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Measuring the Higgs mass at TESLA

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Abstract. We report on the accuracy of the measurement of the Higgs boson mass that would be achieved in a linear collider operating at a centre-of-mass energy of 350 GeV, assuming an integrated luminosity of 500 fb^{-1}. For that we have exploited the exclusive Higgs decays into b quarks and W bosons. The Higgs mass is determined with an accuracy of about 40 MeV for $m_{\mathrm{H}} = 120$ GeV and 80 MeV for $m_{\mathrm{H}} = 180$ GeV.

INTRODUCTION

The mass of the Higgs boson predicted by the Higgs mechanism [1] is a free parameter of the Standard Model [2]. If the Higgs boson is discovered, the accurate determination of its mass becomes a fundamental issue in the future experiments. The measurement of the Higgs production cross section and its decay branching ratios allows to determine the couplings of the Higgs to the gauge bosons and to the fermions and, therefore, to prove the structure of the Higgs sector.

ANALYSIS

The total cross section of the $\mathrm{e^+e^-} \to \mathrm{ZH}$ process can be determined accurately using the recoil mass method [3]. However, this method provides a rather poor measurement of the Higgs boson mass, about 110 MeV for a 120 GeV mass Higgs.

The determination of the Higgs mass is improved significantly by exploiting the kinematics of the decay products of the Higgs and the Z bosons. In particular, we have studied processes with a Higgs boson decaying either into b quarks or W bosons, both for the Z decaying either into quarks or leptons (electrons and muons).

Table 1 lists the final states investigated, indicating their topology in the detector. The numbers quoted are the cross section (in fb) times the branching ratio of each final state for Higgs boson masses of 120, 150 and 180 GeV. The process $\mathrm{ZH} \to \mathrm{q\bar{q}b\bar{b}}$ is dominant at lower Higgs masses, while both $\mathrm{ZH} \to \mathrm{q\bar{q}W^+W^-}$ and the recoil mass method have the largest statistical power at high mass.

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TABLE 1. The cross section (in fb) times the branching ratio of the signal final states for Higgs boson masses of 120, 150 and 180 GeV.

Decay mode	topology	120	150	180
recoil mass	2ℓ + X	10.5	7.6	5.6
$\mathrm{ZH} \to \ell^+\ell^-\mathrm{q\bar{q}}$	2ℓ + 2-jets	8.6	1.7	0.5
$\mathrm{ZH} \to \mathrm{q\bar{q}b\bar{b}}$	4-jets	79.6	16.8	0.4
$\mathrm{ZH} \to \ell^+\ell^-\mathrm{W^+W^-},\ \mathrm{W^\pm} \to \mathrm{q\bar{q}'}$	2ℓ + 4-jets	1.2	5.4	5.6
$\mathrm{ZH} \to \mathrm{q\bar{q}W^+W^-},\ \mathrm{W^\pm} \to \mathrm{q\bar{q}'}$	6-jets	12.9	26.5	26.6
$\mathrm{ZH} \to \mathrm{X}$		158.3	124.4	88.5

The main backgrounds are $\mathrm{e^+e^-} \to \mathrm{q\bar{q}}(\gamma)$, $\mathrm{W^+W^-}$ and ZZ. Other sources of contamination, like $\mathrm{e^+e^-} \to \mathrm{e^+e^-f\bar{f}}$ and $\mathrm{e^+e^-} \to \ell^+\ell^-(\gamma)$, have also been investigated.

This study has been performed for a linear collider operated at a centre-of-mass energy of 350 GeV, assuming an integrated luminosity of 500 fb^{-1}. The detector used in the simulation follows the proposal presented in the TESLA Conceptual Design Report [4]. The simulation of the detector is done with the parametric Monte Carlo program SIMDET [5]. Signal and background events are generated with the PYTHIA Monte Carlo program [6], which includes initial state bremsstrahlung. Beamstrahlung is taken into account using the program CIRCE [7].

The selection of events is done using cuts based on lepton identification, track multiplicity and topological variables like Y_{34}, sphericity and Fox-Wolfram moments. The selected events are forced to be of a particular topology (2ℓ + 2-jets, 2ℓ + 4-jets, 4-jets or 6-jets) using the Cambridge [8] and Durham [9] jet algorithms. Then, a kinematic fit [10] is performed imposing energy and momentum conservation, plus additional constraints depending on the final state under investigation.

