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

Takahiro Mizuno

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2. Full simulation / Event selection

3. Establishment of the new E_{jet} reconstruction Method: Method 4

4. Accuracy of the reconstructed E_{jet}

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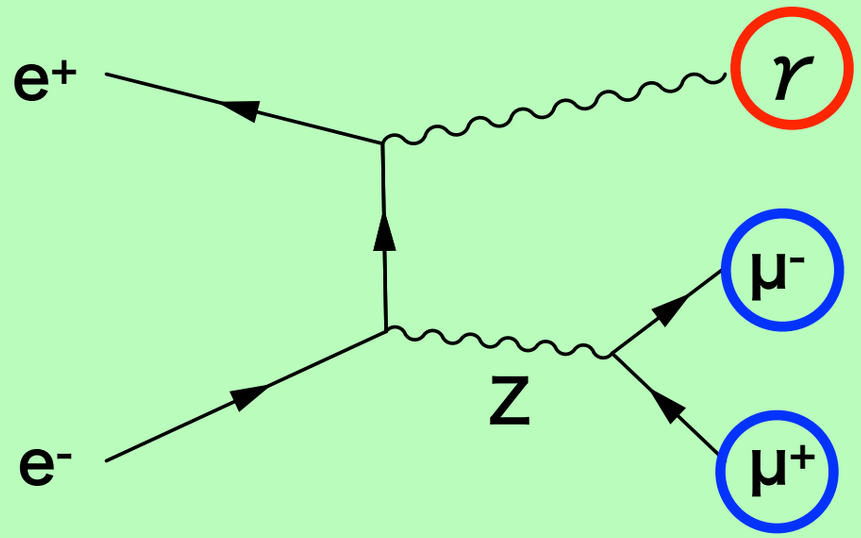
Introduction

- In order to calibrate the jet energy scale, jet energies reconstruction using the $e^+e^- \rightarrow \gamma Z$, $Z \rightarrow$ 2Jets is being studied.

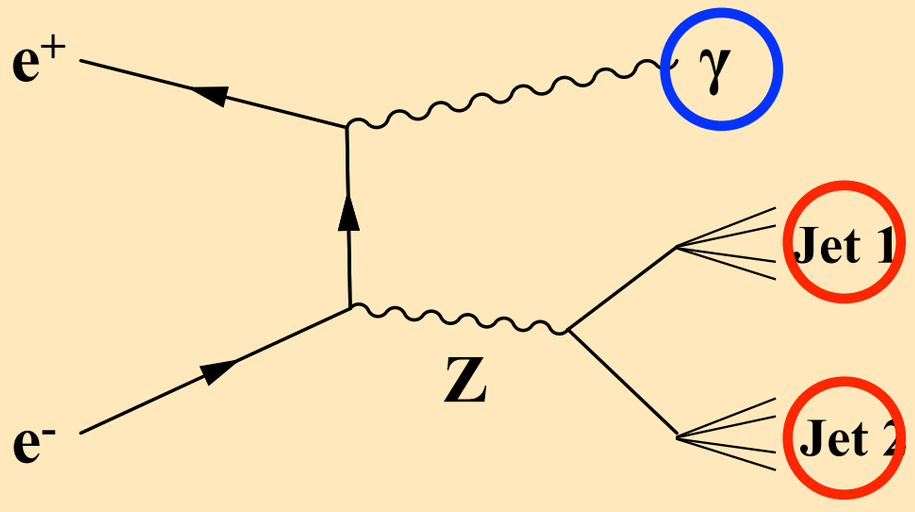
- Full simulation to reconstruct the jet energies is performed. As there found wrong photon choice events after the event selection, we need to consider the cut to exclude them with not noly “MCcut” but also “Realistic cut”.

- Comparison between reconstructed and MCTruth energies of the jets is checked. Method 3 was the best among the 4 possible methods, while we have to choose the best answer from 8 possible solutions.

Photon Energy Scale Calibration



Jet Energy Scale Calibration



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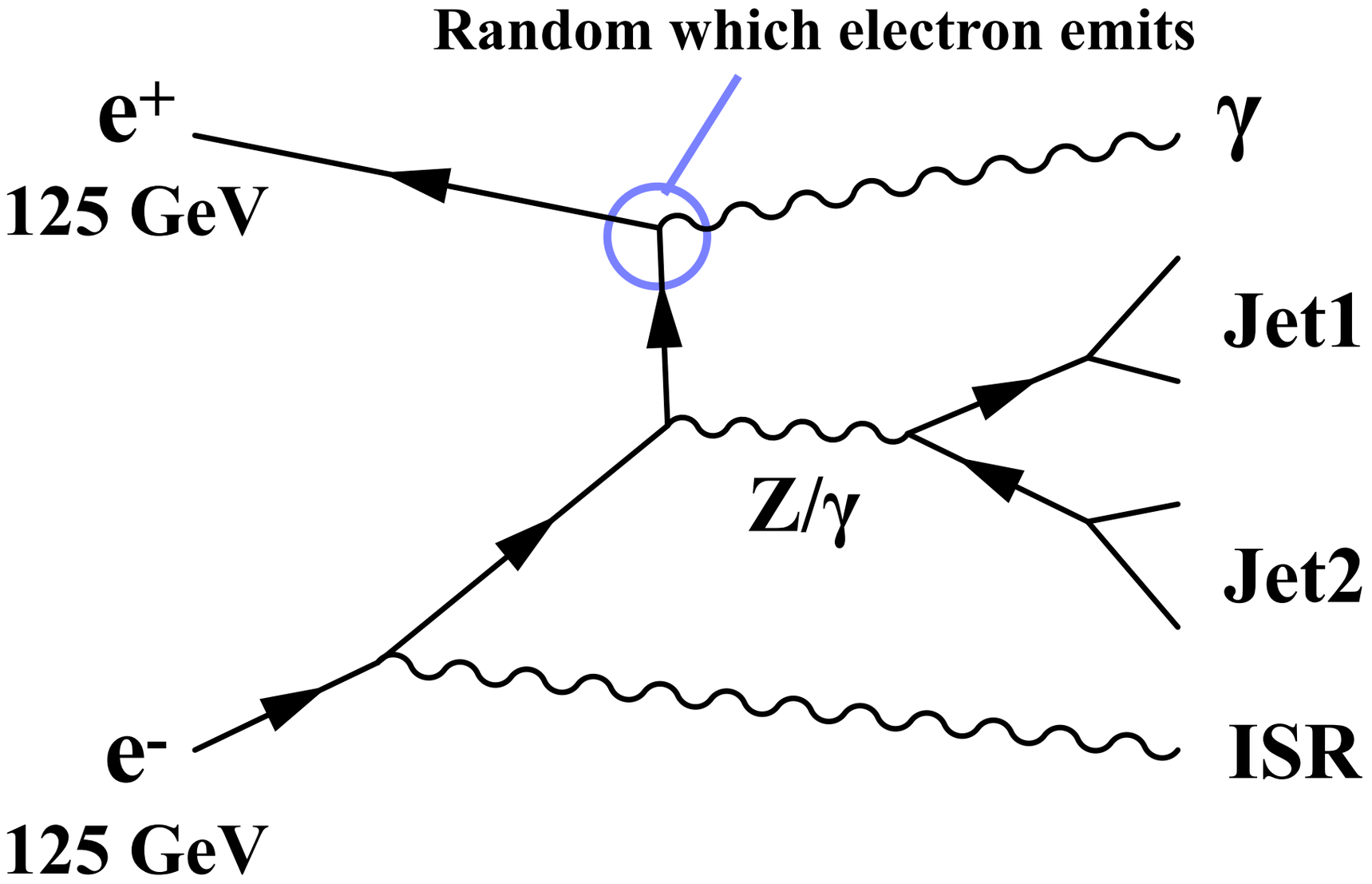
Full simulation

(ILCSOFT version v01-16-02)

- **DBD samples**, at **E_{CM}= 250 GeV** with $\int Ldt=900fb^{-1}$ each for 2 beam polarizations: (P_e-, P_e+) = (-0.8, +0.3) and (+0.8, -0.3).
- To make things clear, overlay removal by MCTruth link is implemented.



Event selection

Signal Photon Selection

Events signature = **1 isolated energetic photon + 2 jets**

Signal photon is selected as follows:
1. choose neutral particles with particle ID = 22 (Pandora PFA ID)
2. require energy > 50 GeV
3. choose the photon candidate with energy closest to 108.4 GeV

Other photons inside the cone (with the angle $\cos\theta > 0.998$ from the signal photon) are merged with the signal photon.

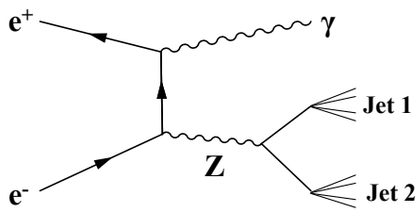
Jet Clustering

- All Particle Flow Objects (PFOs) other than the selected photon are clustered into 2 jets with Durham algorithm (done by LCFIPlus)
- The jet with higher reconstructed energy is defined as “jet 1” and the other as “jet 2”

