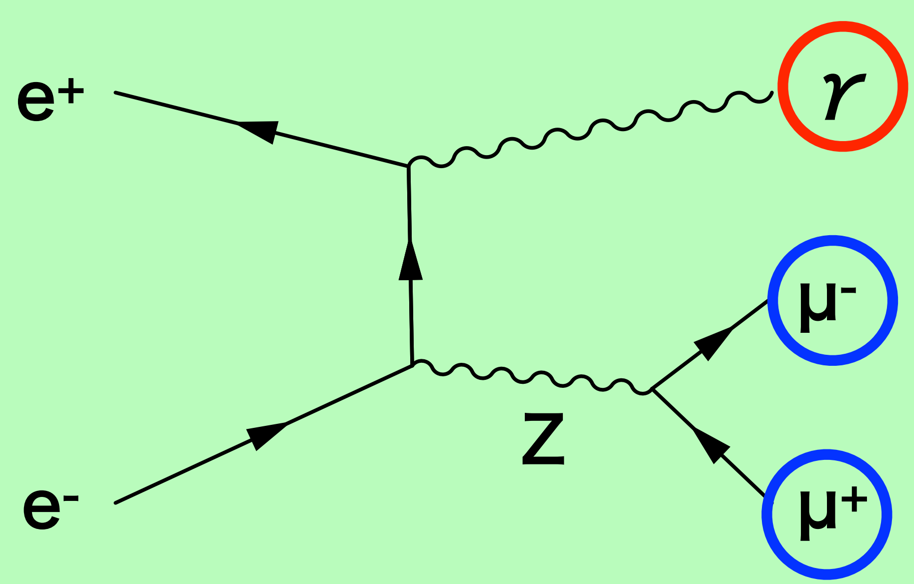
Status on e^+e^- -> γZ process
Jet Energy Calibration

Takahiro Mizuno

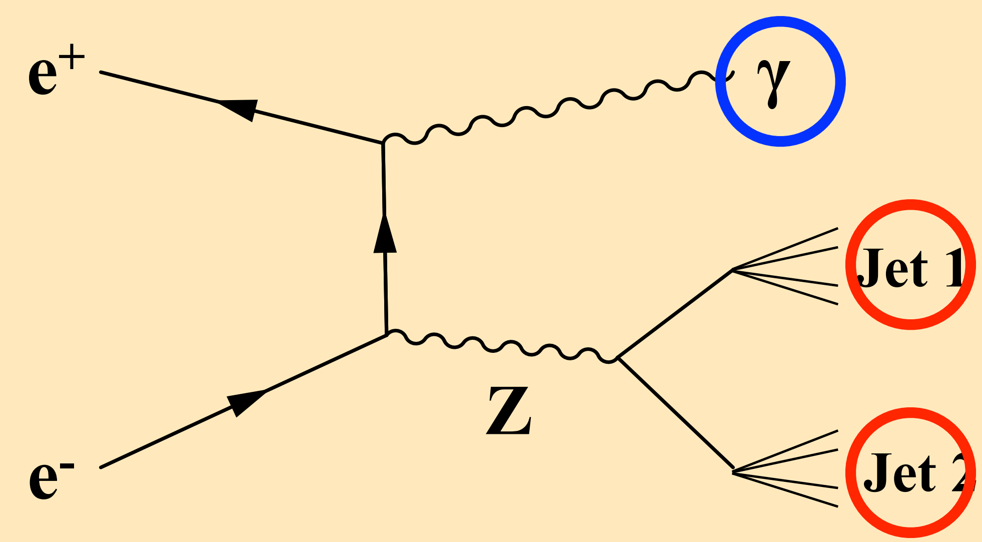
Introduction

- 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 $e^+e^- \to \gamma Z$, $Z \to 2$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



Today's talk

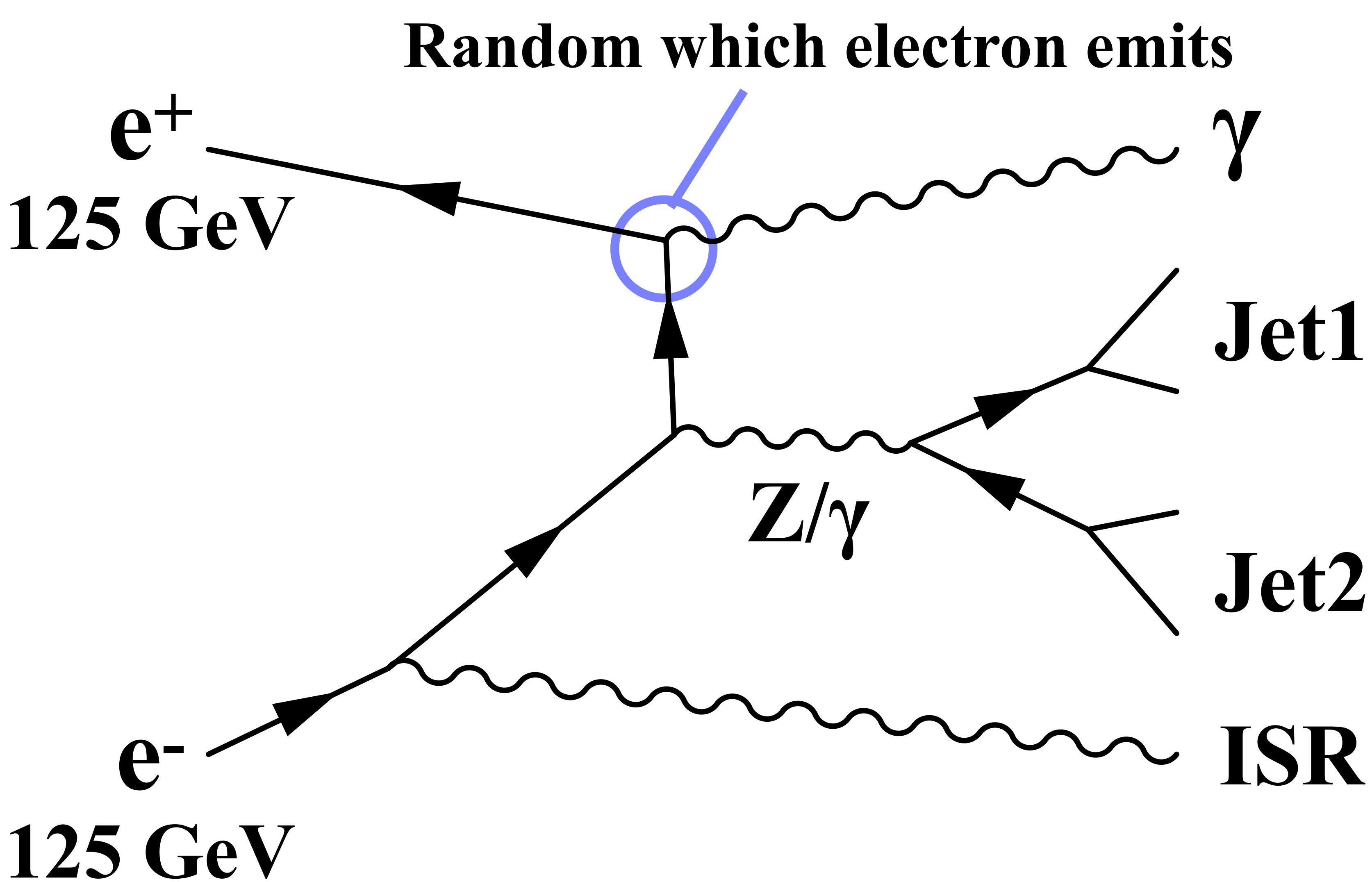
1. **Shift to the 250 GeV analysis**
2. **Method comparison result**
3. **Method 3 study**

Today's talk

1. **Shift to the 250 GeV analysis**
2. **Method comparison result**
3. **Method 3 study**

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

Jet Energy Reconstruction Method

Basic ideas: apply momentum conservation
Inputs: measured jet directions and mass and photon directions

