Status on $e^+e^- \to \gamma Z$ process
Jet Energy Calibration

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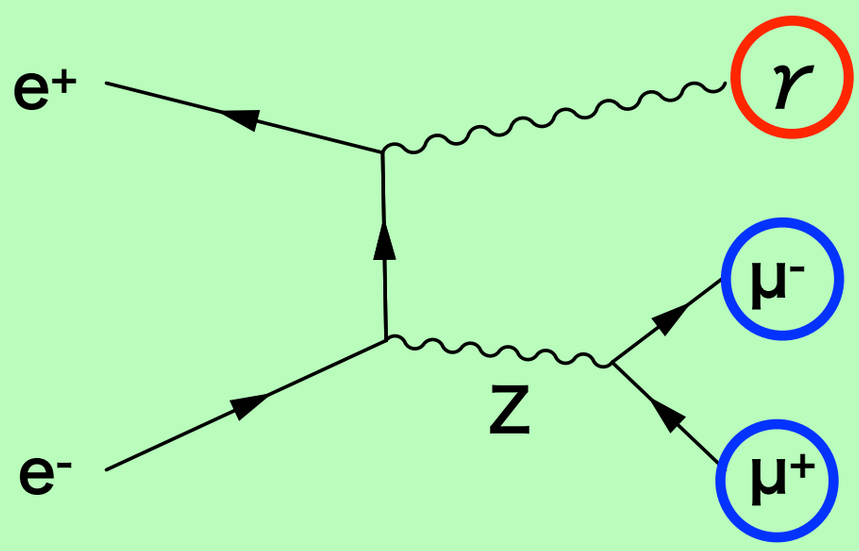
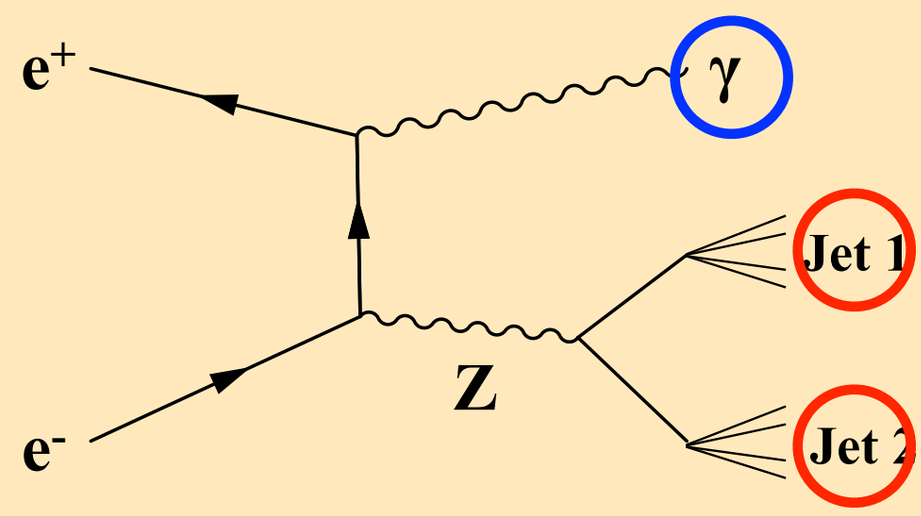
Introduction

- 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 $e^+e^- \rightarrow \gamma Z$ process.
- Using similar energy reconstruction methods, jet energies in the $e^+e^- \rightarrow \gamma Z$, $Z \rightarrow$ 2Jets can be reconstructed.
- If the jet energies can be correctly reconstructed, the $e^+e^- \rightarrow \gamma Z$ process is useful for the jet energy calibration.

Photon Energy Scale Calibration



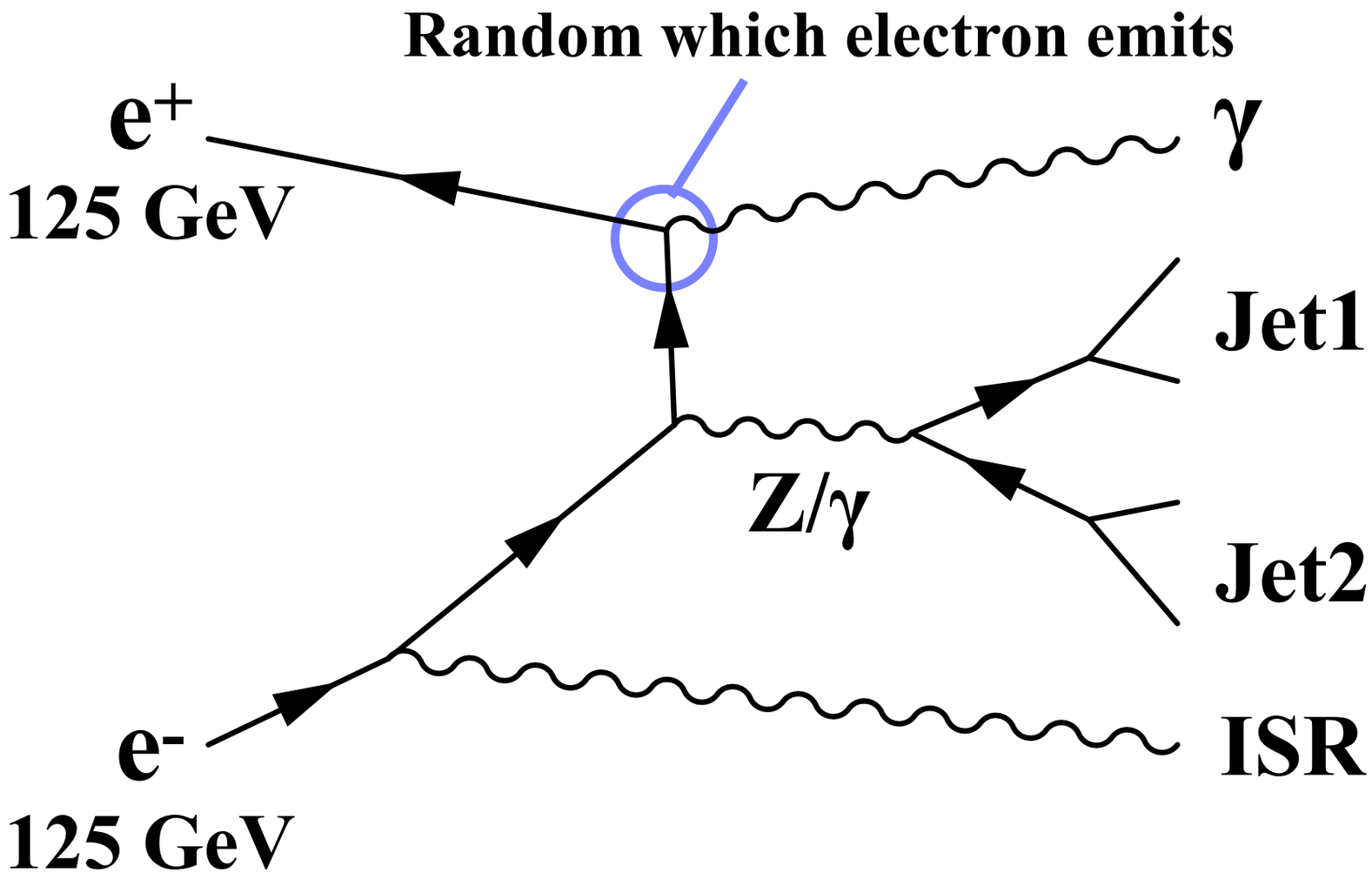
Jet Energy Scale Calibration



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

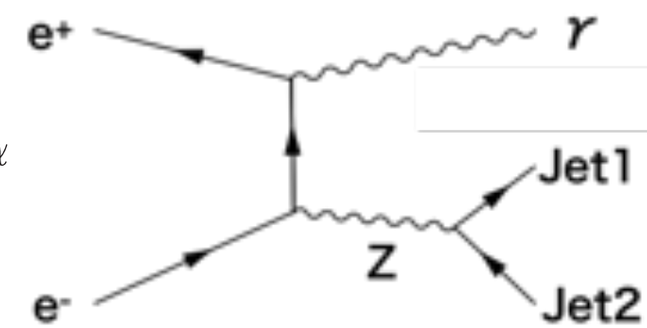
- All PFOs other than the selected photon are clustered into 2 jets with Durham algorithm (done by LCFIPlus)
- The higher energy jet (in PFO) is defined as “jet 1” and lower one as “jet 2”
- For comparison with MCtruth, all final state particles from 2 quarks are clustered into 2 jets

Reconstruction Method

Based on 4-momentum conservation

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

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 (θ_{J1},θ_{J2},θ_γ,φ_{J1},φ_{J2},φ_γ,m_{J1},m_{J2}) -> Determine (P_{J1},P_{J2},P_γ)

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

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 (θ_{J1},θ_{J2},θ_γ,φ_{J1},φ_{J2},φ_γ,m_{J1},m_{J2}) -> Determine (P_{J1},P_{J2},P_γ,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

Irrational equation for each sign of the ISR -> 8 possible solutions

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**

Reconstruction Method

Method 3: Consider ISR and solve the full equation
Using (θ_{J1},θ_{J2},θ_γ,φ_{J1},φ_{J2},φ_γ,m_{J1},m_{J2}) -> Determine (P_{J1},P_{J2},P_γ,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

Irrational equation for each sign of the ISR -> 8 possible solutions

Had to solve two quartic equations and choose the best answer!
-> Are there any easier expression?

Reconstruction Method

Jet mass "m" can be expressed as "P/γβ" (P: momentum of the jet)
-> Irrational equation ① is reduced to be a linear equation!

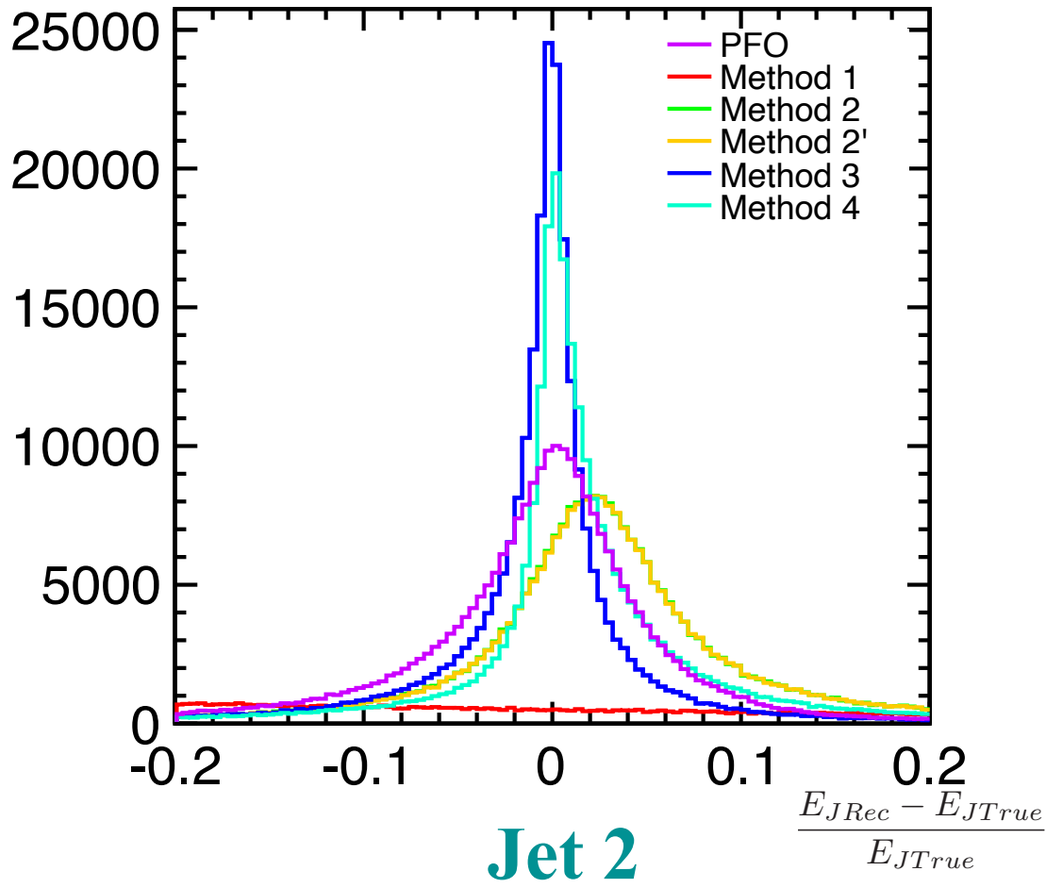
Method 4: Represent the equation with P_{ISR}
Using (θ_{J1},θ_{J2},θ_{γ},φ_{J1},φ_{J2},φ_{γ},$\gamma\beta_{J1}$,$\gamma\beta_{J2}$) -> Determine (P_{J1},P_{J2},P_{γ},P_{ISR})

