

# Study of EIC Calorimeters Using Fun4All

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# Index

- Introduction
  - Aim of the analysis
  - Details of calorimeters
  - Simulation Parameters
  
- Energy resolution plots for Electron
  - CEMC plots
  - FEMC plots
  - EEMC plots
  
- Energy resolution plots for Pion
  - Forward calorimeter plots
  - Barrel calorimeter plots
  
- Summary & Next Steps

# Introduction

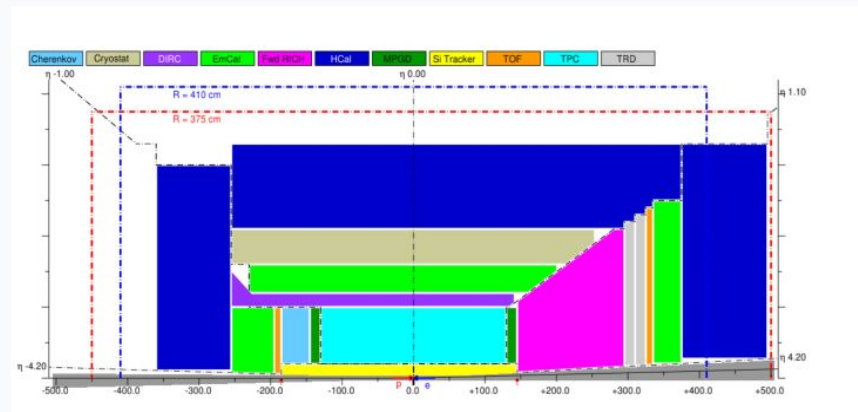
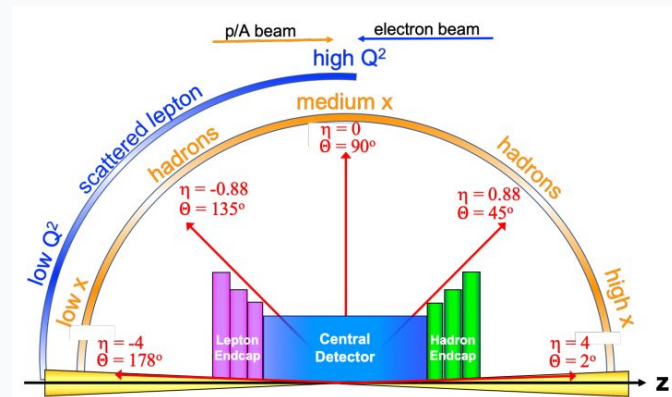
# Aim of the analysis

- To perform parameterization of the energy resolution of various Fun4All calorimeters
  - Simplest case:
    - ➡ A rudimentary **direction-based clustering** method is employed
    - ➡ **Noise** from readout channels is **Turned Off**.

# Details for EIC Calorimeters

Calorimeters in Fun4All layout :

- Backward Region:
  - EEMC (Electron EMCal) - PWO crystals
- Barrel Region:
  - CEMC (Central EMCal)
  - HCALIN (Inner HCal) - Steel absorber + plastic scintillator
  - HCALOUT (Outer HCal) - Aluminium absorber + plastic scintillator
- Forward Region:
  - FEMC (Forward EMCal) - Lead Scintillator sampling calorimeter
  - FHCAL (Forward HCal)



Reference: [EIC Yellow Report](#)

# Simulation Parameters

- Particles:  $e^-$ ,  $\pi^-$
- Pseudorapidity range ( $\eta$ ): -4 to 4
- Azimuth range ( $\Phi$ ):  $-\pi$  to  $+\pi$
- Cuts employed:
  - Detector-wise geta cuts
  - Manual Clustering cuts: Circular cuts on  $d\phi$  ( $t\phi$  -  $g\phi$ ) and  $d\theta$  ( $t\theta$  -  $\theta$ )
  - Energy cut on the **aggregated tower energy\*** : **100 MeV**
- Photon digitization: turned off

## Statistics

Group 1	Group 2
100000 (0-30 GeV)	100000 (0-30 GeV)
50000 (0-10 GeV)	50000 (0-2 GeV)

\*Aggregate tower energy refers to the sum of the energies recorded by all the towers hit by the incident particle's shower in one event.

# Electron

CEMC, FEMC, EEMC

tphi : tower  $\phi$   
gphi : generated  $\phi$

ttheta : tower  $\theta$   
gtheta : generated  $\theta$

te/ te<sub>agg</sub> : aggregate tower energy  
ge : generated energy

# Calibration methods

## Group 1

- Obtain Tprofile plots for the calorimeters' te/ge vs ge plots.
- Fitting the TProfile plots with a fit function
- Use this fit function to calibrate the tower energy of the respective calorimeter.

$$\text{te(calibrated)} = \text{te(raw)}/\text{FitFunction}$$

## Group 2

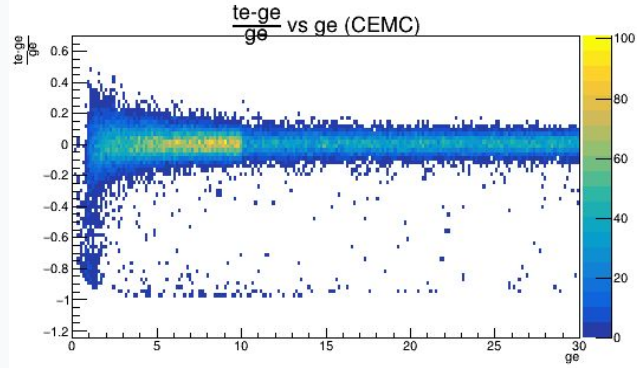
- Obtain Tprofile plots for the calorimeters' te/ge plots.
- Use bin-wise mean values of the TProfile of te/ge as the calibration factor. (The first slice is manually calibrated for electrons)
- Use this calibration factor to calibrate the tower energies of the respective calorimeter.

$$\text{te(calibrated)} = \text{te(raw)}/\text{CalibrationFactor}$$

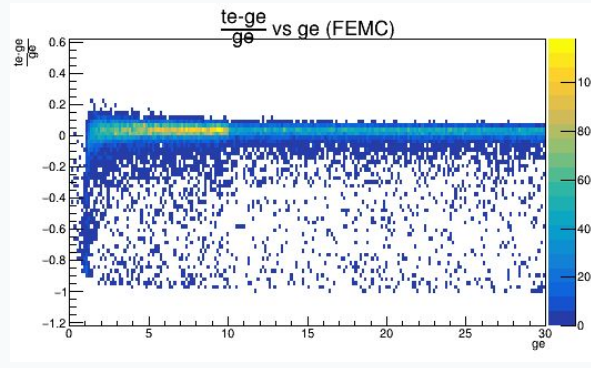


# Electron

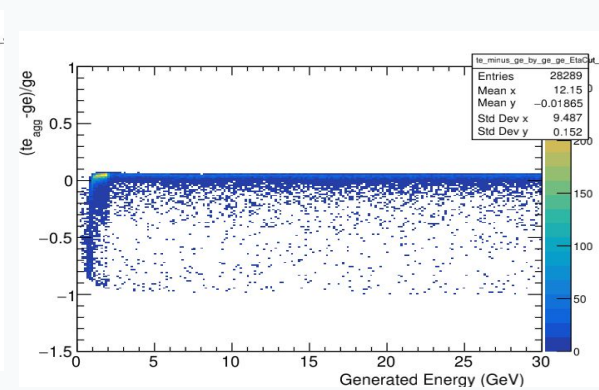
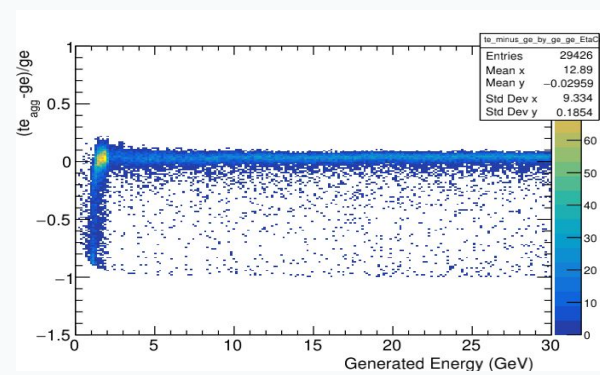
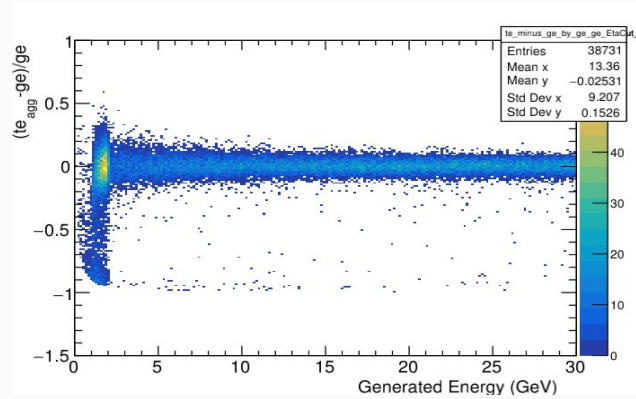
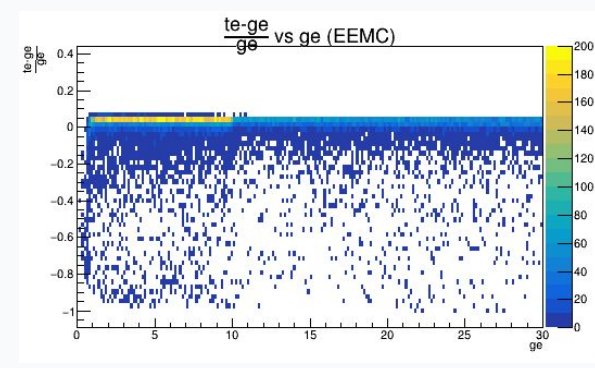
## CEMC



## FEMC

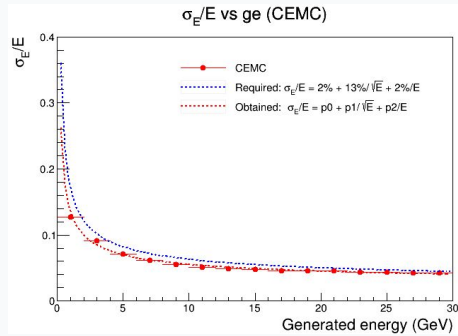


## EEMC



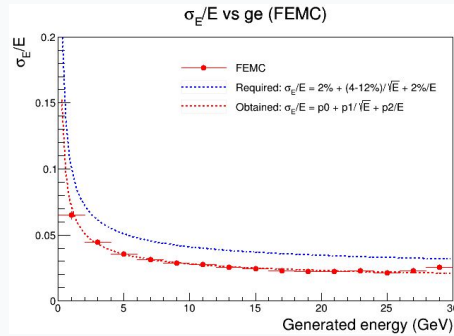
# Electron

## CEMC



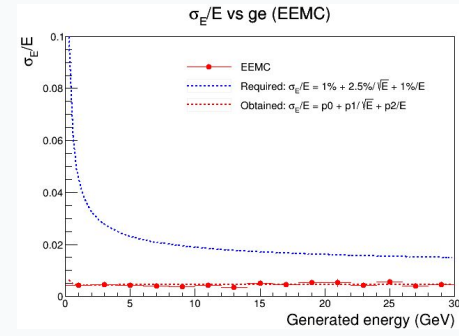
$$\sigma_E/E = 2.05\% + 10.53\%/\sqrt{E} + 2\%/E$$

## FEMC

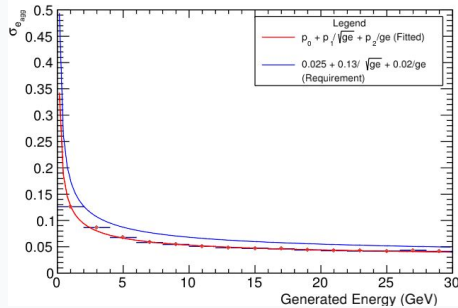


$$\sigma_E/E = 1.16\% + 4.85\%/\sqrt{E} + 1.08\%/E$$

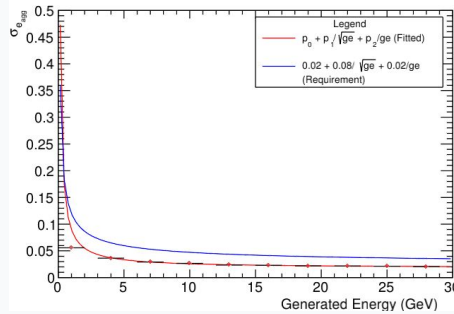
## EEMC



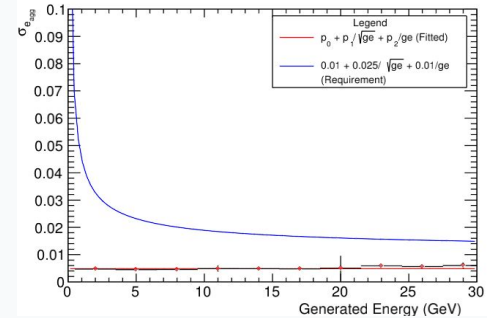
$$\sigma_E/E = 0.49\% - 0.16\%/\sqrt{E} + 0.12\%/E$$



$$\sigma_E/E = 2.28\% + 9.19\%/\sqrt{E} + 1.23\%/E$$



$$\sigma_E/E = 1.71\% + 0.5\%/\sqrt{E} + 6.56\%/E$$



$$\sigma_E/E = 0.48\%$$

- The energy resolution values obtained are **permissible** according to the minimum requirements stipulated by the JLab Detector Matrix.

