Measurement of Higgs Mass and Cross Section at a Linear Collider

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We have studied the potential accuracy with which the Higgs boson mass and production cross section can be measured in the process $e^+e^- \to Z^0H, Z^0 \to l^+l^-, H \to X$ at a Linear Collider (LC) operated at 350 GeV and 500 GeV center-of-mass energies with integrated luminosities of 500 fb^{-1}. Using a Monte Carlo interpolation fit method, we find the Higgs mass can be determined with an accuracy of about 60 MeV at $\sqrt{s}$ = 350 GeV, degrading to 120 MeV at $\sqrt{s}$ = 500 GeV for Higgs masses between 115 and 160 GeV. The relative precision of cross section is measured to be $\Delta\sigma/\sigma \sim 3\%$ at $\sqrt{s}$ = 350 GeV and $\sim 4.7\%$ at $\sqrt{s}$ = 500 GeV over the same mass range.

1. Introduction

Precise determinations of Higgs boson mass and cross section are important goals in future high energy e^+e^- linear collider experiments Abe et al. [2001], Aguilar-Saavedra et al. [2001]. Precision electroweak data in the framework of the Standard Model predict the mass of the Higgs boson, allowing a crucial cross check of electroweak symmetry breaking models if and when the Higgs boson is discovered. In addition, measuring the production cross section accurately allows determination of absolute Higgs decay branching ratios. Here we explore the accuracy with which the Higgs mass and cross section can be determined at a linear collider operated at 350 GeV and 500 GeV center-of-mass energies, considering Higgs masses between 115 and 160 GeV. For this study, we use the 2001 North American baseline detector designs (LD for "Large" and SD for "Silicon").

2. Analysis

The Higgs mass can be simply determined assuming recoil in the process $e^+e^- \to Z^0H, Z^0 \to \ell^+\ell^-, H \to X$ ($\ell = e, \mu$). The recoil mass is defined as:

$$M_H^{\text{recoil}} = \sqrt{s - 2\sqrt{s} \cdot E_{\ell^+\ell^-} + M^2_{\ell^+\ell^-}}$$

where s is the center-of-mass energy squared, $E_{\ell^+\ell^-}$ is the energy of the lepton pair from Z^0 decay, while $M_{\ell^+\ell^-}$ is the pair's invariant mass. The main backgrounds of this analysis are $e^+e^- \to Z^0Z^0$, W^+W^-, but other sources of contamination, including Bhabha events, are also investigated.

All Monte Carlo events in this analysis were generated by the Pandora-Pythia Version 2.1 package Peskin [1999], Sjostrand [1994] which includes initial state radiation, beamsstrahlung, hadron fragmentation and final state QCD/QED radiation. In addition, the electron beam is polarized to −80%. The Java Analysis Studio(JAS) Johnson [1998] package was used with fast Monte Carlo simulation to analyze the events, assuming the LD and SD baseline detectors Abe et al. [2001], Schumm [2001], Tracking-Group [2001].

These studies are performed for a Next Linear Collider operated at center-of-mass energies of 350 GeV and 500 GeV with integrated luminosities of $500 fb^{-1}$ each, assuming Higgs mass between 115 and 160 GeV. Events are selected using a cut-based approach, according to the following criteria:

(1) A candidate lepton must have an energy greater than 10 GeV.

(2) The polar angle of a lepton must satisfy $|cos\theta_e| < 0.9$.

(3) There must be at least 2 lepton candidates in the event.

