

# Update on $e^+e^- \rightarrow Z$ gamma benchmark analysis

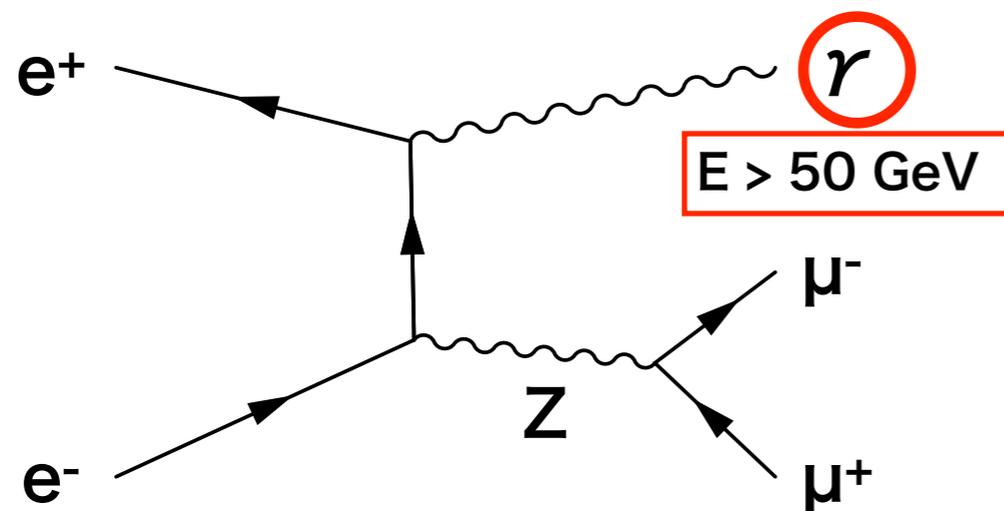
SOKENDAI

**Takahiro Mizuno**

# Status report on $e^+e^- \rightarrow \text{gamma Z}$ analysis

- I'm working on [photon energy calibration.](#)
- I newly checked
  - (1) Resolved Energy of Muon
  - (2) Resolved Energy of Photon  
when using measured muons' energy in addition to  
measured angle data
  - (3) Distribution of Photon Energy and Photon Angle in PFO
  - (4) ISR Energy distribution
  - //(5) Estimation of Energy Resolution

# Determine the energy of photon and muons based on measured direction angle



**Direction Angle**  
 $\theta$ : azimuthal angle  
 $\phi$ : polar angle

- 4-momentum conservation is considered.
- The mass of muon is neglected.

Case 1:

Using  $(\theta_{\mu^-}, \theta_{\mu^+}, \theta_{\gamma}, \phi_{\mu^-}, \phi_{\mu^+}, \phi_{\gamma})$   
 -> Determine  $(E_{\mu^-}, E_{\mu^+}, E_{\gamma})$

Case 2: Consider **Beamstrahlung**

Using  $(\theta_{\mu^-}, \theta_{\mu^+}, \theta_{\gamma}, \phi_{\mu^-}, \phi_{\mu^+}, \phi_{\gamma})$   
 -> Determine  $(E_{\mu^-}, E_{\mu^+}, E_{\gamma}, E_{\text{ISR}})$

Case 3: Consider **Beamstrahlung**  
 and **Crossing Angle**

Using  $(\theta_{\mu^-}, \theta_{\mu^+}, \theta_{\gamma}, \phi_{\mu^-}, \phi_{\mu^+}, \phi_{\gamma})$   
 -> Determine  $(E_{\mu^-}, E_{\mu^+}, E_{\gamma}, E_{\text{ISR}})$

Case 4: Case 3 using muons' energies

Using  $(\theta_{\mu^-}, \theta_{\mu^+}, \theta_{\gamma}, \phi_{\mu^-}, \phi_{\mu^+}, \phi_{\gamma}, E_{\mu^-}, E_{\mu^+})$   
 -> Determine  $(E_{\gamma}, E_{\text{ISR}})$

## • Case 1

$$\begin{cases} E_{\mu} + E_{\mu^+} + E_{\gamma} = 500 \\ E_{\mu} \sin\theta_{\mu} \cos\phi_{\mu} + E_{\mu^+} \sin\theta_{\mu^+} \cos\phi_{\mu^+} + E_{\gamma} \sin\theta_{\gamma} \cos\phi_{\gamma} = 0 \\ E_{\mu} \sin\theta_{\mu} \sin\phi_{\mu} + E_{\mu^+} \sin\theta_{\mu^+} \sin\phi_{\mu^+} + E_{\gamma} \sin\theta_{\gamma} \sin\phi_{\gamma} = 0 \\ E_{\mu} \cos\theta_{\mu} + E_{\mu^+} \cos\theta_{\mu^+} + E_{\gamma} \cos\theta_{\gamma} = 0 \end{cases}$$

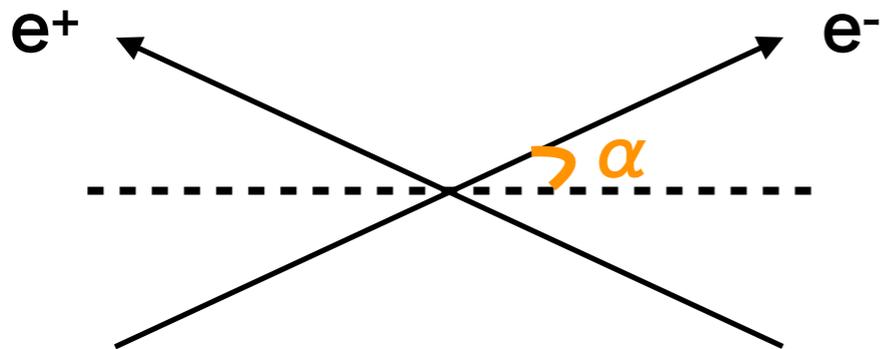
## • Case2: Consider **Beamstrahlung**

$$\begin{cases} E_{\mu} + E_{\mu^+} + E_{\gamma} + |P_{ISR}| = 500 \\ E_{\mu} \sin\theta_{\mu} \cos\phi_{\mu} + E_{\mu^+} \sin\theta_{\mu^+} \cos\phi_{\mu^+} + E_{\gamma} \sin\theta_{\gamma} \cos\phi_{\gamma} = 0 \\ E_{\mu} \sin\theta_{\mu} \sin\phi_{\mu} + E_{\mu^+} \sin\theta_{\mu^+} \sin\phi_{\mu^+} + E_{\gamma} \sin\theta_{\gamma} \sin\phi_{\gamma} = 0 \\ E_{\mu} \cos\theta_{\mu} + E_{\mu^+} \cos\theta_{\mu^+} + E_{\gamma} \cos\theta_{\gamma} + P_{ISR} = 0 \end{cases}$$

# • Case 3: Consider **Beamstrahlung** + **Crossing Angle**

$$\left\{ \begin{array}{l} E_{\mu} + E_{\mu^+} + E_{\gamma} + |P_{ISR}| = 500 \\ E_{\mu} \sin\theta_{\mu} \cos\phi_{\mu} + E_{\mu^+} \sin\theta_{\mu^+} \cos\phi_{\mu^+} + E_{\gamma} \sin\theta_{\gamma} \cos\phi_{\gamma} + |P_{ISR}| \sin\alpha = 500 \sin\alpha \\ E_{\mu} \sin\theta_{\mu} \sin\phi_{\mu} + E_{\mu^+} \sin\theta_{\mu^+} \sin\phi_{\mu^+} + E_{\gamma} \sin\theta_{\gamma} \sin\phi_{\gamma} = 0 \\ E_{\mu} \cos\theta_{\mu} + E_{\mu^+} \cos\theta_{\mu^+} + E_{\gamma} \cos\theta_{\gamma} \pm |P_{ISR}| \cos\alpha = 0 \end{array} \right.$$

Crossing Angle ( $\equiv 2\alpha$ )



$$\alpha = 7.0 \text{ mrad}$$

## • Case 4: Using measured muon energies

$$\left\{ \begin{array}{l} E_{\mu} + E_{\mu^+} + E_{\gamma} + |P_{ISR}| = 500 \\ E_{\mu} \sin\theta_{\mu} \cos\phi_{\mu} + E_{\mu^+} \sin\theta_{\mu^+} \cos\phi_{\mu^+} + E_{\gamma} \sin\theta_{\gamma} \cos\phi_{\gamma} + |P_{ISR}| \sin\alpha = 500 \sin\alpha \\ E_{\mu} \sin\theta_{\mu} \sin\phi_{\mu} + E_{\mu^+} \sin\theta_{\mu^+} \sin\phi_{\mu^+} + E_{\gamma} \sin\theta_{\gamma} \sin\phi_{\gamma} = 0 \\ E_{\mu} \cos\theta_{\mu} + E_{\mu^+} \cos\theta_{\mu^+} + E_{\gamma} \cos\theta_{\gamma} \pm |P_{ISR}| \cos\alpha = 0 \end{array} \right.$$

## • Case 4': Using measured muon energies

$$\left\{ \begin{array}{l} E_{\mu} + E_{\mu^+} + E_{\gamma} + |P_{ISR}| = 500 \\ E_{\mu} \sin\theta_{\mu} \cos\phi_{\mu} + E_{\mu^+} \sin\theta_{\mu^+} \cos\phi_{\mu^+} + E_{\gamma} \sin\theta_{\gamma} \cos\phi_{\gamma} + |P_{ISR}| \sin\alpha = 500 \sin\alpha \\ E_{\mu} \sin\theta_{\mu} \sin\phi_{\mu} + E_{\mu^+} \sin\theta_{\mu^+} \sin\phi_{\mu^+} + E_{\gamma} \sin\theta_{\gamma} \sin\phi_{\gamma} = 0 \\ E_{\mu} \cos\theta_{\mu} + E_{\mu^+} \cos\theta_{\mu^+} + E_{\gamma} \cos\theta_{\gamma} \pm |P_{ISR}| \cos\alpha = 0 \end{array} \right.$$

This is of no use when  $\sin\phi_{\gamma}=0$  ??

# Status report on $e^+e^- \rightarrow \text{gamma Z}$ analysis

- I'm working on photon energy calibration.

