The Mindanao Forum, Vol XV, No. 2 (December 2000)

JSF Simulation of Total Higgs Decay Width Measurement via the 6-jet Higgs channel at JLC

ALLISTER LEVI C. SANCHEZ
ANGELINA M. BACALA
AKIYA MIYAMOTO
KEISUKE FUJII

Abstract

The existence and physical properties of the Higgs boson H^0 *will be investigated experimentally in the proposed Asian Joint Linear Collider (JLC). In preparation for such future activity, we conducted a study presented in this paper.*

There is a possibility of measuring the total Higgs decay width $\Gamma_{total}(H^0 \to X)$ *at JLC using the so-called 6-jet Higgs channel* $e^+e^- \to Z^0H^0 \to q\bar{q}WW^* \to q\bar{q}q\bar{q}q\bar{q}$. *Here we simulated the measurement of this process using the JLC Study Framework (JSF). We assumed a Higgs boson having a mass* $m_H = 120GeV$. *We set the JLC center-of-mass energy at* $\sqrt{s} = 300GeV$ *and an integrated luminosity* $\int Ldt = 500fb^{-1}$. *Only the following possible backgrounds were considered:* $e^+e^- \to Z^0(\to X)H^0(\to b\bar{b})$, $e^+e^- \to Z^0Z^0$, $e^+e^- \to W^+W^-$, $e^+e^- \to q\bar{q}$, *and* $e^+e^- \to e^{\mp}\nu W^{\pm}$.

Several physical cuts were applied on both signal and background events. The obtained relative error in $\Gamma_{total}(H^0)$ *is* $\Delta\Gamma_{total}(H^0)/\Gamma_{total}(H^0)$ *=37.2%.*

Keywords: Higgs boson, Higgs decay width, Joint Linear Collider, JLC Study Framework

---

ALLESTER LEVI S. SANCHEZ is a summa cum laude graduate in his BS Physics degree. Currently, he is pursuing a MS Physics degree at MSU-IIT. Dr. ANGELINA M. BACALA is a faculty member of the Physics Department, College of Science and Mathematics at MSU-IIT. AKIYA MIYAMOTO and KEISUKE FUJII are from the Institute of Particle and Nuclear Science, KEK, Japan.

1 Introduction

The advances in the field of high energy physics in the last century has revolutionized our understanding of nature, particularly our knowledge of the fundamental components of matter, which we call *elementary particles*, and their physical interactions. This understanding is mainly based on the theoretical framework known as the *Standard Model* (SM) [1]. The importance of the SM is very explicit in the fact that practically all observed high energy physics phenomena reasonably agree with the SM predictions.

The Standard Model is thus a good, practical theory. As a theory, however, it also has its flaws. For example, it cannot explain why particles have mass. Or, put it another way, why do some particles have mass while others do not. This has led physicists to believe that there must be a theory which acts like a high energy superset of the SM, in the same manner that Einstein's theory of relativity is to Newtonian mechanics when we deal with velocities comparable to the speed of light.

The problem of why particles have mass made physicists theorize the existence of the so-called *Higgs field*. In theory, this field interacts with other particles to give them mass. The existence of this field correspondingly requires the existence of a particle called the *Higgs boson*, H^0. This particle has not been observed yet, but the search is still going on.

To discover and study the Higgs boson, the Asian Committee for Future Accelerators (ACFA) [2] proposed the construction of the Joint Linear Collider (JLC) [3]. The JLC is a linear electron-positron collider. A schematic diagram of this project is shown in Figure 1. and its accelerator parameters are given in [4]. Figure 2 shows the design of the JLC detector. In the first phase of its operation (JLC-1) it is expected to have a maximum center-of-mass energy $\sqrt{s} = 300GeV$. As such, JLC is expected to shed light into the still-unchartered physics beyond the Standard Model. This paper presents the results of a preparatory study on one of the many possible physical scenarios at JLC, given this project's enormous scale and physical importance.

2 The 6-jet Higgs Channel at JLC

The expected processes to be produced from the high-energy e^+e^- collisions at the center of the JLC detector are shown in Figure 3 in terms of their cross sections. The expected SM Higgs branching fractions are shown in Figure 4. In this paper we focus on the so-called *6-jet Higgs channel*. First of all, we assume that the Higgs boson exists and has a mass $m_H = 120GeV$. Also, we assume that the colliding e^- and e^+ beams have a combined center-of-mass energy $\sqrt{s} = 300GeV$. In this process, the colliding electron and positron annihilates each other to create a Z^0

boson and a H^0 boson. Subsequently, the Z^0 decays into a quark-antiquark pair. In turn the $q\bar{q}$ pair fragments into two "sprays" of particles, having about the same directions as the q and $\bar{q}$, called *jets*. The H^0, on the other hand, decays into a WW^* boson pair. Each W boson then decays to a $q\bar{q}$ pair. Thus, we observe 6 jets in the final state.

