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$d\sigma/dy$ distribution of $Z/\gamma^* \to ee$ decay mode

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Abstract

We report on the measurement of the rapidity distribution, $d\sigma/dy$, over the full kinematic range for e^+e^- pairs in the Z boson region of $66 < M_{ee} < 116$ GeV/c^2. The data sample is consistent of 850 pb^{-1} of $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV taken by the Collider Detector at Fermilab. $d\sigma/dy$ are compared with theory prediction.

1. Introduction

Measurements of rapidity distribution and total cross section of Drell-Yan pairs in the Z boson region provide a stringent test of QCD calculations in leading order(LO), next to leading order(NLO). Figure 1 shows the Feynman diagram for γ^*/Z boson production in the $p\bar{p}$ collision. In leading order, the process is $q+\bar{q} \to \gamma^*/Z$, i.e. a quark from the p annihilates with the anti-quark from the $\bar{p}$ to form a virtual γ^* or Z boson.Two partons, carrying momentum fractions $x1$ and $x2$, participate in the interaction. The final state from this process are two leptons from the γ^*/Z decays.The emission of gluons in the initial state is taken into account in calculations which include next to leading order(NLO) corrections in the strong interaction. In LO, the momentum fraction $x_1(x_2)$ carried by the partons from the proton(antiproton) is related to the rapidity(y) of the Z boson via the equation:

$$x_1 = M_Z e^{y} s^{-1/2} \quad , \; x_2 = M_Z e^{-y} s^{-1/2} \tag{1}$$

where s is the center of mass energy and M_z is the mass of Z boson. Figure 2 shows $x_1(x_2)$ as a function of y.

In this analysis, $d\sigma(\gamma^*/Z)/dy$ distribution are measured using dielectrons from γ^*/Z decays. This analysis extends the measurement in the dielectron channel to high rapidity by including e^+e^- pairs in plug-plug regions of the detector.

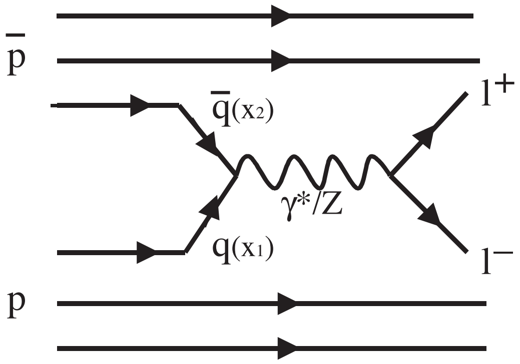


Figure 1: This is Feynman diagram for γ^*/Z production in a $p\bar{p}$ collision.

2. Data sample

2.1. Data

This data is produced from bhel0d,bhel0h and bhel0i which is passed 6.1.2 ProductionExe and pass17. $Z\_NOTRACK$ trigger is used for central-central, central-plug, and plug-plug region. DQM v13 good run electron is required, specially, DQM v10 good run electron with silicon is used for plug-plug region because of phoenix track requirement in this region. The data size is $844.2pb^{-1}$ in central-central and central-plug region and $781.5pb^{-1}$ in plug-plug region. $Z\_NOTRACK$ starts from run number=143938, so luminosity is counted after that.

2.2. MC

Monte Carlo data are used for study of detector acceptance and Z efficiency. Datasets were generated and simulated using version 5.3.1 and 6.1.2 of the CDF Run 2 software(zewk6d and zewkad). We use 8M PYTHIA Drell-Yan $Z^0/\gamma^* \to e^+e^-$ events.

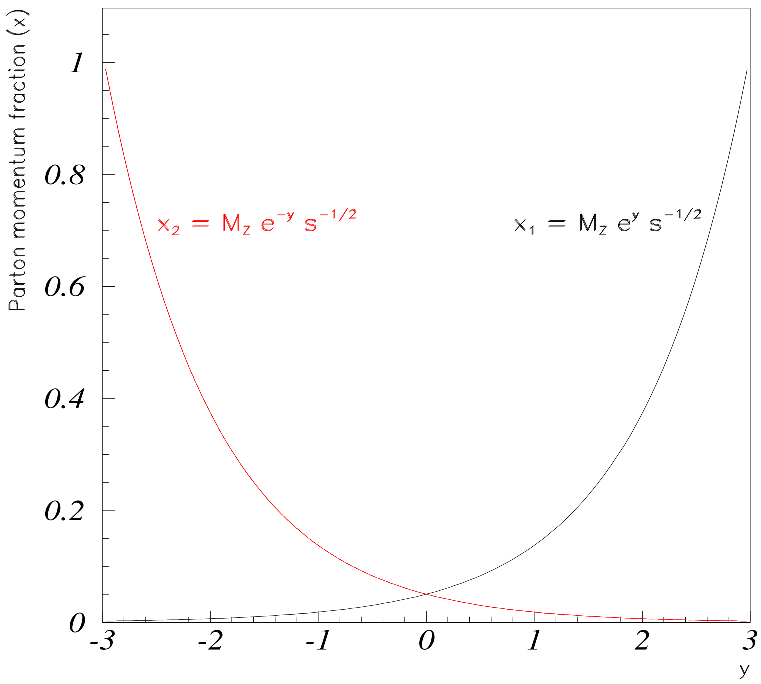


Figure 2: This plot shows the relation between the momentum fraction, x and rapidity of Z boson.

3. Luminous Region Acceptance

We require $|z_{vertex}| < 60cm$. The estimation of the associated efficiency is described in CDF 6331[1] and has the result

$$\epsilon_{vertex} = 95.0 \pm 0.2(stat.) \pm 0.3(syst.) \tag{2}$$

4. Trigger Efficiency

We consider events triggering the $Z\_NOTRACK$ trigger path. $Z\_NOTRACK$ has $L1\_EM8$, $L2\_TWO\_EM16$, and $L3\_TWO\_ELECTRON18$ trigger path. Table 1 explain the condition of each level. To get $Z\_NOTRACK$ trigger efficiency for one plug electron, we select Z(CP) passing $CENTRAL\_ELECTRON18$ trigger path,and then check $Z\_NOTRACK$ trigger bit. And to get $Z\_NOTRACK$ trigger efficiency for one central electron, we select Z(CP) passing $PLUG\_ELECTRON\_20$ trigger path,and then check $Z\_NOTRACK$ trigger bit. For the trigger efficiency of one central electron is already efficient, so there's no eta dependency. So, we use only one Et dependant trigger efficiency for the central electron. But, the trigger efficiency of one plug electron gets lower in higher eta region. So, we divide the eta into 5 region, which the last bin is combined with east and west side to get enough statistics. The Et dependant trigger effieicny is fitted with error function. And we convolute the Et dependant trigger efficiency into the rapidity depentant trigger efficiency with $Z \to ee$ MC sample. In MC, Z decays two electrons and the electron has Et,whihc is E_{t1} and E_{t2} corrected by energy scale. Then, the trigger efficiency in the rapidity of Z is $\epsilon(E_{t1}) \times \epsilon(E_{t2})$. Figure 3 shows the trigger efficiency which depends on E_t and Figure 4 shows the trigger efficiency in rapidity of Z.
Table 2 summarizes the trigger efficiency in each region. And Figure 4 shows the trigger efficiency in rapidity.

$$\epsilon(\mathsf{Z\_NOTRACK, centralel}) = \frac{\mathsf{Z\_NOTRACK\ \ \&\ \ PLUG\_ELECTRON20\ \ \&\ \ Z(CP)}}{\mathsf{PLUG\_ELECTRON20\ \ \&\ \ Z(CP)}} \tag{3}$$

$$\epsilon(\mathsf{Z\_NOTRACK, plugel}) = \frac{\mathsf{Z\_NOTRACK\ \ \&\ \ ELECTRON\_CENTRAL18\ \ \&\ \ Z(CP)}}{\mathsf{ELECTRON\_CENTRAL18\ \ \&\ \ Z(CP)}} \tag{4}$$

	cuts
$L1\_EM8$	$hadEm(central) > 0.125$ $E_t(central) > 8\ GeV$ $hadEm(plug) > 0.125$ $E_t(plug) > 8\ GeV$
$L2\_TWO\_EM16$	$numberofEmObject = 2$ $hadEm > 0.125$ $E_t > 16\ GeV$ $0.0 < \|eta\| < 3.6$
$L3\_TWO\_ELECTRON18$	$numberofEmObject = 2$ $E_t(central) > 18\ GeV$ $E_t(plug) > 18\ GeV$

Table 1: $Z\_NOTRACK$ trigger path condition

Region	total	east	west
Z_{cc}	0.99999 ± 0.00001	0.99999 ± 0.00001	0.99999 ± 0.00001
Z_{cp}	0.94962 ± 0.00033	0.94875 ± 0.00047	0.95049 ± 0.00047
Z_{pp}	0.98217 ± 0.00033	0.98091 ± 0.00048	0.98342 ± 0.00045

Table 2: $Z\_NOTRACK$ trigger efficiency

5. Phoenix Track Efficiency

The phoenix track is required for one electron of Z(PP) to reduce the background. Plug region doesn't have any special tracker only for itself , so the background level in plug-plug topoloty is higher than any other one. Phoenix tracking efficiency for a plug electron is measured in data. To estimate this efficiency, we select the Z(CP) events and see the plug leg. The efficiency is defined as the number of events passing all plug ID cuts and having a phoenix track divided the number of events passing all plug ID cuts. The first plot of Figure 5 shows this track efficiency in for the data in pseudo-rapidity of the lepton for plug region. We should convolute this track efficiency

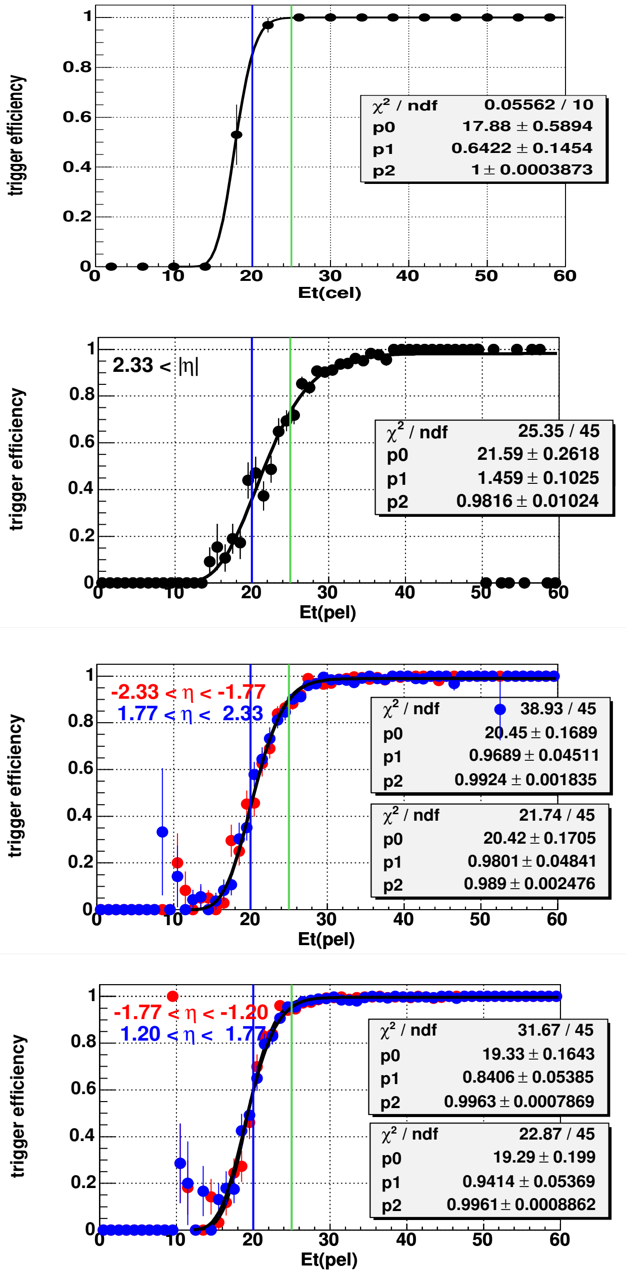


Figure 3: These plots show $Z\_NOTRACK$ trigger efficiency in E_t. The first plot is E_t dependance for the central electron, the other plots is E_t dependance for the plug electron in each eta region. Parameter $p0$ and $p1$ is the mean and the width of the gaussian of the error function. $p2$ is the normalization constant.