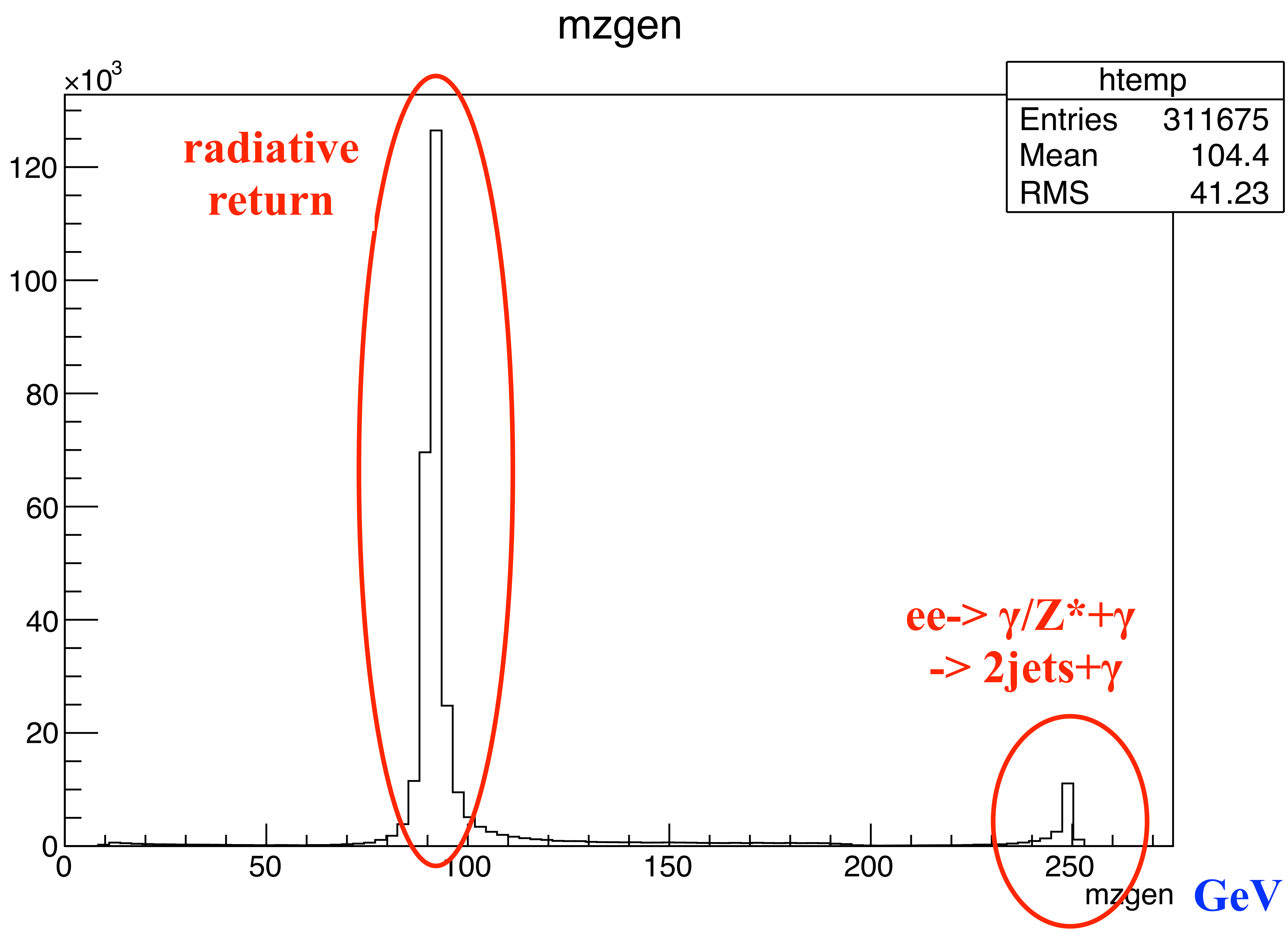
Method 1: Use 3-momentum conservation and ignore ISR
Using $(\theta_{J1},\theta_{J2},\theta_{\gamma},\varphi_{J1},\varphi_{J2},\varphi_{\gamma},)$ -> Determine $(P_{J1},P_{J2},P_{\gamma})$

Method 2': Use transverse momentum conservation and ignore ISR /Use measured P_{γ} as input
Using $(\theta_{J1},\theta_{J2},\theta_{\gamma},\varphi_{J1},\varphi_{J2},\varphi_{\gamma},\mathbf{P_{\gamma}})$ -> Determine (P_{J1},P_{J2})

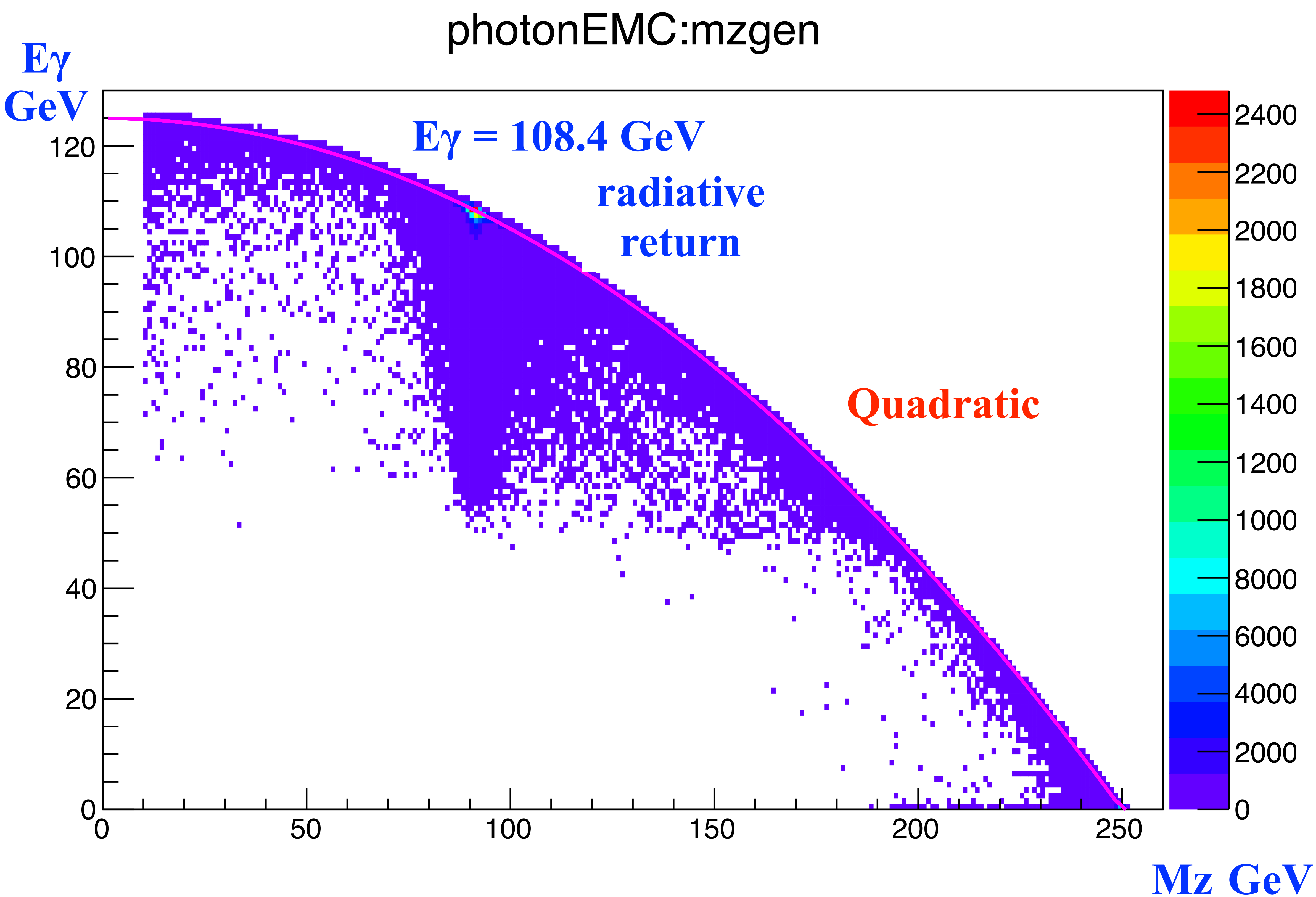
Method 2: Use 4-momentum conservation and consider ISR /Use measured P_{γ} as input
Using $(\theta_{J1},\theta_{J2},\theta_{\gamma},\varphi_{J1},\varphi_{J2},\varphi_{\gamma},m_{J1},m_{J2},\mathbf{P_{\gamma}})$ -> Determine (P_{J1},P_{J2},P_{ISR})

Method 3: Use 4-momentum conservation and 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 $(P_{J1},P_{J2},P_{\gamma},P_{ISR})$

