Benchmark Analysis for e+e- -> gamma Z process

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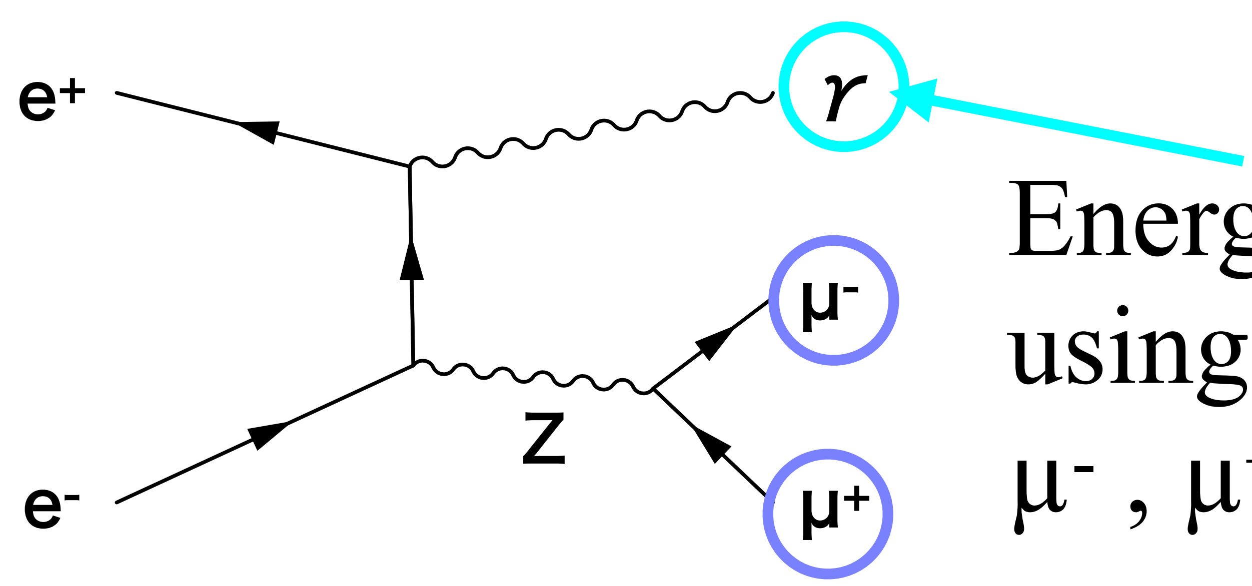
Introduction

Detector Benchmark Motivation

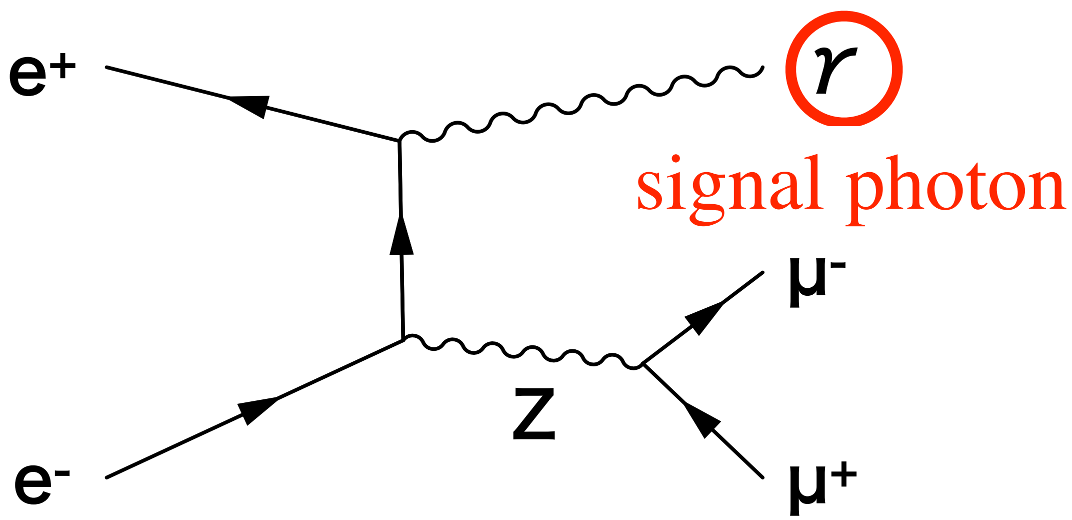
Primary Target of ILC 250: to precisely measure ***the coupling constants between Higgs boson and various other particles***
-> For this, we need to precisely calibrate energy scales for various particles.

- In this talk, we focus on photon energy calibration, using the $e^+e^- \rightarrow \gamma Z$, $Z \rightarrow \mu^+\mu^-$ 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 ($\equiv 2\alpha$)

α = 7.0 mrad

Reconstruction Method

Method B, C: Also 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 B: Energy and Pz Conservation**

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

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

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

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

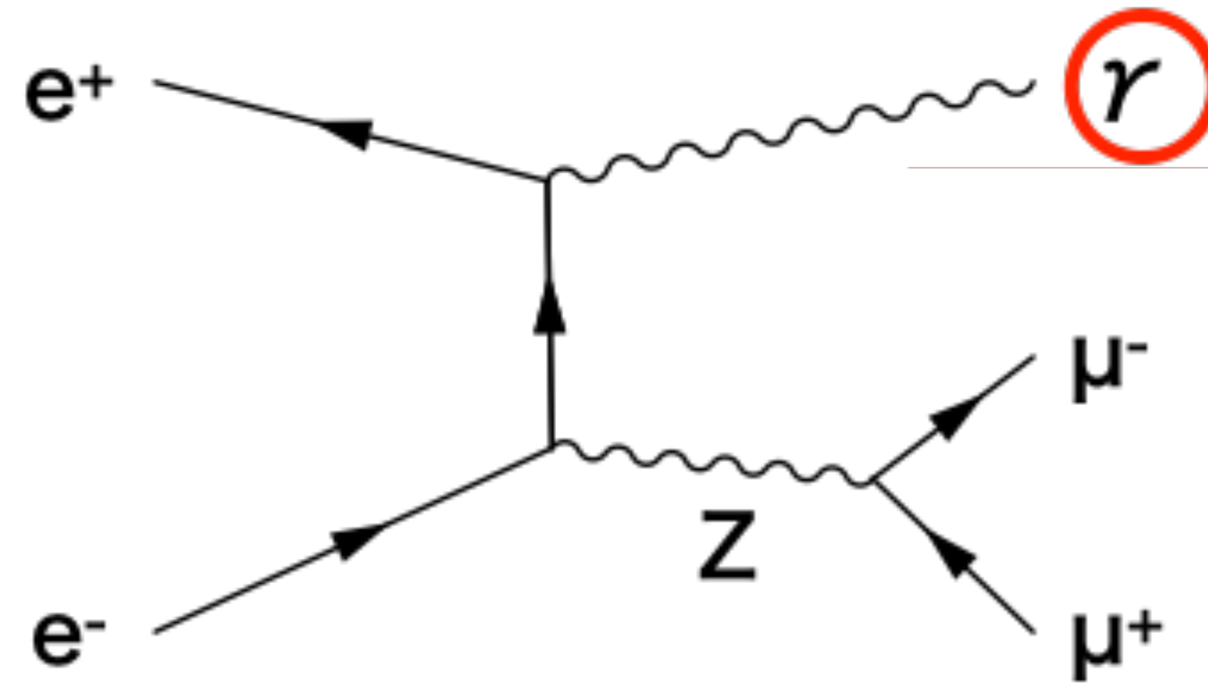
This is of no use when $sin\theta_\gamma$ or $sin\varphi_\gamma$=0 ??

