Precision measurements of Supersymmetry at the International Linear Collider

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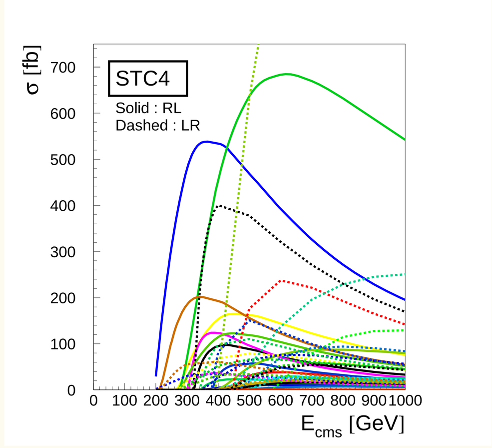
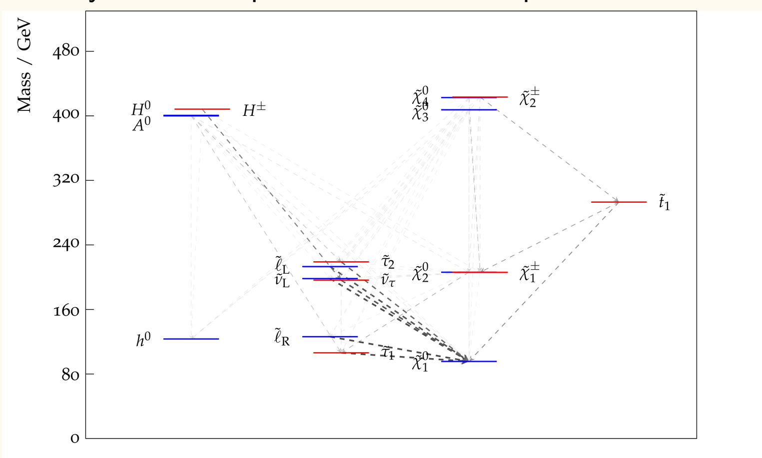
STC4 - MSSM with a rich spectrum

STC4 - for $\tilde{\tau}$-coannihilation model 4 - is a pMSSM model which is allowed by LHC8 data, but still has a very rich spectrum of bosinos and sleptons observable at the ILC running at $E_{\rm CMS}$ from 250 GeV to 1 TeV.
The figures below shows the production cross-section and decay modes of sparticles that can be produced at the ILC.



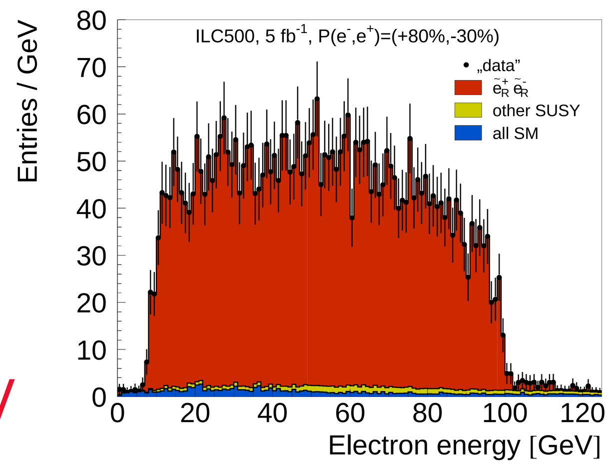


$\tilde{e}_{\rm R}$ - Early discovery

SUSY in a week.

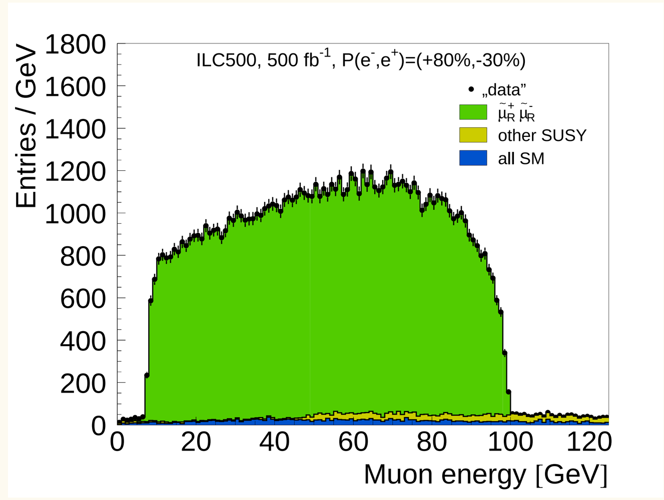
The first channel to manifest itself at the ILC depends on the assumed running scenario. If the ILC starts out as a Higgs factory at $E_{\rm cms} = 250$ GeV, then $e^+e^- \to \tilde{\tau}_1\tilde{\tau}_1$ and $\tilde{\chi}^0_1\tilde{\chi}^0_1\gamma$ would be the first observable channels.
As soon as the centre-of-mass energy is raised past the pair production threshold for right-handed sleptons, in STC4 when $E_{\rm CMS} \gtrsim 270$ GeV, the e^+e^-+ missing 4-momentum signature would see the striking signal shown on the right within a few days!
With $500\,{\rm fb}^{-1}$, the $\tilde{e}_{\rm R}$ and LSP mass can be measured to:

$\delta M_{\tilde{e}_{\rm R}} = 230$ MeV; $\delta M_{\tilde{\chi}^0_1} = 170$ MeV

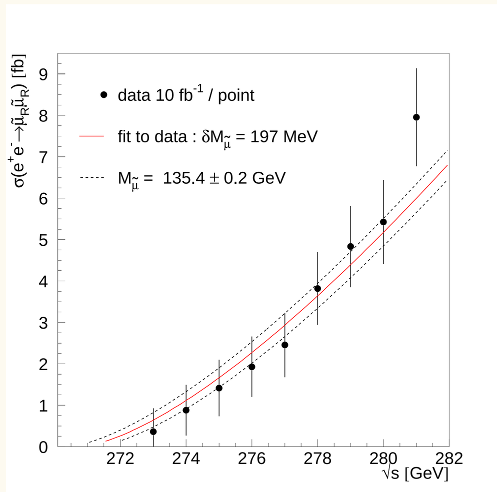


$\tilde{\mu}_{\rm R}$: Kinematic edges vs threshold scan?

The cross-section for $\tilde{\mu}_{\rm R}$ pair production is much lower than for $\tilde{e}_{\rm R}$ due to the absence of a t-channel. Still the $\tilde{\mu}_{\rm R}$ mass can be determined from the kinematic endpoints of the decay muons (left, $500\,{\rm fb}^{-1}$). Alternatively, the tunable center-of-mass energy of the ILC offers the possibility to scan the production threshold near 270 GeV (right, $90\,{\rm fb}^{-1}$).



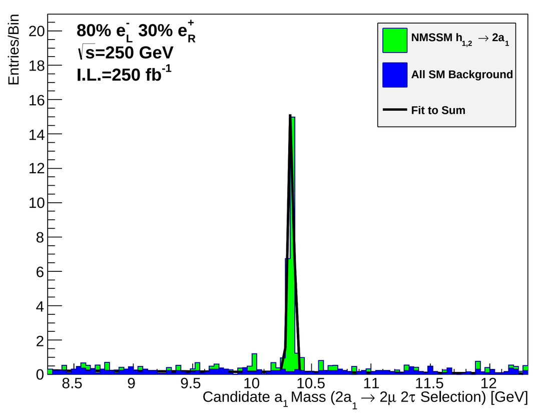
$\delta M_{\tilde{\mu}_{\rm R}} = 500$ MeV
$\delta M_{\tilde{\chi}^0_1} = 380$ MeV



$\delta M_{\tilde{\mu}_{\rm R}} = 200$ MeV
$\delta M_{\tilde{\chi}^0_1} = 200$ MeV

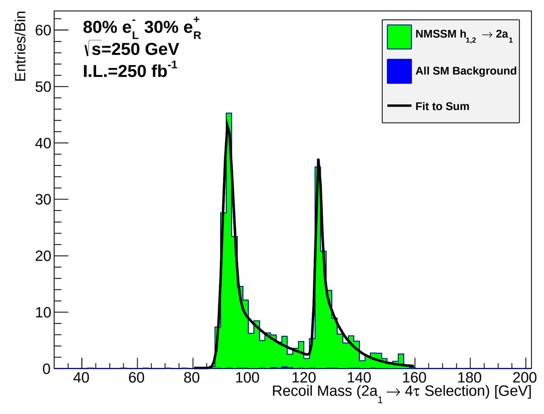
SUSY at $\sqrt{s} = 250$ GeV: NMSSM Higgs

In the NMSSM, the Higgs boson discovered at the LHC does not need to be the lightest Higgs boson. Current limits on invisible decays allow for sizable branching fraction of $h_{1,2} \to a_1 a_1$, where a_1 can be very light down to a few GeV and decays eg. to τ or μ pairs. Already at a 250 GeV ILC, these states can be discovered and their mass precisely measured.



