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

**Teresa Núñez - DESY**

- Motivation of $\tilde{\tau}$ studies
- Limits at LHC and LEP
- $\tilde{\tau}$ searches at the ILC
  - Limits
  - Analysis worst scenario
  - Effect of overlay particles
- Prospects for $\tilde{\tau}$ measurements at the ILC
- Outlook and conclusions

# Motivation for $\tilde{\tau}$ searches

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

**$\tilde{\tau}$ satisfies both conditions**

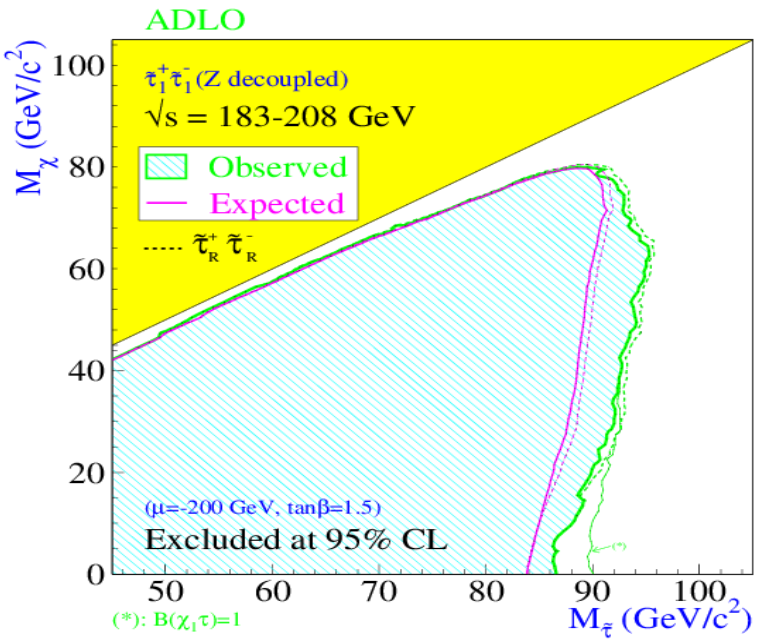
**Scalar superpartner of $\tau$-lepton**

- 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 $Z^0/\gamma$ exchange, lowest σ with no coupling to $Z^0$)
  - decay to LSP and $\tau$, 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 LEP and LHC

## $\tilde{\tau}$ 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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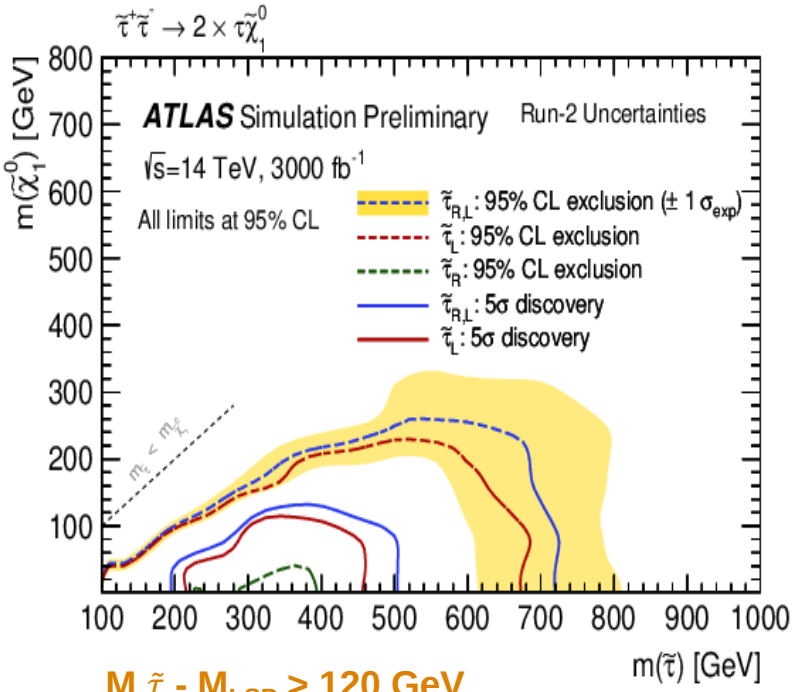
# Limits at LEP and LHC (ctd.)

