CDF/PHYS/ELECTROWEAK/CDFR/8889
Draft 0.0
July 17, 2007

A New Method to Measure Photon ID Efficiency at CDF

J. Deng, A. Goshaw, B. Heinemann, J. Kist , C. Lester, A. Nagano, T. Phillips *Berkeley, Duke and Tsukuba University*

Abstract

We describe the measurement of photons with $E_T > 7$ GeV and $|\eta| < 2.0$ using the CEM and PEM detectors. These are used in the study of $W\gamma$ and $Z\gamma$ events as described in other CDF notes[1, 2]. The photon ID efficiency is based upon the selection of a very pure photon source from final state radiation in $Z \to l^+l^-+ \gamma$ events. This ID efficiency is compared to a complementary measurement[3] that uses electrons as proxies for photons.

1 Introduction

The precision of the measurement of $W\gamma$ and $Z\gamma$ production is limited by our understanding of the selected photon candidates. First the photon ID efficiency must be measured from data using either "pure" electron or photon sources. A new method using a photon source from the final state radiation in $Z \to l^+l^-+ \gamma$ events is described in Section 3. Second the background due to jets passing our photon selection criteria must be evaluated(described in other CDF note). Section 4 summarizes the photon ID efficiencies that will be used in the measurement of of $p\bar{p} \to l^+l^- + \gamma +$ X and of $p\bar{p} \to l\nu + \gamma +$ X production.

The Gen6 Z(ee)γ MC sample (dataset rewk33) is used in this analysis. The electron data (dataset 0d, 0h and 0i) has a total luminosity of $\sim$1 fb^{-1}. The muon data (through period 10) has a total luminosity of $\sim$1.6 fb^{-1}.

2 Photon selection

Photons are selected with $E_T > 7$ GeV and $|\eta| < 2.0$ using the central and forward detectors. We require that the photon is separated from any primary electron or muon by $\Delta R(l\text{-}\gamma)$>0.4. Standard Joint Physics Group photon selection cuts are used. These are summarized in Table 1 and 3.

Variables	Cut
EtCorr	> 7
$\|cesX\|$	< 21 cm
$\|cesZ\|$	$9 < \|cesZ\| < 230$ cm
Had/Em	< 0.125 || < 0.055 + 0.00045 * ECorr
IsoEtCorr	EtCorr < 20: < 0.1 * EtCorr EtCorr ≥ 20: < 2.0 + 0.02 * (EtCorr - 20.0)
Chi2(Strips + Wires)/2	< 20
N track(N3D)	≤ 1
Track Pt	< 1.0 + 0.005 * EtCorr
Cone 0.4 Track Iso	< 2.0 + 0.005 * EtCorr
2nd CES cluster E*sin(θ)	(both strip and wire E individually) EtCorr < 18: < 0.14 * EtCorr EtCorr ≥ 18: < 2.4 + 0.01 * EtCorr

Table 1: Central Photon ID cuts.

Variables	Cut
EtCorr	> 7
$\|cesX\|$	< 21 cm
$\|cesZ\|$	$9 < \|cesZ\| < 230$ cm
Had/Em	≤ 0.125
IsoEtCorr	≤ 5
Track Pt	< EtCorr /2
Cone 0.4 Track Iso	≤ 5

Table 2: Central Photon Denominator cuts for ID efficiency measurement.

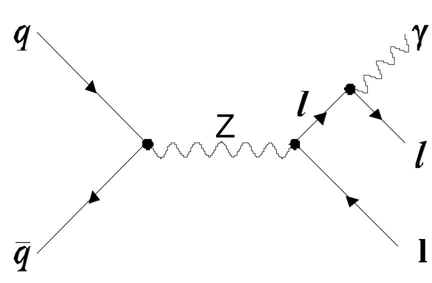

Figure 1: $Z\gamma$ Final State Radiation (FSR).

