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

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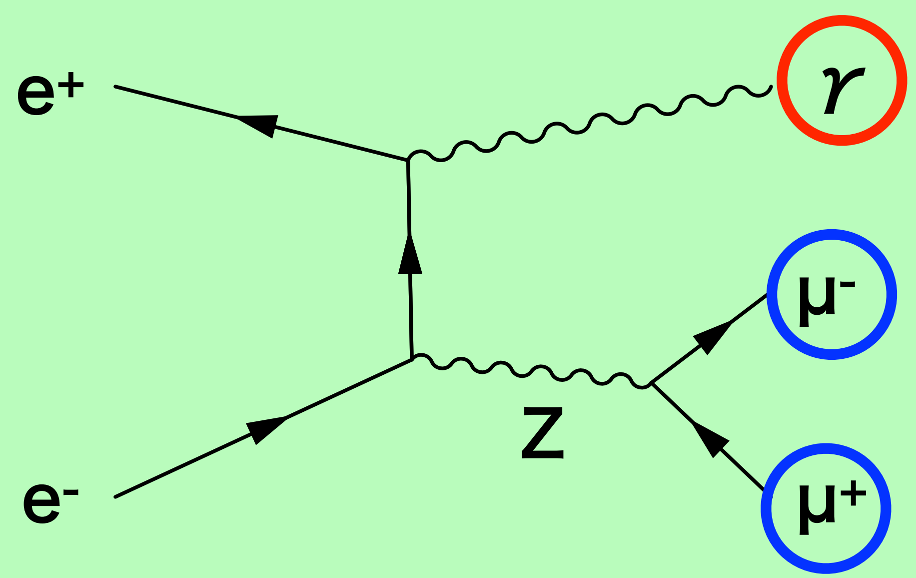
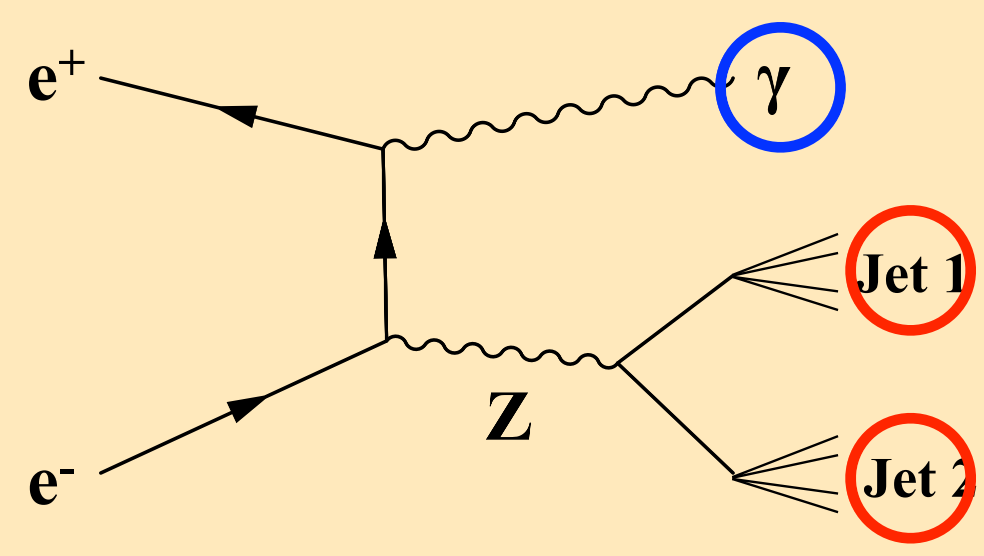
Introduction

- 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

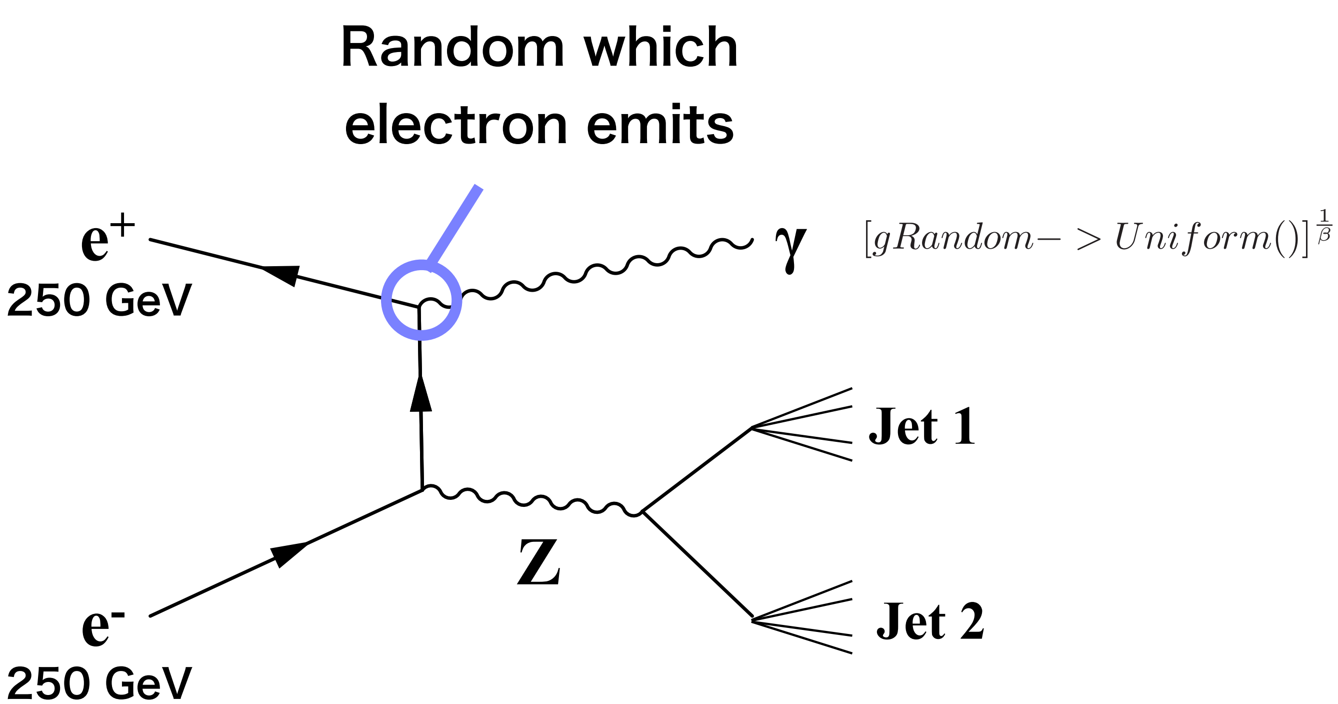


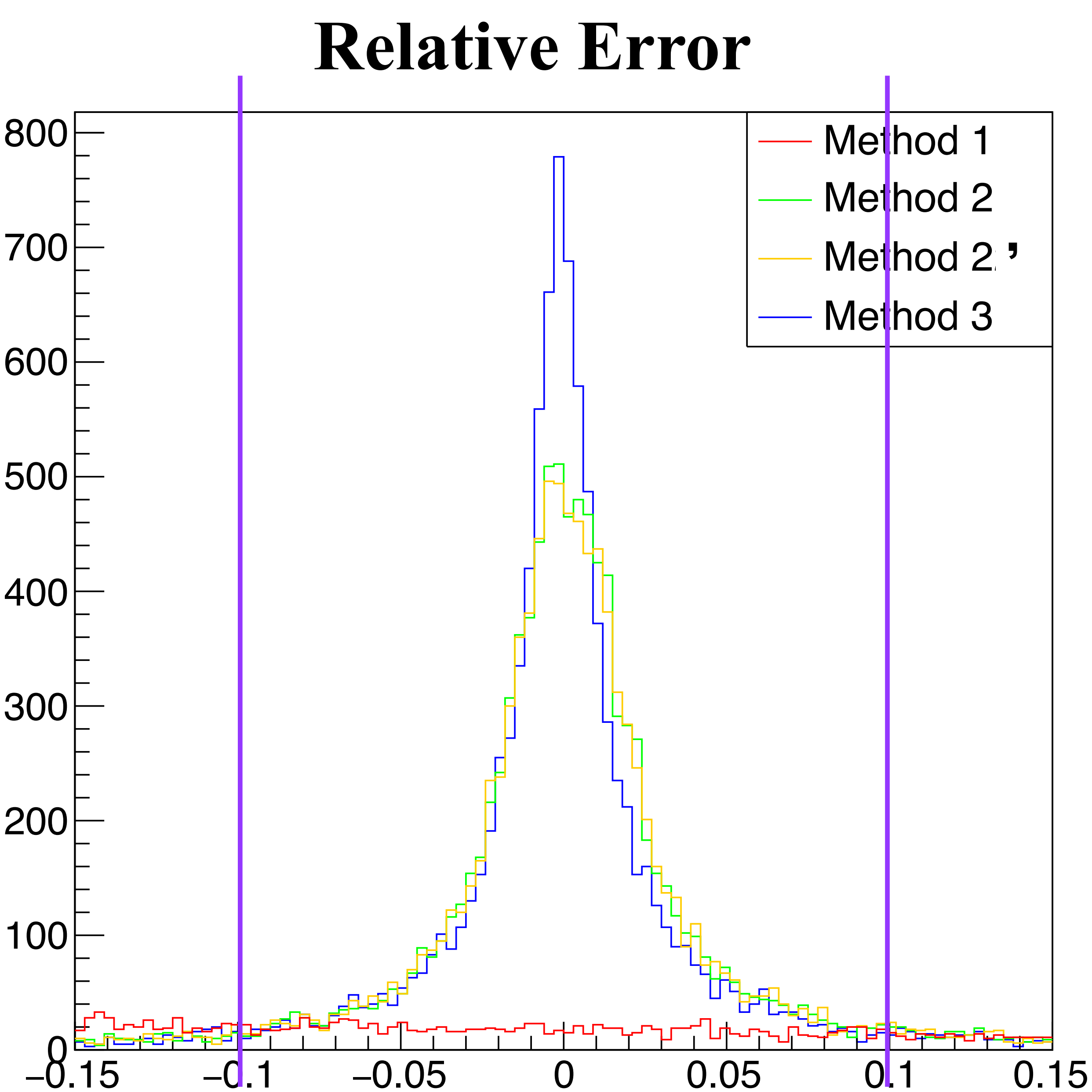
Jet Energy Scale Calibration



Progress last time

As a first step of this calibration, Toy MC simulation to reconstruct the jet energy is performed.
M_{jet} is quoted from the MCTrue jet mass distribution.