- I newly checked

## **(1) Resolved Energy of Muon**

(2) Resolved Energy of Photon

when using measured muons' energy in addition to measured angle data

(3) Distribution of Photon Energy and Photon Angle in PFO

(4) ISR Energy distribution

//(5) Estimation of Energy Resolution

Case 1:

Using  $(\theta_{\mu^-}, \theta_{\mu^+}, \theta_{\gamma}, \phi_{\mu^-}, \phi_{\mu^+}, \phi_{\gamma})$

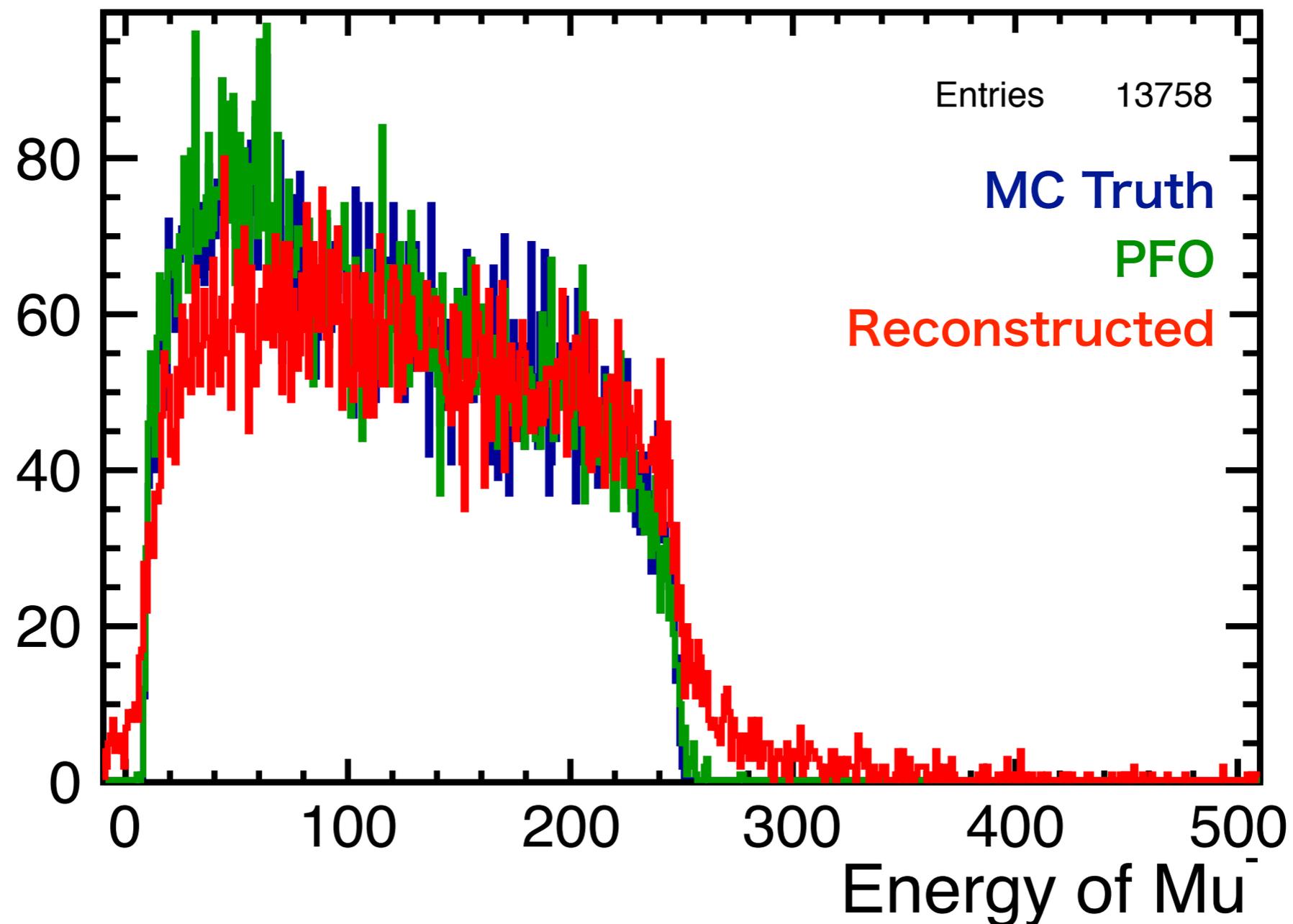
-> Determine  $(E_{\mu^-}, E_{\mu^+}, E_{\gamma})$

Samples:

$|M(\mu^+\mu^-) - 91.2| < 10$  GeV

Large ILD model

Energy of  $\text{Mu}^-$



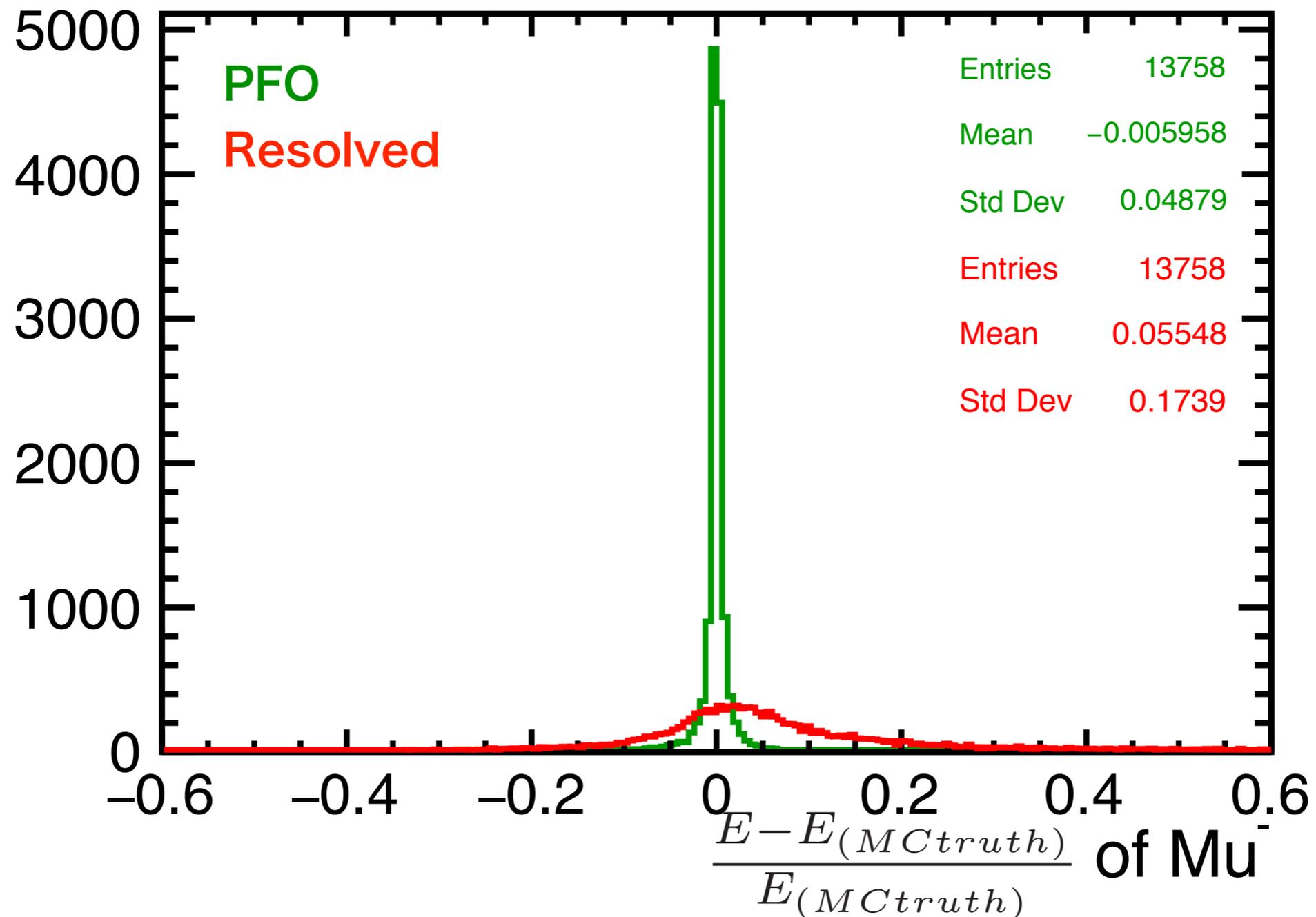
Case 1:

Using  $(\theta_{\mu^-}, \theta_{\mu^+}, \theta_{\gamma}, \phi_{\mu^-}, \phi_{\mu^+}, \phi_{\gamma})$