Variables	Cut
EtCorr	> 7
$\|\eta_{det}\|$	$1.2 < \|\eta_{det}\| < 2.0$
Had/Em	EtCorr < 100: < 0.05
	EtCorr ≥ 100: $< 0.05 + 0.026$ * log(EtCorr / 100)
IsoEtCorr	EtCorr < 20: < 0.1 * EtCorr
	EtCorr ≥ 20: $< 2.0 + 0.02$ * (EtCorr - 20.0)
PEM3x3Chi2	< 10
PES5x9U	> 0.65
PES5x9V	> 0.65
Cone 0.4 Track Iso	$< 2.0 + 0.005$ * EtCorr

Table 3: Plug Photon ID cuts.

Variables	Cut
EtCorr	> 7
$\|\eta_{det}\|$	$1.2 < \|\eta_{det}\| < 2.0$
Had/Em	≤ 0.125
IsoEtCorr	≤ 5
Track Pt	$<$ EtCorr /2
Cone 0.4 Track Iso	≤ 5

Table 4: Plug Photon Denominator cuts for ID efficiency measurement.

3 Photon identification efficiency

The identification efficiency of photons is measured using the CDF detector simulation with corrections (scale factors) determined from data. Photons can fail the selection criteria given in Table 1 and 3 due to conversions before reaching the calorimeter, calorimeter electromagnetic shower fluctuations, or general underlying event activity that causes isolation failures. The latter depends on the environment in which the photon is produced. For the study of $p\bar{p} \to l^+l^- + \gamma + X$ and of $p\bar{p} \to l\nu + \gamma + X$ events it is desirable to measure the photon detection using a "pure" sample of photons isolated in these events. We do this by identifying Z boson production with hard final state radiation off the decay leptons (see Figure 1), and requiring that the $l^+l^- + \gamma$ system has an invariant mass near the Z boson mass . In this section we describe this method for measuring photon detection efficiencies, and the determination of the required detector simulation scale factors.

We start by selecting events with two and only two leptons with $P_T > 20$ GeV/c. The leptons are required to pass the standard Joint Physics Group tight-lepton selection cuts. Muon pairs and CEM-CEM electron pairs are required to have opposite sign, and

CEM-PEM and PEM-PEM electron pairs are also included. The PEM electrons are required to pass the Phoenix tracking requirements. A subset of these events is selected by requiring one and only one photon object in either the central or plug regions. The specific criteria for the photon objects are given in Table 2 and 4 . These are chosen with very loose cuts on the variables used to identify photons, but require the shower position to be in a central or plug fiducial region.

Having identified events with two tight leptons and a ”loose” photon object, we next apply cleanup cuts designed to suppress backgrounds from events other than $p\bar{p} \rightarrow l^+l^- + \gamma$. We require:

- $\not{E}_T$ <10 GeV and $P_T(Z\gamma)$ <10 GeV/c to suppress WW/WZ/ZZ events
- $M_{ll} < 80$ GeV/c^2 to suppress Z + jet events

