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Z Selection in Z + X Analysis

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Abstract

We describe loose Z→ e^+e^- selection criteria designed to maximize Z + X event samples with minimum selection bias on the system X produced in association with the Z boson. The goal is to increase the sensitivity to rare reactions of the type $p\bar{p} \to e^+e^-$ + X which are dominated by statistical uncertainties. The selection criteria we have developed approximately doubles the size of Z boson sample obtained using standard tight electron selection. This will be useful in studies of the diboson channels Zγ, ZW and ZZ, and searches for new phenomena with a Z boson in the final state. This note presents the validation of our loose Z selection criteria by measuring the Z inclusive cross sections using CC, CP and PP electrons.

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Contents

1 Introduction

Z bosons with leptonic decays can be selected with very low backgrounds if tight lepton selection cuts are used. However for many studies the analyses are better optimized with looser lepton selection cuts, allowing increased backgrounds, but significantly increasing the number of accepted Z bosons. The purpose of this note is to describe loose electron selection criteria that significantly increase the sample of Z$\rightarrow e^+e^-$ with modest increases in backgrounds. The Z bosons are divided into three categories according to the electron calorimeter measurement: central-central (CC), central-plug (CP), and plug-plug (PP). For each category the Z acceptance, electron ID efficiency, and backgrounds are measured. These are used to measure the Z inclusive cross sections using these three kinematic regions. The purpose is to validate the Z selection criteria which will then be applied to $p\bar{p} \rightarrow e^+e^-$ + X production where X is a γ, W, Z or new particle.

2 Data sets, Good run list, Triggers, Luminosity

2.1 High Pt Electron Datasets and Good Run List

The high Pt electron datasets bhel0d, bhel0h and bhel0i are used in this analysis. The total integrated luminosity of the data is 1.07 fb^{-1}. The run range and offline production release of the datasets are listed in table 1. We use offline reprocessed Duke Ntuples in this analysis.

dataset	run range	date	Offline Version	Luminosity(pb^{-1})
bhel0d	138425 - 186598	Feb 2002 - Aug 2004	5.3.1	373 +/- 21
bhel0h	190697 - 203799	Dec 2004 - Sep 2005	6.1.2	428 +/- 24
bhel0i	203819 - 212133	Sep 2005 - Feb 2006	6.1.4	274 +/- 16

Table 1: High Pt electron datasets.

All the runs are required to be in the version 13 good run list for Top/EWK/Exotics electron, no silicon. Data collected during the COT compromised period (from Feb 2004 to May 2004) is not used in this analysis.

All selected events are required to fire the ELECTRON_CENTRAL_18 trigger or the Z_NOTRACK trigger. The measurements of the trigger efficiencies are discussed in section 6.

2.2 MC Samples

2.2.1 Inclusive Z Samples

Pythia $Z \to ee$ MC samples are used in the measurements of the Z acceptance, the electron ID efficiencies and scale factors. Table 2 lists the inclusive MC Z samples used in this analysis.

dataset	run range	Offline Version	Mee	Number of Events
zewk6d	141544 - 186598	Pythia 5.3.3	> 20 GeV	3.2 M
zewkad	190753 - 212133	Pythia 6.1.4c	> 30 GeV	6.7 M

Table 2: Pythia $Z \to ee$ MC samples.

2.2.2 Diphoton Samples

Diphoton sample is used to estimate the diphoton background in the PP Z sample (see section 7.4.1).

Details of this sample is listed below:

- dataset: pexo4d
- Pythia 5.3.1 MC
- HEPG-Level filter cuts: two photons with Et >10GeV. This requirement is on the events after Pythia has produced ISR, and before detector simulation[1].
- $\sigma_{LO} = 92.9$pb
- K-Factor = 2.0+-0.4 [2]

3 Electron Selection

In this section, the electron selection for the inclusive $Z \rightarrow ee$ sample is discussed. The requirement for central and plug electron ID cuts is given in section 3.1 and 3.2, respectively. The energy corrections for the electrons are discussed in section 3.4.

The electron ID efficiency measurement is discussed in section 5.

3.1 CEM electron ID cuts

3.1.1 COT Track Selection

Beam-constrained COT tracks are used in the analysis. A set of minimum hit criteria is applied to ensure that only high quality tracks are assigned to the electron candidates. Table 3 lists the track selection criteria. The COT tracks are required to have at least three axial superlayers and two stereo superlayers, each must have at least five out of twelve possible hits. In addition, the interception of the track with the beam axis, z0, must lie within 60 cm of the center of the detector. The distributions of the track variables are plotted in fig 1. The plot shows the distribution of the second electron leg in the $Z \rightarrow ee$ candidate events, where the Z mass is within the window of (66, 116) GeV, and the first electron is required to pass all the loose central electron ID cuts(see Table 4).

Variables	Cut	variable in Duke Ntuple
All COT Tracks:		
# Axial SLs	≥ 3 with ≥ 5 hits per SL	TRACK_trk_nonbc_numHitSL
# Stereo SLs	≥ 2 with ≥ 5 hits per SL	
BC $\lvert z_0 \rvert$	$\leq 60.$	TRACK_trk_cotbc_z0

Table 3: Central electron selection: track quality requirements

3.1.2 Central Electron Selection

Table 4 lists the selection criteria for a loose central electron(LCE). We use the loose central electron baseline cuts[3] recommended by the Joint Physics group, with some modifications. In the table, the text in red shows the cut that is different to the Joint Physics baseline cut. We loose the isolation cut from 0.1 to 0.3. A Lshr and ΔZ cut are added to the ID cuts so that loose central electron is a triggerable object in our Z selection(see section 6.1.3 for more details.).

The candidate electron clusters is required to lie within the well instrumented central calorimeter regions, corresponding to detector $|\eta| < 1.1$. The candidate electrons must have $E_T \geq 20GeV$ and the COT beam-constrained track $P_T \geq 10$(after Larry Pt correction[4]).

Details on the electron selection variables are given below:

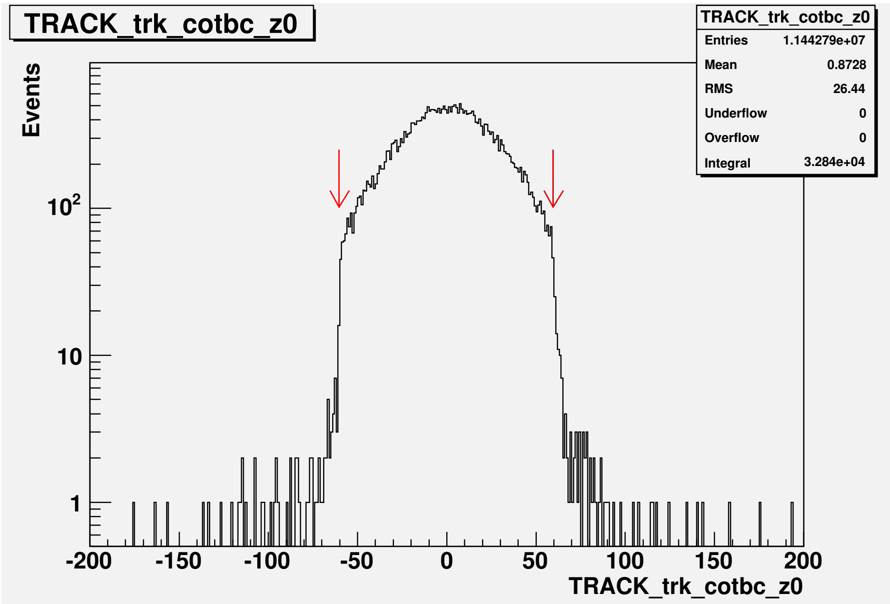

Figure 1: Track Z_0 of the second electron legs in the $Z \to ee$ candidate events, with $66GeV < M_Z < 116GeV$, and the first electron legs satisfy all the loose central electron ID cuts(see Table 4).The arrows show the cuts applied to the Z_0 variable.

- Electron Object:
  An electron object is formed from energy clusters in the calorimeter. An electron cluster is made from a seed tower in the electromagnetic calorimeter and a neighboring(in η) tower in the same calorimeter phi wedge.

- E:
  The total amount of energy is the sum of the electromagnetic and hadronic energy components. It use the 2-tower sum from
  emobj_alg::CEMFourMomentum::TwoTower(emObject, usetrack = true).e();

- E_T :
  E_T is the energy component transverse to the beam line.

- E_{had}/E_{em}:
  The electrons deposit most of their energy in the electromagnetic calorimeter, while hadronic particles spread energies into the hadronic calorimeter. To select electron candidates, we require the ratio of the hadronic energies to the electromagnetic energies, $E_{had}/E_{em} < 0.055 + 0.00045 \cdot \mathrm{E}$, where E is the total energy in the cluster.

- CEMCLST_cem_convflag: not conversion electron (not equal to 1).

- EMCLST_ele_fidEleShrMax: requires FIDUCIAL_CEM(= 1).
  If it is CEM, and not for seed in Tower 9 on West or East, and not seed in Tower 7 of Chimney module, then FIDUCIAL_CEM is set to be true.

- EMCLST_ele_std_calIsoRatio: Isolation energy is corrected for leakage energy. In the loose central electron selection, we require IsoR ≤ 0.3. In the tight central electron selection, IsoR ≤ 0.1 is required.

Variables	Cut	variable in Duke Ntuple
Region	CEM ($\|\eta\| < 1.1$)	EMCLST_ele_det==0
COT track	satisfy loose track quality requirements	
E_T	≥ 20	EMCLST_ele_std_Et
$TrackP_T$	≥ 10	
E_{had}/E_{em}	$\leq 0.055 + 0.00045 \cdot$ EMCLST_ele_std_E	EMCLST_ele_std_hadEm
Conversion	!= 1	CEMCLST_cem_convflag
CES fiducial	= 1	EMCLST_ele_fidEleShrMax
Iso(R=0.4)/E_T	no Iso cut applied yet	
	≤ 0.1 (Joint Physics standard cut)	EMCLST_ele_std_calIsoRatio
	≤ 0.3 (Loose Isolation cut)	
Lshr	≤ 0.4	CEMCLST_cem_std_lshr
$\|\Delta Z\|$	≤ 8	CEMCLST_cem_std_deltaZ

Table 4: Event selection: loose central electron(LCE) ID cuts. The text in red shows the cut that is different to the Joint Physics Standard ID cut.

Table 5 lists the selection criteria for tight central electrons(TCE).

To expand Z acceptance, the loose central electron ID cuts are used to select $Z \rightarrow ee$ candidate events in this analysis.

Variables	Cut	variable in Duke Ntuple
All COT Tracks:		
# Axial SLs	$\geq$ 3 with $\geq$ 5 hits per SL	TRACK_trk_nonbc_numHitSL
# Stereo SLs	$\geq$ 2 with $\geq$ 5 hits per SL	
BC $\lvert z_0 \rvert$	$\leq$ 60.	TRACK_trk_cotbc_z0
Region	CEM ($\lvert\eta\rvert < 1.1$)	EMCLST_ele_det==0
E_T	$\geq$ 20	EMCLST_ele_std_Et
$TrackP_T$	$\geq$ 10	
E_{had}/E_{em}	$\leq$ 0.055	
	+ 0.00045 $\cdot$ EMCLST_ele_std_E	EMCLST_ele_std_hadEm
Conversion	!= 1	CEMCLST_cem_convflag
CES fiducial	= 1	EMCLST_ele_fidEleShrMax
Iso(R=0.4)/E_T	$\leq$ 0.1	EMCLST_ele_std_calIsoRatio
Lshr	$\leq$ 0.2	CEMCLST_cem_std_lshr
E/p (for $P_T < 50$)	$\leq$ 2.0	CEMCLST_cem_std_EOverP
$\lvert\Delta Z\rvert$	$\leq$ 3cm	CEMCLST_cem_std_deltaZ
$Q \cdot \Delta x$	$\geq$ -3.0 cm, $\leq$ 1.5 cm	CEMCLST_cem_std_qDeltaX
$\chi^2_{\rm strips}$	$\leq$ 10.0 cm	CEMCLST_cem_std_cesStripChi

Table 5: Electron selection: tight central electron ID(TCE) cuts

3.2 PEM electron ID

In this section, electron selection in the plug region is discussed.

3.2.1 PEM electron ID variables

The Joint Physics loose plug electron ID cuts are listed in table 6.

In our loose plug electron selection(LPE), we loose PEM 3x3 chi2 cut from 10 to 25. And the η cut is loose from 2.0 to 2.8. The selection criteria is listed in table 7.

Variables	Cut	variable in Duke Ntuple
Region	PEM ($1.1 \leq \|\eta\| < 3.6$)	EMCLST_ele_det==1
PES 2D Eta	$1.2 \leq \|\eta\| \leq 2.0$	PEMCLST_pem_pes2dGlobalEta
$CorrE_T$	≥ 20	
E_{had}/E_{em}	≤ 0.05	EMCLST_ele_std_hadEm
PEM 3x3 chi2	$\leq 10.$	PEMCLST_pem_std_pem3x3Chi
Iso(R=0.4)/E_T	≤ 0.1	EMCLST_ele_std_calIsoRatio

Table 6: Standard Joint Physics group loose plug electron ID cuts.

Variables	Cut	variable in Duke Ntuple
Region	PEM ($1.1 \leq \|\eta\| < 3.6$)	EMCLST_ele_det==1
PES 2D Eta	$1.2 \leq \|\eta\| \leq 2.8$	PEMCLST_pem_pes2dGlobalEta
$CorrE_T$	≥ 20	
E_{had}/E_{em}	≤ 0.05	EMCLST_ele_std_hadEm
PEM 3x3 chi2	$\leq 25.$	PEMCLST_pem_std_pem3x3Chi
Iso(R=0.4)/E_T	no Iso cut applied yet	
	≤ 0.1 (standard Joint Physics cut)	EMCLST_ele_std_calIsoRatio
	≤ 0.3 (loose isolation cut)	

Table 7: Loose plug electron ID(LPE) cuts in this analysis, the text in red shows the cut that is different to the Joint Physics Standard ID cut.

The Joint Physics Tight Plug Electron ID cuts are listed in Table 8.

The tight plug electron(TPE) ID cuts used in this analysis are listed in table 9

Variables	Cut	variable in Duke Ntuple
Region	PEM ($1.1 \leq \|\eta\| < 3.6$)	EMCLST_ele_det==1
PES 2D Eta	$1.2 \leq \|\eta\| \leq 2.0$	PEMCLST_pem_pes2dGlobalEta
$CorrE_T$	≥ 20	
E_{had}/E_{em}	≤ 0.05	EMCLST_ele_std_hadEm
PEM 3x3 chi2	$\leq 10.$	PEMCLST_pem_std_pem3x3Chi
PES 5x9 U	≥ 0.65	PEMCLST_pem_pesU5x9ProfRat
PES 5x9 V	≥ 0.65	PEMCLST_pem_pesV5x9ProfRat
Delta R	≤ 3.0	$\sqrt{(pes_x - pem_x)^2 + (pes_y - pem_y)^2}$
Iso(R=0.4)/E_T	≤ 0.1	EMCLST_ele_std_calIsoRatio

Table 8: Standard Joint Physics group tight plug electron ID cuts.

Variables	Cut	variable in Duke Ntuple
Region	PEM ($1.1 \leq \|\eta\| < 3.6$)	EMCLST_ele_det==1
PES 2D Eta	$1.2 \leq \|\eta\| \leq 2.8$	PEMCLST_pem_pes2dGlobalEta
$CorrE_T$	≥ 20	
E_{had}/E_{em}	≤ 0.05	EMCLST_ele_std_hadEm
PEM 3x3 chi2	$\leq 25.$	PEMCLST_pem_std_pem3x3Chi
PES 5x9 U	≥ 0.65	PEMCLST_pem_pesU5x9ProfRat
PES 5x9 V	≥ 0.65	PEMCLST_pem_pesV5x9ProfRat
Delta R	≤ 3.0	$\sqrt{(pes_x - pem_x)^2 + (pes_y - pem_y)^2}$
Iso(R=0.4)/E_T	≤ 0.1	EMCLST_ele_std_calIsoRatio

Table 9: Tight plug electron(TPE) ID cuts used in this analysis , the text in red shows the cut that is different to the Joint Physics Standard ID cut.

3.2.2 PEM electron Loose ID variables: N-1 Distribution

In this section, the N-1 distributions of the loose plug electron ID variables are showed in figure 2, 3, and 4.

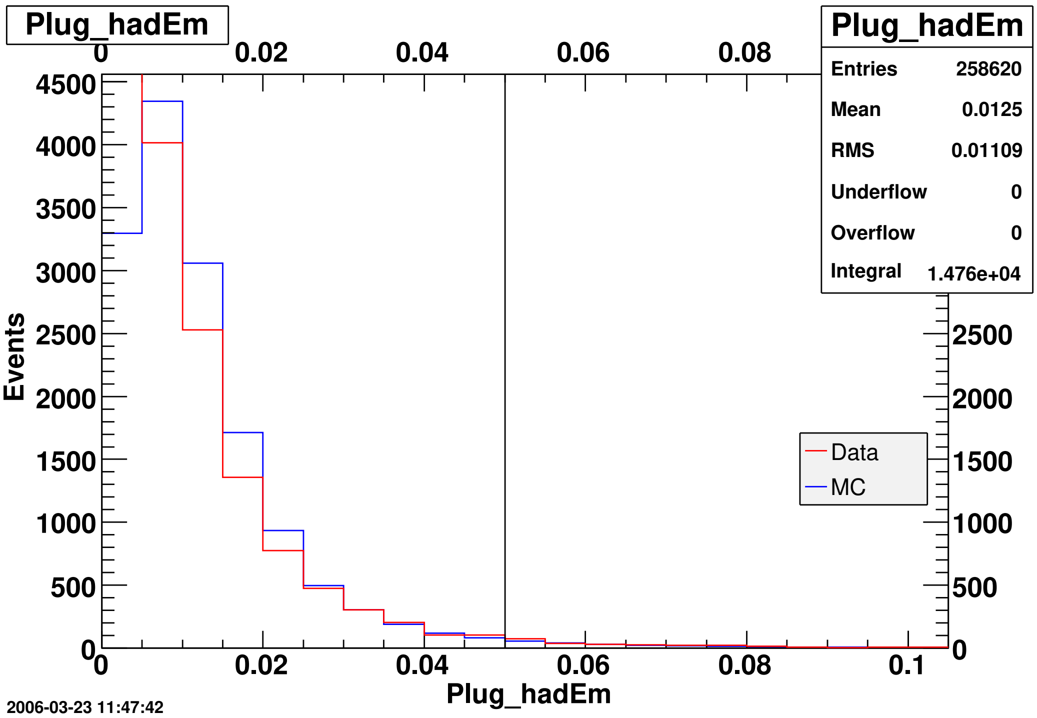

Figure 2: Loose plug ID N-1 plot, the vertical line shows the ID cut value.

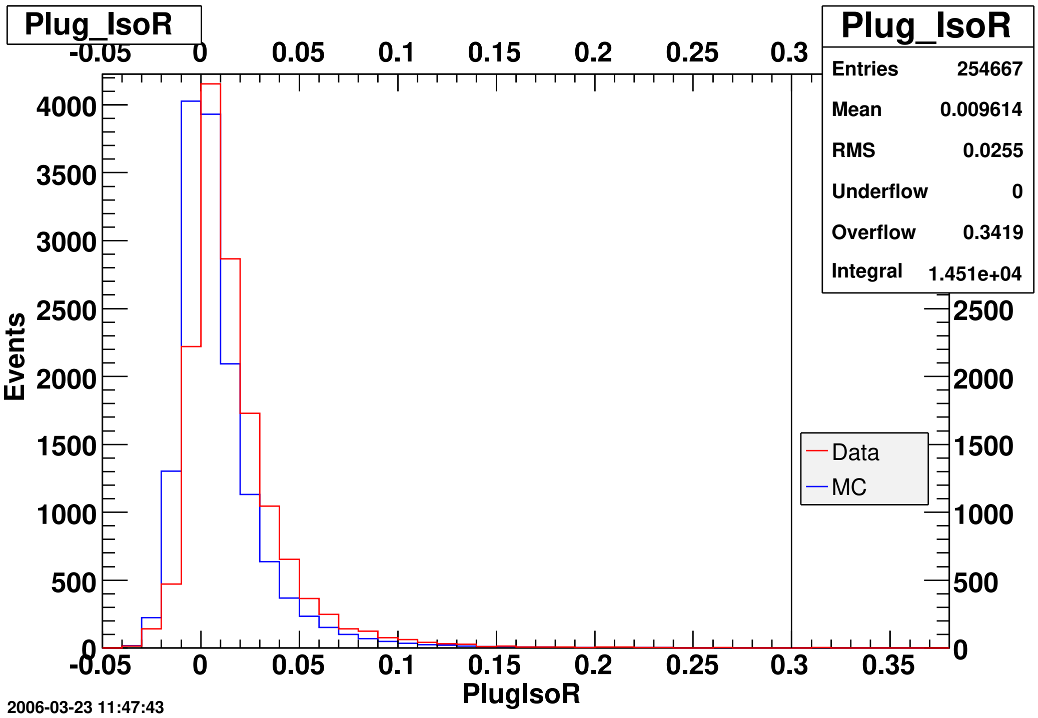

Figure 3: Loose plug ID N-1 plot, the vertical line shows the ID cut value.

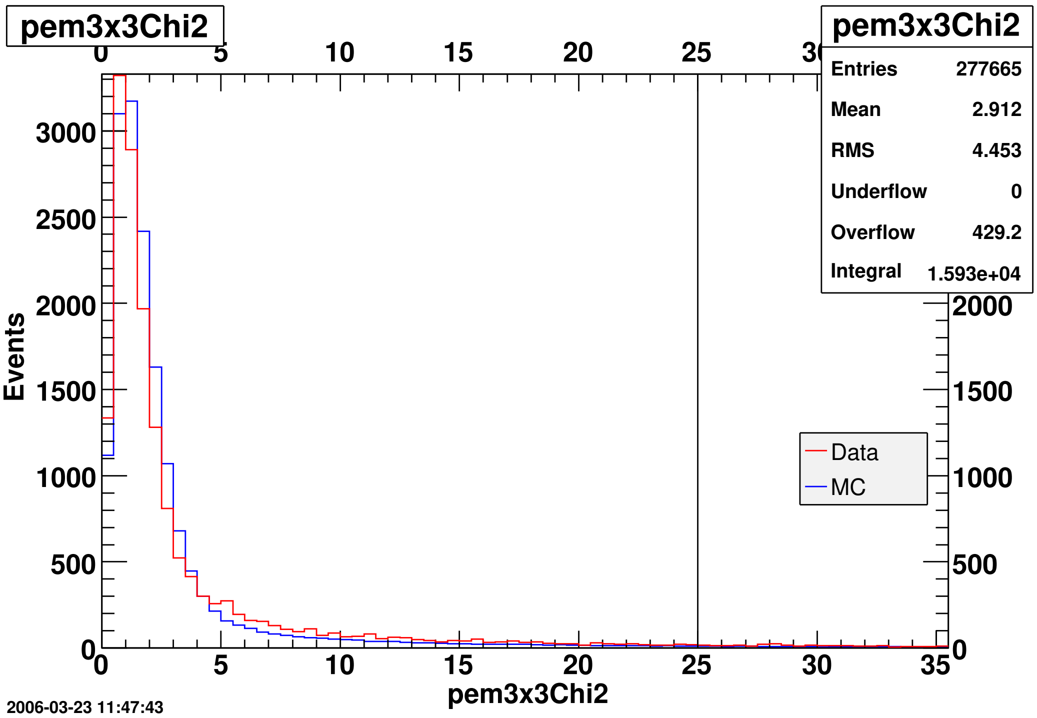

Figure 4: Loose plug ID N-1 plot, the vertical line shows the ID cut value.

3.2.3 PEM electron Tight ID variables: N-1 Distribution

In this section, the N-1 distributions of the tight plug electron ID variables are showed in figure 5, 6, 7, 8, 9, and 10.

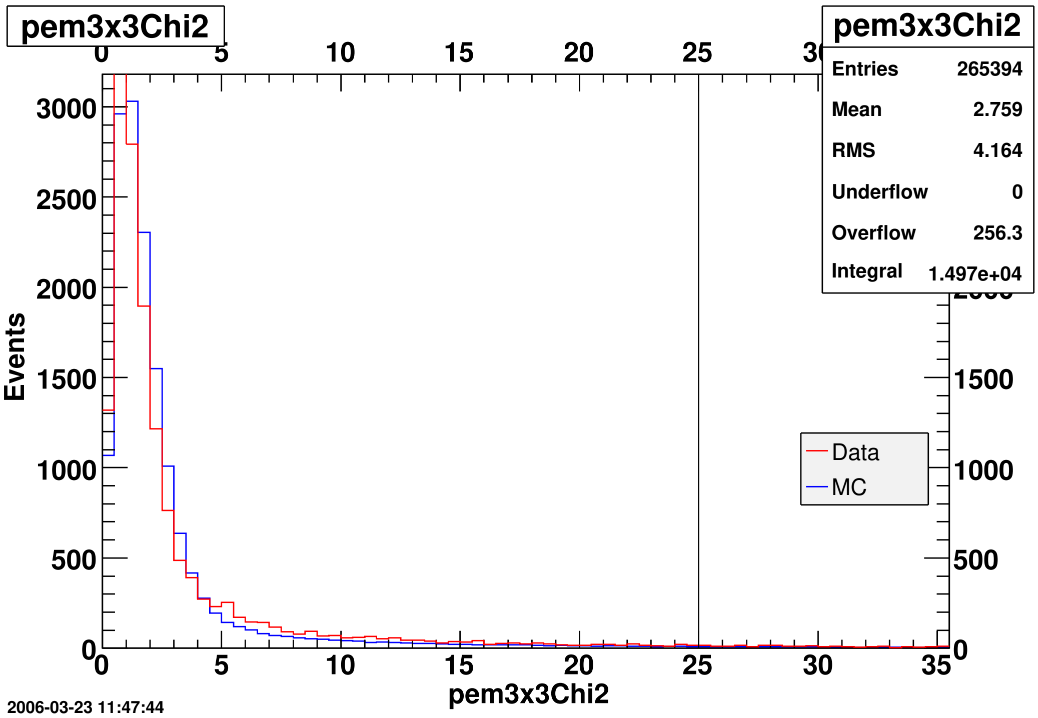

Figure 5: Tight plug ID N-1 plot, the vertical line shows the ID cut value.

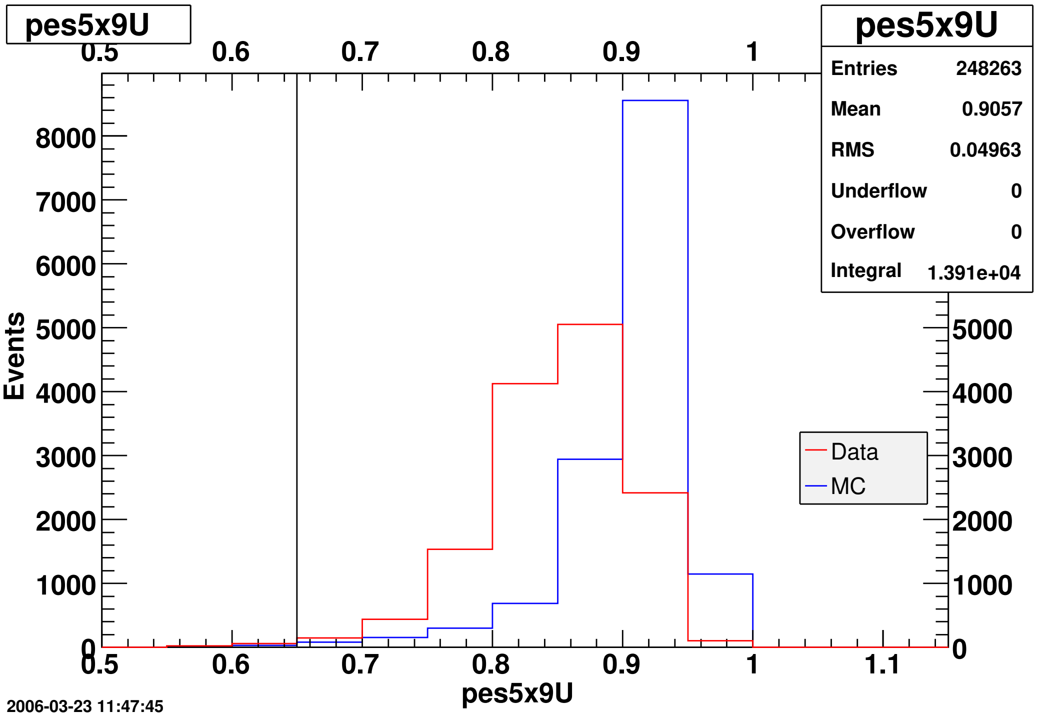

Figure 6: Tight plug ID N-1 plot, the vertical line shows the ID cut value.

