Status on e^+e^- -> γZ process
Jet Energy Calibration

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Today's talk

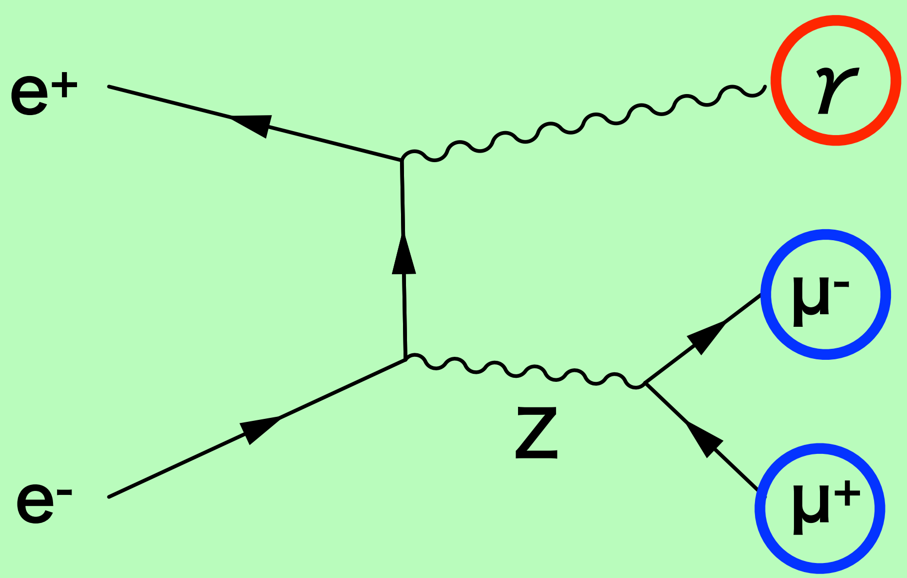
Jet Energy Scale Calibration

1. Introduction
2. Distribution of various observables in current using sample
3. Comparison of the methods to reconstruct the jet energy
4. Summary

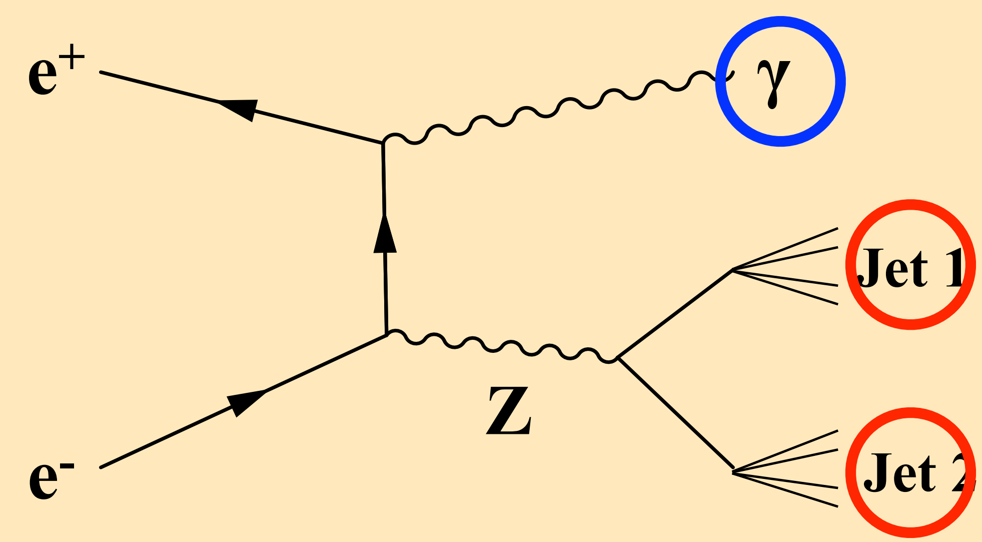
Introduction

- In the photon energy calibration, photon energy can be reconstructed using measured direction of γ and μ^- , μ^+ or additionally muon mass information in the $e^+e^- \to \gamma Z$ process.
- Using similar energy reconstruction methods, jet energies in the $e^+e^- \to \gamma Z$, $Z \to 2\text{Jets}$ can be reconstructed.
- If the jet energies can be correctly reconstructed, the $e^+e^- \to \gamma Z$ process is useful for the jet energy calibration.

Photon Energy Scale Calibration



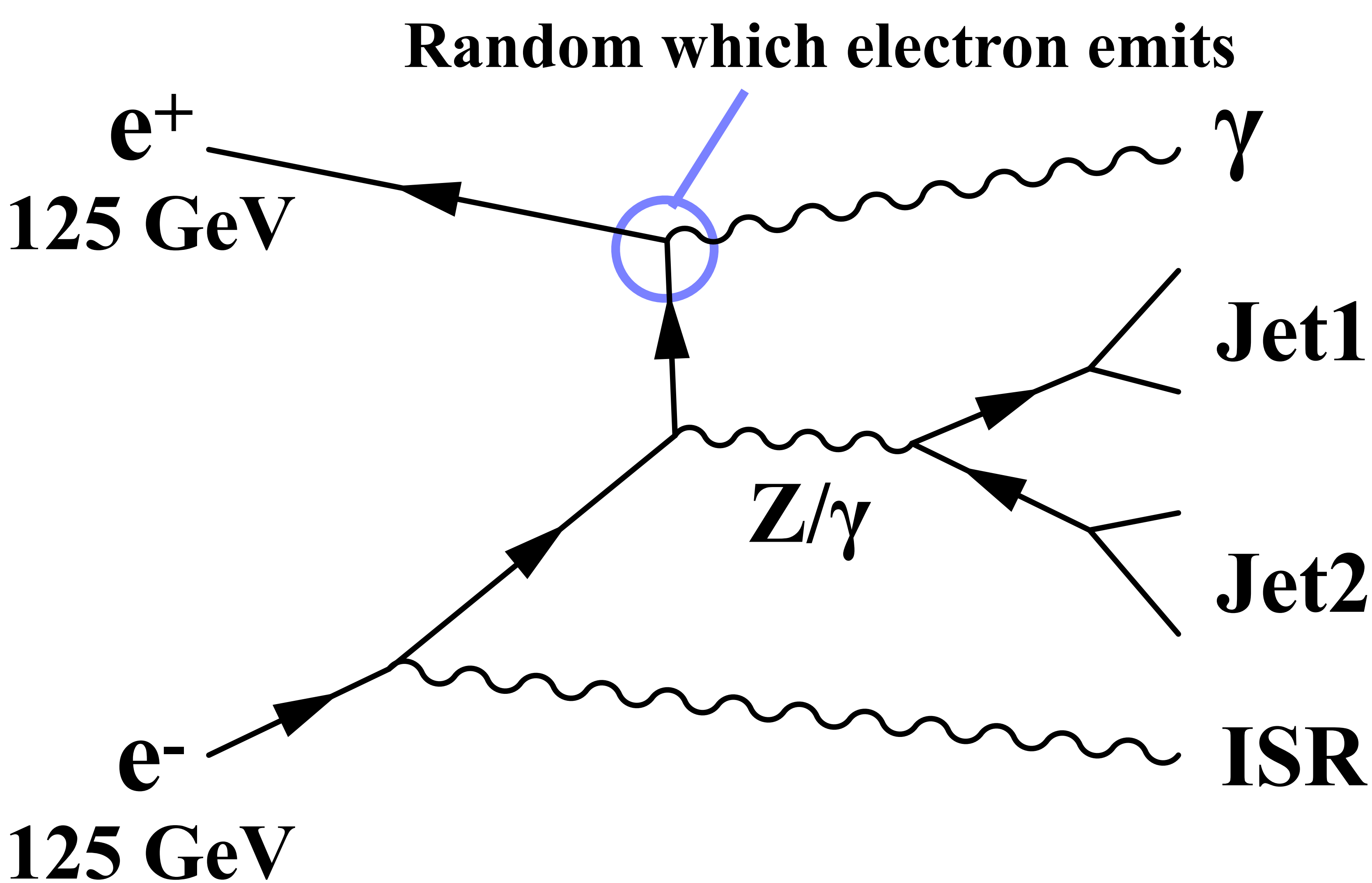
Jet Energy Scale Calibration



Shift to the 250 GeV analysis

- In order to perform 250 GeV analysis, we decided to use DBD samples instead of 500 GeV samples until new sample is validated.

- To make things clear, overlay removal by MCTruth link is implemented.



Process: 2f_z_h

E_{CM}= **250 GeV**

Polarization: e^{-}: Left e^{+}: Right

Full simulation

(ILCSOFT version v01-16-02)

Event Selection

Signature of the events: 1 energetic photon + 2 jets

In order to choose the signal photon,
1. choose neutral particles with particle ID = 22 (Pandora PFA ID)
2. energy > 50 GeV
3. choose the particle closest to 108.4 GeV

If another photon is inside the cone (with the angle $\cos\theta > 0.998$ from the signal photon), it is merged with the signal photon.

