

A Fast Simulation Algorithm for Higgs Recoil Mass Study at ILD

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1 Introduction

The intent of this work is to develop a fast simulation algorithm of the ILD [1] detector concept for the Higgs recoil mass study. We plan to use it for the study of the impact on the Higgs recoil mass measurement with SB2009 beam parameters [6]. The development is based on the generator samples centrally produced by SLAC [5], and takes their full simulation of the ILD detector [4] as reference. Both the generator and full simulation samples are centrally produced for the Letter of Intent (LOI) studies, assuming a center of mass energy (\sqrt{s}) of 250 GeV with a Higgs mass (M_H) of 120 GeV.

The fast simulation of the ILD detector intends to consider the uncertainty of the detector response without full detector simulation. For the Higgs recoil mass analysis, the major detector uncertainty is due to the momentum measurement of the lepton tracks. We take the muons tracks for this study. Therefore the object of the fast simulation is to smear the MC true momentum given by event generation according to the momentum resolution of the detector. It consists of two steps:

- In the first step, we parameterize the momentum resolution of lepton measurement obtained from the full simulation of the ILD detector as a function of the momentum and $\cos\theta$. This is described in Section 2.
- Then, we take the generator samples, smear the momentum MC truth of a given lepton according to the momentum parameterization obtained in the first step. We compared the resulting observable distributions with that obtained from the full simulation. They confirmed with each other. See Section 3 for details.

Thereafter we apply the fast simulation to Higgs recoil mass study at $\sqrt{s}=250$ GeV, and compare the results with those obtained from full simulation. They agree with each other, see Section 4.

2 Parameterization of the Momentum Resolution

The first step is to have the momentum resolution of the ILD detector. We parameterize the momentum resolution of ILD detector as a function of the momentum (P) and $\cos\theta$ of leptons. The momentum resolution function is given by Equation 1.

$$\frac{\Delta P}{P^2} = \begin{cases} a_1 \oplus b_1/P & : |\cos\theta| < 0.78 \\ (a_2 \oplus b_2/P) / \sin(1 - |\cos\theta|) & : |\cos\theta| > 0.78 \end{cases} \quad (1)$$

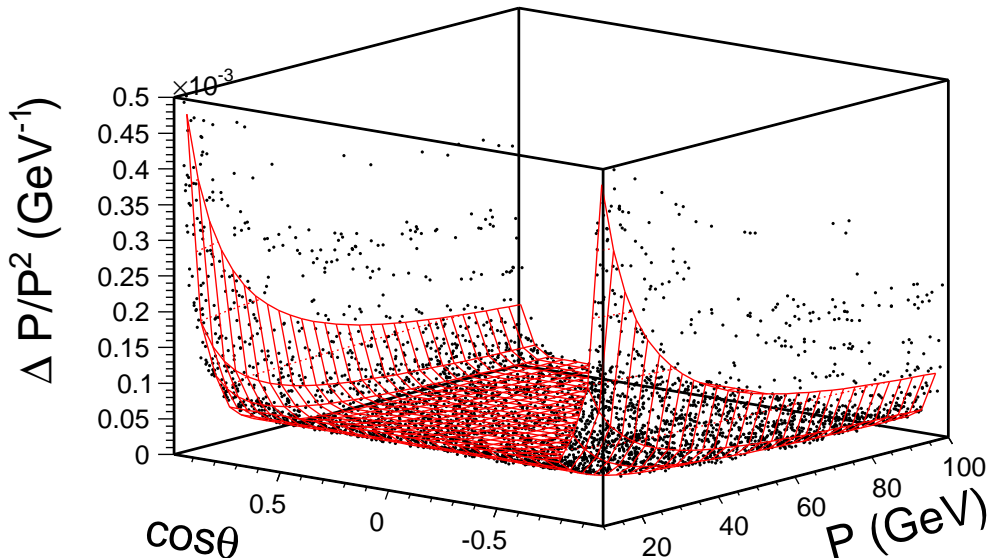


Figure 1: The black scatter plot shows the distribution of momentum resolution of the ILD detector as a function of lepton P and $\cos\theta$ obtained from full simulation of the detector. The red surface shows the fit of Equation 1 to the distribution. The parameters obtained from the fit is shown in Table 1.

a_1	2.08×10^{-5} (1/GeV)
b_1	8.86×10^{-4}
a_2	3.16×10^{-6} (1/GeV)
b_2	2.45×10^{-4}

Table 1: Parameters in Equation 1 obtained by fitting it to the distribution of momentum resolution of the ILD detector shown in Figure 1.

