Studies of EM PhiMod efficiency and shift for $M_W$ Measurement

Junjie Zhu, John Hobbs
State University of New York, Stony Brook, NY

Heidi Schellman
Northwestern University, Evanston, IL

Jan Stark
LPSC, Grenoble, France

1 Introduction

DØ’s central calorimeter contains three concentric barrels of modules: the innermost consists of 32 EM modules, followed by 16 hadronic modules with 6 mm uranium absorber plates, and then 16 copper absorber plates. For the $W$ mass measurement, we require electrons must be located in the CC fiducial region, which means we impose a fiducial requirement that the reconstructed EM cluster is away from the EM module boundaries which retains the interior 80% in azimuth of each module. Fig 1 shows the end view of the central calorimeter and the detailed design of the EM calorimeter in the vicinity of the edge of two modules. Near the very edge of each EM module, there are no electrode pads and the electric field is not uniform. Also since we only collect a small fraction of the charge, the electron response near the boundary region is more degraded in Run II than in Run I.

There are two effects resulting from the geometrical structure of the calorimeter module:

1. PhiMod efficiency: Due to the arrangement of the electrode pads and also the non-uniform electric fields, the efficiency to find electron clusters varies with $\phi$ of the incident particle [1].
2. PhiMod shift: Due to the current EM clustering algorithms and the electronics, the electron cluster angle calculated from the electron energy deposited in the third EM layer $\phi$ is biased towards the center of the module [2]. Understanding of the phimod effect (both efficiency and bias) is important for understanding the measured $Z$ boson transverse momentum distribution, which will affect the electron transverse momentum distribution and thus the electron energy scale and offset. A measurement of the phimod effect and the implementation in wz_epmc for the $W$ mass measurement are described in this note. This note is arranged in the following way: Sect. 2 describes the extrapolation of the track from the primary vertex to EM3 layer, Sect. 3 and Sect. 4 describe the methods used to measure phimod efficiency and bias in real data and GEANT MC.

## 2 Extrapolation of tracks from the primary vertex to EM3

To calculate EM clustering efficiency and PhiMod bias vs PhiMod, we need to extrapolate the electron track from the origin to EM3 layer. We implemented the code that does the EM cluster position correction (EMClusterPosCorr.cpp) and the extrapolation (EMTrackExtrap.cpp) in em_util package into wmass_util package. And we looked at several comparisons between electrons and positrons using both GEANT MC and data to make sure the extrapolation is reasonable. In the em_util extrapolation code, the deflected distance in
EM3 is calculated as $AA/(p_T \times \text{polarity} \times \text{charge})$, where $AA = 22.55$ cm for data and 21.65 cm for GEANT MC (in release p18.10.00). These numbers were determined several years ago and need to be re-determined. Another reason that these numbers need to be re-determined is the magnetic field changed from 2 Tesla to 1.94 Tesla for a large fraction of the data. Fig. 2 shows the phi difference between EM cluster and extrapolated track ($\phi_{EM} - \phi_{trk}^{extra}$) assuming $AA = 0$ cm and $AA = 22.55$ cm for electrons and positrons in GEANT MC. $AA = 0$ cm means no charge corrections made (i.e., no magnetic field) and thus the biggest difference between electrons and positrons is expected, while non-zero $AA$ helps to move the difference smaller. We found that $AA = 21$ cm gives the best agreement between electrons and positrons in GEANT MC, and is also shown in Fig. 2. We also did the same test for electrons and positrons in real data after separating events by solenoid polarity, Fig. 3 shows $\phi_{EM} - \phi_{trk}^{extra}$ between electrons and positrons in real data for positive and negative solenoid polarity respectively. Here we use $AA = 22.55$ cm. As seen from these two plots, $AA = 22.55$ cm is also not the best choice for correcting real data. Fig. 4 shows $\phi_{EM} - \phi_{trk}^{extra}$ between electrons and positrons in real data for $AA = 21$ cm for positive and negative solenoid polarity respectively. Based on these results, we decided to use $AA = 21$ cm for charge corrections in both GEANT MC and real data.