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

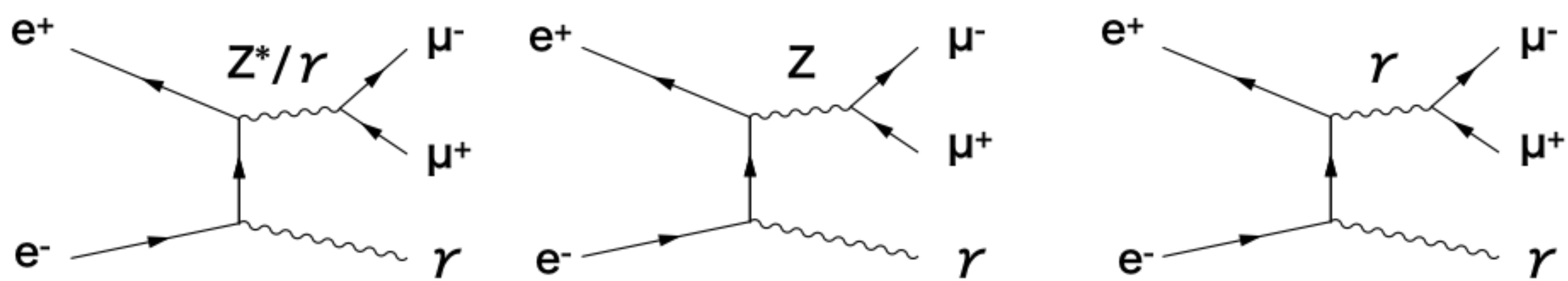
Small ILD model (IDR-S)
TPC outer radius: 146 cm
B Field ~4 T

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.

Step1: 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

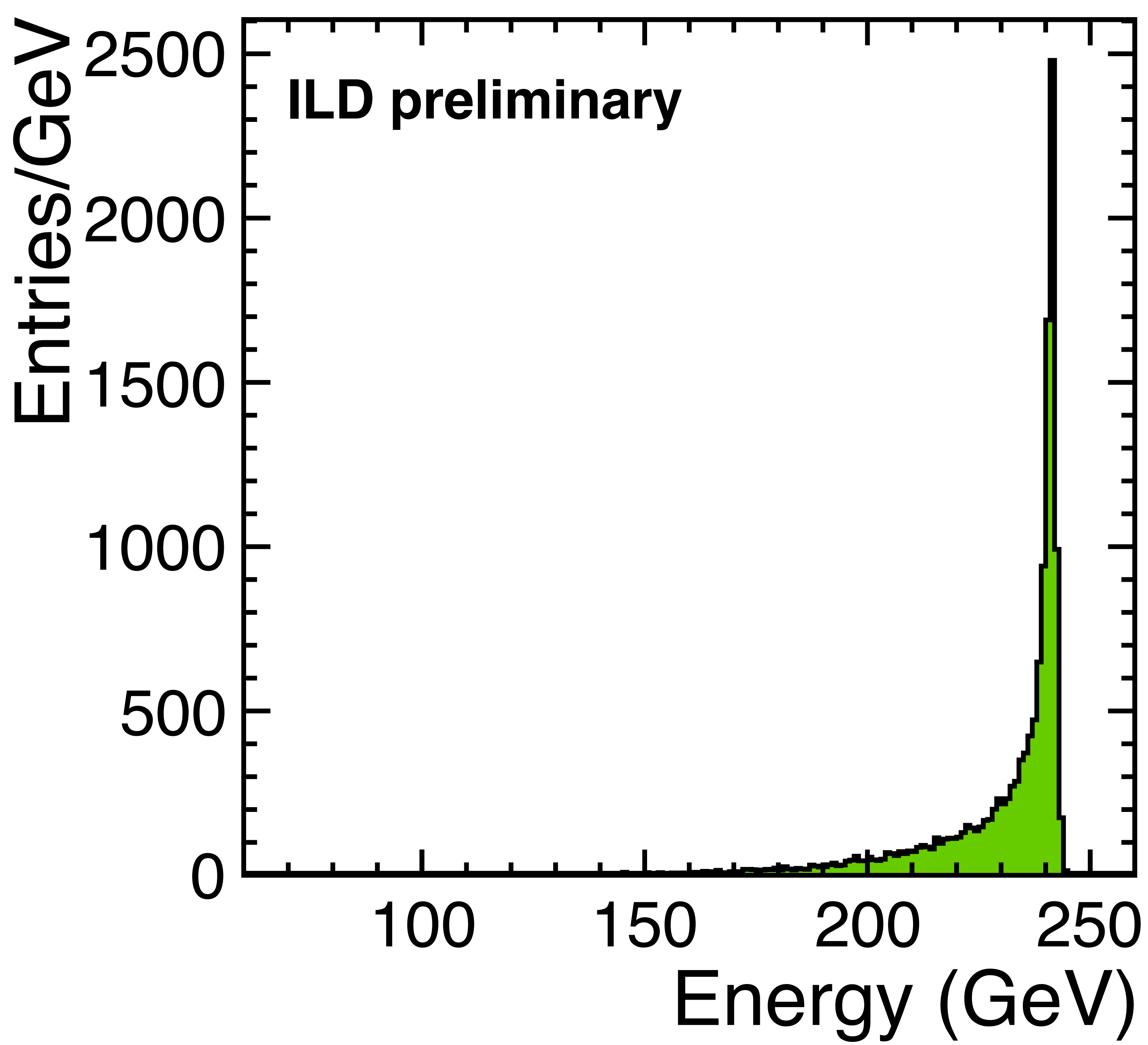
Step2:

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

Step3:

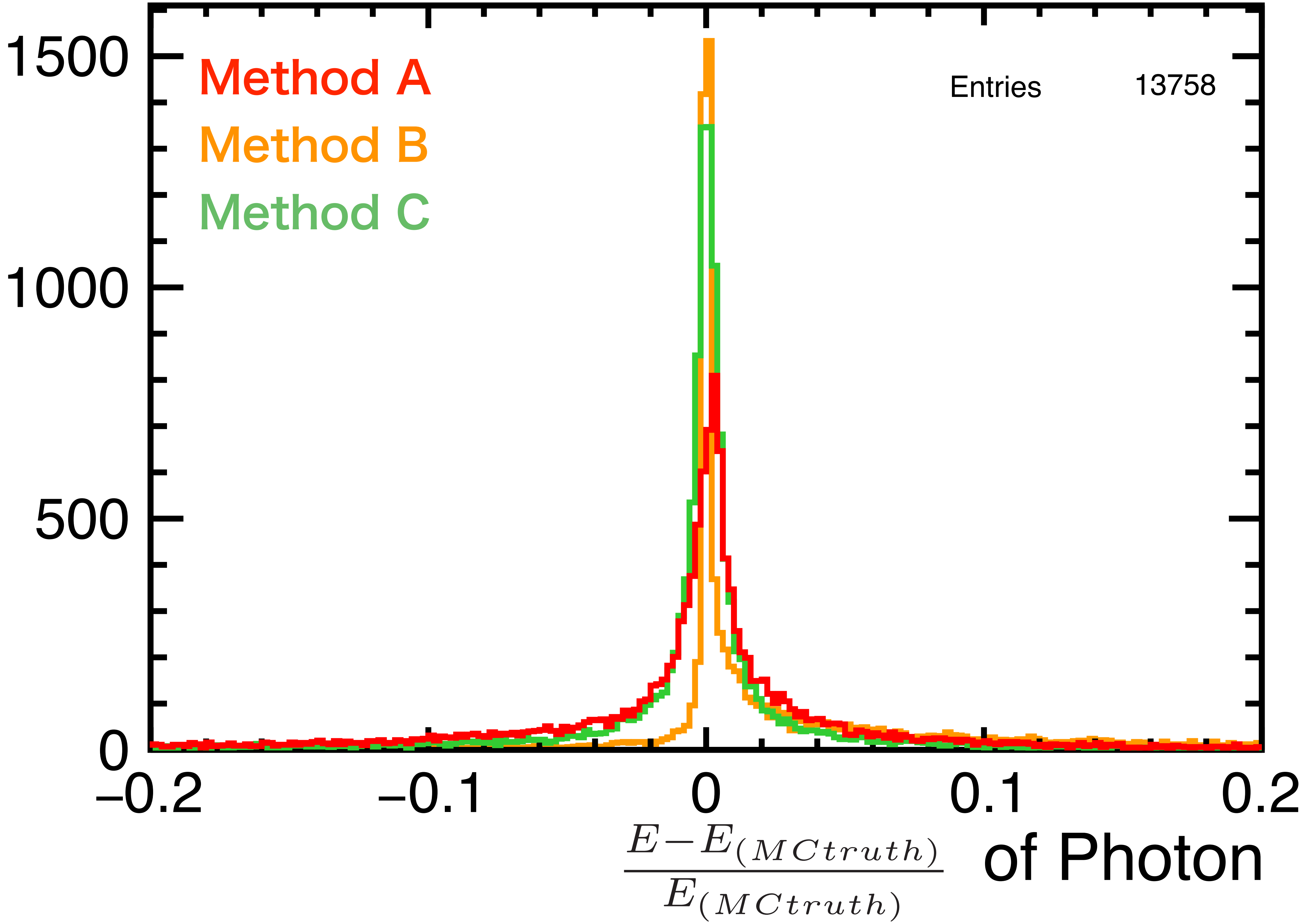
- Demand events to have one isolated photon with more than 50 GeV

MCTruth Energy of Photon



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

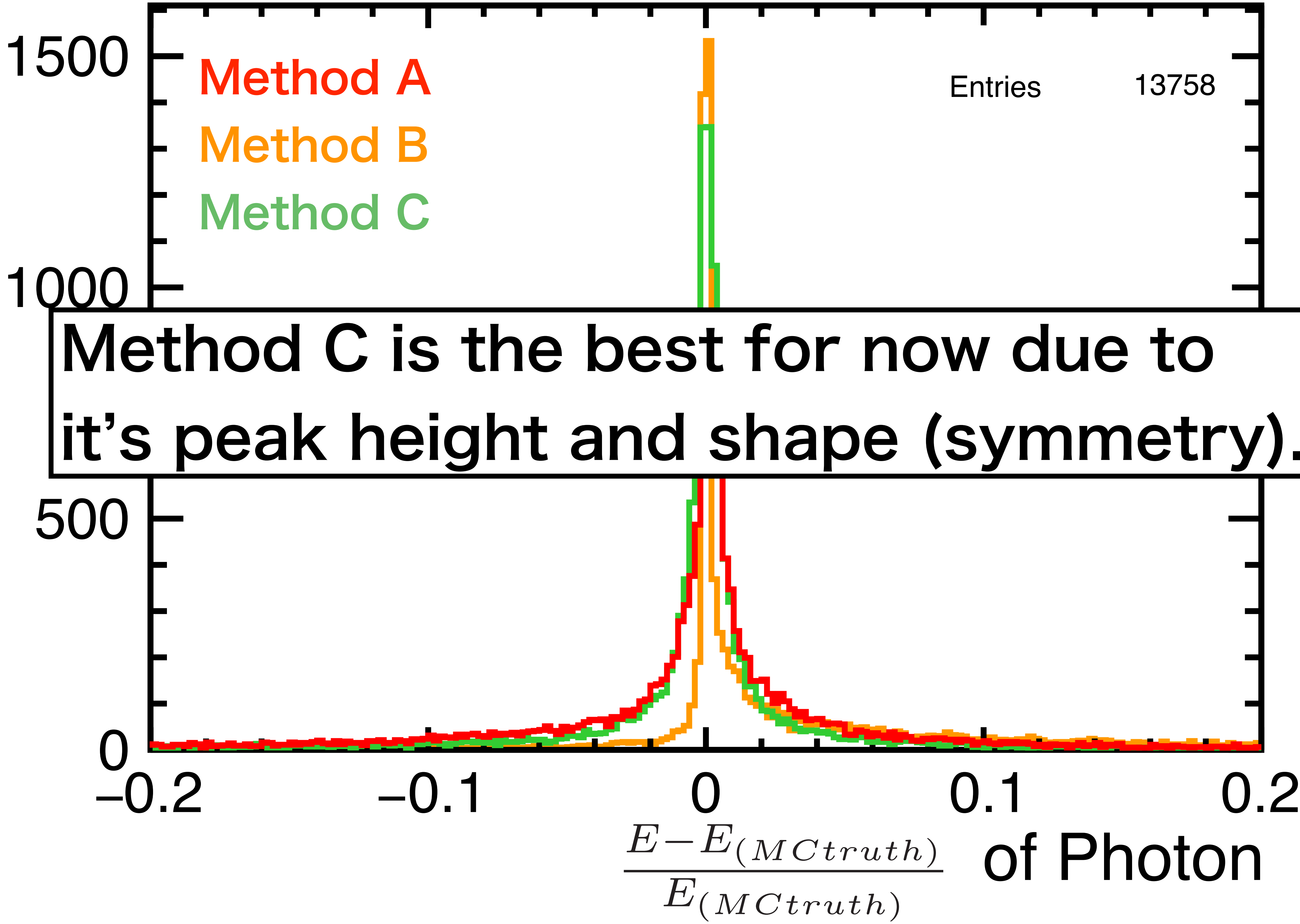
Samples:
|M(μ+μ-)-91.2| < 10 GeV
Large ILD model



