Measurement of Higgs Anomalous Coupling with H → WW* at International Linear Collider

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The measurement of the Higgs coupling to W bosons is an important program at the international linear collider (ILC) to search for the anomaly in the coupling to the gauge bosons. We study the sensitivity of ILC to the Higgs anomalous coupling to W bosons by using ZH → ννWW* events. In this article, we report the status of the study.

1 Introduction

The precise measurements of the Higgs boson properties are crucial to establish the theory of the electroweak symmetry breaking. Especially, the measurement of the Higgs coupling to gauge bosons is important to search for the effect of new physics. We consider the Higgs anomalous coupling to V bosons in this report. The general coupling of the Higgs boson to two V bosons which is consistent with both Lorentz and gauge symmetries can be parametrised as,

\[ L_{HVV} = \frac{2}{\lambda} M_W^2 \left( \frac{1}{v^2} + \frac{a}{\lambda} \right) H W^\pm W^{-\mu} + \frac{b}{\lambda} H W^\pm W^{-\mu} + \frac{\tilde{b}}{\lambda} H \epsilon^{\mu\nu\sigma\tau} W^\nu W^\sigma, \]

where \( M_W \) is the mass of the W boson, \( W^\pm_{\mu\nu} \) is the usual gauge field strength tensor, \( \epsilon^{\mu\nu\sigma\tau} \) is the Levi-Civita tensor, \( v \) is the vacuum expectation value of the Higgs field, \( a, b, \) and \( \tilde{b} \) are real dimensionless coefficients and \( \lambda \) is a cutoff scale. None-zero values of \( a, b, \) and \( \tilde{b} \) imply the existence of anomaly; \( a \) is a scale factor to the standard model Higgs coupling, \( b \) is the coefficient of a CP-even term, and \( \tilde{b} \) is that of a CP-odd term.

Figure 1 shows the theoretical calculation of the angle between two up-type quarks (u or c quark) coming from hadronic decays of W bosons. If we have a finite \( b \) or \( \tilde{b} \)-term, the cross-section and distribution shape change, whereas only the cross-section varies with the \( a \)-term. In this study, we focus on studying the sensitivity of ILC to the \( a \) and \( \tilde{b} \) by using the angular distribution of two up-type quarks.

2 Simulation setup

We study the sensitivity to Higgs anomalous coupling by using ZH → ννWW*, where the Higgs mass is assumed to be 120 GeV. At this Higgs mass, the branching ratio of H → WW* is 15.0%. The center of mass energy is set to be 250 GeV with an integrated luminosity of 250 fb⁻¹. 4-fermion final states (ννqq, qqνν, ℓℓℓℓ, qqℓℓ, qqqq) major part of which is coming from WW and ZZ productions, are considered as the SM background. In order to
suppress the WW background, which would otherwise dominate in this study, we use 80% right-handed polarization for the electron beam and 30% left-handed polarization for the positron beam.

The signal and background events were generated by WHIZARD. We used Mokka [1] for the full simulation of the detector, in which ILD_00 is implemented as the detector model [2]. Pythia6.409 was used for hadronization. The event reconstruction was done by Marlin [3], where LCFIVertex package [4] is used for the flavor tagging of the jets.

3 Analysis

We selected the hadronic decay modes of W bosons from Higgs decay as the signal events to fully reconstruct the Higgs mass. All the events are, therefore, reconstructed as 4-jet events. Then, the Higgs and on-shell W masses are reconstructed by minimizing the $\chi^2$ function defined as,

$$\chi^2 = \frac{(\text{rec}M_H - M_H)^2}{\sigma_H^2} + \frac{(\text{rec}M_W - M_W)^2}{\sigma_W^2},$$

where $\text{rec}M_H$ is a reconstructed Higgs mass, $M_H$ is a Higgs mass (120 GeV), $\text{rec}M_W$ is a reconstructed on-shell W mass, $M_W$ is a W mass (80.4 GeV), and $\sigma_{H(W)}$ is the mass resolution for Higgs(W).

