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

Study of Invariant Mass Resolution of the W Boson

DENNIS AROGANCIA, JINGLE MAGALLANES
HERMOGENES GOOC, ALLISTER LEVI C. SANCHEZ
AGELINA M. BACALA, Ph.D., AKIYA MIYAMOTO
KEISUKE FUJII

Abstract

Our modern understanding on the study of elementary particles is the Standard Model (SM). It has been successful in predicting and explaining the existence and behavior of all known constituent particles in nature. The only remaining particle which the SM predicted to exist is the Higgs boson. It has not been observed experimentally. In the elusive search for this particle the Asian Committee for Future Accelerators (ACFA) has proposed the construction of the Joint Linear Collider (JLC) with center-of-mass energy of 500 GeV to 1.5 TeV. The main purpose of this collider is to discover the Higgs boson. Since this particle is sensitive to precision measurements of the weak bosons we investigate the reaction $e^+e^- \rightarrow e^\pm \nu W^\mp$ *, where the W boson decays into two hadronic jets. This study focuses on the invariant mass measurement of the W boson using the 2-jet decay channel with and without beamsstrahlung (BM) and initial state radiation (ISR) effects. The mass of the W boson can be used to constraint the mass of the Higgs boson [1]. The JLC Study Framework (JSF) is employed for this purpose. The center of mass energy is set at 500 GeV.*

DENNIS C. AROGANCIA, JINGLE MAGALLANES, HERMOGENES GOOD, ALLISTER LEVI SANCHEZ and Dr. ANGELINA M. BACALA are faculty members of the MSU-IIT Physics Department. AKIYA MIYAMOTO and KEISUKE FUJII are from the Institute of Particle and Nuclear Science, KEK, Japan.

Introduction

The Standard Model (SM) asserts that the matter is ultimately composed of three generations of pointlike particles called quarks and leptons and their intermediary particles called gauge bosons. For three decades now, the validity of the SM has been demonstrated in all major experiments in particle physics whether using accelerators or not. For example, the intermediaries for beta decay, called the weak bosons, W, were first measured in 1983 at CERN [2] and the top quark at the Fermilab TEVATRON [3]. The only remaining particle predicted by the Standard Model that has not been found is the Higgs boson. Since the Higgs boson is sensitive to the precision measurements of the weak bosons, we investigate the reaction using computer simulation work at Mindanao's Computational Physics Laboratory. This reaction is dominated by the following Feynman diagrams[4] as shown in *Figure 1*. This reaction is chosen because of its large cross section at JLC energy region due to t-channel diagram. In addition, there is no ambiguity due to gluon exchange among final state quarks for W mass measurement using hadronic decays.