# Pion

CEMC + HCALIN + HCALOUT

FEMC + FHCAL

# Calibration methods

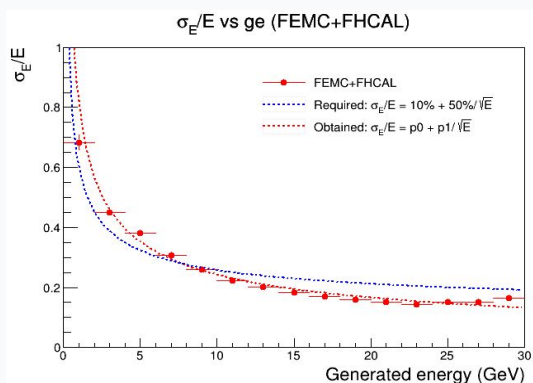
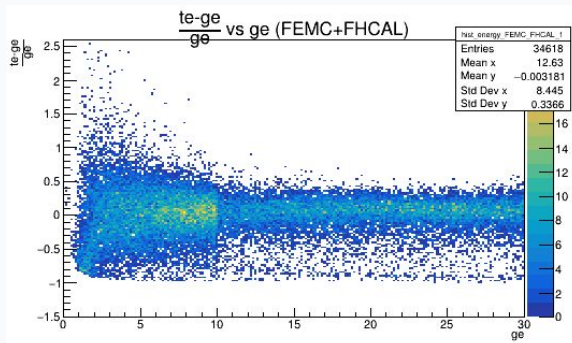
## Group 1

- Obtain Tprofile plots for the individual calorimeters' te/ge vs ge plots.
- Fitting the TProfile plots with a fit function.
- Use this fit function to calibrate the tower energy of the respective calorimeter.
- Multiplying the Mean value of te/ge (as a weight) for each calorimeter to these calibrated energies.  
$$te(scaled) = (te(raw)/FitFunction) * (Mean\ of\ te/ge)$$
- Add the corresponding scaled tower energies of each individual calorimeter.
- Obtain TProfile plot for these summed up scaled te/ge vs ge plots.
- Find the fit function for the same.
- Calculate the final calibrated tower energy  
$$te(calibrated) = te(summed)/FitFunction$$

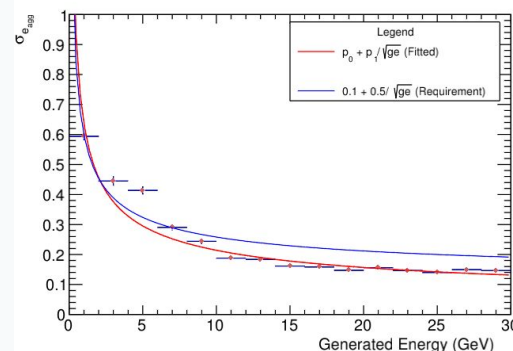
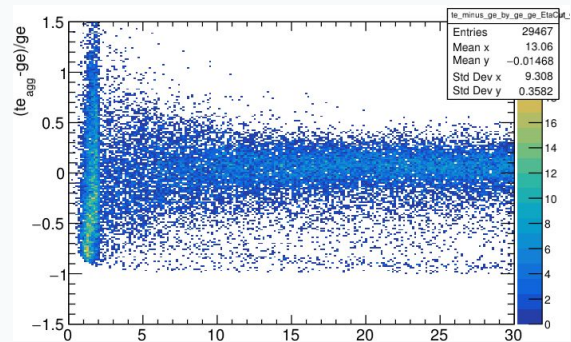
## Group 2

- Obtain Tprofile plots for the individual calorimeters' te/ge vs ge plots.
- Use bin-wise mean values of the TProfile of te/ge as the calibration factor for respective calorimeters.
- Multiply the Mean value of te/ge (as a weight) for each calorimeter with these calibrated energies.  
$$te(scaled) = (te(raw)/CalibrationFactor) * (Mean\ of\ te/ge)$$
- Add the corresponding scaled tower energies of each individual calorimeter.
- Obtain TProfile plot for these summed up and scaled te/ge vs ge plots.
- Use bin-wise mean values of the above Tprofile plot as the calibration factor.
- Calculate the final calibrated tower energy  
$$te(calibrated) = te(summed)/CalibrationFactor2$$

# Pion: FEMC + FHCAL



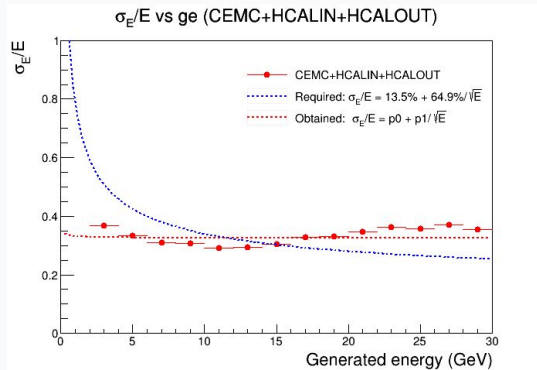
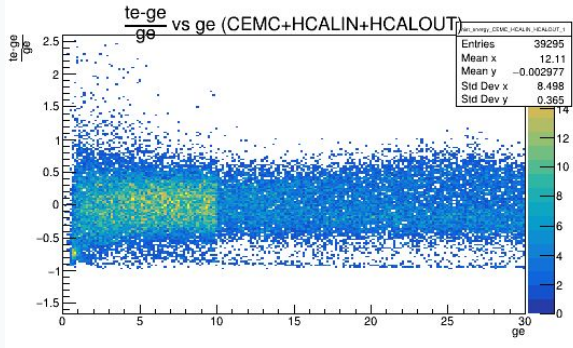
$$\sigma_E/E = -2.06\% + 83.4\%/\sqrt{E}$$



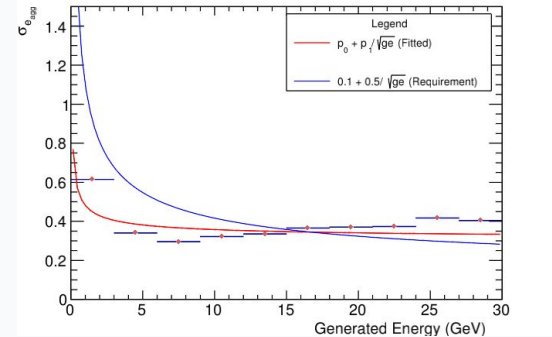
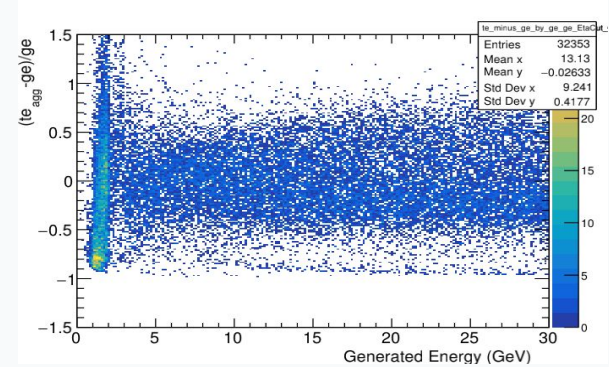
$$\sigma_E/E = 1.83\% + 61.9\%/\sqrt{E}$$

- The obtained hadron energy resolution seems to match the minimum requirements for forward calorimeters for energies greater than 5 GeV.

# Pion: CEMC + HCALIN + HCALOUT



$$\sigma_E/E = 32.25\% + 0.98\%/\sqrt{E}$$



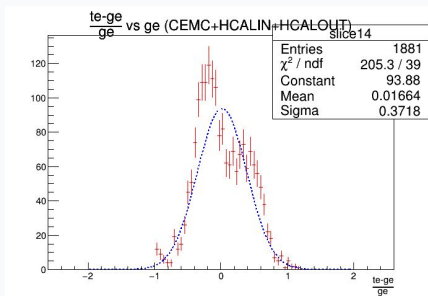
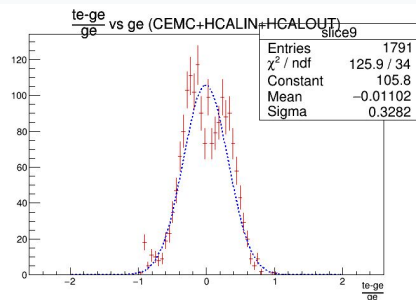
$$\sigma_E/E = 30.0277\% + 18.1573\%/\sqrt{E}$$

- The spread in energy distribution at high energies (>10 GeV) worsens the hadron energy resolution in the case of barrel calorimeters.

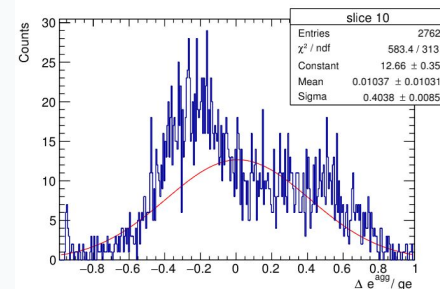
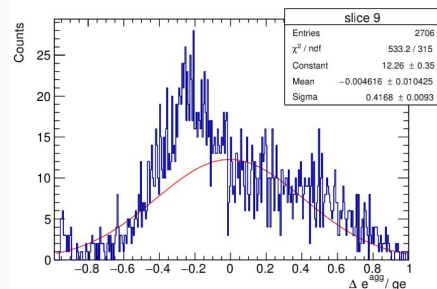


# Problem in Hadron Energy Resolution

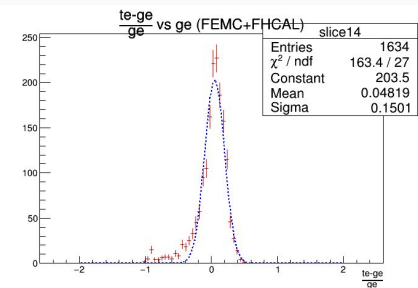
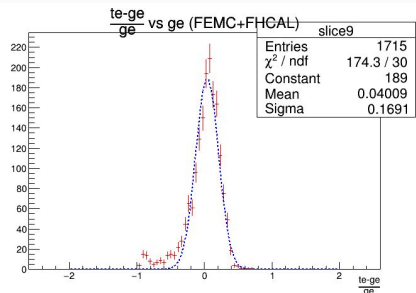
## Barrel Calorimeters:



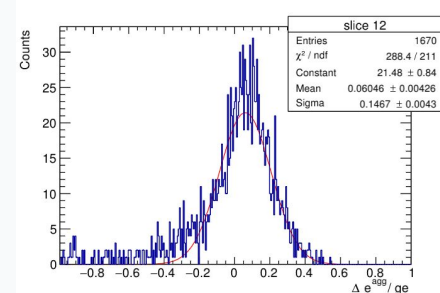
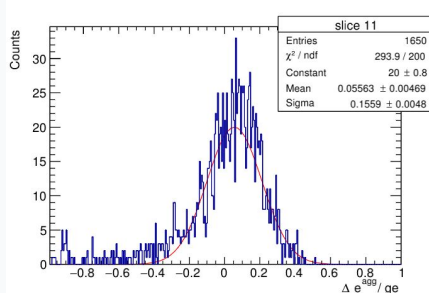
## Barrel Calorimeters:



## Forward Calorimeters:



## Forward Calorimeters:



- The spreading of energies widens the gaussian fitting in case of barrel calorimeters while the calibration seems to work reasonably in the case of forward calorimeters. This spreading could be attributed to the calibration procedure used.

# Summary

- The obtained electron energy resolution for EMCals seems to be reasonable.
- The obtained hadron energy resolution for the Forward Calorimeters seems to match the minimum requirements for incident energies higher than 6 GeV.
- The 'shouldering' in the case of Barrel Calorimeters detecting pions worsens the energy resolution at high energies.



# Next Steps

Need your expert feedback regarding

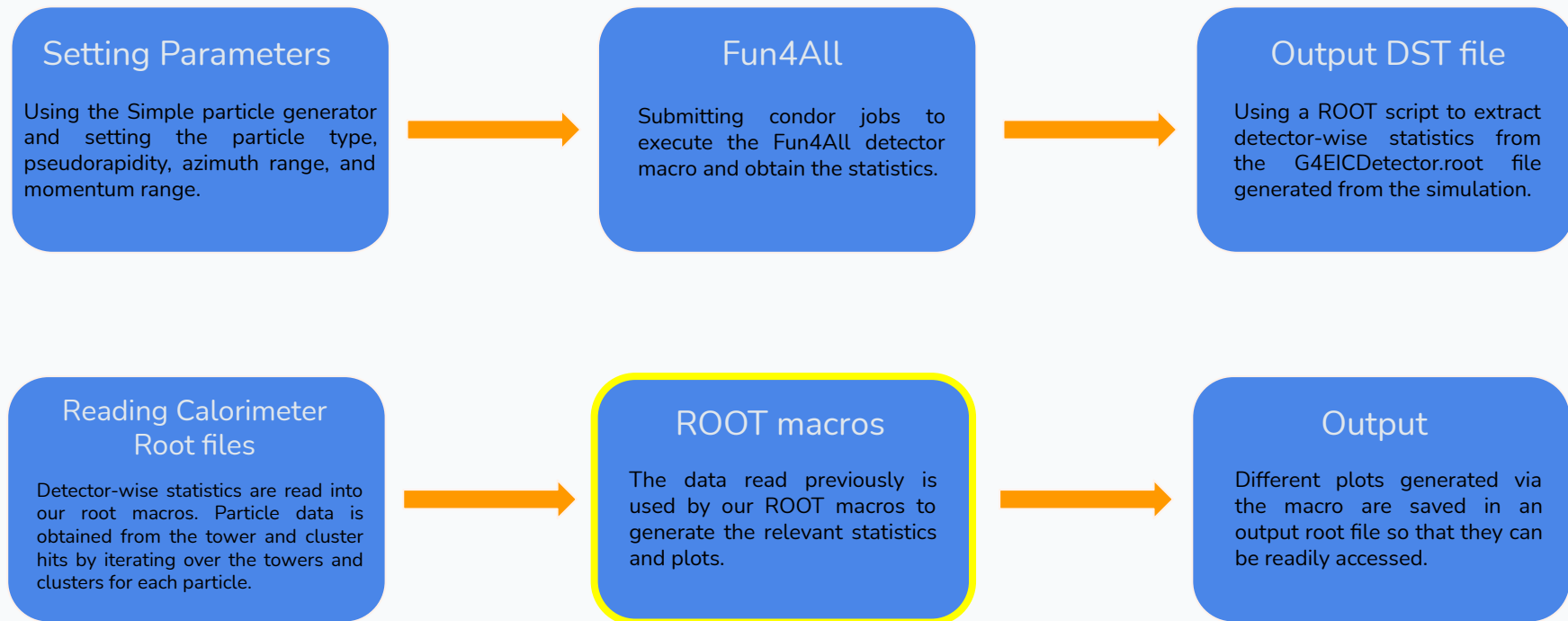
- ▶ Improvement of the clustering method employed on the towers
- ▶ Calibration of the calorimeters

What are your comments/suggestions?

# Backup Slides

# Workflow

Fun4all is a C++ based framework steered by ROOT macros, that runs GEANT4 based full detector simulations, raw data reconstruction, and analysis.



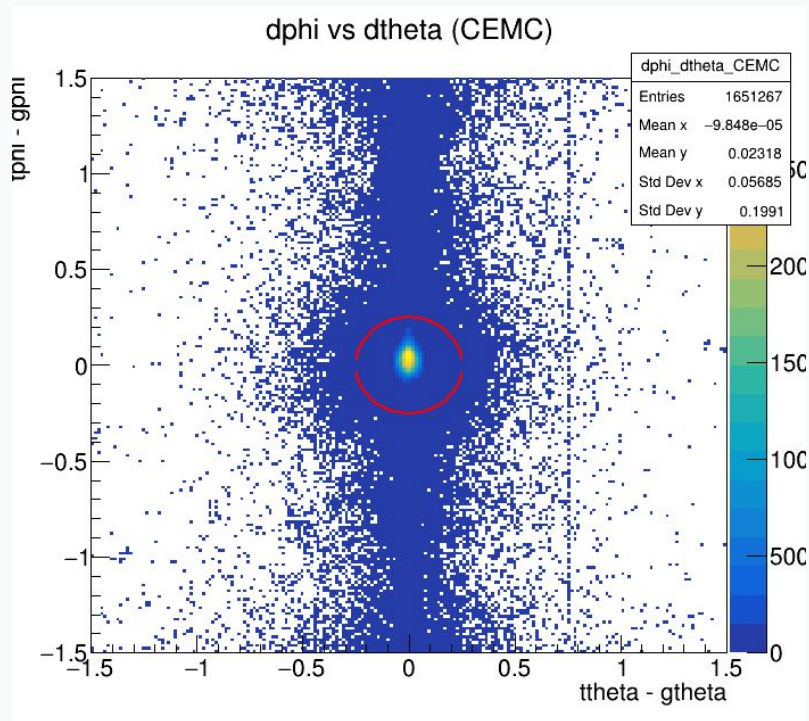
# Eta Cuts Employed

- Detector-wise eta cuts
  - Electron:
    - CEMC:  $\eta = -1.5$  to  $1.2$
    - FEMC:  $\eta = 1.3$  to  $3.3$
    - EEMC:  $\eta = -3.5$  to  $-1.7$
  - Pion:
    - CEMC, HCALIN, HCALOUT:  $\eta = -1.1$  to  $1.1$
    - FEMC, FHCAL:  $\eta = 1.3$  to  $3.3$