Correct photon selection

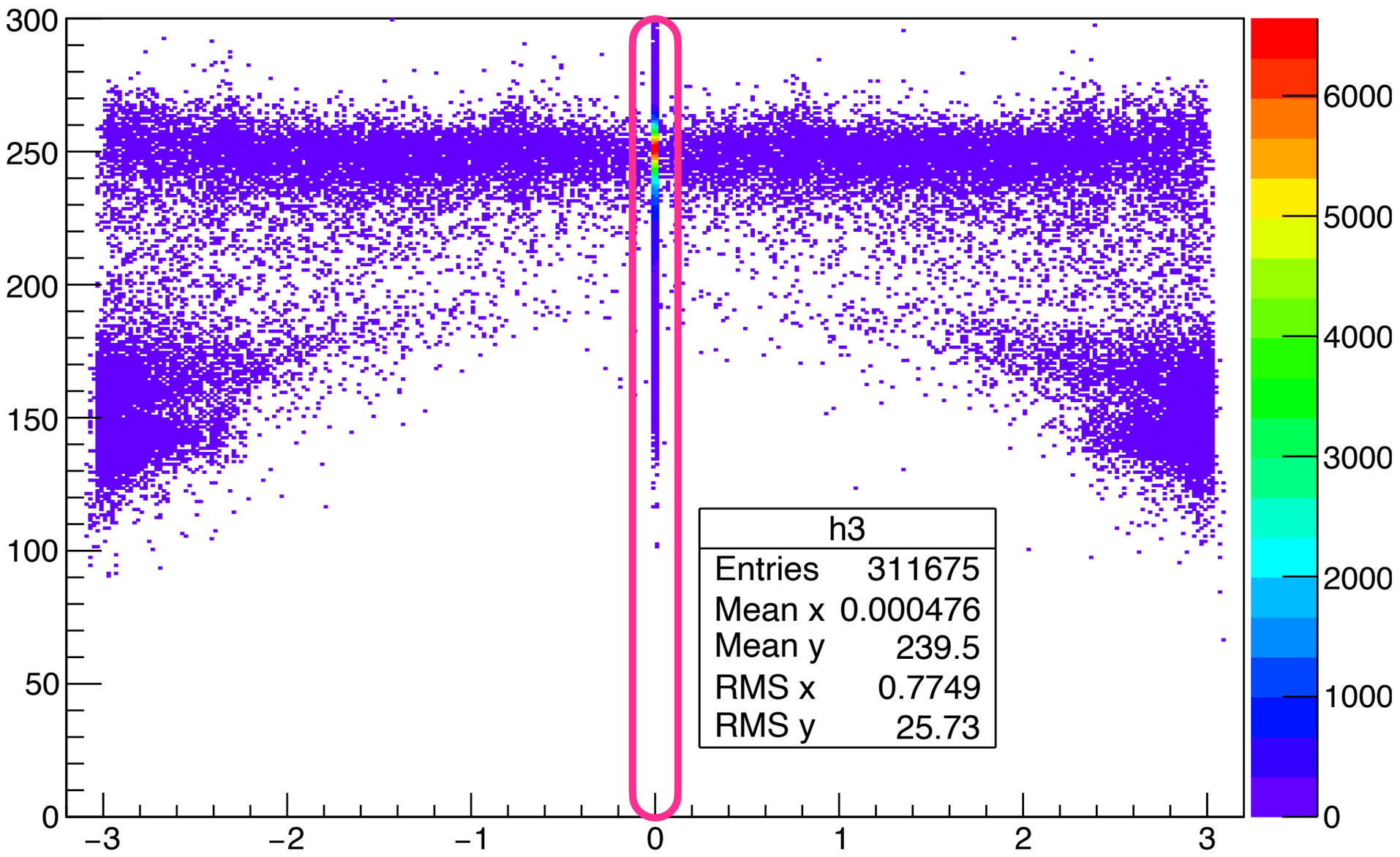
E_{vis} (=E_{j1}+E_{j2}+E_γ) vs. $\Delta\theta_\gamma$ =θ_γ(meas)-θ_γ(MC)

True signal photon: feeble and missing



True signal photon: energetic but missing

Selected photon: from jets



$|\Delta\theta_\gamma|$ <0.01 events: 87.8%

$|\Delta\theta_\gamma|$ >0.01 events: 12.2%

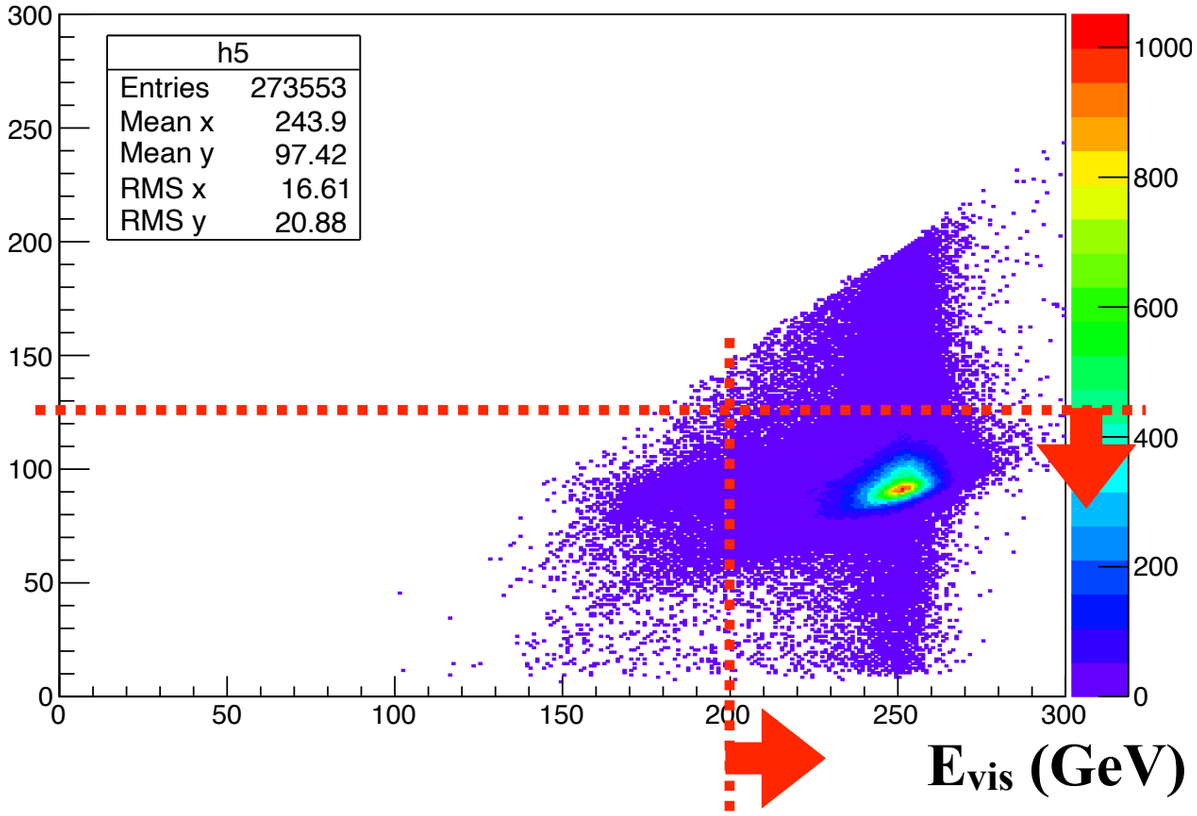
Correct Photon

Correct photon selection cut 1

M_{2j} vs. E_{vis} (=Ej1+Ej2+Eγ)