In the region where the Higgs boson mass is greater than 100 GeV the fraction of events where the Higgs decays into WW^* pair becomes significant. In fact, at $\sqrt{s} = 300GeV$ and $m_H = 120GeV$, the branching ratio $Br(H^0 \rightarrow WW^*) =$ 13.3% [5]. It was also found that a precise measurement of $Br(H^0 \rightarrow WW^*)$, given $m_H > 100GeV$, allows also a precise measurement of the Higgs' total decay width given by $\Gamma_{total}(H \rightarrow X) = \Gamma_{total}(H \rightarrow WW^*)/Br(H \rightarrow WW^*)$ and therefore access to other important quantities such as $\Gamma_{total}(H \rightarrow b\bar{b})$. Furthermore, the expected value of $Br(H \rightarrow WW^*)$ in the SM at $m_H = 120GeV$ differs significantly from the predicted value in the Minimal Supersymmetric Standard Model (MSSM), one of the possible extensions of the SM [6]. Thus, a significant deviation from the predicted SM value could give hints to physics beyond the SM.

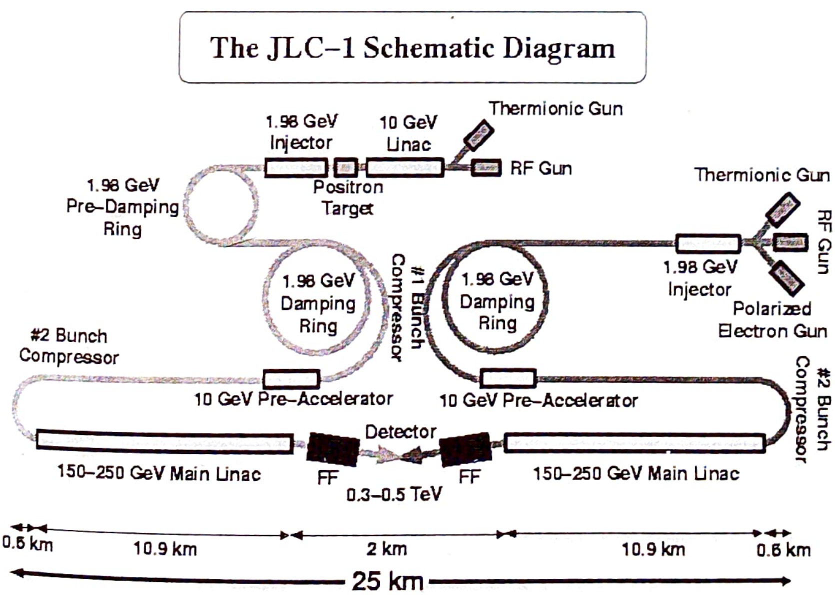

Figure 1. The JLC Project [4].

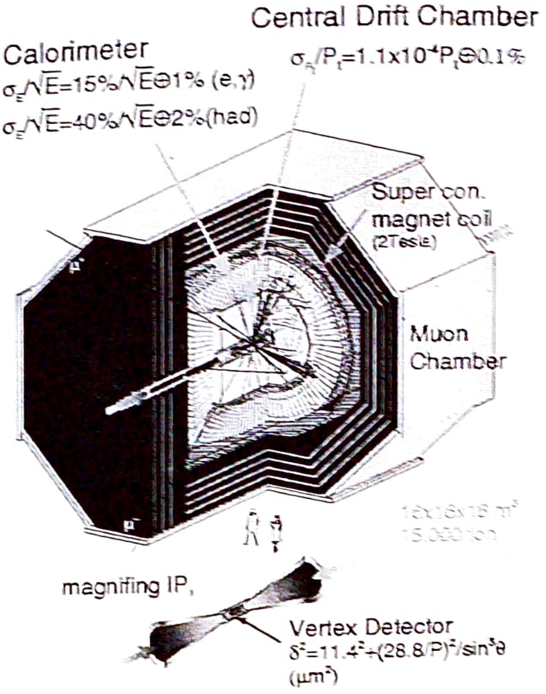

Figure 2. The JLC Detector.

