PoS PROCEEDINGS OF SCIENCE

Search for Exotic Scalars at the International Linear Collider

Mikael Berggren,[a] **María Teresa Núñez Pardo de Vera,**[a] **Bartłomiej Brudnowski,**[b] **Kamil Zembaczyński,**[b] **Aleksander Filip Żarnecki**[b,*]

on behalf of the ILD Concept Group

[a] *Deutsches Elektronen-Synchrotron DESY, Notkestr. 85, 22607 Hamburg, Germany*

[b] *Faculty of Physics, University of Warsaw, Pasteura 5, 02-093 Warsaw, Poland*

E-mail: filip.zarnecki@fuw.edu.pl

While the physics program for the future Higgs factory focuses on measurements of the 125 GeV Higgs boson, 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. Presented in this contribution are prospects for discovering an extra scalar boson produced in association with a Z boson at the ILC running at 250 GeV. Based on a full simulation of the International Large Detector (ILD), decay-mode independent search for the new scalar is presented, exploiting recoil of the scalar against a Z boson decaying into a pair of muons. Also presented are results on the light scalar observation in selected decay channels, where higher sensitivity can be reached with use of hadronic Z boson decays.

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*Speaker

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1. Motivation

In recent years, a general consensus was reached in the particle physics community about the need for the next-generation large infrastructure to be an electron-positron Higgs factory. Precision Higgs boson measurements will be carried out at the collision energy of 240–250 GeV, maximizing the cross section for the Higgs boson production in the so called Higgsstrahlung process, $e^+e^- \to$ Z H, see Fig. 1 (left). However, existence of additional light scalar particles, with masses of the order of or below the mass of the 125 GeV state observed at the LHC, is by far not excluded experimentally and also well motivated theoretically [1, 2]. Higgs factories should be sensitive to exotic scalar production even for very light scalars and small couplings, thanks to clean environment, precision and hermeticity of the detectors.

2. ILC and its experiments

The International Linear Collider (ILC) was proposed as a mature option for the future e^+e^- Higgs factory. The baseline running scenario assumes starting at a centre-of-mass energy of 250 GeV followed by a 500 GeV stage and 1 TeV considered as the possible upgrade [5]. In the assumed 22-year running period the ILC is expected to deliver the integrated luminosities of about 2 ab^{-1} at 250 GeV and 4 ab^{-1} at 500 GeV, with an additional 200 fb^{-1} collected at the top-quark pair-production threshold around 350 GeV. The design includes polarisation for both e^- and e^+ beams, of 80% and 30%, respectively, which is the unique feature of the ILC. Two detector concepts, ILD and SiD, have been developed for the ILC [6, 7], both optimised for the Particle Flow reconstruction.

3. Decay mode independent search

Production of the SM Higgs boson in the Higgsstrahlung process can be tagged, independent of the Higgs decay channel, based on the recoil mass technique, see Fig. 1 (right). Same approach can be used in the search for new exotic light scalar production in the corresponding scalar-strahlung process, $e^+e^- \to$ Z S. For best recoil mass reconstruction Z decays to muon pair can be used, which

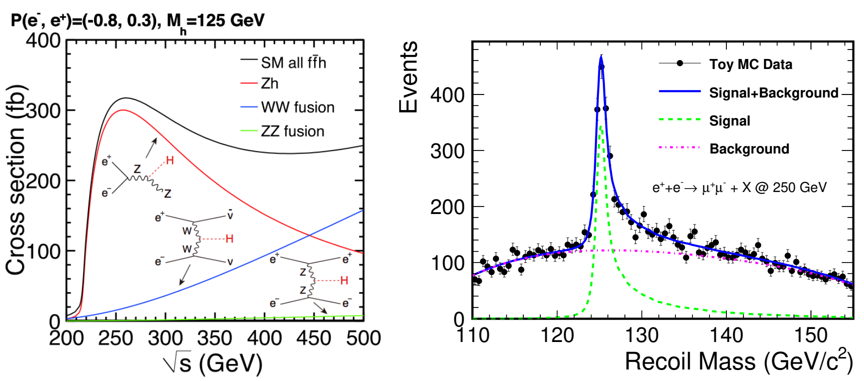

Figure 1: Higgs production at the ILC. Left: cross sections for the three major production processes as a function collision energy [3]. Right: recoil mass spectrum for signal of Higgs boson production and SM background at 250 GeV ILC, for $Z \to \mu^+\mu^-$ selection [4].