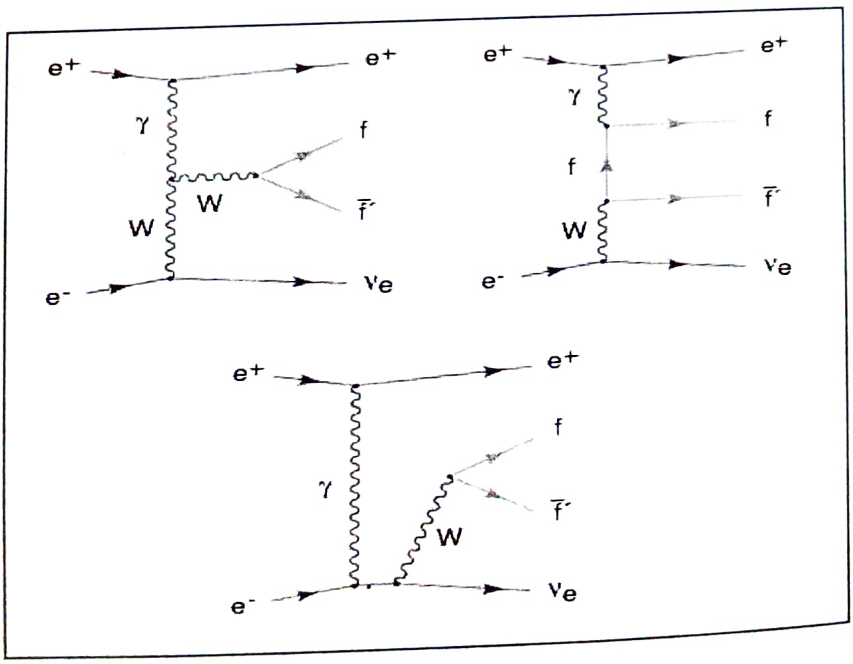

***Figure 1.** Dominant Feynman diagrams for the reaction* $e^+e^- \rightarrow e^{\pm}\nu W^{\mp}$

2 Methodology

2.1 Event generation

$e^+e^- \rightarrow e^+\nu W^\mp$ events are generated using the BASES/SPRING of PhysSim[5] At a center-of-mass energy of 500 GeV, we consider the following backgrounds such as $e^+e^- \rightarrow e^\pm e^\mp Z^0$ and $e^+e^- \rightarrow W^\pm W^\mp$ These are generated using the same event generator as above. We use an integrated luminosity of 100 fb^{-1}. In PhysSim, the generators are used in the following steps:

1. Monte Carlo integration (BASES step),
2. Event generation (SPRING step),
3. Data analysis through GUI

The BASES step is the calculation of cross section in such process. This is necessary for the SPRING step. The center of mass energy is set 500 GeV. Cross sections for the target and background signal are calculated with and without beamstrahlung and initial state radiation (ISR) effects.

The results of the calculation are as follows:

1. With beamstrahlung + ISR
   - enuW process: 6267 ± 5 fb
   - eeZ process: 6837 ± 5 fb
   - WW process: 9684 ± 5 fb
2. With ISR only
   - enuW process: 6411 ± 5 fb
   - eeZ process: 6886 ± 6 fb
   - WW process: 9512 ± 5 fb

In the cross section calculation, some of the constant parameters are: W mass = 80.419 GeV/c^2, Z mass = 91.1882 GeV/c^2, Γ_W = 2.12 GeV and Γ_Z = 2.492 GeV.

2.2 Detector Simulation

Simulation of events is done using the QuickSimulator of JSF wherein a 3 Tesla solenoid is used. Event display is shown through GUI (Graphical User Interfaced) as shown below.