-> Determine  $(E_{\mu^-}, E_{\mu^+}, E_{\gamma})$

Samples:  
 $|M(\mu^+\mu^-) - 91.2| < 10 \text{ GeV}$   
 Large ILD model

Energy Resolution of  $\text{Mu}^-$



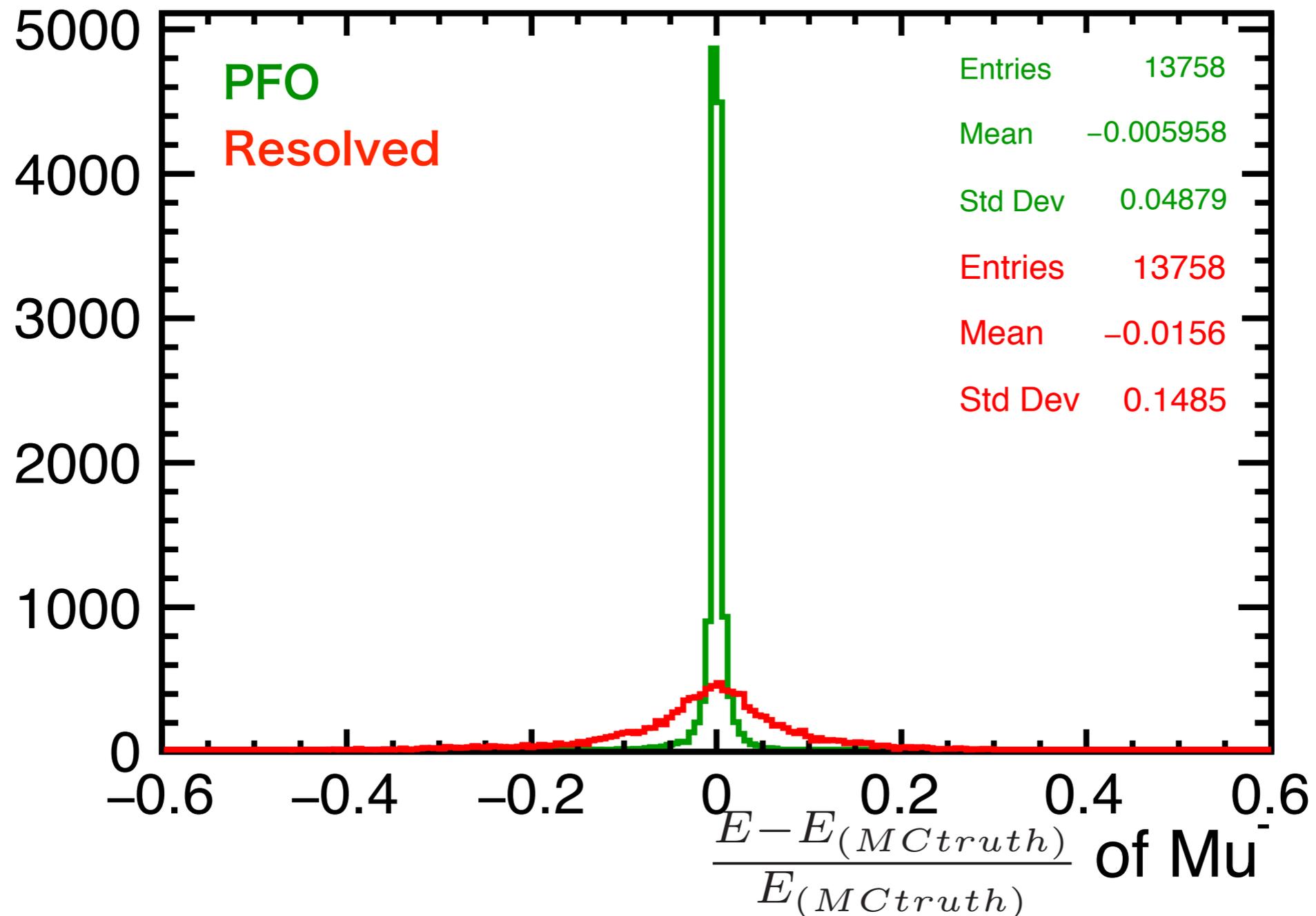
Case 2: Consider **Beamstrahlung**

Using  $(\theta_{\mu^-}, \theta_{\mu^+}, \theta_{\gamma}, \phi_{\mu^-}, \phi_{\mu^+}, \phi_{\gamma})$

-> Determine  $(E_{\mu^-}, E_{\mu^+}, E_{\gamma}, E_{ISR})$

Samples:  
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Energy Resolution of  $\text{Mu}^-$



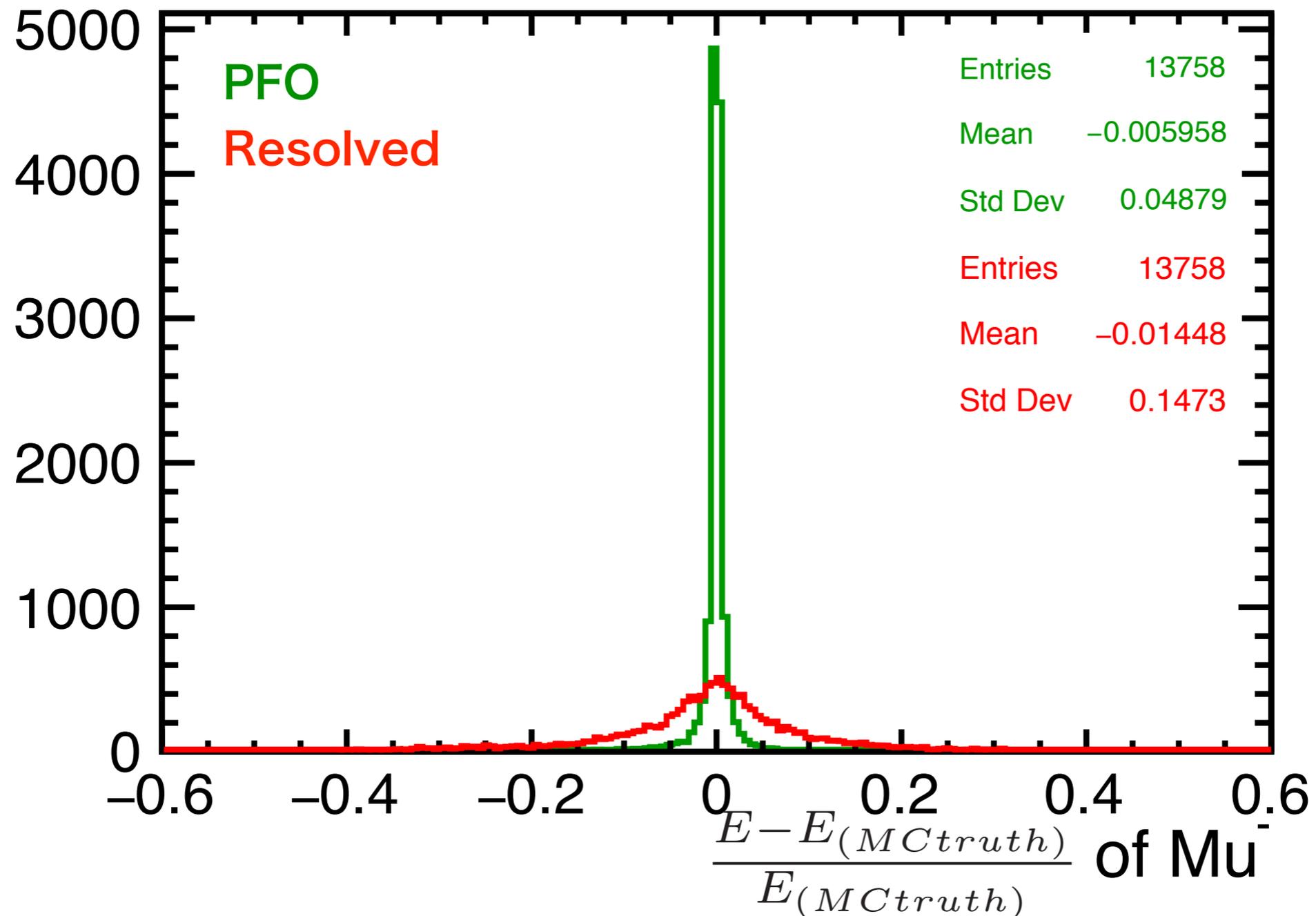
Case 3: Add the effect of **Crossing Angle**

Using  $(\theta_{\mu^-}, \theta_{\mu^+}, \theta_{\gamma}, \phi_{\mu^-}, \phi_{\mu^+}, \phi_{\gamma})$

-> Determine  $(E_{\mu^-}, E_{\mu^+}, E_{\gamma}, E_{ISR})$

Samples:  
 $|M(\mu^+\mu^-) - 91.2| < 10$  GeV  
 Large ILD model

Energy Resolution of  $\text{Mu}^-$



Case 3: Add the effect of **Crossing Angle**

Using  $(\theta_{\mu^-}, \theta_{\mu^+}, \theta_{\gamma}, \phi_{\mu^-}, \phi_{\mu^+}, \phi_{\gamma})$

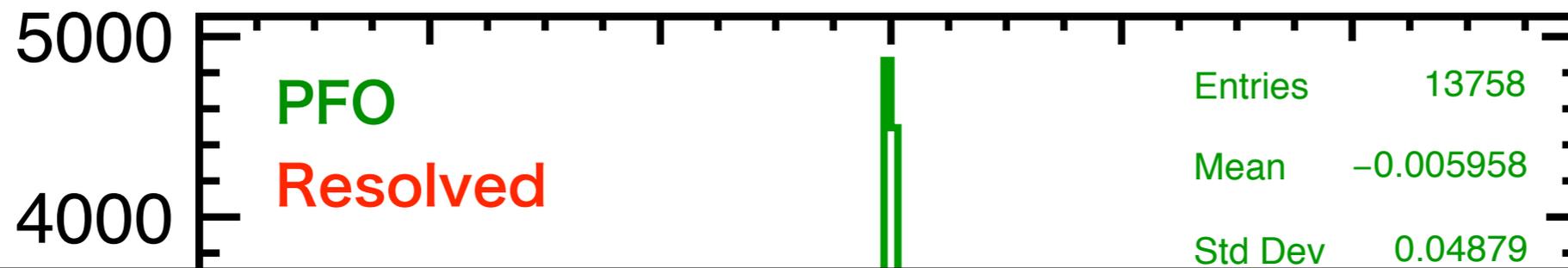
-> Determine  $(E_{\mu^-}, E_{\mu^+}, E_{\gamma}, E_{ISR})$

Samples:

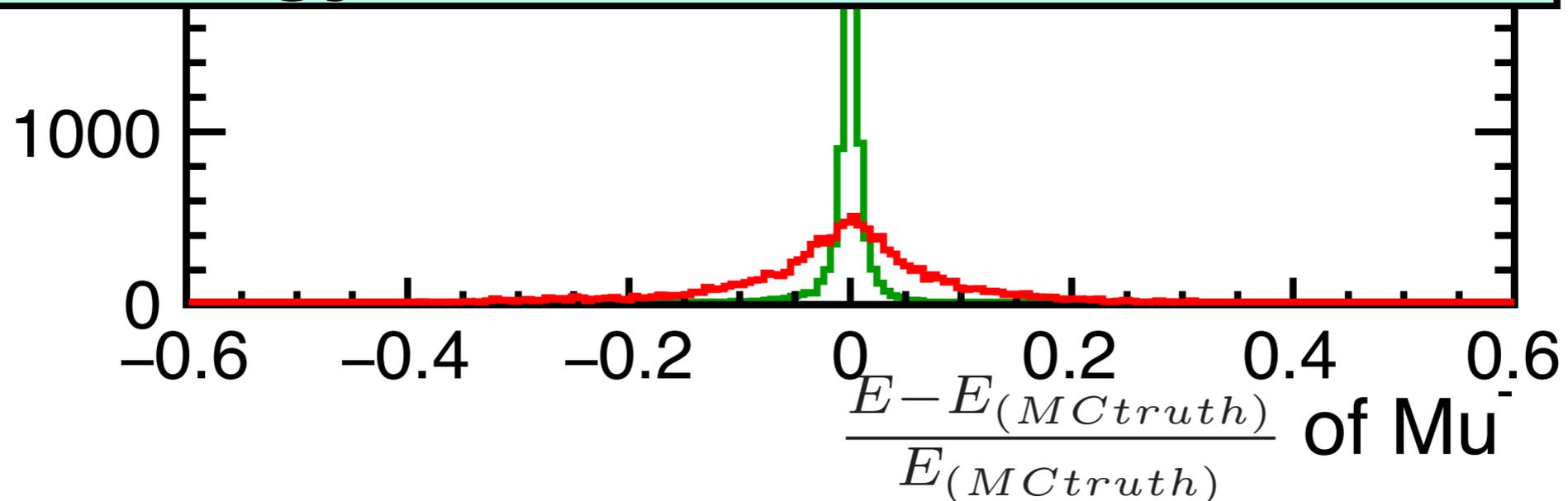
$|M(\mu^+\mu^-) - 91.2| < 10$  GeV

Large ILD model

Energy Resolution of  $\text{Mu}^-$



- Energy Resolution of Muon in **PFO** is **always** better than **resolved** energy resolution.

