A simulation study of the e+e- to gamma Z process for design optimization of the International Large Detector

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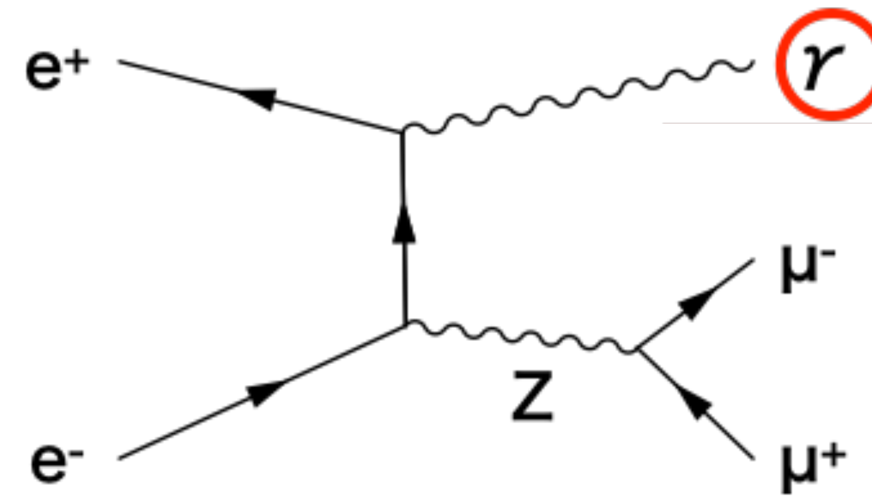
Overview

- Report calibration methods using the **e^+e^- -> γZ process**, focusing on **photon energy measurements** in the ILC



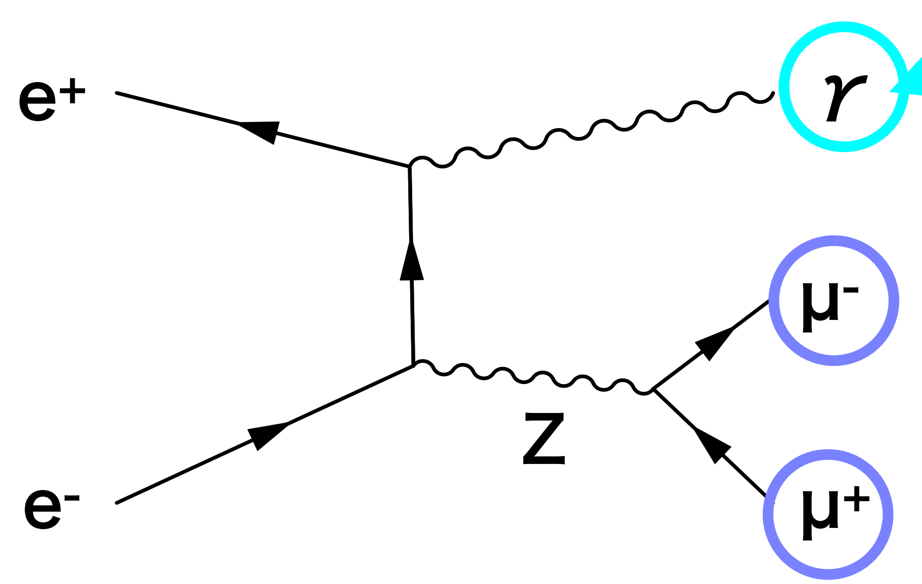
- Using **measured direction angles of μ^- , μ^+ (from Z) and γ, and energy of μ^- , μ^+**, **photon energy** can be reconstructed and calibrated

- Discuss the calibration precision for photon energy

Detector Benchmark Motivation

ILC: optimized to measure *the coupling constants between Higgs boson and other particles*
-> It is important to calibrate the energy scales of various subdetectors for more precise measurements.

- The $e^+e^- \rightarrow \gamma Z$, $Z \rightarrow \mu^+\mu^-$ process contains the radiative return events

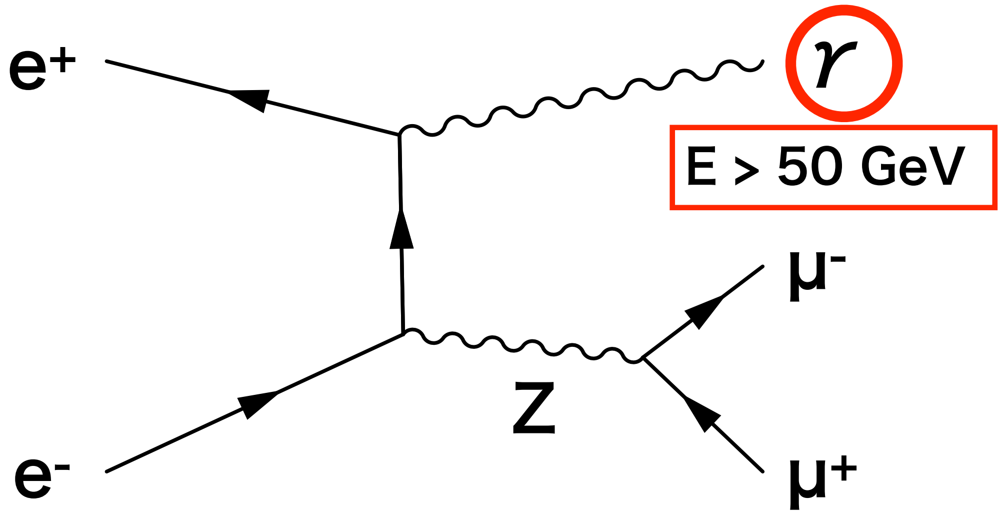


Energy can be reconstructed!!

Calibration for the detectors related to photon energy can be performed.

- Therefore this method is important to calibrate subdetectors related to the photon energy.

Reconstruction Method



- 4-momentum conservation is considered.
- The mass of muon is neglected.
- Several reconstruction methods (Method 3, 4, 4') are considered.

Direction Angle
θ: polar angle
ϕ: azimuthal angle

Method 3: Consider Beamstrahlung and Crossing Angle
Using ($\theta_{\mu^-},\theta_{\mu^+},\theta_\gamma,\varphi_{\mu^-},\varphi_{\mu^+},\varphi_\gamma$) -> Determine ($E_{\mu^-},E_{\mu^+},E_\gamma,E_{ISR}$)

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

Beam Crossing Angle (≡2α)
α = 7.0 mrad

Reconstruction Method

Method 4, 4': Method 3 using Muons' Energies
Using (θ_{μ}-,θ_{μ}+,θ_{γ},φ_{μ}-,φ_{μ}+,φ_{γ},E_{μ}-,E_{μ}+) -> Determine (E_{γ},E_{ISR})

- **Method 4: Energy and Pz Conservation**

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

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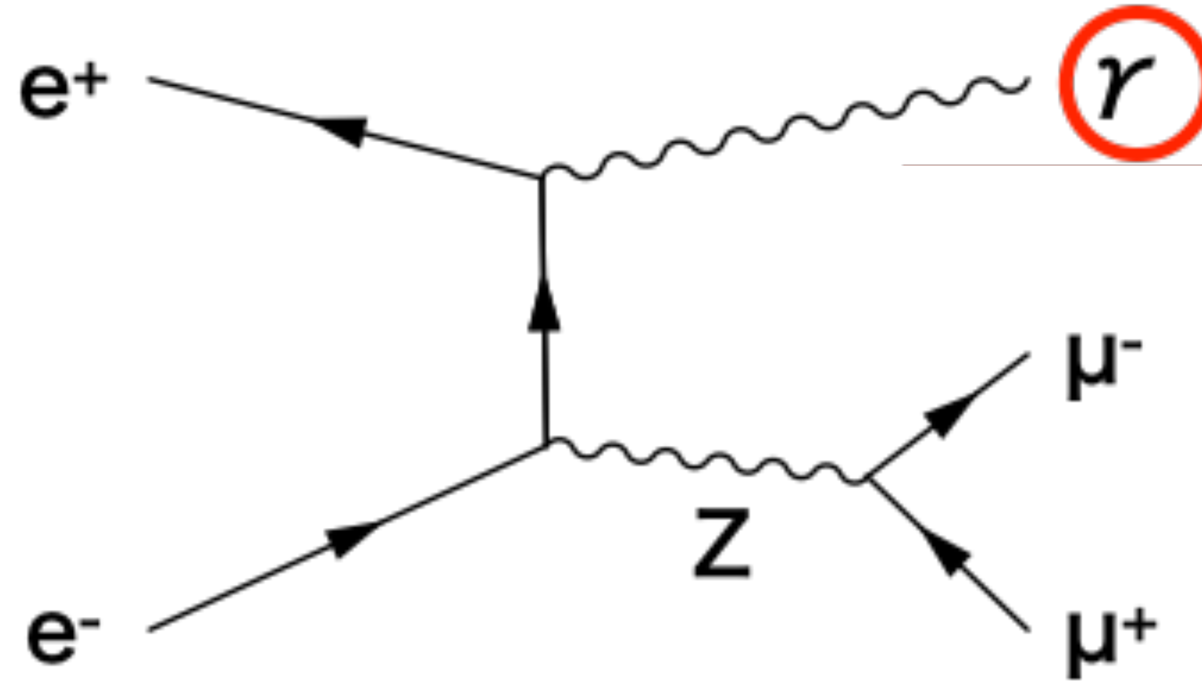
This is of no use when sinθ_{γ} or sinφ_{γ}=0 ??