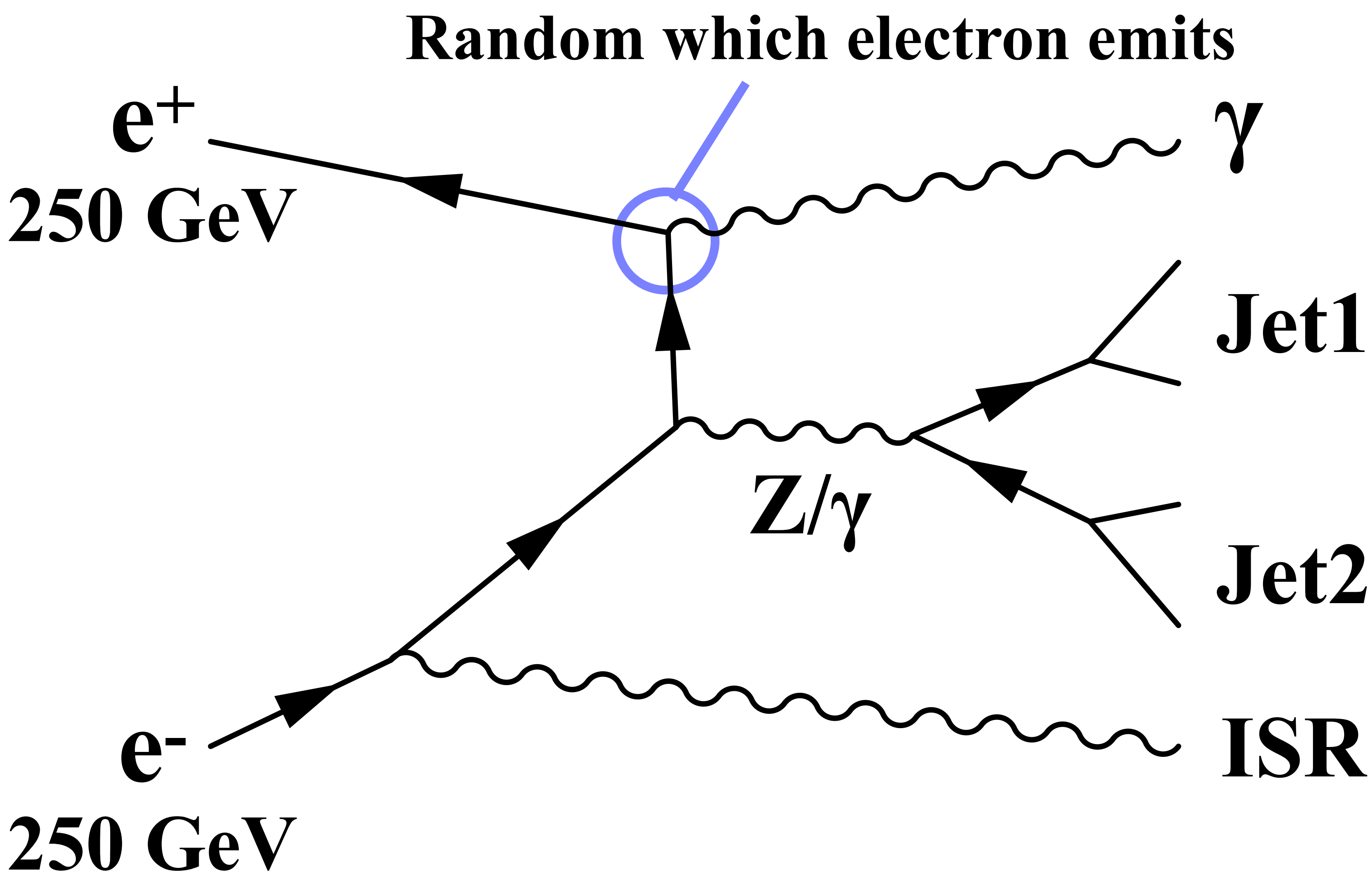




In every method,
Jet Mass Inputs: Smeared 30% in σ
Jet Angles: Smeared 0.3 degree

Full simulation

(ILCSOFT version v02-00-02)



- Process: 2f_z_h (for IDR-L)
- E_{CM}= 500 GeV
- Polarization: e^+: Right e^-: Left

Full simulation

(ILCSOFT version v02-00-02)