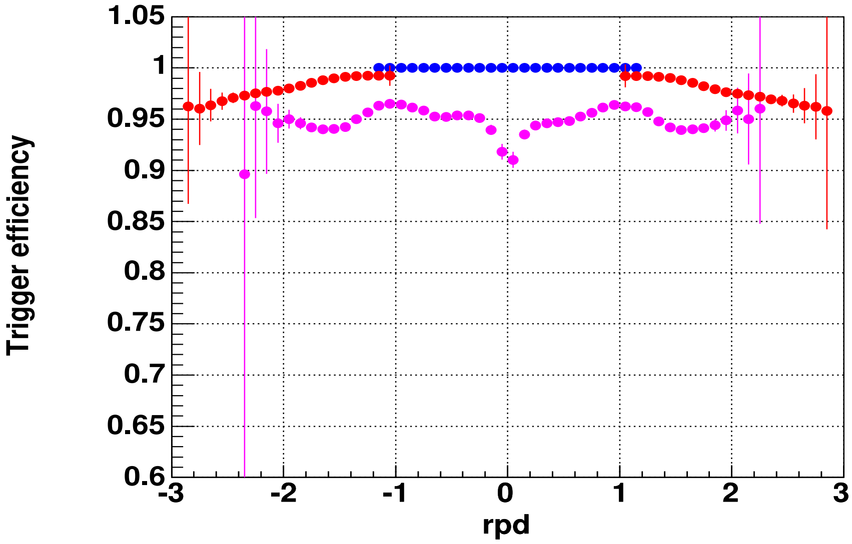


Figure 4: These plots show $Z\_NOTRACK$ trigger efficiency in rapidity. The plot is rapidity dependance after convoluting E_t trigger efficiency for $Z_{cc}, Z_{cp}, and Z_{pp}$ The blue dot is the efficiency for Z_{cc}, the magenta dot is the efficiency for Z_{cp} and the red dot is the efficiency for Z_{pp}.

into rapidity dependance of dielectron. So the same method which we used in $Z\_NOTRACK$ trigger efficiency is used here. The probability that one of two electrons has the phoenix track is

$$\epsilon(y_i) = \epsilon(\eta 1_i) \times (1 - \epsilon(\eta 2_i)) + \epsilon(\eta 2_i) \times (1 - \epsilon(\eta 1_i)) + \epsilon(\eta 1_i) \times \epsilon(\eta 2_i) \quad (5)$$

where $\eta 1_i$ and $\eta 2_i$ are the pseudo rapidity of the two electrons in i-th event. The second plot of Figure 5 shows rapidity dependance of phoenix track efficiency.

6. $Z^0/\gamma^* \to e^+e^-$ candidates

6.1. Central electron variable

The central leg of the Z candidates is selected using the current baseline cuts recommended by the Joint Physics Group. The definitions of quantities, corrections and cuts describing a central electron are used here as given in CDF 6281[3]. We used E_t calculated using $sin(\theta_{track})$ rather than from $z = 0$. And Beam-constrained COT-only tracks with curvature-correction are used. Table 3 summarized the central electron cuts.

Variable	Tight central	Loose central
E_t	$> 25(CC), 20(CP)\ GeV$	$> 25\ GeV$
Fiducial	fidEle = 1 or 4 (CES or Trk)	fidEle = 1 or 4 (CES or Trk)
Had/Em	$< 0.055 + 0.00045 \times E$	$< 0.055 + 0.00045 \times E$
$IsolationE$	< 4.0	< 4.0
P_t	$> 10\ GeV$	$> 10\ GeV$
E/P	$E/P < 2.0 or TrkPt > 50$	
z_{vertex}	$\|z_{track}\| < 60$	$\|z_{track}\| < 60$
COT quality	$AxSLswith5hits/SL > 3$	$AxSLswith5hits/SL > 3$
	$StSLswith5hits/SL > 2$	$StSLswith5hits/SL > 2$
Lshr	< 0.2	
Chi2Strip	< 10	
$Q \times delX$	$-3.0 < Q \times delX < 1.5$	
$\|dZ\|$	< 3.0	

Table 3: central electron cuts

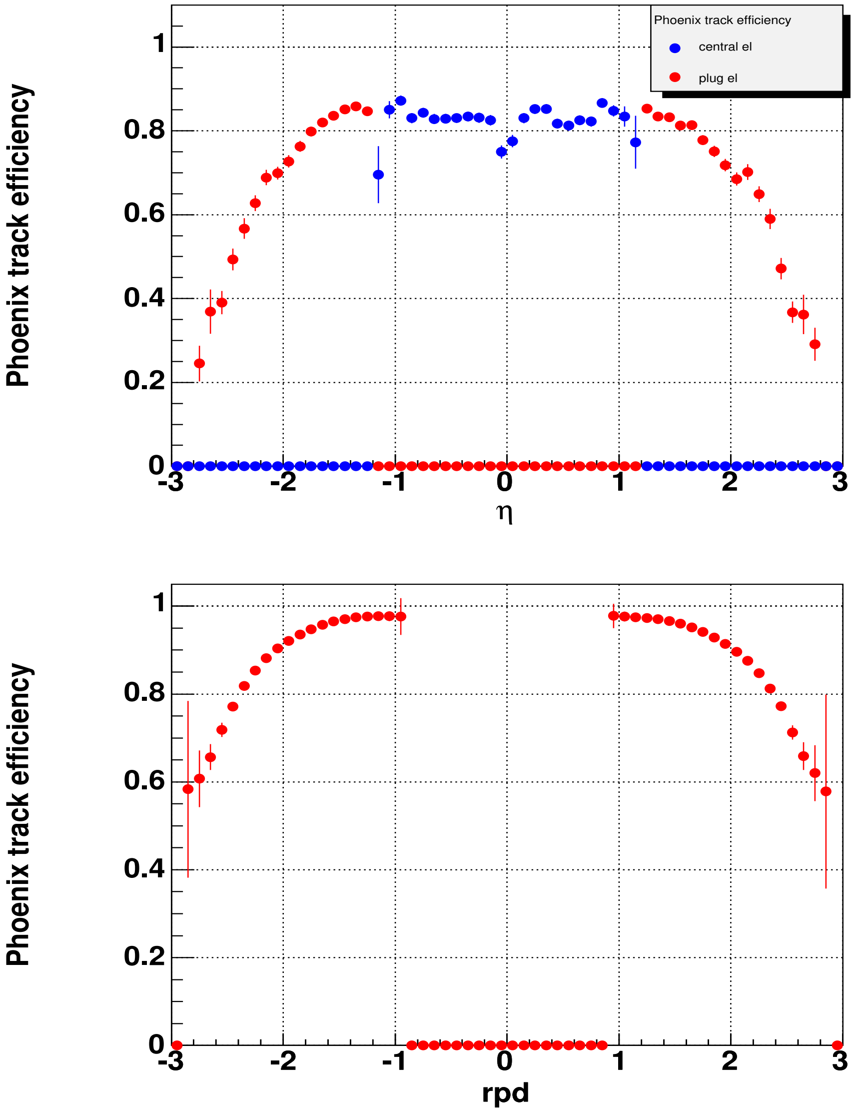


Figure 5: These plots show phoenix track efficiency in η and rapidity. The first plot is η dependance, the second plot is rapidity dependance after convoluting η dependance of track efficiency for one plug electron.

6.2. *Plug electron variable*

The plug leg of the Z candidates is also selected using the current baseline cuts recommended by the Electron Task Force. The definitions of quantities, corrections and cuts describing a plug electron are used here as given in CDF 6642[4]. We used E_t calculated using $sin(\theta_{track})$, use the central leg track for Z(CP) and the phoenix track for Z(PP), rather than from $z = 0$. And Beam-constrained COT-only tracks with curvature-correction are used. Table 4 summarized the plug electron cuts.

Variable	Phoenix electron	Plug electron
E_t	$> 25\ GeV$	$> 20(CP), 25(PP)\ GeV$
Fiducial	$1.2 < \lvert\eta\rvert < 2.8$	$1.2 < \lvert\eta\rvert < 2.8$
Had/Em	< 0.05	< 0.05
$IsolationE$	< 4.0	< 4.0
PemChi2	< 10	< 10
Phoenix SiHit number	> 2	

Table 4: plug electron cuts

6.3. *PPR Energy*

We compare the ratio of PPR Energy over pem3x3 Energy between data and MC in v5.3.1. MC has copper disk in the front of plug detector and phantom layers in the parallel of beam line. There are 10 phantom layers, which four phantom layers have 0.9cm thickness, two have 0.4cm, two have 0.15cm, one has 0.2cm and the other has 0.1cm. MC with these matarial has good agreements of data in the ratio between PPR Energy and total Energy, and the ratio is around 2%. This PPR Energy is added to Plug electron Energy when Z mass is reconstruced. Figure 6 shows this ratio in Detector η.

6.4. *Event Selection*

We consider the events with tight central electron and loose central electron for a central-central, with tight central electron and plug electron for a central-plug , and with phoenix electron and plug electron for a plug-plug $Z^0/\gamma^* \rightarrow e^+e^-$ candidate. In a central-central region, the events with only opposite charge is considered. Using these selection criteria, we find 22276 events of central-central region, 35309 events of central-plug region, and 13382 events

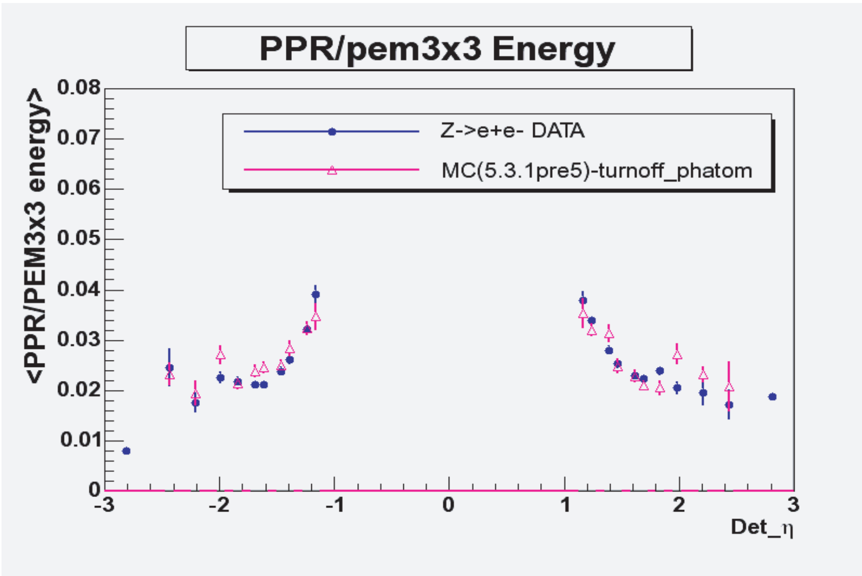


Figure 6: This is the ratio between PPR Energy and total Energy of plug electron in Detertor η. The blue line is data and the pink line is MC.

of plug-plug region in the invariant mass window between 66 and 116 GeV. The mean value of the invariant mass with PPR Energy is 90.93 GeV with width 2.69 in central-central region, 90.63 GeV with width 2.61 in central-plug region, and 90.06 GeV with width 2.98 in plug-plug region. Figure 7 shows the invariant mass and rapidity distribution in each region.

