

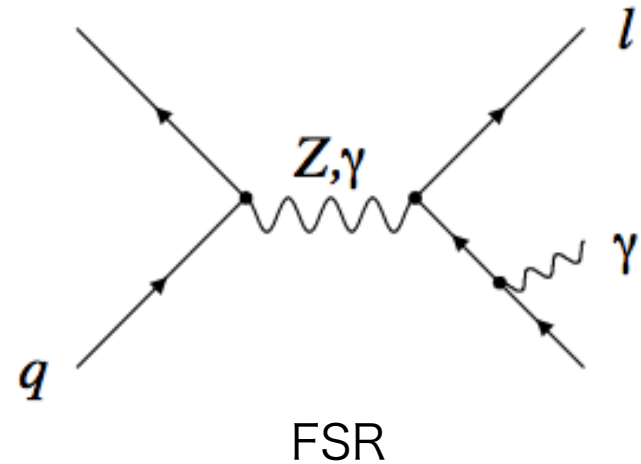
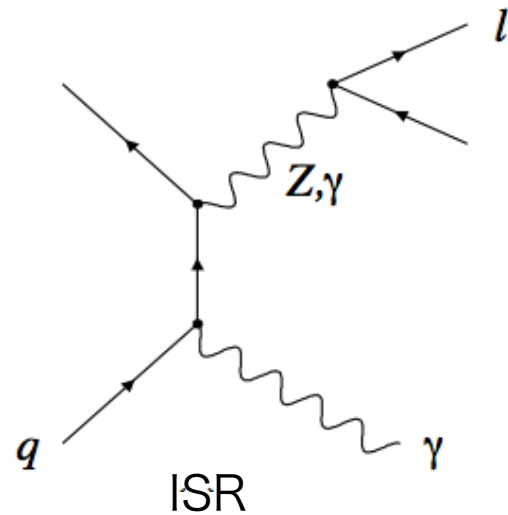
$Z\gamma$  at  $D\emptyset$

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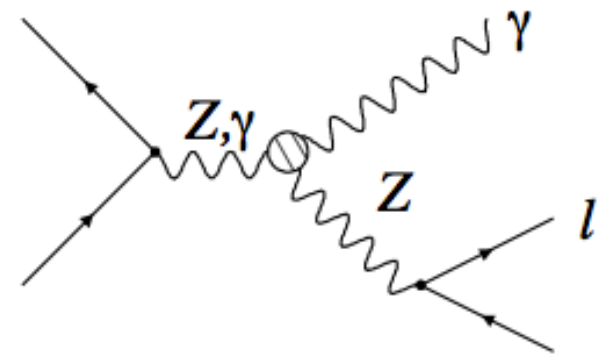
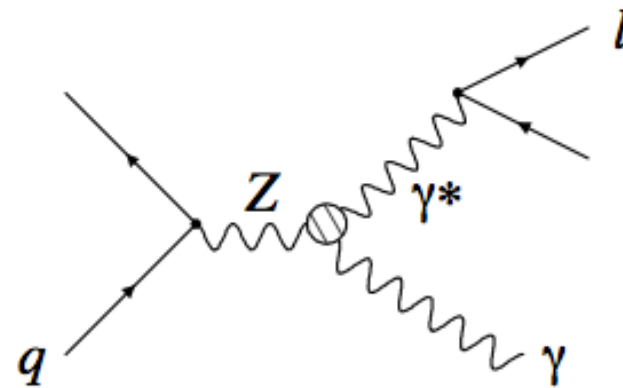
For the  $D\emptyset$  Collaboration