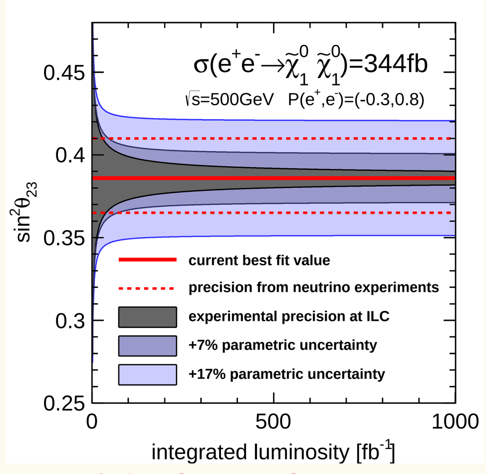
$\delta M_{a_1} = 5$ MeV

$\delta M_{h_{1,2}} = 200$ MeV



Neutrino Mass Generation

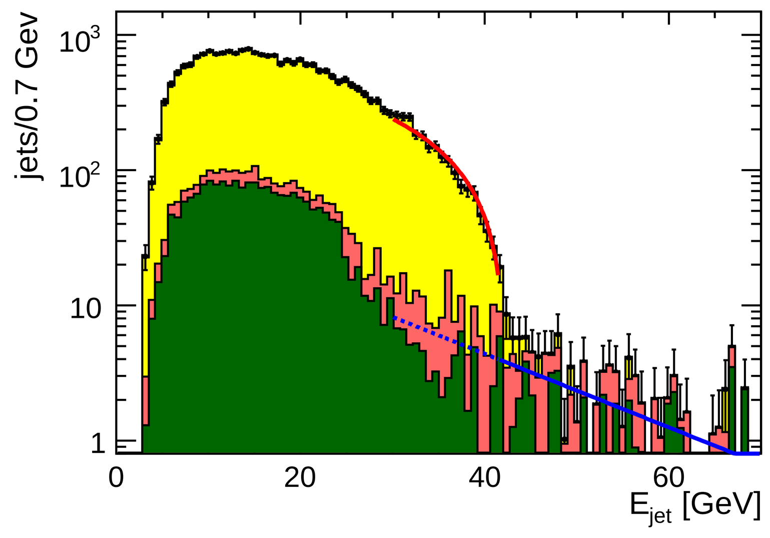
SUSY with bilinear R-parity violation can generate neutrino masses via a low-scale seesaw mechanism. In such scenarios, neutrino observables fix the bRPV couplings. Thus collider measurements of RPV decays can test this mechnism of neutrino mass generation.
At the ILC, the branching ratios for $\tilde{\chi}^0_1 \to \mu W$ and $\tilde{\chi}^0_1 \to \tau W$ can be measured in LSP pair production. At tree-level, their ratio is directly proportional to $\tan^2\theta_{23}$, while loop corrections introduce dependencies on other SUSY parameters.



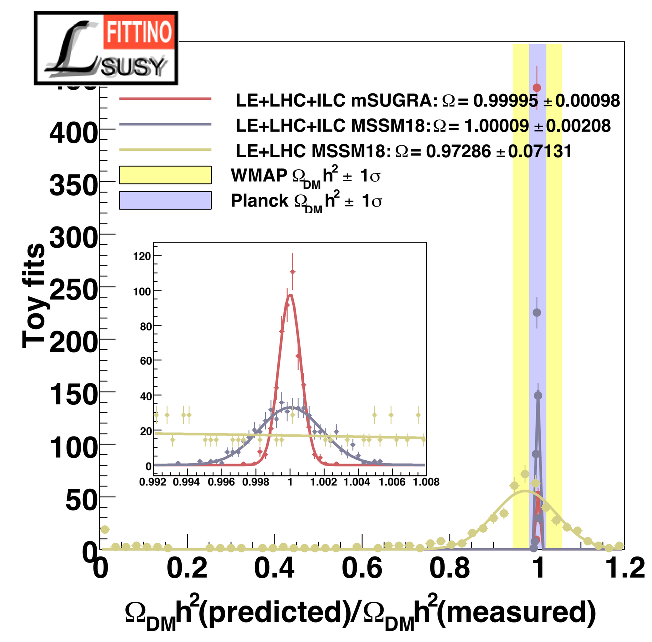
$$\frac{\delta \sin^2\theta_{23}}{\sin^2\theta_{23}} = 4\%\ ({\rm stat.}) \oplus 0.85\%\ ({\rm syst.}) \oplus 7\%\ ({\rm par.})$$

