Photon energy calibration using e+e- to gamma Z process at the ILC

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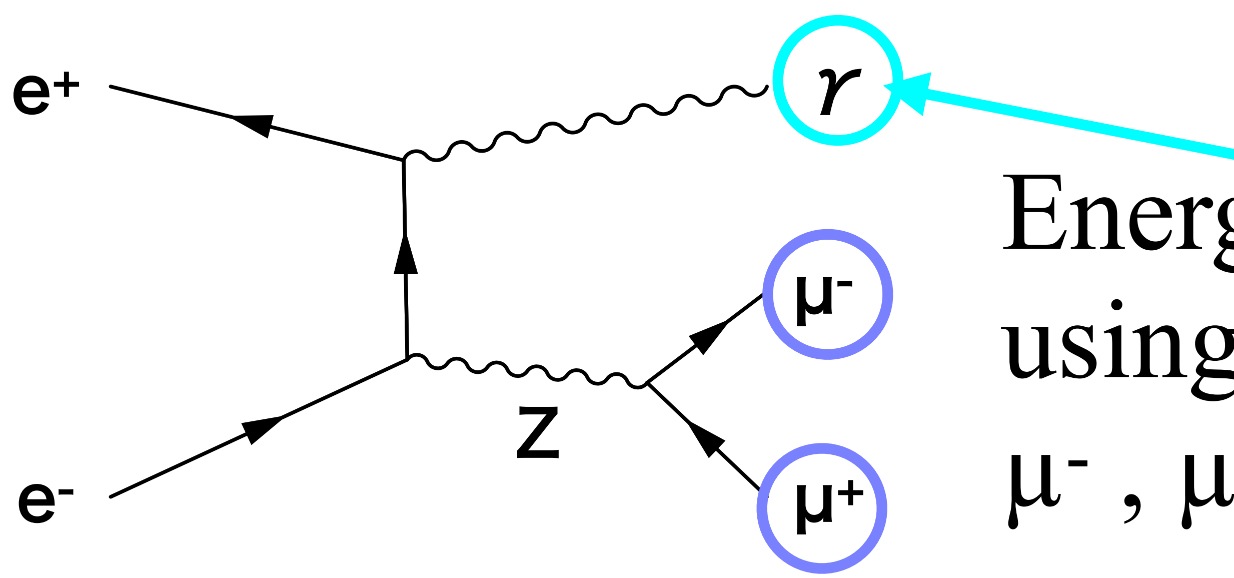
Introduction

Detector Benchmark Motivation

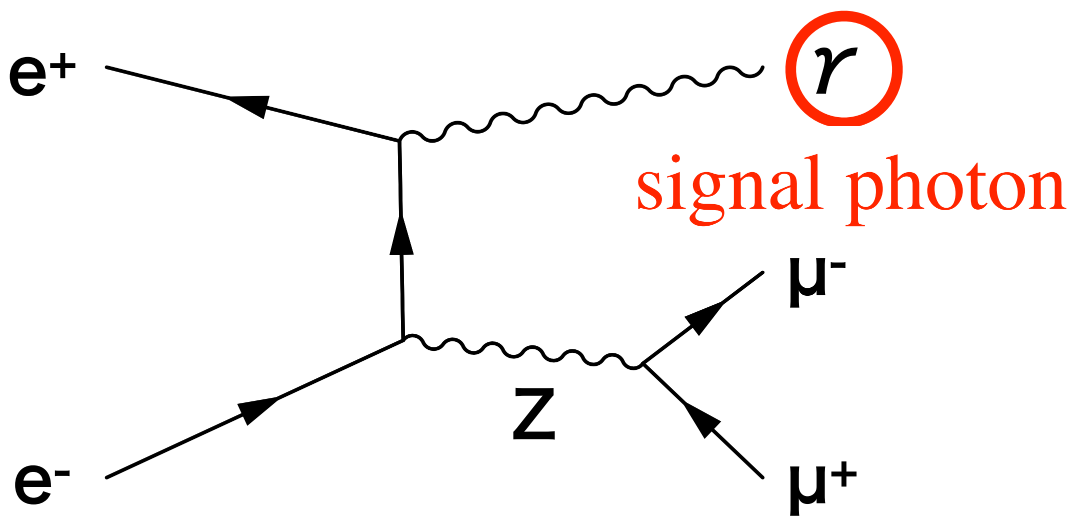
Primary Target of ILC 250: to precisely measure *<u>the coupling constants between Higgs boson and various other particles</u>*
-> For this, we need to precisely calibrate energy scales for various particles.

- In this talk, we focus on photon energy calibration, using the $e^+e^- \to \gamma Z$, $Z \to \mu^+\mu^-$ process.



Energy can be reconstructed, using measured direction of γ and μ^- , μ^+ information.

Reconstruction Method



- 4-momentum conservation is considered.
- The mass of muon is neglected.
- Several reconstruction methods (Method A, B, C) are considered.
- Consider Beamstrahlung and Crossing Angle

Direction Angle
θ: polar angle
ϕ: azimuthal angle

Method A: Using Only Angles

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

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

ISR photon = **additional** unseen photon

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

Reconstruction Method

Method B, C: Also using Muons' Energies
Using ($\theta_{\mu}-,\theta_{\mu}+,\theta_{\gamma},\varphi_{\mu}-,\varphi_{\mu}+,\varphi_{\gamma},E_{\mu}-,E_{\mu}+$) -> Determine ($E_{\gamma},E_{ISR}$)

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

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

Need to decide P_{ISR}. **This is of no use when $\cos\theta_{\gamma} = 0$**

- **Method C: Energy and Py Conservation**

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

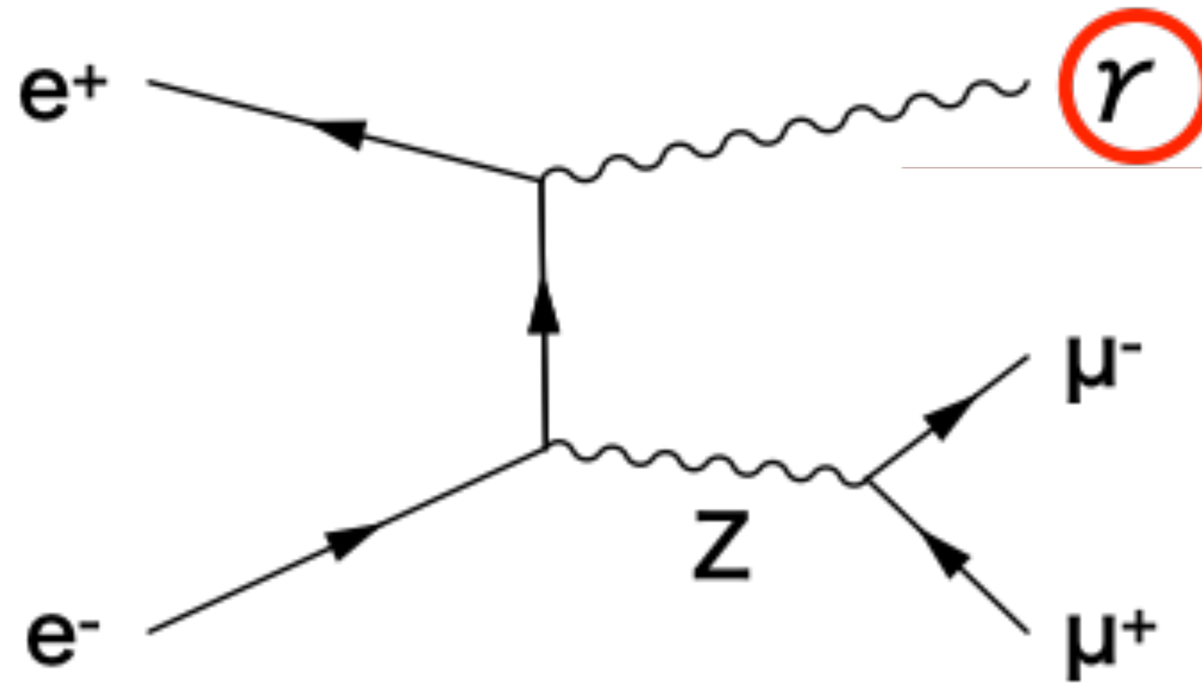
This is of no use when $\sin\theta_{\gamma}$ or $\sin\varphi_{\gamma}=0$??