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

1. Comparison between reconstructed and MCTruth information for the jets

1.1. θ^{J}_{Rec}-θ^{J}_{MC}, φ^{J}_{Rec}-φ^{J}_{MC}

absolute θ difference of each jet

absolute φ difference of each jet

1.2. M^{J}_{Rec}-M^{J}_{MC}

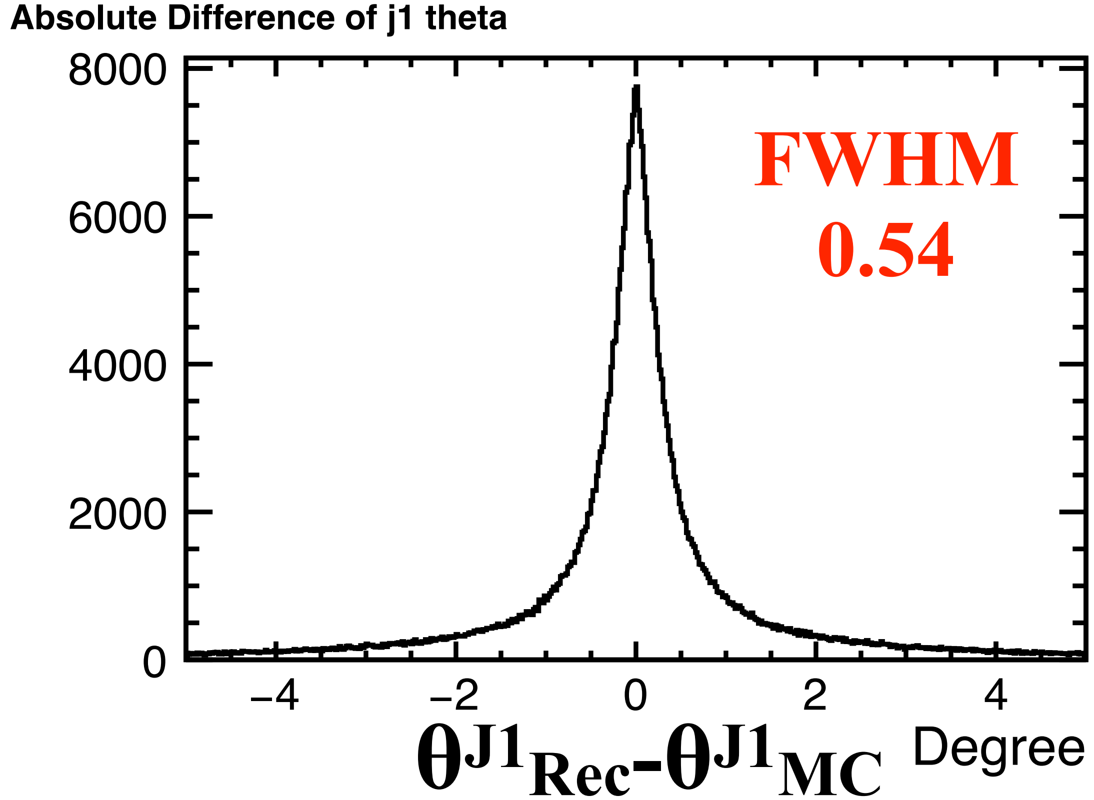
absolute mass difference of each jet

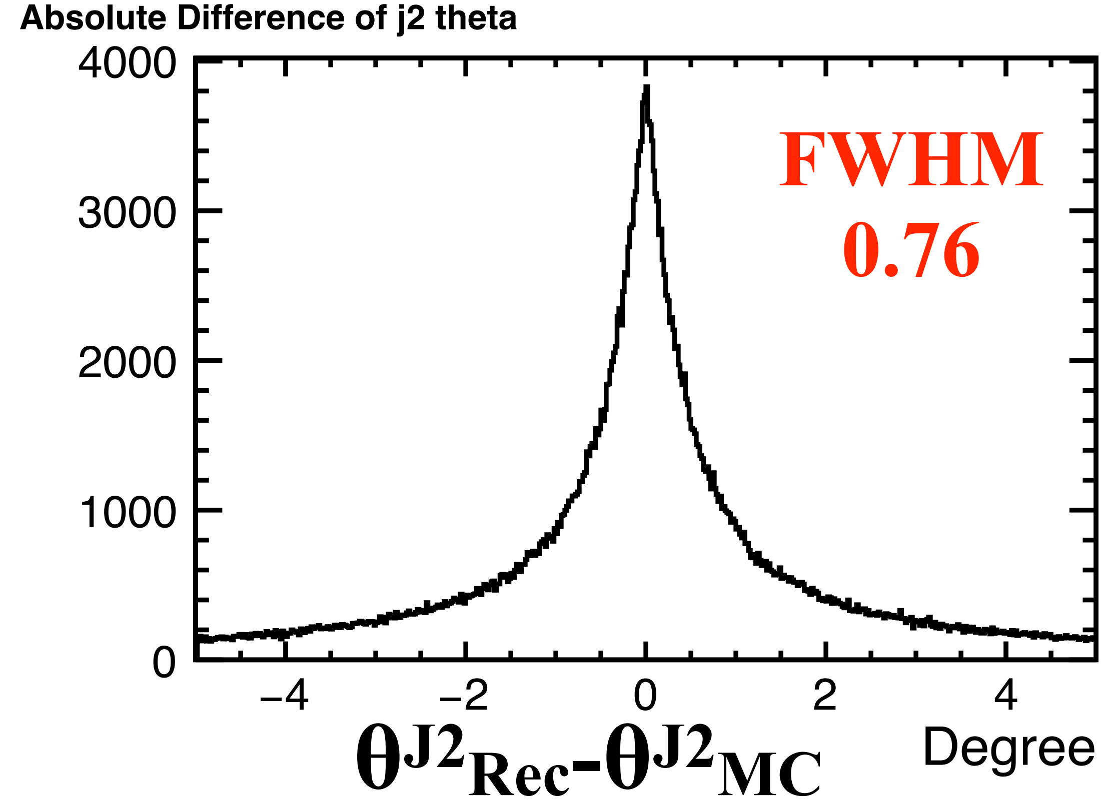
1.3. E^{JSum}_{Reco}-E^{JSum}_{MC}

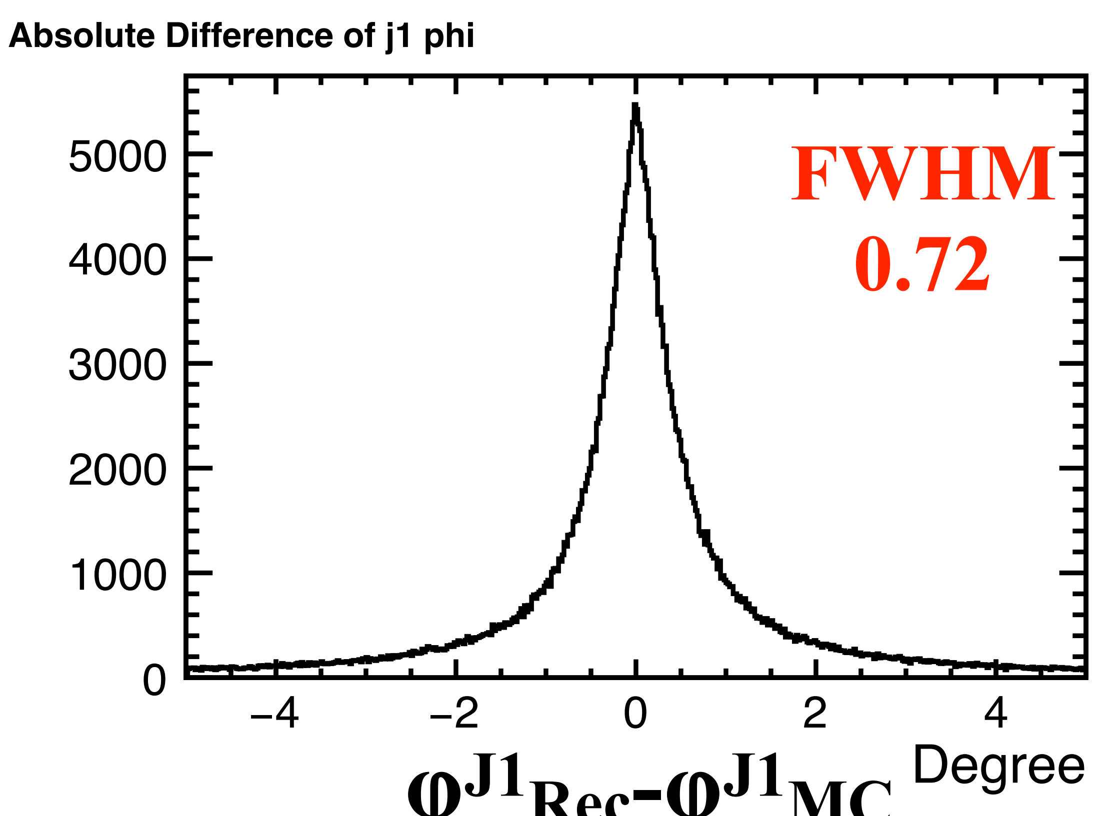
absolute difference of the jet energy sum