However, photon energy can be determined without calculating P_{ISR}.

Simulation Setup

ILCSOFT version v02-00-02

- Full simulation
- geant4 based realistic reconstruction
- export of full reconstruction data



Signal channel: $e^+e^- \to \gamma Z, Z \to \mu^+\mu^-$
contains beamstrahlung and ISR photon
E_{CM} of e^+e^- is 500 GeV.

Both Large ILD model samples and Small ILD model samples are used.

Large ILD model (IDR-L)
TPC outer radius: 180 cm
B Field ~3.5 T

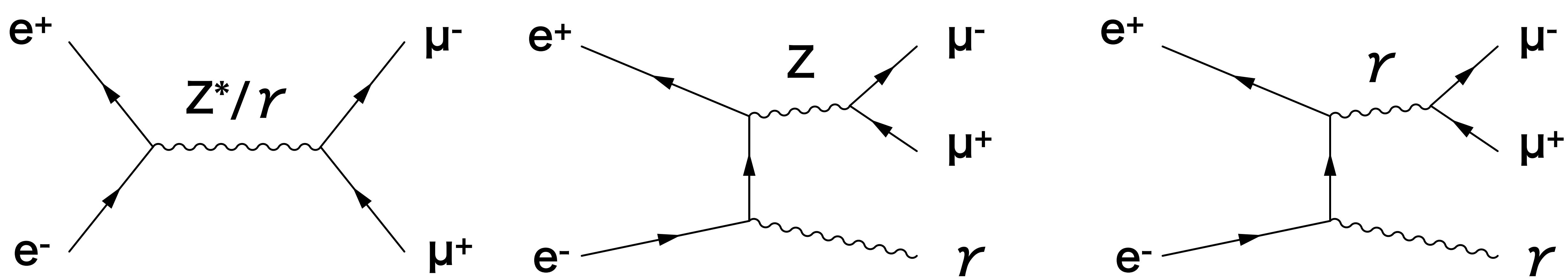
Small ILD model (IDR-S)
TPC outer radius: 146 cm
B Field ~4 T

Event Selection

Signatures of the signal events:
$\mu^+\mu^-$ pair (inv. mass ~Z boson) + one energetic isolated photon

Raw sample requires leptons (μ or τ) in the final state.
In order to pick up our required process, following cuts are applied.

Step1: Events with two isolated muons are selected.
-> 3 diagrams as follows are included in samples.



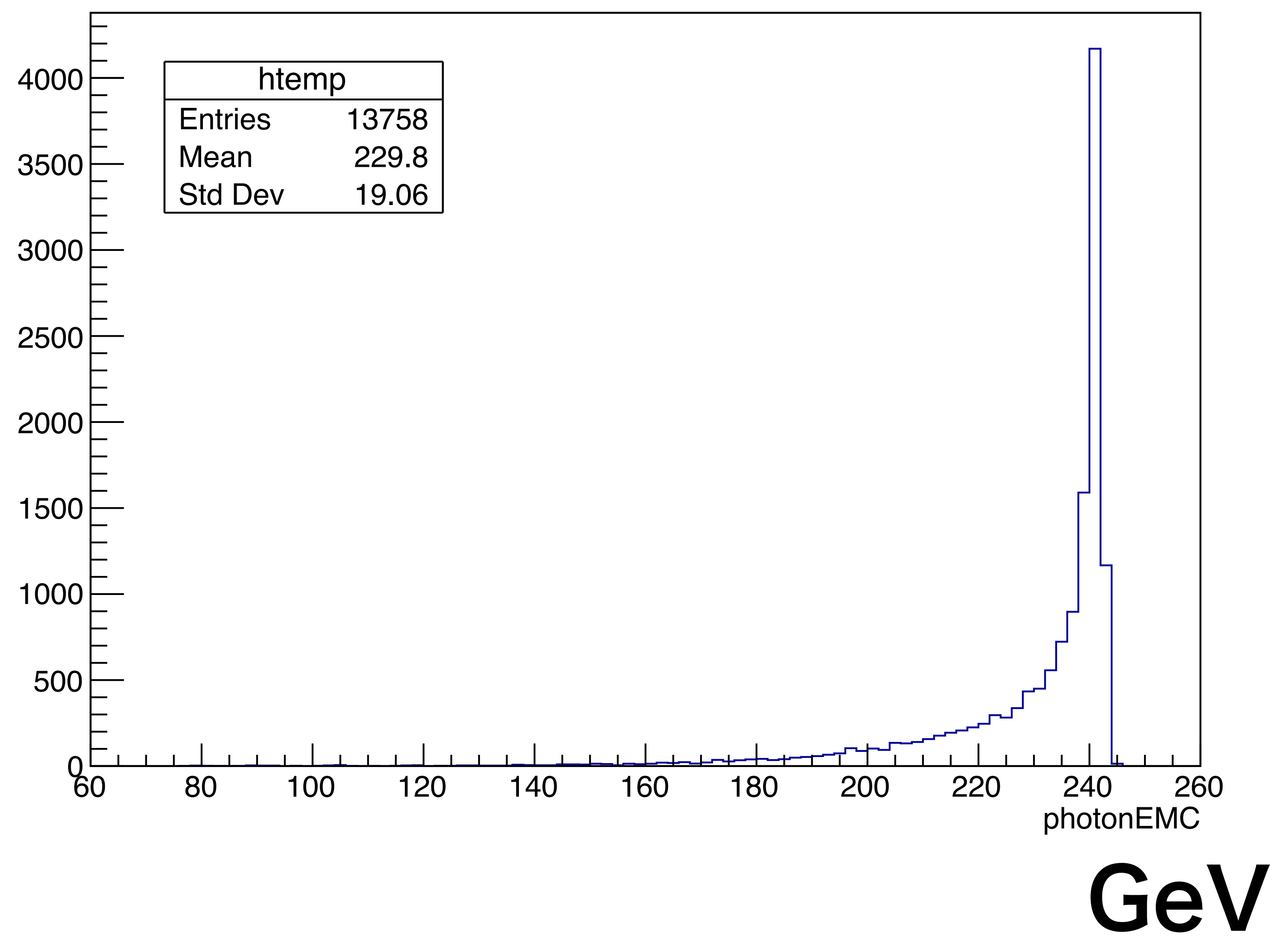
$M(\mu^+\mu^-)$ ~ 500 GeV　　$M(\mu^+\mu^-)$ = 91.2 GeV　　$M(\mu^+\mu^-)$ = 0 GeV

Event Selection

Step2: Events with one isolated photon are selected.

