(e^-,e^+)=(+80\%,-30\%)$
- $\sqrt{s}$ = 500 GeV with 1.6 ab^{-1} integrated luminosity (H-20, I-20 ILC500)

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

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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* -> $\nu\nu$ $\tau\tau$, *WW* -> $\nu\tau$ $\nu\tau$

Almost irreducible

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

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 x M_{LSP} GeV
- Visible mass (m_{vis}). m_{vis} < 2 x ($M_{\tilde{\tau}}$ - 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:

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

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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

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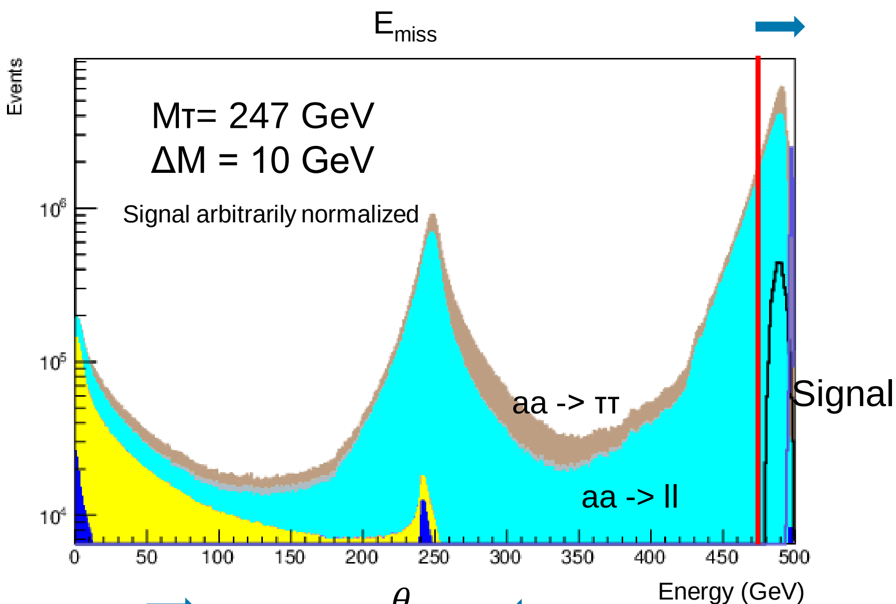
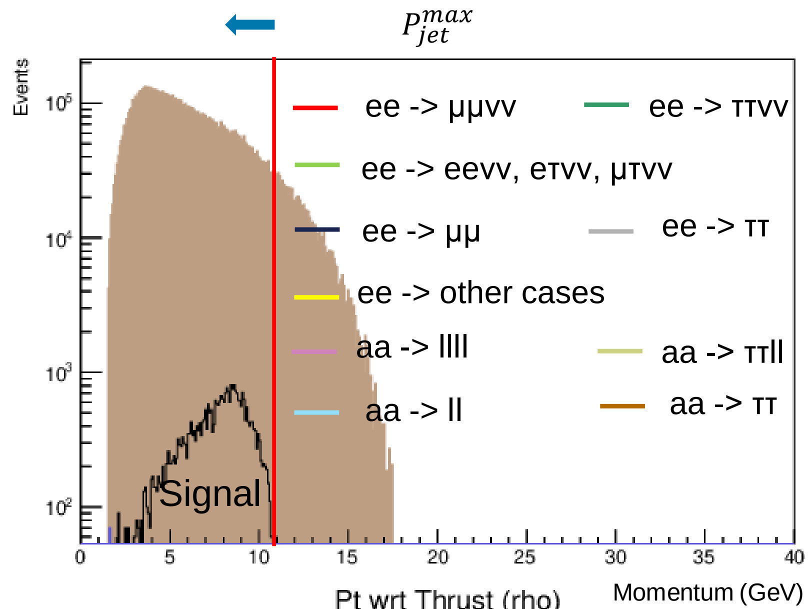
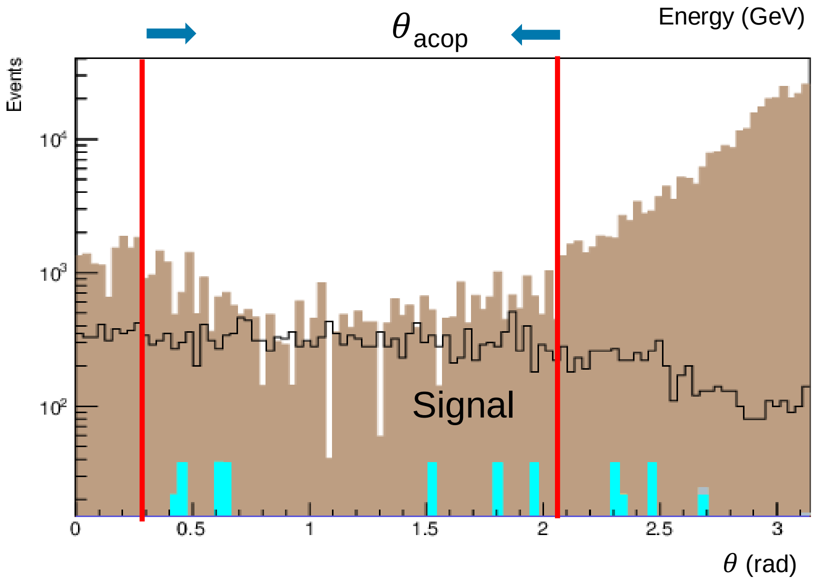
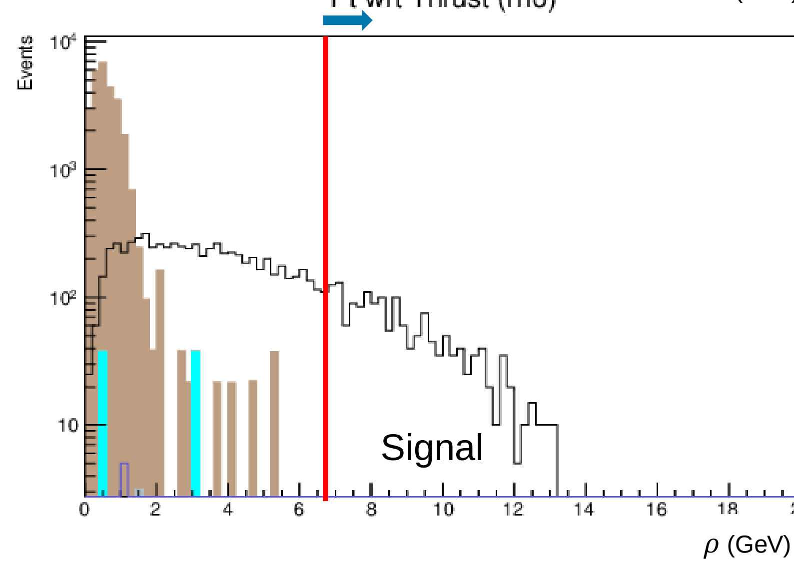
General cuts (ctd.)

