

# Search for Extra Scalars Produced in Association with Muon Pairs at the ILC

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**on behalf of the International Large Detector concept group**

We study the search for an extra scalar boson produced in association with the  $Z$  boson at the International Linear Collider (ILC). The study is performed at center mass energies of 250 GeV and 500 GeV based on the full simulation of the International Large Detector (ILD). In order to be as model-independent as possible, the analysis uses the recoil technique, in particular with the  $Z$  boson decaying into a pair of muons. As a result, exclusion cross-section limits are given in terms of a scale factor  $k$  with respect to the Standard Model Higgs-strahlung process cross section. These results, covering all possible searching regions of the extra scalar at the 250 GeV ILC and 500 GeV ILC, can be interpreted independently of the decay modes of the  $S$ .

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## 1. Introduction

The motivation of our study is to find a new scalar  $S$  in the  $SZZ$  coupling since one or more extra scalars are predicted in many new physics models. However, the properties of 125 GeV scalar measured at the LHC is very similar to the Standard Model (SM) Higgs boson [1]. As a result, the new scalar's coupling will be highly suppressed [2]. Furthermore, the LEP/LHC constraints on the extra scalars always rely on the model details. Thus, a more precise analysis with model-independent assumptions to a scalar with the small coupling is preferred. Although the OPAL collaboration has searched for light scalars (less than 100 GeV) in a model-independent way at LEP, the results are limited by the low luminosity [3]. The International Linear Collider (ILC) is a proposed electron-positron linear collider, whose luminosity will be over a thousand times higher than LEP, which makes the recoil mass technique more accurate to find such extra scalars [4]. And the ILC has higher center of mass energy, which will cover more searching regions for the extra scalar. A preliminary version of this analysis has been reported at LCWS2017 [5] and ICHEP2018[6]. Thus, only the updates from ICHEP2018 is summarized in this contribution.

## 2. Event Generation and Detector Simulation

The signal is  $e^+e^- \rightarrow S + Z$  production, where the  $Z$  boson decays to a pair of muons. The decay branching ratios of  $S$  are fixed as the same as a 125 GeV SM Higgs boson, but no use would be made of this fact. As SM backgrounds, bremsstrahlung and initial state radiation (ISR) are explicitly considered for all events. The event samples are generated with 100% left-handed and right-handed beam polarization, using the Whizard 1.95 Monte Carlo (MC) event generator [7]. Then the samples are reweighted with beam polarizations of  $\pm 80\%$  for the electron beam and  $\pm 30\%$  for the positron beam.

The event samples are generated, simulated and reconstructed for different center-of-mass energies ( $\sqrt{s} = 250$  GeV and 500 GeV). In 250 GeV cases, we use the same setting as the samples generated in the context of the ILC Detailed Baseline Design document [9]. The fractions of integrated luminosity 2000  $fb^{-1}$  are dedicated to the four sign combinations  $(-+, +-, ++, --) = (45\%, 45\%, 5\%, 5\%)$ . The signal benchmark points are chosen as every 5 GeV in the range of  $10 \leq M_{S^0} \leq 160$  GeV (totally 30 signal benchmark points). In 500 GeV cases, we use the detector geometry of ILD\_15(s5)\_v1\_o1, the fractions of integrated luminosity 4000  $fb^{-1}$  are dedicated to  $(-+, +-, ++, --) = (40\%, 40\%, 10\%, 10\%)$ . Totally 48 signal benchmark points are chosen in the range of  $10 \leq M_{S^0} \leq 410$  GeV.