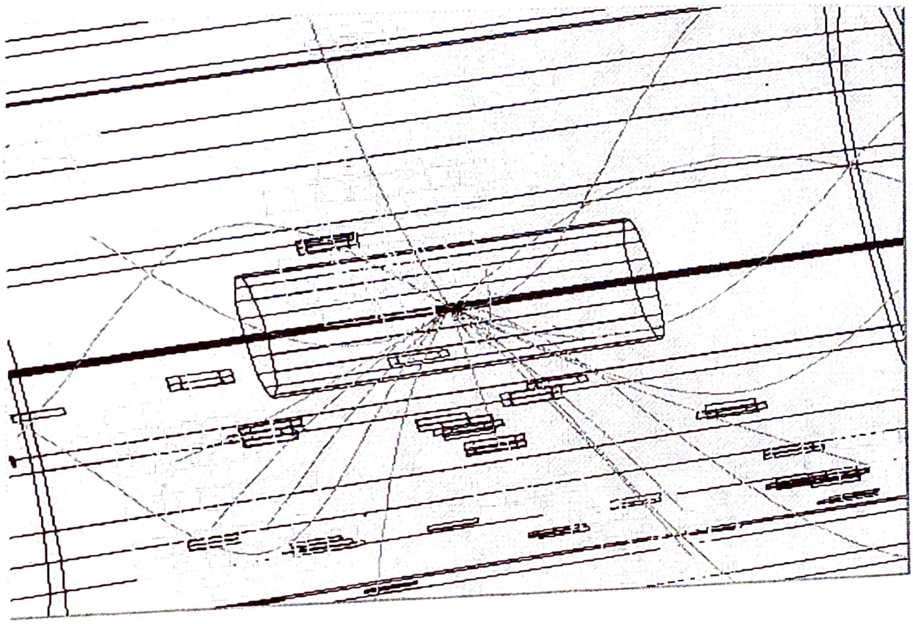

Figure 2. A typical $e^+e^- \rightarrow e^{\pm}\nu W^{\mp}$ *event*

3 Data Analysis

After gathering generated and simulated data, they are analyzed separately. We formulate a selection criteria for each analysis and impose mass fitting using the Lorentzian function [6]. Mass fitting is done to check the consistency of the data being gathered and the correctness of the procedure used.

3.1 Analysis of generator data

The purpose of studying generator data is to check whether we can achieve good W mass resolution and to know the effects of the missing neutrino and undetected particles to the W mass resolution.

Summary of the selection criteria is given below:

- Select events where the W boson decays to quarks
- Remove neutrinos and particles that goes into the beam pipe direction and plot invariant mass of all stable particles
- Apply cuts on generator tracks with cos θ (direction) such as 0.9988, 0.9950, 0.9888, etc.

After plotting the invariant mass of stable particles mass fitting is done to obtain the mass of the W boson. We also calculate the invariant mass difference of the generated W mass and the mass of all stable particles.

3.2 Analysis of simulator data

The background signals for the process $e^{+}e^{-} \rightarrow e^{\pm}\nu W^{\mp}$ which is our target signal are $e^{+}e^{-} \rightarrow e^{\pm}e^{\mp}Z^{0}$ and $e^{+}e^{-} \rightarrow W^{\pm}W^{\mp}$Thus, we imposed the following selection criteria to discriminate these signals from the target signal.

a. With beamstrahlung + ISR

- E_{vis} = visible energy is from 78 GeV to 174 GeV
- P_{t} = transverse momentum is greater than 33 GeV
- P_{l} = longitudinal momentum is less than 10 GeV
- thrust = event thrust is from 0.60 to 0.88
- N_{jet} = number of jets is 2
- E_{jet} = Jet energy is from 25 GeV to 80 GeV
- $|cos\ \theta_{jet}|$ = |cos θ| of jets is less than 0.70

b. With ISR only

Similar as above but with some modifications:

- E_{vis} = visible energy is from 78 GeV to 180 GeV
- P_{t} = transverse momentum is greater than 36 GeV

Jet clustering uses JADE algorithm of PhysSim. Similarly, mass fitting is also employed.

3.3 Mass fitting

In fitting the sample data, we used the Lorenztian function in Breit-Wigner form given by

$$f(s) = \frac{N m_w \Gamma_w s}{\pi[((s - m_w)(s + m_w))^2 + (s\Gamma_w)^2]}$$

where

N - the normalization function

s - the (reconstructed invariant mass)^2

Γ_w - the total width of W

m_w - the mass of W

The input values are the following:

$m_w = 80.419$ GeV

$\Gamma_w = 2.12$ GeV

4 Results

On the analysis of the generator data we are able to obtain a W mass resolution of less 10 MeV which is the expected performance of the JLC detector. If we include detector smearing effects, in which we study the simulator data we obtain a statistical error of more 40 MeV. According to the mass fitting, the difference from the input mass if more than 2 GeV. Table 4.5 shows the statistics of the selection criteria. The result is not satisfactory since we need an order of 100k events for the determination of the W mass. Tables 4.1 and 4.2 summarize the result on the mass fitting. Figures 3 to 6 show the plot on the invariant mass with mass fitting.

