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Search for Light Scalars Produced in Association with a Z boson at the 250 GeV stage of the ILC

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In many models with extended Higgs sectors, e.g. Two Higgs Doublet Model, Next-to-Minimal Supersymmetric Standard Model and Randall Sundrum model, there exists a light scalar S^0, lighter than the Standard Model (SM) like Higgs, and the coupling of S^0ZZ can be very small, as expected from the likeness of the 125 GeV Higgs boson measured at the LHC to the SM Higgs boson. Such a light scalar with suppressed couplings to the Z boson would have escaped detection at LEP due to its limited luminosity. With a factor of 1000 higher luminosity and polarized beams, the International Linear Collider (ILC) is expected to have substantial discovery potential for such states. Furthermore, searches for additional scalars at LEP and LHC are usually dependent on the model details, such as decay channels. Thus, it is necessary to have a more general analysis with model-independent assumptions.

In this work, we perform a search for a light higgs boson produced in association with Z boson at the ILC with a center-of-mass energy of 250 GeV, using the full Geant4-based simulation of the ILD detector concept. In order to be as model-independent as possible, the analysis is performed using the recoil technique, in particular with the Z boson decaying into a pair of muons. As a preliminary result, exclusion cross-section limits for different higgs masses between 10 and 120 GeV are given in terms of a scale factor k with respect to the Standard Model Higgs-strahlung process cross section.

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1. Introduction

In many new physics models, one or more extra scalars are predicted, where a scalar lighter than 125 GeV is well motivated. However, the properties of 125 GeV Higgs boson measured at the LHC is very similar to the Standard Model (SM) prediction [1] If a new light scalar exists, its coupling will be highly suppressed [3]. The LEP/LHC constraints on the extra scalars always rely on the model details. Thus, a more general analysis with model-independent assumptions to a scalar with the small coupling is preferred. Although the OPAL collaboration has searched for light scalars in a model-independent way at LEP, the results are limited by the low luminosity [4]. The International Linear Collider (ILC) is a proposed electron-positron linear collider, whose center-of-mass energy is 250 GeV at the first stage. The luminosity on the ILC design is 1000 times higher than LEP, which makes the recoil mass technique more accurate [5]. In this contribution, we describe the search for a light scalar with a very weak interaction with the Z boson using model-independent analysis on the ILC.

2. Event Generation and Detector Simulation

The signal process is a light scalar S production associated with a Z boson, where the Z boson decays to a pair of muons. The signal benchmark event samples, for every 5 GeV in the range of $10 \leq M_{S^0} \leq 120$ GeV, are generated with 100% left-handed and right-handed beam polarization at a center-of-mass energy of 250 GeV, using the Whizard 1.95 Monte Carlo (MC) event generator [2]. The decay branching ratios of S are the same as a 125 GeV SM Higgs boson, but no use would be made of this fact.

As SM backgrounds, we use the samples generated in the context of the ILC Detailed Baseline Design document [6]. Bremsstrahlung and initial state radiation (ISR) are explicitly considered for all events. The samples are reweighted with beam polarizations of $\pm 80\%$ for the electron beam and $\pm 30\%$ for the positron beam. The fractions of integrated luminosity 2000 fb^{-1} are dedicated to the four sign combinations $(-+,+-,++,--) = (45\%, 45\%, 5\%, 5\%)$.

The International Large Detector (ILD), which is one of two detector concepts being developed for ILC [6], is designed for optimal particle-flow performance [6]. It consists of a vertex detector, a hybrid tracking system, which is realized with a time projection chamber and a combination of silicon tracking, and a calorimeter system. These systems are surrounded by a solenoid producing a 3.5 T magnetic field, and an iron flux return yoke.

The generated events have been simulated with the full Geant4-based simulation of ILD concept. The beam crossing angle of 14 mrad, as well as the beam spectrum, has been also taken into account. Event reconstruction has been performed using the PandoraPFA algorithm to reconstruct individual final state particles, so-called Particle Flow Objects (PFOs), within the Marlin framework.

2.1 Event selection and Background Rejection

The best muon pair candidate is selected by minimizing the following χ^2 function:

$$\chi^2(M_{\mu^+\mu^-}, M_{\mathtt{rec}}) = \frac{(M_{\mu^+\mu^-} - M_Z)^2}{\sigma^2_{M_{\mu^+\mu^-}}} + \frac{(M_{\mathtt{rec}} - M_{S^0})^2}{\sigma^2_{M_{\mathtt{rec}}}} + \tag{2.1}$$

where $\sigma_{M_{\mu^+\mu^-}}$ and $\sigma_{M_{\mathtt{rec}}}$ are determined by a Gaussian fit to the generator-level distributions of $M_{\mu^+\mu^-}$ and $M_{\mathtt{rec}}$. Then, the bremsstrahlung and FSR photons from the muon, identified by its cosine of the polar angle with respect to the isolated muons, are combined with the muon.

Background events are rejected by firstly considering kinematic variables only relied on muons (and the reconstructed Z boson): the invariant mass and transverse momentum of the muon pair, as well as the polar angle of the missing momentum. Then, a BDTG is applied on the following variables: the polar angle of each muon, the polar angle of the muon pair, the opening angle of the muon pair. With these cuts, no information on the decay of S^0 is needed, thus the results will be model-independent.