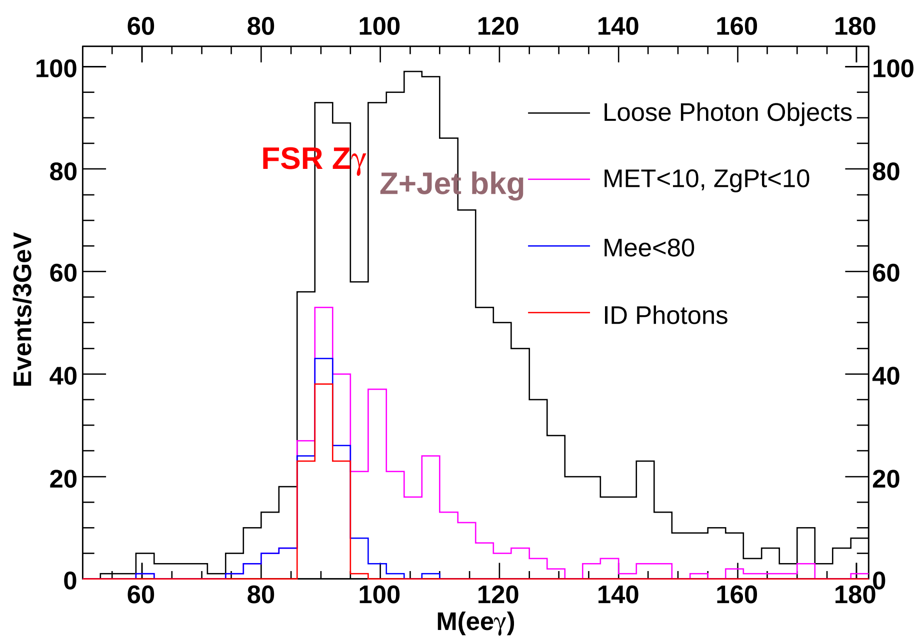

Figure 2: The invariant mass distribution of the $ee\gamma$ three-body system with 1fb^{-1} electron data.

The invariant mass distribution of the three-body system is plotted in Figure 2 for the electron pairs, showing the progressive effect of each of the cleanup cuts on the selection of the $Z \rightarrow l^+l^- + \gamma$ events. Finally, the photons used for the ID efficiency measurement are selected by requiring:

- $86 < M_{ll\gamma} < 96$ GeV/c^2

Figure 3 shows the distribution of the three-body mass of the $Z\gamma$ events used for the ID efficiency measurement.

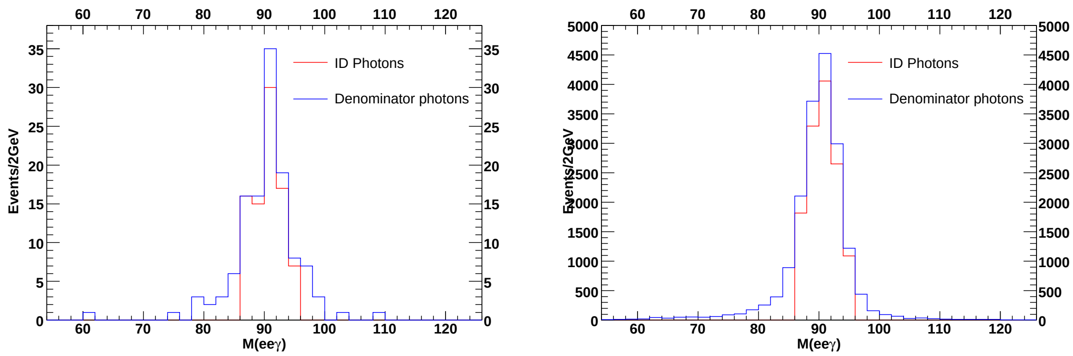

Figure 3: Three body mass distribution of the $Z\gamma$ events used in photon ID efficiency measurement. $Z\gamma$ 1fb electron data (left), rewk33 Zeeγ MC (right).

Table 5 - 9 summarize the number of eeγ and $\mu\mu\gamma$ events surviving all selection cuts, with the number of photons candidates in the central and plug detectors.

The selected photons are then subjected to the photon selection cuts shown in Table 1 and 3. The resulting photon ID efficiencies from the data are compared to those from the Monte Carlo simulation where identical selection cuts are used. The data are divided into subsets depending on the lepton pair selection to test the consistency of the measurements. To select a pure plug photon FSR sample, only events with CEM-PEM and PEM-PEM electron pairs are used. The efficiencies measured from the $Z\gamma$ MC sample (dataset rewk33) are listed in table 10 - 11.

	Events	Efficiency
ID Photon	84	0.91 + 0.03 - 0.03
2ndCesE	88	0.95 + 0.02 - 0.03
Chi2	84	1.00 + 0.00 - 0.01
IsoEt	84	1.00 + 0.00 - 0.01
N3D	84	1.00 + 0.00 - 0.01
TrackIso	85	0.99 + 0.01 - 0.02
TrackPt	85	0.99 + 0.01 - 0.02
Candidates	92	

Table 5: Electron Channel Central Photon total ID efficiency and N-1 ID efficiency with 1fb^{-1} electron data.

Figure 4 - 7 show the distributions of ID efficiency as a function of Photon Et and detector η. The efficiencies are slightly dependent on the photon Et for both central and plug photons. A dependence on the detector η is also observed in the plug region. Figure 8 - 9 show the distribution of scale factors as a function of photon Et.