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



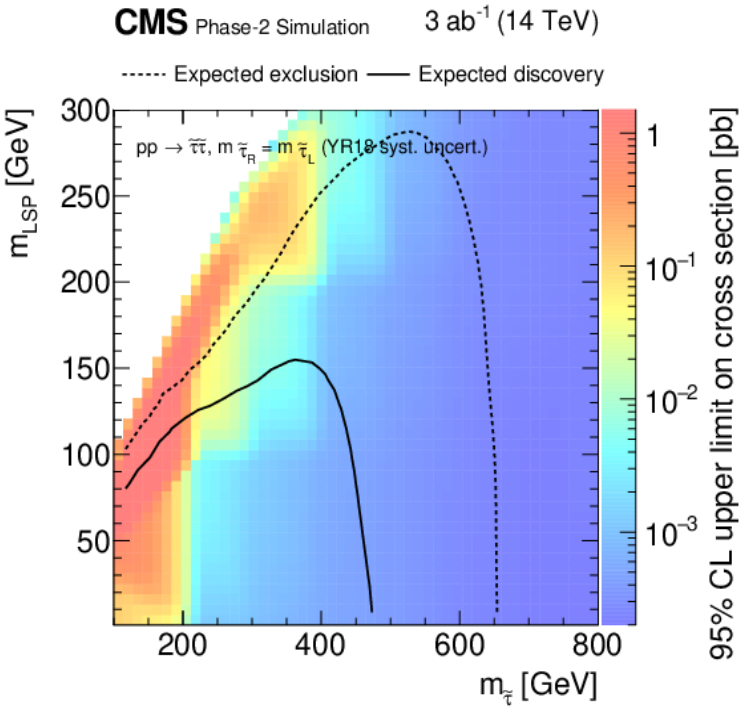

M $\tilde{\tau}$ - $M_{LSP}$ > 120 GeV

ATL-PHYS-PUB-2018-048

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

## 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




CMS PAS FTR-18-010

# Conditions and tools at ILC study

**$\tilde{\tau}$ 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**

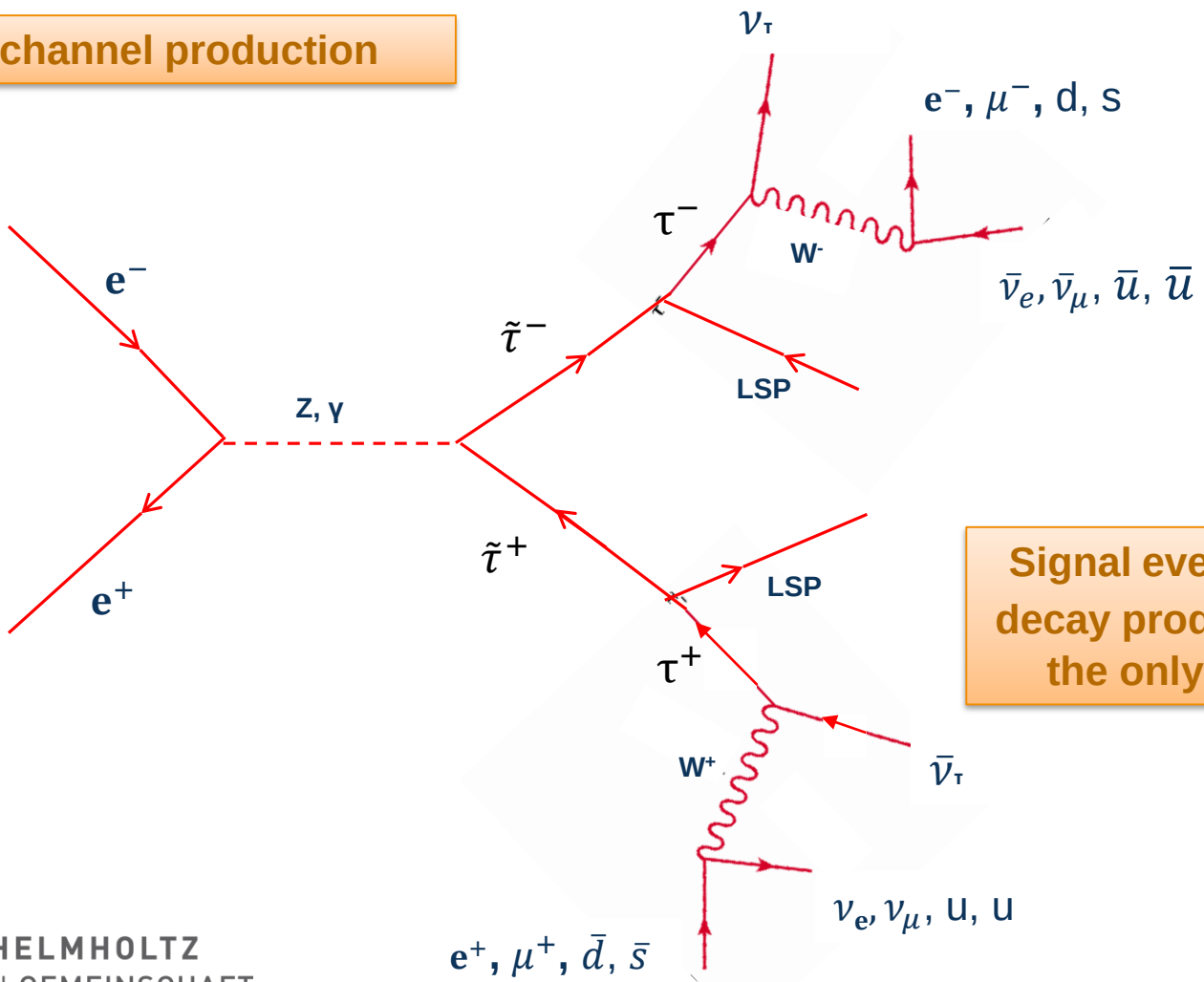
- Polarization $P(e^-,e^+)=(+80\%,-30\%)$
- $\sqrt{s}$ = 500 GeV with 1.6 $ab^{-1}$ integrated luminosity (H-20, I-20 ILC500)

**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 $\tau$'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

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# Background

**SM processes with real or fake missing energy**

**Irreducible**

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

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

**Almost irreducible**

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

**Mis-identification of $\tau$´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)

Clean final state
('no' pile-up)

- Two well identified $\tau$'s and little other activity

**Above 95 % signal efficiency for each of these cuts (excluding for the $\tau$-identification)**

- Maximum jet momentum:

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

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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

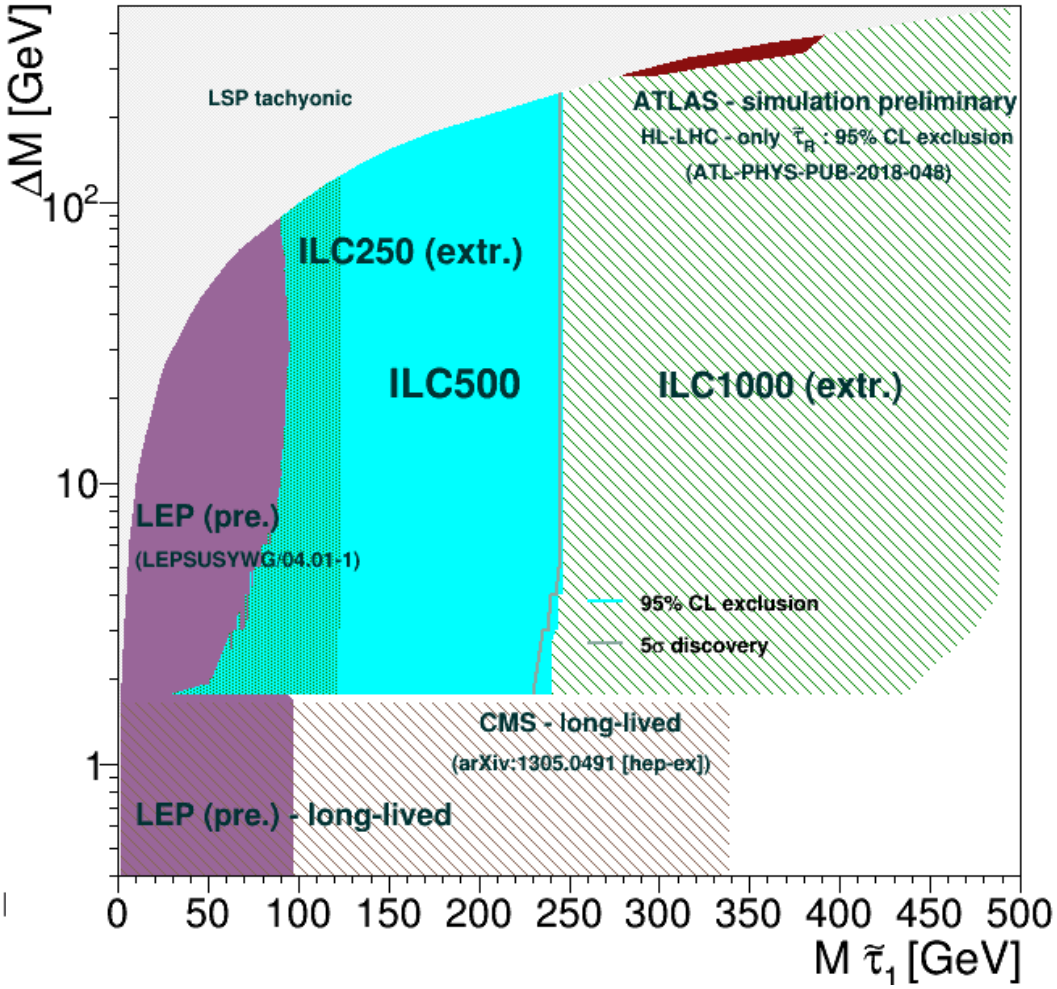
**Cuts against properties of irreducible sources of background**

