$\tilde{\tau}$ searches and measurement prospects at future Higgs factories

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
  - Limits
- Other studies
- Outlook and conclusions

First ECFA Workshop on e+e- Higgs/EW/Top factories
5 October 2022, Hamburg

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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

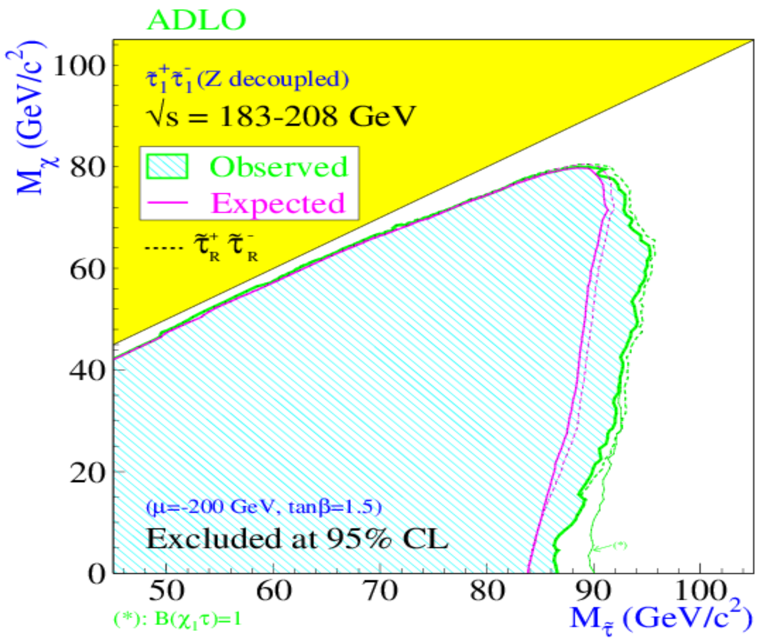
Scalar superpartner of τ-lepton

- 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

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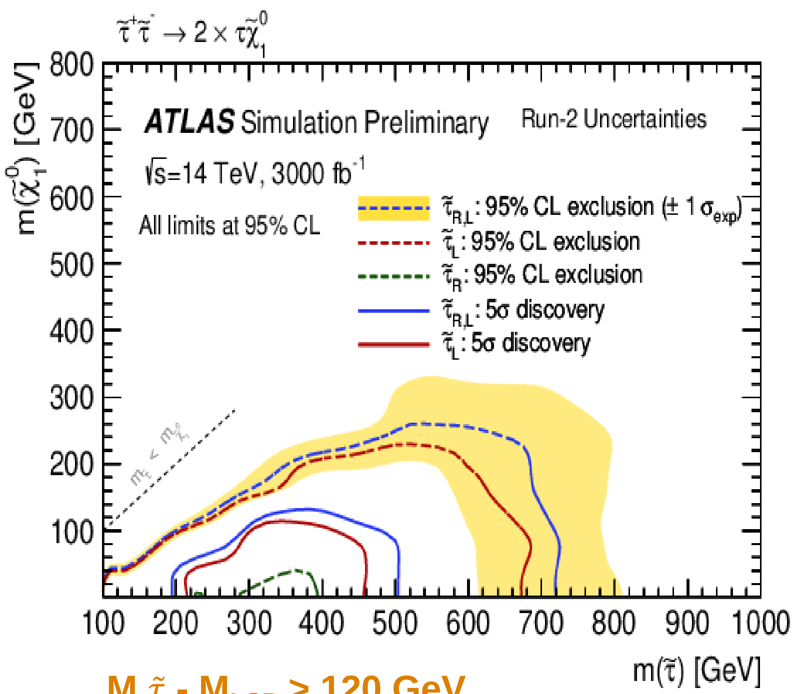
Limits at LEP and LHC (ctd.)

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



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

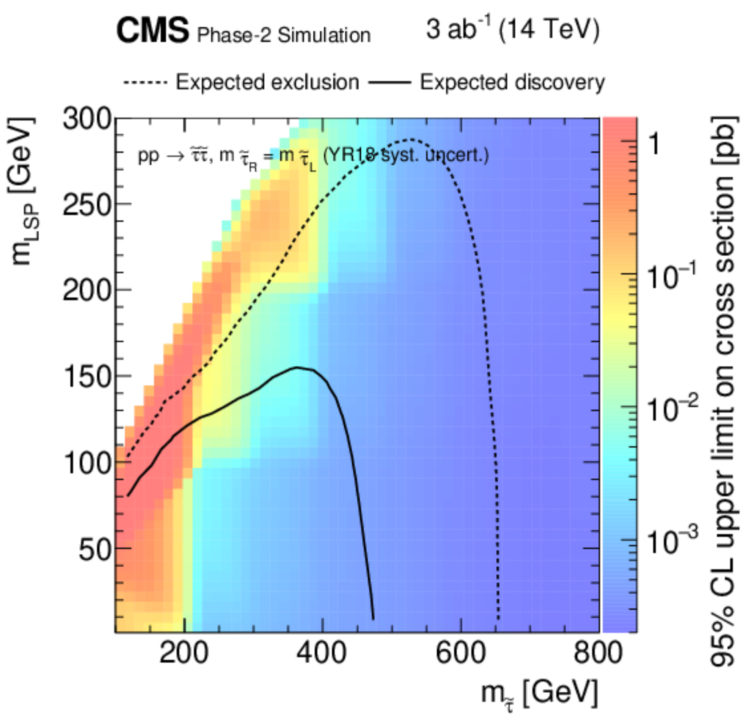
ATL-PHYS-PUB-2018-048

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

Profits in future e^+e^- Higgs/EW/Tops factories

Wrt. previous electron-positron colliders:

- increased luminosity and centre-of-mass energy
- improved technologies

Wrt. hadron colliders:

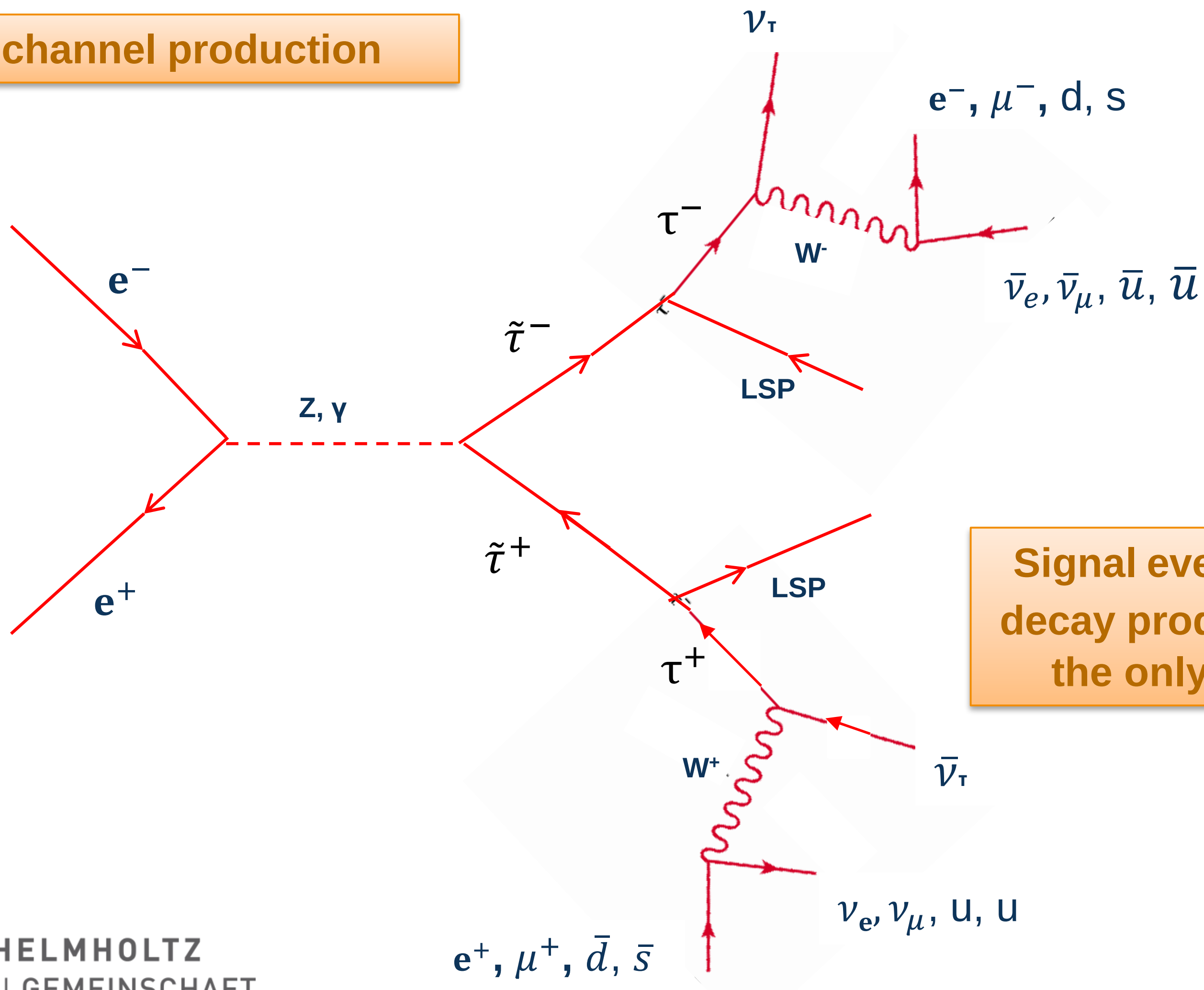
- cleaner environment
- known initial state
- triggerless operation of the detectors

Studies using the full detector simulation and reconstruction procedures of the International Large Detector concept (ILD) at the International Linear Collider (ILC)

- electron-positron collider at $\sqrt{s}$ = 250-500 GeV with upgradability (1TeV)
- electrons (80%) and positrons (30%) polarisations
- clean and reconstructable final state (near absence of pile-up)
- hermetic detectors (almost 4π coverage)

