Jet Energy Scale Calibration using $e^+e^- \rightarrow q q \gamma$

Takahiro Mizuno
SOKENDAI

Current Status

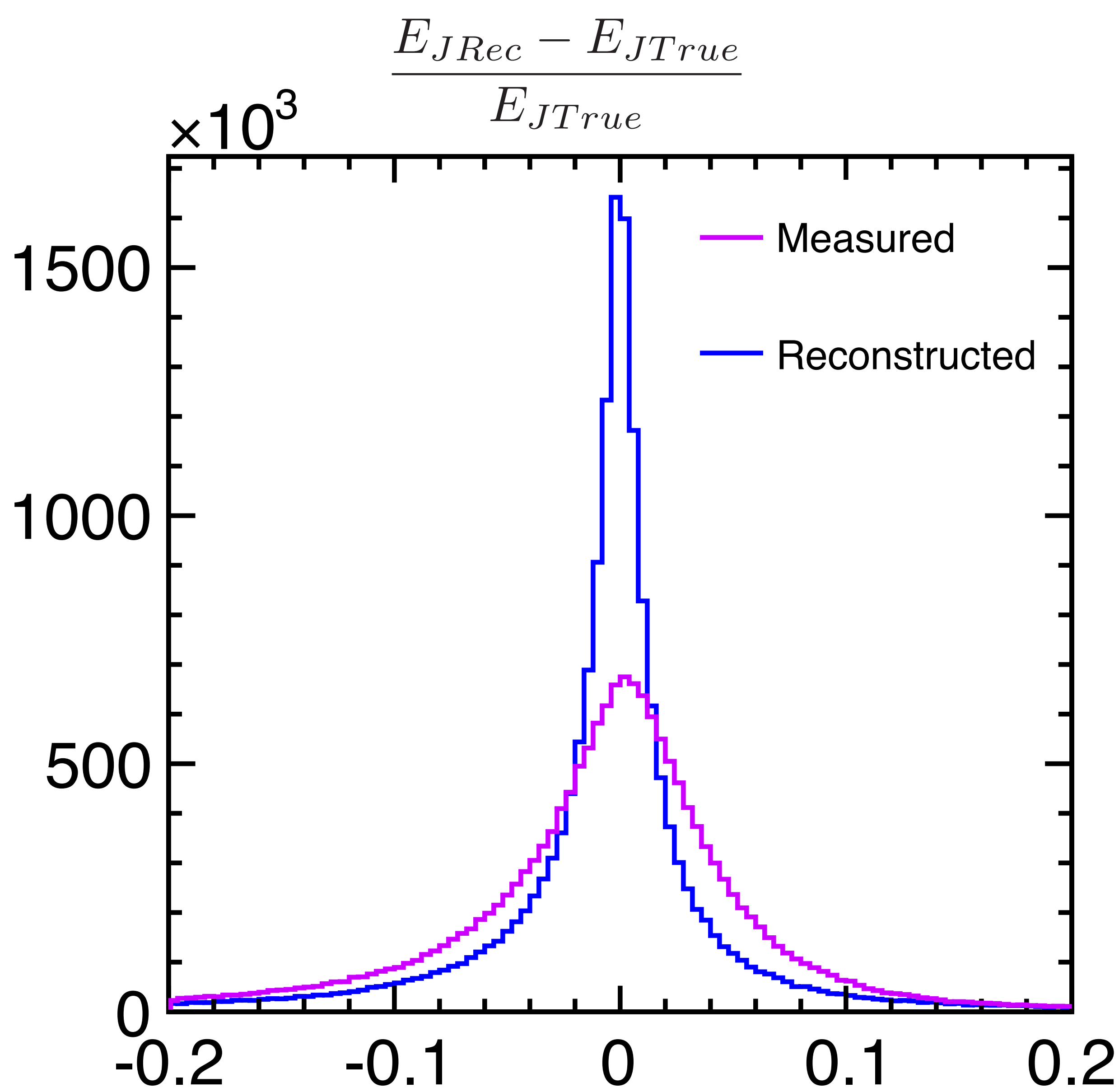
- Reading the study of T. Ueno, ALR measurement preceding work.
- I have a lot of questions!! (e.g. the reason why didn’t use e+e- -> e+e- process)

- Checking the new ILC-250 2f samples (photon PFO energy and angular biases).
- Junping san gave me weight files and some advices on yoke energy muon ID. I am arranging source codes now.

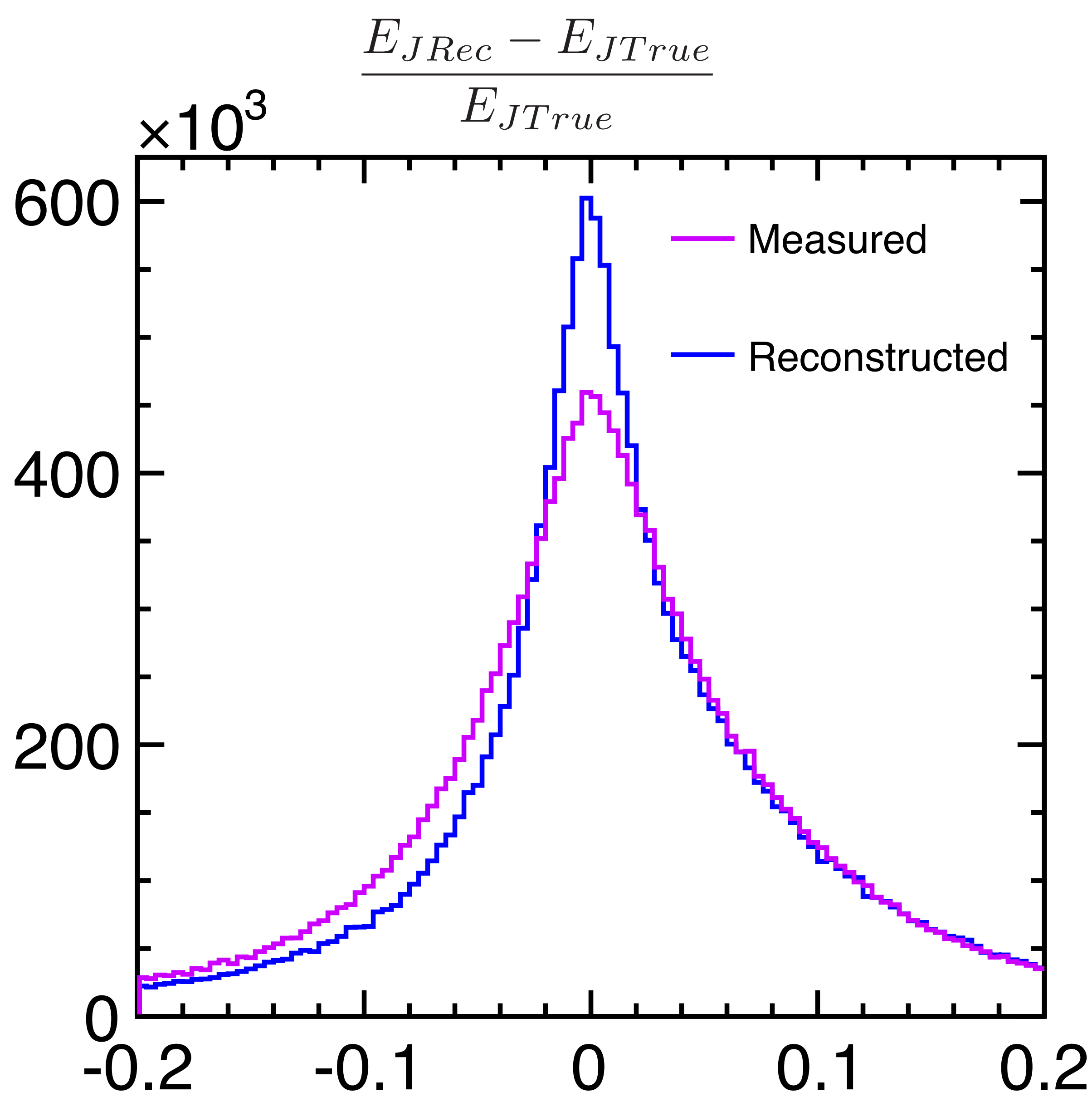
- Gave a presentation on JES calibration at KEK Student Day.
- I got a naive question… -> I will explain.

Jet Energy Reconstruction Result

Jet 1



Jet 2

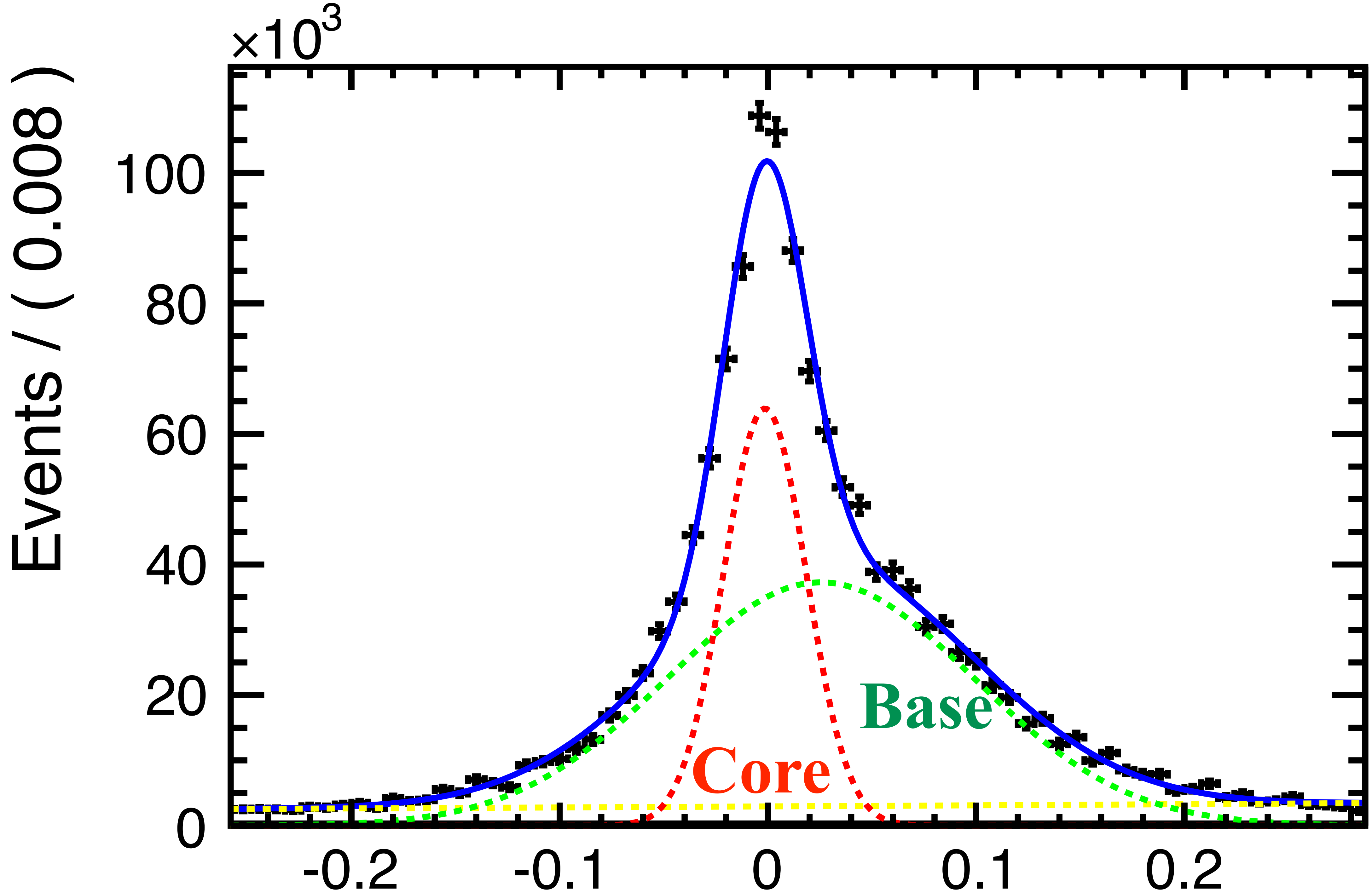


Reconstructed energy not only can calibrate the measured energy, but also has better resolution.

Fit the relative difference of reconstructed jet energy with

Gaus (Core)+Gaus (Base)+exponential

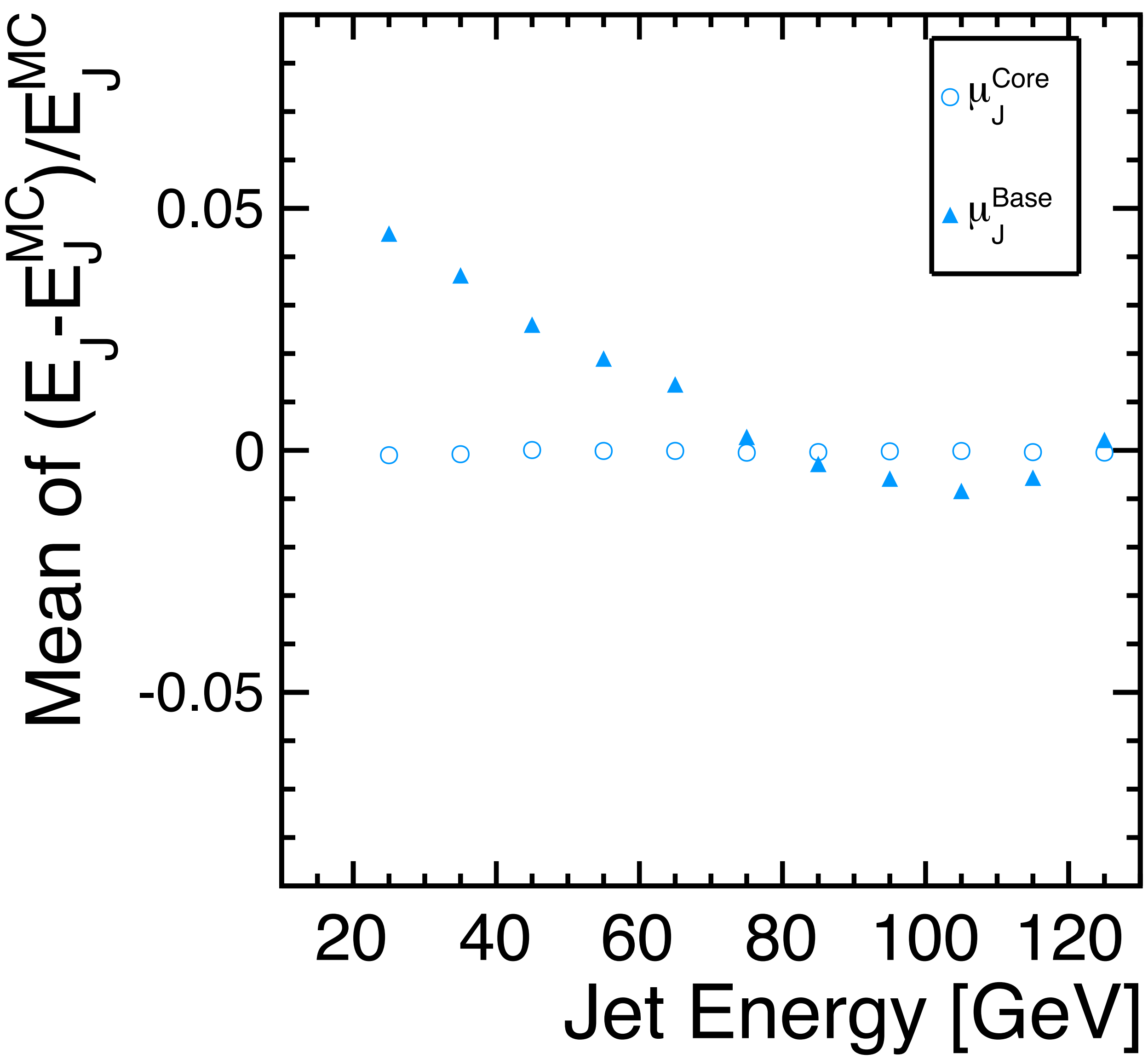
Calibration is based on the mean value of the Gaus (Core).



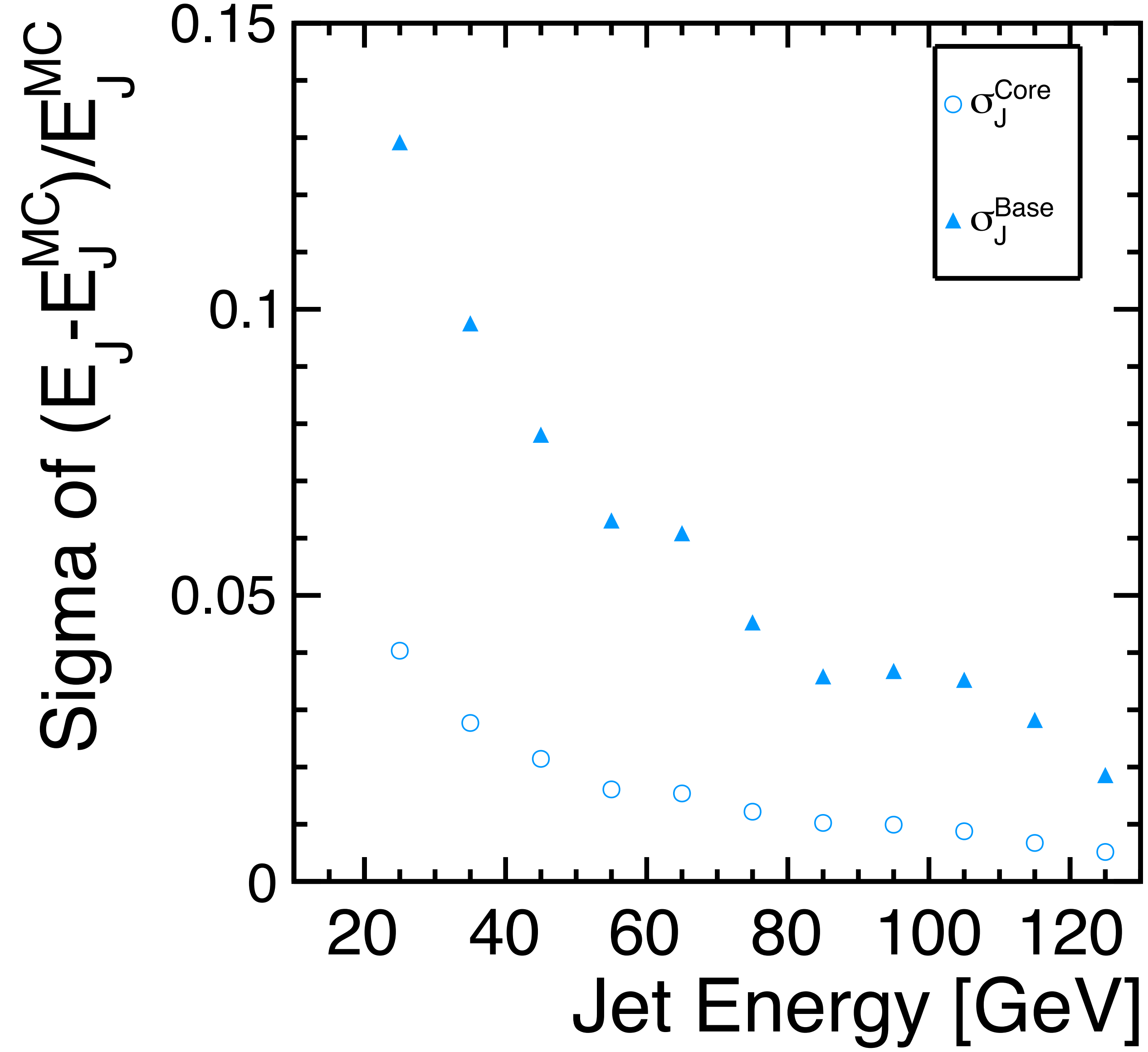
-> Check the theta and energy dependence.