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

Simulation Setup

Full simulation (ILCSOFT version v02-00-02)

- geant4 based realistic detector simulation
- realistic event reconstruction from detector signals.
- With beamstrahlung and additional ISR photon effects



Signal sample: $e^+e^- \to \gamma Z$, $Z \to \mu^+\mu^-$

E_{CM} of e^+e^- is 500 GeV.

Two detector models are considered and compared:

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

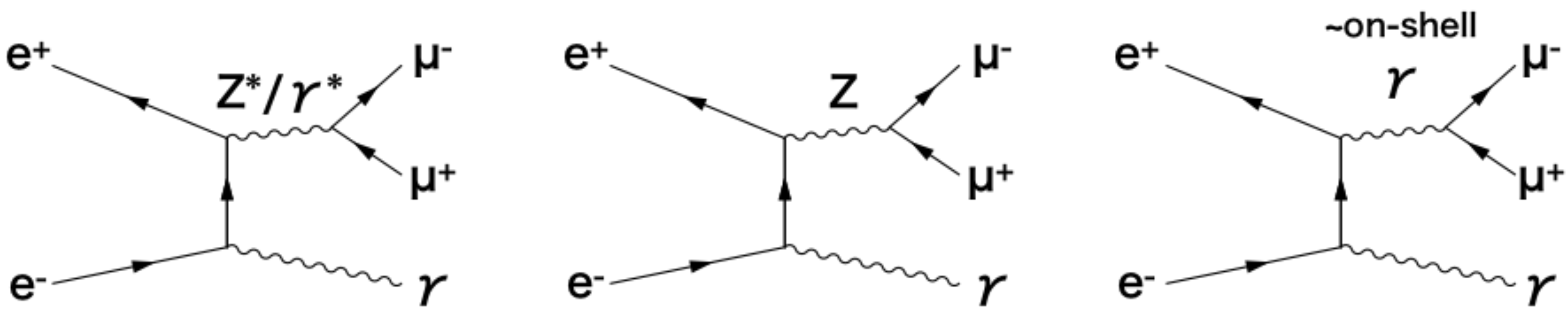
Small ILD model (IDR-S)
TPC outer radius: 146 cm
B Field ~4 T

Event Selection

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

In order to pick up our required process, following cuts are applied.

<u>Step1</u>: Select events with two isolated muons.
-> 3 types of events remain:



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

Event Selection

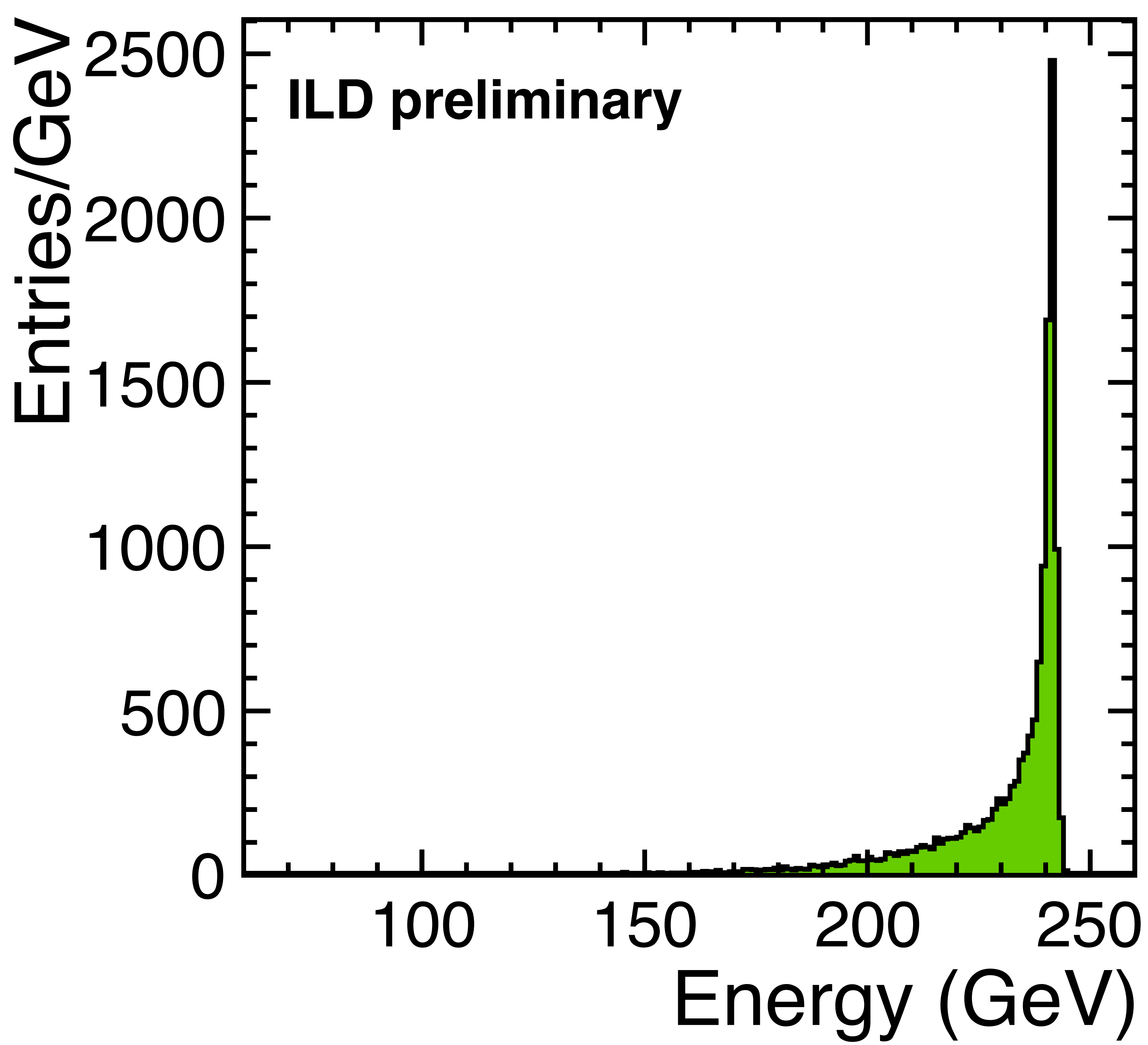
Step2:

- Require invariant mass of two muons M(μ+μ−) to satisfy $|M(\mu^+\mu^-) - 91.2| < 10$ GeV

Step3:

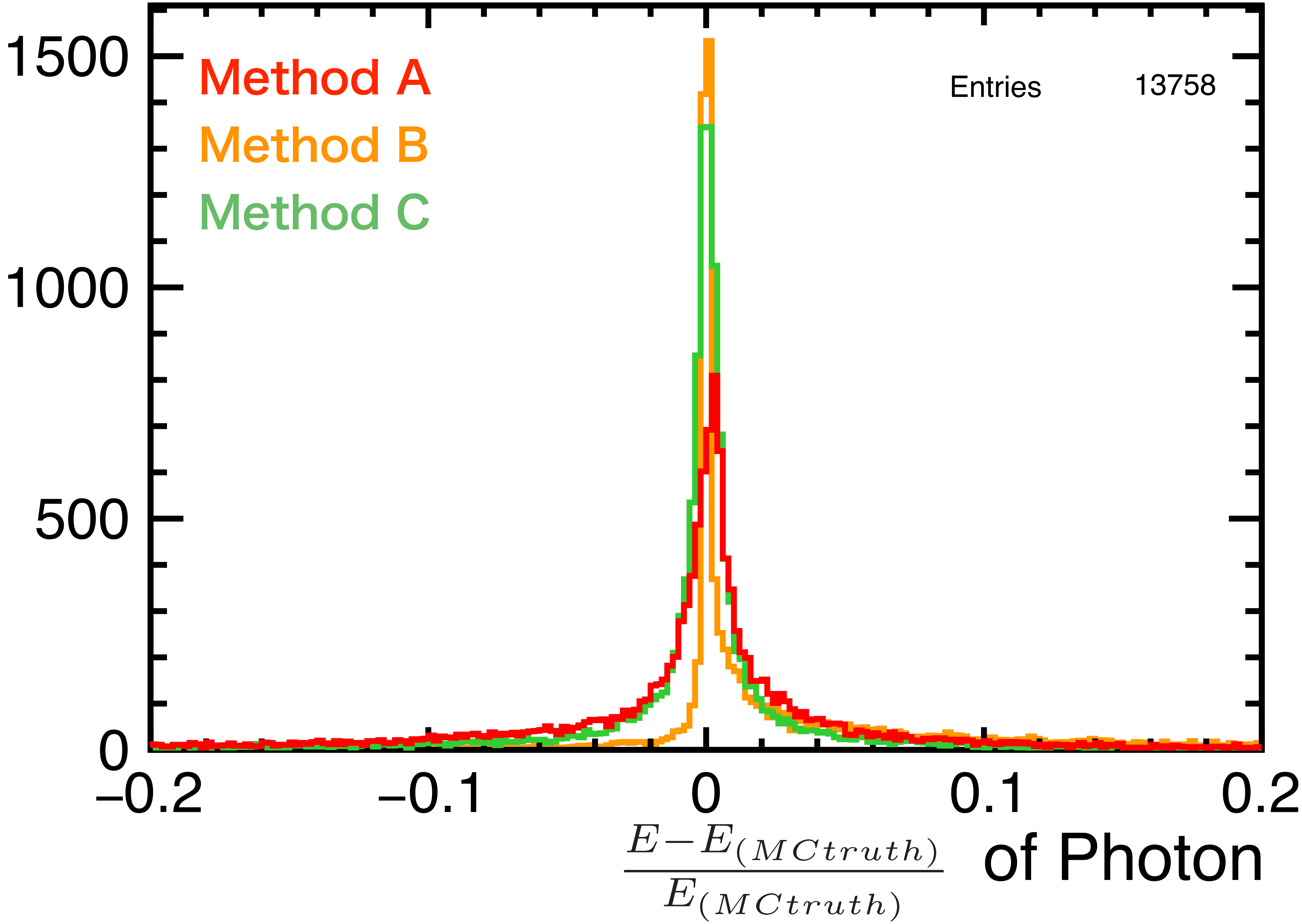
- Demand events to have one isolated photon with more than 50 GeV

MCTruth Energy of Photon



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

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



Method Comparison

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

Samples:
|M(μ+μ-)-91.2| < 10 GeV
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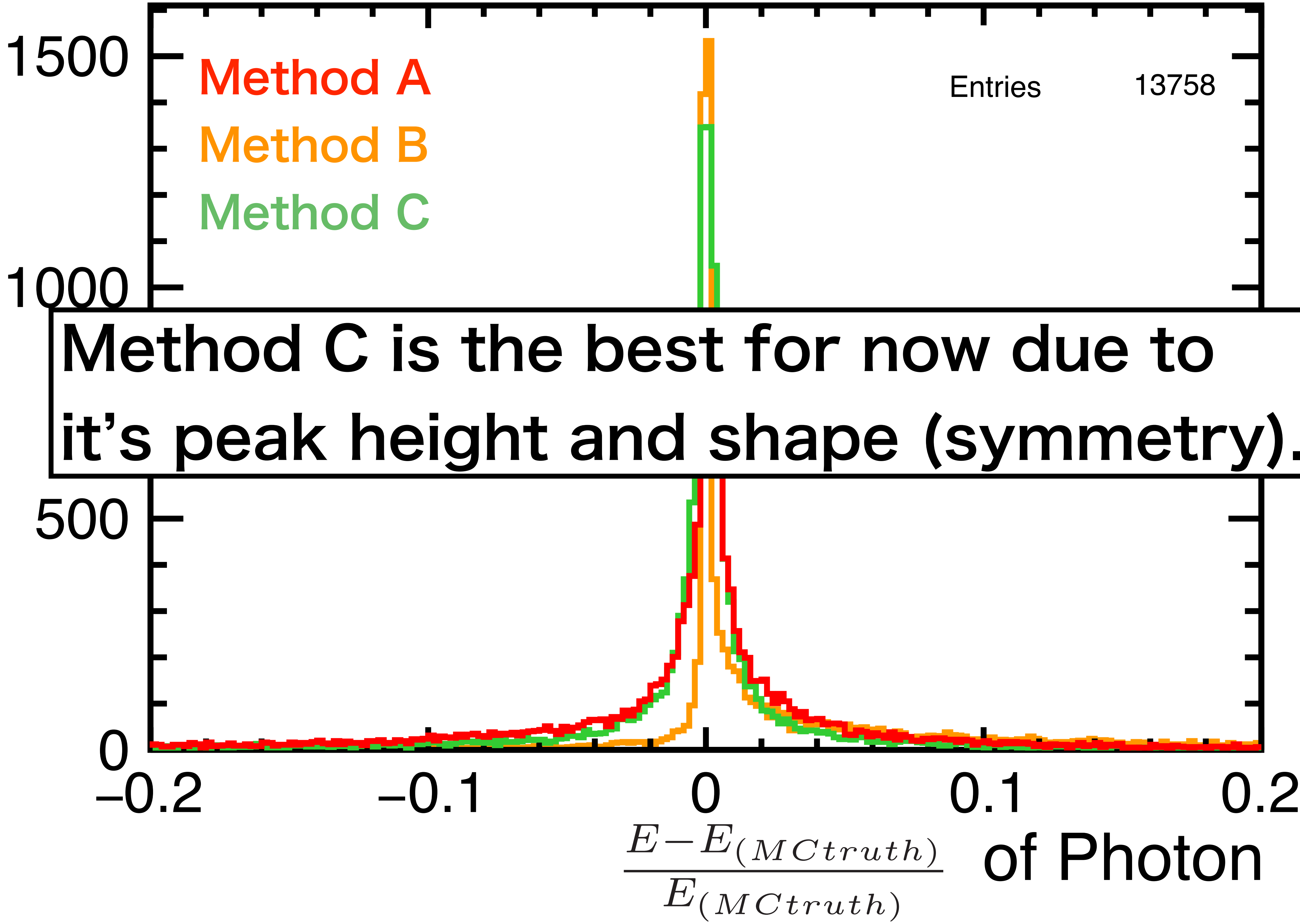

Method C is the best for now due to it's peak height and shape (symmetry).