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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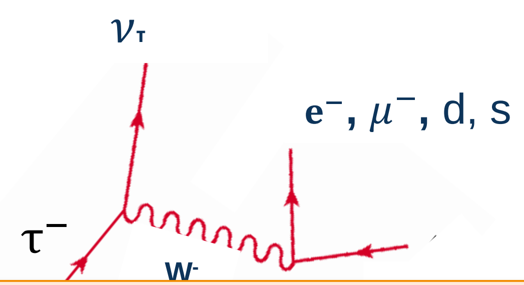
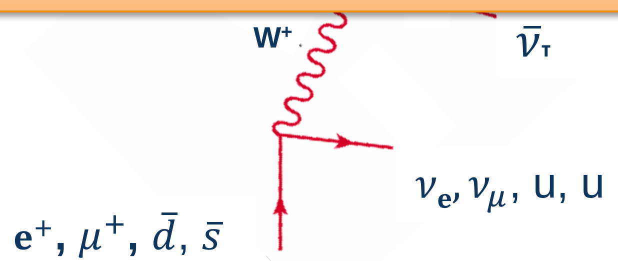
Signal characterization

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



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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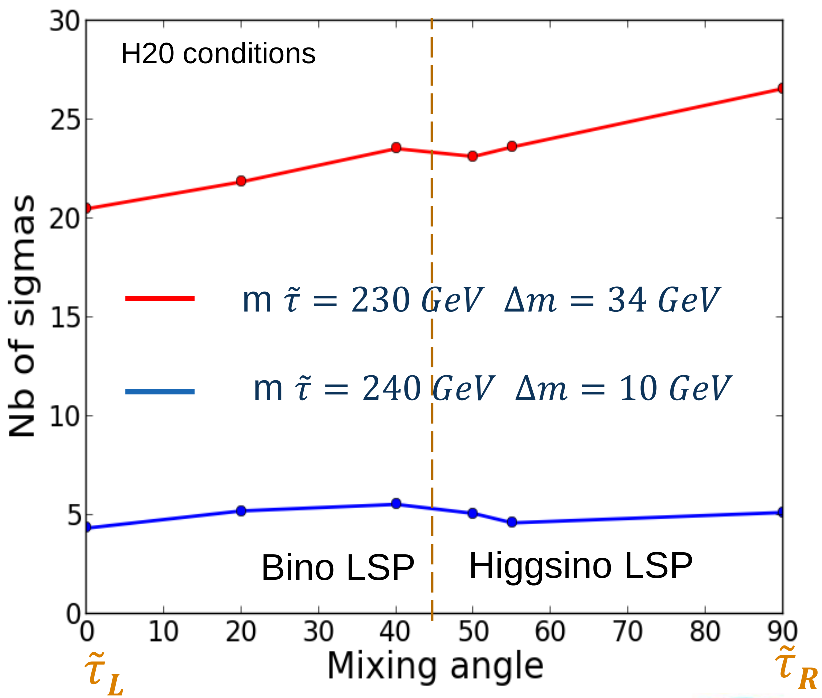
Analysis of worst scenario

Search for "worst" mixing angle …

P(+80%,-30%) and P(-80%, +30%) with integrated luminosity 1.6 ab^{-1} each

- 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)

- 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:

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

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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

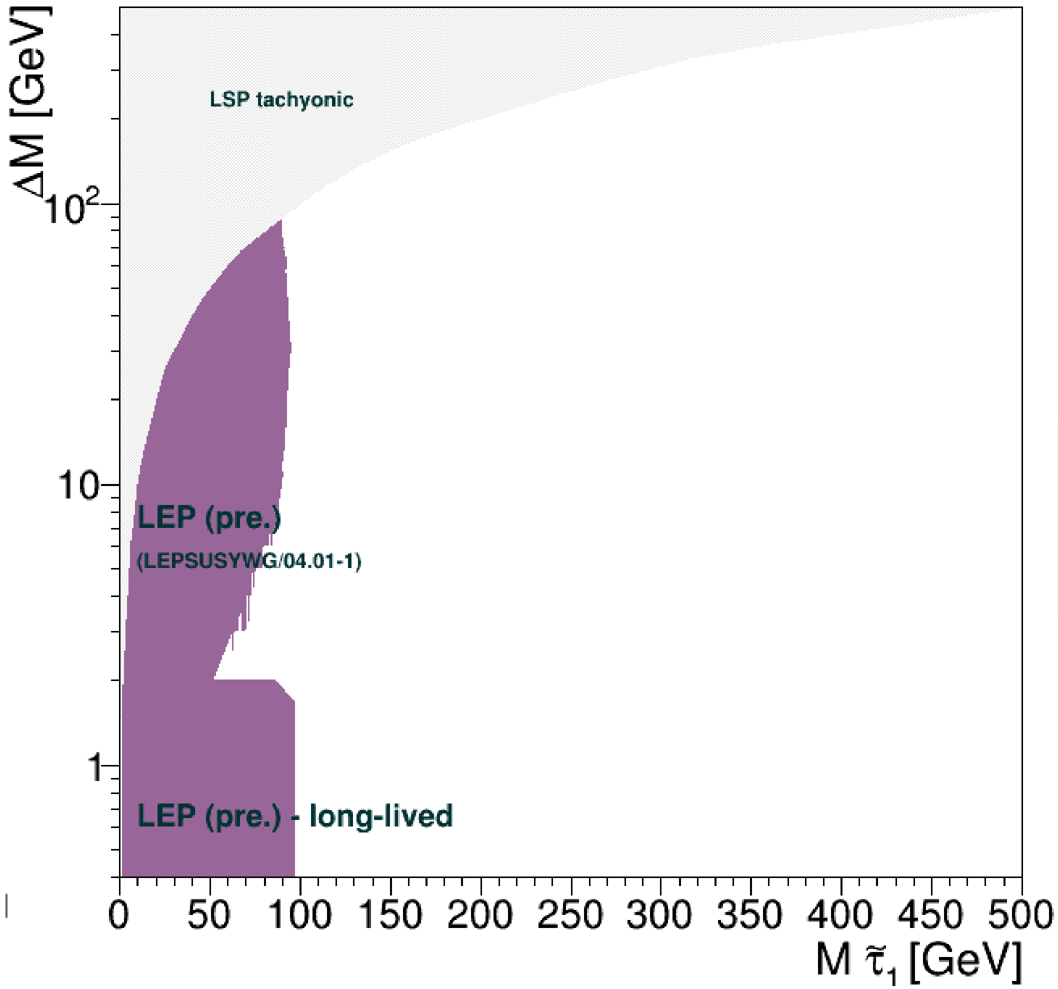
- Charge asymmetry ($\Sigma charge * \cos(polar\_angle)$)
- Difference between visible mass and Z mass