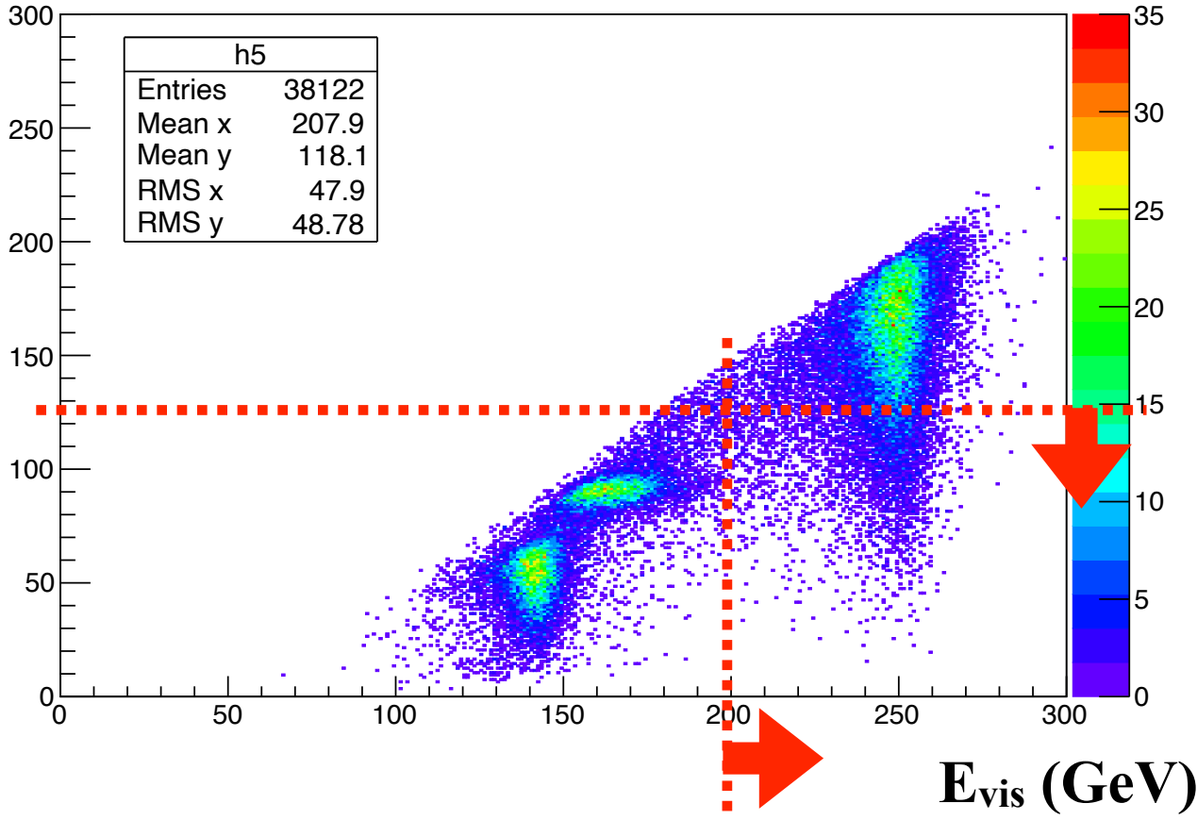
correct photon case

$|\Delta\theta_\gamma| < 0.01$



wrong photon case

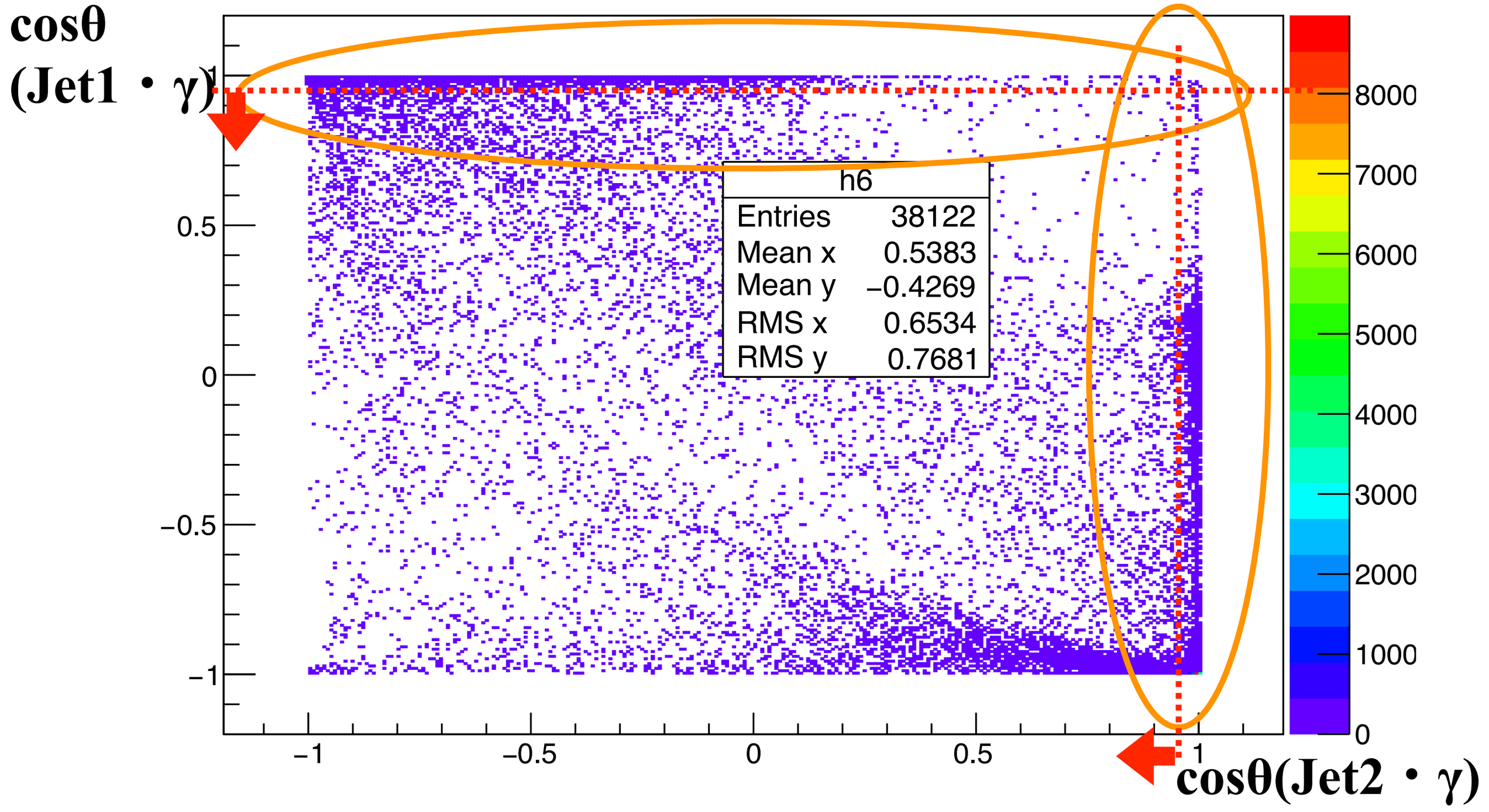
$|\Delta\theta_\gamma| > 0.01$



Cut1: M_{2j} <125 GeV && E_{vis} >200 GeV

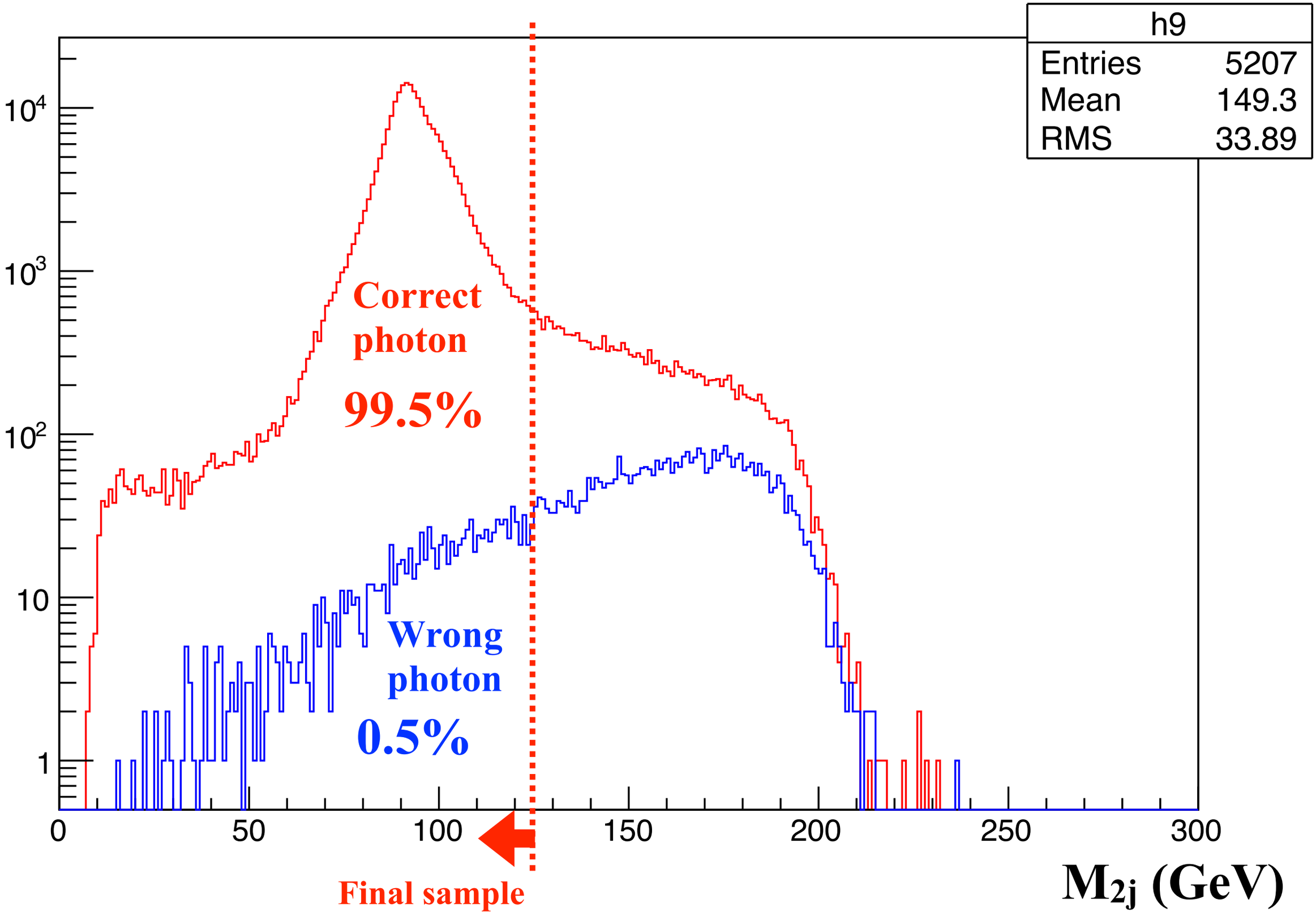
Correct photon selection cut 2

Wrong photons are near jet axes



Cut2: cosθ(Jet1 ・ γ)<0.95 && cosθ(Jet2 ・ γ)<0.95

M_{2j} distribution after all but M_{2j} cut



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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 (θ_{J1},θ_{J2},θ_{γ},φ_{J1},φ_{J2},φ_{γ},) -> Determine (P_{J1},P_{J2},P_{γ})

Method 2': Use transverse momentum conservation and ignore ISR /Use measured P_{γ} as input

Using (θ_{J1},θ_{J2},θ_{γ},φ_{J1},φ_{J2},φ_{γ},$\mathbf{P_{\gamma}}$) -> Determine (P_{J1},P_{J2})

Method 2: Use 4-momentum conservation and consider ISR /Use measured P_{γ} as input

Using (θ_{J1},θ_{J2},θ_{γ},φ_{J1},φ_{J2},φ_{γ},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 (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})

Reconstruction Method

Method 3: Use 4-momentum conservation and 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})

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

Matrix A

Inverse

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

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

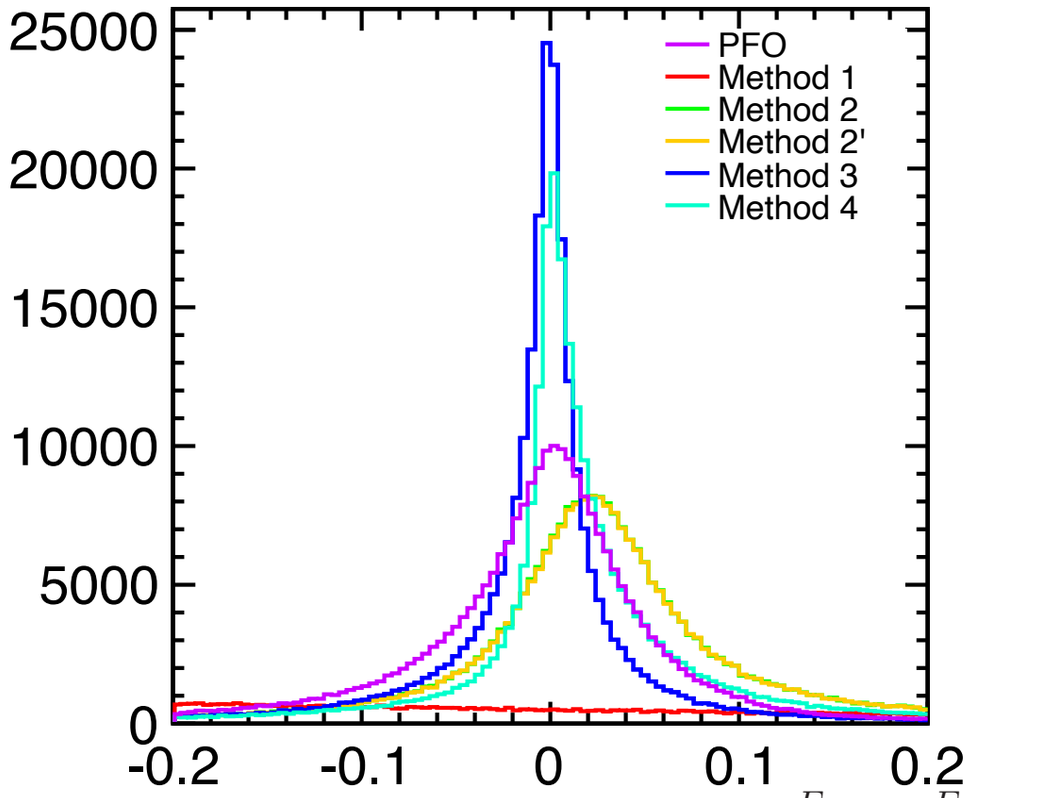
Method 4: Represent the equation with P_{ISR}
Using (θ_{J1},θ_{J2},θ_{γ},φ_{J1},φ_{J2},φ_{γ},$\gamma\beta_{J1}$,$\gamma\beta_{J2}$) -> Determine (P_{J1},P_{J2},P_{γ},P_{ISR})