Method Comparison

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

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



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

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|M(μ+μ-)-91.2| < 10 GeV
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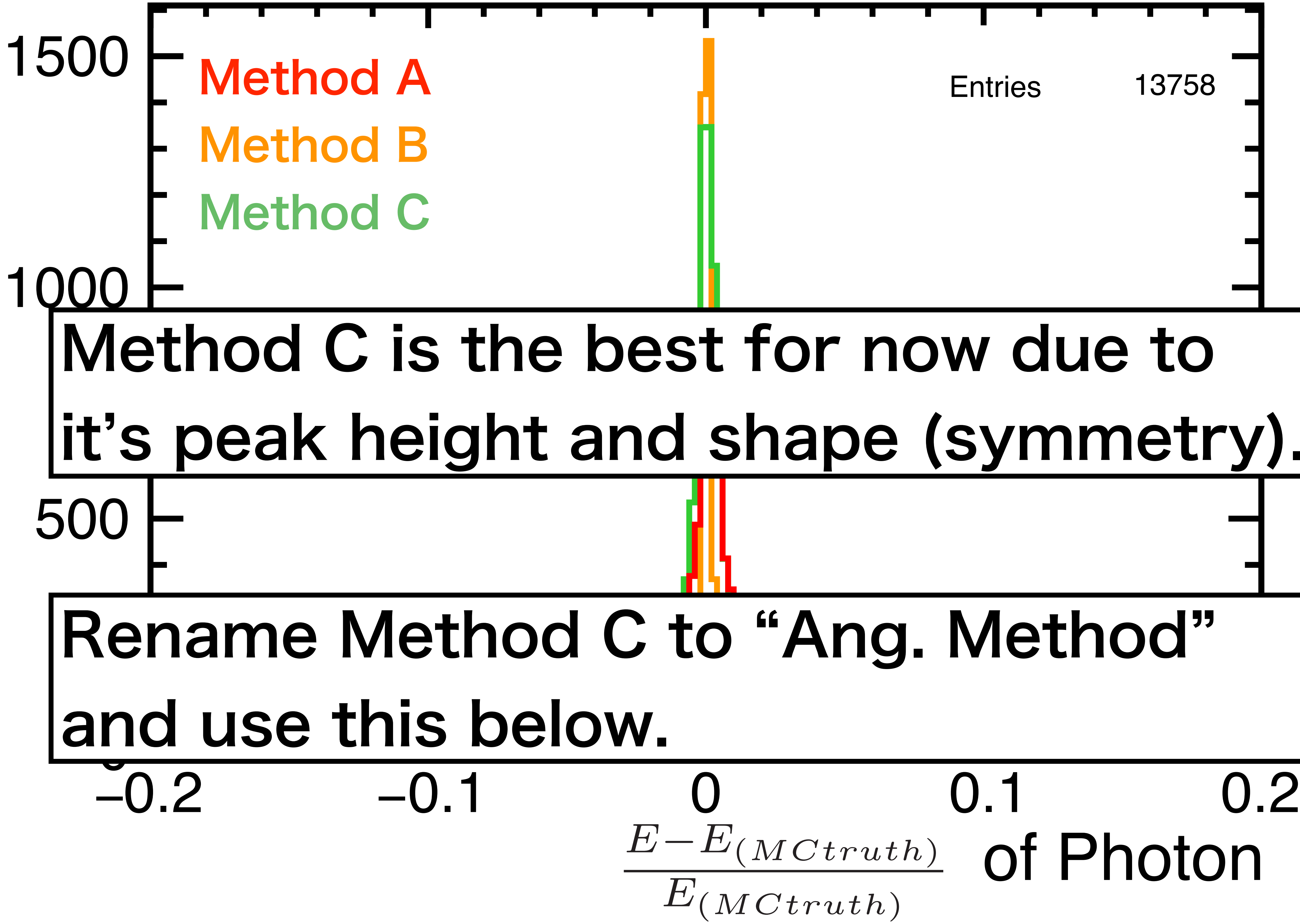