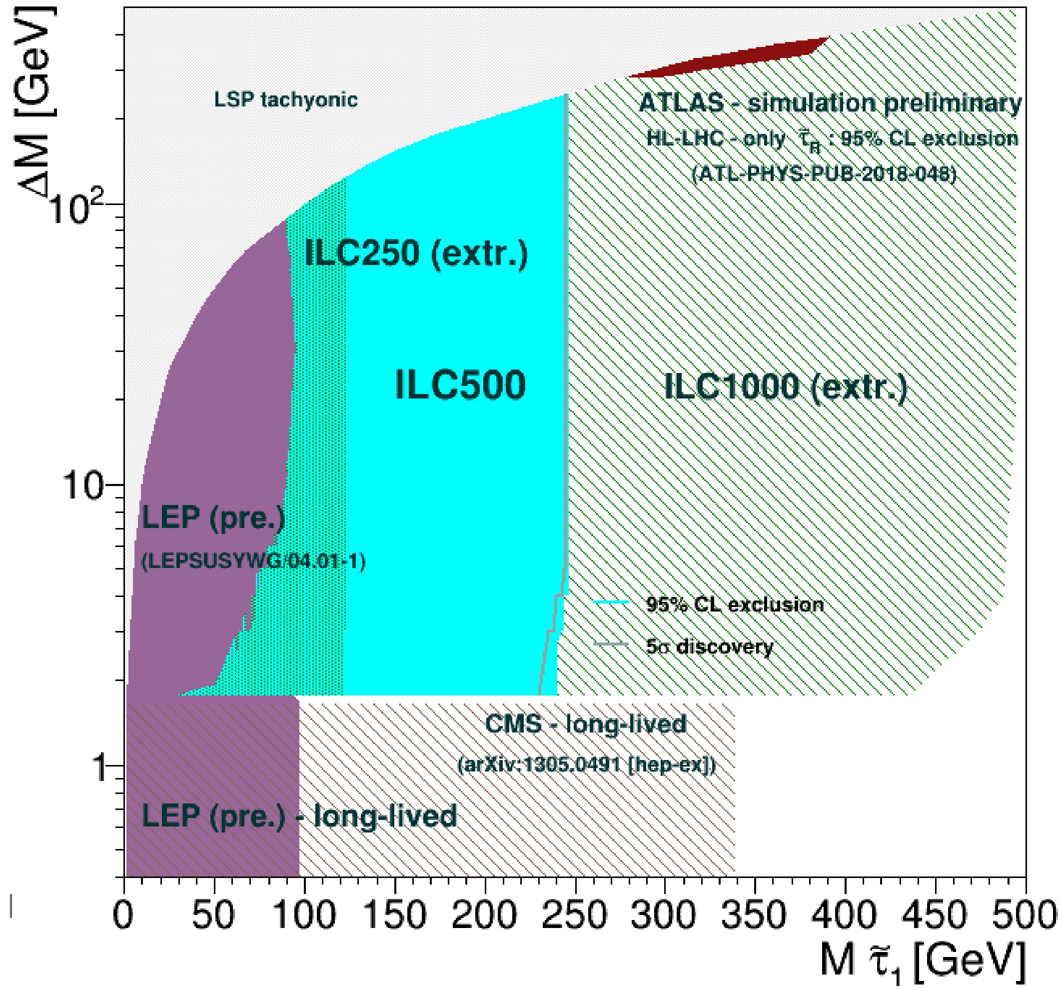








ILC expected limits

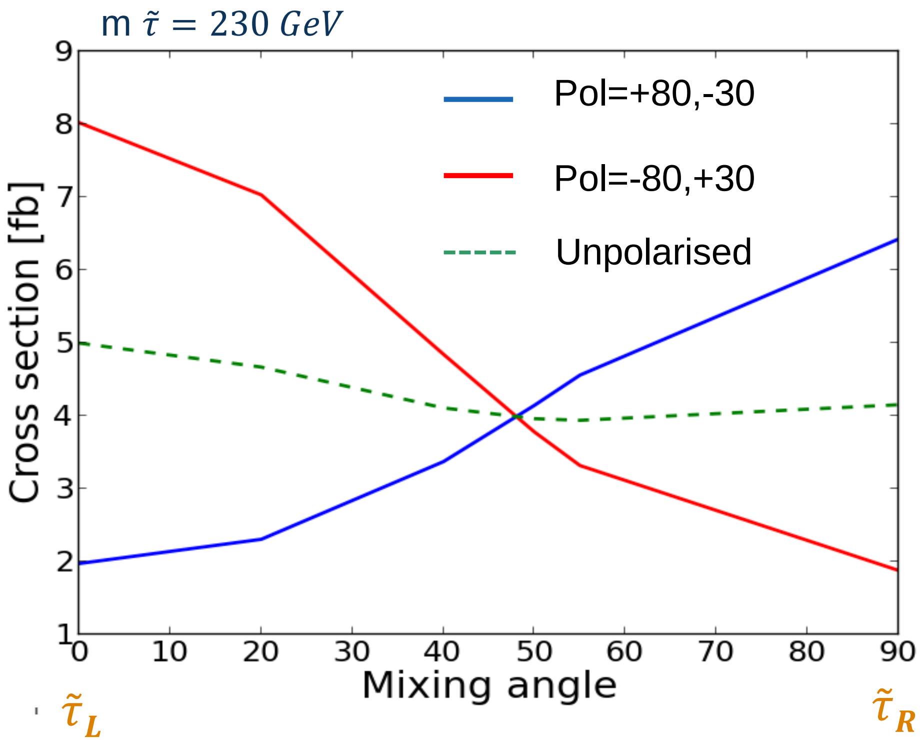


At ILC discovery and exclusion are almost the same

Analysis of worst scenario

Search for "worst" mixing angle

