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ECFA Higgs Factory Study Note: Searches for $\widetilde{\tau}$'s

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We have studied SUSY in the "worst-case" scenario, namely the one where a $\widetilde{\tau}$ NLSP is the only detectable sparticle in reach. The $\widetilde{\tau}$ mixing is tuned such that the cross-section for $\widetilde{\tau}$ pair-production is minimal, and the spectrum of the visible decay products of the τ's from the $\widetilde{\tau}$ decays are as soft as possible. All SM backgrounds, including beam-induced ones are included in a full Geant4 simulation of the ILD concept at ILC operating at 500 GeV. The analysis shows that this process can be excluded *or discovered* at all model-points up to a few GeV below the kinematic limit, also for mass-differences to the LSP down to the mass of the $\widetilde{\tau}$. (Lower mass-differences would yield detector-stable $\widetilde{\tau}$'s, which we assume will have been either excluded or discovered at HL-LHC well before the start of any Higgs factory). This results corroborates, with full simulation, the assumption often made that such a coverage is a given for linear colliders.

The results of the study have been recast to the conditions at other Higgs-factories. For the other linear options, as well as for ILC operating at other energies, the conclusion is largely the same. For the circular options, on the other hand, we find that the much degraded coverage at low angles at these machines will imply that mass-differences below 5 GeV will not be possible to probe.

This work was carried out in the framework of the ILD Concept Group

1 Introduction

The direct pair-production of the super-partner of the τ-lepton, the $\widetilde{\tau}$, is one of the most interesting channels to search for SUSY in. First of all, the $\widetilde{\tau}$ is likely to be the lightest of the scalar leptons. Secondly the signature of $\widetilde{\tau}$ pair production is one of the experimentally most difficult ones. The current model-independent $\widetilde{\tau}$ limits come from analyses performed at LEP. Limits obtained at the LHC do extend to higher masses, but they are only valid under strong assumptions. The future Higgs factories will be powerful facilities for SUSY searches, offering advantages with respect to previous electron-positron colliders as well as to hadron machines. In order to quantify the capabilities of these future e^+e^- colliders, the "worst-case" scenario for $\widetilde{\tau}$ exclusion/discovery has been studied, taking into account the effect of the $\widetilde{\tau}$ mixing on $\widetilde{\tau}$ production cross-section and detection efficiency. To evaluate the latter, the ILD concept, originally developed for the International Linear Collider (ILC), and the ILC beam conditions at a centre-of-mass energy of 500 GeV have been used for detailed simulations, including for the first time the effect of bunch-crossings containing no hard e^+e^- interaction, but only low-p_T hadrons from $\gamma\gamma$ interactions and e^+e^- pairs from beamstrahlung. Still, the obtained exclusion and discovery reaches extend to only a few GeV below the kinematic limit even in the worst-case scenario, also when the $\widetilde{\tau}$ and the Lightest SUSY Particle are quite close in mass. The results of the detailed simulation study are then discussed in view of the experimental environment of other proposed Higgs factory projects.

2 Analysis at ILC-500

This study uses the IDR 500 GeV FullSim samples [1, 2], covering the full SM background with all e^+e^- and $\gamma\gamma$ processes ($> 10^7$ events). The ILC beam-spectrum and pair background were calculated and generated with GuineaPig [3], and low p_T hadrons from a dedicated generator [4]. For the signal, the mass-spectrum was obtained with Spheno [5], and the events were generated with Whizard [6]. The detailed fast simulation SGV [7] with the ILD geometry was used for detector simulation and high-level reconstruction. The pair background and low p_T hadrons were extracted from FullSim, and added to the SGV-produced events.

The event selection targets the typical signature of $\widetilde{\tau}$-pair production, that is events with only two τ-candidates. They are centrally produced, due to the scalar nature of the τ. Because of the invisible LSPs, large missing energy, mass and p_T are expected. An important cut is the one on ρ, the p_T with respect to thrust-axis projected on the plane perpendicular to the beam-axis. ρ will be low in a $e^+e^- \to \tau\,\tau$ event, or generally any $\tau\,\tau$ event with τ's produced back-to-back in the transversal view, even if the event shows both large acoplanarity and large p_T^{miss}. This is because this configuration will only happen if one of the τ's decays such that most momentum is taken by the visible system, while the other does the opposite: most momentum is taken by the neutrino(s). This yields large p_T^{miss} and high acolinearity, but low ρ. There is no such correlation for τ's from $\widetilde{\tau}$ decays, since the τ's are *not* back-to-back in this case.

3 Results for ILC-500, and extrapolations to other higgs-factories

The projection of the limits in the $M_{\widetilde{\tau}}$-ΔM plane for ILC-500 is shown as the solid cyan region in Figure 1. The region for mass differences below the mass of the τ, not included in the current study, is shown for completeness. In the region with ΔM larger than M_τ exclusion and discovery ILC limits are compared to the ones from LEP and LHC. The projected HL-LHC limits are also shown. Since LHC and projected HL-LHC limits are highly model-dependent, the comparison in this case has to be taken with care: here limits considering only the $\widetilde{\tau}_R$-pair production are shown, since, while still being optimistic, they are closest to the ones expected for the lightest $\widetilde{\tau}$ at minimal cross-section. It should be noted that the LHC and HL-LHC projections are only exclusion limits - no discovery potential is expected.