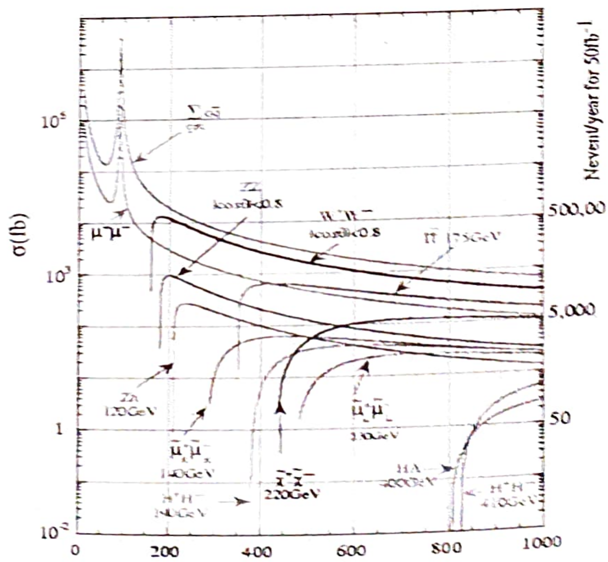

Figure 3. Cross sections of JLC processes.

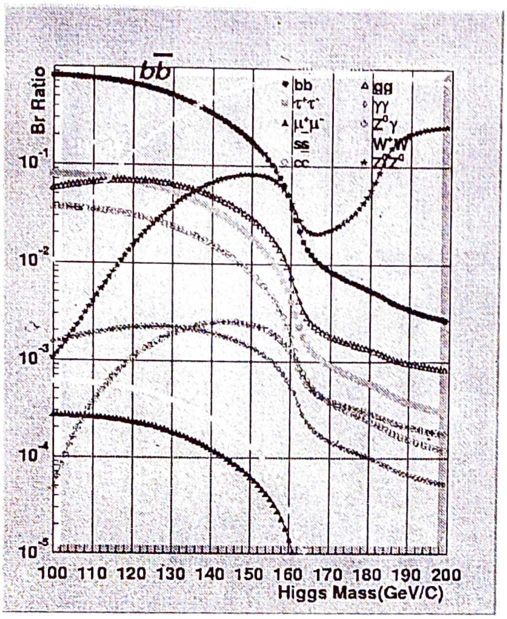

Figure 4. *Higgs branching ratios as a function of its mass.*

Some studies on how to measure the Higgs boson have been presented in [5, 6, 7, 8, 9, 10, 11, 12]. Many of these studies find it easy to use leptonic channels such as $Z(\rightarrow e^+e^-;\mu^+\mu^-)H(\rightarrow X)$ for Higgs mass measurements, cross section, etc. due to their very clean signals. In fact, the total decay width of the Higgs boson can be measured to a relative error level of only 5% via leptonic or semi-leptonic modes of $H\rightarrow WW$ [5, 13]. However, $Br(Z\rightarrow l^+l^-) \approx 10\%$ while $Br(Z\rightarrow hadrons) \approx 70\%$. The case is similar for W. Hence, we must investigate to what extent it is possible to make the 6-jet Higgs channel a feasible measurement option at JLC.

3 Event Generation, Reconstruction and Analysis using JSF

For this study we use the JLC Study Framework [14], a software designed for unified physics studies at JLC based on the object-oriented data analysis framework ROOT [15]. In this unified platform, the separate jobs of event generation, detector response simulation, event reconstruction and data analysis can be conveniently performed. A typical JSF analysis flow and a run session snapshot are shown in Figure 5 and Figure 6, respectively.

e^+e^- events are generated using the Pythia Monte Carlo event generator interface in JSF and by generators available in the Physsim [16] libraries. For this study the expected (actual) number of signal and background events are shown in Table 1. Also shown are the number of events we generated. The background processes considered are only those that might mimic the 6-jet Higgs signal.

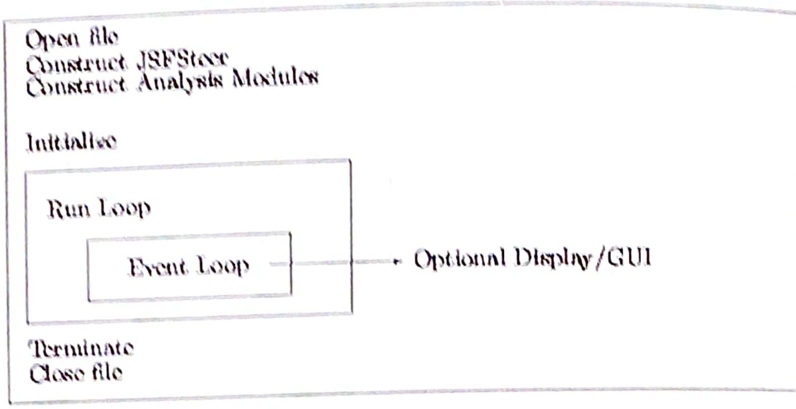

Figure 5. Typical analysis flow in JSF.