![Graph](image)

Figure 2: Phi difference between EM cluster and extrapolated track ($\phi_{EM} - \phi_{trk}^{extra}$) assuming $AA = 0$ cm and $AA = 22.55$ cm (Left) and $AA = 21$ cm (Right) for electrons and positrons in GEANT MC. Red points for electrons and blue points for positrons.

### 3 EM clustering Efficiency vs PhiMod

#### 3.1 Method

Each EM module consists of two cells, each of which covers $1/64$ of $2\pi$, a module is thus about 0.2 radian wide in $\phi$. In this note a module is shown with unit width (the variable...
Phi difference between EM cluster and extrapolated track

-0.015 -0.01 -0.005 0 0.005 0.01 0.015

0

Figure 3: Phi difference between EM cluster and extrapolated track ($\phi^{\text{EM}} - \phi^{\text{extra}}_{\text{trk}}$) for electrons and positrons in data for positive (Left) and negative (Right) solenoid polarity respectively using $AA = 22.55$ cm. Red points for electrons and blue points for positrons.

PhiMod=fmod($32\phi/2\pi, 1.0$) is used), the central value of PhiMod (0.5) is thus the cell boundary, the values close to 0 and 1 are the two edges of the module boundary.

The method we used to derive EM clustering efficiency is described below:

- Start from a $Z \rightarrow ee$ GEANT MC sample or 2EMHighpT data sample which contains both diem and em+track events;

- Select a list of isolated tracks with $p_T > 12$ GeV, the track is isolated if the sum of $p_T$ for the rest tracks inside $\Delta R < 0.2$ cone is less than 2 GeV;

- Select a list of loose EM clusters with the following quality cuts: $p_T > 15$ GeV, ID=10, ±11;

- Loop over all loose EM clusters and find a tag electron defined by $p_T > 25$ GeV, emf> 0.9, iso < 0.15, HMx7 < 12, $|\eta^{\text{det}}| < 1$ and a spatial-matched track with $P(\chi^2) > 0.01$, nsmt > 0 and $p_T > 10$ GeV;

- Find a probe track from the list of isolated tracks, the probe track is further required to have $p_T > 15$ GeV, nsmt > 0, ncf> 8, $\chi^2/dof < 3.3$ and not matched to the tag electron ($\Delta R(\text{tag EM, trk}) > 2$);

- The probe track is extrapolated to EM3 using the code described in Sect. 2 and is required to be in the central region $|\eta^{\text{det}}_{\text{trk}}| < 1$. The invariant mass between the track and the tag electron is required to lie within 75 and 105 GeV. The PhiMod for the extrapolated track is filled in histogram A;

- Loop over all loose EM clusters again and try to find an EM cluster with emf> 0.9, iso < 0.15, $|\eta^{\text{det}}| < 1$ that matches with the probe track ($\Delta R(\text{EM, probe track}) < 0.15$).
Figure 4: Phi difference between EM cluster and extrapolated track ($\phi_{EM} - \phi_{extrak}^{trk}$) for electrons and positrons in data for positive (Left) and negative (Right) solenoid polarity respectively using $AA = 21$ cm. Red points for electrons and blue points for positrons.

If a matched EM cluster is found, then the PhiMod for the extrapolated track is filled in histogram B;

- The EM clustering efficiency vs PhiMod is defined as the ratio of histogram B and histogram A.

EM track invariant mass cut is introduced to remove the QCD backgrounds in real data, Fig. 5 shows the invariant mass for EM and track in real data and GEANT MC (no backgrounds). Only events with EM-track mass between 75 and 105 GeV are used for the efficiency measurement.

Figure 5: Invariant mass distribution of EM and track in real data (Left) and in GEANT MC (Right). The track momentum resolution is worse in data than in GEANT MC, and thus the width for EM-track invariant mass is larger in data than in GEANT MC. A cut of 75 to 105 GeV is made to remove QCD backgrounds in real data.
3.2 Full MC closure test

To make sure the tag-probe method we developed for real data analysis work fine, we also compare the tag-probe result and the MC truth information for GEANT MC events. Before we do this full MC closure test, we also need to make sure the code to extrapolate the generator-level electrons (positrons) to EM3 layer is reasonable, Fig. 6 shows $\phi_{EM} - \phi_{gen}^{extra}$ between electrons and positrons in GEANT MC, reasonable agreement is observed. Fig. 7 shows the phimod efficiency using the tag-probe method and using the MC truth information in GEANT MC events, Red points for MC truth efficiency and blue points for tag-probe method result.