Some well-founded conclusions can be drawn by extrapolating the ILC-500 results to other Higgs factories, or to ILC operating at different energies. A simple argument allows to extrapolate from one E_{CM} to another: if all kinematic cuts are scaled with the ratio of the two energies, the signal-to-background ratio would be the same at model points where the SUSY masses also are scaled with the ratio of the energies.

For the other linear options quite similar results would be expected. At both C^3 and CLIC, the lack of positron polarisation would imply a certain loss in sensitivity, since the effective luminosity for s-channel processes

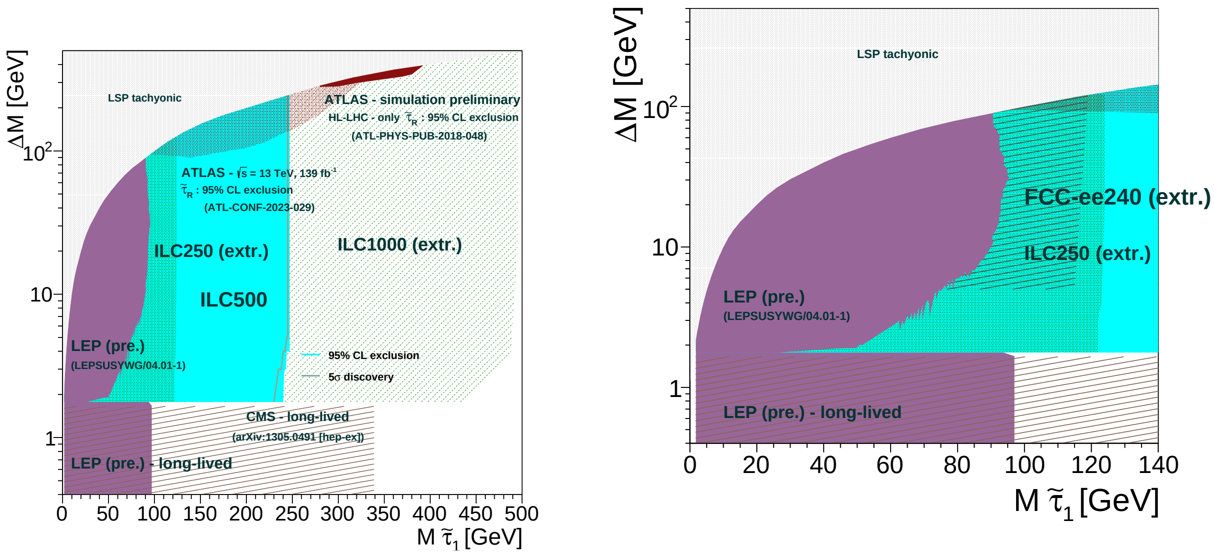

Figure 1: In cyan, the exclusion reach in the ΔM vs. $M_{\tilde{\tau}}$ plane for $\tilde{\tau}$'s for ILC-500 obtained in this study is shown. The discovery reach is shown by the line slightly to the left of the edge of the exclusion region. Also shown is the extrapolations of the current study to ILC-250 and ILC-1000, as well as the current limits. In the zoom shown to the right, also the extrapolated coverage at FCCee-240 is shown (W.I.P.).

would be around 26 % less than under ILC conditions (both beam polarised). Also, Likelihood ratio weighting of samples with different polarisation becomes less powerful with only one beam polarised. At CLIC, the very different bunch-structure of the beams with respect to the ILC or C^3 possibly will have some adverse effects. This would need more study. On the other hand, CLIC is the machine that could ultimately offer the highest E_{CM}, up to 3 TeV.

At the circular machines, FCCee-240 or CepC, not only re-scaling the results to a lower E_{CM} would be needed, but also taking the different beam-conditions into account, and evaluating the effect of the change in detector acceptance. Some of the effects of the various differences between the ILC and the FCCee conditions can readily be found, by (hypothetically) changing the conditions for the ILC-500 analysis. By removing polarisation from the analysis, the increase of effective luminosity is lost, and the possibility to do Likelihood ratio weighting no longer exists. At the circular colliders, it is quite unlikely to have background from beam-beam interactions or low-p_T hadrons in the same bunch-crossing, so this source of background should be removed for the comparison. At the lower mass-differences, less than 10 GeV, the backgrounds is completely dominated by multi-peripheral $\gamma\gamma$ interactions. We can therefore make an estimate of the increase in background from modifying the acceptance of the forward calorimetry at generator level - i.e. replacing the coverage down to 5 mrad at linear machines by 50 mrad - and for the $\gamma\gamma$ background only. We find that e.g. that the signal-point $M_{\tilde{\tau}}$ = 118 GeV and ΔM = 4.8 GeV at FCCee-240 cannot be excluded, even with the combined luminosity of four experiments. This is despite the fact that the corresponding point ($M_{\tilde{\tau}}$ = 245 GeV and ΔM = 10 GeV) at 500 GeV can be excluded, even with unpolarised beams.

The lower B-field and thicker beam-pipe imposed on the detectors at circular machines, which implies worse momentum and impact-parameter resolution, is not expected to have an important impact on this analysis. The introduction of passive material inside the tracking volume from the final focus quadropoles and shielding, as well as the expected syncrotron radiation backgrounds might have an adverse effect, but to study this full detector simulation under FCCee/CepC conditions must be done.

4 References

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