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Event Selection Criteria for the 6-Jet Higgs Channel, At JLC

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Abstract

Higgs boson, the missing piece of the Standard Model has a chance to be discovered at the Joint Linear Collider (JLC). In order to study this elusive particle and find many of its properties we formulate an event selection criteria that will select the 6-jet Higgs channel through computer simulation using the JLC Study Framework (JSF).

Introduction

The Standard Model (SM) [1] Theory has been very successful in explaining in detail the interactions of the physically observed particles. It has become our basis of understanding the many elementary particles in the universe. SM also predicts the existence of few particles that have almost completed the current particle spectrum. At the heart of the SM theory is the broken symmetry [2], a sudden loss of symmetry that gave birth to the prediction of the physical existence of a particle called the Higgs boson. When Higgs boson interacts with other particles, the masses of other particles are generated through the process called the Higgs Mechanism. Today, the very important Higgs boson is the only remaining particle not yet experimentally detected.

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The Asian Committee for Future Accelerators (ACFA) proposed for the construction of the Joint Linear Collider (JLC) [3, 4] with the main purpose of detecting and studying the Higgs particle. The detection of the Higgs boson in the first phase of JLC at $\sqrt{s} = 300GeV$ is promising. The expected mode of Higgs production of this machine is the Higgsstrahlung process, $e^{+}e^{-} \rightarrow Z^{0}H^{0}$. Figure 1 shows the Higgs production modes in a linear collider.

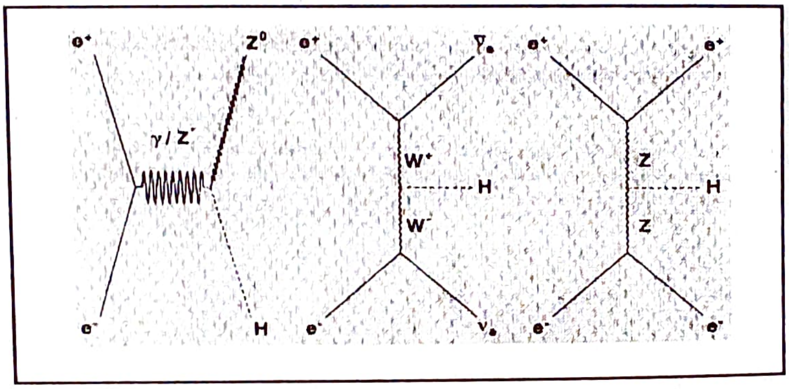

Figure 1. The Feynman diagrams above show different Higgs production modes in a linear collider [5]. The first of the diagrams is the Higgsstrahlung $e^{+}e^{-} \rightarrow Z^{0}H^{0}$ process, the mode being studied at JLC.

The decay mode where Higgs boson decays into two W bosons, $H^{0} \rightarrow WW^{*}$, is being utilized because it has a branching ratio that is greater than 1% for Higgs masses greater than $100GeV$ and increases rapidly with the increase in mass. The channel, $e^{+}e^{-} \rightarrow Z^{0}H^{0} \rightarrow Z^{0}WW^{*}$ also has the possibility of giving the total decay width of the Higgs boson which is given by the equation,

$$\Gamma(H^{0} \rightarrow all) = \frac{\Gamma(H^{0} \rightarrow WW^{*})}{Br(H^{0} \rightarrow WW^{*})} \tag{1}$$

Many studies have been done using leptonic modes [5] due to their cleaner signals but the 6-jet Higgsstrahlung channel, $e^+e^- \to Z^0H^0 \to q\bar{q}WW^* \to q\bar{q}q\bar{q}q\bar{q}$, is given the importance as it has larger hadronic branching ratios of W and Z than leptonic decay modes. In the analysis, we assume that Higgs mass, $m_H = 120GeV$ at the integrated luminosity of $\int Ldt = 500\,fb^{-1}$. For the detector, we used 3-Tesla detector model, which was proposed recently to reduce beam-related backgrounds and to ensure very low beam emittance. The JLC Study Framework (JSF) [6] is used to facilitate most of the computing demands of this simulation.