# Motivation

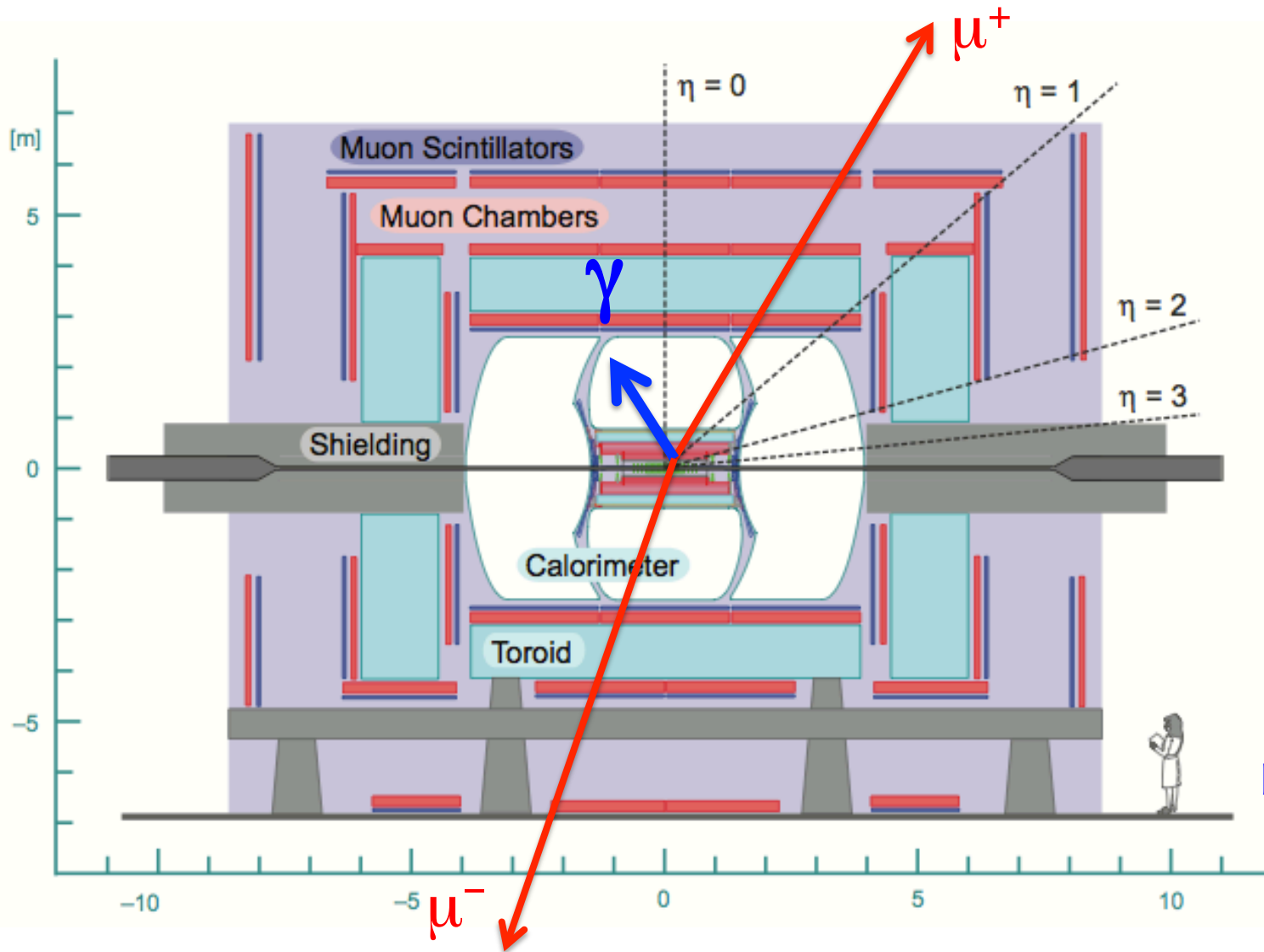
Standard Model:



Anomalous Couplings:



# The DØ Detector



## Muons

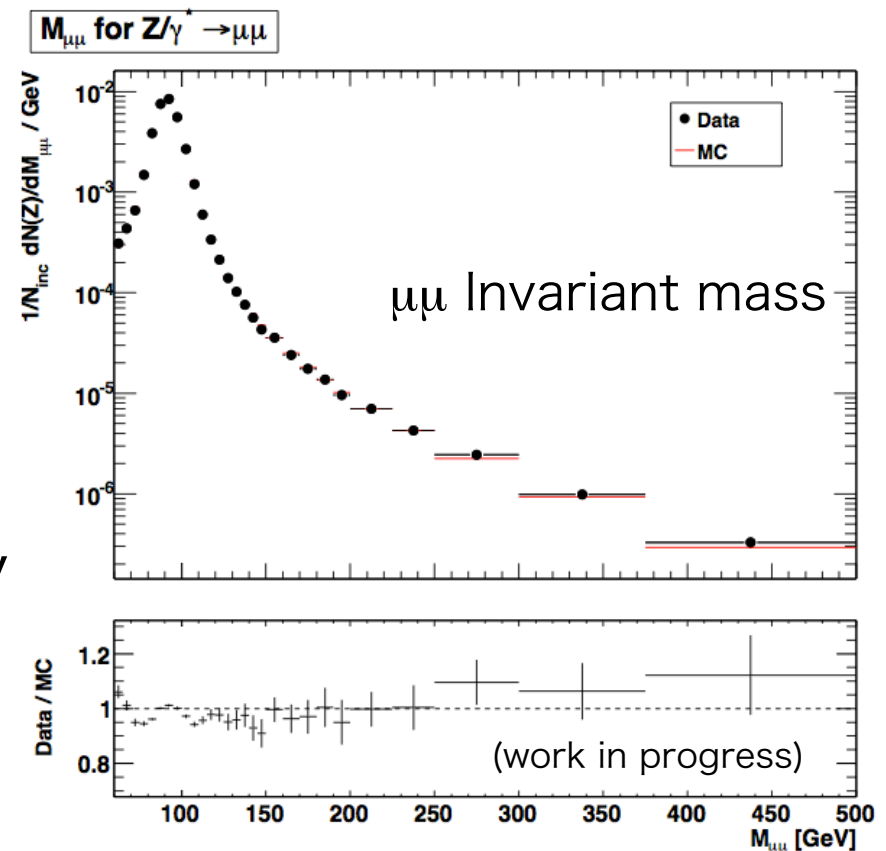
Well isolated  
 $p_T > 15 \text{ GeV}$   
 $|\eta| < 2$   
 $M_{\mu\mu} > 60 \text{ GeV}$   
 $\sim 250\text{K}$  events

