$\tilde{\tau}$ searches and measurements with the ILD concept at the International Linear Collider

Teresa Núñez - DESY

- Motivation of $\tilde{\tau}$ studies
- Limits at LEP and LHC
- $\tilde{\tau}$ searches at the ILC
  - Signal and Background
  - Analysis worst scenario
  - General cuts
  - Effect of overlay particles
  - Limits
- Outlook and conclusions

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Motivation for $\tilde{\tau}$ searches

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

$\tilde{\tau}$ satisfies both conditions

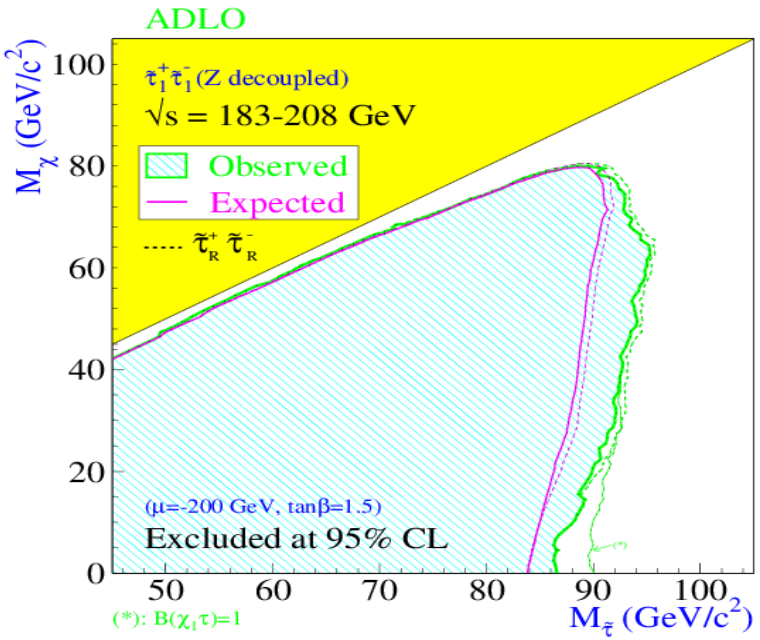
Scalar superpartner of τ-lepton

- 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 LEP and LHC

$\tilde{\tau}$ searches at LEP



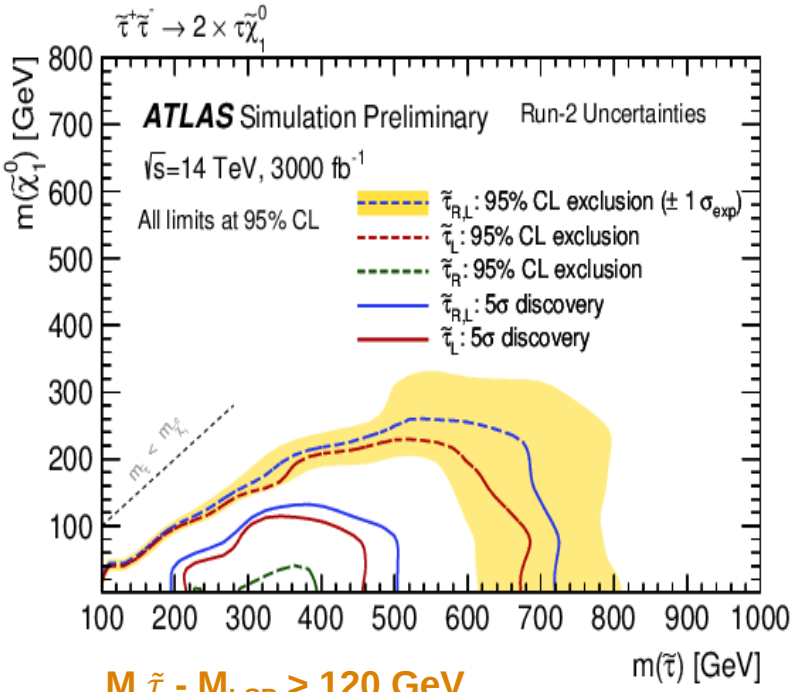
- $\sqrt{s}$ = 183-208 GeV
- Combined four LEP experiments data

LEPSUSYWG/04-01.1

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

Limits at LEP and LHC (ctd.)