	Events	Efficiency
ID Photon	74	0.84 + 0.04 - 0.04
2ndCesE	74	1.00 + 0.00 - 0.02
Chi2	74	1.00 + 0.00 - 0.02
IsoEt	77	0.96 + 0.02 - 0.03
N3D	75	0.99 + 0.01 - 0.02
TrackIso	76	0.97 + 0.01 - 0.02
TrackPt	76	0.97 + 0.01 - 0.02
Candidates	88	

Table 6: Muon Channel Central Photon total ID efficiency and N-1 ID efficiency with $1\mathrm{fb}^{-1}$ muon data.

	Events	Efficiency
ID Photon	112	0.82 + 0.03 - 0.03
2ndCesE	112	1.00 + 0.00 - 0.01
Chi2	113	0.99 + 0.01 - 0.01
IsoEt	120	0.93 + 0.02 - 0.03
N3D	114	0.98 + 0.01 - 0.02
TrackIso	116	0.97 + 0.01 - 0.02
TrackPt	114	0.98 + 0.01 - 0.02
Candidates	137	

Table 7: Muon Channel Central Photon total ID efficiency and N-1 ID efficiency with 1.6 fb^{-1} data.

	Events	Efficiency
ID Photon	196	0.86 + 0.02 - 0.02
2ndCesE	200	0.98 + 0.01 - 0.01
Chi2	197	0.99 + 0.00 - 0.01
IsoEt	204	0.96 + 0.01 - 0.02
N3D	198	0.99 + 0.01 - 0.01
TrackIso	201	0.98 + 0.01 - 0.01
TrackPt	199	0.98 + 0.01 - 0.01
Candidates	229	

Table 8: Muon+Electron Channel Central Photon total ID efficiency and N-1 ID efficiency

	Events	Efficiency
ID Photon	34	0.81 + 0.06 - 0.06
HadEm	34	1.00 + 0.00 - 0.03
IsoEt	34	1.00 + 0.00 - 0.03
PEMChi2	36	0.94 + 0.03 - 0.05
Pes5x9UV	35	0.97 + 0.02 - 0.04
TrackIso	34	1.00 + 0.00 - 0.03
Candidates	42	

Table 9: Electron Channel Plug Photon total ID efficiency and N-1 ID efficiency

	Events	Efficiency
ID Photon	16780	0.88 + 0.00 - 0.00
2ndCesE	16996	0.99 + 0.00 - 0.00
Chi2	16841	1.00 + 0.00 - 0.00
IsoEt	17811	0.94 + 0.00 - 0.00
N3D	16871	0.99 + 0.00 - 0.00
TrackIso	17005	0.99 + 0.00 - 0.00
TrackPt	16917	0.99 + 0.00 - 0.00
Candidates	18984	

Table 10: Electron Channel Central Photon total ID efficiency and N-1 ID efficiency (MC) .

	Events	Efficiency
ID Photon	5829	0.84 + 0.00 - 0.00
HadEm	5905	0.99 + 0.00 - 0.00
IsoEt	6137	0.95 + 0.00 - 0.00
PEMChi2	6124	0.95 + 0.00 - 0.00
Pes5x9UV	5958	0.98 + 0.00 - 0.00
TrackIso	5896	0.99 + 0.00 - 0.00
Candidates	6935	

Table 11: Electron Channel Plug Photon total ID efficiency and N-1 ID efficiency (MC).

