Study of Higgs Boson Production through WW-Fusion at a Linear Collider

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Abstract. We study the feasibility of measuring the cross section of Higgs boson production in the WW–fusion process, $e^+e^- \to \nu_e\bar{\nu}_e H^0$, at a future linear collider at centre–of–mass energies between 350 and 500 GeV. Realistic assumptions for detector resolution effects, b-quark tagging efficiency and background processes are made. Using the decay mode $H^0 \to b\bar{b}$ the cross section can be measured to an accuracy of 3% for a Higgs boson mass of 120 GeV, assuming $500 fb^{-1}$ of data. This measurement can be used to extract the coupling g_{HWW} between Higgs and W bosons and indirectly determine the total decay width of the Higgs boson.

I ANALYSIS

The two dominant production processes at e^+e^- colliders for neutral CP-even Higgs bosons as predicted by the Standard Model (SM) and many extensions such as the Minimal Supersymmetric Standard Model (MSSM) are Higgs–strahlung ($e^+e^- \to H^0Z^0$) and WW–fusion ($e^+e^- \to \nu_e\bar{\nu}_e H^0$). The latter process is dominant at large centre–of–mass energies $\sqrt{s}$ compared to the Higgs boson mass due to its $\log s$ behaviour. It provides access to the coupling g_{HWW} between Higgs and W bosons. This coupling is predicted to be closely linked to the g_{HZZ} coupling ($g_{HWW} = \cos^2\theta_W\, g_{HZZ}$) through $SU(2) \times U(1)$ symmetry.

We simulate events from Higgs–strahlung and WW–fusion using the `WHiZard` event generator [1], which generates the full $b\bar{b}\nu\bar{\nu}$ final state including background processes without Higgs bosons and interference terms. Backgrounds without b–quark final states were simulated with `PYTHIA6.1` [2]. The detector response was simulated using the parametric Monte Carlo `SIMDET3` [3] with the resolution parameters corresponding to the TESLA detector. Special attention has to be given to the simulation of b–tagging. We use a jet-wise topological algorithm to identify b–quarks assuming a five–layer CCD vertex detector [4]. The performance of this algorithm has been parametrised as a function of the jet energy. Requiring a b–quark efficiency of 75%, charm jets are suppressed by a factor 5 to 10, and light quark jets are suppressed by a factor 15 to 100, depending on the jet energy.

The selection requires events with large missing energy and missing transverse momentum. The hadronic system is forced into two jets, both of which are required to be b–tagged. Background is further suppressed by successive cuts on the visible energy, the total transverse momentum, the polar angle of the jets, their opening angle, acoplanarity and the jet finders transition variable from two to three jets, y_{23} and the rejection of event with isolated leptons. Finally, the visible mass is required to be consistent with the Higgs boson mass.

After this selection, an efficiency of approximately 30% for WW–fusion events is retained. Backgrounds from non–b–jets are suppressed to a negligible level while generic $b\bar{b}\nu\bar{\nu}$ background without a Higgs boson in the final state amounts to approximately 10% of the remaining signal. The dominant background to the WW–fusion process is from Higgs–Strahlung, $e^+e^- \to HZ \to b\bar{b}\nu\bar{\nu}$. The two processes can be disentangled due to their different spectrum of the invariant mass recoiling against the decay products of the Higgs boson (which is observed as missing mass in the detector). This spectrum is peaking at m_Z for Higgs–strahlung events while it is expected to be wide and peaking at high masses for the WW–fusion signal. These contributions of the two Higgs production processes and the remaining non–Higgs background are determined from a shape–fit to the missing mass distribution.

II RESULTS

The missing mass spectrum of the simulated data after cuts is shown in Fig. 1 for a Higgs boson mass of 120 GeV and an integrated luminosity of $500 fb^{-1}$ to be taken at $\sqrt{s} = 350$ GeV and 500 GeV, respectively. The contribution from Higgs–strahlung is clearly seen at $\sqrt{s} = 350$ GeV while it is suppressed at 500 GeV both due to the lower cross section and tighter kinematical cuts applied in the selection.