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

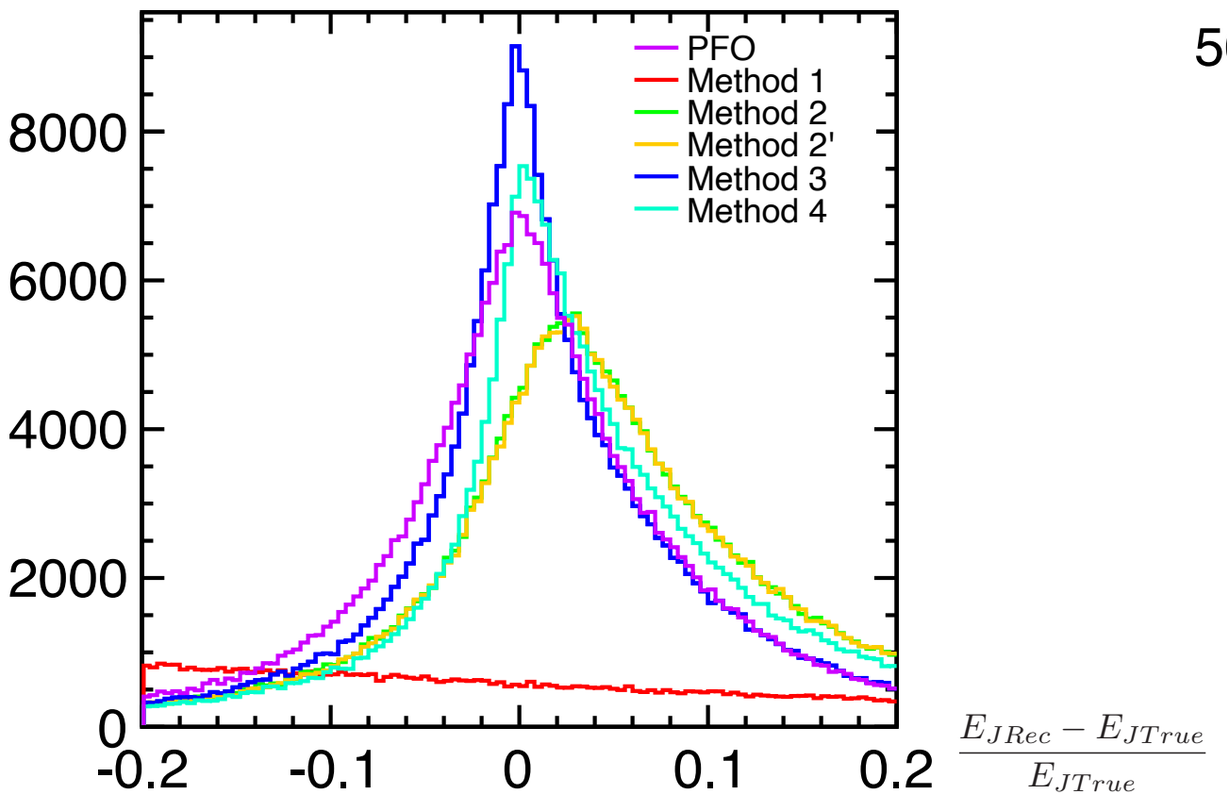
Choose the solution with solved P_{γ} closest to the measured P_{γ}

Relative diff. of energy in each method

Jet 1



Jet 2

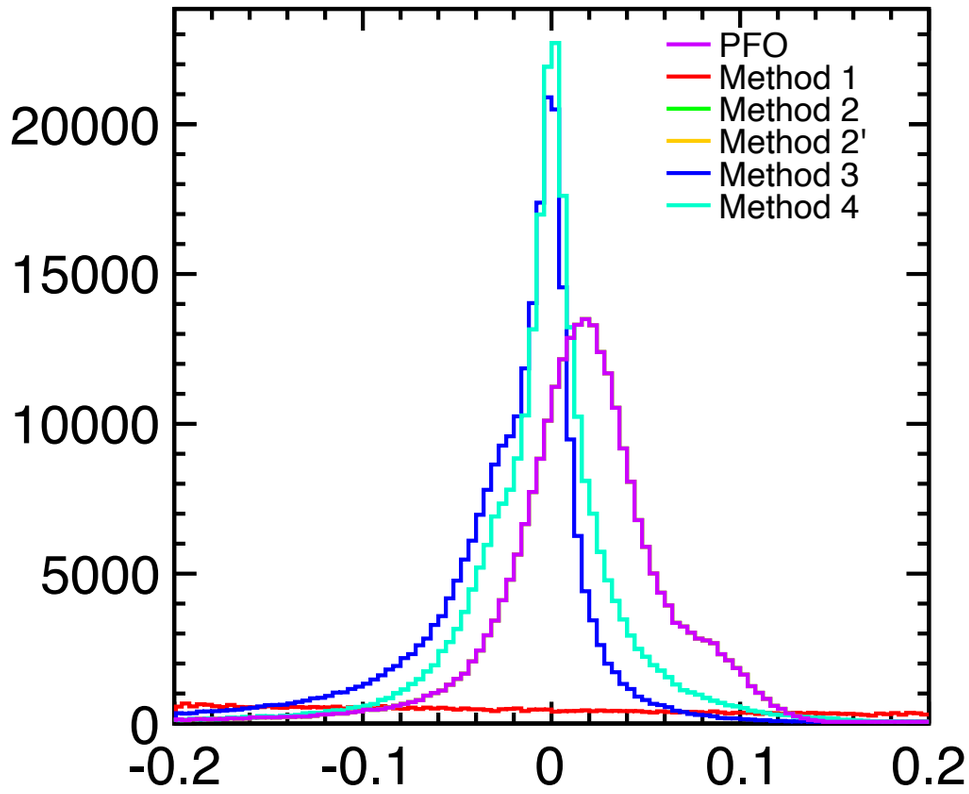


MC Cut:

Correct photon selection

Method 3 has answer

Photon

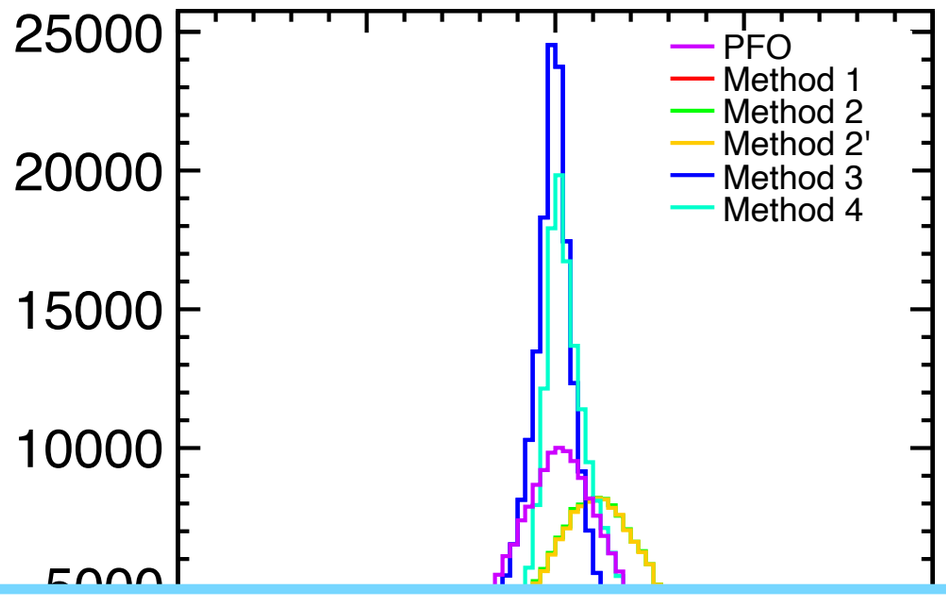


M2 & M2' ≡ PFO $\frac{E_{JRec} - E_{JTrue}}{E_{JTrue}}$

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

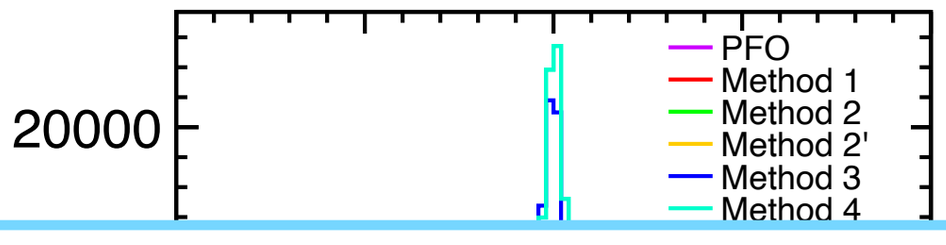
Relative diff. of energy in each method

Jet 1

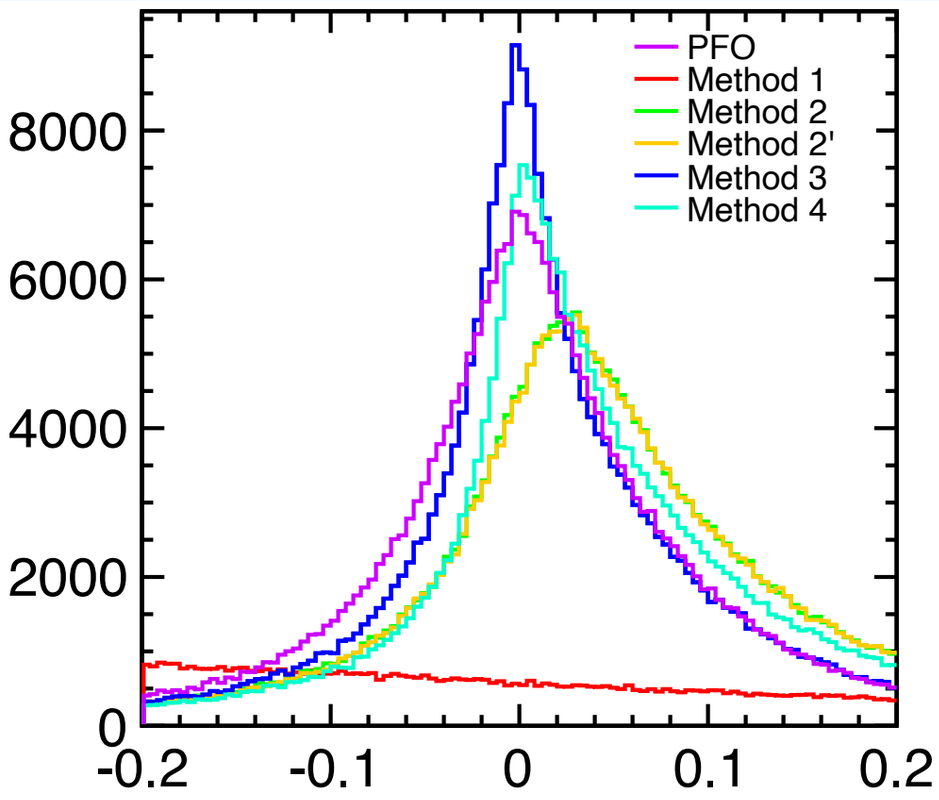


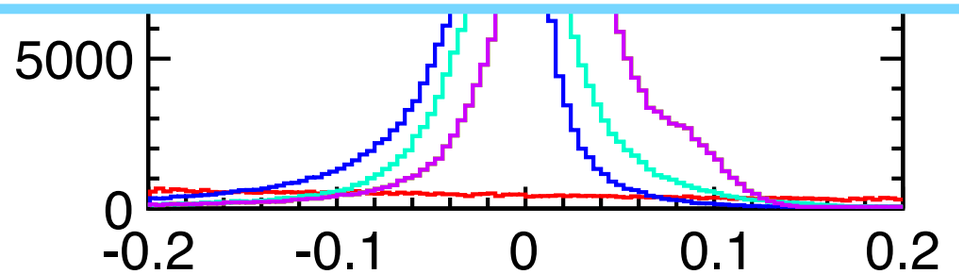
MC Cut:
Correct photon selection
Method 3 has answer

Photon



Investigate the reconstructed E_{jet} using Method 3 in the following.