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

Choose the solution with solved P_{γ} closest to the measured P_{γ}

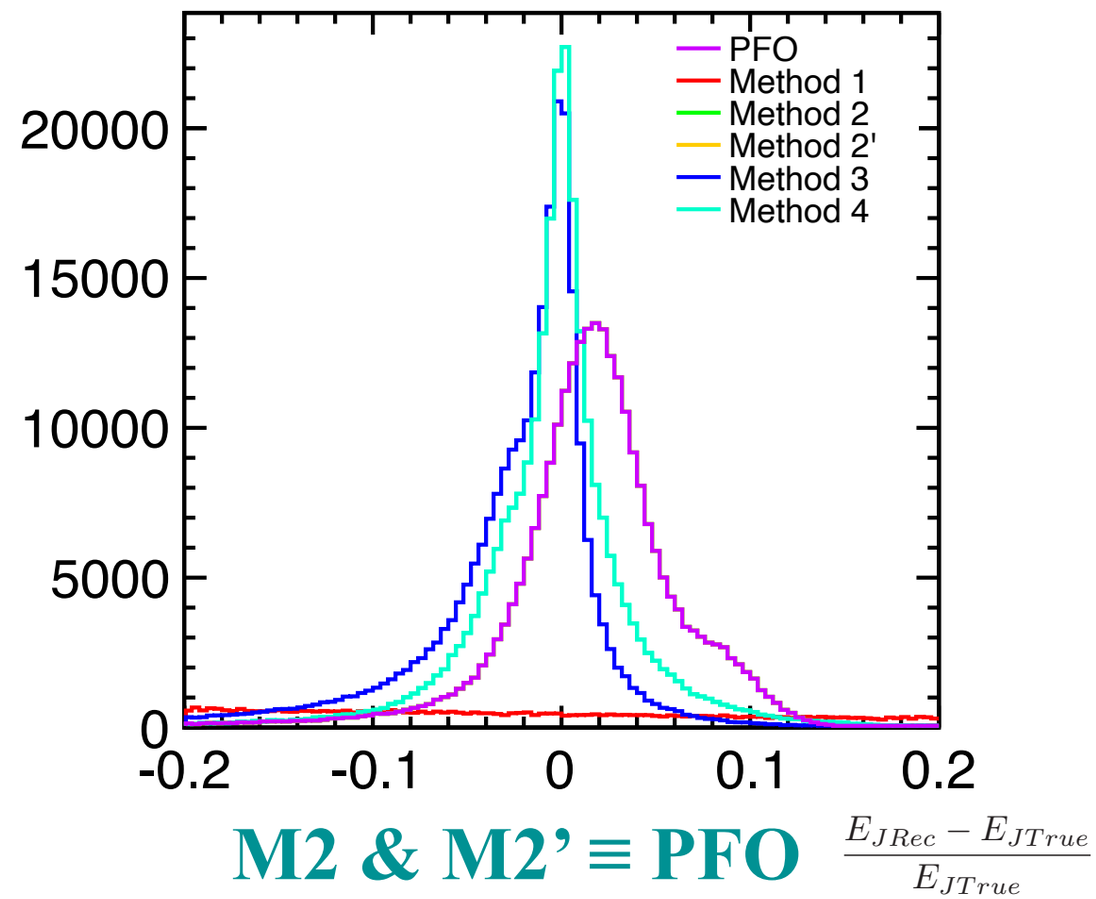
Relative diff. of energy in each method

Jet 1



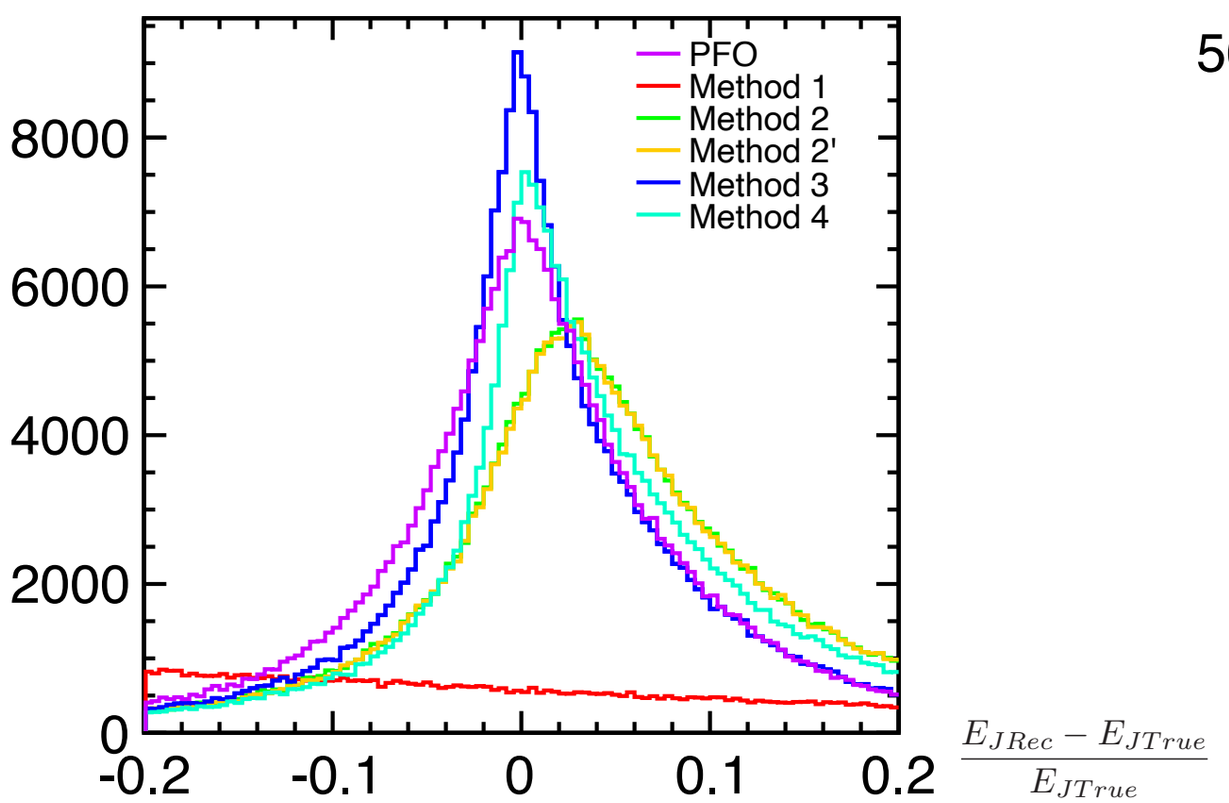
MC Cut:
Correct photon selection
Method 3 has answer

Photon



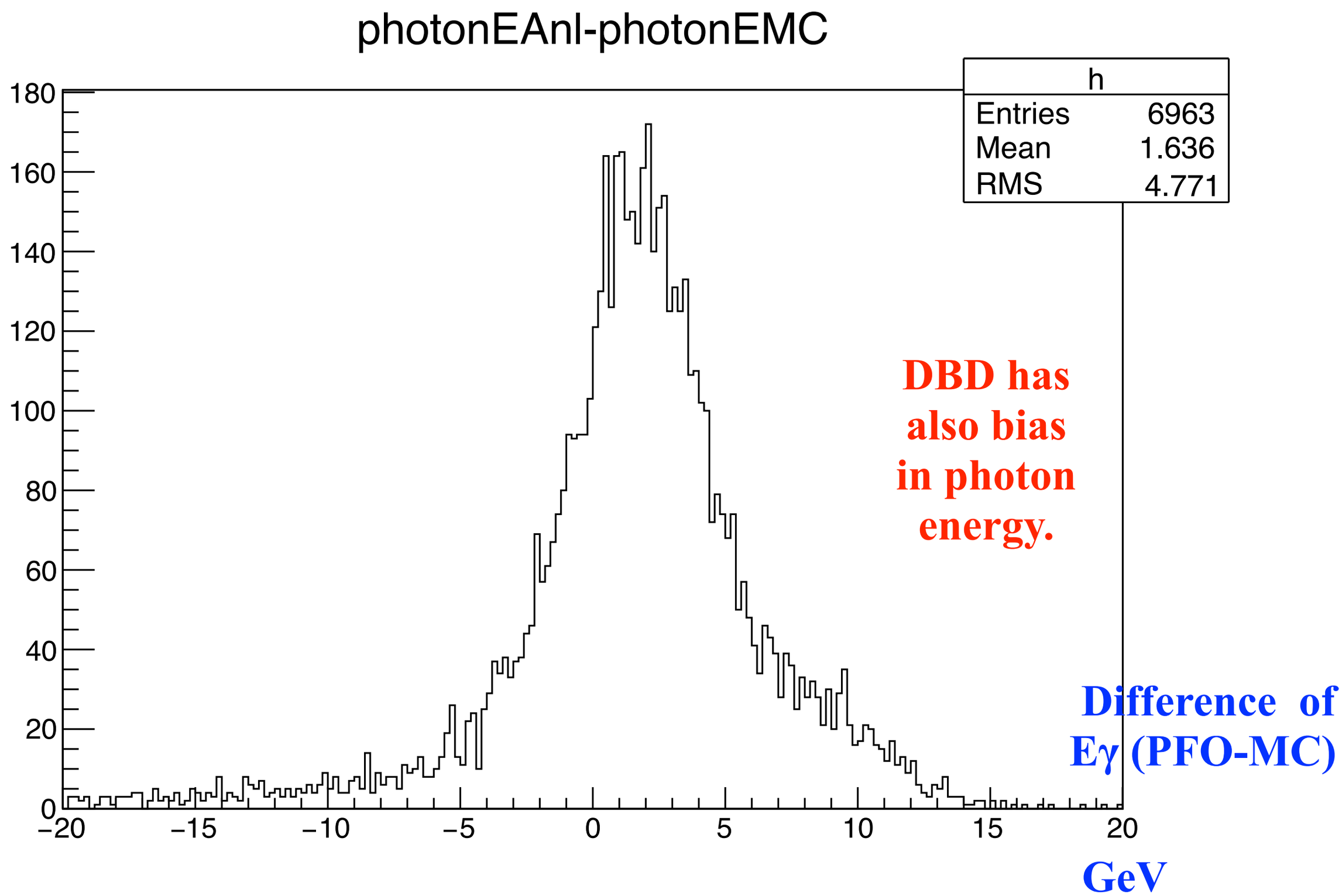
M2 & M2' ≡ PFO

Jet 2

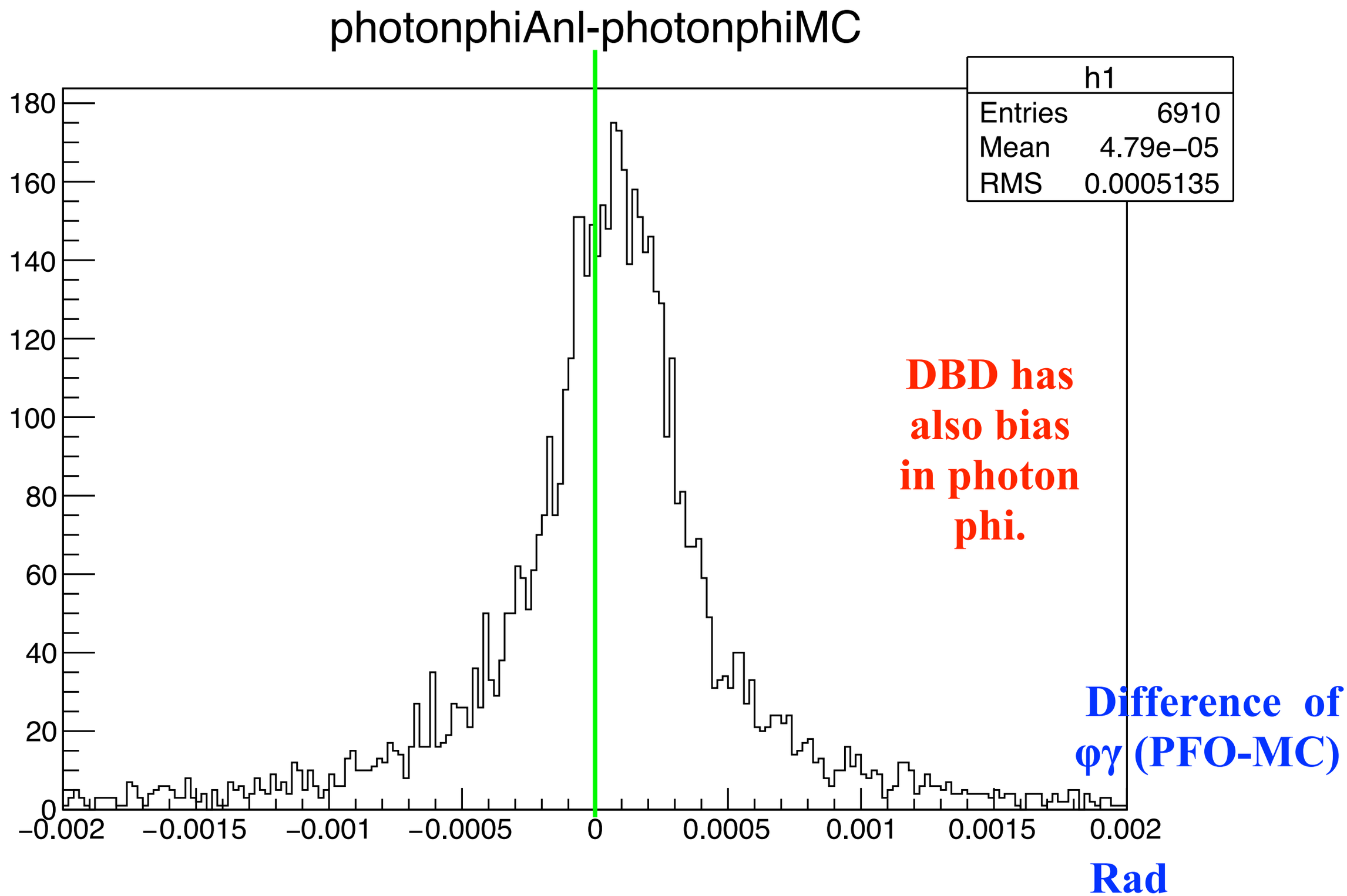


Method 2 and 2' are biased.