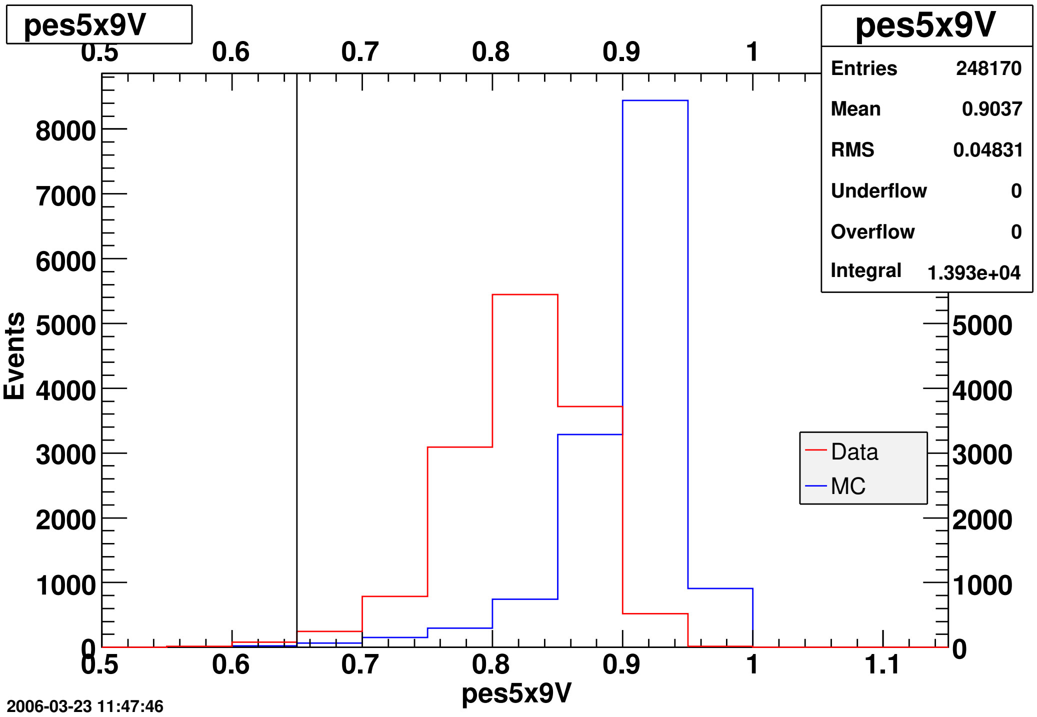

Figure 7: Tight plug ID N-1 plot, the vertical line shows the ID cut value.

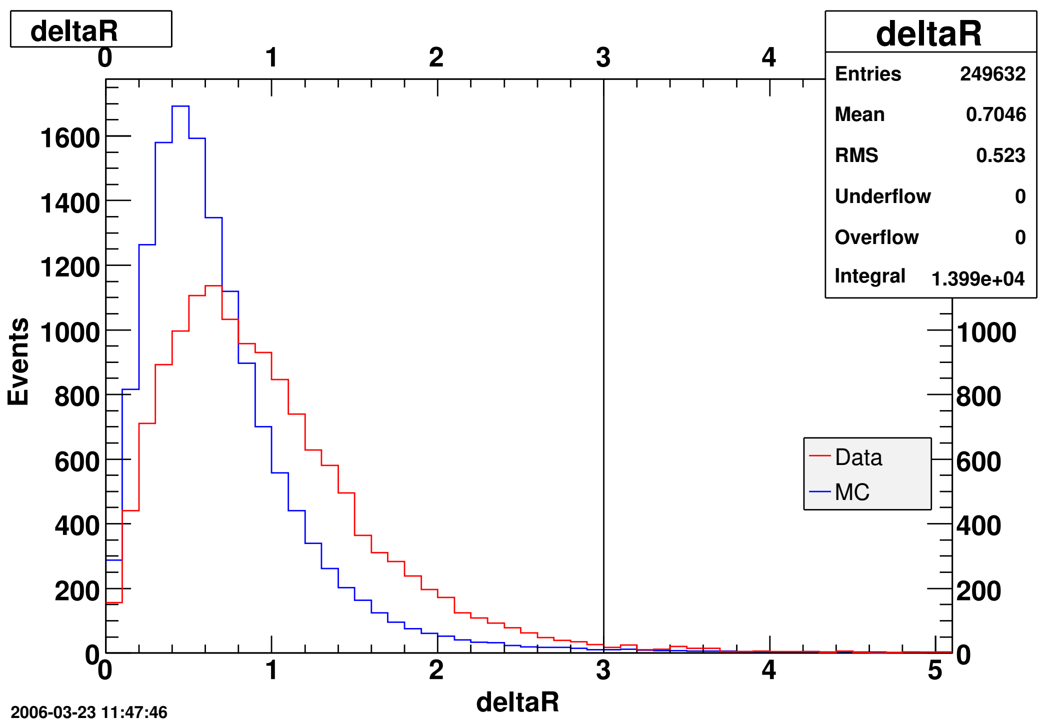

Figure 8: Tight plug ID N-1 ΔR(between PES centroid and PEM centroid) plot, the vertical line shows the ID cut value.

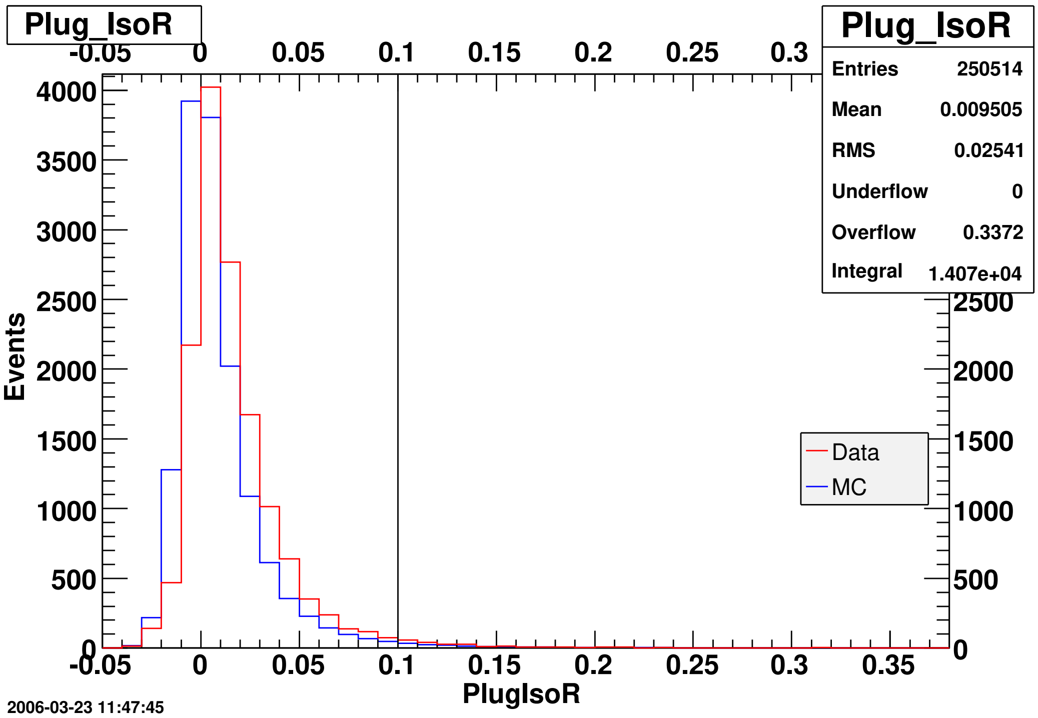

Figure 9: Tight plug ID N-1 plot, the vertical line shows the ID cut value.

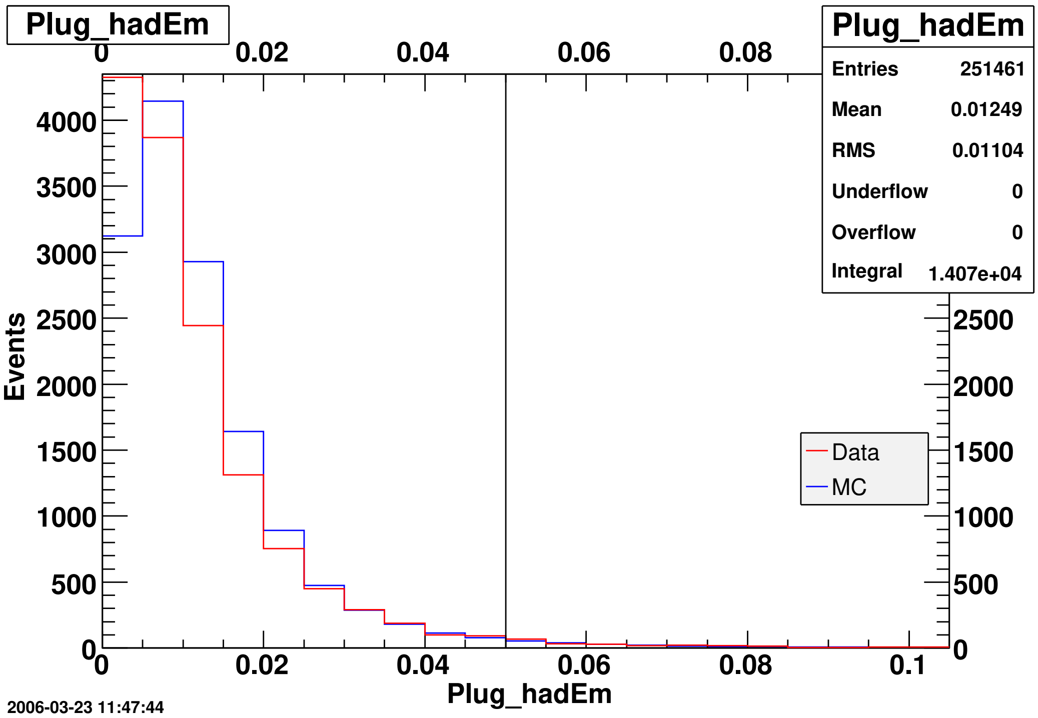

Figure 10: Tight plug ID N-1 plot, the vertical line shows the ID cut value.

3.3 Reconstructing Plug electron energy

In this section, details on reconstructing the plug electron energy are discussed.

The plug electron energy is reconstructed as following[13]:

- Get the raw plug electron energy with face correction:
  faceCorr2x2E = EMCLST_ele_std_E[iem]
  Face Correction is the correction due to the different response of the calorimeter in each wedge. The correction is determined by mapping the calorimeter response across the wedge using test beam data.

- Get the energy deposited in the PPR
  PprE = PEMCLST_pem_std_pprEnergy[ipem].
  pprE is the energy deposited in the Plug PreRadiate detector(PPR), which is the first layer of the PEM.

- Get the leakage energy
  LeakE = EMCLST_ele_isoLkgCorrEnBased[iem].
  Leakage Correction: the electron shower will be fully contained in a 3x3 cluster, but in a 2x2 cluster, there may be some small leakage to neighboring towers. The correction depends on the position of the center of the electron shower.

- Get the face correction factor
  faceCorr = EMCLST_ele_cempemCorrEnBased[iem];

- apply face correction to the leakage energy
  faceCorrLeakE = LeakE / faceCorr;

- Get the corrected Plug Energy
  CorrPlugE = faceCorr2x2E + faceCorrLeakE + PprE;

- apply energy scale factor
  CorrPlugE *= ScaleFac;

- set the four momentum vector:
  VectorPlugE.SetPxPyPzE(EMCLST_ele_std_Ex[iem],Ey, Ez, E);

- scaling the 4Vector to the correct energy:
  VectorPlugE *= CorrPlugE / VectorPlugE.E();

- Get the corrected ET:
  CorrPlugET = VectorPlugE.Pt();

Figure 11 shows the distribution of the reconstructed plug electron energy and the corrections.

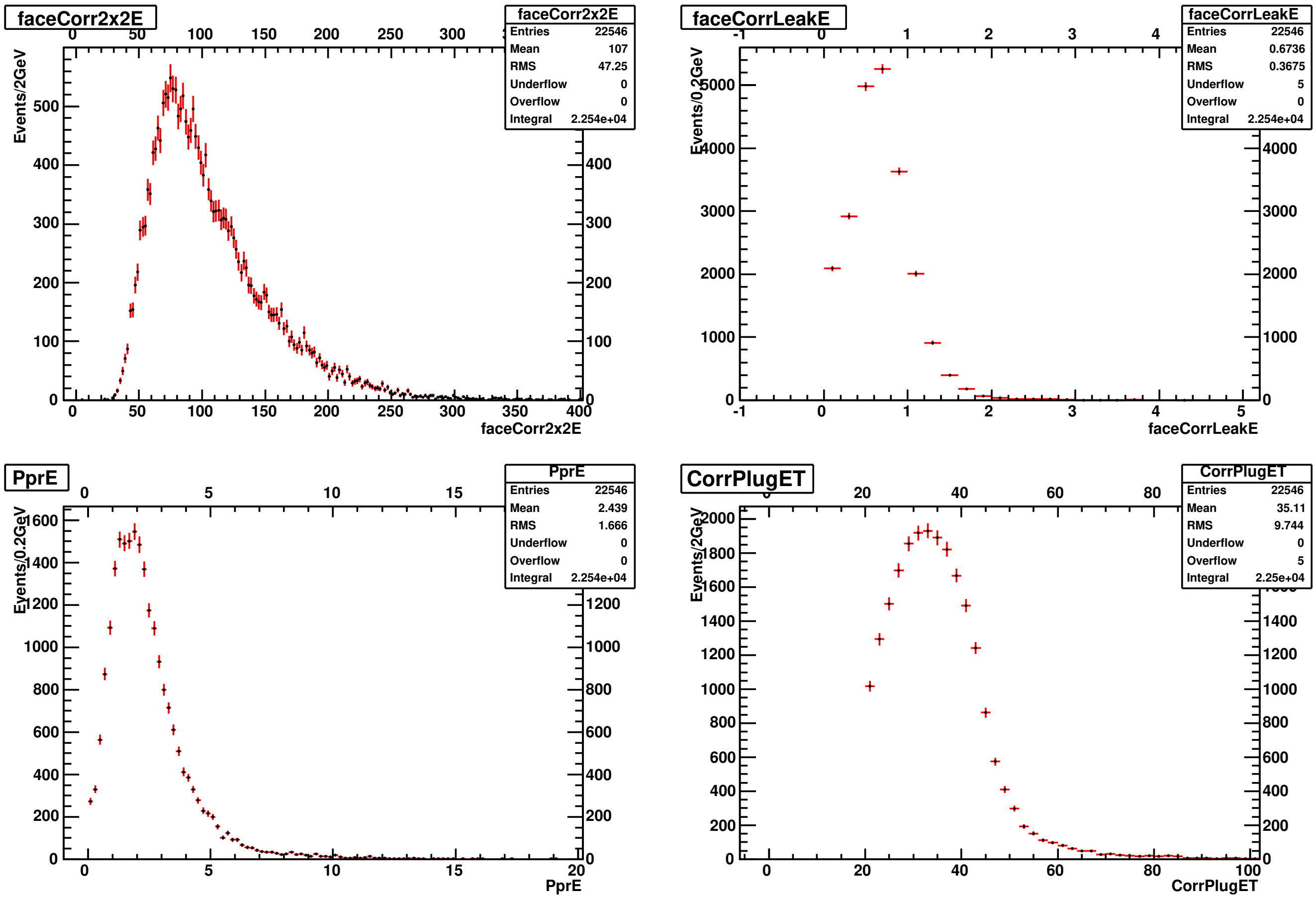

Figure 11: Reconstructing Plug electron energy

3.4 Electron energy Scale factor

In this section, the electron energy corrections are discussed.

Plot 12 shows the invariant di-lepton mass plots for data and MC. The MC plots are normalize to data, such that there are the same number of events within the mass window 86-98 GeV. As can be seen from the plots, data and MC do not give the same peak positions. We apply energy scale factors to the data and MC, to bring the peak positions to 91 GeV. To get a clean sample, the electrons are required to satisfied the tight selection cuts listed in table 5 and table 9. A Gaussian fit with a fit window of 86-98 GeV is used. An energy scale factor is extracted so that the mean value of the Gaussian fit is at 91 GeV.

There are small variations for the three datasets(0d, 0h and 0i), we scale them differently.

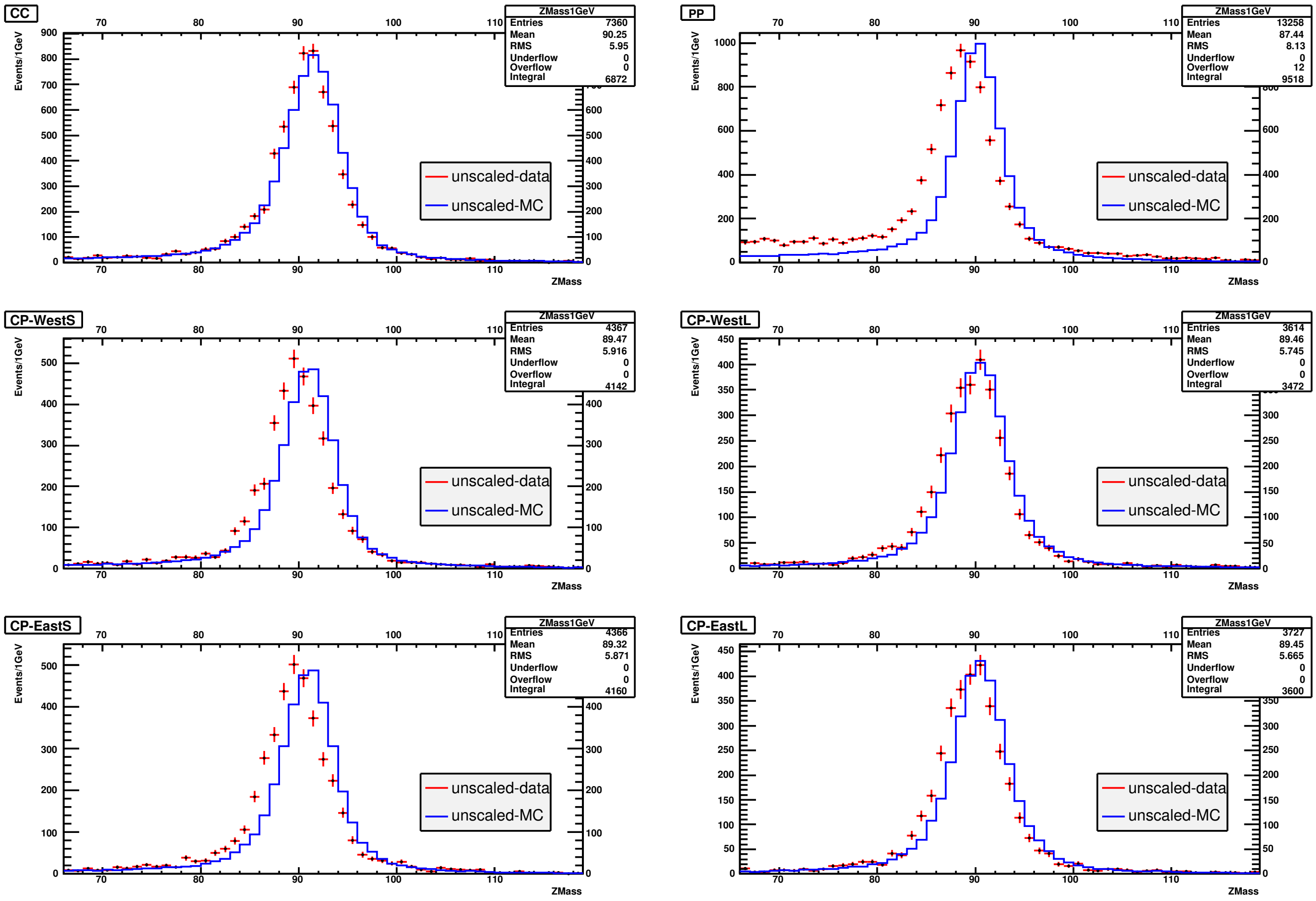

Figure 12: Unscaled di-electron mass spectra. CC: two tight central electrons, PP: two tight plug electrons, CP-West: the plug electron is from the west side of the detector, CP-East: the plug electron is from the east side of the detector. CP-WestS: the range of the plug electron eta is $|\eta| < 1.78$, CP-WestL: the range of the plug electron eta is $|\eta| \geq 1.78$. Similarly for the CP-EastS and CP-EastL.

3.4.1 bhel0d dataset

In this section, the electron energy scale factors for the bhel0d dataset and the zewk6d MC dataset are given.

Figure 13 and figure 14 compare the mass spectra with and without applying energy scale factors. And Figure 15 compare the scaled mass spectra of data and MC, both now are peaked at 91 GeV.

The Z peak positions from the unscaled data and MC samples are listed in table 10. The energy scale factors are listed in table 11.

Figure 16 shows the Gaussian fit to the unscaled-data.

Figure 17 shows the Gaussian fit to the scaled-data.

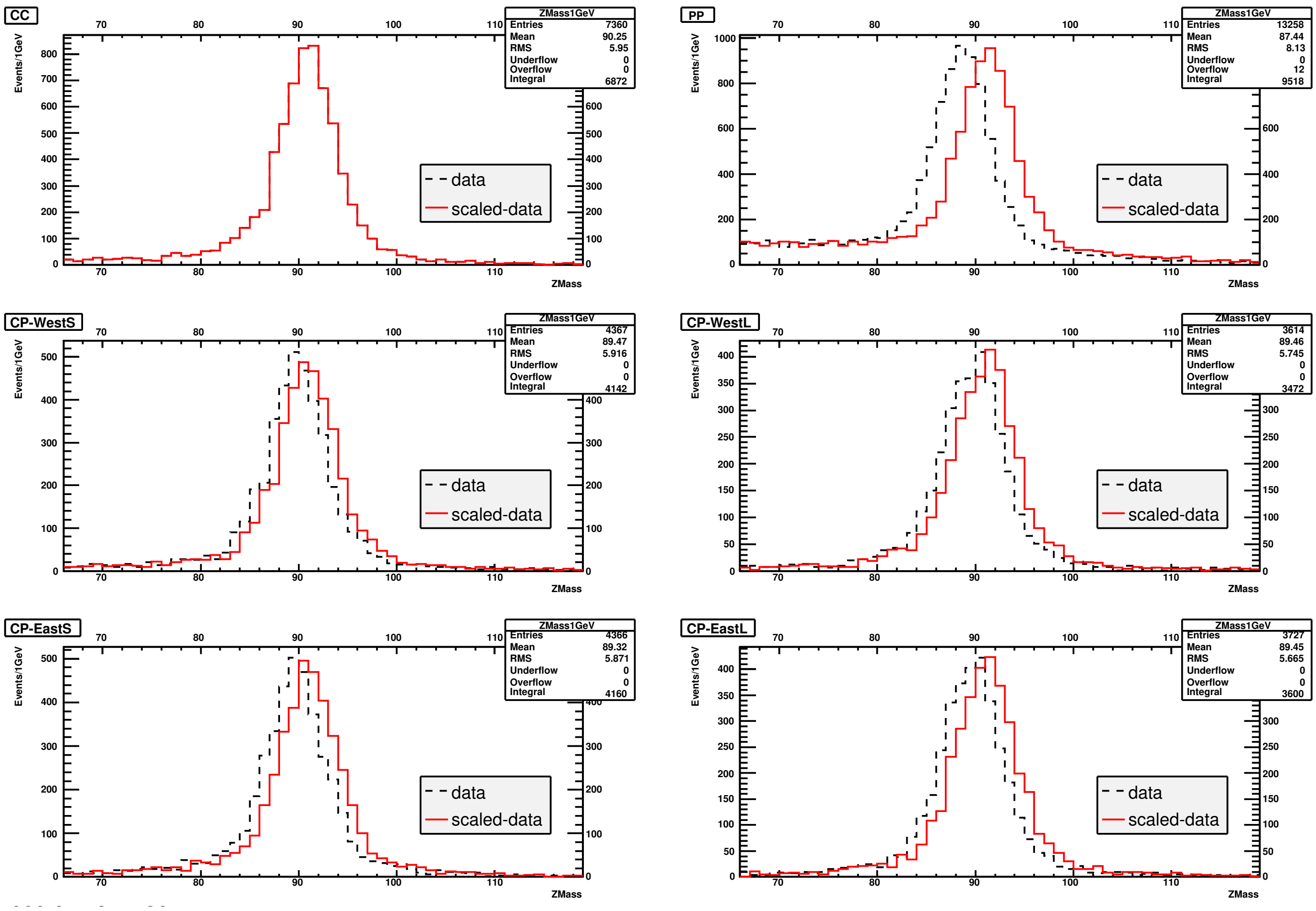

Figure 13: Di-electron mass spectra with and without applying energy scale factors (data).

Region	Data	MC
Central-Central	91.01 ± 0.04	91.44 ± 0.01
Central-Plug		
West($\lvert\eta\rvert < 1.78$)	89.92 ± 0.07	91.01 ± 0.01
West($\lvert\eta\rvert \geq 1.78$)	89.76 ± 0.09	90.51 ± 0.02
East($\lvert\eta\rvert < 1.78$)	89.67 ± 0.09	90.98 ± 0.01
East($\lvert\eta\rvert \geq 1.78$)	89.54 ± 0.10	90.54 ± 0.02
Plug-Plug	88.36 ± 0.11	90.35 ± 0.01

Table 10: Z Peak positions from the unscaled data and MC samples

Figure 18 shows the Gaussian fit to the unscaled-MC.

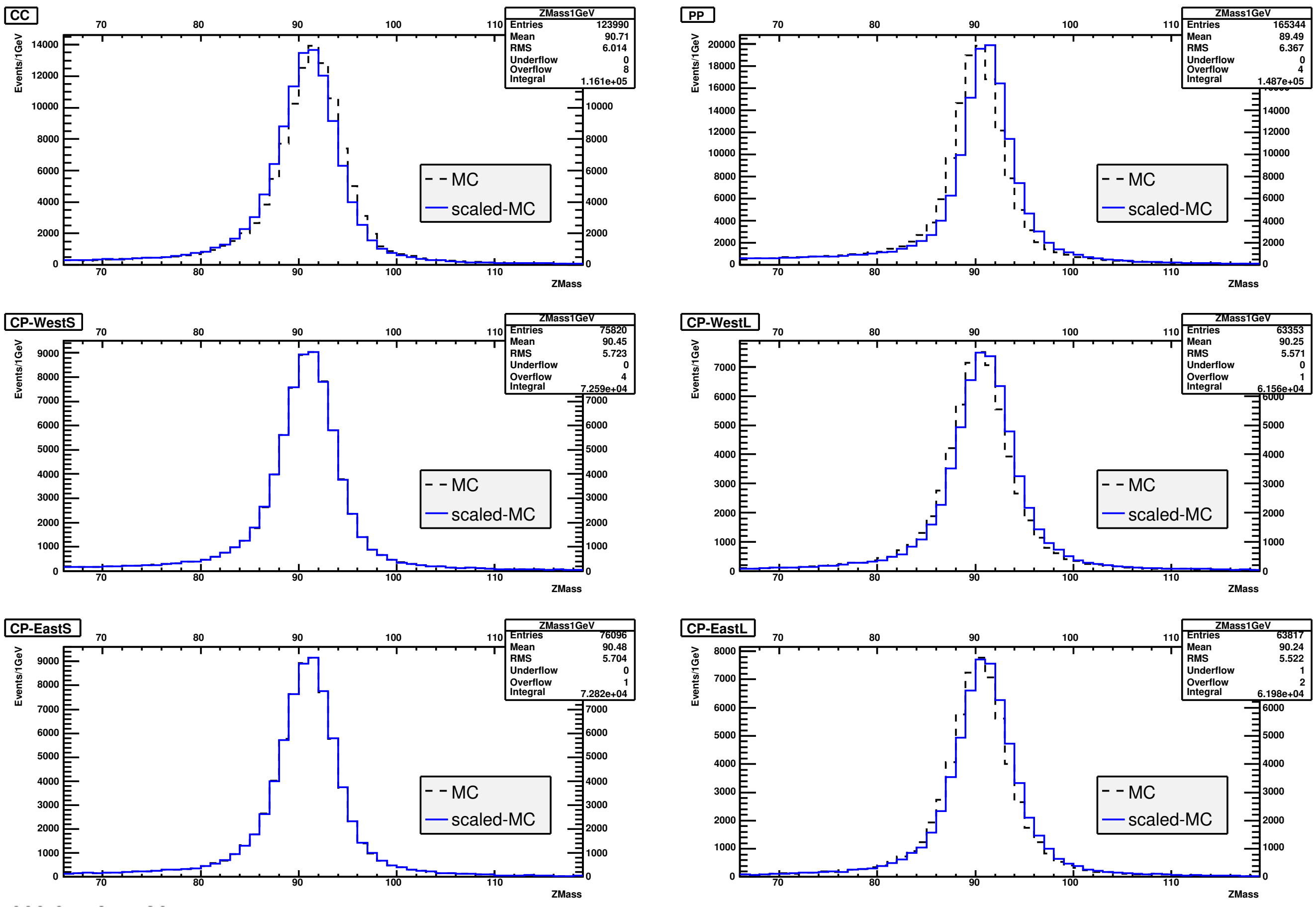

Figure 14: Di-electron mass spectra with and without applying energy scale factors (MC).