M2 & M2' ≡ PFO $\frac{E_{JRec} - E_{JTrue}}{E_{JTrue}}$

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

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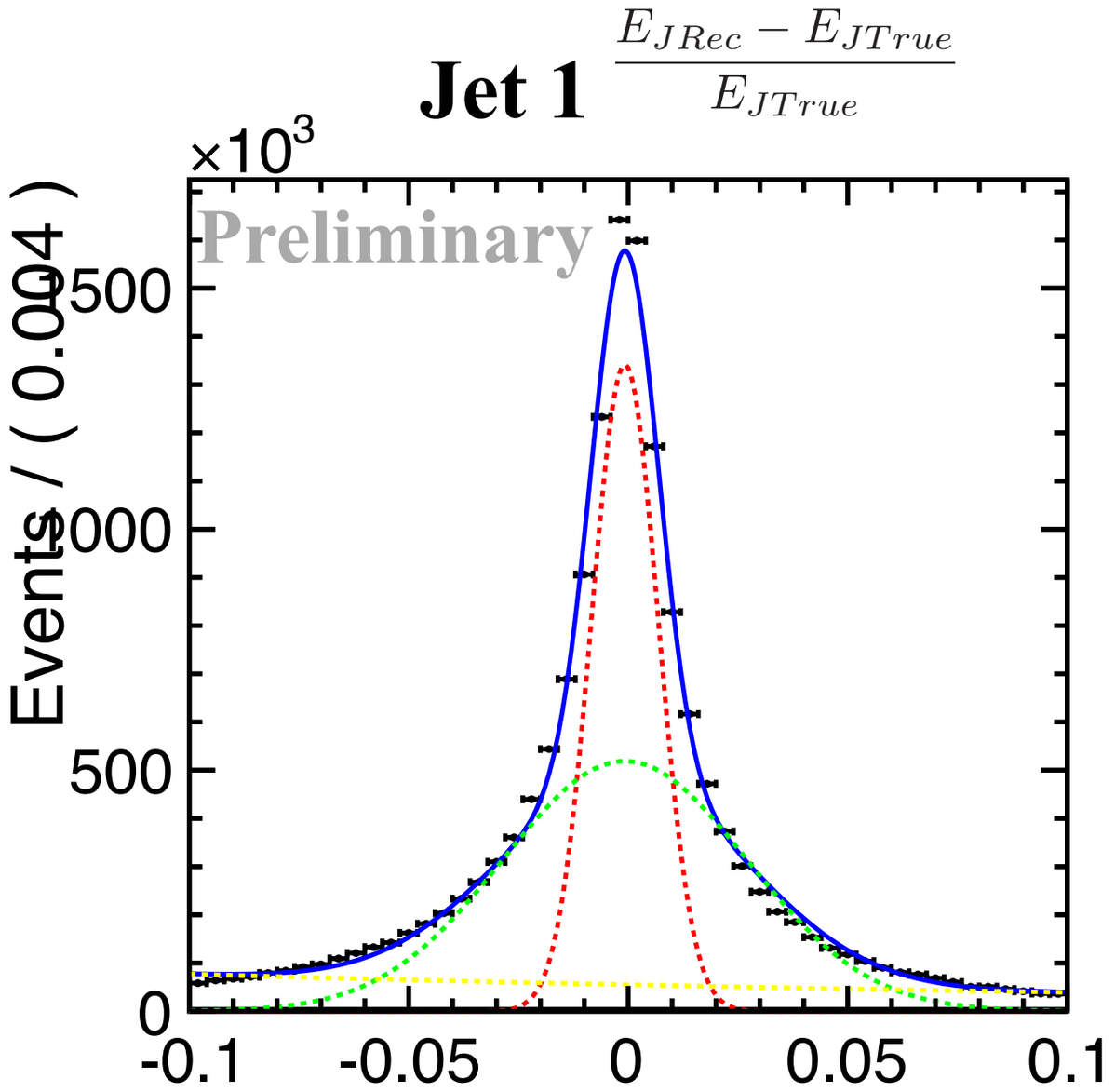
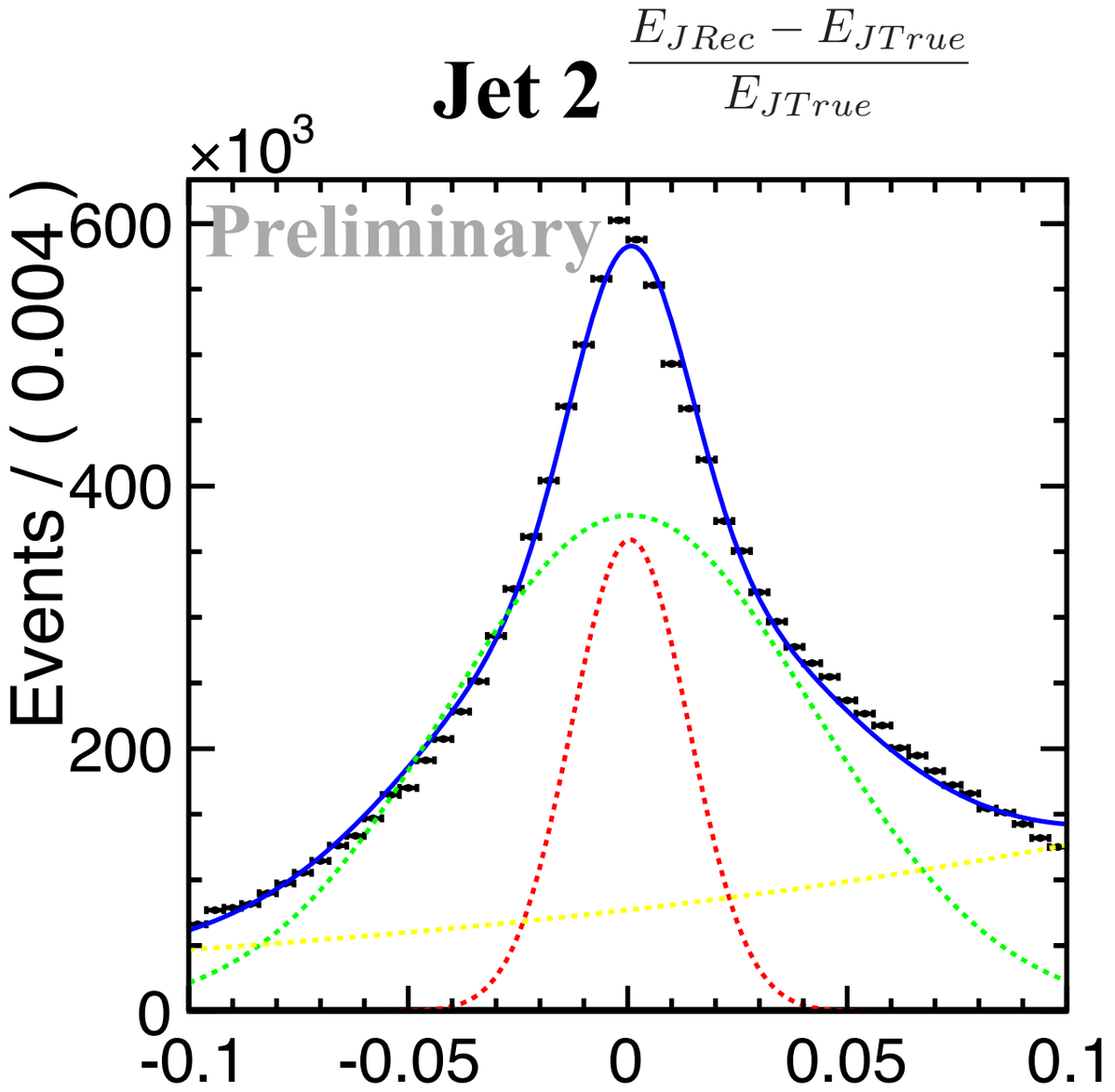
Fit the relative difference of reconstructed jet energy with gaus+gaus+exponential

Mean of the 2 Gaussians are set to be same.



Mean value: (-7.47 ± 0.05) ×10^{-4}



Mean value: (+5.61 ± 0.16) ×10^{-4}

We can reconstruct the jet energy with <8 × 10^{-4} accuracy (Preliminary).
However, Jet 1 has small negative bias and Jet 2 has small positive bias.

Source of the bias

Source of the bias is investigated.
-> 2 major source are found.