- 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

# ILC expected limits

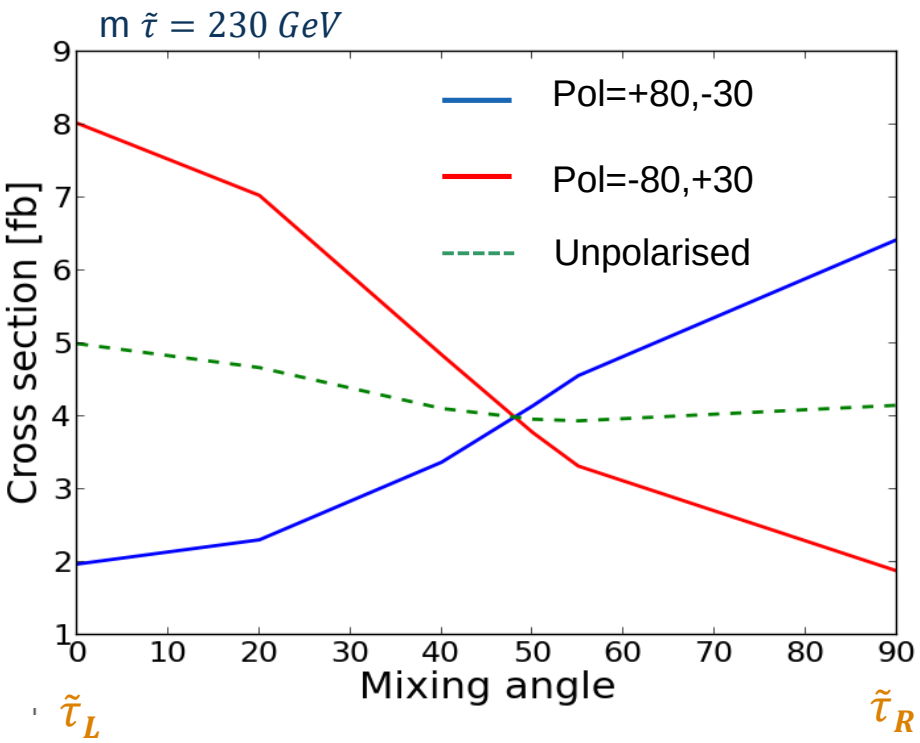



**At ILC discovery and exclusion are almost the same**

# 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

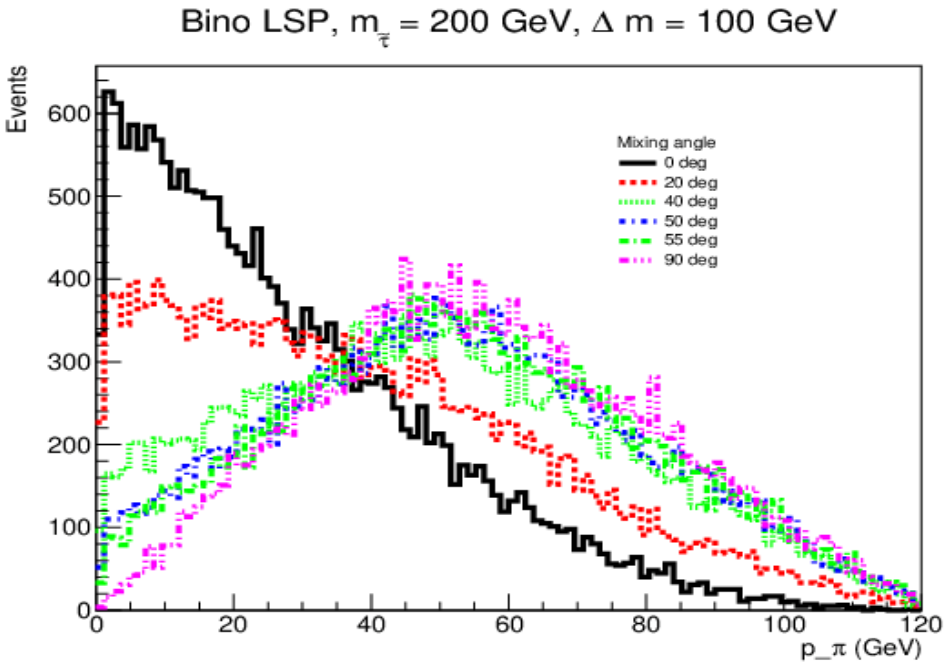
Take into account effect of mixing in cross-section and signal efficiency

- 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 (ctd.)