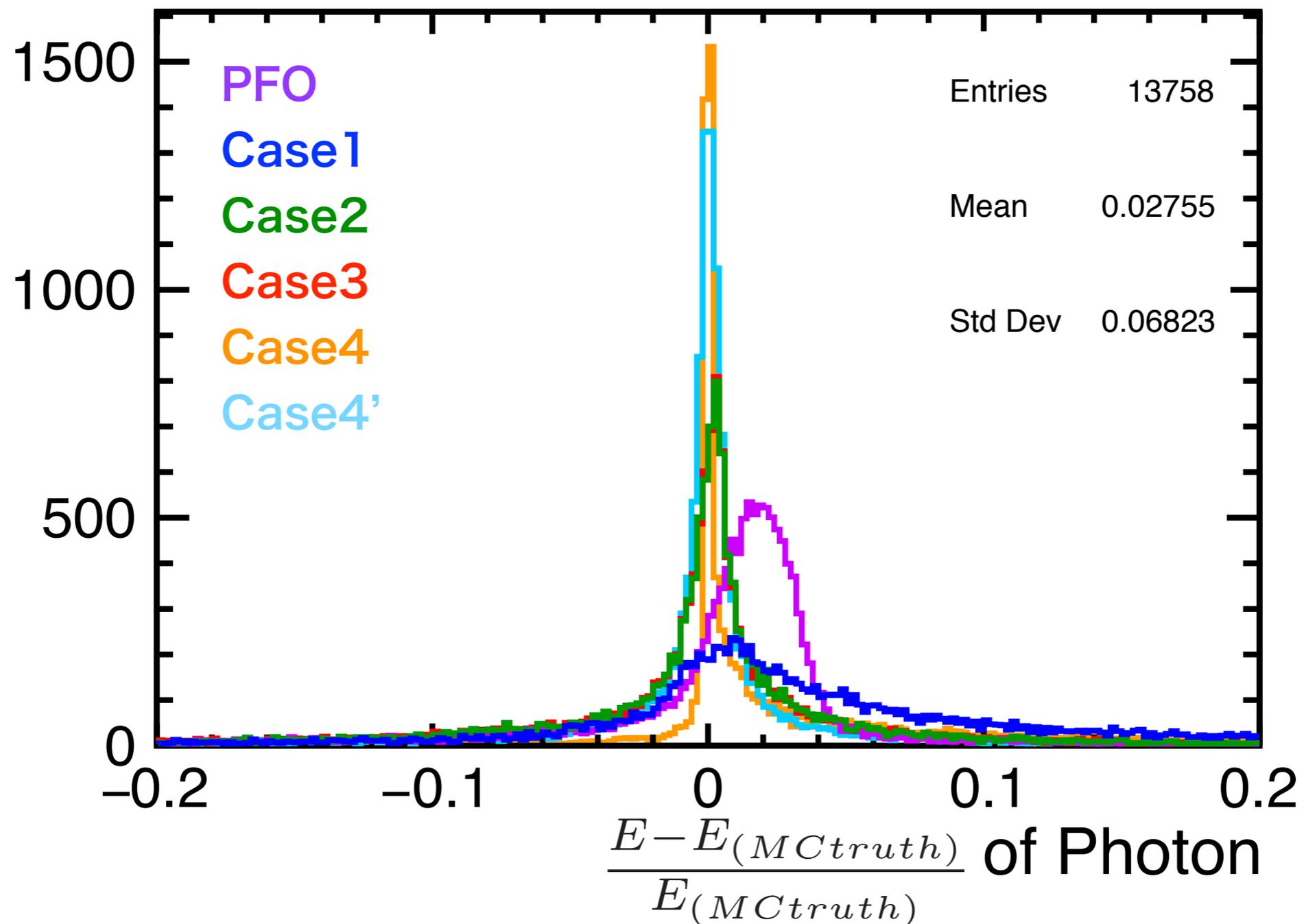


# Status report on $e^+e^- \rightarrow \text{gamma Z}$ analysis

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  - //(5) Estimation of Energy Resolution

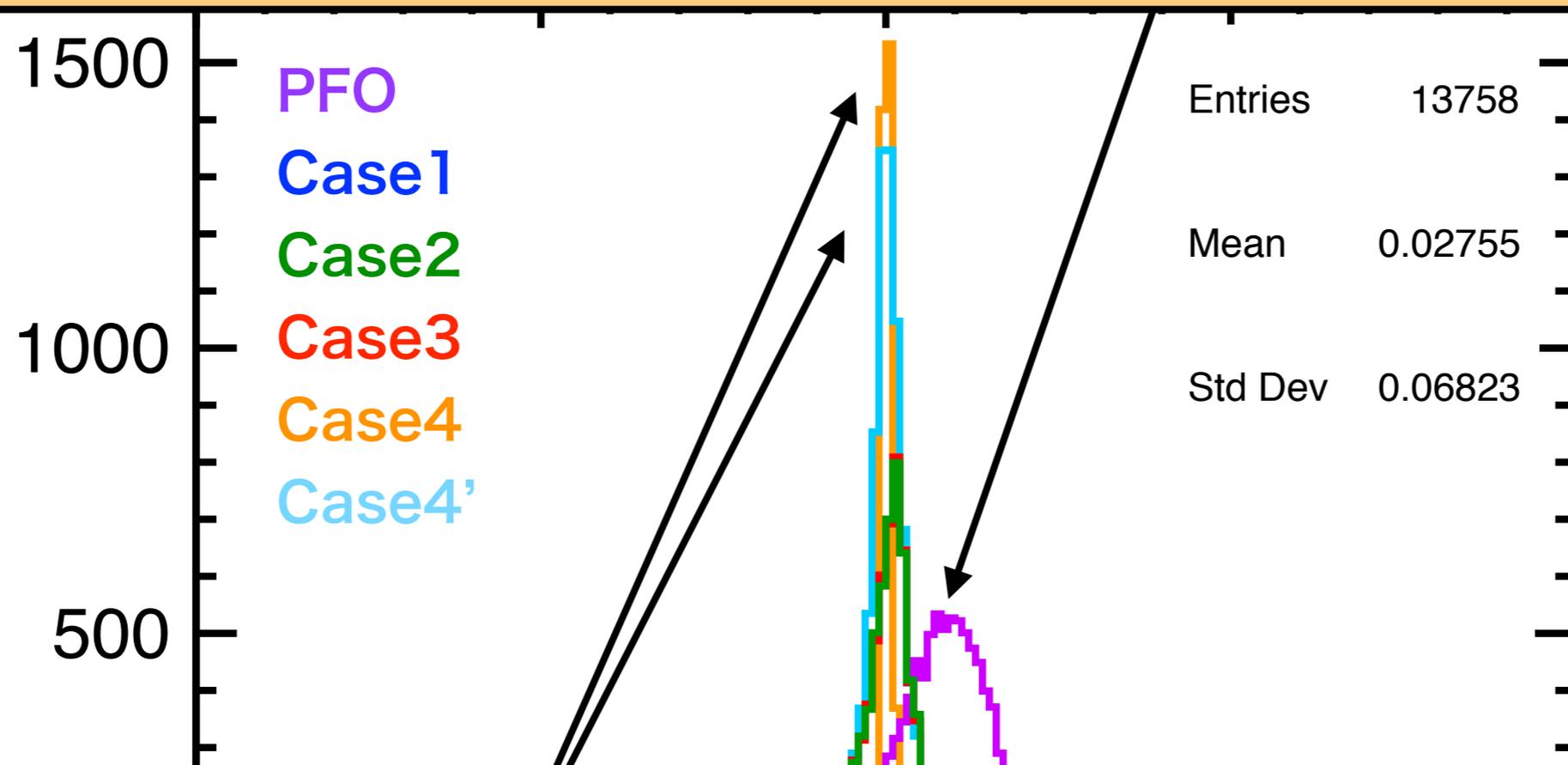
# Resolved Energy of Photon

Energy Resolution of Photon



# Resolved Energy of Photon

- The peak of PFO is shifted to the positive region. I will discuss this later.