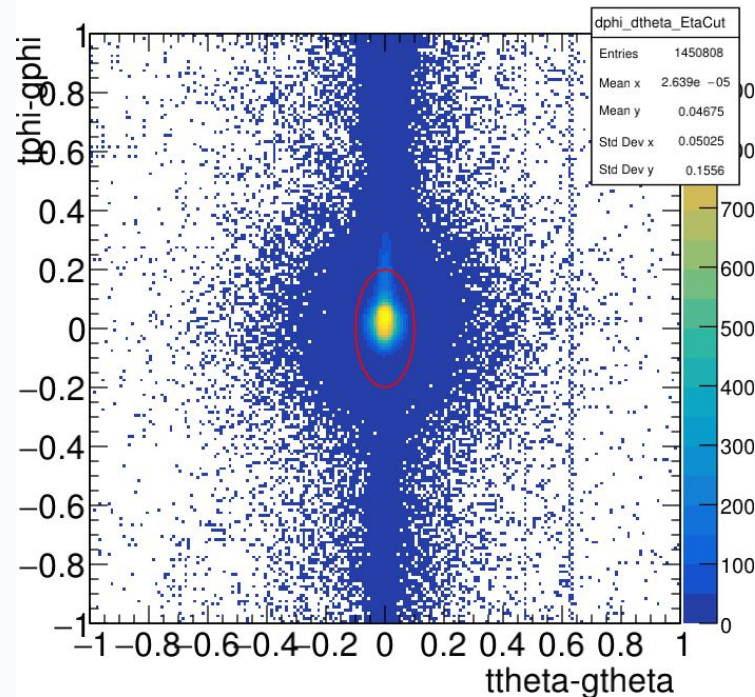
Electron : CEMC

# Electron: CEMC

## Manual Clustering



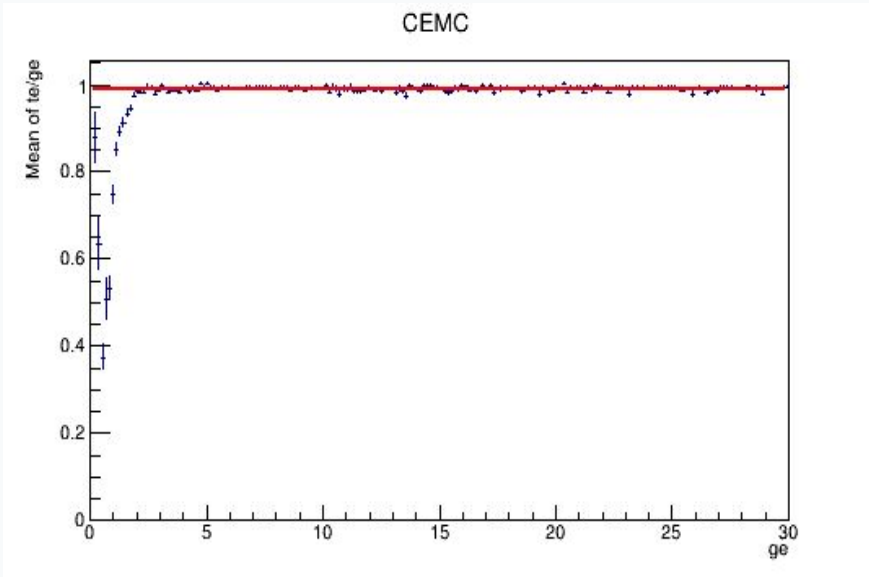
Radius = 0.25 units



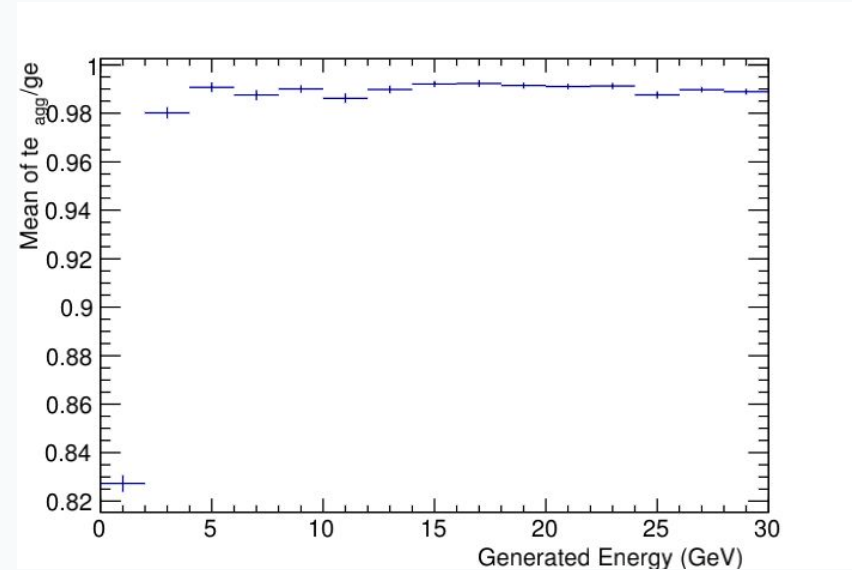
semi-minor axis = 0.10 units  
semi-major axis = 0.20 units

# Electron: CEMC

## TProfile plots for calibration



Calibration Factor = Fit Function for the above plot

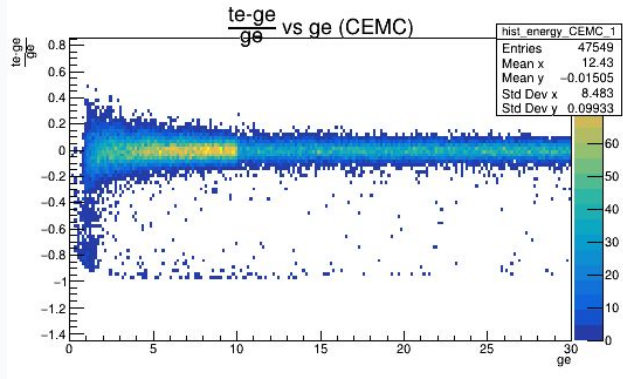


Calibration Factor of first slice = 0.96

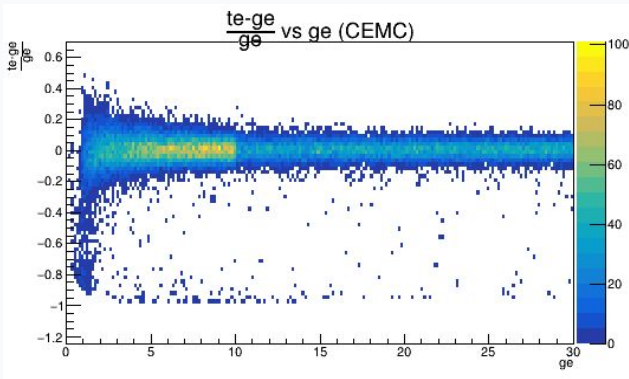
# Electron: CEMC

100 MeV on aggregated tower energy for each event

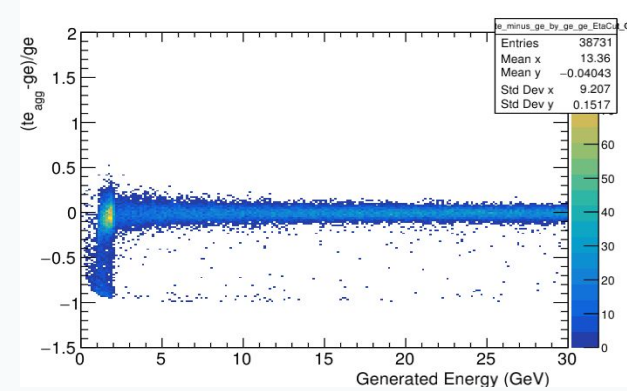
Before Calibration



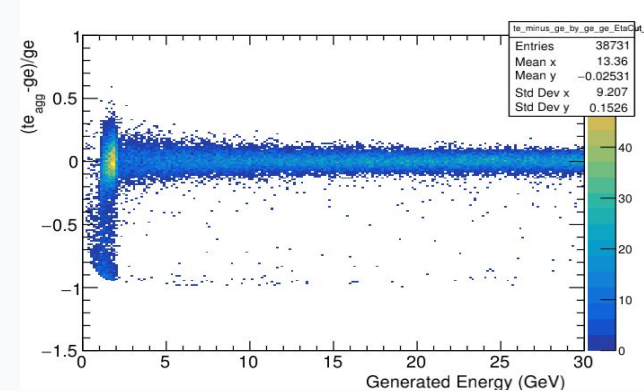
After Calibration



Before Calibration



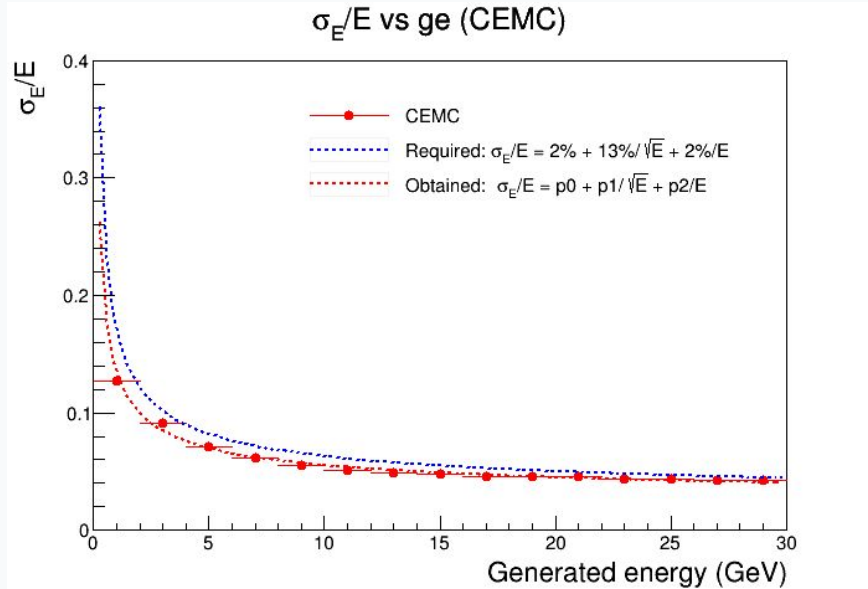
After Calibration



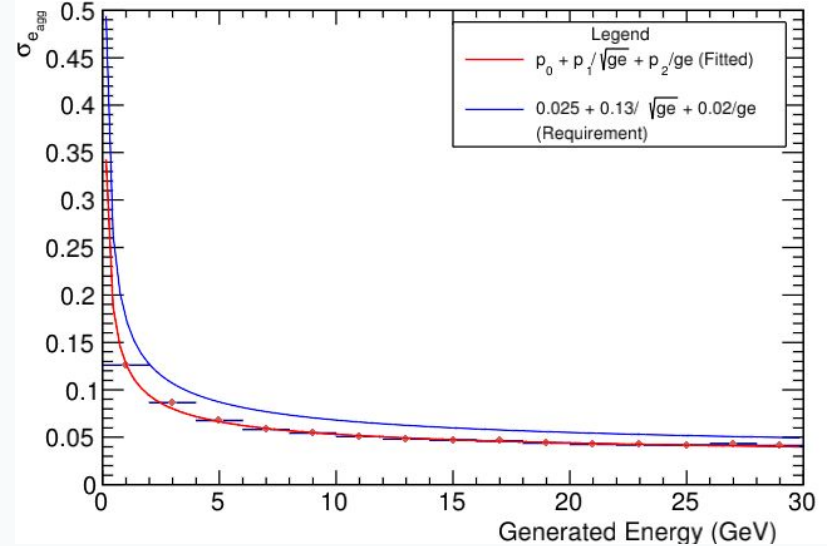


# Electron: CEMC

100 MeV on aggregated tower energy for each event  
After Calibration



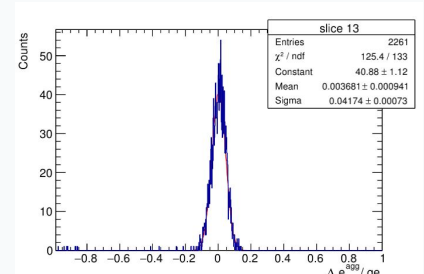
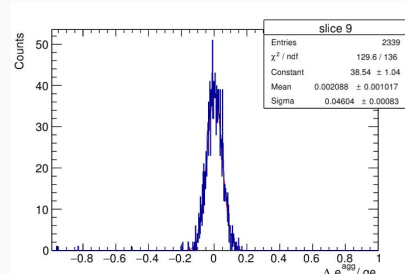
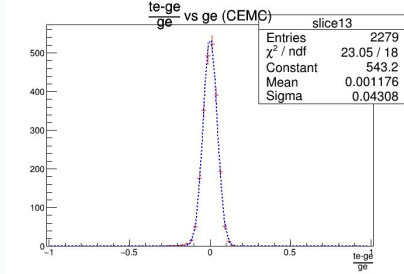
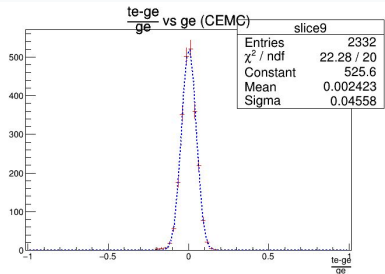
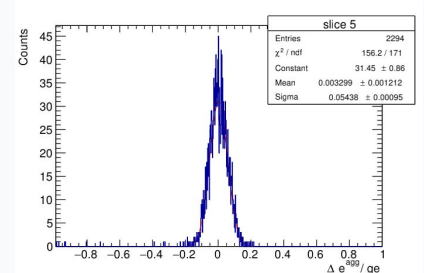
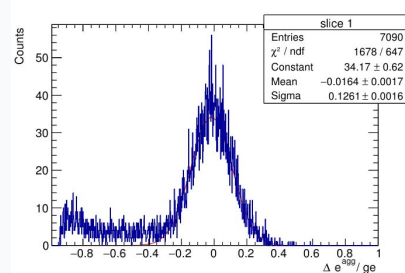
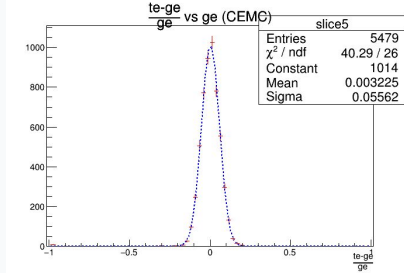
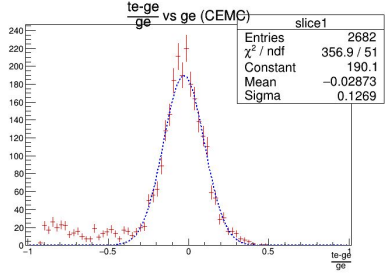
$$\sigma_E/E = 2.0520\% + 10.534\%/\sqrt{E} + 2\%/E$$



$$\sigma_E/E = 2.28119\% + 9.19356\%/\sqrt{E} + 1.23408\%/E$$

# Electron: CEMC

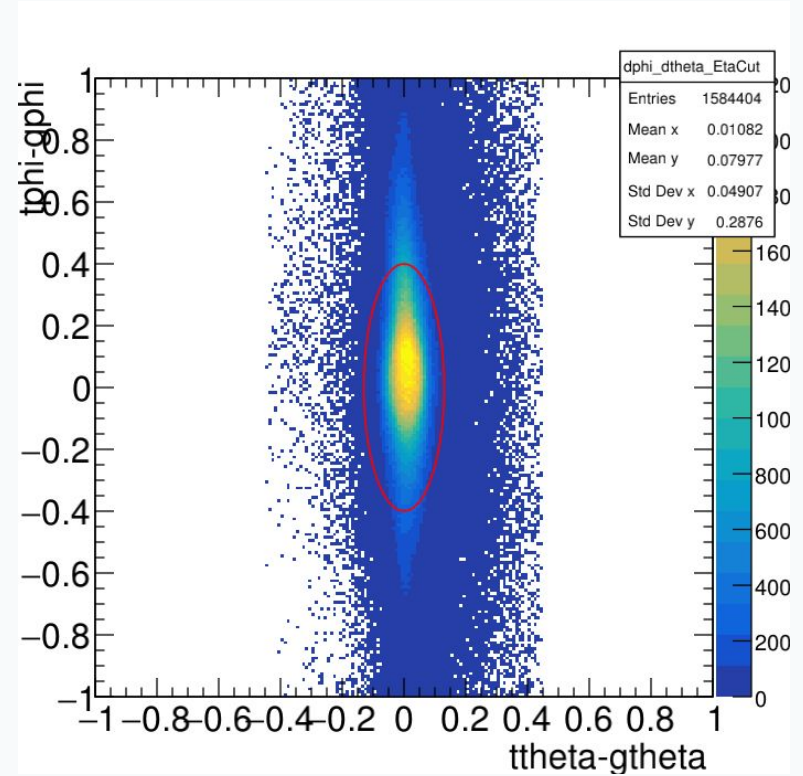
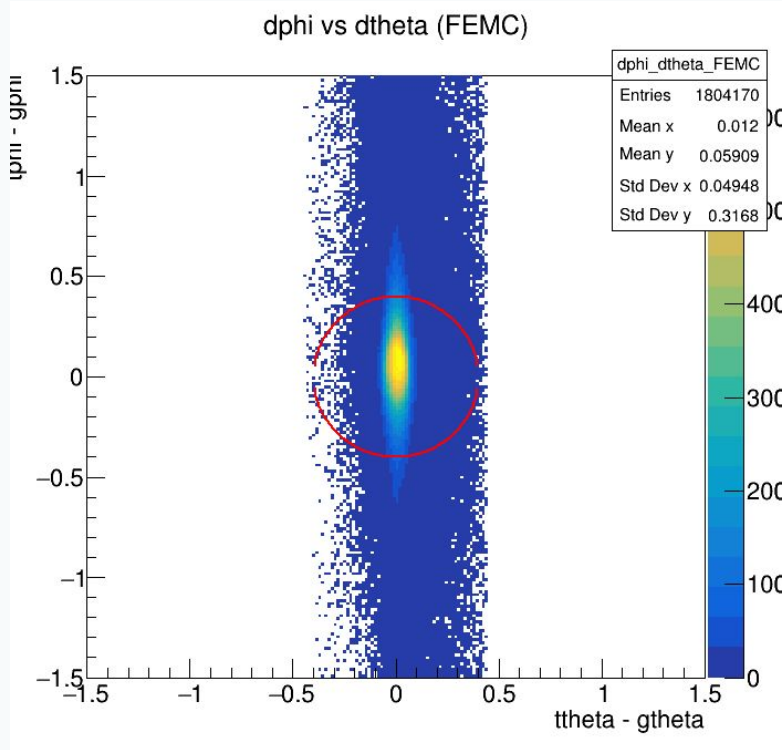
100 MeV on aggregated tower energy for each event  
After Calibration  
Fit Slices