6.5. Energy Scale

We fit the mass distribution of the region, $86 < M_{ee} < 96\ GeV$ with Gaussian function in Data and MC sample. The mean of the mass in MC is higher than the mean of the mass in Data. So, we applied the energy scale into the MC to make the data and mc has the same mean of the mass. The energy scale for the central electron is obtained from the mass of $Z(CC)$. We apply the energy scale of the central electron into $Z(CP)$ and get the energy scale of the plug electron to make the mean of the mass in $Z(CP)$ be same in data and MC.
Table 5 and 6 summarizes the mean of the mass in data and MC from the fit result and the energy scale.

	mass in data	mass in MC(before,after energy scale)
$Z(CC)$	90.93 ± 0.07	$91.61 \pm 0.02 \to 90.96 \pm 0.02$
$Z(CP)$	90.63 ± 0.06	$91.64 \pm 0.01 \to 90.62 \pm 0.01$
$Z(PP)$	90.06 ± 0.05	$91.75 \pm 0.01 \to 90.18 \pm 0.01$

Table 5: The table shows the mean of the mass in data and MC.

	energy scale
central electron	0.9926 ± 0.0008
plug electron	0.9843 ± 0.0014

Table 6: The energy scale of the electron is summarized in the table.

7. Geometric and Kinematic Acceptance and Electron Efficiency

7.1. Geometric and Kinematic Acceptance

The detector acceptance for $Z^0/\gamma^* \to e^+e^-$ events is estimated using PYTHIA Monte Carlo.

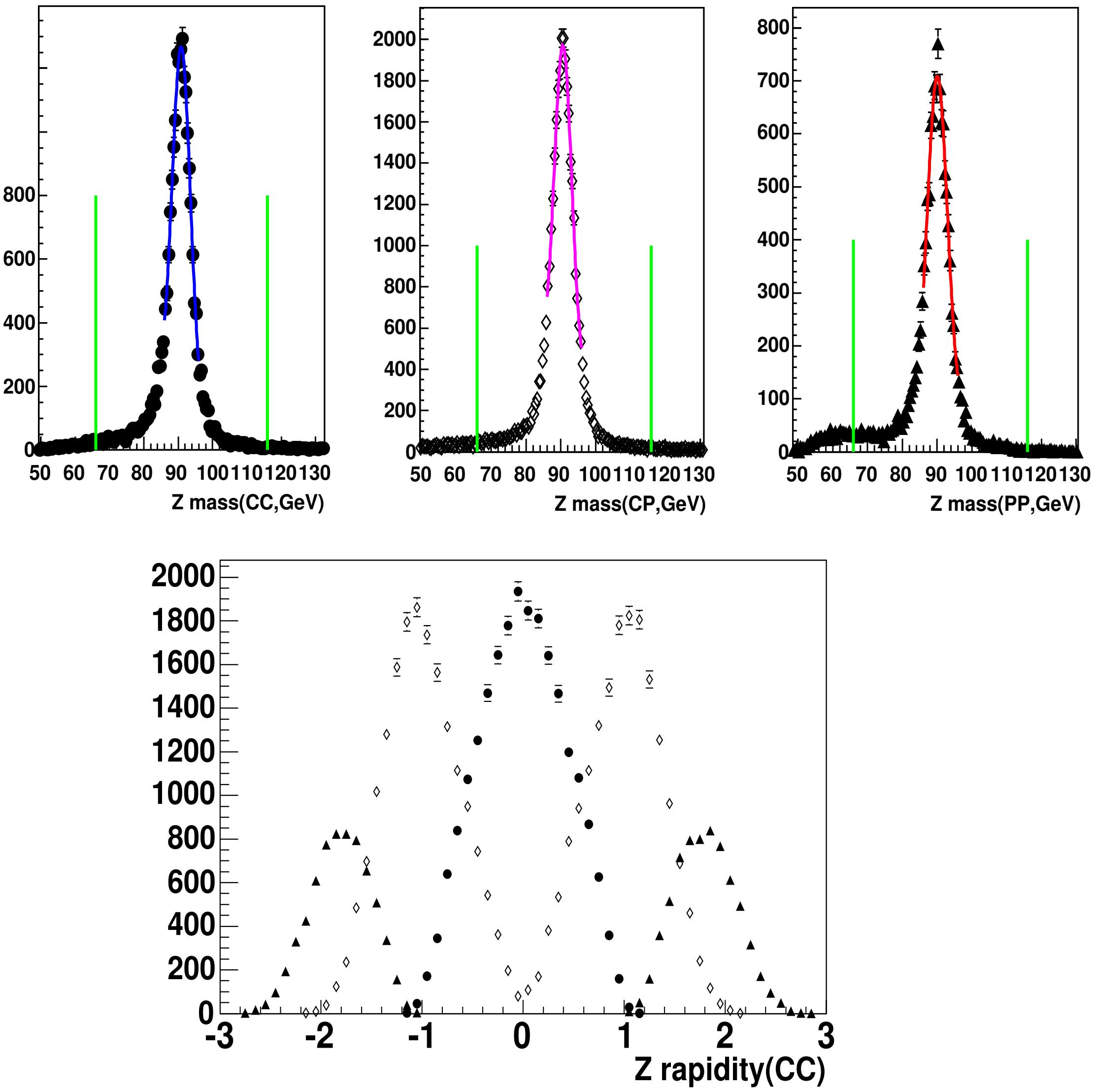


Figure 7: The frist line is the invariant mass distribution, and the second line is the rapidity distribution. The left plots are for central-central region, the middle plots are for central-plug region, and the right plots are for plug-plug region.In rapidity plot, dot means central-central, diamond means central-plug, and triangle means plug-plug region.

Acceptance is defined as N_{reco}/N_{gen}, where N_{gen} and N_{reco} are the number of generated and reconstructed events respectively, with basic geometric and kinematic cuts applied.

For getting N_{gen}, we applied $|z^{gen}_{vertex}| < 60cm$ and $66 < M^{gen}_{ee} < 116GeV$ cuts. And N_{reco} is the number of events applied all kinematic cuts in mass window. Table 7 shows the kinematic cut variables of central and plug electron. The overall acceptance is $12.21 \pm 0.02\%$ in central-central region, $25.84 \pm 0.03\%$ in central-plug region, and $11.63 \pm 0.02\%$ in plug-plug region. We get also the acceptance of each rapidity bin, and this acceptance is used to get $d\sigma/dy$ distribution. Figure 16 shows the acceptance as a function of rapidity.

Variable	central electron	plug electron
E_t	$> 25(CC), 20(CP)\ GeV$	$> 20(CP), 25(PP)\ GeV$
P_t	$> 10\ GeV$	
Fiducial	fidEle = 1 or 4(smx or track)	$1.2 < \vert\eta\vert < 2.8$

Table 7: The kinematic cuts of central and plug electron are described.

7.2. *Electron Efficiency*

1. central electron efficiency

   To get the central electron efficiency, we starts with N_{CC} events with one tight electron and one central electron passing kinematic cuts and $|z_{track}| < 60\ cm$(one central cluster) in mass window, and then apply all the cuts to the central cluster. The electron efficiency is measured for each of them according to the expression

$$\epsilon^i = \frac{\mathsf{N_{TT}} + \mathsf{N_{Ti}}}{\mathsf{N_{CC}} + \mathsf{N_{TT}}} \tag{6}$$

   where N_{TT} is the total number of tight-tight events and N_{Ti} is the number of events satisfying the tight cuts on one leg and the i-th ID cut on the second leg. So, for the total efficiency, when both legs pass the tight cuts, this formula becomes

$$\epsilon_T = \frac{2\mathsf{N_{TT}}}{\mathsf{N_{CC}} + \mathsf{N_{TT}}} \quad \text{(for the tight electron efficiency)} \tag{7}$$

$$\epsilon_L = \frac{\mathsf{N_{TT}} + \mathsf{N_{TL}}}{\mathsf{N_{CC}} + \mathsf{N_{TT}}} \quad \text{(for the loose electron efficiency)} \tag{8}$$

where N_{TL} is the total number of tight-loose events.
We split N_{CC} into $N_{TT} + N_{TTB}$, which N_{TTB} is the events with one tight electron and one central electron passing kinematic cuts, but not tight cuts. And N_{TL} is splitted into $N_{TT} + N_{TLB}$, which N_{TLB} is the events with one tight electron and one loose electron not passing the tight cut. We estimate the background events in each selection with isolation extrapolation method. Table 8 summarize the number of events and the background rate in each selection.

By this formula, the tight central electron efficiency is 0.8295 ± 0.0019 and the loose central electron efficiency is 0.9592 ± 0.0010.

Selection	Events(east,west)	Background rate(east,west)
N_{TT}	16930(8460,8470)	$0.000 \pm 0.000(0.001 \pm 0.001, 0.000 \pm 0.000)$
N_{TLB}	5346(2622,2724)	$0.010 \pm 0.002(0.011 \pm 0.003, 0.009 \pm 0.003)$
N_{TTB}	7347(3598,3749)	$0.053 \pm 0.003(0.056 \pm 0.005, 0.050 \pm 0.004)$

Table 8: The events number and background rate for the central electron efficiency are summarized.

2. plug electron efficiency

   To get the plug electron efficiency, we select Z(CP) events which has tighter central electron and $66 < mass(ee) < 116\ GeV$ mass window. And this efficiency is measured as the number of events passing the all plug ID cuts divided the number of events passing the kinematic cuts.

We also subtract the background rate for numerator and denomenator. The background rate is 0.0028 ± 0.0007 for numerator and 0.0770 ± 0.0015 for denomenator. This background rate is measured by isolation extrapolation method. From this procedure, we get the plug electron efficiency $= 0.8424 \pm 0.0019$(without phoenix track efficiency).
We also check the plug electron efficiency with Z(PP) events. To make the clean sample, we select the phoenix electron with $\Delta R < 3.0$ and $Pes5by9U, V > 0.65$ cut and the plug electron. We measure the plug electron efficiency from Z(PP) with applying the kinematic cut and ID cut on the plug electron leg. We also use $66 < mass(ee) < 116\ GeV$ mass window. In this selection, the background rate is 0.0186 ± 0.0024 for numerator and 0.0692 ± 0.0036 for denomenator. From this procedure, we get the plug electron efficiency $= 0.8173 \pm 0.0036$.
Table 9 summarize the events number and background rate in each selection.

Selection	Events(east,west)	Background rate(east,west)
$N_{TK} from Z(CP)$	39316(19555,19761)	$0.077 \pm 0.002(0.079 \pm 0.002, 0.075 \pm 0.002)$
$N_{TP} from Z(CP)$	30655(15283,15372)	$0.003 \pm 0.001(0.003 \pm 0.001, 0.002 \pm 0.001)$
$N_{TK} from Z(PP)$	12259(6279, 5980)	$0.069 \pm 0.004(0.079 \pm 0.005, 0.059 \pm 0.005)$
$N_{TP} from Z(PP)$	9503(4869, 4634)	$0.019 \pm 0.002(0.021 \pm 0.004, 0.017 \pm 0.003)$

Table 9: The events number and background rate for the plug electron efficiency are summarized.

Electron	Total	East	West
Central tight	0.8295 ± 0.0019	0.8327 ± 0.0026	0.8263 ± 0.0026
Central loose	0.9592 ± 0.0010	0.9604 ± 0.0014	0.9581 ± 0.0014
Plug Z(CP)	0.8424 ± 0.0019	0.8458 ± 0.0027	0.8390 ± 0.0027
Plug Z(PP)	0.8173 ± 0.0036	0.8246 ± 0.0050	0.8098 ± 0.0052

Table 10: The electron ID efficiency are summarized.