Table 4.1 Generator data (Fitted)

with beamstrahlung + ISR	with ISR
$M_W = 80.4448 \pm 0.0035$	$M_W = 80.5090 \pm 0.0034$
$M_{ivm} = 80.4097 \pm 0.0045$*	$M_{ivm} = 80.4173 \pm 0.0045$*

Table 4.2 Simulator data (Fitted)

with beamstrahlung + ISR	with ISR
M_{jj} = 79.0333 ± 0.0623	M_{jj} = 79.1301 ± 0.0614
M_p = 78.6320 ± 0.0484*	M_p = 78.6563 ± 0.0439*

*no cut on |cos θ|

where

M_w - generated W boson mass
M_{ivm} - invariant mass of all stable particles
M_{jj} - jet pair invariant mass
M_p - invariant mass of all detected particles

In the calculation invariant mass difference of the generated W mass and the mass of stable particles, we obtain mass difference of less than 10 MeV if we don't apply cut on the direction of the generator tracks. The assumed performance of the JLC detector is about 80% detection efficiency, thus in our case about 5% of events are covered by the detector. Tables 4.3 and 4.4 show the effect of the cut on the direction of the generator tracks.

Generator data

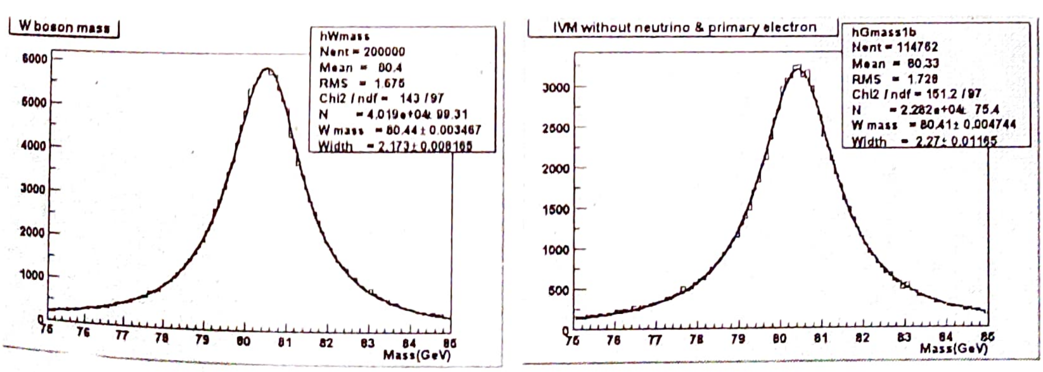

Figure 3. *Invariant mass of generated W and stable particles (without primary electron and neutrino) with beamsstrahlung and initial state radiation.*

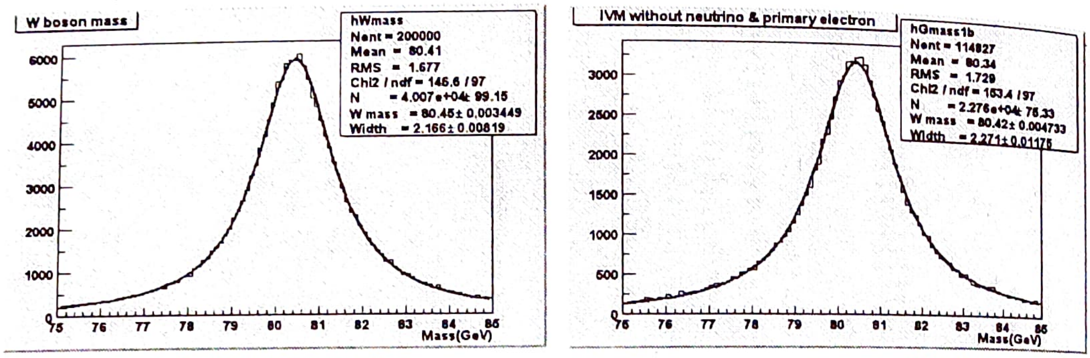

Figure 4. *Invariant mass of generated W and stable particles (without primary electron and neutrino) with initial state radiation only.*