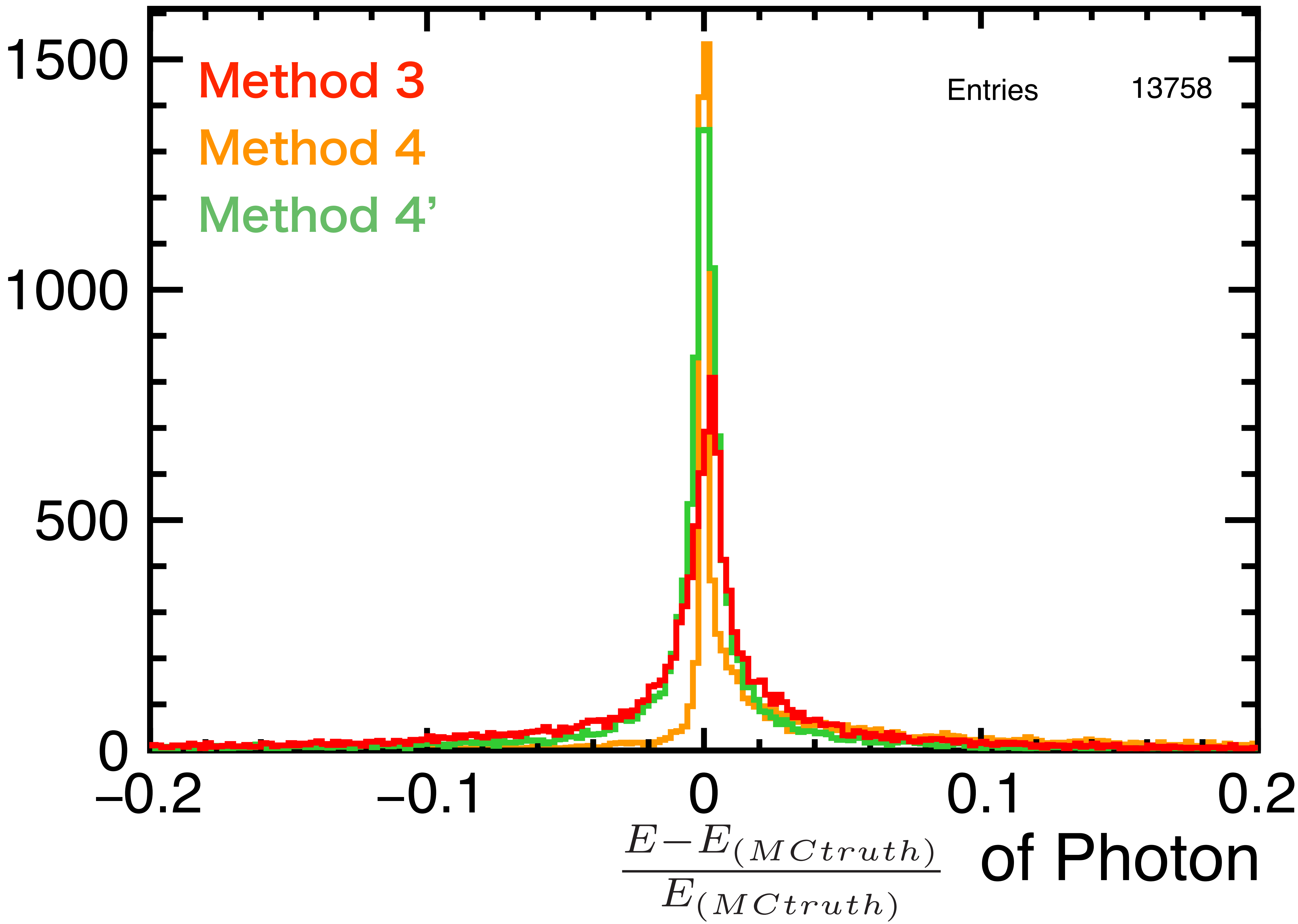
- Invariant mass of two muons $M(\mu^+\mu^-)$ are required to be $|M(\mu^+\mu^-) - 91.2| < 10$ GeV
  .
- Events with one isolated photon are selected
- More than 50 GeV photon events are selected

MCTruth Energy of Photon



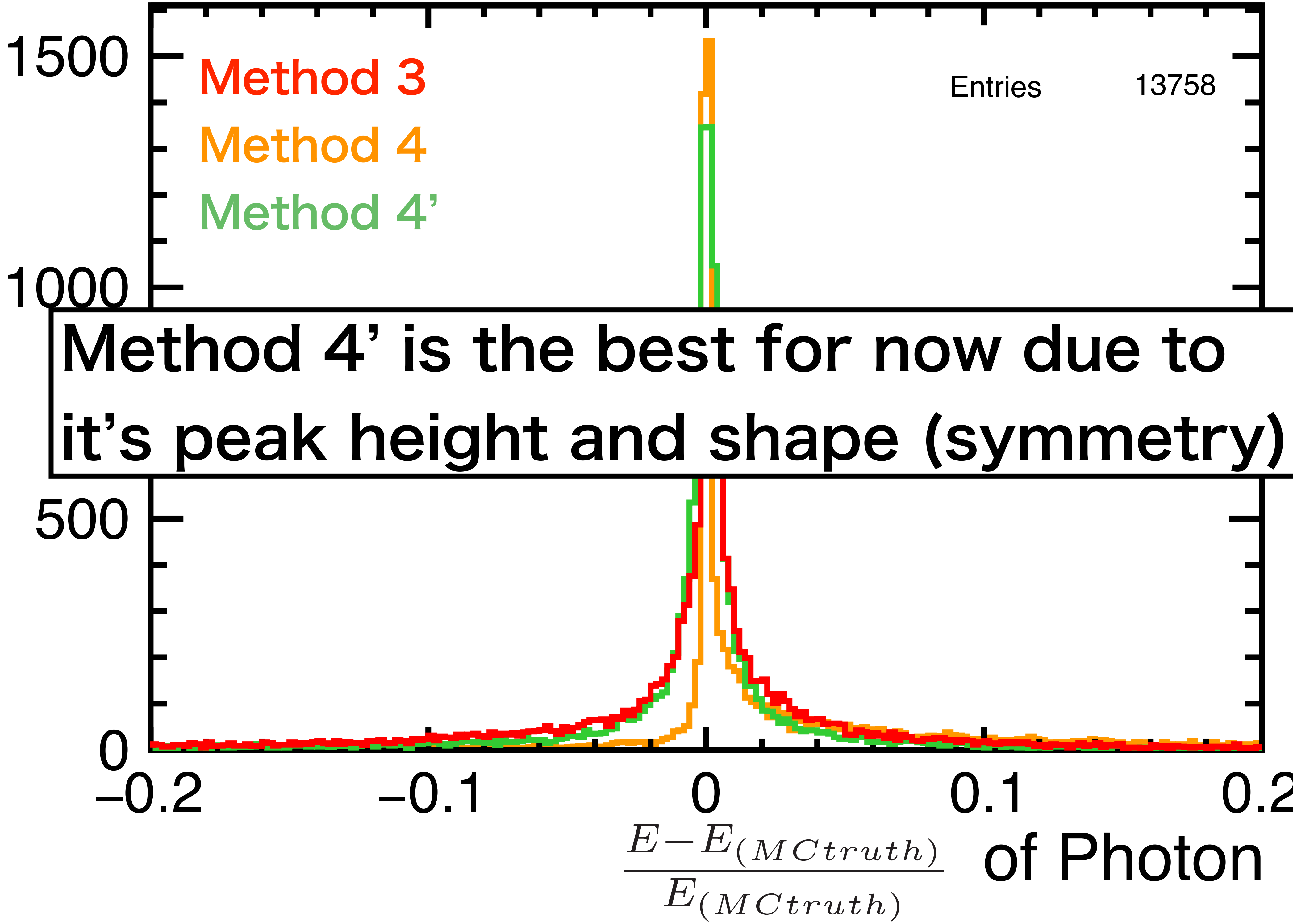
$\frac{E - E_{(MCtruth)}}{E_{(MCtruth)}}$ of Photon