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



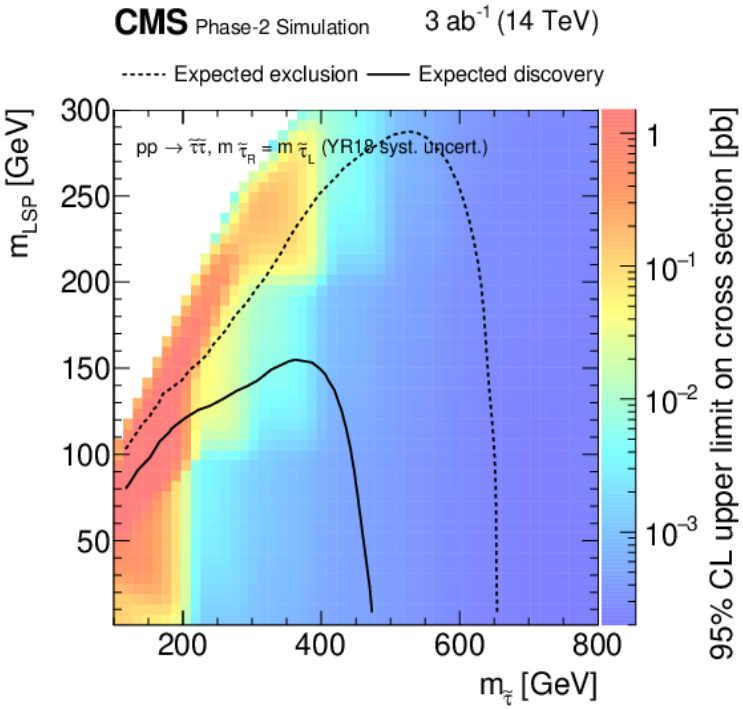
M $\tilde{\tau}$ - M_{LSP} > 120 GeV

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

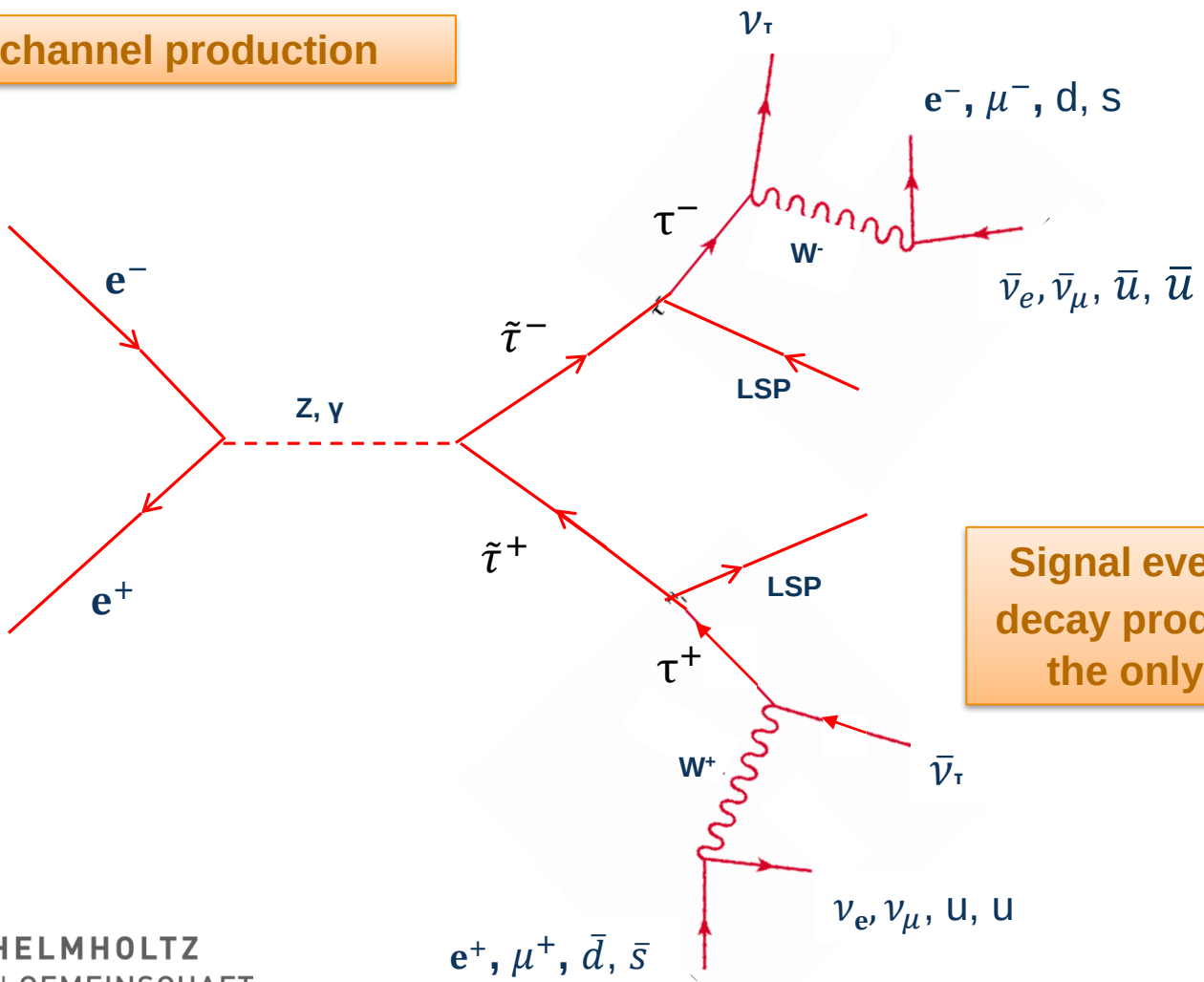
- Two models: $\tilde{\tau}_R$ *and* $\tilde{\tau}_L$
- No mixing
- Two $\tilde{\tau}$ assumed to be mass-degenerate
- No mixing