Region	Data	MC
Central	no correction	0.995
Plug		
West($\|\eta\| < 1.78$)	1.024	1.005
West($\|\eta\| \geq 1.78$)	1.028	1.016
East($\|\eta\| < 1.78$)	1.030	1.005
East($\|\eta\| \geq 1.78$)	1.033	1.015

Table 11: Energy scale factors

Figure 19 shows the Gaussian fit to the scaled-MC.

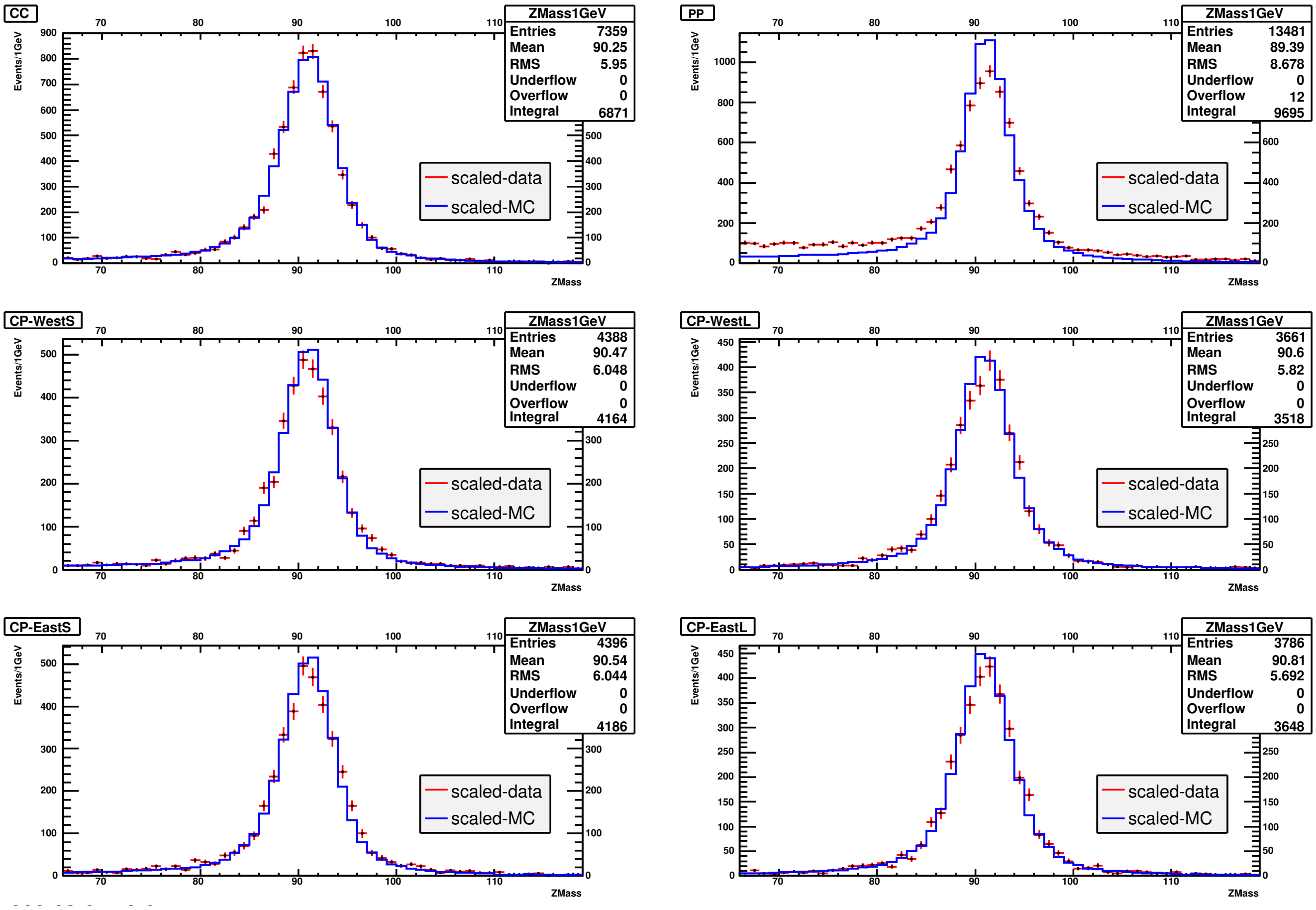

Figure 15: Scaled di-electron mass spectra, data vs MC.

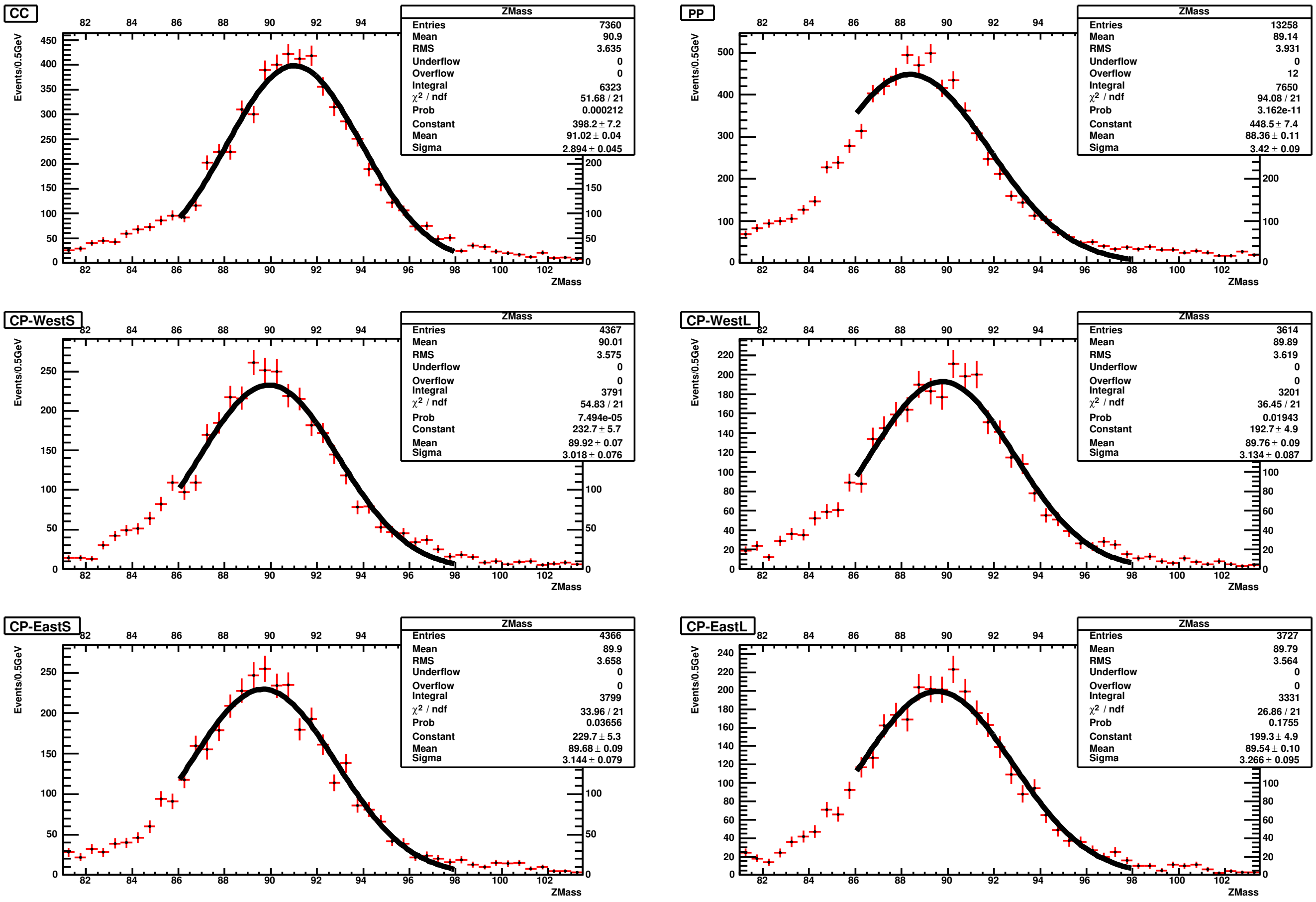

Figure 16: Gaussian fit without energy scale factor, bhel0d dataset

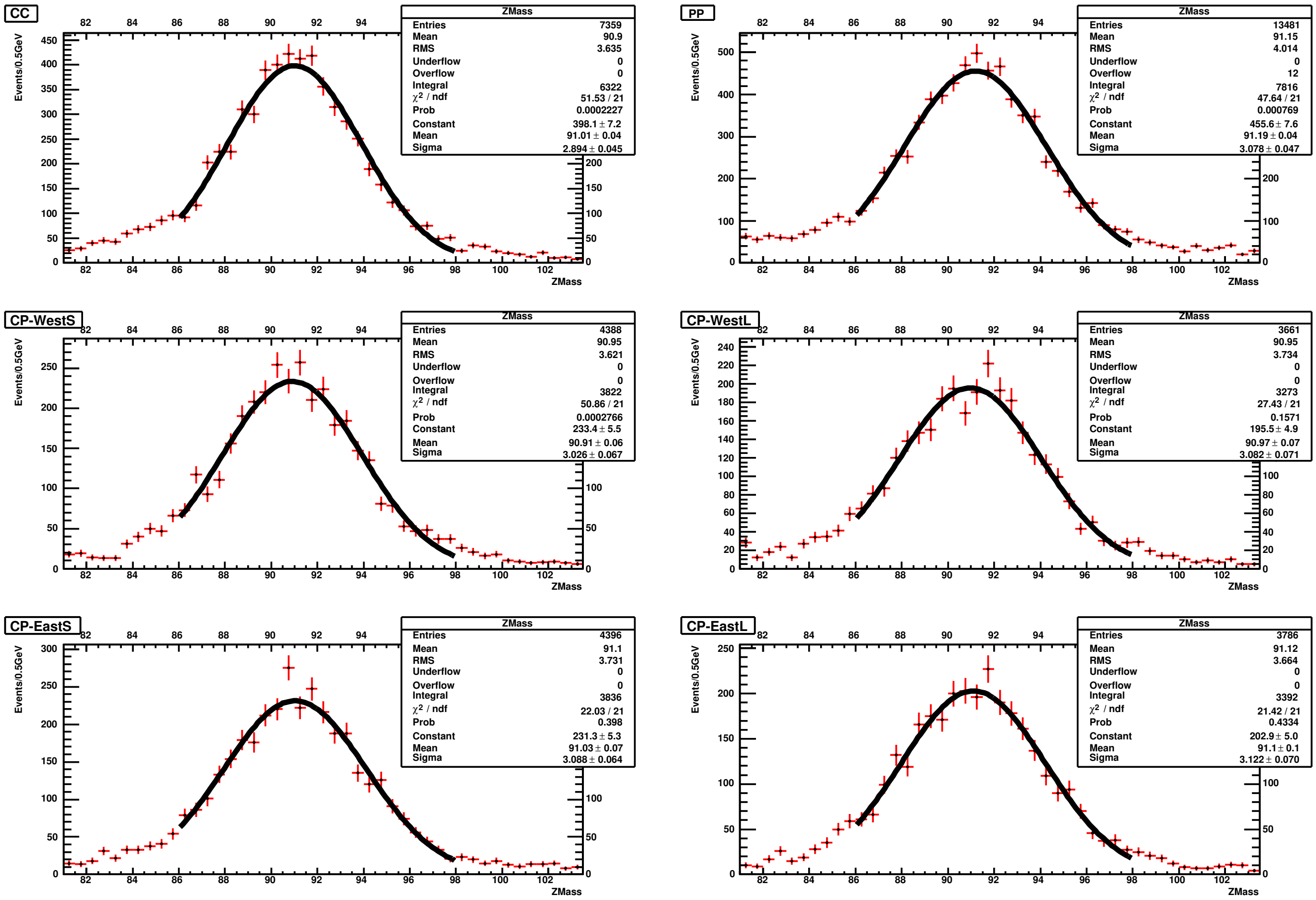

Figure 17: Gaussian fit after energy scale, bhel0d dataset

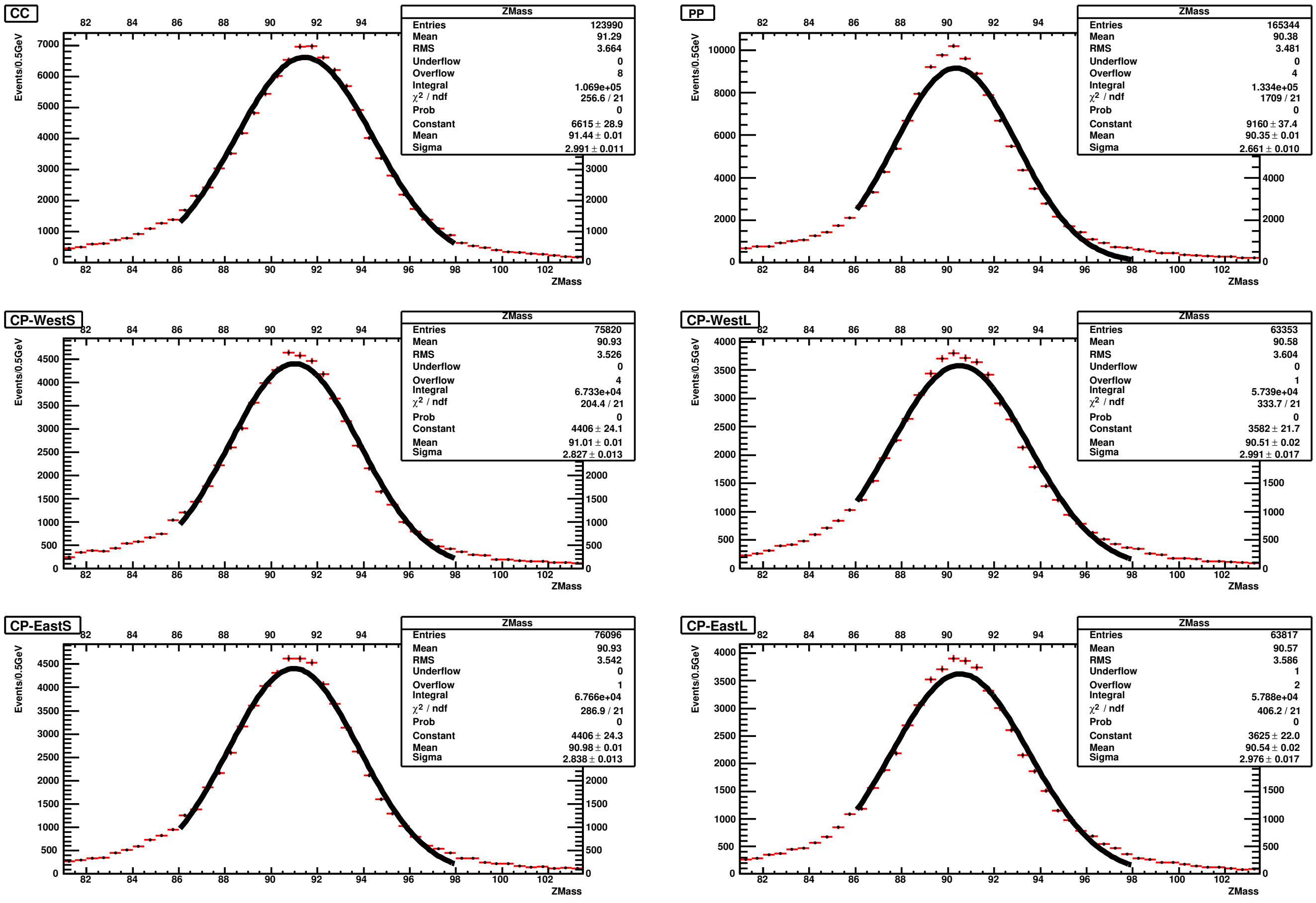

Figure 18: Gaussian fit MC without energy scale factor, zewk6d dataset

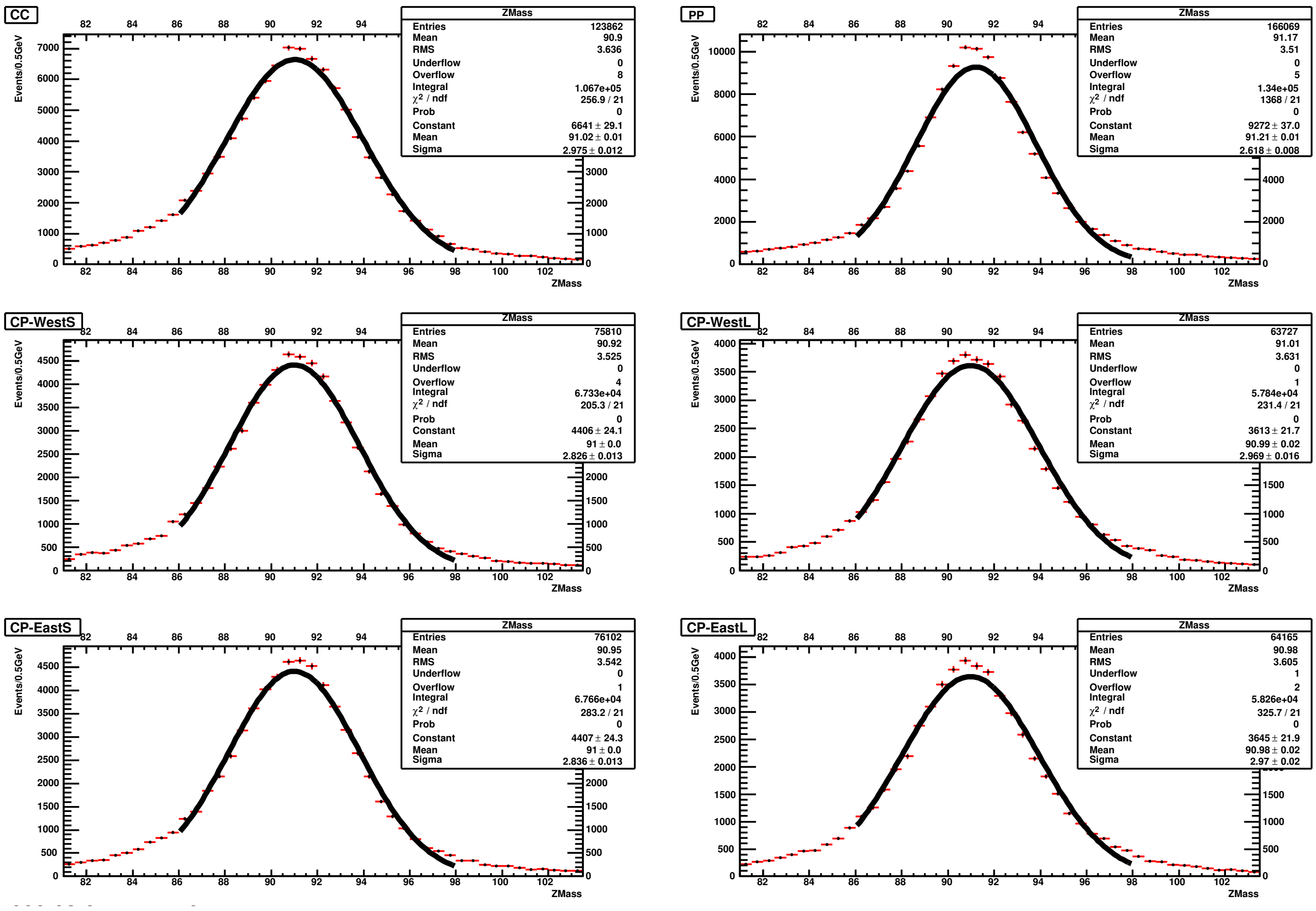

Figure 19: Gaussian fit after energy scale(MC), zewk6d dataset

3.4.2 bhel0h and bhel0i dataset

In this section, the electron energy scale factors for the bhel0h, bhel0i and zewkad dataset are given.

The Z peak positions from the unscaled data and MC samples are listed in table 12 and table 14. The energy scale factors are listed in table 13 and 15 .

Region	Data (0h)	MC
Central-Central	90.77 ± 0.05	91.48 ± 0.01
Central-Plug		
West($\|\eta\| < 1.78$)	89.22 ± 0.09	91.04 ± 0.01
West($\|\eta\| \geq 1.78$)	89.60 ± 0.09	90.54 ± 0.01
East($\|\eta\| < 1.78$)	89.41 ± 0.09	91.03 ± 0.01
East($\|\eta\| \geq 1.78$)	89.47 ± 0.10	90.57 ± 0.02
Plug-Plug	86.77 ± 0.26	90.37 ± 0.01

Table 12: Z Peak positions from the unscaled data and MC samples, bhel0h and zewk9d datasets

Region	Data(0h)	MC
Central	1.003	0.995
Plug		
West($\|\eta\| < 1.78$)	1.038	1.004
West($\|\eta\| \geq 1.78$)	1.029	1.015
East($\|\eta\| < 1.78$)	1.033	1.005
East($\|\eta\| \geq 1.78$)	1.032	1.015

Table 13: Energy scale factors

Figure 20 shows the Gaussian fit to the scaled-data for bhel0h dataset.
Figure 21 shows the Gaussian fit to the scaled-data for bhel0i dataset.
Figure 22 shows the Gaussian fit to the scaled-MC.

Region	Data (0i)	MC
Central-Central	90.61 ± 0.06	91.48 ± 0.01
Central-Plug		
West($\|\eta\| < 1.78$)	89.38 ± 0.09	91.04 ± 0.01
West($\|\eta\| \geq 1.78$)	89.73 ± 0.11	90.54 ± 0.01
East($\|\eta\| < 1.78$)	89.41 ± 0.11	91.03 ± 0.01
East($\|\eta\| \geq 1.78$)	89.62 ± 0.12	90.57 ± 0.02
Plug-Plug	87.64 ± 0.23	90.37 ± 0.01

Table 14: Z Peak positions from the unscaled data and MC samples, bhel0i and zewk9d datasets

Region	Data(0i)	MC
Central	1.004	0.995
Plug		
West($\|\eta\| < 1.78$)	1.032	1.004
West($\|\eta\| \geq 1.78$)	1.024	1.015
East($\|\eta\| < 1.78$)	1.031	1.005
East($\|\eta\| \geq 1.78$)	1.027	1.015