Mean and Sigma Energy Dependence

Mean of the Fitting Gaussian



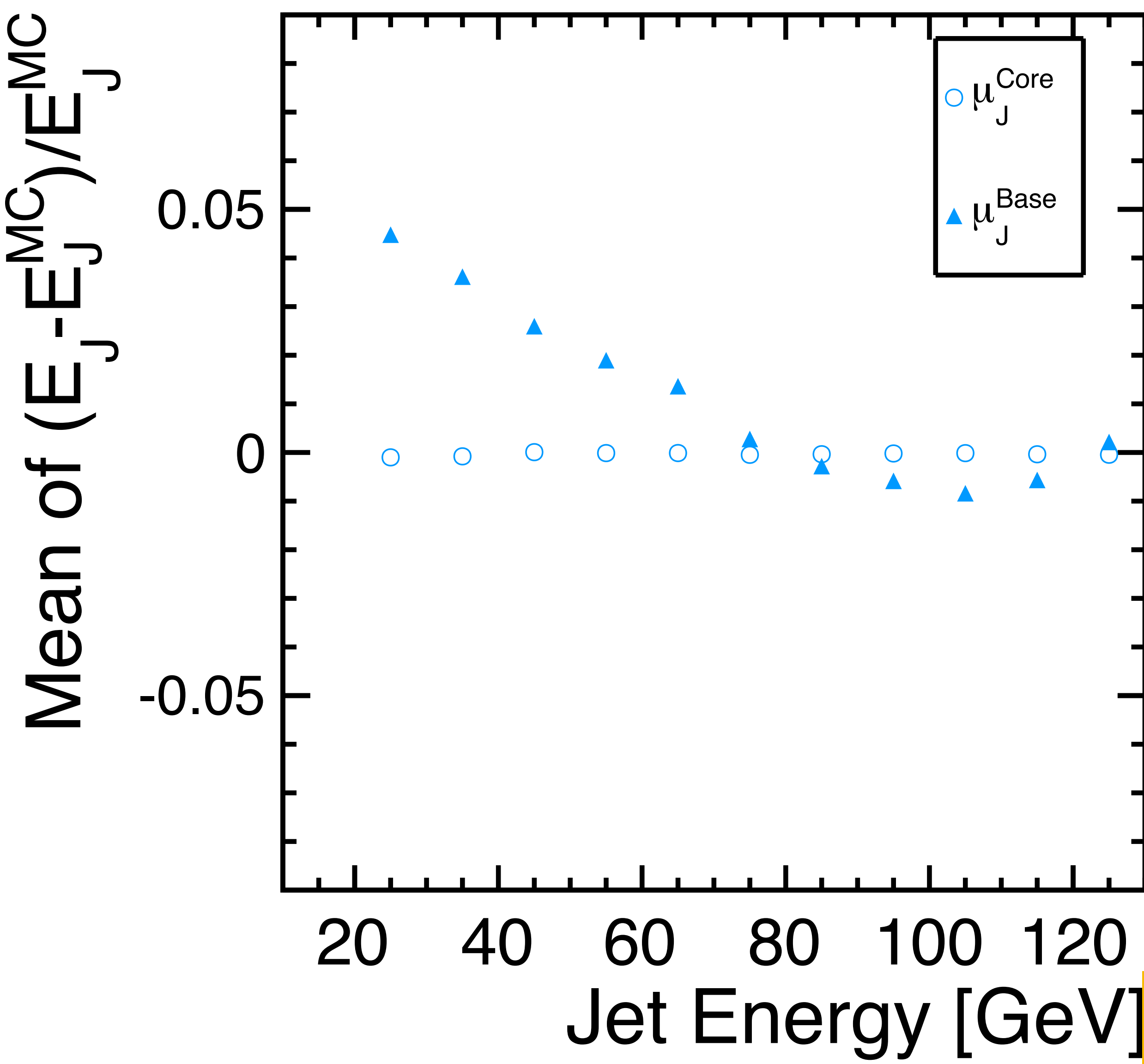
Sigma of the Fitting Gaussian



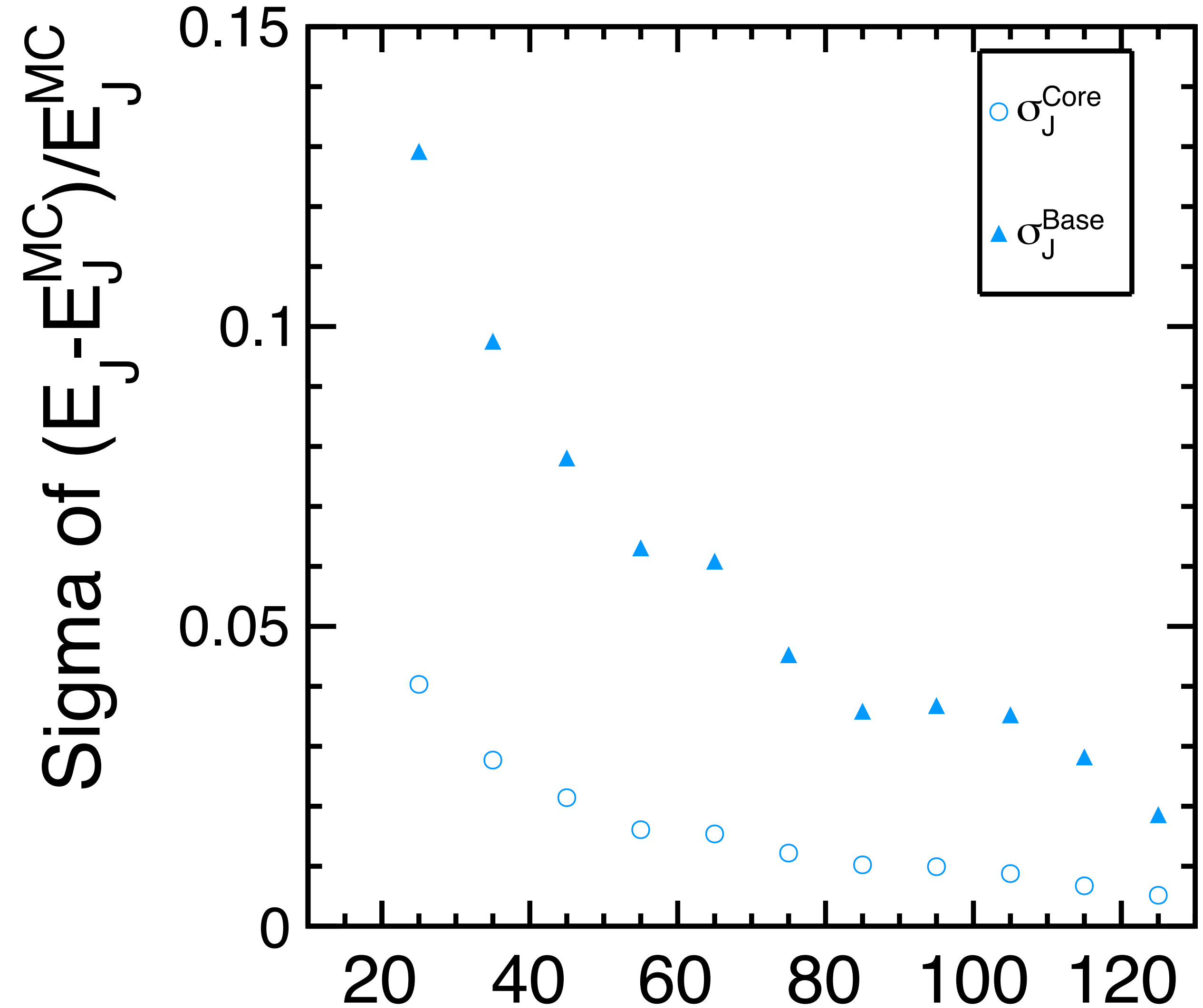
Mean value of the core gaussian is order of 10^{-4} independent on the jet energy.
Sigma value is smaller in the higher energy.

Mean and Sigma Energy Dependence

Mean of the Fitting Gaussian



Sigma of the Fitting Gaussian



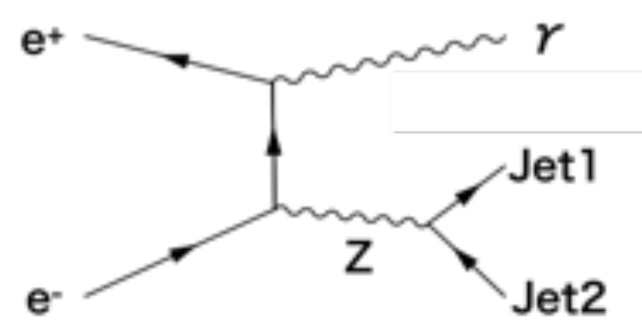
What is the cause of this dependence?

Mean value of the core gaussian
jet energy.
Sigma value is smaller in the higher energy.

Reconstruction Method

Main idea: it is possible to reconstruct jet energies based on jet angles and masses using 4-momentum conservation

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



Direction Angle
θ: polar angle
ϕ: azimuthal angle

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

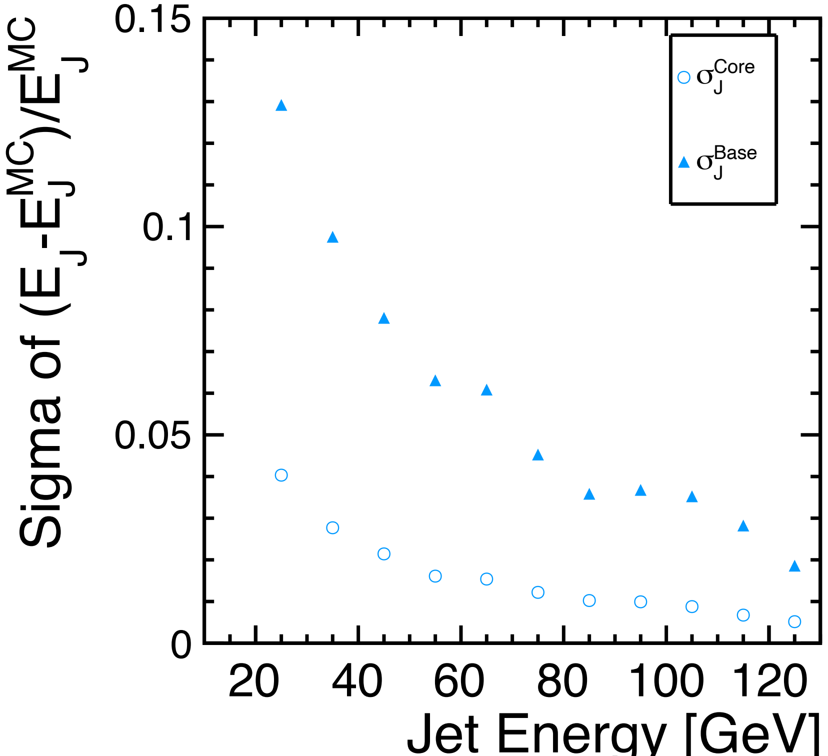
Matrix A → Inverse

Beam Crossing Angle ≡2α = 14.0 mrad
ISR photon = additional unseen photon

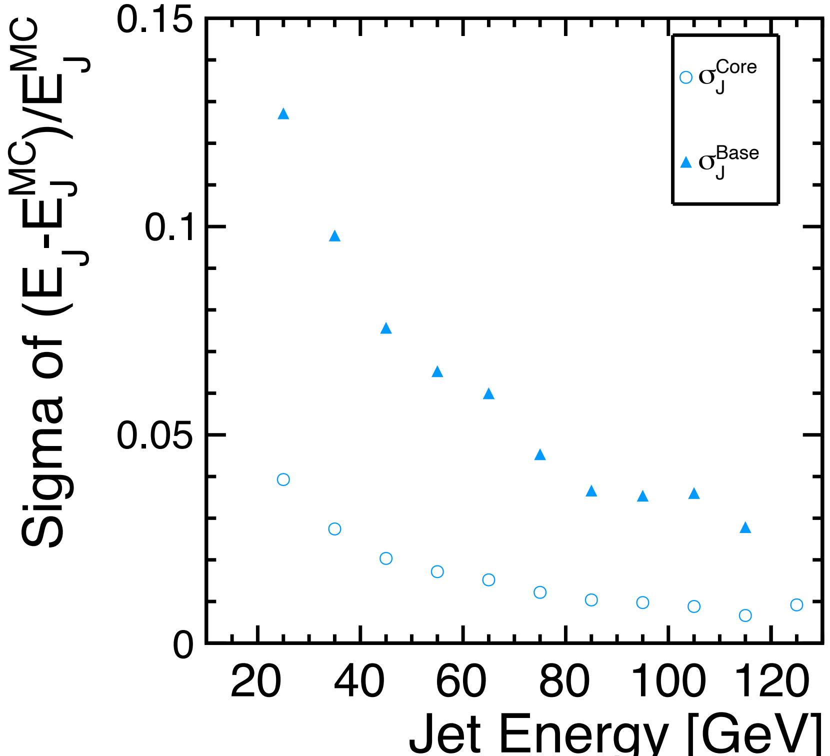
Irrational equation for each sign of the ISR -> 8 possible solutions

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**

Original



Photon E and Angles-cheated



Inputs and outputs

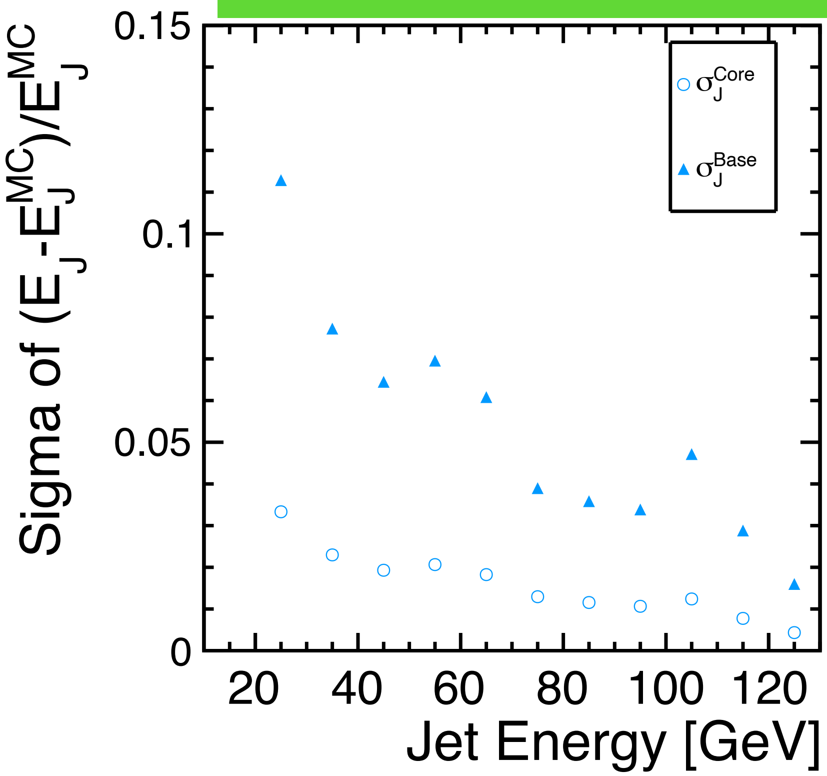
Using

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

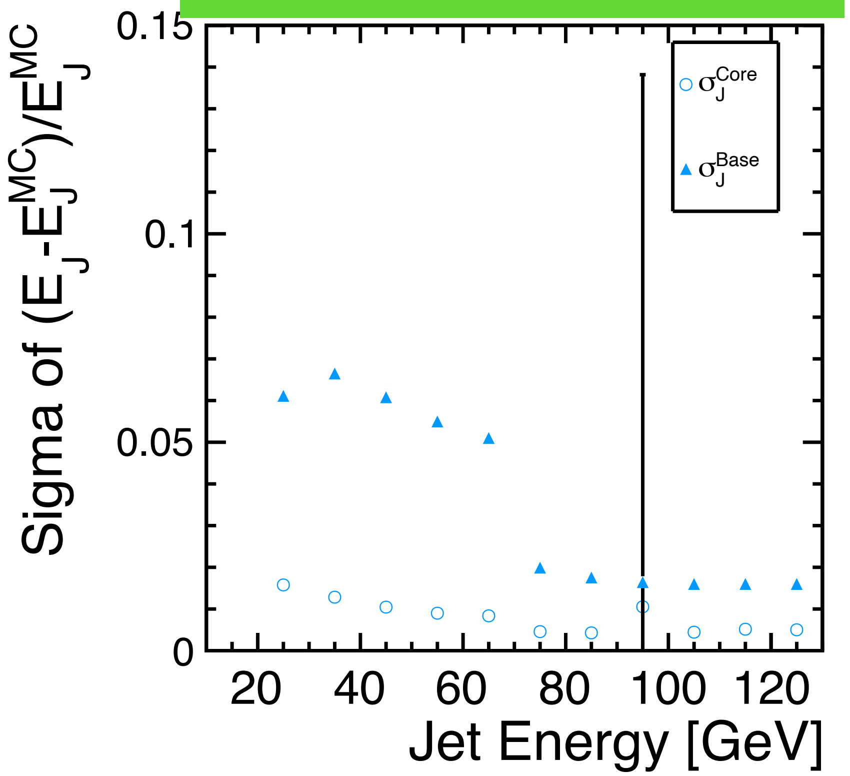
Determine

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

Jet Mass-cheated



Jet Angles-cheated



Jet angles measurement at HCAL

(also jet mass)