The recoil mass deistributions are obtained after applying these cuts, which is shown in Figure. 1. According to the recoil mass distribution, the main backgrounds depend on the scalar mass. In the small mass region, the two fermions background $e^+e^- \to Z \to \mu^+\mu^-$ with an energetic ISR photon is the overwhelming background; while in the Z pole region, the ZZ process with one Z boson decaying to a muon pair is an irreducible background. The two fermion background can be further rejected by taking into account ISR photon return effects. The ISR photon vero cuts are applied to the ISR photons in the center region and forward region, separately.

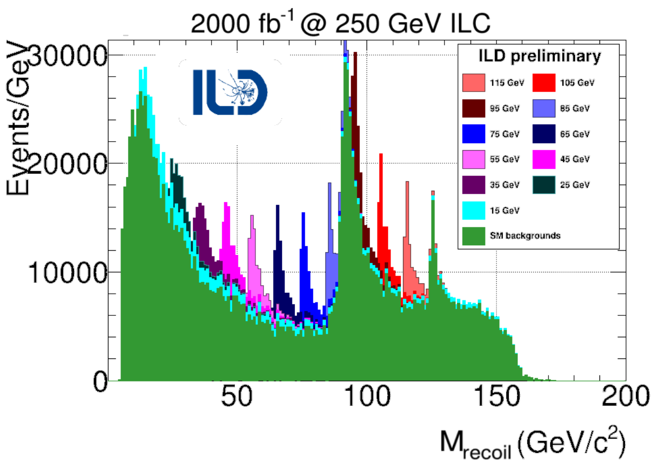

Figure 1: The recoil mass distributions for signal and backgrounds after the cuts.

3. Results

The 95% confidence level upper bounds on k, defined as $k = \frac{\sigma_{S^0 Z}}{\sigma_{H_{SM} Z}(m_{H_{SM}} = m_{S^0})}$, is calculated for each benchmark point, based on the likelihood method, which is shown in Figure. 2

In Figure. 2 (a), the red and magenta points are the results with/without the ISR photon veto cuts on the level of PFOs, which shows the two fermion background can be efficiently discarded by applying ISR photon veto cut in the small mass region. The black points are the results using MC truth particles with the detector simulation, which reflect the best reconstruction capability.

In Figure. 2 (b), the ILC results are compared with the LEP. The red points are 2 σ exclusion limits for $\int Ldt = 2000\ fb^{-1}$ and $\sqrt{S} = 250$ GeV at the ILC, while the red line was obtained with the recoil mass method by OPAL Collaboration [4] at LEP ones. Also shown with the blue line is the model-dependent results from LEP, combining measurements by ALEPH, DELPHI, L3 and

OPAL [7], in which the decay modes of the scalars were utilized. In general, the ILC exclusion limits will reach 10^{-2} , and are one or two orders better than the OPAL recoil results and even than the LEP traditional results.

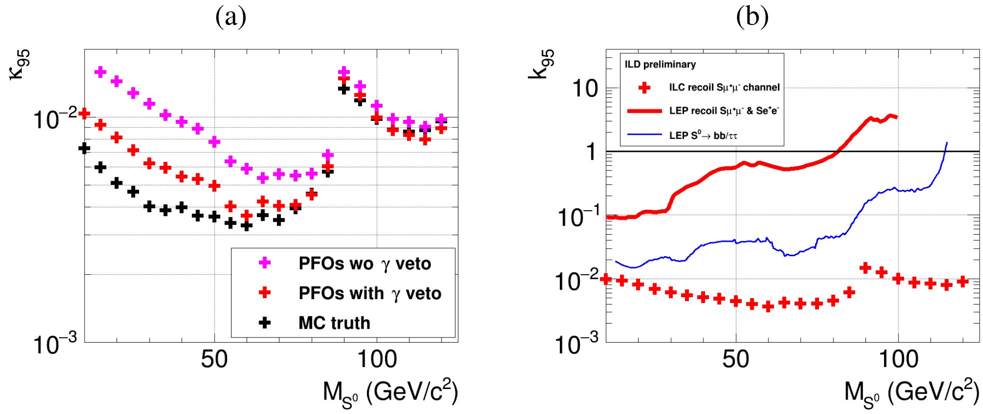

Figure 2: The 2 σ exclusion limits for the cross section scale factor k for different scalar masses. (a) the effects for ISR photon veto cuts and the reconstruction efficiency. (b) the comparison between the LEP and ILC results.

4. Conclusions

By applying the recoil technique, the potential of the ILC to search for scalars has been investigated at $\sqrt{S} = 250$ GeV, with the full simulation of the ILD detector concept. The method is optimized for signal selection and background rejection to be independent of the scalar decay modes. 2 σ expected exclusion limits for the cross section scale factor k_{95} are shown for scalar mass from 10 GeV to 120 GeV. It is one or two orders of magnitude more sensitive than LEP, and covering substantial new phase space.

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