Table 15: Energy scale factors

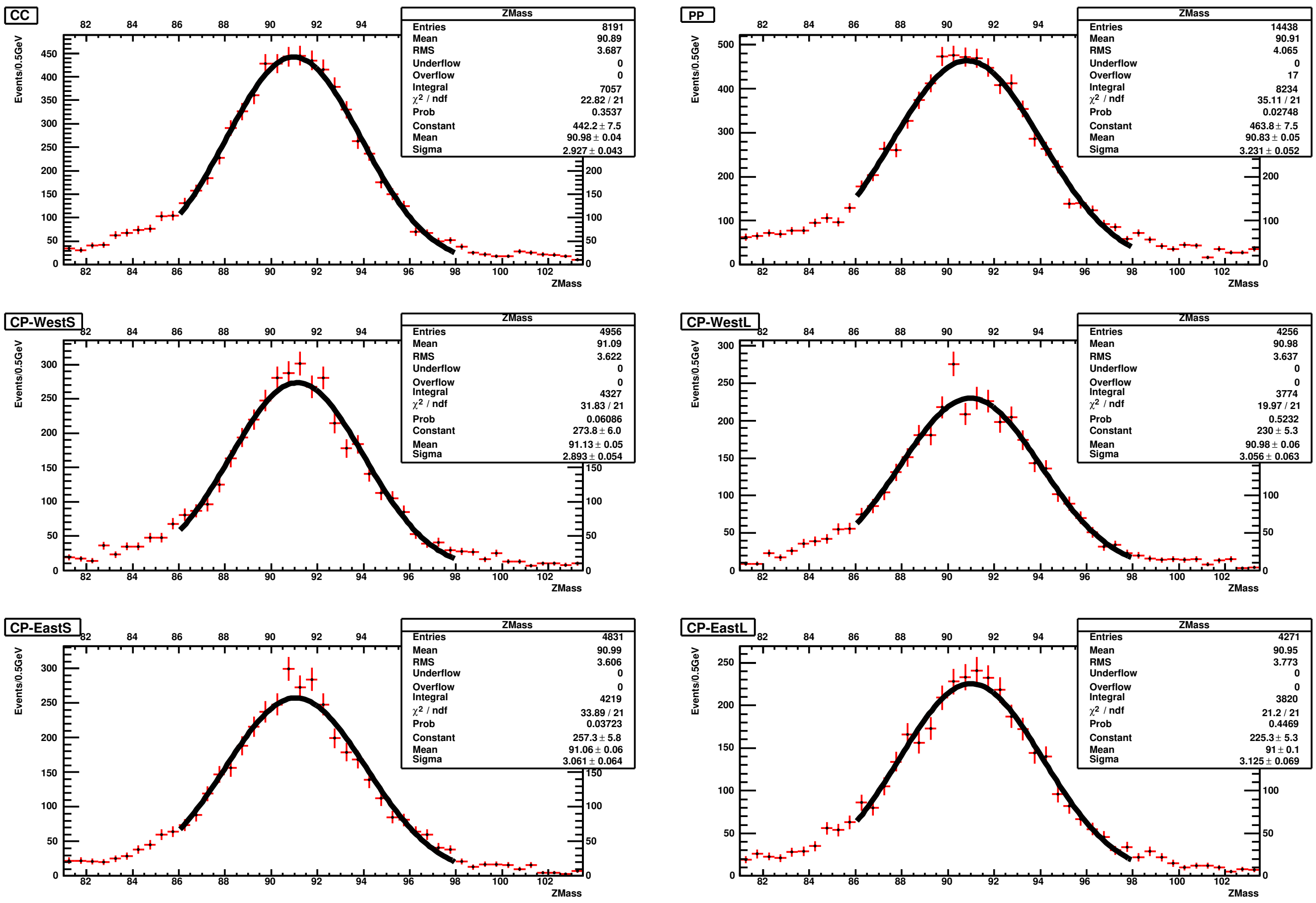

Figure 20: Gaussian fit after energy scale, bhel0h dataset

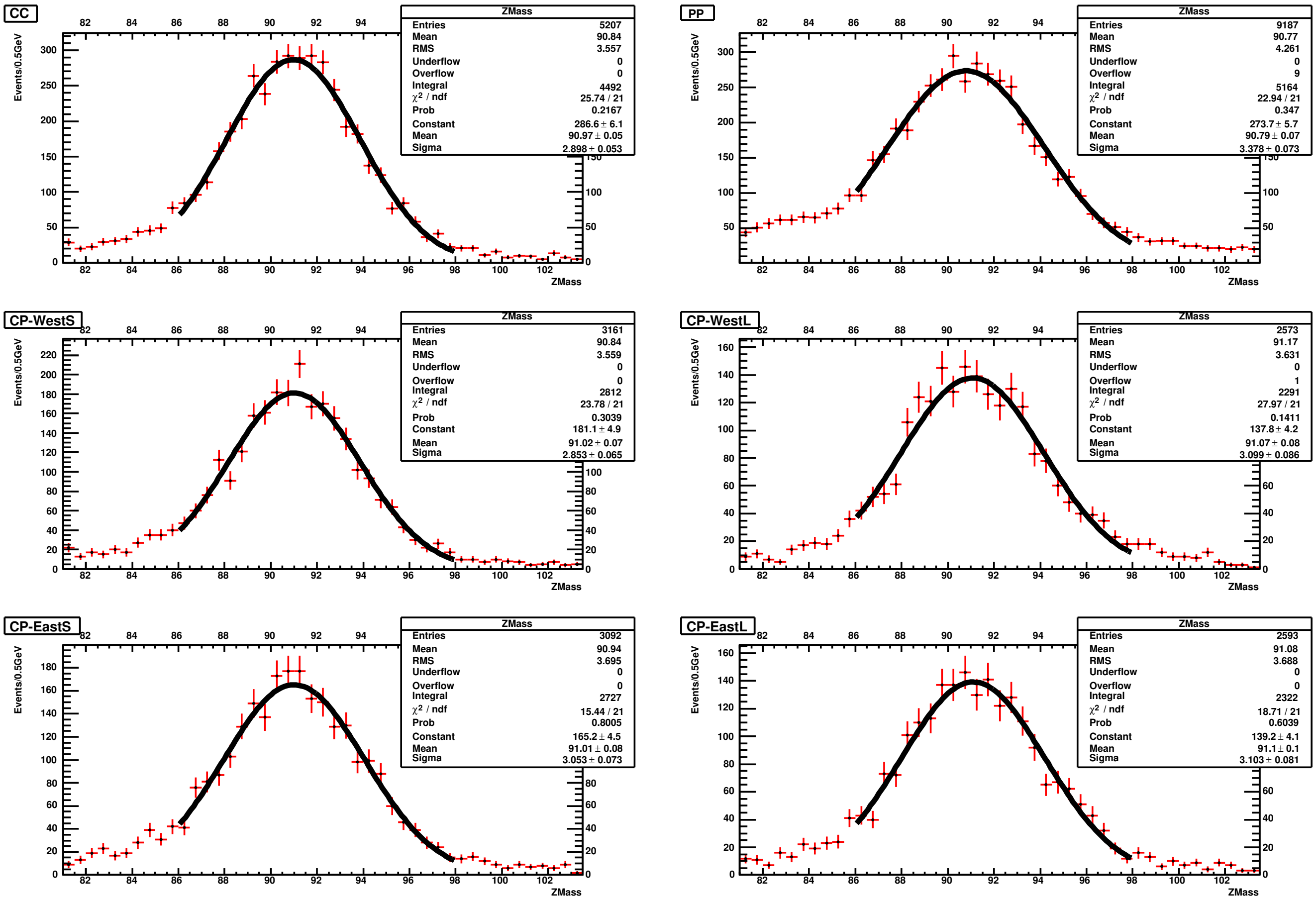

Figure 21: Gaussian fit after energy scale, bhel0i dataset

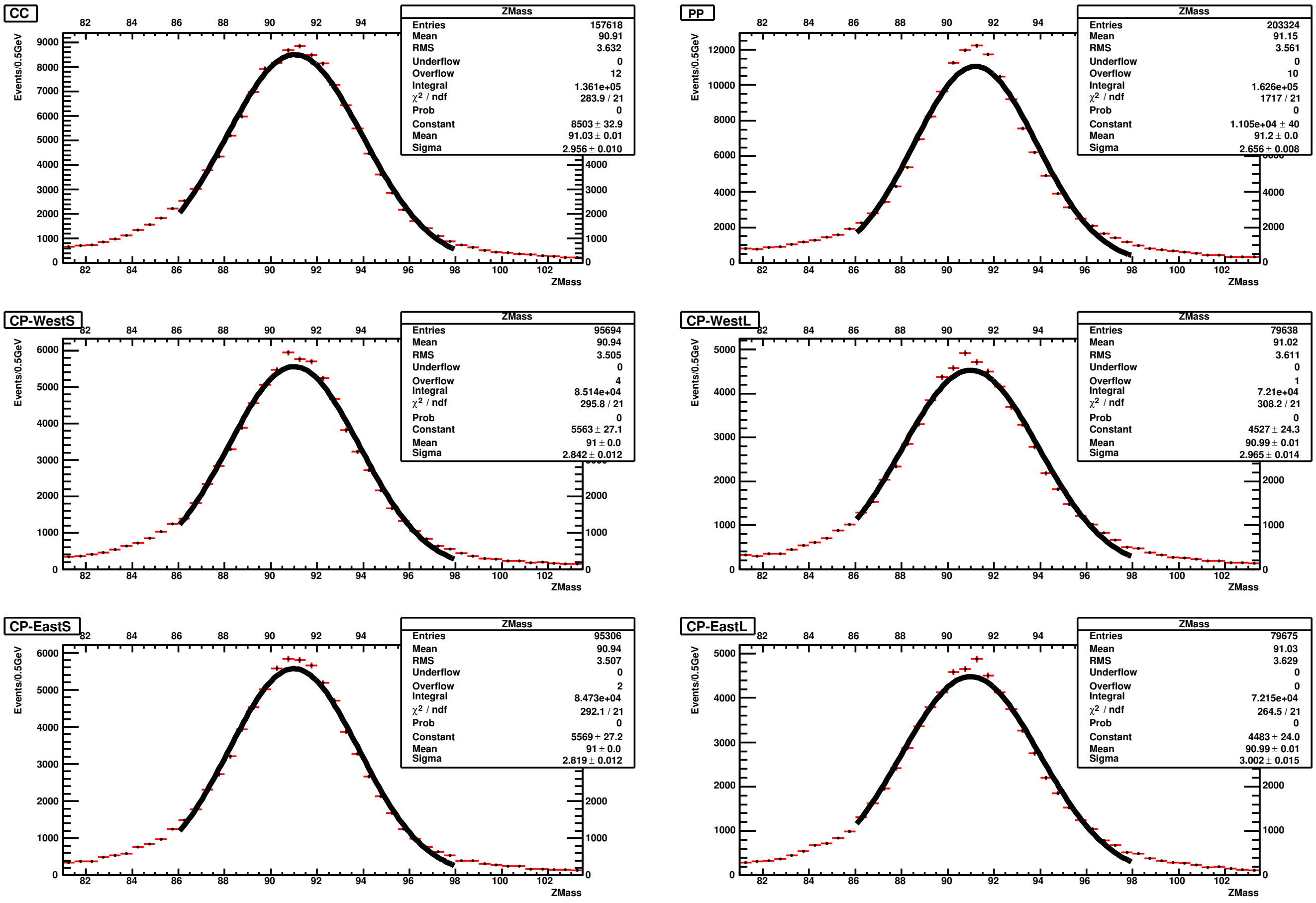

Figure 22: Gaussian fit after energy scale(MC), zewk9d dataset

3.5 Z Mass resolution in MC

Figure 23 compares the width of Z mass peak in data and in MC. For PP Z(top-right figure), as can be seen from the plot, the Z width is narrower in MC than in data, which indicates that some smearing on the MC energy resolution of the plug electrons is needed.

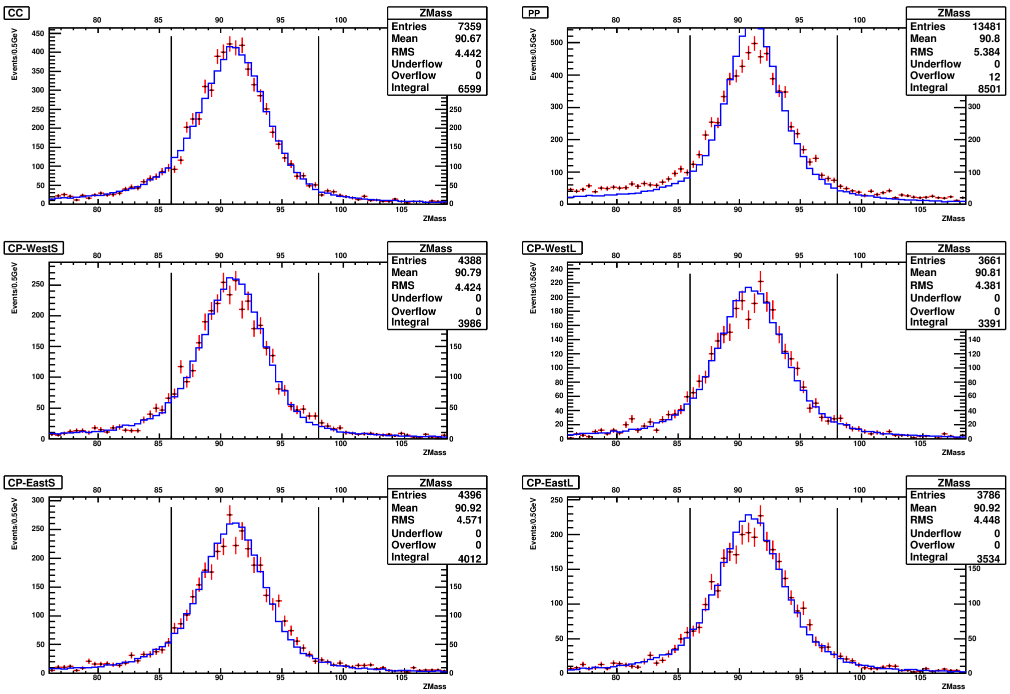

Figure 23: Data/MC Z Mass distribution without smearing MC energy resolution of the plug electrons

The smearing is performed as below:

- Apply smearing to MC Plug Electron only
- E' = a E, where a is the energy scale factor, to bring the Z pole mass to 91 GeV
- E" = Gaus(aE, b), use Gaussian smearing to adjust Z mass width
- scan through the two-dimensional space a-b, find the parameters a and b that gives the best agreement in Z pole mass and width using CP Zee data, given by a quality metric:

$$Q = e^{-\left(\frac{M_Z^{data}-M_Z^{MC}}{M_Z^{data}}\right)^2} e^{-\left(\frac{\Gamma_Z^{data}-\Gamma_Z^{MC}}{\Gamma_Z^{data}}\right)^2}$$

Figure 24 shows the Z mass plot after smearing plug electron energy resolution in MC. The agreement between data and MC in the PP region is much improved.

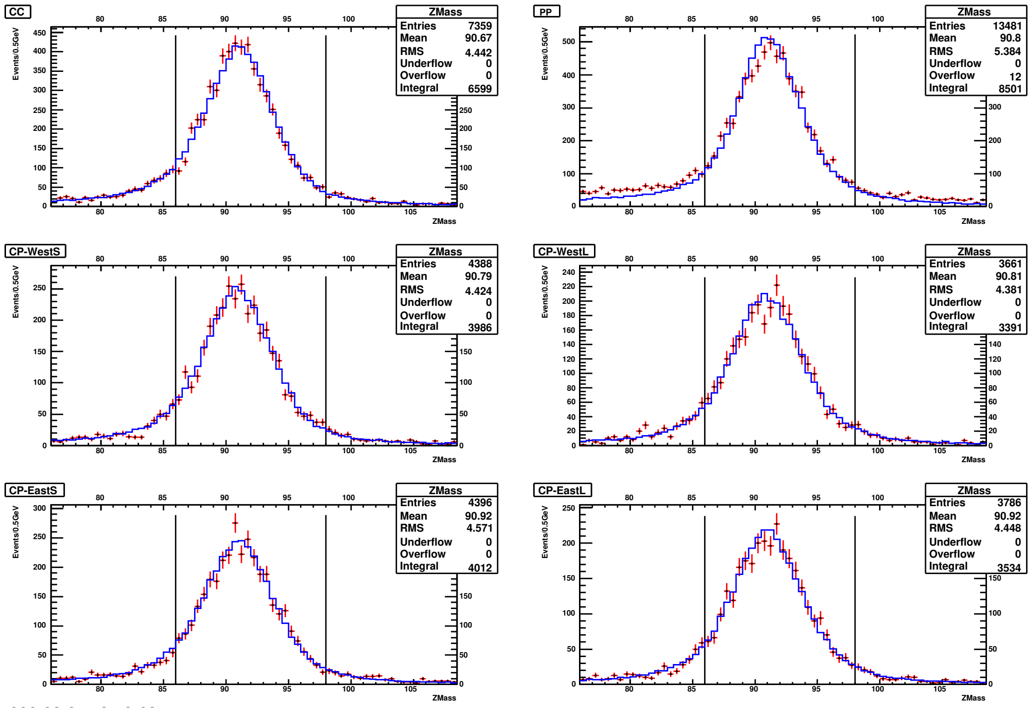

Figure 24: Z Mass resolution after smearing energy resolution of the plug electrons

4 Acceptance

4.1 MC Samples

The Z→ee MC samples(table 2) from Electroweak group are used to study the signal acceptance. For Gen5 data, zewk6d MC is used, which is Z → ee Pythia MC, reprocessed with offline production release 5.3.3. The minimum Zee mass at generator level is 20 GeV. The first run is 141544, the last run is 186598. There are a small number of runs that has a problem in generating the event vertex in these runs. These runs are excluded in the sample, which corresponds to about 9 pb^{-1} out of 330.

For Gen6 data, zewkad MC is used, which is Z → ee Pythia MC, reprocessed with offline production release 6.1.4c. The minimum Zee mass at generator level is 30 GeV. The first run is 190753, the last run is 212133.

4.2 Acceptance in the CC Region

We measure the fraction of Z events that pass the geometry and kinematic requirements in the CC channel, where the both electron legs from Z decay are in the central region($|\eta| \leq 1.1$). Events with the primary event vertex outside 60.0 cm of the detector origin along the beam line, are removed from both the numerator and denominator. The selection efficiency of the event vertex requirement is measured separately (see 8.3).

We measure the inclusive $\gamma^*/Z \rightarrow ee$ cross-section in the invariant mass range 66 GeV/$c^2 \leq M_{ee} \leq 116$ GeV/c^2. The MC samples used to measure the acceptance are generated with a minimum invariant mass of 20 GeV(30 GeV for zewkad dataset). The invariant mass of the di-lepton at the generator level is required to lie within the mass range 66 GeV/$c^2 \leq M_{ee}(Gen) \leq 116$ GeV/c^2. Events generated outside our allowed range do not contribute to the denominator, but can contribute to the numerator due to the effects of radiative and detector resolution. Therefore, the invariant mass requirement at the generator level is only applied to the denominator, not the numerator.

Table 16 gives the acceptance of Z→ee events in CC region for 0d dataset. Events are required to have at least two EM Clusters in central region that satisfies the corresponding selection criteria listed in the table 16. The reconstructed invariant mass is required to lie within the mass window 66 GeV/$c^2 \leq$ Mee(Rec) ≤ 116 GeV/c^2.

In addition, the reconstructed electrons are required to match the electrons at the generator level. The matching criteria are: $\Delta R(e_{Gen}, e_{Rec}) < 0.05$(see figure 25).

Table 17 and 18 show CC acceptance using zewkad MC, for 0h and 0i dataset run range, respectively.

The acceptance for selecting CC Z events is ∼11%.

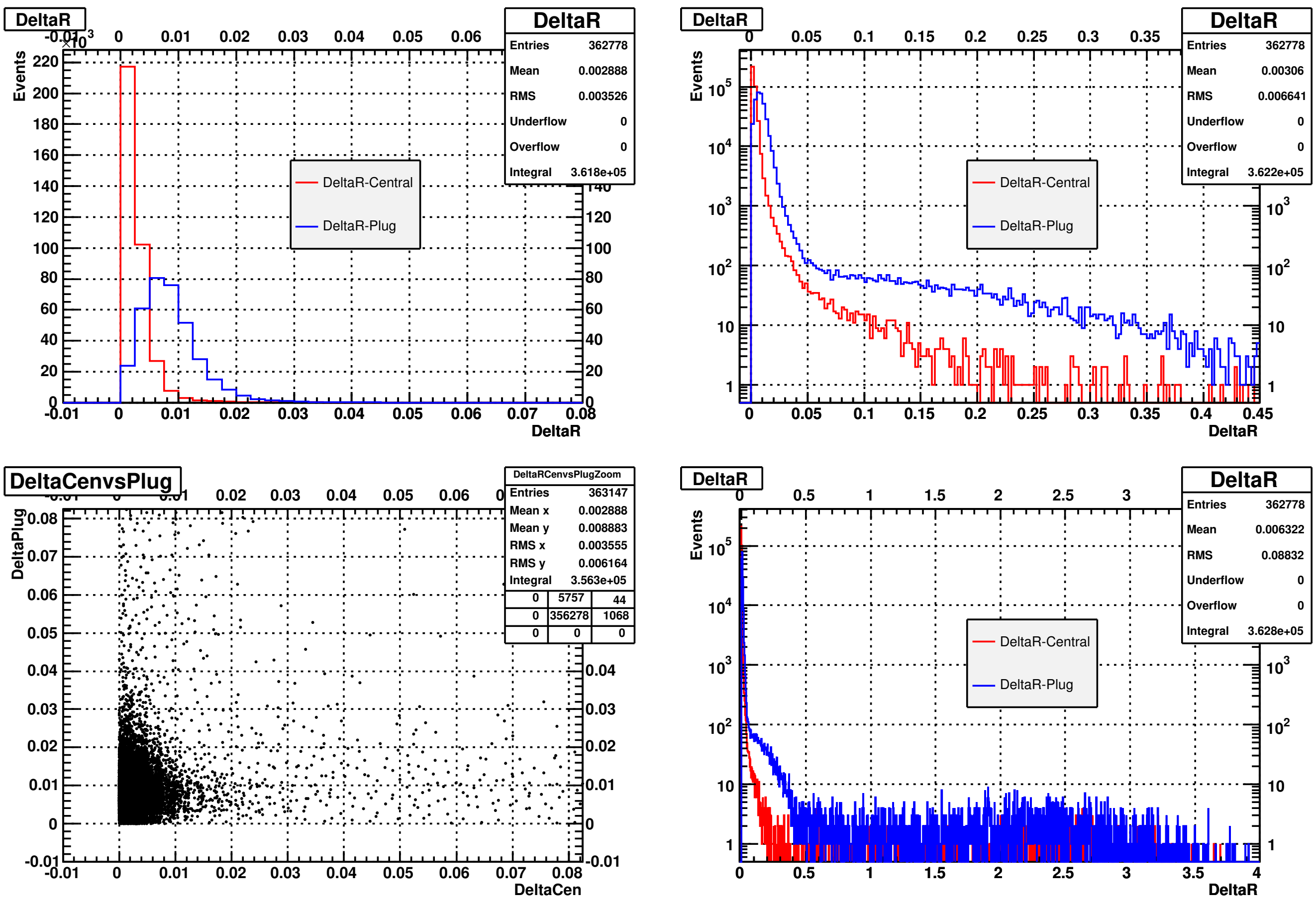

Figure 25: HEPG Matching DeltaR

4.3 Acceptance in the CP Region

We measure the fraction of Z events that pass the geometry and kinematic requirements in the CP channel, where the first electron leg from Z decay is in the central region($|\eta| \leq 1.1$) and the second electron leg is in the plug region($1.2 \leq |\eta| \leq 2.8$).

Table 19 gives the acceptance of Z$\rightarrow$ee events in CP region for 0d dataset. Events are required to have at least one EM Cluster in central region and one EM Cluster in plug region that satisfies the corresponding selection criteria listed in the table 19.

Table 20 and 21 show CP acceptance using zewkad MC, for 0h and 0i dataset run range, respectively.

The acceptance for selecting CP Z events is $\sim$23%.

Selection Criteria	Number of Events	Net Acceptance
Total Events	3.22568e+06	-
Good Run	3.11168e+06	-
$\|Z_{vtx}\| \leq 60$ cm	3.01684e+06	-
66 GeV/$c^2 \leq$ Mee(Gen) $\leq$ 116 GeV/c^2 (Gen Mass cut on denominator only)	1.54163e+06	-
Central EM Cluster (det = 0)	1.85913e+06	1.206
Calorimeter Fiducial Cuts (fidEleShrMax = 1)	1.62556e+06	1.054
Electron Beam-Constrained Track $P_T \geq 10$ GeV/c	1.16091e+06	0.753
EM Cluster $E_T \geq 20$ GeV	873291	0.5665
Second Central EM Cluster (det = 0)	592372	0.3843
Second Calorimeter Fiducial Cuts (fidEleShrMax = 1)	412936	0.2679
Second Electron Beam-Constrained Track $P_T \geq 10$ GeV/c	229857	0.1491
Second EM Cluster $E_T \geq 20$ GeV	189263	0.1228
Two EM Cluster	189263	0.1228
66 GeV/$c^2 \leq$ Mee(Rec) $\leq$ 116 GeV/c^2	176386	0.1144
OS	173441	0.1125
$\|VertexZ\| \leq 60$ cm	173310	0.1124
Matching HEPG($\Delta R \leq 0.05$)	172339	0.1118
Trigger fired	172332	0.1118

Table 16: Z→ ee CC channel Selection Acceptance. zewk6d MC

4.4 Acceptance in the PP Region

We measure the fraction of Z events that pass the geometry and kinematic requirements in the PP channel, where both electrons from Z decay are in the forward region($1.2 \leq |\eta| \leq 2.8$). In addition, we require the two electrons are from the same side of the detector. Events, where the two electrons are from the opposite side of the detector, are mostly background events.

Table 23 and 24 show PP acceptance using zewkad MC, for 0h and 0i dataset run range, respectively.

The acceptance for selecting PP Z events is ∼9%.

4.5 Correct for slow trigger efficiency turning on at low Pt/Et

There is a slow turn-on of the trigger efficiency at the low Pt/Et region. To correct for the effect of this slow turn-on, a trigger efficiency weight is applied to MC samples event by event when calculating the signal acceptance. See section 6 for more details.

Selection Criteria	Number of Events	Net Acceptance
Total Events	6772028	-
Good Run	3987754	-
$\lvert Z_{vtx}\rvert \leq 60$ cm	3821994	-
66 GeV/$c^2 \leq$ Mee(Gen) $\leq$ 116 GeV/c^2 (Gen Mass cut on denominator only)	1954429	-
Central EM Cluster (det = 0)	2376988	1.2162 $\pm$ nan
Calorimeter Fiducial Cuts (fidEleShrMax = 1)	2071980	1.0601 $\pm$ nan
Electron Beam-Constrained Track $P_T \geq 10$ GeV/c	1473514	0.7539 $\pm$ 0.0003
EM Cluster $E_T \geq 20$ GeV	1109021	0.5674 $\pm$ 0.0004
Second Central EM Cluster (det = 0)	776502	0.3973 $\pm$ 0.0004
Second Calorimeter Fiducial Cuts (fidEleShrMax = 1)	535226	0.2739 $\pm$ 0.0003
Second Electron Beam-Constrained Track $P_T \geq 10$ GeV/c	292244	0.1495 $\pm$ 0.0003
Second EM Cluster $E_T \geq 20$ GeV	240740	0.1232 $\pm$ 0.0002
Two EM Cluster	240740	0.1232 $\pm$ 0.0002
66 GeV/$c^2 \leq$ Mee(Rec) $\leq$ 116 GeV/c^2	224225	0.1147 $\pm$ 0.0002
OS	220640	0.1129 $\pm$ 0.0002
$\lvert VertexZ\rvert \leq 60$ cm	219666	0.1124 $\pm$ 0.0002
Matching HEPG($\Delta R \leq 0.05$)	218557	0.1118 $\pm$ 0.0002
Trigger Efficiency Weighted	218557	0.1118 $\pm$ 0.0002

Table 17: Z$\rightarrow$ ee CC channel Selection Acceptance. Statistical uncertainties are shown. Using zewkad MC sample, 0h dataset run range.

Selection Criteria	Number of Events	Net Acceptance
Total Events	6772028	-
Good Run	2550597	-
$\lvert Z_{vtx}\rvert \leq 60$ cm	2440858	-
66 GeV/c^2 $\leq$ Mee(Gen) $\leq$ 116 GeV/c^2	1247788	-
(Gen Mass cut on denominator only)		
Central EM Cluster (det = 0)	1521188	1.2191 $\pm$ nan
Calorimeter Fiducial Cuts (fidEleShrMax = 1)	1325423	1.0622 $\pm$ nan
Electron Beam-Constrained Track $P_T \geq 10$ GeV/c	940393	0.7536 $\pm$ 0.0004
EM Cluster $E_T \geq 20$ GeV	708583	0.5679 $\pm$ 0.0004
Second Central EM Cluster (det = 0)	499061	0.4000 $\pm$ 0.0004
Second Calorimeter Fiducial Cuts (fidEleShrMax = 1)	343666	0.2754 $\pm$ 0.0004
Second Electron Beam-Constrained Track $P_T \geq 10$ GeV/c	186440	0.1494 $\pm$ 0.0003
Second EM Cluster $E_T \geq 20$ GeV	153437	0.1230 $\pm$ 0.0003
Two EM Cluster	153437	0.1230 $\pm$ 0.0003
66 GeV/c^2 $\leq$ Mee(Rec) $\leq$ 116 GeV/c^2	143015	0.1146 $\pm$ 0.0003
OS	140710	0.1128 $\pm$ 0.0003
$\lvert VertexZ\rvert \leq 60$ cm	139937	0.1121 $\pm$ 0.0003
Matching HEPG($\Delta R \leq 0.05$)	139210	0.1116 $\pm$ 0.0003
Trigger Efficiency Weighted	139198	0.1116 $\pm$ 0.0003

Table 18: Z$\rightarrow$ ee CC channel Selection Acceptance. Statistical uncertainties are shown, using zewkad MC sample, 0i dataset run range.

Selection Criteria	Number of Events	Net Acceptance
Total Events	3225677	-
Good Run	3111683	-
$\lvert Z_{vtx}\rvert \leq 60$ cm	3016836	-
66 GeV/c^2 $\leq$ Mee(Gen) $\leq$ 116 GeV/c^2	1541630	-
(Gen Mass cut on denominator only)		
Central EM Cluster (det = 0)	1859126	1.2059 $\pm$ nan
Calorimeter Fiducial Cuts (fidEleShrMax = 1)	1625563	1.0544 $\pm$ nan
Electron Beam-Constrained Track $P_T \geq 10$ GeV/c	1160908	0.7530 $\pm$ 0.0003
EM Cluster $E_T \geq 20$ GeV	873291	0.5665 $\pm$ 0.0004
Plug EM Cluster (det = 1)	534530	0.3467 $\pm$ 0.0004
PES2dGlobalEta ($1.20 \leq \lvert\eta\rvert \leq 2.80$)	431764	0.2801 $\pm$ 0.0004
Plug EM Cluster $E_T \geq 20$ GeV	378551	0.2456 $\pm$ 0.0003
Plug EM Cluster $Had/EM \leq 0.125$	377399	0.2448 $\pm$ 0.0003
Two EM Cluster	377399	0.2448 $\pm$ 0.0003
66 GeV/c^2 $\leq$ Mee(Rec) $\leq$ 116 GeV/c^2	362040	0.2348 $\pm$ 0.0003
$\lvert VertexZ\rvert \leq 60$ cm	361707	0.2346 $\pm$ 0.0003
Matching HEPG($\Delta R \leq 0.05$)	354255	0.2298 $\pm$ 0.0003
Trigger Efficiency Weighted	352802	0.2288 $\pm$ 0.0003

Table 19: Z$\rightarrow$ ee CP channel Selection Acceptance. Statistical uncertainties are shown. Using zewk6d MC sample, 0d dataset run range.

Selection Criteria	Number of Events	Net Acceptance
Total Events	6772028	-
Good Run	3987754	-
$\|Z_{vtx}\| \leq 60$ cm	3821994	-
66 GeV/$c^2 \leq$ Mee(Gen) $\leq$ 116 GeV/c^2	1954429	-
(Gen Mass cut on denominator only)		
Central EM Cluster (det = 0)	2376988	1.2162 $\pm$ nan
Calorimeter Fiducial Cuts (fidEleShrMax = 1)	2071980	1.0601 $\pm$ nan
Electron Beam-Constrained Track $P_T \geq 10$ GeV/c	1473514	0.7539 $\pm$ 0.0003
EM Cluster $E_T \geq 20$ GeV	1109021	0.5674 $\pm$ 0.0004
Plug EM Cluster (det = 1)	683738	0.3498 $\pm$ 0.0003
PES2dGlobalEta ($1.20 \leq \|\eta\| \leq 2.80$)	538812	0.2757 $\pm$ 0.0003
Plug EM Cluster $E_T \geq 20$ GeV	480957	0.2461 $\pm$ 0.0003
Plug EM Cluster $Had/EM \leq 0.125$	479422	0.2453 $\pm$ 0.0003
Two EM Cluster	479422	0.2453 $\pm$ 0.0003
66 GeV/$c^2 \leq$ Mee(Rec) $\leq$ 116 GeV/c^2	459563	0.2351 $\pm$ 0.0003
$\|VertexZ\| \leq 60$ cm	457198	0.2339 $\pm$ 0.0003
Matching HEPG($\Delta R \leq 0.05$)	451376	0.2310 $\pm$ 0.0003
Trigger Efficiency Weighted	450486	0.2305 $\pm$ 0.0003

Table 20: Z$\rightarrow$ ee CP channel Selection Acceptance. Statistical uncertainties are shown. Using zewkad MC sample, 0h dataset run range.

Selection Criteria	Number of Events	Net Acceptance
Total Events	6772028	-
Good Run	2550597	-
$\|Z_{vtx}\| \leq 60$ cm	2440858	-
66 GeV/c^2 $\leq$ Mee(Gen) $\leq$ 116 GeV/c^2	1247788	-
(Gen Mass cut on denominator only)		
Central EM Cluster (det = 0)	1521188	1.2191 $\pm$ nan
Calorimeter Fiducial Cuts (fidEleShrMax = 1)	1325423	1.0622 $\pm$ nan
Electron Beam-Constrained Track $P_T \geq 10$ GeV/c	940393	0.7536 $\pm$ 0.0004
EM Cluster $E_T \geq 20$ GeV	708583	0.5679 $\pm$ 0.0004
Plug EM Cluster (det = 1)	437893	0.3509 $\pm$ 0.0004
PES2dGlobalEta ($1.20 \leq \|\eta\| \leq 2.80$)	344308	0.2759 $\pm$ 0.0004
Plug EM Cluster $E_T \geq 20$ GeV	307421	0.2464 $\pm$ 0.0004
Plug EM Cluster $Had/EM \leq 0.125$	306463	0.2456 $\pm$ 0.0004
Two EM Cluster	306463	0.2456 $\pm$ 0.0004
66 GeV/c^2 $\leq$ Mee(Rec) $\leq$ 116 GeV/c^2	293731	0.2354 $\pm$ 0.0004
$\|VertexZ\| \leq 60$ cm	291912	0.2339 $\pm$ 0.0004
Matching HEPG($\Delta R \leq 0.05$)	287931	0.2308 $\pm$ 0.0004
Trigger Efficiency Weighted	286409	0.2295 $\pm$ 0.0004

Table 21: Z$\rightarrow$ ee CP channel Selection Acceptance. Statistical uncertainties are shown. Using zewkad MC sample, 0i dataset run range.

