Study of the Higgs Boson Property in $ZH \to q\bar{q}H$

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Abstract

Higgs boson is the Standard Model (SM) particle predicted as the origin of the mass. Precise measurement of the Higgs boson properties is an important issue of the International Linear Collider (ILC) experiment. We studied the measurement accuracy of the Higgs boson property in the $ZH \to q\bar{q}H$ multi-jet process with the cut-based analysis assuming the 120 GeV Higgs mass at $\sqrt{s}=250$ GeV with the ILD detector model.

Key words : Liner collider, Higgs boson

1 Introduction

International Linear Collider (ILC)[1] is a future e^+e^- collider experiment for the precise measurement and the validation of the Standard Model (SM) physics, especially for the measurement of the Higgs boson property, even the discovery of the Higgs boson will be realized in Large Hadron Collider (LHC) experiment. In the SM, light Higgs boson mass (M_H) is predicted around the 114.4 GeV $\leq M_H \leq$ 160 GeV from the study in Large Electron Positoron Collider (LEP)[2] and Tevatron [3] experiment. SM Higgs boson is mainly produced through the Higgs-strahlung (ZH) process, which associated with the Z boson as shown in Fig. 1. The largest production cross-section via ZH mode is obtained around the center-of-mass energy ($\sqrt{s}$) at the ZH production threshold region as shown in Fig. 2 (a). Since the Z boson mainly decays to $q\bar{q}$ pair, the largest Higgs boson production cross-section via ZH process is obtained through the $ZH \to q\bar{q}H$ process. Therefore, we study the Higgs boson property with the largest production cross-section process of $ZH \to q\bar{q}H$.

Since Higgs boson mainly decays to $b\bar{b}$ pair at the Higgs mass below 140 GeV region as shown in Fig. 2 (b), the final state of the $ZH \to q\bar{q}H$ process forms the four-jet.

In ILC experiment, there are three detector concepts, SiD, ILD and 4^{th} for the ILC detector, and each concept submit their own Letter of Intent (LOI) and validated by ILC Detector Advisory Group (IDAG). In order to achieve the best jet energy resolution in multi-jet environment, ILD adopt the Particle Flow Algorithm (PFA) suited detector design. In this analysis, we study the measurement accuracy of the Higgs boson property with the direct reconstruction of the Higgs boson with the full detector simulation for $ZH \to q\bar{q}H$ jet mode with the ILD detector model.

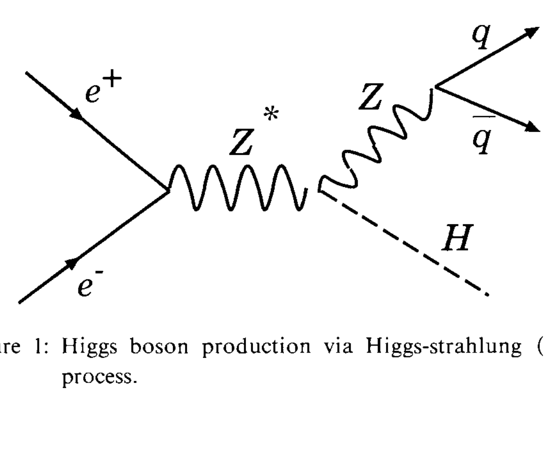

Figure 1: Higgs boson production via Higgs-strahlung (ZH) process.