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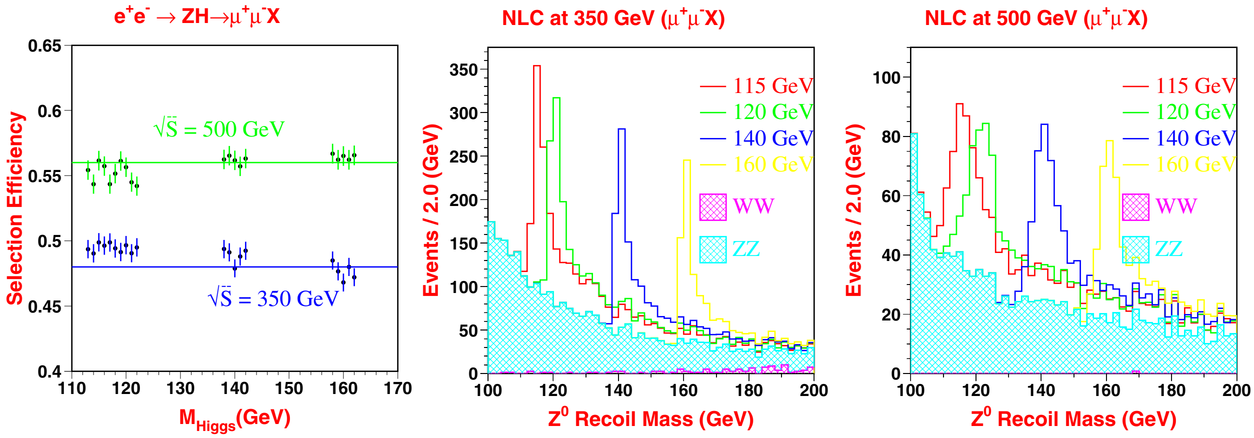

Figure 1: Left: Selection efficiency of $e^+e^- \to Z^0H \to \mu^+\mu^-X$ plotted vs Higgs mass between 113 and 162 GeV. Green points are signal efficiencies at $\sqrt{s} = 500$ GeV and blue points are for $\sqrt{s} = 350$ GeV. Center: The recoil mass distributions of $e^+e^- \to Z^0H \to \mu^+\mu^-X$ for Higgs boson masses at 115(red), 120(green), 140(blue) and 160(yellow) GeV, along with the background contributions from Z^0Z^0(cyan) and W^+W^-(magenta) at $\sqrt{s} = 350$ GeV. Right: The corresponding recoil mass distributions at $\sqrt{s} = 500$ GeV.

(4) The invariant mass of the lepton pair must lie within 5 GeV of the Z^0 mass.

(5) The polar angle of two-lepton system must lie in the barrel region, $|cos\theta_{e^+e^-}| < 0.6$.

(6) The opening angle between the two leptons should satisfy $|cos\theta_{e^+\leftrightarrow e^-}| > -0.7$.

Cut (5) is used to suppress Z^0Z^0 background, while Cut (6) reject background from W^+W^-. The selection efficiency for signal is about 48% for 350 GeV center-of-mass energy. The signal efficiency is higher, 56%, at a 500 GeV machine, mainly because the higher Lorentz boost of the leptons from Z^0 decay leads to a smaller average opening angle. The selection efficiency of the $\mu^+\mu^-X$ channel as a function of Higgs mass is shown in the left plot of Figure 1.

After selection, the recoil mass distributions of signal and the background for the channel $e^+e^- \to Z^0H \to \mu^+\mu^-X$ are shown in the center and the right plot of Figure 1.

3. Gaussian and Polynomial fit

Two mass-fit methods were explored for this study. In the first, the recoil mass spectra are fitted by the sum of analytic signal and background functions, with the signal described by a Gaussian distribution and the background by a polynomial. A binned χ^2 fit is performed with two free parameters, the mass and the width. The raw recoil mass resolution is about 1.6 GeV at $\sqrt{s} = 350$ GeV and 3.0 GeV at $\sqrt{s} = 500$ GeV for the LD detector, with narrower distributions seen for the SD detector, as shown in the left part of Figure 2. There is only modest dependence of recoil mass resolution on the Higgs mass itself.

This analytic fitting technique yields a measured mass slightly larger than the true Higgs mass used in signal generation because of initial state radiation. This bias can be evaluated and corrected by fitting both data and Monte Carlo events with the same technique. The accuracy of such a mass determination is found to be about 100 MeV at $\sqrt{s} = 350$ GeV, degrading to 300–400 MeV at $\sqrt{s} = 500$ GeV. There is a small dependence upon Higgs mass value, with higher masses yielding smaller uncertainties because of lower background contamination.