is better at high E_J

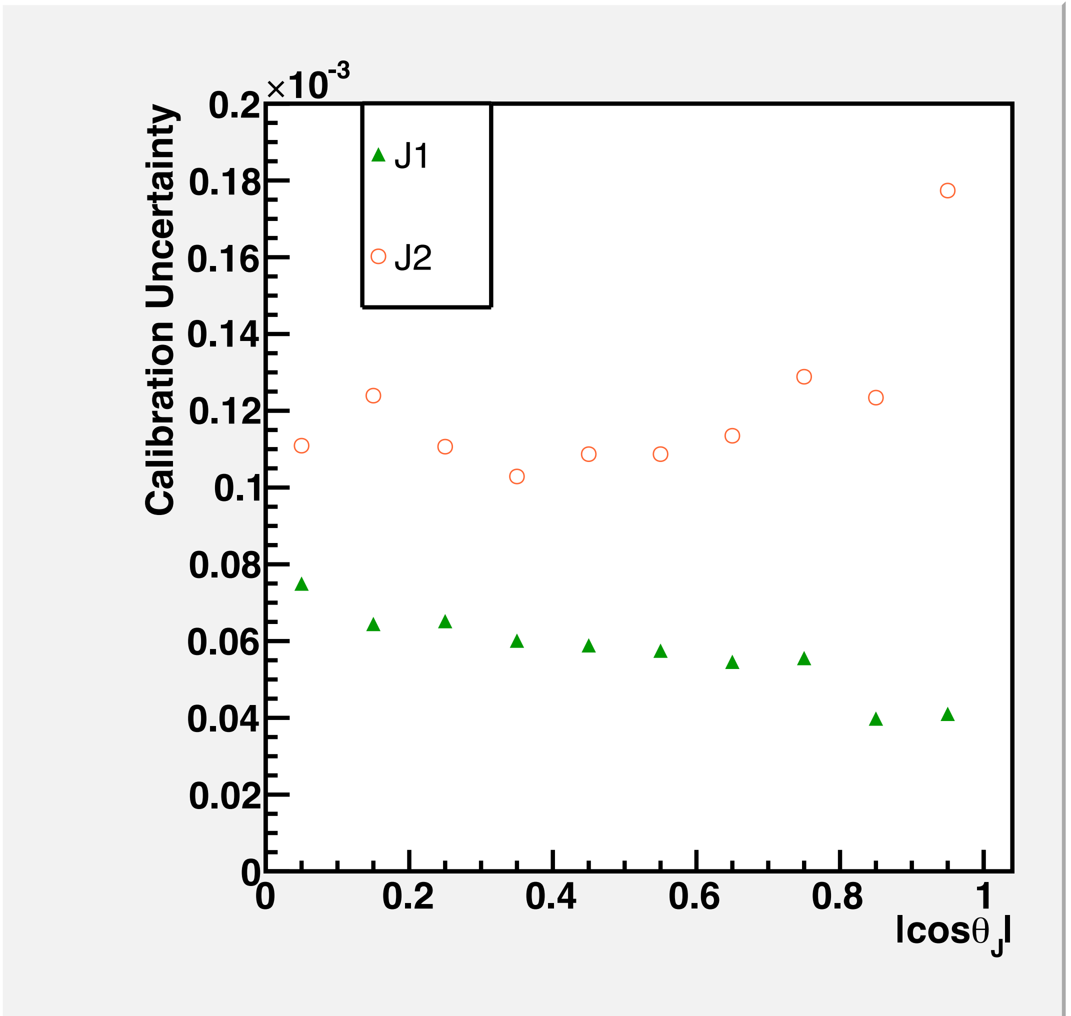
Backup

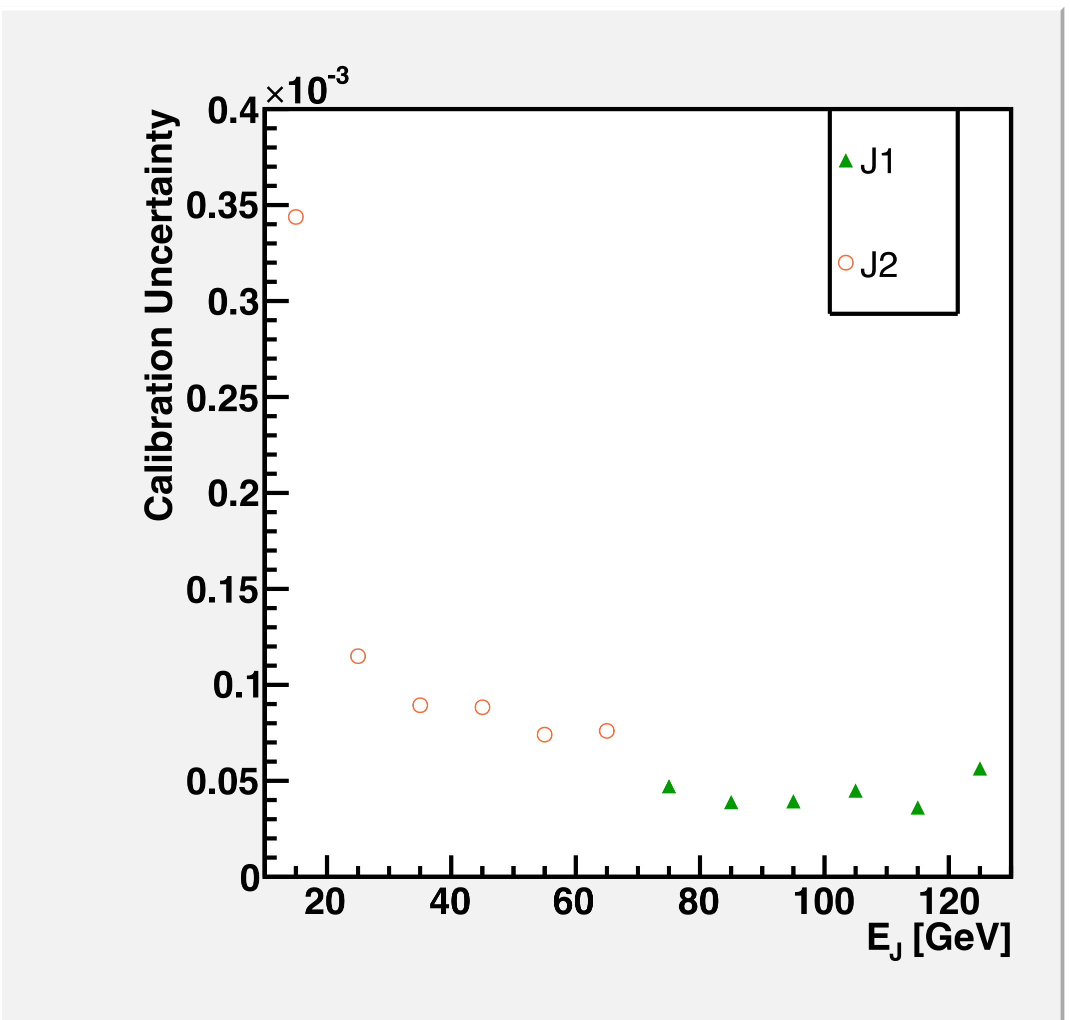
Calib. Uncertainty

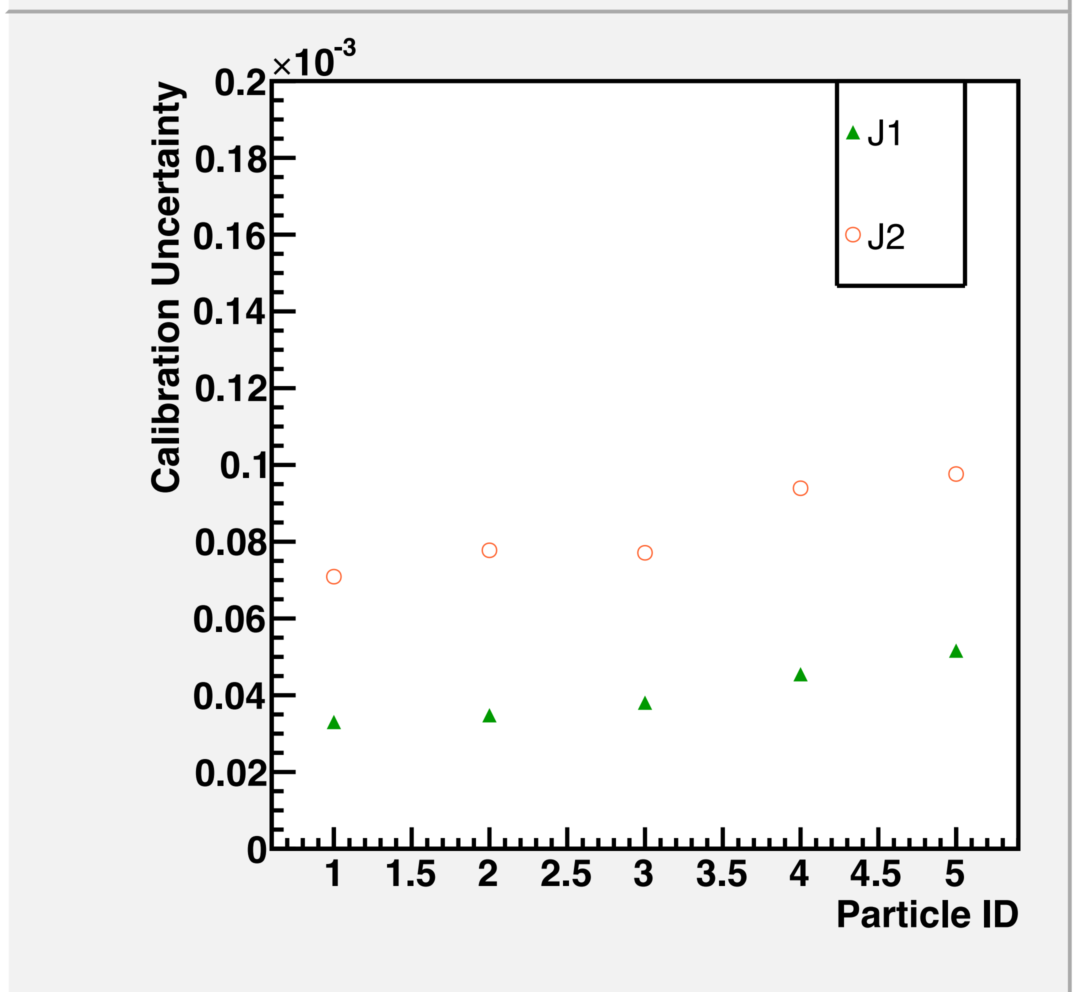
Calibration uncertainty :=

$$\sqrt{(\Delta\mu_{PFO})^2 + (\Delta\mu_{M3})^2}$$

Square root of the squared sum of the error of the mean

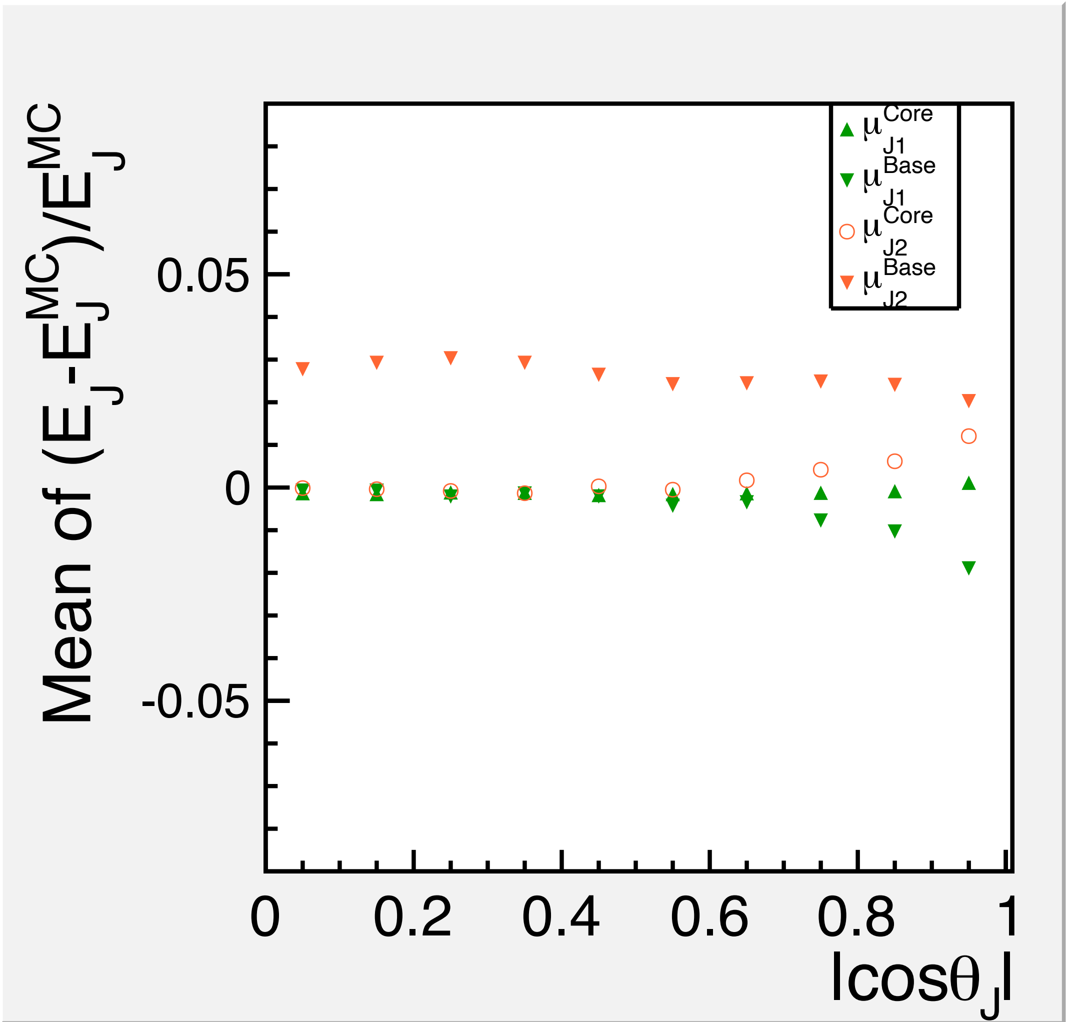


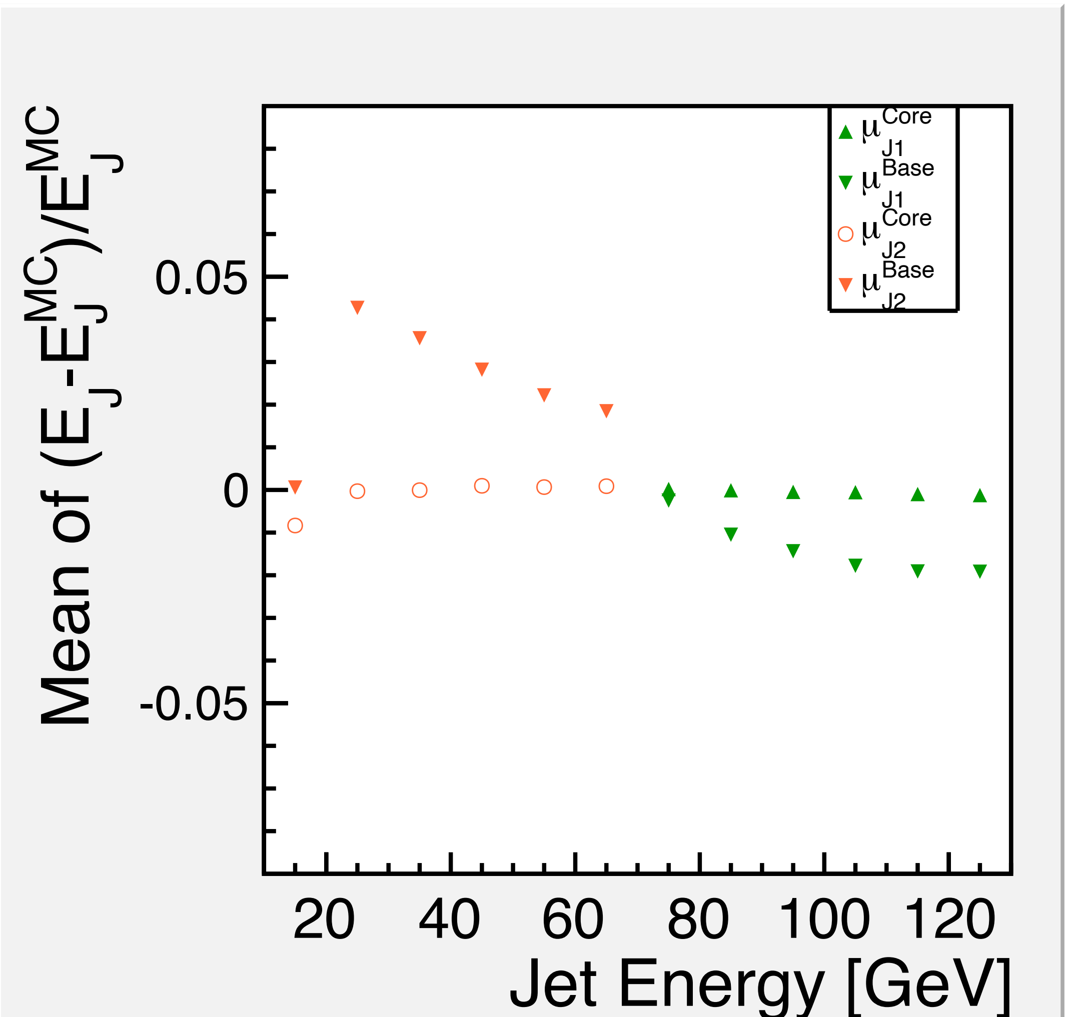


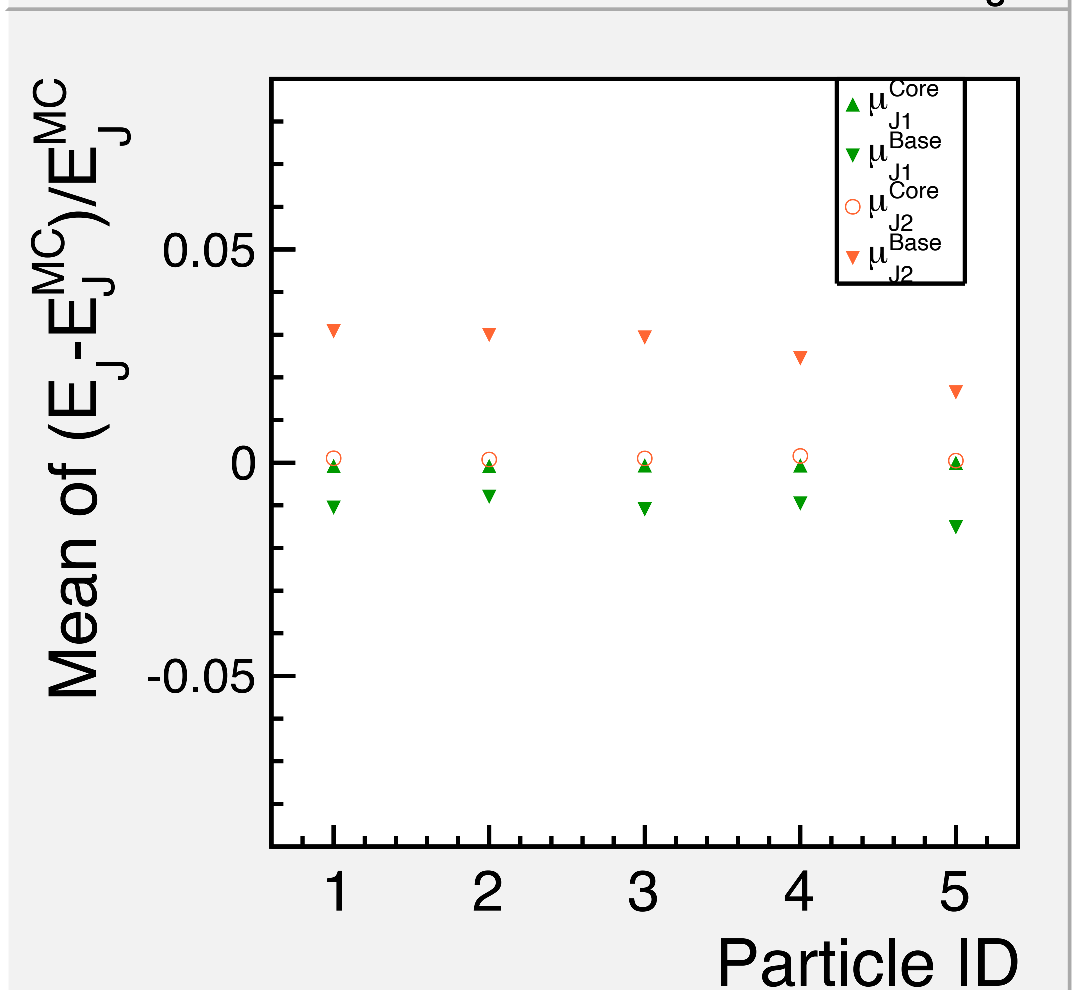


Mean Value

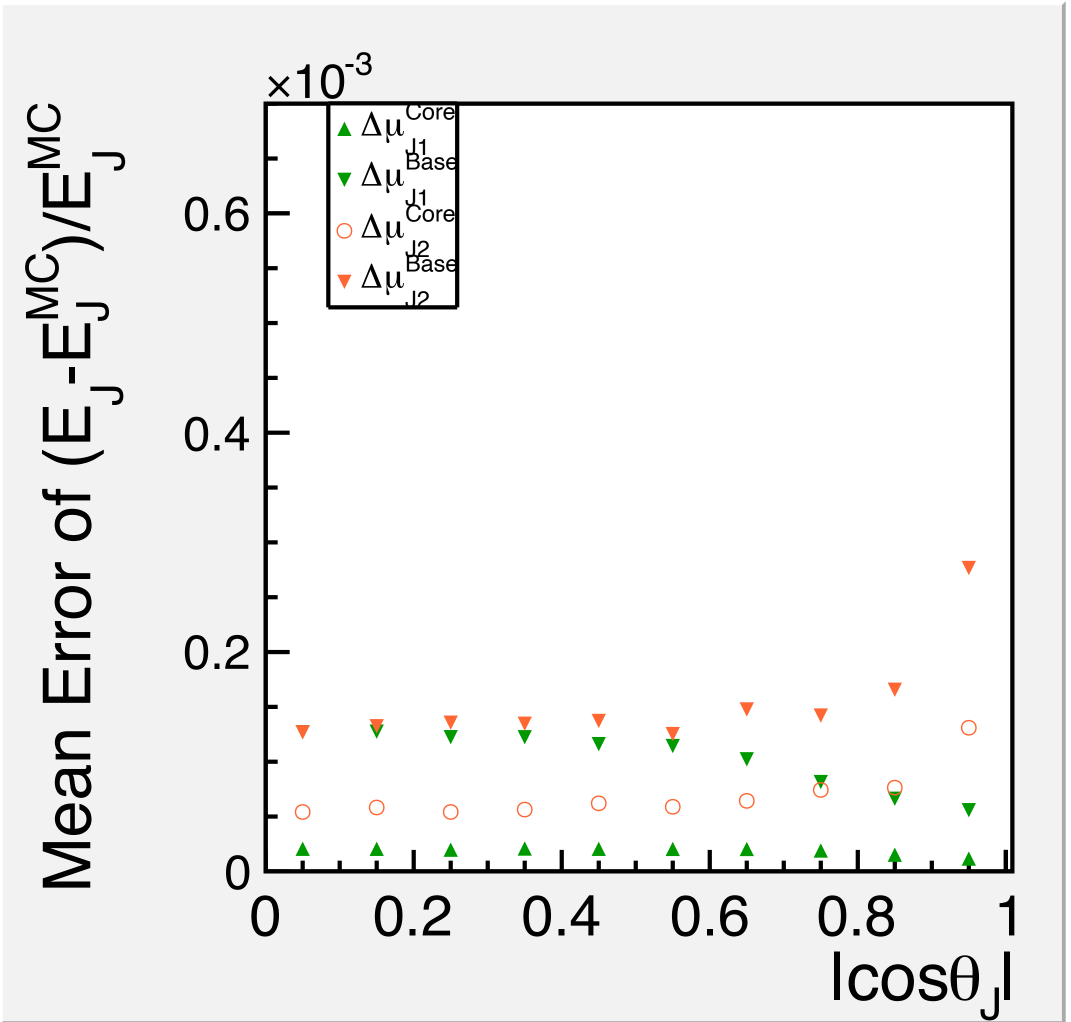
Particle ID := flavor of the seed of the jet