Simulator data

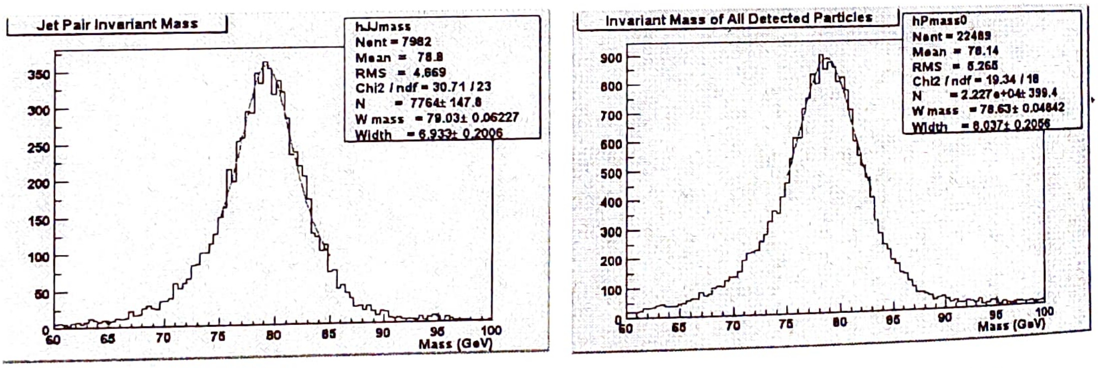

Figure 5. *Invariant mass of jet pair and all detected particles with beamsstrahlung and initial state radiation.*

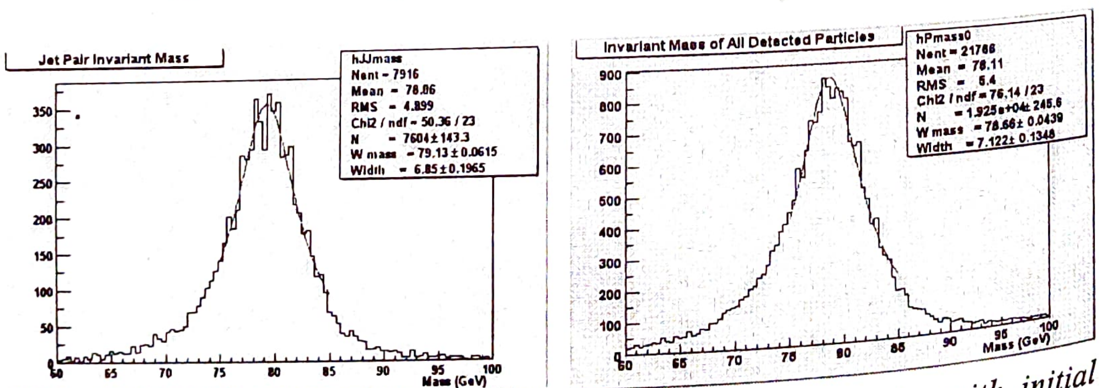

Figure 6. *Invariant mass of jet pair and all detected particles with initial state radiation only.*

Table 4.3. Invariant Mass Difference (with beamstrahlung + ISR)

Histogram ID	Number of Events	Fraction (%)	Selection Criteria
Gdmass	135148	100.00	Total Events
Gdmass1b	121692	90.00	Without neutrino
Gdmass2b	113484	83.97	$\lvert\cos\theta\rvert < 0.9988$
Gdmass3b	97984	72.50	$\lvert\cos\theta\rvert < 0.9950$
Gdmass4b	82060	60.72	$\lvert\cos\theta\rvert < 0.9888$
Gdmass5b	67100	49.64	$\lvert\cos\theta\rvert < 0.9800$
Gdmass6b	40540	30.00	$\lvert\cos\theta\rvert < 0.9500$
Gdmass7b	21834	16.15	$\lvert\cos\theta\rvert < 0.9000$
Gdmass8b	12716	9.41	$\lvert\cos\theta\rvert < 0.8500$
Gdmass9b	7568	5.60	$\lvert\cos\theta\rvert < 0.8000$
Gdmass10b	2612	1.97	$\lvert\cos\theta\rvert < 0.7000$