Samples:
|M(μ⁺μ⁻)-91.2| < 10 GeV
Large ILD model



$\frac{E - E_{(MCtruth)}}{E_{(MCtruth)}}$ of Photon

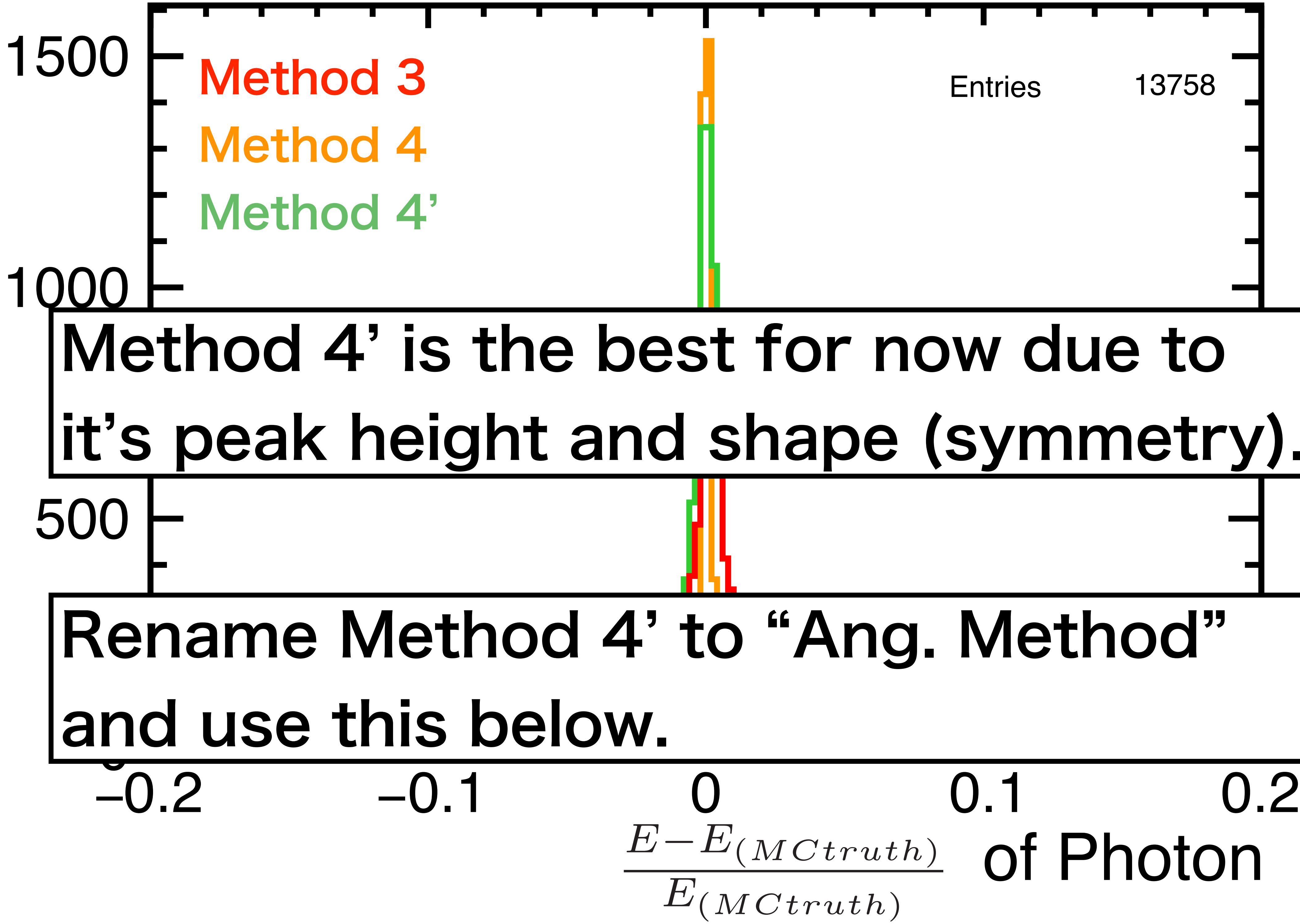
Samples:
|M(μ+μ-)-91.2| < 10 GeV
Large ILD model



Method 4' is the best for now due to it's peak height and shape (symmetry).

$\frac{E-E_{(MCtruth)}}{E_{(MCtruth)}}$ of Photon

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

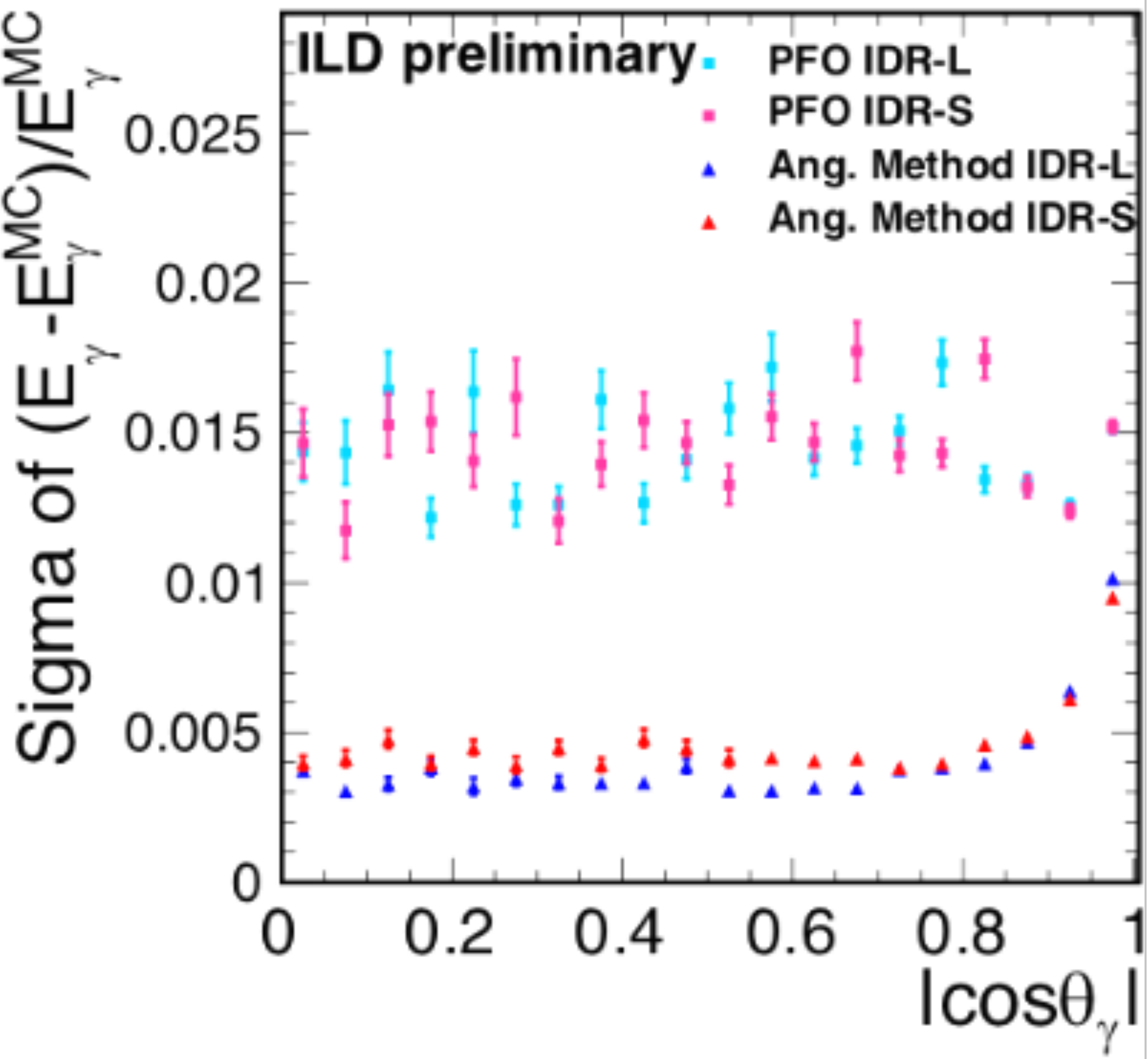


Method 4’ is the best for now due to it’s peak height and shape (symmetry).

Rename Method 4’ to “Ang. Method” and use this below.