3. ϵ_Z

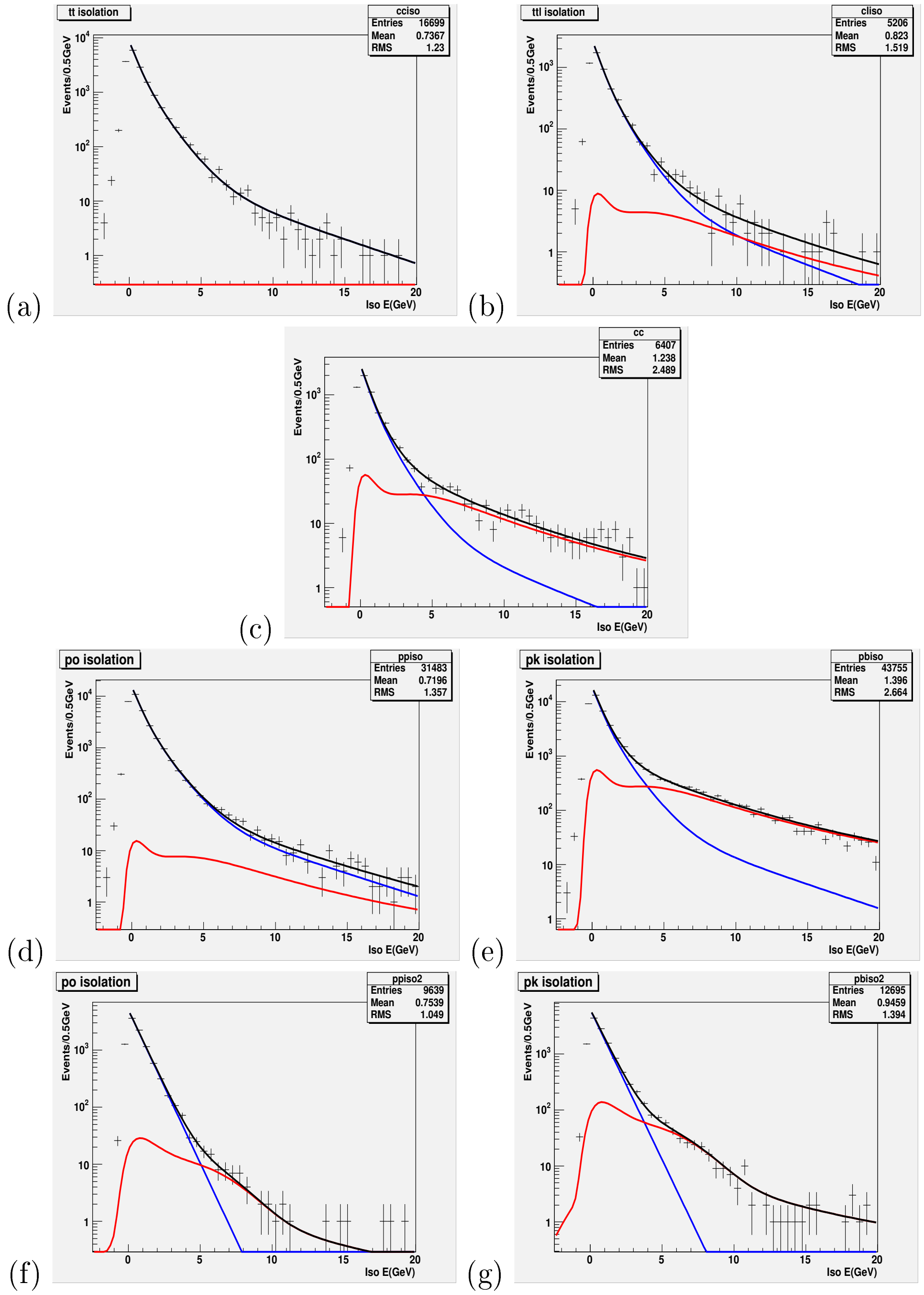


Figure 8: (a) fit result of N_{TT} events (b) fit result of N_{TLB} (c) fit result of N_{TTB} events (d) fit result of $N_{TK} fromZ(CP)$ (e) fit result of $N_{TP} fromZ(CP)$ (f) fit result of $N_{TK} fromZ(PP)$ (g) fit result of $N_{TP} fromZ(PP)$. The red line is the background shape, the blue line is the signal shape and the black line is combined shape of the signal and background.

We get ϵ_Z of each region as follows:
For central-central Z,

$$\epsilon_Z(CC) = \epsilon_{\mathsf{T}} \times (2 \cdot \epsilon_{\mathsf{L}} + \epsilon_{\mathsf{T}}) \tag{9}$$

For central-plug Z,

$$\epsilon_Z(CP) = \epsilon_{\mathsf{T}} \times \epsilon_{\mathsf{P}} \tag{10}$$

For plug-plug Z,

$$\epsilon_Z(PP) = \epsilon_{\mathsf{P}} \times \epsilon_{\mathsf{P}} \tag{11}$$

So, $\epsilon_Z(CC)$ is 0.9033 ± 0.0022, $\epsilon_Z(CP)$ is 0.6988 ± 0.0022, and $\epsilon_Z(PP)$ is 0.7097 ± 0.0057.
Table 11 summarizes the Z efficiency from electron ID efficiency.

Selection	Total	East	West
Z(CC)	0.9033 ± 0.0022	0.9061 ± 0.0031	0.9006 ± 0.0031
Z(CP)	0.6988 ± 0.0022	0.7043 ± 0.0032	0.6933 ± 0.0032
Z(PP)	0.7097 ± 0.0057	0.7154 ± 0.0068	0.7039 ± 0.0068

Table 11: The Z reconstruction efficiency are summarized.

4. efficiency shape from MC

   To get ϵ_Z as a function of rapidity, we obtain the efficiency shape from MC , and then normalize to ϵ_Z from data.
   Figure 5 shows efficiency shape in MC sample.

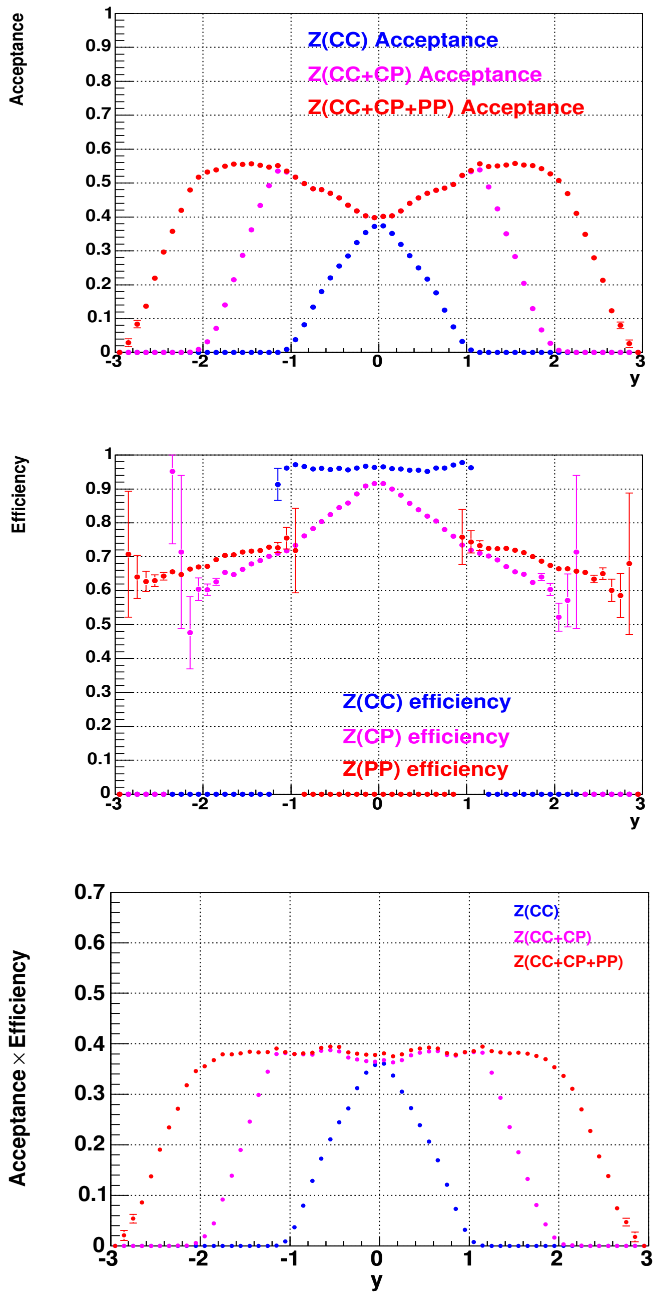


Figure 9: The first plot shows the acceptance, the second one shows the efficiency of Z in rapidity, and the last one shows acceptnace $\times$ efficiency in rapidity.

8. Background Study

The main source of background in this analysis is dijet background, so we measure this background rate with isolation extrapolation method. This method is to measure the background by extrapolating the background from high isolation E tail into the signal region.

8.1. *Signal and Background selection*

Table 12 and 13 summarize the selection crateria for the signal and background shape. We assume that the events which has unisolated object on one leg come from the dijet events. For the signal shape, very tight isolation cut is applied on the other leg to make the clean sample. We use the same background shape for the central electron from Z(CC) and Z(CP). We apply loose cut to the other leg to increase the statics for the background shape. For the plug background shape of Z(CP), we apply the loose central cut and anti iso and anti hadem cut on the other leg. For the plug background shape from Z(PP), Pemchi2 cut is removed on the other leg to increase the statistics. Figure 18 shows the isolation shape and mass distribution of the background sample for each category. In the mass distribution, the background sample doesn't have many Z events with loose central cut on the other leg. So, we decide to use the loose central cut for the background shape.
For the plug background shape from Z(PP), we removed the pem3x3chi2 cut on the other leg to get more statistics. In the mass distribution, we find that there are not much Z contribution.
It's hard to measure Z events in the background sample with dielectron mass.. So, we don't remove Z events from the background sample here.
In the background selection, $W + jet/\gamma$ proccess can be included in the background sample. So, we need to remove these contamination from the background shape. To remove it, we use 6.4M $W + jet/\gamma$ MC events(wewkfe) and count $W + jet/\gamma$ events with the background selection. We already apply the selection of choosing jet-like events on the other leg, so the isolation shape of the probe leg from $W + jet/\gamma$ is same with the isolation shape with the signal selection because the probe leg is the electron from W. So, we use the signal isolation distribution scaled by the total number of $W + jet/\gamma$ events which is counted in $W + jet/\gamma$ MC sample with background selection. To normalize $W + jet/\gamma$ MC sample size to data, we use the number of W events with $MET > 30GeV$ in data and MC. Then, we found 399 events in $W + jet/\gamma$

MC and 35 events in Data. So, the normalization factor is 0.0877.

	For central electron	For plug electron
signal shape	Z(CC) events 66 $<$ $mass$ $<$ 116 GeV e1 : tight central ID cut except isoE e2 : loose central ID cut except isoE & hadEm $hadEm < 0.05$ $isoE < 2$	Z(CP) (or Z(PP)) events 66 $<$ $mass$ $<$ 116 GeV e1 : plug ID cut except isoE e2 : tight central ID cut (tight plug ID cut) except isoE & hadEm $hadEm < 0.05$ $isoE < 2$
background shape	Z(CC) events 66 $<$ $mass$ $<$ 116 GeV e1 : tight central ID cut except isoE e2 : loose central ID cut except trkpt cut except isoE & hadEm $hadEm > 0.05$ $isoE > 4\ GeV$ remove $W + jet, \gamma$ events	Z(CP) events 66 $<$ $mass$ $<$ 116 GeV e1 : plug ID cut except isoE e2 : loose central ID cut (loose plug ID cut) except isoE & hadEm $hadEm > 0.05$ $isoE > 5\ GeV$ remove $W + jet, \gamma$ events

Table 12: The selection cut for the signal and background shape is summarized. e1 : probe leg, e2 : the other leg

8.2. Fitting of signal and background shape

To get the signal and background shape, we fit the isolation shape with signal and background selection. In the isolation extrapolation method, it's very important to fit the high isolation tail. But, the statistics in the high isolation E is not enough to fit well. So, we use the maximum log likelihood fit with Poisson probability to fit the high isolation region well.