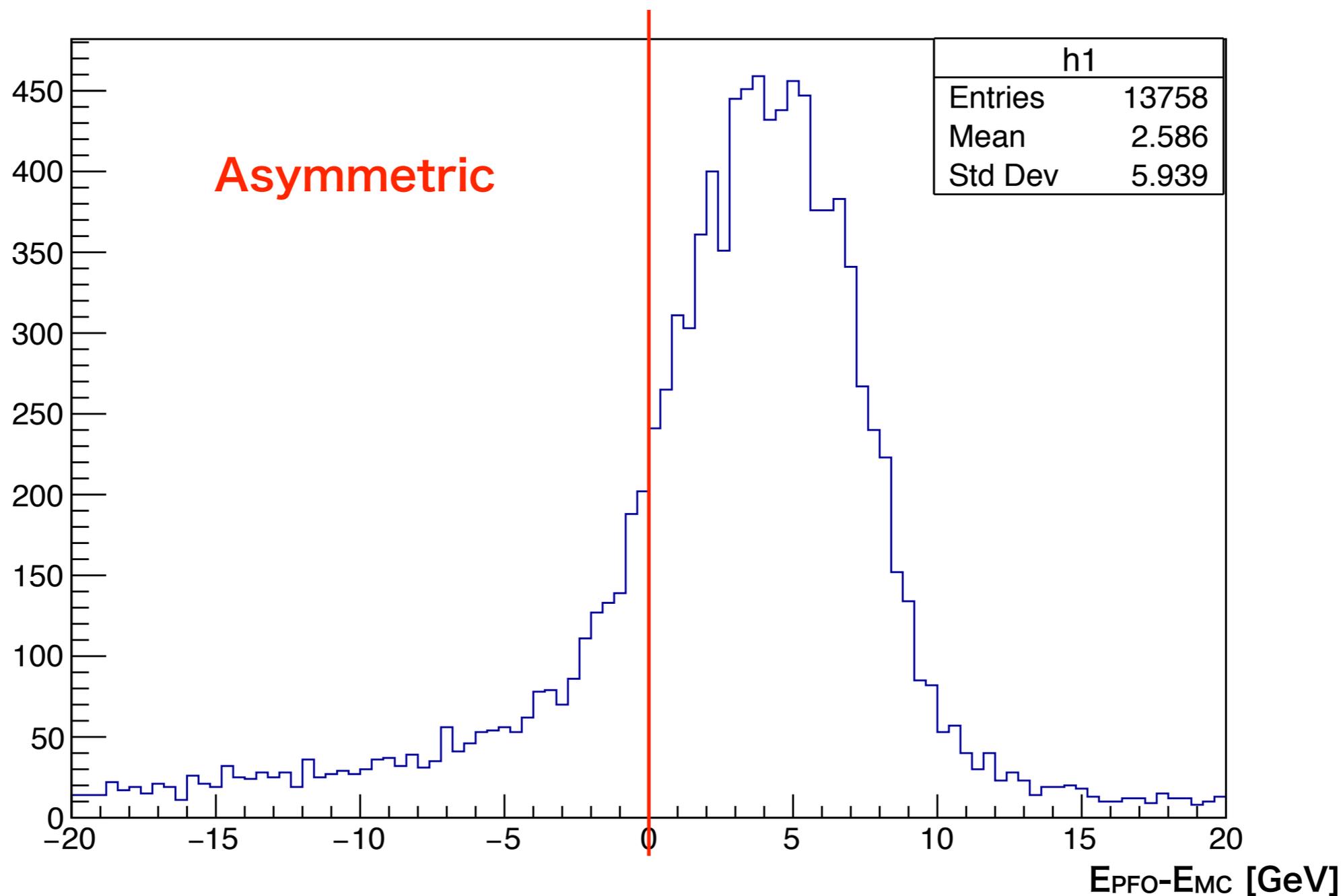
- Case 4 and 4' are the best.  
(It depends on the angle which is the better.)  
In the end, all 4 equations are to be considered.

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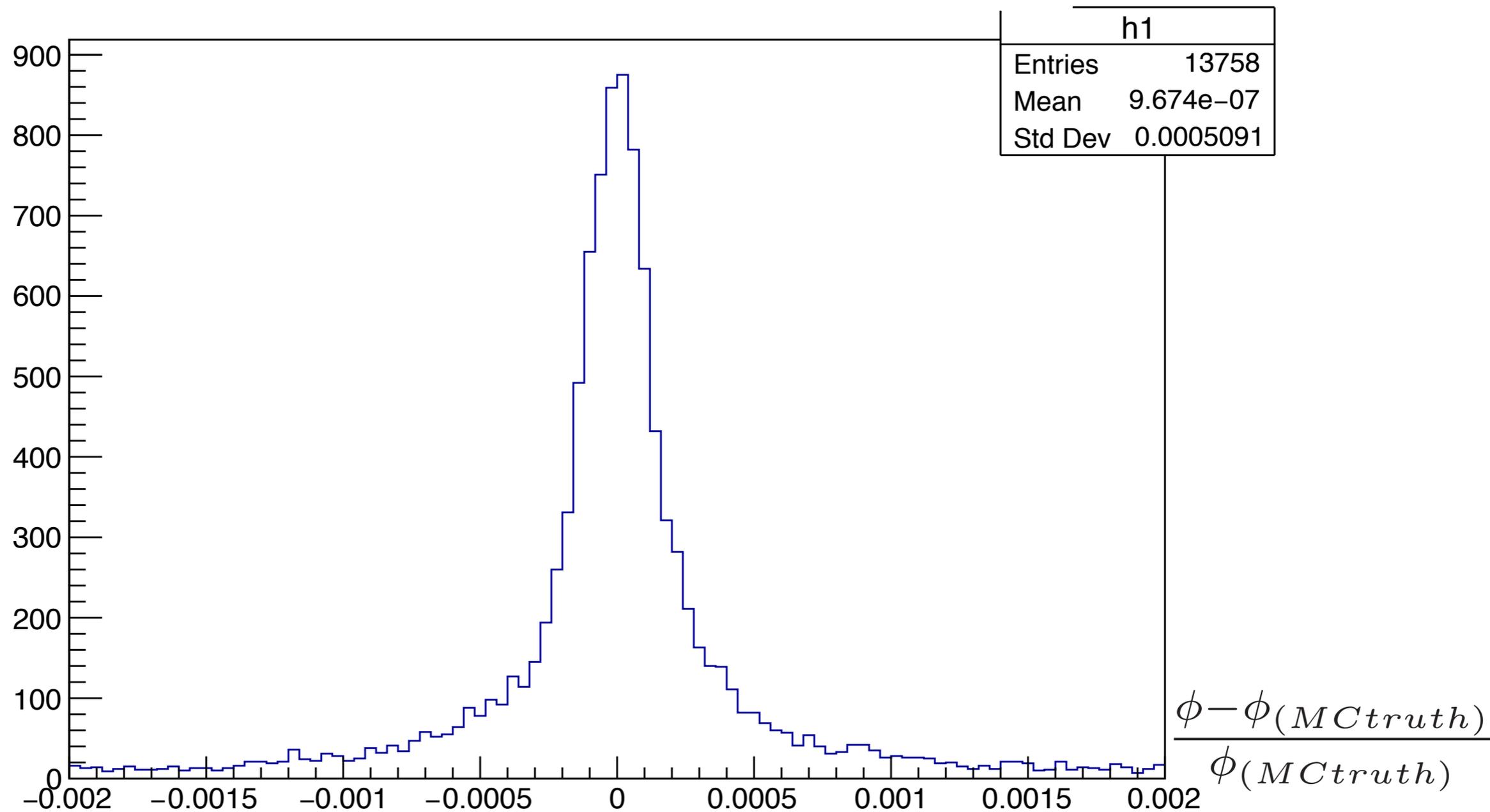
# Distribution of PFO Photon Energy

Samples:  
 $|M(\mu^+\mu^-)-91.2| < 10$  GeV  
Large ILD model



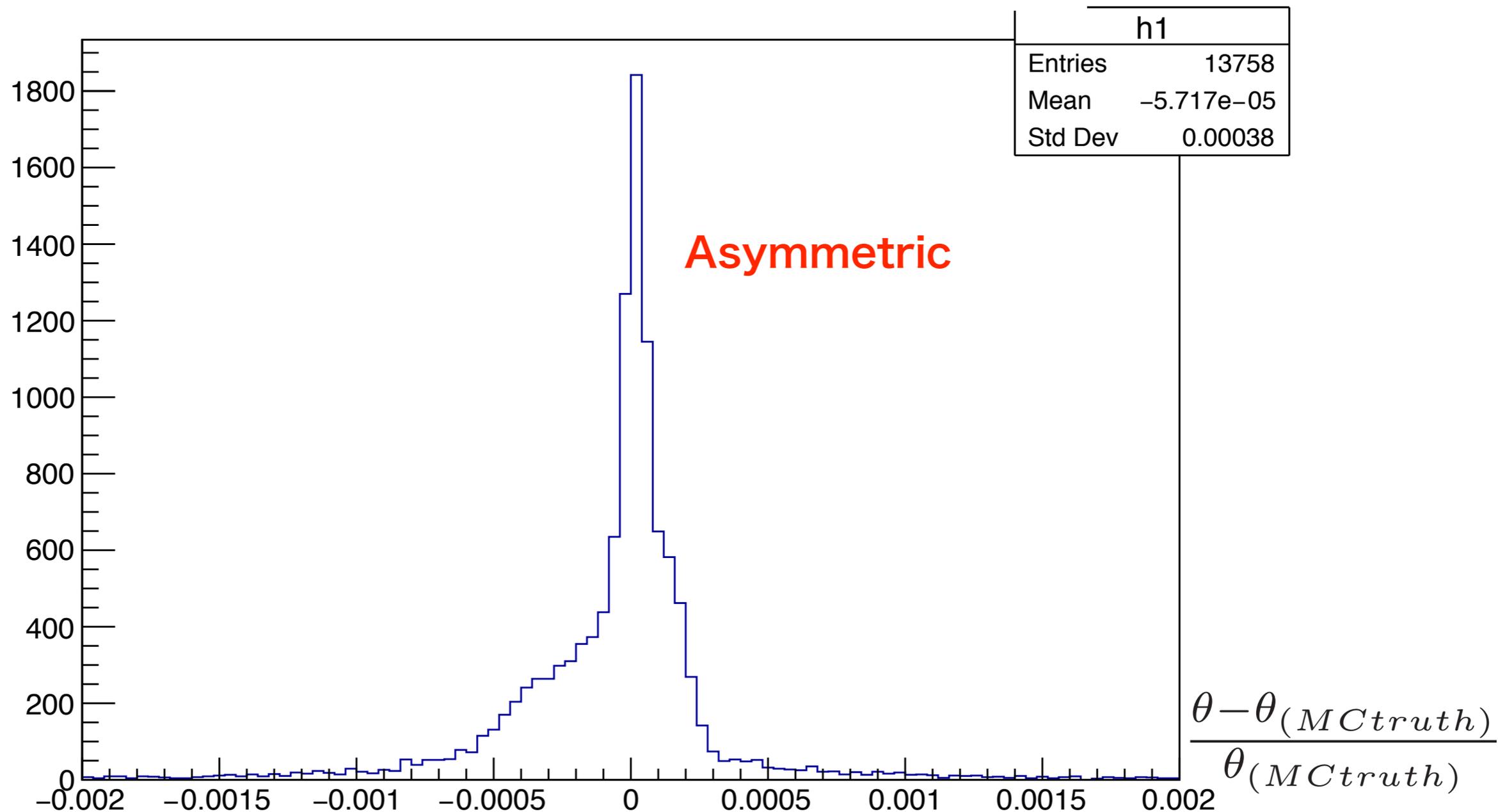
# Distribution of PFO Photon Angle (phi)