Methodology

As prerequisite the necessary software must be installed in a computer with a Linux operating system, in the following order: (1) CERNLIB, (2) ROOT, (3) LCLIB, (4) JSF, and (5) PhysSim.

Event Generation

Each event is generated according to the Standard Model using Pythia Monte Carlo Event Generator. The Higgs boson is assumed to have a mass of $m_H = 120GeV$. The current experimental lower bound of the Higgs boson mass obtained by LEP2 is $113GeV$. From the global fit to the electroweak data the upper bound of the Higgs boson mass at 95% confidence level is $220GeV$ [7, 8, 9]. By default, initial state radiation (ISR) effects are included.

Before we can generate the events we have to determine first the number of events to be generated for the target and background signals. The number of events N_E is given by the product of cross section σ_E and the integrated luminosity $\int Ldt$.

$$N_E = \sigma_E \int Ldt \tag{2}$$

At JLC-I, the luminosity is set at $L = 8 \times 10^{33} / cm^2 / s$ and the center-of-mass energy at $\sqrt{s} = 300 GeV$ to avoid large backgrounds from top pair productions. For this study, we generated events corresponding to the integrated luminosity of $500 fb^{-1}$. The cross section and the number of events corresponding to this integrated luminosity is summarized in Table 1.

Signal/Background	σ_{SM} (pb)	Br (%)	Number of Events to be Generated
$e^+e^- \to Z^0H^0$	0.183		91500
$e^+e^- \to Z^0H^0 \to q\bar{q}q\bar{q}q\bar{q}$		4.56	4174
$e^+e^- \to Z^0(\to X)H^0(\to b\bar{b})$		67.8	*62037*
$e^+e^- \to Z^0Z^0$	1.03		*515000*
$e^+e^- \to W^+W^-$	13.2		*6600000*
$e^+e^- \to qq(\gamma)$	31.7		*15850000*

Table 1. *The cross section and branching ratios of each signal with their corresponding expected number of events.*

To generate these events we use the Pythia Monte Carlo Generator in JSF. Each of the process were generated separately since we know the target signal and the background signals and how much they are. *Table 2* shows the different events and their corresponding number of generated events.

Signal/Background	Number of Events to be Generated
$e^+e^- \to Z^0H^0$	3906
$e^+e^- \to Z^0H^0 \to q\bar{q}q\bar{q}q\bar{q}$	62037
$e^+e^- \to Z^0(\to X)H^0(\to b\bar{b})$	515000
$e^+e^- \to Z^0Z^0$	660000
$e^+e^- \to W^+W^-$	660000
$e^+e^- \to qq(\gamma)$	660000

Table 2. Lists the generated number of events per signal.

Detector Simulation

To model the JLC Detector and produce combined tracks in the detector, the JSF Quick Simulator was employed. The default configurations of the JLC detector [6] used are the following: 1. Beam pipe: radius = 2*cm*, thickness = 0.15% in radiation length (RL), 2. VTX: 4 layers (r = 2.4*cm*, 3.6*cm*, 4.8*cm*, 6.0*cm* and z = 5.0*cm*, 7.5*cm*, 10.0*cm*, 12.5*cm, respectively*), $|\cos\theta|<0.90$, $\sigma_{r\phi} = 4\mu m$, thickness = 300 *m*, 3. Support Tube: r = 40*cm*, thickness = 1% RL, 4. CDC: r = 45*cm* ~ 155*cm*, $|z| < 155cm$, $\sigma_{r\phi}$ = 85 *m*, $\sigma_Z = 3mm$, Number of sampling: 50, 5. Solenoid: 3Tesla.