High polarised beams

Properties that the background often "does not" have

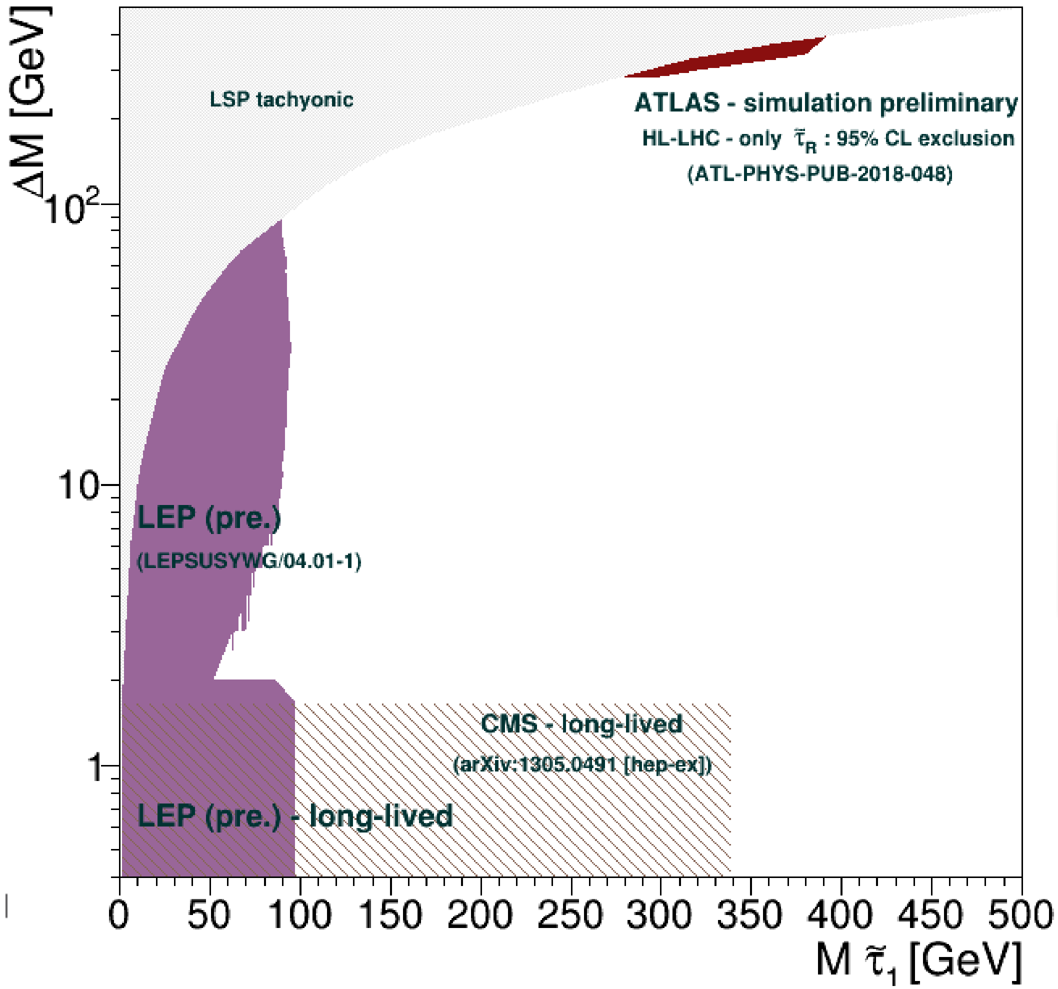
- Low energy in small angles
- Low energy of isolated neutral clusters