The $\mathrm{ZH} \to \ell^+\ell^-\mathrm{b\bar{b}}$ and $\mathrm{q\bar{q}b\bar{b}}$ final states

These final states are characterised by two isolated leptons and two jets or four jets. Tracks and calorimetric energy deposits not classified as isolated leptons are grouped into jets. The kinematic fit performed on these events imposes the additional constraint of the invariant mass of the two leptons or two jets assigned to the Z to be equal to the Z mass.

In the 4-jet sample, the signal is enhanced by using the event b-tag [11], which quantifies the number of jets in the event that contain a b quark decay. We assume a b-tag efficiency of 80% independent of the jet energy. The effect in the $\mathrm{ZH} \to \mathrm{q\bar{q}b\bar{b}}$ sample of requiring a minimum number of b-jets in the event is displayed in Figure 1. The background is strongly reduced by requiring the events to contain at least two b-jets, whereas the signal is only slightly affected. The result of the fit for events with b-tag ≥ 2 is also shown in Figure 1. Similar distributions for other masses and channels can be found elsewhere [12].

Table 2 summarises the accuracy on the determination of m_{H} for the different final states and their combination, for Higgs masses between 120 and 180 GeV. The

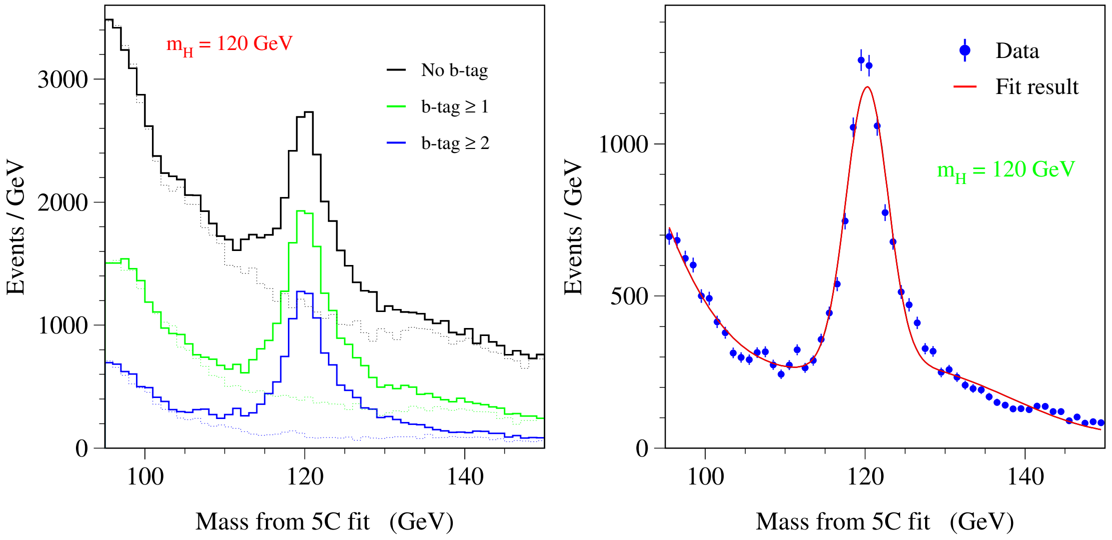

FIGURE 1. Left, the invariant mass of the two jets assigned to the Higgs (m_{H} = 120 GeV), in ZH $\to$ q$\bar{\mathrm{q}}$q$\bar{\mathrm{q}}$ events, for different requirements on the b-tag. The dashed lines indicate the background contribution. Right, the result of the fit for events with b-tag ≥ 2.

TABLE 2. Absolute accuracy on the determination of m_{H} and relative accuracy on the determination of the cross section, for m_{H} = 120, 150 and 180 GeV.