For each event, the generated particles showers in the detector and detector signals such as VTX and CDC track parameters and calorimeter cell hit information are created. These signals are used to create track-cluster combined particle information for physics analysis. *Figure 2* shows a simulated Higgsstrahlung event at JLC.

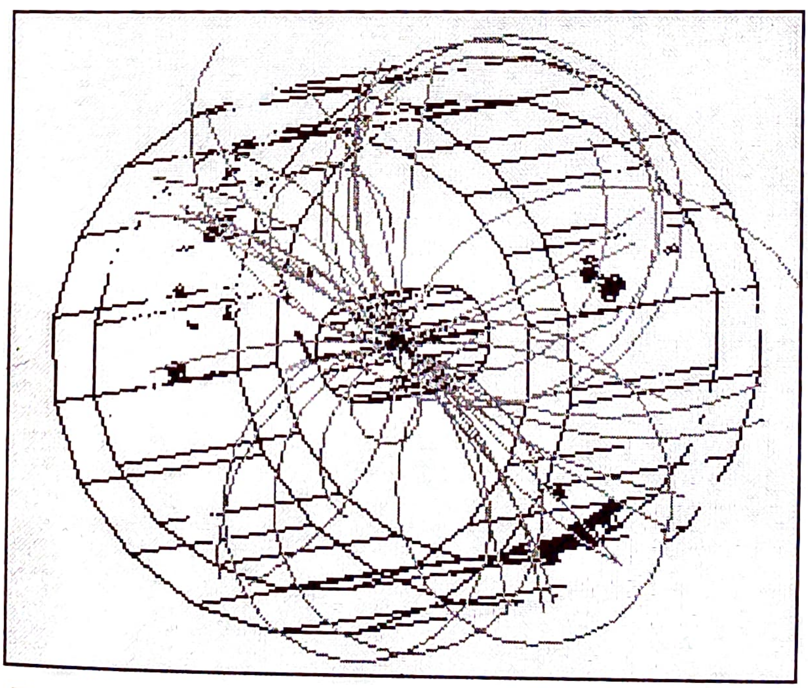

Figure 2. A simulated Higgsstrahlung process at 3 Tesla JLC.

The different event information such as the visible energy of the events, transverse momentum of the events, momentum along the direction of the beam, number of charged particles per event, event thrust (based on the linear sums of particle momenta), number of jets required for each event, energy of each jet produced, cosine of the angle between a pair of jets, number of charged tracks produced, mass distribution of Z bosons, mass distribution of W bosons, momentum of the Z bosons, and the number of off-vertex tracks can be plotted in a histogram to aid in the formulation of the event selection criteria.

Before we can see their histograms we have to cluster the tracks produced per event to reconstruct the jets through a certain measure of distance. We used JADE algorithm through the ANLJadeEjetFinder class in the Physics Simulator (PhysSim) in this process. Y_{cut} value used for clustering was 0.01, the distance parameter. When the number of jets is 6, we find Z and W pairs of jets as follows: (a) Select any two jets with total invariant mass that could qualify as the Z boson. If no jet pair qualifies, reject the event. (b) The remaining 4 jets are then assumed to have come from the Higgs boson. (c) From these 4 jets, pick two whose total invariant mass qualifies as W boson. If no such pairs exist, reject the event. (d) The remaining 2 jets are assumed to be from W*. (e) Go back to 2-5 until all unique combinations are exhausted.

The distributions of the visible energy, the transverse momentum, the momentum along the beam and the number of charged particles are shown in Figure 3 to Figure 6. Major backgrounds come from $e^+e^- \rightarrow W^+W^-$ process. In these figures, we can see clear separation of target signals and backgrounds, it is quite simple therefore to select target from background signals by putting some cuts on the variables. Histograms of other variables are also shown in Figure 7 to Figure 16.

