



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

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We study the search for an extra scalar S 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 predicted results, covering all possible searching regions of the extra scalar at the 250 GeV ILC and the 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 that of 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 same as the 125 GeV 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 ILD Detailed Baseline Design document [8]. 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 samples generated in the context of the ILD Design Report [9], 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. Event reconstruction has been performed using the PandoraPFA algorithm to reconstruct individual final state particles, so-called Particle Flow Objects (PFOs).

2.1 Event selection and Background Rejection

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

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

37 where $M_{\mu^+\mu^-}$ and M_{recoil} are the invariant mass and the recoil mass of the muon pair, and $\sigma_{M_{\mu^+\mu^-}}$
 38 and $\sigma_{M_{\text{recoil}}}$ are determined by a Gaussian fit to the generator-level distributions of $M_{\mu^+\mu^-}$ and
 39 M_{recoil} . Then, the bremsstrahlung and final state radiation photons from the muon are combined
 40 with the muon.

41 Background events are rejected by firstly considering kinematic variables only relied on muons
 42 (and the reconstructed Z boson): the invariant mass and transverse momentum of the muon pair, as
 43 well as the polar angle of the missing momentum. Then, a BDTG is trained using 6 input variables
 44 based on TMVA [10]: muon pair invariant mass, the polar angle of each muon, the polar angle of
 45 the muon pair, the opening angle of the muon pair, and the acoplanarity. Finally, taking into account
 46 the ISR photon return effects, the two fermion background can be further rejected by ISR energy
 47 veto cuts. With these cuts, no information on the decay of S^0 is needed, thus the expected results
 will be model-independent. The recoil mass distributions are obtained after these cuts (Figure 1).

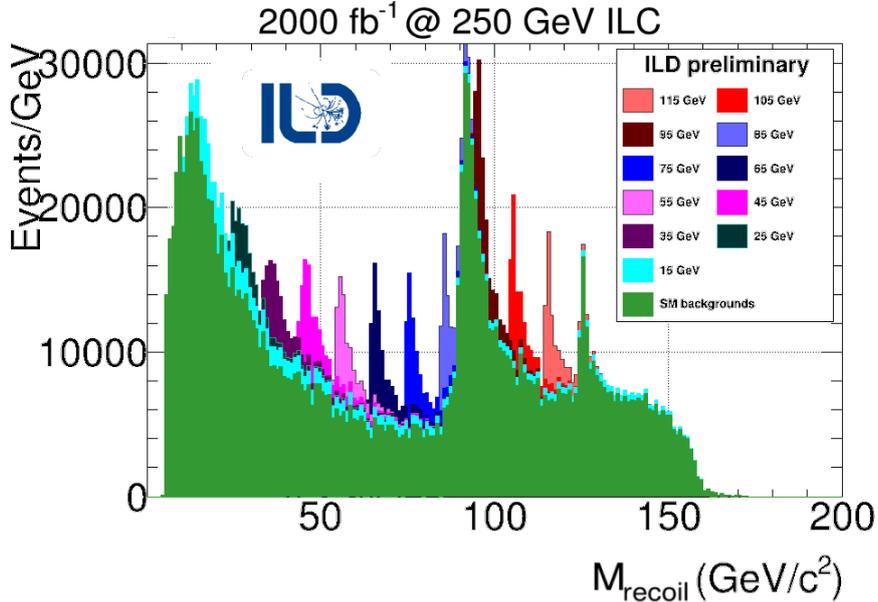


Figure 1: The recoil mass distributions for signal and backgrounds at the 250 GeV center of mass energy. These distributions are before the ISR veto cuts.

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49 3. Results

50 A likelihood analysis is applied for calculating 2σ expected exclusion limits on k with a bin-
 51 by-bin comparison between the signal and background recoil mass histograms for each benchmark
 52 points, where k is defined as

$$k = \frac{\sigma_{S^0Z}}{\sigma_{H^{SM}Z}(m_{H^{SM}} = m_{S^0})}. \quad (3.1)$$

53 In Figure 2, the ILC results at 250 GeV are compared with the LEP results directly. The red
 54 points are 2σ exclusion limits for $\int Ldt = 2000 \text{ fb}^{-1}$ and $\sqrt{S} = 250 \text{ GeV}$ at the ILC, while the red
 55 line was obtained with the recoil mass method by the OPAL Collaboration [3] at LEP with about
 56 0.8 fb^{-1} data in total. Also shown with the blue line is the model-dependent results from LEP,
 57 combining measurements by ALEPH, DELPHI, L3, and OPAL [11], in which the decay modes of