Photon energy bias in DBD

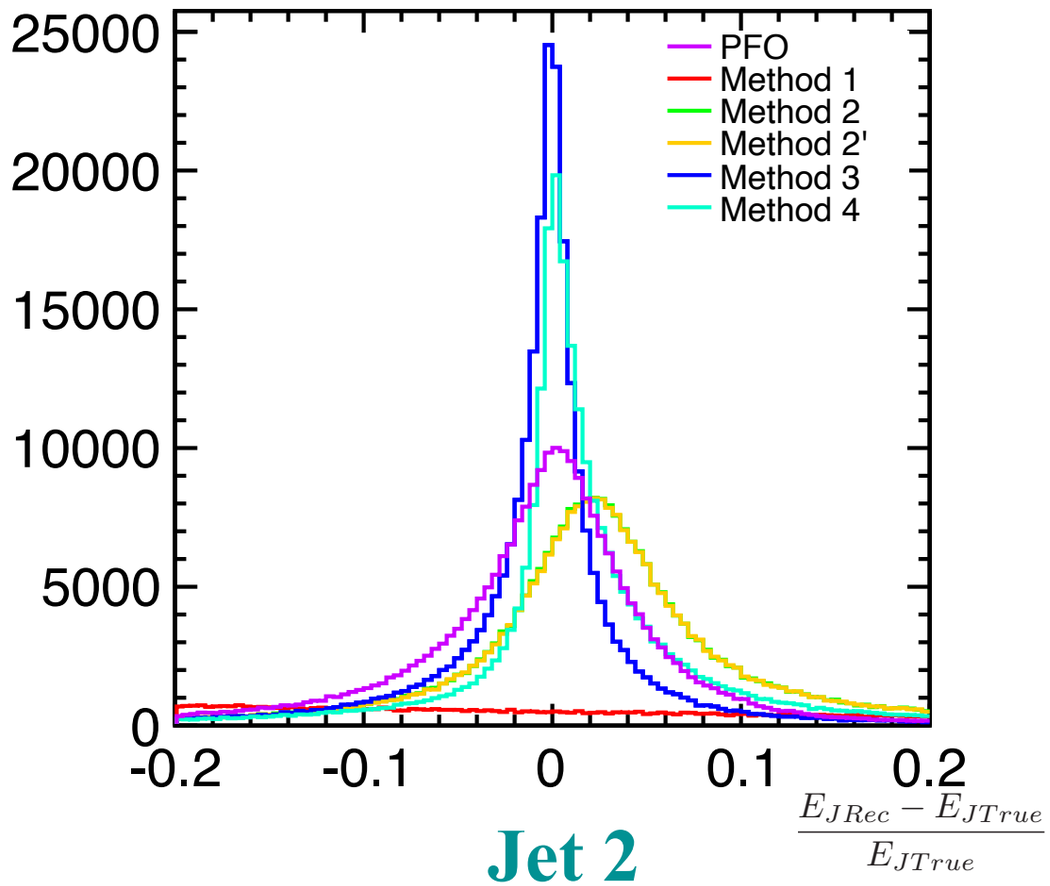


Photon phi bias in DBD

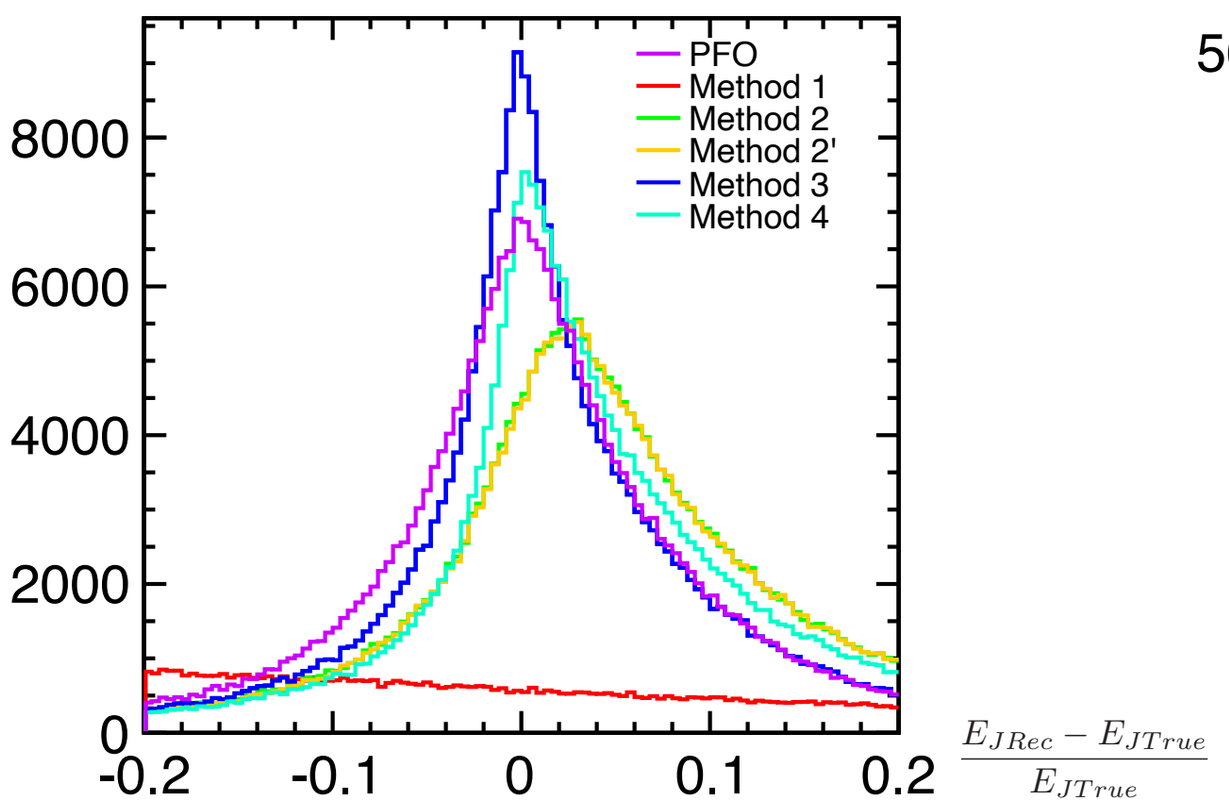


Relative diff. of energy in each method

Jet 1

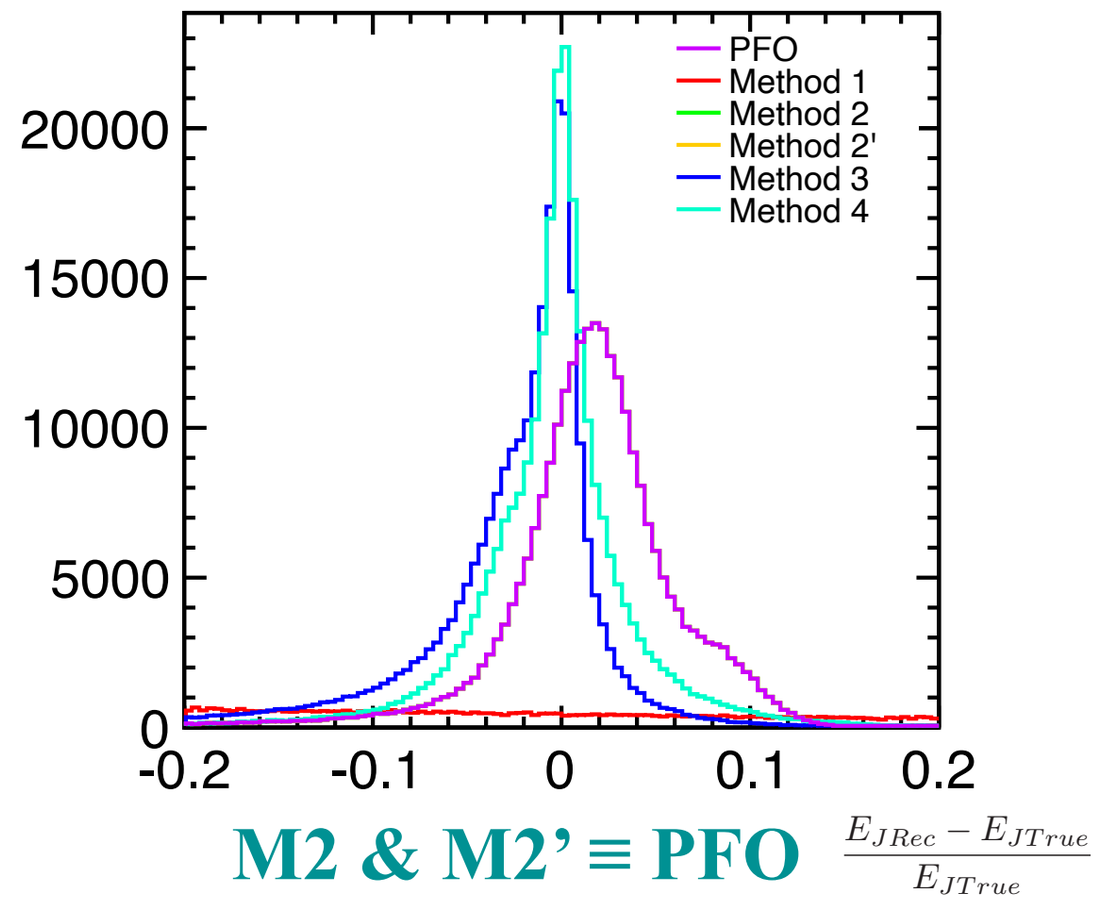


Jet 2



MC Cut:
Correct photon selection
Method 3 has answer

Photon



M2 & M2' ≡ PFO

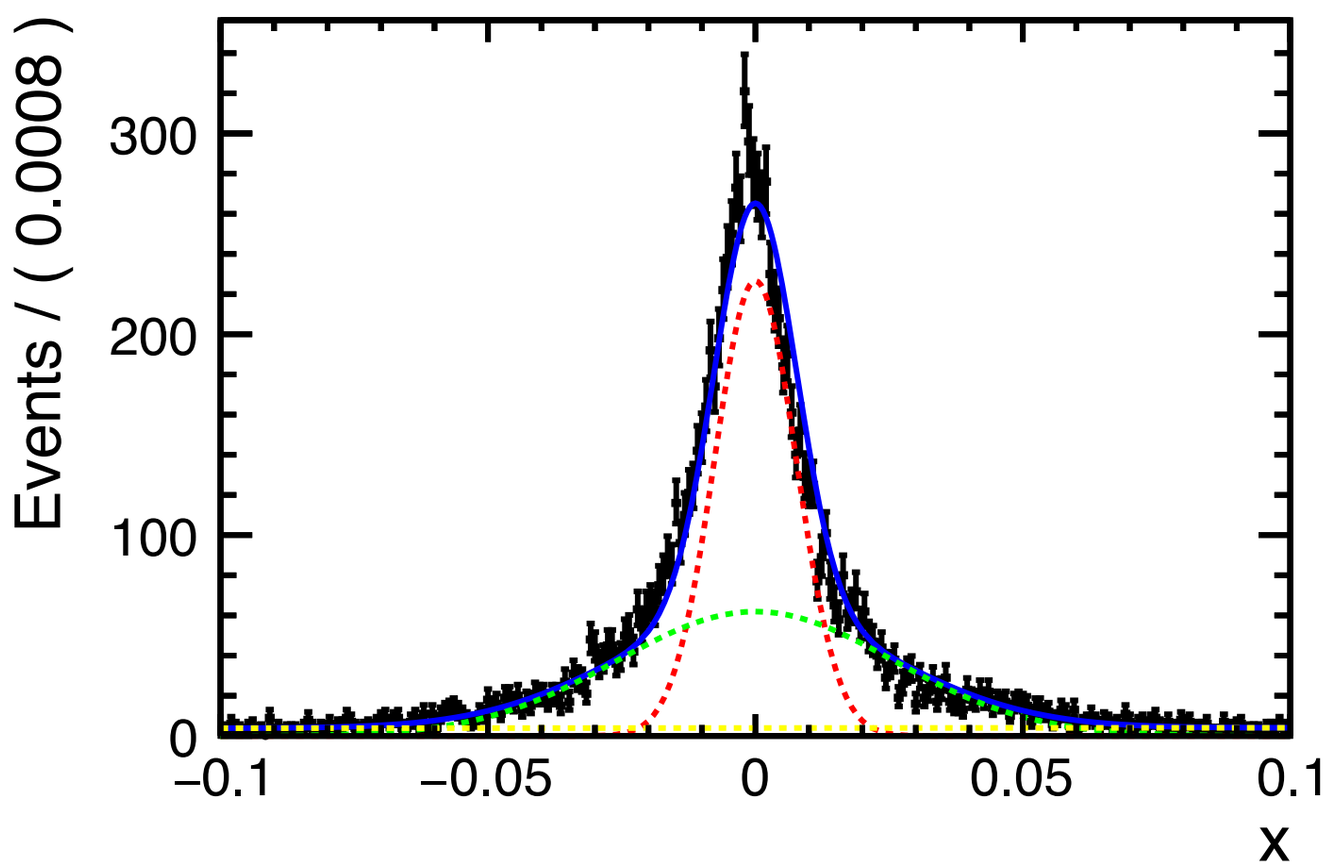
Method 3 is the best judging from peak height and symmetry.

Relative difference of reconstructed jet energy dependence on jet θ and φ

To perform the calibration, angle dependence of Method 3 reconstructed jet energy is checked.

MC-Level cut is imposed: Correct photon selection & Method 3 has answer

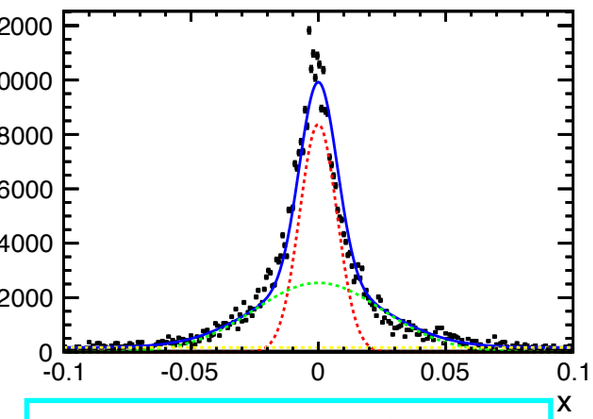
Normalized to 900fb^{-1} for each eLpR and eRpL events and integrated



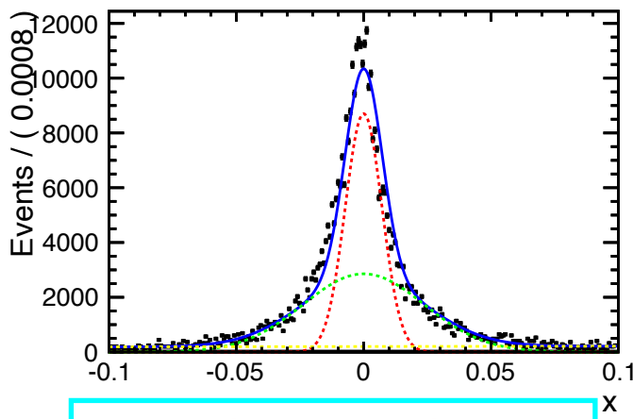
Fit the relative difference of reconstructed jet energy with gaus+gaus+linear func. Mean of the 2 Gaussians are set to be same.