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




- Signal efficiency depends on spectrum of detectable $\tau$ decays
- Spectrum of $\tau$ decay products depends on $\tau$ polarisation
- $\tau$ 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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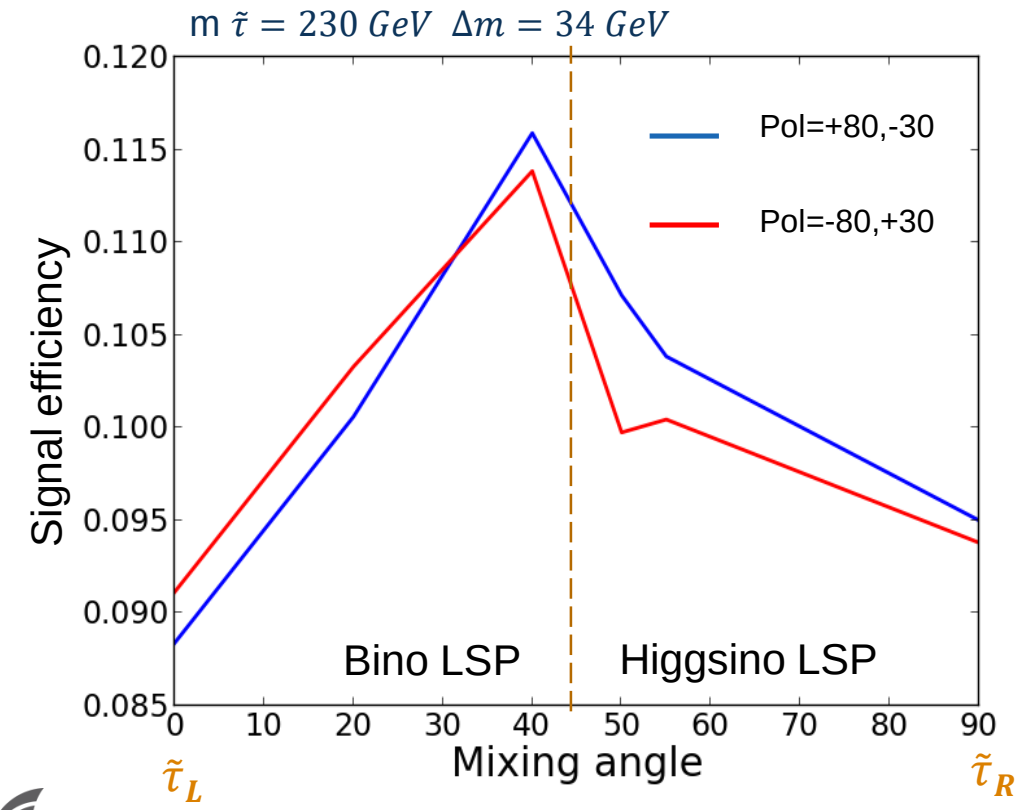
# Analysis of worst scenario (ctd.)

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




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

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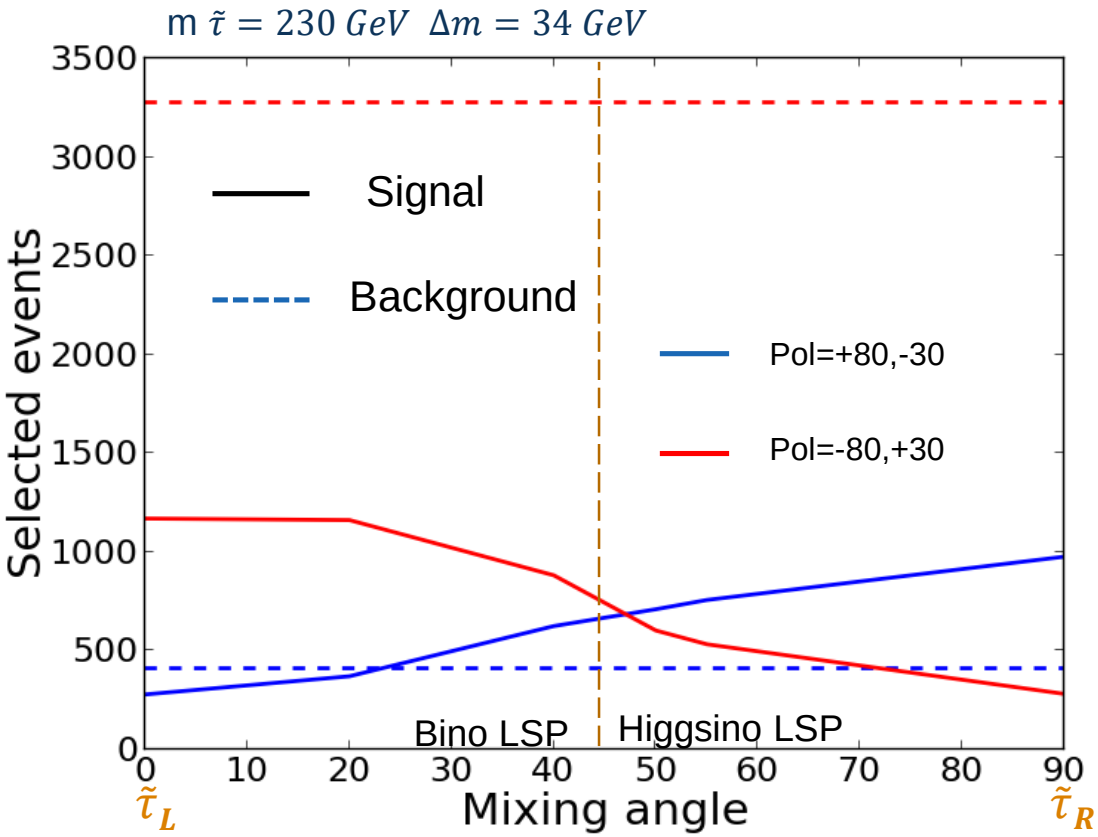
# Analysis of worst scenario (ctd.)