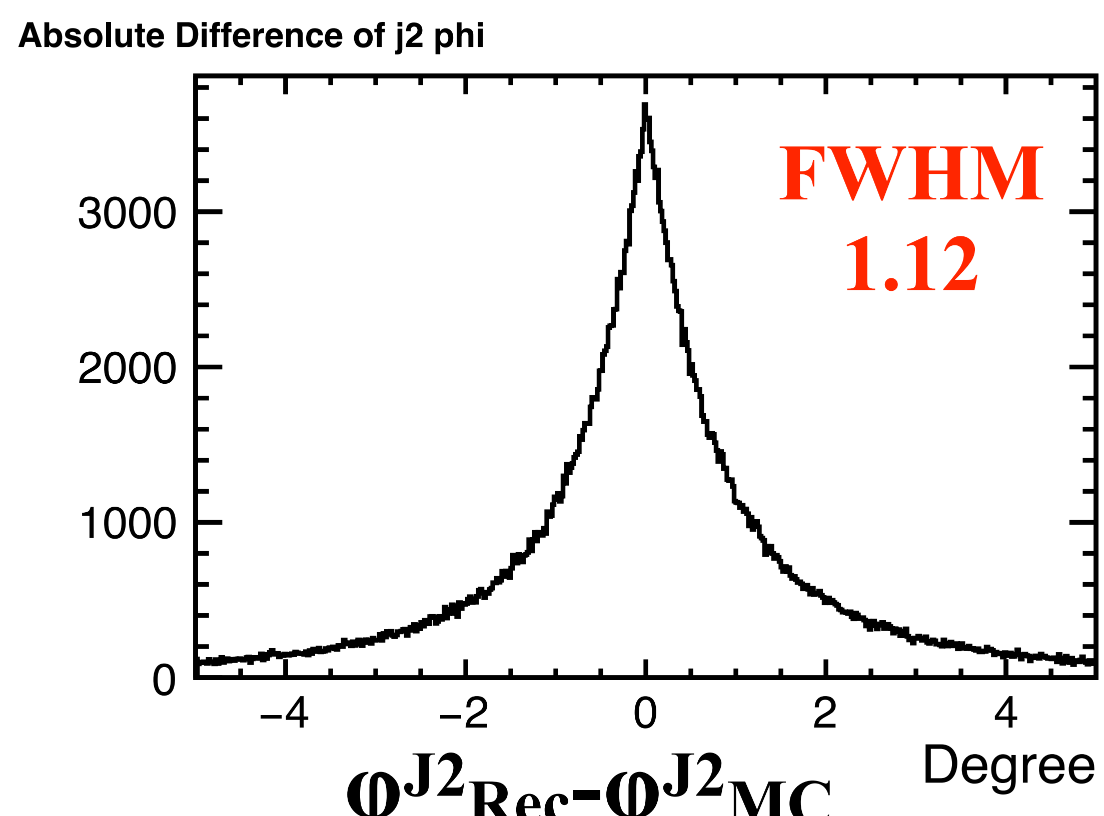
1.1. θ & φ difference

Jet 1 | **Jet 2**



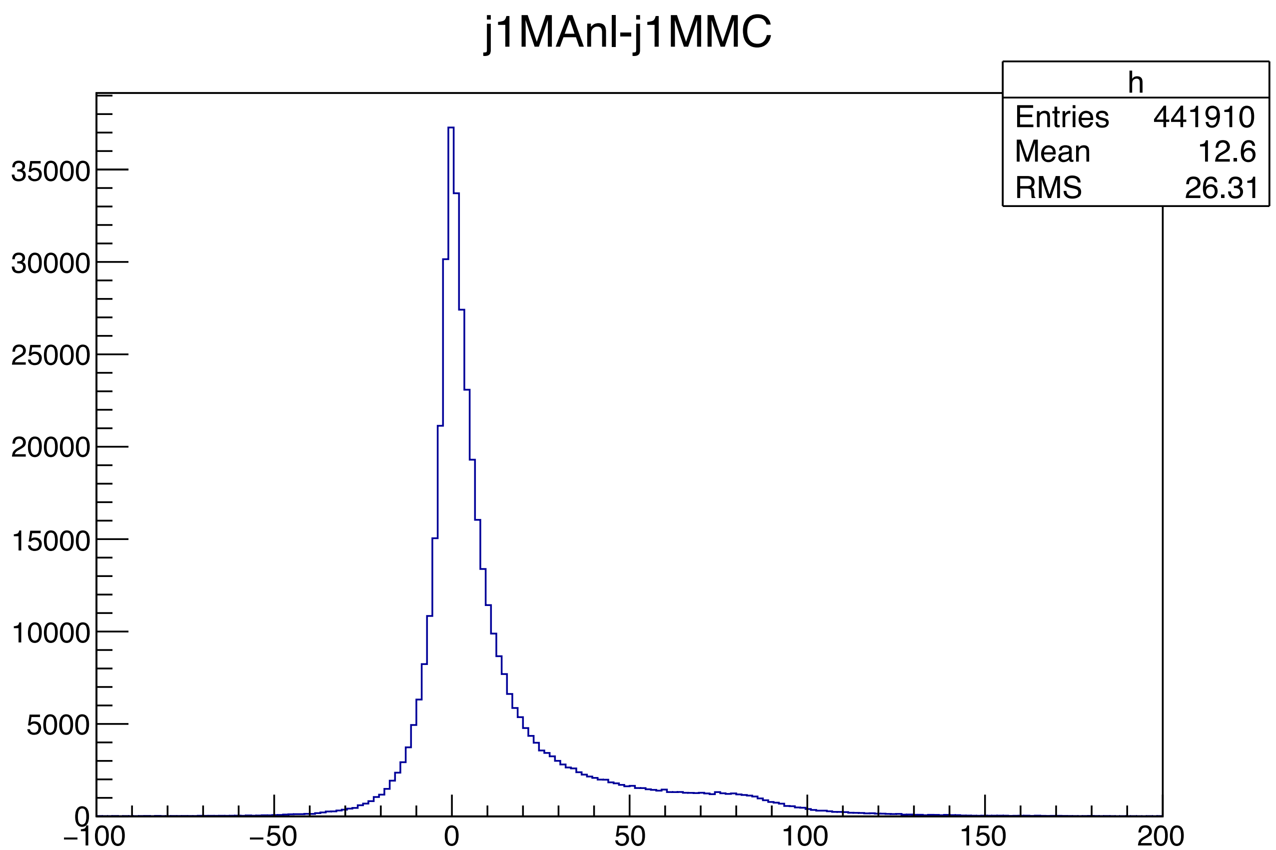






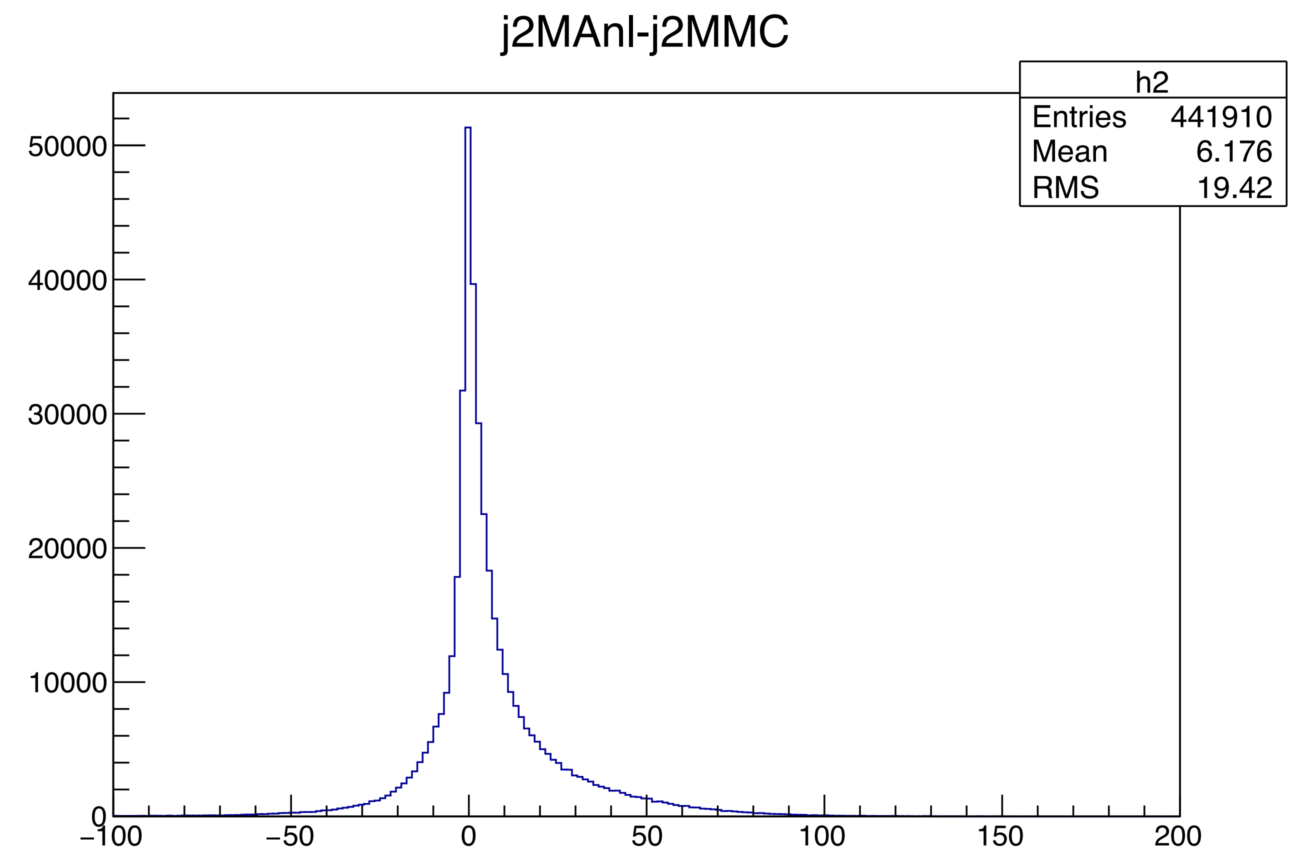
1.2. Jet mass difference

$M^{J1}_{Rec}-M^{J1}_{MC}$



GeV

$M^{J2}_{Rec}-M^{J2}_{MC}$

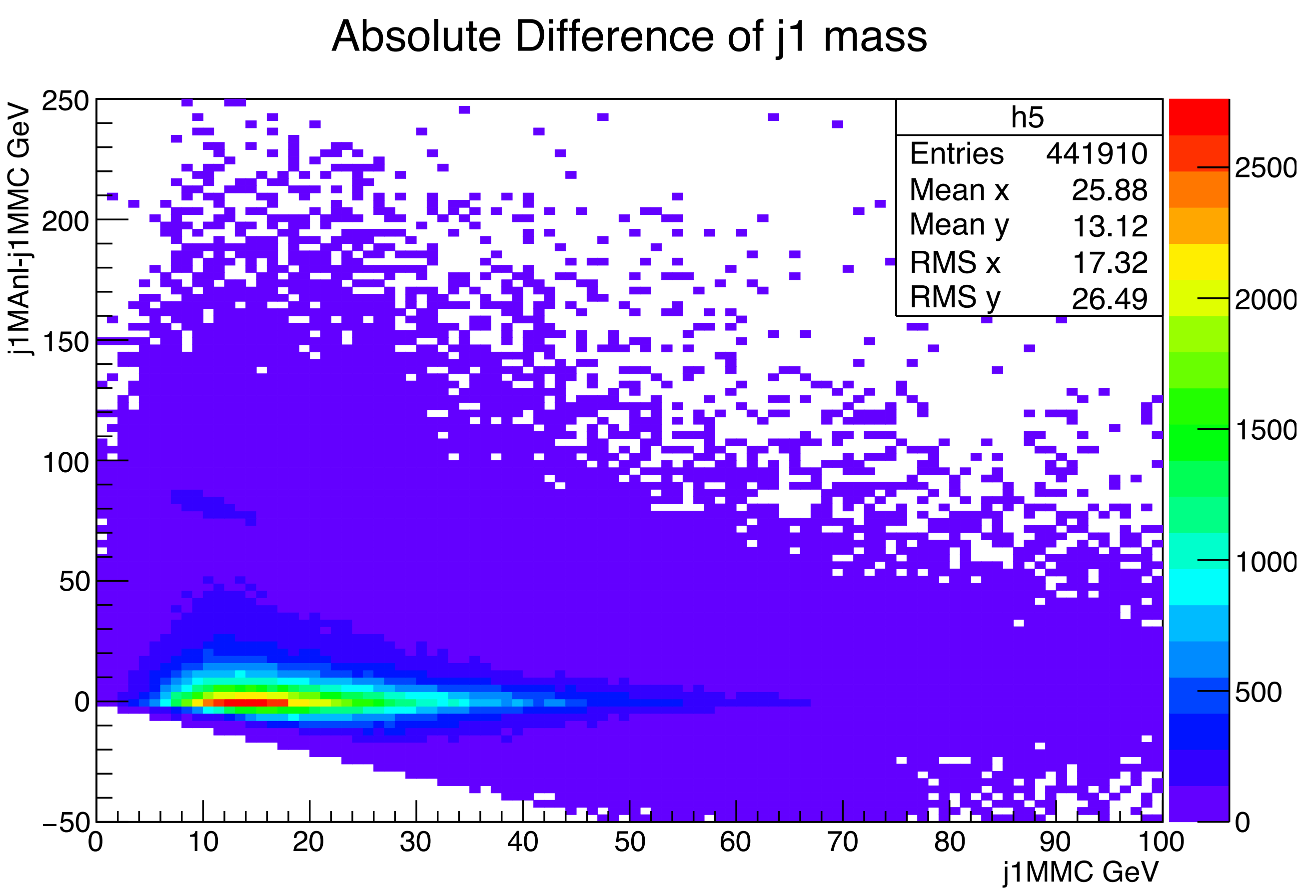


GeV

- **Reconstructed jet mass sometimes differs from the truth largely.**
  -> Its jet mass dependence is checked.