Samples:  
 $|M(\mu^+\mu^-) - 91.2| < 10$  GeV  
Large ILD model



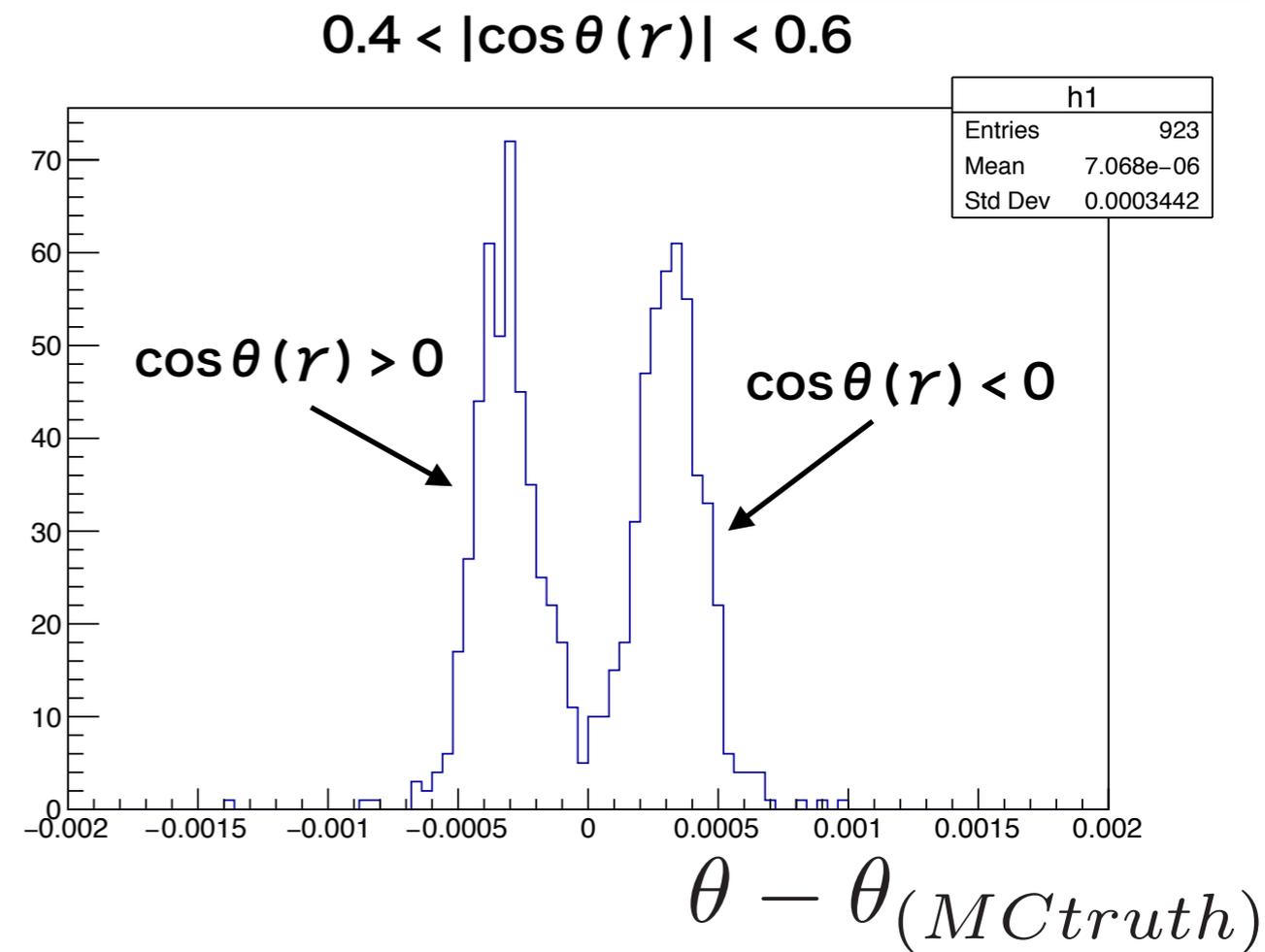
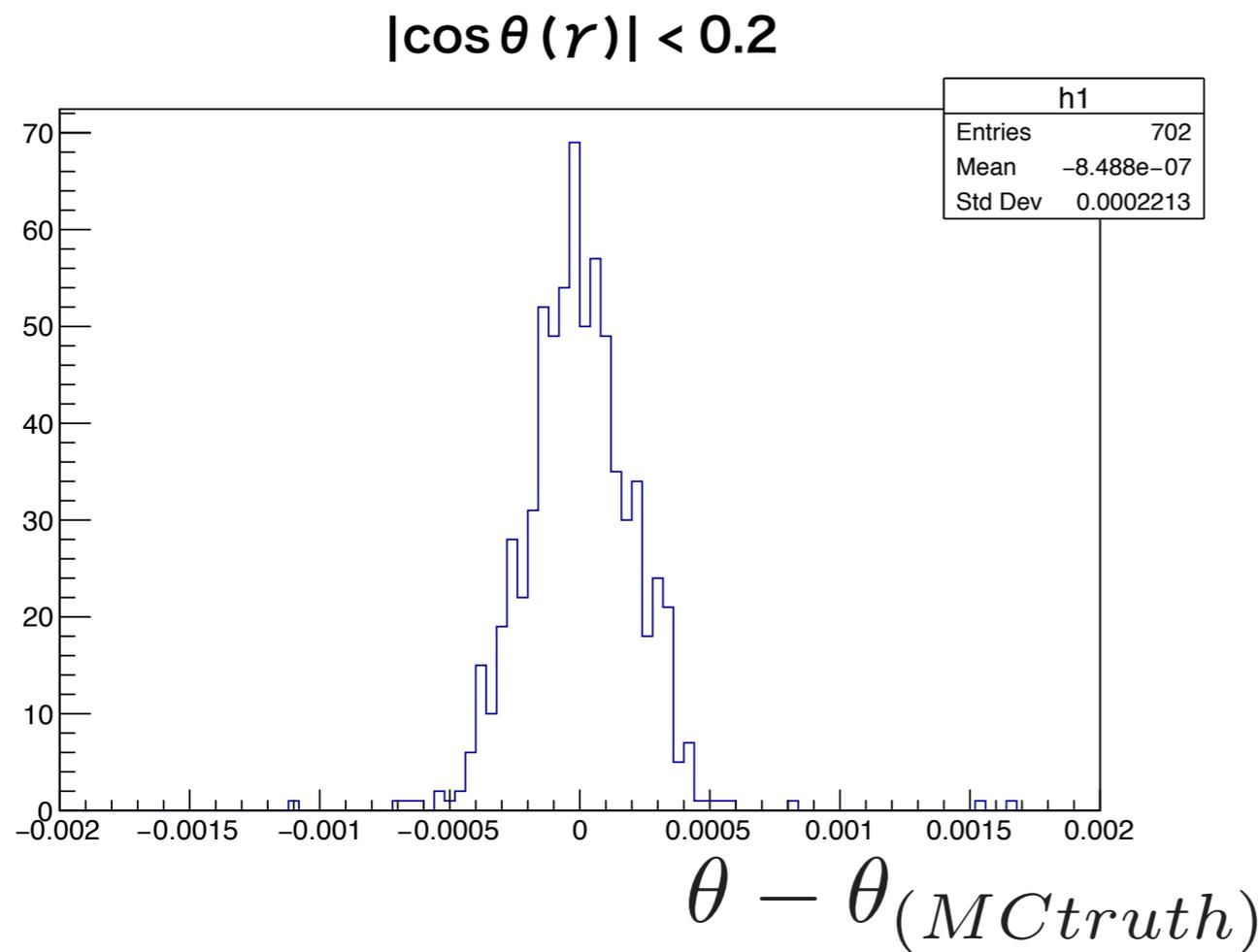
# Distribution of PFO Photon Angle (theta)

Samples:  
 $|M(\mu^+\mu^-) - 91.2| < 10$  GeV  
Large ILD model



# Distribution of PFO Photon Angle (theta)

Samples:  
 $|M(\mu^+\mu^-) - 91.2| < 10 \text{ GeV}$   
 Large ILD model



When theta is larger, bias gets more prominent.

In the PFO, the center of shower seems to be shifted to B-field direction due to the B field.

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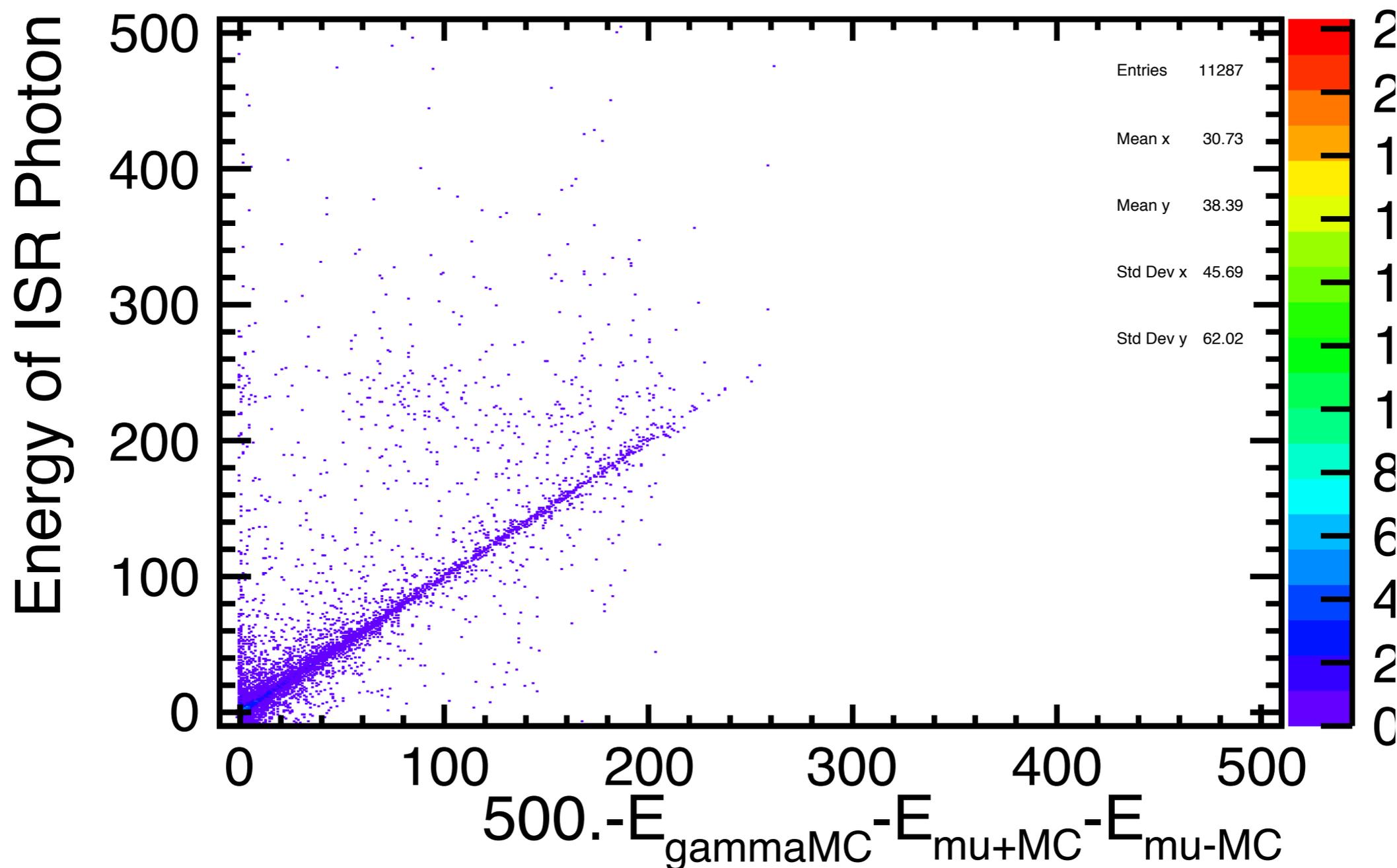
Case 4': Case 3 using muons' energies