Table 4.4. Invariant Mass Difference (with ISR only)

Histogram ID	Number of Events	Fraction (%)	Selection Criteria
Gdmass	134660	100.00	Total Events
Gdmass1b	121524	90.20	Without neutrino
Gdmass2b	112984	83.90	$\lvert\cos\theta\rvert < 0.9988$
Gdmass3b	97300	72.25	$\lvert\cos\theta\rvert < 0.9950$
Gdmass4b	81348	60.40	$\lvert\cos\theta\rvert < 0.9888$
Gdmass5b	66788	49.60	$\lvert\cos\theta\rvert < 0.9800$
Gdmass6b	40044	29.70	$\lvert\cos\theta\rvert < 0.9500$
Gdmass7b	21200	15.74	$\lvert\cos\theta\rvert < 0.9000$
Gdmass8b	12016	8.92	$\lvert\cos\theta\rvert < 0.8500$
Gdmass9b	7160	5.30	$\lvert\cos\theta\rvert < 0.8000$
Gdmass10b	2604	1.90	$\lvert\cos\theta\rvert < 0.7000$

Table 4.5. Statistics of the selection criteria

	enuW	eeZ	WW
With BM + ISR			
No cut	626700	683600	968400
Nchg ≥ 3	428268	467691	113763
Evis [78,174]	296349	136373	19233
P_t ≥ 33 GeV	211681	13763	9109
Pl ≤ ± 10 GeV	22489	637	697
Thrust[0.60, 0.88]	14772	343	382
Ejet[25,80]	13312	327	353
Cosjetmax ≤ 0.7	7982	77	77
With ISR only			
No cut	641100	688600	951200
Nchg ≥ 3	437665	468818	100272
Evis [78,180]	309558	144689	18012
P_t ≥ 33 GeV	210224	7548	7486
Pl = ± 10 GeV	21766	471	503
Thrust[0.60, 0.88]	14667	267	282
Ejet[25,80]	13167	236	263
Cosjetmax ≤ 0.7	7916	16	36

5. Summary and Conclusion

In this study, we have focused on the measurement of the W boson mass with and without beamstrahlung and initial state radiation (ISR) effects at center of mass of 500GeV. From the process $e^+e^- \rightarrow e^{\pm}\nu W^{\mp}$ the statistical error of W mass for 200k events, which corresponds to about the integrated luminosity of 31.9 fb^{-1}, is less than 10 MeV, when effects due to detector smearing are neglected. Regarding on the plot on the cut of the cos θ versus the number of events, about 50% of the events has tracks whose |cos θ| < 0.9800 and if we lost tracks the reconstructed mass of the W boson is different with the generated one by more than 100 MeV most of the case. When detector effects are included, the statistical error is more than 40 MeV while the shift of the mass from the input value is more than 1 GeV. The large systematic effect is due to the limited detector acceptance and resolutions. The initial event selection criteria was able to discriminate most of the background signals in the two-jet selection. Further study to understand the source of systematic effects and improved analysis method is now in progress.

Acknowledgment

Our deepest thanks to MSU-IIT for providing technical support, CHED for the financial support to our school, and most especially to our collaborators at KEK, Japan.

References

[1] ACFA Linear Collider Working Group, *Particle Physics Experiments at JLC,* KEK report 2001-11, August 2001

[2] UA1 Collaboration, Physics Letters B , 122, 103 (1983); UA2 Collaboration, Physics Letters B, 122, 476 (1983)

[3] H. Przysiezniak, *Precision Electroweak Measurements*, hep-ex/0101008, January 2001

[4] L3 Collaboration, *Production of Single W Bosons at LEP*. CERN-PPE/97-28, March 2001

[5] Webpage for the Physics Study Libraries: http://www-kek.jp/subg/offlphyssim

[6] Private communications with Prof. Akiya Miyamoto