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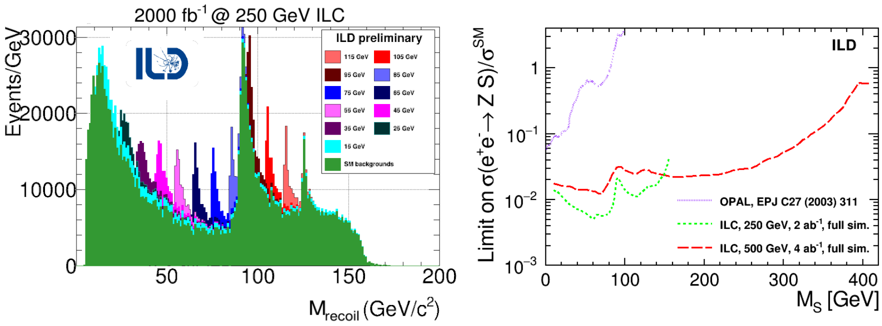

Figure 2: Left: the recoil mass distributions after the selection cuts for signal of light scalar production and SM backgrounds processes for ILC running at 250 GeV. Right: expected 95% C.L. limits on the scalar production cross section, relative to the SM scalar production cross section at given mass, for ILC running at 250 GeV and 500 GeV [8, 9].

were exploited in the full simulation studies performed within ILD [8, 9]. Shown in Fig. 2 (left) is the recoil mass distribution expected for SM background processed at 250 GeV ILC together with expectations for different signal hypothesis. Expected limits on the scalar production cross section, relative to the SM scalar production cross section at given mass, are compared with LEP limits based on the similar approach in Fig. 2 (right). Expected sensitivity of the experiment at the future e^+e^- Higgs factory is an order of magnitude better than the existing LEP limit and the mass range probed can be significantly extended as well.

4. Search for S $\rightarrow \tau^+\tau^-$

As some of the discrepancies from SM predictions observed in LEP and LHC data suggested possible existence of the new scalar with mass of about 95 GeV and enhanced branching ratio to the $\tau^+\tau^-$ final state [1], we decided to consider this decay channel as the possible discovery scenario. Event samples used for the presented study were generated using Whizard [10, 11] version 3.1.2. Both background (including 125 GeV Higgs boson production assuming nominal couplings) and light scalar signal production were modeled using the built-in `SM_CKM` model. The ILC beam energy profile, as simulated with GuineaPig, was taken into account based on Circe2 parametrisation and hadronisation was simulated with the Pythia 6 [12]. The fast detector simulation framework Delphes [13] was used to simulate detector response, with built-in cards for parametrisation of the ILC detector, `delphes_card_ILCgen.tcl` [14].

Depending on the decays of the two tau leptons, three decay channels can be considered for the signal events: hadronic (with both taus decaying hadronically), semi-leptonic (with one leptonic tau decay) and leptonic (with leptonic decays of both taus). As a tight selection, we require each tau lepton to be identified either as an isolated lepton (and missing p_T) or hadronic jet with τ-tag. However, as the efficiency of tau jet tagging implemented in Delphes is relatively poor (at most 70%), we also consider loose selection of hadronic and semi-leptonic events, when we require only one identified tau candidate (isolated lepton or τ-tagged jet) and three untagged hadronic jets, and take the jet with smaller invariant mass as the second tau candidate. To correct for the neutrino energy, we use the so called collinear approximation [15]. For high energy tau leptons,

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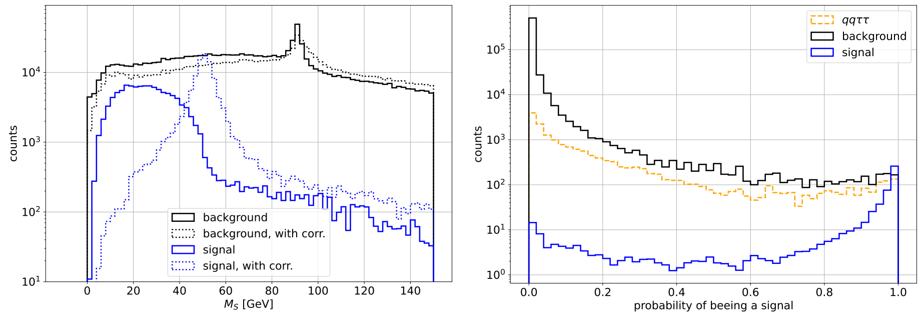

Figure 3: Left: reconstructed invariant mass of the two tau candidates after tight selection for SM background (black) and signal of 50 GeV scalar production (blue) before (solid) and after (dashed) collinear correction. Right: example of the BDT response distribution for 50 GeV scalar signal (blue) and SM background (black) events, for tight semi-leptonic event selection and ILC running with $e^-_L e^+_R$ polarisation combination.