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

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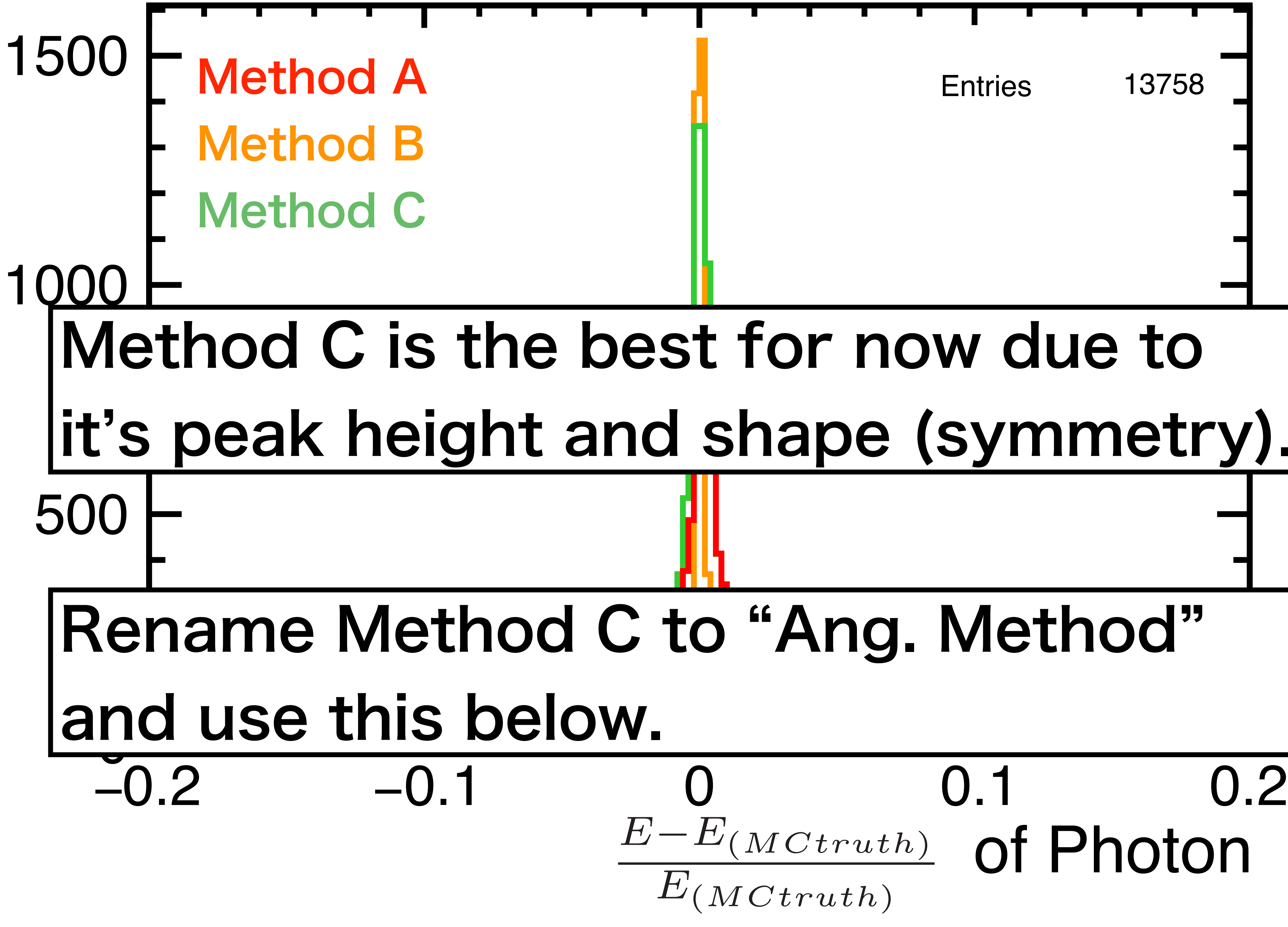
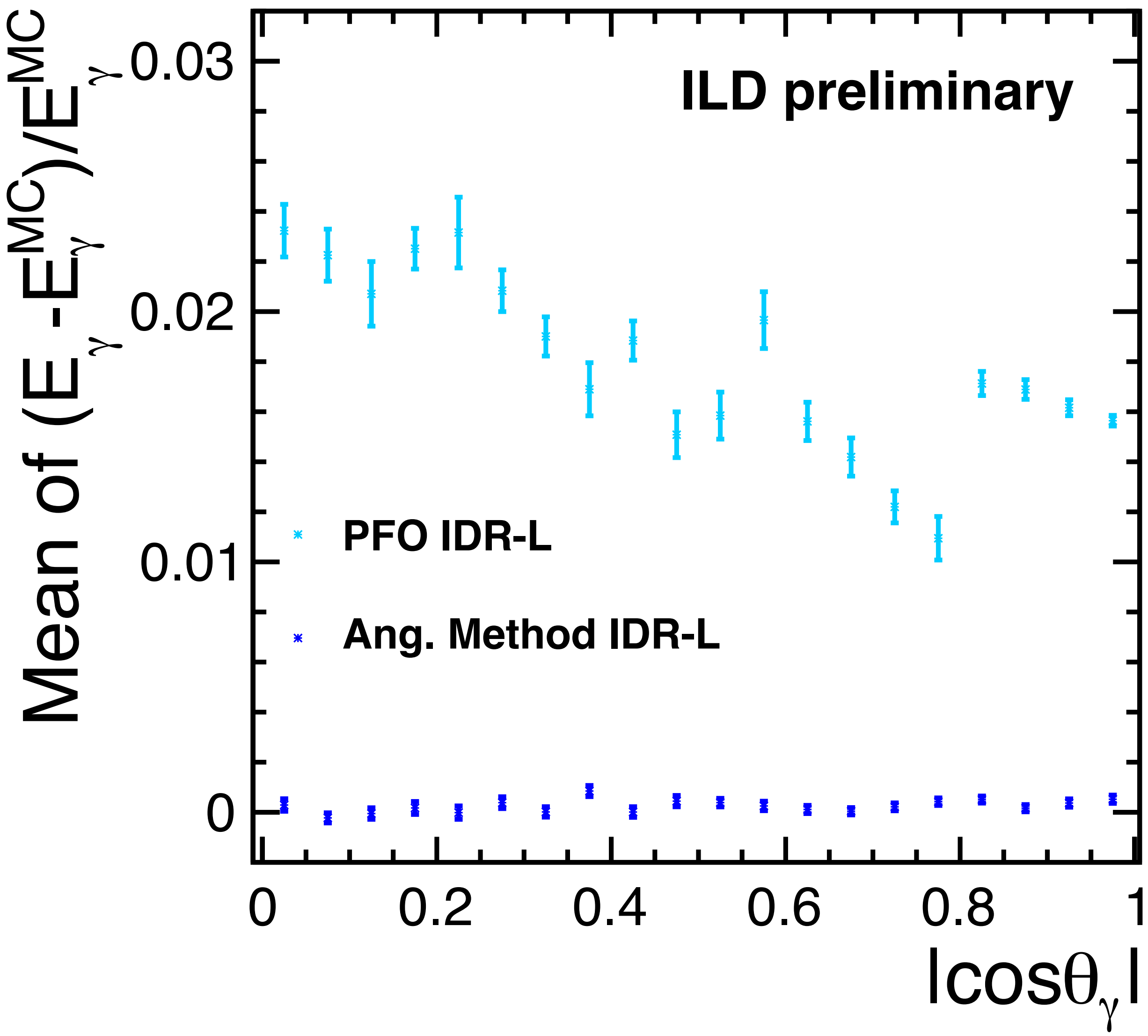


Method C is the best for now due to it's peak height and shape (symmetry).

Rename Method C to "Ang. Method" and use this below.

Calibration of the Measured Energy

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



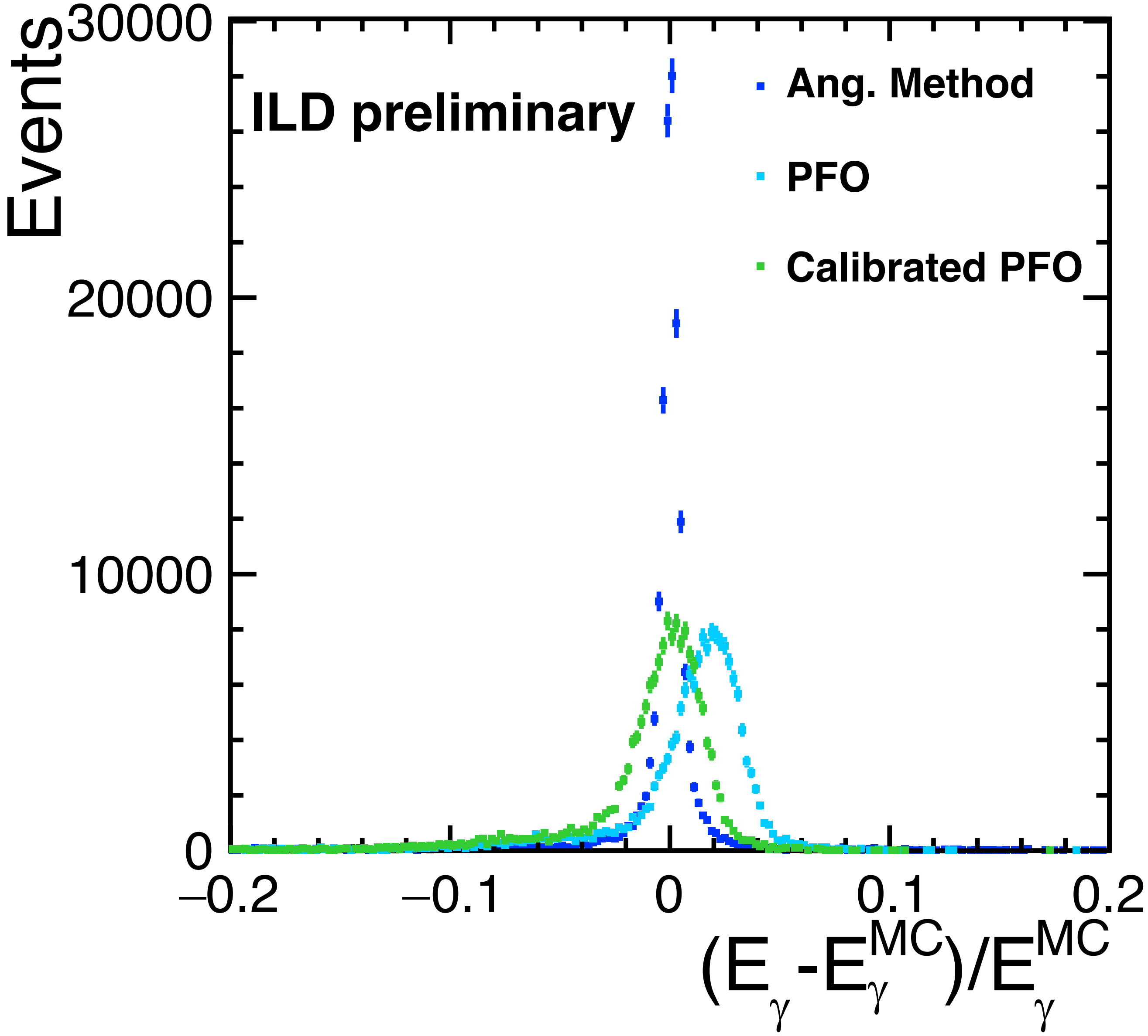
-> PFO energy data is divided into 20 groups by the value of $|\cos\theta_\gamma|$.
Calibration is performed by each value range of $|\cos\theta_\gamma|$.