Electron : FEMC

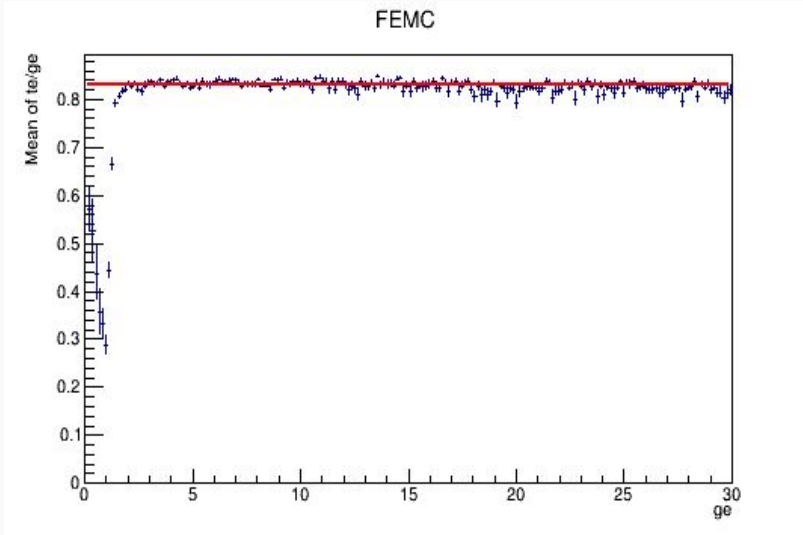
# Electron: FEMC

## Manual Clustering

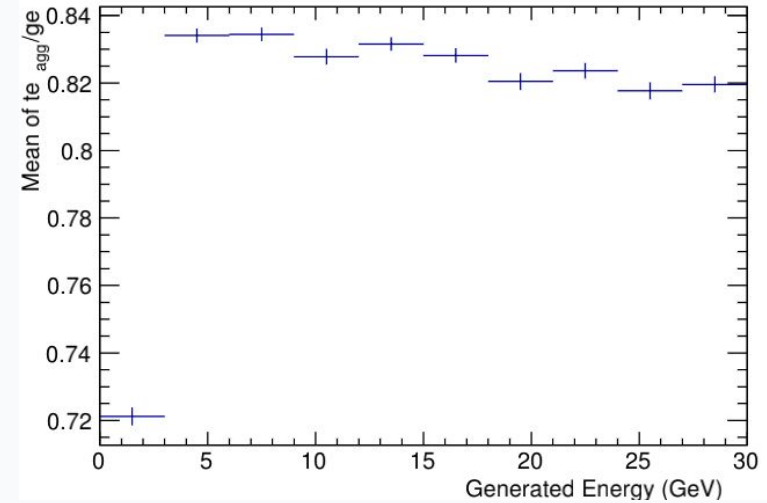


# Electron: FEMC

100 MeV on aggregated tower energy for each event  
TProfile plots for calibration



Calibration Factor = Fit Function for the above plot

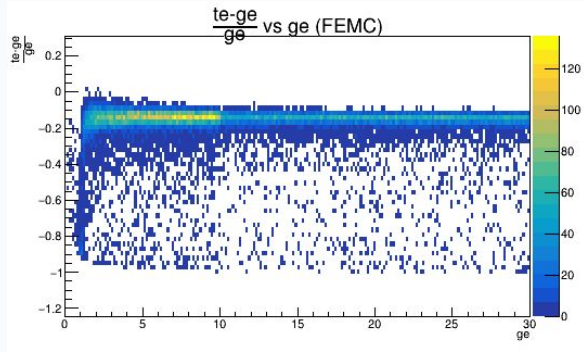


Calibration Factor of first slice = 0.82

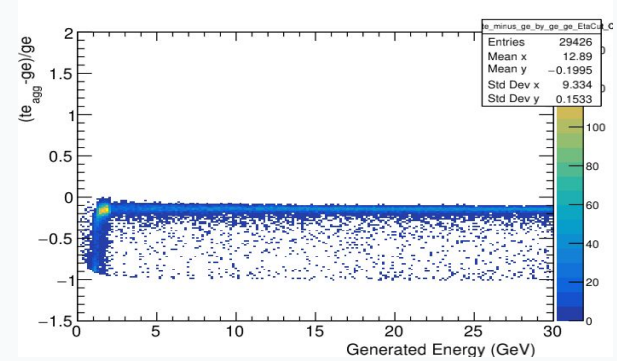
# Electron: FEMC

100 MeV on aggregated tower energy for each event

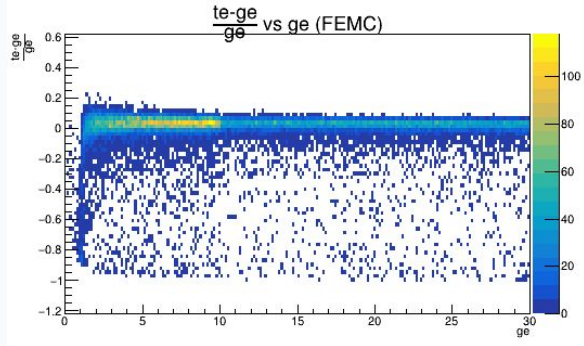
Before Calibration



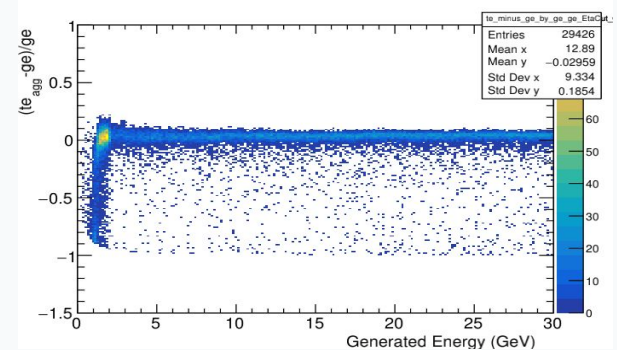
Before Calibration



After Calibration



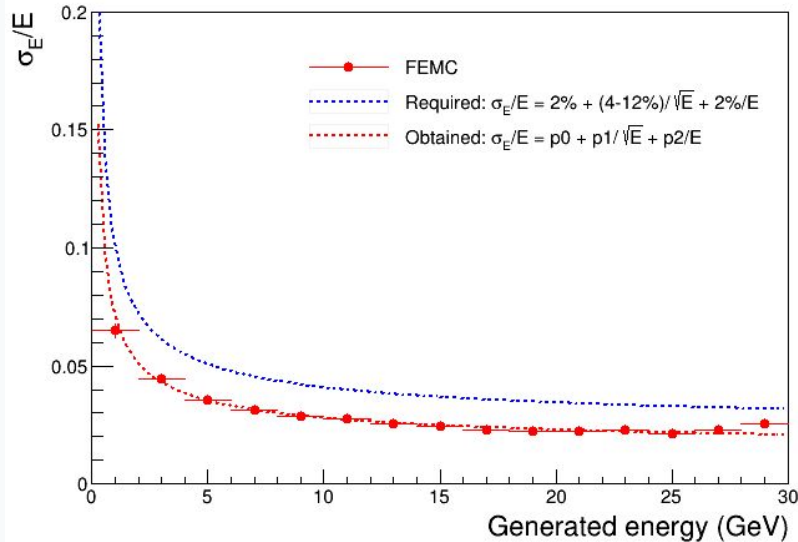
After Calibration



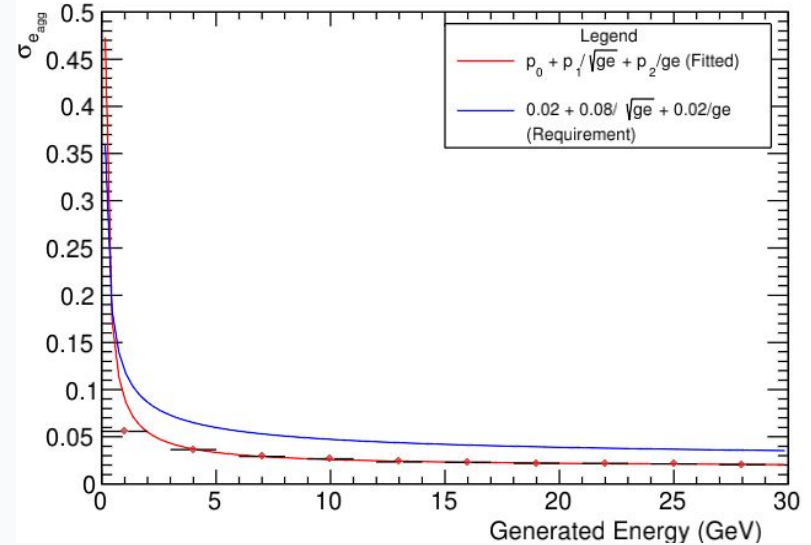
# Electron: FEMC

100 MeV on aggregated tower energy for each event  
After Calibration

$\sigma_E/E$  vs  $ge$  (FEMC)



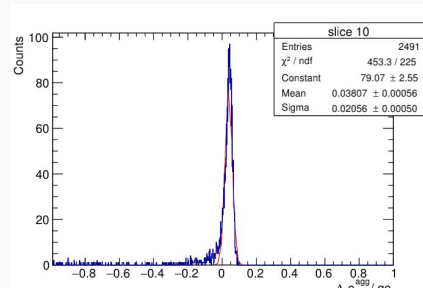
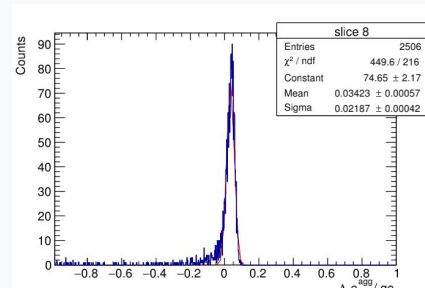
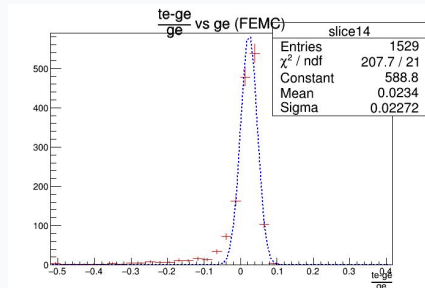
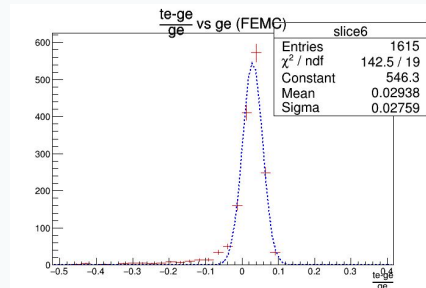
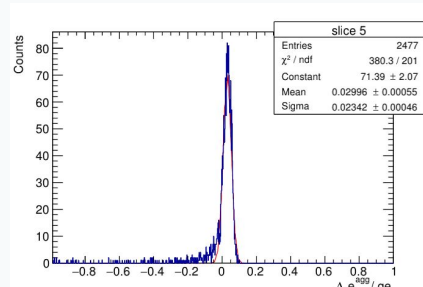
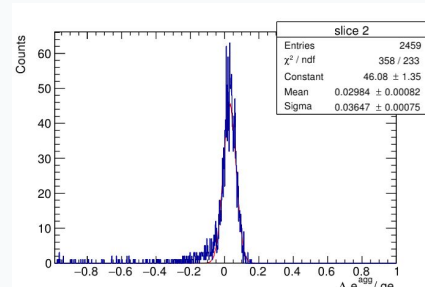
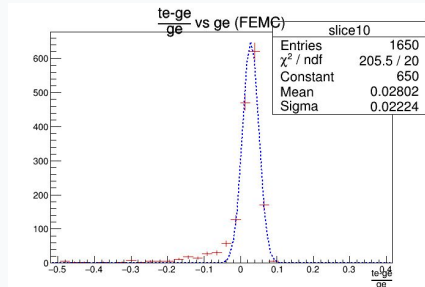
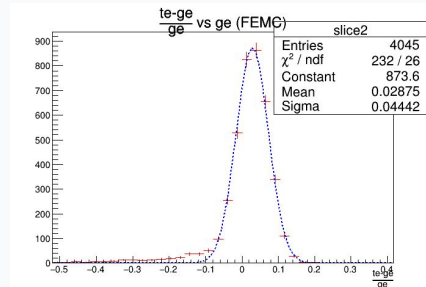
$$\sigma_E/E = 1.15892\% + 4.84642\%/\sqrt{E} + 1.08484\%/E$$