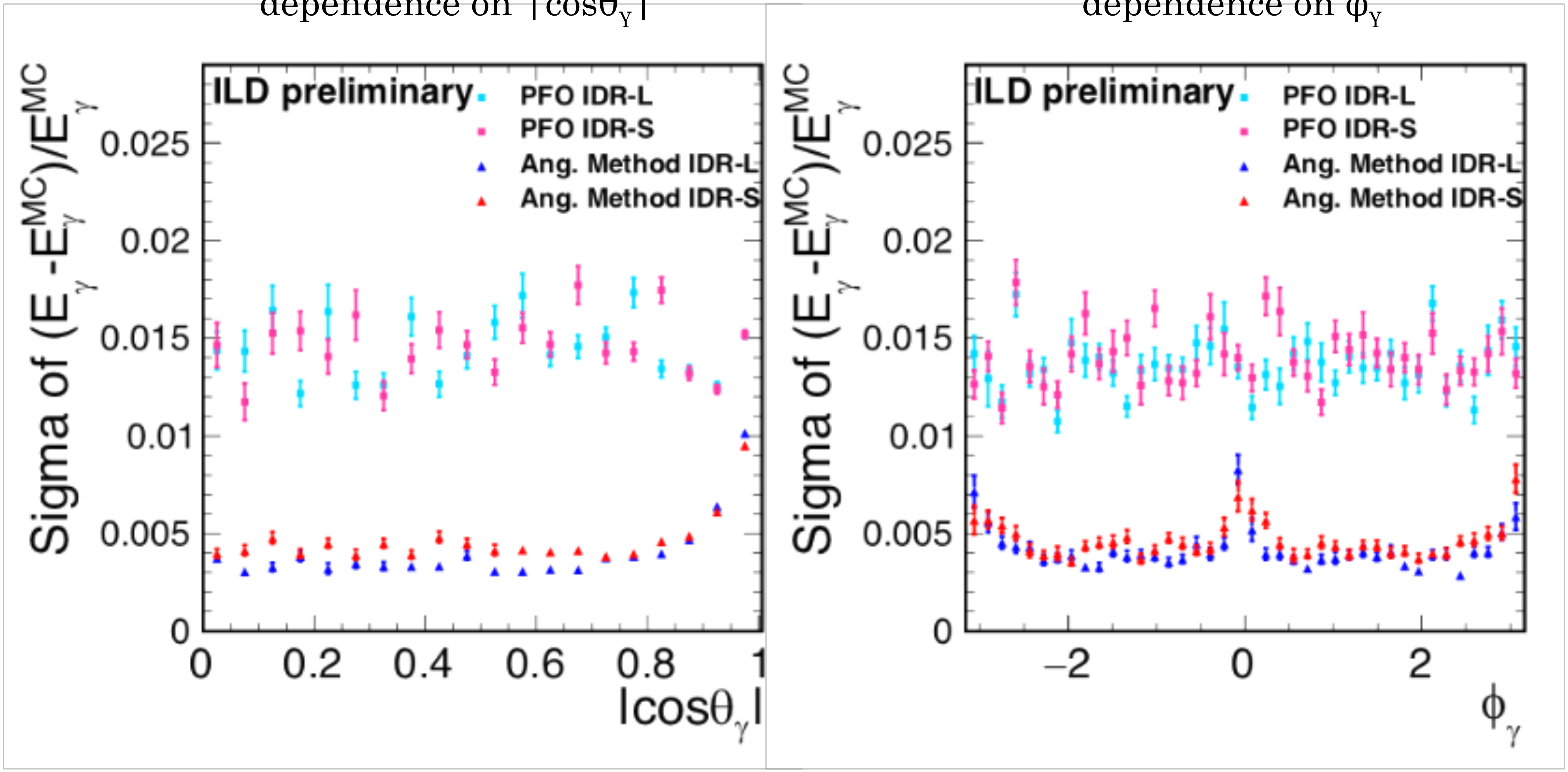
Method C is the best for now due to it's peak height and shape (symmetry).

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

Demonstration of the Validity of Ang. Method

Sigma of $(E-E_{MC})/E_{MC}$

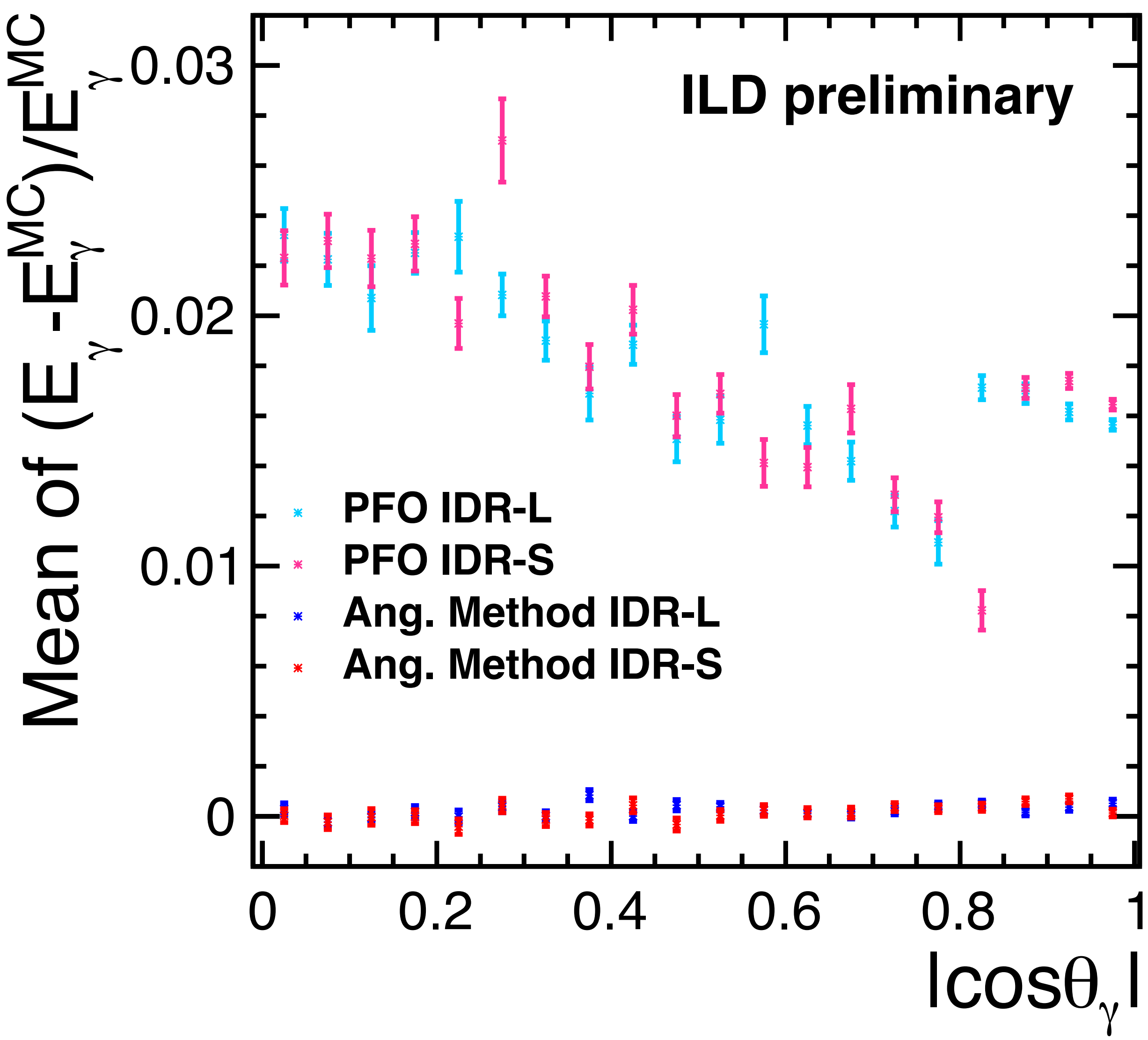
dependence on $|\cos\theta_\gamma|$ dependence on φ_γ



