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ILD sensitivity to light scalar production with taonic decay

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While the main goal of the electron-positron Higgs factory is to measure precisely the Higgs boson properties, production of new exotic light scalars is still not excluded by the existing experimental data, provided their coupling to the gauge bosons is sufficiently suppressed. In this contribution sensitivity of the future Higgs factory experiment to exotic light scalar particle production in association with a Z boson, assuming scalar decays to tau lepton pairs is discussed. This work was carried out in the framework of the ILD concept group as a contribution to the New exotic scalars (EXscalar) focus topic.

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1 Analysis framework

The study is based on samples of background and signal events generated with WHIZARD 3.1.2 [1] using built-in SM_CKM model, for ILC running at 250 GeV. For the signal, it is assumed that a light exotic scalar particle is produced in the scalar-strahlung process, $e^+e^- \to ZS$, where Z decays hadronically while S decays into two τ leptons. Signal events are generated by varying the mass of the SM Higgs boson and forcing it to decay into two τ leptons. All relevant 4 and 2-fermion final states were considered as background together with the contribution from the SM Higgs. ISR and luminosity spectra for ILC running at 250 GeV were taken into account. H-20 running scenario [2, 3] for ILC was assumed with $\pm 80\%$ and $\pm 30\%$ polarisation for e^- and e^+ beam respectively. Fast simulation of detector response was performed with Delphes ILCgen model [4, 5].

2 Event selection

To extract events with desired signature pre-selection cuts were applied. It was required that there are no isolated leptons or photons in the event, neither in the electromagetic calorimeter, the LumiCal nor the BeamCal, and two hadronic jets (which were enforced by running the clustering algorithm in exclusive mode). Five categories of signal events were considered, as described in Table 1, depending on the assumed tau decay channels and the number of τ-tagged jets. For the loose selection, introduced due to relatively poor tagging efficiency for τ jets (about 70%), only one identified τ candidate is required (τ-tagged jet or isolated lepton) and the lightest untagged jet was taken as the second τ candidate.

event category	isolated leptons	tight selection	loose selection
hadronic	0	4 jets, 2 with τ-tag	4 jets, 1 with τ
semi-leptonic	1	3 jets, 1 with τ-tag	3 jets with no τ-tag
leptonic	2	2 jets with no τ-tag	

Table 1: Tight and loose selection conditions for pre-selection and classification of events.

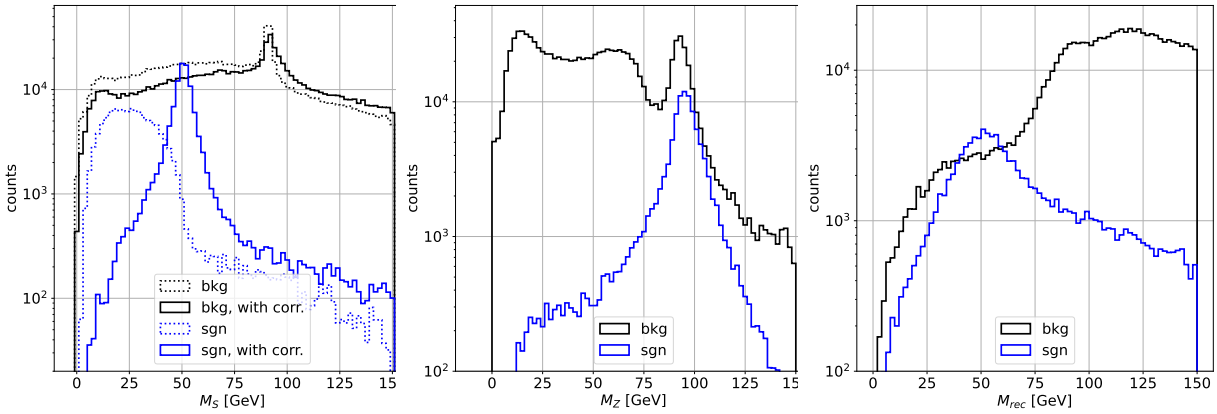
3 Event reconstruction and classification

Due to escaping neutrinos carrying part of the four-momentum, a dedicated correction procedure is required to properly reconstruct the invariant mass of the new scalar decaying into two τ leptons. The so called collinear approximation was used in which one assumes that τ leptons from the decay of the scalar have large boost and thus their decay products, including neutrinos, follow the initial τ directions. Neutrino energies can be then calculated from transverse momentum conservation:

$$\vec{p}_{\mathrm{T}}^{\,miss} = E_{\nu_1} \cdot \vec{n}_1 + E_{\nu_2} \cdot \vec{n}_2 \,,$$

where $\vec{n}_1$ and $\vec{n}_2$ are transverse components of τ candidate directions. The impact of the correction procedure on the scalar candidate invariant mass distribution is visible in Figure 1(a). In Figure 1(b) and Figure 1(c) the distribution of the invariant mass of the Z and the invariant mass recoiling against Z boson are presented respectively. The two untagged jets are assumed to be the Z.

