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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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12 1 Analysis framework

13 The study is based on samples of background and signal events generated with WHIZARD 3.1.2 [1] using
 14 built-in SM_CKM model, for ILC running at 250 GeV. For the signal, it is assumed that light exotic scalar
 15 particle is produced in scalar-strahlung process, $e^+e^- \rightarrow ZS$, where Z decays hadronically while S decays
 16 into two τ leptons. Signal events are generated by varying Higgs boson mass in the SM and forcing it to decay
 17 into two τ leptons. All relevant 4 and 2-fermion final states were considered as background together with the
 18 contribution from SM-like Higgs boson. ISR and luminosity spectra for ILC running at 250 GeV were taken
 19 into account. H-20 running scenario [2, 3] for ILC was assumed with $\pm 80\%$ and $\pm 30\%$ polarisation for e^-
 20 and e^+ beam respectively. Fast simulation of detector response was performed with Delphes ILCgen model
 21 [4, 5].

22 2 Event selection

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

30 3 Event reconstruction and classification

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

$$36 \vec{p}_\tau^{miss} = E_{\nu_1} \cdot \vec{n}_1 + E_{\nu_2} \cdot \vec{n}_2,$$

37 where \vec{n}_1 and \vec{n}_2 are transverse components of τ candidate directions. The impact of the correction procedure
 38 on the scalar candidate invariant mass distribution is visible in Figure 1(a). In the Figure 1(b) and Figure 1(c)
 39 the distribution of Z invariant mass and invariant mass recoiling against Z boson are presented respectively.
 40 Two untagged jets are taken as Z candidate. For the most efficient event classification, separate Boosted
 41 Decision Tree classifier [6] was trained for each event category and beam polarisation combination, resulting
 42 in 20 independent classifiers. In addition to the variables describing the reconstructed S and Z candidates,
 43 as well as the total reconstructed energy and the recoil mass, y_{23} and y_{34} variables from clustering algorithm
 44 were included in the variable set used for event classification.

45 4 Results

46 The expected limits on the exotic scalar production cross section, relative to the SM predictions for given mass,
 47 are presented in figure Figure 2(a). Comparison of limits obtained for different event classes show that the

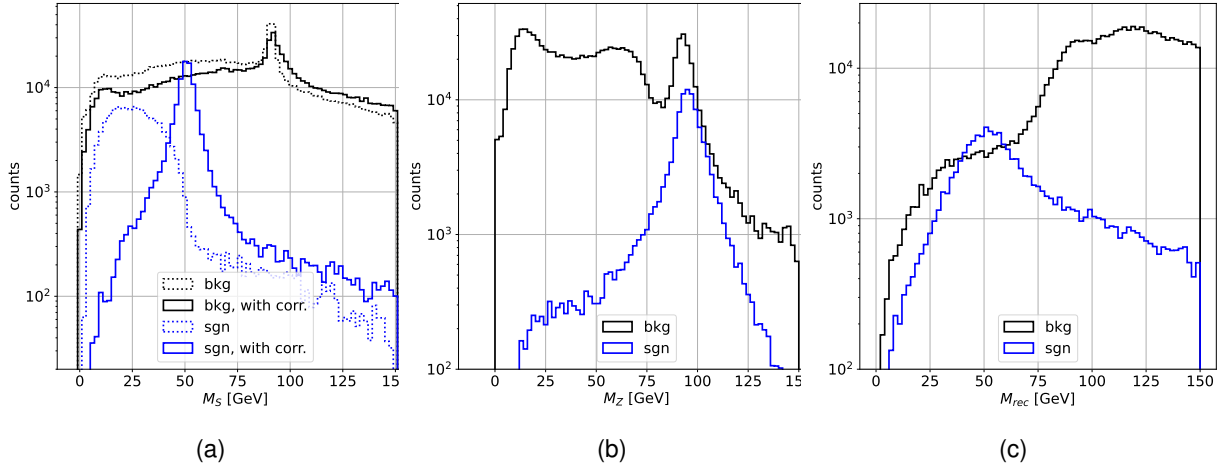


Figure 1: Distributions of reconstructed variables after pre-selection for background (black) and signal (blue) events for scalar mass of 50 GeV and $e_L^- e_R^+$ polarisation. (a) Distribution of reconstructed scalar S invariant mass, before (dashed line) and after (solid line) correction for escaping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

48 best limits are obtained for tight semi-leptonic selection, due to high statistics and relatively low background
 49 level. Including loose selection categories improves the limits by further 20-30%. Shown is figure Figure 2(b)
 50 is the comparison of limits for the two polarisation settings with high integrated luminosity, $e_L^- e_R^+$ and $e_R^- e_L^+$.
 51 Similar limits are obtained for the two configurations and limits corresponding to the combined analysis of the
 52 four polarisation configurations, according to H-20 running scenario, correspond to about 10% improvement
 53 with respect to results obtained with the same integrated luminosity for the unpolarised beam.

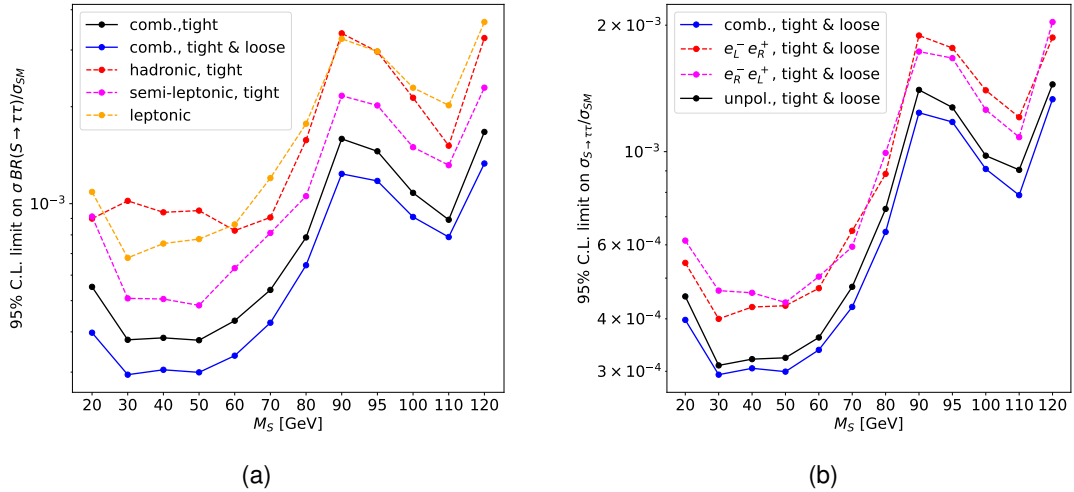


Figure 2: Expected 95% C.L. cross section limits on the light scalar production cross section times di-tau branching ratio for ILC running at 250 GeV, assuming H-20 running scenario. (a) Comparison of combined limits with limits obtained for different event categories. (b) Comparison of combined limits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

54 Impact of the uncertainties in theory predictions and data sample luminosities on the presented limits was
 55 found to be negligible.

56 5 Conclusions

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

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