$|\cos\theta\gamma| < 0.95$ $\pi/40 < |\phi\gamma| < 39\pi/40$

Calibration of the Measured Energy

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



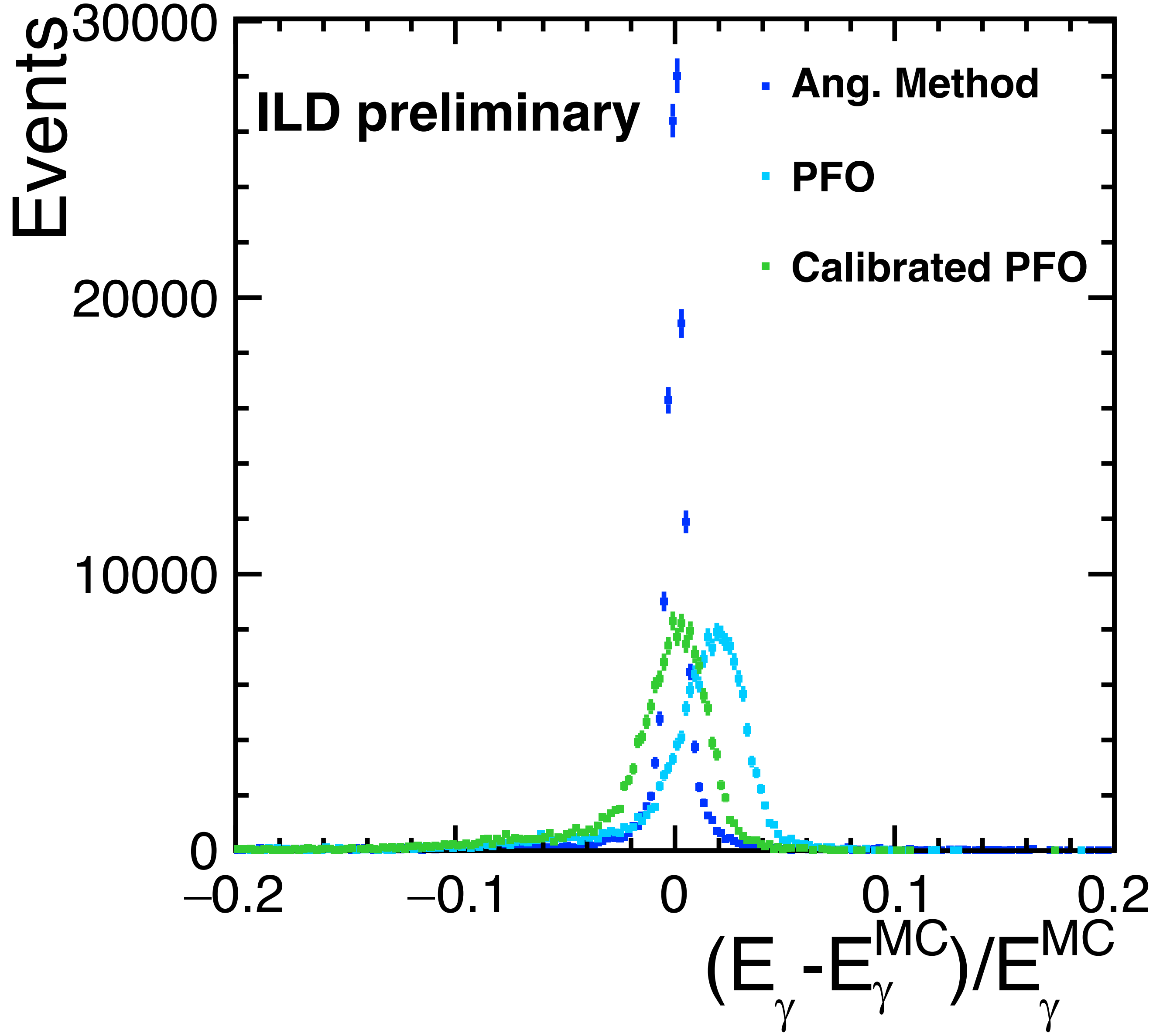
-> PFO energy data is divided into 20 groups by the value of $|\cos\theta_\gamma|$.
Calibration is performed by each value range of $|\cos\theta_\gamma|$.

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

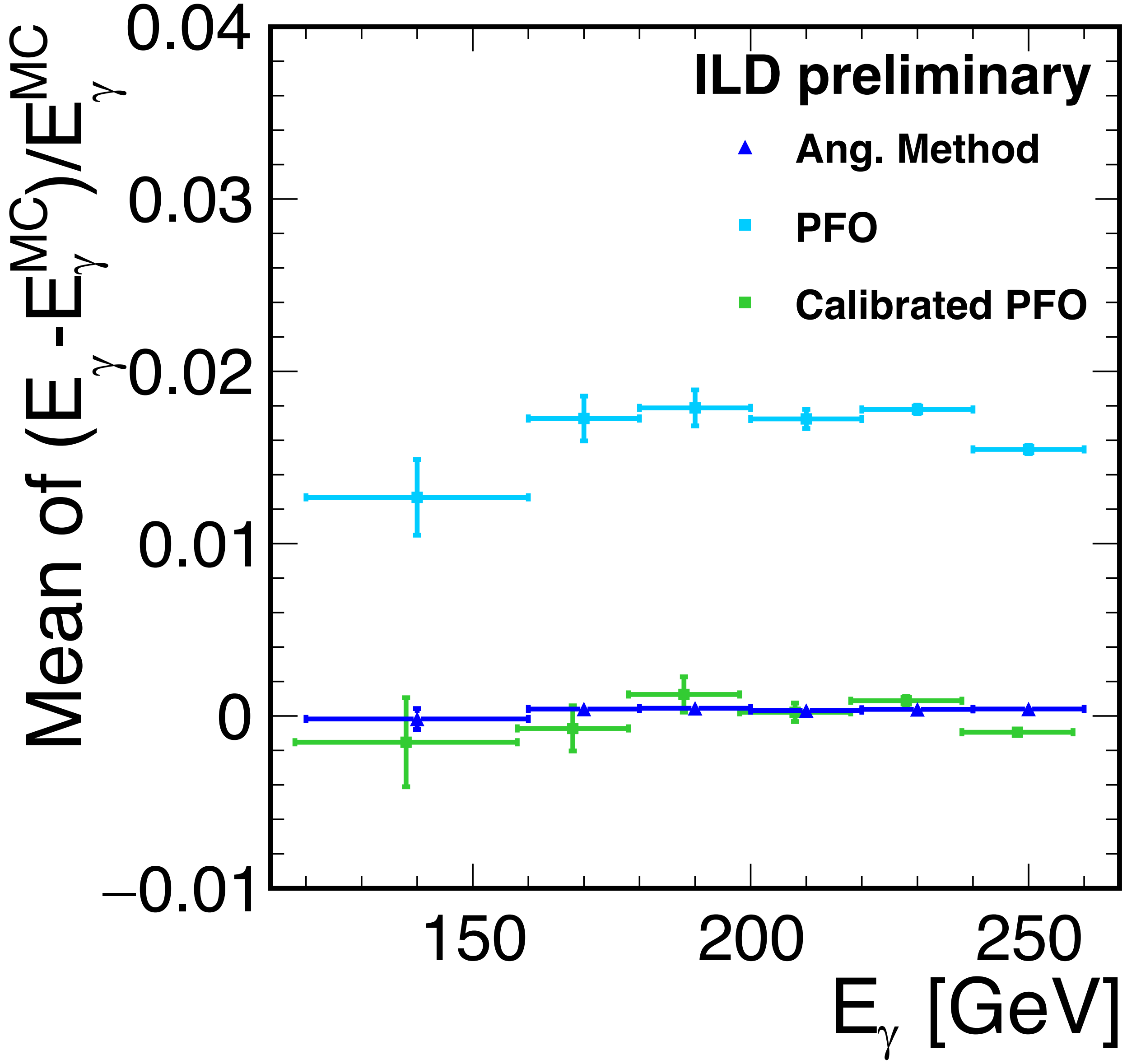
$$Calibrated\ PFO\ Energy = PFO\ Energy \times Calibration\ Factor\ (\theta_\gamma)$$