**Selected background and signal events**

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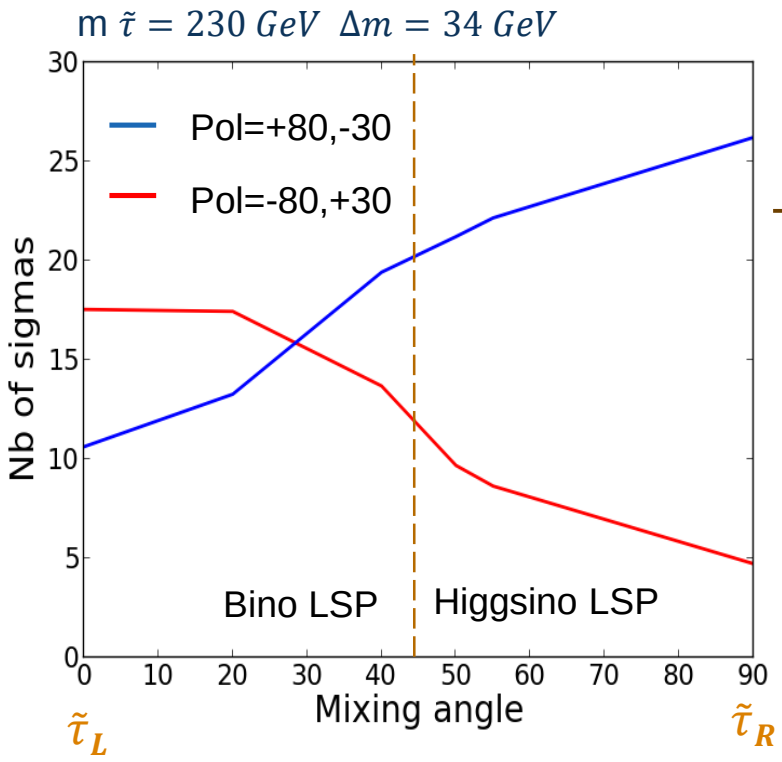
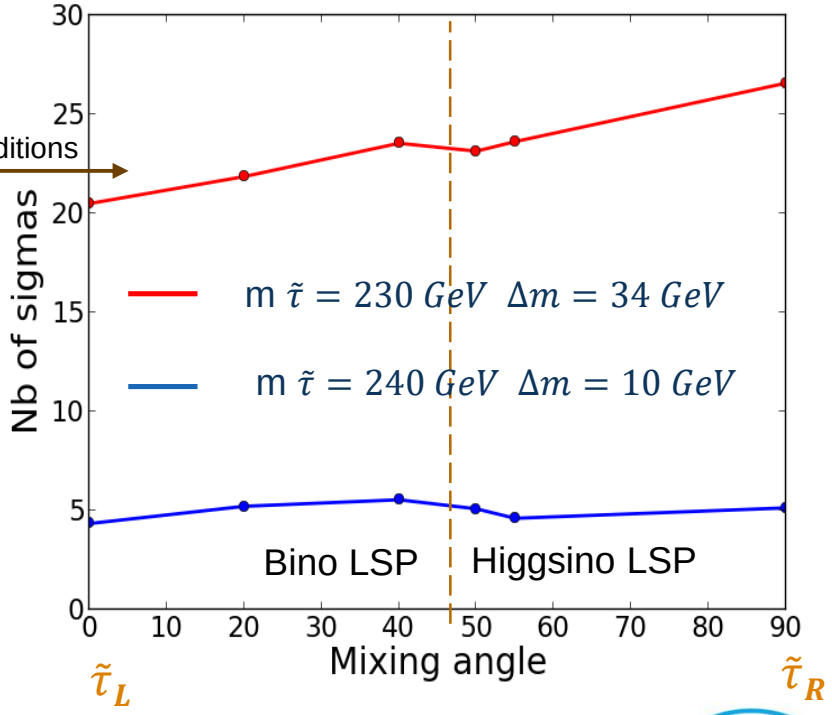
# Analysis of worst scenario (ctd.)

**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**

# Overlay tracks

In previous study background and signal events were reconstructed by sgv fast simulation

**Check effect of full reconstructed events in $\tilde{\tau}$ searches**

Main difference:

Low $p_T$ hadrons from γγ interactions

Electrons and positrons from beamstrahlung

87% (13%) overlay particles identified as pions ($e^+/e^-$)

At ILC with $\sqrt{s}$ = 500 GeV in average 1.05 $\gamma\gamma$-background events per bunch

~1400 $\gamma\gamma$-background events per train

# Overlay tracks (ctd.)

Samples:

- Background: ILD full simulated files
- Signal: generated by whizard and reconstructed by sgv + overlay tracks from full simulated background files

**Search for algorithm reducing overlay tracks**

Based on:

- transverse momentum
- angular distribution
- impact parameter significance

Overlay tracks:

- low transverse momentum
- forward direction
- displaced vertices

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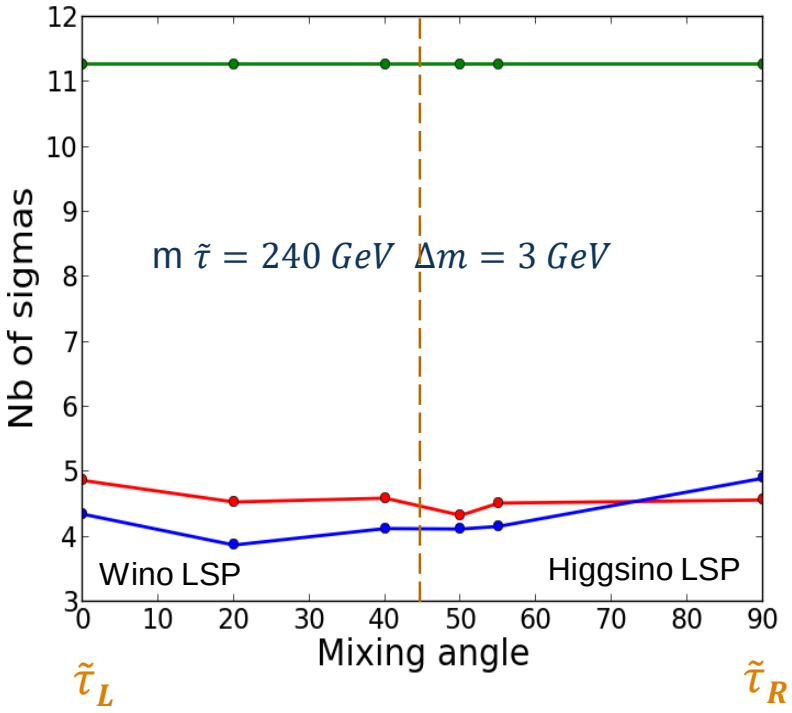
# Effect of overlay tracks

