Higgs Branching Ratio Measurements at a Future Linear Collider [1]

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Abstract. The next Linear Collider should provide the capability to measure with precision the Higgs branching ratios, constraining the models of electroweak symmetry breaking. The precision of a proposed CCD vertex detector is studied for 120 GeV/c^2 and 140 GeV/c^2 Higgs production at $\sqrt{s} = 500\ GeV$.

INTRODUCTION

The measurement of Higgs branching ratios is one of the premier goals of the next Linear Collider. [1] These branching ratios are an important discriminate between competing models of electroweak symmetry breaking, such as the Standard Model and the Minimal Supersymmetric Model. [2] This physics goal drives the physics performance of the high energy linear collider detector, as it demands excellent vertexing, tracking and calorimetry. In a companion paper presented at this workshop we discuss the impact of vertex detector parameters on this physics measurement. [3] Here we present results for the standard configuration (c1 in [3]) which is based on an improved version of the SLD CCD vertex detector. [4]

ANALYSIS

We studied the intermediate mass Higgs boson of masses 120 and 140 GeV/c^2, produced in the reaction $e^+e^- \to Z^0h$. The leptonic decays of the Z are tagged, and the results are scaled up by a factor of four as an estimate for adding the hadronic Z decay. [5] The principal backgrounds to the clean measurement of this intermediate mass Higgs come from the production of W and Z boson pairs, and quark pairs. Signals and backgrounds are generated with the Pandora simulation program, [6] with parton showers and hadronization done by PYTHIA. [7] We

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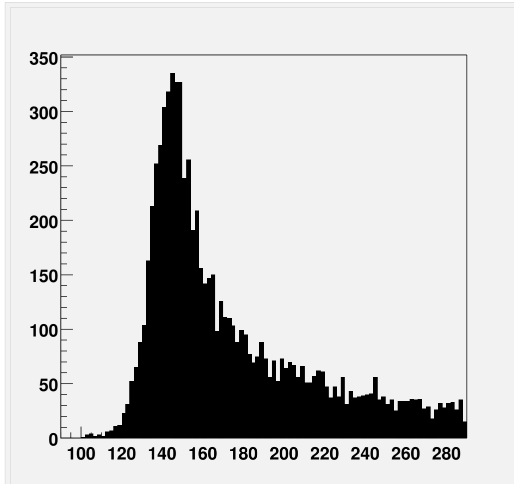

FIGURE 1. Mass (GeV/c^2) recoiling from the Z in $e^+e^- \rightarrow Zh(140)$.

assume 500 fb^{-1} of integrated luminosity, split equally between 80% right-handed electron polarization, and 80% left-handed electron polarization.

The event selection begins by tagging the Z decay to two leptons, with a $|\cos\theta_Z| < 0.6$, and a recoiling mass consistent with the Higgs mass. Events are selected if $|M_{l^+l^-} - M_Z| < 10\ GeV/c^2$ and $M_h - 10\ GeV/c^2 < M_{recoil} < M_h + 20\ GeV/c^2$. Figure 1 presents the recoil mass distribution. The high energy tail from initial state radiation and beamstrahlung is clear. Only 32% (36%) of the signal events pass this initial selection requirement for a Higgs mass of 120 GeV/c^2 (140 GeV/c^2).

Events are futher refined by a set of cuts optimized for each decay mode of the Higgs. Initially events are chosen with these cuts, but in an improved analysis (described below) these cut parameters provide the basis for a neural net selection. The following discussion of the cut analysis refers to cut parameters used for the Higgs mass of 140 GeV/c^2. Slightly different values were used for 120 GeV/c^2.

$\underline{h \rightarrow WW^*}$ The $h \rightarrow WW^*$ events are identified either through the two jet plus charged lepton channel, or the four jet channel. For the two jet channel the event is required to have a reconstructed Higgs mass between 110 and 200 GeV/c^2, or below 70 GeV/c^2, and an isolated high momentum lepton. The lepton momentum must be greater than 10 GeV/c with less than 10 GeV in the $\cos(\theta) > 0.95$ cone. The Higgs decay track multiplicity must exceed 6.

The four jet channel must have a reconstructed mass between 130 and 200 GeV/c^2. The event is forced into four jets by the jet finder by varying the y_{cut} parameter. One of the two jet pairs is required to have a dijet mass within 10 GeV/c^2 of the W. The thrust in the Higgs rest frame must exceed 0.88, and the y_{cut} value which reduces the number of jets from three to two (y_{32}) must be greater than 0.04. Finally, no lepton from the Higgs decay may exceed 10 GeV.

$\underline{h \rightarrow \tau^+\tau^-}$ The reconstructed Higgs mass must be greater than the Z mass, or the reconstructed mass, where the missing mass of the event is included as coming from the Z, must be greater than the Z mass. The reconstructed mass must also be less than 200 GeV/c^2. The Higgs decay track multiplicity must be less than or equal to 6.