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

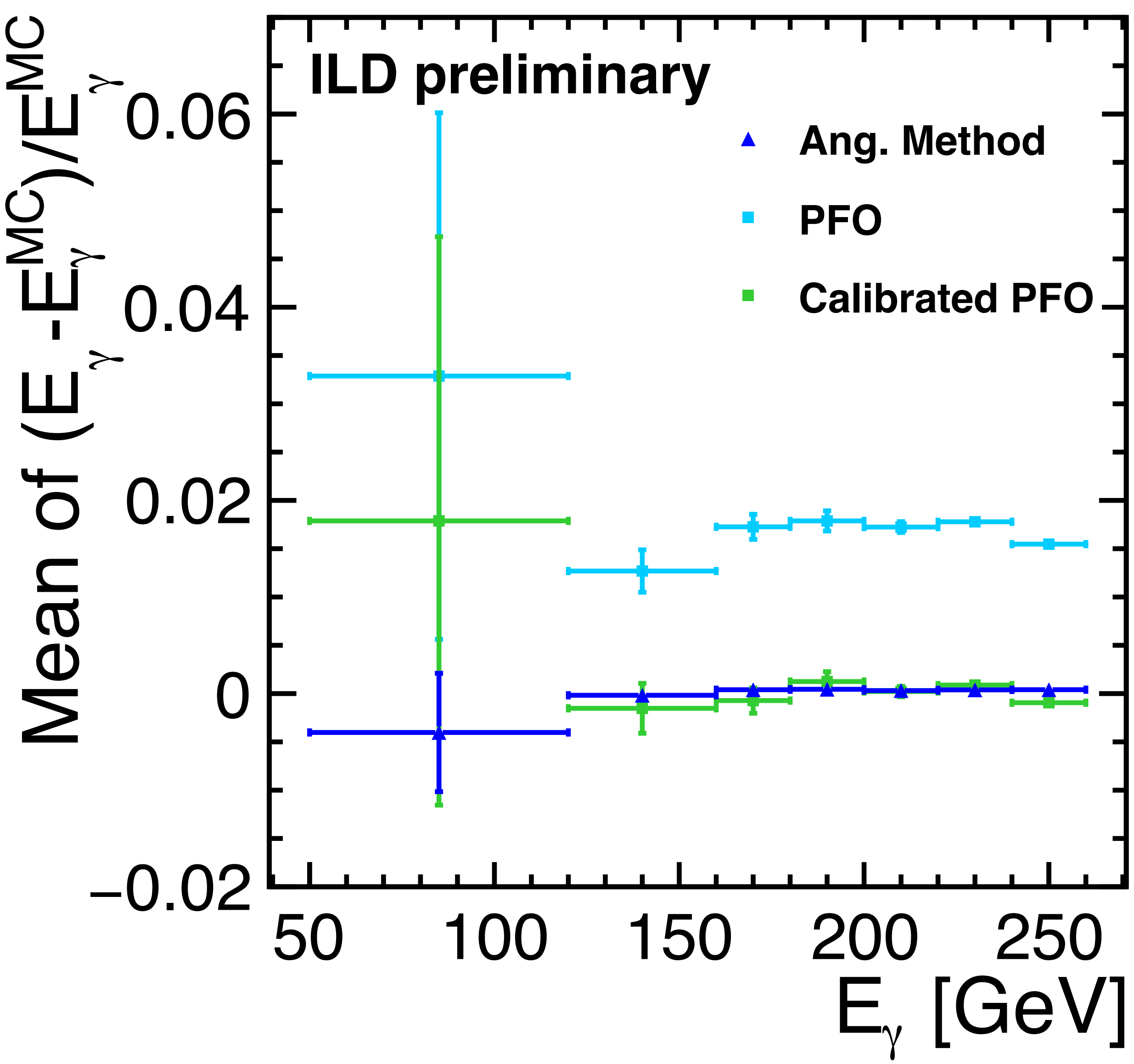
$$Calibrated\ PFO\ Energy = PFO\ Energy \times Calibration\ Factor\ (\theta_\gamma)$$

Calibration Result

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



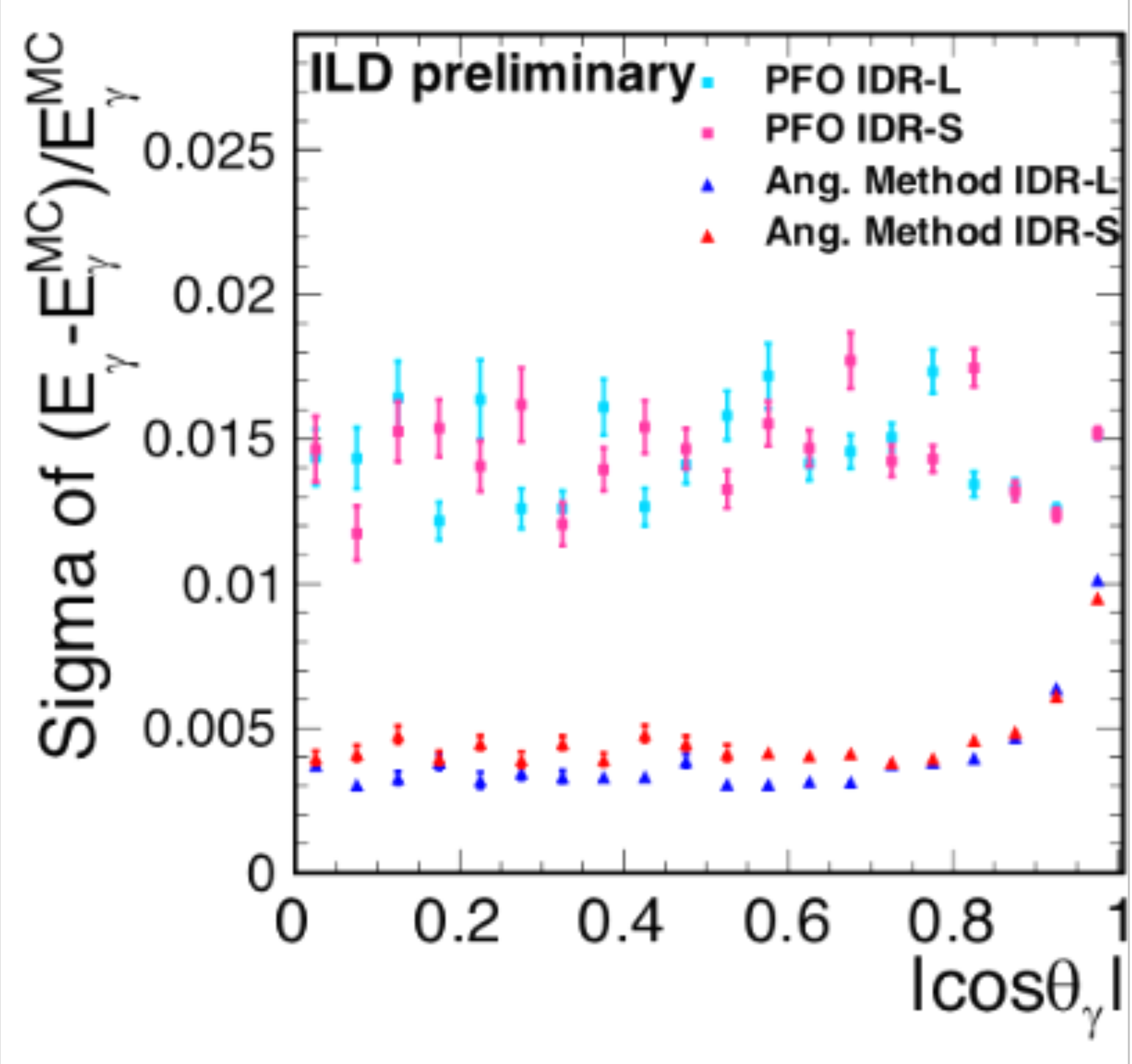
Mean of $(E-E_{MC})/E_{MC}$ dependence on E_γ