Selection Criteria	Number of Events	Net Acceptance
Total Events	3225677	-
Good Run	3111683	-
$\|Z_{vtx}\| \leq 60$ cm	3016836	-
66 GeV/c^2 $\leq$ Mee(Gen) $\leq$ 116 GeV/c^2 (Gen Mass cut on denominator only)	1541630	-
Plug EM Cluster (det = 1)	2366761	1.5352 $\pm$ nan
PES2dGlobalEta (1.20 $\leq \|\eta\| \leq$ 2.80)	1896360	1.2301 $\pm$ nan
Plug EM Cluster $E_T \geq 20$ GeV	957450	0.6211 $\pm$ 0.0004
Plug EM Cluster $Had/EM \leq 0.125$	955479	0.6198 $\pm$ 0.0004
Second Plug EM Cluster (det = 1)	969111	0.6286 $\pm$ 0.0004
Second PES2dGlobalEta (1.20 $\leq \|\eta\| \leq$ 2.80)	490553	0.3182 $\pm$ 0.0004
Second Plug EM Cluster $E_T \geq 20$ GeV	191668	0.1243 $\pm$ 0.0003
Second Plug EM Cluster $Had/EM \leq 0.125$	190305	0.1234 $\pm$ 0.0003
Two EM Cluster	191170	0.1240 $\pm$ 0.0003
66 GeV/c^2 $\leq$ Mee(Rec) $\leq$ 116 GeV/c^2	168761	0.1095 $\pm$ 0.0003
$\|VertexZ\| \leq 60$ cm	168402	0.1092 $\pm$ 0.0003
Matching HEPG($\Delta R \leq 0.05$)	157309	0.1020 $\pm$ 0.0002
Trigger Efficiency Weighted	150711	0.0978 $\pm$ 0.0002
Same-Side	149134	0.0967 $\pm$ 0.0002

Table 22: Same-side Z$\rightarrow$ ee PP channel Selection Acceptance. Statistical uncertainties are shown. Using zewk6d MC, 0d dataset.

Selection Criteria	Number of Events	Net Acceptance
Total Events	6772028	-
Good Run	3987754	-
$\lvert Z_{vtx}\rvert \leq 60$ cm	3821994	-
66 GeV/$c^2 \leq$ Mee(Gen) $\leq$ 116 GeV/c^2 (Gen Mass cut on denominator only)	1954429	-
Plug EM Cluster (det = 1)	3001784	$1.5359 \pm$ nan
PES2dGlobalEta ($1.20 \leq \lvert\eta\rvert \leq 2.80$)	2301815	$1.1777 \pm$ nan
Plug EM Cluster $E_T \geq 20$ GeV	1215209	0.6218 ± 0.0003
Plug EM Cluster $Had/EM \leq 0.125$	1212484	0.6204 ± 0.0003
Second Plug EM Cluster (det = 1)	1240588	0.6348 ± 0.0003
Second PES2dGlobalEta ($1.20 \leq \lvert\eta\rvert \leq 2.80$)	568560	0.2909 ± 0.0003
Second Plug EM Cluster $E_T \geq 20$ GeV	243844	0.1248 ± 0.0002
Second Plug EM Cluster $Had/EM \leq 0.125$	242120	0.1239 ± 0.0002
Two EM Cluster	243096	0.1244 ± 0.0002
66 GeV/$c^2 \leq$ Mee(Rec) $\leq$ 116 GeV/c^2	213660	0.1093 ± 0.0002
$\lvert VertexZ\rvert \leq 60$ cm	212560	0.1088 ± 0.0002
Matching HEPG($\Delta R \leq 0.05$)	192263	0.0984 ± 0.0002
Trigger Efficiency Weighted	180545	0.0924 ± 0.0002
Same-Side	177810	0.0910 ± 0.0002

Table 23: Z$\rightarrow$ ee PP channel Selection Acceptance. Statistical uncertainties are shown. Using zewkad MC sample, 0h dataset run range.

Selection Criteria	Number of Events	Net Acceptance
Total Events	6772028	-
Good Run	2550597	-
$\|Z_{vtx}\| \leq 60$ cm	2440858	-
66 GeV/c^2 $\leq$ Mee(Gen) $\leq$ 116 GeV/c^2 (Gen Mass cut on denominator only)	1247788	-
Plug EM Cluster (det = 1)	1918000	1.5371 $\pm$ nan
PES2dGlobalEta (1.20 $\leq \|\eta\| \leq$ 2.80)	1469073	1.1773 $\pm$ nan
Plug EM Cluster $E_T \geq 20$ GeV	776817	0.6226 $\pm$ 0.0004
Plug EM Cluster $Had/EM \leq 0.125$	775050	0.6211 $\pm$ 0.0004
Second Plug EM Cluster (det = 1)	795614	0.6376 $\pm$ 0.0004
Second PES2dGlobalEta (1.20 $\leq \|\eta\| \leq$ 2.80)	362715	0.2907 $\pm$ 0.0004
Second Plug EM Cluster $E_T \geq 20$ GeV	155125	0.1243 $\pm$ 0.0003
Second Plug EM Cluster $Had/EM \leq 0.125$	153983	0.1234 $\pm$ 0.0003
Two EM Cluster	154586	0.1239 $\pm$ 0.0003
66 GeV/c^2 $\leq$ Mee(Rec) $\leq$ 116 GeV/c^2	135678	0.1087 $\pm$ 0.0003
$\|VertexZ\| \leq 60$ cm	134828	0.1081 $\pm$ 0.0003
Matching HEPG($\Delta R \leq 0.05$)	121164	0.0971 $\pm$ 0.0003
Trigger Efficiency Weighted	109027	0.0874 $\pm$ 0.0003
Same-Side	107654	0.0863 $\pm$ 0.0003

Table 24: Z$\rightarrow$ ee PP channel Selection Acceptance. Statistical uncertainties are shown. Using zewkad MC sample, 0i dataset run range.

5 Electron ID Efficiency Measurement

5.1 Central Electron ID Efficiency

To measure central electron ID efficiency, we follow the method used in CDF note 7950, "Electron Identification in Offline Release 6.1.2"[5].

We measure the central electron ID efficiency as the fraction of number of electrons passing the central electron identification selection cuts(table 4). All electrons are required to satisfy the acceptance requirements listed in table 16. To reduce background in our sample, we require at least one central electron in the event passing the tight selection cuts listed in table 5. Events with more than two central electrons are vetoed. To further reduce background, a tight invariant mass cut of 75 GeV/c^2 $\leq$ Mee $\leq$ 105 GeV/c^2 is applied. The two electrons in the events must have opposite sign charges.

The electron counting method[5] is used to calculate the efficiency. If both electrons of the Z event pass the trigger and loose central electron(LCE) requirements, both are counted as probe electrons. If only one pass the trigger and LCE requirements, only the electron it makes a Z with is counted as a probe electrons. Let N_{probe} be the number of probe electrons, and N_{lid} the number of LCE electrons, the efficiency for the loose central electron selection is given as:

$$\epsilon_{lid} = \frac{N_{lid}}{N_{probe}}$$

We measure the efficiency in the following order: loose ID efficiency, loose isolation (IsoR$<$ 0.3) efficiency, tight isolation(IsoR$<$ 0.1) efficiency and tight ID efficiency. The electron candidates used to measure each group of selection efficiency are required to pass all the selection requirements ordered prior the one being measured. For example, to measure the efficiency of the tight central electron(TCE) ID requirement, the probe electrons must pass the loose central electron ID requirements and the tight isolation requirement.

The same-sign Z events(with trident correction) are used to estimate background. The background is given as:

$$N^{bkg} = N^{SS}_{Data} - N^{OS}_{Data} \times N^{SS}_{MC}/N^{OS}_{MC}$$

The efficiency with background subtraction is then:

$$\epsilon_{lid} = \frac{N_{lid} - N^{bkg}_{lid}}{N_{probe} - N^{bkg}_{probe}}$$

5.1.1 Central Electron ID Efficiency, bhel0d Dataset

Table 25 lists the input parameters to central electron ID and isolation efficiency measurements using CC $Z \to ee$ candidate events. The scale factor of data to MC is calculated.

Data						
Efficiency Measurement	Symbol	Number of Probe Ele	Number passing Selection Criteria	Probe Ele Bkg	Passing Ele Bkg	Eff
Loose ID	$\epsilon_{\rm lid}^{\rm cen}$	18516	17704	143.9	40.3	0.961
Loose Isolation	$\epsilon_{\rm liso}^{\rm cen}$	17651	17598	37.9	35.4	0.997
Tight Isolation	$\epsilon_{\rm tiso}^{\rm cen}$	17249	16900	34.7	33.9	0.980
Tight ID	$\epsilon_{\rm tid}^{\rm cen}$	15007	13114	23.6	13.1	0.874
MC						
Efficiency Measurement	Symbol	Number of Probe Electrons	Number passing Selection Criteria	Efficiency	SF(Data/MC)	
Loose ID	$\epsilon_{\rm lid}^{\rm cen}$	305308	292748	0.959	1.003	
Loose Isolation	$\epsilon_{\rm liso}^{\rm cen}$	291989	291230	0.997	1.000	
Tight Isolation	$\epsilon_{\rm tiso}^{\rm cen}$	285757	280284	0.981	0.999	
Tight ID	$\epsilon_{\rm tid}^{\rm cen}$	250807	221330	0.882	0.991	

Table 25: Input parameters to central electron identification and isolation efficiency measurements using number of electrons in central-central $Z \to ee$ candidates. bhel0d dataset

The total isolation cut efficiency for a central electron with IsoR < 0.1 is:

$$\epsilon_{\rm liso}^{\rm Cen} * \epsilon_{\rm tiso}^{\rm Cen} \text{ (Data)} = 0.977$$
$$\epsilon_{\rm liso}^{\rm Cen} * \epsilon_{\rm tiso}^{\rm Cen} \text{ (MC)} = 0.978$$

The total selection efficiency for tight central electron is :

$$\epsilon_{\rm lid}^{\rm Cen} * \epsilon_{\rm liso}^{\rm Cen} * \epsilon_{\rm tiso}^{\rm Cen} * \epsilon_{\rm tid}^{\rm Cen} \text{ (Data)} = 0.821$$
$$\epsilon_{\rm lid}^{\rm Cen} * \epsilon_{\rm liso}^{\rm Cen} * \epsilon_{\rm tiso}^{\rm Cen} * \epsilon_{\rm tid}^{\rm Cen} \text{ (MC)} = 0.828$$

And total scale factor for tight central electron is : 0.992

5.1.2 Central Electron ID Efficiency, bhel0h and bhel0i Dataset

The total central electron selection efficiencies for bhel0h dataset is listed in table 26.

Data						
Efficiency Measurement	Symbol	Number of Probe Ele	Number passing Selection Criteria	Probe Ele Bkg	Passing Ele Bkg	Eff
Loose ID	$\epsilon_{\text{lid}}^{\text{cen}}$	21097	20056	169.9	27.7	0.957
Loose Isolation	$\epsilon_{\text{liso}}^{\text{cen}}$	19997	19938	24.3	20.9	0.997
Tight Isolation	$\epsilon_{\text{tiso}}^{\text{cen}}$	19486	19034	14.6	8.2	0.977
Tight ID	$\epsilon_{\text{tid}}^{\text{cen}}$	16851	14668	6.6	4.8	0.871
MC						
Efficiency Measurement	Symbol	Number of Probe Electrons	Number passing Selection Criteria	Efficiency	SF(Data/MC)	
Loose ID	$\epsilon_{\text{lid}}^{\text{cen}}$	387712	371430	0.958	0.999	
Loose Isolation	$\epsilon_{\text{liso}}^{\text{cen}}$	370435	369440	0.997	1.000	
Tight Isolation	$\epsilon_{\text{tiso}}^{\text{cen}}$	361777	354114	0.979	0.998	
Tight ID	$\epsilon_{\text{tid}}^{\text{cen}}$	317253	280392	0.884	0.985	

Table 26: Input parameters to central electron identification and isolation efficiency measurements using number of electrons in central-central $Z \rightarrow ee$ candidates. bhel0h dataset

The total isolation cut efficiency for a central electron with IsoR < 0.1 is:

$$\epsilon_{\text{liso}}^{\text{Cen}} * \epsilon_{\text{tiso}}^{\text{Cen}} \text{ (Data)} = 0.974$$
$$\epsilon_{\text{liso}}^{\text{Cen}} * \epsilon_{\text{tiso}}^{\text{Cen}} \text{ (MC)} = 0.976$$

The total selection efficiency for tight central electron is :

$$\epsilon_{\text{lid}}^{\text{Cen}} * \epsilon_{\text{liso}}^{\text{Cen}} * \epsilon_{\text{tiso}}^{\text{Cen}} * \epsilon_{\text{tid}}^{\text{Cen}} \text{ (Data)} = 0.812$$
$$\epsilon_{\text{lid}}^{\text{Cen}} * \epsilon_{\text{liso}}^{\text{Cen}} * \epsilon_{\text{tiso}}^{\text{Cen}} * \epsilon_{\text{tid}}^{\text{Cen}} \text{ (MC)} = 0.827$$

And total scale factor for tight central electron is : 0.982

The total central electron selection efficiencies for bhel0i dataset is listed in table 27.

Data						
Efficiency Measurement	Symbol	Number of Probe Ele	Number passing Selection Criteria	Probe Ele Bkg	Passing Ele Bkg	Eff
Loose ID	$\epsilon_{\rm lid}^{\rm cen}$	13543	12850	85.2	22.3	0.953
Loose Isolation	$\epsilon_{\rm liso}^{\rm cen}$	12808	12766	20.7	19.0	0.997
Tight Isolation	$\epsilon_{\rm tiso}^{\rm cen}$	12489	12212	17.2	15.4	0.978
Tight ID	$\epsilon_{\rm tid}^{\rm cen}$	10783	9354	8.4	1.2	0.868
MC						
Efficiency Measurement	Symbol	Number of Probe Electrons	Number passing Selection Criteria	Efficiency	SF(Data/MC)	
Loose ID	$\epsilon_{\rm lid}^{\rm cen}$	246660	236054	0.957	0.996	
Loose Isolation	$\epsilon_{\rm liso}^{\rm cen}$	235384	234714	0.997	1.000	
Tight Isolation	$\epsilon_{\rm tiso}^{\rm cen}$	229474	224234	0.977	1.001	
Tight ID	$\epsilon_{\rm tid}^{\rm cen}$	200824	177414	0.883	0.983	

Table 27: Input parameters to central electron identification and isolation efficiency measurements using number of electrons in central-central $Z \rightarrow ee$ candidates. bhel0i dataset

The total isolation cut efficiency for a central electron with IsoR < 0.1 is:

$\epsilon_{\rm liso}^{\rm Cen} * \epsilon_{\rm tiso}^{\rm Cen}$ (Data) $= 0.975$

$\epsilon_{\rm liso}^{\rm Cen} * \epsilon_{\rm tiso}^{\rm Cen}$ (MC) $= 0.974$

The total selection efficiency for tight central electron is :

$\epsilon_{\rm lid}^{\rm Cen} * \epsilon_{\rm liso}^{\rm Cen} * \epsilon_{\rm tiso}^{\rm Cen} * \epsilon_{\rm tid}^{\rm Cen}$ (Data) $= 0.807$

$\epsilon_{\rm lid}^{\rm Cen} * \epsilon_{\rm liso}^{\rm Cen} * \epsilon_{\rm tiso}^{\rm Cen} * \epsilon_{\rm tid}^{\rm Cen}$ (MC) $= 0.824$

And total scale factor for tight central electron is : 0.979

5.1.3 Central Electron ID Efficiency, 1 fb^{-1}

The efficiencies and scale factors for the full $1fb^{-1}$ dataset are summarized in table 28.

dataset	Efficiency	Data	MC	Scale Factor
bhel0d	Loose ID	0.961	0.959	1.003
	Loose Iso	0.997	0.997	1.000
	Tight Iso	0.980	0.981	0.999
	Tight ID	0.874	0.882	0.991
bhel0h	Loose ID	0.957	0.958	0.999
	Loose Iso	0.997	0.997	1.000
	Tight Iso	0.977	0.979	0.998
	Tight ID	0.871	0.884	0.985
bhel0i	Loose ID	0.953	0.957	0.996
	Loose Iso	0.997	0.997	1.000
	Tight Iso	0.978	0.977	1.001
	Tight ID	0.868	0.883	0.983

Table 28: The efficiencies and scale factors for central electron, bhel0d/0h/0i dataset.

5.2 Plug Electron ID Efficiency

We measure the plug electron ID efficiency as the fraction of number of events passing the plug electron identification selection cuts(table 7). All events are required to satisfy the acceptance requirements listed in table 19. To reduce background in our sample, we require the central electron in the event passing the tight selection cuts listed in table 5. Events with more than one central and one plug electron are vetoed. To further reduce background, a tight invariant mass cut of 75 GeV/$c^2 \leq$ Mee $\leq$ 105 GeV/c^2 is applied. As in the Central ID efficiency measurement, we measure the plug ID efficiency in the following order: loose ID, loose iso, tight iso and tight ID. The efficiency is determined as:

$$\epsilon_i = \frac{N_{\mathrm{TCEM\_i}}}{N_{\mathrm{TCEM\_P}}},$$

where:

- $N_{\mathrm{TCEM\_A}}$ is the number of events that satisfy the requirements mentioned above, where there is a tight central electron in the event, and the plug electron passes the acceptance requirement, and the invariant mass lies within the window of 75 GeV/$c^2 \leq$ Mee $\leq$ 105 GeV/c^2 .

- $N_{\mathrm{TCEM\_i}}$ is a subset of events from $N_{\mathrm{TCEM\_A}}$. In addition, the plug electron satisfies the ith selection criteria.
  i=0: plug loose ID (table 7)
  i=1: loose isolation cut($\Delta R < 0.3$)
  i=2: tight isolation cut($\Delta R < 0.1$)
  i=3: plug tight ID (table 9)

- $N_{\mathrm{TCEM\_P}}$ is a subset of events from $N_{\mathrm{TCEM\_A}}$,
  when i=0: $N_{\mathrm{TCEM\_P}} = N_{\mathrm{TCEM\_A}}$;
  when i=1, 2, 3: $N_{\mathrm{TCEM\_P}} = N_{\mathrm{TCEM\_(i-1)}}$.

For the N-1 ID efficiency, the previous formula becomes:

$$\epsilon_i = \frac{N_{\mathrm{TCEM\_TPEM}}}{N^i_{\mathrm{N-1}},}$$

where:

- $N_{\mathrm{TCEM\_TPEM}}$ is the number of events where the plug electrons pass all the cuts listed in table 7 for loose N-1 ID efficiency measurement. And for tight plug electron N-1 ID efficiency measurement, the plug electrons are required to pass all the cuts listed in table 9(tight ID).

- $N^i_{\mathrm{N-1}}$ is the number of events where the plug electrons pass all but the ith cuts.

5.2.1 Loose Plug Electron N-1 ID Efficiency

The N-1 distribution plots for the ID variables are showed in figure 2, 3, and 4.

The N-1 Efficiency for loose plug electron ID(table 7), with PEM3x3Chi cut at 25 are listed in table 29 (Data) and table 30 (MC). For comparison, the N-1 efficiency with PEM3x3Chi cut at 10 are listed in table 31 (Data) and table 32 (MC).

As shown in the tables, the PEM 3x3 Chi2 $\leq$ 10.0 cut has a lower efficiency than the other cuts. We increase the cut from 10 to 25 for our loose plug electron selection.

Cuts	Events	Efficiency
Had/EM $\leq$ 0.05	15987	0.9772
PEM3x3Chi2$\leq$ 25.0	16521	0.9456
Loose Iso $\leq$ 0.3	15652	0.9981
Loose-PEM	15622	1

Table 29: Plug N-1 loose ID Efficiency (DATA)

Cuts	Events	Efficiency
Had/EM $\leq$ 0.05	271188	0.9825
PEM3x3Chi2$\leq$ 25.0	277665	0.9596
Loose Iso $\leq$ 0.3	266723	0.999
Loose-PEM	266443	1

Table 30: Plug N-1 loose ID Efficiency (MC)

Cuts	Events	Efficiency
Had/EM $\leq$ 0.05	14776	0.9806
PEM3x3Chi2$\leq$ 10.0	16521	0.8771
Loose Iso $\leq$ 0.3	14511	0.9986
Loose-PEM	14490	1

Table 31: Plug N-1 loose ID Efficiency for data, PEM3x3Chi2 cut at 10

Figure 26 shows the PEM 3x3Chi2 cut N-1 efficiency with a cut at 10 and 25, the top plot shows the N-1 efficiency with tight plug electron cuts, the bottom plot shows the N-1 Efficiency with loose plug electron cuts. As can be seen in the figure, the efficiency is lower at low ET for PEM 3x3Chi2 cut at 10.

Cuts	Events	Efficiency
Had/EM $\leq$ 0.05	258620	0.9839
PEM3x3Chi2$\leq$ 10.0	277665	0.9164
Loose Iso $\leq$ 0.3	254667	0.9992
Loose-PEM	254451	1

Table 32: Plug N-1 ID Efficiency

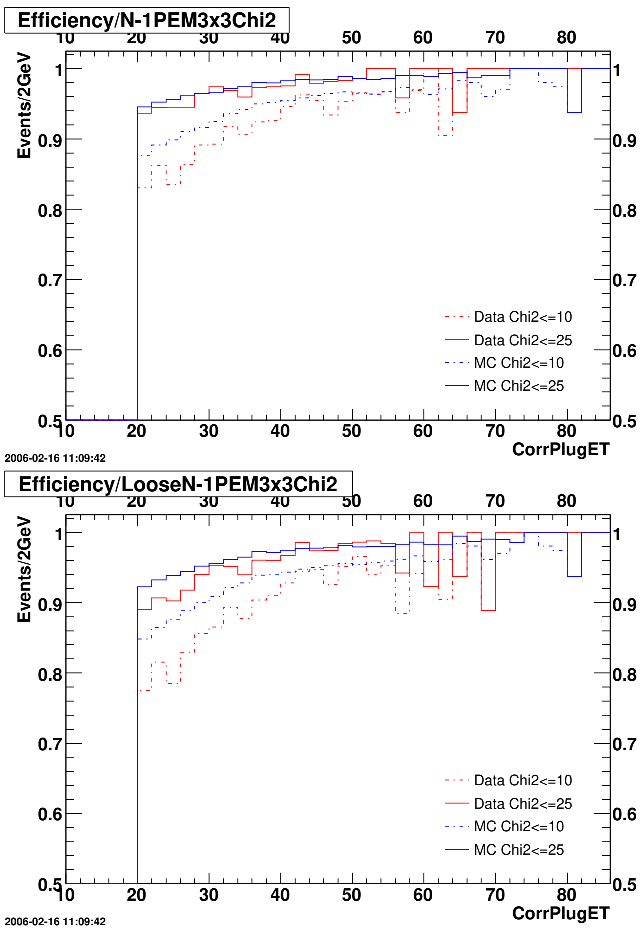

Figure 26: Plug N-1 Efficiency: PEM 3x3 chi2. Top : plug tight electron N-1 efficiency, bottom: plug loose electron N-1 efficiency.

5.2.2 Tight Plug Electron N-1 ID Efficiency

The N-1 distribution plots of the tight plug electron ID variables are showed in figure 5, 6, 7, 8, 9, and 10.

The N-1 efficiencies for the tight plug electron selection cuts are listed in table 33(data) and table 34(MC) . As shown in the tables, the PEM 3x3 Chi2 $\leq$ 10.0 cut has a lower efficiency than the other cuts. We increase the cut from 10 to 25, and measure the N-1 efficiencies again, the results are shown in table 35(data) and table 36(MC) .

Cuts	Events	Efficiency
Had/EM $\leq$ 0.05	14080	0.982
PEM3x3Chi2$\leq$ 10.0	15264	0.9059
Tight Iso $\leq$ 0.1	14077	0.9822
Pes5x9U$\geq$ 0.65	13912	0.9939
Pes5x9V$\geq$ 0.65	13932	0.9925
$\Delta R \leq 3.0$	14000	0.9876
Tight-PEM	13827	1

Table 33: Tight plug electron N-1 ID efficiency for data, PEM3x3Chi2 cut at 10

Cuts	Events	Efficiency
Had/EM $\leq$ 0.05	251461	0.9842
PEM3x3Chi2$\leq$ 10.0	265394	0.9325
Tight Iso $\leq$ 0.1	250514	0.9879
Pes5x9U$\geq$ 0.65	248263	0.9969
Pes5x9V$\geq$ 0.65	248170	0.9972
$\Delta R \leq 3.0$	249632	0.9914
Tight-PEM	247487	1

Table 34: Tight plug electron N-1 ID Efficiency from the zewk6d MC sample, PEM3x3Chi2 cut at 10 .

Cuts	Events	Efficiency
Had/EM $\leq$ 0.05	15058	0.9796
PEM3x3Chi2$\leq$ 25.0	15264	0.9664
Tight Iso $\leq$ 0.1	15089	0.9776
Pes5x9U$\geq$ 0.65	14844	0.9937
Pes5x9V$\geq$ 0.65	14865	0.9923
$\Delta R \leq 3.0$	15003	0.9832
Tight-PEM	14751	1

Table 35: Tight plug electron N-1 ID efficiency (Data), PEM3x3Chi2 cut at 25.

Cuts	Events	Efficiency
Had/EM $\leq$ 0.05	262237	0.983
PEM3x3Chi2$\leq$ 25.0	265394	0.9713
Tight Iso $\leq$ 0.1	261544	0.9856
Pes5x9U$\geq$ 0.65	258599	0.9968
Pes5x9V$\geq$ 0.65	258514	0.9972
$\Delta R \leq 3.0$	260750	0.9886
Tight-PEM	257781	1

Table 36: Plug tight electron N-1 ID efficiency, zewk6d MC sample, PEM3x3Chi cut at 25.

5.2.3 Total Plug ID Efficiency, bhel0d Dataset

Table 37 lists the input parameters to plug electron ID and isolation efficiency measurements using CP $Z \rightarrow ee$ candidate events. The scale factor of data to MC is calculated.

Data						
Efficiency Measurement	Symbol	Number of Probe Ele	Number Passing Selection Criteria	Probe Ele Bkg	Passing Ele Background	Eff
Loose ID	$\epsilon_{\mathrm{lid}}^{\mathrm{plug}}$	17554	15829	468.1	93.9	0.921
Loose Isolation	$\epsilon_{\mathrm{liso}}^{\mathrm{plug}}$	15829	15797	93.9	94.2	0.998
Tight Isolation	$\epsilon_{\mathrm{tiso}}^{\mathrm{plug}}$	15797	15438	94.2	81.8	0.978
Tight ID	$\epsilon_{\mathrm{tid}}^{\mathrm{plug}}$	15438	14898	81.8	73.4	0.965
MC						
Efficiency Measurement	Symbol	Number of Probe Electrons	Number passing Selection Criteria	Efficiency	SF(Data/MC)	
Loose ID	$\epsilon_{\mathrm{lid}}^{\mathrm{plug}}$	287108	269665	0.939	0.981	
Loose Isolation	$\epsilon_{\mathrm{liso}}^{\mathrm{plug}}$	269665	269355	0.999	0.999	
Tight Isolation	$\epsilon_{\mathrm{tiso}}^{\mathrm{plug}}$	269355	265652	0.986	0.992	
Tight ID	$\epsilon_{\mathrm{tid}}^{\mathrm{plug}}$	265652	260565	0.981	0.984	

Table 37: Input parameters to plug electron identification and isolation efficiency measurements using central-plug $Z \rightarrow ee$ candidates.

The total isolation cut efficiency for a plug electron with IsoR < 0.1 is:

$\epsilon_{\mathrm{liso}}^{\mathrm{plug}} * \epsilon_{\mathrm{tiso}}^{\mathrm{plug}}$ (Data) = 0.976 $\epsilon_{\mathrm{liso}}^{\mathrm{plug}} * \epsilon_{\mathrm{tiso}}^{\mathrm{plug}}$ (MC) = 0.985

The total selection efficiency for a tight plug electron is :

$$\epsilon_{\mathrm{lid}}^{\mathrm{plug}} * \epsilon_{\mathrm{liso}}^{\mathrm{plug}} * \epsilon_{\mathrm{tiso}}^{\mathrm{plug}} * \epsilon_{\mathrm{tid}}^{\mathrm{plug}} \text{ (Data)} = 0.868$$

$$\epsilon_{\mathrm{lid}}^{\mathrm{plug}} * \epsilon_{\mathrm{liso}}^{\mathrm{plug}} * \epsilon_{\mathrm{tiso}}^{\mathrm{plug}} * \epsilon_{\mathrm{tid}}^{\mathrm{plug}} \text{ (MC)} = 0.908$$

And the total scale factor for tight plug electron is : 0.956

Side-band subtraction method is used to estimate the background in the CP event selection. Detail of the method is discussed in 7.2. For simplicity, background subtraction is only done for the total efficiency measurements, not for any of the N-1 efficiency measurements.

5.2.4 Total Plug ID Efficiency, bhel0h and bhel0i Dataset

The total plug electron selection efficiencies for bhel0h dataset are listed in table 38.