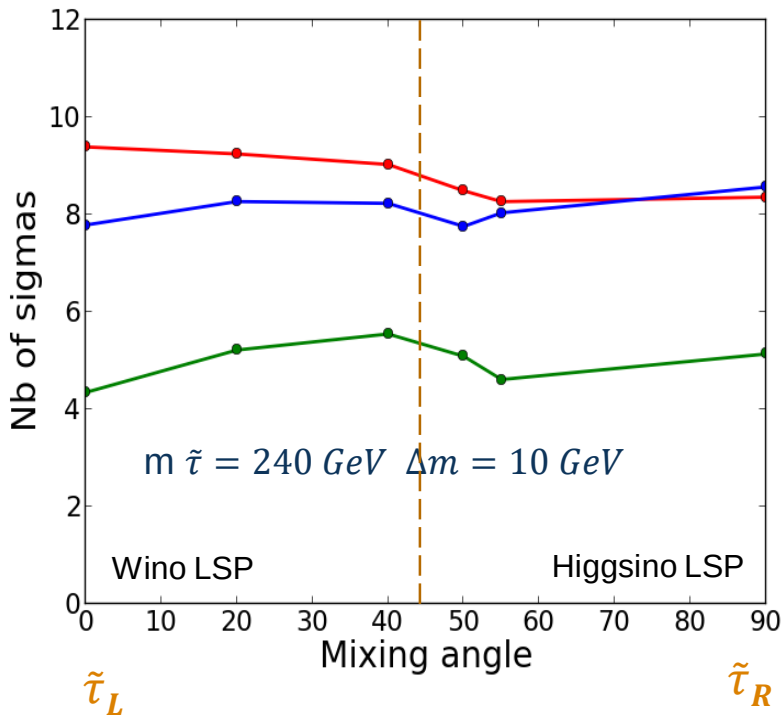
Full simulation

Not overlay cut

Overlay cut

SGV




**Likelihood-ratio statistic used to weight both polarisations (H20 conditions)**

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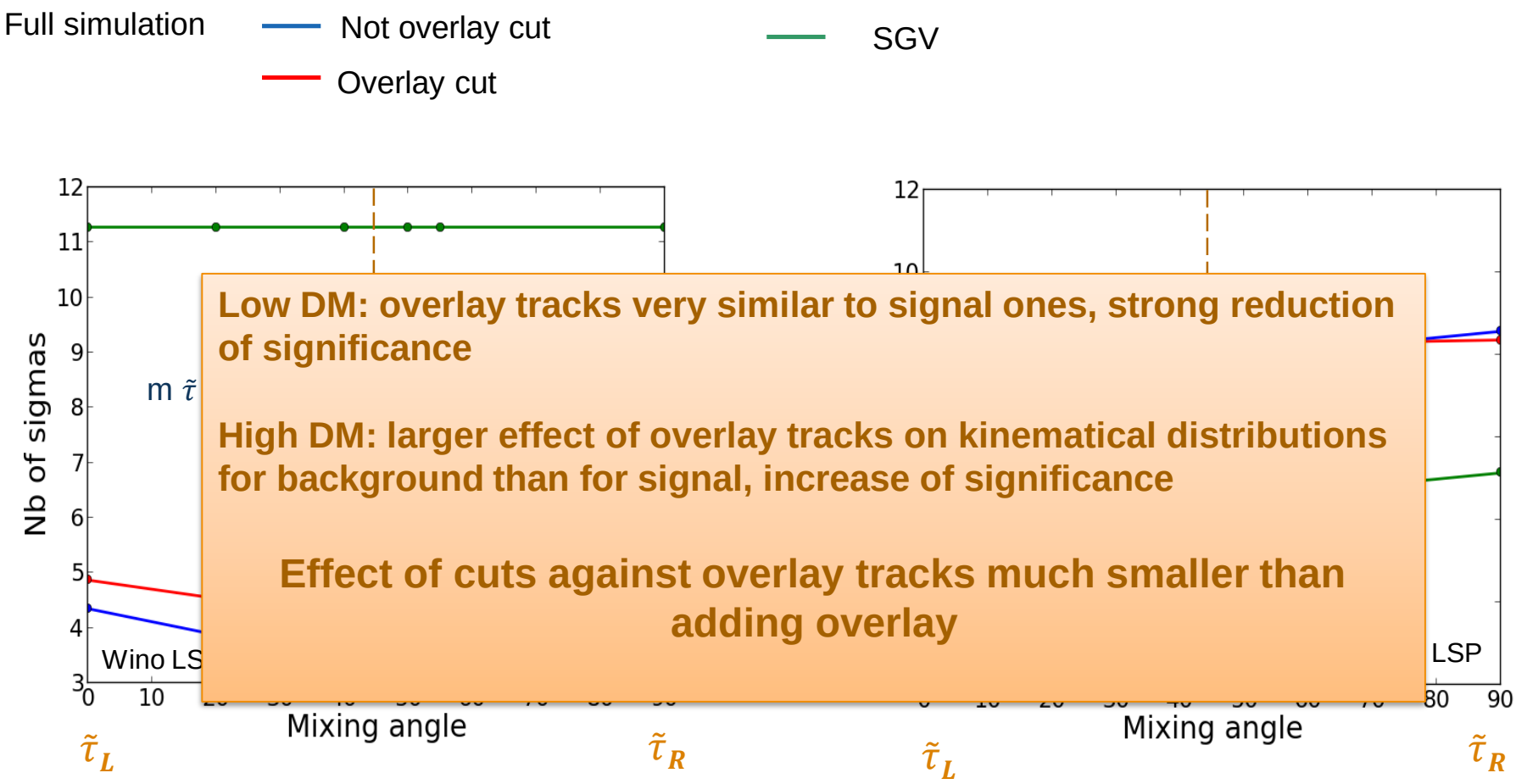
# Effect of overlay tracks




**Low DM: overlay tracks very similar to signal ones, strong reduction of significance**

**High DM: larger effect of overlay tracks on kinematical distributions for background than for signal, increase of significance**

**Effect of cuts against overlay tracks much smaller than adding overlay**

**Likelihood-ratio statistic used to weight both polarisations (H20 conditions)**

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# “Only overlay” events as misidentified $\tilde{\tau}$ events (preliminary)

At ILC with $\sqrt{s}$ = 500 GeV in average 1.05 $\gamma\gamma$-background events per bunch

~1400 $\gamma\gamma$-background events per train

Taking overlay particles without any additional cut

Cuts DM = 10 GeV: no events passing cuts (< 0.001% -> < 0.014 events/train – 0.07 events/sec)

Cuts DM = 2 GeV: 0.35% events passing cuts (4.9 events/train – 24.5 events/sec)