Table 14 and 17 summarizes the fitting function for the signal and background. We use the combined exponential function for the signal shape and the combined function with landau and gaussian for the background function. For

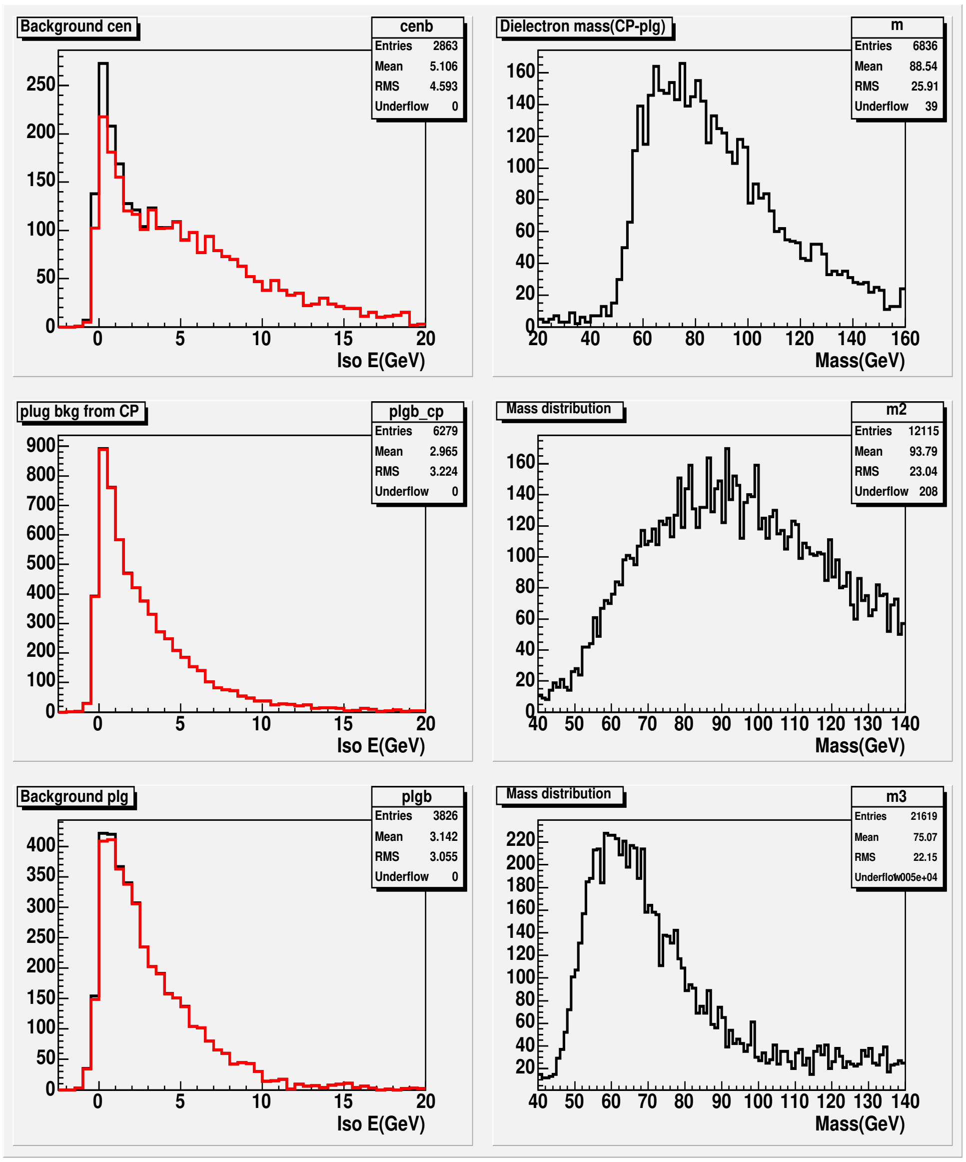


Figure 10: The left plots is the isolation shape of the background events and the right plots is the dielectron mass of the background selection. The top plots are for the central electron and the middle plots are for the plug electron from Z(CP) and the bottom plots are for the plug electron from Z(PP). Black line is before subtracting $W + jet/\gamma$ events and red line is after subtracting it.

Variable	Tight central	Loose central	Tight(Loose) plug
E_t	$> 25\ GeV$	$> 25\ GeV$	$> 25\ GeV$
Fiducial	fidEle = 1 or 4	fidEle = 1 or 4	$1.2 < \|eta\| < 2.8$
Had/Em	$< 0.055 + 0.00045 \times E$	$< 0.055 + 0.00045 \times E$	< 0.05
$IsolationE$	$< 4.0\ GeV$	$< 4.0\ GeV$	$< 4.0\ GeV$
P_t	$> 10\ GeV$	$> 10\ GeV$	
E/P	< 2.0		
z_{vertex}	$\|z_{track}\| < 60$	$\|z_{track}\| < 60$	
Lshr	< 0.2		
Chi2Strip	< 10		
$Q \times delX$	$-3.0 < Q \times delX < 1.5$		
$\|dZ\|$	< 3.0		
PEMChi2			< 10(no cut)

Table 13: The selection cut for tight, loose central and plug electron is summarized.

the signal shape, we find that there's background contamination in the high isolation region. So, we get the real signal shape by iterating the signal shape. To interate the signal shape, we fit the signal shape with three or two exponential function(Eq. (12)), which is defined as $F_s(x)$ and the background shape with two landau or landau+gaussian function, which is defined as $F_b(x)$(Eq. (13)).

$$F_s(x) = p0 \times e^{(-p1 \times x)} + p2 \times e^{(-p3 \times x)} + p4 \times e^{(-p5 \times x)} \tag{12}$$

$$F_b(x) = p0 \times Landau(x, p1, p2) + p3 \times Landau(x, p4, p5) \tag{13}$$

And we define $F_s'(x)$ which is combined function with signal and background shape. All parameters for the signal and background shape is obtained from the previous fitting. In Eq. (14), $F_s(x)$ is the signal shape from Eq. (12) and $F_b(x)$ is the background shape from Eq(13).

$$F_s'(x) = p0' \times ((1 - f_b) \times F_s(x) + f_b \times F_b(x)) \tag{14}$$

where $F_s(x)$ and $F_b(x)$ are normalized function.

We measure the background rate in the signal selection with the dielectron mass distribution of high isolation region($isoE > 3GeV$) in signal selection. The background rate from the dielectron mass distribution is defined as R_b in Eq (15). To get R_b, we select the events passed $isolation > 3GeV$ of the probe leg in signal selection and fit the mass distribution with gaussian and 3-polinomial function. f_b in Eq. (14) which is the total background rate in the signal sample is calculated by solving Eq. (15). In Eq. (15), all parameters except f_b are fixed. After getting f_b from Eq. (15), we put f_b into Eq. (14) and refit the signal shape with $F_s'(x)$ setting the parameters of $F_s(x)$ free. We use the new fitting result from $F_s(x)$ for the real signal shape. Figure 11 shows the mass distribution with $isolation > 3GeV$ of the probe leg.
Figure 12 to Figure 15 shows the fitting result of the signal and background shape.

$$R_b = \frac{\int_3^{inf} p0' \times f_b \times F_b(x)}{\int_2^{inf} F_s'(x)} \tag{15}$$

	Signal shape
central el from Z(CC,CP)	$p0 \times e^{(-p1\times x)} + p2 \times e^{(-p3\times x)} + p4 \times e^{(-p5\times x)}$
plug el from Z(CP)	$p0 \times e^{(-p1\times x)} + p2 \times e^{(-p3\times x)} + p4 \times e^{(-p5\times x)}$
plug el from Z(PP)	$p0 \times e^{(-p1\times x)} + p2 \times e^{(-p3\times x)}$

Table 14: The fitting function for the signal shape is summarized.

8.3. Fitting of isolation E

We fit the isolation E distribution with the signal and background shape from the previous section. We selecte the events only in the mass range, $66 < M < 116\ GeV$. For the cross check, we measure the background rate on the central leg and plug leg from Z(CP) or the phoenix leg and plug leg from Z(PP) separately. The Eq. (16) is the fit function for the isolation distribution and the Eq. (17) is used for calculating the background rate.

$$F(x) = A \times ((1 - B) \times F_s(x) + B \times F_b(x)) \tag{16}$$

where $F_s(x)$ and $F_b(x)$ is nomarlized function in the region $\int_0^{inf}$. Parameter A is the normalization factor and parameter B is the background fraction.

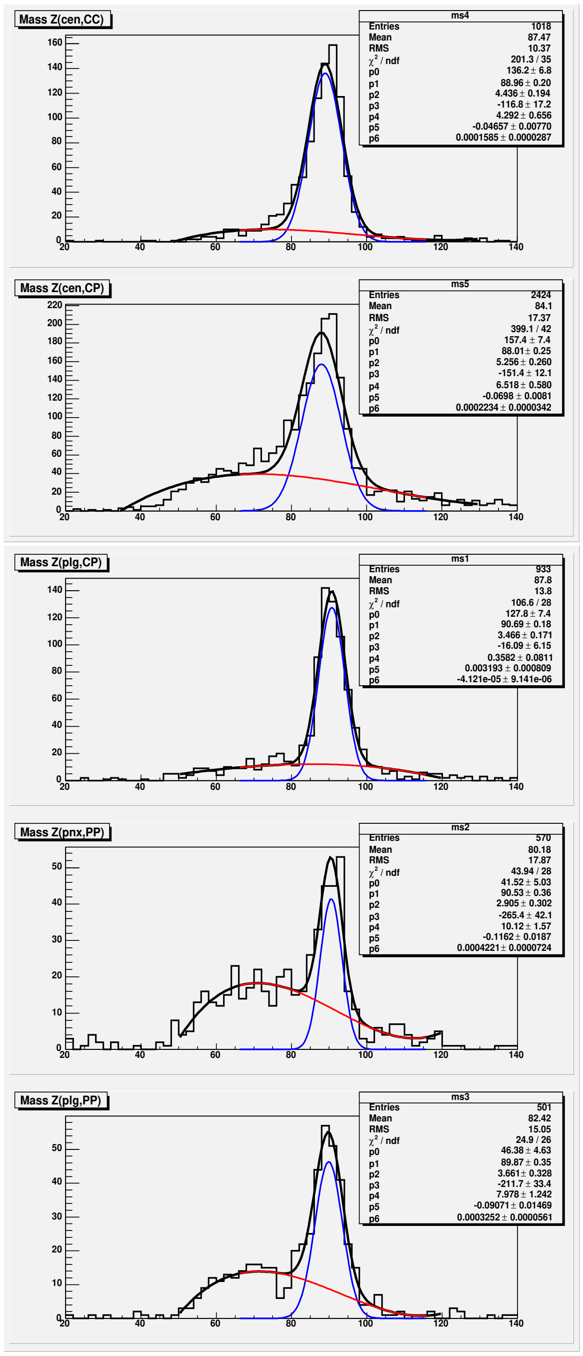


Figure 11: The top two plots are the mass distribution of the central leg from Z(CC) and Z(CP) with $isolation > 3\ GeV$ and the bottom three plots are the mass distribution of the plug leg from Z(CP) and Z(PP) with $isolation > 3\ GeV$.

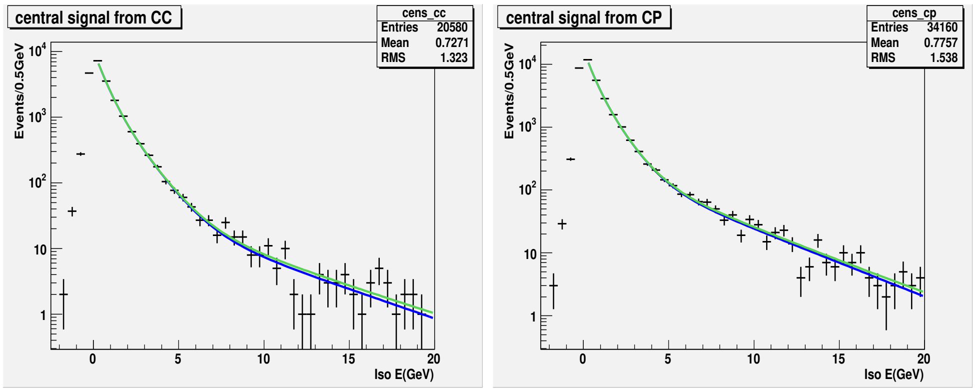


Figure 12: The left plot is the fitting result of the signal shape of the central electron from Z(CC) and the right plot is the fitting result from Z(CP). Green line is included the background component and blue line is signal shape itself.

