PROCEEDINGS OF SCIENCE

ILC Higgs Physics Potential

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Higgs factories based on e^+e^- colliders have the potential to measure the complete profile of the Higgs boson at a level of precision that goes qualitatively beyond the expected capabilities of LHC and HL-LHC. In this contribution, we will review the program of Higgs boson coupling measurements expected from the International Linear Collider, including the most recent updates. These measurements span the range of e^+e^- center-of-mass energies from 250 GeV to 1 TeV, and include precision measurements of the Higgs self-coupling.

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1. Introduction

The International Linear Collider (ILC) is one of the proposed future e^+e^- collider. Its center-of-mass energy ($\sqrt{s}$) starts from 250 GeV which is suitable for the precision Higgs measurements in the Higgsstralhung process (Zh), but it is upgradable up to 1 TeV enabling access to rare Higgs decays, Higgs self-coupling and BSM signatures in the Higgs sector. The polarized beams will be used at the ILC; 80% for electrons and 30% for positrons improving precision of measurements combining different polarization settings. In this contribution, we will discuss the Higgs physics potential at the ILC, mainly based on the Ref. [1]. Many new physics models predict the deviations of the Higgs couplings from the SM, and the size of deviation is estimated to be small, typically a few % to $\sim$ 10% [2]. To observe such a small deviation, we need precise measurements of the Higgs boson. The evaluation of the precision of Higgs measurements is based on the full detector simulation of the International Large Detector (ILD) concept and/or Silicon Detector (SiD) concept [3].

2. Higgs Measurement Program at the ILC

2.1 Recoil Mass Measurement

The key measurement of the Higgs boson at lepton colliders is the measurement of the absolute size of an inclusive cross-section σ_{Zh} by using the recoil technique to $e^+e^- \to Zh$ process. Figure 1 left shows the Feynman diagram of $e^+e^- \to Zh$ with the decay of $Z \to \mu^+\mu^-$. Since the initial state of e^+e^- collision is well-known, the mass of the Higgs boson can be determined only by measuring muon momenta, without looking at any Higgs decay products. Figure 1 right shows the spectrum of the recoil mass taken from Ref. [4]. This recoil technique is also applicable for $Z \to e^+e^-$ and $Z \to q\overline{q}$ decay channel and have been analyzed in Refs. [4, 5]. Assuming the twenty years running scenario of the ILC with beam polarization sharing [6–8], the mass of the Higgs boson M_h can be measured with a precision of 14 MeV, σ_{Zh} can be determined with 0.7% precision, and the hZZ coupling g_{hZZ} can be measured with 0.4% relative statistical uncertainty.

2.2 Higgs Self-Coupling Measurement

The measurement of trilinear Higgs self-coupling is quite important because this measurement allows testing the Higgs mechanism by measuring the Higgs potential directly. However, this measurement is very challenging due to its small cross section and the interference between signal and background.

Full simulation studies are performed by using $e^+e^- \to Zhh$ process with $Z \to q\overline{q}/\nu\overline{\nu}/\ell^+\ell^-$ and $hh \to b\overline{b}b\overline{b}/b\overline{b}WW^*$ channels at $\sqrt{s}$ = 500 GeV. With 4 ab^{-1} statistics, a precision of 16.8% can be achieved on the cross-section measurement of $e^+e^- \to Zhh$ [9–11]. Assuming the SM with one free parameter of the trilinear self-coupling, this corresponds to an uncertainty of 27% on that coupling. At $\sqrt{s}$ = 1 TeV, the $e^+e^- \to \nu\overline{\nu}hh$ process becomes dominant channel. With 8 ab^{-1} data, the studies [10–12] show that, in the same context of varying the trilinear Higgs coupling only, this coupling can be determined to 10% in relative statistical uncertainty. However, these estimates are conservative since the improvements are expected because we have better tools and techniques of flavor tagging, jet reconstruction, and kinematic fitting to reconstruct the Higgs self-coupling.