## Photon

Well isolated  
 $p_T > 10 \text{ GeV}$   
 $|\eta_\gamma| < 1.1$   
 $\Delta R(\mu-\gamma) > 0.7$   
 No track match  
 1000 events

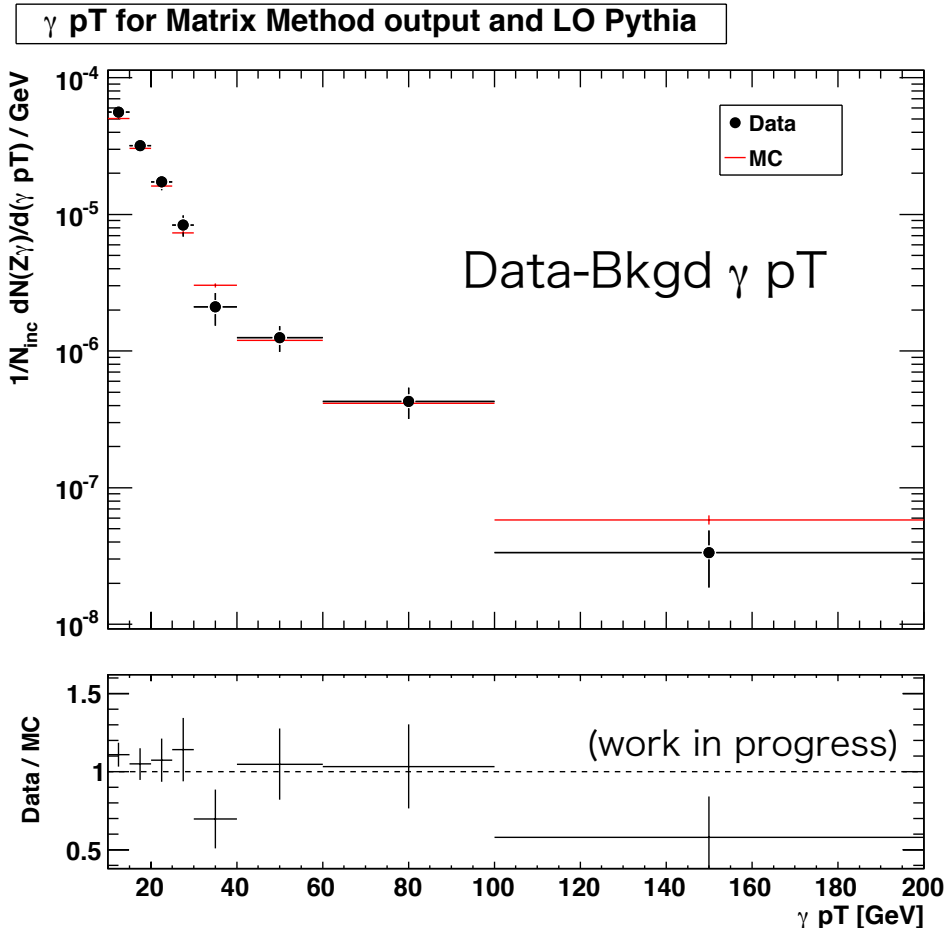
# Monte Carlo Comparison

- 40M  $Z/\gamma^* \rightarrow \mu\mu$  Pythia
- GEANT3
- Real events overlaid
  - Simulates pileup
- Pythia version 6.409
- Reweighted
  - Measured Z pT
  - Instantaneous luminosity profile
  - z of the vertex
  - Efficiencies
  - Smearing



