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ILD sensitivity to light scalar production with invisible decays

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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 invisible scalar decays 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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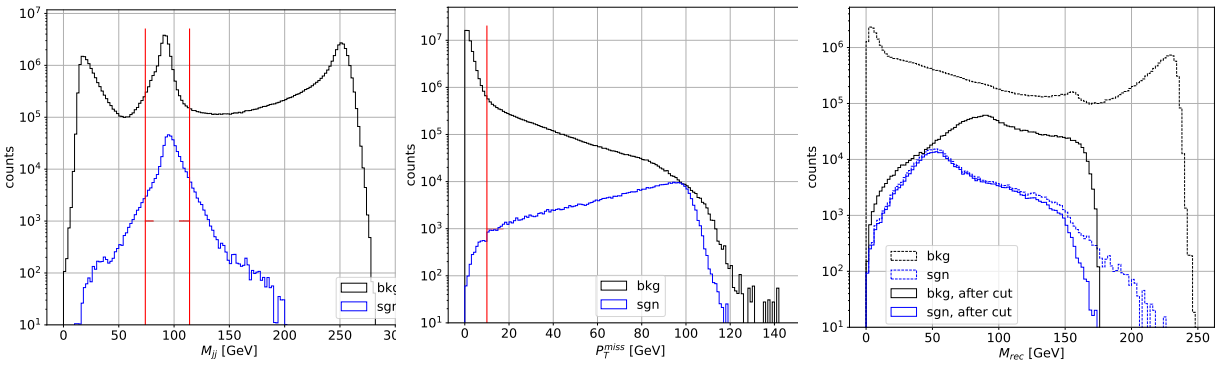
1 Analysis framework

Presented study is based on the framework developed previously for the search of light exotic scalar production with decays into two taus [1]. Considered is scalar production in the scalar-strahlung process, $e^+e^- \to Z\,S$, with hadronic Z decays (for highest sensitivity) and S decays into invisible final state (eg. dark sector). Samples of background and signal events were generated with WHIZARD 3.1.2 [2] using built-in SM_CKM model. For signal events SM Higgs boson mass in the model was set to the considered scala mass and only its decay into four neutrinos was allowed. For the background, all relevant 4 and 2-fermion final states were considered including contribution from SM-like Higgs boson as well as from processes with beamstrahlung or EPA photons in the initial state. ISR and luminosity spectra for ILC running at 250 GeV were taken into account. H-20 running scenario [3, 4] 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 [5, 6].

2 Pre-selection

Two stage pre-selection was used to select events consistent with the expected signal signature. First, rejected were all events with isolated leptons or photons reconstructed in the detector (including also forward calorimeters, LumiCal and BeamCal). All reconstructed objects were then clustered into two jets (using Durham algroithm in exclusive mode). Selected for the analysis were events with reconstructed di-jet invariant mass in the ± 20 GeV window around the Z mass and the missing transverse momentum greater than 10 GeV. Distributions of the considered variables and the applied pre-selection kinematic cuts are presented in Figure 1(a) and Figure 1(b). Figure 1(c) presents invariant mass recoiling against Z boson candidate before and after the cuts. Pre-selection significantly improves signal to background ratio and thus makes training ML classifiers faster and more precise.



(a) (b) (c)