Using  $(\theta_{\mu^-}, \theta_{\mu^+}, \theta_{\gamma}, \phi_{\mu^-}, \phi_{\mu^+}, \phi_{\gamma}, E_{\mu^-}, E_{\mu^+})$

-> Determine  $(E_{\gamma}, E_{ISR})$

Samples:  
 $|M(\mu^+\mu^-) - 91.2| < 10 \text{ GeV}$   
 $|\sin\phi(\gamma)| > 0.2$   
 Large ILD model

Energy of ISR Photon



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**//(5) Estimation of Energy Resolution**

# Case 4': Case 3 using muons' energies

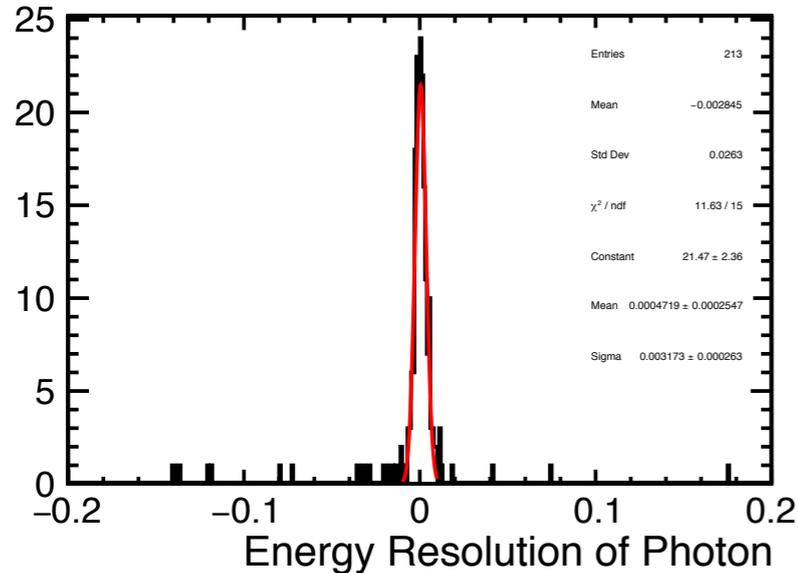
Using  $(\theta_{\mu^-}, \theta_{\mu^+}, \theta_{\gamma}, \phi_{\mu^-}, \phi_{\mu^+}, \phi_{\gamma}, E_{\mu^-}, E_{\mu^+})$

-> Determine  $(E_{\gamma}, E_{ISR})$

Samples:  
 $|M(\mu^+\mu^-) - 91.2| < 10 \text{ GeV}$   
 $0.4 < |\sin\phi(\gamma)| < 0.8$   
 Large ILD model