Jet Clustering

- All PFOs other than the selected photon are clustered into 2 jets with Durham algorithm (done by LCFIPlus)
- The higher energy jet (in PFO) is defined as “jet 1” and lower one as “jet 2”
- For comparison with MCtruth, all final state particles from 2 quarks are clustered into 2 jets

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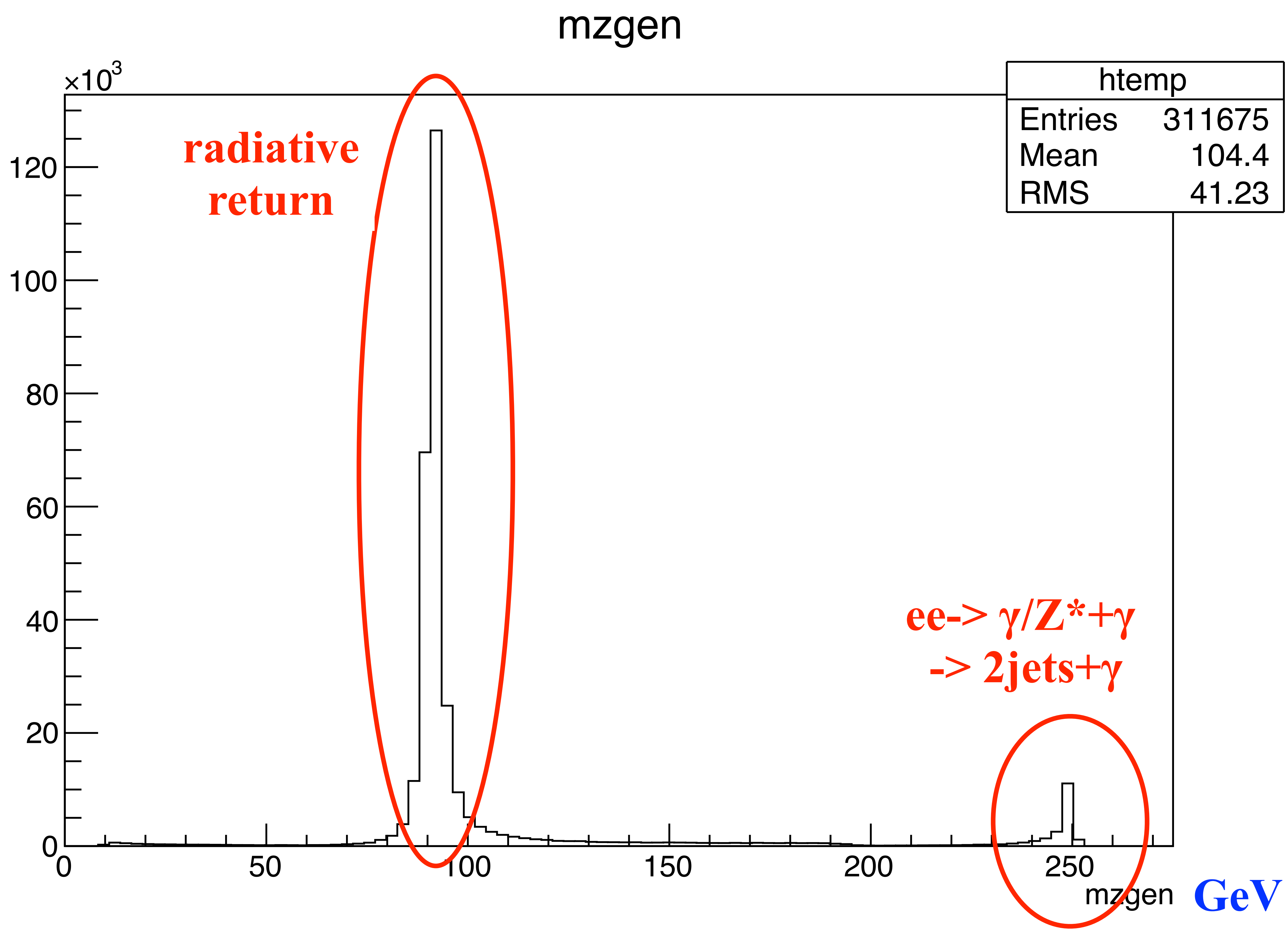
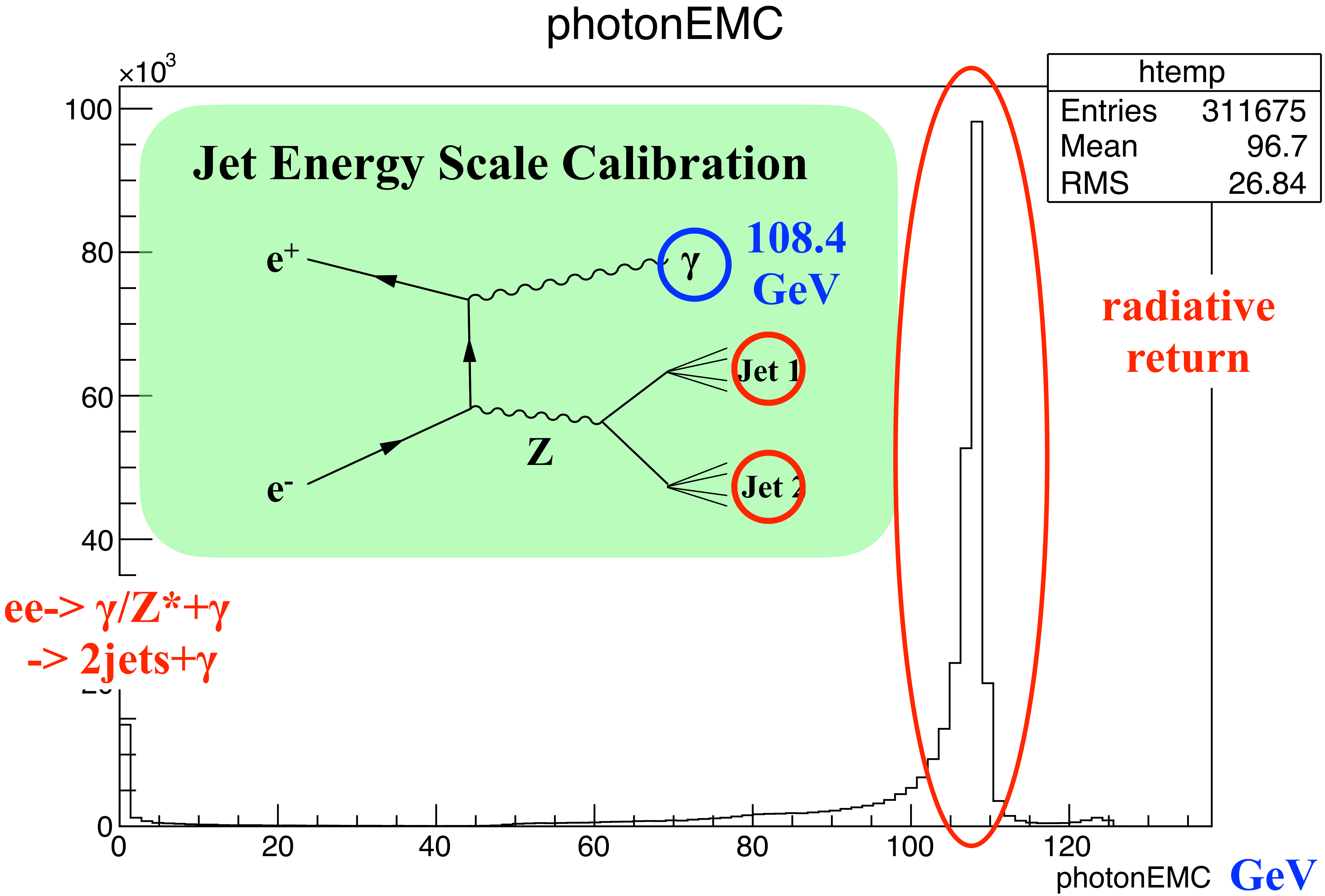
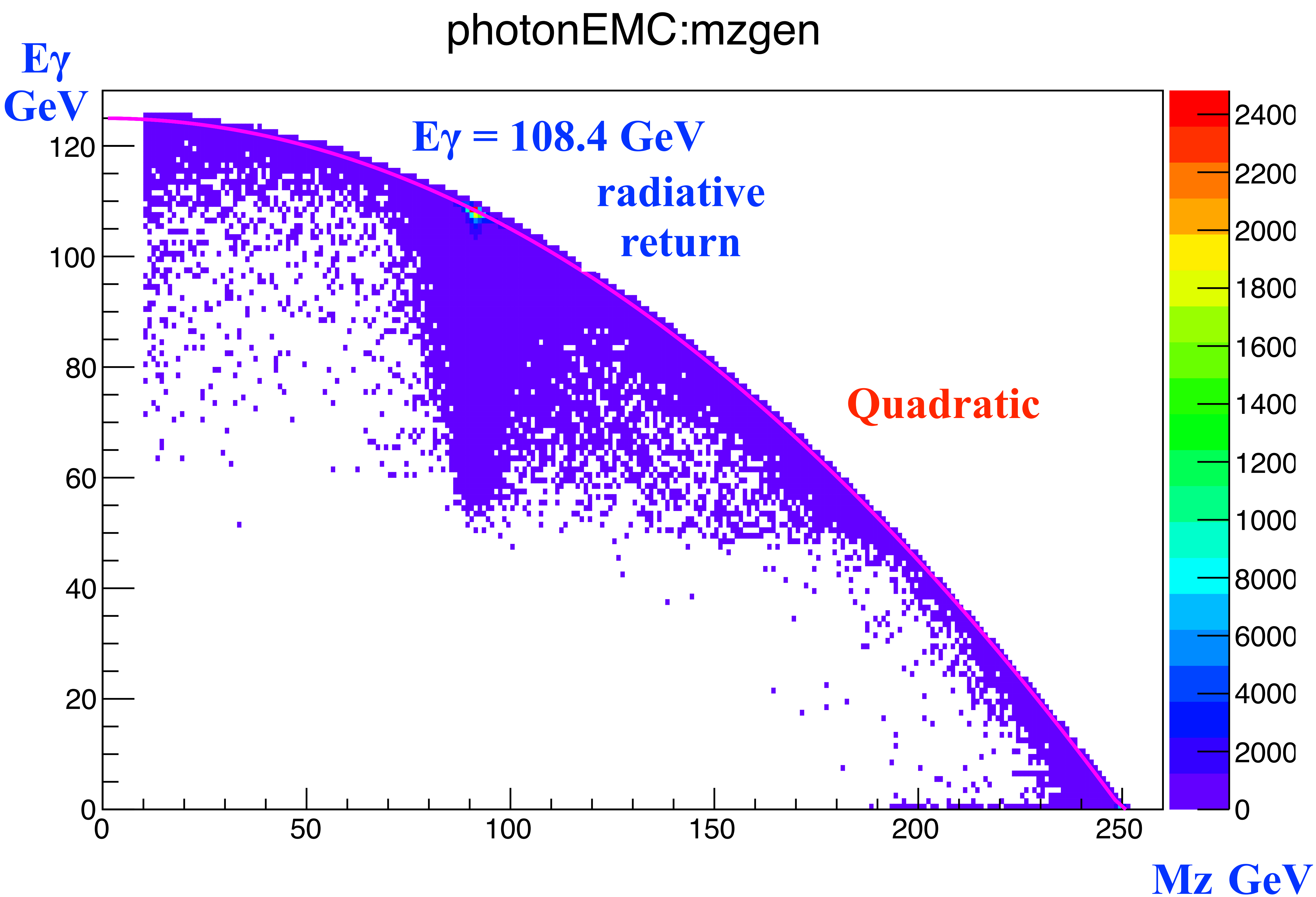
Mz distribution