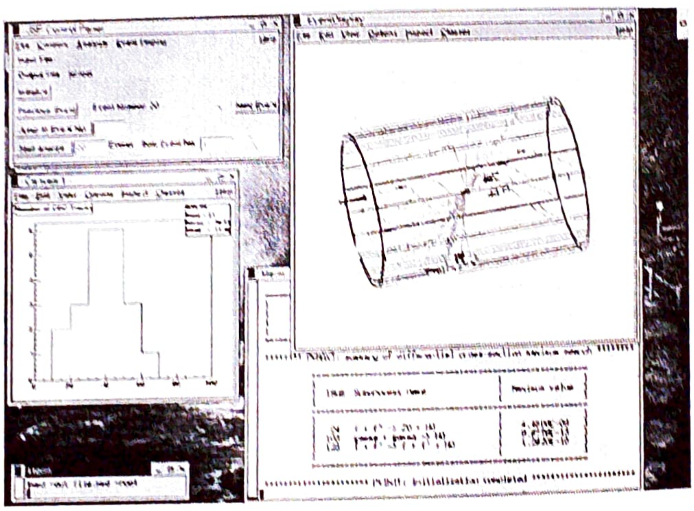

Figure 6. A JSF run session.

Table 1. *Cross sections and number of events expected [5] and generated.*

Signal/Bkgd.	$\sigma_{SM}(pb)$	Br(%)	Expected	Generated
$E^+e^- \rightarrow ZH$	0.183		91500	
$ZH \rightarrow$ 6jets		4.27	3906	3906
$ZH \rightarrow b\overline{b}$		67.8	62037	62037
$E^+e^- \rightarrow Z^0Z^0$	1.03		515000	515000
$E^+e^- \rightarrow W^+W^-$	13.2		6500000	2860000
$E^+e^- \rightarrow q\overline{q}\ (\gamma)$	31.7		16000000	1980000
$E^+e^- \rightarrow e\nu W$	2.26		1300000	44000

We assumed JLC beam parameters and detector configuration as given in [4]. These values are set in the JSF configuration file:

- Beam pipe: radius = 2cm, thickness = 0.15% radiation length (RL).
- Vertex: 4 layers (r = 2.4, 3.6, 4.8, 6.0cm), $|\cos\theta| < 0.90$, $\sigma_{r\phi} = \sigma_z = 4\mu m$, thickness = 1% RL/layer.
- Support tube: r = 40cm, thickness = 1% RL.
- CDC: r = 45cm ~ 230cm, $|z| < 230cm$, $\sigma_{r\phi} = 85\mu m$, $\sigma_z = 3mm$, $N_{sampling}$ = 100.
- Solenoid: 2 Tesla.

Detector simulation and event reconstruction are done using the JSFQuickSim, the JLC Quick Simulator. To cluster jets we use the JadeEJetFinder in the Physsim library. In order to select the 6-jet Higgs signals and reject background events we came up with the following event selection criteria:

- The total visible energy must be $E_{vis} \geq 240 GeV$.
- The total transverse momentum must have magnitude $\boldsymbol{P}_t \leq 15 GeV$.
- The total momentum along the beam direction must be $\boldsymbol{P}_l \leq 60 GeV$.
- The number of charged tracks $N_{chg} \geq 42$.
- The event thrust must be within the interval 0.6 to 0.8.
- After clustering tracks using ANLJadeEJetFinder with initial $y_{cut} = 0.01$, the number of jets must be $N_{jets} \geq 6$. Then force-cluster the remaining events into 6 jets.
- Each jet must have an energy $E_{jet} \leq 15 GeV$.
- All jets must be directed at an angle $|\cos\theta_{jet}| \leq 0.9$.
- Each jet must contain at least 5 tracks, i.e., $N_{trksjet} \geq 5$.
- Find Z^0 jet pair that satisfies the following: $76 GeV \leq M_Z \leq 106 GeV$ and $85 GeV \leq |\boldsymbol{P}_Z| \leq 120 GeV$. The combined mass of 2 of the remaining 4 jets must obey $65 GeV \leq M_W \leq 95 GeV$.
- The number of tracks with $b_{norm} > 3$ (off-vertex tracks) must be at most 5.

The result of the application of these cuts are given in Table 2, showing cut yield values, and Figure 7, Figure 88, Figure 9, showing arbitrarily scaled histograms (for easily locating the cut values) of physical variables used in the event selection process. Note that $e\nu W$ events are no longer included as they are totally eliminated right after the second cut. From this we can calculate the relative error $\Delta\Gamma_H/\Gamma_H$ of total Higgs width.