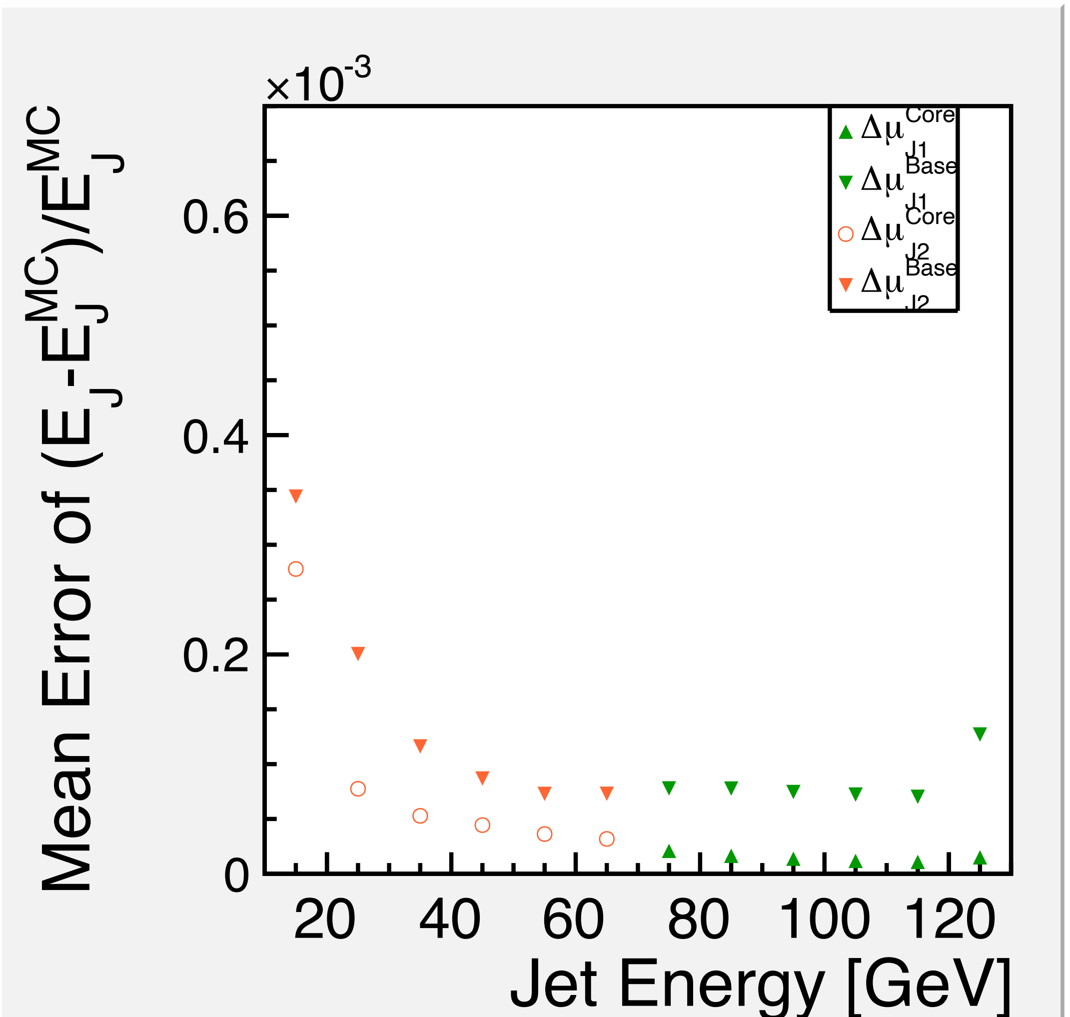


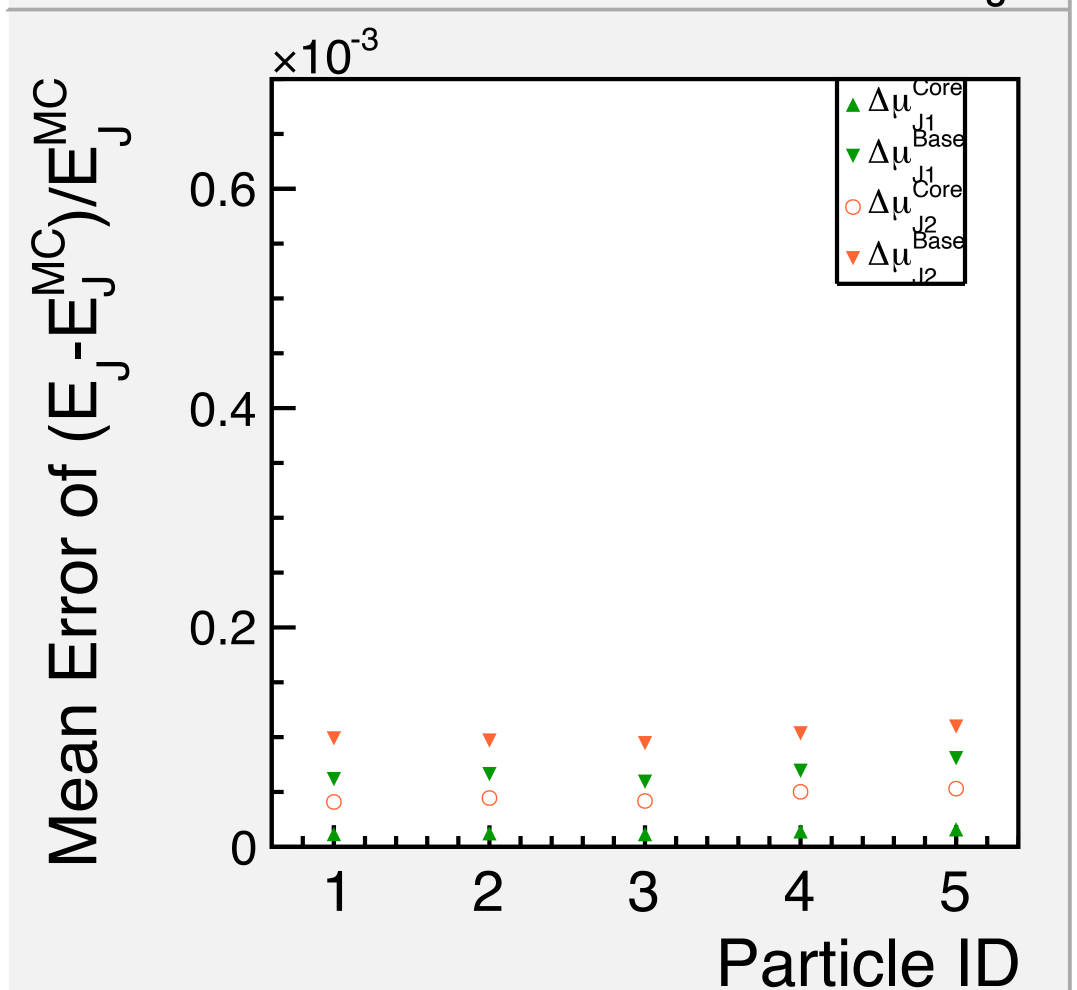




Mean Error

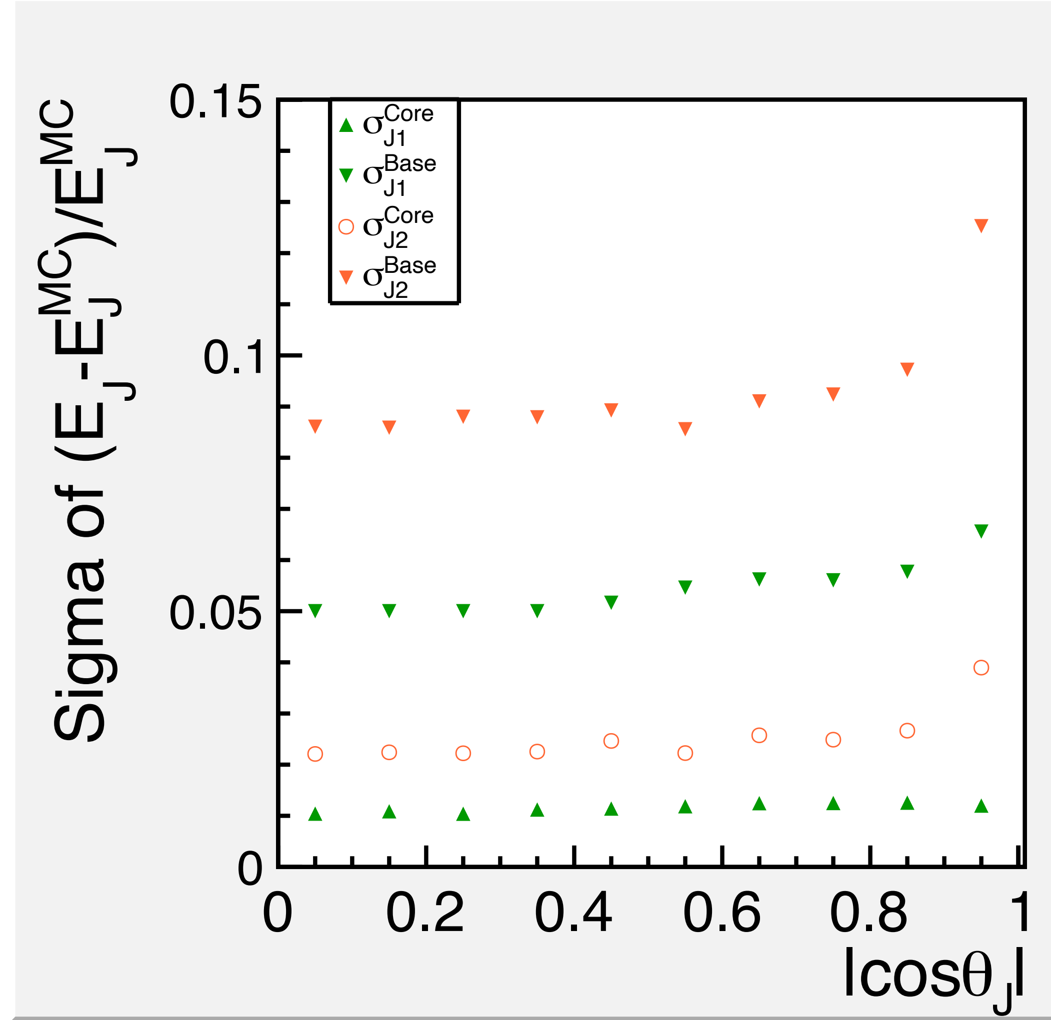

×10⁻³
Mean Error of (E_J-E_J^MC)/E_J^MC
|cosθ_J|
0
0.2
0.4
0.6
0.8
1

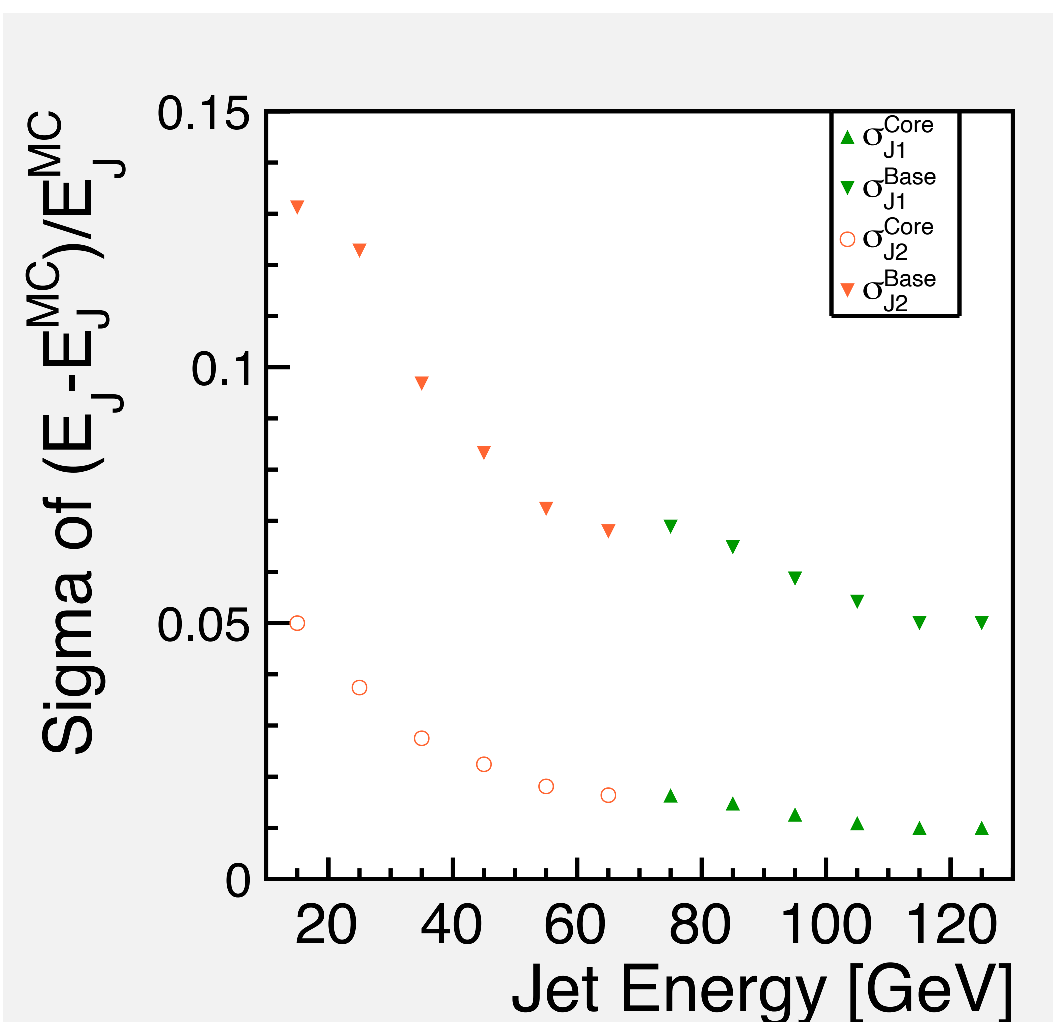

×10⁻³
Mean Error of (E_J-E_J^MC)/E_J^MC
Jet Energy [GeV]
20
40
60
80
100
120

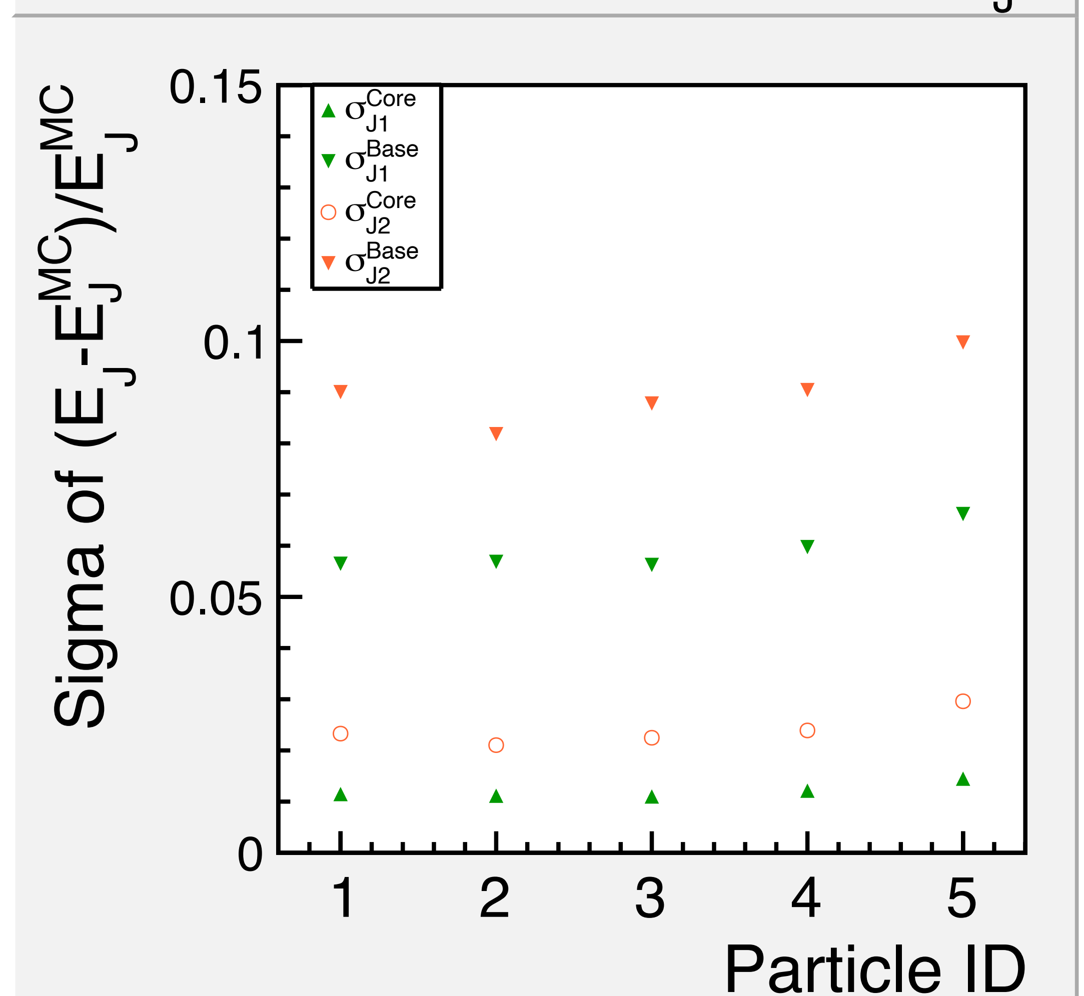

×10⁻³
Mean Error of (E_J-E_J^MC)/E_J^MC
Particle ID
1
2
3
4
5