Inputs and outputs

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})

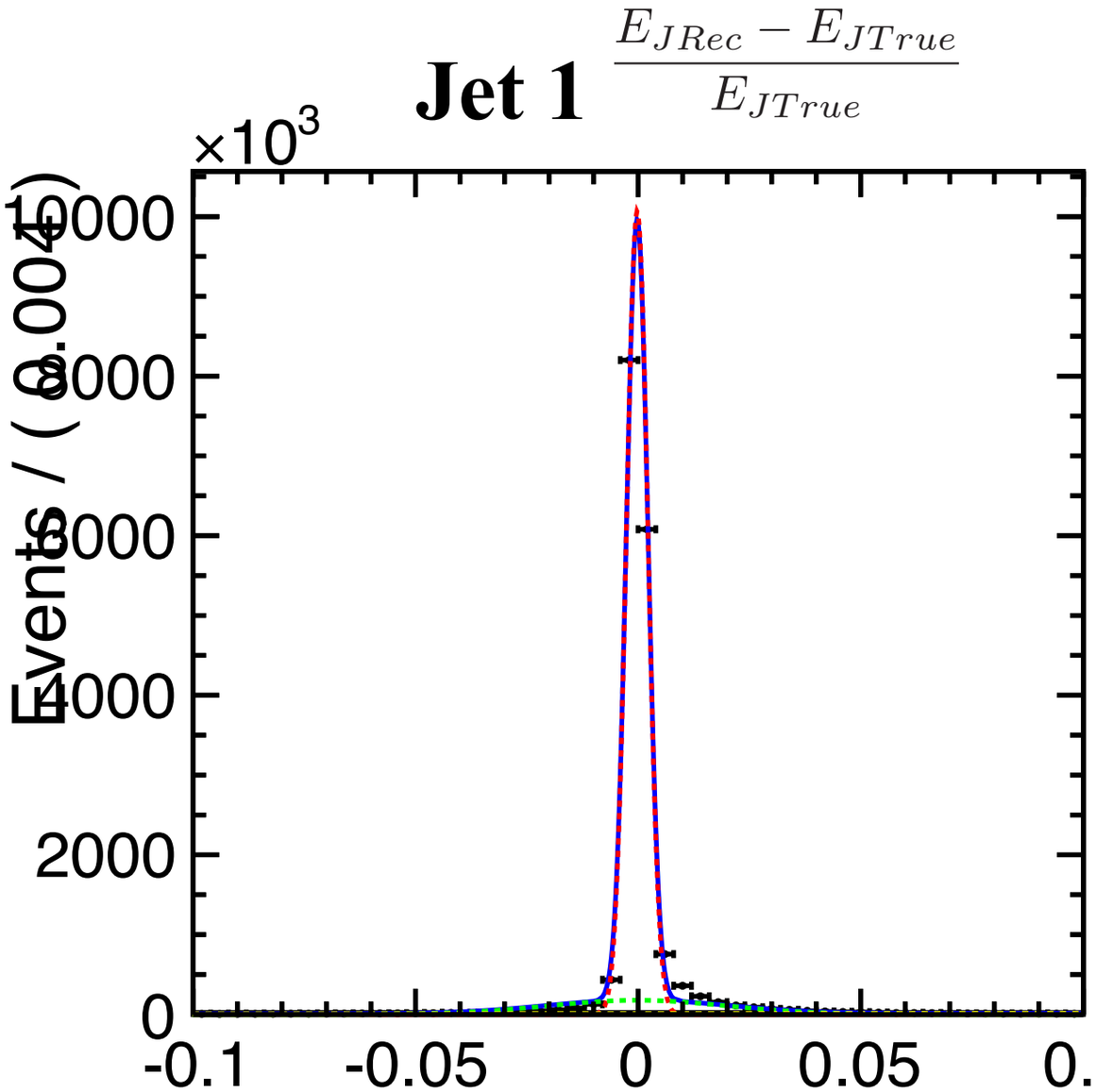
$$\begin{cases} \sqrt{P_{J1}^2+m_{J1}^2}+\sqrt{P_{J2}^2+m_{J2}^2}+|P_\gamma|+|P_{ISR}| = E_{CM} \quad ① \\ \begin{pmatrix} sin\theta_{J1}cos\phi_{J1} & sin\theta_{J2}cos\phi_{J2} & sin\theta_\gamma cos\phi_\gamma \\ sin\theta_{J1}sin\phi_{J1} & sin\theta_{J2}sin\phi_{J2} & sin\theta_\gamma sin\phi_\gamma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

Matrix A → Inverse

(A) Beam energy spread
(B) Error of the jet mass inputs

Source (A): Beam energy spread

When all inputs are all MCtruth,

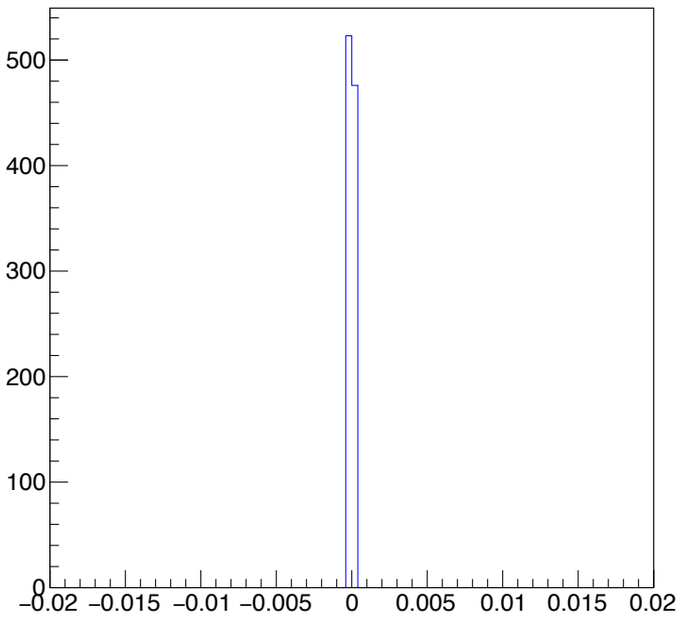


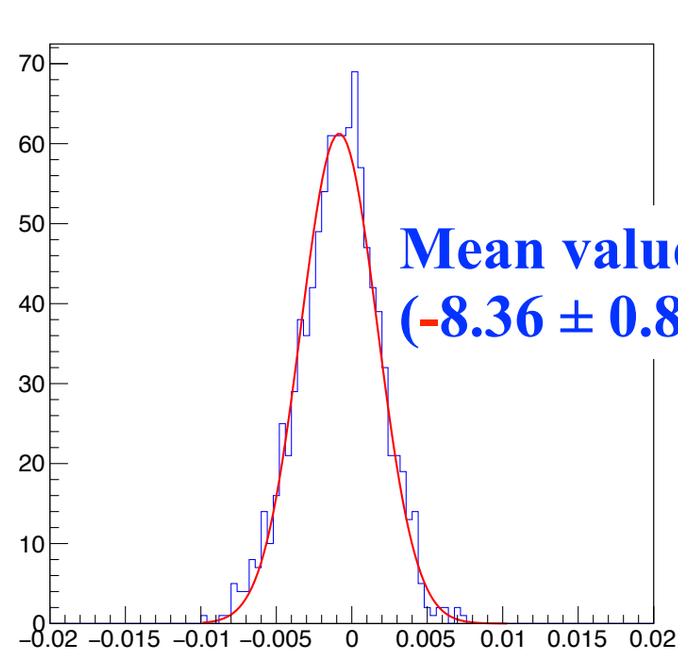
Mean value: (-1.97 ± 0.01) ×10^{-4}

No beam energy smearing

With beam energy smearing (0.3%)