After the mass reconstruction, event selection is applied to suppress background events dominating the signal events. At first, the reconstructed Higgs mass ($\text{rec}M_H$) is required to be $110 \text{ GeV} < \text{rec}M_H < 130 \text{ GeV}$. Since a $Z$ boson decays into a neutrino pair in the signal mode, the missing mass should have a peak at the $Z$ mass. We, therefore, select events with $70 \text{ GeV} < m_{\text{miss}} < 140 \text{ GeV}$.

The main background in this analysis is the final states from $WW$ and $ZZ$. The angular distributions of these processes have a peak at the forward and backward region. For that reason, we require the angle of the reconstructed Higgs with respect to the beam axis ($\cos\theta_H$) to be $|\cos\theta_H| < 0.95$. Then, we investigate the distribution of $Y$-value, which is expected to be small to reconstruct $\nu\nu qq$ and $\nu\ell$ events as 4-jet events. We, therefore, select the events with $Y_- > 0.0005$, where $Y_-$ is the threshold $Y$-value to reconstruct the events as 4 jets from 3 jets.
After the selection cuts so far, the dominant background becomes $\ell q q$. The lepton in the $\ell q q$ comes from the leptonic decay of $W$ and it has larger energy than leptons from jets. We require the maximum track energy ($E_{\text{trk}}$) to be below 30 GeV.

Since we consider $ZH \rightarrow \nu \nu WW^*$ as the signal mode, $ZH \rightarrow \nu \nu bb$ is a background in this analysis. For that reason, $ZH \rightarrow \nu \nu bb$ events are rejected by using $b$-tagging. We require the number of $b$-tagged jets ($4-jet N_b$) to be $4-jet N_b \leq 1$. Since $ZH \rightarrow \nu \nu b$ has 2 jets in the final state, the events are reconstructed as 2-jet events for more effective $b$-tagging. Then, we select events with the number of $b$-tagged jets ($2-jet N_b$) of 0.

After all the selection cuts, we do a likelihood analysis as follows. We use $M_{\text{miss}}$, $\cos \theta_H$, $Y_\gamma$, $4-jet N_b$, and the number of the charged tracks as the input variables of the likelihood function. Then, we set the likelihood cut position to maximize the signal significance. We obtain the signal significance of 7.6 with likelihood cut position of 0.79. Figure 2 shows the distribution of the reconstructed Higgs mass after all the cuts. Fitting Fig. 2 with a double Gaussian and a second order polynomial, we obtain the accuracy of $\text{BR}(H \rightarrow WW^*)$ of 15.7%, assuming that the measurement accuracy of the $ZH$ cross-section is 2.5%.

We study to reconstruct the angular distribution of two up-type quarks from the decays of $W$ bosons. We apply double $c$-tagging to select the two up-type quarks ($c$ quark) in $ZH \rightarrow \nu \nu WW^* \rightarrow \nu \nu cscs$. The selection efficiency is 88%. Figure 4 shows the angular distributions of two $c$-tagged jets. Since the distribution has a peak near $\phi = 0$ rad., the distribution seems to have the angular information of two up-type quarks. The jet reconstruction, however, becomes less efficient at $\phi = 0$ and $\pi$ rad., because the separation of the jet clusters is difficult there. For that reason, the number of events at $\phi = 0$ decreases in Fig. 4.

To obtain the distribution for $ZH$ events, we evaluate the background contamination by fitting the Higgs mass distributions for each bin of the angular distribution. After subtracting the estimated background events from Fig. 3(b), we obtain $\chi^2/\text{ndf}$ of 0.9. We can, therefore, evaluate the background contamination within the statistical error. Subtracting the estimated background, we obtained the angular distribu-
Table 1: Cut summary.

tion of $ZH$ events as shown in Fig. 4. For the next step, we will evaluate the sensitivity to the anomalous coupling.

4 Summary

We have studied the sensitivity to the Higgs anomalous coupling to $W$ bosons at ILC by using $ZH \rightarrow \nu\nu W W^*$. The angular distribution of two up-type quarks from the decays of two $W$ bosons has information of the Higgs anomalous coupling of the CP-odd term. After the selection cuts and likelihood analysis, the angular distribution can be reconstructed for $ZH$ events. For the next step, we will evaluate the sensitivity to the Higgs anomalous coupling.

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