$$\sigma_E/E = 1.70581\% + 0.50221\%/\sqrt{E} + 6.56204\%/E$$

# Electron: FEMC

100 MeV on aggregated tower energy for each event  
After Calibration  
Fit Slices

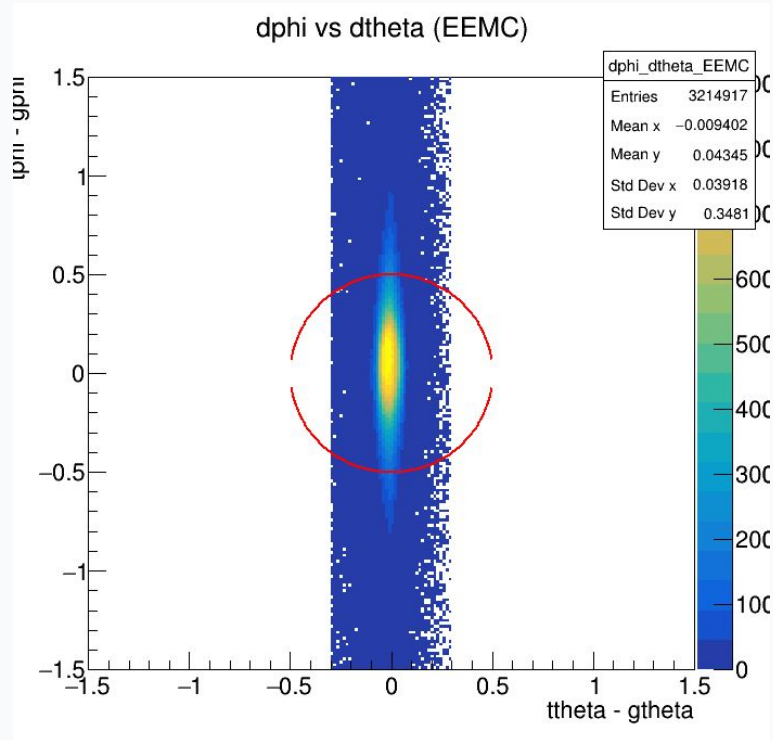




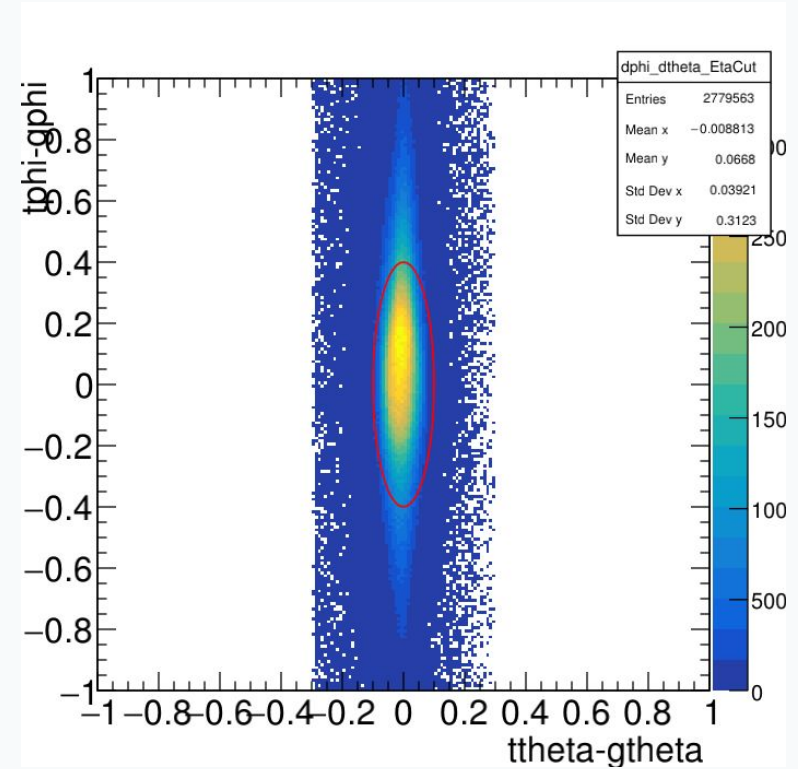
Electron : EEMC

# Electron: EEMC

## Manual Clustering



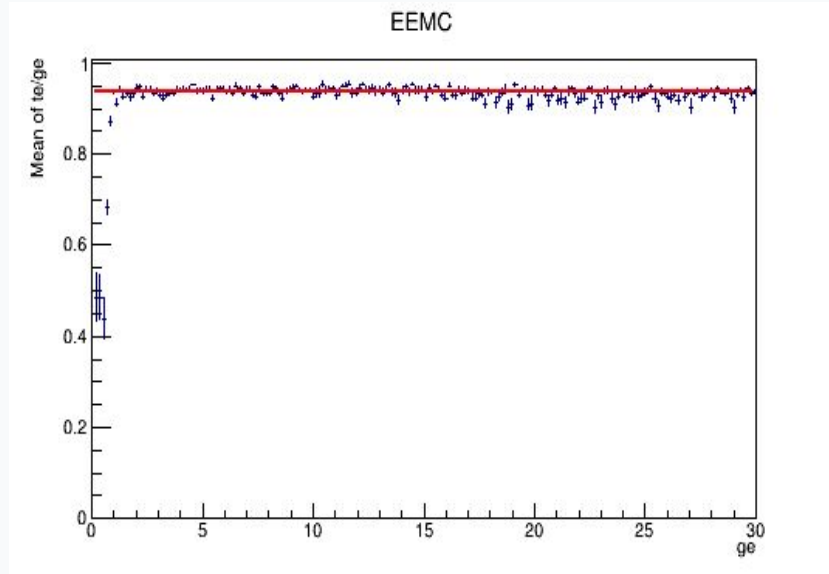
Radius = 0.50 units



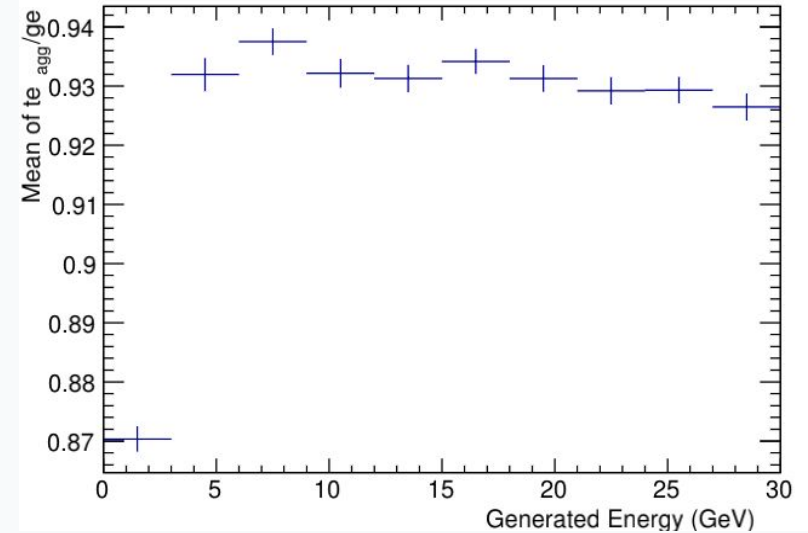
semi-minor axis = 0.10 units  
semi-major axis = 0.40 units

# Electron: EEMC

100 MeV on aggregated tower energy for each event  
TProfile plots for calibration



Calibration Factor = Fit Function for the  
above plot

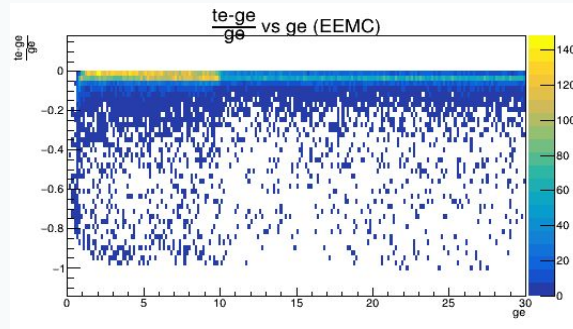


Calibration Factor of first slice = 0.93

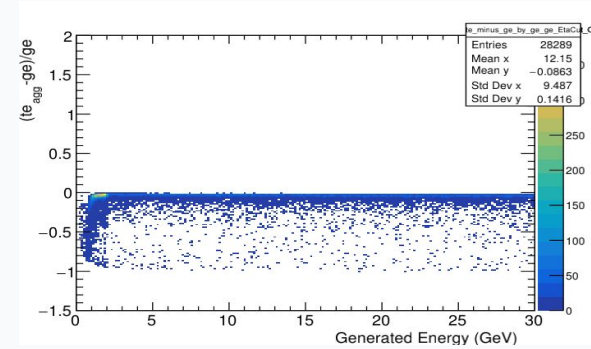
# Electron: EEMC

100 MeV on aggregated tower energy for each event

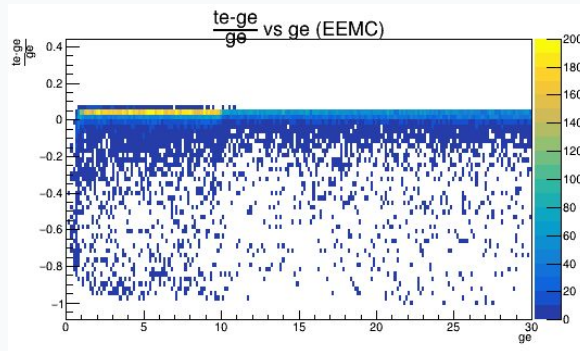
Before Calibration



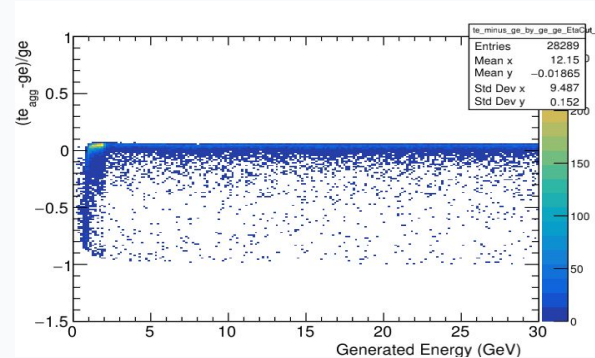
Before Calibration



After Calibration

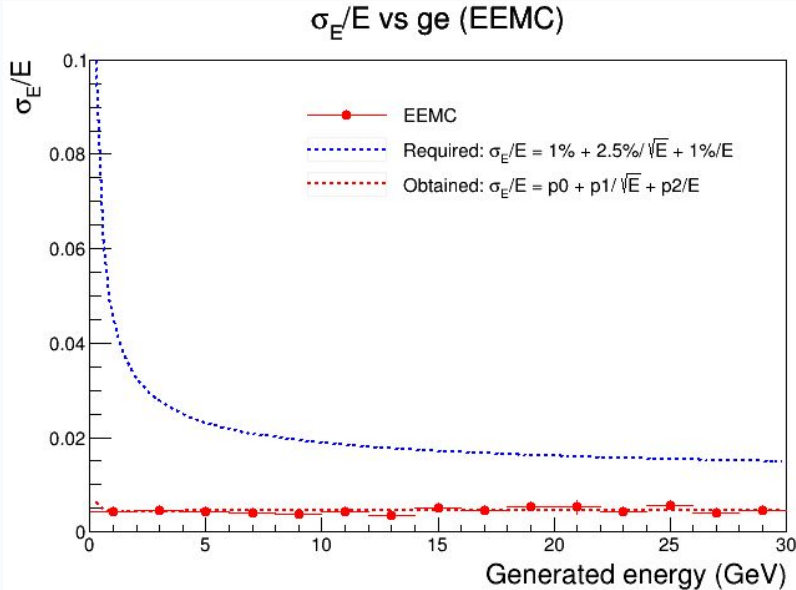


After Calibration

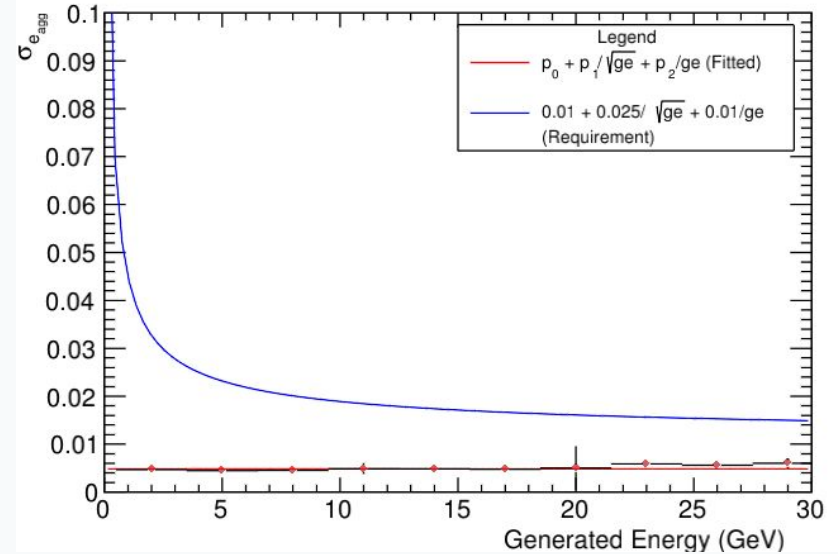


# Electron: EEMC

100 MeV on aggregated tower energy for each event  
After Calibration



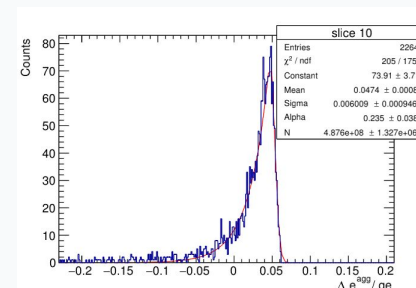
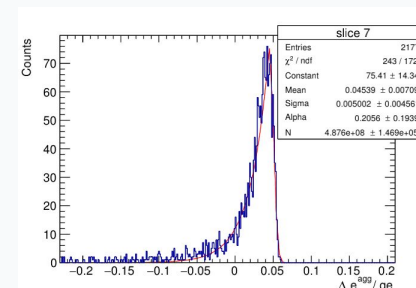
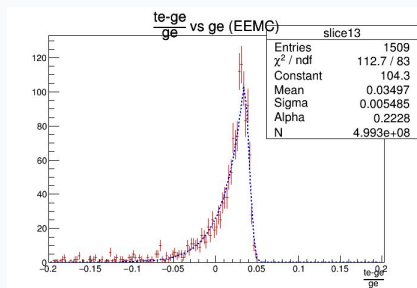
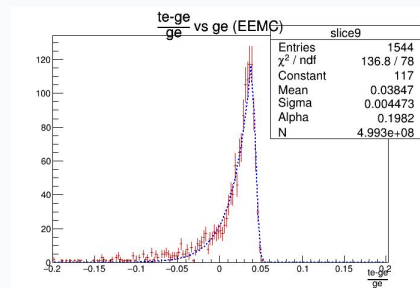
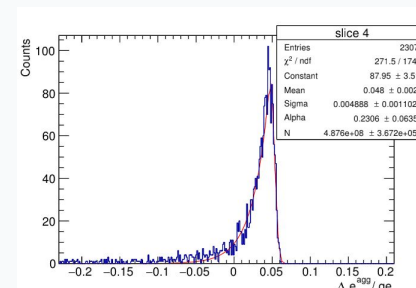
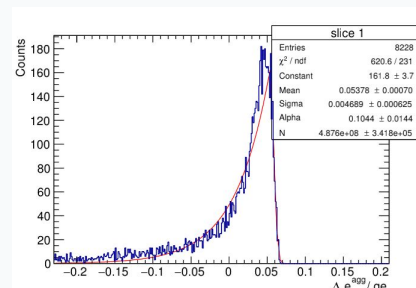
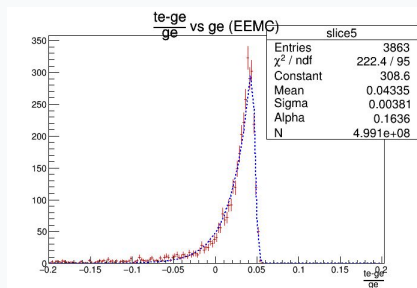
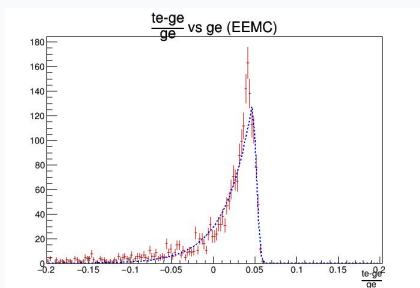
$$\sigma_E/E = 0.493094\% - 0.162239\%/\sqrt{E} + 0.117333\%/E$$



$$\sigma_E/E = 0.483728\%$$

# Electron: EEMC

100 MeV on aggregated tower energy for each event  
After Calibration  
Fit Slices

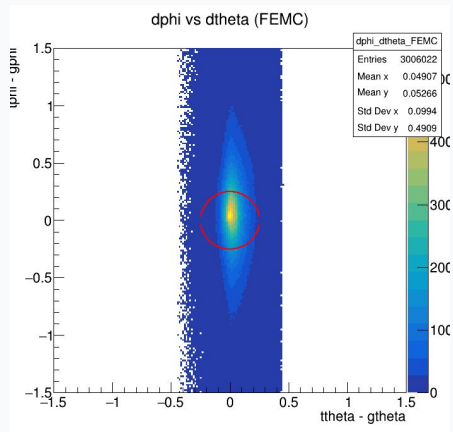


Pion : FEMC + FHCAL

# Pion: FEMC + FHCAL

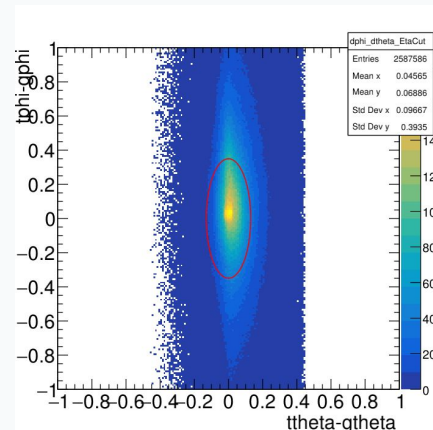
## Manual Clustering

FEMC:



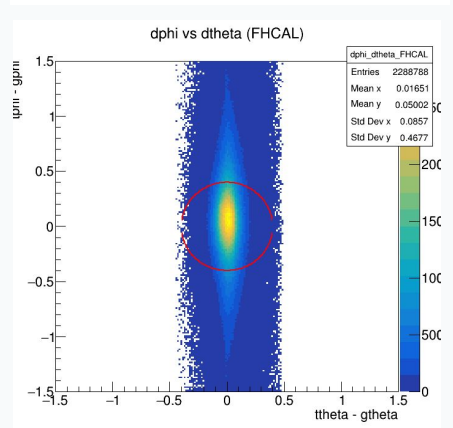
Radius = 0.25 units

FEMC:



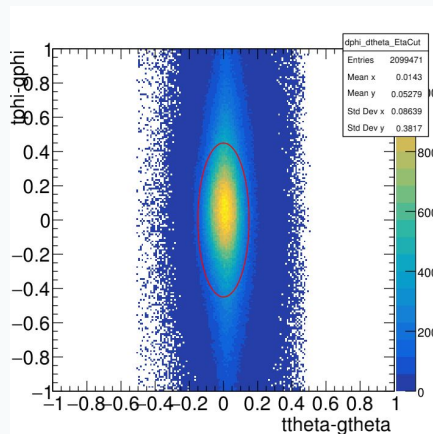
semi-minor axis = 0.13 units  
semi-major axis = 0.35 units

FHCAL:



Radius = 0.40 units

FHCAL:

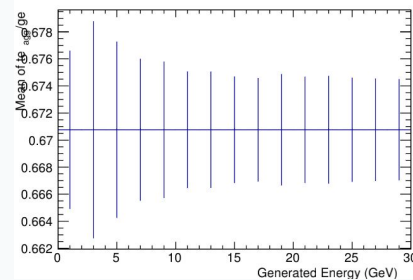
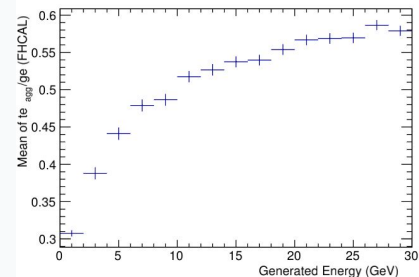
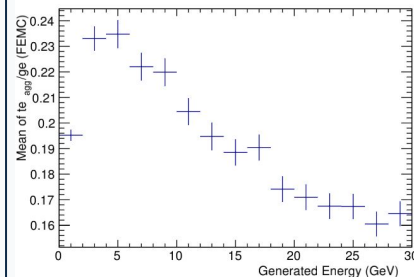
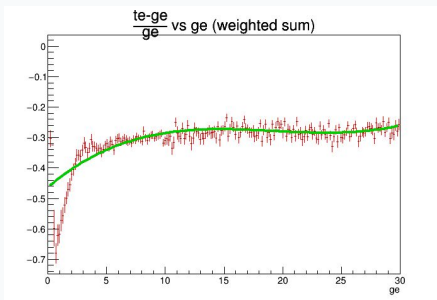
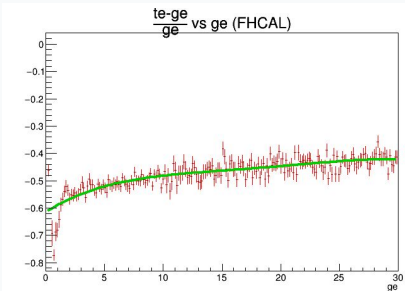
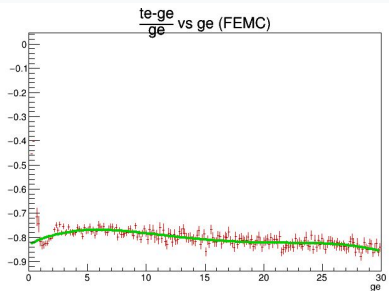


semi-minor axis = 0.13 units  
semi-major axis = 0.35 units



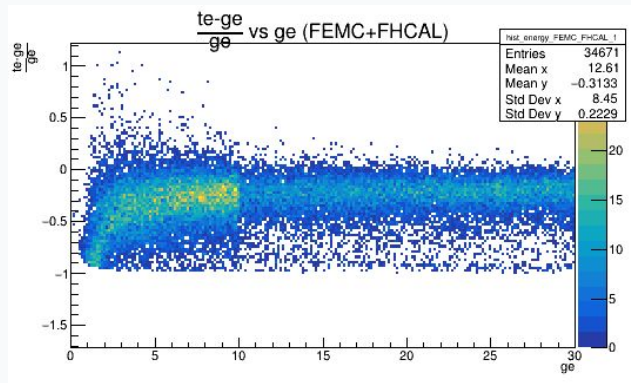
# Pion: FEMC + FHCAL

## Steps involved in calibration

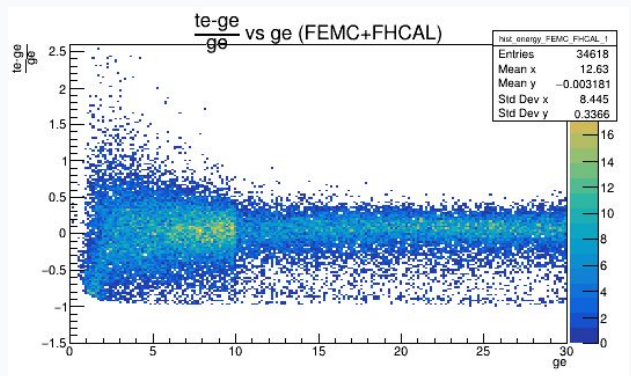


# Pion: FEMC + FHCAL

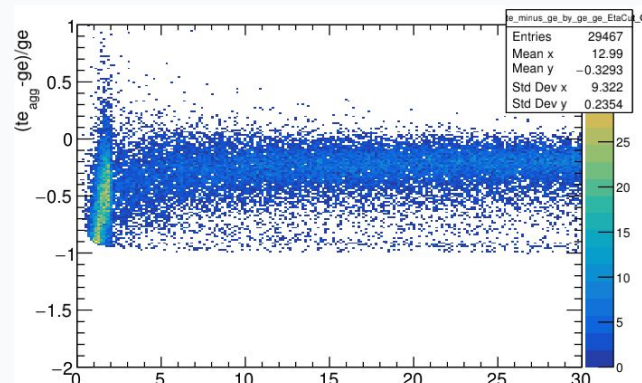
Before Calibration



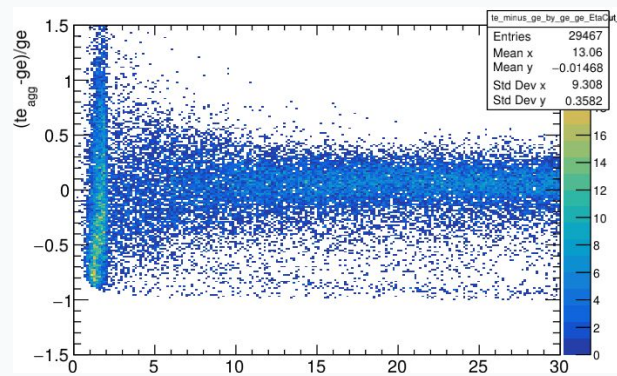
After Calibration



Before Calibration

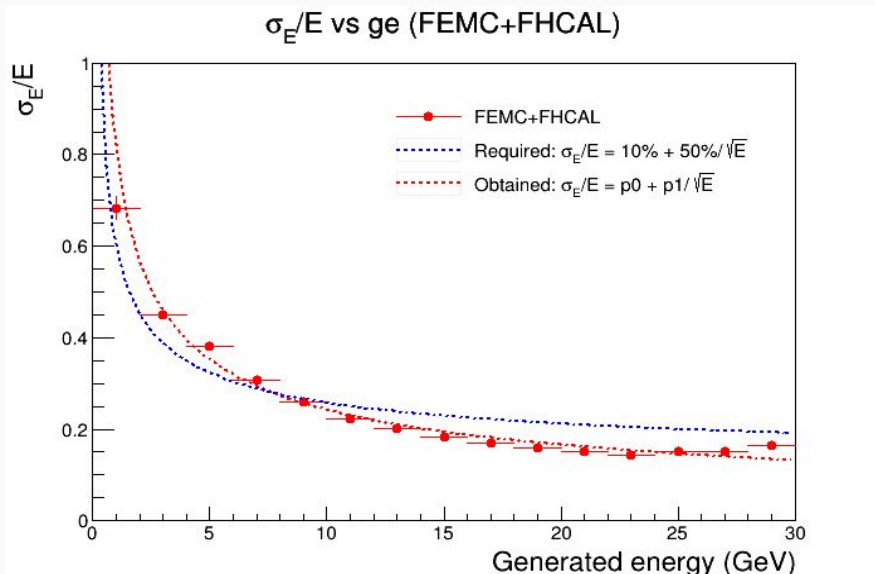


After Calibration

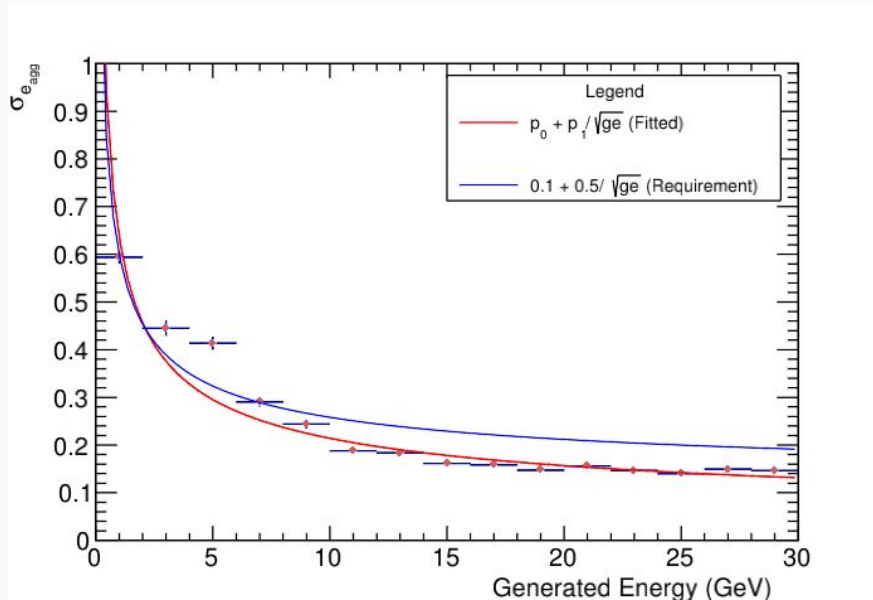


# Pion: FEMC + FHCAL

## After Calibration



$$\sigma_E/E = -2.06291\% + 83.4022\%/ \sqrt{E}$$



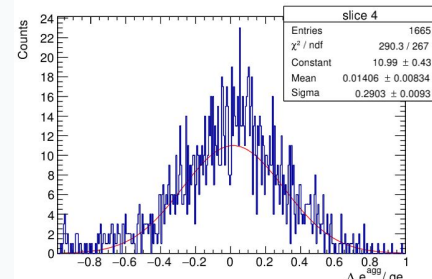
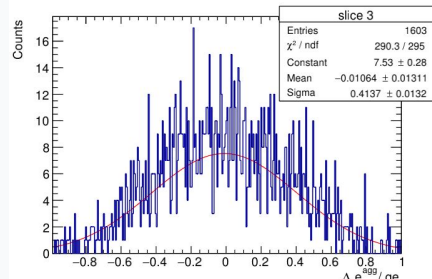
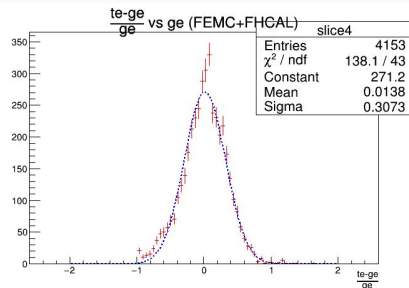
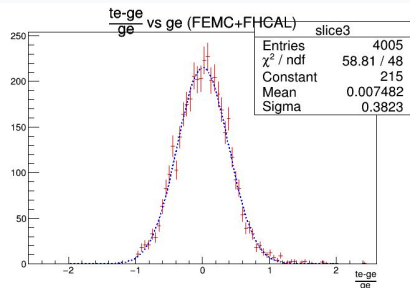
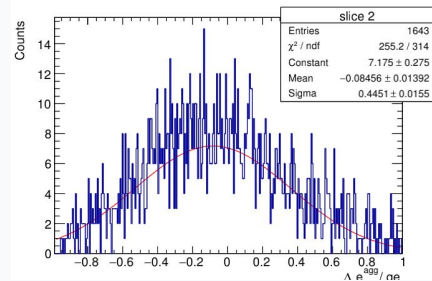
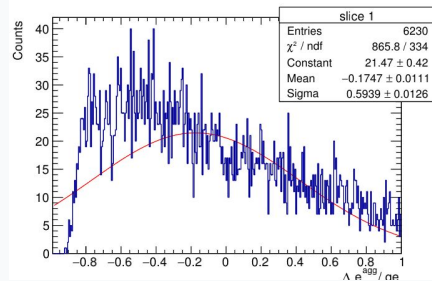
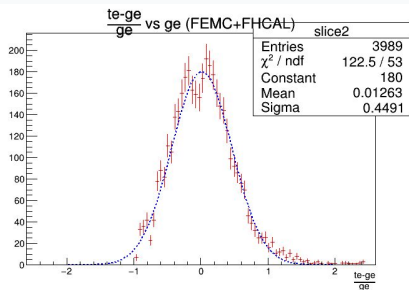
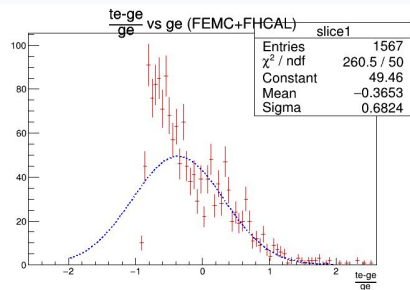
$$\sigma_E/E = 1.83350\% + 61.9024\%/ \sqrt{E}$$

- The obtained hadron energy resolution seems to match the minimum requirements for forward calorimeters.