Equation 1 is thus fitted to the distribution of momentum resolution got from the full simulation of the ILD detector, as shown in Figure 1. In this figure, the black scatter plot shows the momentum resolution as a function of P and $\cos\theta$ from ILD detector full

simulation, and the red surface is the fit of Equation 1 to the distribution of momentum resolution. The momentum resolution for a given lepton is obtained by propagation of the error matrix of its track reconstruction. The fitted parameters are shown in Table 1.

3 Momentum Smearing

The second step of the fast simulation is to smear the MC true momentum from the event generation according to the momentum resolution function we just obtained. For each lepton, we define a Gaussian function, and set the MC true momentum as the mean of this Gaussian function, the ΔP as the sigma. Thereafter, we generate a random number according to this Gaussian function, and this random number is the momentum after fast simulation.

In order to validate the method, we compare the M_{dl} and M_H distributions of this fast simulation with the full simulation at $\sqrt{s}=250$ GeV. Figure 2 shows this comparison. They agree with each other.

4 Application at $\sqrt{s}=250$ GeV

In this section, we apply the fast simulation algorithm to study the Higgs recoil mass measurement at $\sqrt{s}=250$ GeV, and compare the results with those using the full simulation samples. Our full simulation study is detailed in reference [3, 2, 1].

For this propose, we take the SLAC generator samples under study, use the $ZH \rightarrow \mu^+\mu^-X$ channel, assume the luminosity is 250 fb^{-1} and the beam longitudinal polarization is -80% for e^- beams and $+30\%$ for e^+ beams. The considered background are the WW and ZZ reactions, since our full simulation study proves they are the irreducible major backgrounds, and all the other background like $e^+e^- \rightarrow \mu^+\mu^-$ can be sufficiently eliminated [3]. The corresponding cross-sections for the signal and background are given in Table 2.

Reaction	Cross-Section
$ZH \rightarrow \mu\mu X$	11.67 fb
WW	481.68 fb
ZZ	1196.79 fb

Table 2: Reactions and cross sections. The signal is indicated by bold face letters.

The analysis procedure [3] after the fast simulation is similar to that of our study based on the full simulation samples:

- A cut based background suppression. The cuts are defined in Table 3. These cuts are independent of the Higgs decay mode.
- A Likelihood further rejection of background [3]. The variables employed in this Likelihood suppression are also independent of the Higgs decay mode.