CMS PAS FTR-18-010

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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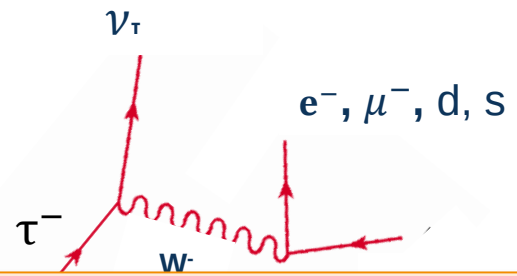
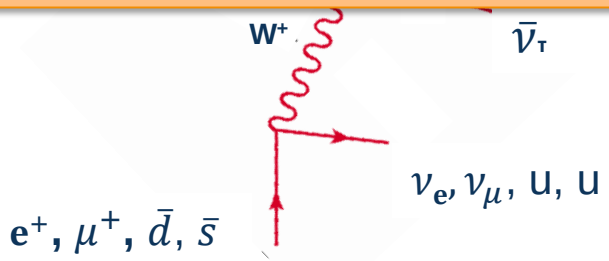
Signal characterization

s-channel production



Signature:

- large missing energy and momentum
- large fraction of detected activity in central detector (isotropic production of scalar particles)
- large angle between the two τ-lepton directions
- unbalanced transverse momentum
- zero 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 μ)
- $ee \rightarrow \tau\tau$ + ISR, $ee \rightarrow \tau\tau\ ee$, $\gamma\gamma \rightarrow \tau\tau$

Mis-identification of τ´s or of missing momentum

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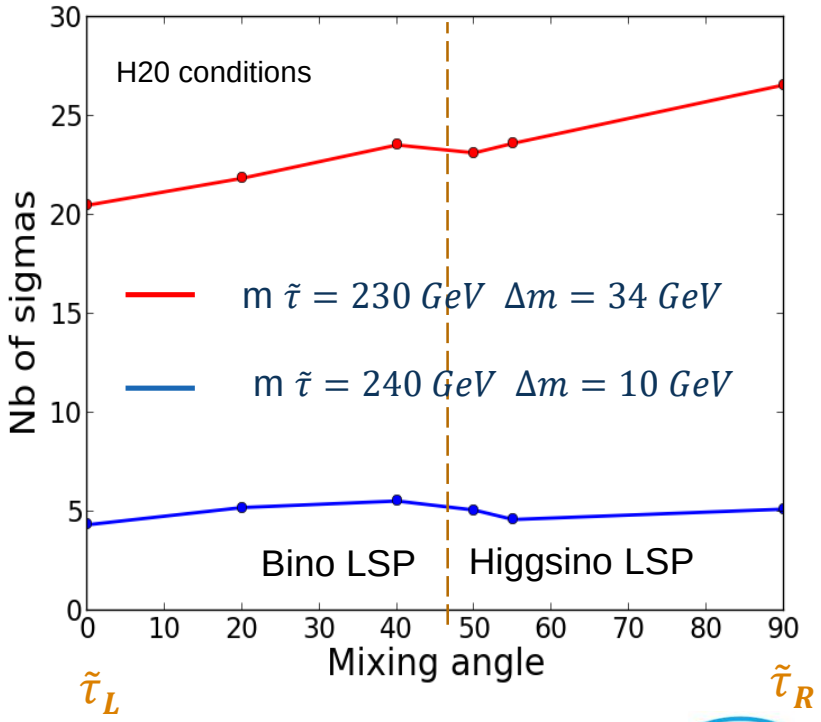
Analysis of worst scenario

Search for “worst” mixing angle …

- weighting contribution of both polarisations (likelihood-ratio statistics) using ILC conditions
- taking into account effect of mixing not only on cross-section but also on signal efficiency



53 degrees $\tilde{\tau}$ mixing ->lowest cross-section for unpolarized beams

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

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 τ's and little other activity

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

- Maximum jet momentum:

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

Triggerless operation

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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