# Pion: FEMC + FHCAL

## After Calibration

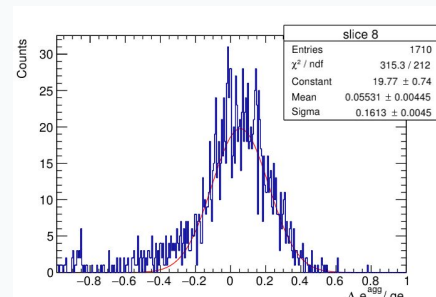
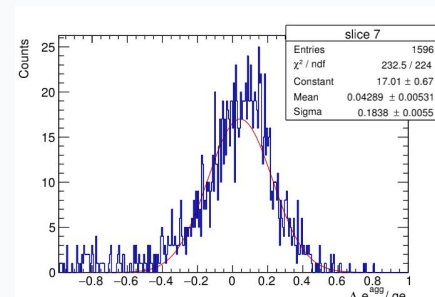
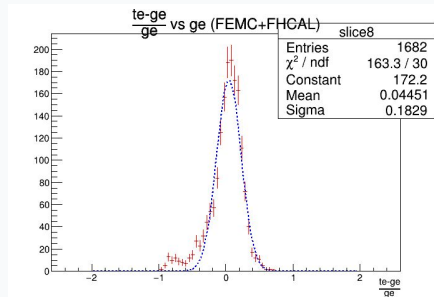
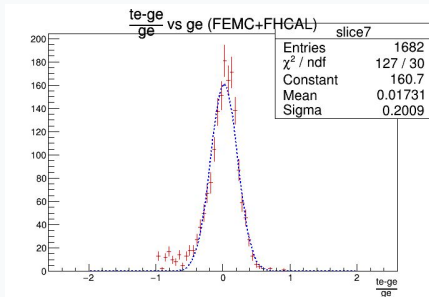
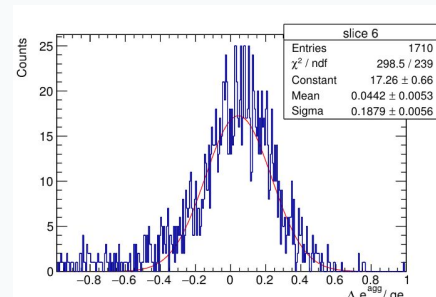
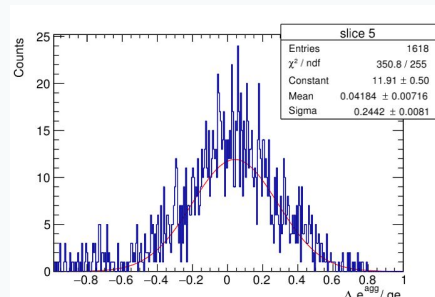
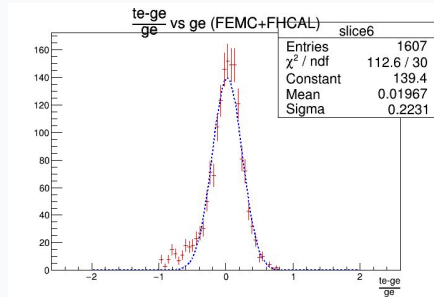
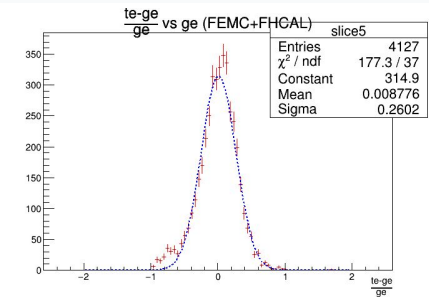
### Fit Slices



# Pion: FEMC + FHCAL

## After Calibration

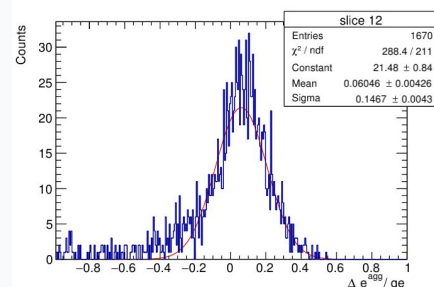
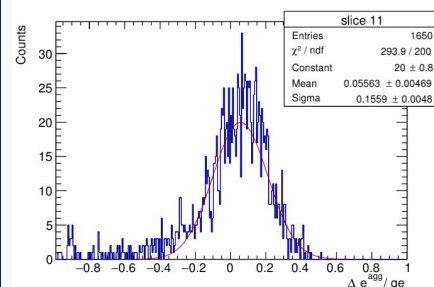
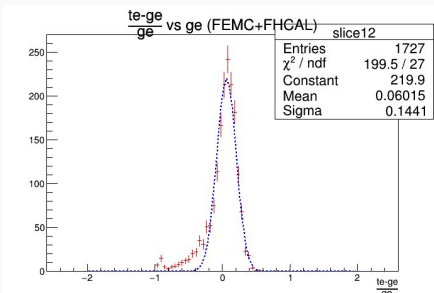
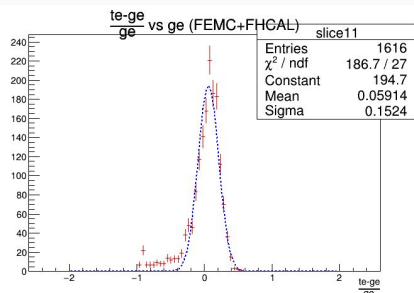
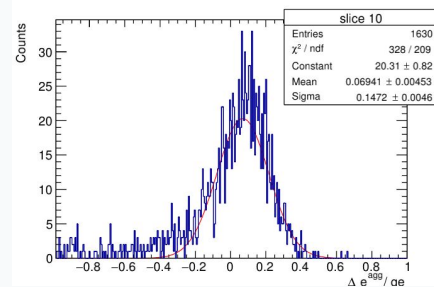
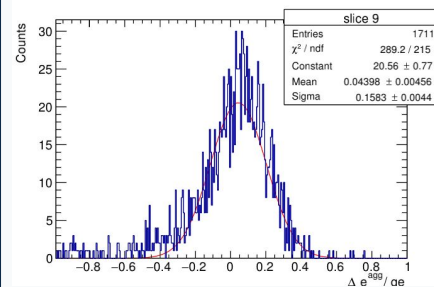
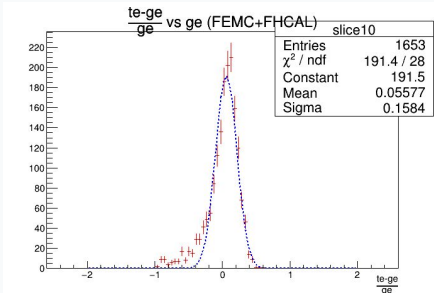
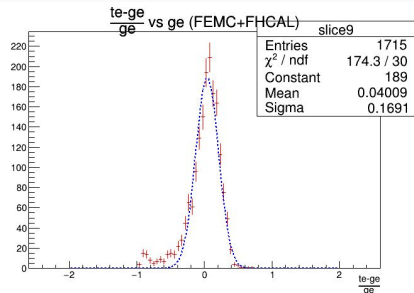
### Fit Slices



# Pion: FEMC + FHCAL

## After Calibration

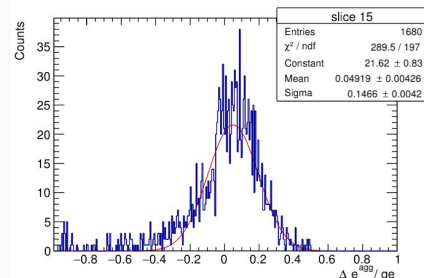
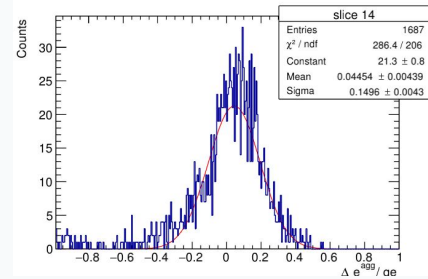
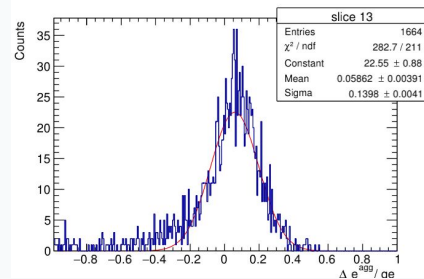
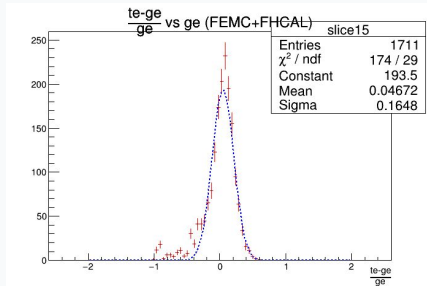
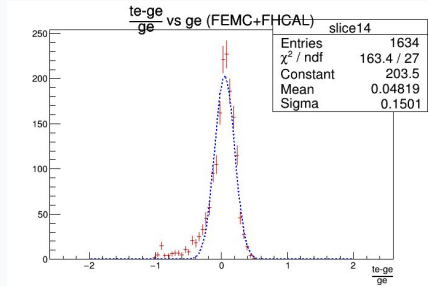
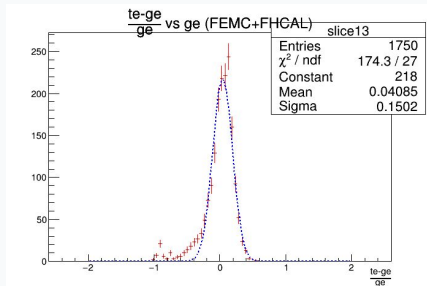
### Fit Slices



# Pion: FEMC + FHCAL

## After Calibration

### Fit Slices



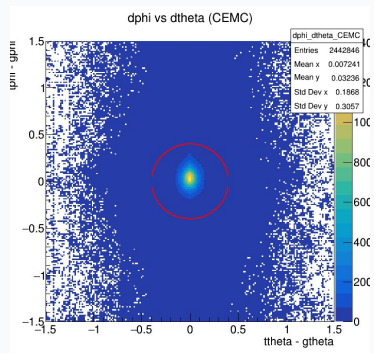
Pion : CEMC + HCALIN + HCALOUT



# Pion: CEMC + HCALIN + HCALOUT

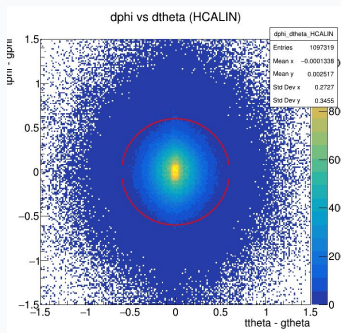
## Manual Clustering

CEMC:

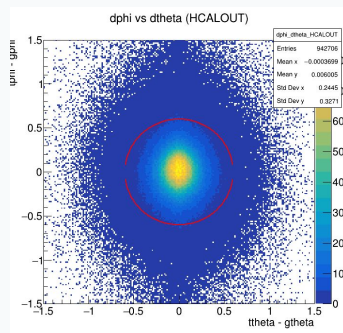


Radius = 0.40 units

HCAL:

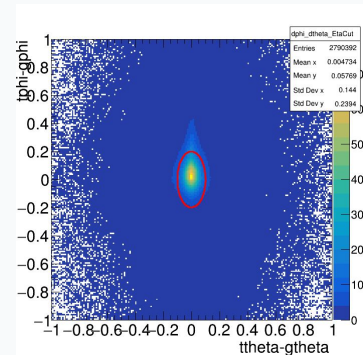


Radius = 0.60 units



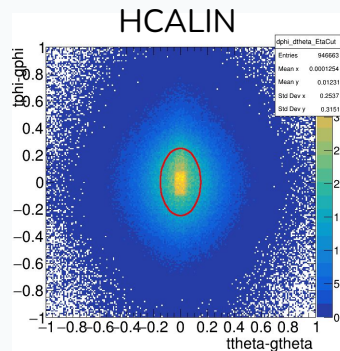
Radius = 0.60 units

CEMC:

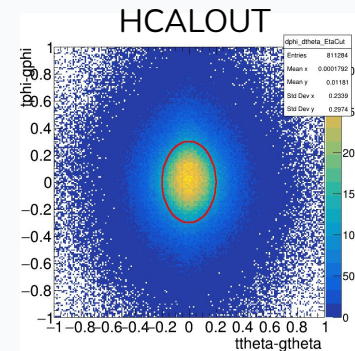


semi-minor axis = 0.10 units  
semi-major axis = 0.20 units

HCAL:



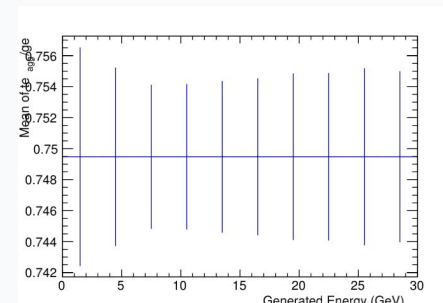
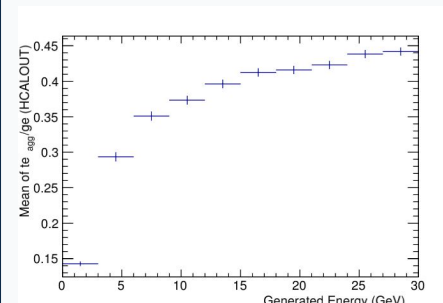
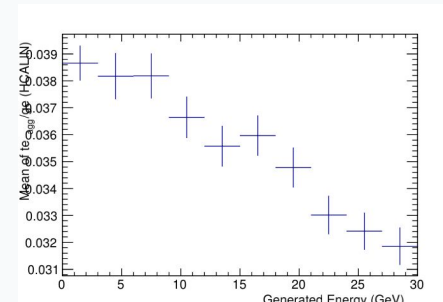
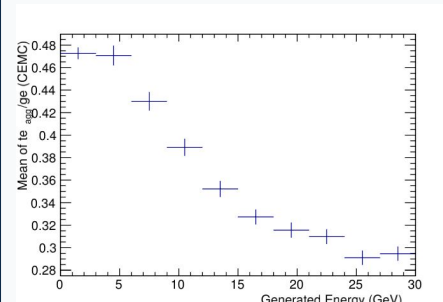
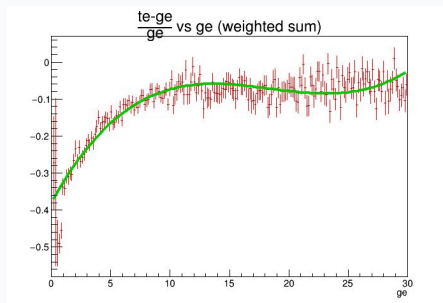
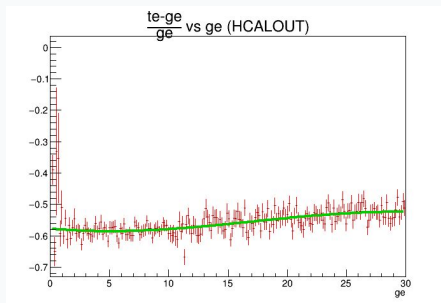
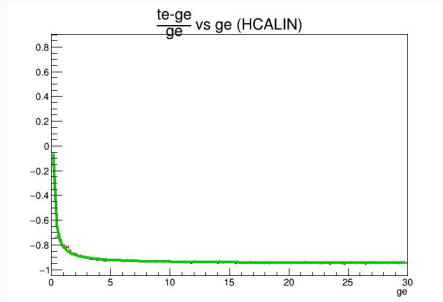
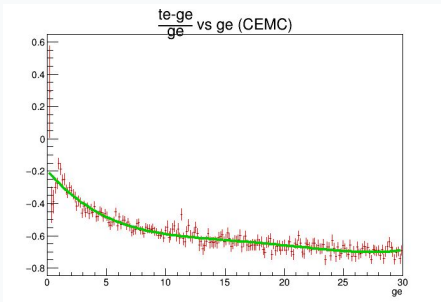
semi-minor axis = 0.15 units  
semi-major axis = 0.25 units