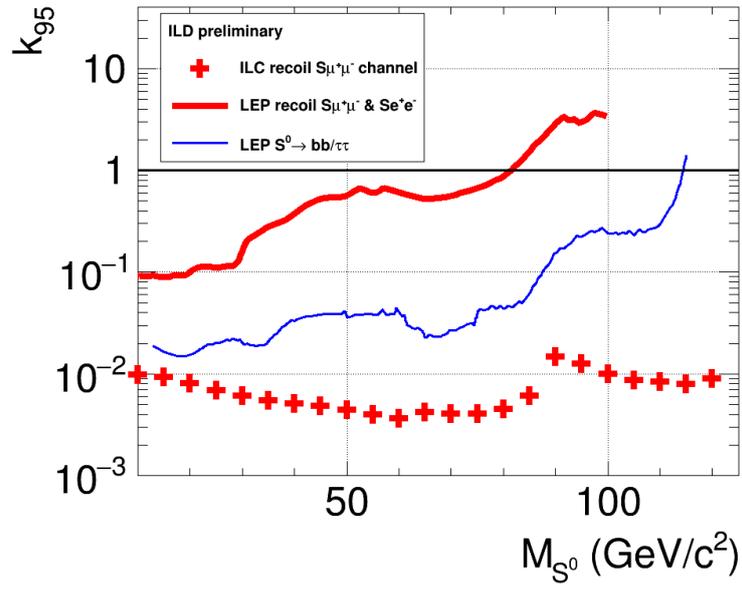


Figure 2: The directly comparison between the LEP and ILC simulation results, where k^{95} is the 2σ exclusion limits for the cross section scale factor k hereinafter.

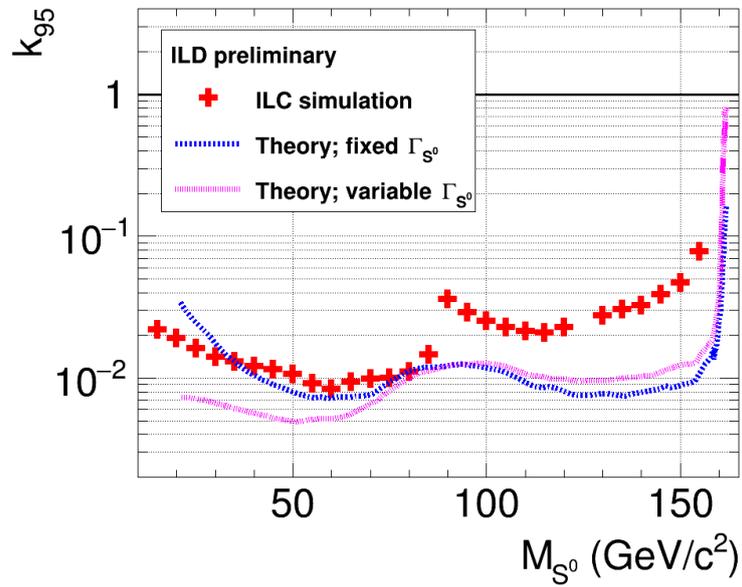


Figure 3: The comparison between the theoretical LEP extrapolation results and ILC expected results.

58 the scalars were utilized. In general, the ILC exclusion limits will reach 10^{-2} , and are one or two
 59 orders better than the OPAL recoil results and even better than the LEP traditional results.

60 In Figure 3, the ILC theoretical predictions, which are extrapolated from the LEP measure-
 61 ments with fixed (variable) scalar width, are compared with the ILC simulation results [12]. The
 62 theoretical predictions combine $S\mu^+\mu^-$ and Se^+e^- channels, while the ILC simulation results
 63 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
 64 are projected with 500 fb^{-1} luminosity with $P(e^-, e^+) = (-80\%, +30\%)$. From the figure, the
 65 ILC simulation results agree to the theoretical predictions with fixed scalar width in the low mass
 66 region. However, the theoretical predictions extrapolate the expected background events in an in-
 67 terval around the Z pole region [12], so there is no Z pole peak in the theoretical curves; at the same
 68 time, the theoretical predictions don't include SM Higgs background, as a result, they are better
 than simulation results in the high mass region.