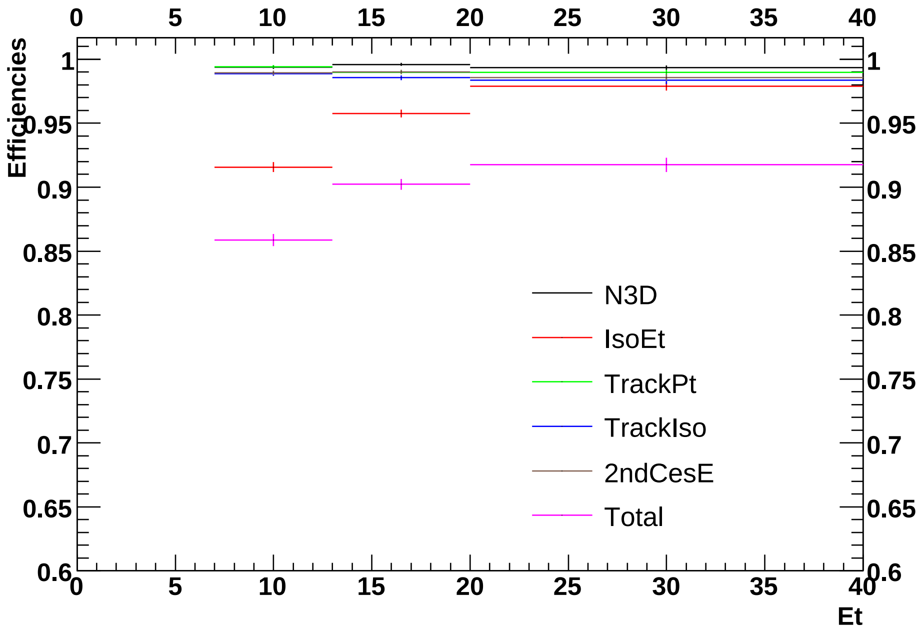

Figure 4: Central Photon N-1 ID efficiency as a function of photon Et measured from rewk33 $Z\gamma$ MC sample

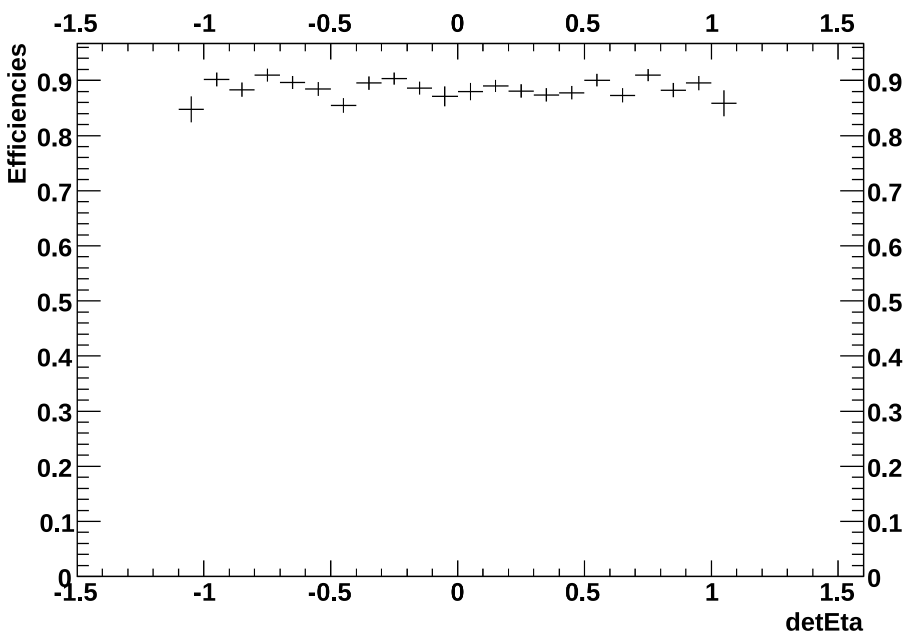

Figure 5: Central Photon ID efficiency as a function of η measured from rewk33 $Z\gamma$ MC sample