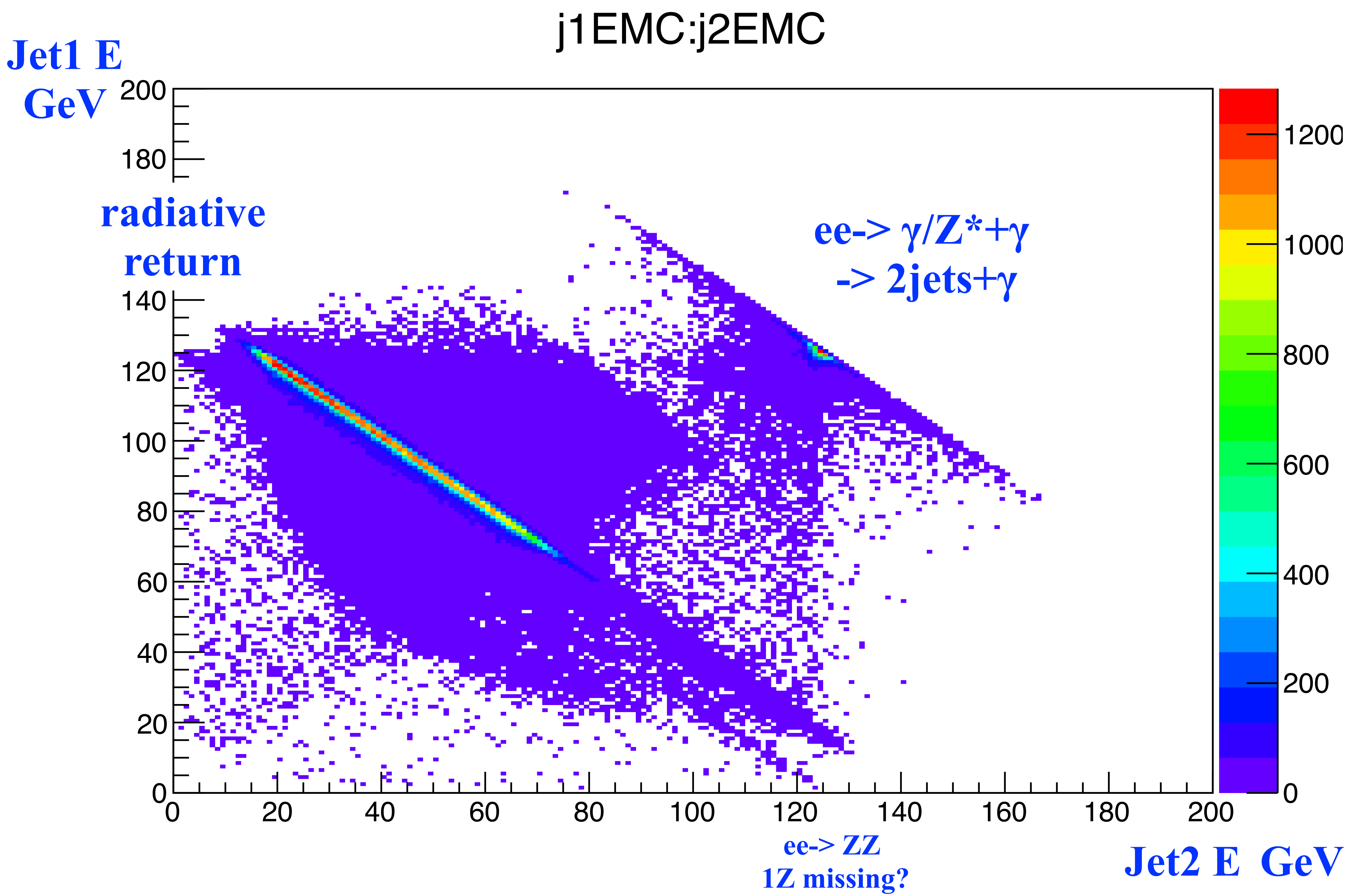
Mz distribution



Photon energy & Mz distribution



MC jet energies distribution



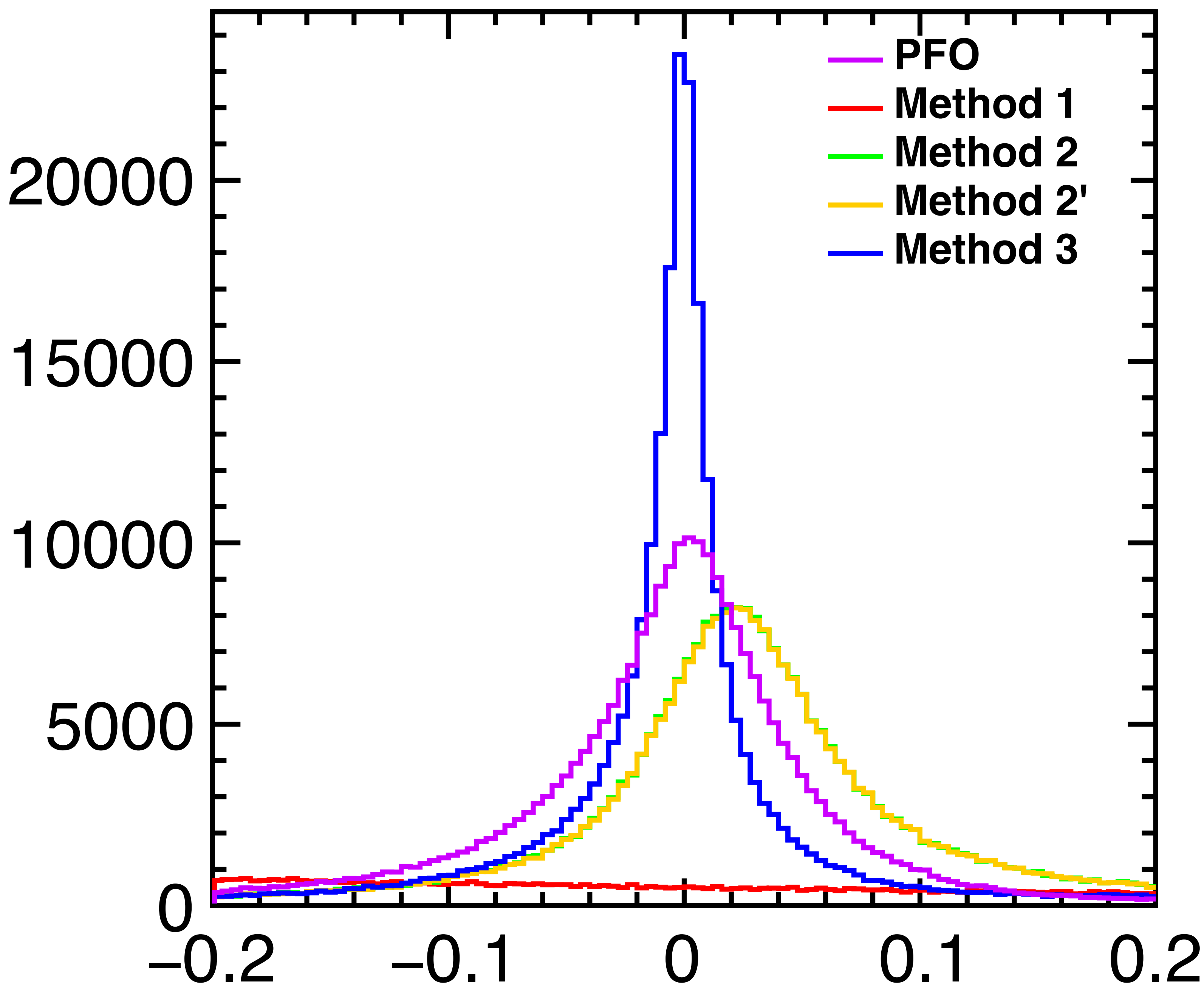
Today’s talk

1. Shift to the 250 GeV analysis

2. Method comparison result

3. Method 3 study

Method comparison of jet1 E difference for correct photon selection events