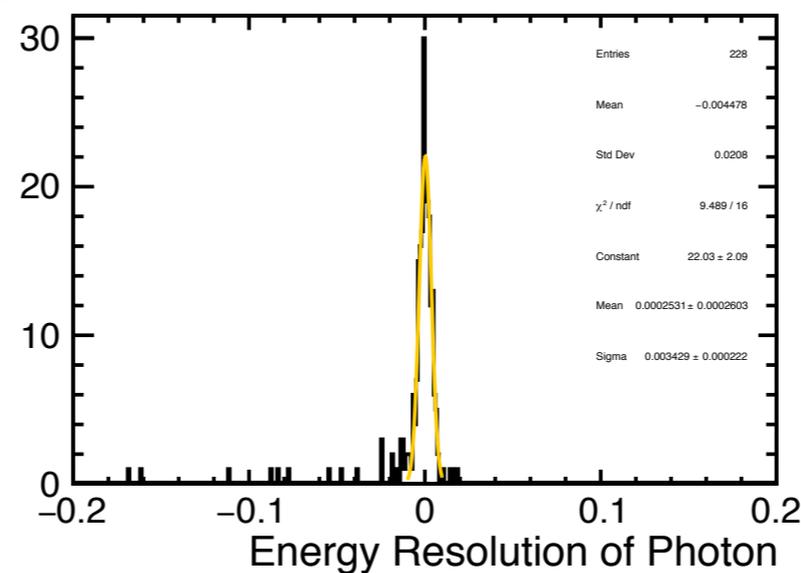
$|\cos\theta(\gamma)| < 0.2$

Energy Resolution of Photon



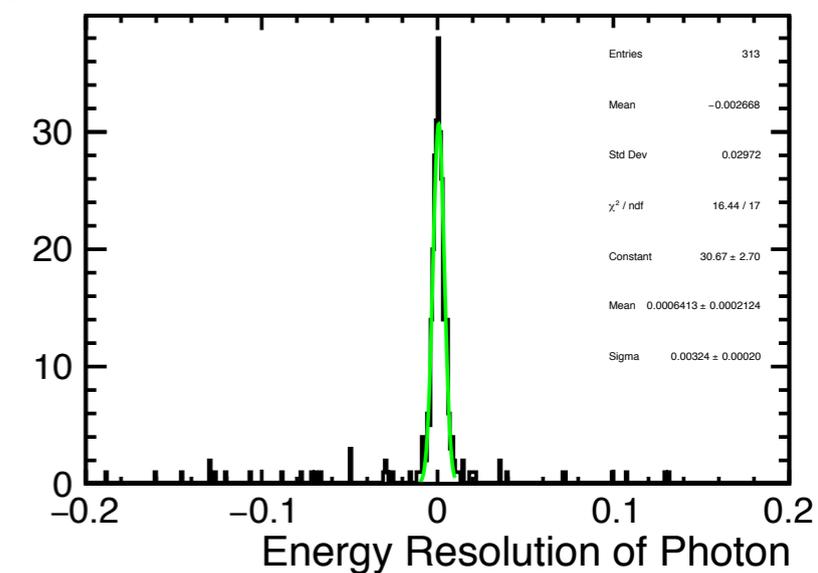
$0.2 < |\cos\theta(\gamma)| < 0.4$

Energy Resolution of Photon



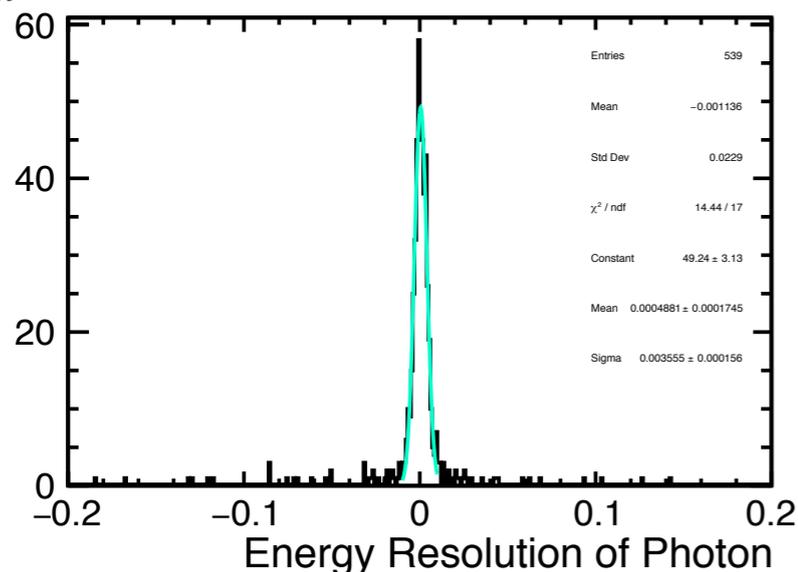
$0.4 < |\cos\theta(\gamma)| < 0.6$

Energy Resolution of Photon



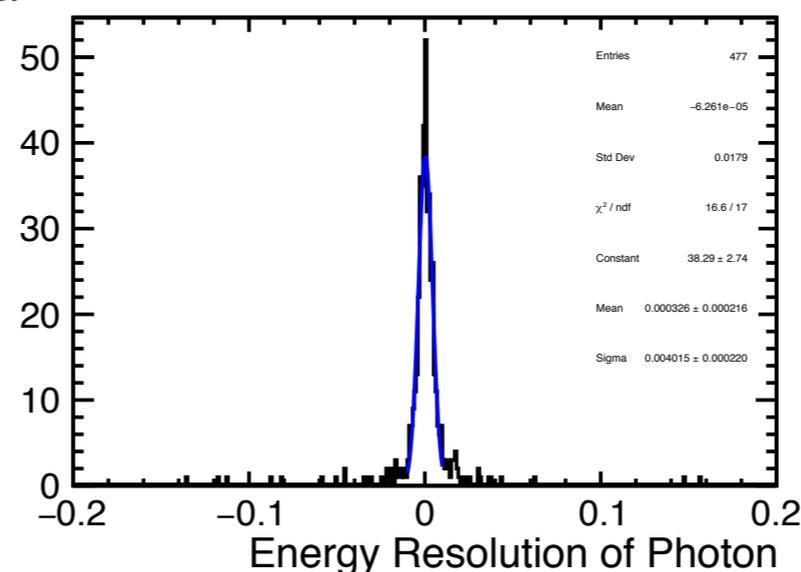
$0.6 < |\cos\theta(\gamma)| < 0.8$

Energy Resolution of Photon



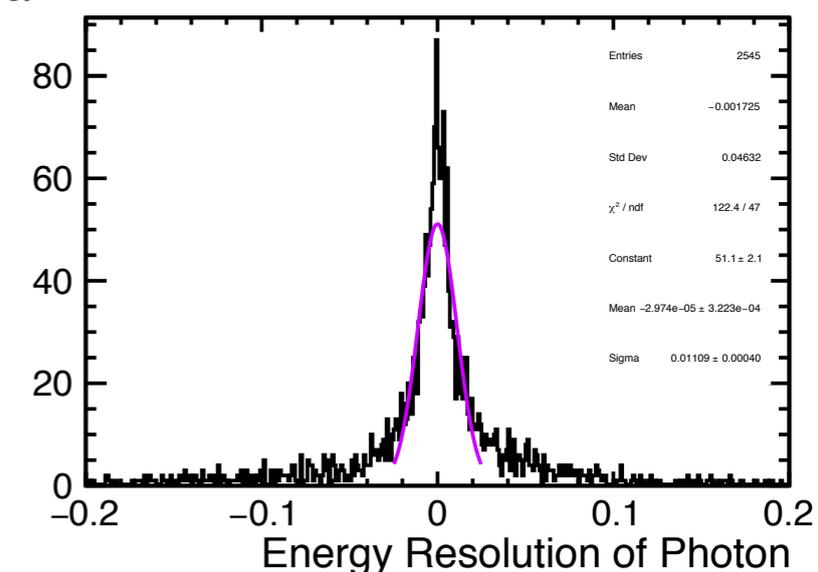
$0.8 < |\cos\theta(\gamma)| < 0.9$

Energy Resolution of Photon



$0.9 < |\cos\theta(\gamma)|$

Energy Resolution of Photon



# Case 4': Case 3 using muons' energies

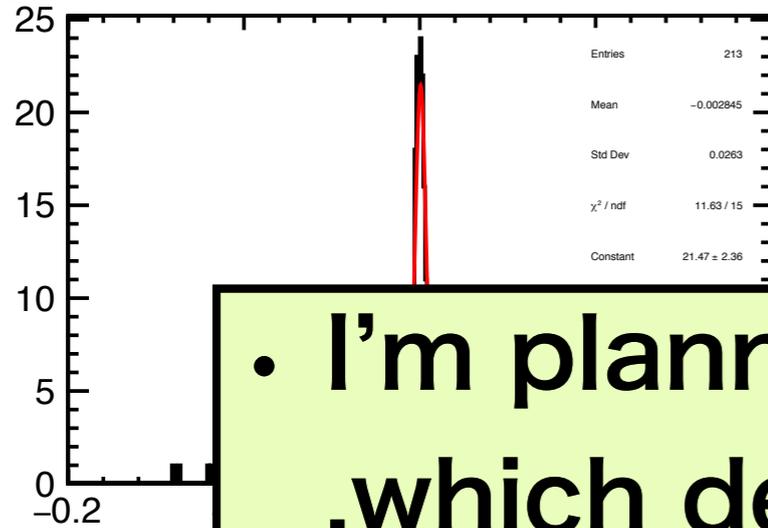
Using  $(\theta_{\mu^-}, \theta_{\mu^+}, \theta_r, \phi_{\mu^-}, \phi_{\mu^+}, \phi_r, E_{\mu^-}, E_{\mu^+})$

-> Determine  $(E_r, E_{ISR})$

Samples:  
 $|M(\mu^+\mu^-) - 91.2| < 10 \text{ GeV}$   
 $0.4 < |\sin\phi(r)| < 0.8$   
 Large ILD model

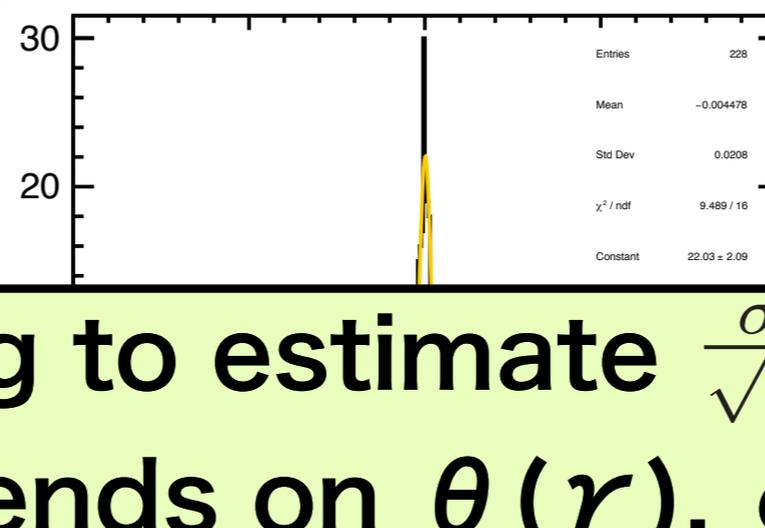
$|\cos\theta(r)| < 0.2$

Energy Resolution of Photon



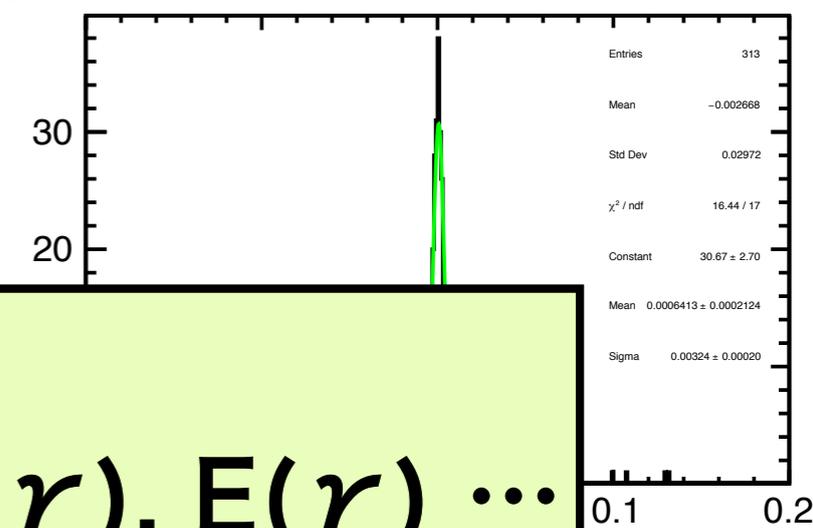
$0.2 < |\cos\theta(r)| < 0.4$

Energy Resolution of Photon



$0.4 < |\cos\theta(r)| < 0.6$

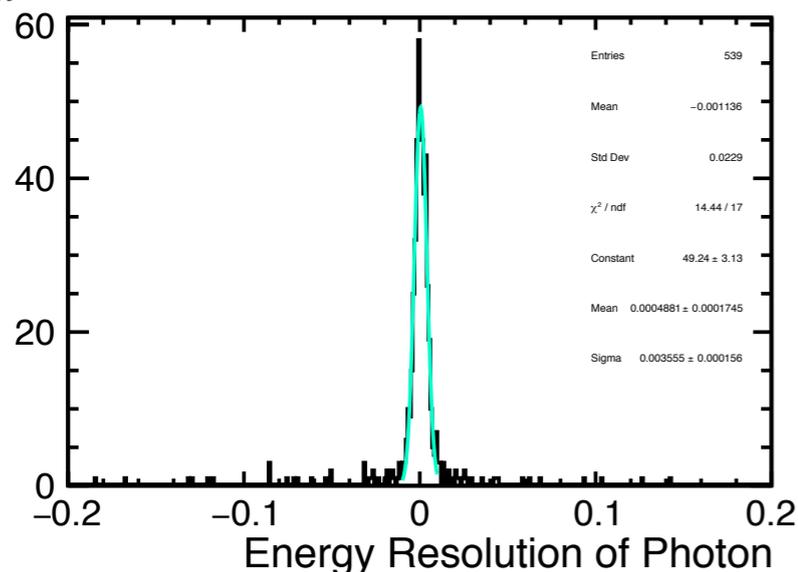
Energy Resolution of Photon



• I'm planning to estimate  $\frac{\sigma}{\sqrt{n}}$ , which depends on  $\theta(r), \phi(r), E(r) \dots$

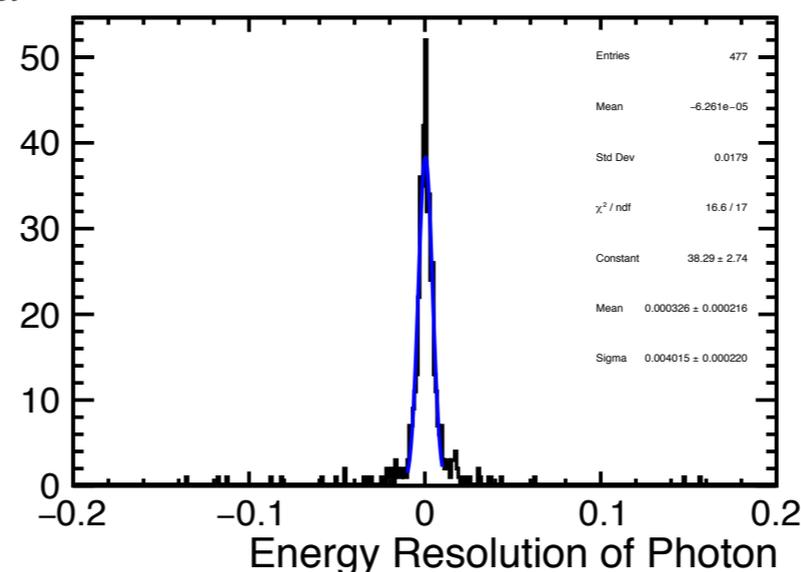
$0.6 < |\cos\theta(r)| < 0.8$

Energy Resolution of Photon



$0.8 < |\cos\theta(r)| < 0.9$

Energy Resolution of Photon



$0.9 < |\cos\theta(r)|$

Energy Resolution of Photon

