$\tilde{\tau}$ 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

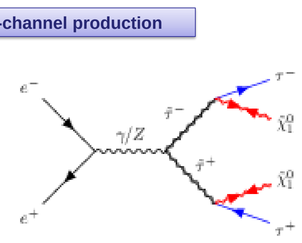
Satisfies both conditions SUSY searches are focused on:
best motivated NLSP candidates and most difficult scenarios

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

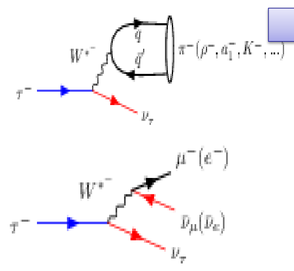
SUSY models with a light $\tilde{\tau}$ can accommodate the observed relic density ($\tilde{\tau}$ - neutralino coannihilation)

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



τ decays



Signal events with the (visible) decay products of two τ's being the only detectable activity

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**

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

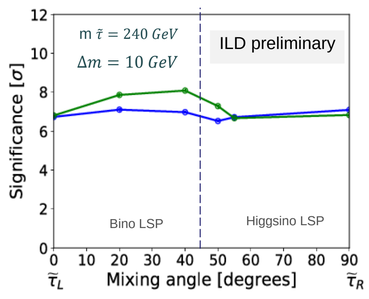
Beam induced backgrounds in e^+e^- colliders

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

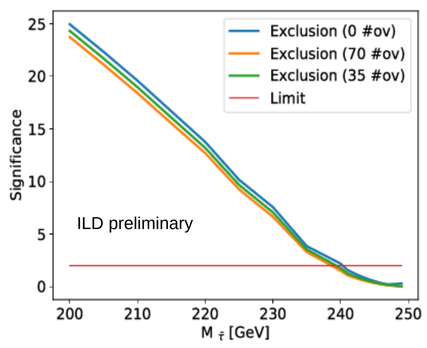
A suppression stronger than 10^{-9} is needed to make the background from overlay-only events negligible

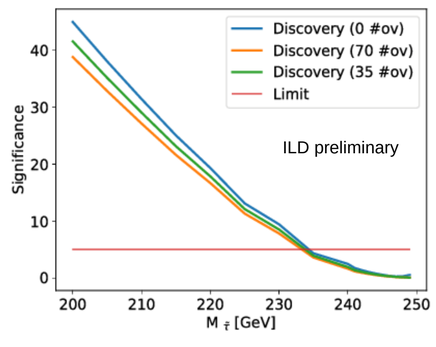
70 (30) overlay-only events expected for each polarisation at the Δ M = 2 (Δ M = 10) GeV model point

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:



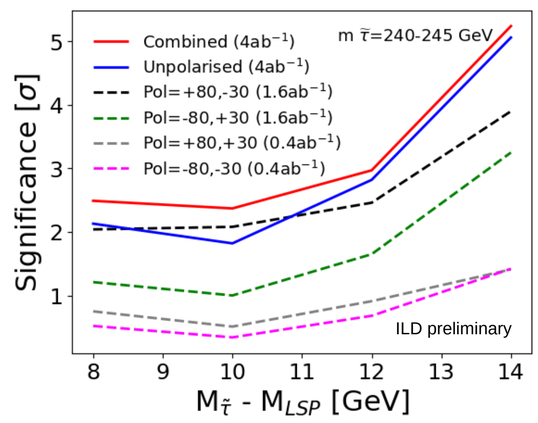


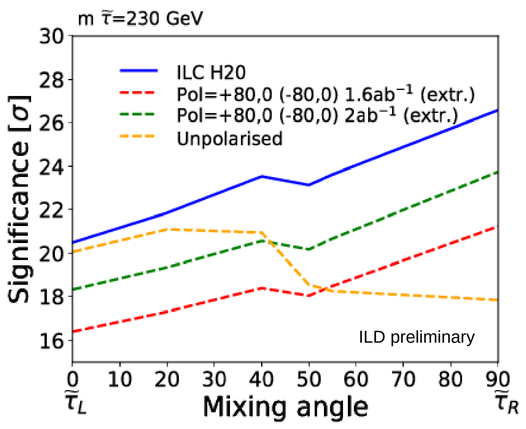
Additional cuts based on ISR and vertex requirements needed for M= 2 GeV

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

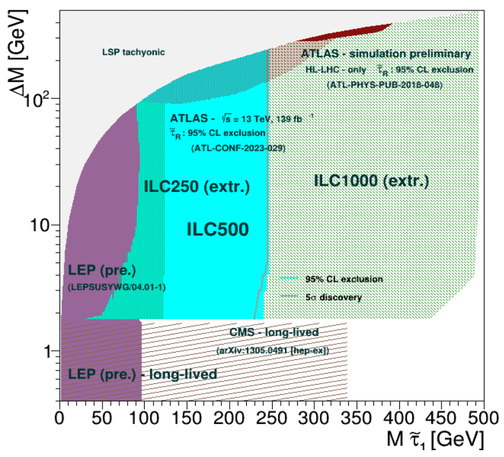
Current model-independent limits for $\Delta M > \tau$ mass from LEP

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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