![Figure 6: Phi difference between EM cluster position and the extrapolated generator-level particle position ($\phi_{EM} - \phi_{gen}^{extra}$) for electrons and positrons in GEANT MC. Red points for electrons and blue points for positrons.](image)

3.3 Bias due to the tag electron requirement

To measure the PhiMod efficiency in real data, we had to require a tag electron in order to reduce the QCD background and to make sure the probe track is a real electron track, this requirement may bias the PhiMod efficiency. The main reason for the possible bias is the two electrons are mainly back-to-back for low $Z$ boson $p_T$, if one electron is inside the edge region of one Phi module, the other electron is also intend to be in the edge region of another Phi module. To measure this bias, we measured the PhiMod efficiency with and without tag-electron requirement in GEANT MC, as shown in Fig. 8.
3.4 Results for PhiMod efficiency

Fig. 9 shows the efficiency of finding an EM cluster vs PhiMod in GEANT MC (Left) and in real data (Right). The PhiMod efficiency is very flat for the central module region (0.05 < \( \PhiMod < 0.95 \)), and decreases quickly as the track approaches either edge of the module.

4 PhiMod bias for real data

Fig. 10 shows \( \text{fmod}(32(\phi_{EM} - \phi_{trk})/2\pi, 1.0) \) vs PhiMod of the extrapolated track position across the module. Since \( \phi_{trk} \) is unbiased, there is a strong tendency for \( \phi_{EM} \) to move towards the center of the module. We also checked the dependence on electron \( p_T \) and physics \( \eta \).

Fig. 11 shows the PhiMod shift for three different electron \( p_T \) regions: red for \( 25 < p_T < 35 \) GeV, green for \( 35 < p_T < 40 \) GeV and blue for \( 40 < p_T < 45 \) GeV. Fig. 12 shows the PhiMod shift for three different electron \( \eta \) regions: red for \( |\eta| < 0.25 \), green for \( |\eta| < 0.5 \) and blue for \( |\eta| < 1 \).

5 \( Z \) boson \( p_T \) dependence

The \( \text{acc} \times \text{eff} \) for \( Z \) boson strong depends on \( Z \) boson \( p_T \) for CC-CC events due to the PhiMod cut, the reason is described in Sect. 4 and also can be found in Ref. [1]. A measurement of the \( \text{acc} \times \text{eff} \) vs \( Z \) boson \( p_T \) in GEANT MC and fast MC simulations is a good closure test of the PhiMod efficiency and PhiMod shift measurements, as shown in Fig. 13.
Figure 8: Phi crack efficiency with (Red) and without (Blue) the tag-electron requirement in GEANT MC.

References


Figure 9: PhiMod efficiency as a function of the extrapolated track PhiMod in GEANT MC (Left) and in real data (Right).
Figure 10: Difference between $\phi_{EM}$ and $\phi_{trk}$ (fmod($32(\phi_{EM} - \phi_{trk})/2\pi, 1.0)$) in module units vs track phimod (fmod($32\phi_{trk}/2\pi, 1.0$)). Top: 2D plot; Right: profile plot.
Figure 11: PhiMod shift for three different electron $p_T$ regions: red for $25 < p_T < 35$ GeV, green for $35 < p_T < 40$ GeV and blue for $40 < p_T < 45$ GeV.

Figure 12: PhiMod shift for three different electron $\eta$ regions: red for $|\eta| < 0.25$, green for $|\eta| < 0.5$ and blue for $|\eta| < 1$.
Figure 13: Z boson $\text{acc} \times \text{eff}$ vs Z boson $p_T$ for GEANT MC (Blue) and fast MC (Red) simulations.