Method 3 Jet 1 energy resolution θ dependence

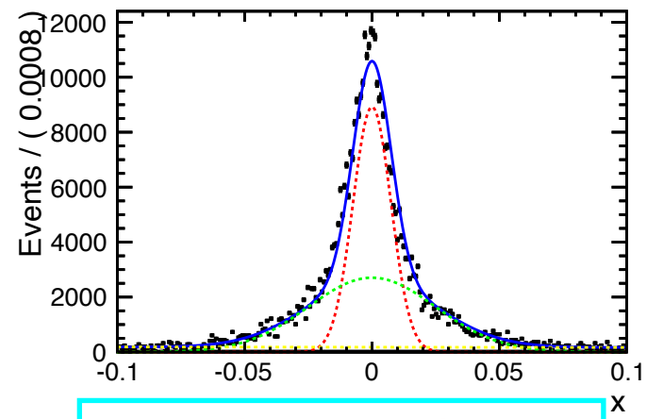
0.0<|cosθ$_{J1}$|<0.1



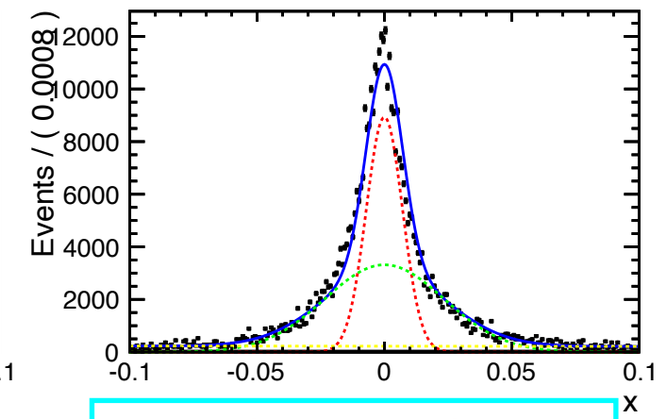
0.1<|cosθ$_{J1}$|<0.2



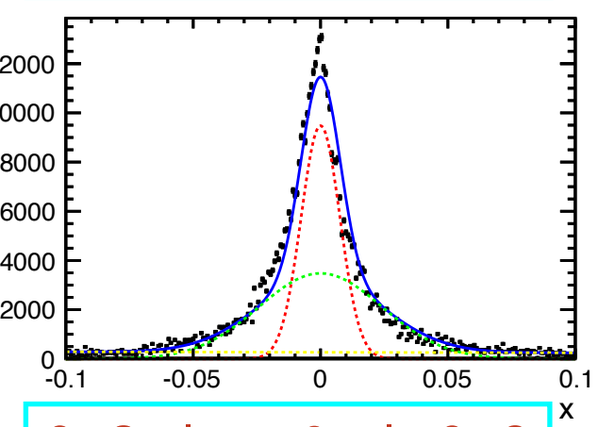
0.2<|cosθ$_{J1}$|<0.3



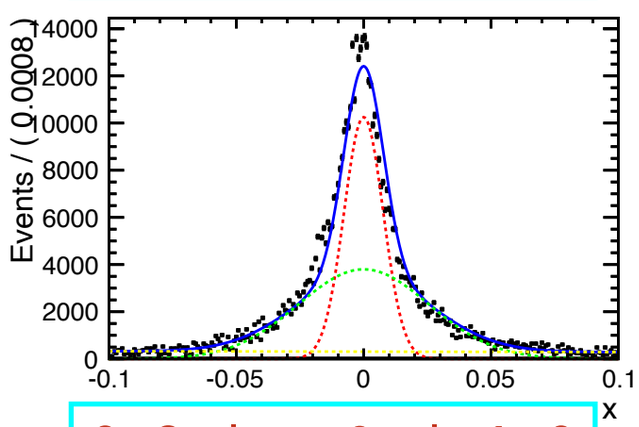
0.3<|cosθ$_{J1}$|<0.4



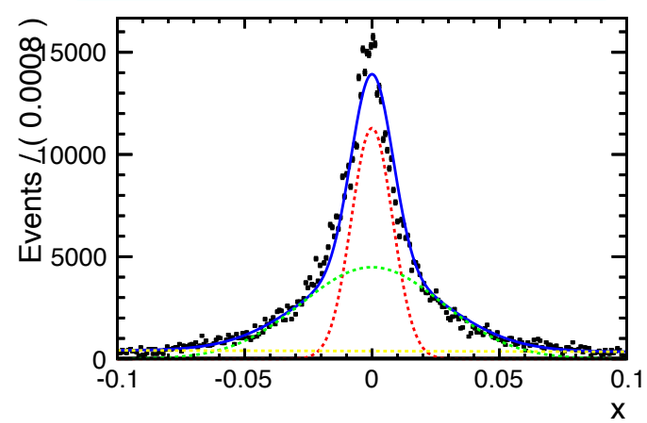
0.4<|cosθ$_{J1}$|<0.5



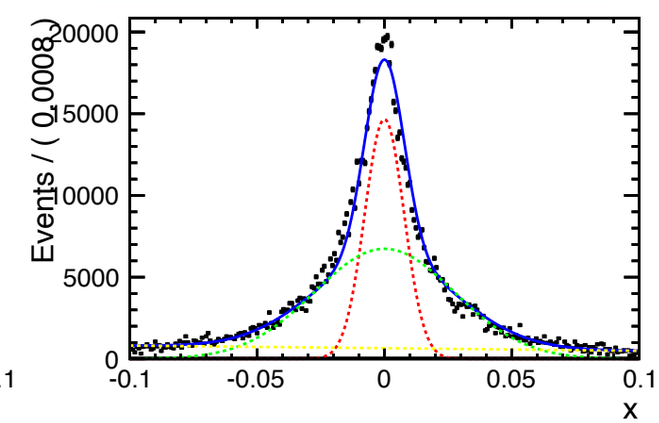
0.5<|cosθ$_{J1}$|<0.6



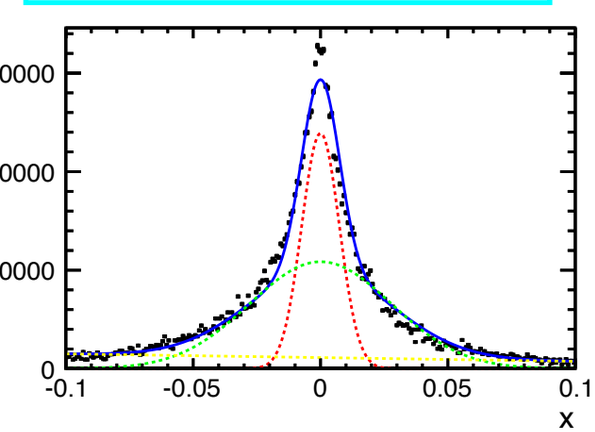
0.6<|cosθ$_{J1}$|<0.7