Data						
Efficiency Measurement	Symbol	Number of Probe Ele	Number Passing Selection Criteria	Probe Ele Bkg	Passing Ele Background	Eff
Loose ID	$\epsilon_{\rm lid}^{\rm plug}$	40268	35884	1213.2	252.2	0.912
Loose Isolation	$\epsilon_{\rm liso}^{\rm plug}$	35884	35826	252.2	235.0	0.999
Tight Isolation	$\epsilon_{\rm tiso}^{\rm plug}$	35826	34718	235.0	191.0	0.970
Tight ID	$\epsilon_{\rm tid}^{\rm plug}$	34718	33680	191.0	187.9	0.970

MC					
Efficiency Measurement	Symbol	Number of Probe Electrons	Number passing Selection Criteria	Efficiency	SF(Data/MC)
Loose ID	$\epsilon_{\rm lid}^{\rm plug}$	722492	671962	0.930	0.981
Loose Isolation	$\epsilon_{\rm liso}^{\rm plug}$	671962	671100	0.999	1.000
Tight Isolation	$\epsilon_{\rm tiso}^{\rm plug}$	671100	659548	0.983	0.987
Tight ID	$\epsilon_{\rm tid}^{\rm plug}$	659548	645106	0.978	0.992

Table 38: Input parameters to plug electron identification and isolation efficiency measurements using central-plug $Z \to ee$ candidates. bhel0h dataset.

The total isolation cut efficiency for a plug electron with IsoR < 0.1 is:

$$\epsilon_{\rm liso}^{\rm plug} * \epsilon_{\rm tiso}^{\rm plug}\ ({\rm Data}) = 0.969 \qquad \epsilon_{\rm liso}^{\rm plug} * \epsilon_{\rm tiso}^{\rm plug}\ ({\rm MC}) = 0.982$$

The total selection efficiency for a tight plug electron is :

$$\epsilon_{\rm lid}^{\rm plug} * \epsilon_{\rm liso}^{\rm plug} * \epsilon_{\rm tiso}^{\rm plug} * \epsilon_{\rm tid}^{\rm plug}\ ({\rm Data}) = 0.858$$

$$\epsilon_{\rm lid}^{\rm plug} * \epsilon_{\rm liso}^{\rm plug} * \epsilon_{\rm tiso}^{\rm plug} * \epsilon_{\rm tid}^{\rm plug}\ ({\rm MC}) = 0.893$$

And the total scale factor for tight plug electron is : 0.956

The total plug electron selection efficiencies for bhel0i dataset are listed in table 39.

Data						
Efficiency Measurement	Symbol	Number of Probe Ele	Number Passing Selection Criteria	Probe Ele Bkg	Passing Ele Background	Eff
Loose ID	$\epsilon_{\mathrm{lid}}^{\mathrm{plug}}$	25398	22588	531.1	73.6	0.905
Loose Isolation	$\epsilon_{\mathrm{liso}}^{\mathrm{plug}}$	22588	22542	73.6	68.5	0.998
Tight Isolation	$\epsilon_{\mathrm{tiso}}^{\mathrm{plug}}$	22542	21822	68.5	51.9	0.969
Tight ID	$\epsilon_{\mathrm{tid}}^{\mathrm{plug}}$	21822	21120	51.9	49.0	0.968

MC					
Efficiency Measurement	Symbol	Number of Probe Electrons	Number passing Selection Criteria	Efficiency	SF(Data/MC)
Loose ID	$\epsilon_{\mathrm{lid}}^{\mathrm{plug}}$	459246	425648	0.927	0.977
Loose Isolation	$\epsilon_{\mathrm{liso}}^{\mathrm{plug}}$	425648	425066	0.999	1.000
Tight Isolation	$\epsilon_{\mathrm{tiso}}^{\mathrm{plug}}$	425066	416680	0.980	0.988
Tight ID	$\epsilon_{\mathrm{tid}}^{\mathrm{plug}}$	416680	407320	0.978	0.990

Table 39: Input parameters to plug electron identification and isolation efficiency measurements using central-plug $Z \rightarrow ee$ candidates. bhel0i dataset.

The total isolation cut efficiency for a plug electron with IsoR < 0.1 is:

$\epsilon_{\mathrm{liso}}^{\mathrm{plug}} * \epsilon_{\mathrm{tiso}}^{\mathrm{plug}}$ (Data) $= 0.967$ $\qquad$ $\epsilon_{\mathrm{liso}}^{\mathrm{plug}} * \epsilon_{\mathrm{tiso}}^{\mathrm{plug}}$ (MC) $= 0.979$

The total selection efficiency for a tight plug electron is :

$\epsilon_{\mathrm{lid}}^{\mathrm{plug}} * \epsilon_{\mathrm{liso}}^{\mathrm{plug}} * \epsilon_{\mathrm{tiso}}^{\mathrm{plug}} * \epsilon_{\mathrm{tid}}^{\mathrm{plug}}$ (Data) $= 0.847$

$\epsilon_{\mathrm{lid}}^{\mathrm{plug}} * \epsilon_{\mathrm{liso}}^{\mathrm{plug}} * \epsilon_{\mathrm{tiso}}^{\mathrm{plug}} * \epsilon_{\mathrm{tid}}^{\mathrm{plug}}$ (MC) $= 0.887$

And the total scale factor for tight plug electron is : 0.955

5.2.5 Total Plug ID Efficiency, 1fb^{-1}

The efficiencies and scale factors for the full $1fb^{-1}$ dataset are summarized in table 40.

dataset	Efficiency	Data	MC	Scale Factor
bhel0d	Loose ID	0.921	0.939	0.981
	Loose Iso	0.998	0.999	0.999
	Tight Iso	0.978	0.986	0.992
	Tight ID	0.965	0.981	0.984
bhel0h	Loose ID	0.912	0.930	0.981
	Loose Iso	0.999	0.999	1.000
	Tight Iso	0.970	0.983	0.987
	Tight ID	0.970	0.978	0.992
bhel0i	Loose ID	0.905	0.927	0.977
	Loose Iso	0.998	0.999	1.000
	Tight Iso	0.969	0.980	0.988
	Tight ID	0.968	0.978	0.990

Table 40: The efficiencies and scale factors for plug electron, bhel0d/0h/0i dataset.

6 Trigger Efficiency Measurement

Two triggers, ELECTRON_CENTRAL_18 trigger and Z_NOTRACK trigger, are used in the analysis. In the inclusive Z and $Z\gamma$ event selection, either ELECTRON_CENTRAL_18 trigger or Z_NOTRACK trigger is required to be fired.

Details on the ELECTRON_CENTRAL_18 trigger efficiency measurement are given in section 6.1. The Z_NOTRACK trigger efficiency measurement is given in section 6.2. In section 6.3, the total trigger efficiencies in Z and $Z\gamma$ event selection are calculated.

6.1 ELECTRON_CENTRAL_18 Trigger Efficiency

We assume that the calorimeter requirements of the ELECTRON_CENTRAL_18 trigger are 100% efficiency. The efficiency of the tracking requirements of the ELECTRON_CENTRAL_18 trigger is measured using the W_NOTRACK trigger, which is based solely on the calorimeter quantities. The trigger efficiency can then be determined from the fraction of W events that satisfies the tracking requirements.

6.1.1 ELECTRON_CENTRAL_18 and W_NOTRACK Trigger Path

Table 41 lists the requirements of ELECTRON_CENTRAL_18 trigger and W_NOTRACK trigger. Details are given below:

- L1: Cut on E_T of a single CEM tower and P_T of the XFT track extrapolated to it. $E_T > 8$ GeV and $P_T >$8.34 GeV are required.
- L2: Require a CEM cluster from the "high-E_T" CEM clustering pass. The XFT track should extrapolate to the seed tower. Had/Em cut of 0.125 is applied. $E_T > 16$ GeV and $P_T >$8 GeV are required.
- L3: Require a central EM offline cluster with $E_T \geq 18$ GeV and a COT track with $P_T \geq 9$ GeV extrapolated to the EM cluster.
- Lshr, cenDeltaZ, ZVert = 2 and nTowersHadem = 3 requirements are added after Jan. 2005 Shutdown, run 159603.

We assume 100% efficiency of the calorimeter cluster requirements at each level. To measure the efficiencies of the tracking requirements of the electron trigger path, we select events from the W_NOTRACK trigger path, that satisfies the selection criteria of $W \to e\nu$ Events(table 42). The fraction of events that satisfies the tracking requirements of the electron trigger path at each level, gives the efficiency for the corresponding tracking requirement at that level. The procedure to calculate the efficiency at each level is as following:

[2] If ZVert = 2, the transverse energy will be calculated using the angle of the track, instead of using the Z0 of the track and the calorimeter cluster centroid. If nTowersHadEm = 3, the cenHadEm will be calculated using three hadronic towers.

Trigger	Level	Calorimeter	Tracking
ELECTRON_CENTRAL_18	L1	ET_CENTRAL $\geq$ 8GeV HAD_EM_CENTRAL$\leq$ 0.125	XFT_PT $\geq$ 8.34GeV/c
	L2	$\lvert\eta\rvert \leq$1.317 ET $\geq$ 16GeV HAD_EM$\leq$ 0.125	XFT_PT $\geq$ 8GeV/c
	L3	CalorRegion = 0 (CENTRAL) cenET $\geq$ 18GeV cenHadEM$\leq$ 0.125 From run 159603 LShr $\leq$ 0.4 cenDeltaZ $\leq$ 8 ZVert = 2^2 nTowersHadEm = 3^2	cenTrackPt $\geq$ 9GeV/c
W_NOTRACK	L1	ET $\geq$ 8GeV $\not\!\!E_T \geq$ 15GeV	none
	L2	ET $\geq$ 20GeV $\not\!\!E_T \geq$ 15GeV	none
	L3	ET $\geq$ 25GeV $\not\!\!E_T \geq$ 25GeV	none

Table 41: ELECTRON_CENTRAL_18 trigger path, from Physics Table: PHYSICS_3_00[3]

- assume 100% efficiencies of the calorimeter cluster requirements at each level
- use events from W_NOTRACK trigger path
- Select $W \rightarrow e\nu$ events (table 42)
- determine the efficiencies of the tracking requirements at each level
- $\epsilon(\text{L1\_PT8}) = \frac{\text{\# of Candidates Passing L1\_PT8}}{\text{number of W Candidates}}$
- $\epsilon(\text{L2\_PT8}) = \frac{\text{\# of Candidates Passing L1\_PT8 \& L2\_PT8}}{\text{\# of W Candidates Passing L1\_PT8}}$
- $\epsilon(L3\_PT9) = \frac{\text{\# of Candidates Passing L1\_PT8 \& L2\_PT8 \& L3\_PT9}}{\text{\# of W Candidates Passing L1\_PT8 \& L2\_PT8}}$

- $\epsilon(ELECTRON\_CENTRAL\_18) = \frac{\text{\# of Candidates Passing L1\_PT8 \& L2\_PT8 \& L3\_PT9}}{\text{\# of W Candidates}}$

6.1.2 W Event Selection

Electron candidates are required to satisfy the selection criteria listed in table 3 (track selection) and table 4(Electron ID). The W event selection criteria is listed in Table 42. The $\not\!\!E_T$ is calculated using the electron beam-constrained ZVertex as the event vertex.

Variables	Cut	variable in Duke Ntuple
Loose Central Electron	table 3 (track selection)	
	table 4(Electron ID)	
Electron ET	≥ 25	EMCLST_ele_std_Et
$\not\!\!E_T$	≥ 25	TRKDET_trkdet_cotbc_met

Table 42: W→ $e\nu$ Event selection

6.1.3 Trigger Efficiency for Loose Central Electron

A Lshr and a ΔZ requirement are added to L3 trigger of the ELECTRON_CENTRAL_18 trigger path after run 159603(see section 6.1.1). Table 43 and 44 show the trigger efficiencies for data collected before and after run 159603, respectively. In both tables, no Lshr and ΔZ are applied to the loose central electron selection. As shown in these tables, the measured trigger efficiency drops from 96% to 91% for data collected after run 159603 because the trigger requirements are tighter than the loose electron ID requirements. This suggests that a Lshr and a ΔZ requirements should be added to the loose central electron(LCE) ID cuts (see table 4). The efficiency is measured again with these two cuts added to the LCE ID. The result is listed in table 45, the total trigger efficiency is now 96% for the full Gen5 run range.

The trigger efficiencies for bhel0h and bhel0i datasets are listed in table 46 and 47 , respectively.

Figure 27 shows the trigger efficiency distribution as a function of the electron Pt. There is a slow turn-on of the efficiency at the low Pt region. To correct for the effect of this slow turn-on, a trigger efficiency weight is applied to MC samples event by event when calculating the signal acceptance. For bhel0d dataset, the fitting function used is a polynomial of degree 4(equation 1), the fitting range is $10 \leq Pt \leq 20$GeV . For events with $20 < Pt \leq 80$ GeV, the average efficiency given in table 45 is used. For events with $Pt > 80$ GeV, an efficiency of 100% is assigned to the MC events.

	Trigger	Events	Efficiency
0:	total	26282449	
1:	GoodRun	6529513	
2:	W-NOTRACK	575218	
3:	WEvent	61089	
4:	L1CEM8PT8	59583	0.9753
5:	L2CEM16PT8	59301	0.9953
6:	L3CEM18PT9	58601	0.9882
7:	L1-L3	58601	0.9593

Table 43: ELECTRON_CENTRAL_18 trigger Efficiency, data collected before run 159603. No Lshr and ΔZ cuts in the loose central electron selection.

	Trigger	Events	Efficiency
0:	total	26282449	
1:	GoodRun	13203061	
2:	W-NOTRACK	1505206	
3:	WEvent	196509	
4:	L1CEM8PT8	190656	0.9702
5:	L2CEM16PT8	189663	0.9948
6:	L3CEM18PT9	178516	0.9412
7:	L1-L3	178516	0.9084

Table 44: ELECTRON_CENTRAL_18 trigger Efficiency, data collected after run 159603. No Lshr and ΔZ cuts in the loose central electron selection.

	Trigger	Events	Efficiency
0:	total	26294253	
1:	GoodRun	19714810	
2:	W-NOTRACK	2078383	
3:	WEvent	239944	
4:	L1CEM8PT8	232986	0.971
5:	L2CEM16PT8	232255	0.9969
6:	L3CEM18PT9	230416	0.9921
7:	L1-L3	230416	0.9603

Table 45: ELECTRON_CENTRAL_18 trigger Efficiency, with Lshr and ΔZ cuts in the loose central electron selection. bhel0d dataset.

$$\begin{aligned} \epsilon(Pt) = a0 + a1 * Pt + a2 * Pt^2 + a3 * Pt^3 + a4 * Pt^4 \\ a0 = -2.12553 \quad a1 = 0.717327 \quad a2 = -0.0629792 \\ a3 = 0.00246476 \quad a4 = -3.62147e-05 \end{aligned} \tag{1}$$

	Trigger	Events	Efficiency
0:	total	2.00074e+07	
1:	GoodRun	1.81185e+07	
2:	W-NOTRACK	1.85911e+06	
3:	WEvent	284892	
4:	L1CEM8PT8	280123	0.9833
5:	L2CEM16PT8	279277	0.997
6:	L3CEM18PT9	276851	0.9913
7:	L1-L3	276851	0.9718

Table 46: ELECTRON_CENTRAL_18 trigger Efficiency, bhel0h dataset.

	Trigger	Events	Efficiency
0:	total	1.23375e+07	
1:	GoodRun	1.13647e+07	
2:	W-NOTRACK	1.1255e+06	
3:	WEvent	179762	
4:	L1CEM8PT8	176677	0.9828
5:	L2CEM16PT8	176144	0.997
6:	L3CEM18PT9	174435	0.9903
7:	L1-L3	174435	0.9704

Table 47: ELECTRON_CENTRAL_18 trigger Efficiency, bhel0i dataset.

Figure 28 and 29 shows the trigger efficiency for bhel0h and bhel0i datasets, respectively. The fitting functions used for bhel0h and bhel0i datasets are given in equation 2.

$$\begin{aligned} \epsilon(Pt) &= 1 - \frac{a0}{Pt - a1} \\ a0 = 0.382818 \quad a1 &= 6.9343 \qquad \text{(bhel0h)} \\ a0 = 0.453581 \quad a1 &= 6.14415 \qquad \text{(bhel0i)} \end{aligned} \tag{2}$$

6.1.4 Total Trigger Efficiency in Z and $Z\gamma$ Event Selection

The total ELECTRON_CENTRAL_18 trigger efficiency in Z or $Z\gamma$ event selection can be determined as following:

- CC Z events: $\epsilon^{Ele18} = 1 - (1 - \epsilon(Pt_1)) \times (1 - \epsilon(Pt_2))$
- CP Z events: $\epsilon^{Ele18} = \epsilon(Pt)$

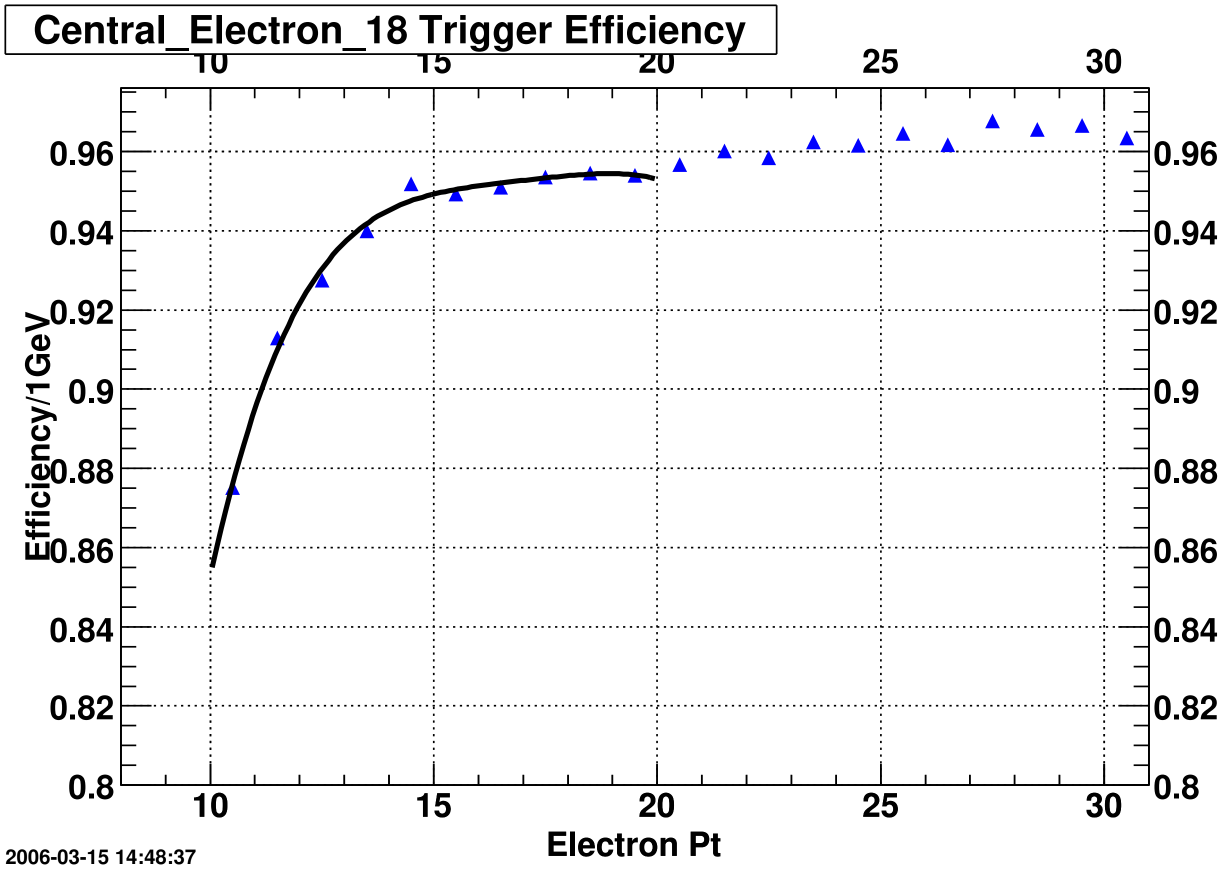

Figure 27: Electron_Central_18 trigger efficiency as a function of electron Pt. Slow turn on at low Pt, apply trigger Efficiency weight to MC event by event. bhel0d dataset.

- PP Z events: $\epsilon^{Ele18} = 0$
- Pt is the central electron track Pt

6.2 Z_NOTRACK Trigger Efficiency

Table 48 lists the requirements of Z_NOTRACK trigger path at each level.

To measure Z_NOTRACK trigger efficiency, we select events from the ELECTRON_CENTRAL_18 trigger path. For each selected event, there must be two electrons, passing central/plug electron ID cuts. To reduce backgrounds, the electrons must pass the tight ID cuts(table 5 and 9), and the di-lepton invariance mass must be within the mass window: 75-105 GeV/c^2. The E_T of the first central electron's is required to be greater than 28 GeV, where the ZNOTRACK trigger is fully efficient. The Z_NOTRACK trigger efficiency is measured as a function of the second electron E_T. For CC events, the two electrons must have opposite signs.

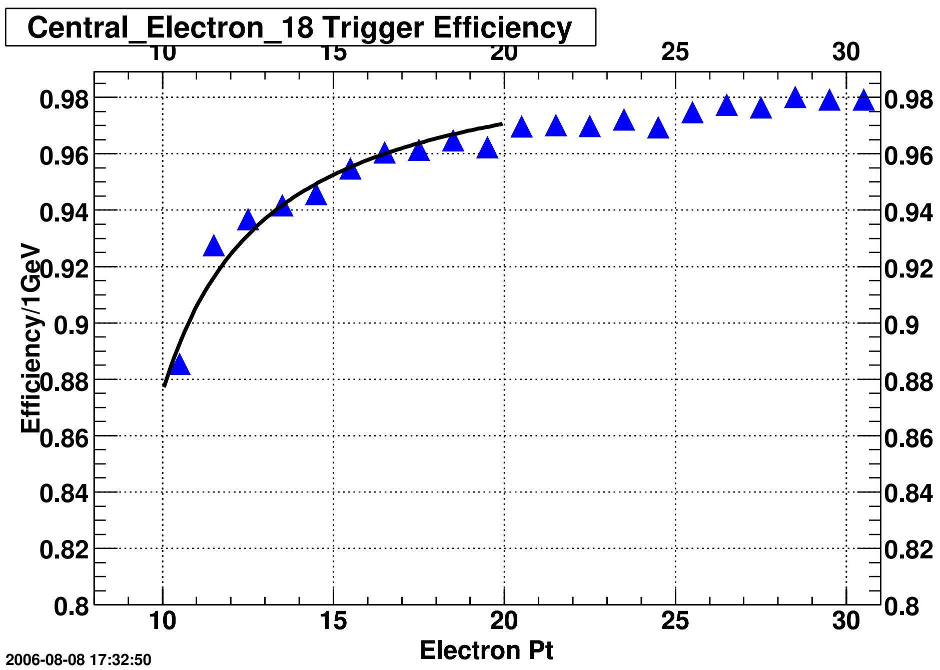

Figure 28: Electron_Central_18 trigger efficiency as a function of electron Pt. Slow turn on at low Pt, apply trigger Efficiency weight to MC event by event. bhel0h dataset.

The Z_NOTRACK trigger efficiencies for central and plug electrons, are listed in table 49 and 50, respectively.

The Z_NOTRACK trigger efficiencies for bhel0h and bhel0i datasets are listed in table 51, 52, 53 and 54. The L1 efficiencies for bhel0i dataset are lower than the other two datasets. More studies are needed to understand why.

Figure 30 and 31 show the trigger efficiencies as a function of the second electron Et from CC and CP Z events, respectively. A slow turn-on is observed at the low Et region. To correct for the effect of this slow turn-on, a trigger efficiency weight is applied to MC samples event by event when calculating the signal acceptance.

For efficiency in the central region, the fitting function is a polynomial of degree 2(equation 3), the fitting range is $20 \leq Et \leq 30$GeV . For events with $30 < Et \leq 50$ GeV, the average efficiency given in table 49 is used. For events with $Et > 50$ GeV, an efficiency of 100% is assigned to the MC events.

$$\epsilon_{Cen}(Et) = a0 + a1 * Et + a2 * Et^2 \tag{3}$$
$$a0 = 0.147128 \qquad a1 = 0.0570858 \qquad a2 = -0.000961815$$

For efficiency in the plug region, the fitting function is a polynomial of degree 5(equation 4), the fitting range is $20 \leq Et \leq 50$GeV . For events with $Et > 50$ GeV,

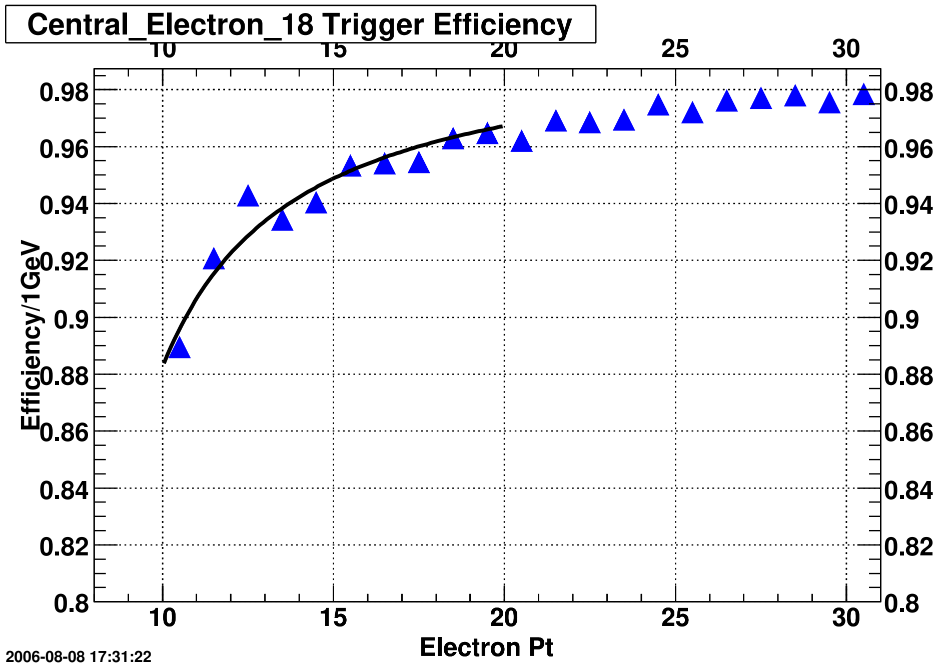

Figure 29: Electron_Central_18 trigger efficiency as a function of electron Pt. Slow turn on at low Pt, apply trigger Efficiency weight to MC event by event. bhel0i dataset.

an efficiency of 100% is assigned to the MC events.

$$\epsilon_{Cen}(Et) = a0 + a1 * Et + a2 * Et^2 + a3 * Et^3 + a4 * Et^4 + a5 * Et^5 \tag{4}$$
$$a0 = -12.8846 \qquad a1 = 1.61699 \qquad a2 = -0.0753011$$
$$a3 = 0.0017478 \qquad a4 = -2.01889e-05 \qquad a5 = 9.27732e-08$$

The Z_NOTRACK trigger efficiencies as a function of the second electron Et for bhel0h and bhel0i datasets are shown in figure 32, 33, 34 and 35.

For bhel0h dataset, in the central region, the average efficiency given in table 51 is used. For efficiency in the plug region, the fitting function is given in equation 5, the fitting range is $20 \leq Et \leq 32$GeV . For events with $32 < Et \leq 40$ GeV, the average efficiency given in table 52 is used. For events with $Et > 40$ GeV, an an efficiency of 100% is assigned to the MC events.

$$\epsilon_{Plug}(Et) = a0 + a1 * Et + a2 * Et^2 \tag{5}$$
$$a0 = -2.39407 \qquad a1 = 0.214734 \qquad a2 = -0.00341704$$

Trigger	Level	Calorimeter	Tracking
Z_NOTRACK	L1_TWO_EM8	ET_CENTRAL $\geq$ 8GeV HAD_EM_CENTRAL$\leq$ 0.125 ET_PLUG $\geq$ 8GeV HAD_EM_PLUG $\leq$ 0.125	none
	L2_TWO_EM16	$\|\eta\|$ $\leq$3.6 ET $\geq$ 16GeV HAD_EM$\leq$ 0.125 NUMBER=2	none
	L3_TWO_ELECTRON18	CalorRegion = 2 (both CENTRAL and PLUG) cenET $\geq$ 18GeV plugET $\geq$ 18GeV ZVert = 2^2 nTowersHadEm = 3^2 nEmObj = 2	none

Table 48: Z_NOTRACK trigger path, from Physics Table: PHYSICS_2_05[17]

Cuts	Events	Efficiency
ET28GeV	6547	
L1-CC	6547	1
L2-CC	6546	0.9998
L3-CC	6488	0.9911
Total L1-L3	6488	0.991

Table 49: Z_NOTRACK Efficiency from CC Z events, bhel0d dataset.

Cuts	Events	Efficiency
ET28GeV	11200	
L1-CP	11200	1
L2-CP	10779	0.9624
L3-CP	10651	0.9881
Total L1-L3	10651	0.951

Table 50: Z_NOTRACK Efficiency from CP Z events, bhel0d dataset

For bhel0i dataset, in the central region, the fitting function is given in equation

Cuts	Events	Efficiency
ET28GeV	7347	
L1-CC	7347	1
L2-CC	7342	0.9993
L3-CC	7342	1
Total L1-L3	7342	0.9993

Table 51: Z_NOTRACK Efficiency from CC Z events, bhel0h dataset.