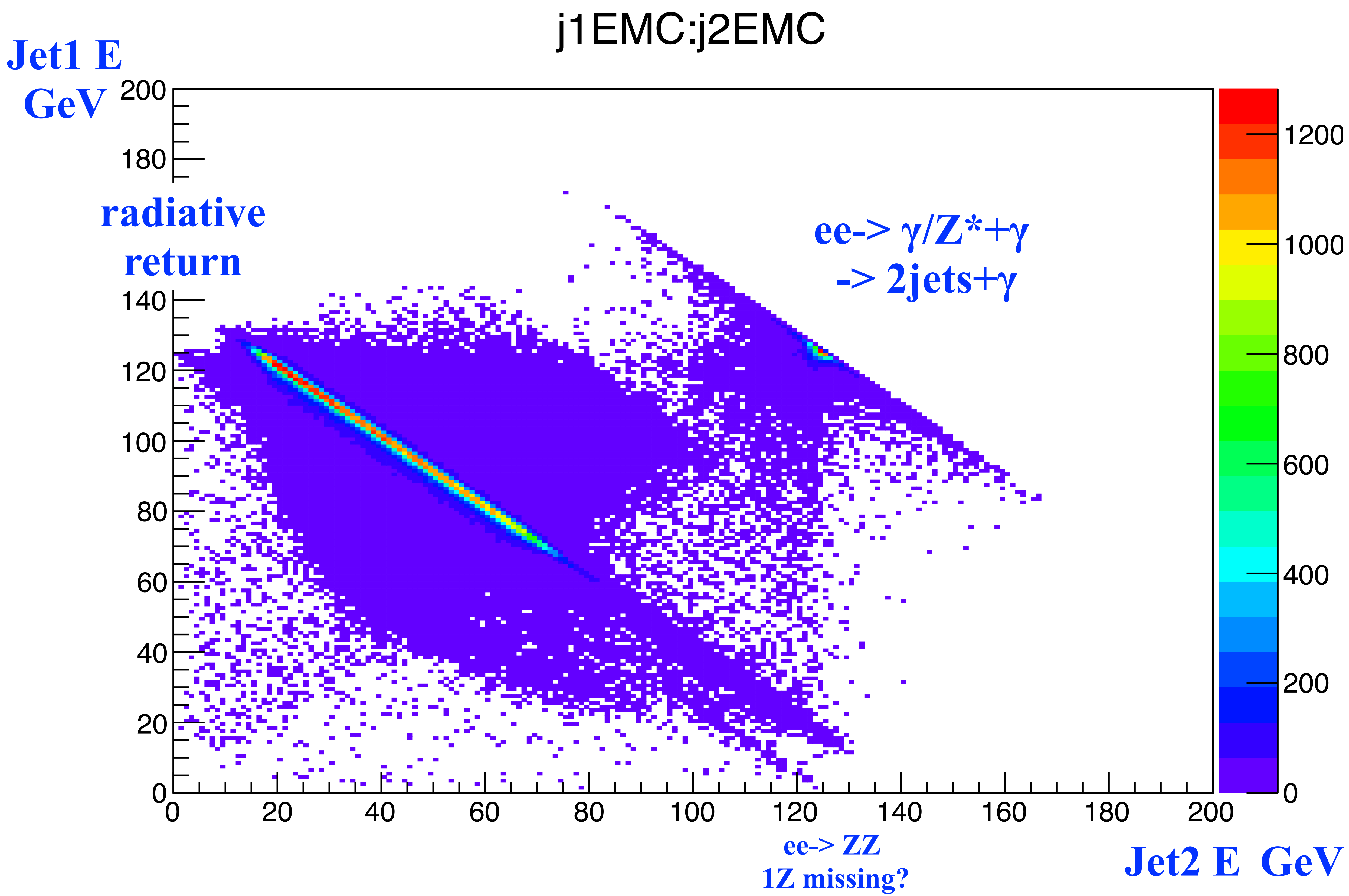
Photon energy distribution



Photon energy & Mz distribution



MC jet energies distribution



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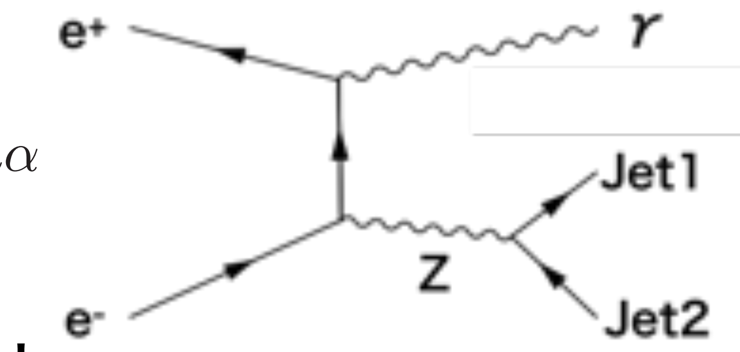
Reconstruction Method

Basic ideas: apply momentum conservation

$$\begin{cases} \sqrt{P_{J1}^2+m_{J1}^2}+\sqrt{P_{J2}^2+m_{J2}^2}+|P_\gamma|+|P_{ISR}| = \mathbf{E_{CM}} \\ P_{J1}sin\theta_{J1}cos\phi_{J1}+P_{J2}sin\theta_{J2}cos\phi_{J2}+P_\gamma sin\theta_\gamma cos\phi_\gamma+|P_{ISR}|sin\alpha = \mathbf{E_{CM}}\, sin\alpha \\ P_{J1}sin\theta_{J1}sin\phi_{J1}+P_{J2}sin\theta_{J2}sin\phi_{J2}+P_\gamma sin\theta_\gamma sin\phi_\gamma = 0 \\ P_{J1}cos\theta_{J1}+P_{J2}cos\theta_{J2}+P_\gamma cos\theta_\gamma \pm |P_{ISR}|cos\alpha = 0 \end{cases}$$



Beam Crossing Angle ≡2α : α = 7.0 mrad

Direction Angle
θ: polar angle
ϕ: azimuthal angle

- ISR photon = **additional** unseen photon
- Several reconstruction methods (Method 1, 2’, 2,and 3) are considered.

Method 1: Ignore ISR

Using ($\theta_{J1},\theta_{J2},\theta_\gamma,\varphi_{J1},\varphi_{J2},\varphi_\gamma,m_{J1},m_{J2}$) -> Determine ($P_{J1},P_{J2},P_\gamma$)

$$\begin{cases} \sqrt{P_{J1}^2+m_{J1}^2}+\sqrt{P_{J2}^2+m_{J2}^2}+|P_\gamma| = \mathbf{E_{CM}} \\ \begin{pmatrix} sin\theta_{J1}cos\phi_{J1} & sin\theta_{J2}cos\phi_{J2} & sin\theta_\gamma cos\phi_\gamma \\ sin\theta_{J1}sin\phi_{J1} & sin\theta_{J2}sin\phi_{J2} & sin\theta_\gamma sin\phi_\gamma \\ cos\theta_{J1} & cos\theta_{J2} & cos\theta_\gamma \end{pmatrix} \begin{pmatrix} P_{J1} \\ P_{J2} \\ P_\gamma \end{pmatrix} = \begin{pmatrix} \mathbf{E_{CM}}\, sin\alpha \\ 0 \\ 0 \end{pmatrix} \end{cases}$$