ILC expected limits



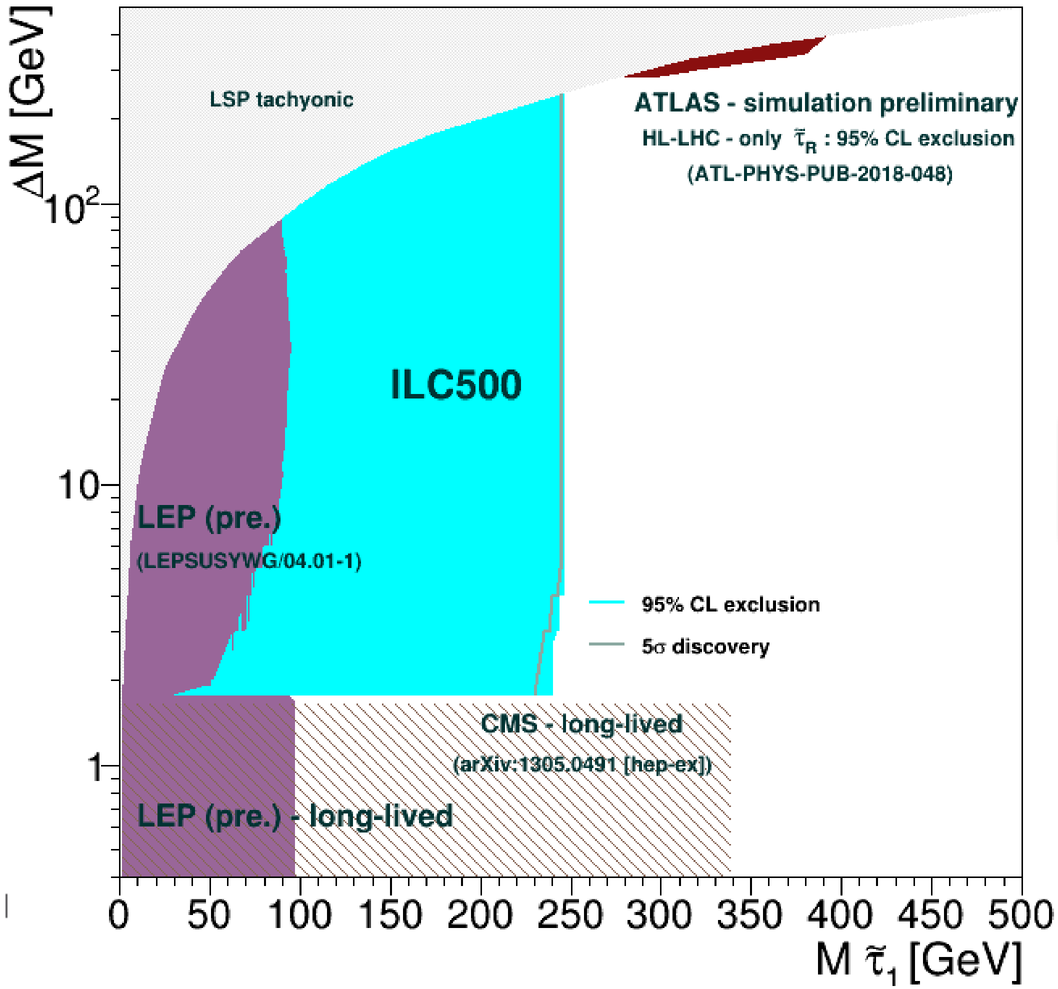
Current model-independent limits for ΔM > τ mass come from LEP