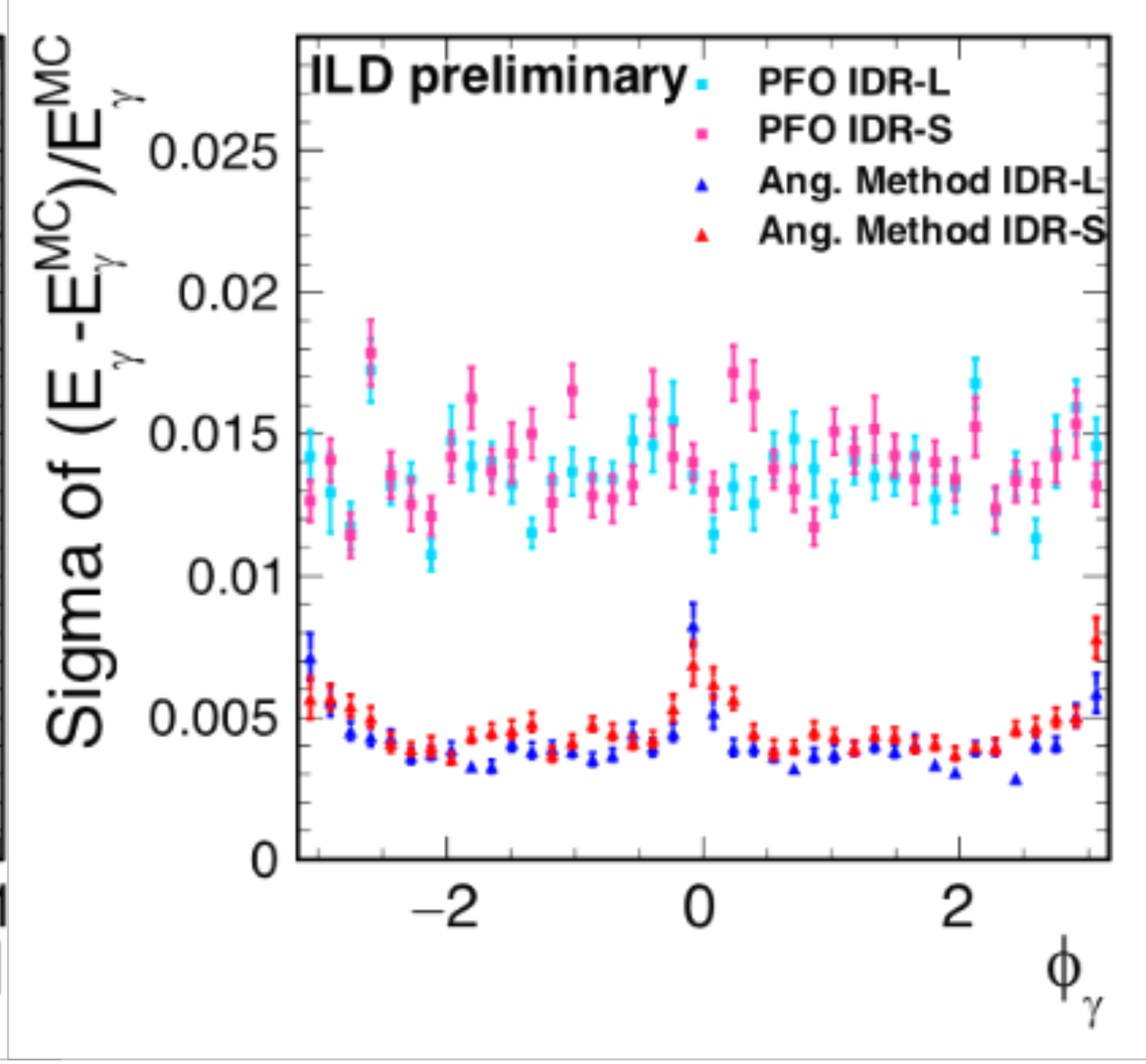


Demonstration of the Validity of Ang. Method

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

dependence on φ_γ



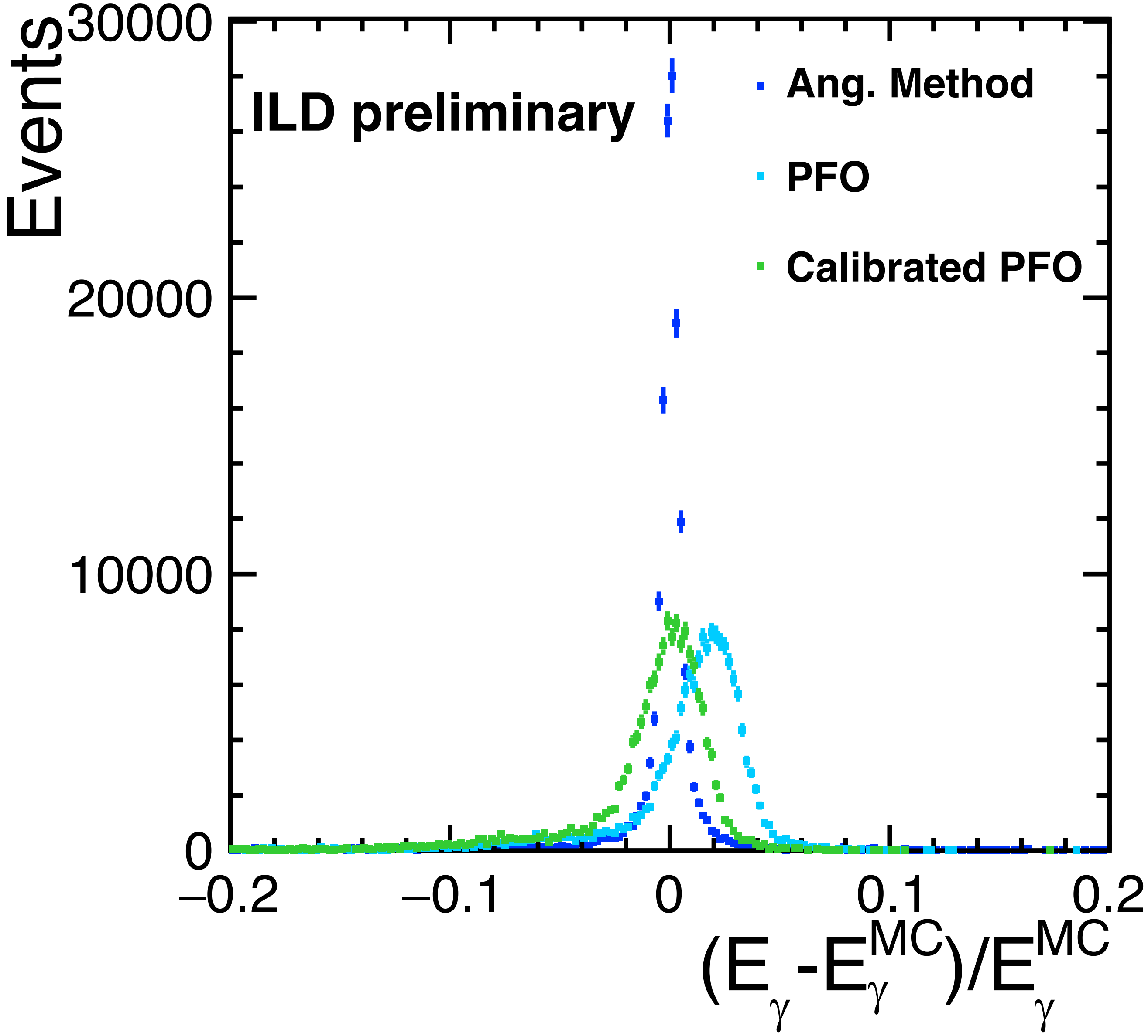


$|\cos\theta\gamma| < 0.95$