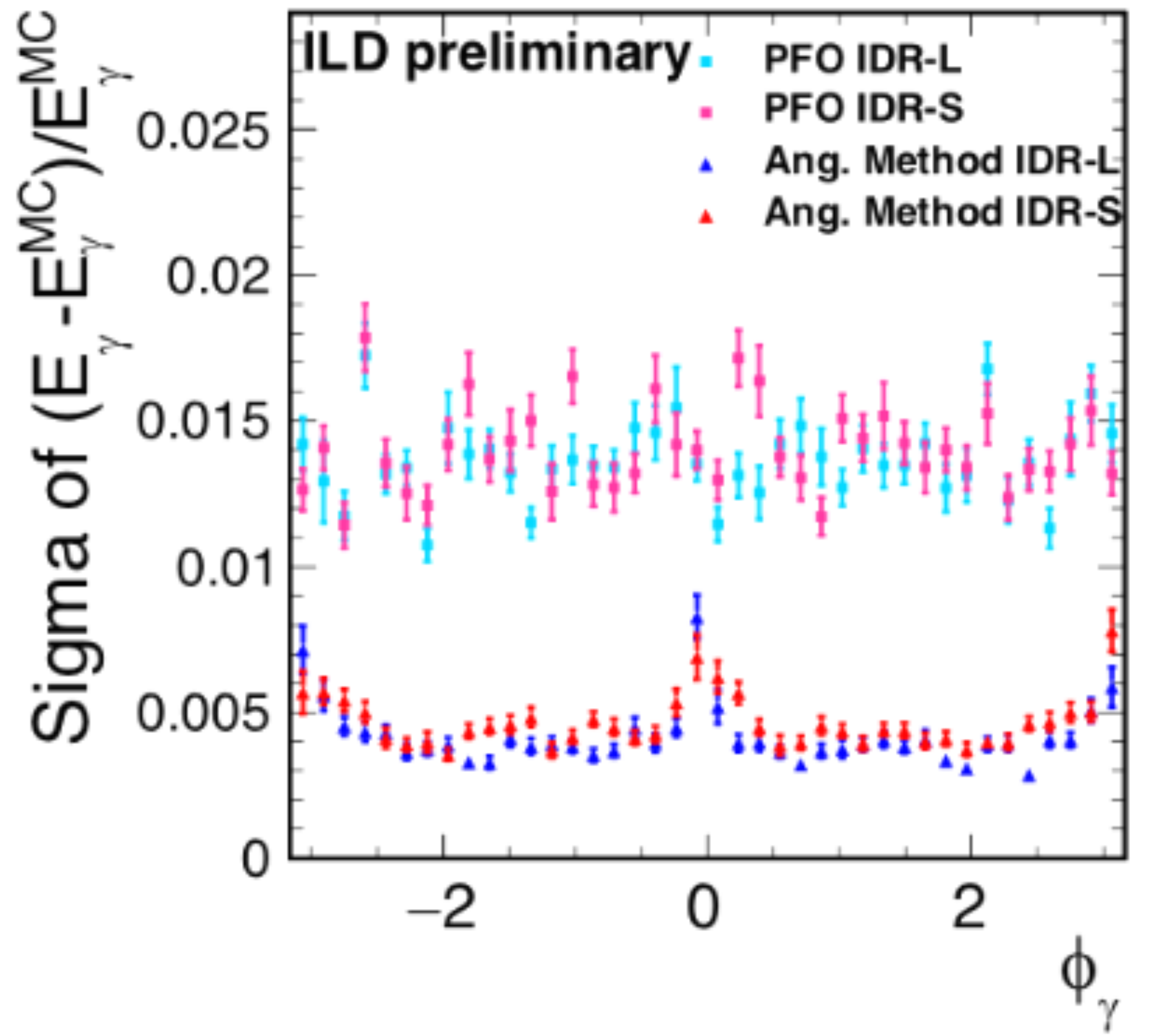
Demonstration of the validity of Ang. Method

Sigma of $(E-E_{MC})/E_{MC}$
dependence on $|\cos\theta_\gamma|$



$|\cos\theta\gamma| < 0.95$

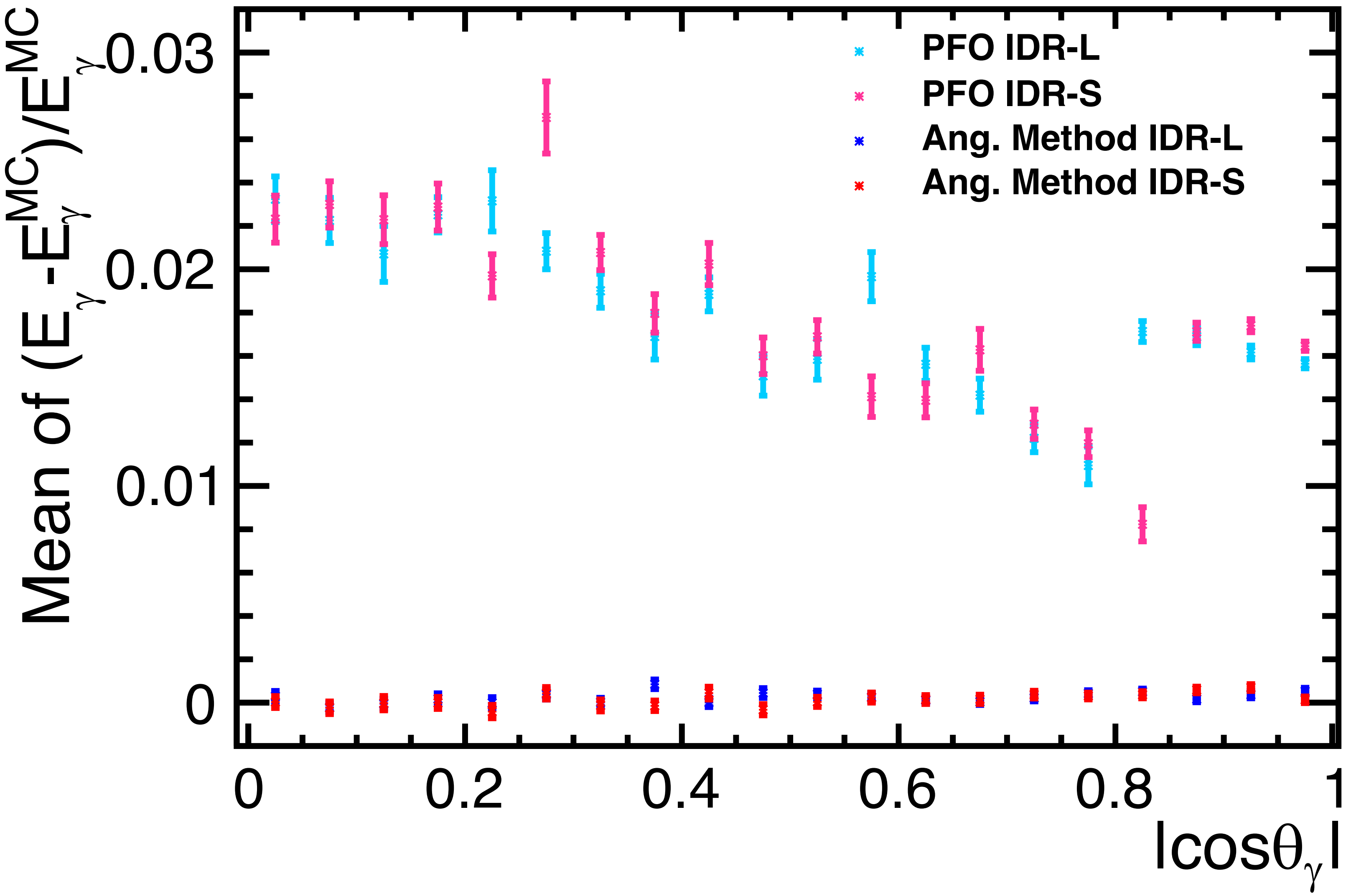
dependence on φ_γ



$\pi/40 < |\phi\gamma| < 39\pi/40$

Calibration of the Measured Energy

- It is shown that the PFO has large dependence on $|\cos\theta_\gamma|$.