Toy MC Simulation



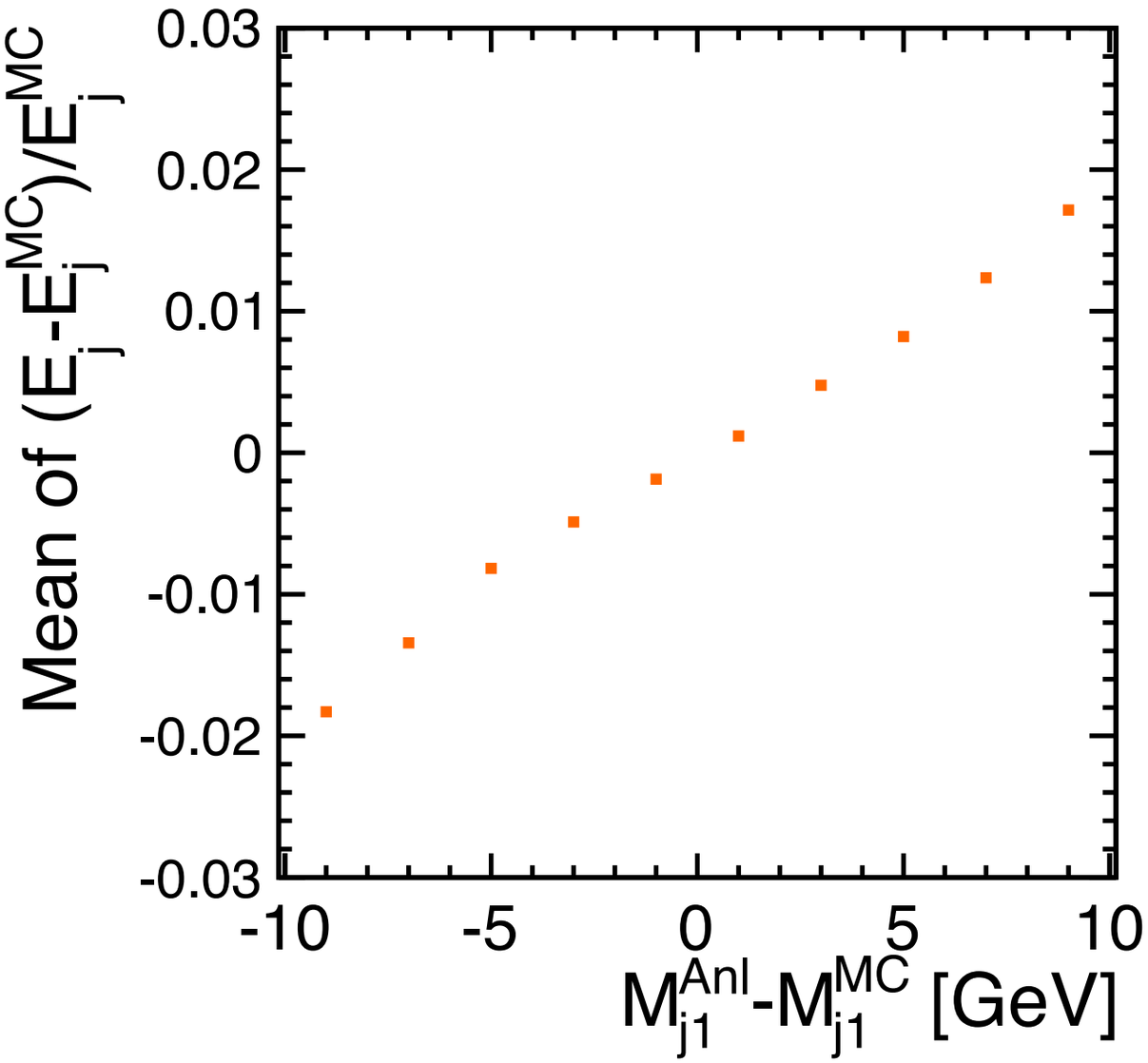


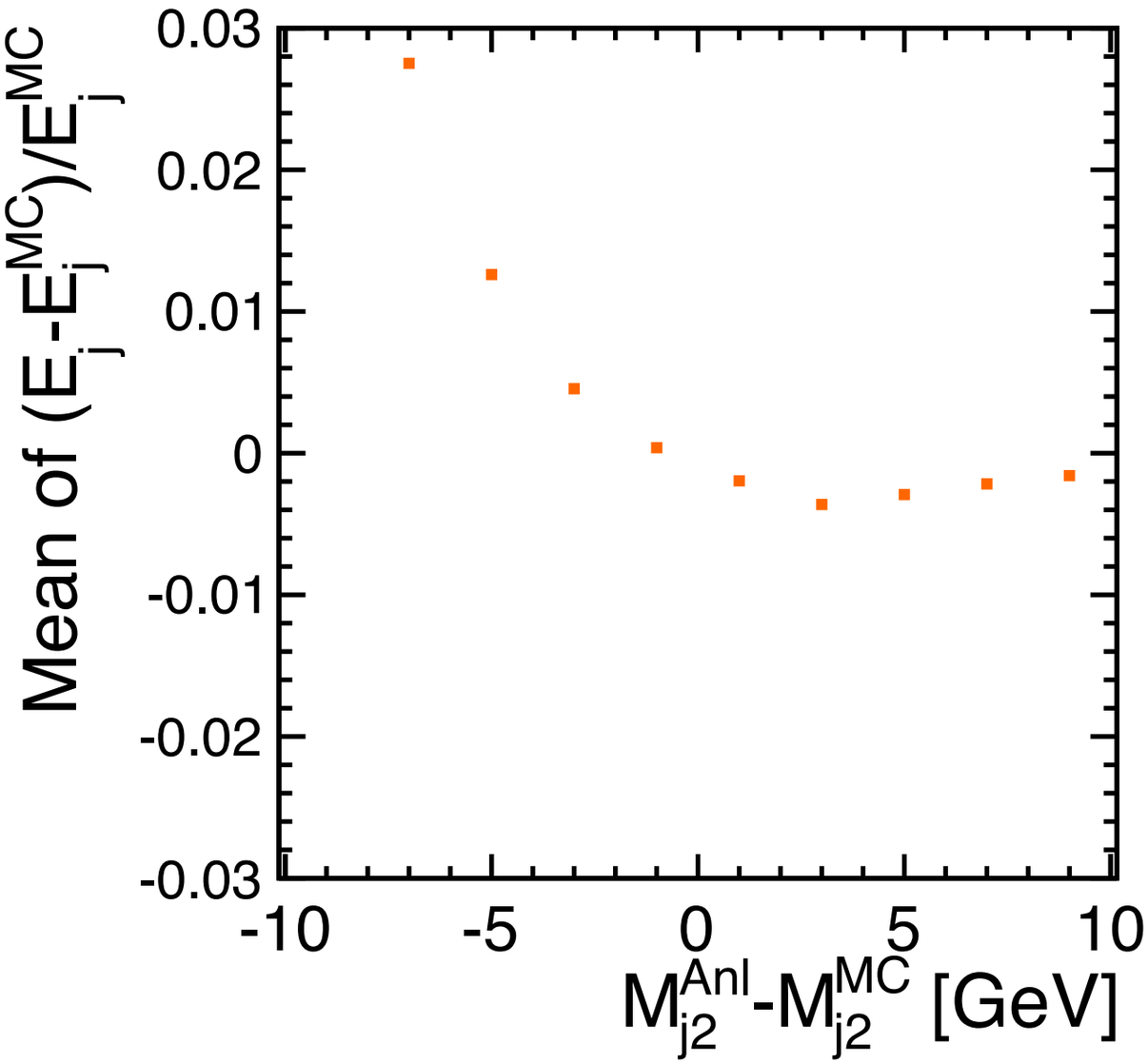
Mean value: (-8.36 ± 0.85) ×10^{-4}

Beam energy spread causes negative bias in jet 1 reconstructed energy.
Positive bias in Jet 2 is also confirmed as well.

Source (B): Error of the jet mass inputs

Mean value of the fitting function for the Jet 1 $\frac{E_{JRec} - E_{JTrue}}{E_{JTrue}}$ as a function of the input jet mass deviation





Large dependence on both jet 1 mass and jet 2 mass input deviations. If $<8 \times 10^{-4}$ accuracy is necessary, compensation to the reconstructed jet energy should be introduced.

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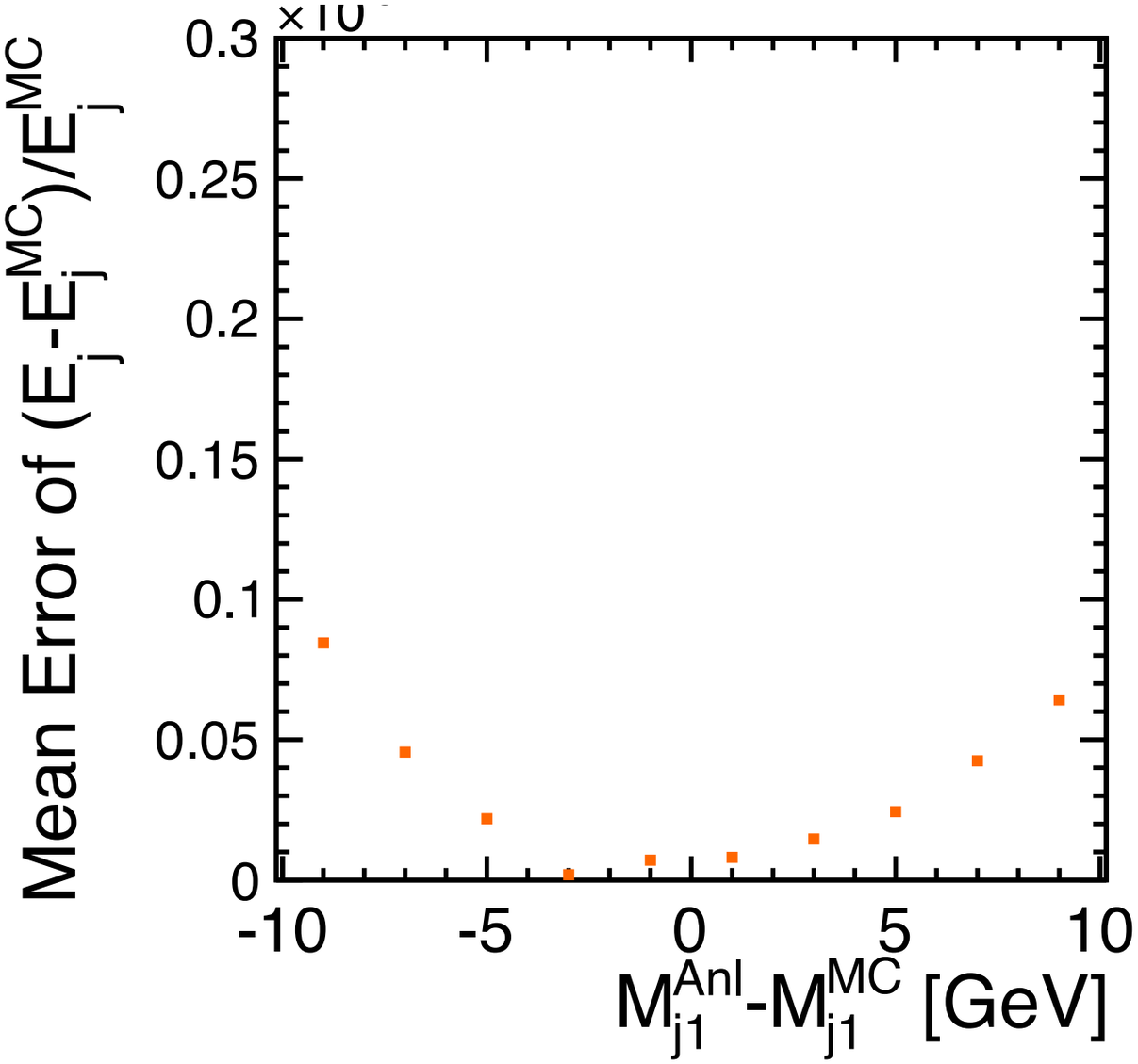
Conclusion