Sigma Value

Particle ID := flavor of the seed of the jet

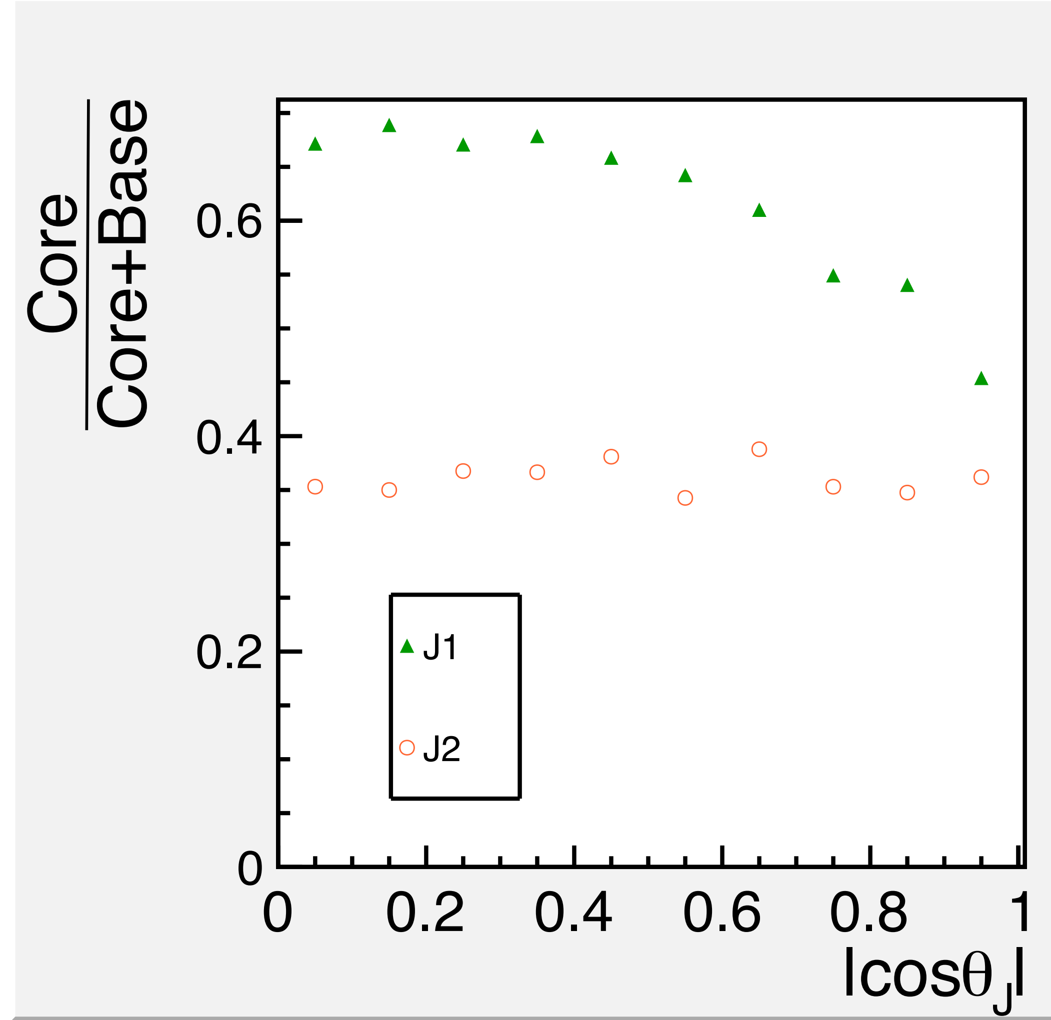


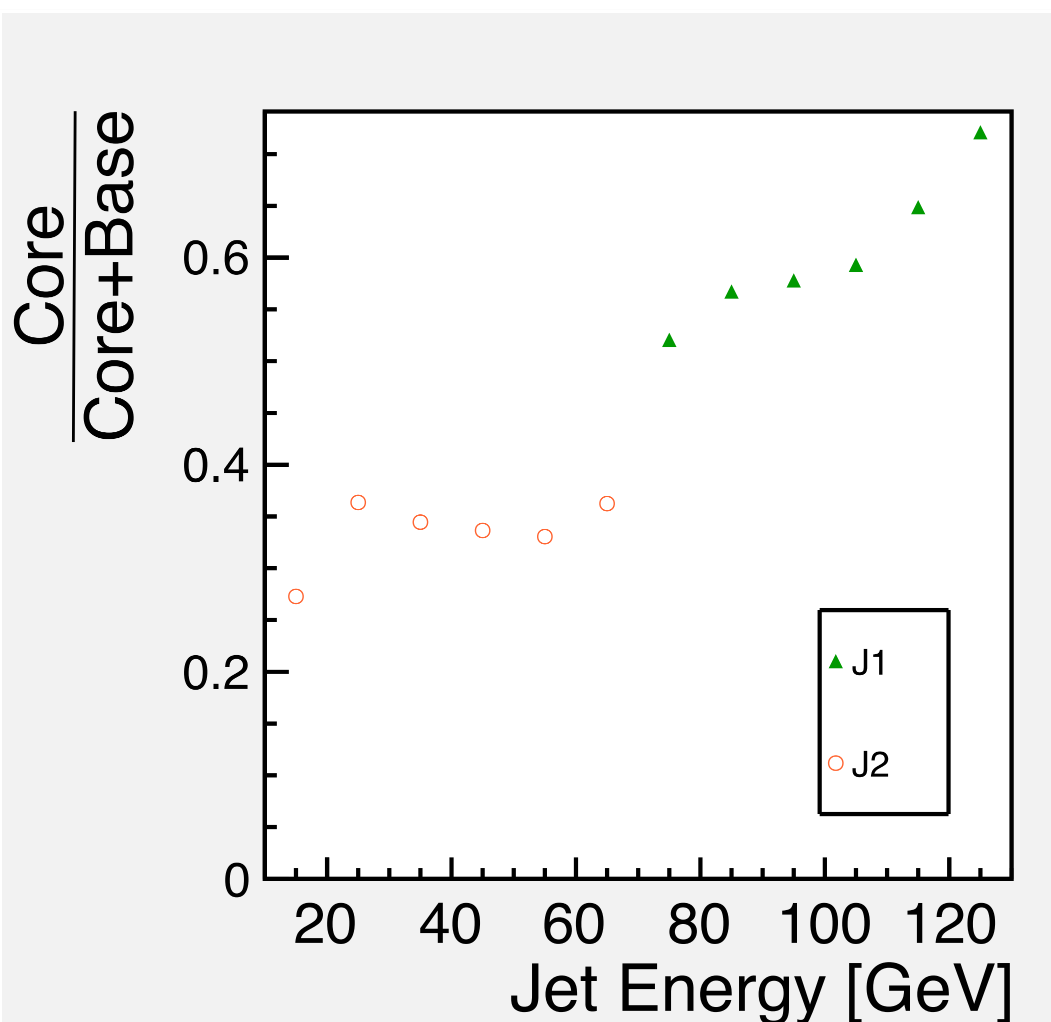


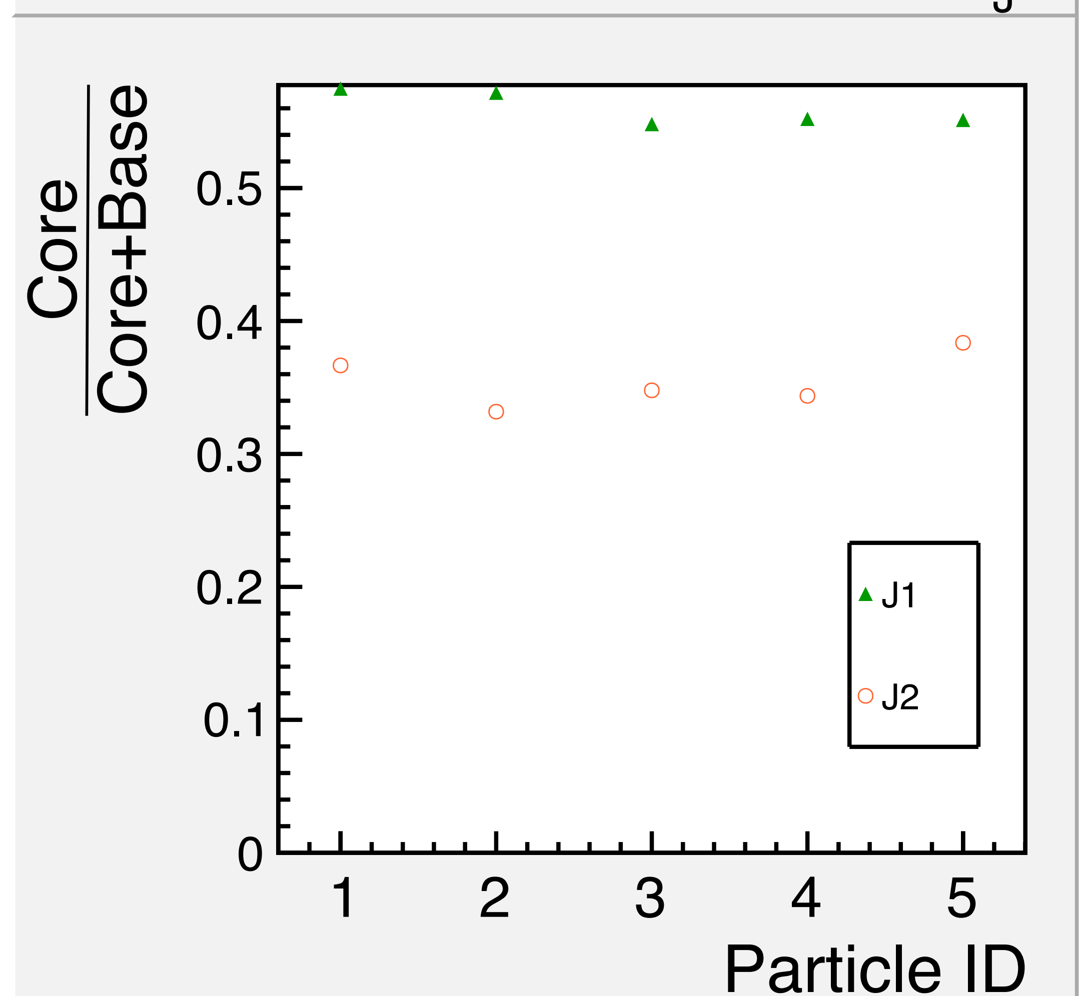


Fraction

Fraction := Size of the fitting Gaussian Core/(Core+Base)





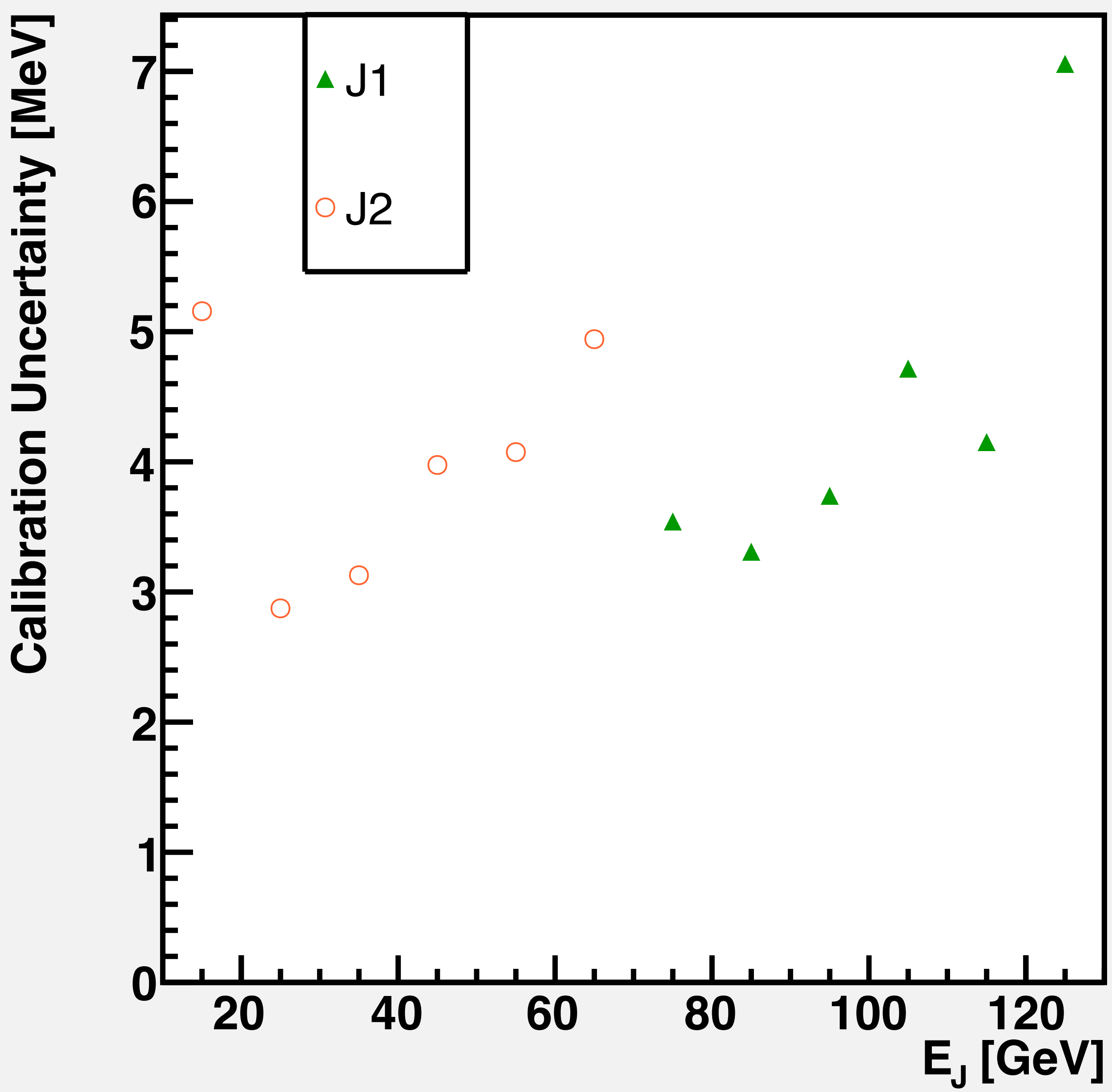


Calib. Uncertainty

Calibration uncertainty :=

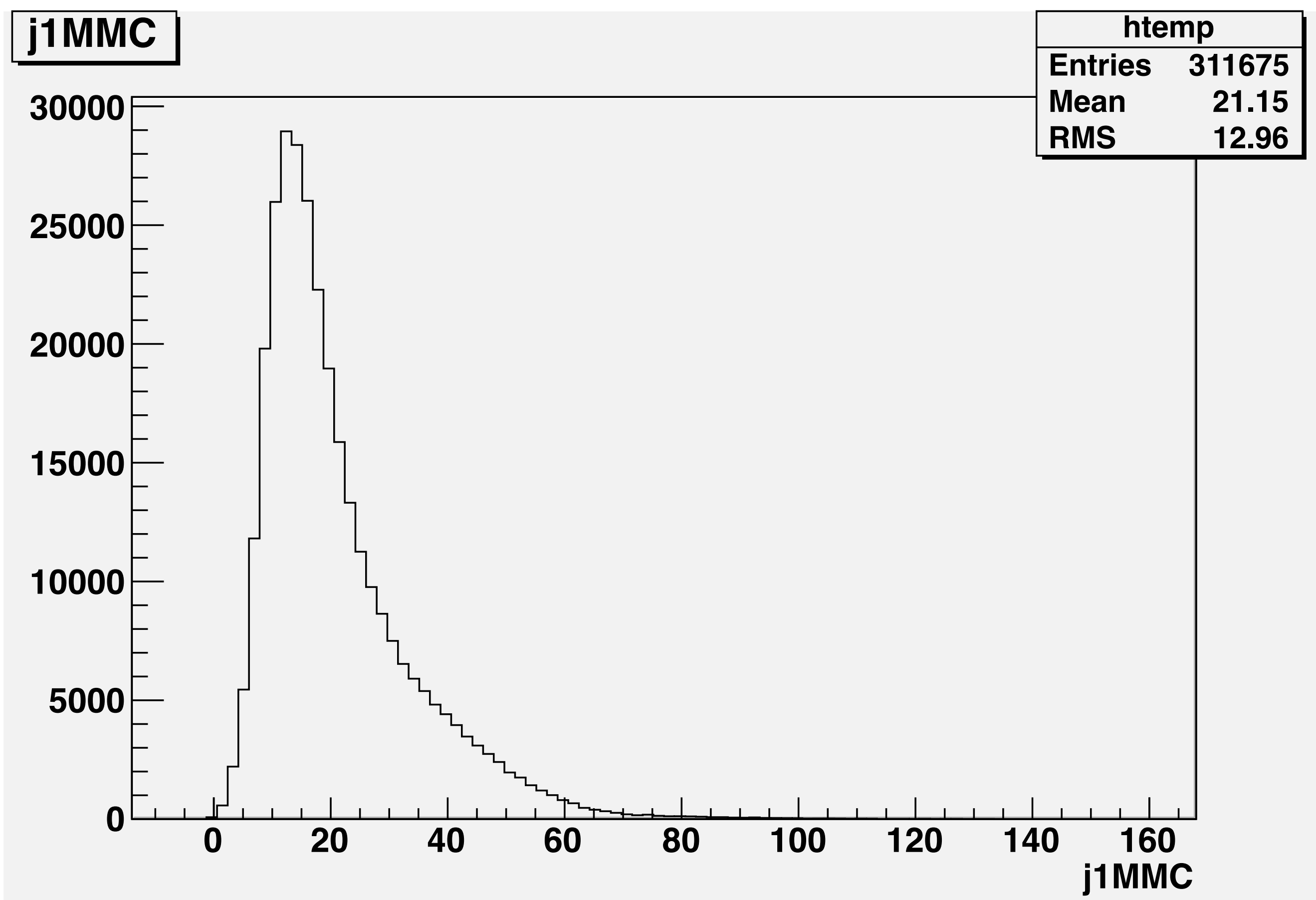
$$\sqrt{(\Delta\mu_{PFO})^2 + (\Delta\mu_{M3})^2}$$