The cosmic connection: $\tilde{\tau}$ mass and cross-section

Especially in $\tilde{\tau}$-coannihilation scenarios, a precise determination of the $\tilde{\tau}$ sector is essential in order to be able to predict the expected relic density with sufficient precision to test whether the $\tilde{\chi}^0_1$ is indeed the dominant Dark Matter constituent.
With the ILC at $E_{\rm CMS} = 500$ GeV, the $\tilde{\tau}_1$ mass can be determined to 200 MeV, and the $\tilde{\tau}_2$ mass to 5 GeV from the endpoint of the τ-jet energy spectrum. Production cross section for both these modes can be determined at the level of 4%
By using all available collider observables to determine the SUSY parameters, one can predict the relic density based on the assumption that the $\tilde{\chi}^0_1$ is the only contribution to Dark Matter.
This was studied by the Fittino group in a similar model, in particular the $\tilde{\chi}^0_1$ and $\tilde{\tau}_1$ properties were identical to STC4.
Fit with 18 free parameters, and predict $\Omega_{\rm CDM}h^2$.

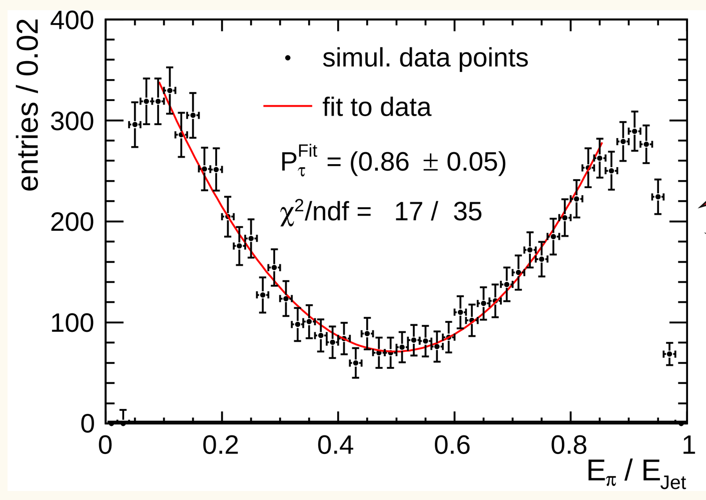


$\delta M_{\tilde{\tau}_1} = 200$ MeV
$\delta M_{\tilde{\tau}_2} = 5$ GeV

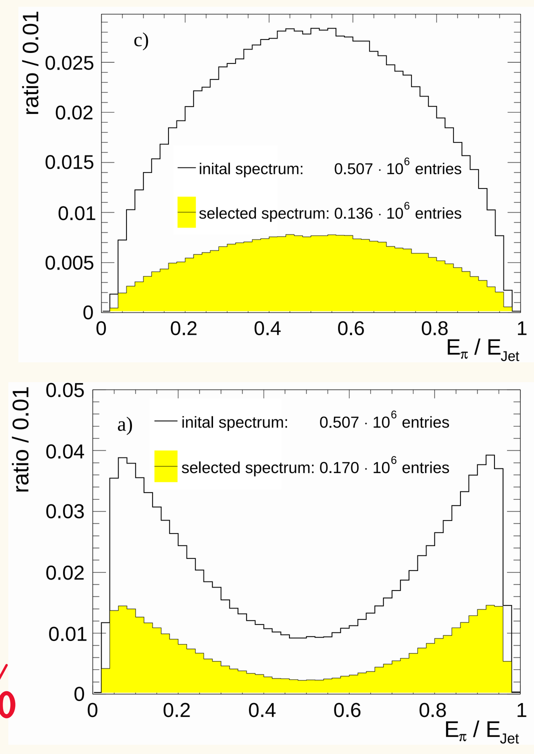


The ILC at full speed: τ polarisation and mixing and $\tilde{\chi}^0_1$ nature

The polarisation of τ-leptons from the $\tilde{\tau}_1$ decay, which gives access to the $\tilde{\tau}_1$ and $\tilde{\chi}^0_1$ mixing - gauginos conserve chirality, higgsinos flips it - can be measured with an accuracy better than 10%, eg. from $\tau \to \pi^+\nu_\tau$ decays. from decays to ρ-mesons ($\tau \to \rho^+\nu_\tau \to \pi^+\pi^0\nu_\tau$). In this case, the observable $R = E_\pi/E_{jet}$ can be used to measure the τ-polarisation to $\pm 5\%$ by a fit of templates to the data.
