

## Precision Higgs Measurements at the 250 GeV ILC

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The plan for the International Linear Collider (ILC) is now being prepared as a staged design, with the first stage of  $2 \text{ ab}^{-1}$  at 250 GeV and later stages achieving the full project specifications with  $4 \text{ ab}^{-1}$  at 500 GeV. The proceedings will present the capabilities for precision Higgs boson measurements at 250 GeV. It will show that the 250 GeV stage of the ILC will already provide many compelling results in Higgs physics, with new measurements unavailable at the Large Hadron Collider, model-independent determinations of key parameters, and tests for and possible discrimination of a variety of scenarios for new physics.

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## 1. Introduction

The 125 GeV Higgs boson was discovered at the Large Hadron Collider (LHC) in 2012 [1–3]. Concluding from measurements on couplings and properties based on current accumulated data of approximately  $100 \text{ fb}^{-1}$  by the LHC, which corresponds to precisions of 10%–20% [4], it still remains the Higgs boson in the Standard Model (SM). Meanwhile, the 13–14 TeV LHC run has not observed any new indications of a new particle. This indicates additional Higgs bosons or supersymmetric particles, which appear in theories beyond the SM (BSM) such as minimal supersymmetric SM (MSSM) where the Higgs sector is extended as various two Higgs doublet models (2HDMs), will be considerably heavy if any.

In such a case, the theories such as the 2HDMs phenomenologically indicate implications that coupling strengths of the lightest BSM Higgs boson to the SM particles will be identical to those of the SM Higgs boson due to suppression depending on the scale of the heavier Higgs boson, which is known as the decoupling limit of the Higgs models [5]. When generally adapting the decoupling limit for the BSM models in the same manner, typical deviations of the Higgs couplings from the SM expectations due to corrections by the theoretical parameters are predicted to be 10% level or rather small [6]. Therefore, to detect indications of the deviations and its pattern, reaching precision of 1% level is required, and the International Linear Collider (ILC) with the 250 GeV operation is expected to be capable of measuring the Higgs couplings with the 1% precision.

## 2. A framework based on effective field theory

Traditionally the  $\kappa$ -framework has been often employed to evaluate the Higgs couplings [7]. An application of the  $\kappa$ -framework, however, is limited only for the leading order consideration because of problems on internal consistency and model-independence confronting the evaluation:

- There is no relation between the scaling parameters of  $\kappa_V$  although the symmetry breaking is imposed with the assumption of  $SU(2) \times U(1)$  gauge symmetry.
- All contributions due to higher order radiative corrections by the SM particles are regarded as one single  $\kappa$  factor although it is composed of several of the other  $\kappa$  factors.
- Assuming new (next leading order) tensor structures composed of field strength tensors which have momentum dependence, certain production process and a corresponding decay process do not match each other in terms of the scaling.

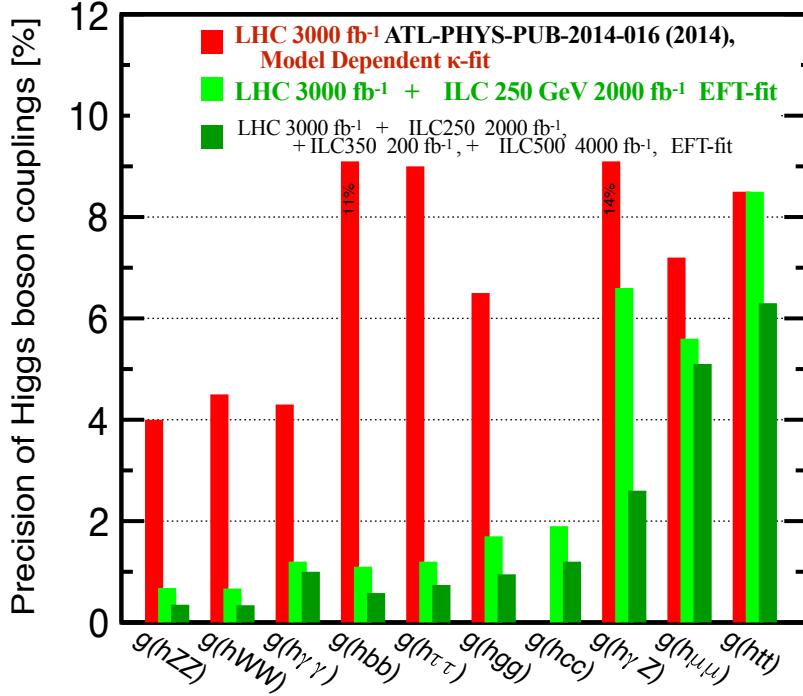
In contrast, a framework of the Effective Field Theory (EFT) can deal with those problems naturally by putting proper physics-driven higher order field operators. The effective Lagrangian under the ILC-EFT framework has been established based on dimension-6 field operators, where the number of parameters which must be simultaneously decided is 23 including the EFT coefficients, renormalizing SM parameters, and Higgs decays unpredicted with the SM [8].