Square root of the squared sum of the error of the mean



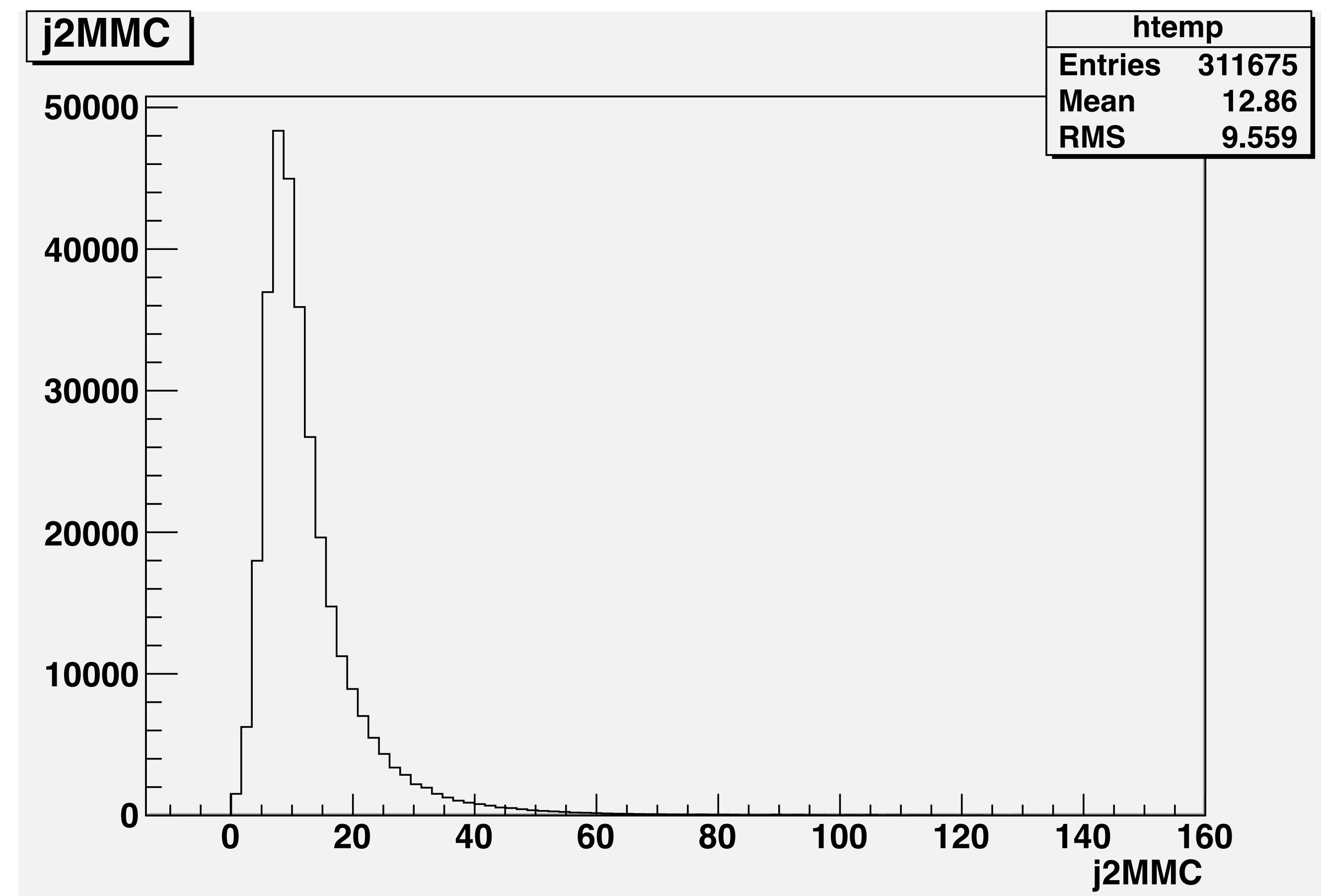
Jet mass distribution

Jet1



M_{Jet1} GeV

Jet2



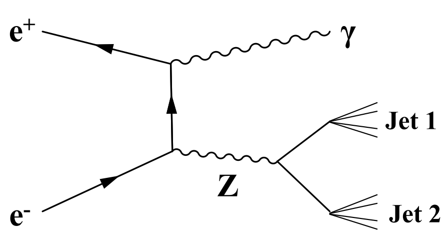
M_{Jet2} GeV

Correct photon selection

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

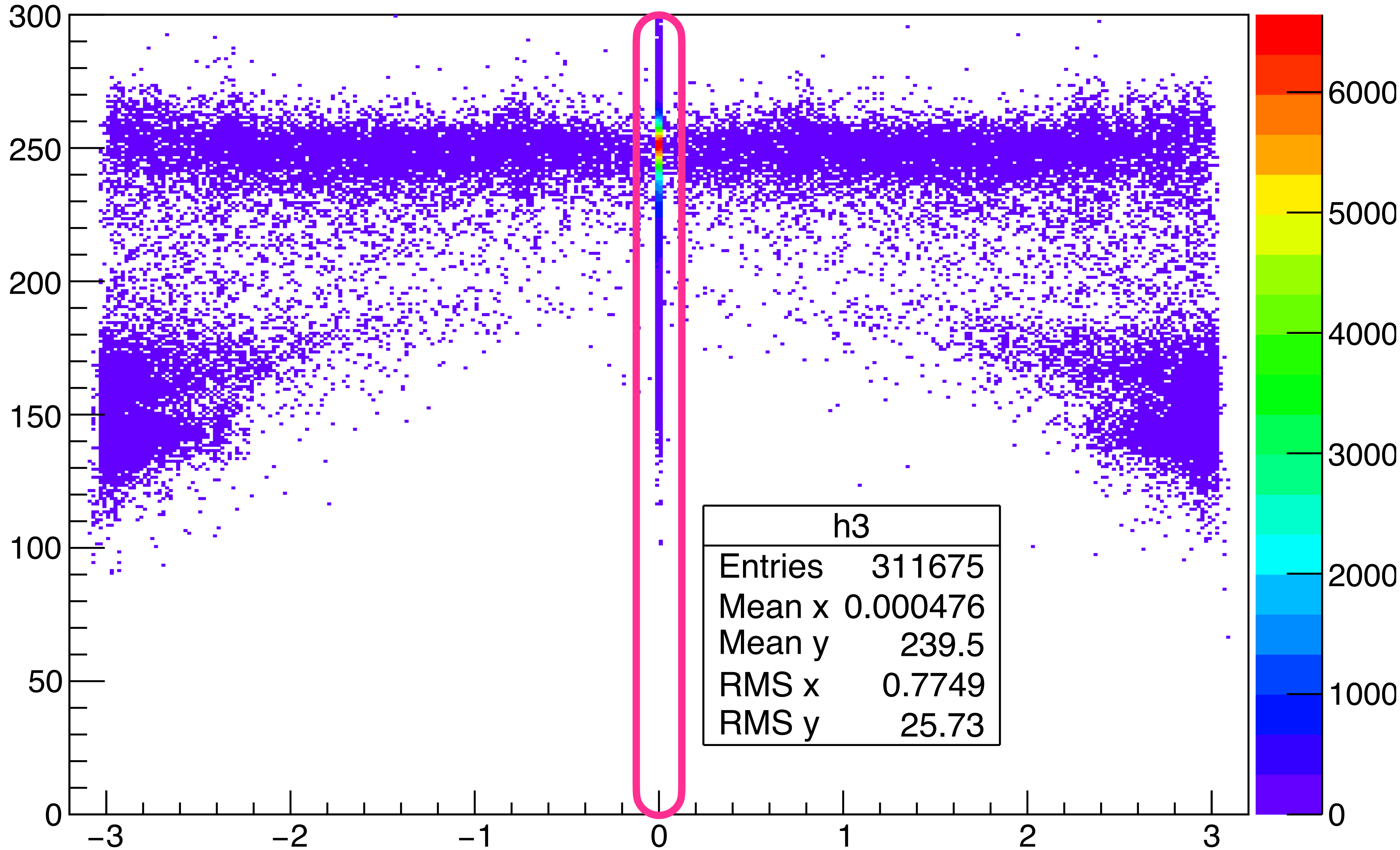
E_{vis} (GeV)

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%

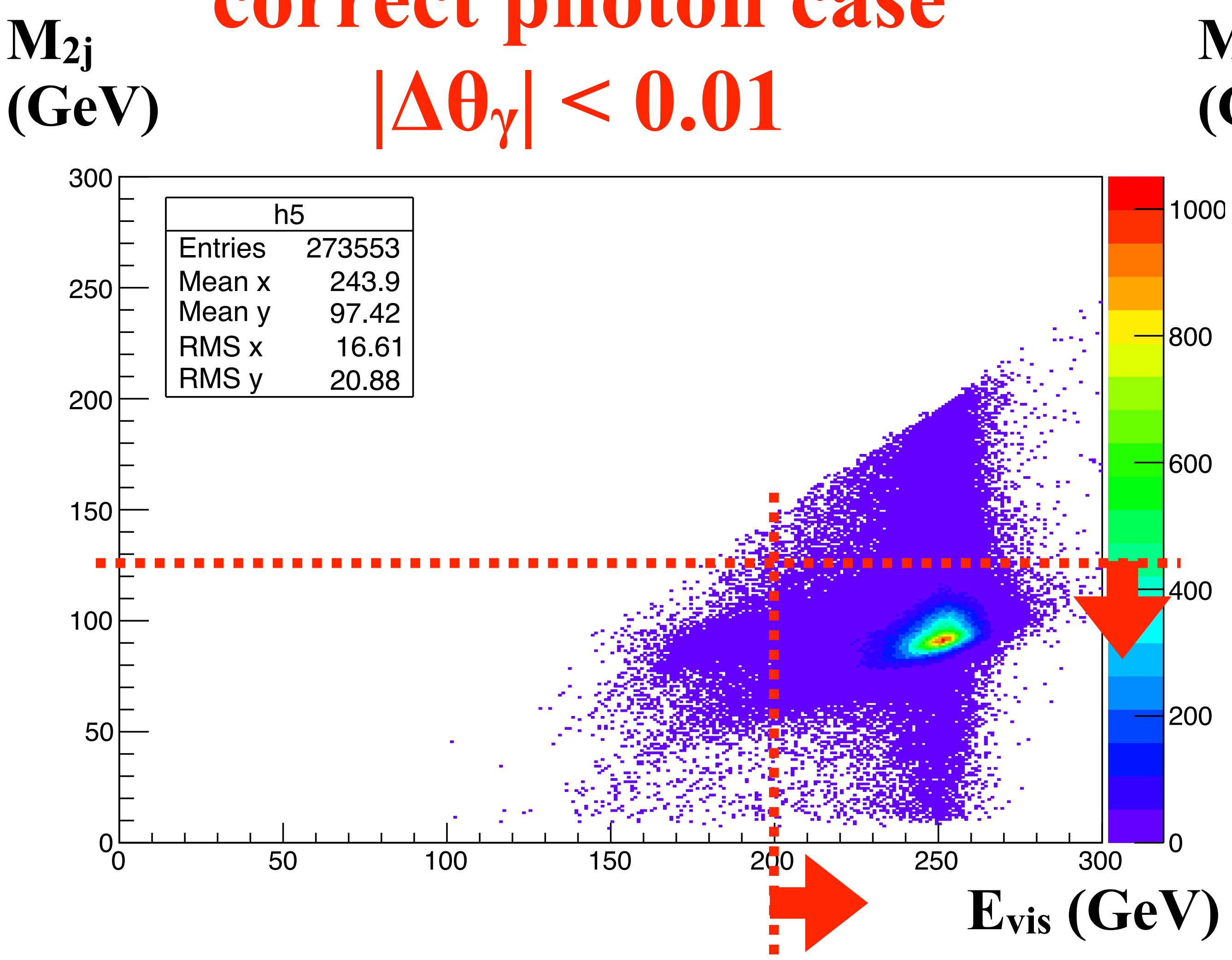
Correct Photon

$\Delta\theta_{\gamma}$ (rad)

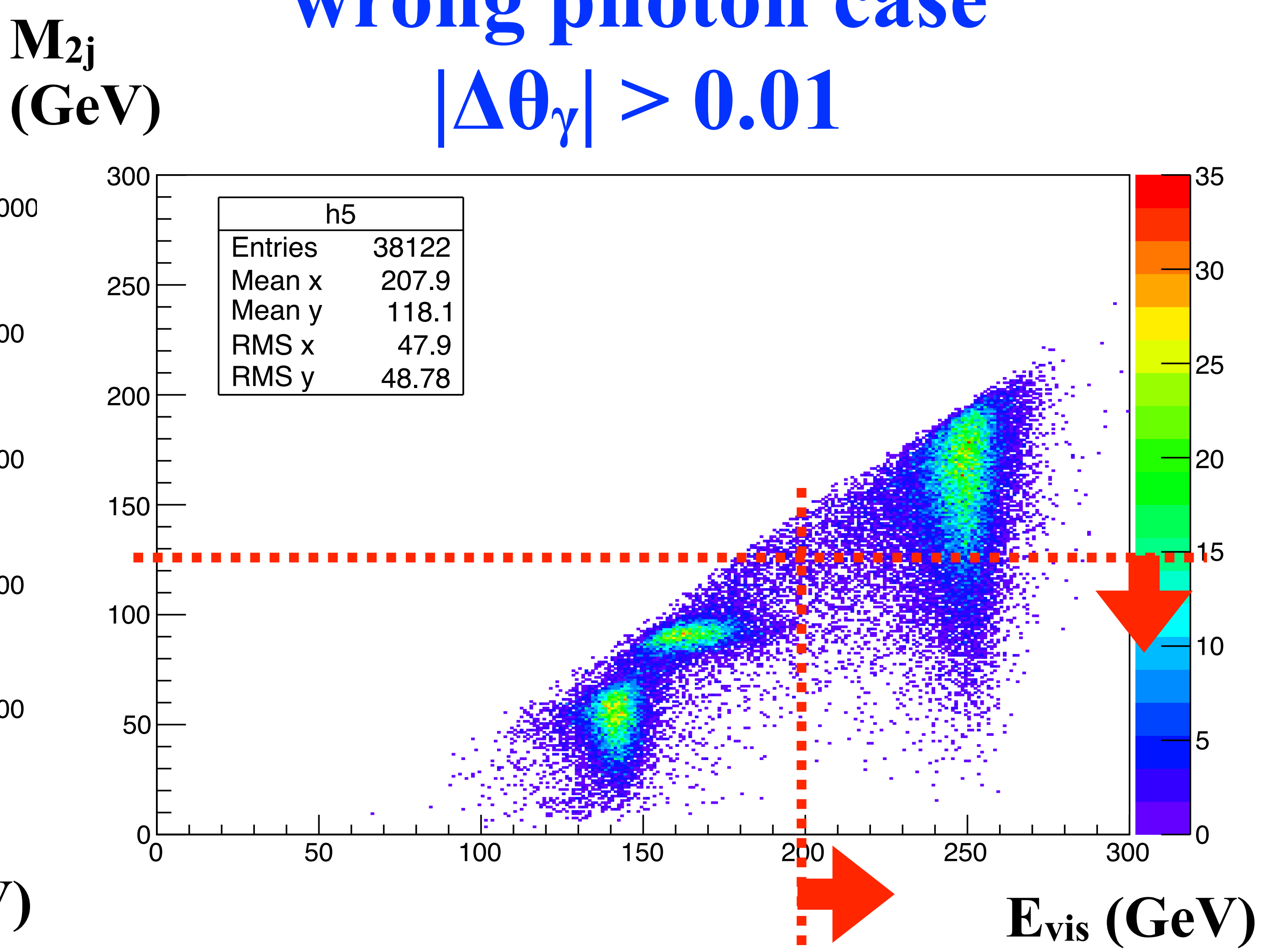
Correct photon selection cut 1

M_{2j} vs. E_{vis} (=Ej1+Ej2+Eγ)

correct photon case
$|\Delta\theta_\gamma| < 0.01$



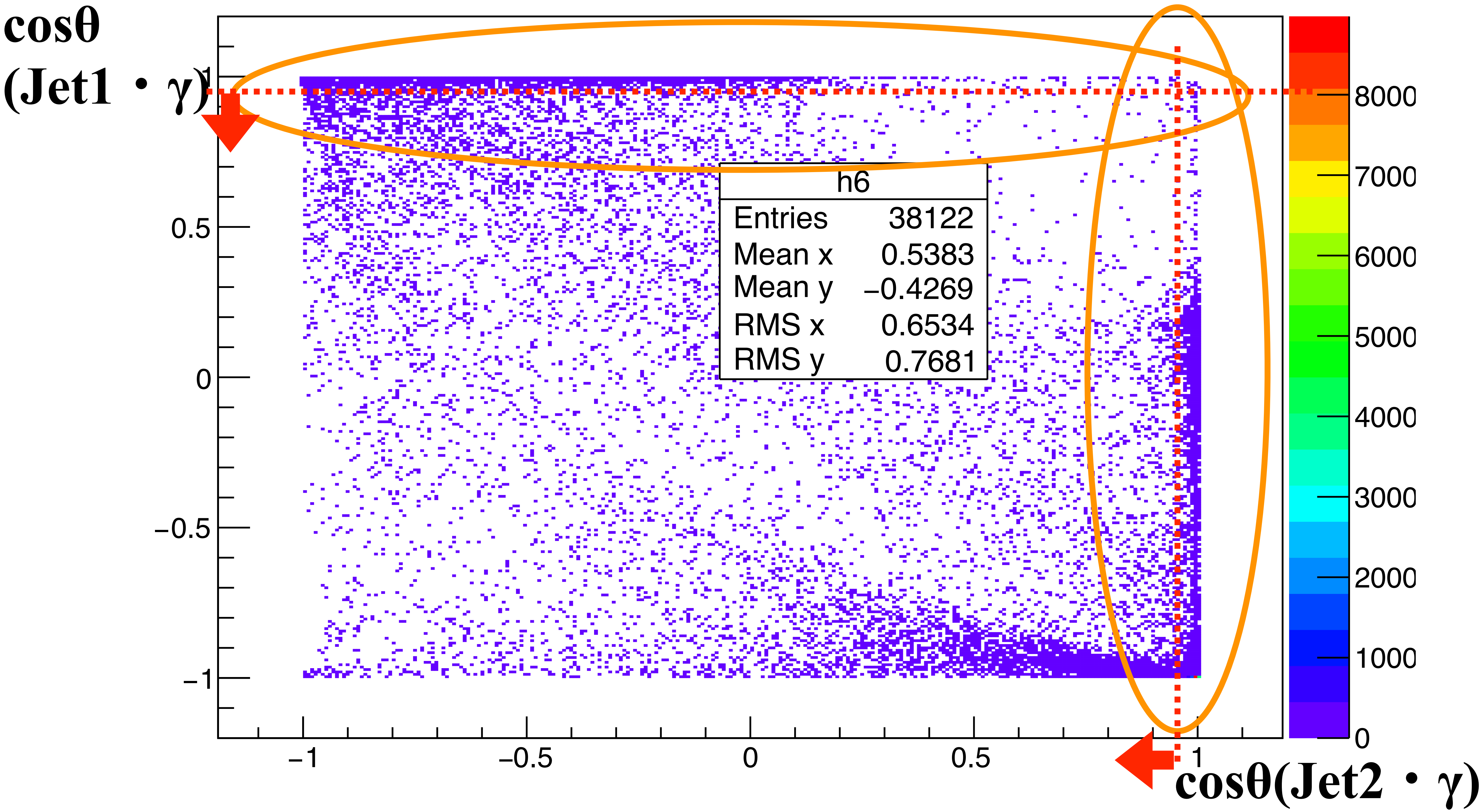
wrong photon case
$|\Delta\theta_\gamma| > 0.01$