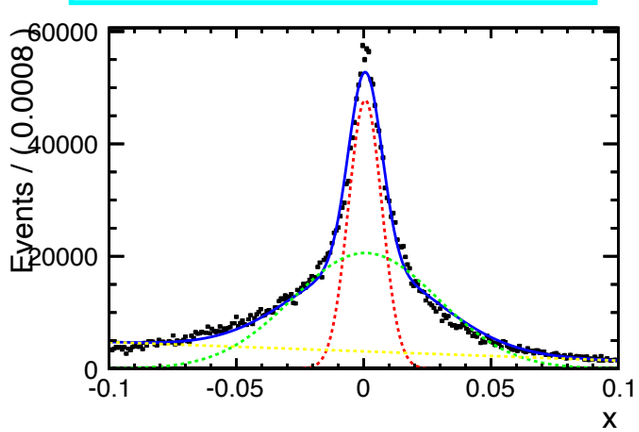
0.7<|cosθ$_{J1}$|<0.8



0.8<|cosθ$_{J1}$|<0.9



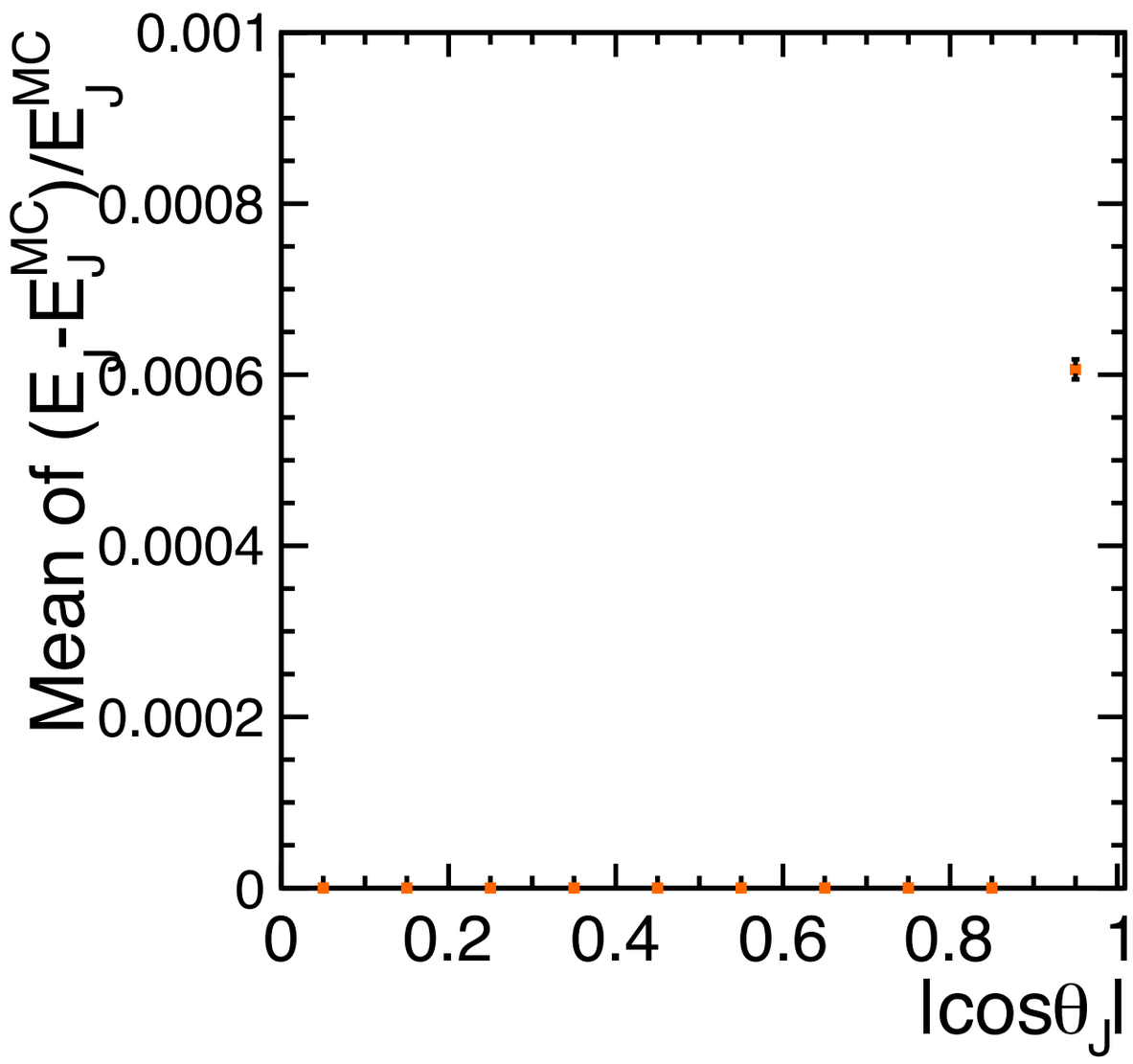
0.9<|cosθ$_{J1}$|<1.0



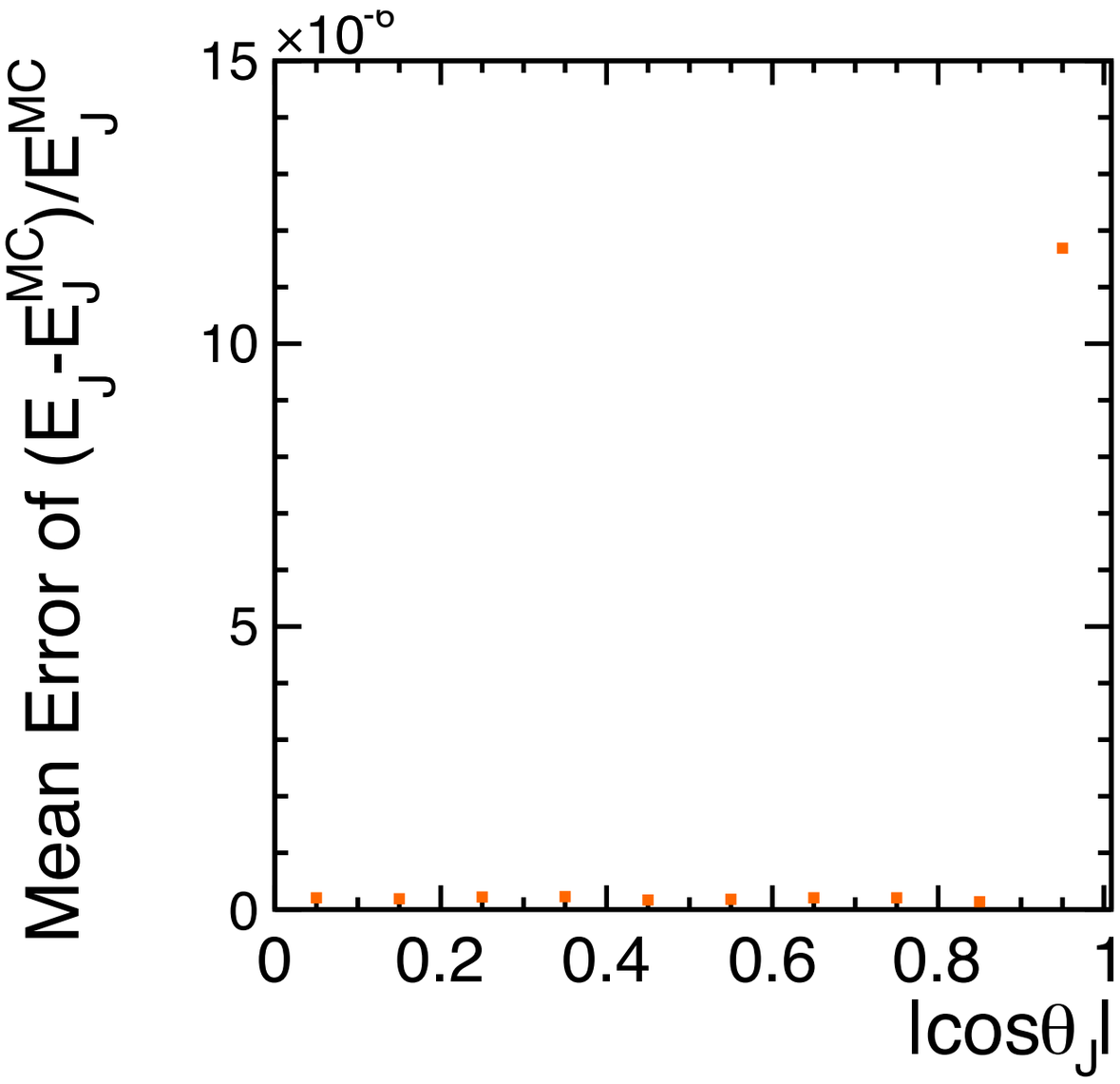
$$\frac{E_{JRec} - E_{JTrue}}{E_{JTrue}}$$

Method 3 Jet 1 energy resolution θ dependence

Mean of $\frac{E_{JRec} - E_{JTrue}}{E_{JTrue}}$



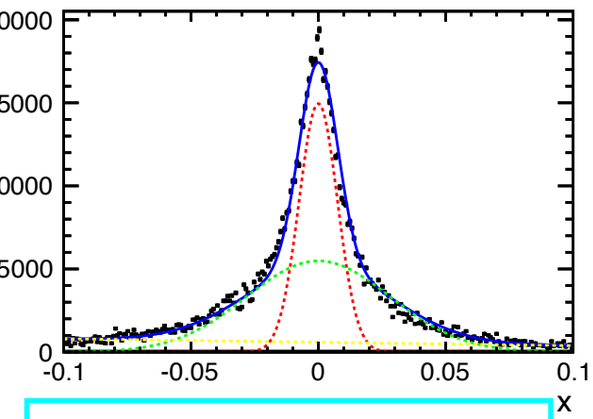
Error of mean



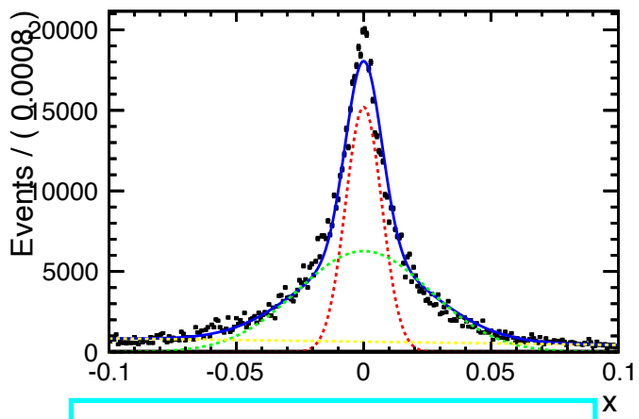
Drastically bad in very forward and backward region.