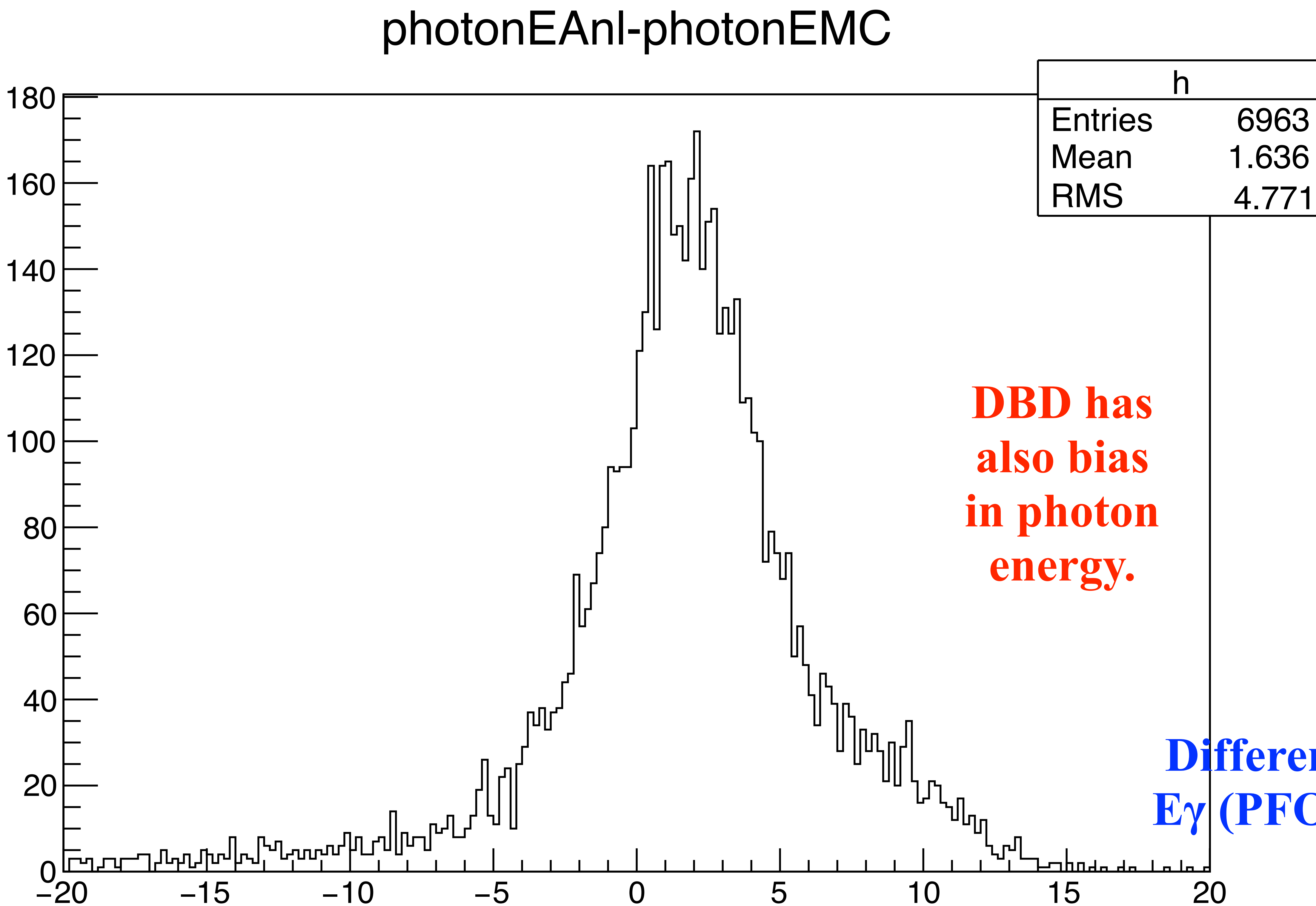
Relative Difference

Method 3 is the best.

① Method 2 and 2' have positive shift.

② Method 3 distribution has tail and is not symmetric.

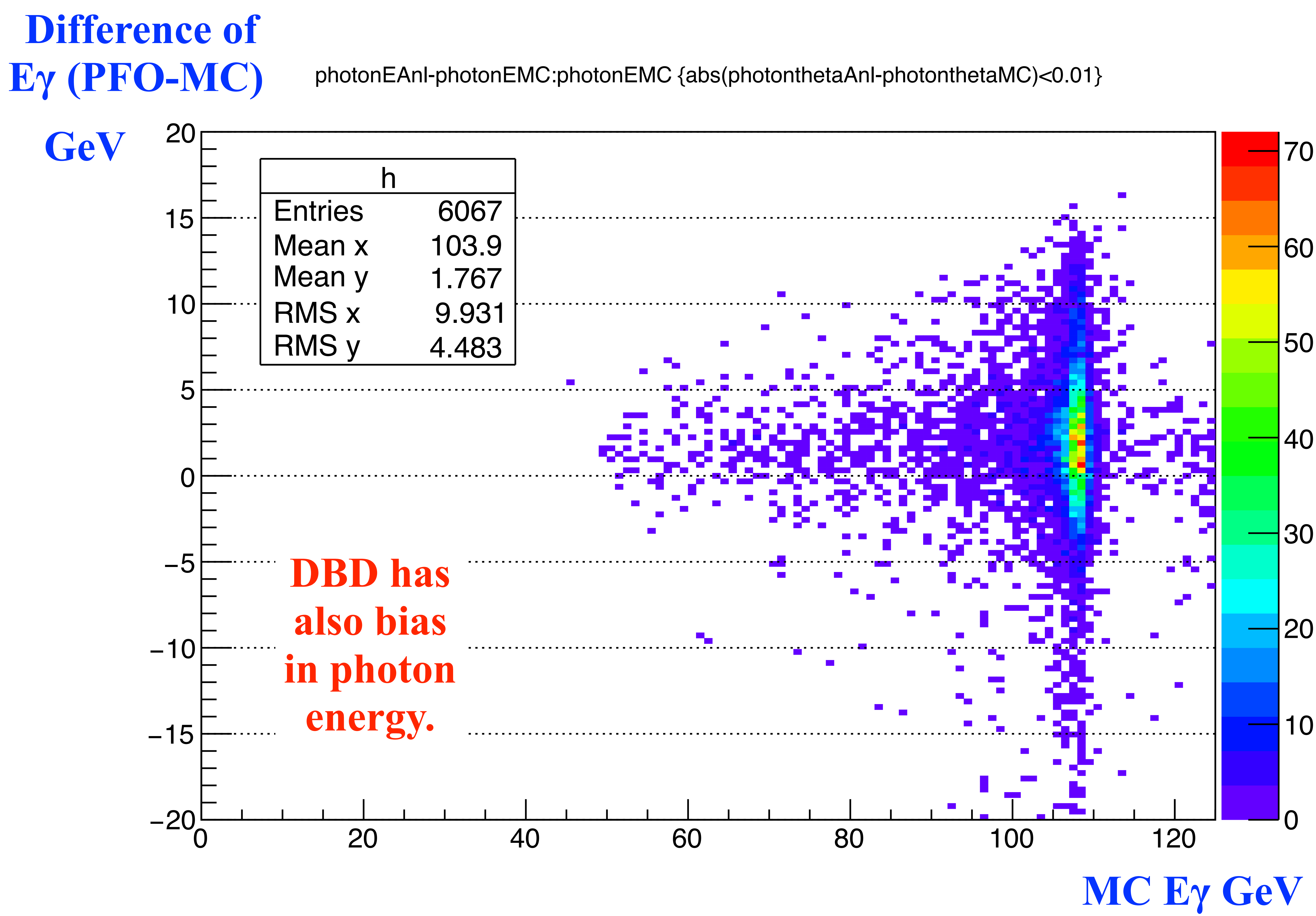
Photon energy bias in DBD



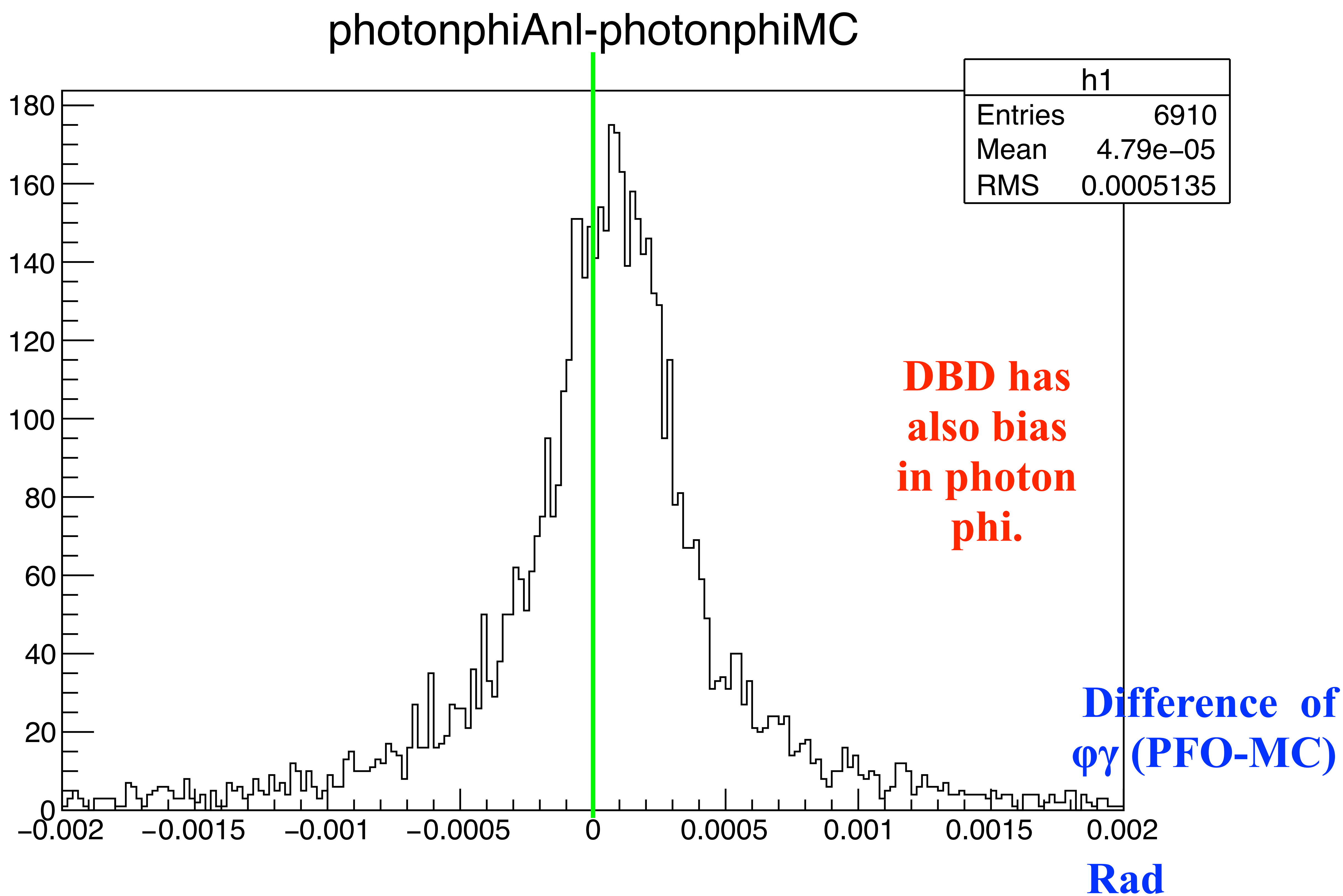
Difference of Eγ (PFO-MC)