4 Measurement of $\Gamma_{total}(H^0 \rightarrow X)$

We now discuss the calculation of $\Gamma_{total}(H^0)$ following the one given by A. Miyamoto in [17]. In the Higgsstrahlung process $e^+e^- \rightarrow ZH$, where $H \rightarrow WW^*$,

$$N_{WW} = c_0 \cdot \sigma_{total} \cdot Br(H \rightarrow WW^*)$$

where N_{WW} is the number of observed events in WW^* mode. σ_{total} is the total cross section of the Higgsstrahlung process, $Br(H \rightarrow WW^*)$ is the branching ratio of $H \rightarrow WW^*$, and c_0 is a constant. σ_{total} and $Br(H \rightarrow WW^*)$ can be expressed by the partial widths of $H \rightarrow ZZ$ and of $H \rightarrow WW$ and the total width of $H \rightarrow X$ as

$$\sigma_{total} = c_1 \cdot \Gamma_{HZZ} \text{ and } Br(H \rightarrow WW) = \Gamma_{HWW} / \Gamma_{HZZ}$$

where c_1 is a constant. In the $SU(2) \times U(1)$ model of gauge bosons there is a relationship between Γ_{HWW} and Γ_{HZZ} from which we may write

$$\Gamma_{total} = \frac{\sigma_{total}}{c_1 \cdot c_2 \cdot Br(H \rightarrow WW)} = \frac{c_0 \cdot \sigma^2_{otal}}{c_1 \cdot c_2 \cdot N_{WW}}$$

where $c_2 = \Gamma_{HZZ} / \Gamma_{HWW}$. Thus we can obtain Γ_{total} from the observed number of events, if σ_{total} is known.

σ_{total} is obtainable in many ways. To mention one, we can measure $e^+e^- \rightarrow Z(\rightarrow l^+l^-)H$. Here we only have to measure the leptonic pair from the Z boson and the production of H is identified from the recoil mass of the l^+l^- system. This procedure does not rely on the decay mode of H and is therefore suitable to search for Higgs bosons without any model dependence of the H decay mode. If σ_{total} = 150fb and the detection efficiency of 50% is achieved, then we can expect 2250 events in the $e^+e^-/\mu^+\mu^-$ channel for 500fb^{-1} of integrated luminosity. In this case the statistical error of σ_{total} is 2% and would be good enough to compare to the error of $Br(H \rightarrow WW^*)$.

Table 2. *Final cut yields.*

Cuts	6 jets	$H \rightarrow b\bar{b}$	ZZ	WW	$q\bar{q}$
No cut	3906	62037	515000	2860000	1980000
$E_{vis} \geq 240GeV$	3717	44011	278125	1609105	616384
$P_t \leq 15GeV$	3522	36198	256736	1205935	581426
$P_l \leq 60GeV$	3518	36168	256297	1202724	580202
$N_{chg} \geq 42$	2620	17940	63948	194448	45208
Thrust [0.6,0.8]	2065	13096	24365	21540	8401
$N_{jets} \geq 6$	762	1518	2853	3749	709
$E_{jet} \leq 15GeV$	681	1294	2460	3288	597
$\lvert\cos\theta_{jet}\rvert \leq 0.9$	411	749	1122	1473	314
$N_{trksjet} \geq 5$	358	654	879	1007	274
$M_Z, \lvert P_Z \rvert, M_W$	85	135	128	116	43
$N_{off\text{-}VTX} \leq 5$	72	69	102	103	30
Higgs entries	72	69	102	103	30
Extrapolated Higgs entries	72	69	102	234	242

Note now that the above analysis assumes the correctness of the SM, which means there exists a SM Higgs boson. However, even if we do not assume an SM Higgs particle, provided that the coupling of *H* to *WW* and the coupling of *H* to *ZZ* are universal, it can be shown that

$$\Gamma_{total} = \frac{\eta \int L dt}{N_{WW*}} \cdot \frac{\Gamma^{SM}_{HWW*}}{\sigma^{SM}} (\sigma^{x})^2$$

where η is the detection efficiency (the ratio of observed events to the generated events). $\Gamma^{SM}{}_{HWW*}$ and σ^{SM} are the partial width of $H \to WW^*$ and the total Higgsstrahlung cross section, respectively, according to the Standard Model. σ^{x} is the Higgsstrahlung cross section without the SM assumption and will be measurable after Higgs discovery at the collider.

In any case, the actual value of $\Gamma_{total}(H \to X)$ will be determined by experiment. From the extrapolated values observed *H* events (plus background) in table \ref{cutres} we can calculate the relative error in the measurement of $\Gamma_{total}(H \to X)$:

$$\frac{\Delta\Gamma_{total}}{\Gamma_{total}} \cong \frac{\Delta N_{WW*}}{N_{WW*}} = \frac{\sqrt{S+B}}{S} = \frac{\sqrt{72+69+102+242+234}}{72} \approx 37.2\%$$

where *S* is the number of 6-jet signals observed after the cuts and *B* is the number of background events mimicking the signal. Only N_{WW*} is considered to be the main contributor of statistical error since σ's and Γ_{HWW} can be measured quite accurately.