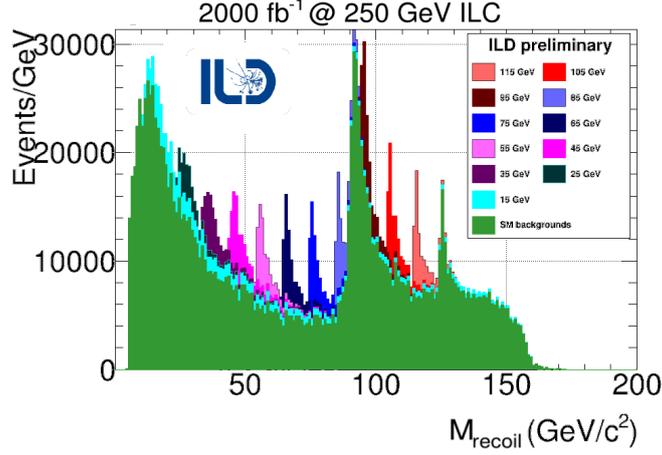
### 2.1 Event selection and Background Rejection

Firstly, a pair of oppositely charged muons is selected by minimizing the following  $\chi^2$  function:

$$\chi^2(M_{\mu^+\mu^-}, M_{\text{rec}}) = \frac{(M_{\mu^+\mu^-} - M_Z)^2}{\sigma_{M_{\mu^+\mu^-}}^2} + \frac{(M_{\text{rec}} - M_{S^0})^2}{\sigma_{M_{\text{rec}}}^2} + \quad (2.1)$$

where  $\sigma_{M_{\mu^+\mu^-}}$  and  $\sigma_{M_{\text{rec}}}$  are determined by a Gaussian fit to the generator-level distributions of  $M_{\mu^+\mu^-}$  and  $M_{\text{rec}}$ . Then, the bremsstrahlung and final state radiation photons from the muon 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 trained using 6 input variables based on TMVA [8]: muon pair invariant mass, the polar angle of each muon, the polar angle of the muon pair, the opening angle of the muon pair, and the acoplanarity. Finally, taking into account the ISR photon return effects, the two fermion background can be further rejected by ISR energy veto cuts. With these cuts, no any information on the decay of  $S^0$  is needed, thus the results will be model-independent. The recoil mass distributions are obtained after these cuts (Figure. 1).



**Figure 1:** The recoil mass distributions for signal and backgrounds in the 250 GeV center of mass energy. These distributions are before the ISR veto cuts.

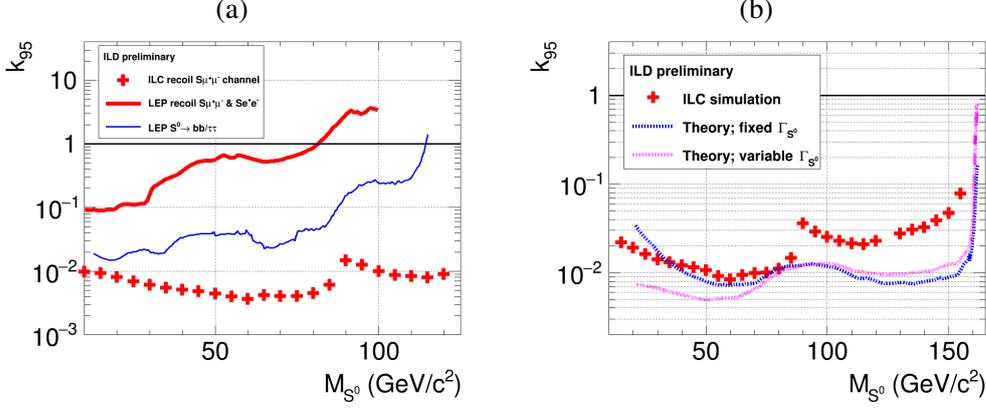
### 3. Results

A likelihood analysis is applied for calculating  $2\sigma$  expected exclusion limits on  $k$ , defined as  $k = \frac{\sigma_{S^0Z}}{\sigma_{H^{SM}Z}(m_{H^{SM}}=m_{S^0})}$ , with a bin-by-bin comparison between the signal and background recoil mass histograms for each benchmark points.

In Figure. 2 (a), the ILC results at 250 GeV are compared with the LEP results directly. The red points are  $2\sigma$  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 [3] at LEP with totally about  $0.8 fb^{-1}$  data. Also shown with the blue line is the model-dependent results from LEP, combining measurements by ALEPH, DELPHI, L3, and OPAL [10], 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 better than the LEP traditional results.