# Background Subtraction

## Matrix Method



## Matrix Method

$$N_{data}(O_{NN} > 0.1) = N_{\gamma} + N_{jet}$$

$$N_{data}(O_{NN} > 0.75) = \epsilon_{\gamma} N_{\gamma} + \epsilon_{jet} N_{jet}$$

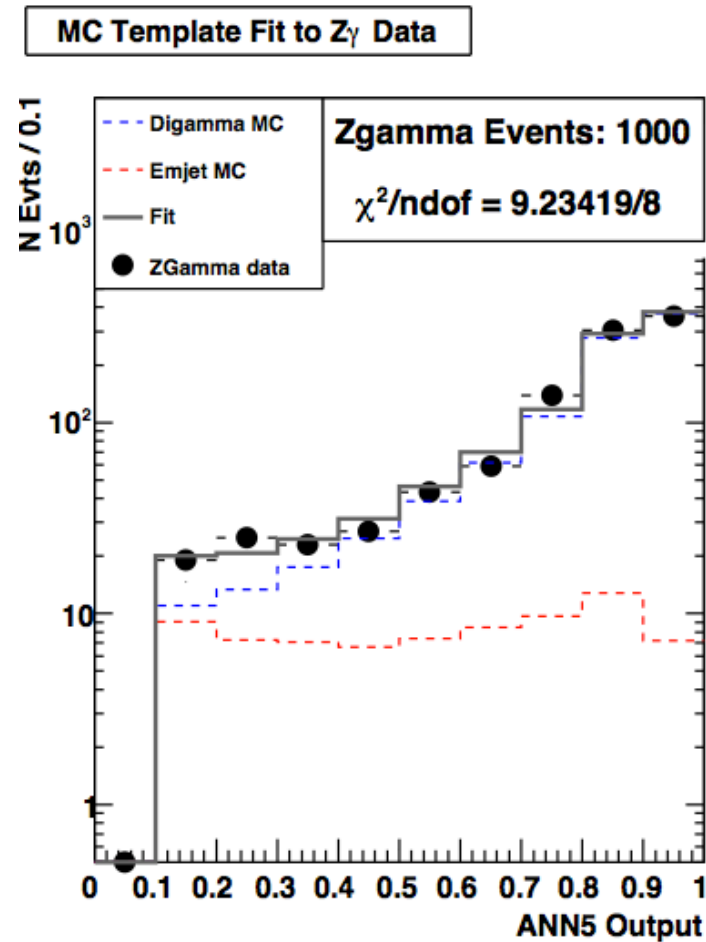
Estimates  $946.8 \pm 44.5$  signal events out of 1000  $Z_{\gamma}$  events measured.

# Background Subtraction

## Template Method

### Template Method

Estimates  $922.4 \pm 24.0$   
signal events out of 1000  
 $Z\gamma$  events measured.



# Cross Sections

- Generator level cuts:  $\gamma$   $p_T > 10$  GeV,  $M_{\mu\mu} > 60$  GeV,  $|\eta_\gamma| < 1$ ,  $\Delta R(\mu-\gamma) > 0.7$

$$\sigma(\mu\mu\gamma)_{data} = \frac{N_{\mu\mu\gamma}^{data} (A_{cc} \times \epsilon_{ID})_{\mu\mu\gamma}^{-1}}{N_{\mu\mu}^{data} (A_{cc} \times \epsilon_{ID})_{\mu\mu}^{-1}} \times \kappa \times \sigma(\mu\mu)_{FEWZ}^{NNLO}$$