Method 3 Jet 1 energy resolution φ dependence

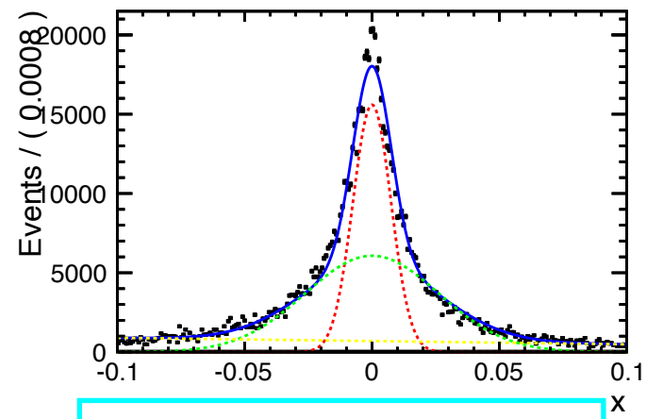
$-\pi<\varphi_{J1}<-0.8\pi$



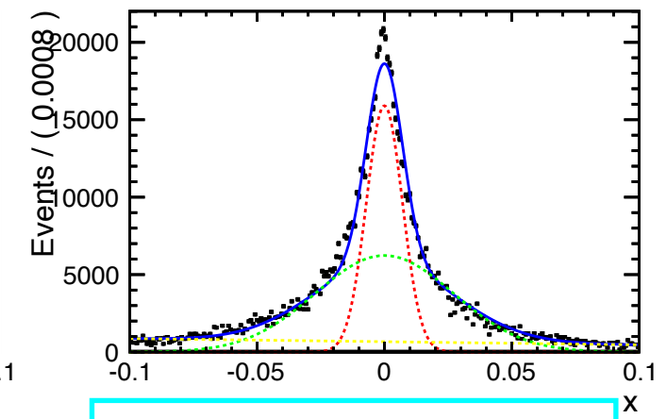
$-0.8\pi<\varphi_{J1}<-0.6\pi$



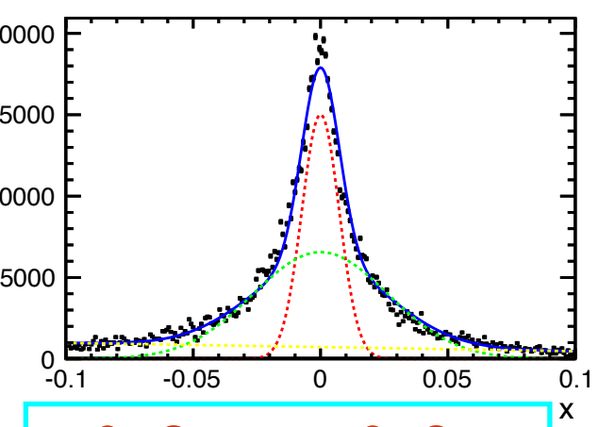
$-0.6\pi<\varphi_{J1}<-0.4\pi$



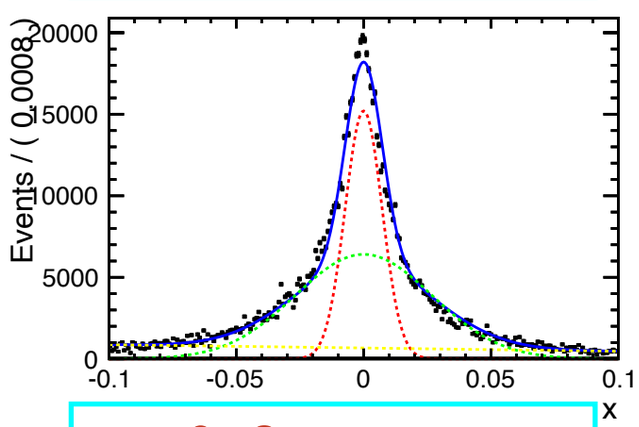
$-0.4\pi<\varphi_{J1}<-0.2\pi$



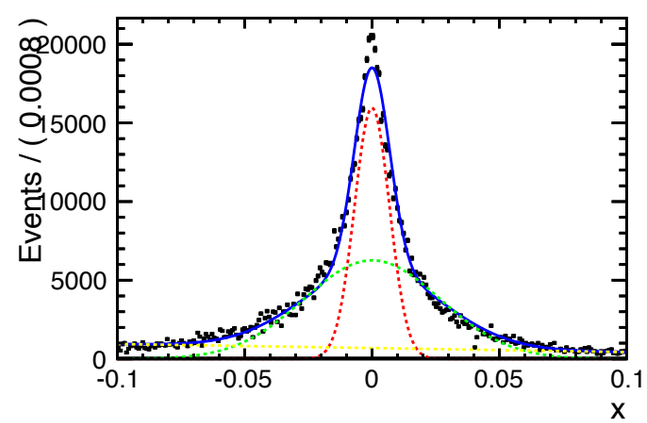
$-0.2\pi<\varphi_{J1}<0$



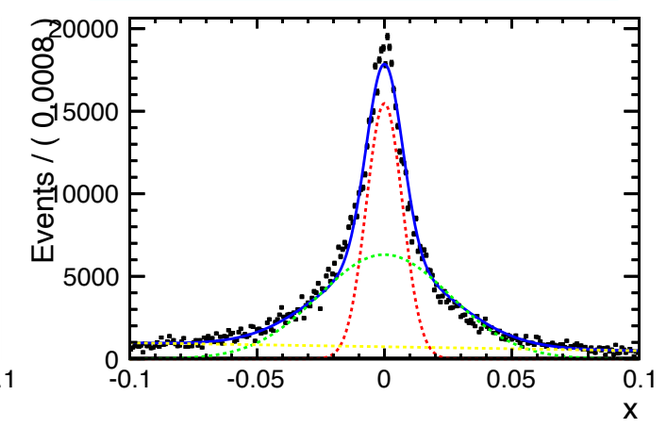
$0<\varphi_{J1}<0.2\pi$



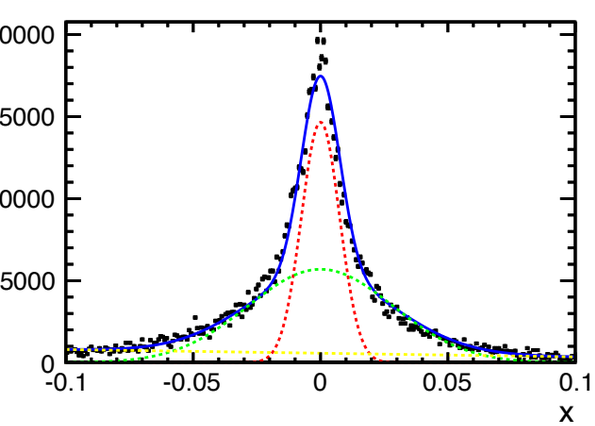
$0.2\pi<\varphi_{J1}<0.4\pi$



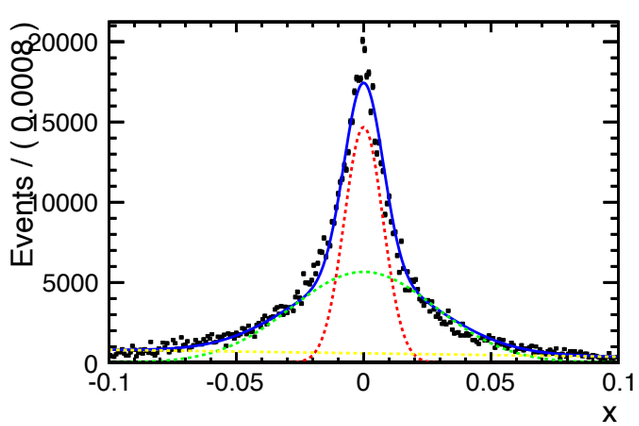
$0.4\pi<\varphi_{J1}<0.6\pi$



$0.6\pi<\varphi_{J1}<0.8\pi$



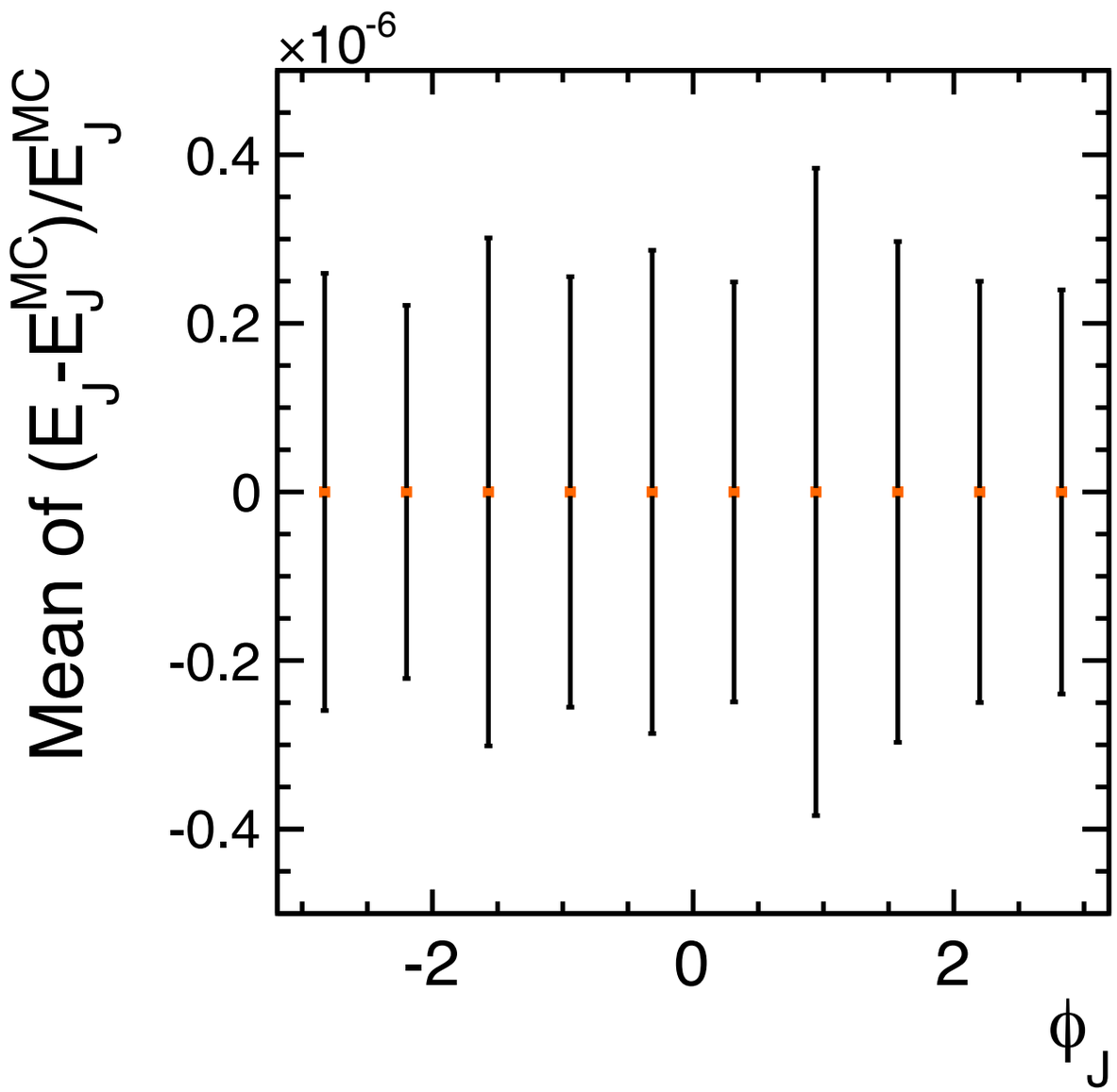
$0.8\pi<\varphi_{J1}<\pi$



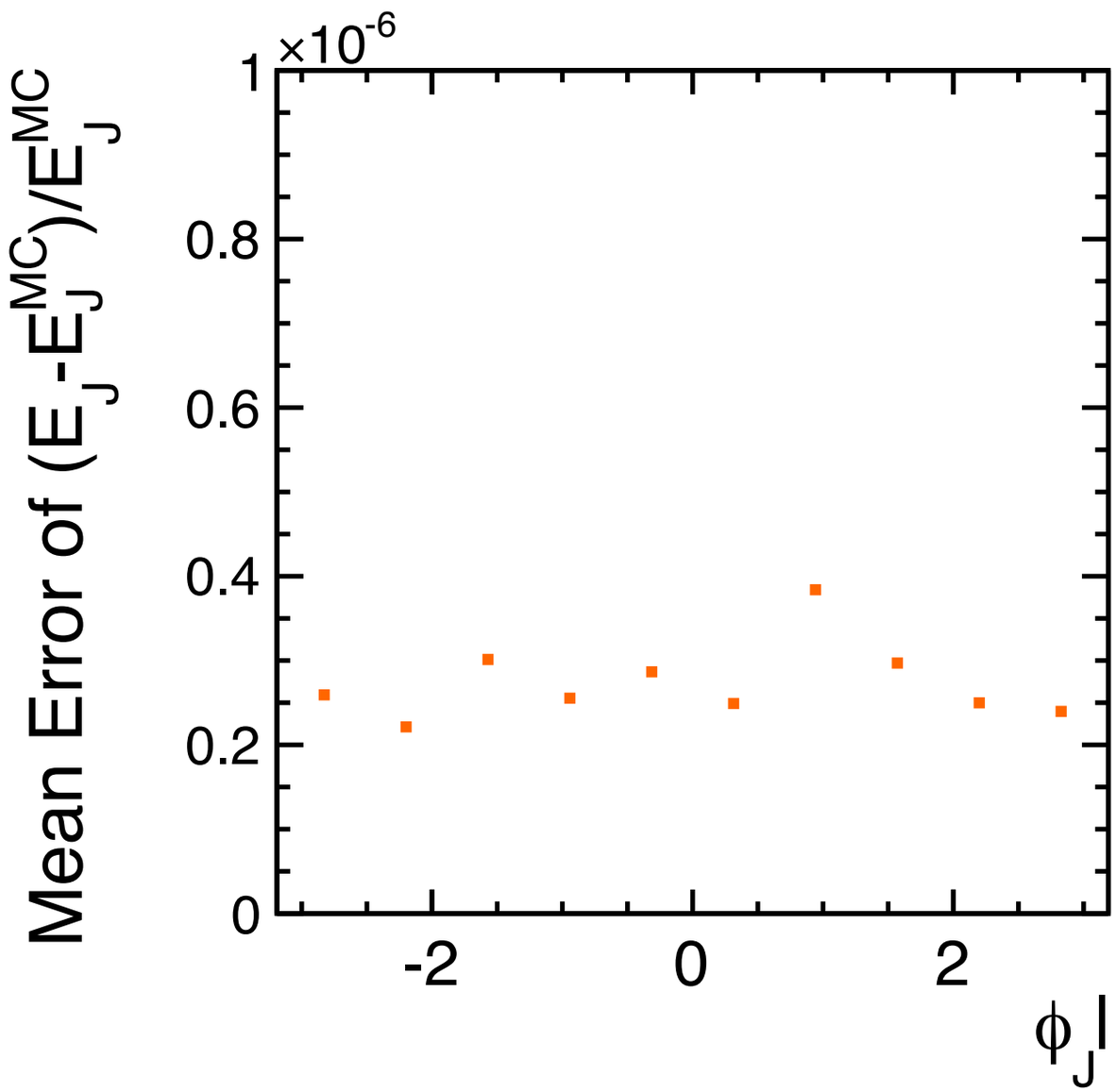
$$\frac{E_{JRec}-E_{JTrue}}{E_{JTrue}}$$