In Figure. 2 (b), the ILC theoretical predictions, which are extrapolated from the LEP measurements with fixed (variable) scalar width, are compared with the ILC experimental results. The theoretical predictions combine  $S\mu^+\mu^-$  and  $Se^+e^-$  channels, while the ILC experimental results only use  $S\mu^+\mu^-$  channel, but divide the results by  $\sqrt{2} (k_{95} = k_{95}^{exp}(S\mu^+\mu^-)/\sqrt{2})$ . These results are projected with  $500 fb^{-1}$  luminosity with  $P(e^-, e^+) = (-80\%, +30\%)$ . From the figure, the ILC experimental results agree to the theoretical predictions with fixed scalar width in the low mass region. However, the theoretical predictions extrapolate the expected background events in an interval around the  $Z$  pole region, so there is no the  $Z$  pole peak in the theoretical curves; at the same

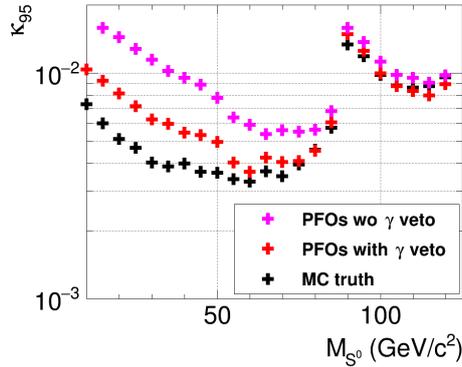
time, the theoretical predictions don't include SM Higgs background, as a result, they are better than experimental results in the high mass region.



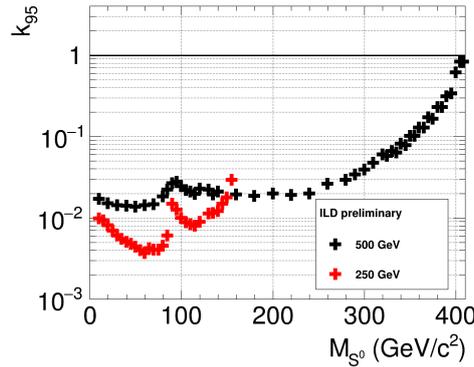
**Figure 2:** The  $2\sigma$  exclusion limits for the cross section scale factor  $k$  for different scalar masses. (a) The directly comparison between the LEP and ILC results. (b) comparison between the theoretical LEP extrapolation results and ILC results.

In Figure. 3, a comparison is given among the MCtruth inputs and the PFO inputs. The red and magenta points are the results with/without the ISR photon veto cuts on the level of PFOs, because the two fermion background can be efficiently discarded by considering the ISR effects. Thus, the ISR photon reconstructed efficiency will affect the result significantly. The black points are the results after photon veto cuts using MCtruths with the detector simulation, which reflect the best searching capability. And the difference between MCtruths and PFOs results shows we can improve the results with better photon reconstructions.

In Figure. 4, we show the preliminary exclusion limits for 500 GeV ILC. In the low mass region, the 500 GeV results are worse than 250 GeV cases mainly due to the suppressed cross sections, while they cover a larger searching region. Especially when  $M_S < 300$  GeV,  $k_{95}$  is in the order of  $10^{-2}$ , which could set strong model-independent constraints for the extra scalars.



**Figure 3:** The effects for ISR photon veto cuts and the reconstruction efficiency.



**Figure 4:** Preliminary Final Exclusion Limits for 250/500 GeV ILC.

#### 4. Conclusions

By applying the recoil technique, the potential of the ILC to search for scalars has been investigated at  $\sqrt{s} = 250$  GeV and 500 GeV, with the full simulation of the ILD detector concept. The method is optimized to be independent of the scalar decay modes.  $2\sigma$  expected exclusion limits for the cross section scale factor  $k_{95}$  are shown for scalar mass from 10 GeV to 160 GeV when  $\sqrt{s} = 250$  GeV and from 10 GeV to 410 GeV when  $\sqrt{s} = 500$ . They are one or two orders of magnitudes more sensitive than LEP, and covering substantial new phase spaces.

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