In fact, advantages from the EFT are not only to deal with the problems but also be possible to increase observables since the EFT makes the parameters relate. Because of this reason, even observables which are not directly related to the Higgs boson come to get useful to determine the Higgs couplings. Furthermore, by exploiting beam polarization of the ILC, which is one of the strong functions, the observable is doubled. Therefore, all the potential of the ILC is possible to be extracted under the EFT framework, and the ILC will reach the 1% precisions for the Higgs couplings.

### 3. Higgs couplings measurements at 250 GeV

The following observables and information are available to determine the Higgs couplings:

- Direct observations of the Higgs related observables such as inclusive measurement of the  $ZZH$  coupling based on the recoil mass technique, various cross-section $\times$ branching fraction measurements [6], and also differential cross-section measurements of the Higgs related processes, which are sensitive to new Lorentz structures [9].
- Observations on the triple gauge couplings through the  $e^+e^- \rightarrow W^+W^-$  process [10, 11].
- Electroweak precision observables for constraining the renormalized SM parameters [10].
- Combinations of the beam polarizations can double above observables.
- Higgs observables on  $\gamma\gamma$  and  $\gamma Z$  provided by the High Luminosity LHC (HL-LHC) operation, which are input as the ratio to remove systematics of the measurements [12].



**Figure 1:** The plot is referred from the reference [13], which illustrates the precisions of the Higgs couplings evaluated with the global fitting under the ILC-EFT framework (light green). The precisions achievable with ATLAS under the  $\kappa$ -framework [12] is also shown as the comparison (red).

Using these observables mentioned in the above, global fitting was performed to evaluate the reachable precisions of the Higgs couplings to the SM particles at the 250 GeV ILC, whose analysis is described in detail in two papers [13, 14]. Fig. 1 is illustrating the precisions of the Higgs couplings given by ATLAS only under the  $\kappa$ -framework after the HL-LHC operation and ones after combining with the 250 GeV ILC under the EFT-framework. The plot illustrating with the 250 GeV ILC indicates that the precisions of the couplings for  $ZZ$  and  $WW$  reach 1% below and ones for  $bb$ ,  $\tau\tau$ , and  $gg$ , which are restricted due to systematics in the LHC, are significantly improved. It's also shown that ones for  $\gamma\gamma$  and  $\gamma Z$  are improved, which is owing to synergy with the

HL-LHC results. The precision for  $cc$  can be acquired with the 250 GeV ILC because of huge QCD backgrounds in the LHC although one for  $tt$  is not improved due to the given energy. The precisions of the couplings for the vector bosons, up-type and down-type quarks, and third-generation lepton will reach the 1% level.

#### 4. A conclusion

It is concluded that the precisions for the Higgs couplings to the SM particles achievable with the 250 GeV ILC is the 1% level or below which is the required precisions for discriminating the various BSM models which can not be covered by the HL-LHC. The capability of judging the BSM models are discussed in the reference [14] by exemplifying the representative BSM models. The ILC incontestably has the capability to decide a direction of the new physics and its scale.

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