Method 3 Jet 1 energy resolution φ dependence

Mean of $\frac{E_{JRec} - E_{JTrue}}{E_{JTrue}}$



Error of mean



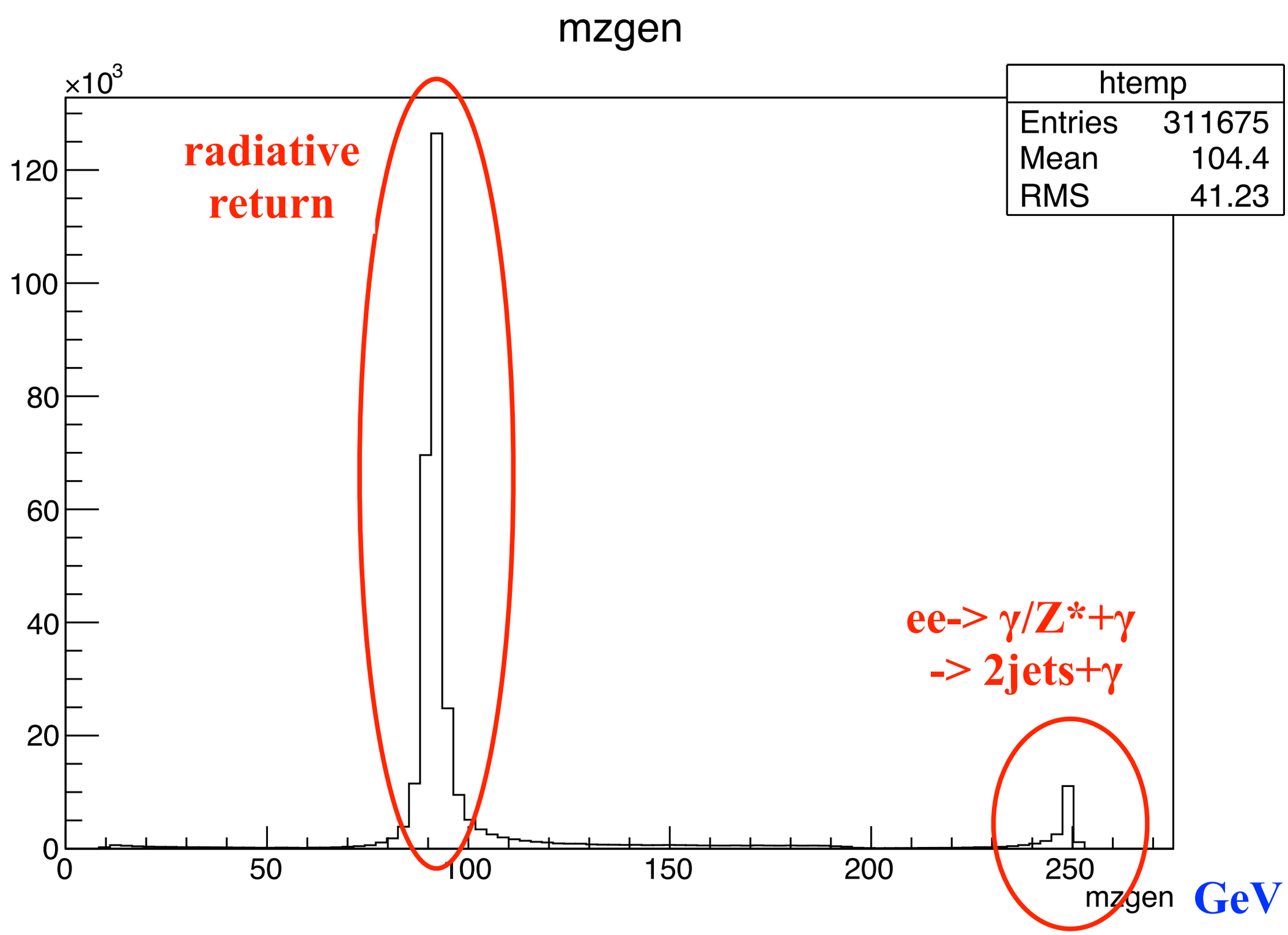
Seems to have no φ dependence.

Summary

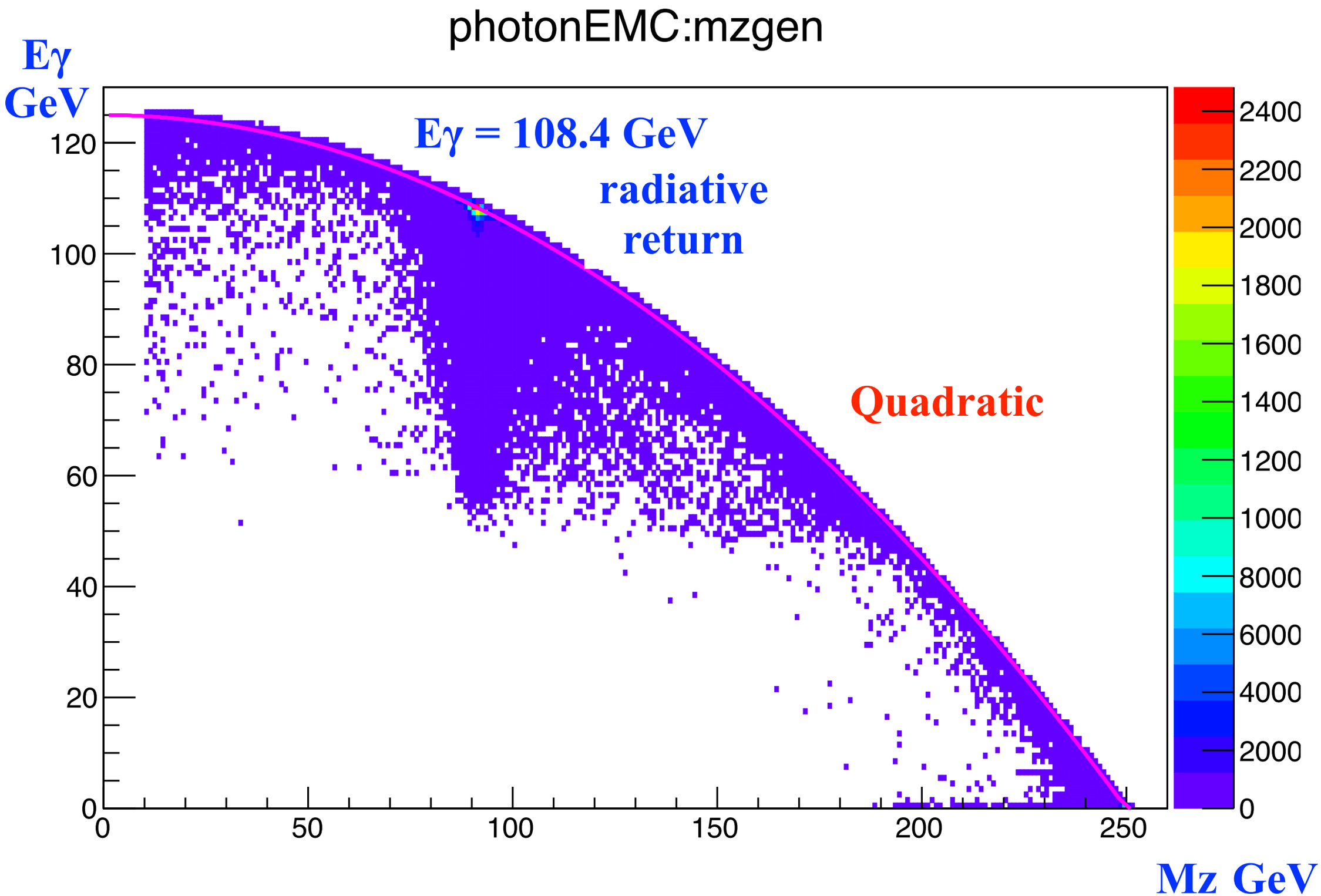
- In order to perform 250 GeV analysis, we decided to use DBD samples instead of current using samples until new sample is validated.
- The distributions of reconstructed jet energies using Method 2 and 2' have positive shift mainly because of the photon energy and angle biases in PFO.
- Method3 is the best among the 5 methods to reconstruct the jet energy due to the peak height and symmetry.
- Angle dependences of Method3 reconstructed jet energy are checked. No φ dependence is found while there found θ dependence.