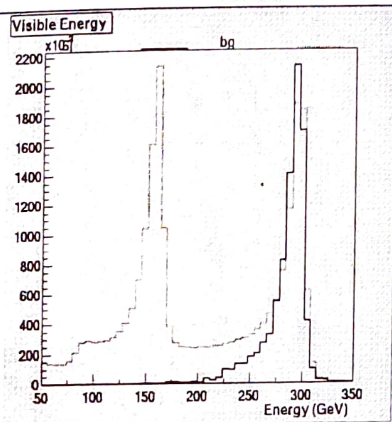

Figure 3. Visible Energy

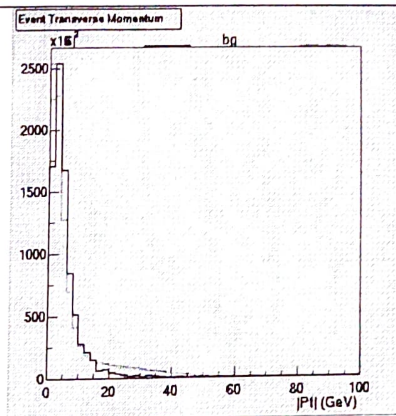

Figure 4. Transverse Momentum

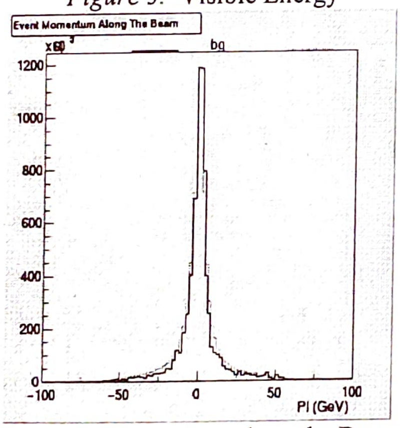

Figure 5. Momentum along the Beam

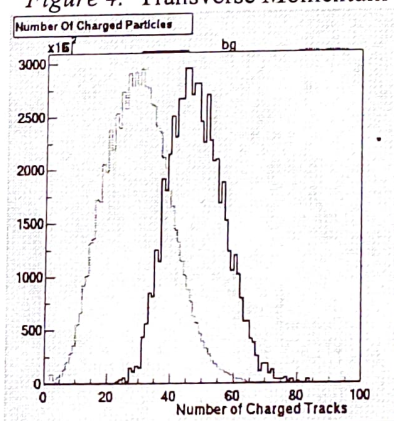

Figure 6. Number of Charged Tracks

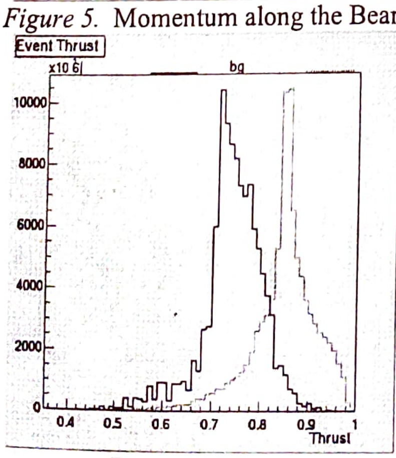

Figure 7. Thrust

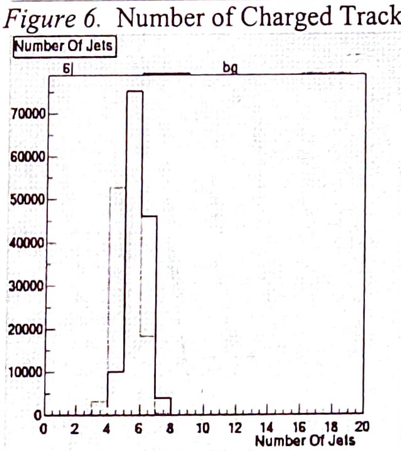

Figure 8. Number of Jets

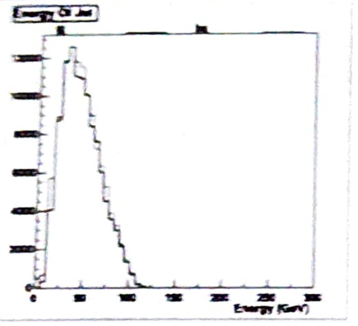

Figure 9. Energy of Jets

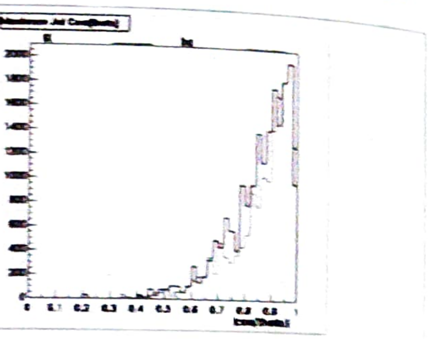

Figure 10. Angle between Jets

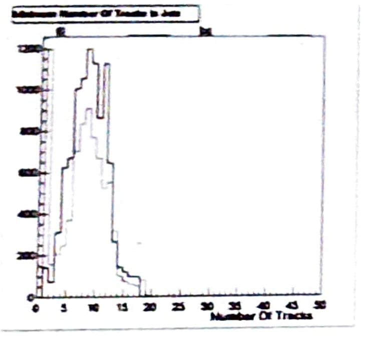

Figure 11. Number of Tracks from Jets