GeV

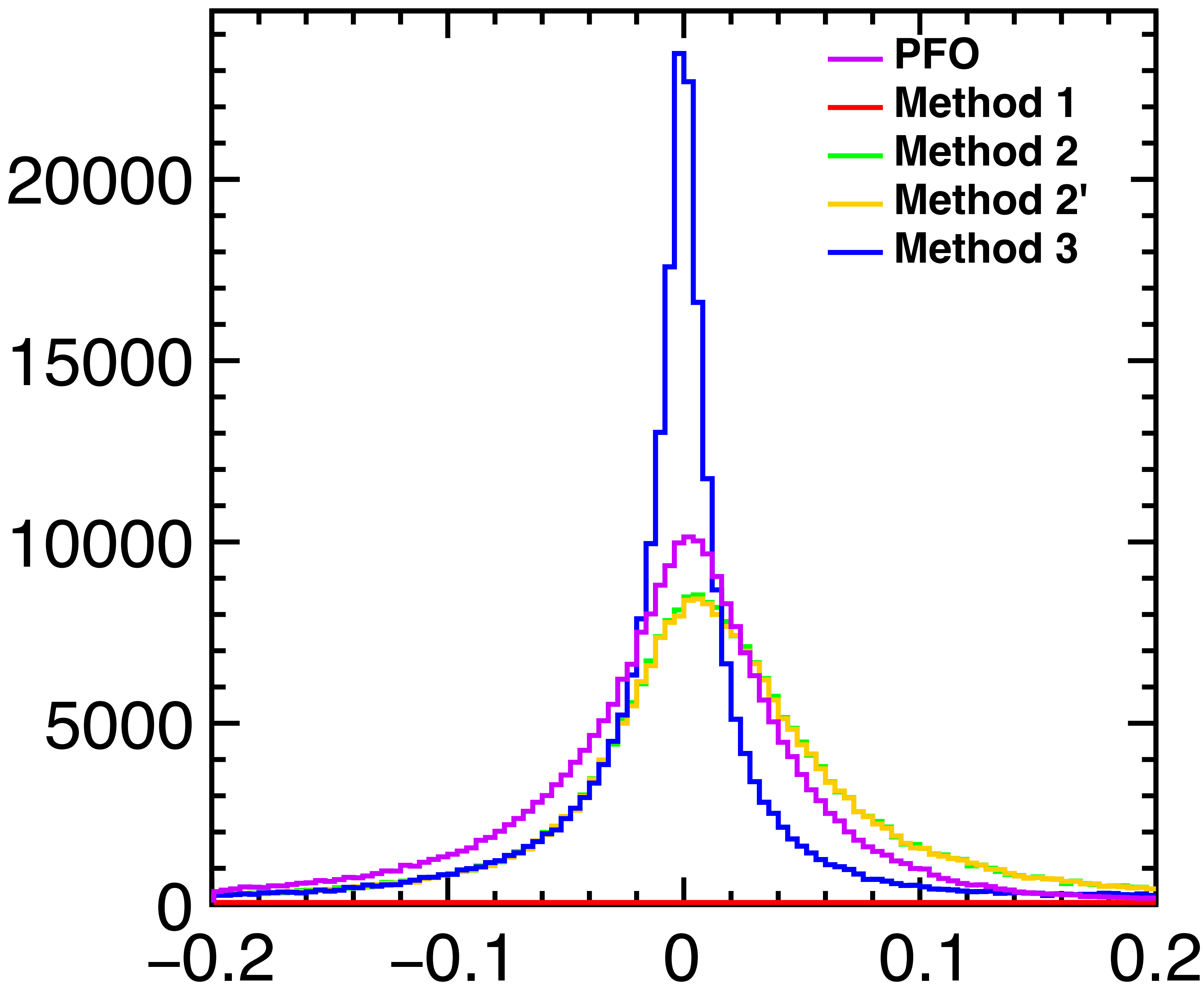
Photon energy bias in DBD



Photon phi bias in DBD



Method comparison of jet1 E difference for correct photon selection events



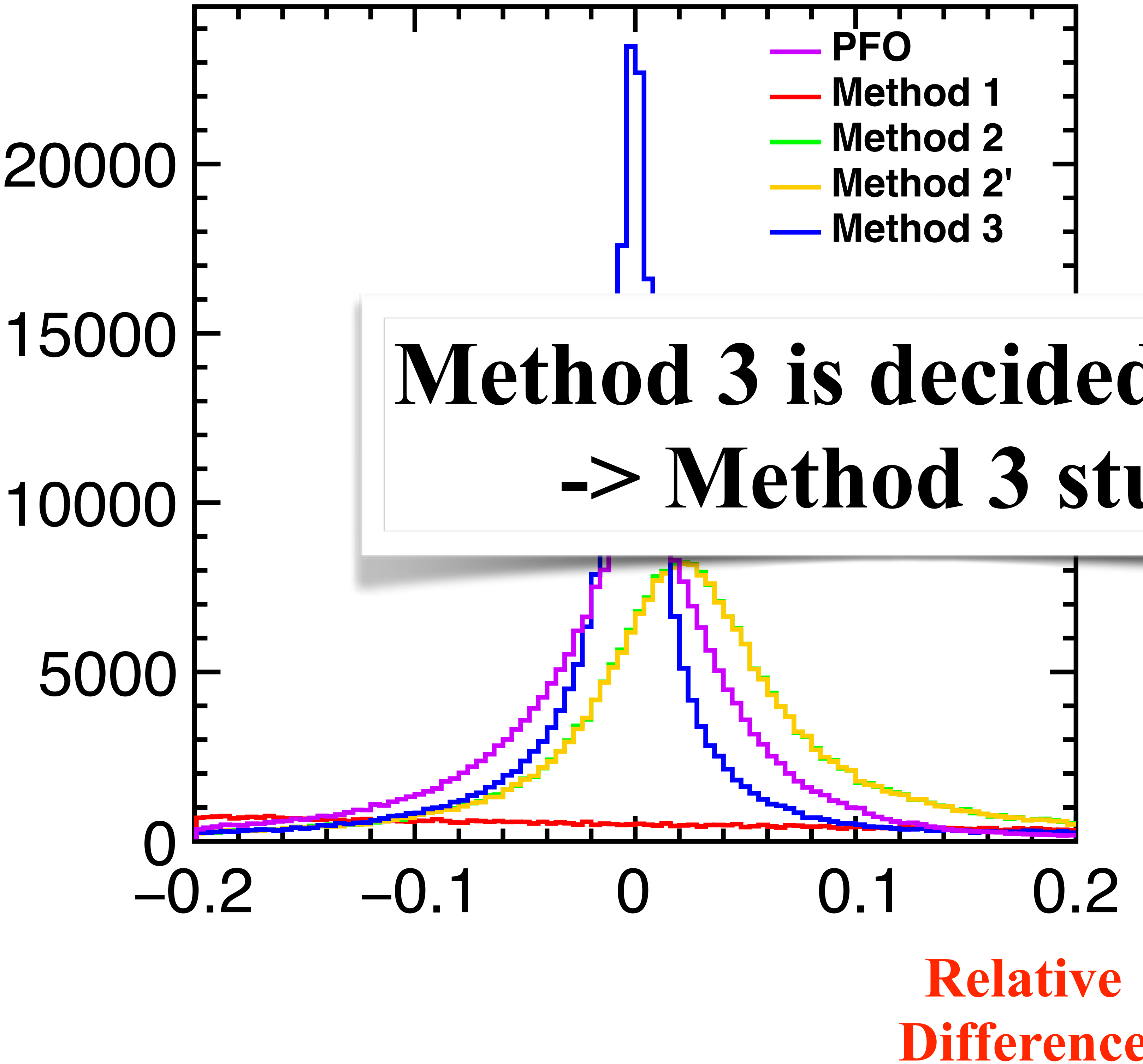
Relative Difference

Using "Smeared MCtruth Eγ", "MCtrue θγ, φγ" as input in Method 2 and 2' .

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

Still Method 3 is the best.

Method comparison of jet1 E difference for correct photon selection events



Method 3 is decided to use.
-> Method 3 study

Method 3 is the best.

① Method 2 and 2'

tive shift.

d 3

distribution
has tail and
is not symmetric.