Matrix A —— Inverse

Reconstruction Method

Method 2': Use measured P_γ as input and Ignore ISR
Using ($\theta_{J1},\theta_{J2},\theta_\gamma,\varphi_{J1},\varphi_{J2},\varphi_\gamma,m_{J1},m_{J2},P_\gamma$) -> Determine ($P_{J1},P_{J2}$)

$$\left\{ \begin{pmatrix} sin\theta_{J1}cos\phi_{J1} & sin\theta_{J2}cos\phi_{J2} \\ sin\theta_{J1}sin\phi_{J1} & sin\theta_{J2}sin\phi_{J2} \end{pmatrix} \begin{pmatrix} P_{J1} \\ P_{J2} \end{pmatrix} = \begin{pmatrix} E_{CM}\, sin\alpha - sin\theta_\gamma cos\phi_\gamma P_\gamma \\ -sin\theta_\gamma sin\phi_\gamma P_\gamma \end{pmatrix} \right.$$

Method 2: Use measured P_γ as input and Ignore ISR
Using ($\theta_{J1},\theta_{J2},\theta_\gamma,\varphi_{J1},\varphi_{J2},\varphi_\gamma,m_{J1},m_{J2},P_\gamma$) -> Determine ($P_{J1},P_{J2},P_{ISR}$)

$$\left\{ \begin{array}{l} \sqrt{P_{J1}^2 + m_{J1}^2} + \sqrt{P_{J2}^2 + m_{J2}^2} + |P_\gamma| + |P_{ISR}| = E_{CM} \quad (1) \\ \begin{pmatrix} sin\theta_{J1}cos\phi_{J1} & sin\theta_{J2}cos\phi_{J2} & sin\alpha \\ sin\theta_{J1}sin\phi_{J1} & sin\theta_{J2}sin\phi_{J2} & 0 \\ cos\theta_{J1} & cos\theta_{J2} & \pm cos\alpha \end{pmatrix} \begin{pmatrix} P_{J1} \\ P_{J2} \\ |P_{ISR}| \end{pmatrix} = \begin{pmatrix} E_{CM}\, sin\alpha - sin\theta_\gamma cos\phi_\gamma P_\gamma \\ -sin\theta_\gamma sin\phi_\gamma P_\gamma \\ -cos\theta_\gamma P_\gamma \end{pmatrix} \end{array} \right.$$

Matrix A

Inverse

2 solutions for each sign of P_{ISR}
-> choose the best answer which satisfies (1) better

Reconstruction Method

Method 3: Consider ISR and solve the full equation
Using ($\theta_{J1},\theta_{J2},\theta_\gamma,\varphi_{J1},\varphi_{J2},\varphi_\gamma,m_{J1},m_{J2}$) -> Determine ($P_{J1},P_{J2},P_\gamma,P_{ISR}$)

$$\begin{cases} \sqrt{P_{J1}^2+m_{J1}^2}+\sqrt{P_{J2}^2+m_{J2}^2}+|P_\gamma|+|P_{ISR}| = \mathbf{E_{CM}} \quad ① \\ \begin{pmatrix} sin\theta_{J1}cos\phi_{J1} & sin\theta_{J2}cos\phi_{J2} & sin\theta_\gamma cos\phi_\gamma \\ sin\theta_{J1}sin\phi_{J1} & sin\theta_{J2}sin\phi_{J2} & sin\theta_\gamma sin\phi_\gamma \\ cos\theta_{J1} & cos\theta_{J2} & cos\theta_\gamma \end{pmatrix} \begin{pmatrix} P_{J1} \\ P_{J2} \\ P_\gamma \end{pmatrix} = \begin{pmatrix} (\mathbf{E_{CM}}-|P_{ISR}|)sin\alpha \\ 0 \\ \pm|P_{ISR}|cos\alpha \end{pmatrix} \end{cases}$$

Matrix A

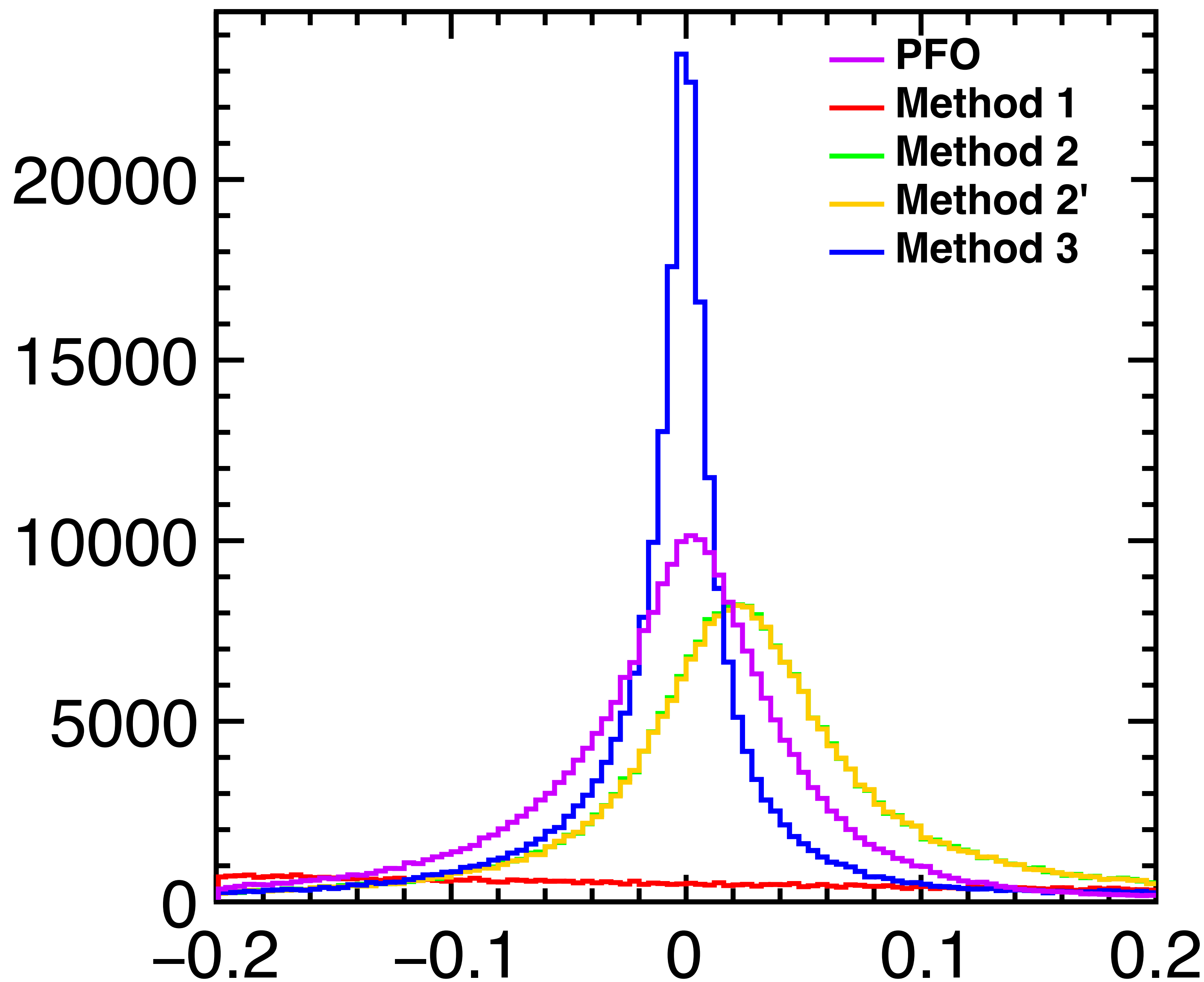
Inverse

The first equation ① becomes a quartic equation of $|P_{ISR}|$.

-> 8 Possible Solutions!
(2 direction options of ISR × 4 solutions for each quartic equation)

Choose the solution with (i) real and positive value
(ii) solved P_γ closest to the measured P_γ