As mentioned earlier, the best possible measurement is at the level of 5% relative error with the use of the leptonic $H \to WW^*$ decay modes. Therefore, the above method for measuring the 6-jet Higgs channel must be improved to make it a feasible Higgs measurement at the linear collider.

5 Summary

We have investigated the possibility of using the fully hadronic 6-jet Higgs channel at JLC to measure the total decay width of the Higgs boson using the JLC Study Framework. The value of the relative error of $\Gamma_{total}(H \to X)$ obtained through this method is quite large compared to the superior measurement using leptonic or semi-leptonic channels of $H \to WW^*$. Nevertheless, efforts could be made to improve the technique for dealing with the 6-jet channel.

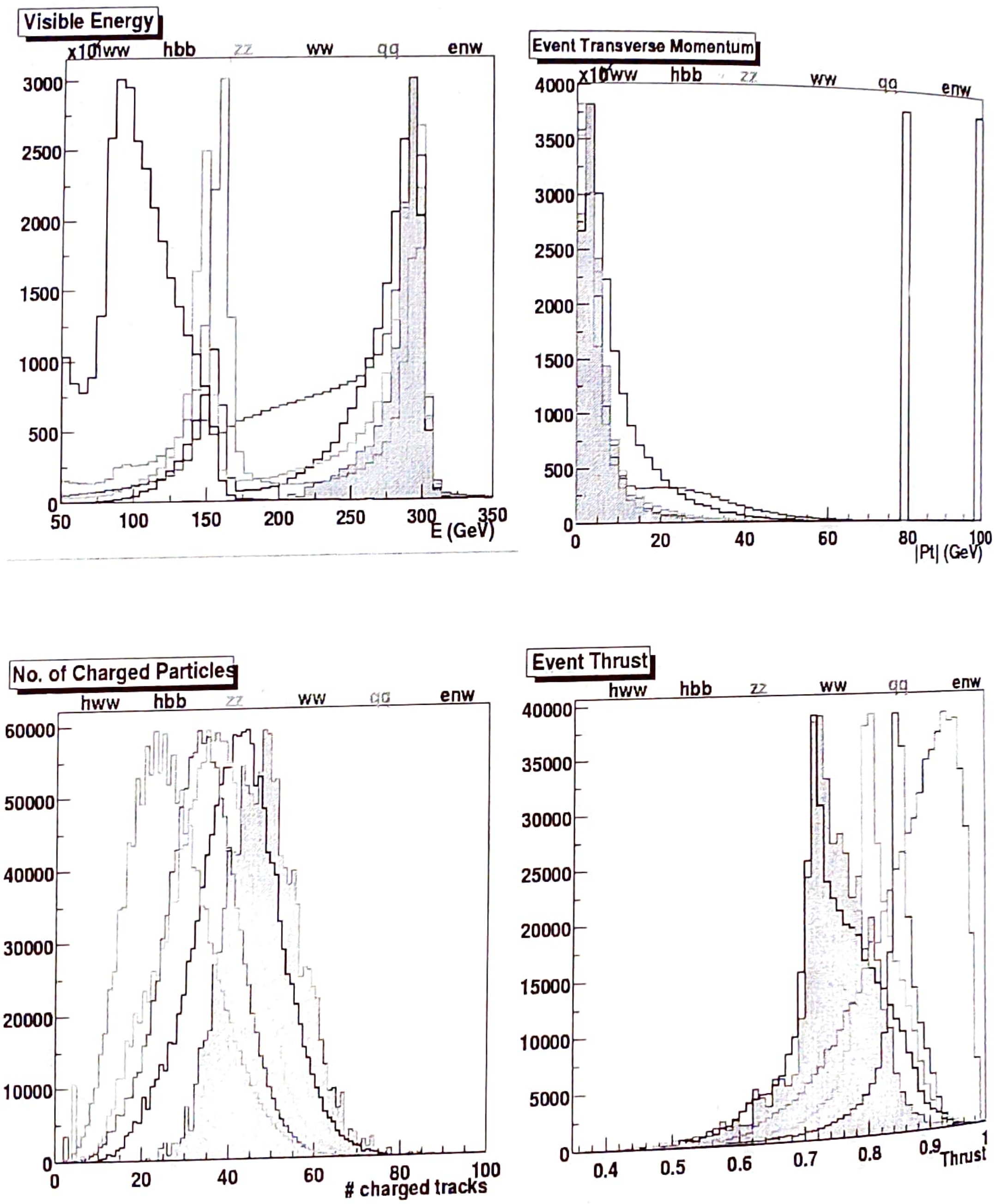

Figure 7. Arbitrarily scaled histograms of cut variables.

