Physics potential for the measurement of $\sigma(HZ) \times BR(H \to WW^*)$ at the 250 GeV ILC

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Abstract

The potential of measurement of the relative statistical uncertainty of the $(HZ) \times BR(H \to WW^*)$ decay, at the International Linear Collider (ILC) has been presented. The study is performed at the lowest energy stage of the proposed staged ILC, the 250 GeV. The full simulation Monte Carlo samples are used with the International Large Detector (ILD) model. Fully hadronic final state has been analyzed using an integrated luminosity of 500 fb^{-1}. The multivariate analysis technique is used for the estimation of relative statistical uncertainty, $\Delta(\sigma \cdot BR)/(\sigma \cdot BR)$.

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1 Introduction

After the discovery of the Higgs boson, the measurements obtained at the LHC, in every respect, are confirmed to be in the agreement with the Standard model predictions. However, both the experimental and theoretical uncertainties leave room for the presence of new physics [1], since the foreseen differences between the measured values to those of the Standard

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model are, in many cases, bellow current precision. Therefore, the possible path for the search of the new physics is to reveal the deviations in the measurement of the observables that are sensitive to the presence of these phenomena. One of the proposed high precision machines is the electron-positron collider ILC (International Linear Collider). The important part of the physics program at ILC are the precise measurements of the Higgs boson properties, at the first place the measurements of its couplings. The Standard model predicts strict linear dependence as the function of masses of corresponding particles. The shape and the nature of the eventual deviations of the couplings can signify the proposed model of the new physics. The precision of the coupling measurements of an order of few percents is needed to be sensitive to these deviations [1].

The ILC physics case of 250 GeV has been elaborated in detail [2] and the comprehensive set of studies of the foreseen physics program have been performed in full simulation [3]. It was shown that the necessary sensitivity can be successfully achieved at ILC collider.

The talk presents the results of the measurement of the Higgs decay into a pair of W bosons, at the nominal center-of-mass energy, 250 GeV of ILC, using Higgstrahlung as Higgs production process. The relative statistical accuracy of the measurement of the $\sigma(HZ) \times BR(H \to WW^*)$, allowing the extraction of the precision of $\frac{g^2_{HZZ} {g_{HWW}}^2}{\Gamma}$.

2 Simulation and analysis tools

A common linear collider software package, ILCSoft, is used. Signal and background samples are simulated using the Whizard 1.95 [4] event generator, including initial state radiation and a realistic luminosity spectrum. The hadronisation and fragmentation of the Higgs and vector bosons were simulated using Pythia 6.4 [5]. For the completeness, $\gamma\gamma$ to hadrons background, although negligible at this energy stage, is overlaid over each generated event sample before reconstruction. Particle reconstruction and identification was done using the particle flow technique, implemented in the Pandora particle-flow algorithm (PFA) [7, 8]. The ILD_o1_v05 detector model is used.

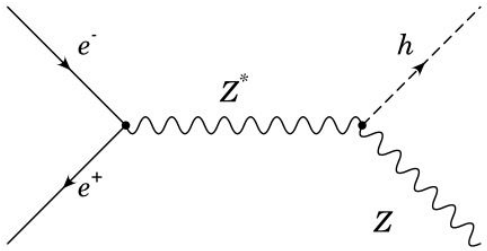

Figure 1: Left: The Feynman diagram of the dominant Higgs production processes (Higgsstrahlung).

Table 1: List of considered background processes, with the corresponding cross-sections, preselection and final selection efficiency. The last column gives the number of events in the final sample. The $\sqrt{s} = 250$ GeV with integrated luminosity of 500fb^{-1} is assumed.

Process	$\sigma[fb]$	ϵ_{pres} [%]	ϵ_{tot} [%]	evts$_{fin}$
signal	36.5	89.2	30.0	5600
other Higgs decays	309.8	54.7	4.1	6338
$e^+e^- \to$ 2f hadronic	129148.6	1.5	$< 10^{-2}$	5410
$e^+e^- \to$ 4f WW hadronic	14874.3	33.5	0.2	14961
$e^+e^- \to$ 4f WW/ZZ hadronic	12383.3	33.8	0.2	13340
$e^+e^- \to$ 4f ZZ hadronic	1402.0	42.9	1.0	7178
$e^+e^- \to$ 4f WW semileptonic	18781.0	0.5	$< 10^{-5}$	/
$e^+e^- \to$ 4f ZZ semileptonic	1422.1	$5 \cdot 10^{-4}$	$< 10^{-2}$	49

3 Event samples

The staged concept of ILC [9], foresees the first stage at $\sqrt{s} = 250$ GeV. The dominant Higgs production channel is the Higgsstrahlung, with the cross section of 346 fb, including the maximal left beam polarization of (e^-,e^+) = (-80%, +30%). The Feynman diagram of the Higgsstrahlung Higgs production channel is shown in the Figure 1.
The analyzed signal events are fully hadronic, where all the bosons in the event, the Z boson, as well as both W bosons decay hadronically. The corresponding signal cross-section is 36.5 fb. The signal and background processes that are considered are listed in the Table 1.