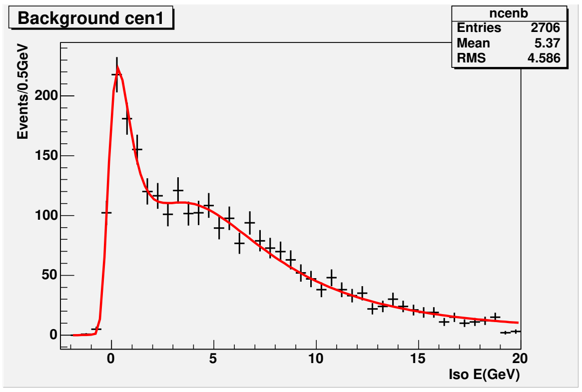


Figure 13: The plot is the fitting result of the background shape of the central electron.

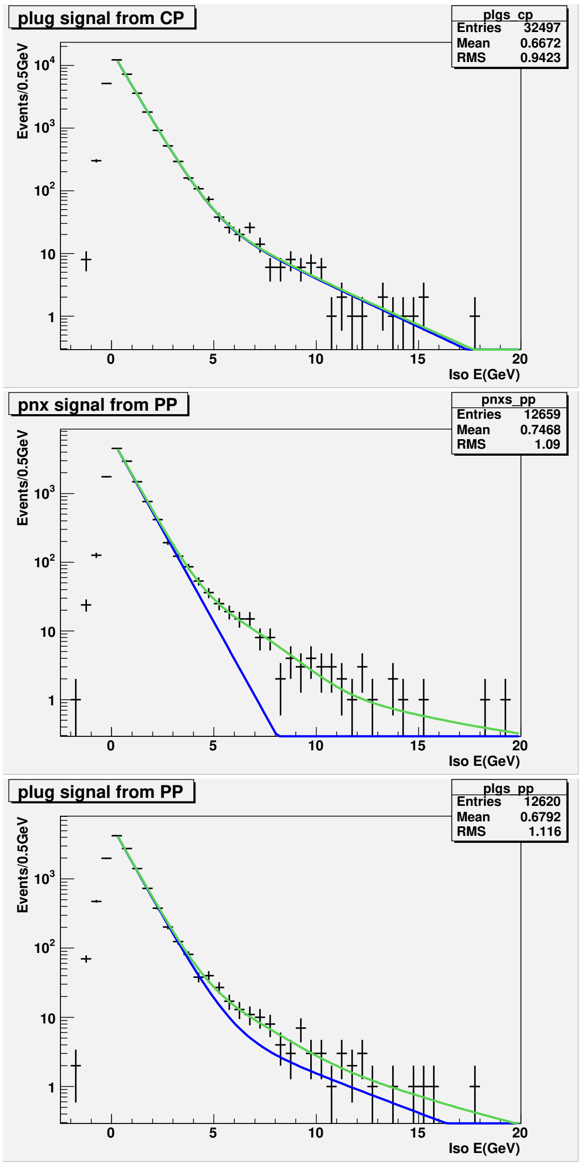


Figure 14: The top plot is the plug signal shape from Z(CP), the middle plot is the signal shape of phoenix leg from Z(PP), and the bottom plot is the signal shape of the plug leg from Z(PP). Green line is included the background component and blue line is signal shape itself.

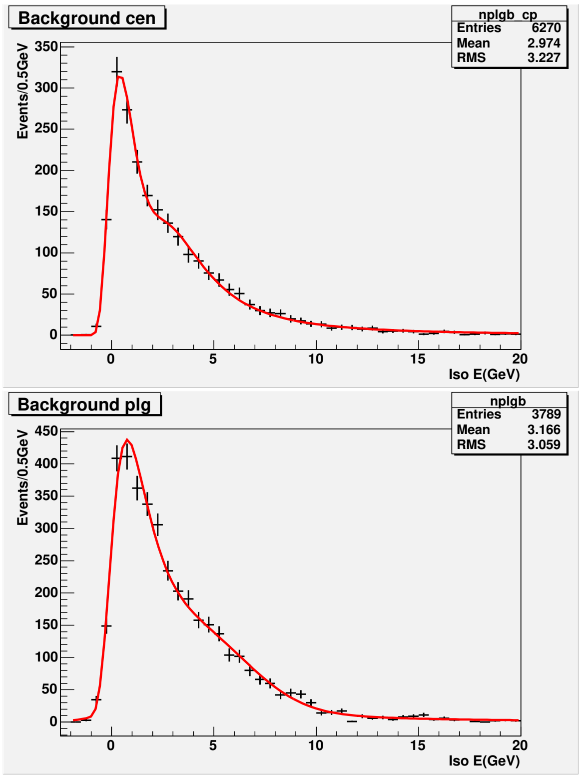


Figure 15: The top plot is the plug background shape from Z(CP), the bottom plot is the background shape of plug leg from Z(PP).

parameter	el from Z(CC)	el from Z(CP)
p0	$2.86e+0 \pm 3.71e-1$	$1.67e+1 \pm 1.79e+0$
p1	$8.40e-1 \pm 2.65e-2$	$2.28e+0 \pm 1.31e-1$
p2	$6.50e+0 \pm 4.61e-1$	$1.22e+1 \pm 1.31e+0$
p3	$1.92e+0 \pm 5.28e-2$	$1.01e+0 \pm 3.45e-2$
p4	$4.73e-2 \pm 1.80e-2$	$4.86e-1 \pm 7.64e-2$
p5	$2.05e-1 \pm 2.20e-2$	$2.47e-1 \pm 1.33e-2$

Table 15: The fitting parameters for the signal shape of central electron are summarized.

parameter	el from Z(CP)	pnx el from Z(PP)	plg el from Z(PP)
p0	$3.05e+1 \pm 3.10e+0$	$5.00e+0 \pm 1.66e-1$	$4.76e+0 \pm 1.87e+0$
p1	$1.29e+0 \pm 4.01e-2$	$1.23e+0 \pm 1.06e-2$	$1.21e+0 \pm 1.72e-2$
p2	$2.29e+1 \pm 3.23e+0$	$2.67e-1 \pm 6.04e-1$	$1.61e-2 \pm 2.33e-2$
p3	$1.29e+0 \pm 5.23e-2$	$1.23e+0 \pm 8.82e-1$	$2.58e-1 \pm 7.68e-2$
p4	$4.22e-1 \pm 1.14e-1$	-	-
p5	$3.53e-1 \pm 3.04e-2$	-	-

Table 16: The fitting parameters for the signal shape of plug electron are summarized.

$$Background\ rate = \frac{\int_{-3}^{4} A \times B \times F_b(x)dx}{number\ of\ events\ with\ iso\ <\ 4\ GeV} \tag{17}$$

From fitting the isolation shape, we get the background rate $0.42 \pm 0.10\%$ for Z(CC), $1.07 \pm 0.10\%$ for the central leg from Z(CP), $0.77 \pm 0.16\%$ for the plug leg from Z(CP), $3.12 \pm 0.25\%$ for the phoenix leg from Z(PP), and $2.23 \pm 0.26\%$ for the plug leg from Z(PP).
Figure 16, 17, and 18 shows the fitting result of each leg from Z(CC), Z(CP), and Z(PP). And Table 20 summarizes the parameters from the fitting and Table 21 summarizes the background rate in the sample.

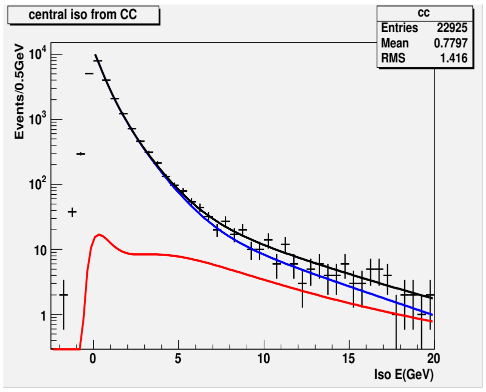
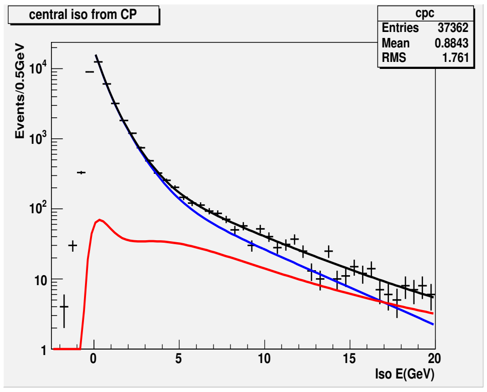


Figure 16: This plot shows the fitting result of central electron from Z(CC). Red line is background, blue line is signal and black line is combined one.



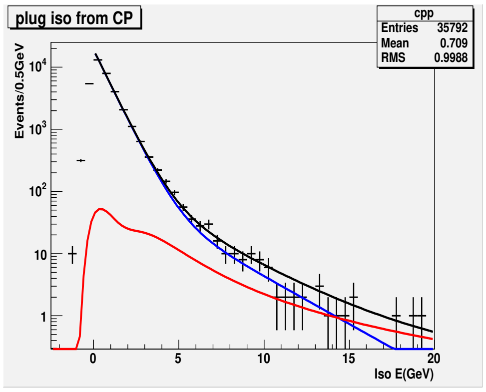


Figure 17: The left plot shows the fitting result of central leg from Z(CP) and the right plog shows the fitting result of plug leg from Z(CP). Red line is background, blue line is signal and black line is combined one.

	Background shape
central el from Z(CC)	$p0 \times Landau(x, p1, p2) + p3 \times Landau(x, p4, p5)$
plug el from Z(CP)	$p0 \times Landau(x, p1, p2) + p3 \times Landau(x, p4, p5)$
plug el from Z(PP)	$p0 \times Landau(x, p1, p2) + p3 \times Gaussian(x, p4, p5)$

Table 17: The fitting function for the background shape is summarized

parameter	cel from Z(CC)	pel from Z(CP)	pel from Z(PP)
p0	$1.17e + 3 \pm 7.54e + 1$	$1.75e + 3 \pm 6.76e + 1$	$2.28e + 3 \pm 7.53e + 1$
p1	$3.78e - 1 \pm 6.57e - 2$	$5.08e - 1 \pm 3.84e - 2$	$8.62e - 1 \pm 4.27e - 2$
p2	$3.80e - 1 \pm 4.12e - 2$	$4.60e - 1 \pm 2.12e - 2$	$6.24e - 1 \pm 2.72e - 2$
p3	$5.25e + 2 \pm 3.34e + 1$	$3.94e + 2 \pm 3.86e + 1$	$8.27e + 1 \pm 8.32e + 0$
p4	$4.76e + 0 \pm 2.71e - 1$	$3.50e + 0 \pm 1.76e - 1$	$4.58e + 0 \pm 1.95e - 1$
p5	$1.92e + 0 \pm 7.72e - 2$	$8.98e - 1 \pm 6.27e - 2$	$2.50e + 0 \pm 1.25e - 1$

Table 18: The fitting parameters for the background shape are summarized.

	R_b	f_b
cen el from Z(CC)	0.1821 ± 0.0126	0.0196
cen el from Z(CP)	0.4113 ± 0.0115	0.0711
plug el from Z(CP)	0.3150 ± 0.0163	0.0315
pnx el from Z(PP)	0.6509 ± 0.0233	0.1423
plug el from Z(PP)	0.4789 ± 0.0247	0.0782

Table 19: This table summarizes R_b and f_b value.