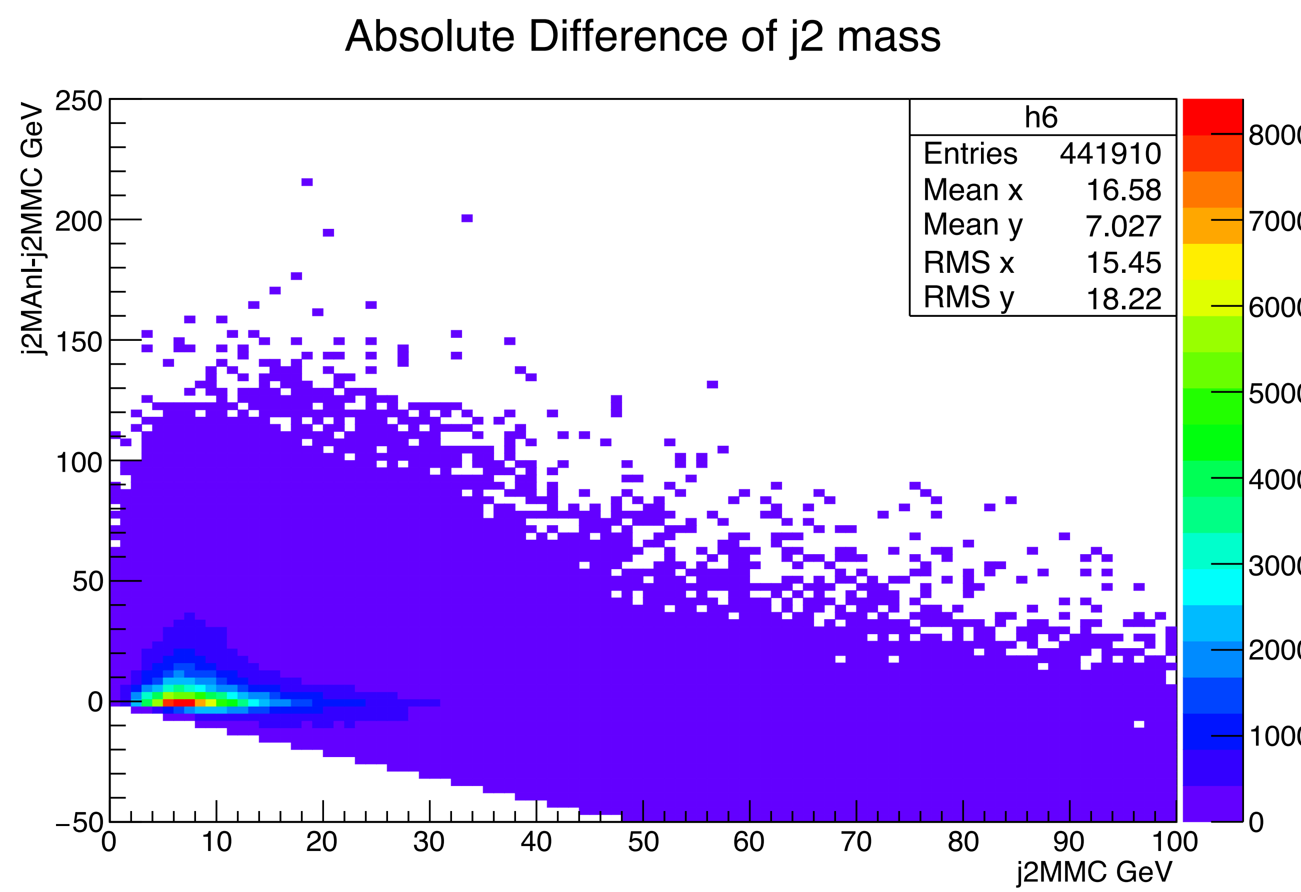
1.2. Jet mass difference dependence on jet mass

$M^{J1}{}_{Rec}-M^{J1}{}_{MC}$



$M^{J1}{}_{MC}$ GeV

$M^{J2}{}_{Rec}-M^{J2}{}_{MC}$

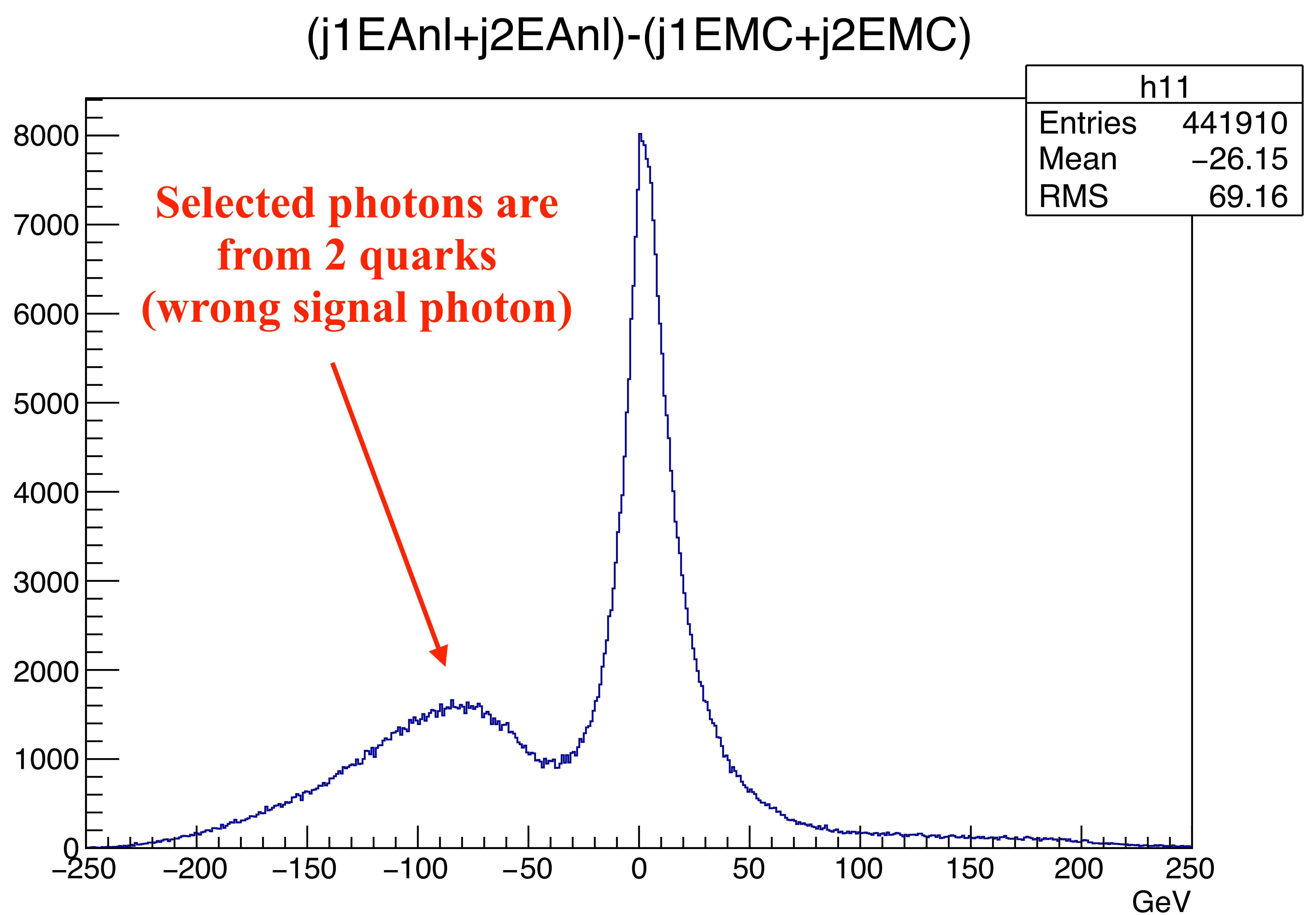


$M^{J2}{}_{MC}$ GeV

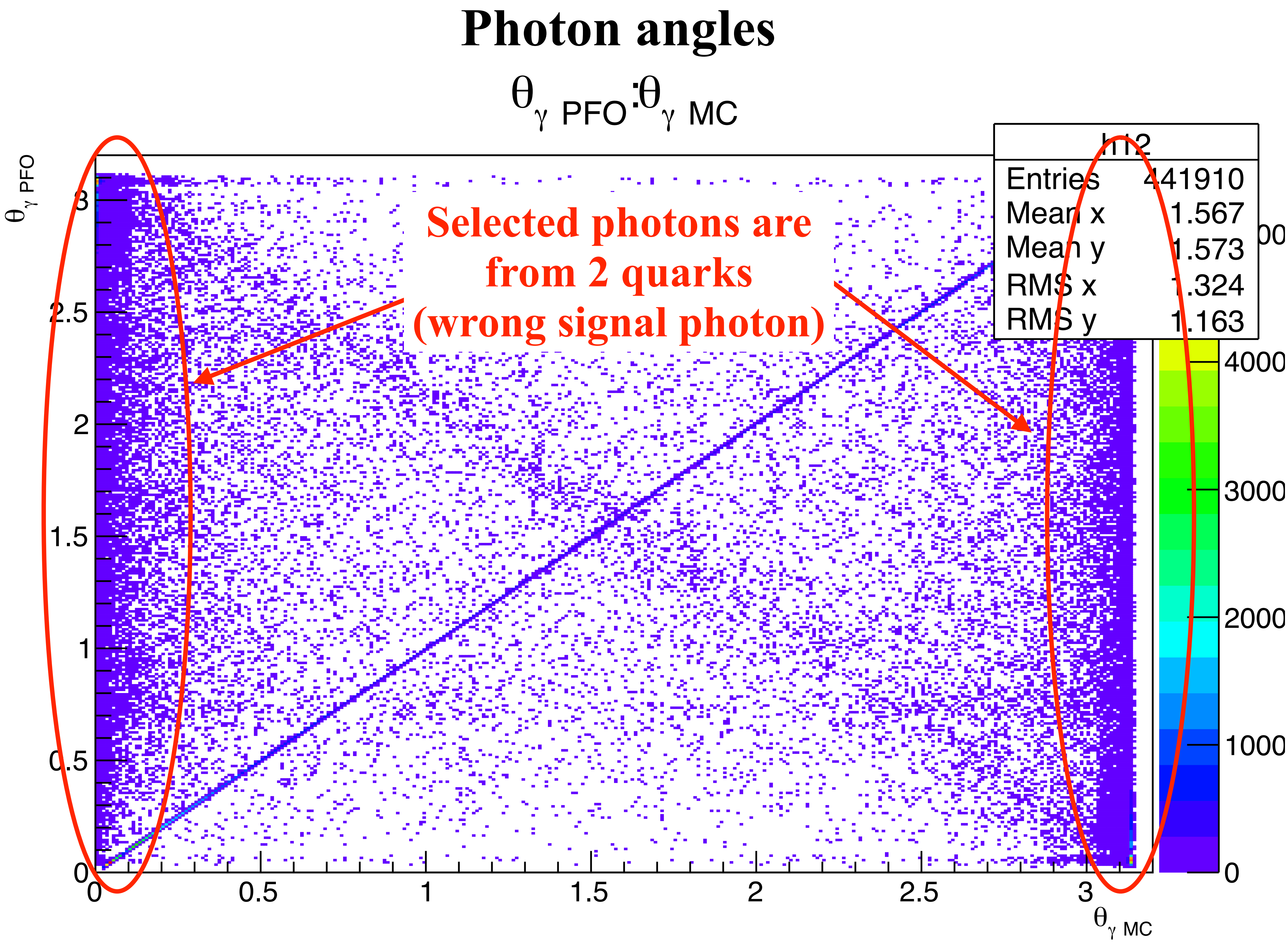
- **Mass resolution is sometimes very bad (> O(1)).**

When the jet is lighter, the resolution is worse.