4. Monte Carlo Interpolation fit

The second fitting method used here is more accurate and is based on Monte Carlo interpolation. Several Monte Carlo samples are generated for different Higgs mass values surrounding a nominal desired central value and used to create fitting function shapes. For example, to estimate the measurement accuracy for a 140 GeV Higgs, we produced five Monte Carlo samples with $M_{\text{Higgs}} = 138 - 142$ GeV at 1 GeV spacing. Another Monte Carlo sample, generated at 140 GeV, is treated as “data” and its recoil mass distribution

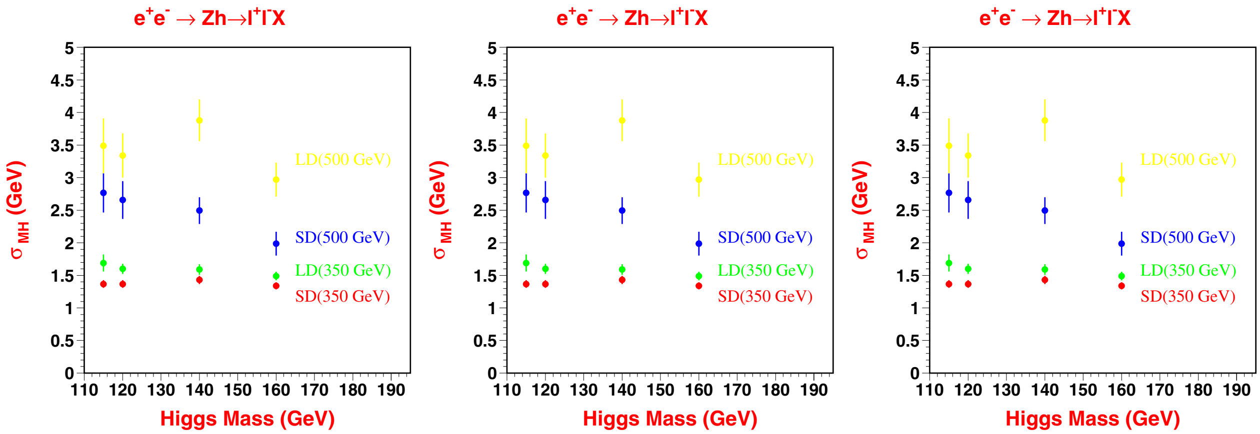

Figure 2: Left: The raw recoil mass resolution of $e^+e^- \to Z^0H \to l^+l^-X$ plotted vs Higgs mass for the LD and SD baseline designs at 300 GeV and 500 GeV center-of-mass energies. Center: The Higgs mass measurement accuracy plotted vs Higgs mass, where green and yellow points correspond to $\sqrt{s} = 500$ GeV, while red and blue points correspond to $\sqrt{s} = 350$ GeV. Right: The cross section of signal as a function of the Higgs boson mass, blue lines are Standard Model(SM) expectation values, red points with error bars are the cross section at $\sqrt{s} = 350$ GeV, green points with error bars are the cross section at $\sqrt{s} = 500$ GeV, assuming an integrated luminosity of 500 fb^{-1}.

fitted to an interpolation of the Monte Carlo distributions, where again the goodness of fit is defined by a binned χ^2. The fitted parameters are the mass and the cross section. This method automatically corrects for biases due to any effects correctly modelled in the Monte Carlo simulation, and avoids degraded precision from non-optimal analytic modelling of resolution.

The Higgs mass accuracy obtained from the Monte Carlo interpolation fit is plotted vs the Higgs boson mass in the center of Figure 2. Here, results from the large detector and the silicon detector at $\sqrt{s} = 350$ and 500 GeV are compared. The accuracy of Higgs mass measured with the LD detector design is about 60 MeV at $\sqrt{s} = 350$ GeV, degrading to 120 MeV at $\sqrt{s} = 500$ GeV. Somewhat better accuracy is provided by the SD design.

The cross sections of $e^+e^- \to Z^0H \to l^+l^-X$ measured for the Higgs mass between 115 and 160 GeV are shown in the right plot of Figure 2. The relative precision of the cross section measurement is determined to be $\Delta\sigma/\sigma \sim 3\%$ at $\sqrt{s} = 350$ GeV and $\sim 4.7\%$ at 500 GeV for both baseline detector designs.

It is clear that for a light or intermediate Higgs mass, better precision on both mass and production cross section are obtained at $\sqrt{s} = 350$ GeV than at $\sqrt{s} = 500$ GeV. Our results appear to be consistent with an earlier European study at 350 GeV which assumed a detector design with significantly worse momentum resolution Garcia-Abia and Lohmann [1999].

We explore the dependence of Higgs mass measurement and cross section precision on charged particle tracking resolution elsewhere in these proceedings Yang and Riles [2001]. Future studies will include incorporation of measured jets from hadronic Higgs decay with a kinematic fit and a revisit of these findings using fully simulated and reconstructed events.

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