High polarised beams

Properties that the background often "does not" have

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

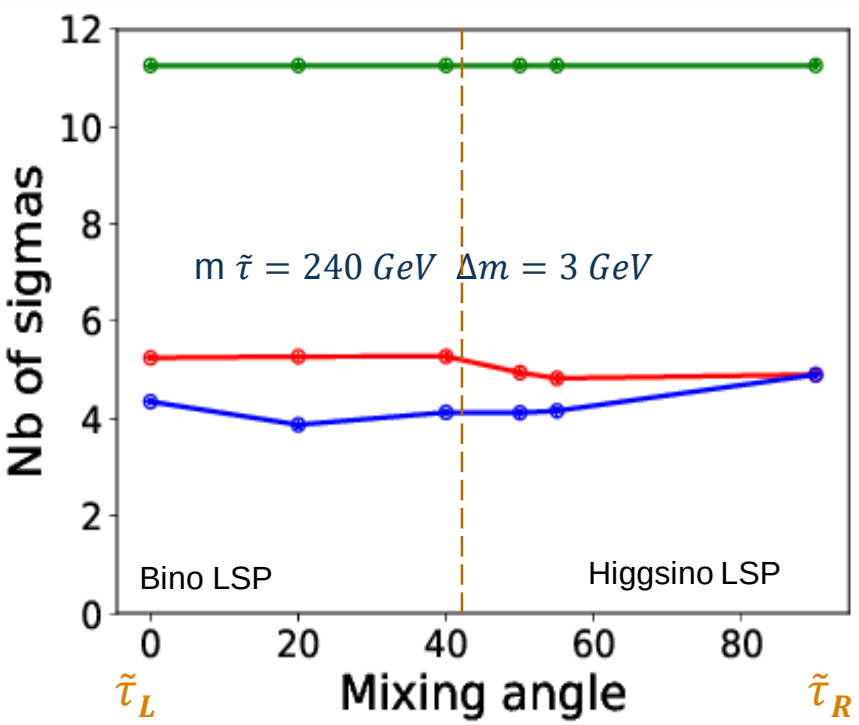
Effect of overlay particles

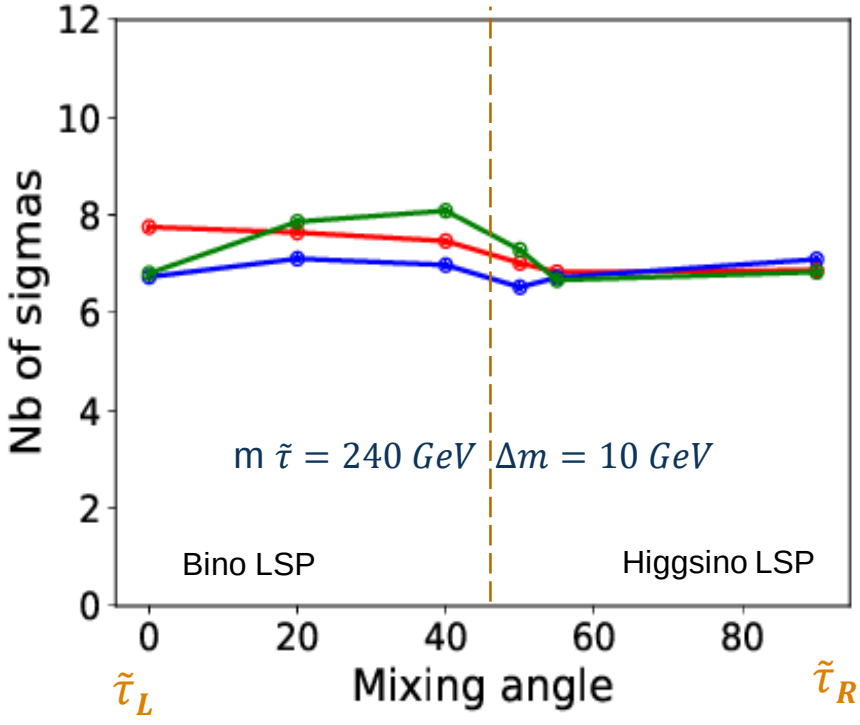
Full simulation

Not cut on overlay tracks

Cut on tracks based on transversal momentum, angular distribution and input parameter significance

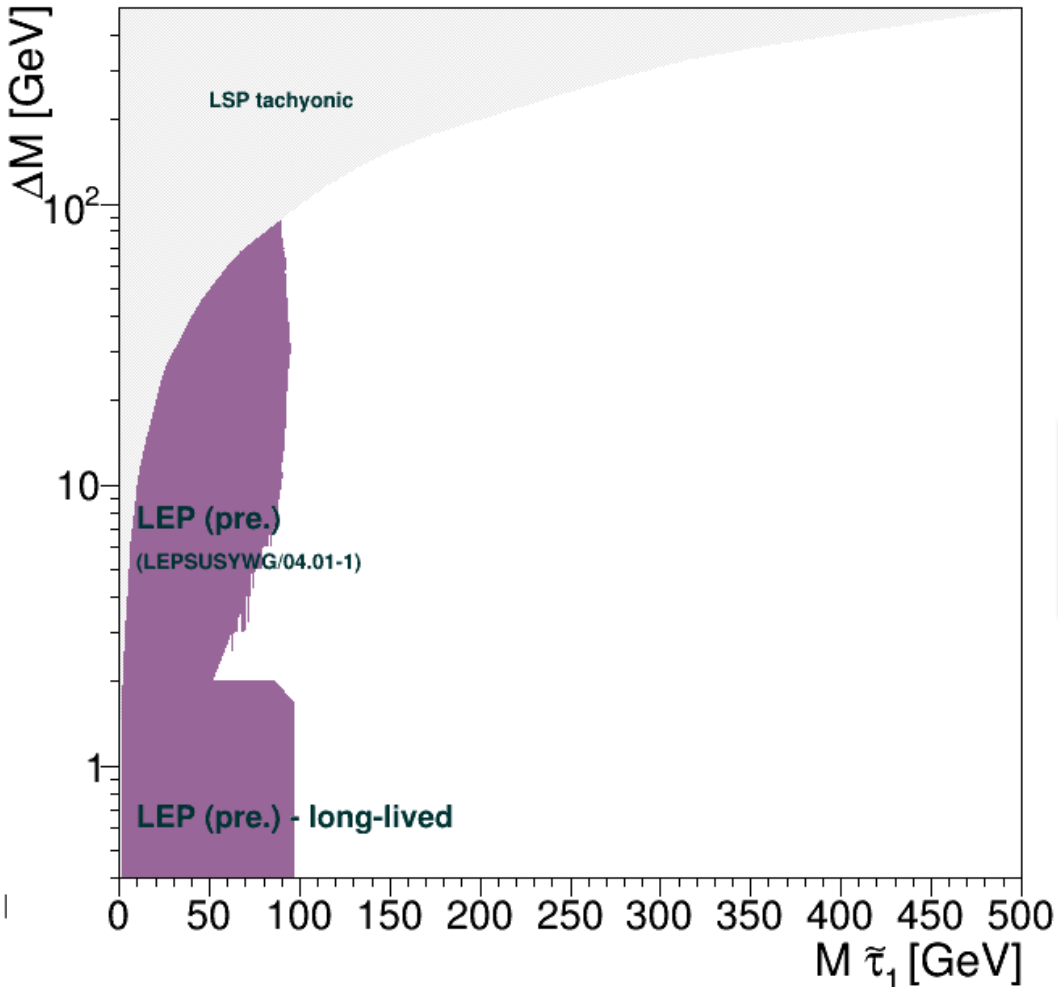
Fast simulation (SGV) – not overlay tracks