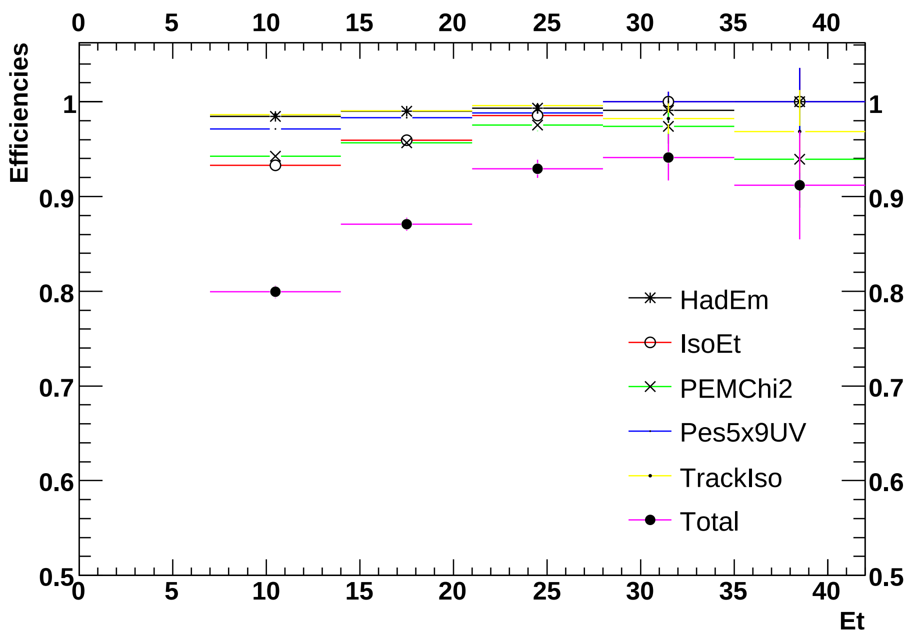

Figure 6: Plug Photon N-1 ID efficiency as a function of Photon Et measured from rewk33 $Z\gamma$ MC sample

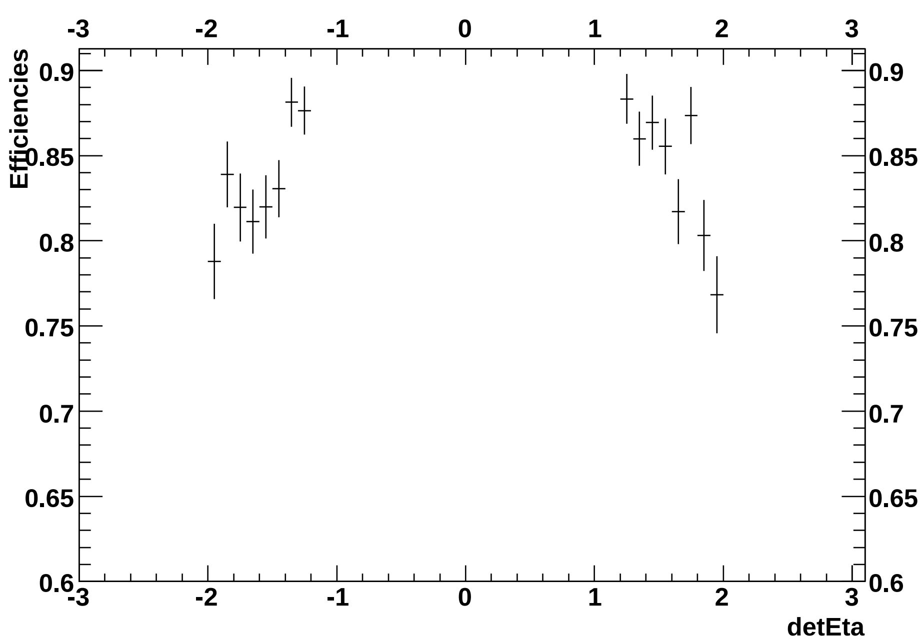

Figure 7: Photon ID efficiency as a function of η measured from rewk33 $Z\gamma$ MC sample