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



Use ILC conditions weighting contribution of both polarisations

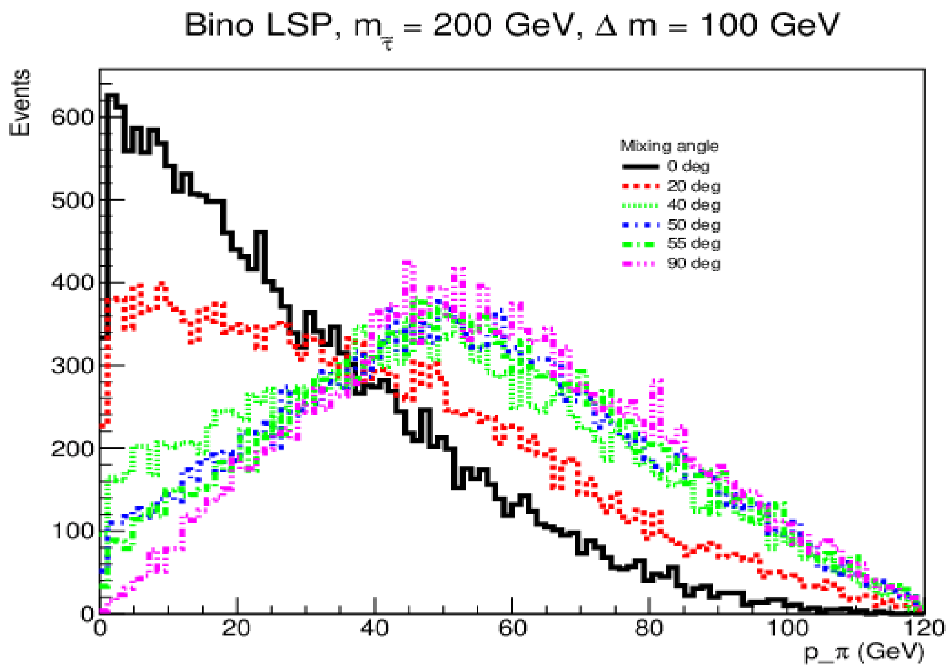
Take into account effect of mixing in cross-section and signal efficiency