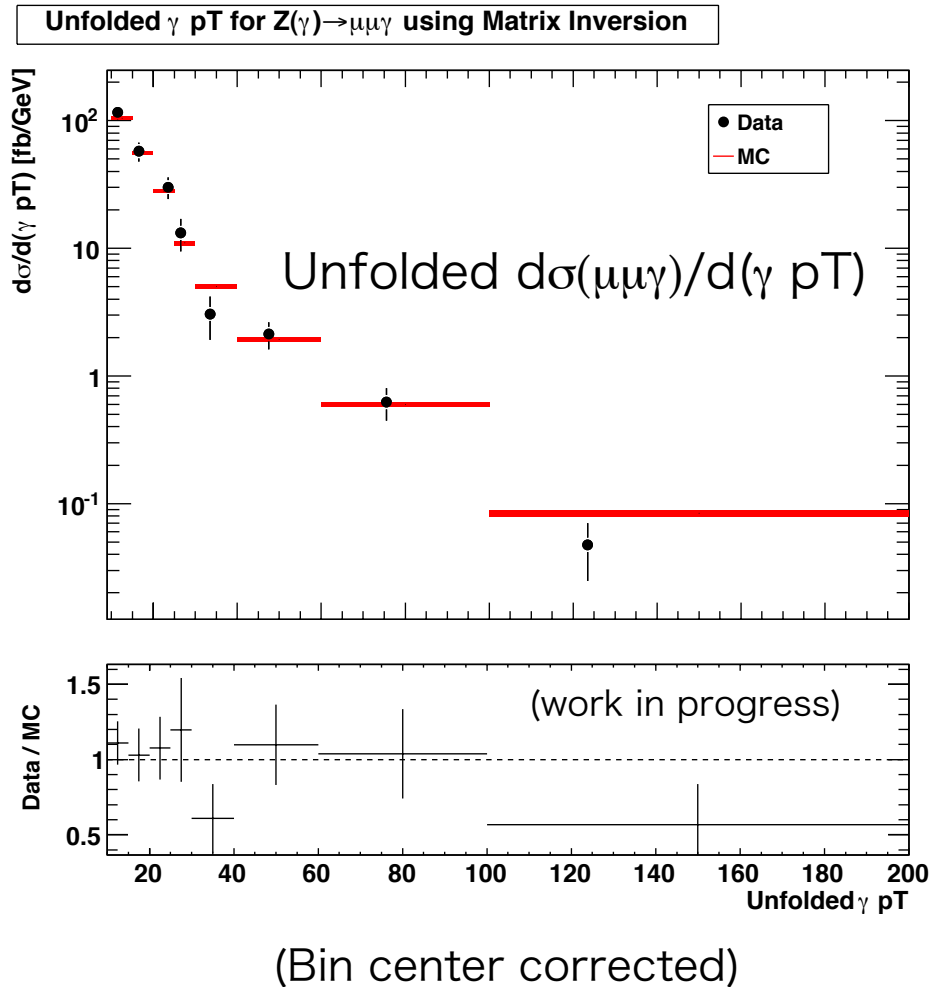
Template Method:  $\sigma(\mu\mu\gamma) = 1.15 \pm 0.1$  (stat+sys) pb.

Matrix Method:  $\sigma(\mu\mu\gamma) = 1.18 \pm 0.050$  (stat)  $\pm 0.1$  (sys) pb.

Theory Prediction at NNLO QCD (FEWZ) and LO QED (PYTHIA):

