Impact of Tracker Design on Higgs Mass and Cross Section Resolutions

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We have studied the impact of charged track resolution on Higgs mass and production cross section measurement in the process $e^+e^- \rightarrow Z^0H, Z^0 \rightarrow e^+e^-, H \rightarrow X$, assuming a 140 GeV Standard Model Higgs and the Next Linear Collider(NLC) operated at 350 GeV and 500 GeV center of mass energies with integrated luminosities of 500 fb^{-1}. Using fast Monte Carlo simulations of the 2001 North American baseline detector designs (LD and SD), we confirm that the Higgs mass resolution is sensitive to momentum resolution, but insensitive to track angular resolution. The cross section resolution and hence absolute branching fraction resolution are insensitive to angular and momentum resolutions. The SD detector provides a more accurate measurement than the LD of the Higgs mass.

I. INTRODUCTION

The precise determinations of the Higgs boson mass and cross section are important goals in future high energy e^+e^- linear collider experiments [1, 2] and may affect the design of the detectors. We study the sensitivity of the Higgs mass and cross section measurements to the resolution of charged particle track reconstruction, using the 2001 North American baseline detector designs (LD for "Large" and SD for "Silicon"). While our results on Higgs measurements are based on fast Monte Carlo simulations, we also show comparisons in track resolution between the fast simulation and the present versions of full simulation & reconstruction.

II. TRACK MOMENTUM RESOLUTION

To illustrate why it is premature to carry out these studies using full Monte Carlo simulation, we show in FIG. 1 comparisons of resolutions for the LD and SD detector baselines. The solid curves show expected resolutions from an analytic approach [3], and the dots show resolutions determined for different polar angle regions for fast and full Monte Carlo simulation of samples of 100K tracks in hadronic background events. While the fast Monte Carlo simulation results are in good agreement with expectation, the full Monte Carlo simulation, including track reconstruction, is clearly far from optimum.

III. ANALYSIS

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

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

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 $e^+e^- \rightarrow Z^0Z^0$, 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 [4, 5] 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) [6] package was used with fast Monte Carlo simulation to analyze the events, using the LD and SD baseline detectors [1, 3, 7].

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. The expected production cross sections of signal with 140 GeV Higgs mass hypothesis are $4.57 fb^{-1}$ and $2.35 fb^{-1}$ for 350 GeV and 500 GeV center-of-mass energies, respectively. Events are selected using a cut-based approach, according to the following criteria:

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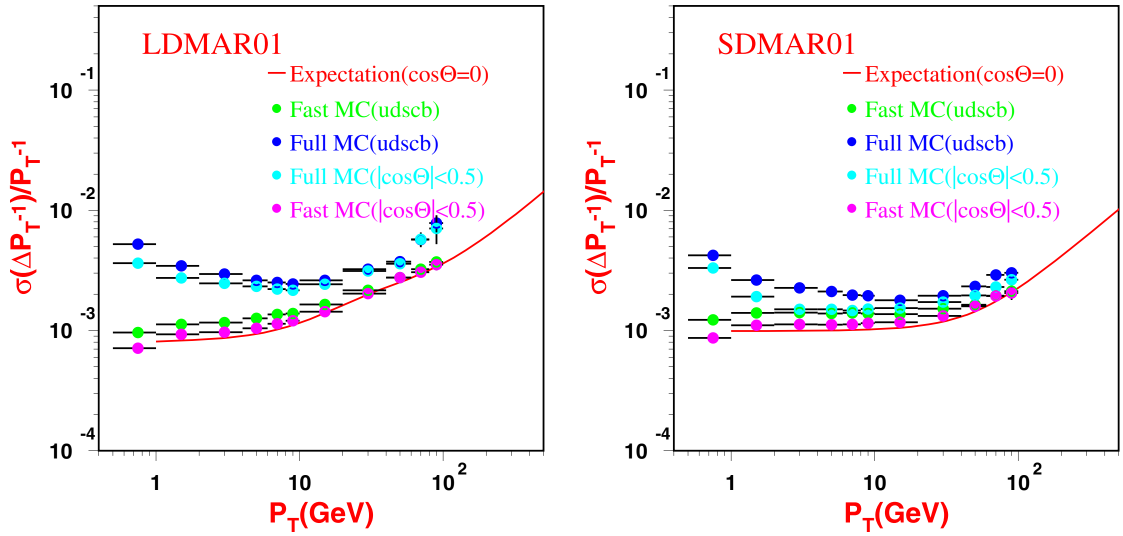

FIG. 1: Left – the track momentum resolution from the large detector plotted vs transverse track momentum. The red curve shows the expected momentum resolution for a track with $cos\theta = 0$; the green and blue points show resolutions from fast MC and full detector simulation MC for $|cos\theta| < 0.9$, respectively. The magenta and cyan points show the same for $|cos\theta| < 0.5$. Right – corresponding results for the SD detector.