Larger effect of overlay tracks in low DM case since they are more similar to the signal ones: strong reduction of significance

ILC expected limits



Current model-independent limits for $\Delta M > \tau$ mass come from LEP

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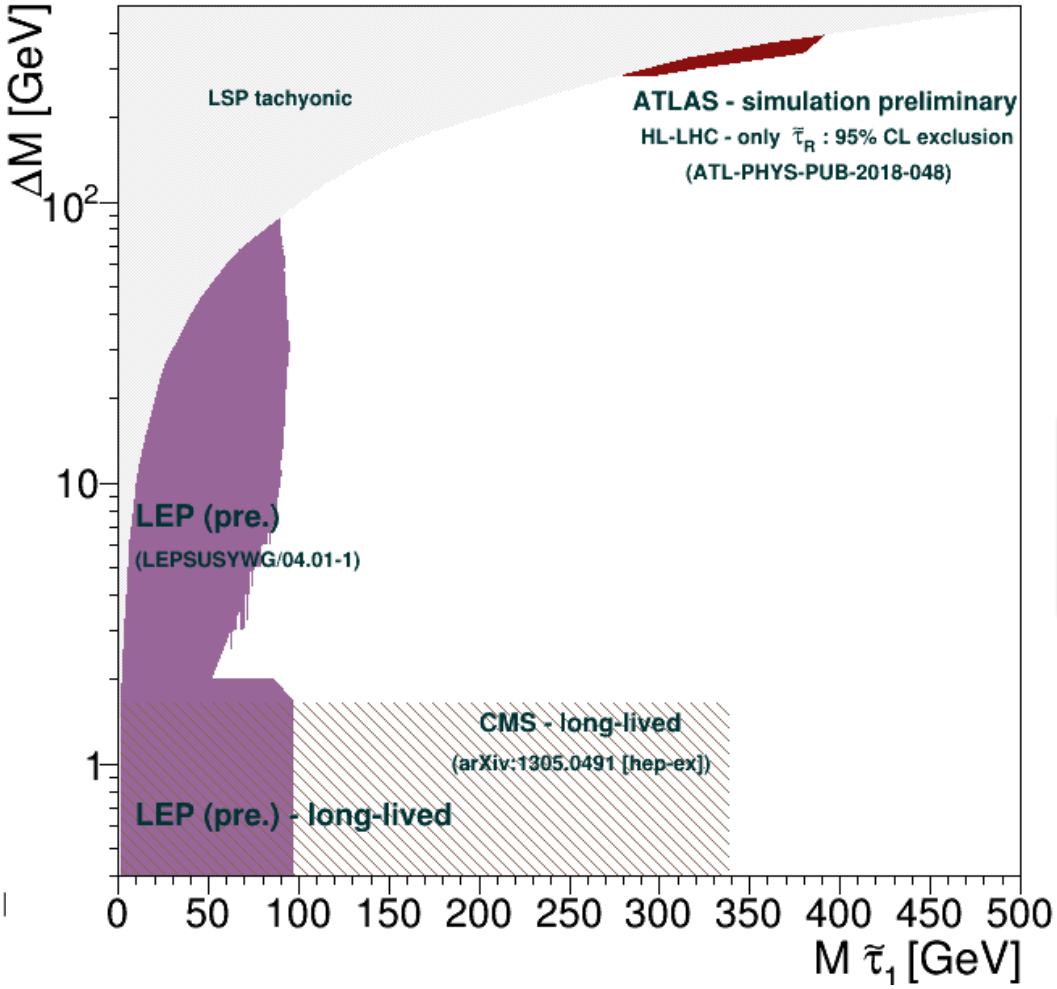