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

Calibration Result

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



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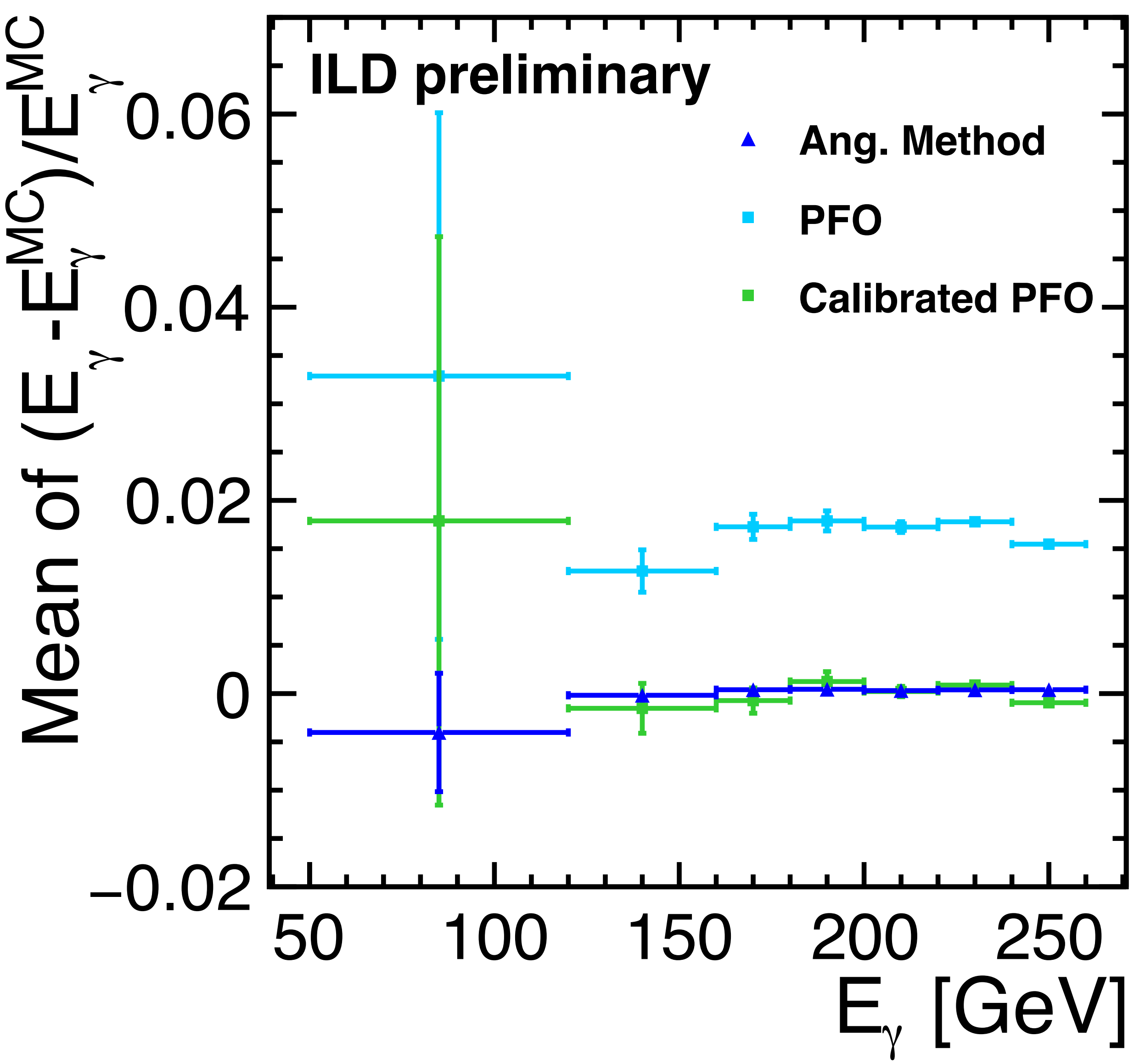
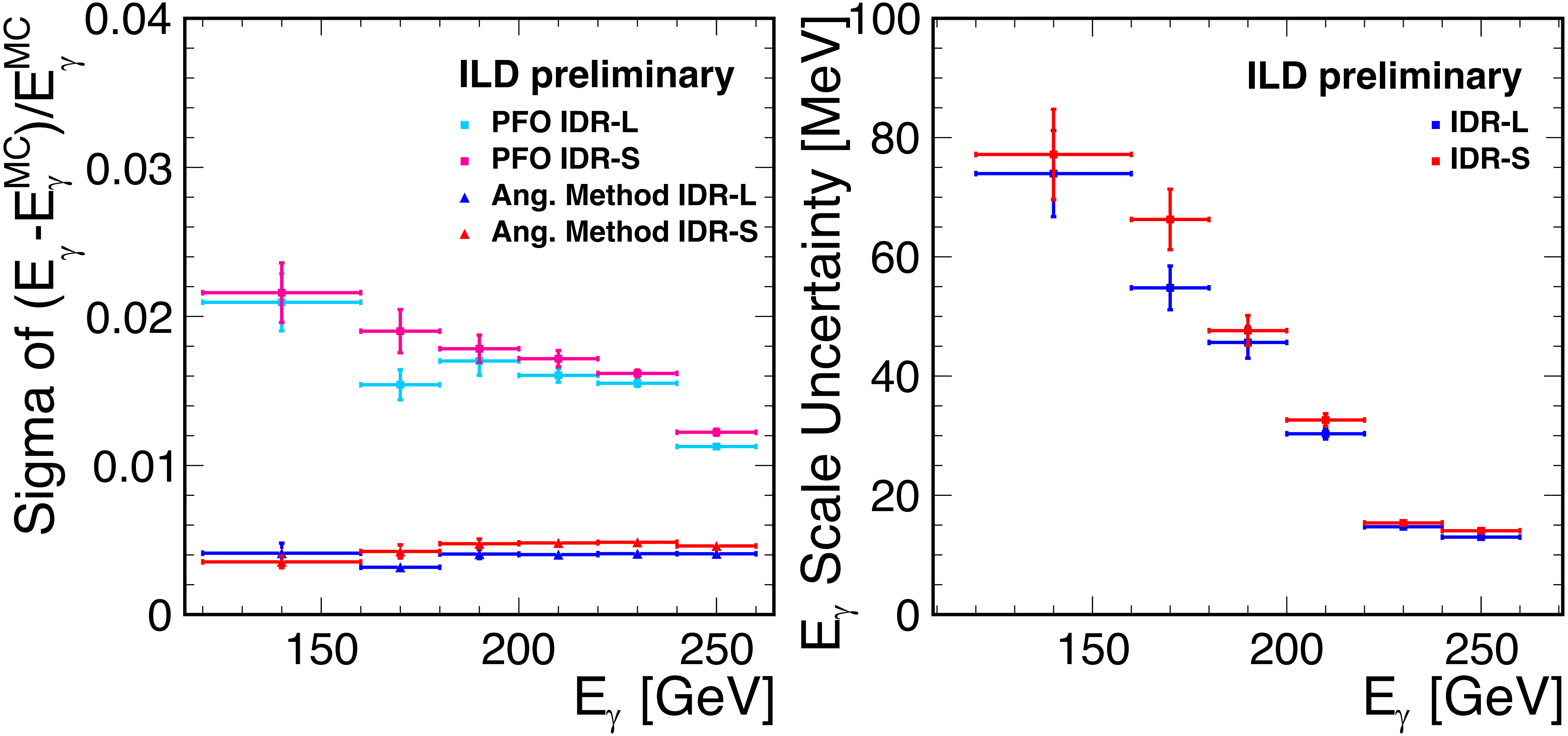