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

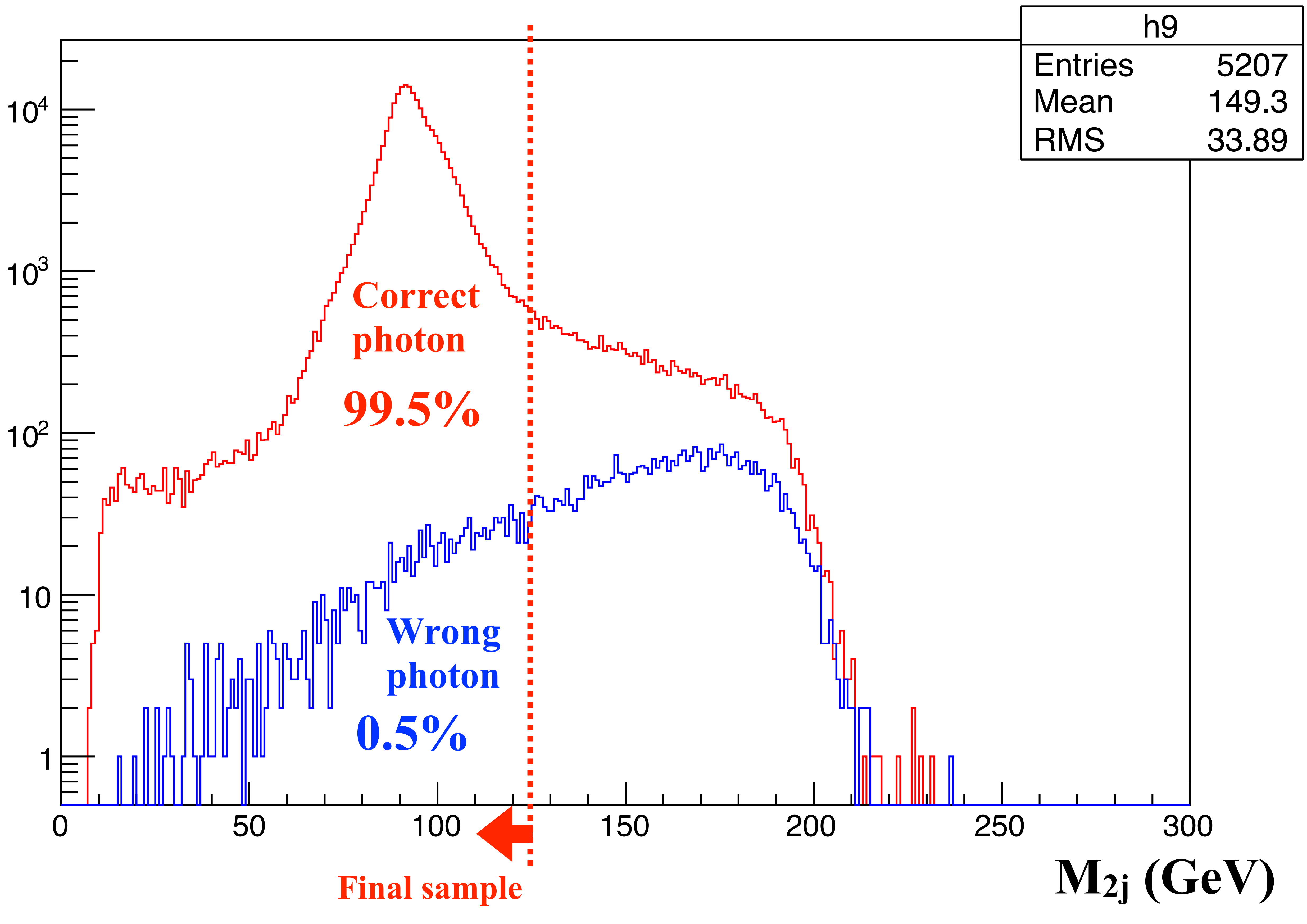
Correct photon selection cut 2

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



Source of the bias

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

Inputs and outputs

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

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

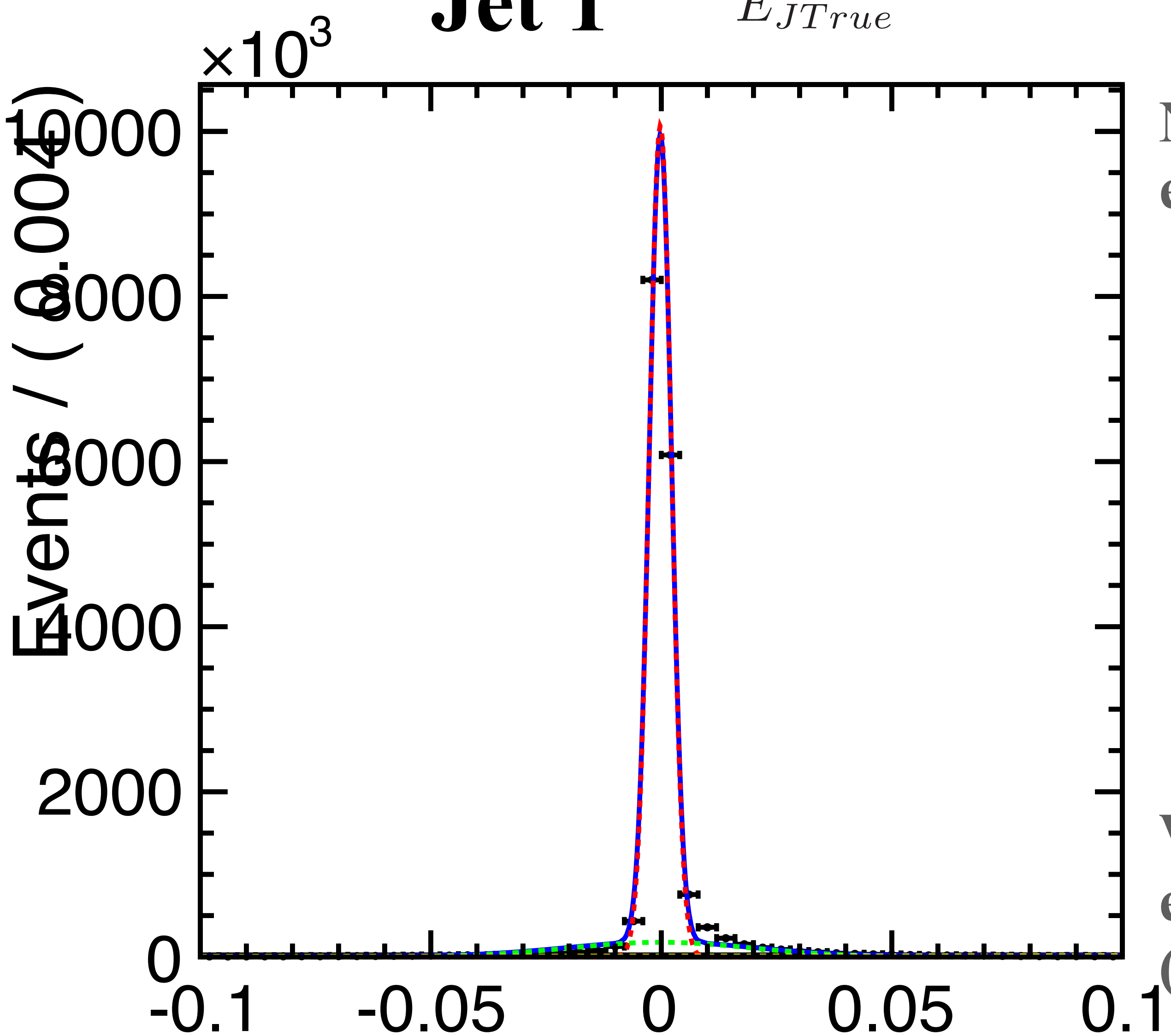
Matrix A → Inverse

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

Source (A): Beam energy spread

When all inputs are all MCtruth,

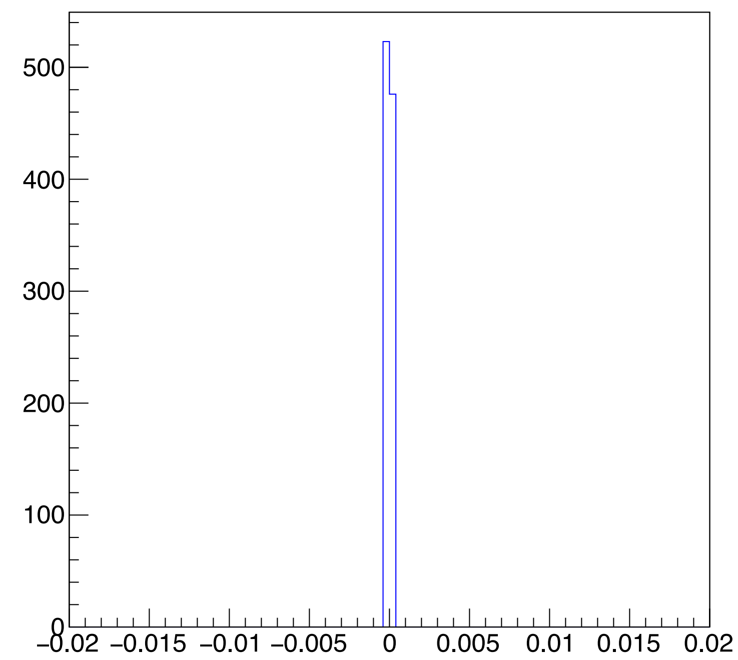
Jet 1 $\frac{E_{JRec} - E_{JTrue}}{E_{JTrue}}$



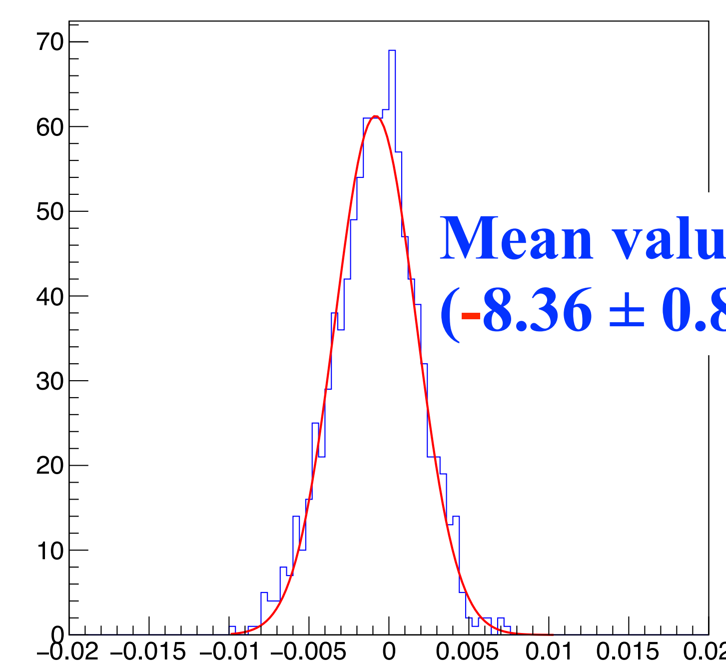
Mean value: (-1.97 ± 0.01) ×10^{-4}

Toy MC Simulation

No beam energy smearing



With beam energy smearing (0.3%)

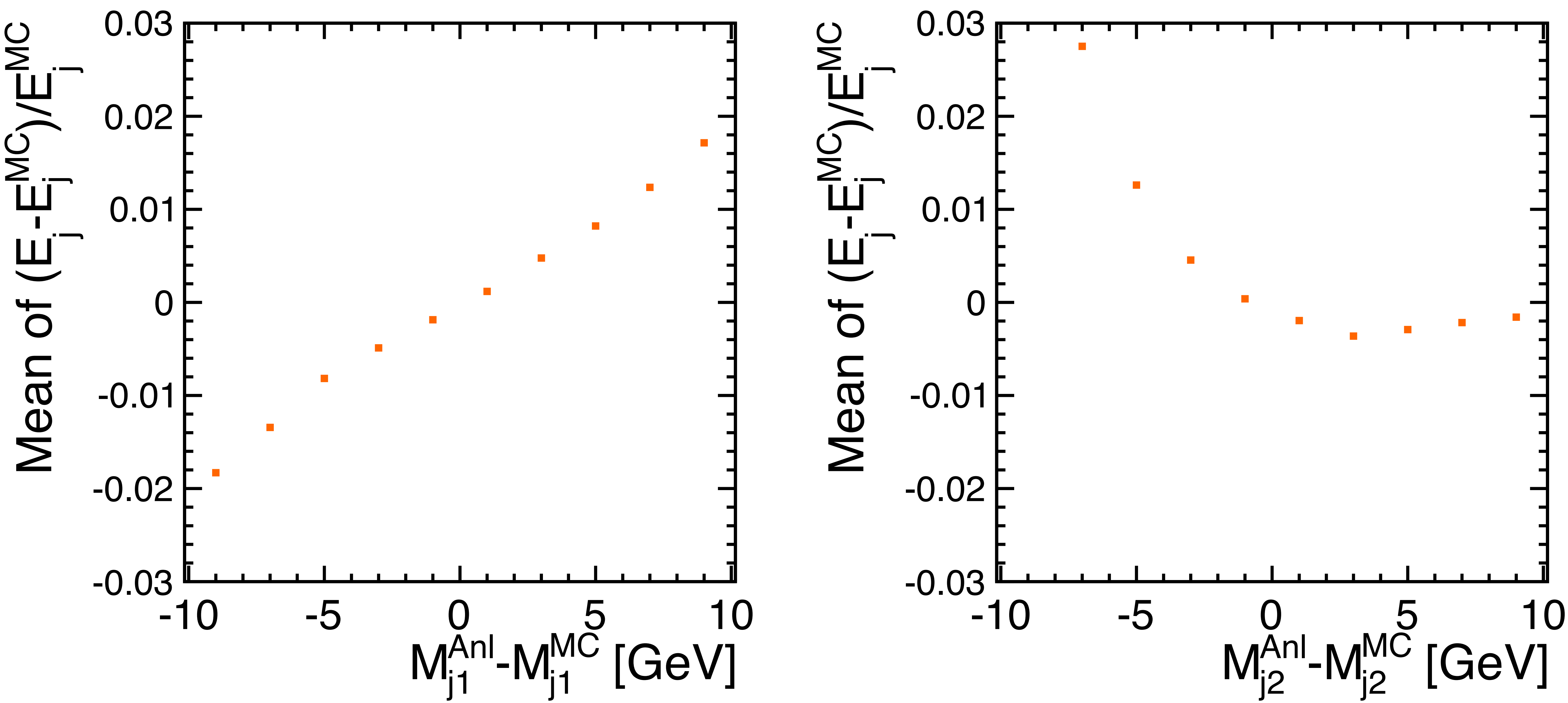


Mean value: (-8.36 ± 0.85) ×10^{-4}

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

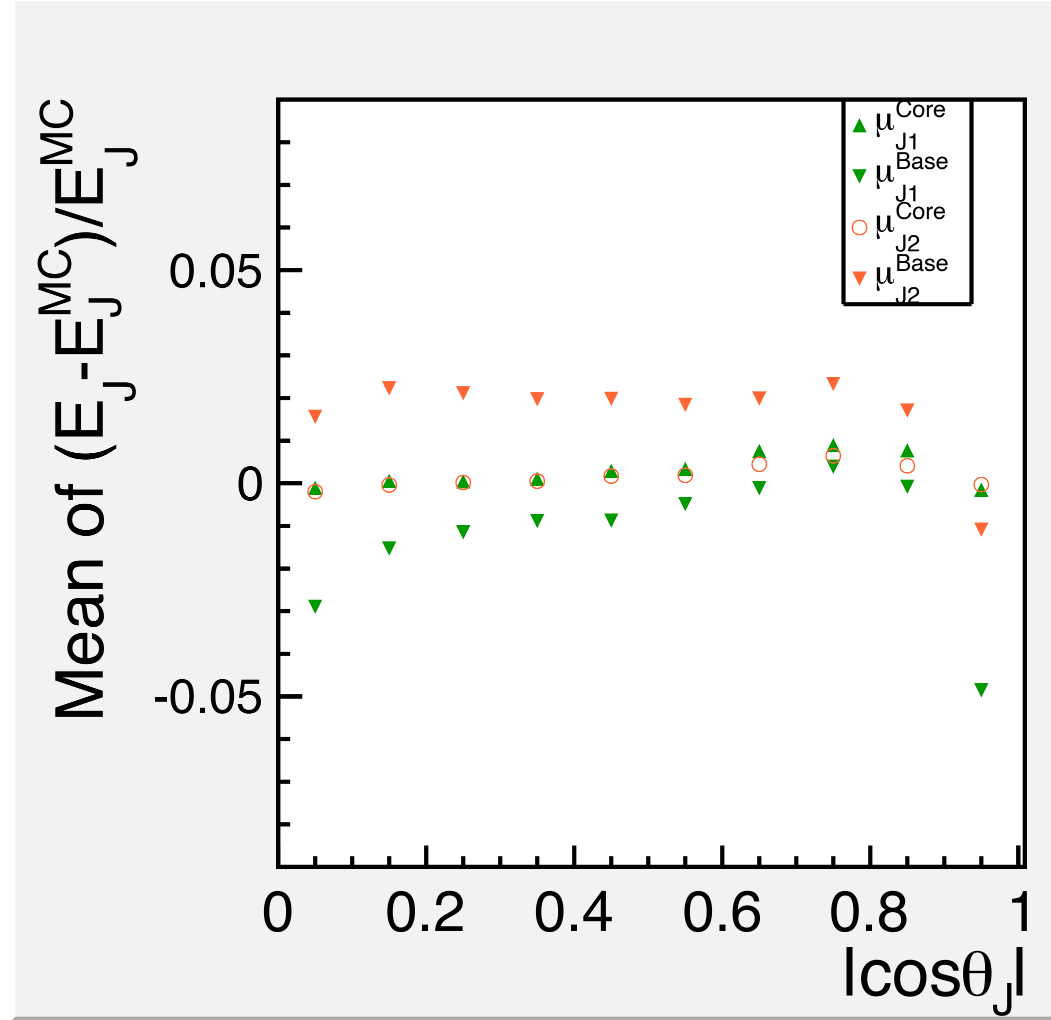
Mean value of the fitting function for the Jet 1 $\frac{E_{JRec} - E_{JTrue}}{E_{JTrue}}$
as a function of the input jet mass deviation

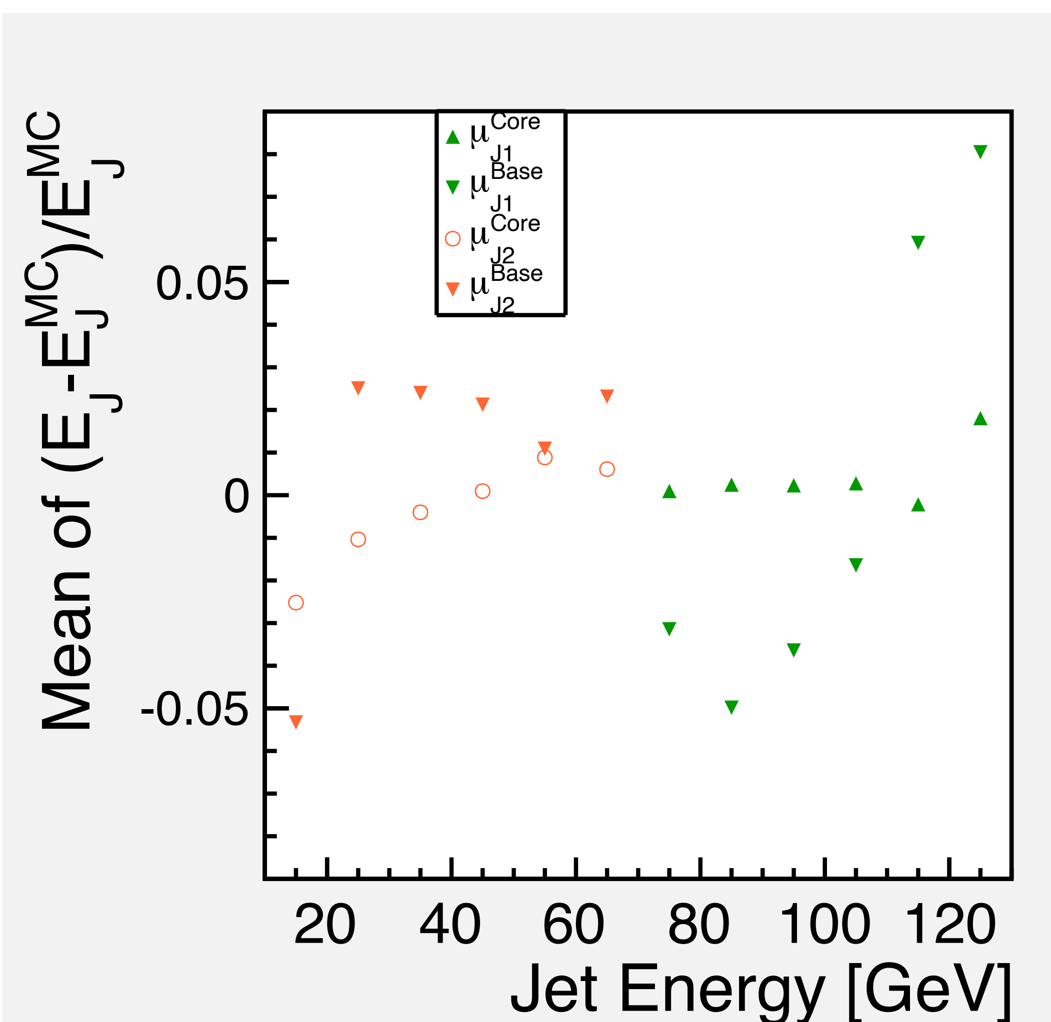


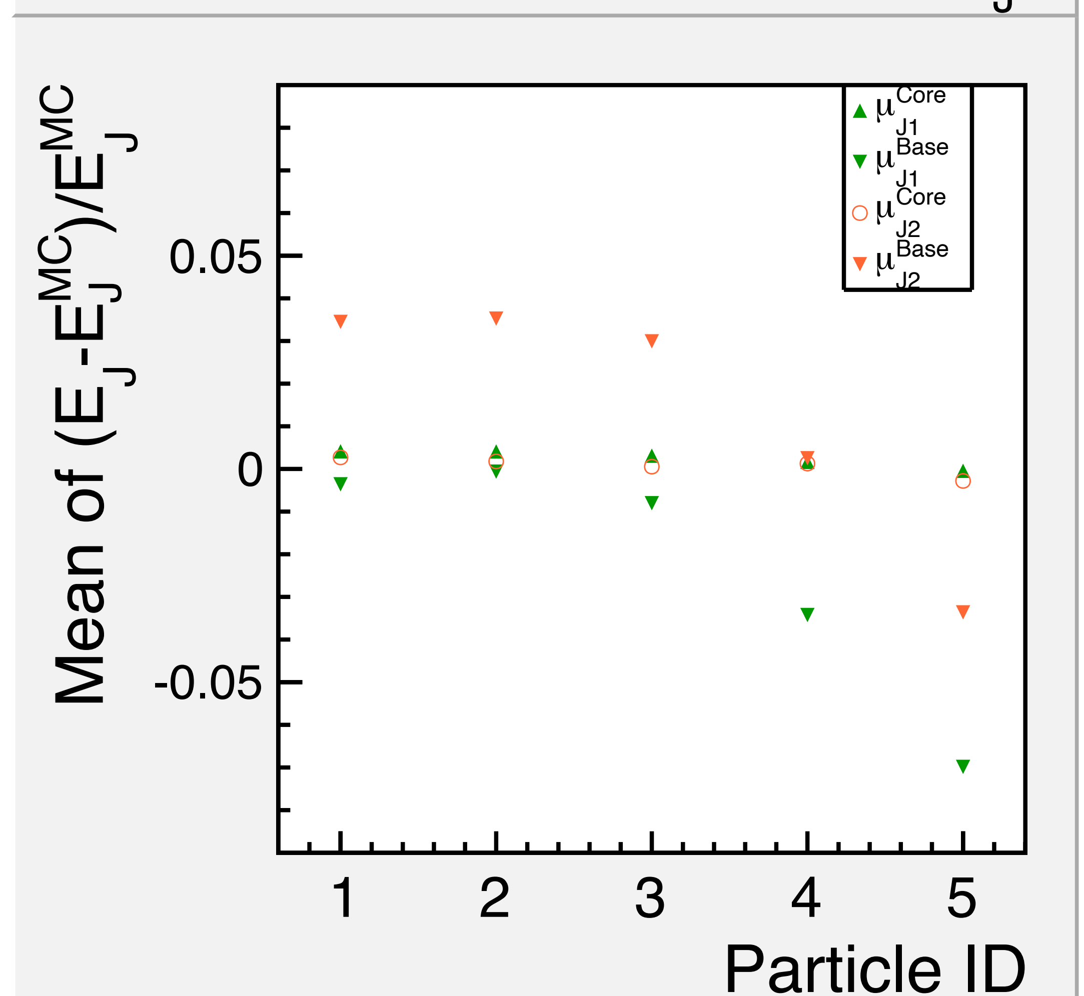
Large dependence on both jet 1 mass and jet 2 mass input deviations. If $< 8 \times 10^{-4}$ accuracy is necessary, compensation to the reconstructed jet energy should be introduced.