$$\sigma(\mu\mu\gamma)_{MC} = 1.12 \pm 0.04 \text{ pb}$$

# Unfolded Results



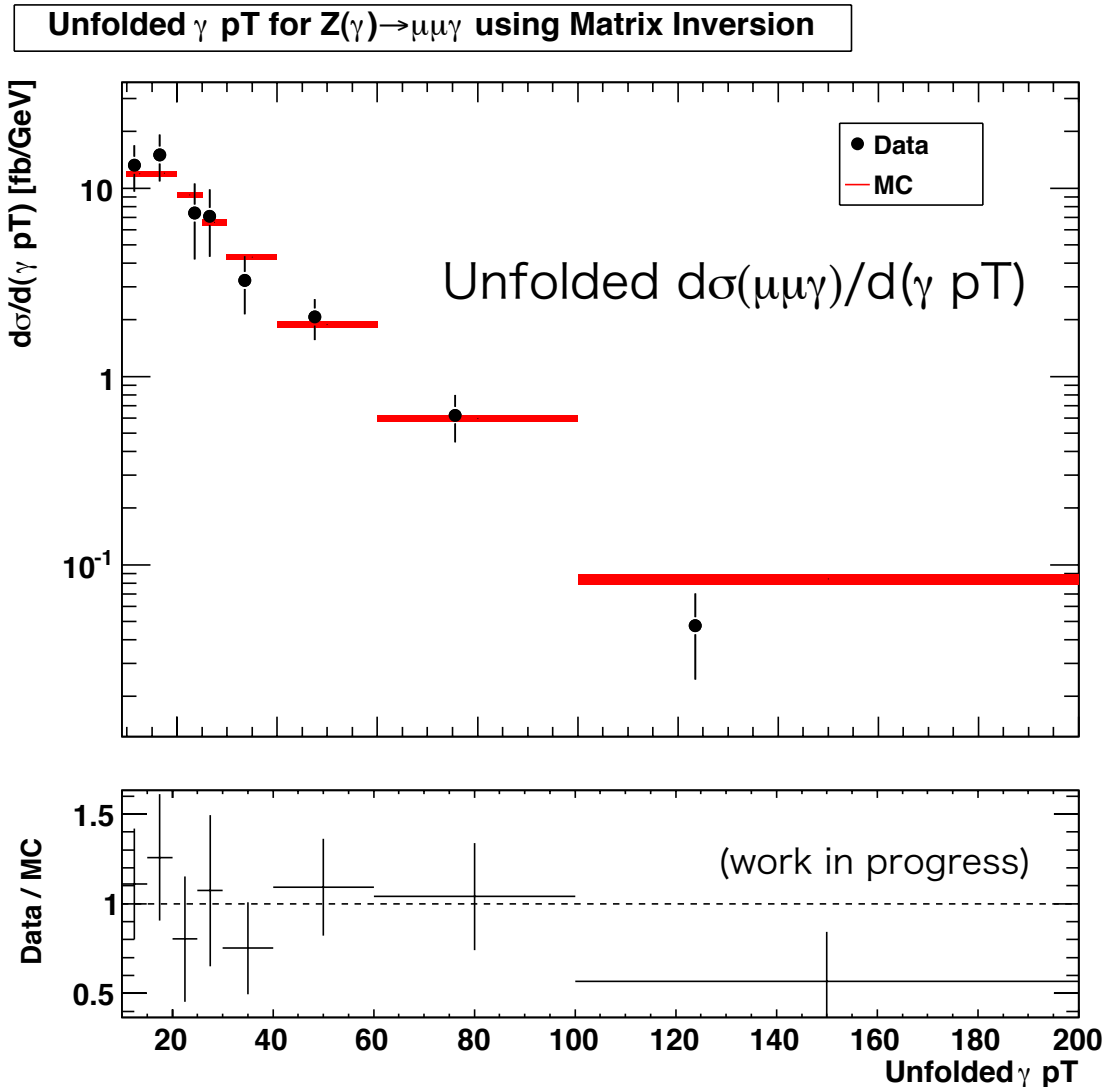
## Smearing Inversion Unfolding

$$(A_{cc} \times \epsilon_{ID})_{\alpha}^{-1} \times \sum_{i=1}^{N_{bins}} M_{i\alpha}^{-1} \times \kappa_i \times R_i = G_{\alpha}$$

Uses matrix method background estimation.  
Error bars from standard error propagation.



# Unfolded Results for $M_{\mu\mu\gamma} > 110$ GeV



# Summary and Outlook

- Using  $6.22 \text{ fb}^{-1}$  of data, more statistics than any other analysis of  $Z\gamma$  in this channel.
- Robust photon selection with small ( $\sim 7\%$ ) background contribution.
- Precise cross section measurement of  $Z \rightarrow \mu\mu\gamma$  production.
- Unfolded distribution can be compared to any  $Z \rightarrow l\bar{l}\gamma$  model.