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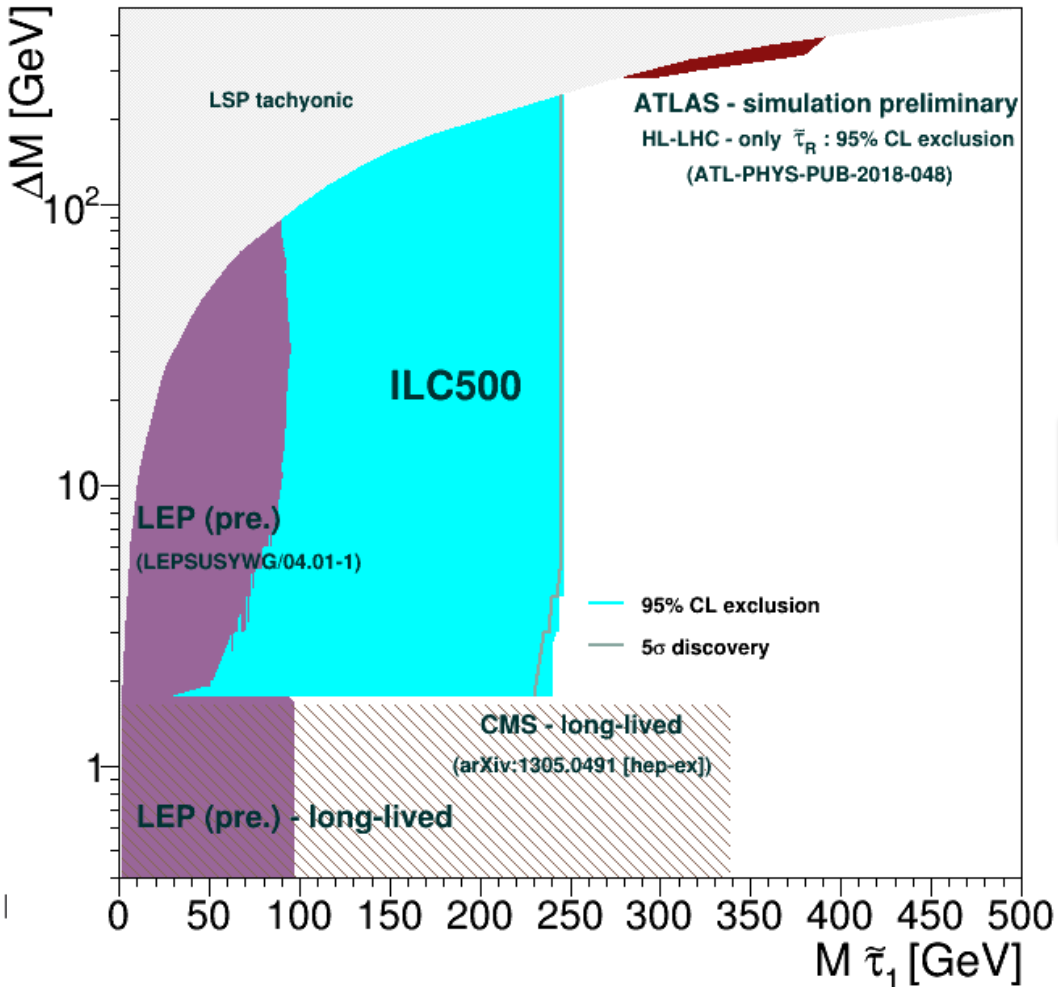