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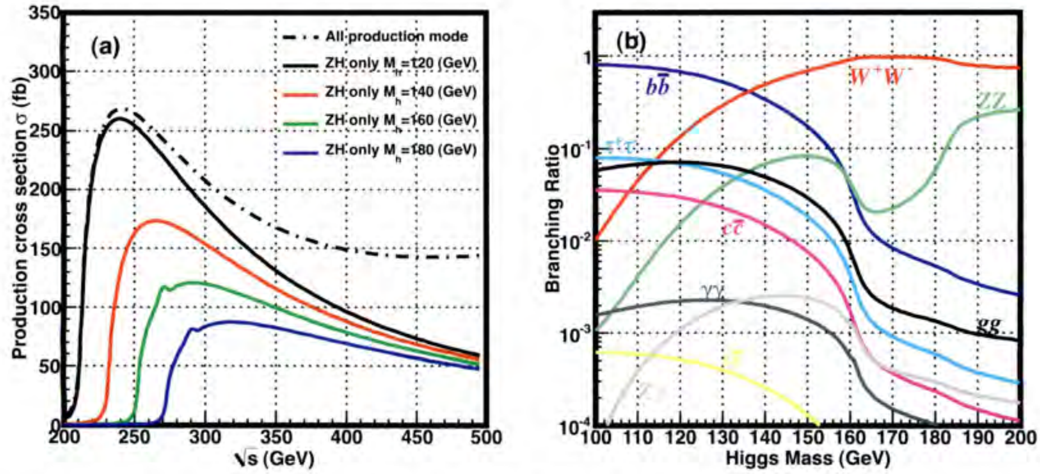

Figure 2: (a). Production cross-section of the Higgs boson and (b). branching ratio of the Higgs decay, as a function of the Higgs mass.

2 Analysis tools and MC samples

For full detector simulation study, we use the ILD detector model based Monte Carlo (MC) full simulation package called Mokka. which is based on the MC simulation package Geant4 [4]. Generated MC hits are reconstructed and smeared in the reconstruction package called MarineReco which includes the PFA package called PandoraPFA [5]. Generated samples are saved in the ILC common data format called LCIO [6]. For the event reconstruction, we use the useful analysis package library called Anlib and each analysis procedure is handled through JSF [8] based on Root [7]. In this analysis, we assume the center-of-mass energy around the ZH production threshold of $\sqrt{s}=250$ GeV and the light Higgs mass of $M_H=120$ GeV. Each data sample is scaled to the integrated luminosity of $\mathcal{L}=250\text{fb}^{-1}$ and the beam polarization to $P(e^+,e^-)=(+30\%,-80\%)$. The main backgrounds for $ZH\rightarrow q\bar{q}b\bar{b}$ are considered as following processes: $e^+e^-\rightarrow Z^*/\gamma\rightarrow q\bar{q}$, $WW/ZZ\rightarrow qq'q''q'''$ or $q\bar{q}q\bar{q}'$, $\ell\ell q\bar{q}$, $\nu\bar{\nu}q\bar{q}$, $WW\rightarrow\ell\nu qq'$ and $ZZ\rightarrow\ell\ell\ell\ell$.

2.1 Event reconstruction

Since the final state of the $ZH\rightarrow q\bar{q}H$ mode forms four-jet, after the PandoraPFA clustering, forced four-jet clustering based on Durham jet-clustering algorithm has applied. In order to select the best jet pair combination from the four-jet, following χ^2 value is evaluated,

$$\chi^2=\left(\frac{M_{12}-M_Z}{\sigma_{M_Z}}\right)^2+\left(\frac{M_{34}-M_H}{\sigma_{M_H}}\right)^2 \qquad (1)$$

where M_{12} is Z candidate di-jet mass, M_{34} is a Higgs candidate di-jet, $M_{Z/H}$ are the Z, H boson masses, and $\sigma_{M_{Z/H}}$ are a sigma of the distribution of the reconstructed Z/H boson mass, respectively. In order to select the best jets pair combination, $\chi^2<10$ is required for the reconstructed jets pair. In order to correct the escape energy from the heavy quark decay including neutrinos, kinematic five constraints (5C) fit is applied with following constraints,

$\sum_i P_i=0$, $\sum_i E_i=\sqrt{s}=250$ GeV, $M_{12}=M_Z=91.2$ GeV.