The $\tilde{\tau}$ mixing itself can be extracted in several ways: Comparing the cross-section at different beam-polarisations, determining the cross-section for $\tilde{\tau}_1\tilde{\tau}_2$ production, or from the comparing the masses of the (un-mixed) $\tilde{e}$:s and $\tilde{\mu}$:s to $M_{\tilde{\tau}_1}$ and $M_{\tilde{\tau}_2}$.



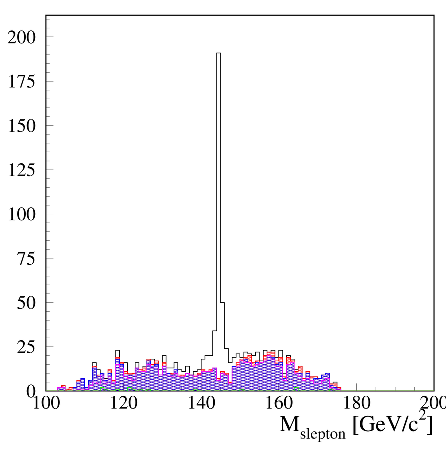
$\delta {\rm Pol}_\tau = 5\%$

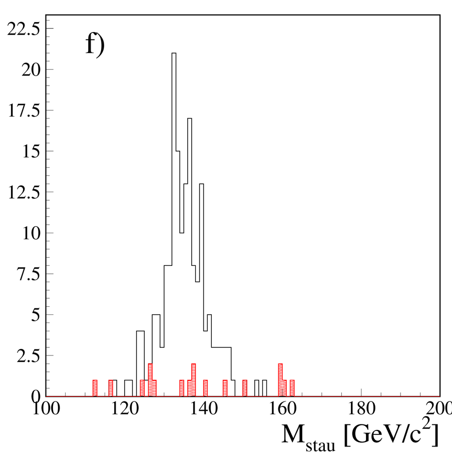


Cascade decays and slepton reconstruction:

SUSY is a peak !

A particularly interesting channel is $e^+e^- \to \tilde{\chi}^0_2\tilde{\chi}^0_2$ and the $\tilde{\chi}^0_2$ decay to $\tilde{\mu}_{\rm R}\mu$ or to $\tilde{e}_{\rm R}e$), even if the branching ratio is at the level of a few percent like in our example point. These cascade decays can be fully kinematically constrained at the ILC, and would promise to yield even lower uncertainties on the $\tilde{\mu}_{\rm R}$ and $\tilde{e}_{\rm R}$ masses than the threshold scans, of the order of 25 MeV. This is estimated on an earlier study in a scenario with about twice as large branching ratios for the considered decay mode, where a precision of 10 MeV was found. The corresponding distribution of the reconstructed $\tilde{\mu}_{\rm R}$ mass is shown including all SM and SUSY backgrounds. Even the dominating decays to $\tilde{\tau}_1\tau$ can be constrained as shown in the right part and could yield comparable results to a threshold scan.





More info:

- H. Baer and J. List, Phys. Rev. D **88** (2013) 055004 [arXiv:1307.0782 [hep-ph]].
- P. Bechtle, & al. Phys. Rev. D **82**, 055016 (2010) [arXiv:0908.0876 [hep-ex]].
- M. Berggren, in "Proceedings, LCWS 2004, Paris, France, " arXiv:hep-ph/0508247.
- P. Bechtle, & al. Eur. Phys. J. C **66** (2010) 215 [arXiv:0907.2589 [hep-ph]].
- T. Liu and C. T. Potter, arXiv:1309.0021 [hep-ph].
- B. Vormwald and J. List, Eur. Phys. J. C **74** (2014) 2720 [arXiv:1307.4074 [hep-ex]].
- http://www.linearcollider.org/ILC/Publications/Technical-Design-Report