Cuts	Events	Efficiency
ET28GeV	12961	
L1-CP	12961	1
L2-CP	12581	0.9707
L3-CP	12533	0.9962
Total L1-L3	12533	0.967

Table 52: Z_NOTRACK Efficiency from CP Z events, bhel0h dataset.

Cuts	Events	Efficiency
ET28GeV	4676	
L1-CC	4471	0.9562
L2-CC	4469	0.9996
L3-CC	4467	0.9996
Total L1-L3	4467	0.9553

Table 53: Z_NOTRACK Efficiency from CC Z events, bhel0i dataset.

Cuts	Events	Efficiency
ET28GeV	8263	
L1-CP	7819	0.9463
L2-CP	7607	0.9729
L3-CP	7593	0.9982
Total L1-L3	7593	0.9189

Table 54: Z_NOTRACK Efficiency from CP Z events, bhel0i dataset.

6, the fitting range is $20 \leq Et \leq 30$GeV . For events with $30 < Et \leq 50$ GeV, the average efficiency given in table 53 is used. For events with $Et > 50$ GeV, an efficiency of 100% is assigned to the MC events.

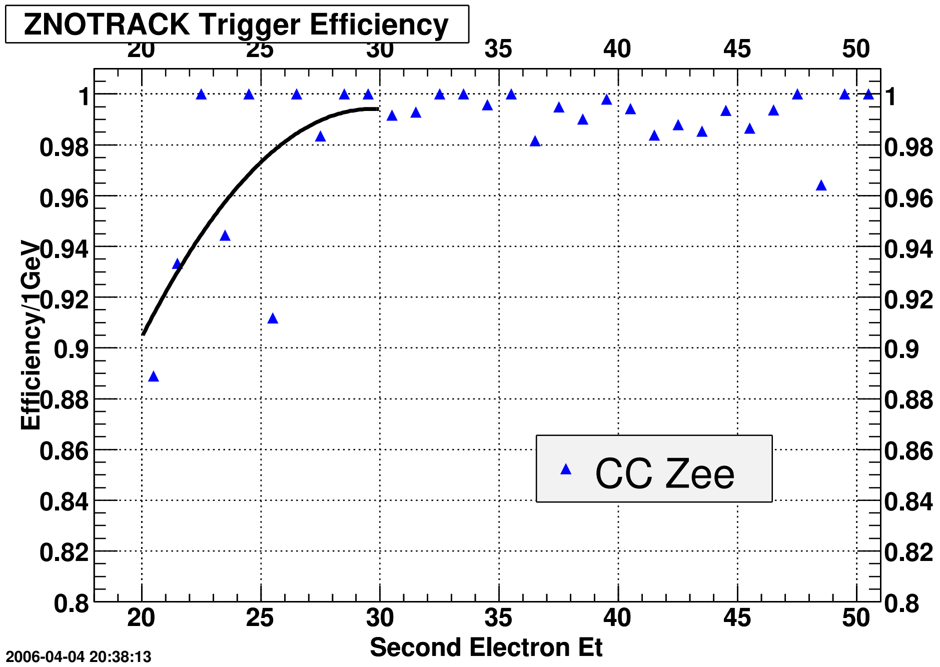

Figure 30: ZNOTRACK trigger efficiency in the central region, as a function of the second Electron Et, 28 GeV Et Cut on the first electron. Slow turn on at low Et, a trigger Efficiency weight is applied to MC event by event. bhel0d dataset.

$$\epsilon(Pt) = 1 - \frac{a0}{Pt - a1} \tag{6}$$

$$a0 = 0.839071 \quad a1 = 17.0195 \qquad \text{(bhel0i, central region)}$$

$$a0 = 1.19276 \quad a1 = 18.089 \qquad \text{(bhel0i, plug region)}$$

For efficiency in the plug region, the fitting function used is given in equation 6, the fitting range is $20 \leq Et \leq 50$GeV . For events with $Et > 50$ GeV, an efficiency of 100% is assigned to the MC events.

6.2.1 Total Trigger Efficiency in Z and $Z\gamma$ Event Selection

The total Z_NOTRACK trigger efficiency in Z event selection can be determined as following:

- CC Z events: $\epsilon^{Z\_NOTRACK} = \epsilon_{Cen}(Et_1) \cdot \epsilon_{Cen}(Et_2)$
- CP Z events: $\epsilon^{Z\_NOTRACK} = \epsilon_{Cen}(Et_1) \cdot \epsilon_{Plug}(Et_2)$
- PP Z events: $\epsilon^{Z\_NOTRACK} = \epsilon_{Plug}(Et_1) \cdot \epsilon_{Plug}(Et_2)$

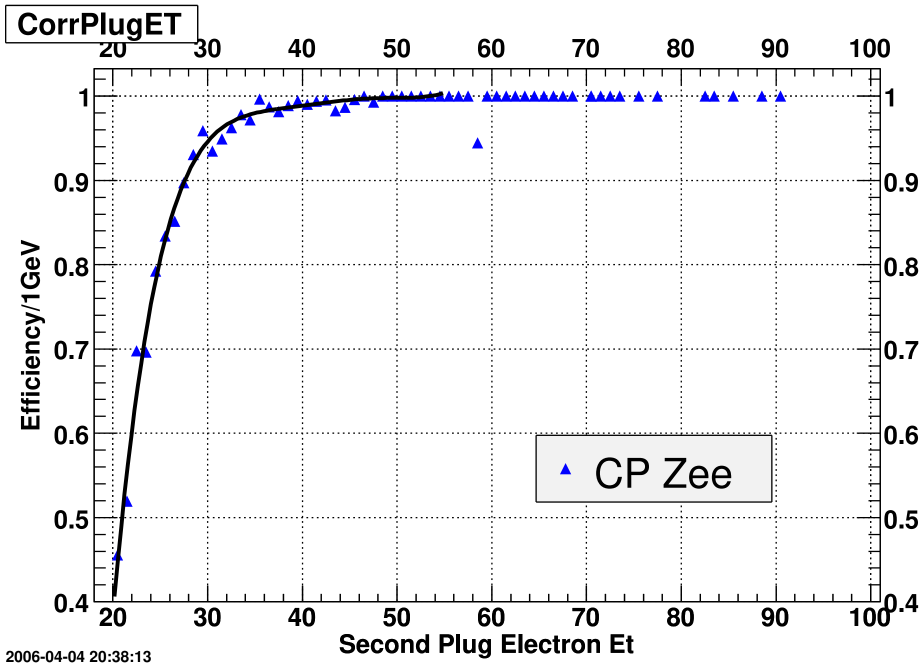

Figure 31: ZNOTRACK trigger efficiency in the plug region, as a function of the second Electron Et, 28 GeV Et Cut on the first electron. Slow turn on at low Et, a trigger Efficiency weight is applied to MC event by event. bhel0d dataset.

- Et_1 and Et_2 are the Et of the two electrons.

For $Z\gamma$ events, the photon must be included in the trigger efficiency calculation. The total trigger efficiency for $Z\gamma$ events with a central photon, is determined as following:

- Calculate efficiencies $\epsilon_i(Et_i)$, i = 1, 2, 3
  where Et_i are the Et of the two electrons and the photon
- Find the 1st and 2nd highest efficiencies ϵ_1 and ϵ_2
- $\epsilon^{Z\_NOTRACK} = \epsilon_1 \cdot \epsilon_2$

6.3 Total Trigger Efficiency

The total trigger efficiency in the inclusive Z or $Z\gamma$ event selection is then given as:
$\epsilon_{trig} = 1 - (1 - \epsilon^{Ele18}) \times (1 - \epsilon^{Z\_NOTRACK})$
For CC Z selection, the total trigger efficiency is $\sim$ 100%(see table 16).
For CP Z selection, the total trigger efficiency is $\sim$ 99.6%(see table 19).
For PP Z selection, the total trigger efficiency is $\sim$ 96%(see table 22).

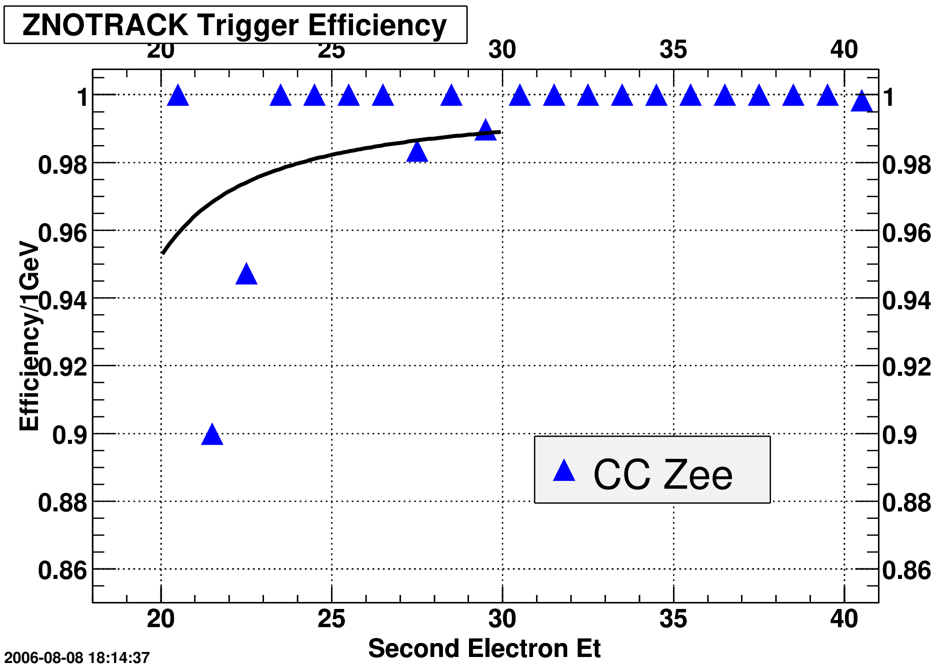

Figure 32: ZNOTRACK trigger efficiency as a function of the second Electron Et, 28 GeV Et Cut on the first electron. A trigger Efficiency weight is applied to MC event by event. bhel0h dataset.

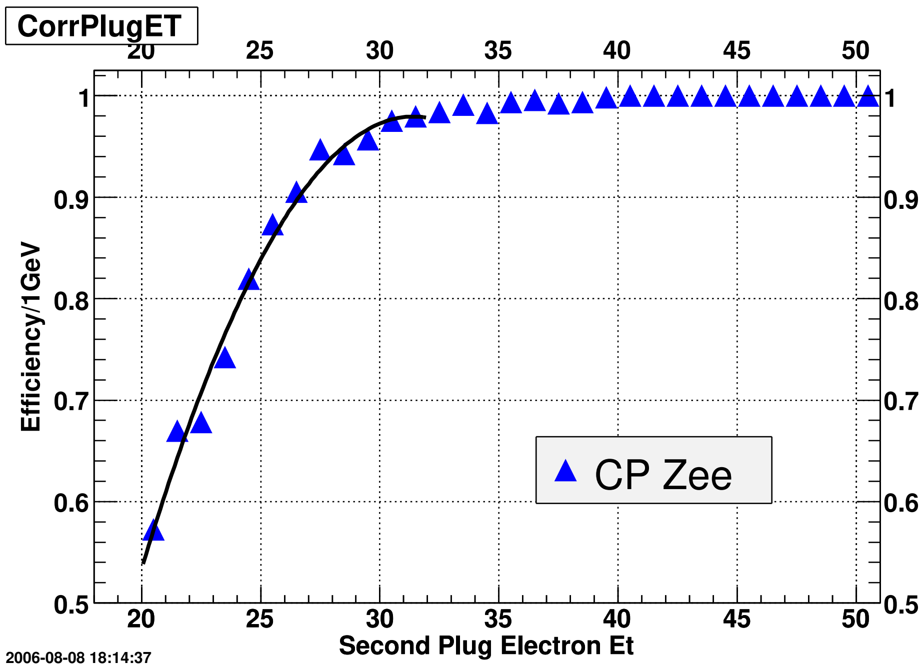

Figure 33: ZNOTRACK trigger efficiency as a function of the second Electron Et, 28 GeV Et Cut on the first electron. Slow turn on at low Et, a trigger Efficiency weight is applied to MC event by event. bhel0h dataset.

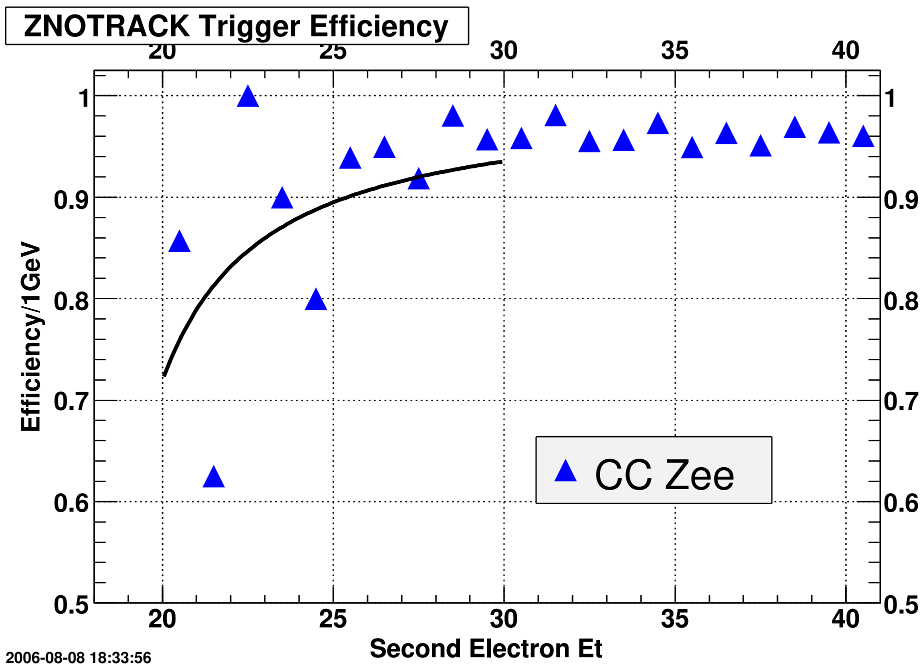

Figure 34: ZNOTRACK trigger efficiency as a function of the second Electron Et, 28 GeV Et Cut on the first electron. Slow turn on at low Et, a trigger Efficiency weight is applied to MC event by event. bhel0i dataset.

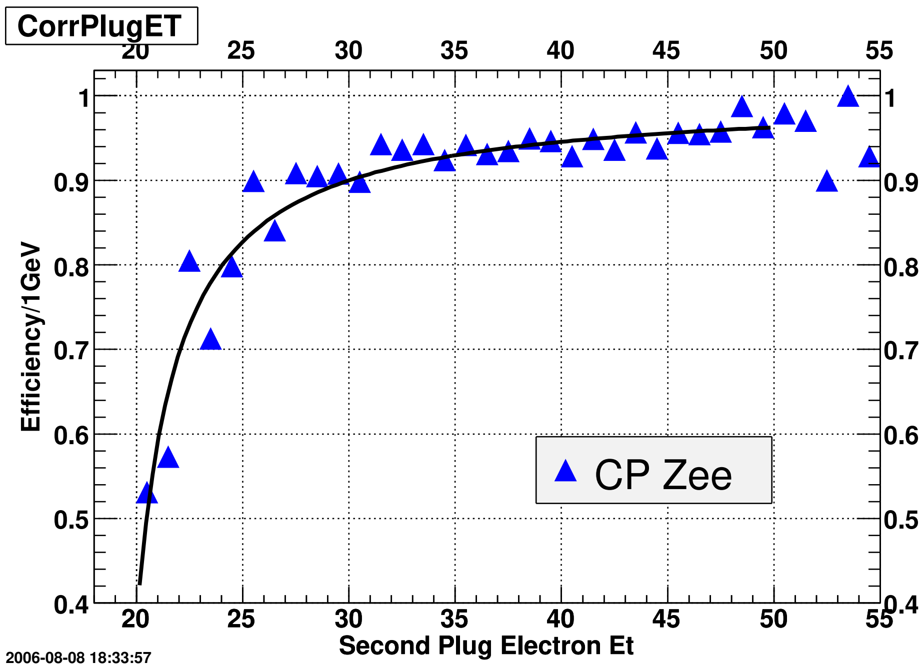

Figure 35: ZNOTRACK trigger efficiency as a function of the second Electron Et, 28 GeV Et Cut on the first electron. Slow turn on at low Et, a trigger Efficiency weight is applied to MC event by event. bhel0i dataset.

7 Background Estimation

QCD background is resulting from jets faking electrons. In this section, side-band method for QCD background estimation is discussed. The shape of the background is estimated using electron+jets sample.

7.1 QCD background shape

The main background source in the Z selection is QCD events, where a jet is miss-identified as an electron. To get a shape of the QCD background, we use the high Pt electron datasets, require there is one and only one electron in the events. The central electron must satisfy the loose electron selection criteria listed in table 4. The plug electron must satisfy the loose plug electron selection criteria listed in table 7. To identify a jet, we use the cuts in the loose electron selection, but veto the HadEm and Isolation cuts(see table 55 and 56). The mass spectra of M_{ej} gives an estimation of the shape of the QCD background events in our sample.

Variables	Central Loose Electron ID Cuts	Central Jet Selection Cuts
All COT Tracks:		
# Axial SLs	≥ 3 with ≥ 5 hits per SL	≥ 3 with ≥ 5 hits per SL
# Stereo SLs	≥ 2 with ≥ 5 hits per SL	≥ 2 with ≥ 5 hits per SL
BC $\lvert z_0\rvert$	$\leq 60.$	$\leq 60.$
Region	CEM ($\lvert\eta\rvert < 1.1$)	CEM ($\lvert\eta\rvert < 1.1$)
E_T	≥ 20	≥ 20
$TrackP_T$	≥ 10	≥ 10
Conversion	!= 1	!= 1
CES fiducial	= 1	= 1
E_{had}/E_{em}	≤ 0.055	> 0.055
	$+ 0.00045 \cdot$ EMCLST_ele_std_E	$+ 0.00045 \cdot$ EMCLST_ele_std_E
Iso(R=0.4)/E_T	≤ 0.3 (loose isolation cut)	> 0.3
Lshr	≤ 0.4	–
$\lvert\Delta Z\rvert$	≤ 8	–

Table 55: Central loose electron ID Cuts and central jet selection cuts

7.2 QCD Background Estimation – Side-band Subtraction Method

The background is estimated as in the following procedure:

- Normalize MC to Data in the mass window 86-98 GeV
- Get the difference: Diff(M_{ee}) = Data - MC

Variables	Plug Electron ID Cuts	Plug Jet Selection Cuts
Region	PEM ($1.1 \leq \lvert\eta\rvert < 3.6$)	PEM ($1.1 \leq \lvert\eta\rvert < 3.6$)
PES 2D Eta	$1.2 \leq \lvert\eta\rvert \leq 2.8$	$1.2 \leq \lvert\eta\rvert \leq 2.8$
$CorrE_T$	≥ 20	≥ 20
E_{had}/E_{em}	≤ 0.05	> 0.05
PEM 3x3 chi2	$\leq 25.$	—
Iso(R=0.4)/E_T		
	≤ 0.3 (loose isolation cut)	> 0.3

Table 56: Plug loose electron ID cuts and plug jet selection cuts

- Normalize Bkg-Shape(M$_{ej}$) spectra in the upper sideband($116 \leq M_{ee} \leq 220$ GeV) to Diff(M$_{ee}$) spectra
- Get background estimation using integral of bin 66-116 GeV in Bkg-Shape(M$_{ej}$) spectra
- Loop:
  Normalize MC to (Data- QCD Bkg) in the mass window 86-98 GeV
  repeat step 2-4

Figure 41 and 37 show the background estimation in CP and CC channels for bhel0d dataset. Figure 38 and 39 show the background estimation in CP and CC channels for bhel0h dataset.

7.3 Systematic Uncertainties

7.3.1 Systematic Uncertainties – CC Channel

For the central region, by assuming that the signs of the electrons for QCD background are uncorrelated, the number of QCD background events can be estimated using same-sign method. The QCD background equals the number of same-sign events observed in data, corrected for trident events:

$N^{bkg} = N^{SS}_{Data} - N^{OS}_{Data} \times N^{SS}_{MC}/N^{OS}_{MC}$

Table 57 compares the background estimations using the side-band subtraction method and the same-sign method. The systematic error on the QCD background estimation is taken to be the difference between the two methods.

Dataset	Z region	Signal	Side-band method	Same-sign method	Difference
bhel0d	CC	9403	83.9	51.4 ± 8.7(stat)	40%

Table 57: CC Z QCD background estimation, dataset bhel0d.

Figure 40 compares these two methods.

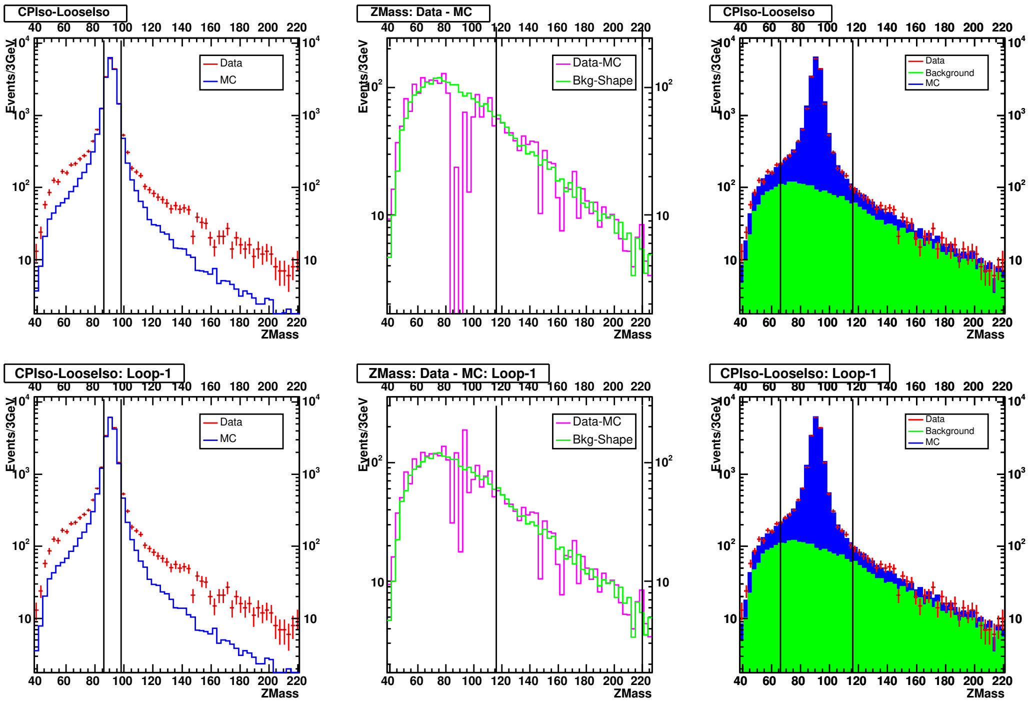

Figure 36: Zee CP background subtraction using upper side-band for normalization, bhel0d dataset

7.3.2 Systematic Uncertainties – CP Channel

In the side-band subtraction method, the upper side-band($116 \leq M_{ee} \leq 220$) or the lower side-band($40 \leq M_{ee} \leq 66$) can be used for normalization. The difference in the results is assigned as the systematic uncertainty for the QCD background estimation in the CP channel(see table 58).

Figure 41 shows the background estimation in CP region, using lower side-band for normalization.

Dataset	Z region	Signal	upper side-band normalization	lower side-band normalization	Difference
bhel0d	CP	20236	1563.4	1769.8	13 %

Table 58: CP Z QCD background estimation, dataset bhel0d.

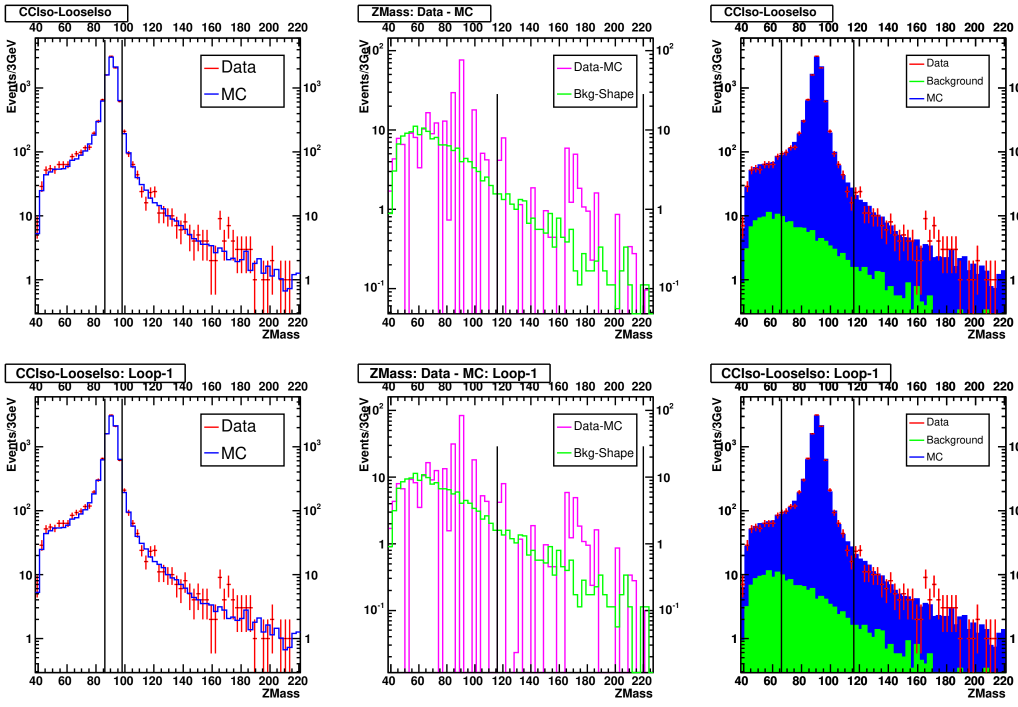

Figure 37: Zee CC background subtraction, bhel0d dataset

7.4 Background Estimation in PP Region

7.4.1 Diphoton backgrounds in PP channel

As shown in the Plug Electron ID variables table 7 , there is no track requirement, therefore diphoton events could also pass the PP Z selection. The Pythia diphoton sample pexo4d(see section 2.2.2) is used to study the background from diphoton production.

Table 59 shows the acceptance x Efficiency and the number of expected diphoton background events before and after Z Mass cut.

Cuts	Acceptance x Efficiency	$\gamma\gamma$ Event	$66 \leq$ M($\gamma\gamma$) ≤ 116
PPLPE-LPE	0.0141	975.3	336.3
PPoneTightIso	0.0141	974.7	336.1
PPIso-LooseIso	0.0140	972.5	335.3
PPIso-Iso	0.0136	942.9	326.2
PPTPE-Iso	0.0136	942.0	325.8
PPTPE-TPE	0.0128	888.0	308.6

Table 59: PP background Events from Diphoton sample, $373pb^{-1}$.