- 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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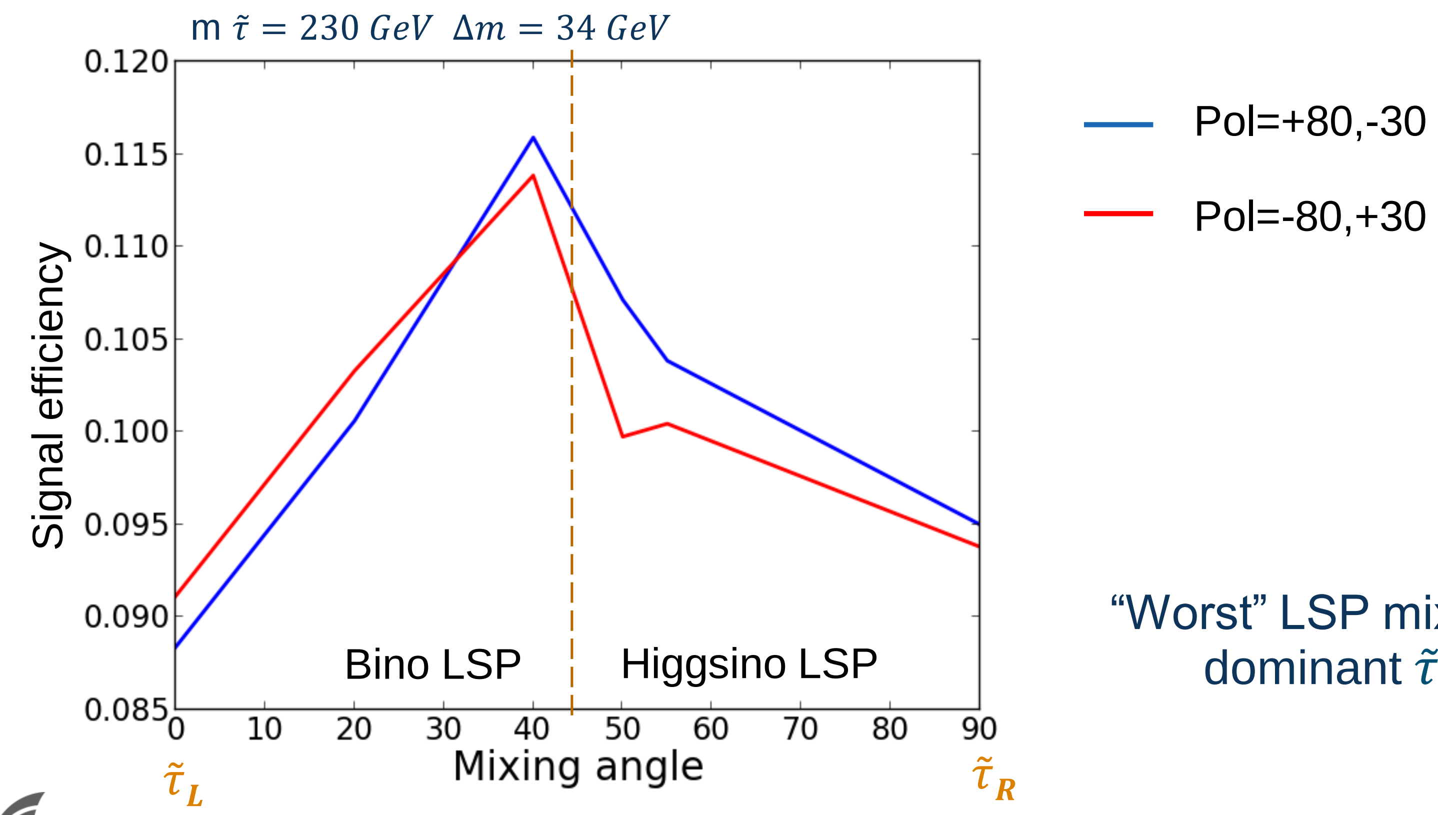
Analysis of worst scenario

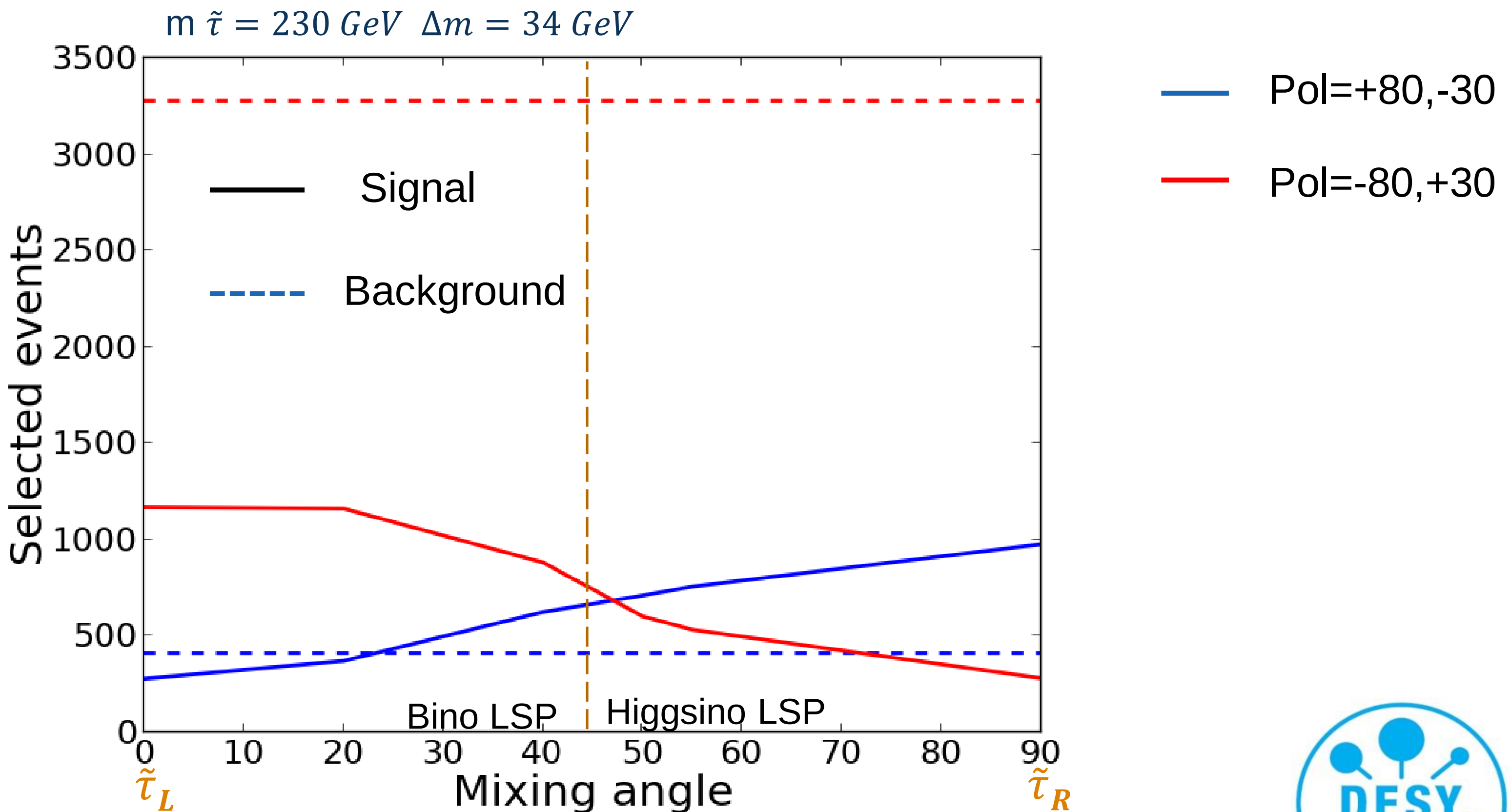
Dependence of signal efficiency on $\tilde{\tau}$ mixing