$\underline{h \to b\bar{b}}$ The particles recoiling from the Z are forced into two jets. The di-jet mass is required to be between 120 GeV/c^2 and 200 GeV/c^2. Secondary vertices within the jets are searched for with the topological vertexing algorithm developed by SLD [8], and the p_T corrected mass (m_{p_T}) from this algorithm is required to be greater than 2.0 GeV/c^2.

$\underline{h \to c\bar{c}}$ The particles recoiling from the Z are forced into two jets. The di-jet mass is required to be between 130 GeV/c^2 and 200 GeV/c^2. Secondary vertices within the jets are searched for with the topological vertexing algorithm developed by SLD [8], and the p_T corrected mass (m_{p_T}) from this algorithm is required to be less than 2.0 GeV/c^2. The expect jet momentum for the tagged jet is reconstructed from the Z and the vertex detector measured jet direction. The observed jet momentum is required to be greater than 45% of the expected momentum and fewer than ten of the tracks in the event can miss the primary vertex by greater than $3\sigma(N_{sig})$.

$\underline{h \to gg}$ If the event fails to tag on any of the other decay modes, the $h \to gg$ tag is attempted. The Higgs decay products must reconstruct to a mass between 120 GeV/c^2 and 200 GeV/c^2. If there are no secondary vertices detected, and there are no leptons from the Higgs decay products with momenta in excess of 1 GeV/c, the event is tagged as $h \to gg$.

<u>Neural net analysis</u> To refine the cut-based analysis, the parameters used to separate the signals and backgrounds were incorporated into a neural net analysis. [9] The fourteen parameters are listed in Table 1. The cut values (p_{cut}) shown are those used at 140 GeV/c^2 are derived from the above analysis, and the parameters were mapped to the interval [0,1] by the map $p \mapsto e^{-(p/p_{cut})^2 ln2}$. Two sets of neural net cuts were studied. Table 2 shows for each decay mode the number of signal and background events tagged and the principal background process for the loosest neural net cuts. Tighter cuts reduced the background, but in most channels did not improve the error. (The exception was the $\tau\tau$ channel.) The results of this analysis are presented in Table 3.

TABLE 1. Neural net tagging parameters (p) and the cut values (p_{cut}) used in the parameter mapping for $M_h = 140\ GeV/c^2$

parameter (p)	cut value (p_{cut})	parameter (p)	cut value (p_{cut})
$p_{l^\pm max}$	10 GeV/c	$Nsig$	10
E_{cone}	10 GeV/c	$n_{vertices}(jet1)$	2
$m_{W(recon)}$	m_W	$n_{vertices}(jet2)$	2
$thrust_{Higgs}$	0.88	$m_{p_T}(jet1)$	2 GeV/c^2
y_{32}	0.04	$m_{p_T}(jet2)$	2 GeV/c^2
n_{tracks}	6	$p_{jet}/p_{kin}(jet1)$	0.45
$m_{H(recon)}$	110 GeV/c^2	$p_{jet}/p_{kin}(jet2)$	0.45

TABLE 2. Principal backgrounds to Higgs decay modes in the loosest cut analysis.

	$M_H = 120GeV/c^2$			$M_H = 140GeV/c^2$		
	Events	BG	main BG source	Events	BG	main BG source
$h \to b\bar{b}$	1353	141	$e^+e^- \to Z^0Z^0$	731	41	$e^+e^- \to Z^0Z^0$
$h \to WW^*$	253	395	$e^+e^- \to Z^0Z^0$	827	120	$e^+e^- \to Z^0Z^0$
$h \to c\bar{c}$	39	323	$e^+e^- \to Z^0Z^0$	22	91	$h \to b\bar{b}$
$h \to gg$	67	136	$e^+e^- \to Z^0Z^0$	60	145	$h \to WW^*$
$h \to \tau^+\tau^-$	59	136	$e^+e^- \to Z^0Z^0$	57	183	$e^+e^- \to W^+W^-$

TABLE 3. Neural-net branching ratio measurement errors.

	$M_H = 120GeV/c^2$		$M_H = 140GeV/c^2$	
	BR(120)	error	BR(140)	error
$h \to b\bar{b}$	69 %	±2.0 %	34 %	±1.3 %
$h \to WW^*$	14 %	±1.5 %	51 %	±1.9 %
$h \to c\bar{c}$	2.8%	±1.3 %	1.4 %	±0.67 %
$h \to gg$	5.2%	±1.9 %	3.5 %	±2.4 %
$h \to \tau^+\tau^-$	7.1%	±1.1 %	3.6 %	±0.6 %

CONCLUSIONS

The CCD vertex detector proposed for the next Linear Collider can measure the Higgs branching ratios with excellent sensitivity, and will limit the viable models of electroweak symmetry breaking.

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