8.4. Systematic error from the parameter

The fitting parameters from the signal and background shape is the biggest source on the systematic error because the final fitting for the isolation shape is sensitive to the shape itself. So, we estimate the systematic error from the shape by changing the parameters of the shape. To calculate the background rate in the sample, we use two parameters(normalization factor and background fraction) from the final isolation fitting and six parameters from the background shape. The error from two parameter of the final isolation fitting

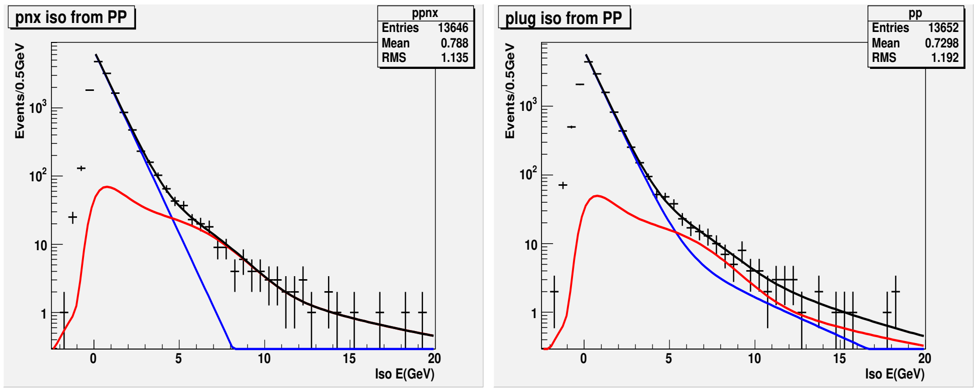


Figure 18: The left plot shows the fitting result of phoenix leg from Z(PP) and the right plog shows the fitting result of plug leg from Z(PP). Red line is background, blue line is signal and black line is combined one.

	p0	p1
central el from Z(CC)	$8.78e+3 \pm 6.63e+1$	$1.15e-2 \pm 2.52e-3$
central el from Z(CP)	$1.39e+4 \pm 8.22e+1$	$2.98e-2 \pm 2.69e-3$
plug el from Z(CP)	$1.50e+4 \pm 8.66e+1$	$1.15e-2 \pm 2.37e-3$
phoenix el from Z(PP)	$5.83e+3 \pm 5.52e+1$	$4.86e-2 \pm 3.90e-3$
plug el from Z(PP)	$5.50e+3 \pm 5.24e+1$	$3.68e-2 \pm 4.23e-3$

Table 20: The parameters from Eq.(5) are summarized.

is already took account of statistic error. So, we only consider the parameters from the background shape. To change 1σ of χ^2 from the fit, we change one parameter(p_i) value with δp_i,which is $p_i + \delta p_i$ or $p_i - \delta p_i$, and fix other parameters. Then, we calculate the background rate with the changed parameter. We repeat this proccess with each parameter,p_i. From this proccessing, we get the difference of the background rate between with p_i and $p_i + \delta p_i\ or\ p_i - \delta p_i$. We take the biggest difference as a systematic error from the parameter. Table 22 summarizes the total systematic error of the parameters. Figure 19 shows the background rate and background difference in each trial.

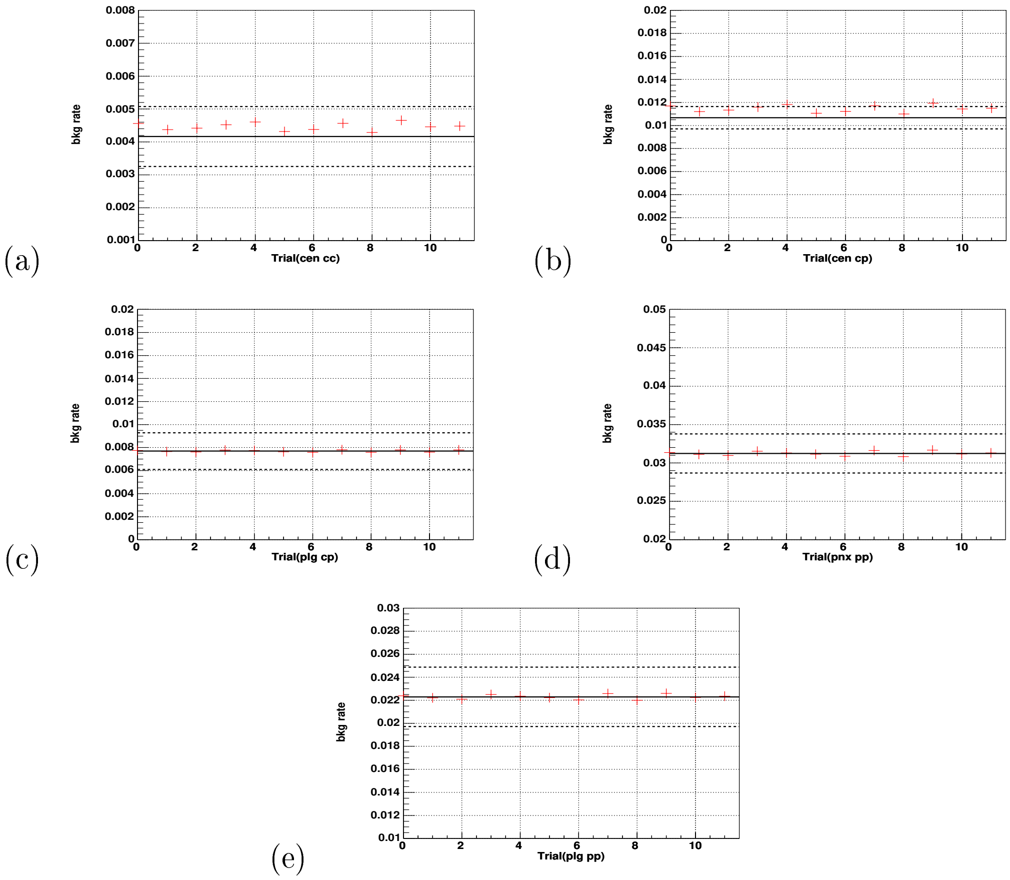


Figure 19: (a) systematic error of the central leg from Z(CC) (b) systematic error of the central leg from Z(CP) (c) systematic error of the plug leg from Z(CP) (d) systematic error of the phoenix leg from Z(PP) (e) systematic error of the plug leg from Z(PP)

Background Rate	Total	East	West
central el from Z(CC)	0.0042 ± 0.0010	0.0040 ± 0.0013	0.0043 ± 0.0013
central el from Z(CP)	0.0107 ± 0.0010	0.0097 ± 0.0014	0.0116 ± 0.0014
plug el from Z(CP)	0.0077 ± 0.0016	0.0092 ± 0.0023	0.0064 ± 0.0021
phoenix el from Z(PP)	0.0312 ± 0.0025	0.0360 ± 0.0038	0.0264 ± 0.0034
plug el from Z(PP)	0.0223 ± 0.0026	0.0213 ± 0.0037	0.0232 ± 0.0037

Table 21: The background rate in the mass range, $66 < M < 116$ GeV, are summarized.

8.5. Conclusion

We measure QCD background in $Z/\gamma^* \to ee$ events with the isolation extrapolation method. The background rate is a for Z(CC), a for the central leg and a for the plug leg from Z(CP), and a for the phoenix leg and a for the plug leg from Z(PP).
Table 22 summarizes the systematic error and Table 23 summarizes the background rate and errors.
To plug in the background distribution in rapidity, we make the rapidity distribution with the events passed the background selection and normalize the distribution with the total background rate. Figure 20 shows the rapidity distribution of the background events.

9. Systematic study

9.1. Material effect

We consider the material effect as one source of the systematics. To get the systematic error from the material, we use three different sample. One is the default sample with standard central and -1/6 X0 plug material, the central extra material sample has 1% of X0 more material in the central region and the plug extra material sample has 1/6 X0 more material in the plug region. We compared the accptance of the central extra material or the plug extra material sample with that of the default sample. Figure 21 (a) shows the ratio of the acceptance between the extra material sample and the default sample. With the acceptance ratio, we get the cross section difference and Figure 21 (b) shows $\Delta\sigma/\sigma$ from the material effect in each rapidity bin.

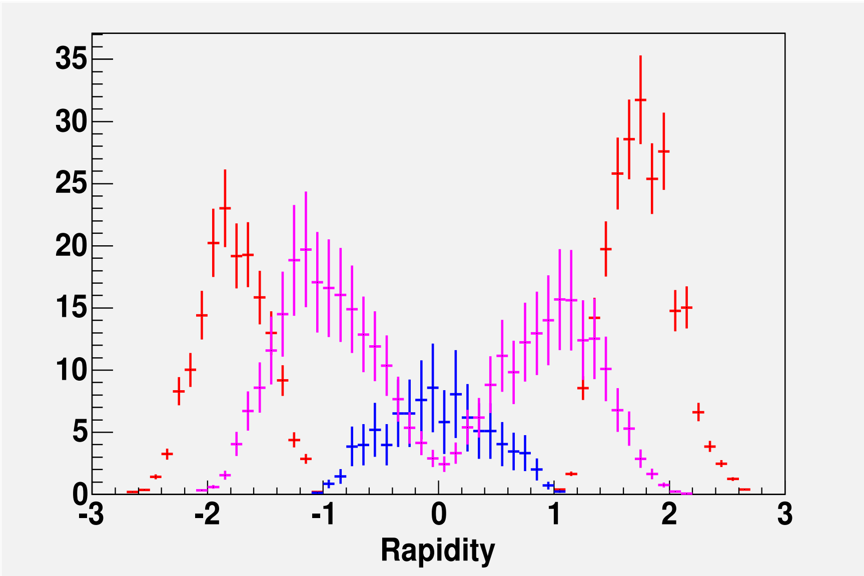
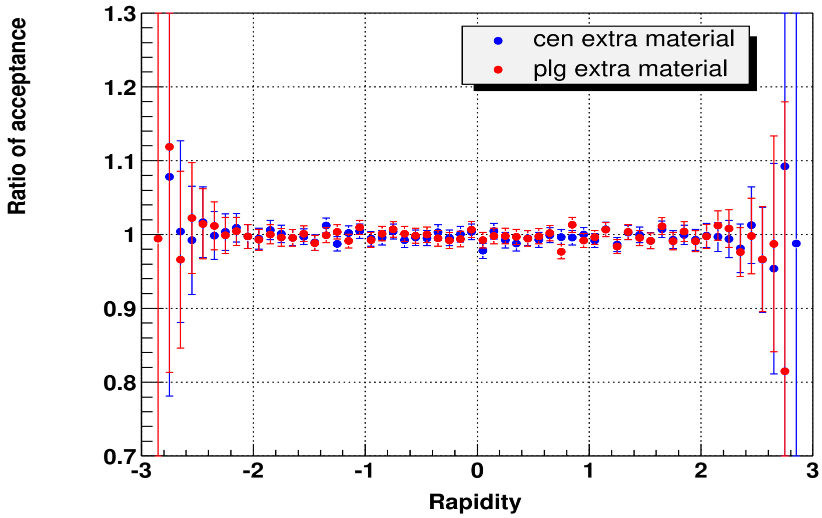
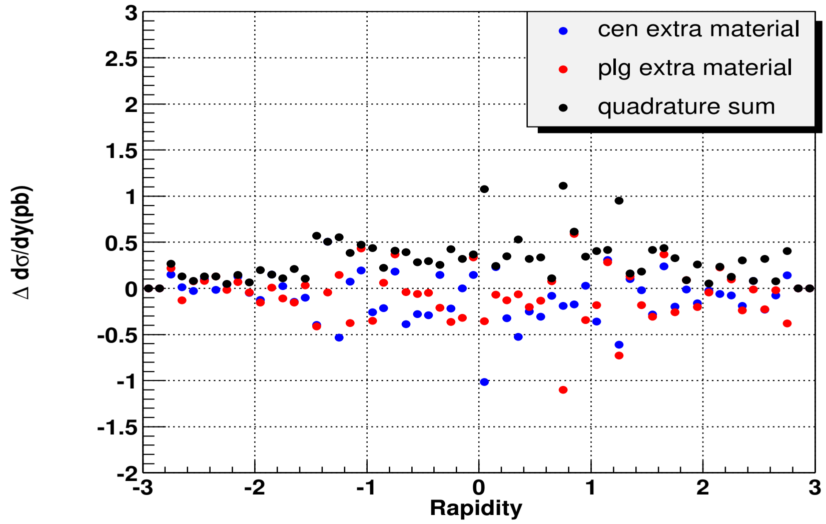


Figure 20: This plot shows the rapidity distribution of the background events. The blue line is Z(CC) events, the magenta line is Z(CP) events, and the red line is Z(PP) events.