ILC expected limits



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

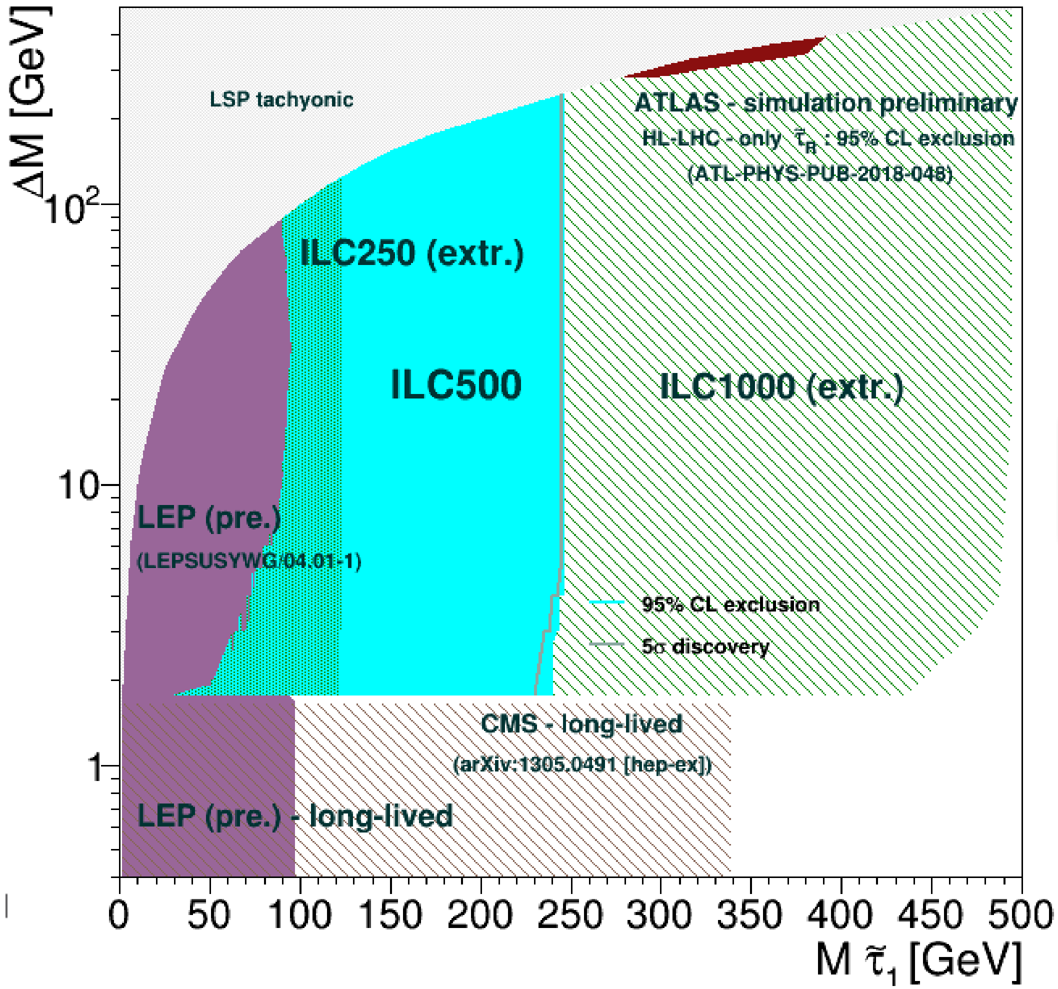
ILC expected limits



At ILC discovery and exclusion are almost the same

arXiv:2105.08616

ILC expected limits



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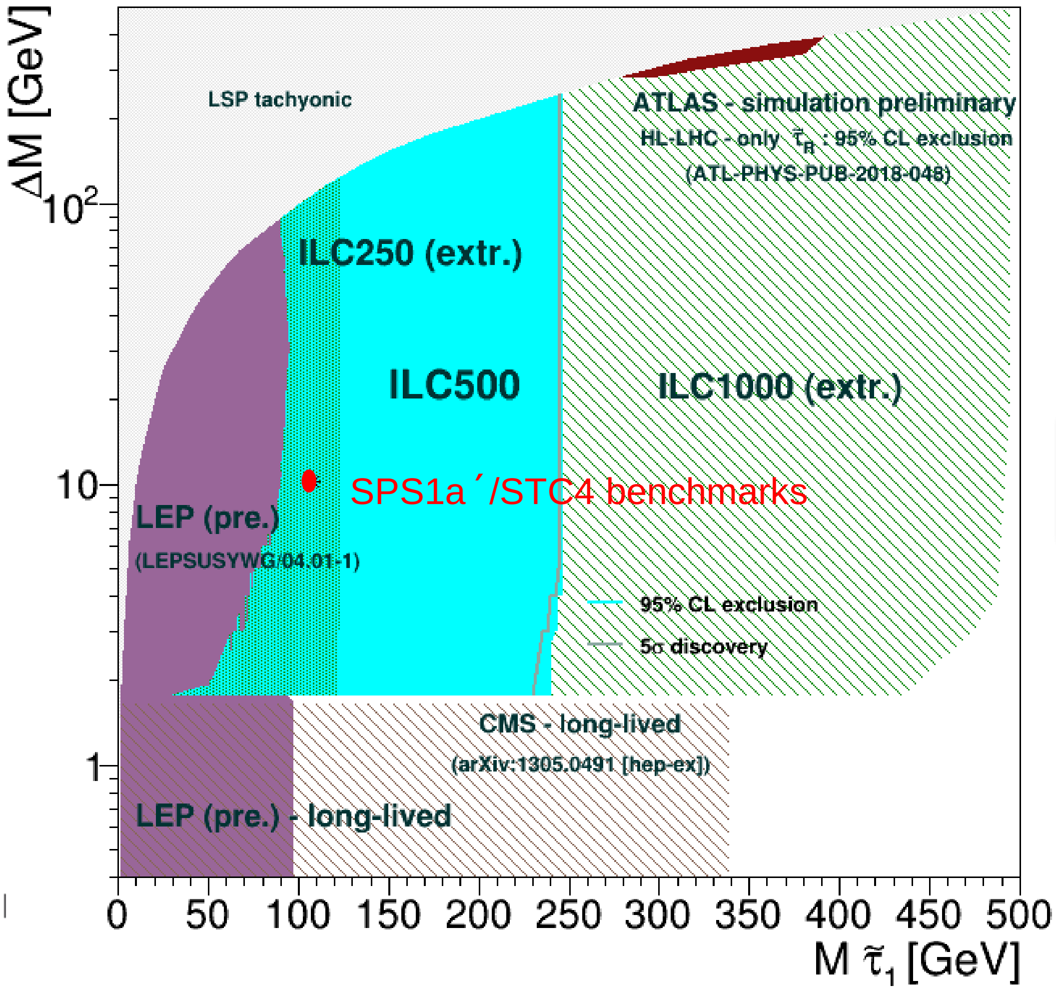
[arXiv:2105.08616](https://arxiv.org/abs/2105.08616)

