# $\tilde{\tau}$ searches at future $e^+e^-$ colliders

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**The direct pair-production of the tau-lepton superpartner, $\tilde{\tau}$, is one of the most interesting channels to search for SUSY.**

**Future electron-positron colliders are ideally suited for $\tilde{\tau}$ searches, featuring many advantages with respect to previous electron-positron colliders and hadron ones.**

**Specifically for the well-motivated small mass differences between $\tilde{\tau}$ and neutralino, accelerator and detector conditions play an important role in the study. The impact of these conditions on the $\tilde{\tau}$-pair production sensitivity has been evaluated.**

## Motivation for stau searches

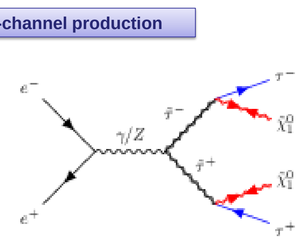
**Satisfies both conditions SUSY searches are focused on:**
**best motivated NLSP candidates and most difficult scenarios**

- 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, low σ since $\tilde{\tau}$-mixing suppresses coupling to the $Z^0$)
  - decay to LSP and $\tau$, implying more difficult signal identification than the other sfermions

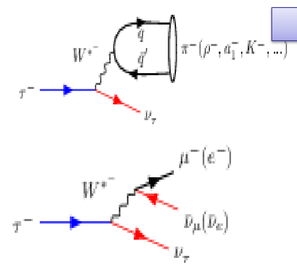
**SUSY models with a light $\tilde{\tau}$ can accommodate the observed relic density ($\tilde{\tau}$ - neutralino coannihilation)**

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

**s-channel production**




**$\tau$ decays**




**Signature:**
- **large missing energy and momentum**
- **large fraction of detected activity in central detector (isotropic production of scalar particles)**
- **large angle between the two $\tau$-lepton directions**
- **unbalanced transverse momentum**
- **zero forward-backward asymmetry**

**Signal events with the (visible) decay products of two $\tau$'s being the only detectable activity**

Signal reconstructed by the SGV fast simulation, beam-spectrum and photons in the beam added from the full simulated background samples

- $\sqrt{s}$ = 500 GeV (extrapolated to 250 GeV and 1 TeV)
- Both main polarisations, P(+80%, -30%) and P(-80%, +30%), with $\mathcal{L}$ = 1.6 $ab^{-1}$ each (H20 scenario)
- Including all SM and beam-induced backgrounds

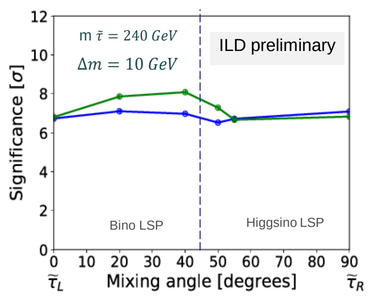
## Beam induced backgrounds in $e^+e^-$ colliders

$e^+e^-$ beams are accompanied by real (beamstrahlung) and virtual (Weizsäcker-Williams process) photons.

Interaction between them produce:

- $e^+e^-$ pairs (by scattering of two real photons), $10^5$ pairs per bunch crossing, very low $p_T$ (< 1GeV), curl up in magnetic field, interesting for BeamCal studies
- low $p_T$ hadrons (by vector meson fluctuations of real or virtual photons), <1.05> events per bunch crossing at $\sqrt{s}$ = 500 GeV, low $p_T$, travelling through the detector

**$\gamma\gamma$ interactions are independent of the $e^+e^-$ process, but can happen simultaneously to it (overlay-on-physics events ) or not (overlay-only events)**




**Effect of overlay-on-physics events**

Full simulation

Fast simulation (SGV) – not overlay tracks

## Effect of overlay-only events

Overlay-only events are ~$10^3$ times higher than any SM background included in the analysis

$\gamma\gamma \rightarrow low\ pT\ hadrons$ similar to visible products from $\tilde{\tau}$ production for small (≤ 10 GeV) LSP-$\tilde{\tau}$ mass differences

Overlay-only events can be misidentified as signal events

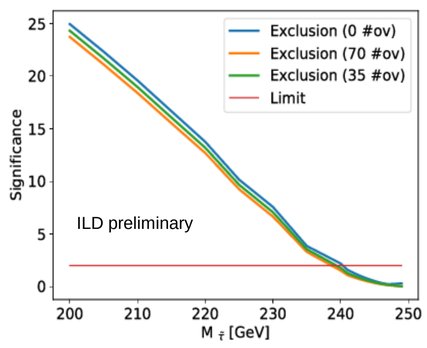
A suppression stronger than $10^{-9}$ is needed to make the background from overlay-only events negligible