# Backup Slides

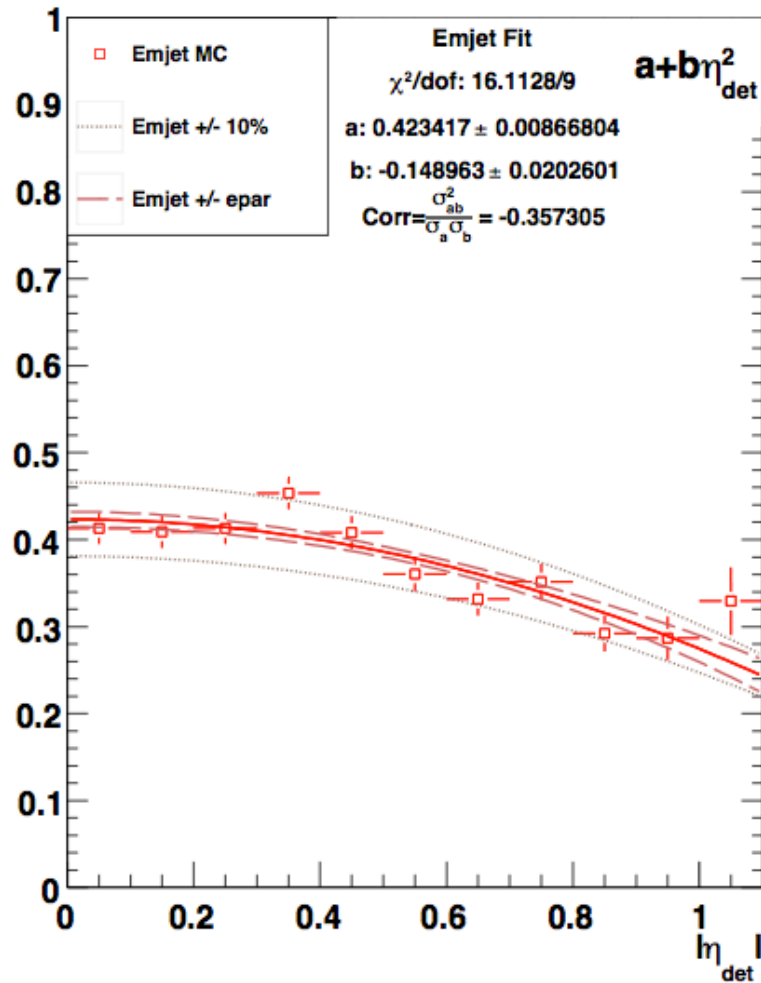
# Theory Cross Section Prediction

$$\sigma(\mu\mu\gamma)_{MC} = \frac{N_{\mu\mu\gamma}^{MC}}{N_{\mu\mu}^{MC}} \times \sigma(\mu\mu)_{FEWZ}^{NNLO}$$

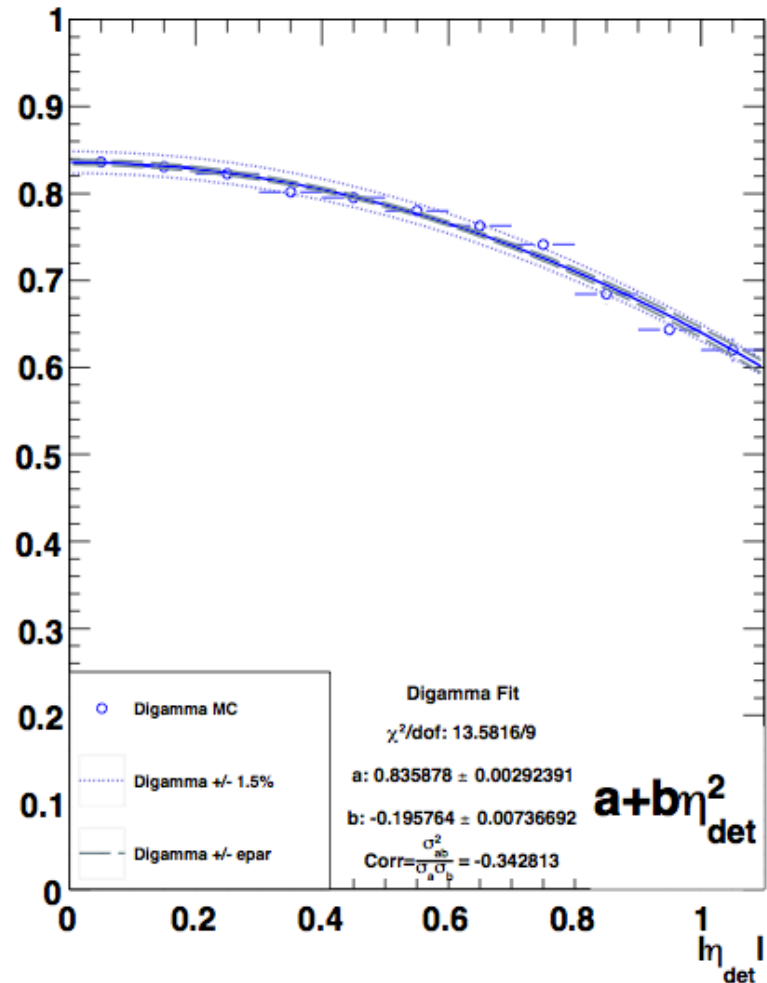
Uncertainties from: PDF and integration error of FEWZ