(a)



(b)

Figure 21: Plot (a) is the acceptance ratio between the extra material sample and the default sample. Plot (b) is the $\Delta\sigma/\sigma$ from the material effect in each rapidity bin.

Total	r with p_i	sys. error
central el from Z(CC)	0.0042 ± 0.0010	0.0005
central el from Z(CP)	0.0107 ± 0.0010	0.0013
plug el from Z(CP)	0.0077 ± 0.0016	0.0001
phoenix el from Z(PP)	0.0312 ± 0.0025	0.0004
plug el from Z(PP)	0.0223 ± 0.0026	0.0003
East	r with p_i	sys. error
central el from Z(CC)	0.0040 ± 0.0013	0.0005
central el from Z(CP)	0.0097 ± 0.0014	0.0011
plug el from Z(CP)	0.0092 ± 0.0023	0.0001
phoenix el from Z(PP)	0.0360 ± 0.0038	0.0005
plug el from Z(PP)	0.0213 ± 0.0037	0.0003
West	r with p_i	sys. error
central el from Z(CC)	0.0043 ± 0.0013	0.0005
central el from Z(CP)	0.0116 ± 0.0014	0.0014
plug el from Z(CP)	0.0064 ± 0.0021	0.0001
phoenix el from Z(PP)	0.0264 ± 0.0034	0.0004
plug el from Z(PP)	0.0232 ± 0.0037	0.0003

Table 22: The systematic error from the parameters is summarized. r means the background rate.

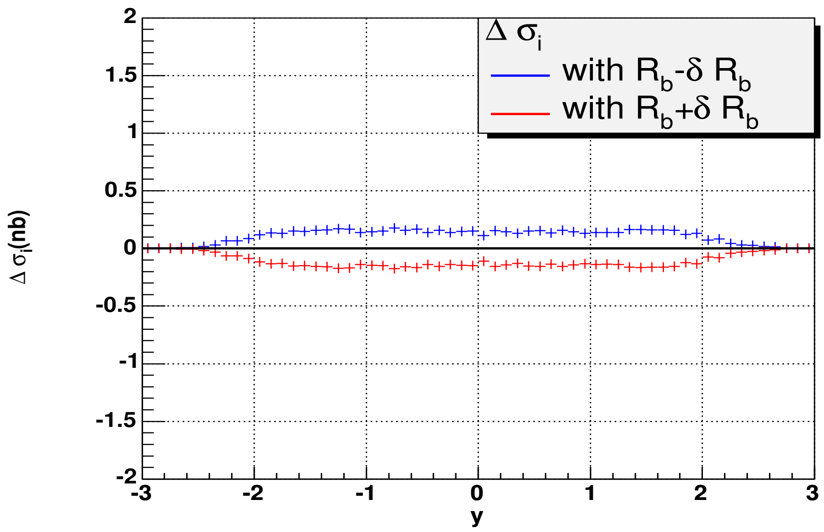
9.2. Background estimation

We estimate the systematic error from the background estimation. We change the background rate with $\pm 1\sigma$ and get the cross section difference. Figure 22 (a) is the $\Delta\sigma$ with $\pm 1\sigma$ changes of the background rate and Figure 22 (b) is the $\Delta\sigma/\sigma$ from the systematics of the background estimation in the rapidity.

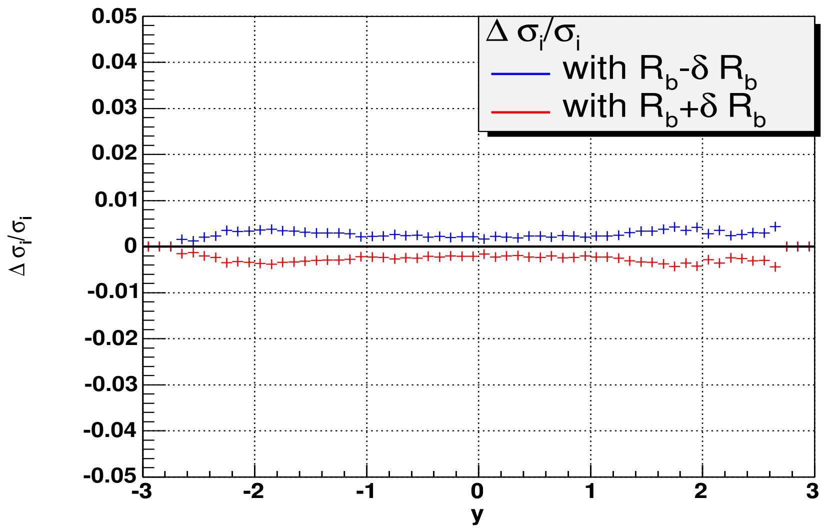
10. $d\sigma/dy$ distribution of $Z^0/\gamma^* \to e^+e^-$

$d\sigma/dy$ is obtained by this formula.

$$\frac{\mathsf{d}\sigma(\gamma^*/\mathsf{Z})}{\mathsf{dy}} = \frac{\mathsf{N_{sig}(y)} - \mathsf{N_{bkg}(y)}}{\mathsf{A_z(y)} \cdot \epsilon_{\mathsf{trig}} \cdot \epsilon_{\mathsf{zvertex}} \cdot \epsilon_{\mathsf{Z}}(\mathsf{y}) \cdot \int \mathsf{Ldt}} \tag{18}$$



(a)



(b)

Figure 22: Plot (a) is the $\Delta\sigma$ with $\pm 1\sigma$ background changes and plot (b) is the $\Delta\sigma/\sigma$ in the rapidity.

	background rate	stat. error	sys. error
central el from Z(CC)	0.0042	0.0010	0.0005
central el from Z(CP)	0.0107	0.0010	0.0013
plug el from Z(CP)	0.0077	0.0016	0.0001
phoenix el from Z(PP)	0.0312	0.0025	0.0004
plug el from Z(PP)	0.0223	0.0026	0.0003

Table 23: The background rate and total systematic error are summerized.

We correct the data with the rapidity depentent efficiencies. Figure 24 shows $d\sigma/dy$ distribution and Figure 25 shows $d\sigma/dy$ distribution of East and West side. From $d\sigma/dy$ distribution, we get $\sigma = 253.338 \pm 1.048 \pm 0.309$. We use NLO CTEQ6.1 theory prediction to compare with data.

References

1. W. Sakumoto, "Event $|Z_{vtx}| < 60cm$ Cut Efficiency for Run II", CDF Note 6331
2. Jason Nielsen, Lauren Tompkins, Greg Vermendi, Doug Hoffman, Young-Kee Kim, "Trigger Efficiencies for High E_T Electrons", CDF Note 6234
3. Giulia Manca, Young-Kee Kim, "Z^0 Cross Sectio

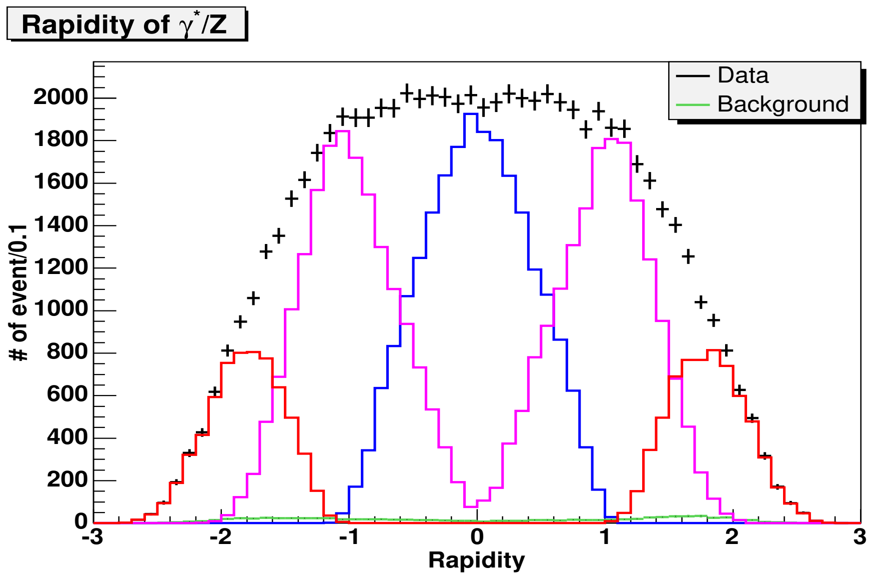


Figure 23: This plot is the rapidity distribution of $Z^0/\gamma^* \rightarrow e^+e^-$ decay.

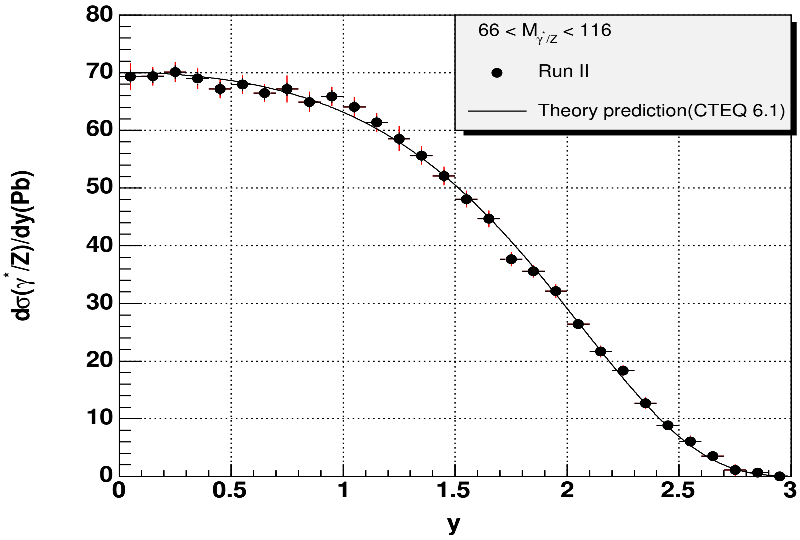


Figure 24: This plot is $d\sigma/dy$ distribution of $Z^0/\gamma^* \rightarrow e^+e^-$ decay. The point is Run2 data and the Black solid line is theory prediction. The error with black line is the statistic error and the error with red line is the systematic error.

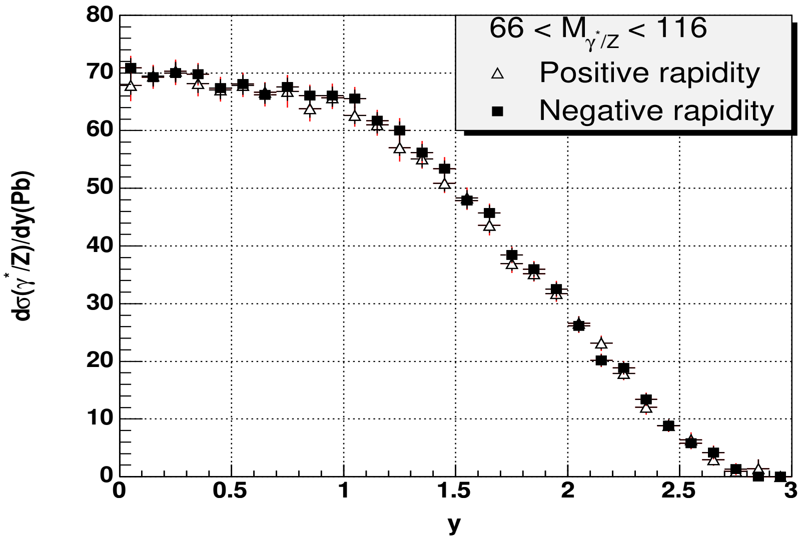


Figure 25: This plot shows $d\sigma/dy$ distribution of $Z^0/\gamma^* \to e^+e^-$ decay in East and West side. The error with black line is the statistic error and the error with red line is the systematic error.