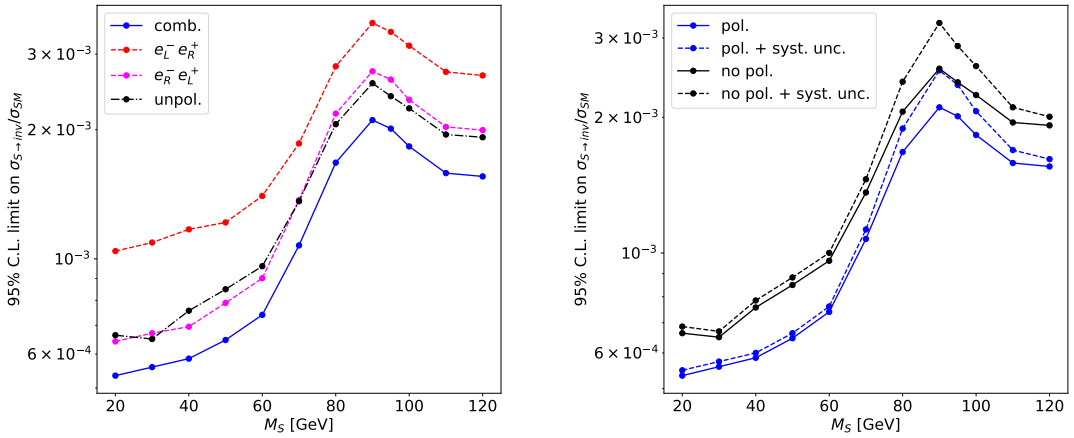
Figure 1: Distributions of reconstructed variables for background (black) and signal (blue) events for scalar mass of 50 GeV and $e_L^- e_R^+$ polarisation: (a) di-jet invariant mass with pre-selection acceptance region indicated, (b) missing transverse momentum with pre-selection cut indicated and (c) recoil mass before pre-selection (dashed lines) and after pre-selection cuts (solid lines).

3 Reconstruction and classification

Following input variables were used for event classification: di-jet (Z candidate) invariant mass and energy, missing transverse momentum, cosine of the Z polar angle, angle between two jets, recoil mass (corresponding to S mass for signal events), y_{23} and y_{34} variables from clustering algorithm. For most efficient event classification, separate Boosted Decision Tree [7] classifiers were trained for each beam polarisation configuration, resulting in four BDTs for each considered scalar mass. Background sample with $q\bar{q}l\nu$ in the final state was found to be the dominant background source.

4 Results

The expected limits on exotic scalar production cross section, calculated from the template fit to the BDT response distributions, are presented in figure Figure 2(a). One should note that $e_R^- e_L^+$ running is expected to result significantly better limits than $e_L^- e_R^+$ running with the same luminosity. This is expected from the suppression of the $W^+ W^-$ production, which contribute to the main background channel. Similar limits are obtained with 900 fb^{-1} collected with preferred polarization configuration as for 2 ab^{-1} with unpolarized beam. Combined analysis of the four polarisation configurations, according to H-20 running scenario, results in about 20% improvement with respect to the same integrated luminosity with the unpolarized beams.



(a) (b)

Figure 2: Expected 95% C.L. cross section limits on the light scalar production cross section times invisible branching ratio for ILC running at 250 GeV, assuming H-20 running scenario. (a) Comparison of combined limits with limits obtained for different polarisation configurations. (b) Comparison of combined limits with and without polarisation and with and without systematic effects.

To test possible impact of systematic effects on the extracted cross section limits nine additional nuisance parameters were introduced in the template fit procedure: four describing luminosity uncertainties of the data samples (for four polarization settings) and five for the uncertainties in the theoretical predictions (for $\bar{q}q$, W^-W^+, ZZ, $e^\pm\gamma$ and $\gamma\gamma$ processes). Impact of systematic uncertainties is significant, as indicated in Figure 2(b), especially for the region of scalar masses around $W^\pm$ and Z boson masses. The impact of systematic effects is also slightly bigger for unpolarized beam than for polarised one, as expected.

5 Conclusion

Sensitivity of the ILD detector operating at the 250 GeV ILC for discovering new exotic scalar particles was studied for the hypothesis of invisible new scalar decays. Hadronic decays of the Z boson produced in association with the new scalar were considered for maximum sensitivity. The expected 95% C.L. limits on the scalar production cross section times the invisible branching ratio, relative to the SM production cross section, were calculated in the mass range between 20 and 120 GeV. Results correspond to about order of magnitude increase in sensitivity with respect to the model independent study [8], assuming invisible decays of the new scalar dominate. Running with polarized beams, according to H-20 running scenario, results in about 20% limit improvement compared to running with unpolarised beam. Impact of systematic uncertainties was found to be significant and should be studied in more detail.

6 References

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