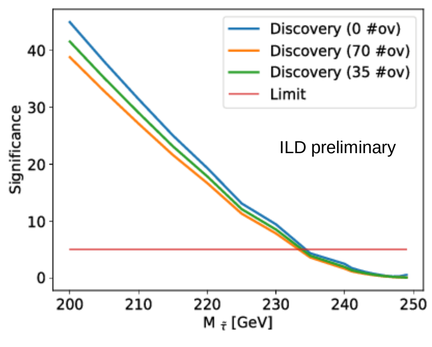
**70 (30 ) overlay-only events expected for each polarisation at the Δ M = 2 (Δ M = 10) GeV model point**

**For Δ M = 2 (Δ M = 10) GeV, remaining SM background of the order of (two orders of magnitude larger than) the remaining overlay-only events**

**Negligible effect for Δ M = 10 GeV**

**Effect for Δ M = 2 GeV:**



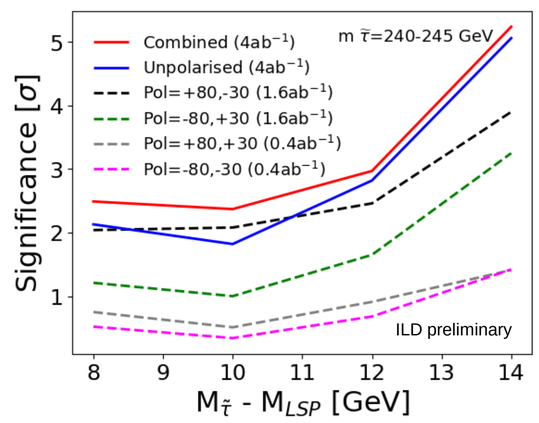



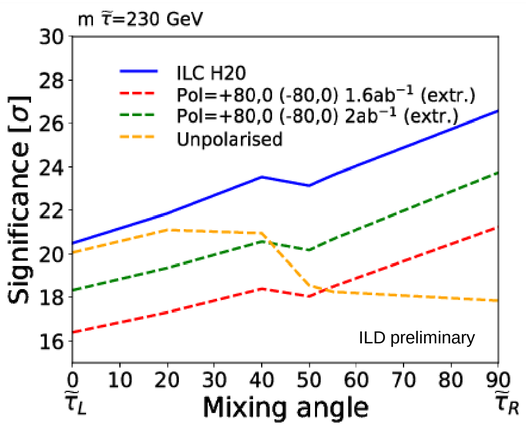

Additional cuts based on ISR and vertex requirements needed for M= 2 GeV

Results to be considered as the worst case, due to lack of statistics sets of independent cuts used to get the required suppression without killing all the overlay-only events

## Effect of accelerator and detector features in $\tilde{\tau}$-pair production sensitivity

- Beam-induced backgrounds at Linear Colliders can be mitigated up to small residual impact of ~1GeV on highest reachable mass for lowest ΔM
- Higher centre-of-mass energies cover much more parameter space, higher luminosity gives only very little improvement, ex. increase of ILC250 luminosity from 2 to 10 $ab^{-1}$ affects the $\tilde{\tau}$ mass limit only by 5 GeV
- Hermeticity of detector crucial, with an MDI region as currently discussed for FCCee detectors, mass differences below 5 GeV very likely can not be probed
- Triggerless operation big advantage when searching for unknown signatures
- Polarisation in both beams provides more sensitivity than only in one beam or none polarisation




## Limits

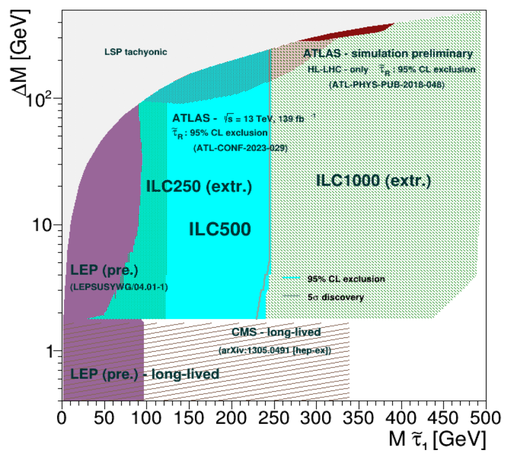
**Current model-independent limits for $\Delta M > \tau$ mass from LEP**

**Exclude a $\tilde{\tau}$ with mass below 26.3 GeV for any mixing and any $\Delta M > \tau$ mass**

**Limits from LHC and HL-LHC prospects highly model dependent**

**Without discovery potential for the most well-motivated scenarios: $\tilde{\tau}$ coannihilation or $\tilde{\tau}_R$ pair production**

**Even after HL-LHC $\tilde{\tau}$ -LSP mass plane almost 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 limit**

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