Calibration Result

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



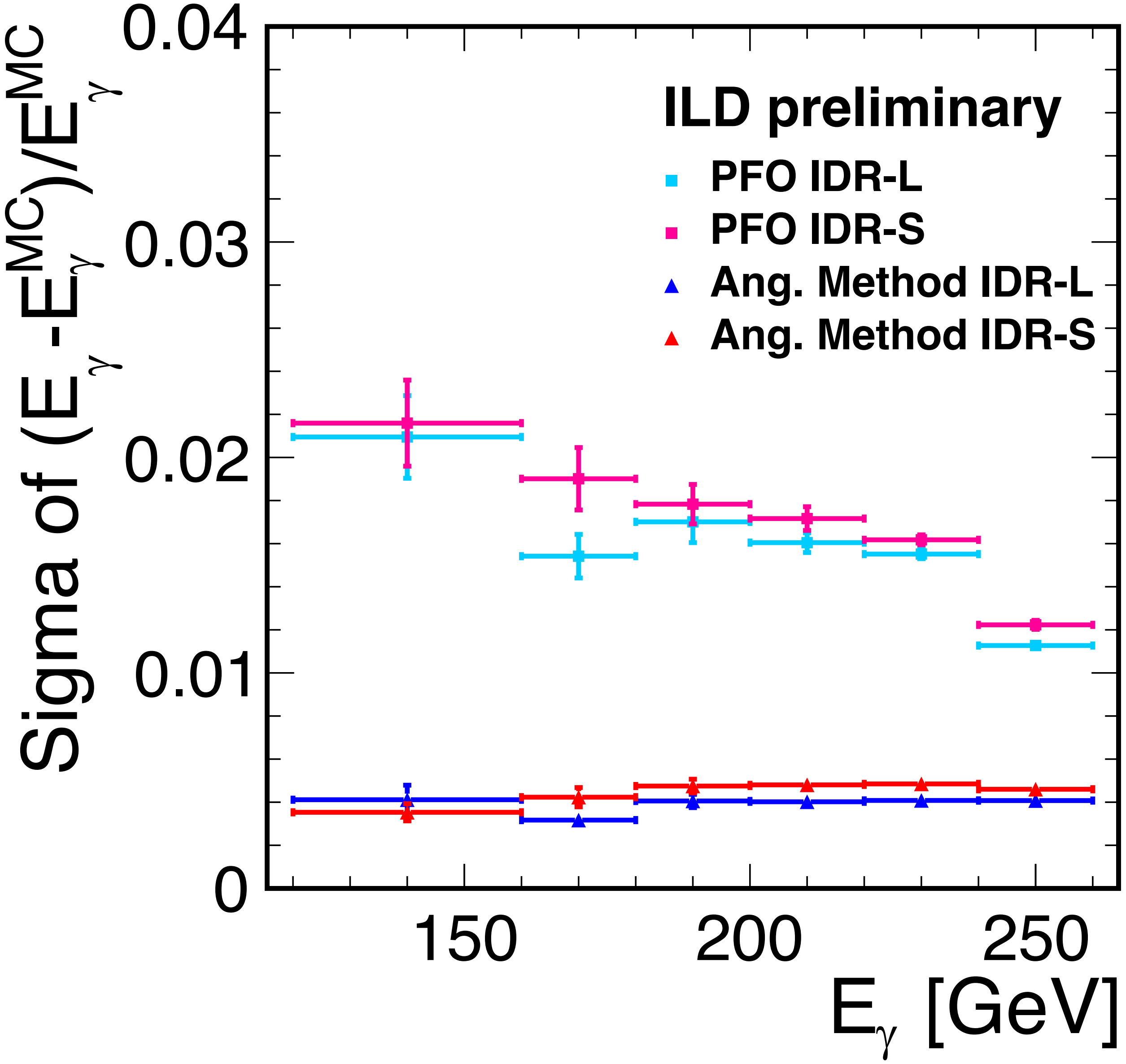
Mean of $(E-E_{MC})/E_{MC}$ dependence on E_γ