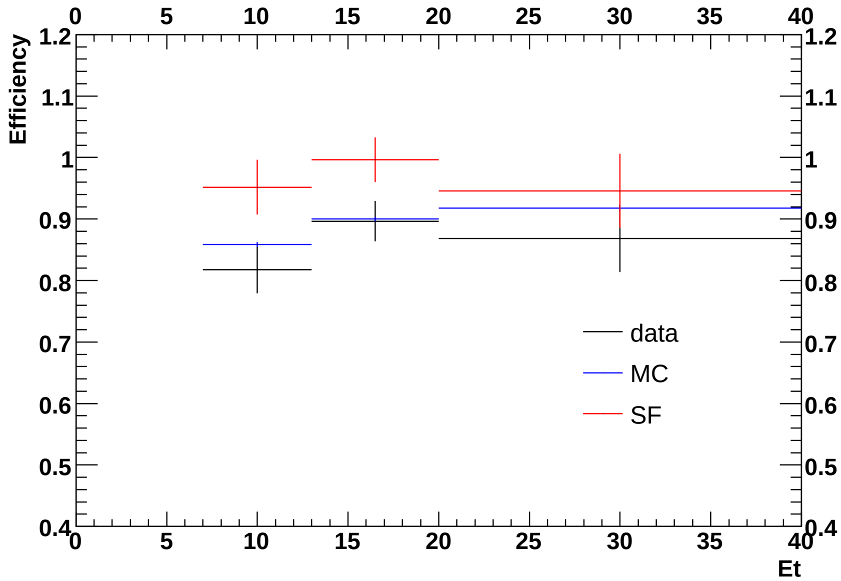

Figure 8: Central Photon ID efficiency and Scale Factor.

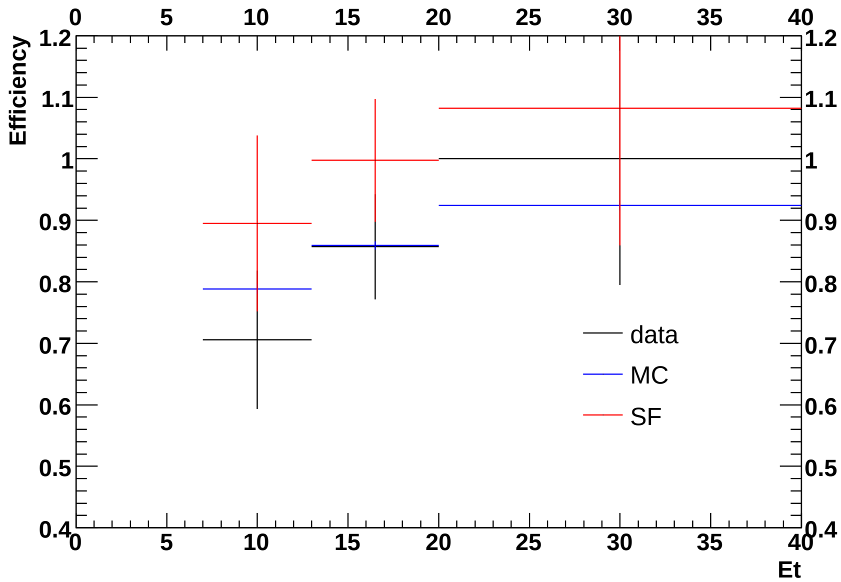

Figure 9: Plug Photon ID efficiency and Scale Factor.

This measurement is limited by statistics. To roughly estimate the systematic uncertainty of the measurement, the following cuts are varied, and the changes in the efficiencies and scale factors are evaluated:

- Background effects:
  - Three body mass : $86 < M_{ll\gamma} < 96$
  - Change to $76 < M_{ll\gamma} < 106$, let in Z + jet backgrounds
  - Track Pt : Track Pt < Et/2
  - Compare to no Track Pt cut: let in charge particle backgorunds
- Isolation effects:
  - Electron and γ separation: $\Delta R(e, \gamma) > 0.4$
  - Change to $\Delta R(e, \gamma) > 0.7$ and compare

As shown in Table 12, there are $\sim$ 2-3 % changes in the scale factors when the invariant mass window and $\Delta R(e, \gamma)$ requirement are varied (all within the statistics error). A 1% error is assigned as the systematic uncertainty.

	Data	MC	Scale Factor
Default	0.91 ± 0.03	0.88 ± 0.00	1.03 ± 3 % (stat)
$76 < M_{ee\gamma} < 106$	0.88 ± 0.03	0.88 ± 0.00	1.00 ± 3 % (stat)
no Track Pt cut	0.90 ± 0.03	0.88 ± 0.00	1.02 ± 3 % (stat)
$\Delta R(e, \gamma) > 0.7$	0.94 ± 0.03	0.90 ± 0.00	1.04 ± 3 % (stat)

Table 12: Estimate systematic uncertainty for photon ID scale factor.