(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
(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.

IV. COMPARISON AND CONCLUSION

After selection, the recoil mass distributions for different track resolutions are shown in the left of FIG. 2. To quantify reconstruction resolution, the raw recoil mass is fitted by a single Gaussian distribution; the resulting fitted standard deviation is plotted in the center and right of FIG. 2 as function of scale factors of track resolution parameters. Not surprisingly, the raw recoil mass resolution is sensitive to track momentum magnitude resolution, but not to track angular resolution. Hence the SD detector gives a narrower distribution than the LD detector. It should be noted, however, that initial state radiation leads to a highly asymmetric resolution function, poorly approximated by a Gaussian function.

Hence to quantify better the effect on final derived Higgs mass and cross section of track resolution parameters, a resolution-model-independent Monte Carlo interpolation fit method [8] was used. The results are shown in FIG. 3 where it is confirmed that the Higgs mass determination is indeed sensitive to track resolution for the parameters of 2001 North American baseline detector designs, while the production cross section determination is not. Consequently, the measurement of absolute values of Higgs branching ratios for a low-mass Higgs particle does not significantly influence the choice of tracking detector design at a linear collider.

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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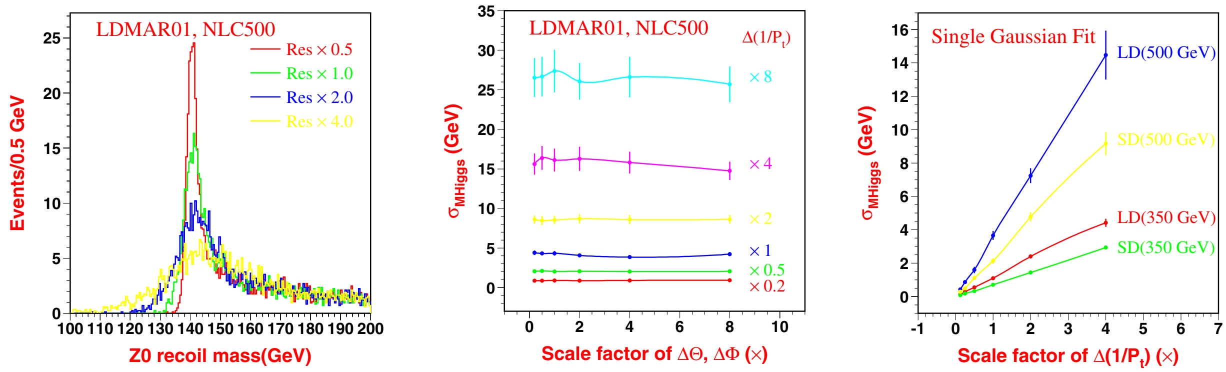

FIG. 2: Left - comparison of recoil mass distributions from the large detector when baseline track resolutions are scaled by factors ranging from 0.5 to 4.0 at 500 GeV. Center – raw recoil mass resolutions for various angular resolution scale factors. Right – raw recoil mass resolutions for various momentum magnitude resolution scale factors, where red and blue points correspond to the LD design at 350 GeV and 500 GeV, respectively. The green and yellow points correspond to the SD design.

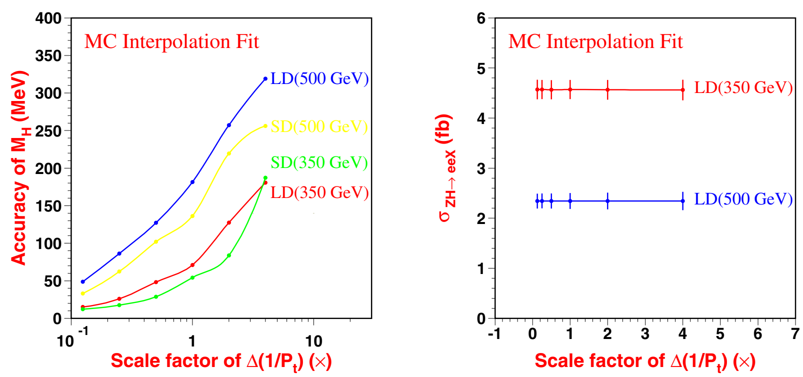

FIG. 3: Left – accuracy of Higgs mass determination, using a Monte Carlo interpolation fit method, plotted vs track momentum resolution scale factor. The red and blue points are results based on the LD design at 350 and 500 GeV, respectivley. The yellow and green points correspond to the SD design. Right, cross section determination and uncertainty for $e^+e^- \to Z^0H, Z^0 \to e^+e^-, H \to X$ plotted vs track momentum resolution scale factor for the LD design at 350 and 500 GeV.

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