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

Analysis of worst scenario

Selected background and signal events



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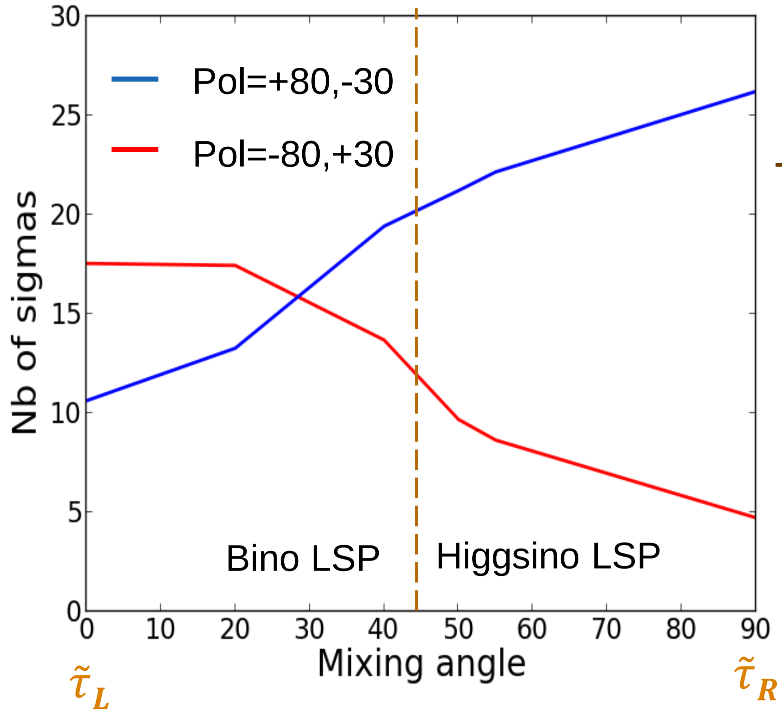
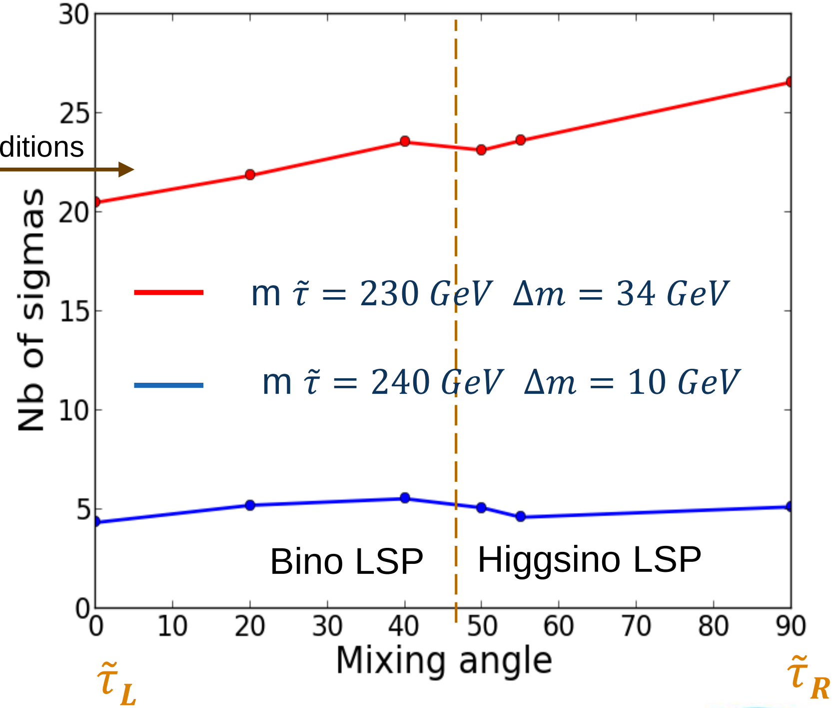
Analysis of worst scenario