	Δm_{H} in MeV			$\Delta\sigma/\sigma$ in %		
Decay mode	120	150	180	120	150	180
recoil mass	110	90	95	2.6	3.2	3.8
ZH $\to \ell^+\ell^-\mathrm{q\bar{q}}$	70	90	–	3.0	4.7	–
ZH $\to \mathrm{q\bar{q}b\bar{b}}$	45	170	–	1.1	3.4	–
ZH $\to \ell^+\ell^-\mathrm{W^+W^-}$, $\mathrm{W^\pm \to q\bar{q}'}$	310	160	160	13.0	4.0	3.3
ZH $\to \mathrm{q\bar{q}W^+W^-}$, $\mathrm{W^\pm \to q\bar{q}'}$	250	130	150	12.0	3.4	2.9
Combined	38	63	80	1.0	1.9	2.2

relative accuracies on the cross section are also listed in Table 2.

The ZH $\to \ell^+\ell^-\mathrm{W^+W^-}$ and $\mathrm{q\bar{q}W^+W^-}$ final states

We consider W boson decays into two quarks, giving rise to topologies with either two leptons and four jets or six jets. In the case of ZH $\to \ell^+\ell^-\mathrm{W^+W^-}$ events, the invariant mass of the two leptons is required to be consistent with the Z mass. This suppresses most of the background. For ZH $\to \mathrm{q\bar{q}W^+W^-}$ events, the kinematic fit constrains one of the dijets to have the Z mass. In both final states, the remaining two jet pairs are constrained to be consistent with the W mass for m_{H} = 180 GeV, while one dijet is allowed to be off-shell for m_{H} = 120 and 150 GeV.

The mass spectra for the ZH $\to \ell^+\ell^-\mathrm{W^+W^-}$ and $\mathrm{q\bar{q}W^+W^-}$ channels, after the kinematic fit, are shown in Figure 2, together with the fit results. The results of

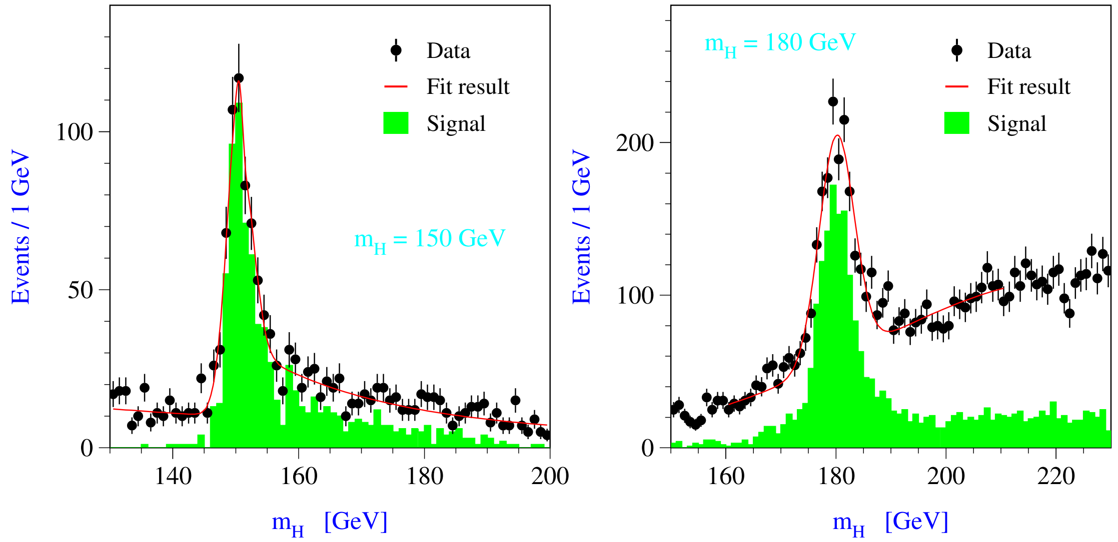

FIGURE 2. The invariant mass, after the kinematic fit, of the four jets assigned to the Higgs decay (left) in the ZH $\rightarrow \ell^+\ell^-\mathrm{W}^+\mathrm{W}^-$ final state for m_H = 150 GeV and (right) in the ZH $\rightarrow \mathrm{q\bar{q}W^+W^-}$ final state for m_H = 180 GeV.

the fits are summarised in Table 2, for Higgs masses between 120 and 180 GeV.

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