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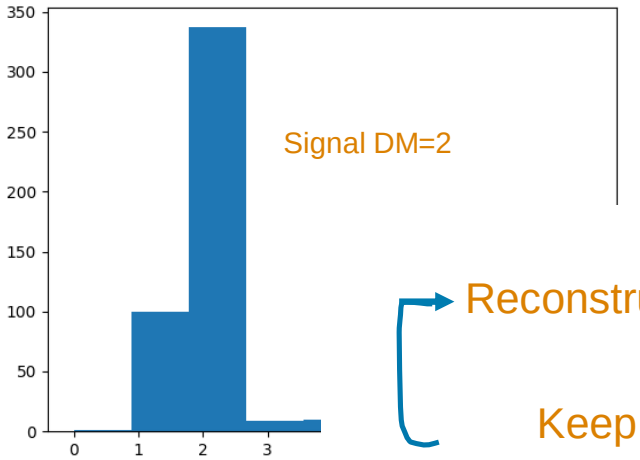
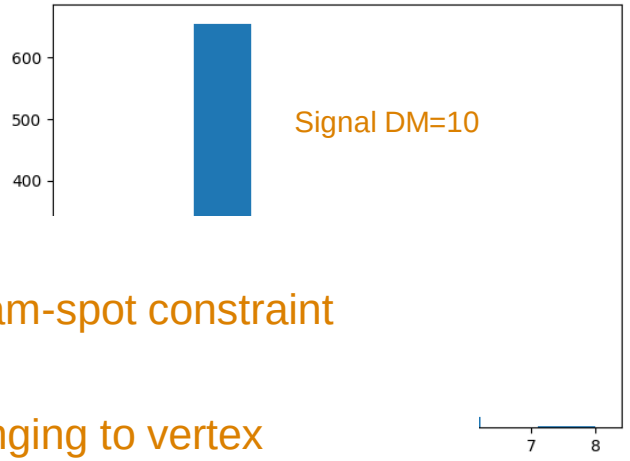
# “Only overlay” events as misidentified $\tilde{\tau}$ events (preliminary) (ctd.)

# remaining tracks after vertexing (at least two track vertex with beam-spot constraint)

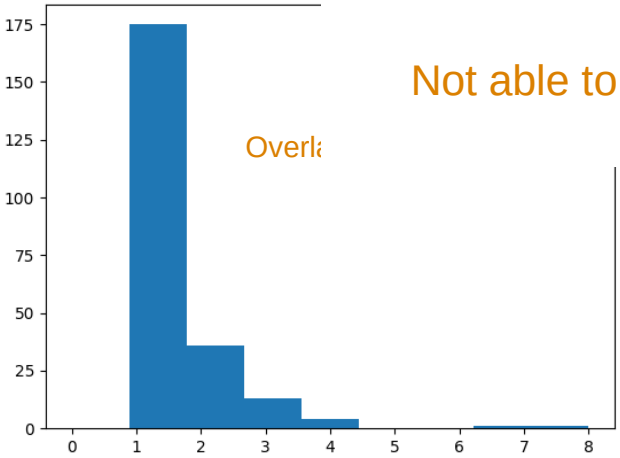


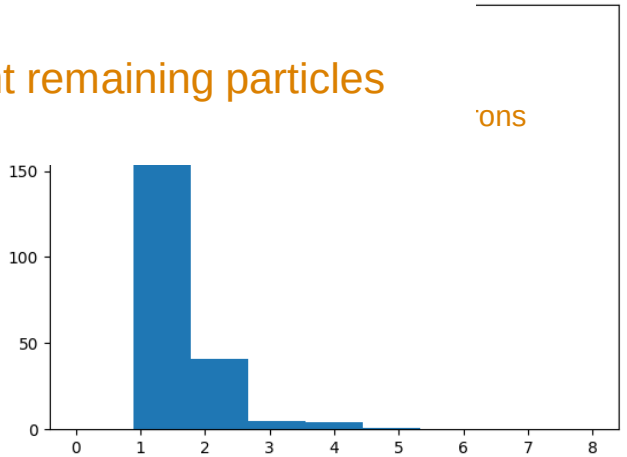




Reconstruct vertex with beam-spot constraint

Keep particles not belonging to vertex

Not able to create vertex: count remaining particles



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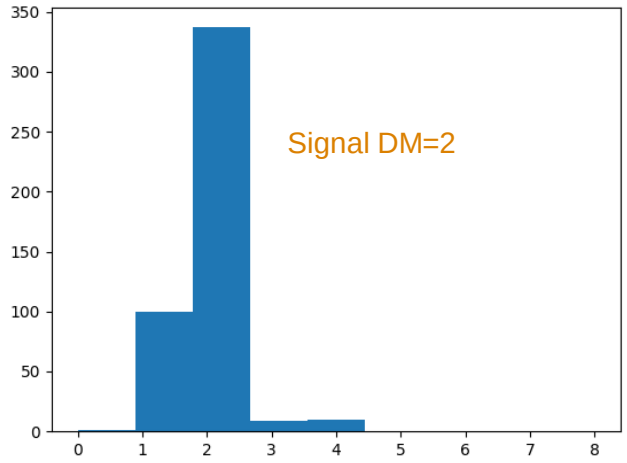