ILC expected limits



At ILC discovery and exclusion are almost the same

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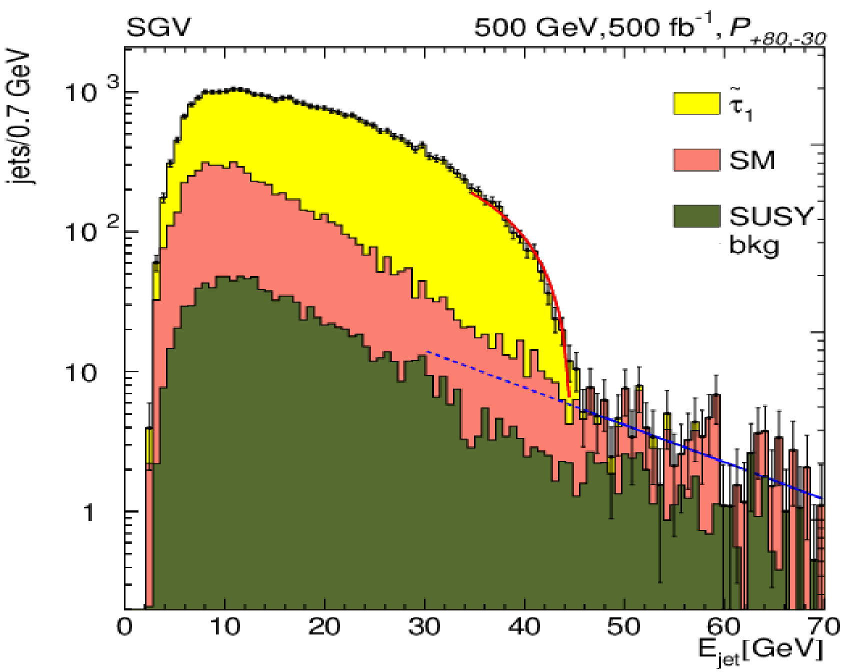
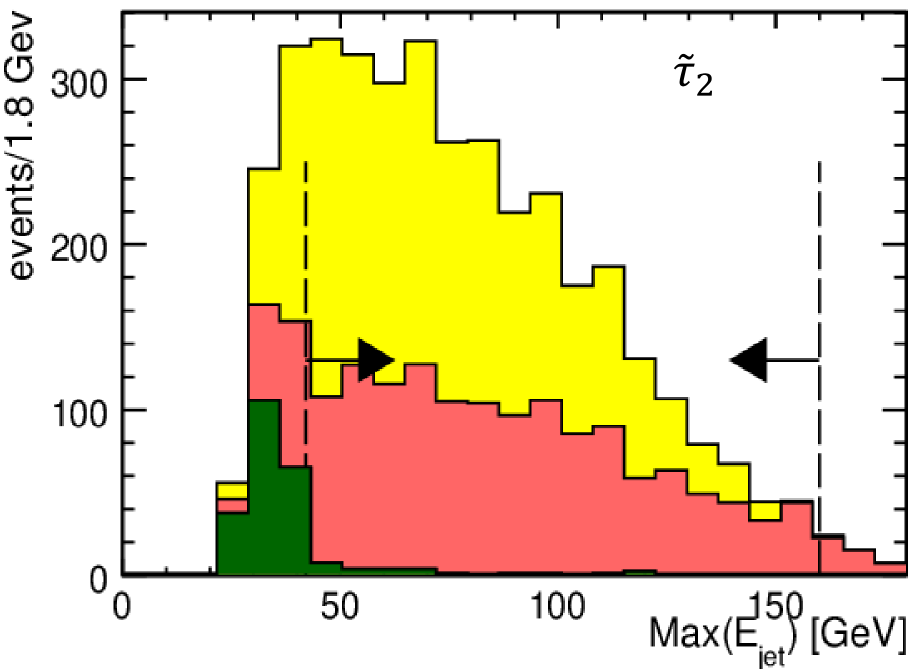
Prospects for $\tilde{\tau}$ measurements at the ILC

$M_{\tilde{\tau}}$ 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

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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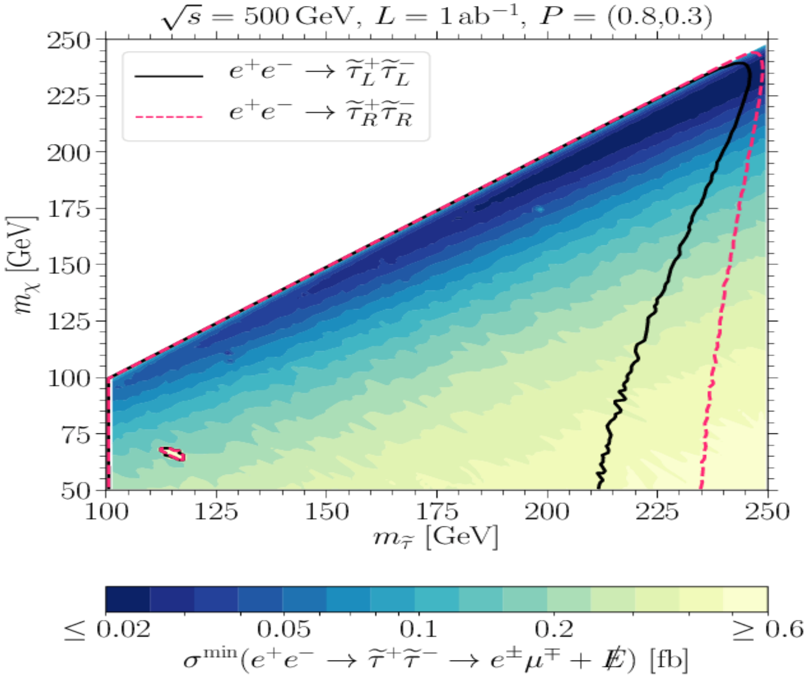
Other studies