Today’s talk

1. **Shift to the 250 GeV analysis**
2. **Method comparison result**
3. **Method 3 study**

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 ($P_{J1},P_{J2},P_\gamma,P_{ISR}$)

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

Matrix A

Inverse

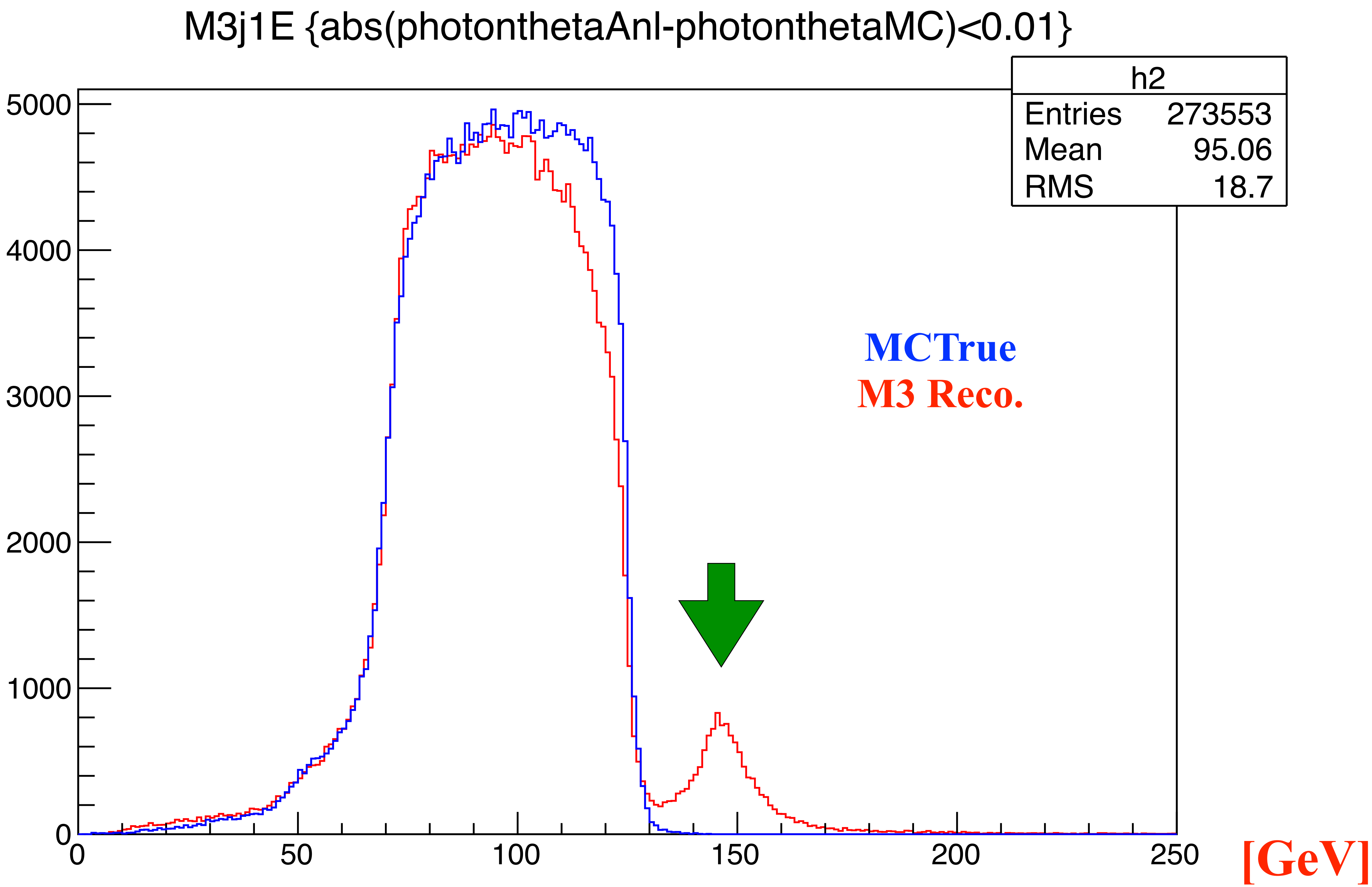
The first equation ① becomes a quartic equation of $|P_{ISR}|$.

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

Choose the solution with (i) real and positive value with <$E_{CM}/2$
(ii) solved P_γ closest to the measured P_γ

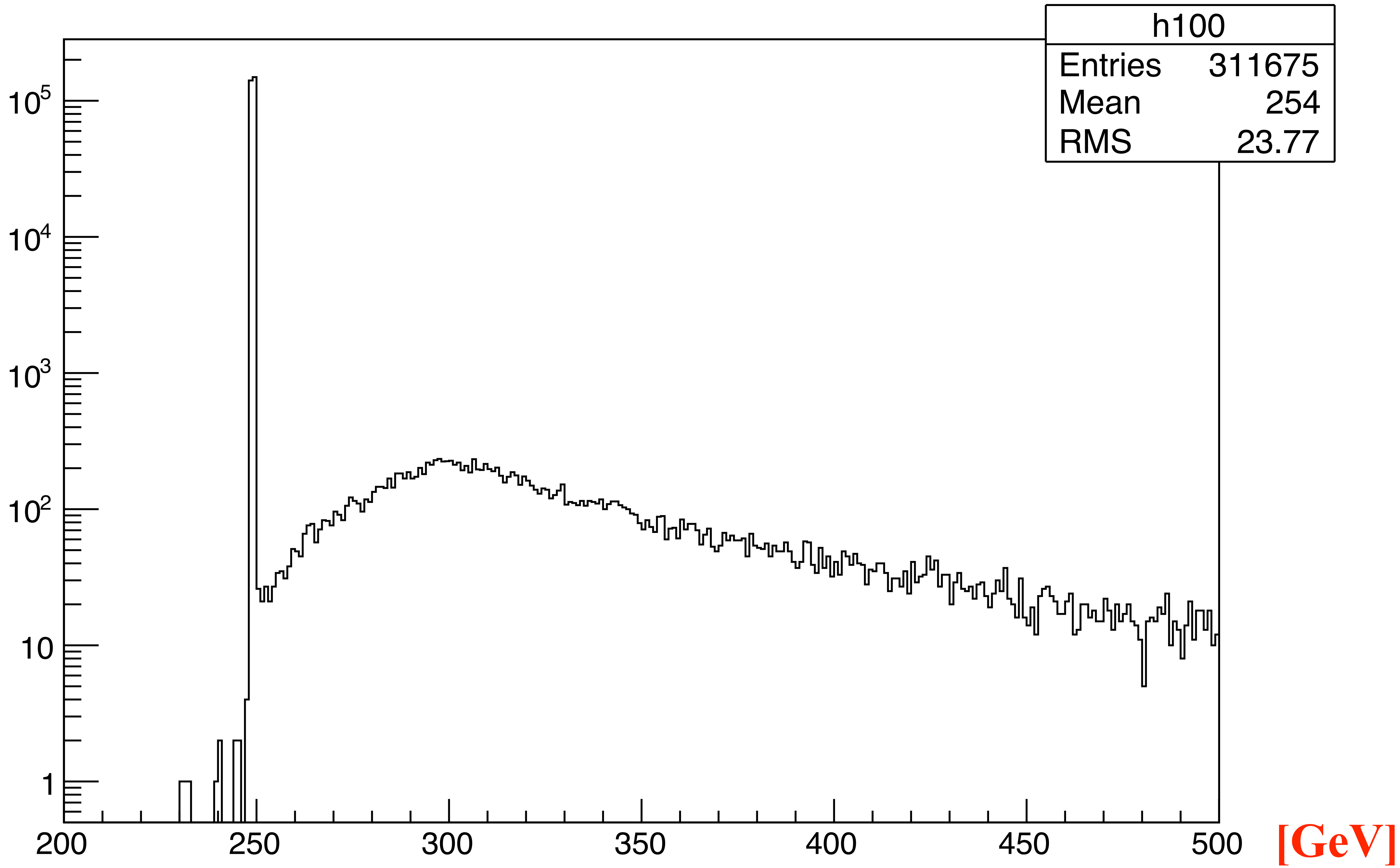
Problem: unexpected bump in reconstructed jet energy

Method 3 Jet1 energy distribution



Sum of the M3 Reconstructed Energy

Reconstructed $\sqrt{P_{J1}^2 + m_{J1}^2} + \sqrt{P_{J2}^2 + m_{J2}^2} + |P_\gamma| + |P_{ISR}|$



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)
The first equation ① is an irrational equation!

-> We should be careful when removing radicals $\sqrt{P_{J1}^2+m_{J1}^2}$ and $\sqrt{P_{J2}^2+m_{J2}^2}$.
(Extraneous roots!!)