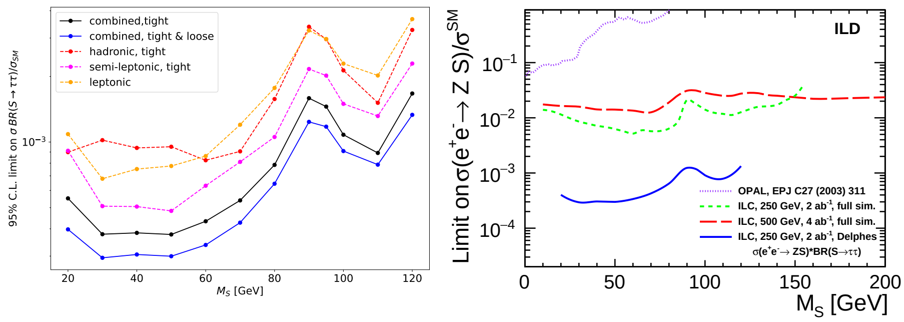

Figure 4: Expected 95% C.L. cross section limits on the light scalar production cross section times di-tau branching ratio for ILC running at 250 GeV. Left: comparison of combined limits with limits obtained for different event categories. Right: combined limits compared with limits resulting from decay independent study.

decay products are highly boosted in the initial lepton direction and one can therefore assume that the initial tau lepton, escaping neutrino and the observed tau candidate are collinear. With this assumption neutrino energies, and thus also corrected tau candidate energies, can be found from the transverse momentum balance. Shown in Fig. 3 (left) are the mass distributions of the tau candidate pairs in signal and background events, before (solid) and after (dashed) collinear correction. After the correction, the scalar mass can be reconstructed with about 5 GeV precision, also for semi-leptonic and leptonic events.

For best event classification, we consider each event category and each beam polarisation combination separately, resulting in 20 independent BDTs trained for event classification, for each scalar mass considered. Example of BDT response distribution is presented in Fig. 3 (right). Expected exclusion limits, assuming no deviation from SM predictions are observed, are presented in Fig. 4. As expected, the semi-leptonic event selection results in the strongest limits, combining high event statistics (about 47% of decays) with background lower than for the hadronic channel. Including loose selection categories improves the expected limits by 20-30% for the whole considered mass range. When comparing to the decay independent limits, we can state that the targeted analysis results in more than an order of magnitude increase in sensitivity.

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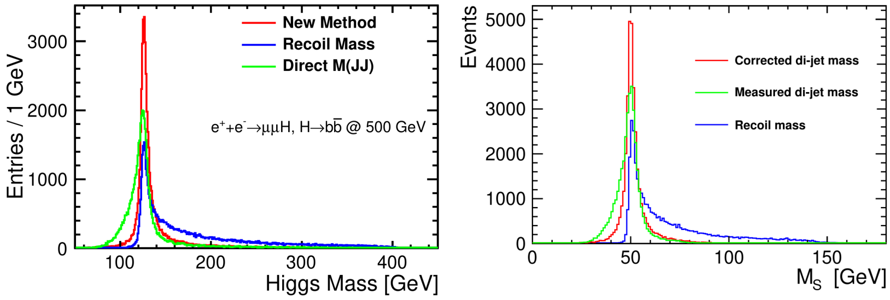

Figure 5: Invariant mass of two jets reconstructed using raw jet energies, corrected jet energies and recoil method. Left: full simulation results for the 125 GeV Higgs boson production at 500 GeV ILC [16]. Right: Delphes simulation results for the signal of 50 GeV scalar production at 250 GeV ILC.

5. Search for $S \to b\bar{b}$

If the structure of new light scalar couplings to SM particles is similar to that of the SM Higgs boson then the decay to $b\bar{b}$ is expected to dominate down to the masses of the order of 10 GeV. As huge hadronic background is expected from pair production of W bosons, leptonic Z boson decays are explored in this search channel. Again, conservation of transverse momentum can be used to improve invariant mass reconstruction for the new scalar based on the well measured leptonic final state and jet angles. This is shown in Fig. 5, where reconstructed di-jet mass distributions are compared before and after jet energy correction for 125 GeV Higgs boson [16] and new scalar of 50 GeV. One can clearly see that jet energy correction based on the transverse momentum conservation significantly improves scalar mass measurement and allows to obtain precision much better than with uncorrected jet energies or the recoil method.

6. Conclusions

BSM scenarios involving light scalars, with masses accessible e^+e^- Higgs factories, are still not excluded by existing data. Sizable production cross sections for new scalars can also coincide with non-standard decay patterns, so different decay channels should be considered. Strong limits are already expected from decay independent searches, based on recoil mass reconstruction. More than an order of magnitude higher search sensitivity is expected for light scalar decays to tau pairs, if this is a dominant decay channel. Studies of other decay channels are ongoing and the results are being prepared for the ECFA e^+e^- Higgs/EW/top factory study report.

Acknowledgments

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