After the χ^2 cut to select the best jet pair combination, background reduction cuts are applied. We require the following selection criteria,

1. Visible energy : $200\leq E_{vis}\leq 270$ GeV;
2. Longitudinal momentum of the Z : $|P_{tZ}|<70$ GeV;
3. Higgs production angle : $|\cos\theta_H|<0.85$ to reduce the ZZ background;
4. Thrust : $thrust<0.9$;
5. Number of particles in each jet : $N_{PFO}>10$;
6. Maximum and minimum jet energy fraction : $E_{min}/E_{max}>0.25$;
7. Maximum momentum of jet : $50<P_{jmax}<100$ GeV;
8. Y Plus : $YPlus>2.0\times10^{-4}$;
9. Y Minus : $Yminus>1.0\times10^{-3}$;
10. Minimum angle of Z-H jets : $20<\theta_{ZHjmin}<135$;

11. Maximum angle of Z-H jets : $110 < \theta_{ZHjmax}$;
12. b-tagging : $P_{btag} > 0.5$ from LCFIVTX package.

where *thrust* is defined as

$$T = Max \frac{\sum_i |\vec{p}_i \cdot \vec{n}|}{|\vec{p}_i|} \tag{2}$$

YPlus and *YMinus* values are the threshold of Y-values used in the jet clustering topology which reconstructed from four-jet to five-jet or three-jet, respectively. Since the main backgrounds in four-jet mode is ZZ/WW, thrust and Higgs production angle cuts are effectively separate the signal and ZZ background from the difference of event shape. None jet-like background events are reduced by the number of particles (N_{PFO}) cut. Minimum and maximum angles between Z and H candidate jets are also used for the separation by the event shape difference between ZH event and the backgrounds. Table. 1 shows the background reduction summary after the selections.

Finally, we apply the vertex tagging selection for the neural net output of the b-likeness analyzed in the vertexing package called LCFIVTX in ilcsoft. In event reduction, $\ell\ell\ell\ell$ four-leptonic background can be suppressed completely and the remaining backgrounds are $qqqq$ and qq.

3 Results

Reconstructed Higgs mass distribution after the selection of $ZH\to q\bar{q}b\bar{b}$ is fitted with the function of

Table 1: Background reduction summary table before the flavour tagging.

Events	Generated	All cut	Eff.
Signal			
$ZH\to q\bar{q}H$	52507	24043	45.79%
$ZH\to q\bar{q}b\bar{b}$	34963	18625	53.27%
$ZH\to q\bar{q}c\bar{c}$	1915	1017	53.12%
Background			
$qqqq$	4.05×10^6	804065	19.86%
qq	3.54×10^7	109094	0.31%
$\nu\ell qq$	4.11×10^6	85	0.00%
$\ell\ell qq$	398324	145	0.04%
$\nu\nu qq$	149979	0	0.00%
$\ell\ell\ell\ell$	762975	0	0.00%

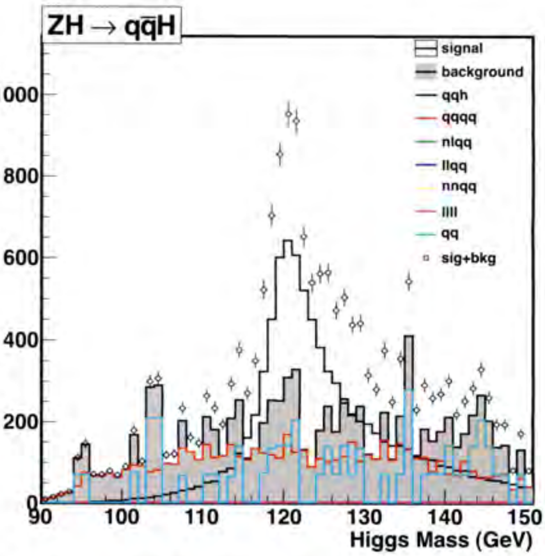

Figure 3: Reconstructed Higgs mass distribution in $ZH\to q\bar{q}b\bar{b}$ process.

Gaussian convoluted Gaussian with the exponential function assuming the background, as shown in Fig. 3. From the reconstructed distribution, Higgs mass ($M_H = 120$GeV at MC) is reconstructed with the measurement accuracy of cross-section to $ZH\to q\bar{q}b\bar{b}$ as $\delta\sigma/\sigma\sim5\%$.

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