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 ($P_{J1},P_{J2},P_\gamma,P_{ISR}$)

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

Matrix A

Inverse

Modified criteria to choose the best answer

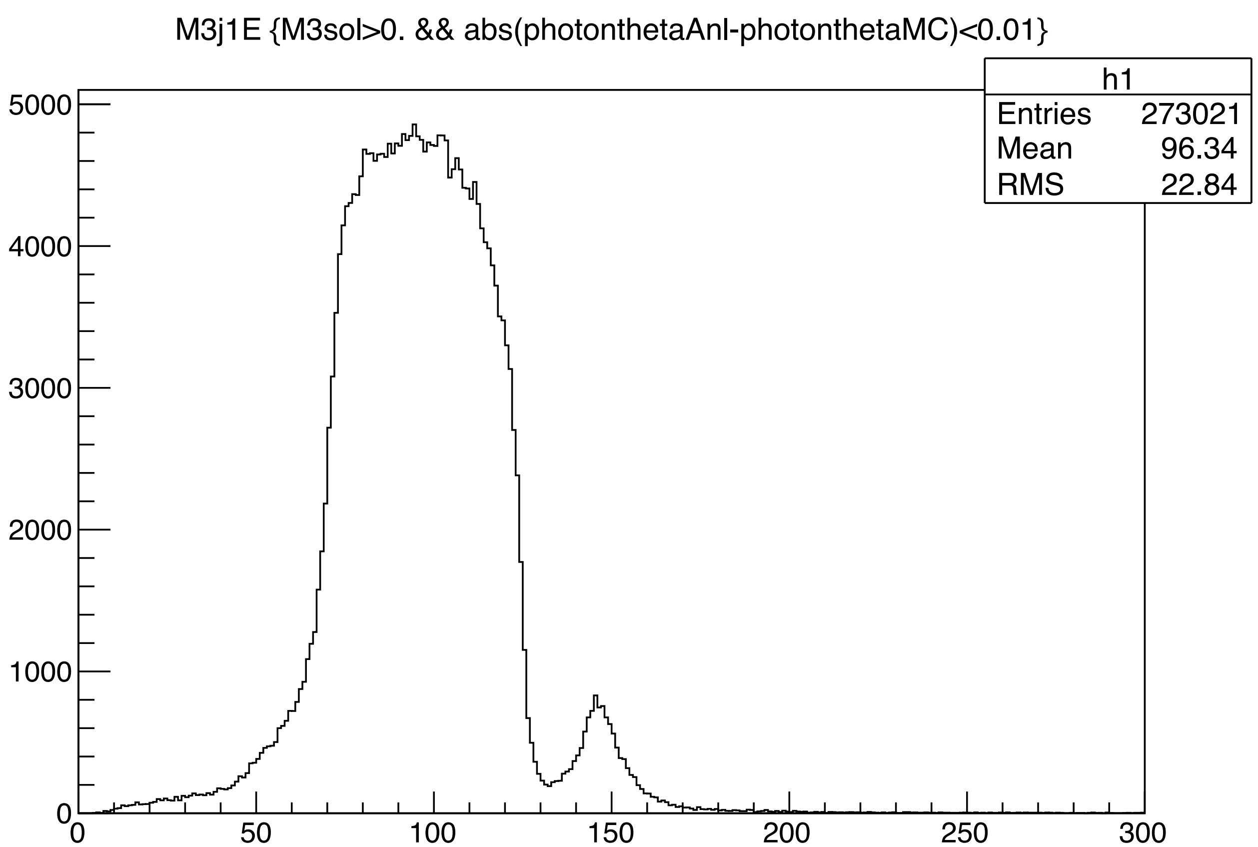
Choose the solution with

- **(i) Real and positive value with <$E_{CM}/2$**
- **(ii) $\sqrt{P_{J1}^2+m_{J1}^2}$ >0 and $\sqrt{P_{J2}^2+m_{J2}^2}$ >0**
- **(iii) P_{J1}, P_{J2}, P_γ >0**
- **(iv) solved P_γ closest to the measured P_γ**

Problem: unexpected bump in reconstructed jet energy

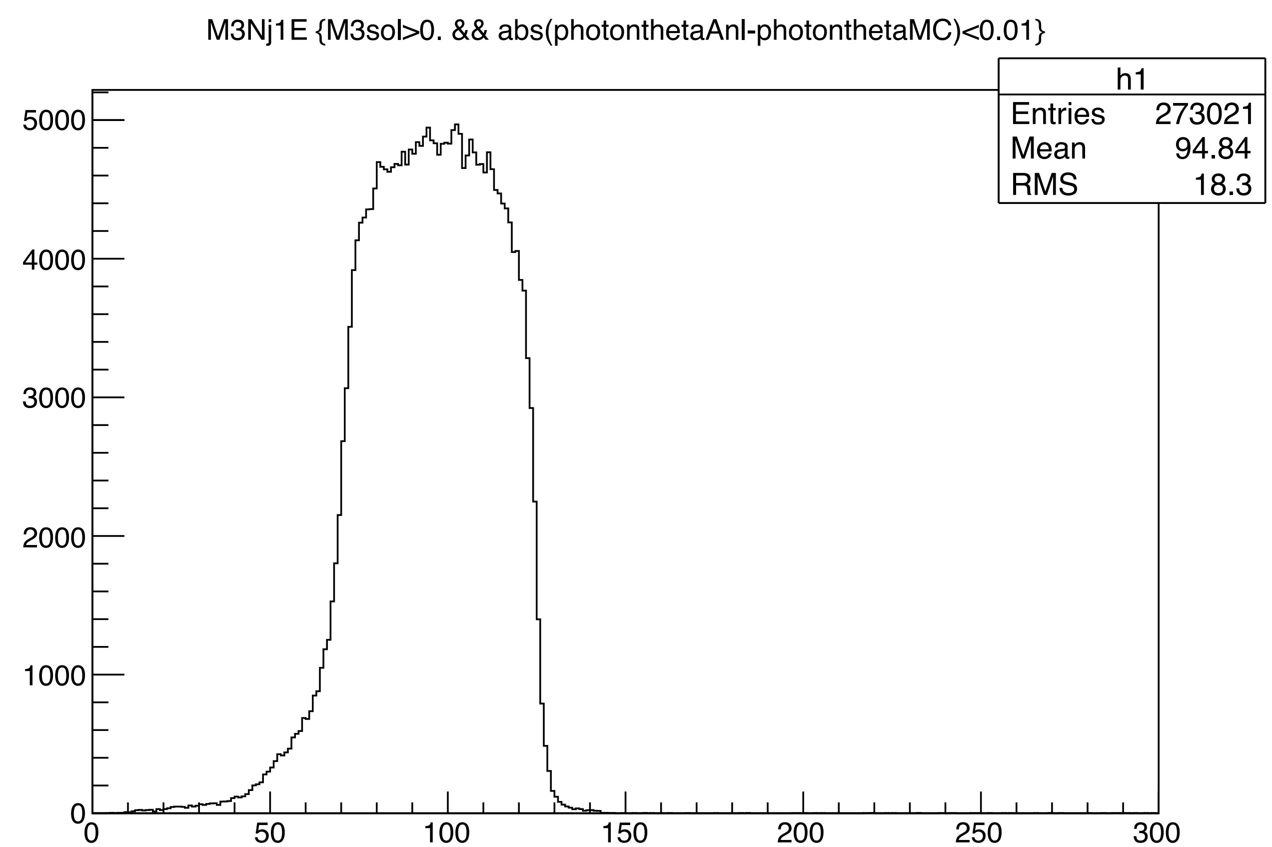
Method 3 Jet1 energy distribution

Conventional M3



[GeV]