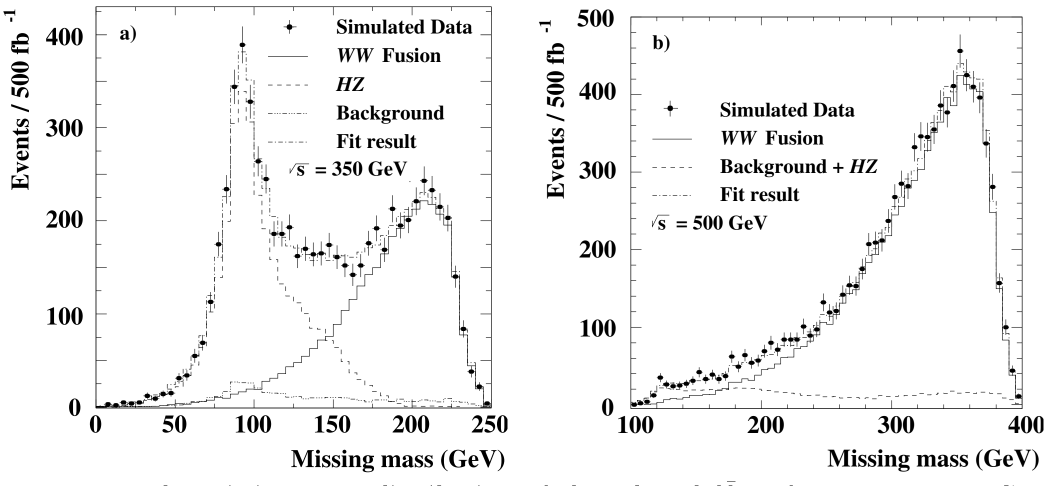

FIGURE 1. *The missing mass distribution of the selected* $b\bar{b}\nu\bar{\nu}$ *for* $m_H = 120$ *GeV at* $\sqrt{s} = 350$ *GeV (left) and* $\sqrt{s} = 500$ *GeV (right). The integrated luminosity is 500* fb^{-1}.

The extraction of the total WW–fusion cross section relies on the measurement of the $H \to b\bar{b}$ branching ratio [5]. Since this branching ratio drops rapidly as the Higgs boson mass approaches the threshold for $H \to W^+W^-$, the expected precision for the cross section measurement does as well. This could be possibly overcome by a selection of $e^+e^- \to H\nu\bar{\nu} \to W^+W^-\nu\bar{\nu}$ events which has not been carried out yet. Taking into account the uncertainties from the fit and from the branching ratio measurement, the expected statistical precision for the cross section measurement for WW–fusion varies from 2.8% to 13.0% for m_H = 120 GeV to 160 GeV for $\sqrt{s}$ = 500 GeV (see Table 1). The numbers for $\sqrt{s}$ = 350 GeV are slightly worse due to the lower production cross section and higher Higgs–strahlung background. Due to the large number of signal events, systematic uncertainties from non–Higgs backgrounds are presumably small. The uncertainty arising from the shape of the Higgs–strahlung spectrum can be determined by exploiting different beam–polarisations which have different effects on the contributions of the two processes, allowing to determine them individually.

TABLE 1. Results on the precision of the WW–fusion measurement and the extraction of the total Higgs width.

$\sqrt{s}$	m_H	$\Delta\sigma_{WW-\mathrm{Fusion}}$	$\Delta\Gamma_{tot}$
350	120	3.3%	
	140	4.7%	
	160	–	
500	120	2.8%	6.1%
	140	3.7%	4.5%
	160	13.0%	13.4%

III INTERPRETATION

The cross section for WW–fusion is at leading order and neglecting small interference terms only depending on the coupling g_{HWW} of the Higgs boson to W–bosons which can be extracted from this measurement with a precision of 1.4% to 6.5% for m_H = 120 GeV to 160 GeV. In a global fit of all Higgs couplings [6] which can be determined at the linear collider the impact is significant (see Fig. 2).

When combined with the measurement [7] of the branching ratio BR(H $\to$ W$^+$W$^-$), this measurement can be used to extract the total decay width of the Higgs boson, using the relation $\Gamma_{tot} = \Gamma_{HWW}/\mathrm{BR}(\mathrm{H} \to \mathrm{W}^+\mathrm{W}^-)$ where Γ_{HWW} can be calculated from the measured cross section for WW–fusion. This method yields and uncertainty of 4.5% to 13.4% for m_H between 120 GeV and 160 GeV. It is the most precise method to determine the total Higgs boson decay width without many model assumptions in this Higgs boson mass range.

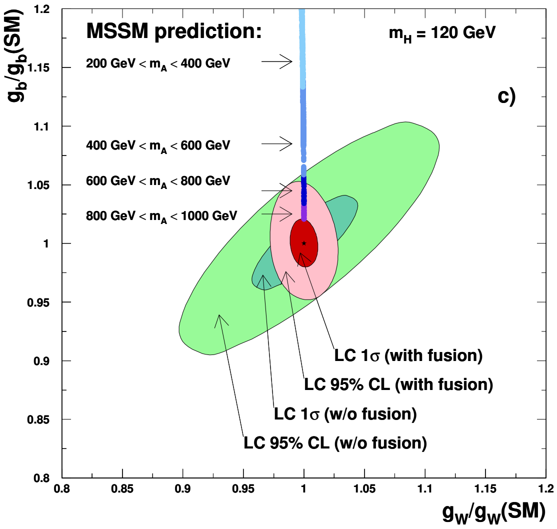

FIGURE 2. *Global fit to extract the couplings of the Higgs boson. Shown is the plane of the g_{Hbb} versus the g_{HWW} coupling. The large ellipses are the errors without the WW–fusion measurement. The vertical line gives the range of MSSM predictions for various masses of the CP–odd Higgs boson.*

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