At ILC discovery and exclusion are almost the same

arXiv:2105.08616

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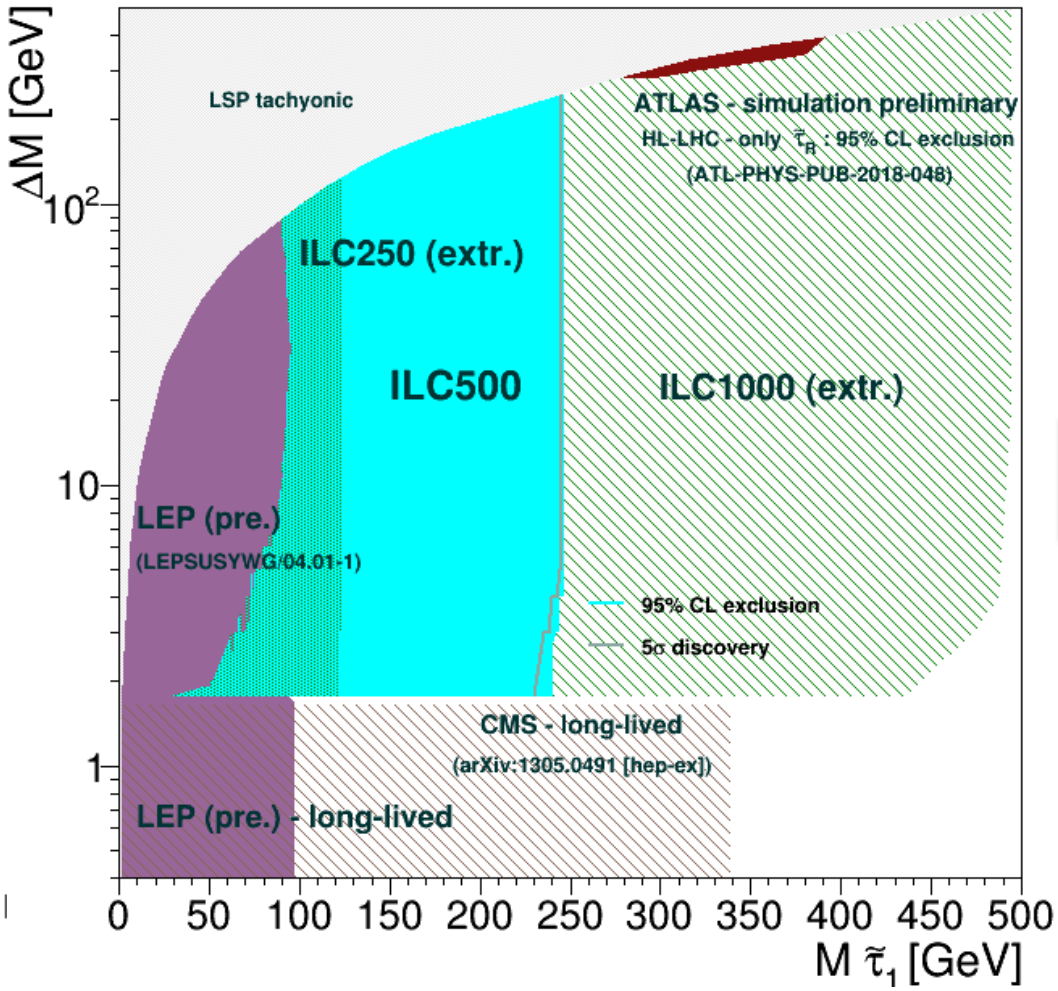

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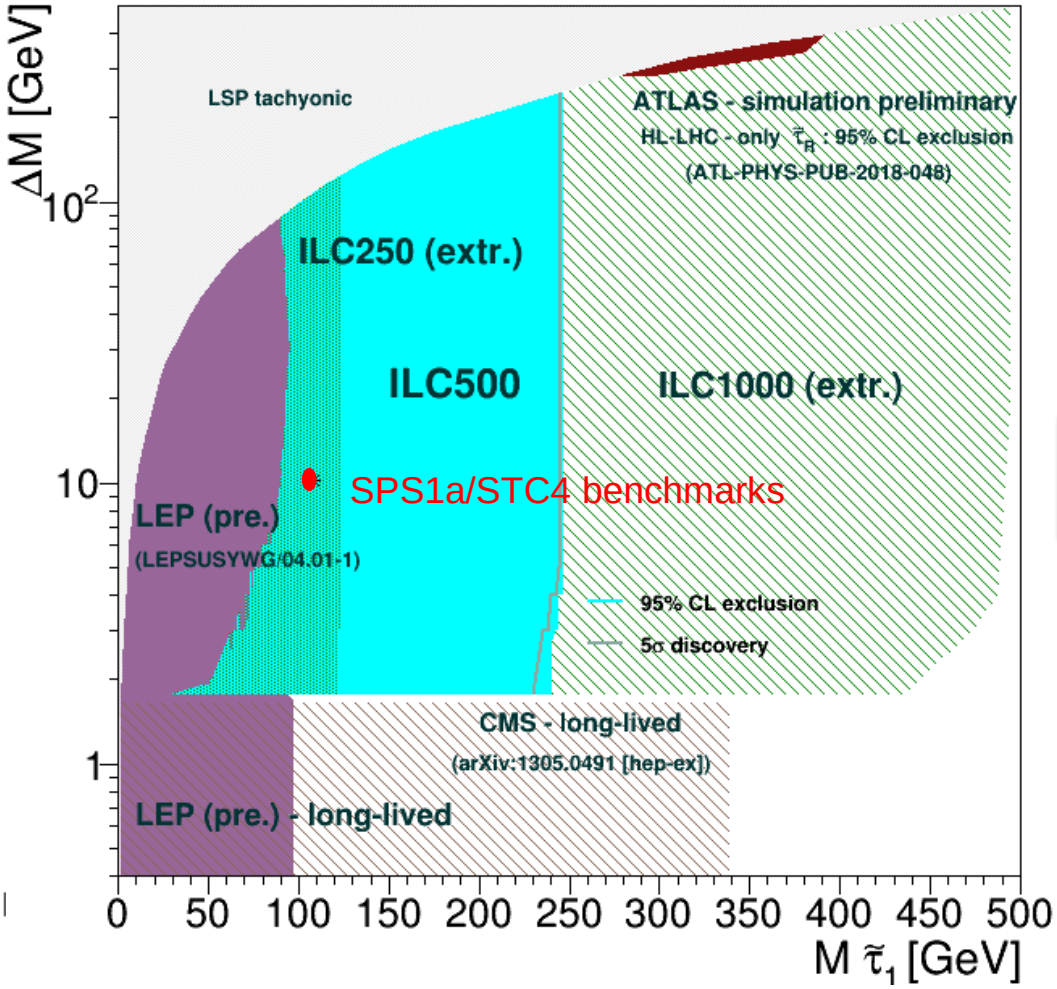