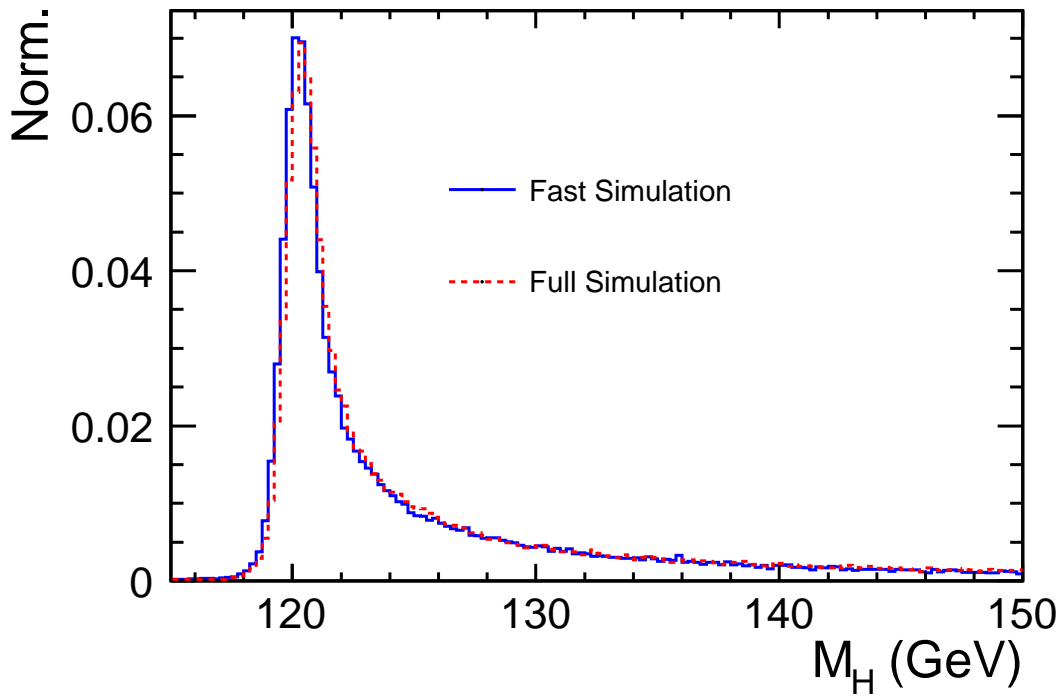
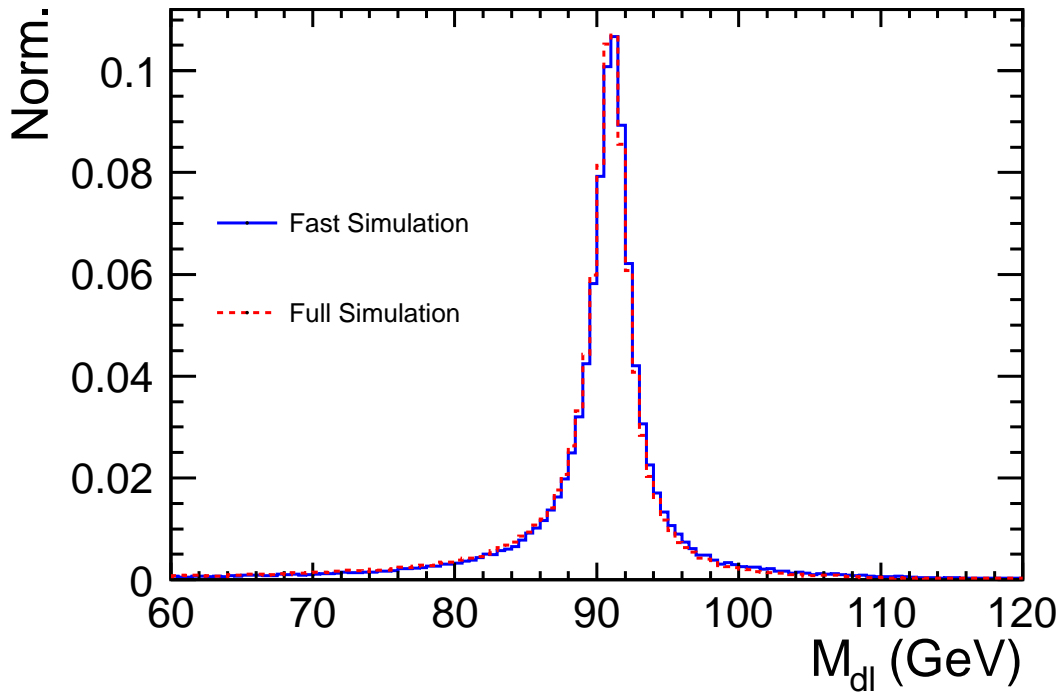


Figure 2: Comparison of the invariant mass M_{dl} of the lepton pair (top) and the recoil mass M_H (bottom) distributions from fast simulation and full simulation of the ILD detector at $\sqrt{s}=250$ GeV.

- The resulting recoil mass (M_{recoil}) spectrum of signal and background is fitted to derive the results of the M_H and the ZH cross-section measurement [3]. We choose the physics motivated function [3] to describe the signal.