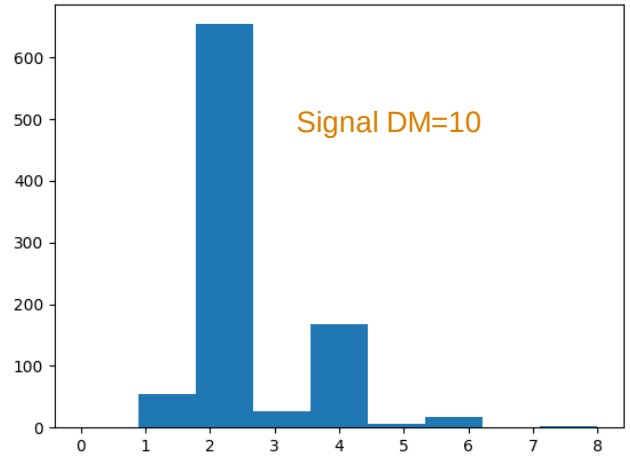


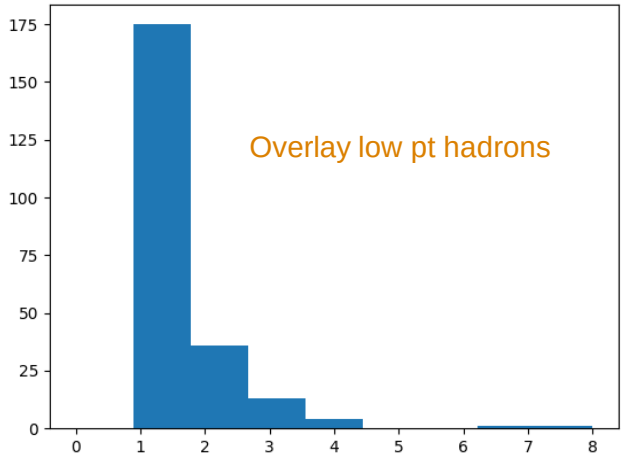


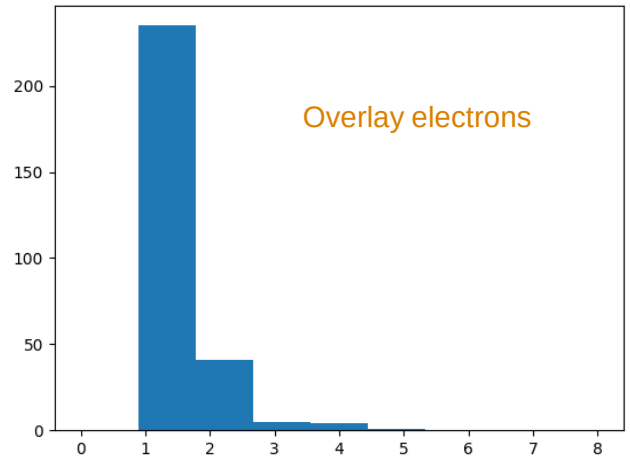

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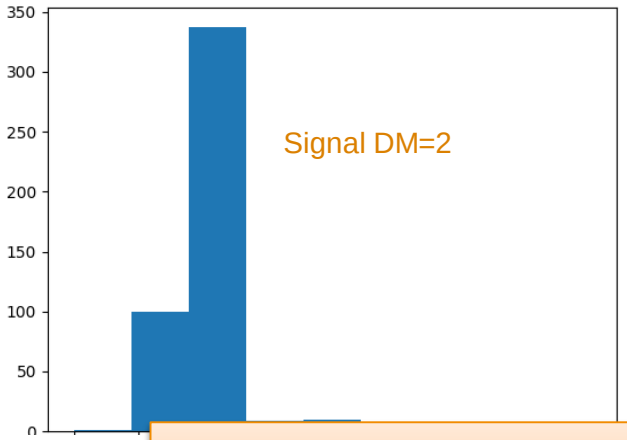
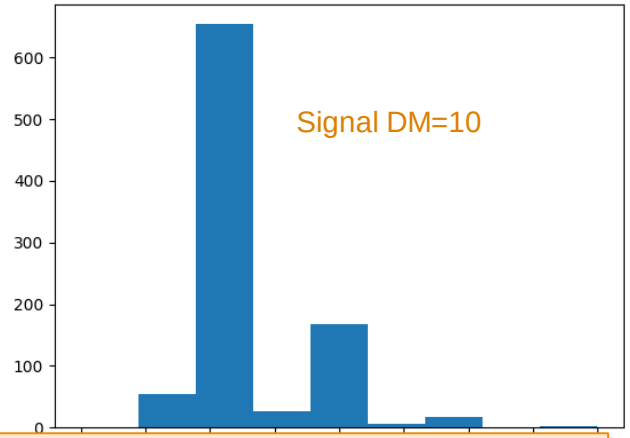
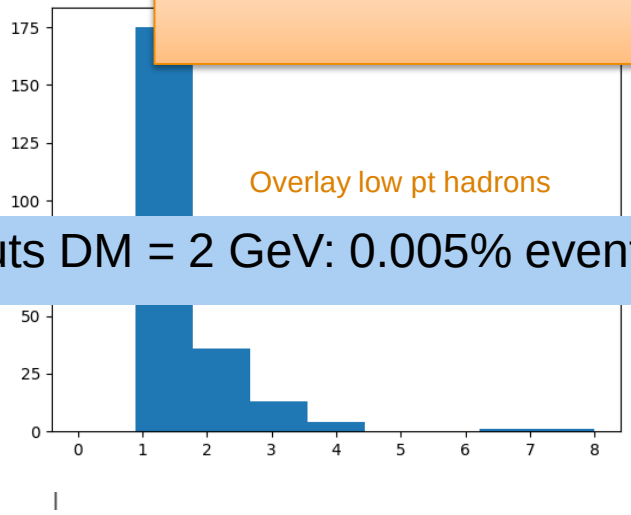
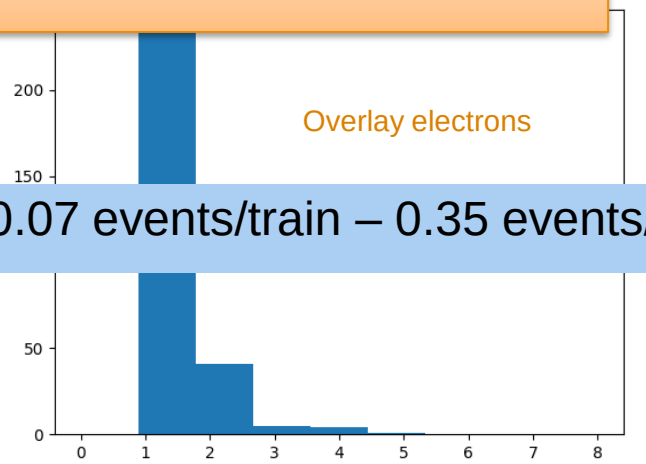



**Reduce only overlay events based on track multiplicity after vertexing**




Cuts DM = 2 GeV: 0.005% events passing cuts (0.07 events/train – 0.35 events/sec)

# 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
- $\tau$ polarisation and $\tilde{\tau}$ mixing angle

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- Beam energy 500 GeV and integrated luminosity of 500 $fb^{-1}$ per beam polarization (expected one 1600 $fb^{-1}$)

**Per mil-level mass-measurements and per cent-level cross-section, polarization and mixing-angle measurements will be possible at the ILC**

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# Outlook/Conclusions

- 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
- Effect of overlay tracks on signal/background ratio for $\tilde{\tau}$ searches was analysed:
  - high DM: overlay harms background more than signal, increase of significance wrt sgv
  - low DM: overlay very similar to signal, strong reduction of significance

  In both cases effect of cuts against overlay tracks much smaller than adding overlay at all
- Study of "only overlay" events as possible misidentified $\tilde{\tau}$ events is undergoing
- If $\tilde{\tau}$´s exist in the kinematic range of the ILC, precision measurements of $\tilde{\tau}$ properties are possible at few percent level
- Contribution to Snowmass paper will be done on time

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