Method comparison of jet1 E difference for correct photon selection events



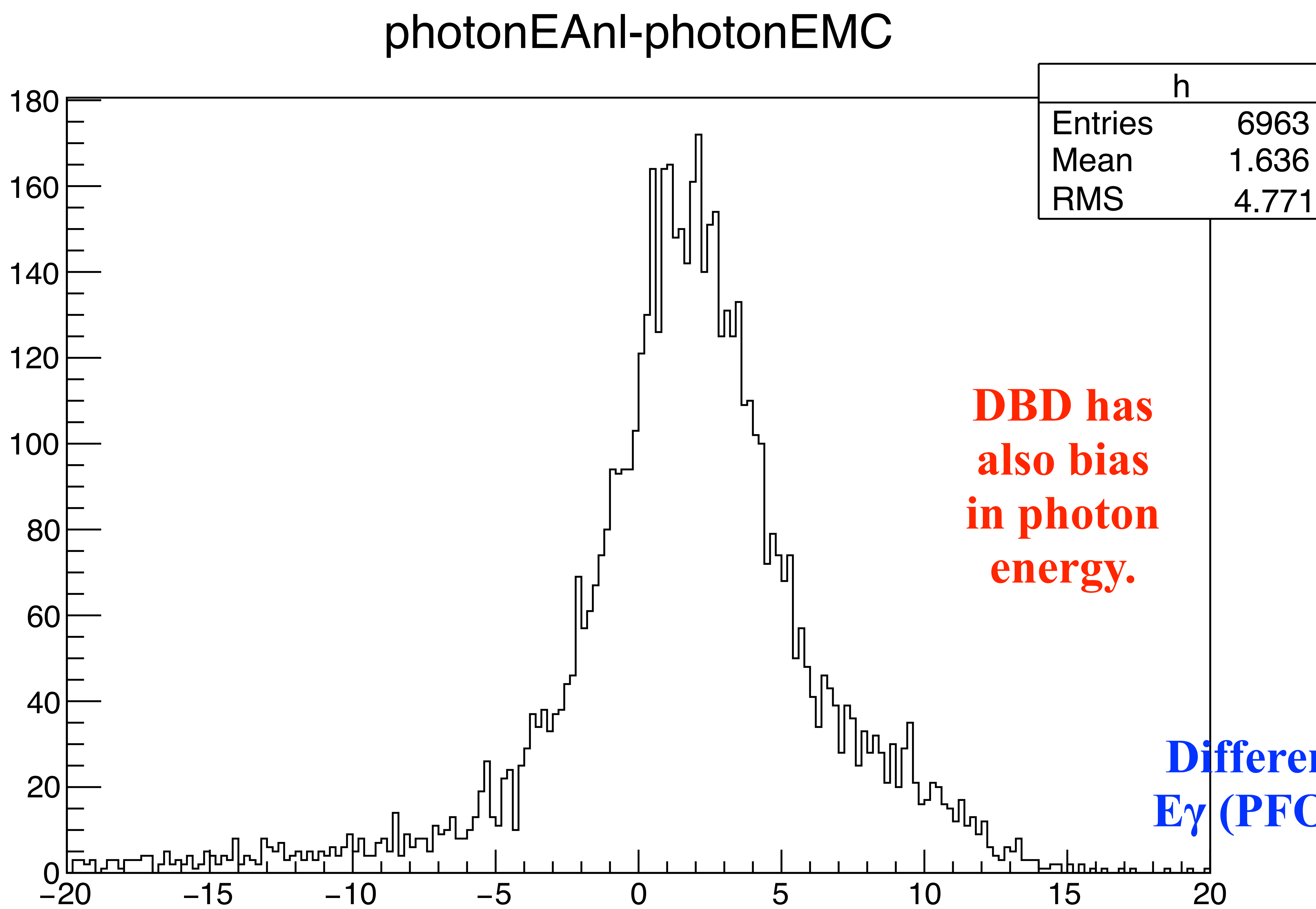
Relative Difference

Method 3 is the best.

① Method 2 and 2' have positive shift.

② Method 3 distribution has tail and is not symmetric.

Photon energy bias in DBD

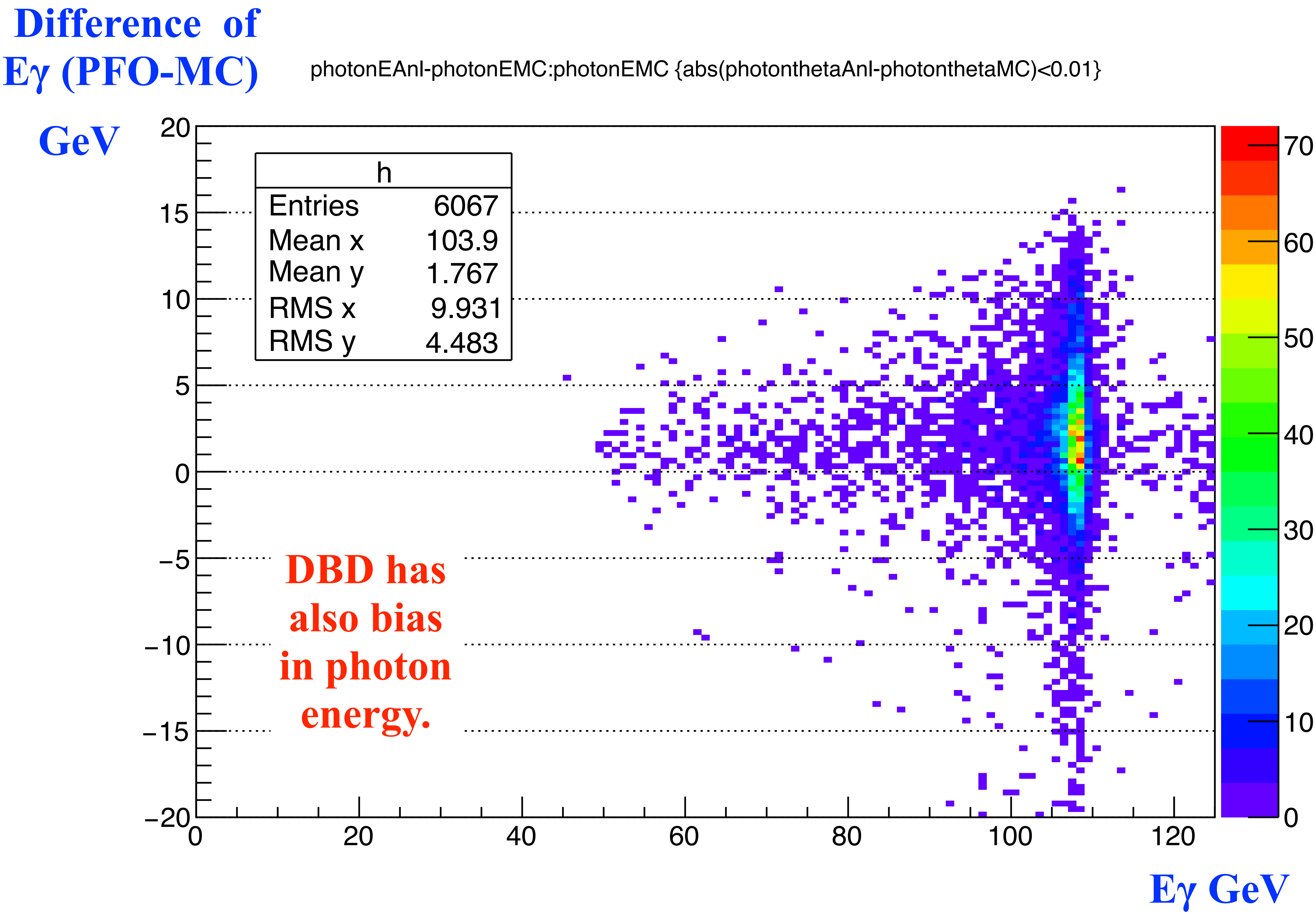


DBD has also bias in photon energy.

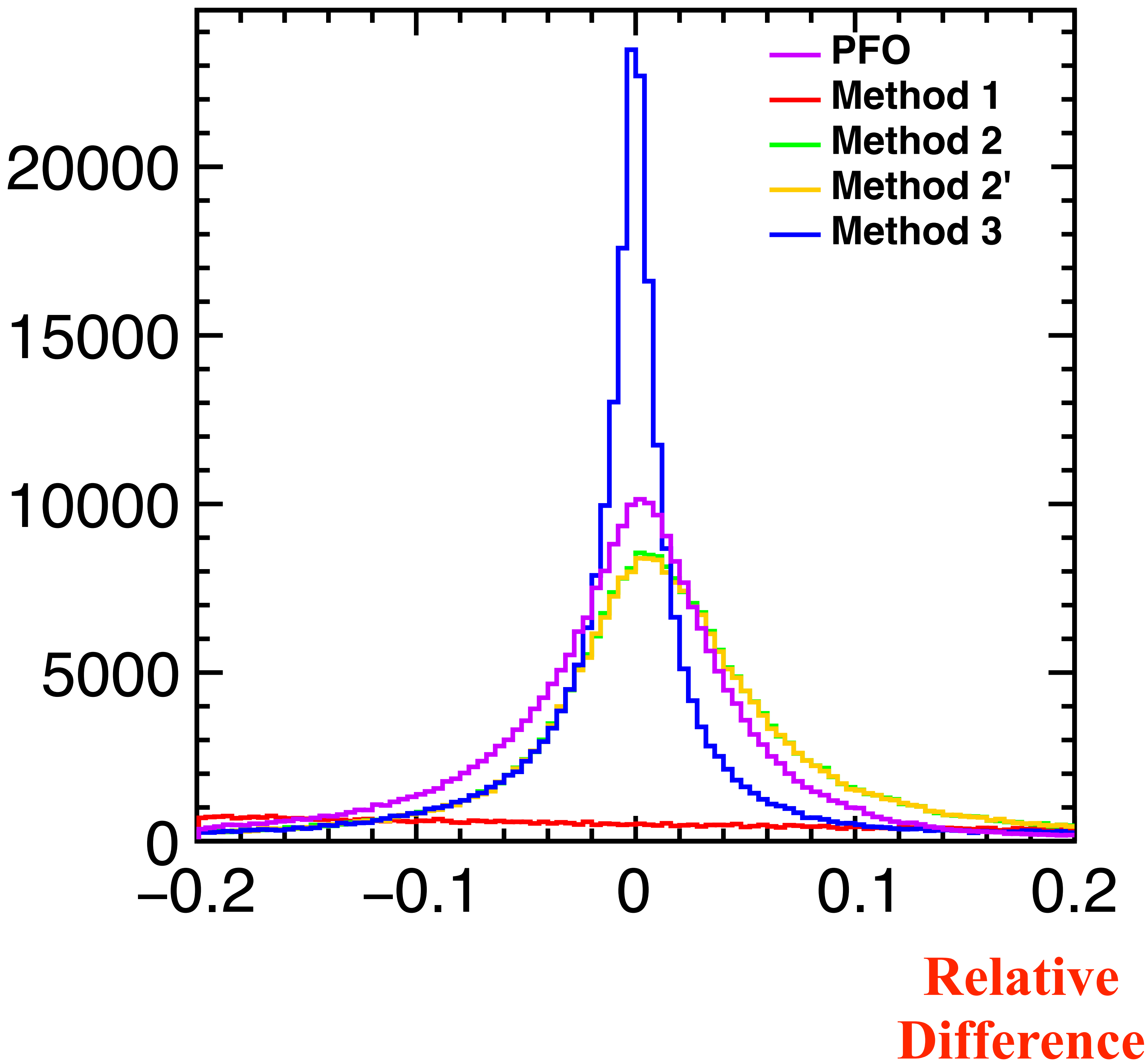
Difference of Eγ (PFO-MC)