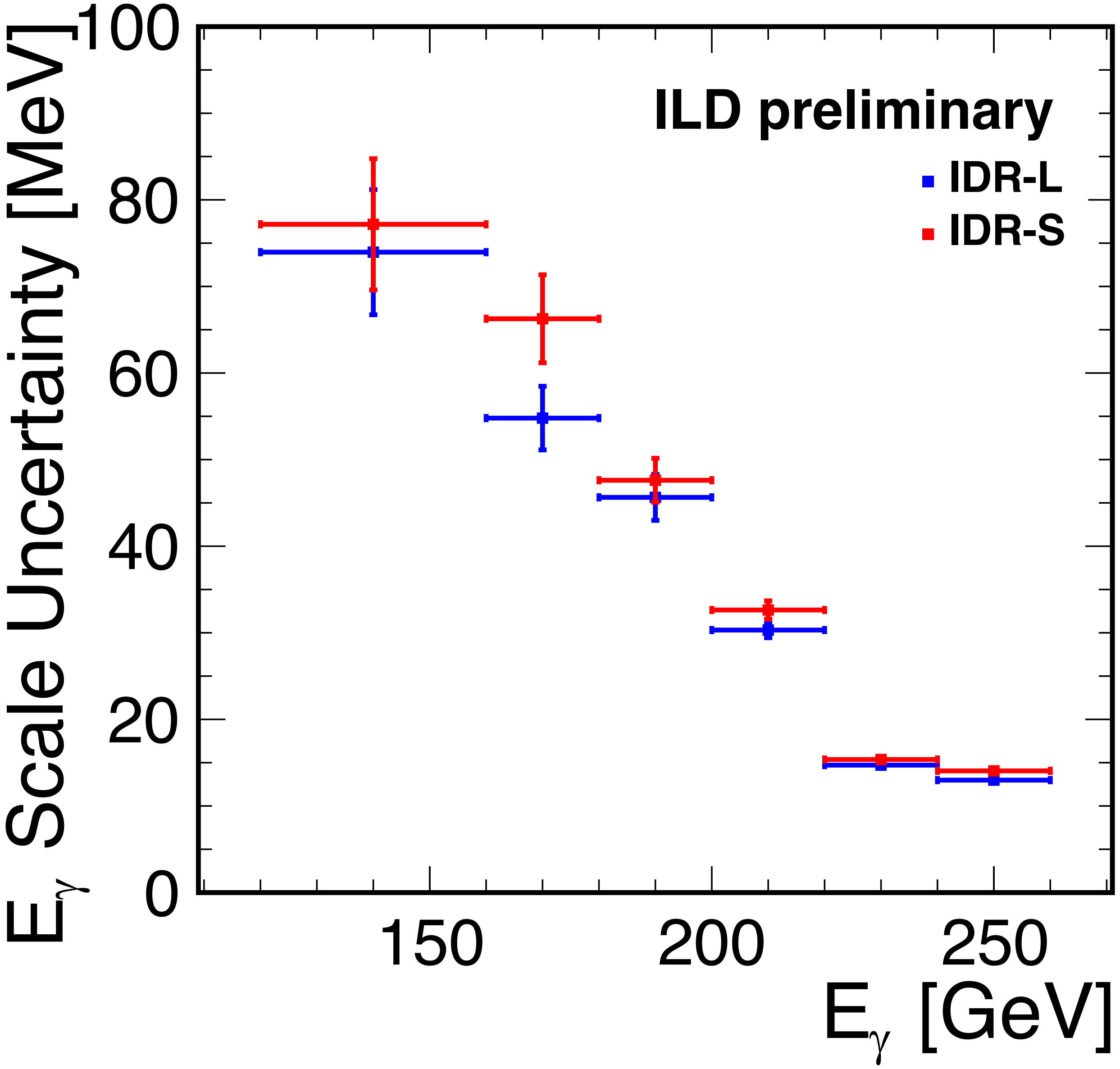
E_γ Scale Uncertainty

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

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



E_γ Scale Uncertainty

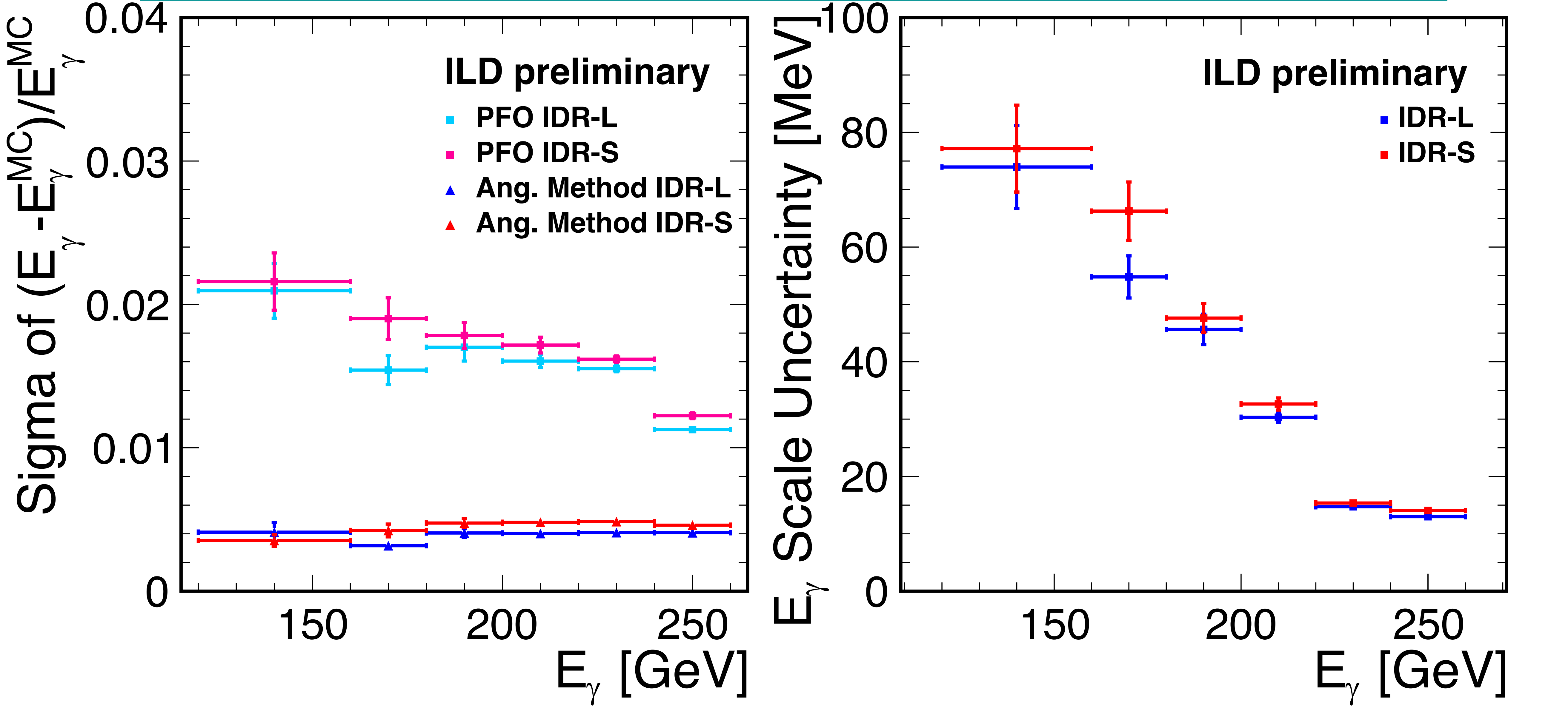


E_γ Scale Uncertainty

- E_γ

S

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



Conclusion

- We found photon energy resolution using Ang. Method is better than PFO when $|\cos\theta_\gamma| < 0.95$ 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.