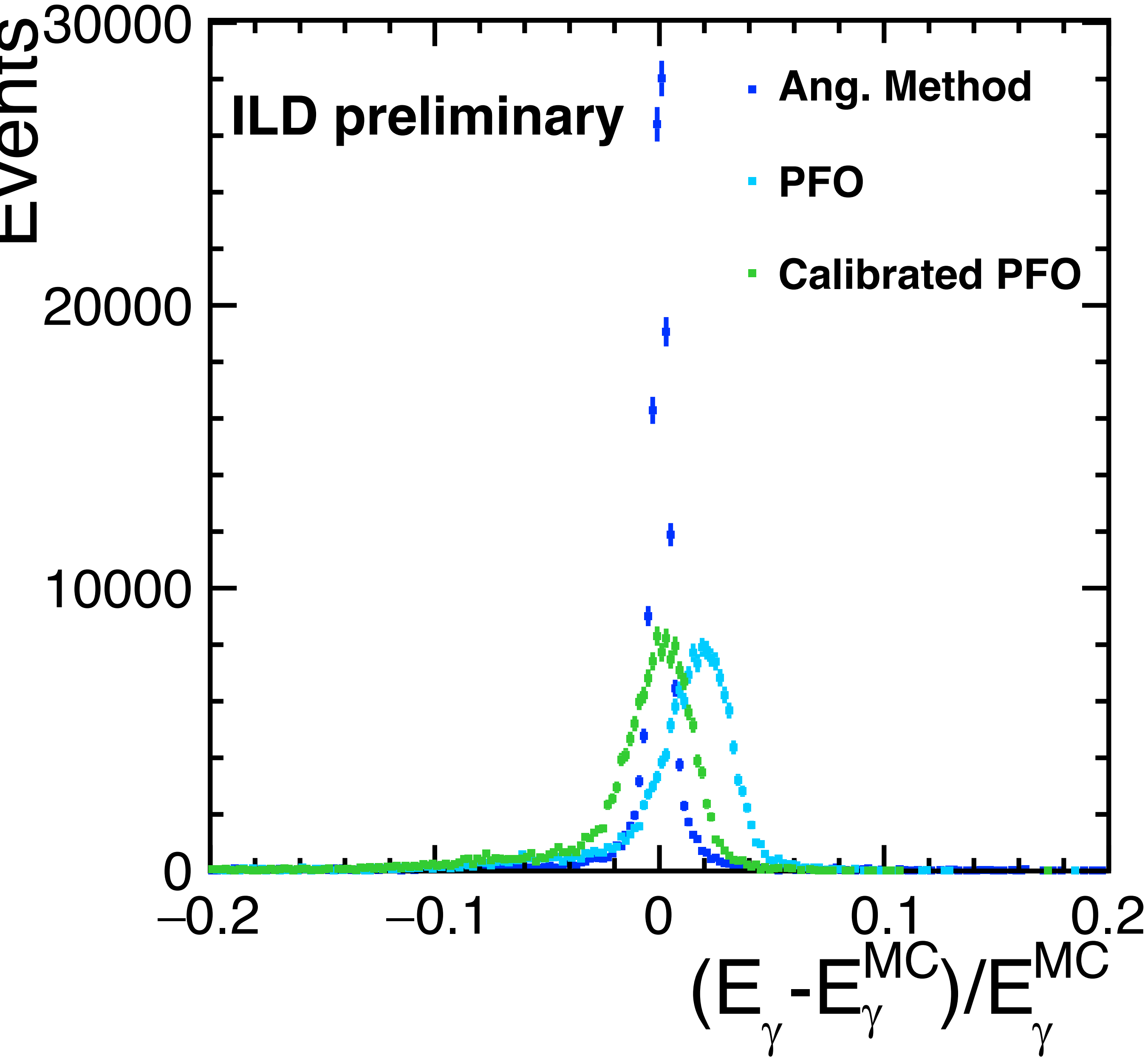
–> PFO energy data is divided into 20 groups by the value of $|\cos\theta_\gamma|$.
Calibration is performed by each value range of $|\cos\theta_\gamma|$.

$$Calibration\ Factor\ (\theta_\gamma) = \ Mean\ E_{Ang.Method}(\theta_\gamma)/Mean\ E_{PFO}(\theta_\gamma)$$

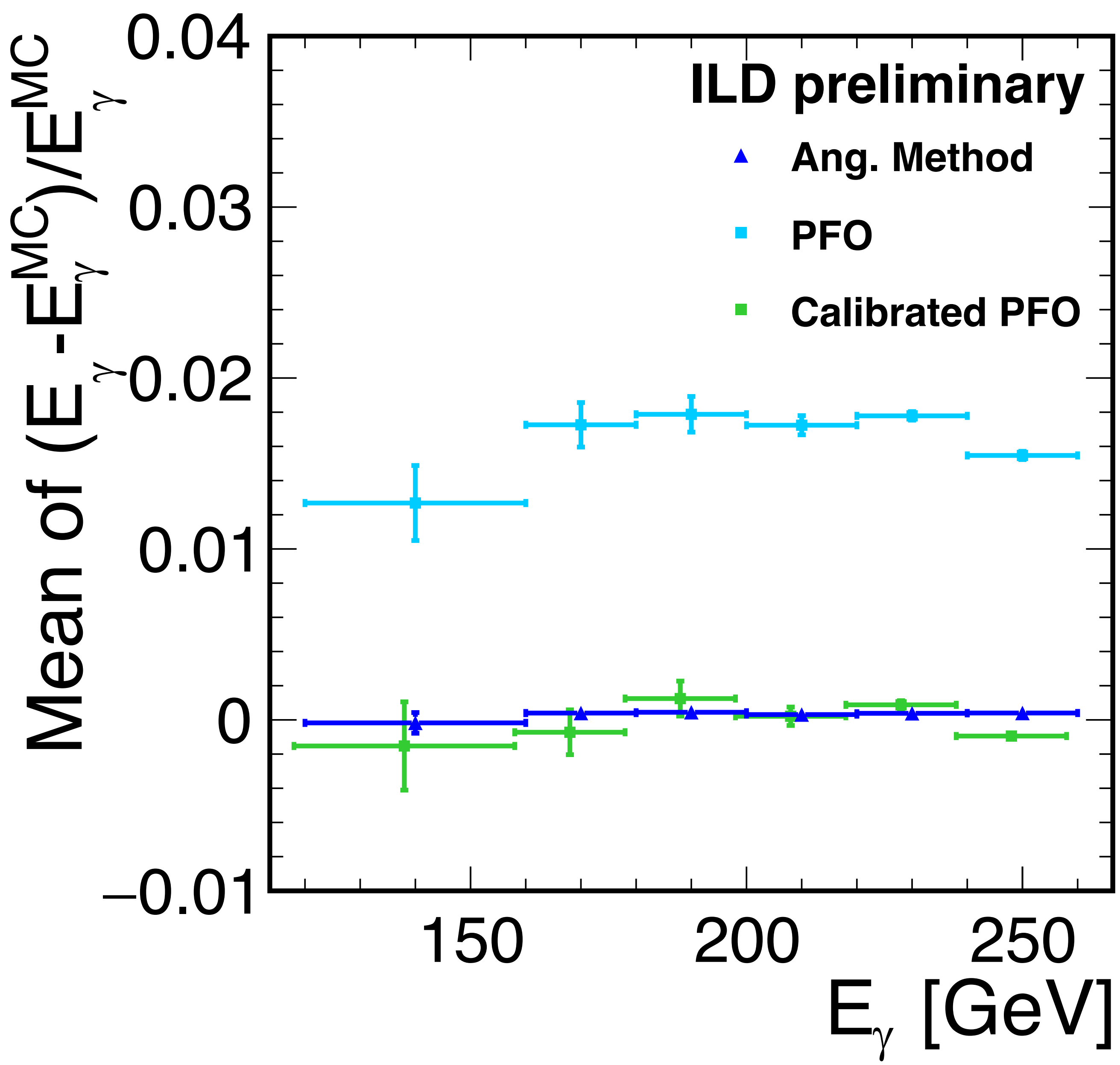
$$Calibrated\ PFO\ Energy = PFO\ Energy \times Calibration\ Factor\ (\theta_\gamma)$$

Calibration Result

Comparison of $(E\text{-}E_{MC})/E_{MC}$ among PFO, calibrated PFO, and Ang. Method