For the most efficient event classification, separate Boosted Decision Tree classifiers [6] were trained for each event category and beam polarisation combination, resulting in 20 independent classifiers. In addition to the variables describing the reconstructed S and Z candidates, as well as the total reconstructed energy and the recoil mass, the y_{23} and y_{34} variables from the jet clustering algorithm were included in the variable set used for event classification.

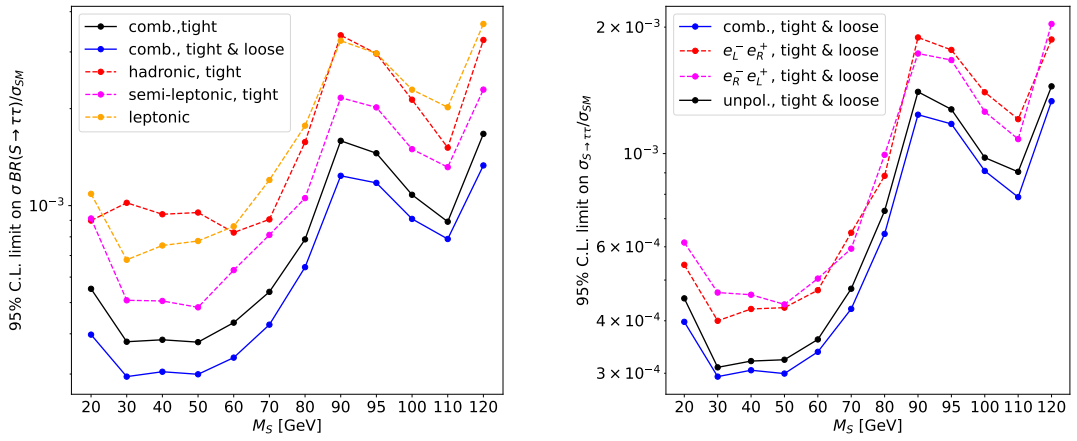


(a) (b) (c)

Figure 1: Distributions of reconstructed variables after pre-selection for background (black) and signal (blue) events for scalar mass of 50 GeV and $e_L^- e_R^+$ polarisation. (a) Distribution of reconstructed scalar S invariant mass, before (dashed line) and after (solid line) correction for escaping neutrinos. (b) Distribution of Z candidate - two jets without τ-tag - invariant mass. (c) Distribution of mass recoiling against Z candidate.

4 Results

The expected limits on the exotic scalar production cross section times di-tau branching ratio, relative to the total scalar production cross section predicted by the SM for given mass, are presented in Figure 2(a). Comparison of limits obtained for different event classes show that the best limits are obtained for the tight semi-leptonic selection, due to high statistics and relatively low background level. Including the loose selecion categories improves the limits by further 20-30%. Shown in Figure 2(b) is the comparison of limits for the two polarisation settings with high integrated luminosity, $e_L^- e_R^+$ and $e_R^- e_L^+$. Similar limits are obtained for the two configurations and limits corresponding to the combined analysis of the four polarisation configurations, according to H-20 running scenario, correspond to about 10% improvement with respect to results obtained with the same integrated luminosity for the unpolarised beam. The impact of the uncertainties in theory predictions and data sample luminosities on the presented limits was found to be negligible.



(a) (b)

Figure 2: Expected 95% C.L. cross section limits on the light scalar production cross section times di-tau branching ratio for ILC running at 250 GeV, assuming H-20 running scenario. (a) Comparison of combined limits with limits obtained for different event categories. (b) Comparison of combined limits with limits obtained for different beam polarisation configurations.

5 Conclusions

Sensitivity of the ILD detector operating at the 250 GeV ILC for the new exotic scalar production was studied for the assumed exotic scalar decay into tau leptons. The expected 95% C.L. limits on scalar production cross section times its branching ratio to τ lepton pairs, relative to the SM production cross section for given mass, were presented in the mass range below 125 GeV. Results correspond to over an order of magnitude improvement in sensitivity with respect to the decay mode independent study [7]. However, the result is competitive only if the scalar branching ratio for di-tau decays is 10% or more because the branching ratio is included in the limits.

6 References

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