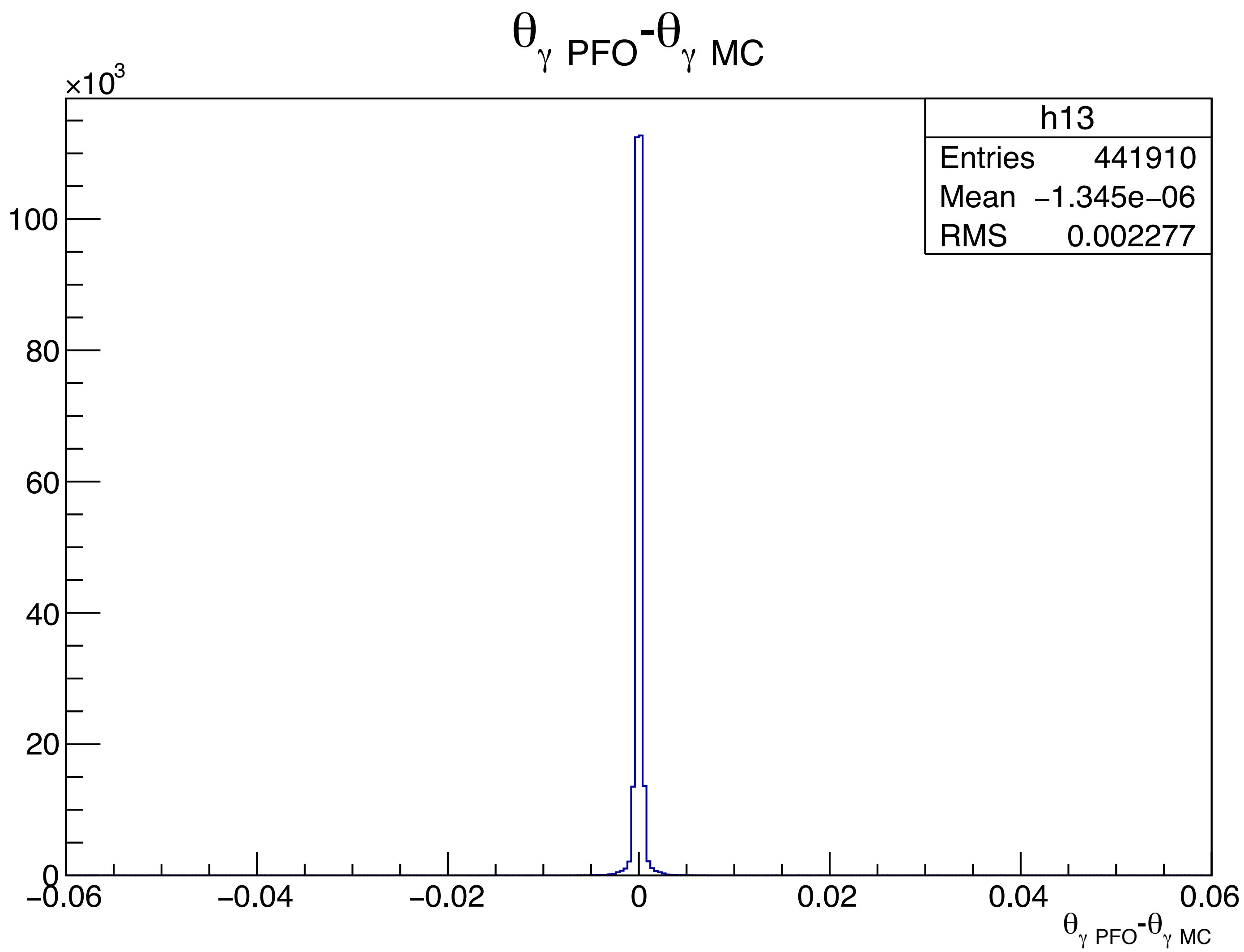
1.3. Difference of the jet energy sum



1.3. Difference of the jet energy sum



1.3. Difference of the jet energy sum



Cut "|θγPFO-θγMC| <0.01" is appropriate.

"|θγPFO-θγMC| <0.01" events: 262705 (59%)
"|θγPFO-θγMC| >0.01" events: 179205 (41%)

For this moment, this MCcut will be applied so as to separate events with correct and wrong photons and study jet energy resolution