GeV

Photon energy bias in DBD



Method comparison of jet1 E difference Correct photon selection events



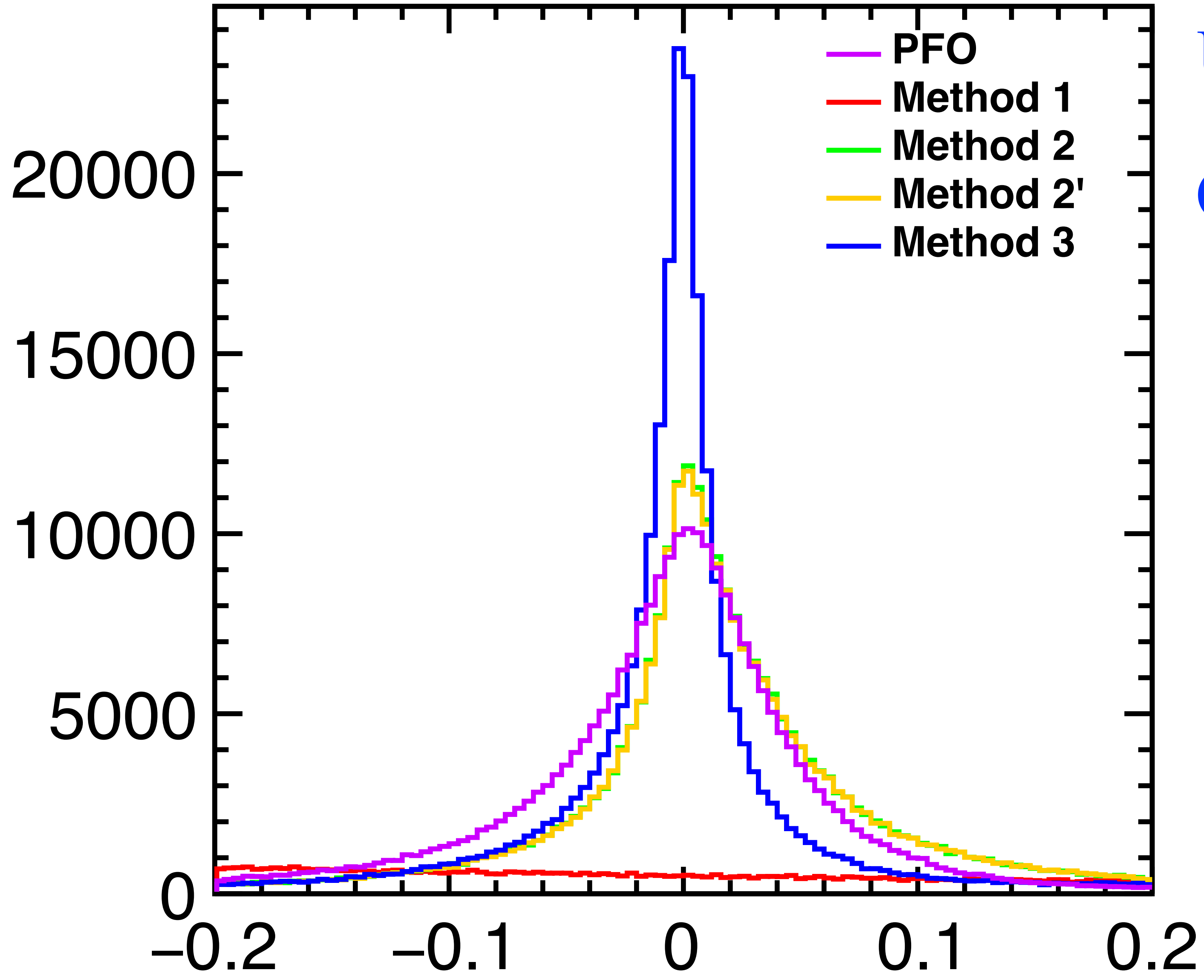
Using "Smeared MCtruth Eγ" as input in Method 2 and 2'.

"EγMC+0.17*sqrt(EγMC)*gRandom->Gaus() +0.01*EγMC*gRandom->Gaus();

The positive shift was mitigated.

There are biases on theta and phi.

Method comparison of jet1 E difference Correct photon selection events

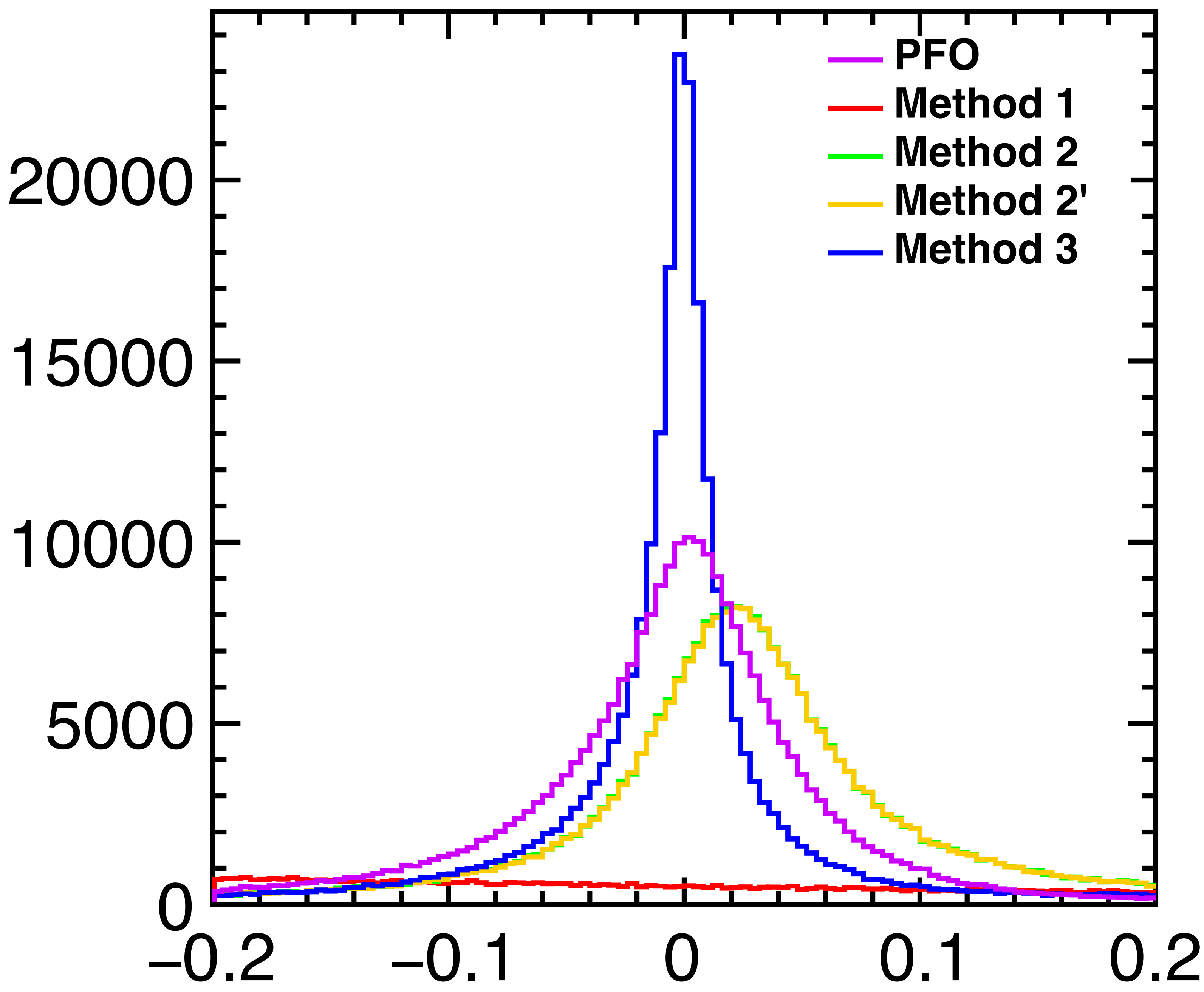


Using MCtrue Eγ, θγ, φγ

(Eγ not smeared)

Relative Difference

Method comparison of jet1 E difference for correct photon selection events



Relative Difference

Method 3 is the best.

① Method 2 and 2' have positive shift.

② Method 3 distribution has tail and is not symmetric.