For reference, the result [3] measured from electron samples are listed in Table 13. This is measured in a different kinematic range($Et > 15GeV$, $|\eta| < 2.8$), and a small difference in the efficiencies is observed. The scale factors measured from both methods are consistent.

Eff(%)	Data	MC	Scale Factor
Central	90.85 ± 0.73	92.61 ± 0.16	$0.98 \pm 0.75\%$ (stat) $\pm 1\%$ (syst)
Plug	80.08 ± 0.51	87.21 ± 0.11	$0.92 \pm 0.52\%$ (stat) $\pm 1\%$ (syst)

Table 13: Old method. Photon ID efficiencies and scale factors using Zee samples [3]. $Et_{\gamma} > 15$ GeV, $|\eta| < 2.8$.

4 Summary

A new method is developed to measure the photon ID efficiency directly from a pure FSR $Z\gamma$ photon sample. The result is summarizes in Table 14. The MC simulation agrees quite well with the data. This method is limited by statistics. With more statistics, it should become a precise method to measure the photon ID efficiency.

Eff	Data	MC	Scale Factor
Central	0.86 ± 0.02	0.88 ± 0.00	0.98 ± 2 % (stat) ± 1 % (syst)
Plug	0.81 ± 0.06	0.84 ± 0.00	0.96 ± 7 % (stat) ± 1 % (syst)

Table 14: Photon ID efficiencies and scale factors using FSR photon samples. $Et_{\gamma} > 7$ GeV, $|\eta| < 2.0$.

5 Questions and Answers

In this section, questions and answers from pre-blessing are documented.

Question 1: Did you check SF vs number of reconstructed-vertices?

Answer:

- Photon IsoEt is corrected for number of vertices:
  - IsoEt Correction = 0.3563 * (NVertx - 1)
- check Eff vs number of vertices: no strong dependence observed (see Figure 10)

Question 2: Your $\not\!\!E_T$ and $Z\gamma$ Pt requirements throw-away a lot of signal as well. Does that introduce a bias into the estimate of your photon efficiency?

Answer: check with MC.

- With cuts: $\epsilon = 0.88$
- Without cuts: $\epsilon = 0.87$

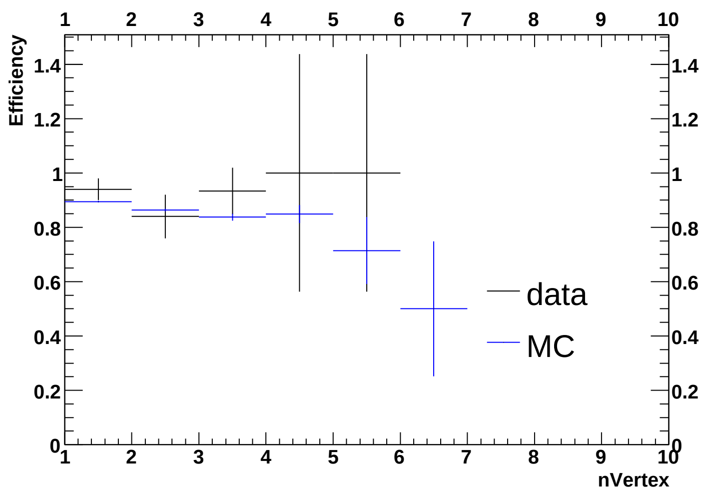

Figure 10: Photon ID efficiency vs number of vertices.

References

[1] J. Deng et al., *Measurement of $Z\gamma$ Production using 1 fb^{-1} of CDF RUN II Data*, CDF note 8506

[2] A. Nagano et al., *Measurement of the $W\gamma \rightarrow e\nu\gamma$ Cross Sections using 1 fb^{-1} of CDF Data*, CDF note 8756

[3] S-M Wynne, *Very High-Pt Photon Efficiency Scale Factors V.2*, CDF note 7947, V2.0.
1 1 1, 11