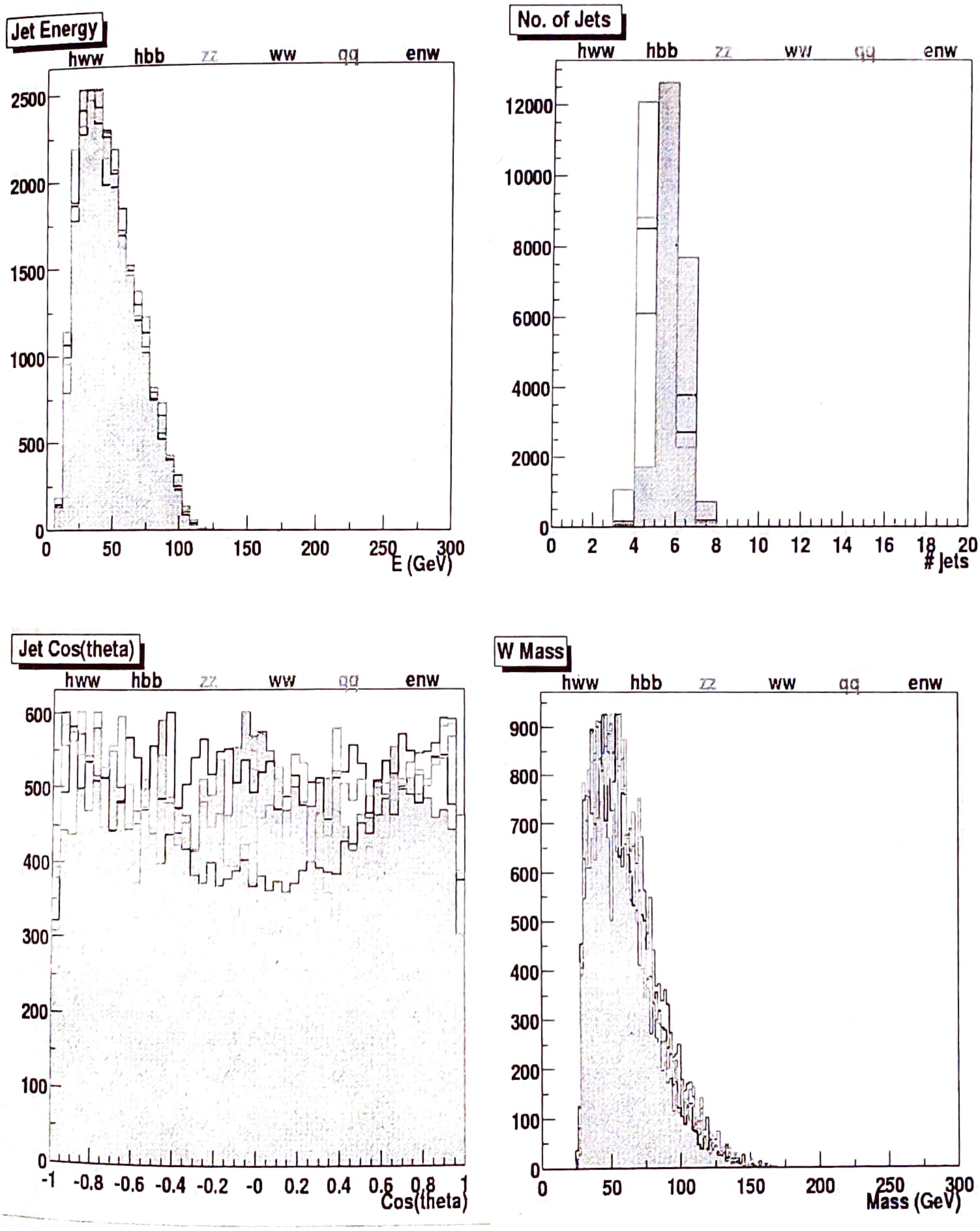

Figure 8. Arbitrarily scaled histograms of cut variables (continued).