Backup

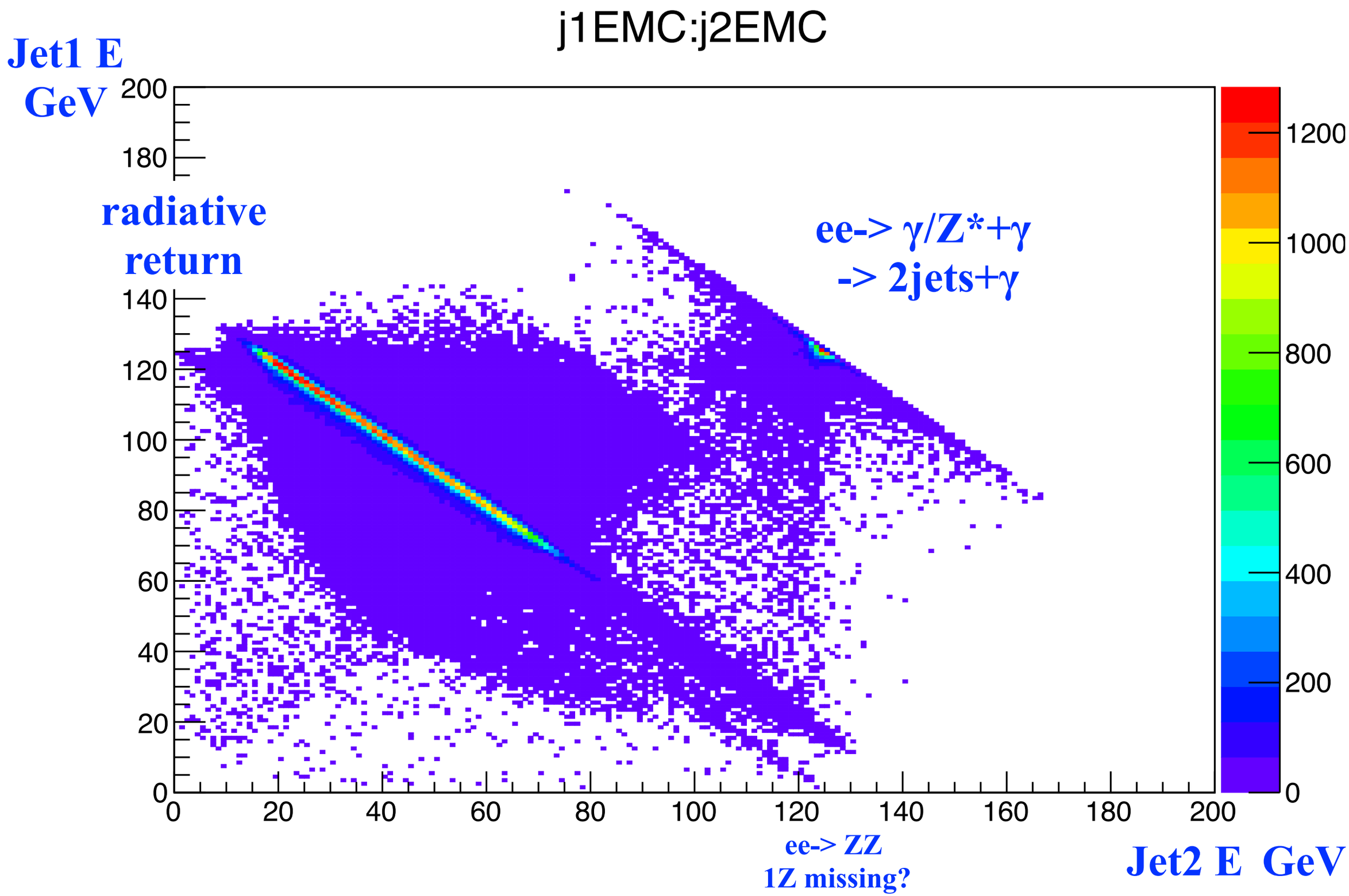
Mz distribution



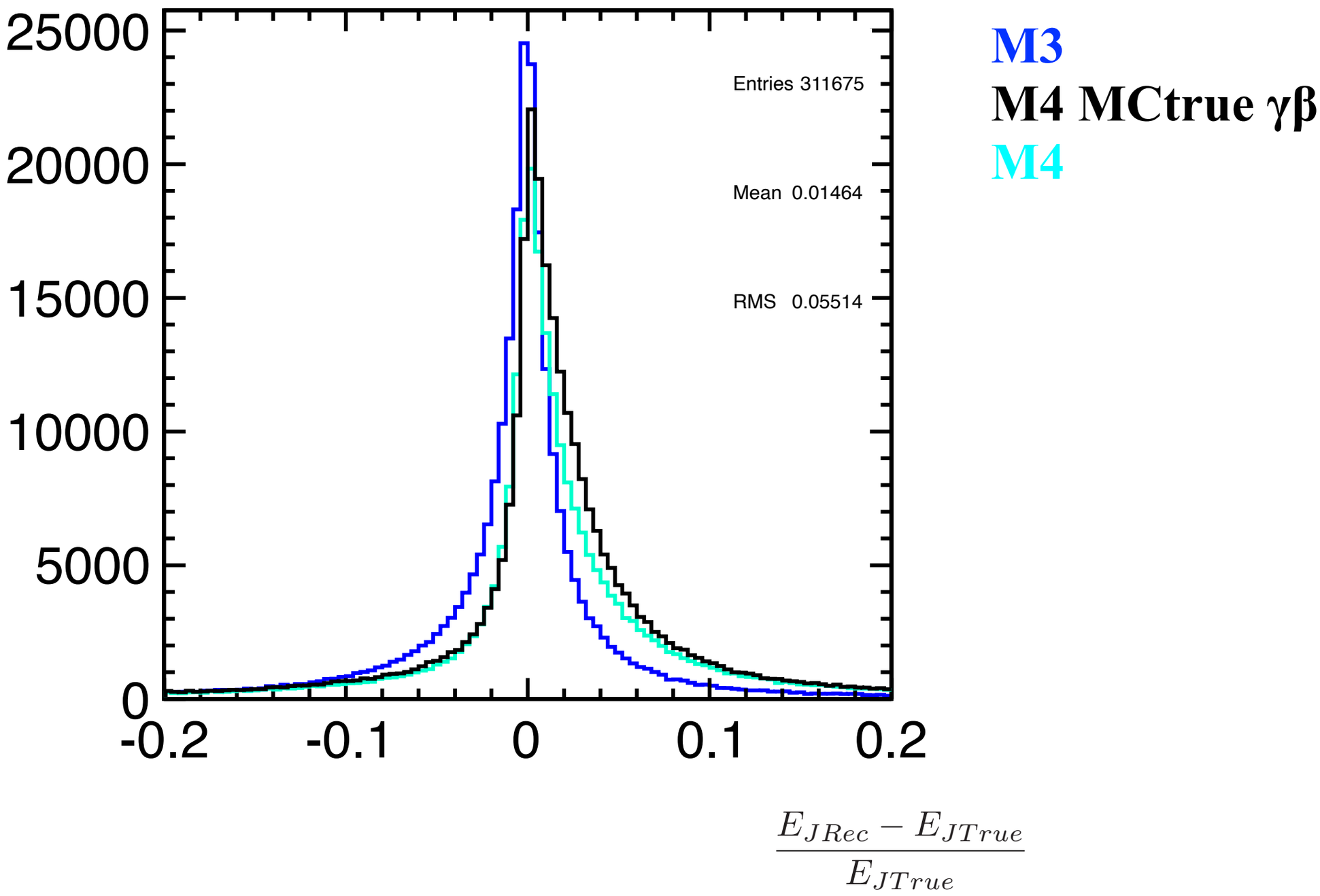
Photon energy & Mz distribution



MC jet energies distribution

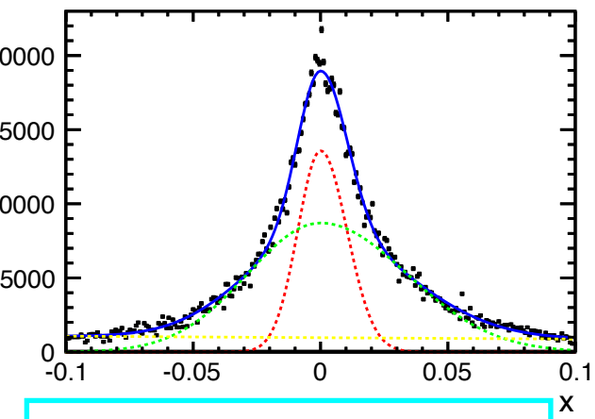


Backup

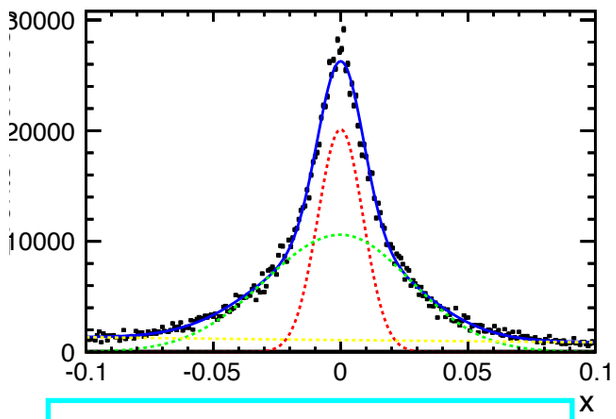

25000
20000
15000
10000
5000
0
-0.2
-0.1
0
0.1
0.2
Entries 311675
Mean 0.01464
RMS 0.05514
M3
M4 MCtrue γβ
M4
$\frac{E_{JRec} - E_{JTrue}}{E_{JTrue}}$

Method 3 Jet 1 energy resolution E dependence

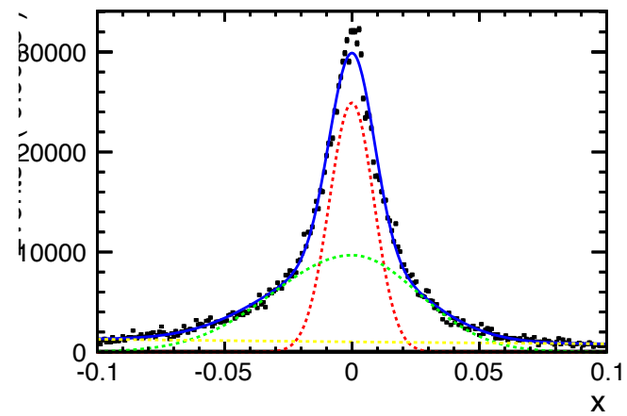
$70<E_{J1}<80$



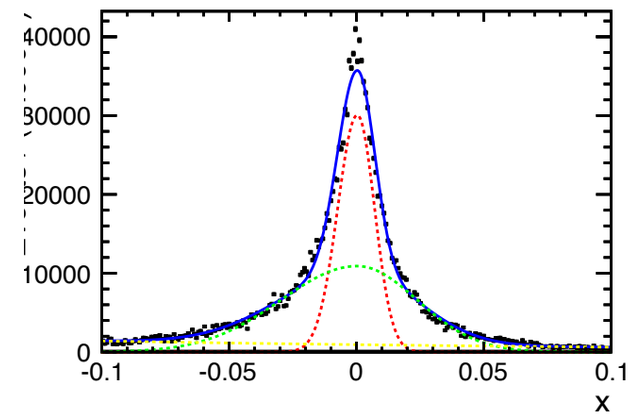
$80<E_{J1}<90$



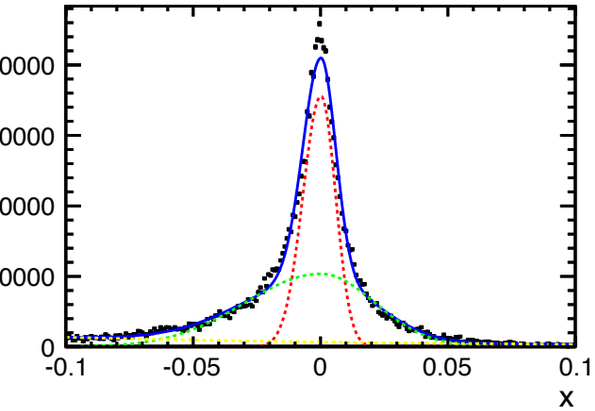
$90<E_{J1}<100$



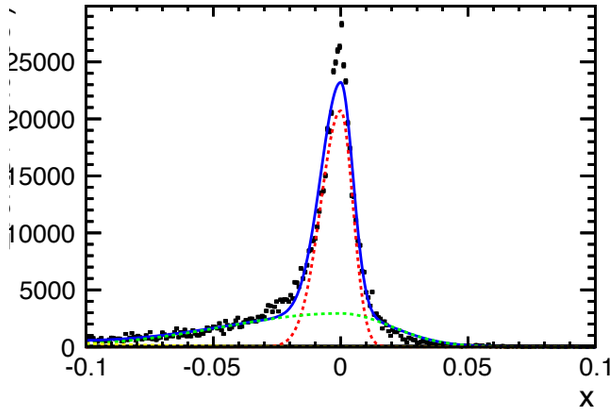
$100<E_{J1}<110$



$110<E_{J1}<120$



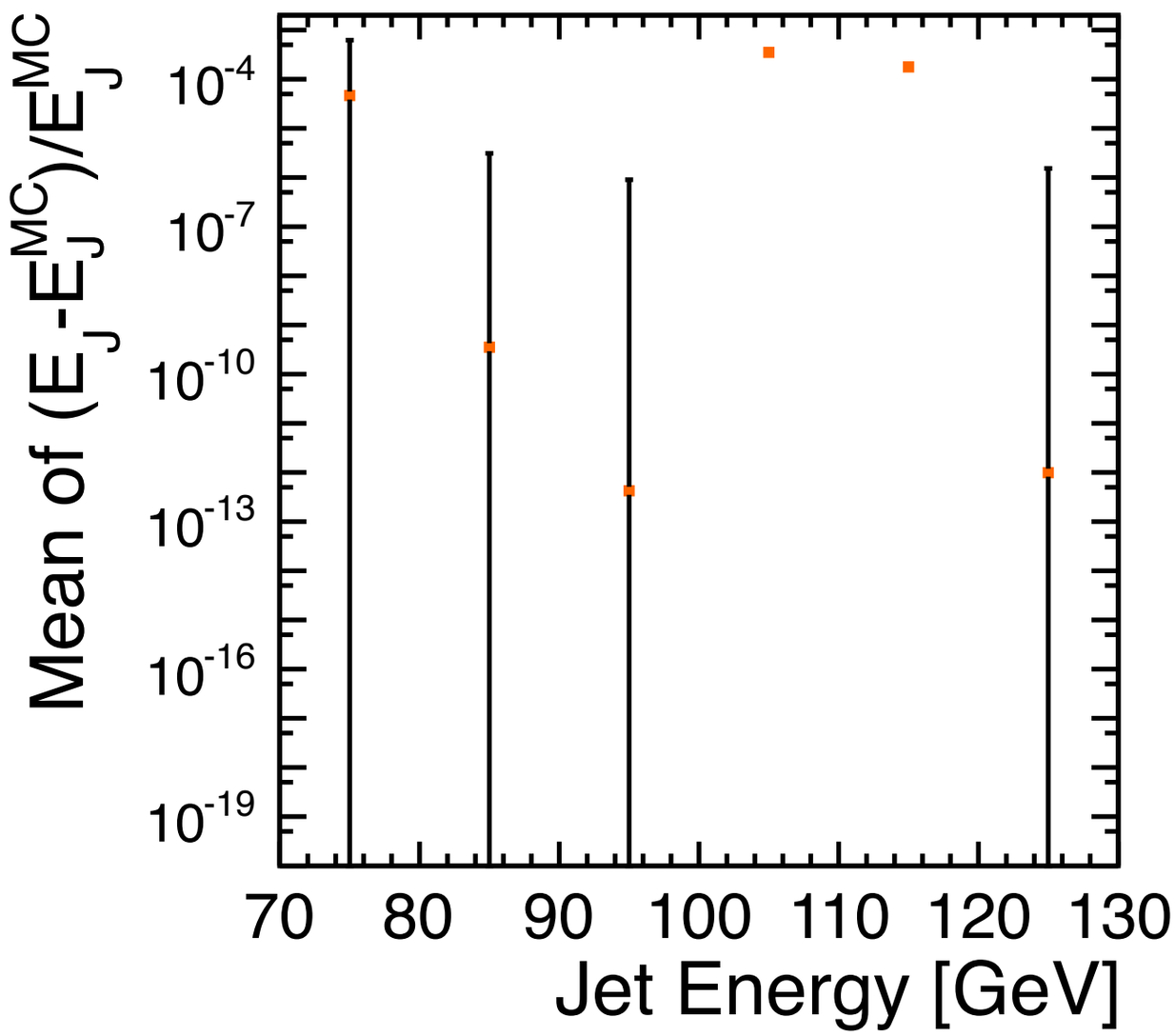
$120<E_{J1}<130$



$$\frac{E_{JRec} - E_{JTrue}}{E_{JTrue}}$$

Method 3 Jet 1 energy resolution E dependence

Mean of $\frac{E_{JRec} - E_{JTrue}}{E_{JTrue}}$



Error of mean