Reconstruction Method

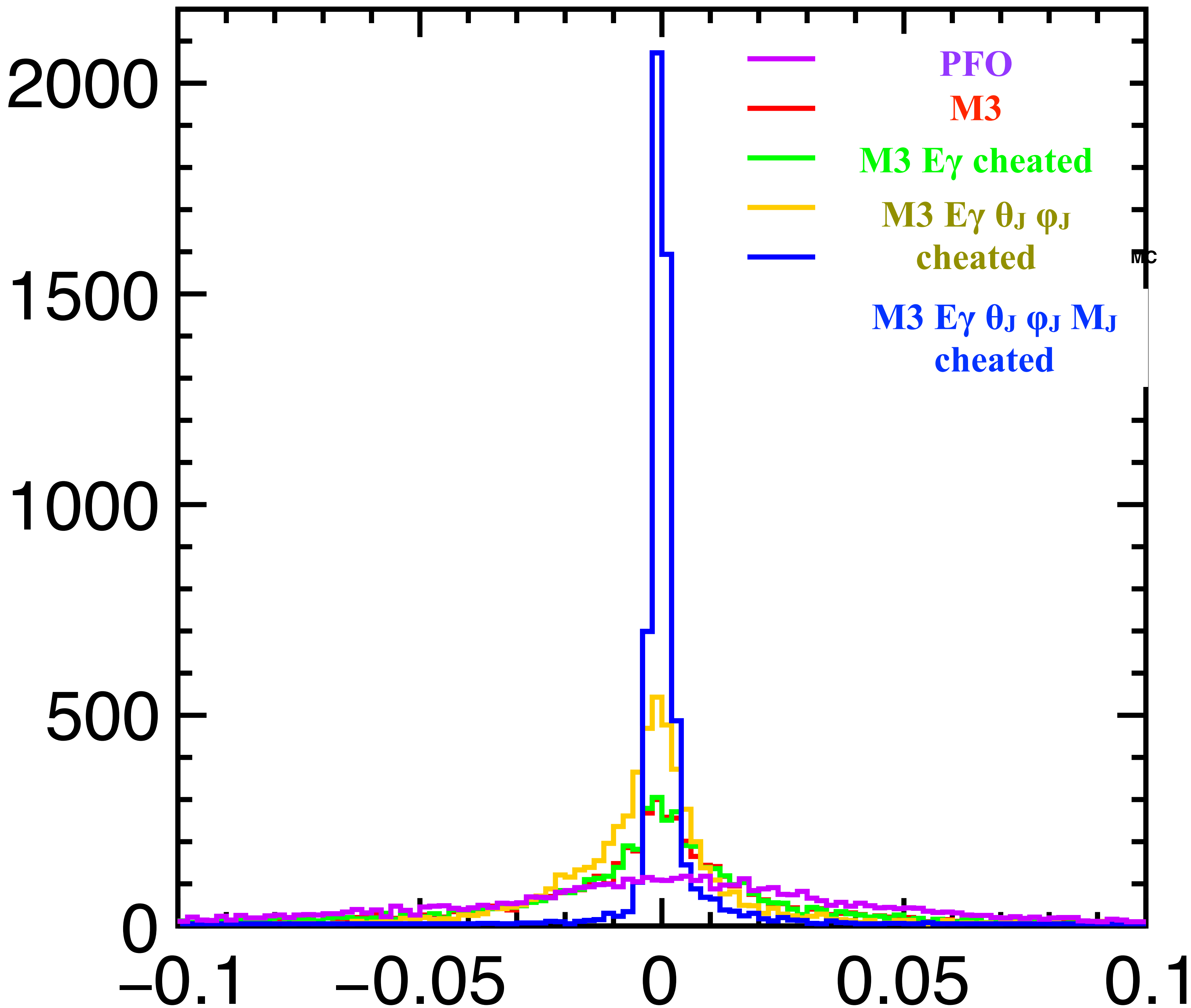
Method 3: Consider ISR and solve the full equation
Using ($\theta_{J1}, \theta_{J2}, \theta_{\gamma}, \varphi_{J1}, \varphi_{J2}, \varphi_{\gamma}, m_{J1}, m_{J2}$) -> Determine ($P_{J1}, P_{J2}, P_{\gamma}, P_{ISR}$)

$$\begin{cases} \sqrt{P_{J1}^2 + m_{J1}^2} + \sqrt{P_{J2}^2 + m_{J2}^2} + |P_\gamma| + |P_{ISR}| = 500 \quad ① \\ \begin{pmatrix} sin\theta_{J1}cos\phi_{J1} & sin\theta_{J2}cos\phi_{J2} & sin\theta_{\gamma}cos\phi_{\gamma} \\ sin\theta_{J1}sin\phi_{J1} & sin\theta_{J2}sin\phi_{J2} & sin\theta_{\gamma}sin\phi_{\gamma} \\ cos\theta_{J1} & cos\theta_{J2} & cos\theta_{\gamma} \end{pmatrix} \begin{pmatrix} P_{J1} \\ P_{J2} \\ P_{\gamma} \end{pmatrix} = \begin{pmatrix} (500 - |P_{ISR}|)sin\alpha \\ 0 \\ \pm|P_{ISR}|cos\alpha \end{pmatrix} \end{cases}$$

Matrix A — Inverse

M3 has 8 inputs.
Some of those inputs are changed to MC ones and it is investigated how the reconstructed energy differences change.

Method 3 of jet1 E difference Correct photon selection events

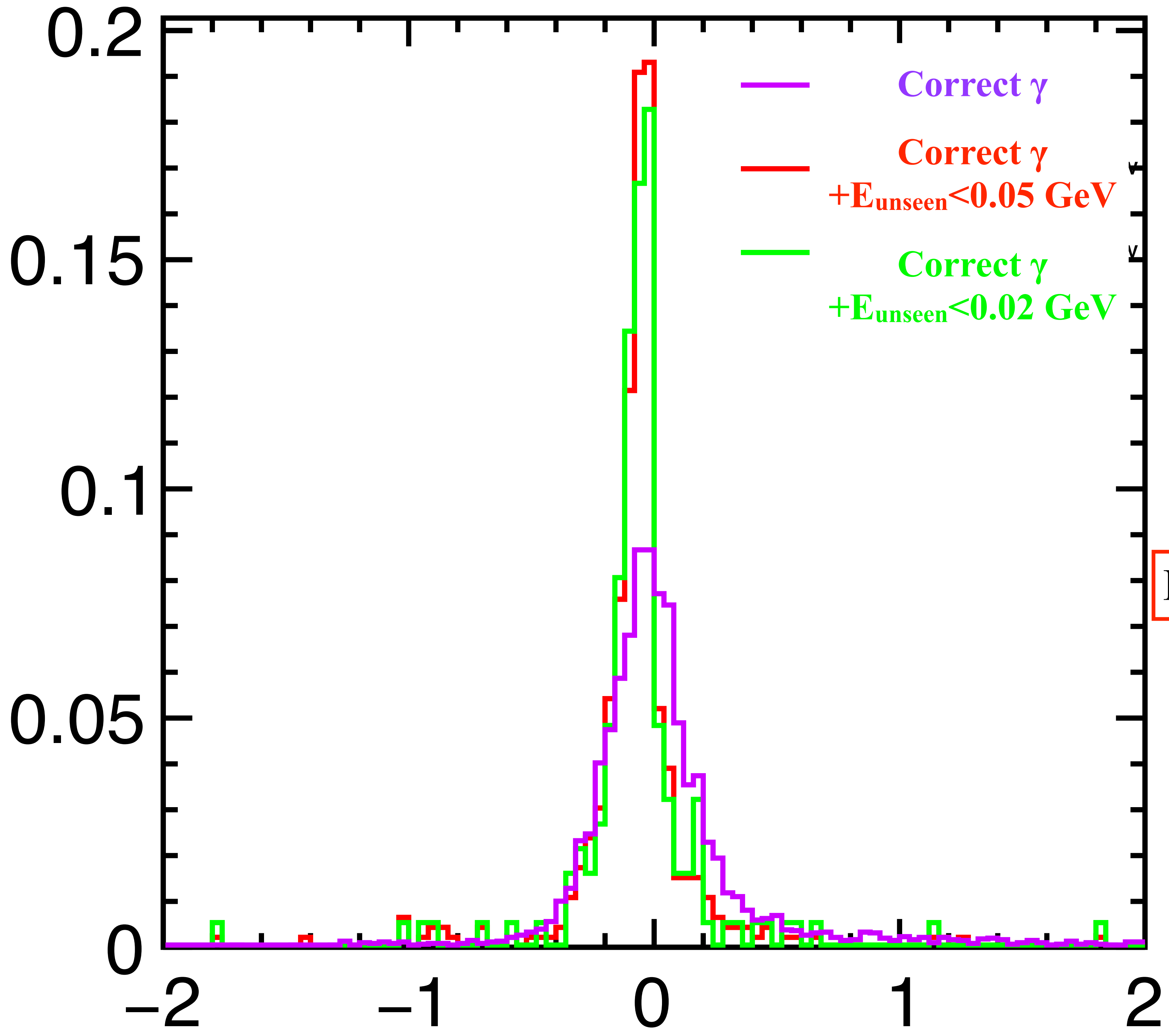


Relative Difference

Even in all inputs are MC case, peak is not symmetric (shift + tail)

-> Absolute differences in all inputs are MC case are checked.