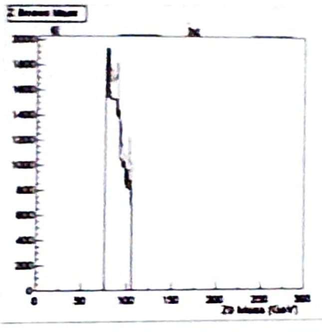

Figure 12. Z Boson Mass Distribution

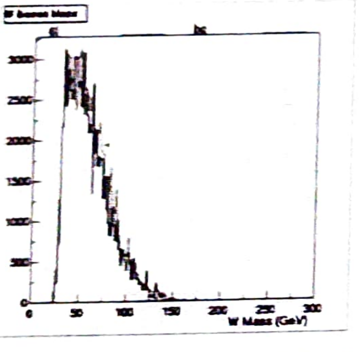

Figure 13. W Boson Mass Distribution

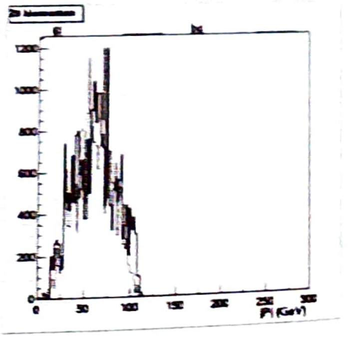

Figure 14. Z Boson Momentum

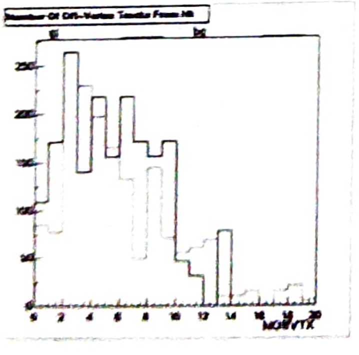

Figure 15. Off-Vertex Tracks from Higgs

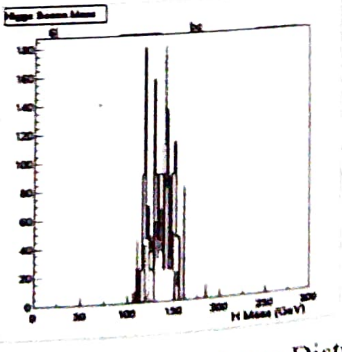

Figure 16. Higgs Boson Mass Distribution

DATA ANALYSIS

The signature of our target process is characterized as no missing energy, high multiplicity and 6 jets consistent with ZWW^* final states. By ocular inspection we formulated the following selection criteria:

1. The Visible Energy of Events $E_{vis} \geq 240GeV$
2. Transverse Momentum of Events $|P_t| \leq 16GeV/c$
3. Momentum along the Beam $|P_l| \leq 16GeV/c$
4. Number of Charged Particles $N_{chg} \geq 40$
5. Event Thrust $Thrust[0.665, 0.785]$
6. Number of Jets $N_{jets} = 6$
7. Energy of Jets $E_{jets} = [21, 300]GeV$
8. Angle between Two Jets $|\cos\theta_{2jets}| \leq 0.98$
9. Number of Charged Tracks $N_{trks} \geq 5$
10. Mass of Z Boson $M_Z[75, 105]GeV/c^2$
11. Mass of W Boson $M_W[75, 95]GeV/c^2$
12. Momentum of Z Boson $P_Z[75, 115]GeV/c$
13. Number of Off-Vertex Tracks $N_{offVTX} \leq 5(b > 3)$

The statistics of event selection for target signal and background processes is summarized in Table 3. Since the number of events generated for the background processes are not sufficient we multiplied factors to get the number of events corresponding to $500 fb^{-1}$. As shown in the last column of the table, we expect 74 (extrapolated value) signal events while the number of background events is 512, whose is only 0.145. Further improvement of selection criteria, especially in jet pairing algorithm are required. The event selection criteria above is based on the histograms of the target as well as the background signals.

Cuts--Signal	$6\,jets$	$Xb\bar{b}$	ZZ	WW	$q\bar{q}(\gamma)$
$NO\ CUTS$	3906	62037	515000	660000	660000
$E_{vis} \geq 240GeV$	3708	44108	278784	371202	205611
$\lvert P_t \rvert \leq 16GeV/c$	3546	36777	259021	281182	194696
$\lvert P_l \rvert \leq 16GeV/c$	3100	31238	214964	229479	163488
$N_{chg} \geq 40$	2550	18363	71109	53450	17967
$Thrust[0.665, 0.785]$	1763	10885	11012	2949	2031
$N_{jets} = 6$	628	1111	1371	513	173
$E_{jets} = [21, 300]GeV$	376	550	784	280	87
$\lvert \cos\theta_{2\,jets} \rvert \leq 0.98$	354	522	729	255	79
$N_{trks} \geq 5$	303	455	513	118	60
$M_Z[75,105]GeV/c^2$ $M_W[75,95]GeV/c^2$ $P_Z[75,115]GeV/c$	69	89	71	16	8
$N_{offVTX} \leq 5 (b > 3)$	69	89	71	16	8
Higgs Entries:	69	89	71	16	8
Expected Number of Generated Events:	4174	62037	515000	6600000	15850000
Extrapolated Value:	74	89	71	160	192

Table 3. Statistics of event selection.

From this *Table 3* we can also compute the relative error (by definition) in the total Higgs width of the Higgs boson [10, 11] as shown below:

$$\frac{\Delta\Gamma_{total}}{\Gamma_{total}} \approx \frac{\sqrt{74+89+71+160+192}}{74} = 32.7\%$$

3. Summary, Suggestions, and Future Plans

We have centered on the formulation of the event selection criteria to accept target signals and discriminate most background signals. The feasibility of the 6-jet Higgs channel at JLC as the process that would be able to give us the value of the total decay width of the Higgs boson does not give good result. Nevertheless, we had formulated the selection criteria of the events through ocular inspection of the histograms. The relative error in $\Gamma_{total}(H \to all)$ calculated also needs improvement since the accepted result should be 20% or lower.

To improve the result, the following is suggested:

1. Improvement of jet selection algorithm.
2. Optimize event selection criteria.
2. Try input mass of $120GeV$ and $160GeV$.
3. Try $ZH \to ZWW^{*} \to q\overline{q}l\nu q\overline{q}$.
4. Lower center-of-mass energy.

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