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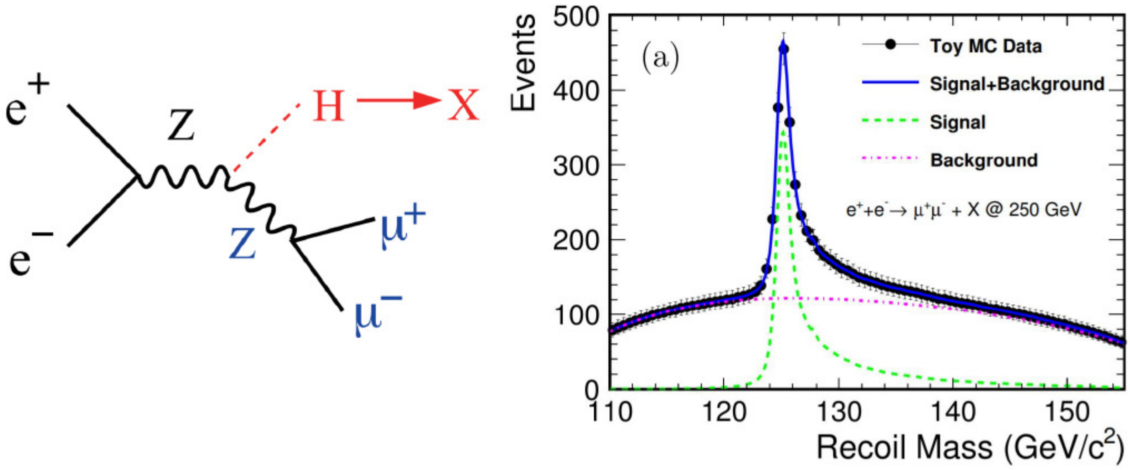

Figure 1: Left: Feynman diagram of $e^+e^- \to Zh$ with $Z \to \mu^+\mu^-$. Right: Recoil mass spectrum of events in the signal region 110-155 GeV at $\sqrt{s} = 250$ GeV. Taken from Ref. [4].

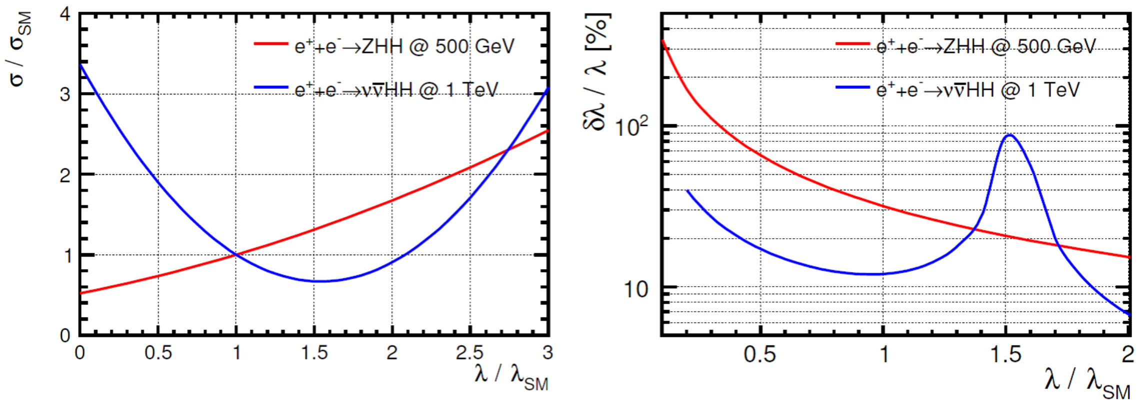

Figure 2: Left: the cross section as a function of λ for $e^+e^- \to Zhh$ and for $e^+e^- \to \nu\bar{\nu}hh$, where values of both λ and σ are scaled to their SM values. Right: expected precisions of λ when λ deviates from its SM value. Taken from Ref. [1].

Since some new physics models, in particular, electroweak baryogenesis models, predict large deviations of the trilinear Higgs coupling from the SM, it is important to see how the expected precisions would change in such cases. Figure 2 left shows the cross-sections of the two double-Higgs production channels as a function of the triple Higgs coupling λ, and Figure 2 right shows the expected precisions of λ at the ILC. Since the interference is different for the two reactions, constructive for $e^+e^- \to Zhh$ but destructive for $e^+e^- \to \nu\bar{\nu}hh$, these two reactions are complementary in determining λ. If λ is a factor of 2 larger than SM value, the $e^+e^- \to Zhh$ process gets very useful and provide $\sim 15\%$ precision for λ.

3. Higgs Couplings — Observables to Couplings

To extract Higgs boson couplings, we use dimension-6 SM Effective Field Theory (EFT) formalism. We use Higgs observables, triple gauge coupling observables, and electroweak precision