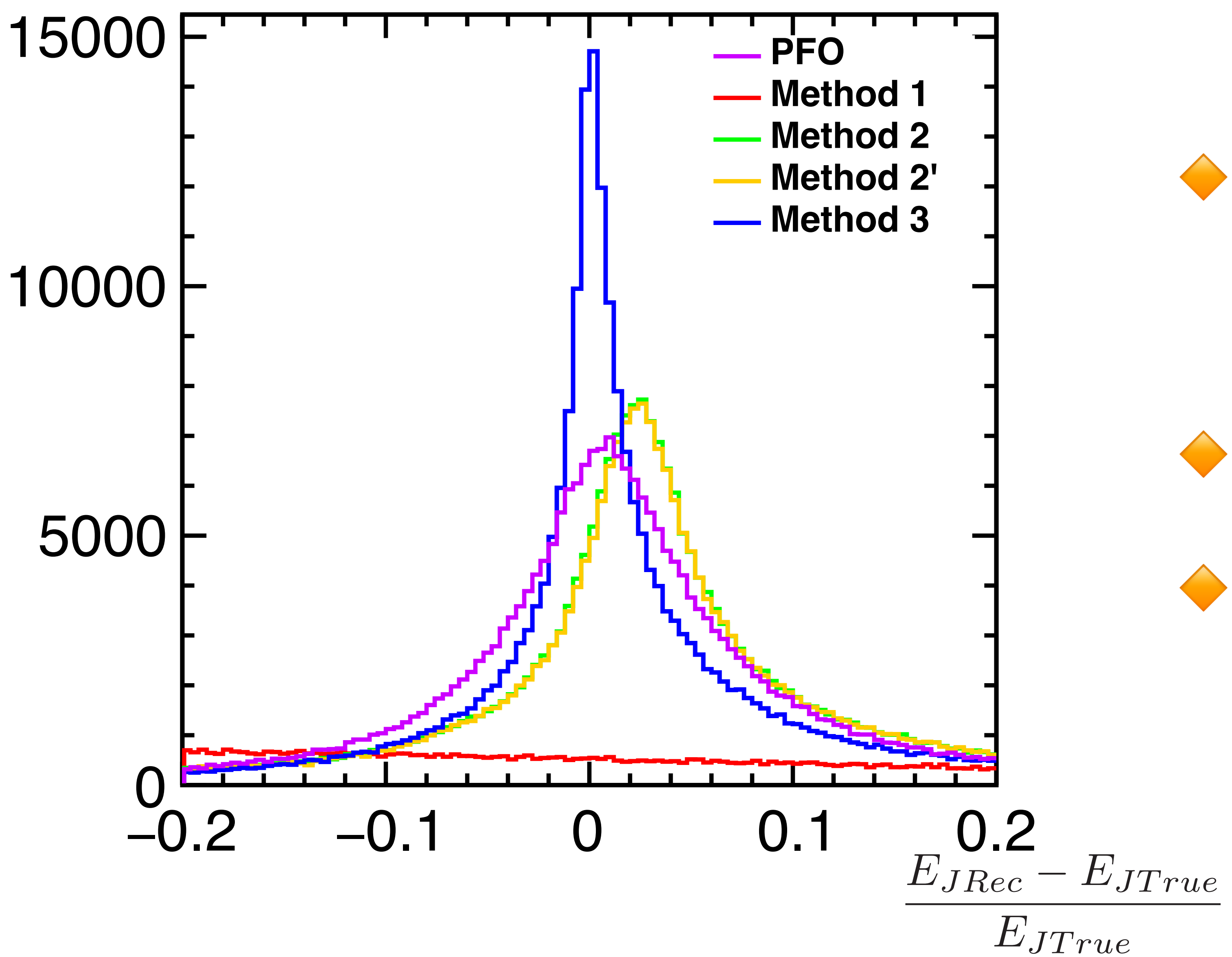
2. Jet Energy Reconstruction Result

2.1. Method comparison result

2.2. Method 3 theta and energy dependence

2.1. Method Comparison

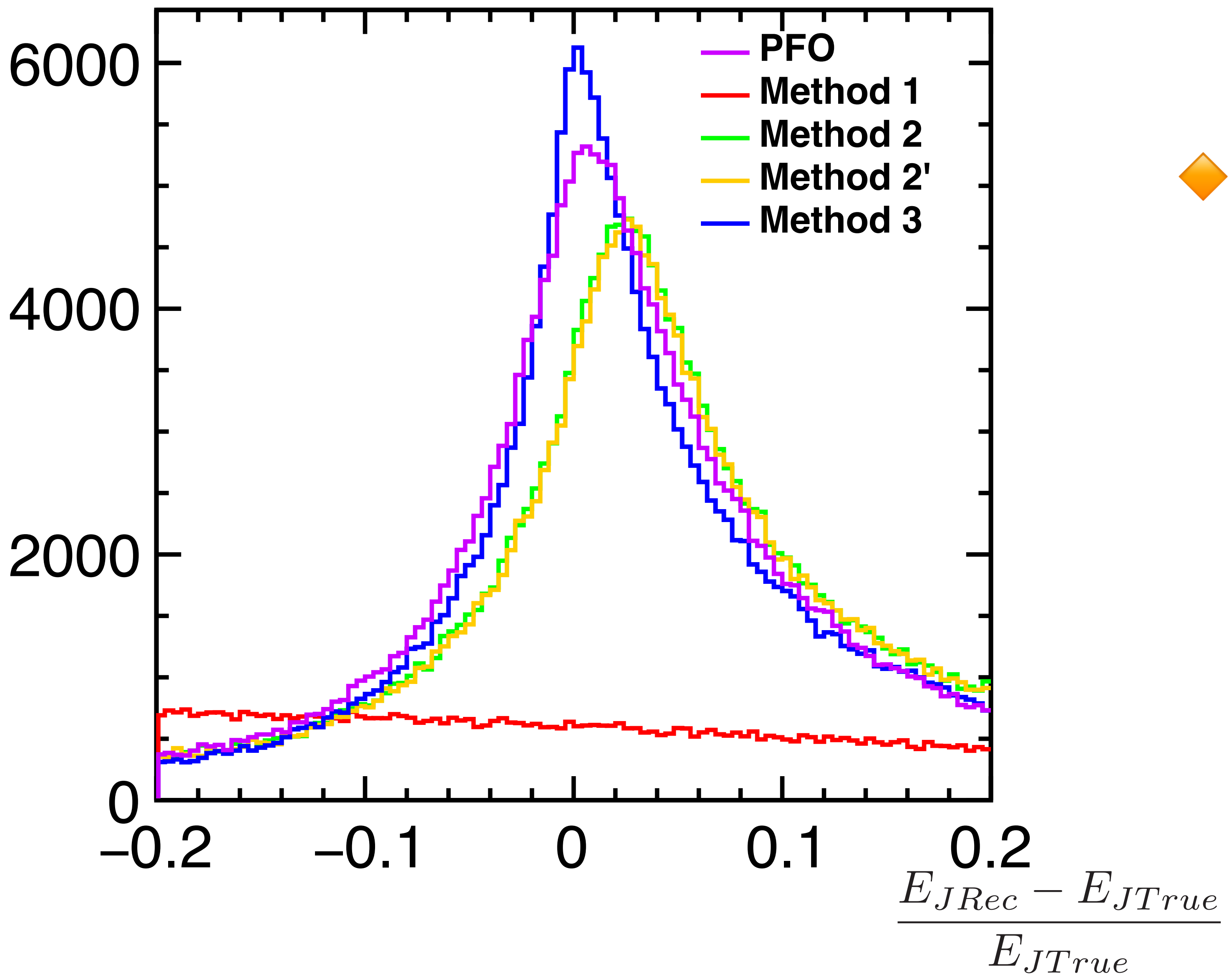
Jet 1
$|\theta\gamma_{PFO}-\theta\gamma_{MC}|<0.01$ events



- **Performance of each method close to the ToyMC result. Method 3 is the best.**
- **Bias in Method 2 and Method 2': due to the bias in reconstructed photon energy**
- **Method 1 is useless.**
- **Method 2/2'/3 are significantly better than the PFO.**

2.1. Method Comparison

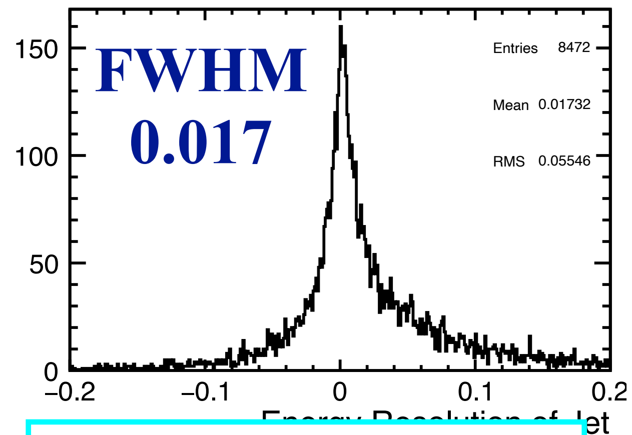
Jet 2
$|\theta\gamma_{PFO}-\theta\gamma_{MC}|<0.01$ events



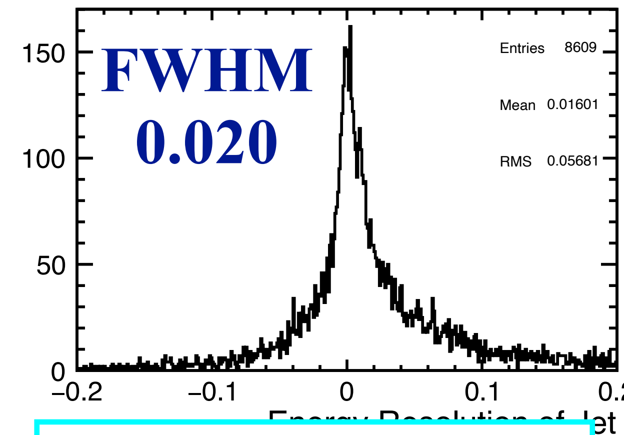
- **All methods results are worse than the jet 1 results and close to the PFO.**
- **Still Method 3 is the best.**