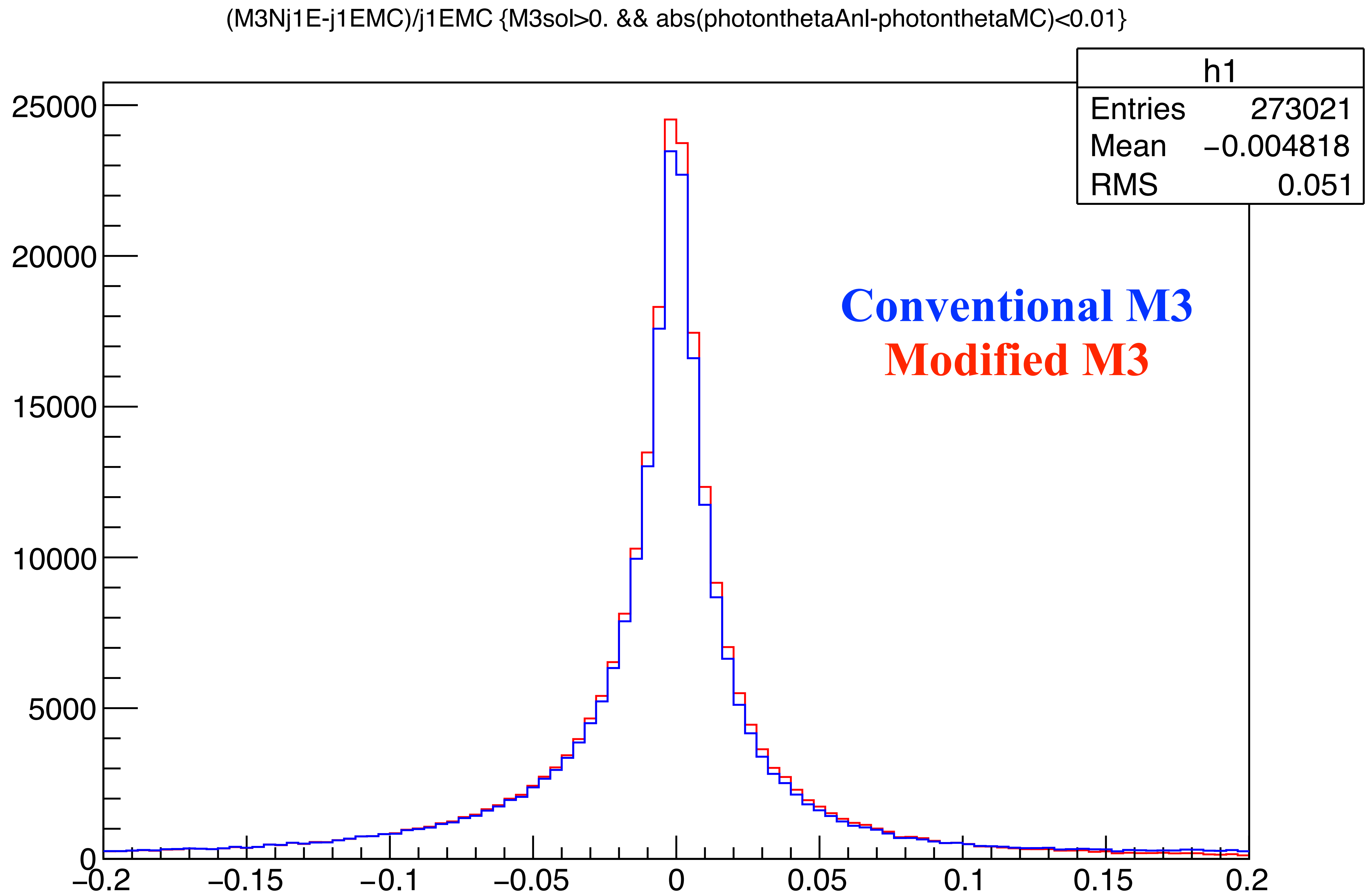
Modified M3



[GeV]

The bump disappeared.

M3 jet1 energy difference



Summary

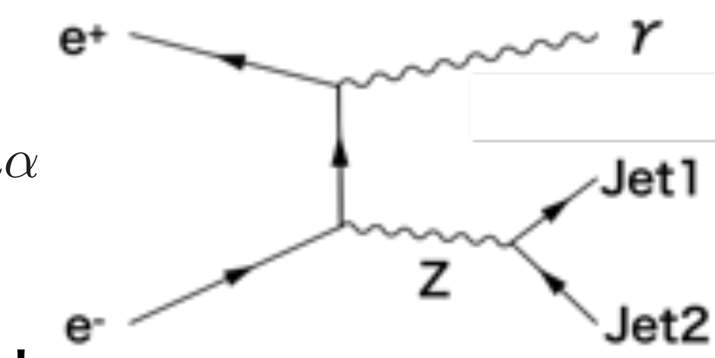
- In order to perform 250 GeV analysis, we decided to use DBD samples instead of current using samples until new sample is validated.
- Photon energy has peaks at ~0 GeV and 109 GeV, and the latter one is from radiative return.
- The distributions of reconstructed jet energies using Method 2 and 2' have positive shift mainly because of the photon energy and angle biases in PFO.
- Method3 is the best among the 4 methods to reconstruct the jet energy.
- Method3 had problem due to extraneous roots. The problem is fixed and the peak of jet1 energy difference becomes slightly sharper.
- For the next step, energy and angle dependences of Method3 reconstructed jet energy will be checked.

Backup

Reconstruction Method

Based on 4-momentum conservation

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



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 ($P_{J1},P_{J2},P_\gamma$)

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

Matrix A — Inverse

Reconstruction Method

Method 2': Use measured P_γ as input and Ignore ISR
Using (θ_{J1},θ_{J2},θ_γ,φ_{J1},φ_{J2},φ_γ,m_{J1},m_{J2},P_γ) -> Determine (P_{J1},P_{J2})

$$\left\{ \begin{pmatrix} sin\theta_{J1}cos\phi_{J1} & sin\theta_{J2}cos\phi_{J2} \\ sin\theta_{J1}sin\phi_{J1} & sin\theta_{J2}sin\phi_{J2} \end{pmatrix} \begin{pmatrix} P_{J1} \\ P_{J2} \end{pmatrix} = \begin{pmatrix} 500sin\alpha - sin\theta_\gamma cos\phi_\gamma P_\gamma \\ -sin\theta_\gamma sin\phi_\gamma P_\gamma \end{pmatrix} \right.$$

Method 2: Use measured P_γ as input and Ignore ISR
Using (θ_{J1},θ_{J2},θ_γ,φ_{J1},φ_{J2},φ_γ,m_{J1},m_{J2},P_γ) -> Determine (P_{J1},P_{J2},P_{ISR})

$$\left\{ \begin{array}{l} \sqrt{P_{J1}^2 + m_{J1}^2} + \sqrt{P_{J2}^2 + m_{J2}^2} + |P_\gamma| + |P_{ISR}| = 500 \quad ① \\ \begin{pmatrix} sin\theta_{J1}cos\phi_{J1} & sin\theta_{J2}cos\phi_{J2} & sin\alpha \\ sin\theta_{J1}sin\phi_{J1} & sin\theta_{J2}sin\phi_{J2} & 0 \\ cos\theta_{J1} & cos\theta_{J2} & \pm cos\alpha \end{pmatrix} \begin{pmatrix} P_{J1} \\ P_{J2} \\ |P_{ISR}| \end{pmatrix} = \begin{pmatrix} 500sin\alpha - sin\theta_\gamma cos\phi_\gamma P_\gamma \\ -sin\theta_\gamma sin\phi_\gamma P_\gamma \\ -cos\theta_\gamma P_\gamma \end{pmatrix} \end{array} \right.$$

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 ($P_{J1},P_{J2},P_\gamma,P_{ISR}$)

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

Matrix A

Inverse

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

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 ($P_{J1},P_{J2},P_{\gamma},P_{ISR}$)

$$\sqrt{P_{J1}^2+m_{J1}^2}+\sqrt{P_{J2}^2+m_{J2}^2}+|P_{\gamma}|+|P_{ISR}| = E_{CM} \quad ①$$

Row	E_{Sum}	E_{ISR}	E_{J1}	E_{J2}	E_{γ}
2	366.53696	72.535351	156.96777	58.569181	79.066051
9	298.62565	9.8457809	146.57377	25.051876	118.63231
10	400.57065	1.3064283	203.00334	75.567307	121.25753
11	426.27959	50.853665	152.64726	88.632330	135.13139
12	333.03742	66.762206	141.00941	42.028016	84.256399
16	282.4159	26.559148	16.589673	128.82622	111.20429
19	279.9828	54.639210	116.56381	15.418981	94.215952
27	281.90901	69.992376	136.99227	16.916738	59.932090
33	382.44162	35.440445	147.82023	66.621390	133.36070
36	386.59473	54.612970	152.68251	68.912223	111.61674
50	279.53136	15.377309	127.38918	15.142176	122.37568
61	297.67282	13.505328	129.46546	24.207362	131.23656
62	282.14231	47.540821	134.59052	16.551790	84.420444
66	313.20207	3.2458796	154.15914	32.042931	124.63790
68	290.91970	17.090852	141.20568	20.714028	112.41749
70	1535.683	55.852535	714.16113	643.52186	123.50819
72	296.60387	10.071965	144.07756	23.526305	119.37677
142	360.68284	25.702743	145.96058	55.722258	134.05892
172	339.58430	12.741662	150.33482	45.249473	132.17298
177	2495.1260	20.447979	1122.7955	1244.3305	108.01703

$$\sqrt{|P_{J1}|^2+m_{J1}^2} + \sqrt{|P_{J2}|^2+m_{J2}^2} + |P_\gamma| + |P_{ISR}| = 500 \quad \cdots ⑧$$

$$|P_{J1}|^2 + m_{J1}^2 = \left(\boxed{500 - \sqrt{|P_{J2}|^2+m_{J2}^2} - |P_\gamma| - |P_{ISR}|}\right)^2$$

$$= |P_{J2}|^2 + m_{J2}^2 - 2\sqrt{|P_{J2}|^2+m_{J2}^2}\,(500-|P_\gamma|-|P_{ISR}|) + (500-|P_\gamma|-|P_{ISR}|)^2$$

$$4(|P_{J2}|^2+m_{J2}^2)(500-|P_\gamma|-|P_{ISR}|)^2 = \left(\boxed{-|P_{J1}|^2 - m_{J1}^2 + |P_{J2}|^2 + m_{J2}^2 + (500-|P_\gamma|-|P_{ISR}|)^2}\right)^2$$

□ **should be required to be positive when solving the equation.**

Now trying to implement this.