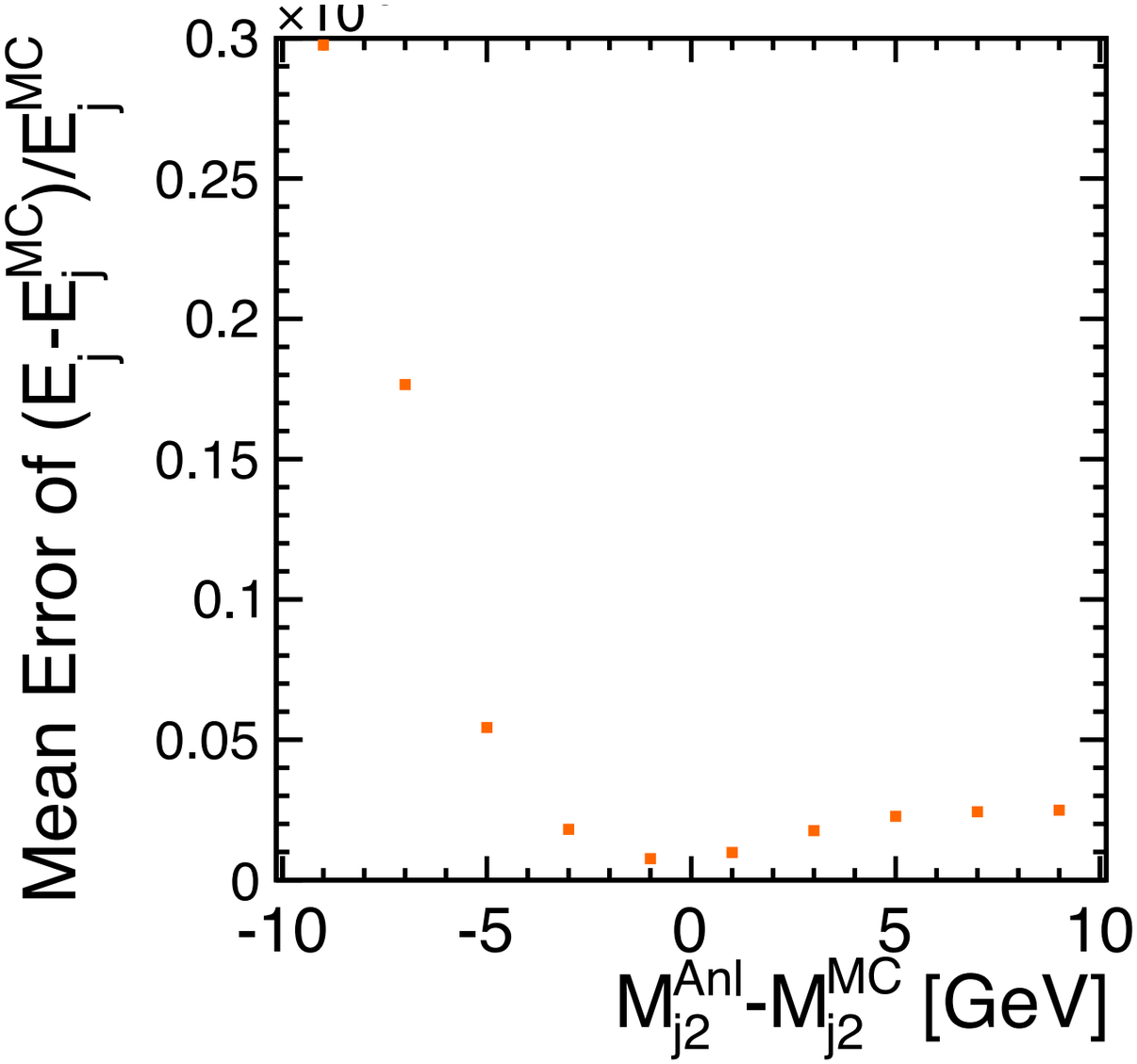
- Full simulation is performed in order to reconstruct the jet energy using the $e^+e^- \rightarrow \gamma Z$, $Z \rightarrow 2$ Jets process.
- Realistic event selection method to exclude the wrong photon selection events is established.
- Jet energy can be reconstructed using the $e^+e^- \rightarrow \gamma Z$, $Z \rightarrow 2$ Jets process. Method 3 is the best among the 5 methods due to the peak height and symmetry.
- Using the Method 3, we can reconstruct the jet energy with 8×10^{-4} accuracy (Preliminary).
- However, reconstructed Jet 1 energy has negative bias and that of Jet 2 has positive bias. There are 2 sources for these biases: (A) Beam energy spread and (B) Error of the jet mass inputs. If $<8 \times 10^{-4}$ accuracy is necessary, compensation to the reconstructed jet energy should be introduced.

Backup

Source (B): Error of the jet mass inputs

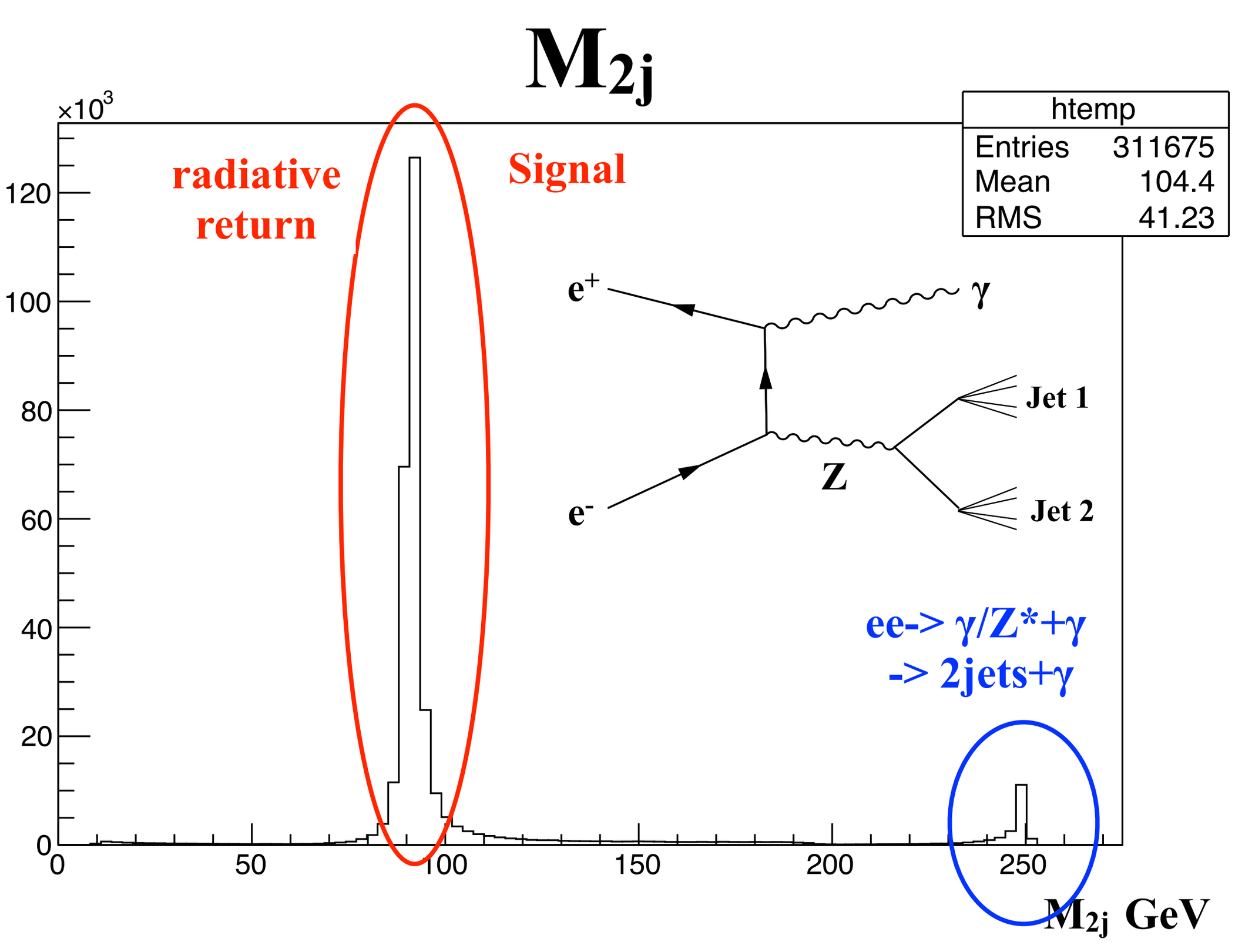
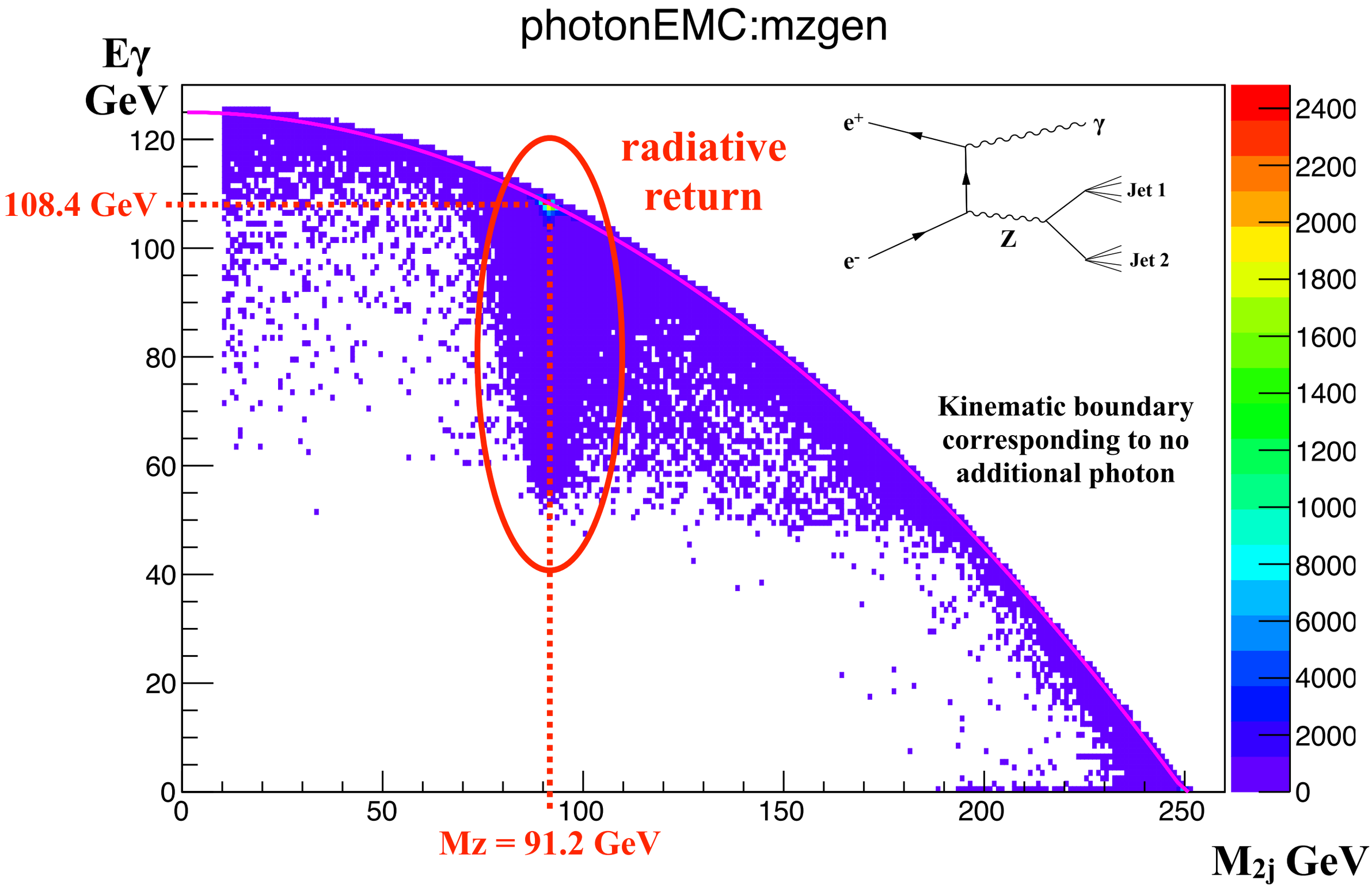
Mean value of the fitting function for the Jet 1 $\frac{E_{JRec} - E_{JTrue}}{E_{JTrue}}$ as a function of the input jet mass deviation





Large dependence on both jet 1 mass and jet 2 mass inputs.
If $<8 \times 10^{-4}$ accuracy is necessary, compensation to the reconstructed jet energy should be introduced.

M_{2j} distribution



Photon energy & M_{2j} distribution