E_γ Scale Uncertainty

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

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

E_γ Scale Uncertainty

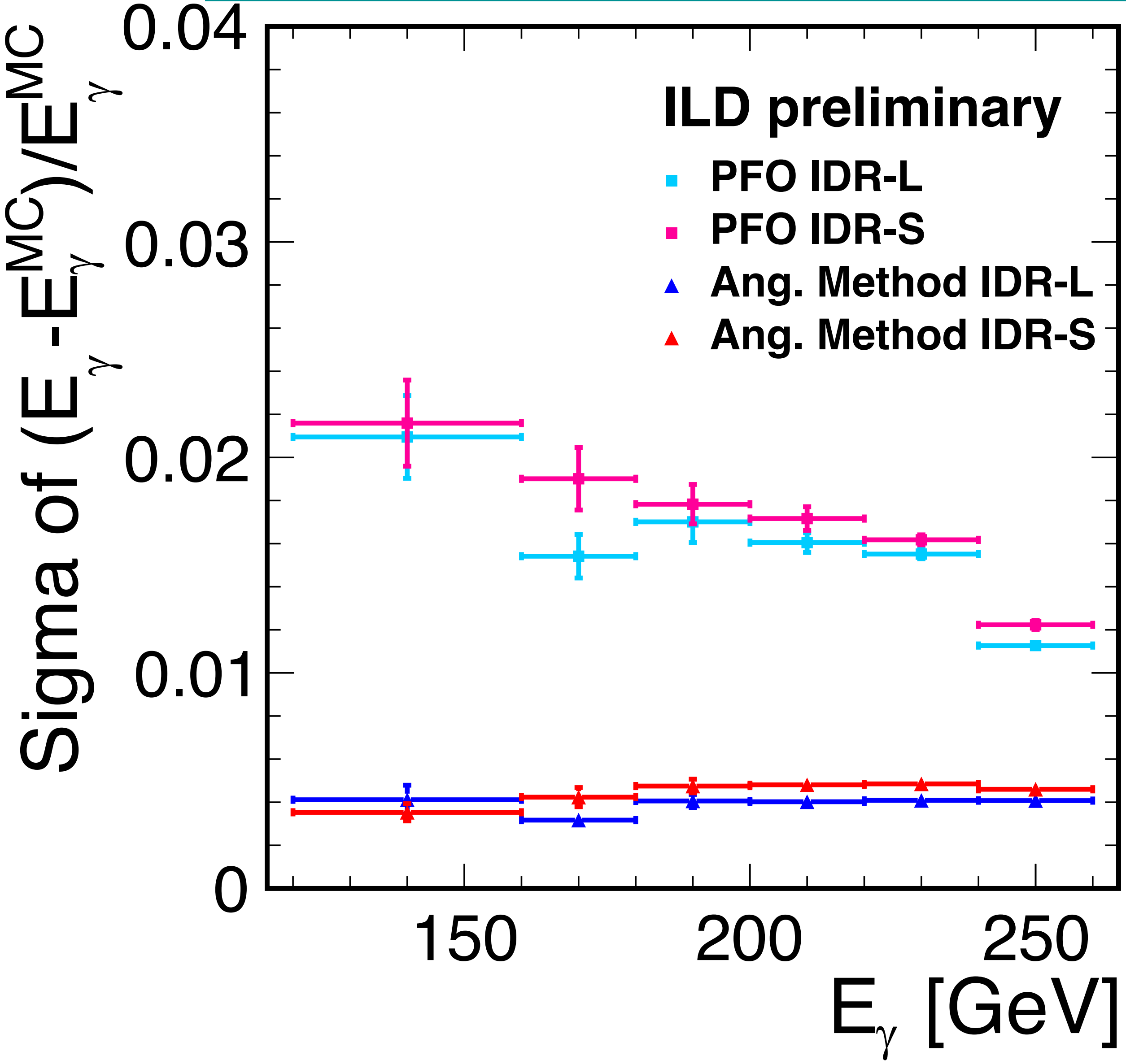


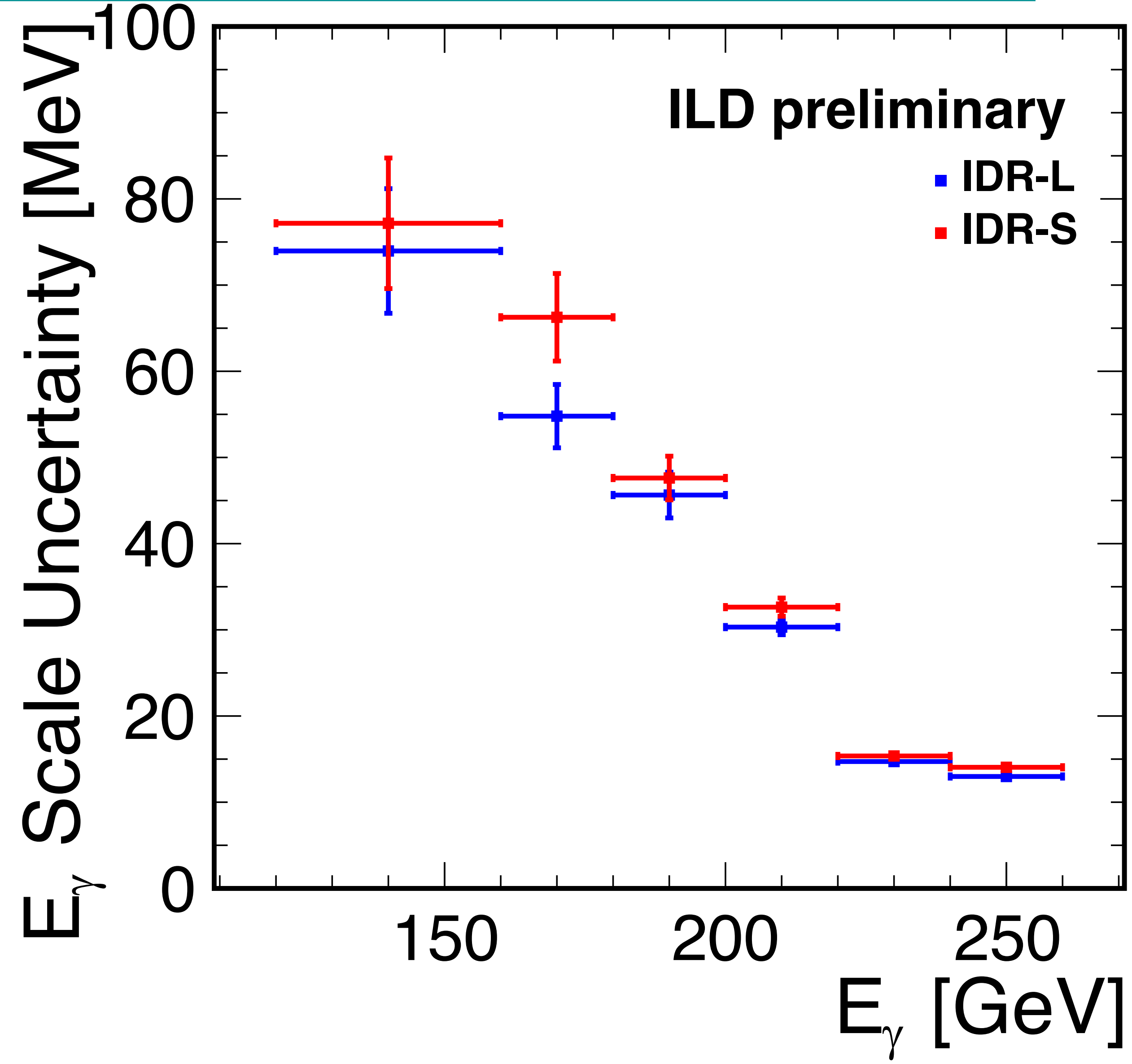
E_γ Scale Uncertainty

- E_γ

S

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





Conclusion

- The methods to calibrate photon energy using e^+e^- -> γZ process are studied.

- Among the kinematical reconstruction methods studied, the Ang. Method is found to be the best due to its good resolution and its symmetric response.

- The resolution of the photon energy kinematically reconstructed by the Ang. Method is better than that of the PFO photon energy for $|\cos\theta_\gamma| < 0.95$ and $\pi/40 < |\varphi_\gamma| < 39\pi/40$.

- We have hence shown that in this region, PFO photon energy can be calibrated using Ang. Method.

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