Likelihood-ratio statistic used to weight both polarisations

m $\tilde{\tau} = 230\ GeV \quad \Delta m = 34\ GeV$



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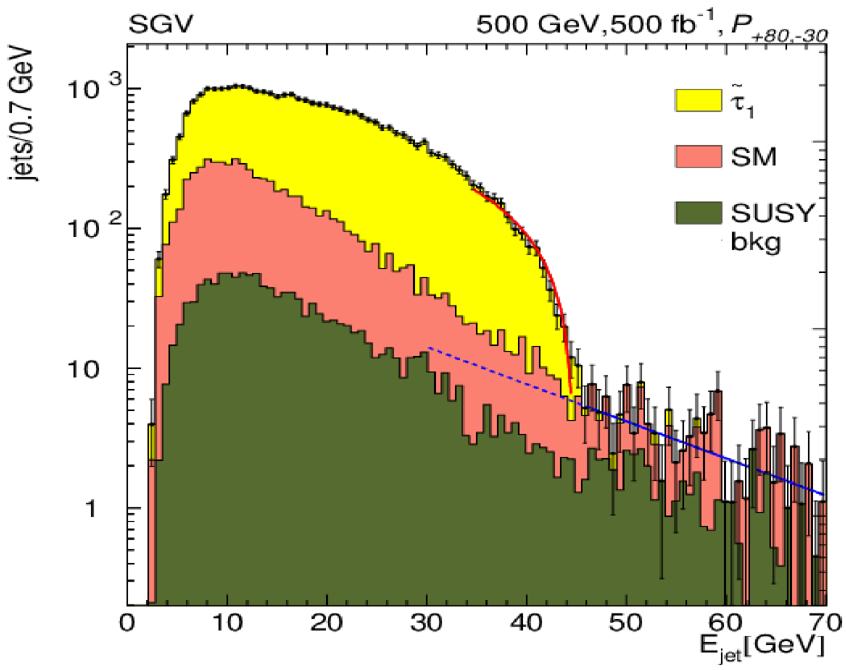
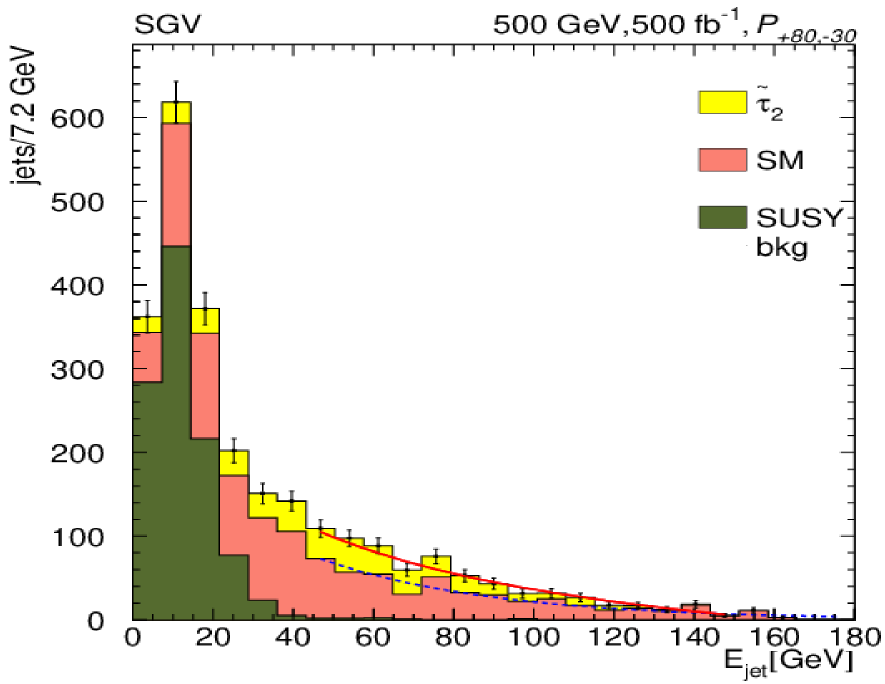
$\tilde{\tau}$ masses fitting end-points