Method 3 of jet1 E difference
Correct photon selection events



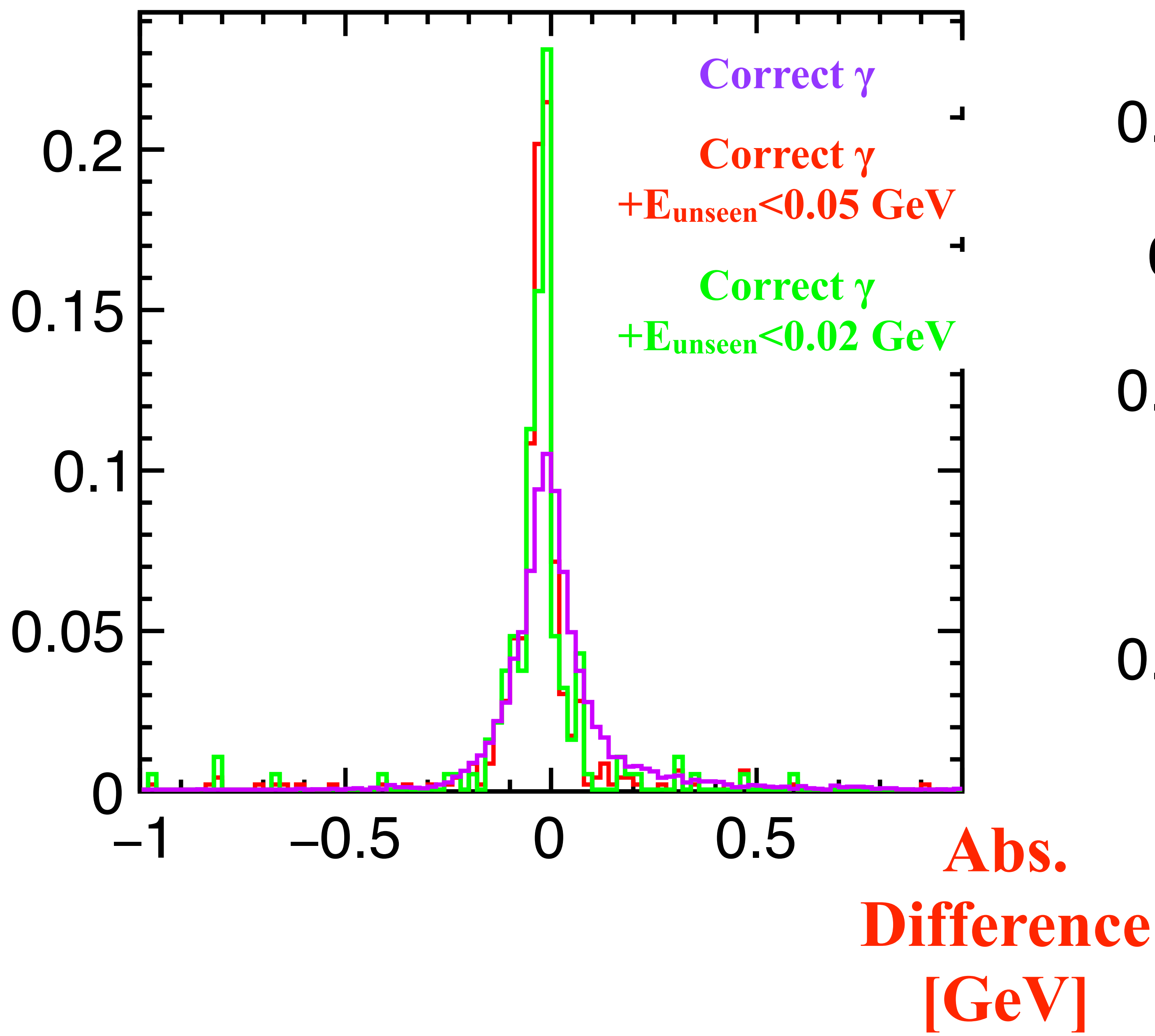
Peak shifted to negative.

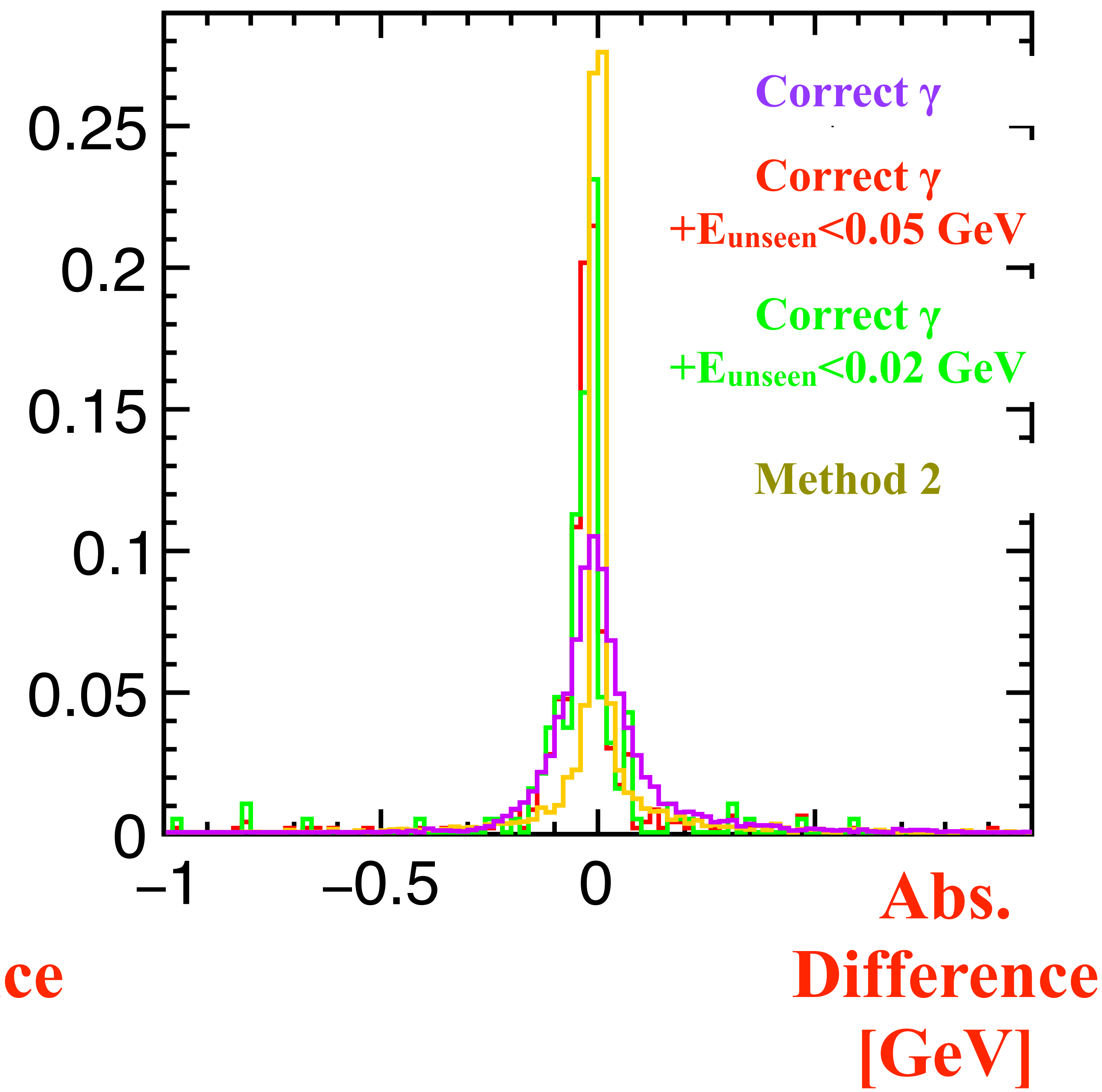
(even when unseen energy is very close to 0.)

$E_{unseen} = E_{CM} - (E\gamma + E_{ISR} + E_{J1} + E_{J2})$

Abs. Difference [GeV]

Method 3 of jet2 E difference
Correct photon selection events





Peak also shifted to negative for jet2

Method 2 (all inputs are MC) doesn’t have such a shift.

Method 3 tail

When calculating P_{J1} and P_{J2}, inversed matrix A^{-1}, which has very huge components (as A has tiny components).

Method 3: Consider ISR and solve the full equation
Using $(\theta_{J1},\theta_{J2},\theta_{\gamma},\varphi_{J1},\varphi_{J2},\varphi_{\gamma},m_{J1},m_{J2})$ -> Determine $(P_{J1},P_{J2},P_{\gamma},P_{ISR})$

$$\begin{cases} \sqrt{P_{J1}^2+m_{J1}^2}+\sqrt{P_{J2}^2+m_{J2}^2}+|P_\gamma|+|P_{ISR}|=500 \\ \begin{pmatrix} sin\theta_{J1}cos\phi_{J1} & sin\theta_{J2}cos\phi_{J2} & sin\theta_{\gamma}cos\phi_{\gamma} \\ sin\theta_{J1}sin\phi_{J1} & sin\theta_{J2}sin\phi_{J2} & sin\theta_{\gamma}sin\phi_{\gamma} \\ cos\theta_{J1} & cos\theta_{J2} & cos\theta_{\gamma} \end{pmatrix} \begin{pmatrix} P_{J1} \\ P_{J2} \\ P_{\gamma} \end{pmatrix} = \begin{pmatrix} (500-|P_{ISR}|)sin\alpha \\ 0 \\ \pm|P_{ISR}|cos\alpha \end{pmatrix} \end{cases}$$

Matrix A → Inverse

If $|P_{ISR}|$ is shifted even slightly, the reconstructed energy shifts even when unseen energy is small.

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Summary

- In order to perform 250 GeV analysis, we decided to use DBD samples instead of current using samples until new sample is validated.
- Photon energy has peaks at 250 GeV and 109 GeV, and the latter one is from radiative return.
- The distributions of reconstructed jet energies using Method 2 and 2’ have positive shift mainly because of the photon energy bias in PFO.
- Method 3 has tail. The reason of this tail is now being investigated.