# Matrix Method Info

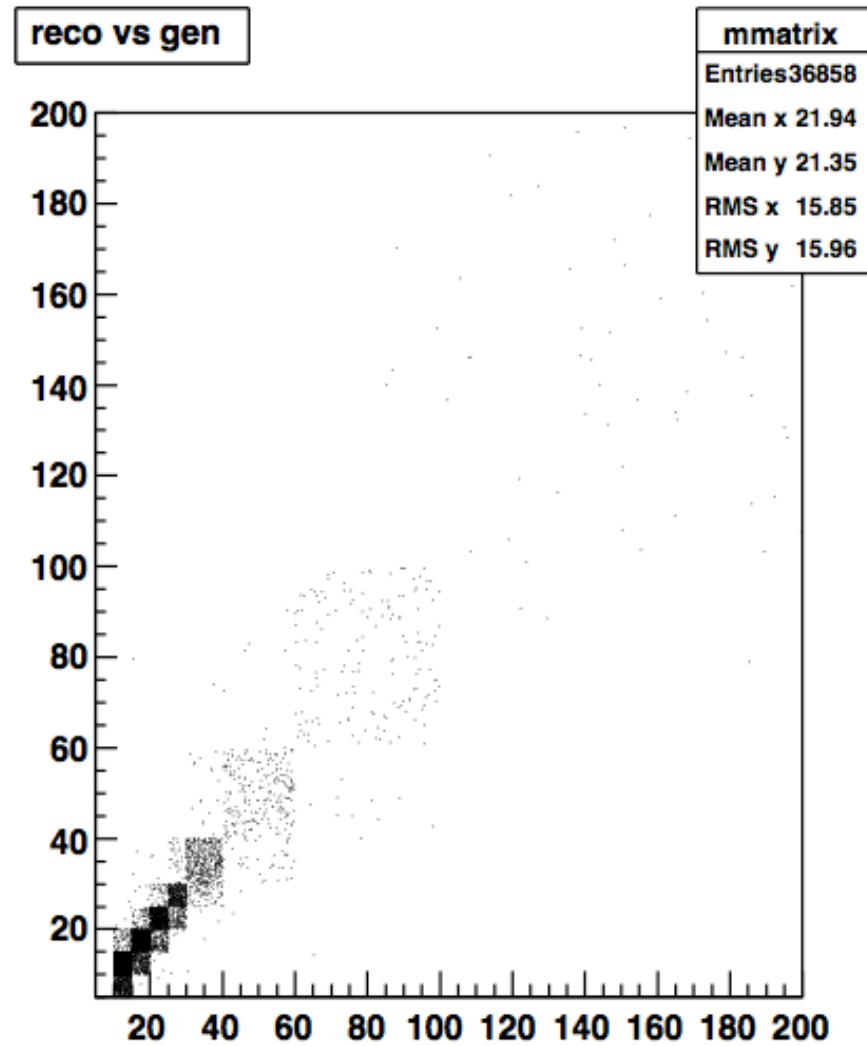
Effs for CCcore0 to pass ANN5>0.75 for  $10 < p_T < 15$



Effs for CCcore0 to pass ANN5>0.75 for  $10 < p_T < 15$



# Smearing Matrix



# CDF Results

- Sept. 2010
  - [http://www-cdf.fnal.gov/physics/ewk/2010/Z\\_gamma/index.html](http://www-cdf.fnal.gov/physics/ewk/2010/Z_gamma/index.html)
  - John Freeman, Max Goncharov, Thomas Phillips, Vadim Rusu.
  - 5 fb<sup>-1</sup>, both muon and electron channels
    - Placed limits on Z $\gamma$  anomalous couplings.
    - No cross section measurement.
    - Photon pT > 70 GeV to ignore Z+jet background.
- Sept. 2009
  - <http://www-cdf.fnal.gov/physics/ewk/2009/zgamma/ZgammaWebPage/index.html>
  - Jianrong Deng, Max Goncharov, Al Goshaw, Thomas Phillips.
  - 1.1 fb<sup>-1</sup> in electron channel, 2 fb<sup>-1</sup> in muon channel.
    - Placed limits on Z $\gamma$  anomalous couplings.
    - Cross section for  $\Delta R(\mu\text{-}\gamma) > 0.7$ ,  $M_{\mu\mu} > 40$  GeV,  $\gamma$  pT > 7 GeV
      - $4.6 \pm 0.2$  (stat)  $\pm 0.3$  (syst)  $\pm 0.3$  (lum) picobarns

# ALIAS Results

- March 2011
  - 35 pb<sup>-1</sup> at  $\sqrt{s} = 7$  TeV.
  - Muon and electron channels.
  - No anomalous coupling limits placed.
  - Cross section for  $\Delta R(\mu\text{-}\gamma) > 0.7$ , GeV,  $\gamma$  pT > 10 GeV
    - Electron channel:  $16.4 \pm 4.5$  (stat)  $\pm 4.3$  (sys)  $\pm 1.8$  (lumi).
    - Muon channel:  $10.6 \pm 2.6$  (stat)  $\pm 2.5$  (sys)  $\pm 1.2$  (lumi).