Cut-Chain
(1) $ \cos \theta_\mu < 0.99$
(2) $P_{Tdl} > 20$ GeV
(3) $M_{dl} \in (80, 100)$ GeV
(4) $acop \in (0.2, 3.0)$
(8) $M_{recoil} \in (115, 150)$ GeV
(9) Likelihood Further Rejection

Table 3: The cut-chain for background suppression.

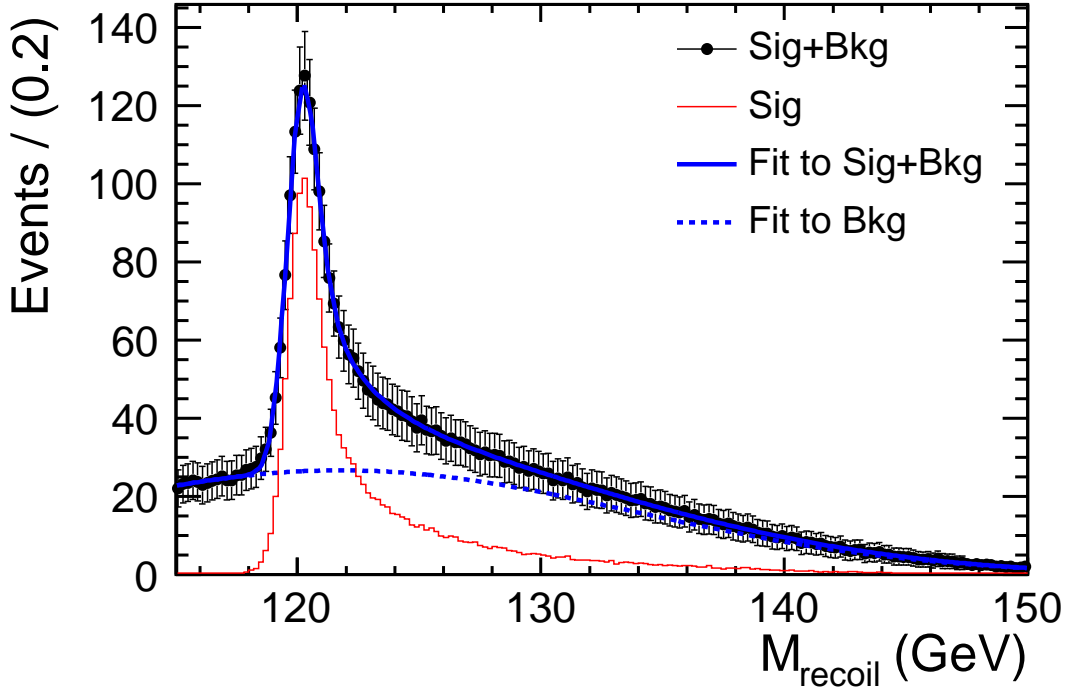


Figure 3: Fit to recoil mass spectrum of signal plus background of this fast simulation study.

The resulting number of signal is $S = 1593$ with an efficiency of $\epsilon = 54.6\%$, the number of background is $B = 2828$, thus the signal over background ratio is $S/B = 56.3\%$. The corresponding numbers from our full simulation study are $S = 1595$, $\epsilon = 54.7\%$, $B = 2563$ and $S/B = 62.2\%$

Figure 3 shows the fit to the recoil mass spectrum of remaining signal and background. An equivalent full simulation plot can be found in reference [3]. From Figure 3, the derived

results of the Higgs mass measurement is $M_H = 120.001 \pm 0.038$ GeV, and of the cross-section is $\sigma = 11.64 \pm 0.39$ fb ($\delta\sigma/\sigma = 3.35\%$). The corresponding results from our full simulation study are $M_H = 120.001 \pm 0.037$ GeV and $\sigma = 11.63 \pm 0.39$ fb ($\delta\sigma/\sigma = 3.35\%$).

The equivalence of the results from fast simulation and full simulation proves our fast simulation algorithm is feasible for the later on study.

References

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