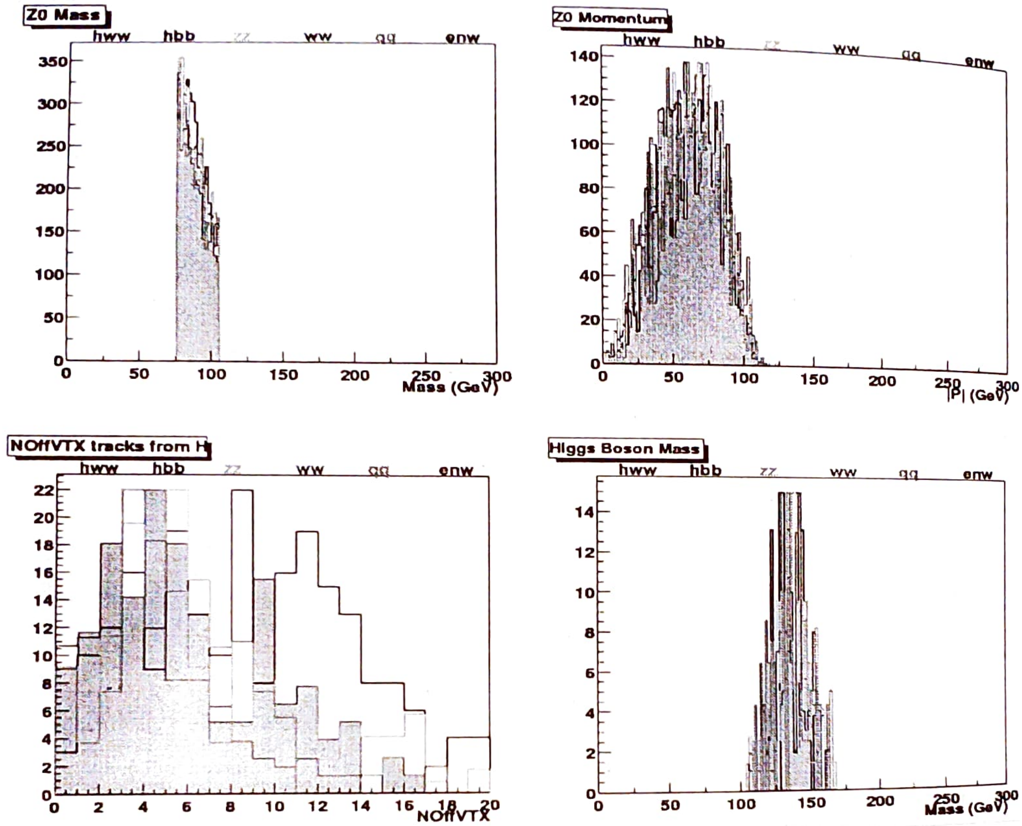

***Figure 9**. Arbitrarily scaled histograms of cut variables (continued).*

References

[1] S. L. Glashow, *Nucl. Phys.* **22** (1961) 579; S. Weinberg, *Phys. Rev. Lett.* **19** (1967); A. Salam, *Proc. 8th Nobel Symp.*, Stockholm, ed. by N. Svartholm (Almqvist and Wiksell, Stockholm, 1968) p. 367.
[2] ACFA Home Page, http://acfahep.kek.jp.
[3] JLC Project Home Page, http://www-jlc.kek.jp.
[4] The JLC Group, *JLC-I*, KEK Report 92-16, Dec. 1992.
[5] I. Nakamura, *Higgs Measurement at JLC-I*, Talk at LCWS99, Sitges, Barcelona, Spain, Apr. 28 - May 5, 1999.
[6] G. Borisov and F. Richard, *Precise measurement of Higgs decay rate into WW* at future e^+e^- Linear Colliders*, Talk at LCWS99; hep-ph/9905413.
[7] M. D. Hildreth, et al., *Phys. Rev.* **D49** (1994) 3441; SLAC-PUB-6358, Oct. 1993.
[8] M. Sachwitz, et al., DESY 97-123E; hep-ph/9706338.
[9] E. Boos, et al., DESY 99-109; hep-ph/9908487.
[10] M. Battaglia, *Measuring Higgs Branching Ratios and telling the SM from a MSSM Higgs Boson at the e^+e^- Linear Collider*, Talk at LCWS99, hep-ph/9910271.
[11] A. Juste, *Higgs Mass Determination from Direct Reconstruction at a Linear e+e- Collider*, Talk at LCWS99, hep-ex/9912041.
[12] P. Garcia-Abia and W. Lohmann, hep-ex/9908065.
[13] S. Yamashita, *Higgs Study at JLC Phase 1*, Talk at 3rd ACFA Workshop on Physics/Detector at the Linear Collider, Taipei, Taiwan, Aug. 9-11, 2000.
[14] JSF Home Page, http://www-jlc.kek.jp/subg/offl/jsf/.
[15] ROOT Home Page, http://root.cern.ch/.
[16] Physsim Home Page, http://www-jlc.kek.jp/subg/offl/physsim/.
[17] A. Miyamoto, *Short memo about $H \rightarrow WW^*$ analysis*, ACFA-SIM private communication, June 12, 2000 (Part 1) and June 22, 2000 (Part 2).