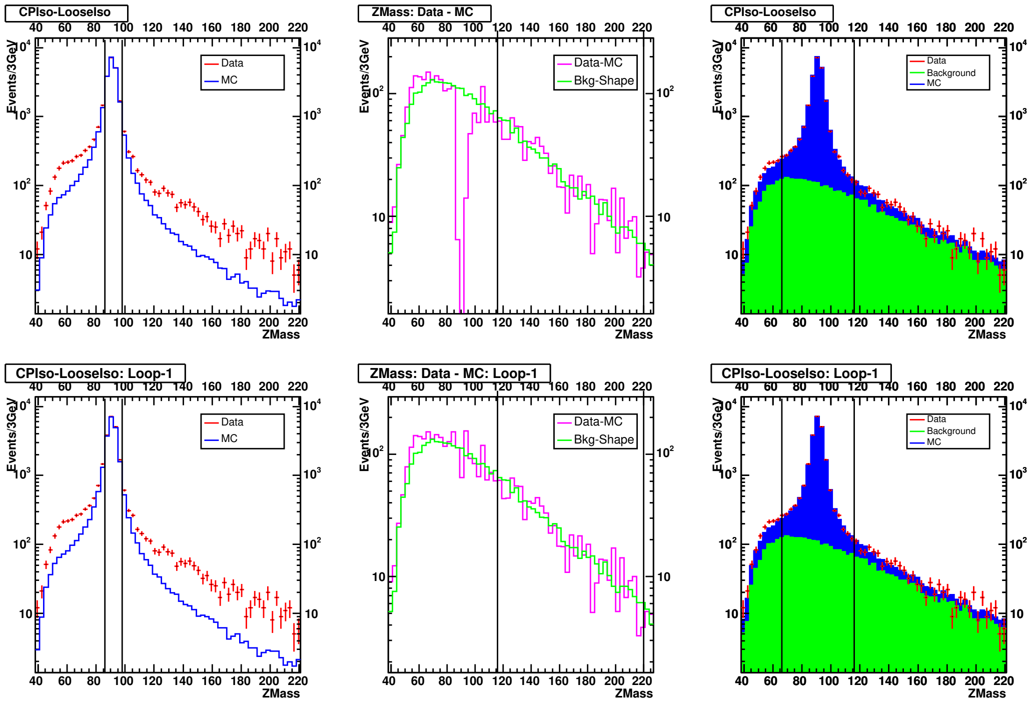

Figure 38: Zee CP background subtraction, bhel0h dataset

7.4.2 Background Subtraction in PP Region

To get background shape

- Use electron-triggered data sample
- For LPE Z samples, electron passes loose plug electron(LPE) ID cuts(table 7)
- For TPE Z samples, electron passes tight plug electron ID(TPE) cuts(table 9)
- Have one and only one electron in the events
- At least one jet in the plug region(table 56)
- Veto events where IsoR(jet) ≤ 0.3
- Get Bkg-Shape(M_{ej}) spectra

Background Estimation: side-band method

- Normalize MC to Data in the mass window 86-98 GeV
- Diff(M_{ee}) = Data - MC - $\gamma\gamma$ Bkg

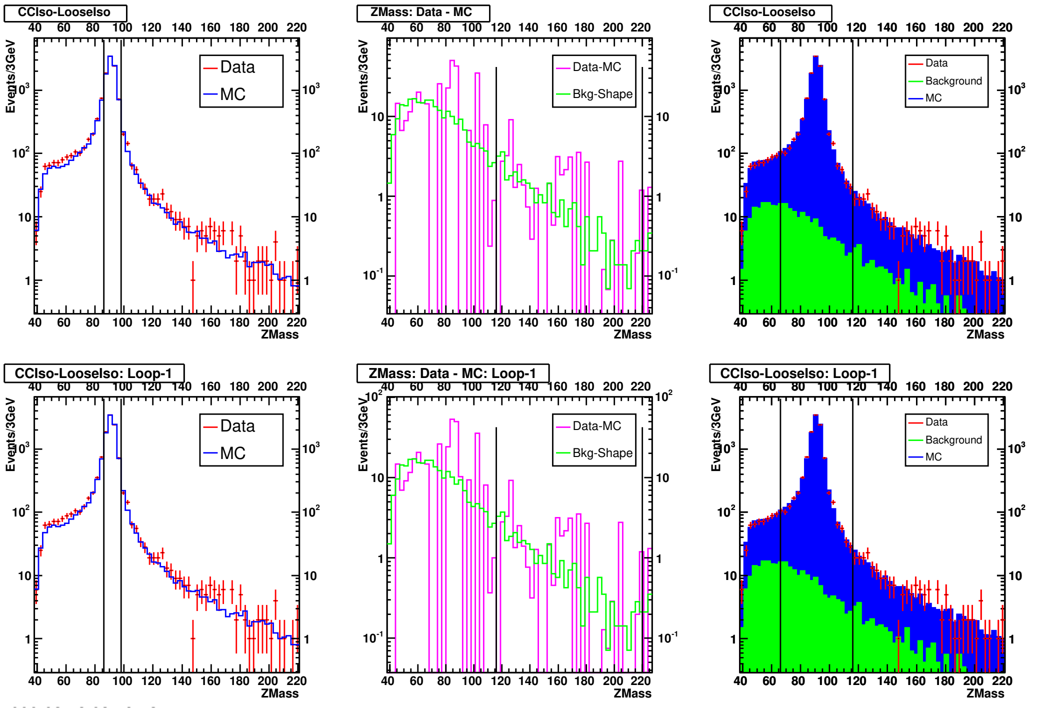

Figure 39: Zee CC background subtraction, bhel0h dataset

- Normalize Bkg-Shape(M_{ej}) in the low sideband(mass 40-66 GeV) to Diff(M_{ee})
- Estimate background using Bins 66-116 GeV in Bkg-Shape(M_{ej}) spectra
- Loop:
  Normalize MC to (Data-$\gamma\gamma$Bkg - Jet Bkg) in the mass window 86-98 GeV
  repeat previous steps

Figure 42 shows the background subtraction in PP channel for bhel0d dataset. The background shape spectrum from the jet template does not describe the background very well, as shown in comparison of the green curve(background shape) and black curve(real background). As a result, the inclusive Z cross section (see table 67) is higher in PP than in the CC and CP regions. We need to develop a method to obtain a shape spectrum that describes the real background better.

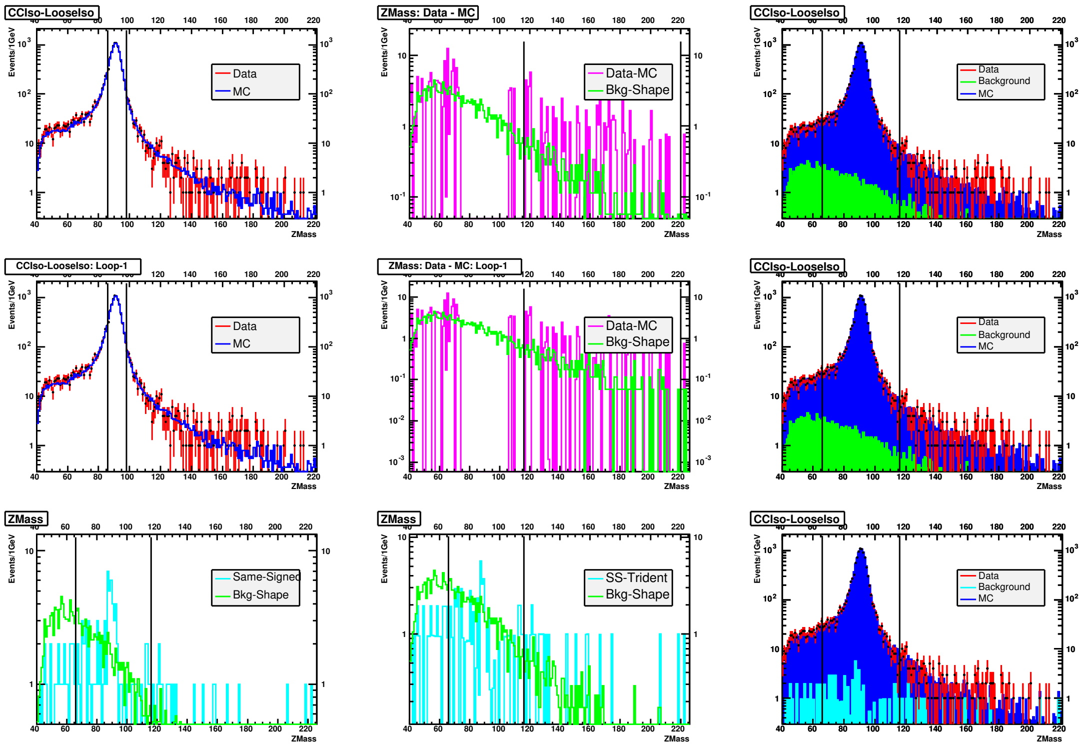

Figure 40: Z ee CC signal and background events: SS method vs side-band method. bhel0d dataset.

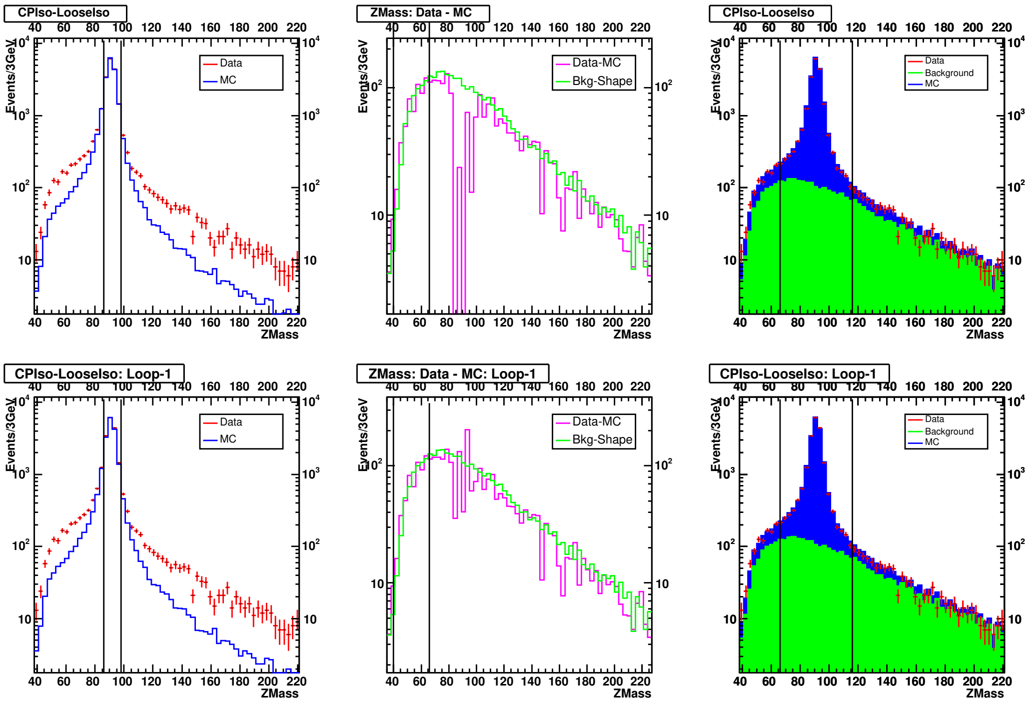

Figure 41: Zee CP background subtraction using lower side-band for normalization, bhel0d dataset

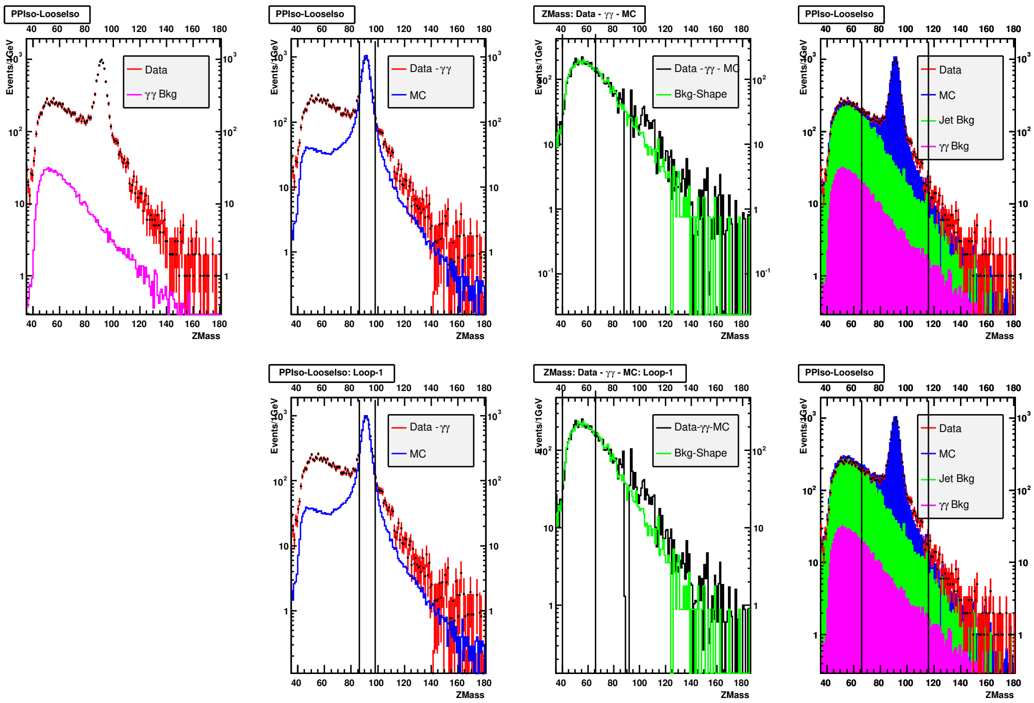

Figure 42: Zee PP Same-Side background subtraction

8 Inclusive Z Cross Section Measurement

8.1 Previous measurements

The previous published result [6] with 72 pb^{-1} of data is:

$$\sigma_{\gamma^*/Z} \cdot Br(\gamma^*/Z \to \ell\ell) = 254.9 \quad \pm \quad 3.3(stat.) \pm 4.6(syst.) \pm 15.2(lum.) \text{ pb},$$

The result of a measurement [7]with 337 pb^{-1} of data is:

$$\sigma_{\gamma^*/Z} \cdot Br(\gamma^*/Z \to \mu\mu) = 261.2 \quad \pm \quad 2.7(stat.) \pm^{+5.8}_{-6.9} (syst.) \pm 15.1(lum.) \text{ pb},$$

8.2 Measure Inclusive Z Cross Section – 1 fb^{-1}

Table table:SigmaZ summarizes the inclusive Z cross section measured with $1fb^{-1}$ of data. The results agree well with the previous measurements.

dataset	Cuts	Signal	Bkg	Bkg/Sig	ϵ_Z	$\epsilon_Z * A_Z$	$\sigma_{\gamma^*/Z} \cdot Br(\gamma^*/Z \to \ell\ell)$(pb)
bhel0h	CC	9403	83.9	0.009	0.870	0.097	257.0 $\pm$ 2.7(stat) $\pm$ 14.6(lum)
373pb^{-1}	CP	20236	1563.4	0.077	0.836	0.191	262.0 $\pm$ 2.0(stat) $\pm$ 14.9(lum)
bhel0d	CC	10696	135.6	0.013	0.870	0.097	253.5 $\pm$ 2.5(stat) $\pm$ 14.4(lum)
428pb^{-1}	CP	23187	1735.0	0.075	0.833	0.192	261.1 $\pm$ 1.9(stat) $\pm$ 14.9(lum)
bhel0i	CC	6840	111.2	0.016	0.868	0.097	253.9 $\pm$ 3.1(stat) $\pm$ 14.5(lum)
274pb^{-1}	CP	14467	1084.2	0.075	0.827	0.190	257.7 $\pm$ 2.3(stat) $\pm$ 14.7(lum)

Table 60: Zee cross-section calculation, dataset bhel0d, 0h and 0i.

8.3 Measure Inclusive Z Cross Section in CC Channel

Z selection in the Central-Central Channel:

- For each event, require at least two high pt electrons:
  two central loose electrons(table 4)
- Both electrons must satisfy the loose isolation cut(IsoR < 0.3)
- At least one electron must satisfy the tight isolation cut(IsoR < 0.1)
- choose events with the invariant mass in the range: $66 < M_{ee} < 116$
- the two electrons have opposite signs

- Use side-band subtraction method to estimate background(see 7.2)

The calculation of the inclusive Z cross section is given in equation 7,

$$\sigma_Z \cdot Br(Z \to \ell\ell) = \frac{N_Z^{\mathrm{obs}} - N_Z^{\mathrm{bck}}}{A_Z \cdot \epsilon_Z \cdot \int \mathcal{L}dt} \tag{7}$$

where:

- $\int \mathcal{L}dt$: integrated luminosity
- A_Z : Z acceptance
- ϵ_Z : total Z selection efficiency
- N_Z^{obs}: Opposite-signed CC $Z \to ee$ events
- N_Z^{bck}: QCD background events where Jets fake electrons

The following efficiencies are included in the total Z selection efficiency calculation:

- ϵ_{vtx} (CDFnote 7324[10])
  - $\epsilon_{\mathrm{vtx}} 0.951 \pm 0.003$ (bhel0d dataset)
  - $\epsilon_{\mathrm{vtx}} 0.960 \pm 0.003$ (bhel0h dataset)
  - $\epsilon_{\mathrm{vtx}} 0.966 \pm 0.003$ (bhel0i dataset)
- $\epsilon_{\mathrm{trk}} = 1.000 \pm 0.004$, (Data/MC ratio, $72pb^{-1}$, CDFnote 7332[6])
- $\epsilon_{\mathrm{rec}} = 0.998 \pm 0.004$, (Data/MC ratio, $72pb^{-1}$, CDFnote 7332[6])
- $\epsilon_{\mathrm{lid}} = 0.961$, ($373pb^{-1}$, table 25)
- $\epsilon_{\mathrm{Liso}} = 0.997$, ($IsoR < 0.3, 373pb^{-1}$, table 25)
- $\epsilon_{\mathrm{Tiso}} = 0.980$, ($IsoR < 0.1, 373pb^{-1}$, table 25)
- $\epsilon_{\mathrm{tid}} = 0.874$, ($373pb^{-1}$, table 25)

- total efficiency for tight electrons identification:
  $\epsilon = \epsilon_{\mathrm{lid}} \cdot \epsilon_{\mathrm{Liso}} \cdot \epsilon_{\mathrm{Tiso}} \cdot \epsilon_{\mathrm{tid}} = 0.961 \cdot 0.997 \cdot 0.980 \cdot 0.874 = 0.821$
- total event selection efficiency for LCE-LCE Z events:
  $\epsilon_{\mathrm{tot}}^{\mathrm{LL}} = \epsilon_{\mathrm{vtx}} \times \epsilon_{\mathrm{trk}}^2 \times \epsilon_{\mathrm{rec}}^2 \times \epsilon_{\mathrm{lid}}^2 = 0.876$
- total event selection efficiency for TCE-TCE Z events:
  $\epsilon_{\mathrm{tot}}^{\mathrm{TT}} = \epsilon_{\mathrm{tot}}^{\mathrm{LL}} \times \epsilon_{\mathrm{Liso}}^2 \times \epsilon_{\mathrm{Tiso}}^2 \times \epsilon_{\mathrm{tid}}^2 = 0.639$

Table 61 shows the result of the inclusive Z cross section in CC channel for bhel0d dataset, where the listed Z selection cuts are:

- CCOS : two opposite-signed loose central electrons(LCE)(table 4);
- CConeTightIso : two OS LCEs, one must satisfy the tight isolation cut(IsoR $<$ 0.1), no isolation requirement on the other electron leg;
- CCIso-LooseIso : two OS LCEs, one passes the tight isolation cut, the other passes the loose isolation cut(IsoR $<$ 0.3);
- CCIso-Iso : two OS LCEs, both pass the tight isolation cut;
- CCTCE-Iso : two OS LCEs, both tight isolated, at least one tight central electron(TCE)(table 5);
- CCTCE-TCE : two OS TCEs.

Cuts	Signal	Bkg	Bkg/Signal	ϵ_Z	$\epsilon_Z * A_Z$	$\sigma_{\gamma^*/Z} \cdot Br(\gamma^*/Z \to \ell\ell)$
CCOS	9651	282.5	0.029	0.876	0.098	256.8 $\pm$ 2.7(stat.) $\pm$ 14.6(lum.) pb
CConeTightIso	9519	154.0	0.016	0.875	0.098	256.8 $\pm$ 2.7(stat.) $\pm$ 14.6(lum.) pb
CCIso-LooseIso	9403	83.9	0.009	0.870	0.097	257.0 $\pm$ 2.7(stat.) $\pm$ 14.6(lum.) pb
CCIso-Iso	8940	37.0	0.004	0.836	0.093	255.7 $\pm$ 2.7(stat.) $\pm$ 14.6(lum.) pb
CCTCE-Iso	8794	13.6	0.002	0.822	0.092	256.2 $\pm$ 2.7(stat.) $\pm$ 14.6(lum.) pb
CCTCE-TCE	6823	0.0	0.000	0.639	0.071	256.3 $\pm$ 3.1(stat.) $\pm$ 14.6(lum.) pb

Table 61: CC Zee cross-section calculation, dataset bhel0d, 373 pb^{-1}.

As can be seen in the table, comparing to the standard "TCE-TCE" Z selection, the size of the "CCIso-LooseIso" Z sample is about $\sim 40\%$ larger with modest background. The "CCIso-LooseIso" Z sample is used in the $Z\gamma$ analysis.

Table 62 and 63 show the results of the inclusive Z cross section in CC channel for bhel0h and bhel0i datasets.

Cuts	Signal	Bkg	Bkg/Signal	ϵ_Z	$\epsilon_Z * A_Z$	$\sigma_{\gamma^*/Z} \cdot Br(\gamma^*/Z \rightarrow \ell\ell)$
CCOS	11021	307.1	0.028	0.876	0.098	255.6 ± 2.5(stat.) ± 14.6(lum.) pb
CConeTightIso	10836	183.9	0.017	0.875	0.098	254.3 ± 2.5(stat.) ± 14.5(lum.) pb
CCIso-LooseIso	10696	135.6	0.013	0.870	0.097	253.5 ± 2.5(stat.) ± 14.4(lum.) pb
CCIso-Iso	10086	42.4	0.004	0.832	0.093	252.4 ± 2.5(stat.) ± 14.4(lum.) pb
CCTCE-Iso	9895	0.0	0.000	0.818	0.091	252.9 ± 2.5(stat.) ± 14.4(lum.) pb
CCTCE-TCE	7614	0.0	0.000	0.630	0.070	252.5 ± 2.9(stat.) ± 14.4(lum.) pb

Table 62: CC Zee cross-section calculation, dataset bhel0h, 428 pb^{-1}.

Cuts	Signal	Bkg	Bkg/Signal	ϵ_Z	$\epsilon_Z * A_Z$	$\sigma_{\gamma^*/Z} \cdot Br(\gamma^*/Z \rightarrow \ell\ell)$
CCOS	7042	256.2	0.036	0.874	0.098	254.3 ± 3.1(stat.) ± 14.5(lum.) pb
CConeTightIso	6925	137.4	0.020	0.874	0.097	254.5 ± 3.1(stat.) ± 14.5(lum.) pb
CCIso-LooseIso	6840	111.2	0.016	0.868	0.097	253.9 ± 3.1(stat.) ± 14.5(lum.) pb
CCIso-Iso	6458	58.7	0.009	0.831	0.093	252.3 ± 3.2(stat.) ± 14.4(lum.) pb
CCTCE-Iso	6330	39.6	0.006	0.816	0.091	252.4 ± 3.2(stat.) ± 14.4(lum.) pb
CCTCE-TCE	4833	0.0	0.000	0.626	0.070	252.9 ± 3.6(stat.) ± 14.4(lum.) pb

Table 63: CC Zee cross-section calculation, dataset bhel0i, 274 pb^{-1}.

8.4 Measure Inclusive Z Cross Section in CP Channel

Z selection in the Central-Plug Channel:

- For each event, require at least two high pt electrons:
  one central loose electron(table 4) and one loose plug electron(table 7)
- Both electrons must satisfy the loose isolation cut(IsoR < 0.3)
- At least one electron must satisfy the tight isolation cut(IsoR < 0.1)
- Choose events with the invariant mass in the range: $66 < M_{ee} < 116$
- Use side-band subtraction method to estimate background(see 7.2)

Cuts	Signal	Bkg	Bkg/Signal	ϵ_Z	$\epsilon_Z * A_Z$	$\sigma_{\gamma^*/Z} \cdot Br(\gamma^*/Z \to \ell\ell)$
CPoneTightIso	20939	2085.2	0.100	0.840	0.192	263.2 $\pm$ 2.0(stat.) $\pm$ 15.0(lum.) pb
CPIso-LooseIso	20236	1563.4	0.077	0.836	0.191	262.0 $\pm$ 2.0(stat.) $\pm$ 14.9(lum.) pb
CPIso-Iso	18240	537.4	0.029	0.801	0.183	259.1 $\pm$ 2.0(stat.) $\pm$ 14.7(lum.) pb
CPTCE-Iso	15987	122.9	0.008	0.701	0.160	265.5 $\pm$ 2.1(stat.) $\pm$ 15.1(lum.) pb
CPTCE-TPE	15420	110.0	0.007	0.676	0.155	265.5 $\pm$ 2.2(stat.) $\pm$ 15.1(lum.) pb

Table 64: CP Zee cross-section calculation, dataset bhel0d, 373 pb^{-1}.

Table 64 shows the result of the inclusive Z cross section in CP channel for bhel0d datasets, where the listed CP Z selection cuts are:

- CPoneTightIso : one LCE(table 4) and one LPE(table 7) . One electron must satisfy the tight isolation cut(IsoR < 0.1), no isolation requirement on the other electron leg;
- CPIso-LooseIso : LCE + LPE , one passes the tight isolation cut, the other passes the loose isolation cut(IsoR < 0.3);
- CPIso-Iso : LCE + LPE , both pass the tight isolation cut;
- CPTCE-Iso : TCE + LPE , both tight isolated. Central electron is a tight central electron(TCE)(table 5);
- CPTCE-TPE : TCE + TPE(table 9).

Table 65 and 66 show the results of the inclusive Z cross section in CP channel for bhel0h and bhel0i datasets.

Cuts	Signal	Bkg	Bkg/Signal	ϵ_Z	$\epsilon_Z * A_Z$	$\sigma_{\gamma^*/Z} \cdot Br(\gamma^*/Z \to \ell\ell)$
CPoneTightIso	24045	2381.0	0.099	0.836	0.193	262.7 $\pm$ 1.9(stat.) $\pm$ 15.0(lum.) pb
CPIso-LooseIso	23187	1735.0	0.075	0.833	0.192	261.1 $\pm$ 1.9(stat.) $\pm$ 14.9(lum.) pb
CPIso-Iso	20600	545.6	0.026	0.790	0.182	257.3 $\pm$ 1.8(stat.) $\pm$ 14.6(lum.) pb
CPTCE-Iso	17968	134.1	0.007	0.688	0.158	262.9 $\pm$ 2.0(stat.) $\pm$ 15.0(lum.) pb
CPTCE-TPE	17414	130.1	0.007	0.667	0.154	262.7 $\pm$ 2.0(stat.) $\pm$ 15.0(lum.) pb

Table 65: CP Zee cross-section calculation, dataset bhel0h, 428 pb^{-1}.

Cuts	Signal	Bkg	Bkg/Signal	ϵ_Z	$\epsilon_Z * A_Z$	$\sigma_{\gamma^*/Z} \cdot Br(\gamma^*/Z \to \ell\ell)$
CPoneTightIso	15017	1476.9	0.098	0.831	0.191	259.4 $\pm$ 2.3(stat.) $\pm$ 14.8(lum.) pb
CPIso-LooseIso	14467	1084.2	0.075	0.827	0.190	257.7 $\pm$ 2.3(stat.) $\pm$ 14.7(lum.) pb
CPIso-Iso	12834	301.5	0.023	0.784	0.180	254.5 $\pm$ 2.3(stat.) $\pm$ 14.5(lum.) pb
CPTCE-Iso	11270	47.2	0.004	0.681	0.156	262.6 $\pm$ 2.5(stat.) $\pm$ 14.9(lum.) pb
CPTCE-TPE	10897	44.7	0.004	0.659	0.151	262.4 $\pm$ 2.5(stat.) $\pm$ 14.9(lum.) pb

Table 66: CP Zee cross-section calculation, dataset bhel0i, 274 pb^{-1}.

8.5 Measure Inclusive Z Cross Section in PP Channel

Z selection in the plug-plug Channel:

- For each event, require at least two high pt electrons:
  two loose plug electrons(table 7)
- Both electrons must satisfy the loose isolation cut(IsoR < 0.3)
- At least one electron must satisfy the tight isolation cut(IsoR < 0.1)
- Choose events with the invariant mass in the range: $66 < M_{ee} < 116$
- The two electrons must be in the same side of the detector(east-west).
- Use side-band subtraction method to estimate background(see 7.4.2)

Table 67 shows the result of the inclusive Z cross section in PP channel for bhel0d dataset , where the listed PP Z selection cuts are:

- PPLPE-LPE : two same-side loose plug electrons(LPE)(table 7)
- PPoneTightIso : two LPEs. One electron must satisfy the tight isolation cut(IsoR < 0.1), no isolation requirement on the other electron leg;

Cuts	Signal	$\gamma\gamma$ Bkg	Jet Bkg	Bkg/Signal	ϵ_Z	$\epsilon_Z * A_Z$	$\sigma_{\gamma^*/Z} \cdot Br(\gamma^*/Z \to \ell\ell)$ (pb)
PPLPE-LPE	11580	335.7	3117.4	0.298	0.807	0.0780	279.6 ± 4.2(stat) ± 15.9(lum)
PPoneTightIso	11415	335.5	2765.3	0.272	0.806	0.0779	286.2 ± 4.1(stat) ± 16.3(lum)
PPIso-LooseIso	11248	334.8	2597.6	0.261	0.803	0.0776	287.4 ± 4.1(stat) ± 16.4(lum)
PPIso-Iso	10068	325.6	1926.0	0.224	0.768	0.0743	282.3 ± 4.0(stat) ± 16.1(lum)
PPTPE-Iso	10022	325.3	1888.7	0.221	0.767	0.0742	282.3 ± 4.0(stat) ± 16.1(lum)
PPTPE-TPE	9210	308.1	1354.4	0.181	0.716	0.0692	292.5 ± 4.0(stat) ± 16.6(lum)

Table 67: Zee PP cross-section calculation, $373pb^{-1}$.

- PPIso-LooseIso : two same-side LPEs , one passes the tight isolation cut, the other passes the loose isolation cut(IsoR < 0.3);
- PPIso-Iso : two same-side LPEs , both pass the tight isolation cut;
- PPTPE-Iso : TPE + LPE , both tight isolated.
- PPTPE-TPE : TPE + TPE(table 9).

Figure 42 shows the background subtraction in PP channel for bhel0d dataset. The background shape spectrum from the jet template does not describe the background very well. As a result, the inclusive Z cross section measured in PP region is higher in PP than in the CC and CP regions. We need to develop a method to obtain a shape spectrum that describes the real background better. The PP channel is not included in the $Z\gamma$ analysis.

9 Summary

We develop a loose Z selection criteria in the electron channel. This approximately doubles the accetapnce obtained using the standard tight electron selection. The measured inclusive Z cross sections agree well with the previous measurements.

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