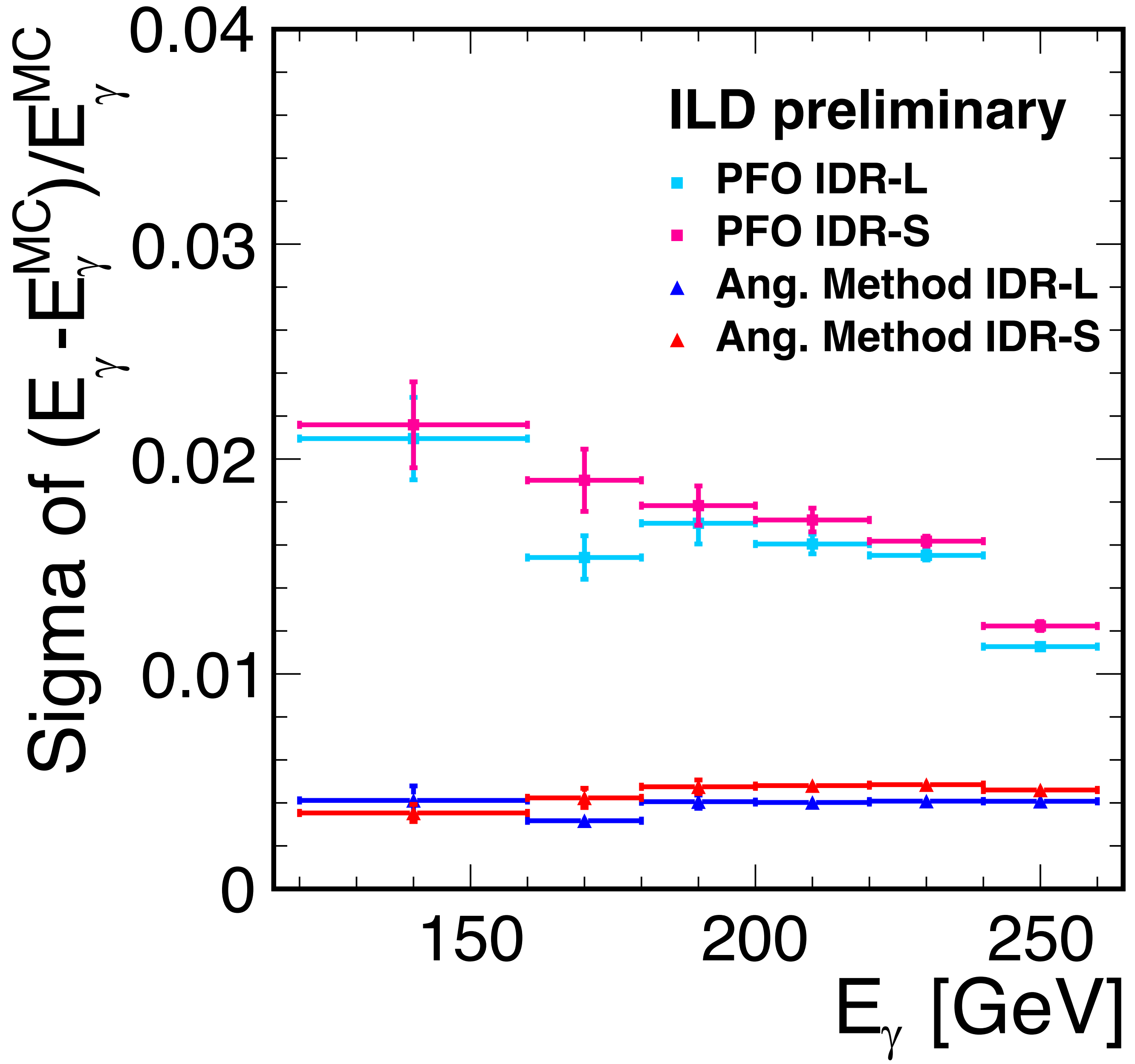
Mean of $(E\text{-}E_{MC})/E_{MC}$ dependence on E_γ



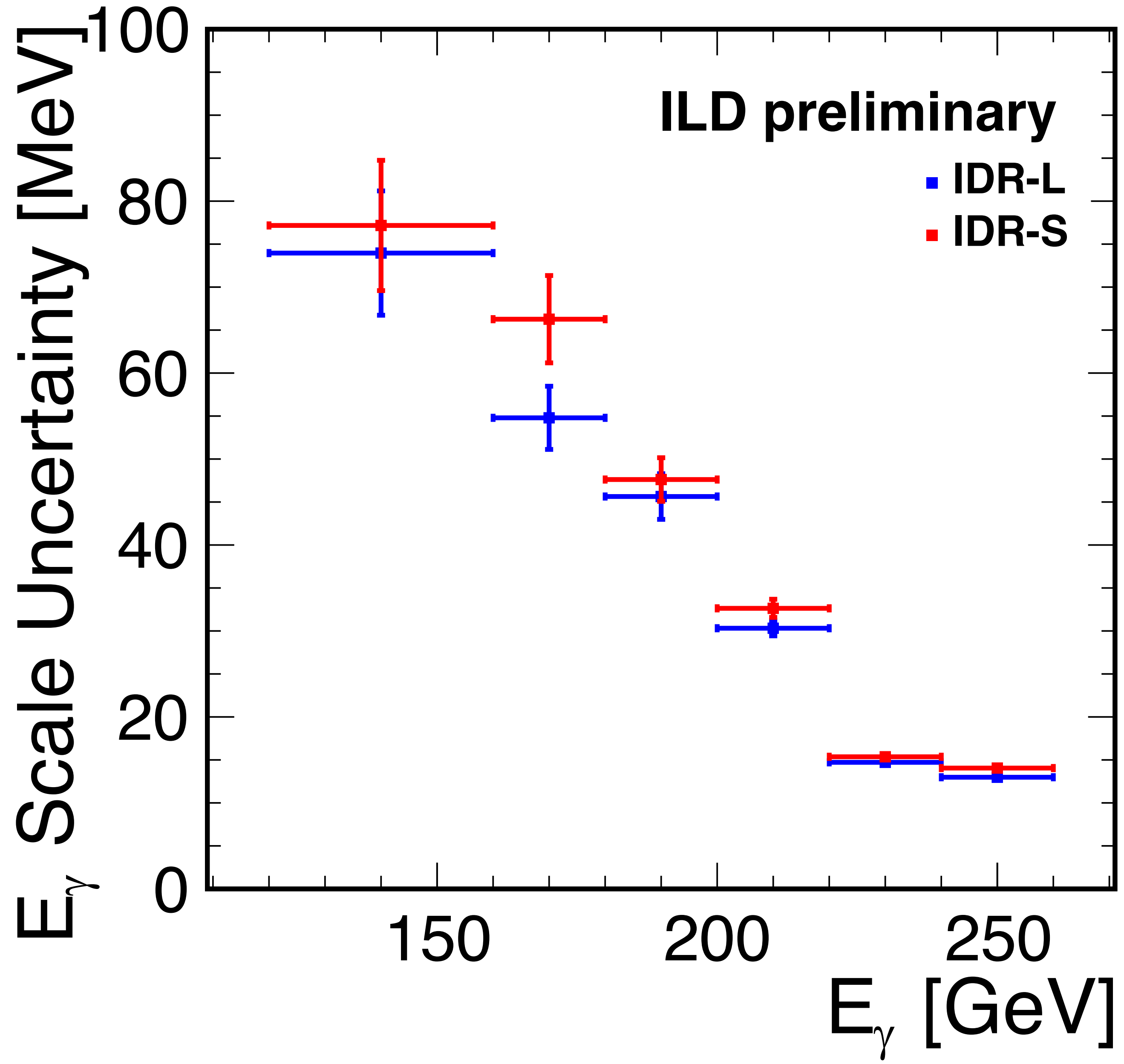
E_γ Scale Uncertainty

- $E_\gamma \, Scale \, Uncertainty = \sqrt{(PFO \, Uncertainty)^2 + (Ang. Method \, Uncertainty)^2}$