4 Event selection

The events are clustered into six jets the k_T clustering algorithm. The b and c-tagging probabilities, as determined by LCFIPlus package, are assigned to each jet in the event, for both, six-jet and additional two-jet hypothesis. In the next step, the signal process is reconstructed by the jet pairing to form candidates for the Z boson and one on-shell and one off-shell W boson, which are coming from Higgs decay. The combination of the pairs of jets, for which the following χ^2 has a minimum, is chosen:

$$\chi^2 = \frac{m_{ij} - m_W}{{\sigma_W}^2} + \frac{m_{kl} - m_Z}{{\sigma_Z}^2} + \frac{m_{ijmn} - m_H}{{\sigma_H}^2}$$

where m_{ij}, m_{kl} are the invariant masses of a di-jet pairs, which are assigned to the real W and the Z boson candidates, while m_{ijmn} is the invariant mass of the jets that comprize the Higgs boson candidate. m_V and σ_V, (V = W, Z, H), are the masses and the widths of the corresponding bosons.

The jet-opening of the clustered jets was optimized according to the criteria of minimal widths and the closest reconstructed mean of the reconstructed dijet mass distributions to that of the Z and the real W boson. The best results are obtained with the jet opening of R=1.5.

The cross-sections of the considered background processes are several orders of magnitude higher than for the signal events (Table 1), therefore at the next step, the background to signal ratio is minimized by the set of preselection criteria prior to the final selection. The list of the preslection variables with the corresponding cut-off values:

- the invariant mass of the Z boson candidate , $m_Z > 70$ GeV,
- the invariant mass of the Higgs boson candidate , $m_H > 100$ GeV,
- the invariant mass of the real W boson candidate, $m_W > 60$ GeV,
- number of particle flow objects, NPFO > 70,
- visible energy, E_{vis} >200 GeV,
- transverse momentum of a single jet, p_T <20 GeV,
- event thrust<0.9,
- -log(y_{45}) < 2.2, -log(y_{56}) <3.0, -log(y_{45}) < 4.4, -log(y_{56}) <4.8,

where -log(y_{ij}) is k_T value at which the jet number is making the transition from the i-th to the j-th number of jets in the event.

The efficiencies of reduction by the preselection are given in Table 1 for signal and background processes.

The final event selection is achieved using the multivariate analysis method, Boosted decision tree (BDT). The set of training background samples, as well as the set of input variables, are optimized. The final event selection is performed using purely hadronic background with the following discriminating input variables:

- the invariant masses of both W bosons, Z and Higgs boson, m_W, m_Z, m_H,
- number of particle-flow objects (NPFO) in the event,
- transverse momentum of jets that comprize the Higgs boson, p_T^{Higgs},
- the highest transverse momentum of a jet in the event, ${p_T}^{max}$,
- jets transitions -log(y_{12}), -log(y_{23}), -log(y_{34}), -log(y_{45}), -log(y_{56}), -log(y_{67}),
- event shape variables (thrust, oblatness, sphericity and aplanarity),
- and second highest flavor tagging probabilities for the two jet hypothesis (btag, ctag),
- angle that comprise the Z boson,
- angle that comprise the real W boson.

The classifier cut value of the final selection, is chosen to minimize the statistical uncertainty of the cross-section $\sigma(HZ) \times BR(H \to WW^*)$, that is to minimize the ratio

$$\frac{\Delta\sigma}{\sigma} = \frac{N_S}{\sqrt{(N_S + N_B)}}, \tag{1}$$

where N_S, N_B are the number of signal and background events after the final selection, respectively. The relative statistical uncertainty of the product of the Higgsstrahlung cross-section and the corresponding branching ratio is calculated as:

The number of signal and background events after the final selection are given in the Table 1.

5 Conclusion

In this talk, the measurement accuracy, $\Delta(\sigma \cdot BR)/(\sigma \cdot BR)$, of the Higgs decay to a W pair is presented. Fully hadronic final states is considered. The study is performed at the first energy stage of the ILC, $\sqrt{s} = 250$ GeV, using Higgsstrahlung Higgs production channel. The assumed beam polarization is P(e^-, e^+) = (-80%, +30%), with the integrated luminosity of 500 fb^{-1} and the mass of Higgs boson of 125 GeV. The signal and background events are fully simulated, including initial state radiation and beam induced background.

The obtained result for the relative statistical uncertainty of the $\sigma(HZ) \cdot BR(H \to WW^*)$ is 4.1%. This particular measurement is important for model independent determination of Higgs total width, and therefore for global fit, and it has been shown that this result improves the total Higgs decay width by of approximately 10%.

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