PFO Mean Value

Particle ID := flavor of the seed of the jet

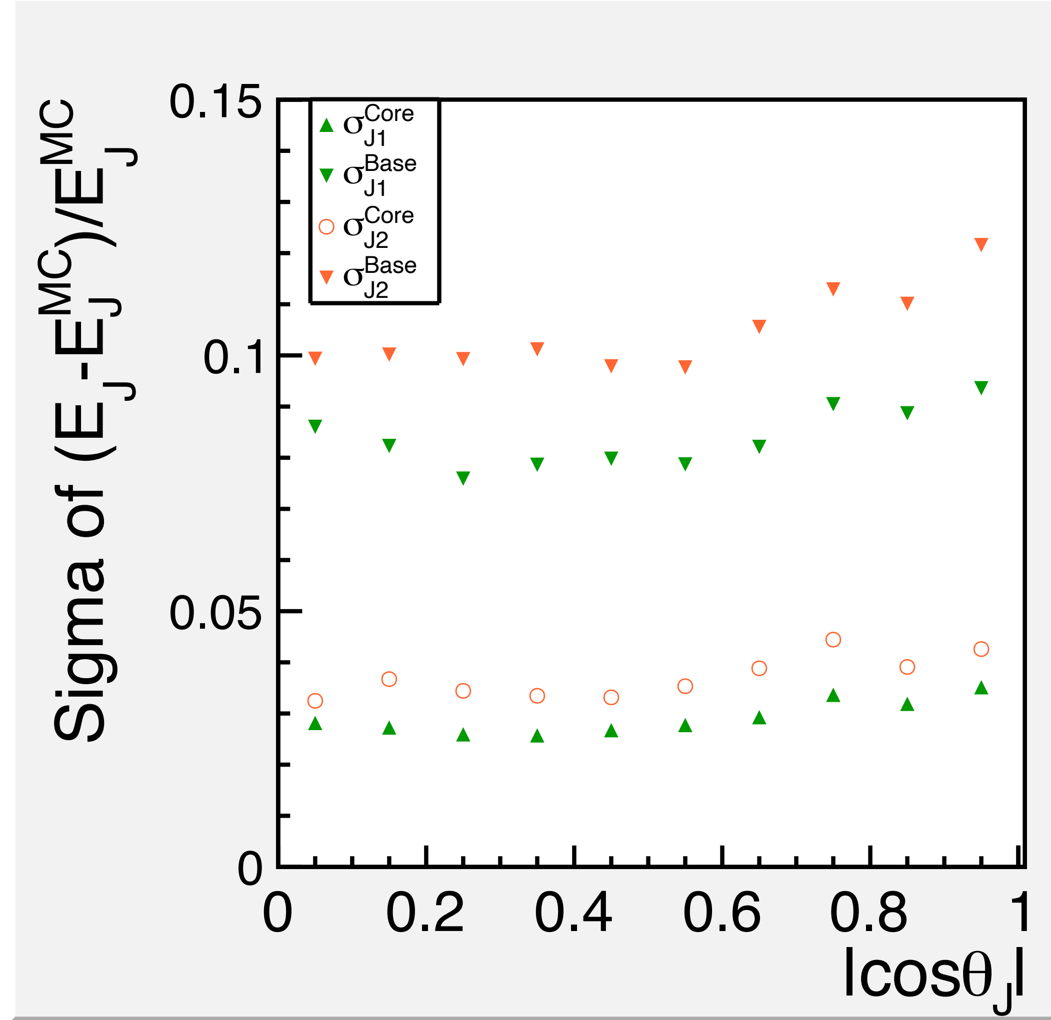


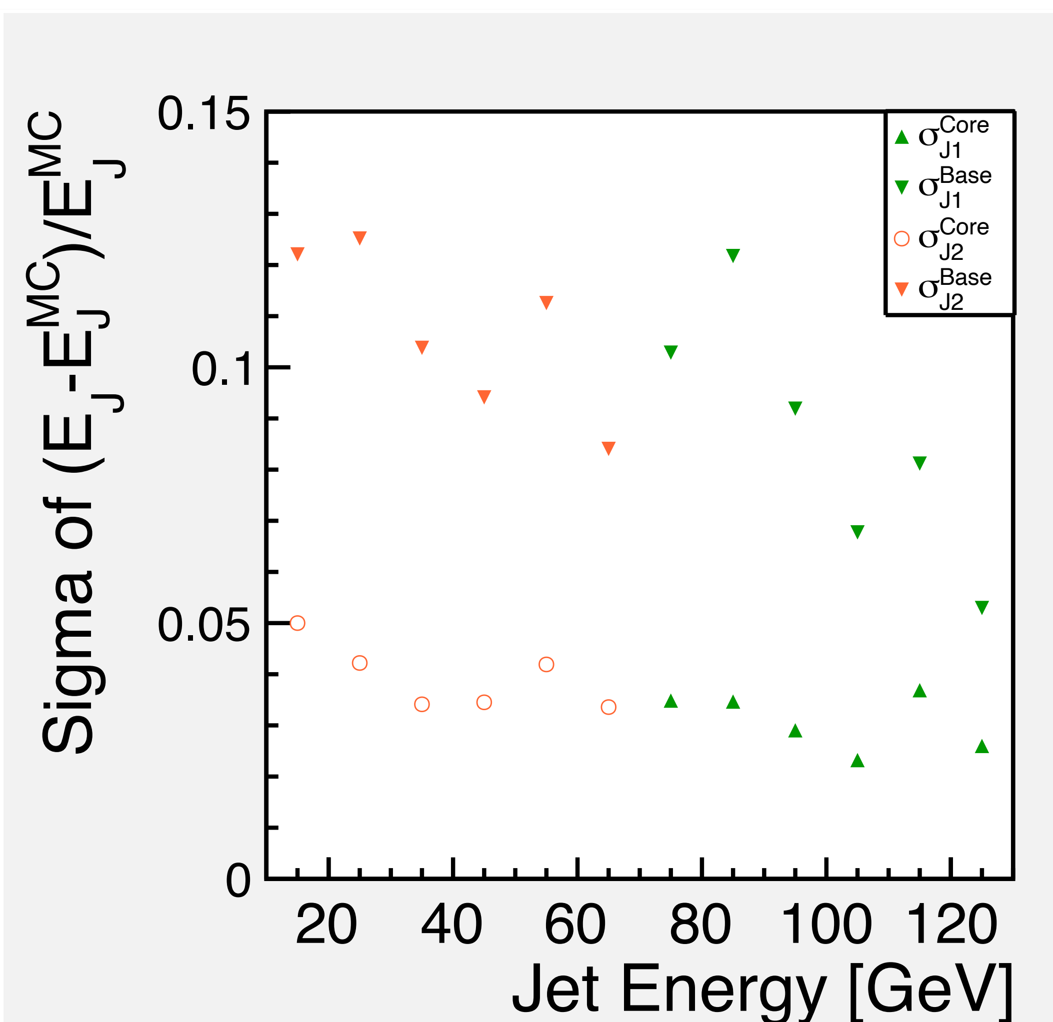


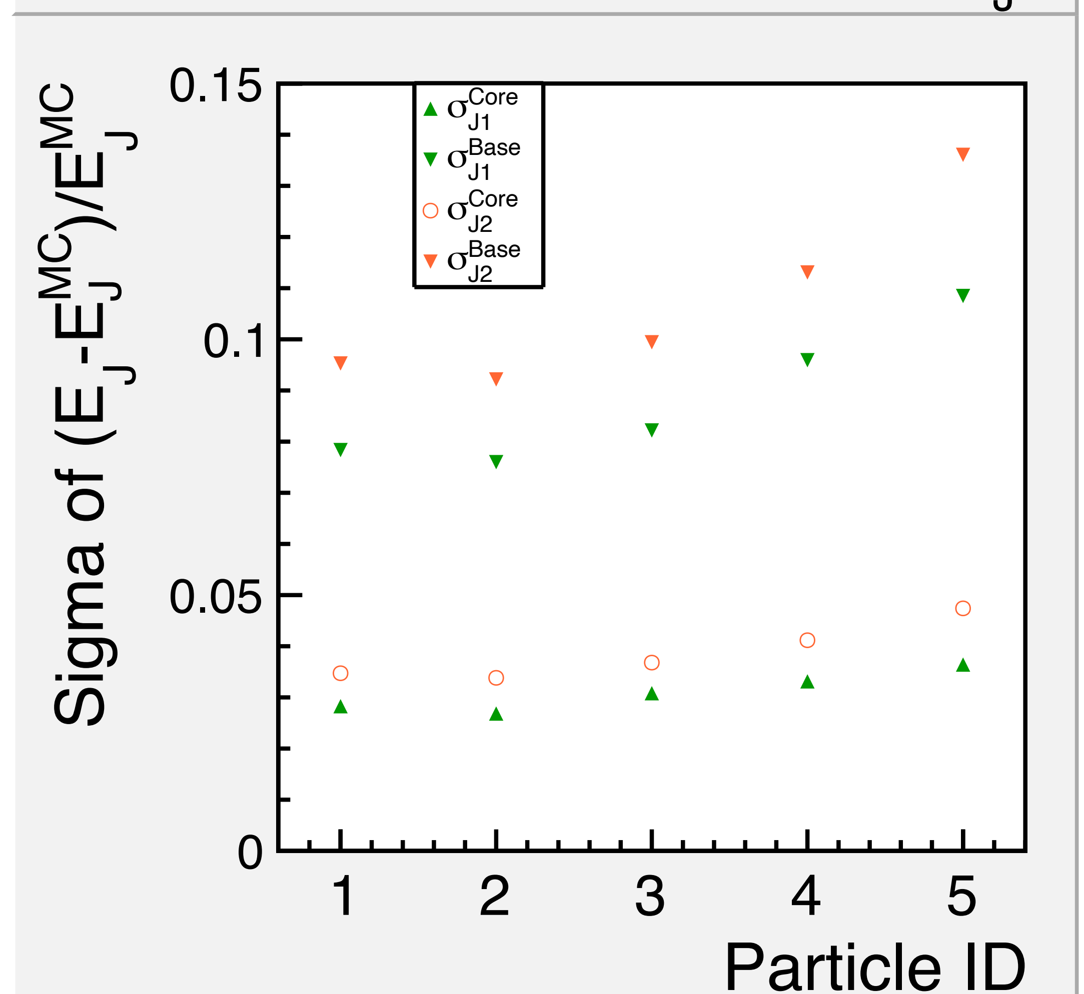


PFO Sigma Value

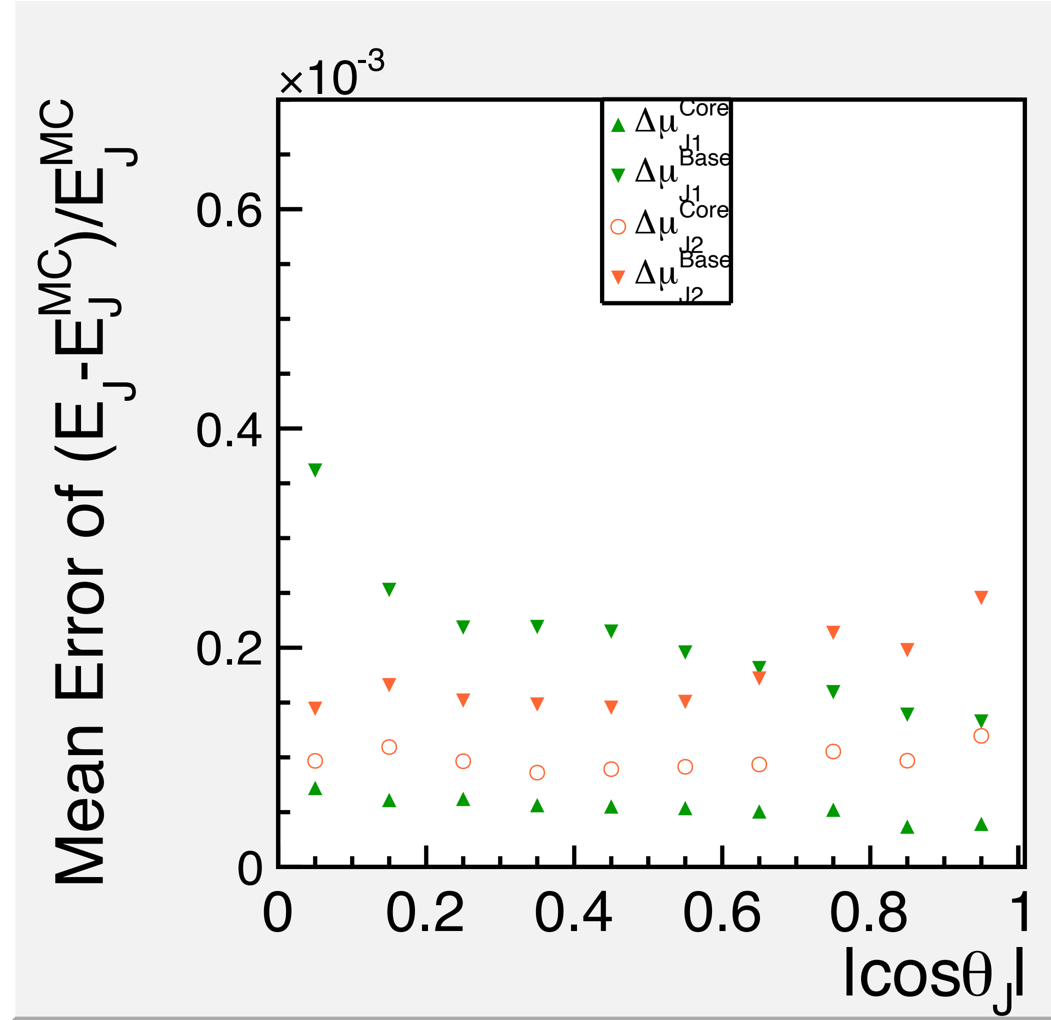
Particle ID := flavor of the seed of the jet

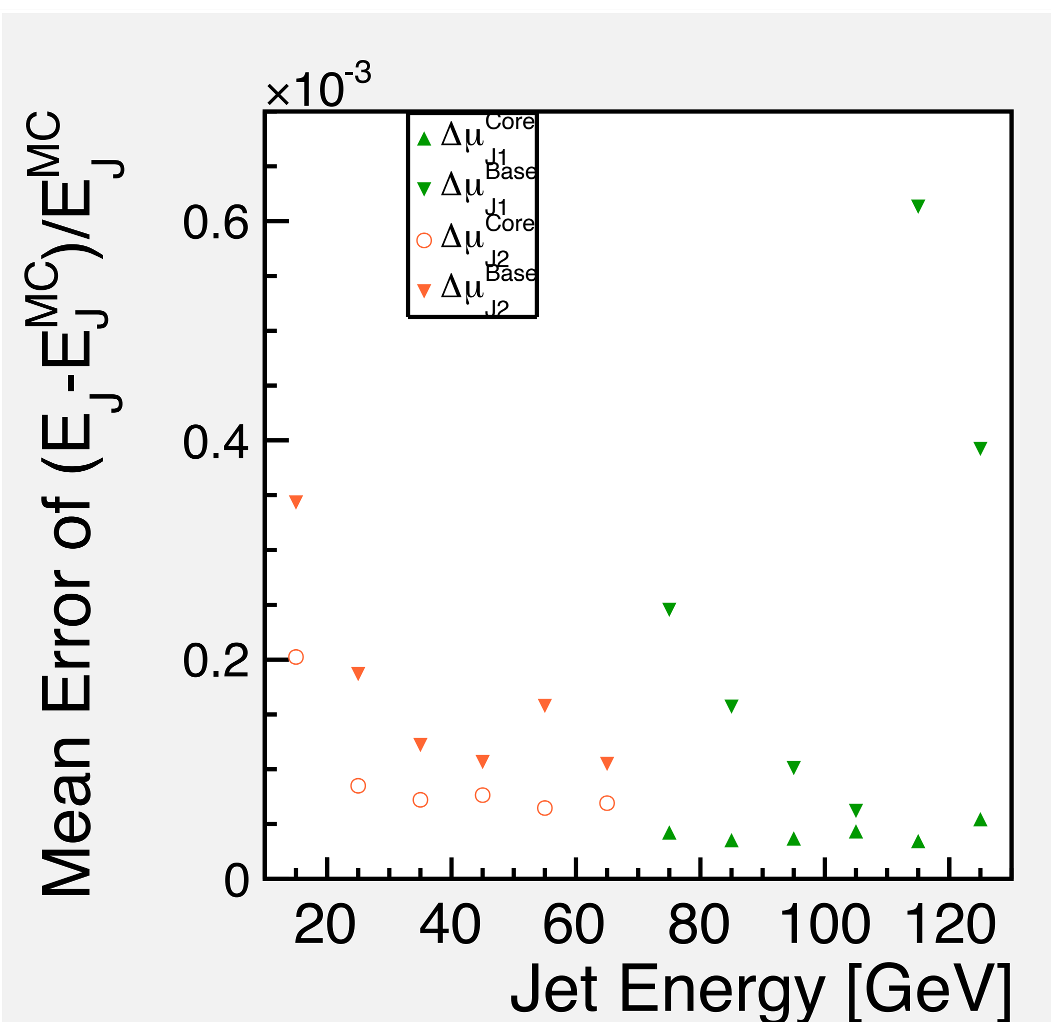


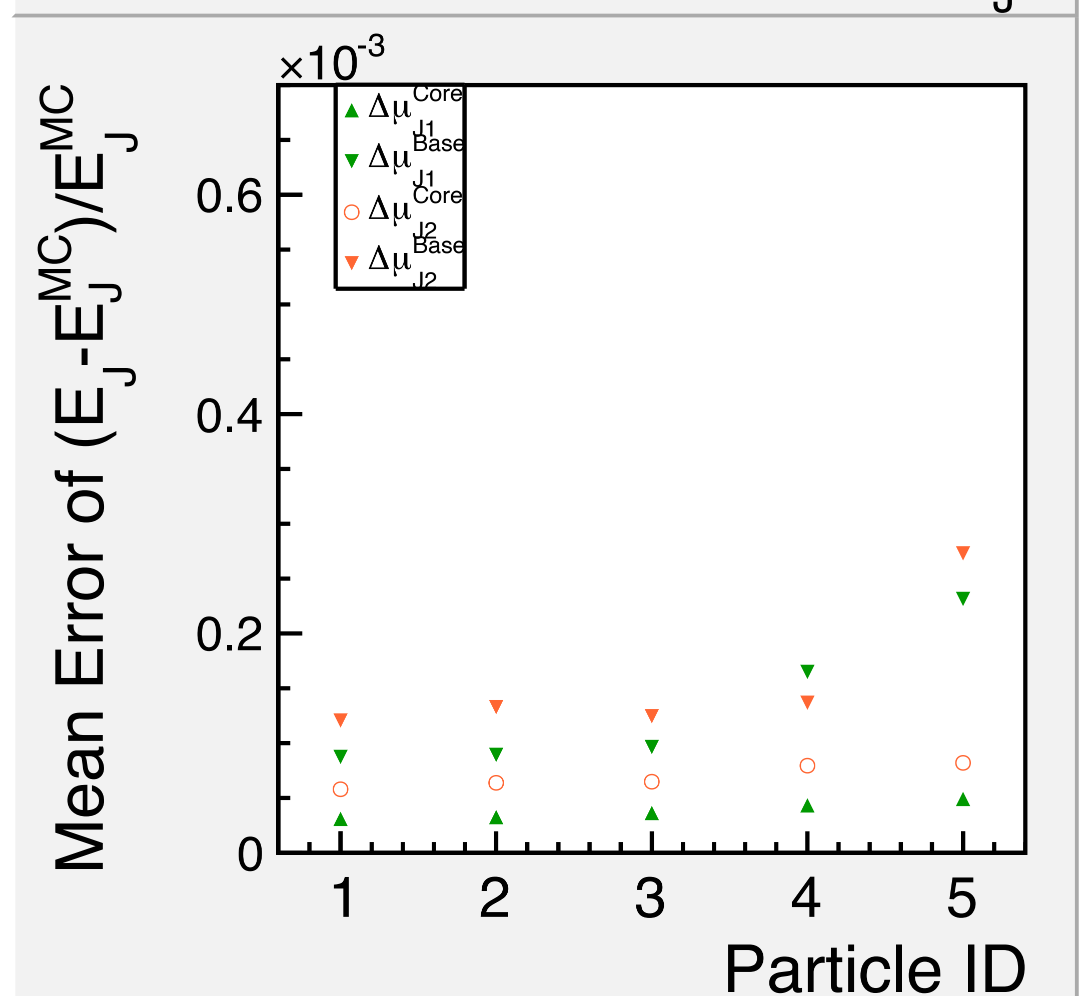




PFO Mean Error







PFO Fraction

Fraction := Size of the fitting Gaussian
Core/(Core+Base)