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



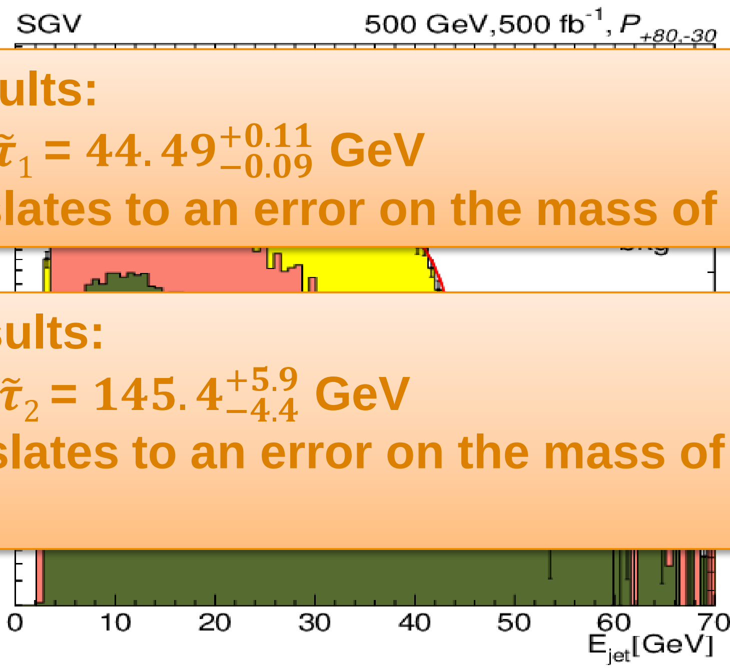


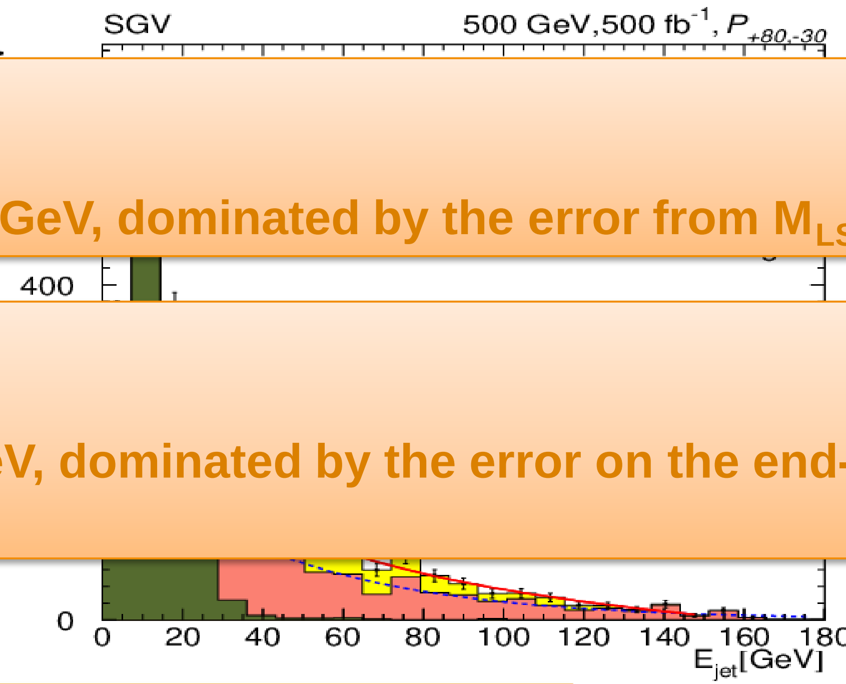
Only upper-end is relevant

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:

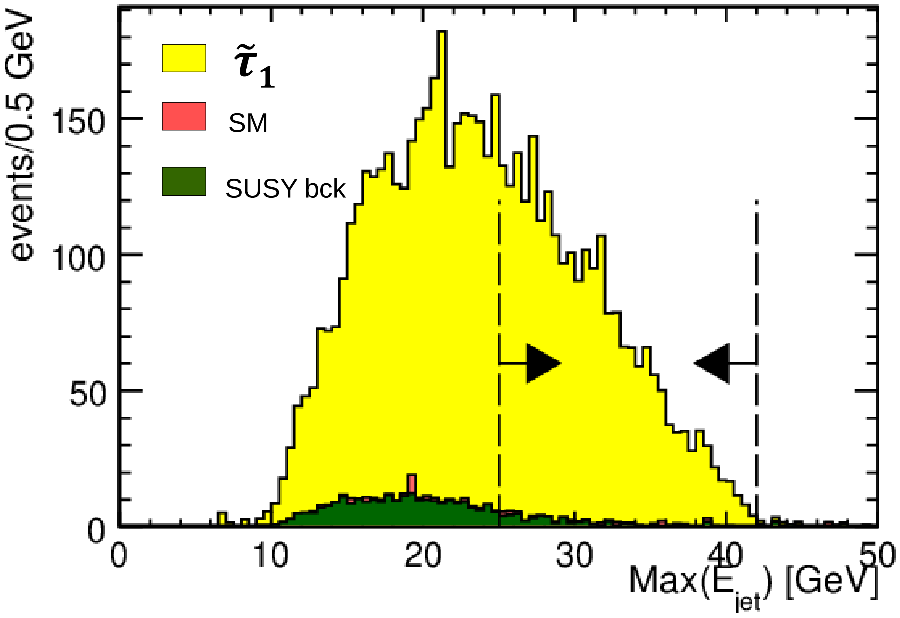
$E_{max,\ \tilde{\tau}_2} = 145.4^{+5.9}_{-4.4}$ GeV

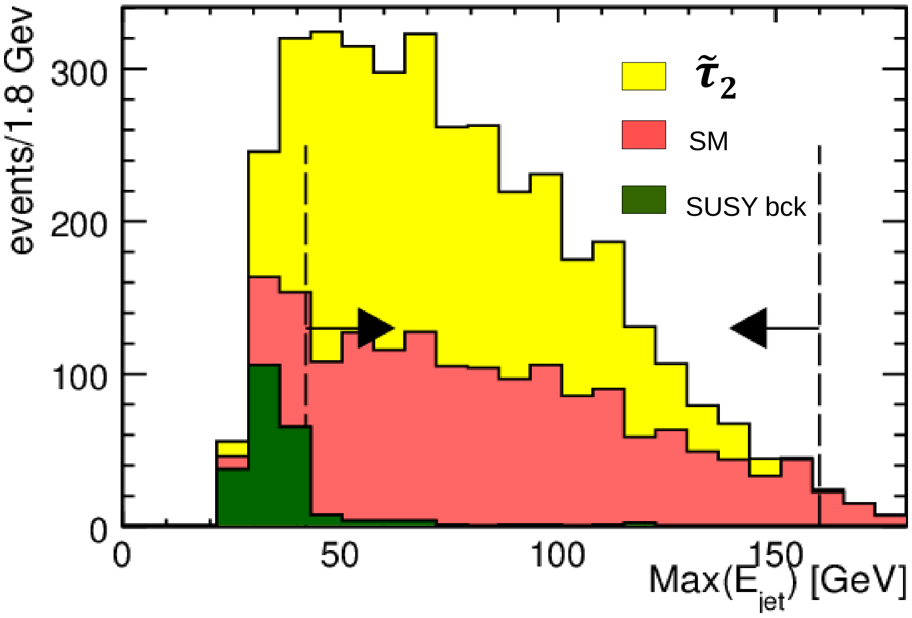
Translates to an error on the mass of 5 GeV, dominated by the error on the end-point