semi-minor axis = 0.20 units  
semi-major axis = 0.30 units

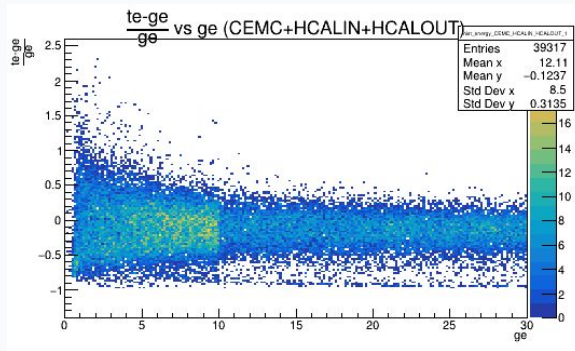
# Pion: CEMC + HCALIN + HCALOUT

## Steps involved in calibration

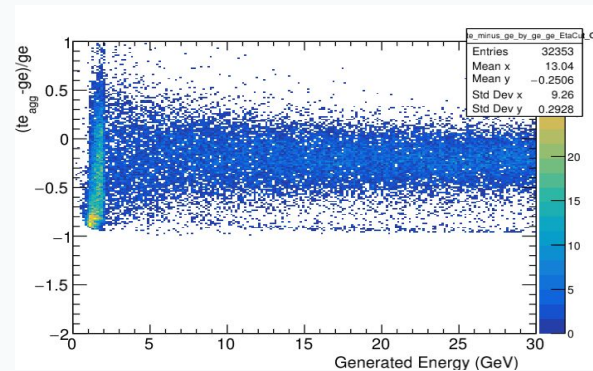


# Pion: CEMC + HCALIN + HCALOUT

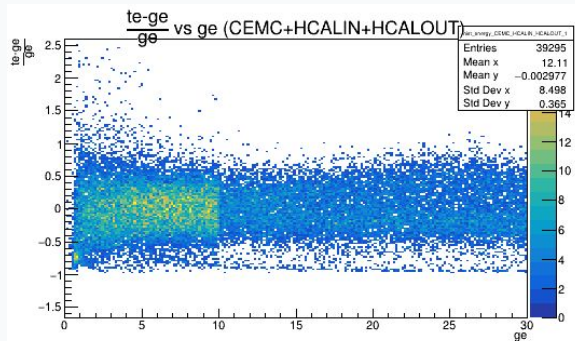
Before Calibration



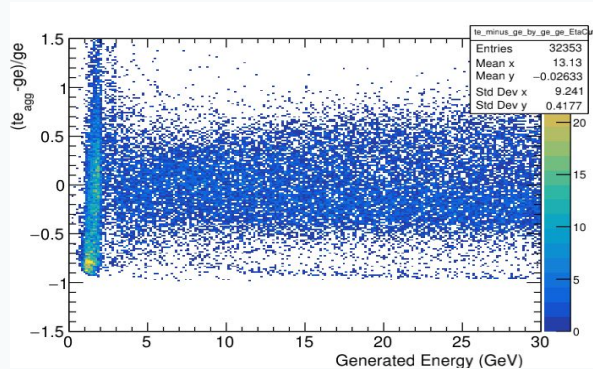
Before Calibration



After Calibration

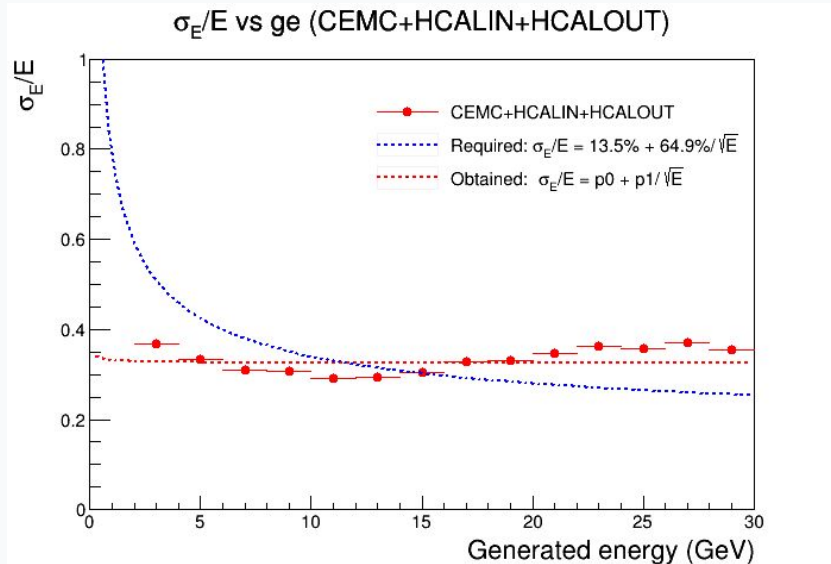


After Calibration

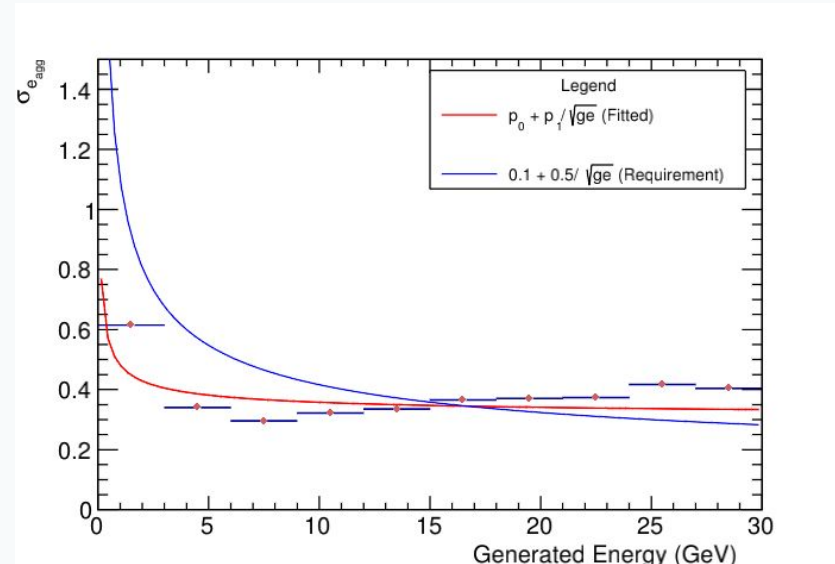


# Pion: CEMC + HCALIN + HCALOUT

## After Calibration



$$\sigma_E/E = 32.253\% + 0.979982\%/\sqrt{E}$$

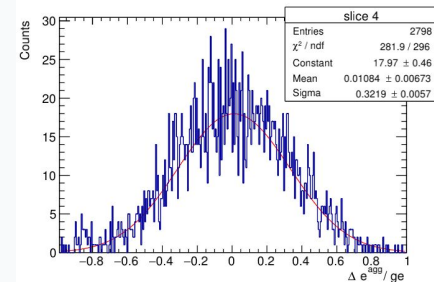
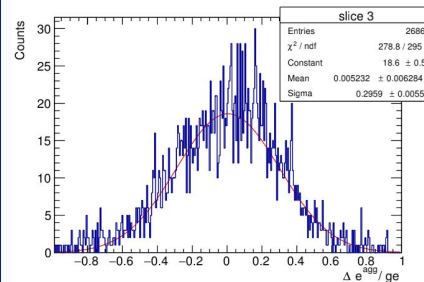
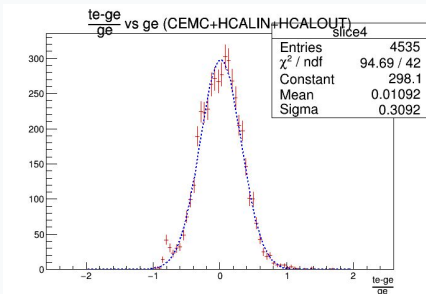
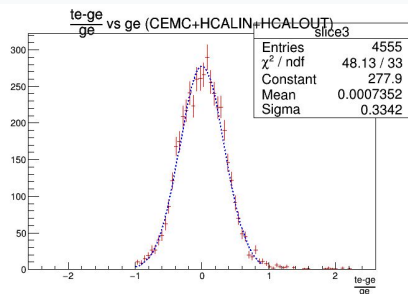
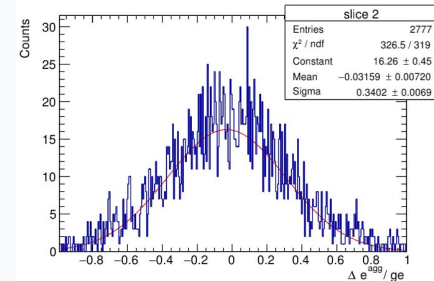
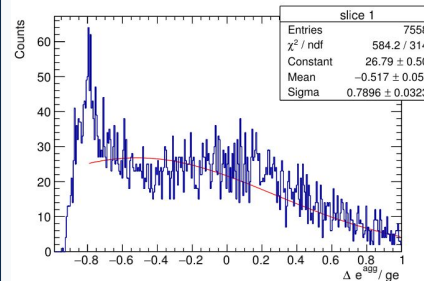
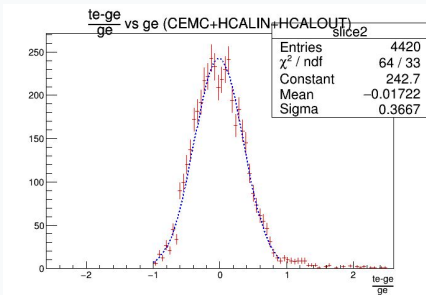
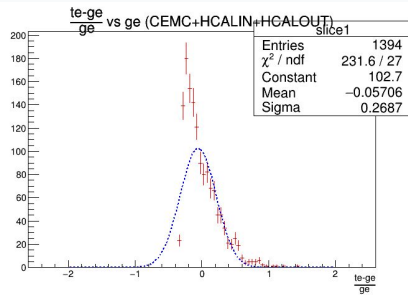


$$\sigma_E/E = 30.0277\% + 18.1573\%/\sqrt{E}$$

# Pion: CEMC + HCALIN + HCALOUT

## After Calibration

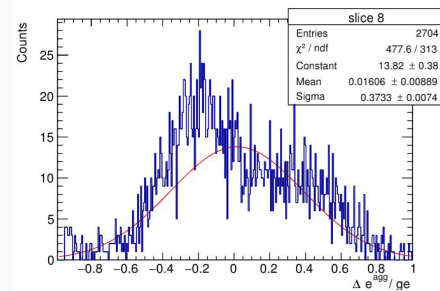
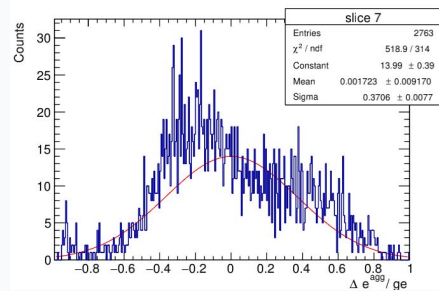
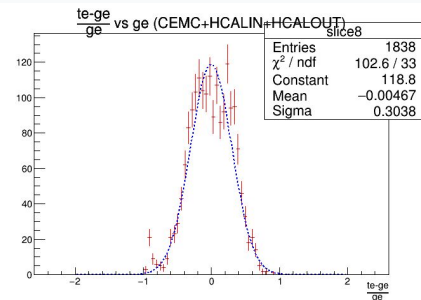
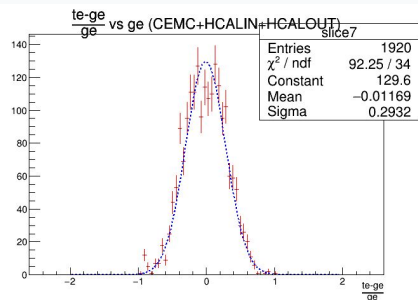
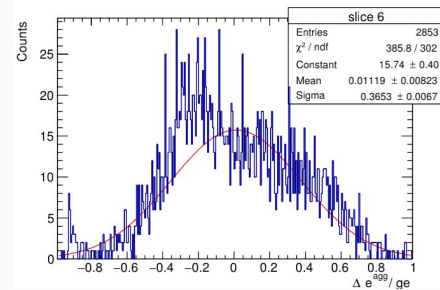
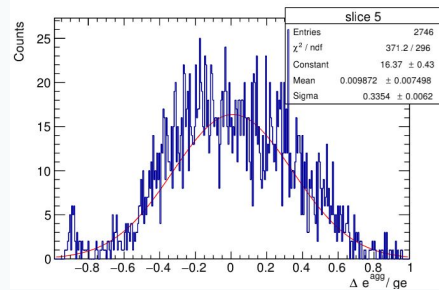
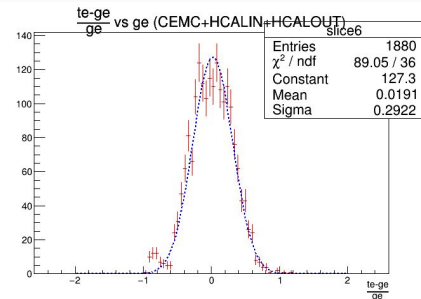
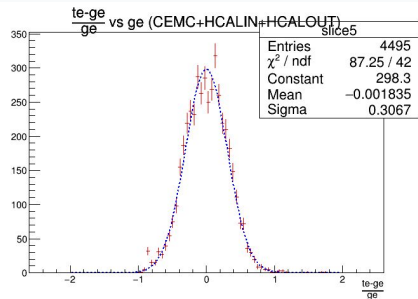
### Fit Slices



# Pion: CEMC + HCALIN + HCALOUT

## After Calibration

### Fit Slices

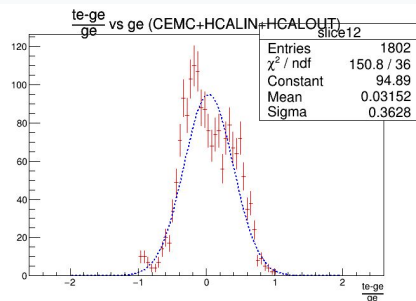
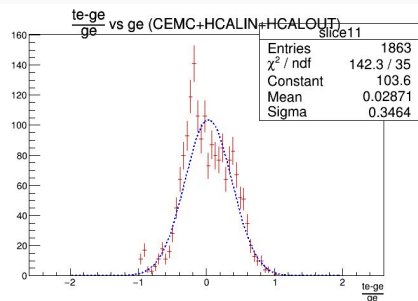
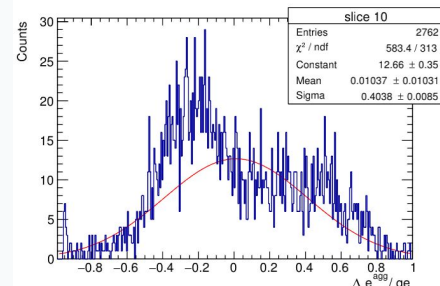
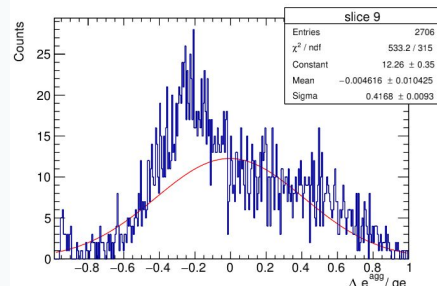
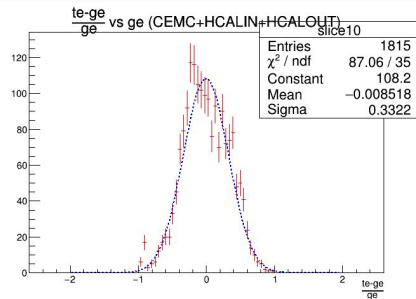
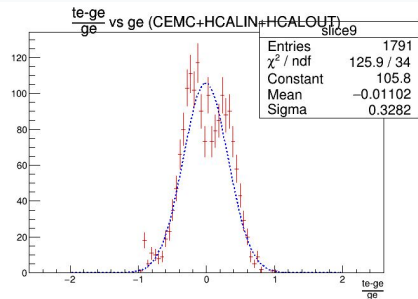




# Pion: CEMC + HCALIN + HCALOUT

## After Calibration

### Fit Slices



# Pion: CEMC + HCALIN + HCALOUT

## After Calibration

### Fit Slices