An example of direct $\tilde{\tau}$ - searches at future electron colliders

Broad class of models for which a future electron collider would be able to directly discover new physics at scenarios that would evade detection at the LHC

Any future electron collider would have ~inmediately reach to new (EW-) charged physics up to its kinematic limit



Phys Rev, D102,015026 (2020)

arXiv:2004.02834 [hep-ph]

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Outlook/Conclusions

- Even after HL-LHC large parts of the $\tilde{\tau}$-LSP mass plane will remain unexplored
- Future electron-positron colliders are ideally suited for $\tilde{\tau}$ searches
- 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
- 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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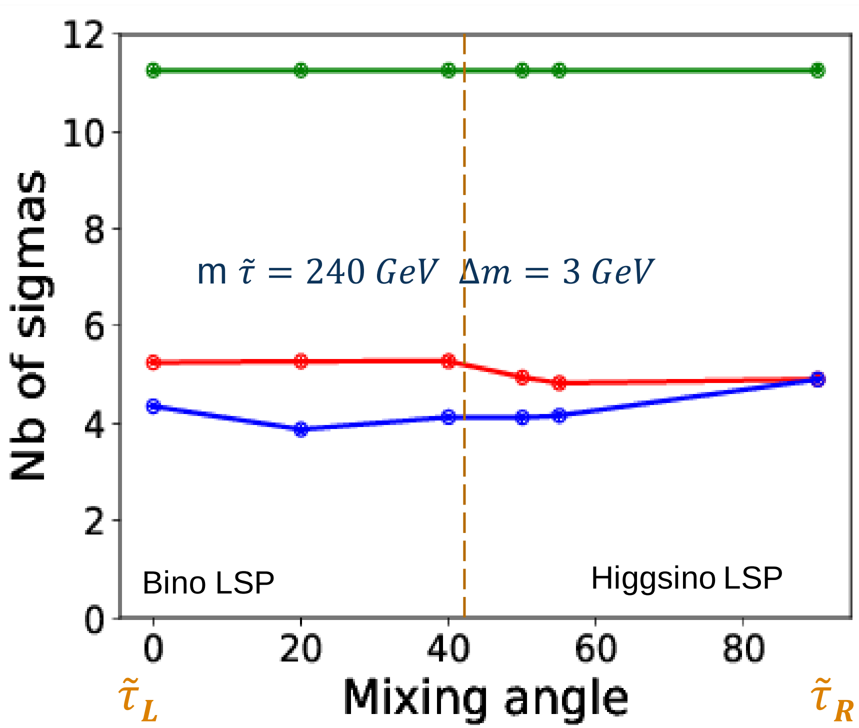
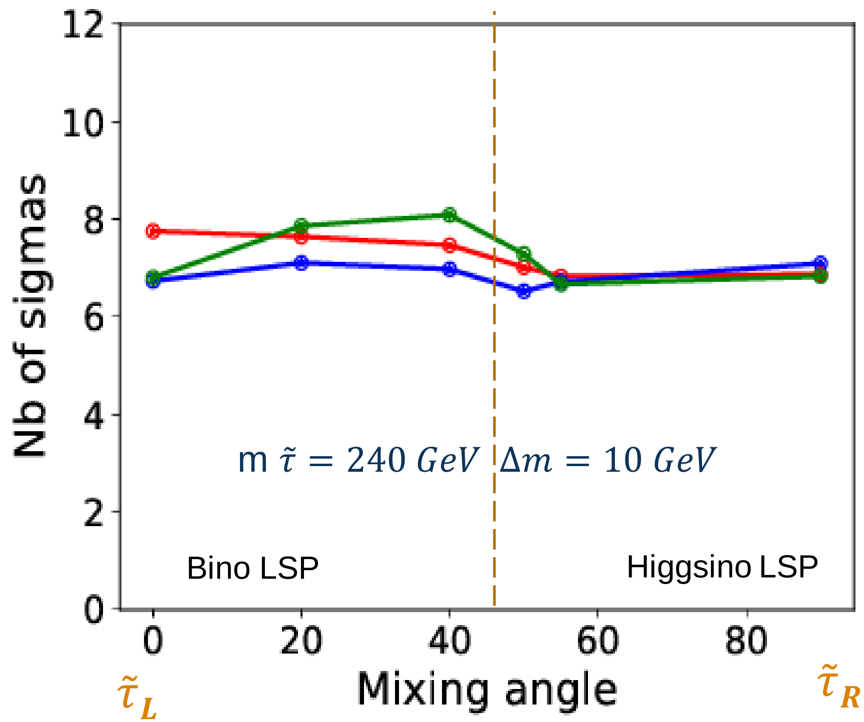
Backup slides

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