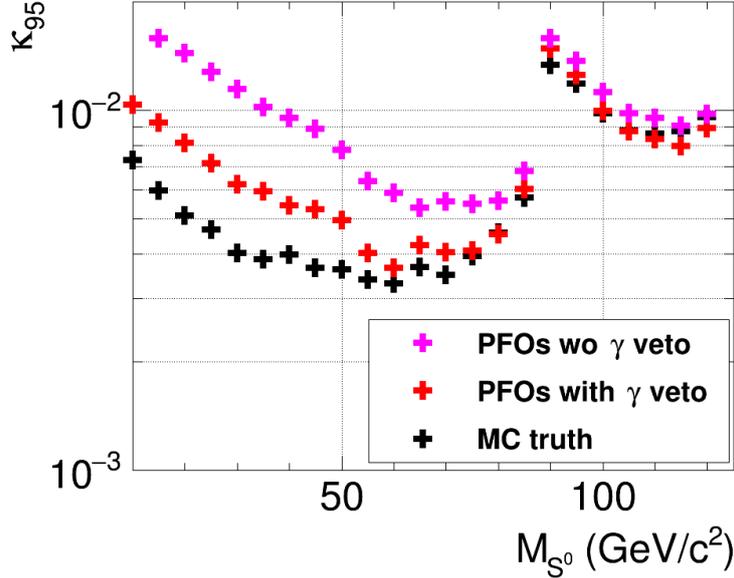


Figure 4: The effects for ISR photon veto cuts and the reconstruction efficiency.

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70 In Figure 4, a comparison is given among the PFO and their corresponding MC simulation
 71 inputs (MCtruth). The red and magenta points are the results with/without the ISR photon veto cuts
 72 on the level of is, because the two fermion background can be efficiently discarded by considering
 73 the ISR effects. Thus, the ISR photon reconstructed efficiency will affect the result significantly.
 74 The black points are the results after photon veto cuts using MCtruths with the detector simulation,
 75 which reflect the best searching capability. And the difference between MCtruths and PFOs results
 76 shows we can improve the results with better photon reconstructions.

77 In Figure. 5, we show the preliminary exclusion limits for the 500 GeV ILC. In the low mass
 78 region, the 500 GeV results are worse than the 250 GeV cases mainly due to the suppressed cross
 79 sections, while they cover a larger searching region. Especially when $M_S < 300 \text{ GeV}$, k_{95} is in the
 80 order of 10^{-2} , which could set strong model-independent constraints for the extra scalars.

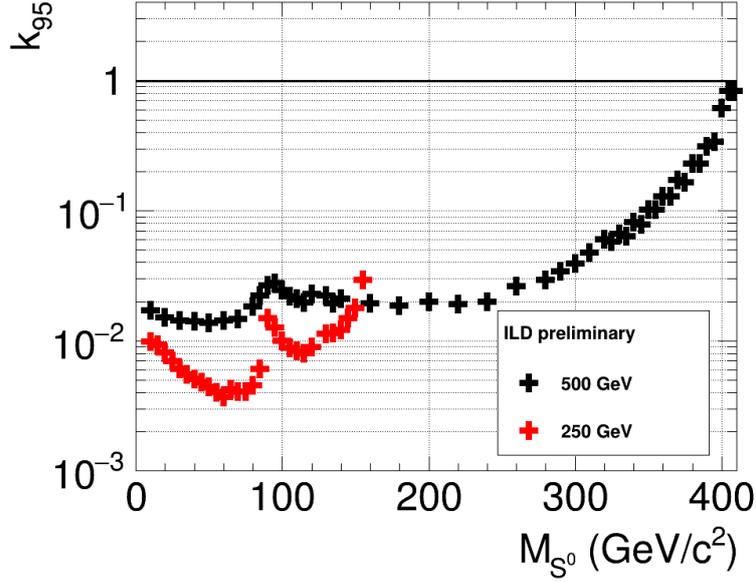


Figure 5: Preliminary Final Exclusion Limits for 250/500 GeV ILC.

81 **4. Conclusions**

82 By applying the recoil technique, the potential of the ILC to search for scalars has been inves-
 83 tigated at $\sqrt{s} = 250$ GeV and 500 GeV, with the full simulation of the ILD detector concept. The
 84 method is optimized to be independent of the scalar decay modes. 2σ expected exclusion limits
 85 for the cross section scale factor k_{95} are shown for scalar mass from 10 GeV to 160 GeV when
 86 $\sqrt{s} = 250$ GeV and from 10 GeV to 410 GeV when $\sqrt{s} = 500$. They are one or two orders of
 87 magnitudes more sensitive than LEP, and covering substantial new phase spaces.

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