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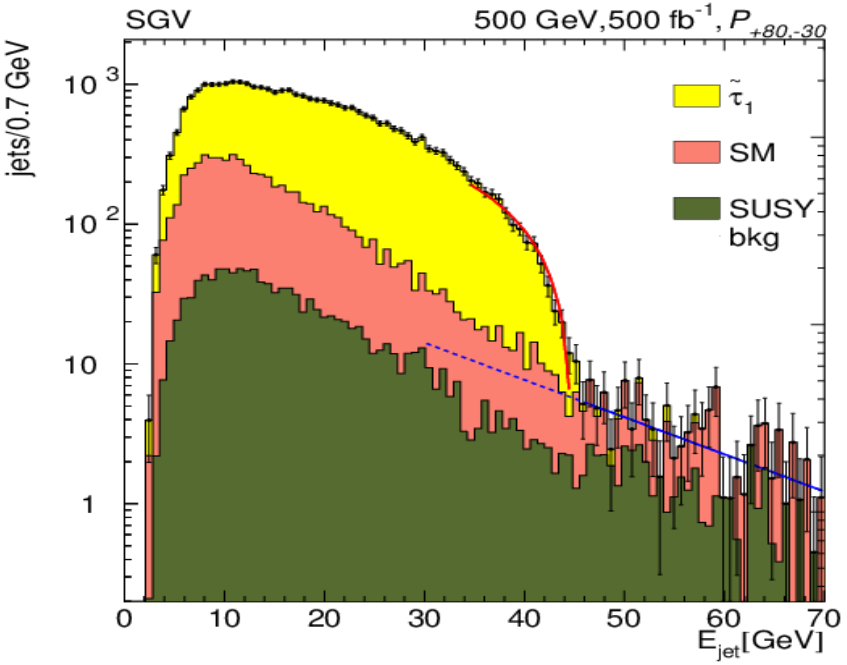
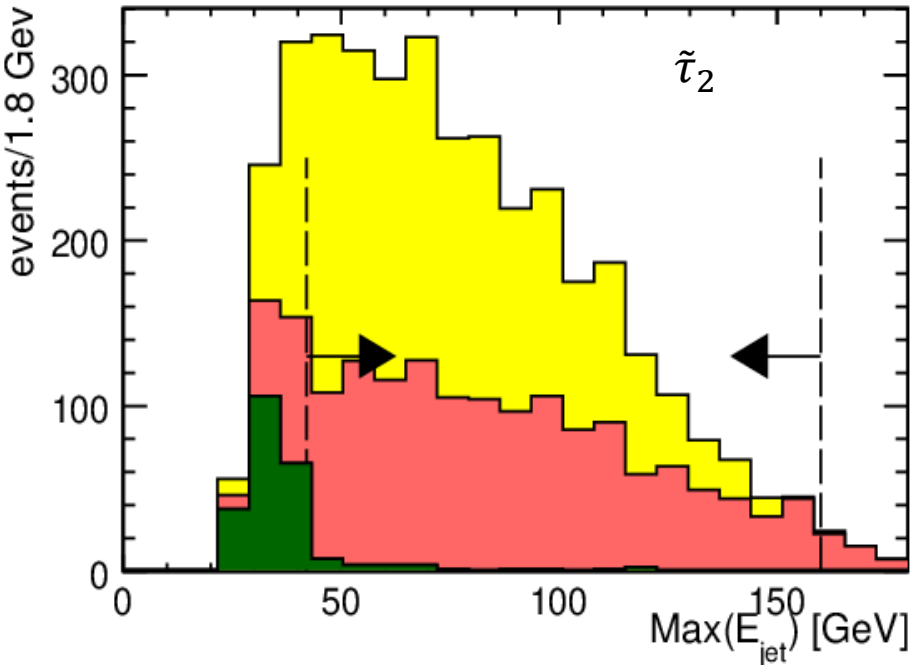
Prospects for $\tilde{\tau}$ measurements at the ILC

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



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

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



EPJC, 76(4),1 (2016)

Phys Rev, D82,055016 (2010)

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

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Prospects for $\tilde{\tau}$ measurements at the ILC (ctd.)

τ polarisation from energy spectrum from τ decays

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

EPJC, 76(4),1 (2016)

Phys Rev, D82,055016 (2010)

Per cent-level measurements are likely possible at the ILC

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Outlook/Conclusions

- Even after HL-LHC large parts of the $\tilde{\tau}$-LSP mass plane will remain unexplored
- ILC will discover/exclude $\tilde{\tau}$'s for any $\tilde{\tau}$-LSP mass difference and any $\tilde{\tau}$-mixing nearly up to the kinematic limits
- 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.

  Strong reduction of significance for low DM, since overlay is very similar to signal.

  Effect of cuts against overlay tracks is smaller or similar than adding overlay at all
- If $\tilde{\tau}$´s exist in the kinematic range of the ILC, precision measurements of $\tilde{\tau}$ properties are possible at few percent level