2.2. Method 3 Jet 1 energy resolution θ dependence

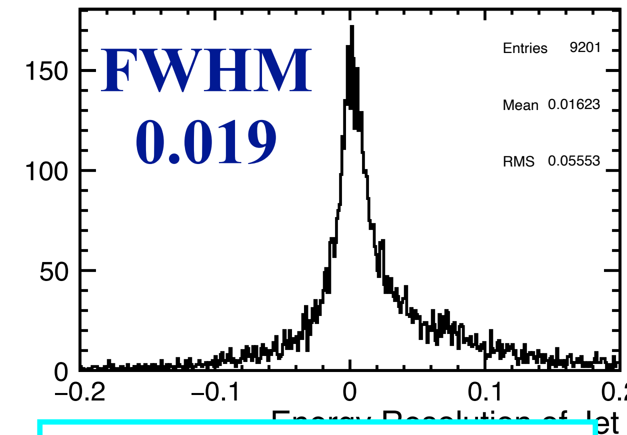
$0.0<|\cos\theta_{J1}|<0.1$



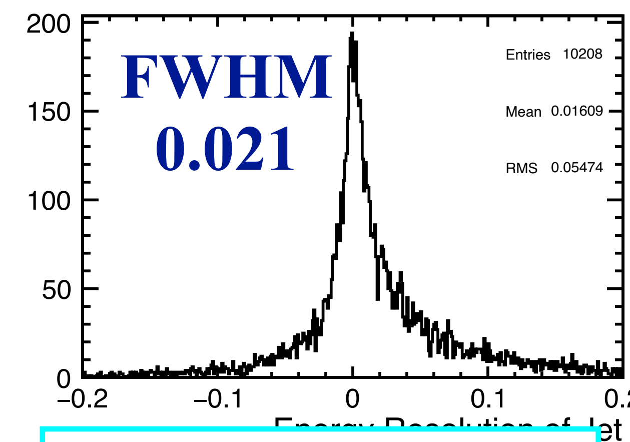
$0.1<|\cos\theta_{J1}|<0.2$



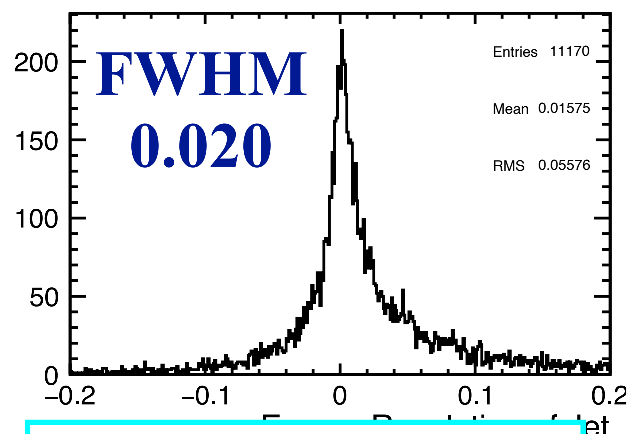
$0.2<|\cos\theta_{J1}|<0.3$



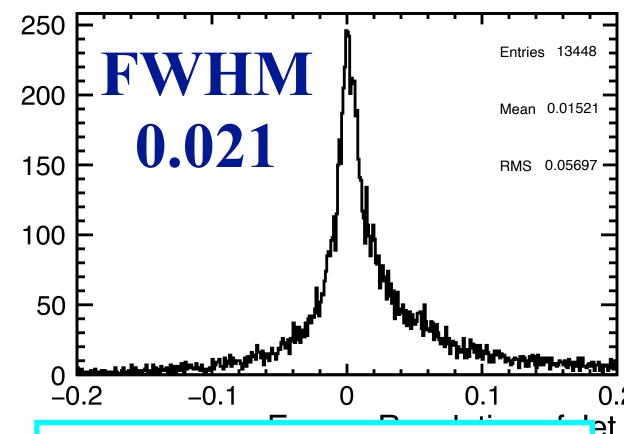
$0.3<|\cos\theta_{J1}|<0.4$



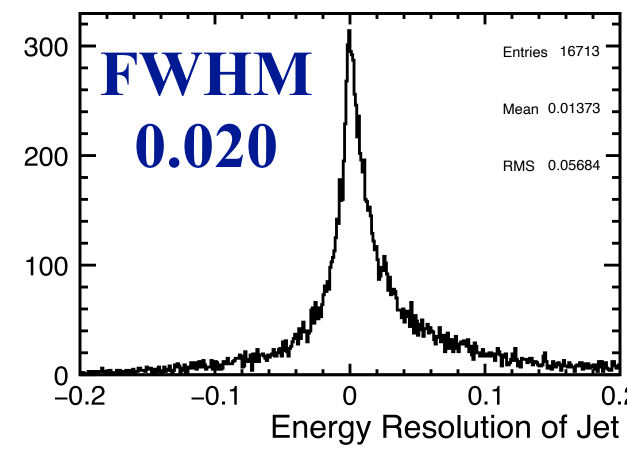
$0.4<|\cos\theta_{J1}|<0.5$



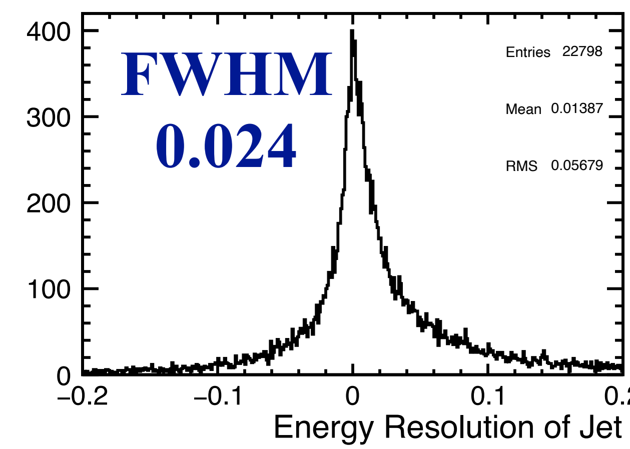
$0.5<|\cos\theta_{J1}|<0.6$



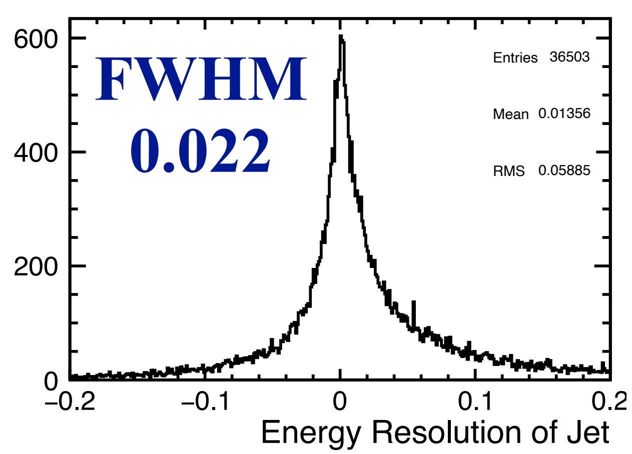
$0.6<|\cos\theta_{J1}|<0.7$



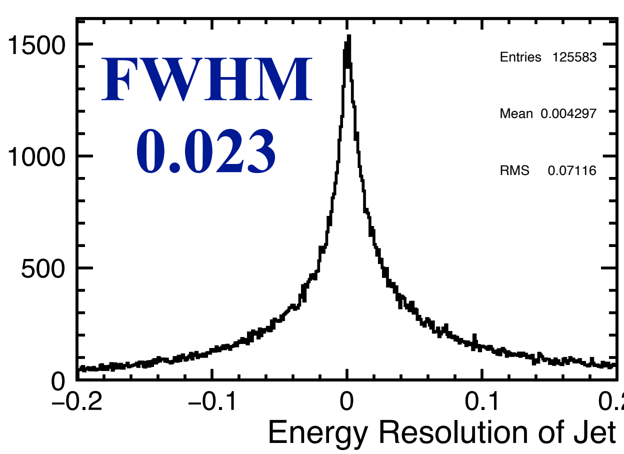
$0.7<|\cos\theta_{J1}|<0.8$



$0.8<|\cos\theta_{J1}|<0.9$



$0.9<|\cos\theta_{J1}|<1.0$

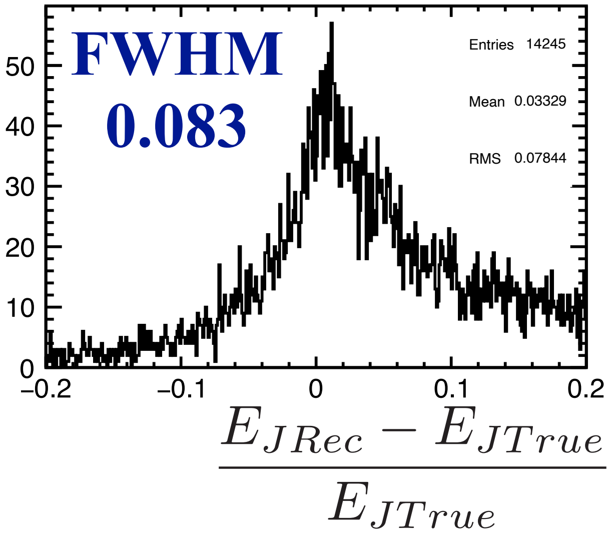


We can see slight θ dependence.
Forward JER is worse.
Distribution is not simple gaussian.

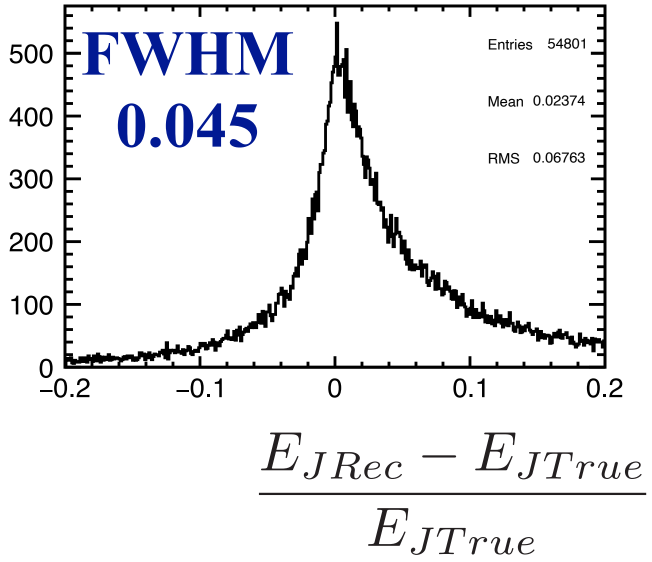
$$\frac{E_{JRec} - E_{JTrue}}{E_{JTrue}}$$

2.2. Method 3 Jet 1 energy resolution Energy dependence

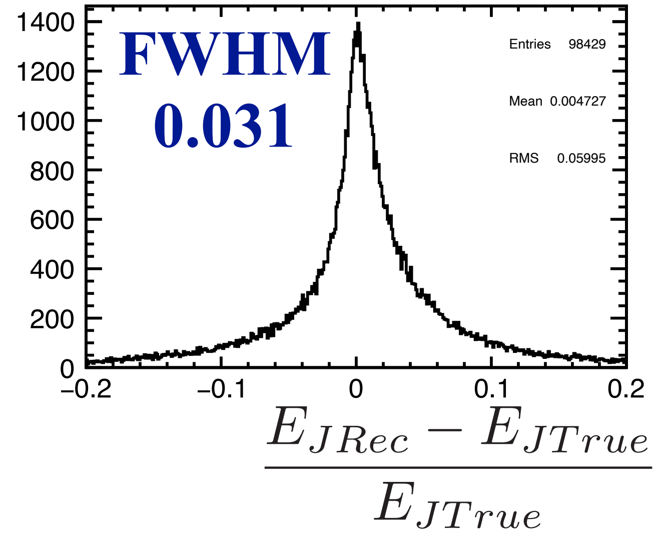
50GeV<E_{J1}<100GeV



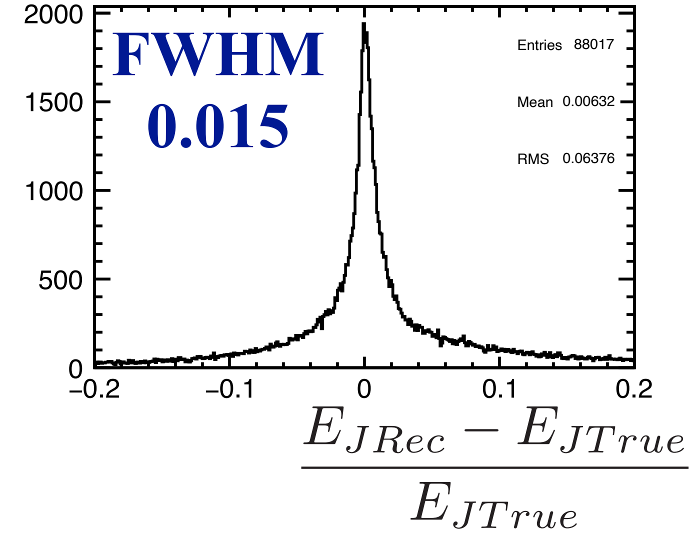
100GeV<E_{J1}<150GeV



150GeV<E_{J1}<200GeV



200GeV<E_{J1}<250GeV



We can see clear jet energy dependence.

For the lower energy jets, JER is worse.

Summary

In order to exclude the wrong photon choice events, we need to develop the realistic cut and compare it with the “$|\theta\gamma PFO-\theta\gamma MC| <0.01$” cut which I am using now.

The cause of the difference between ToyMC and Full simulation should be studied more.

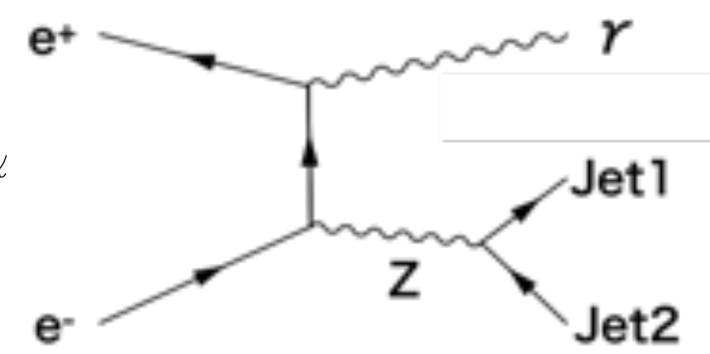
In the end, we need to include background.

Backup

Reconstruction Method

Based on 4-momentum conservation

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



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

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

Matrix A —— Inverse

Reconstruction Method

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

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

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

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

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}