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

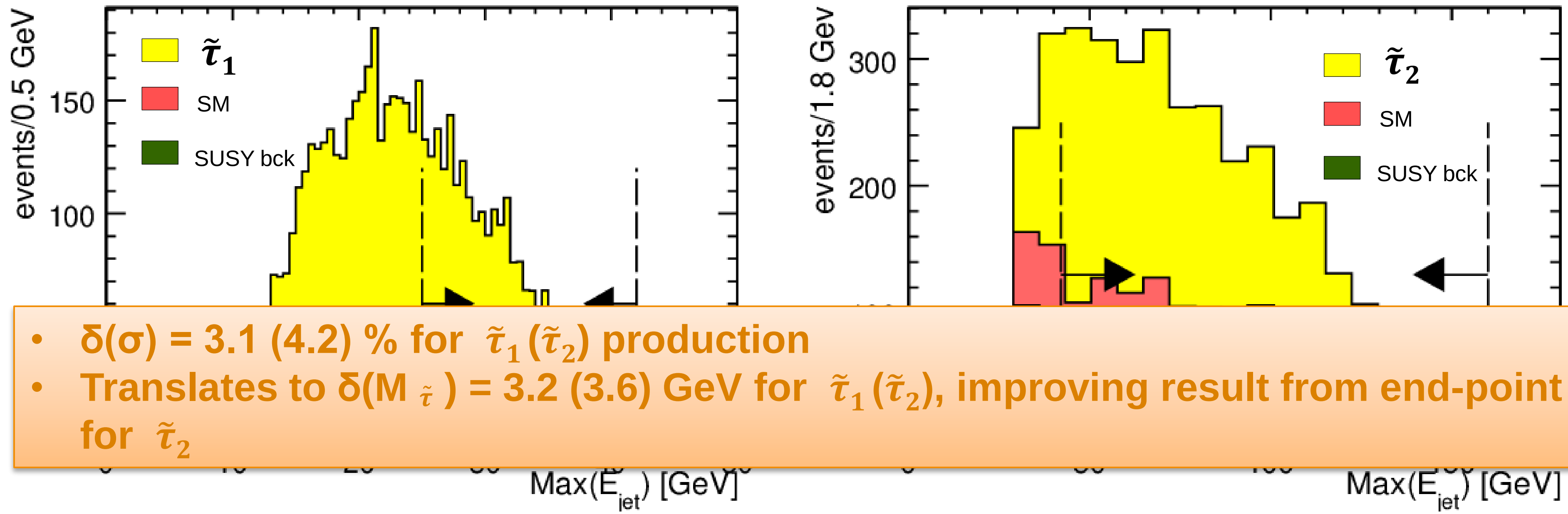




Evaluate cross-sections from regions with lower SUSY background (unknown)

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 $\tilde{\tau}_2$**

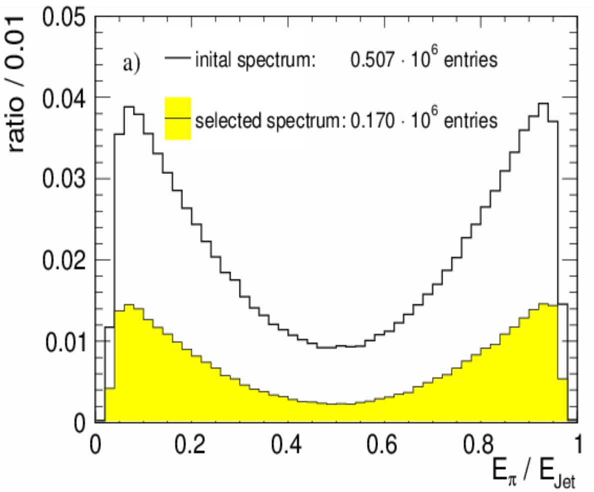
Evaluate cross-sections from regions with lower SUSY background (unknown)

No dependence on M_{LSP}

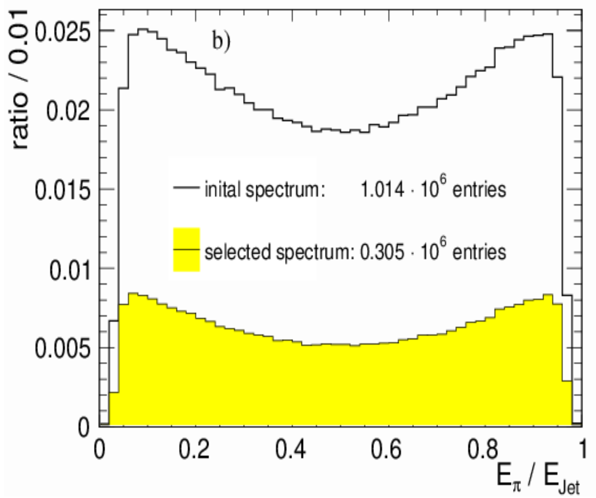
τ polarisation measurements

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

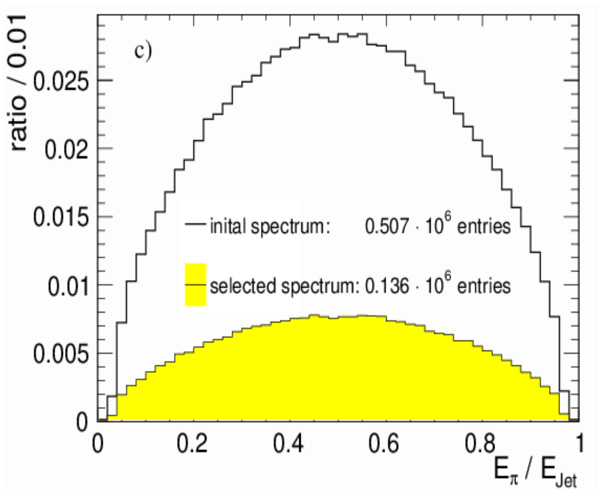
τ leptons right-handed



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

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

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

- 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

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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