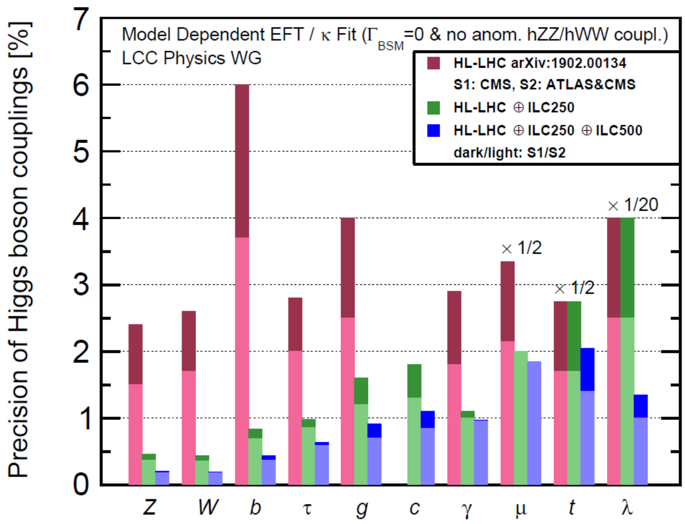

Figure 3: Projected Higgs boson coupling uncertainties for the LHC and ILC using the model-dependent assumptions appropriate to the LHC Higgs coupling fit. HL-LHC S1 is the prospects by CMS, and S2 is ATLAS and CMS. HL-LHC plus ILC S1 is the result based on current full simulation, and S2 is the expected results assuming improvements in analysis techniques and tools. Taken from Ref. [1].

observables as the inputs to the global fit under the EFT framework. We additionally use the ratio of branching ratio from the HL-LHC prospects as the inputs. Details of the precisions of observables and EFT framework can be found in Refs. [1, 13, 14]. Here, we only present the important remarks and results. The Lagrangian used in this EFT framework is Lorentz invariant, gauge invariant, and CP conserving. Though this Lagrangian has 23 free parameters, it is possible to determine all these parameters simultaneously. The Higgs couplings can be extracted in a highly model-independent way in the sense that all models of new physics describable either by the addition of local operators to the SMEFT or by the addition of invisible and exotic Higgs decays. We compare the capabilities of the ILC for precision Higgs measurements to those of the HL-LHC, and it is shown in Figure 3. Since the assumptions for extracting Higgs couplings are different at the LHC and the ILC, it is not easy to compare each other. We have included two additional assumptions in our EFT framework: assume no Beyond-Standard-Model decay of Higgs boson, and no anomalous couplings in hWW and hZZ. Even with the scenario S1, HL-LHC CMS plus ILC250, most of the couplings are reached $\sim 1\%$ precision, and we can robustly claim discovery of deviations from the SM of the size generally expected in new physics models.

In Figure 4, a comparison has been made between polarized and unpolarized beams. When we compare the results of “2 ab^{-1} 250 GeV polarized” and of “5 ab^{-1} 250 GeV unpolarized”, there are no drastic differences. In general, higher statistics always help to improve precision. However, beam polarization allows us to have more independent measurements and have better control of systematics. These facts give us more constraints in the global fitting, which is another factor of the improvement. The beam polarization is a very powerful tool, essentially compensates for a factor of 2.5 luminosity.

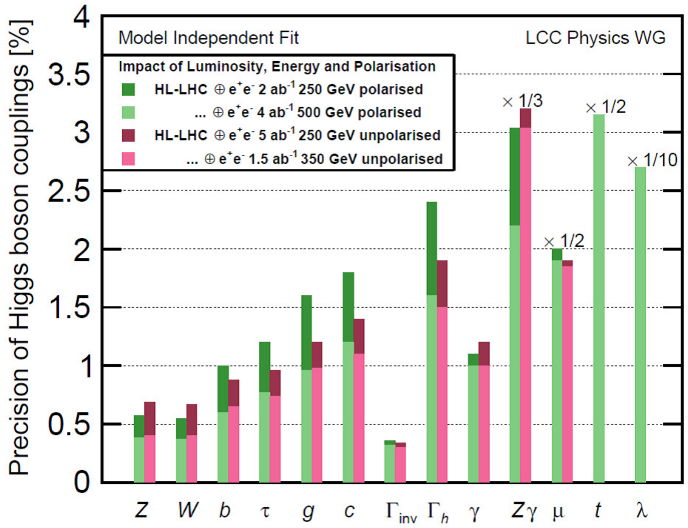

Figure 4: Projected Higgs boson coupling uncertainties with polarized and unpolarized beam under the SMEFT framework. Taken from Ref. [1].

4. Summary

In this contribution, we have discussed the Higgs physics potential at the ILC. The key measurement of Higgs boson at lepton colliders is the measurement of σ_{Zh} using the recoil technique. At the ILC, the mass of Higgs boson can be measured with the precision of 14 MeV, and the σ_{Zh} can be determined with 0.7% precision. The measurement of trilinear Higgs self-coupling is also discussed with conservatively estimated 10% precision with 1 TeV ILC data included. It is possible to determine the Higgs couplings in a highly model-independent way under the EFT framework at the ILC, and most of the couplings are reached $\sim$ 1% precision even at $\sqrt{s}$ = 250 GeV stage. The beam polarization is a very powerful tool, essentially compensates a factor of $\sim$ 2.5 luminosity. A comparison has been made for the prospects of combination with HL-LHC, illustrating the synergy between projects.

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