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Search for invisible decays of the Higgs boson at the ILC

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The existence of dark matter has been established in astrophysics. However, there are no dark matter candidates in the Standard Model (SM). If the dark matter particles or its mediator can not interact with SM fermions or gauge bosons, the Higgs boson is the only the portal to the dark matter. We present that simulation study of a search for invisible decays of the Higgs boson at the ILC with the ILD detector.

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1. Introduction

The existence of dark matter has been established in astrophysics; the rotation curve of a disk galaxy, spacial distributions of luminous baryonic matter and total matter in a collision of galaxy clusters, and an anisotropy spectrum of cosmic microwave background [1], baryon acoustic oscillations [2], and large scale structure of the Universe. However, there are no dark matter candidates in the Standard Model (SM). If the dark matter particles or its mediator can not interact with SM fermions or gauge bosons, the Higgs boson is the only the portal to the dark matter. We present that simulation study of a search for invisible decays of the Higgs boson at the ILC with the ILD detector.

2. ILC and ILD

The International Linear Collider (ILC) is an electron-positron collider. The center-of-mass energy (E_{CM}) is 250GeV at the first stage and upgradable to at least 1TeV at Kitakami site. The length of the ILC is about 20km for the first stage and 50km for the 1TeV upgrade. The ILC has a beam polarization capability of $\pm 80\%$ and $\pm 30\%$ for electron and positron beams, respectively. This is a powerful tool to select the quantum number of intermediate state and to suppress backgrounds. The International Large Detector (ILD) is one of the two detectors at the ILC experiment. The ILD detector is optimize to particle flow algorithm. All the subdetectors, especially caloriemeter system, are highly segmented to track single particle even in caloriemeter system to maximize the jet energy resolution.

3. Run Scenario

The run scenario assumed in this manuscript is based on H-20 scenario [3]. The E_{CM} is initially 250GeV and upgraded to 350GeV and 500GeV. At all three E_{CM}, two polarizations configuration is used $P(e^-, e^+) = (-80\%, +30\%)$ and $P(e^-, e^+) = (+80\%, -30\%)$, named "Left" and "Right", respectively in this manuscript. Table 1 summarizes the integrated luminosity.

Table 1: Integrated Luminosities with H-20 scenario.

Energy [GeV]	"Left" [fb^{-1}]	"Right" [fb^{-1}]
250	1350	450
350	135	45
500	1600	1600

4. Reconstruction

Invisible decays of the Higgs boson can be searched for using a recoil mass technique in $e^+e^- \to ZH$ processes with model independent way. The initial state e^+e^- is known since the electron and positron are both elementary particles and these four momenta are precisely determined by the ILC. The Z boson is reconstructed from either of $q\bar{q}$ or $\ell^+\ell^-$ (ℓ stands for electron or muon) final states. The measured four momentum are very precise for the $\ell^+\ell^-$ final states while these are moderate and getting worse as E_{CM} increase for $q\bar{q}$ final states. The Higgs mass can be reconstructed as recoil mass against Z, $m^2_{\rm rec} = P^2_H = (P_{e^+e^-} - P_Z)^2$. Dominant backgrounds are $e^+e^- \to ZZ, WW$ and $Z\nu\bar{\nu}$. Figure 1 shows recoil mass distributions of $Z \to q\bar{q}$ decays for "Left" and "Right" polarizations [4]. As seen, with "Right" polarization, dominant backgrounds are suppressed.

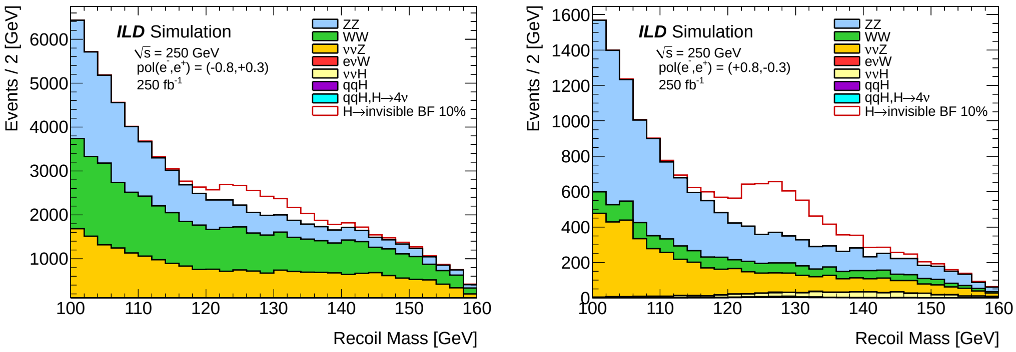

Figure 1: Recoil mass distributions for "Left" and "Right" polarizations.

5. Upper Limits on the Branching Fraction

From the recoil mass distributions for signal and backgrounds, we performed ensemble tests to estimate the upper limit on branching fraction of invisible decays of the Higgs boson. The SM process $H \to ZZ* \to 4\nu$ is also invisible final state and gives the same recoil mass distribution. This known contribution is separately considered in the fit in ensemble test and is not included to the upper limit. The $Z \to q\bar{q}$ [4] and $Z \to \ell^+\ell^-$ [5] are separately analyzed and then combined. Table 2 shows results of upper limits with $Z \to q\bar{q}$ and combined $q\bar{q}$ and $\ell^+\ell^-$ cases for each E_{CM} with the same running time. The integrated luminosities of $250 fb^{1}$, $350 fb^{1}$ and $500 fb^{1}$ are taken at E_{CM}'s of 250GeV, 350GeV and 500GeV, respectively. The upper limit with $q\bar{q}$ final states is much better than that with $\ell^+\ell^-$ thanks to the larger branching fraction. The $\ell^+\ell^-$ contribution is not negligible for 500GeV case since the recoil mass resolution with $q\bar{q}$ is worse at higher E_{CM}. Lower E_{CM} gives better results since the cross section of $e^+e^- \to ZH$ is larger. The upper limit with "Right" polarization is better than that with "Left" polarization since dominant backgrounds are suppressed. The E_{CM} of 250GeV with "Right" polarization gives the best upper limit with the same running time.

Table 3 shows the upper limits based on H-20 scenario. By combining all runs, the upper limit of 0.26% can be achieved at the ILC. This result can be compared with the current model dependent LHC results of 26% and 19% by ATLAS [6] and CMS [7], respectively. ILC will give two orders of magnitudes better result than current LHC experiments.

6. Conclusion

ILC is the ideal place to search for invisible decays of the Higgs boson with model independent

Table 2: Upper limits on the branching fraction of invisible decays of the Higgs boson in percent assuming the same running time for each E_{CM}.

E_{CM} [GeV]	$Z \to q\bar{q}$		$Z \to q\bar{q}$ and $\ell^+\ell^-$	
	"Left"	"Right"	"Left"	"Right"
250	0.95	0.65	0.86	0.61
350	1.49	1.37	1.23	1.10
500	3.16	2.30	2.39	1.73

Table 3: Upper limits on the branching fraction of invisible decays of the Higgs boson in percent based on H-20 scenario.

E_{CM} [GeV]	$Z \to q\bar{q}$			$Z \to q\bar{q}$ and $\ell^+\ell^-$		
	"Left"	"Right"	combined	"Left"	"Right"	combined
250	0.41	0.51	0.32	0.37	0.45	0.28
350	2.40	3.82	2.03	1.98	3.07	1.66
500	1.77	1.29	1.04	1.34	0.97	0.79
combined	–	–	0.30	–	–	0.26

recoil mass technique. With H-20 scenario, an upper limit on branching fraction of H decaying to invisible final state of 0.26% can be achieved.

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