Sigma of $(E\text{-}E_{MC})/E_{MC}$ dependence on E_γ



E_γ Scale Uncertainty

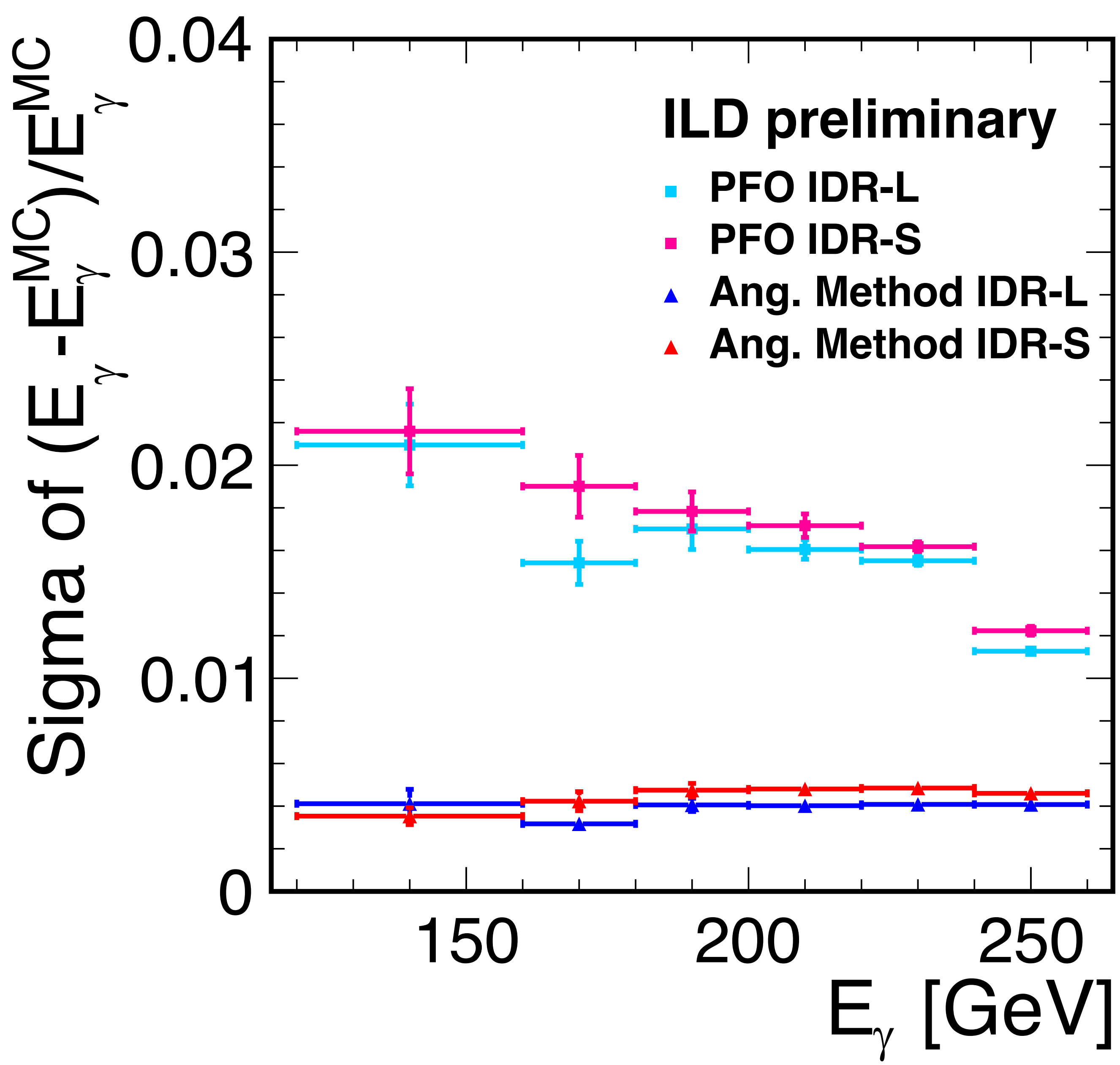


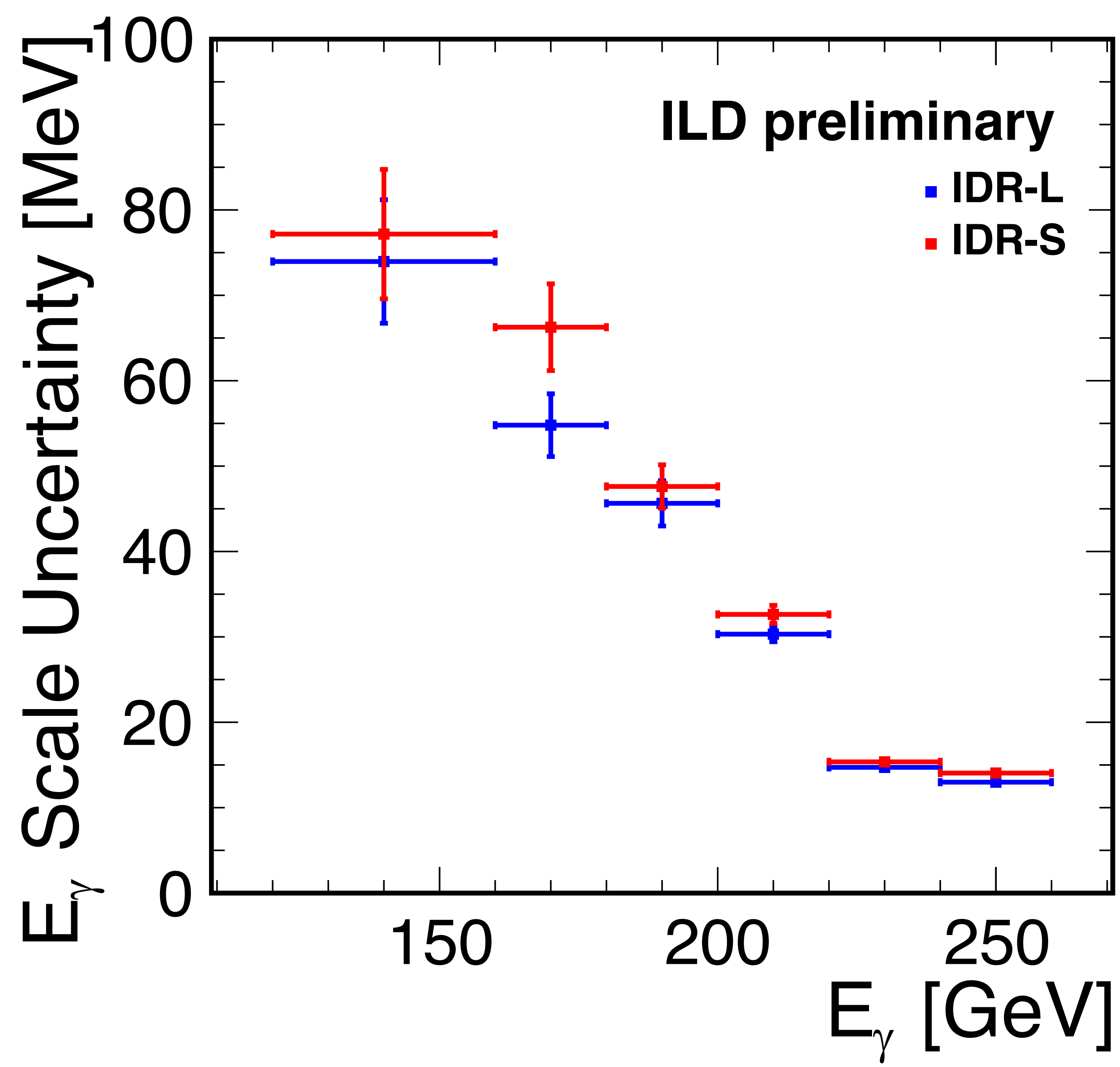
E_γ Scale Uncertainty

- E_γ ... $\overline{2}$

Si

- It is concluded that the photon energy scale uncertainty is less than 100 MeV when the energy of photon is > 120 GeV.





Conclusion

- Photon energy resolution using Ang. Method is better than PFO.
- Calibration of the PFO photon energy is performed.
- It is concluded that the photon energy scale uncertainty is less than 100 MeV when the energy of photon is > 120 GeV.