Study of EMC Position Reconstruction

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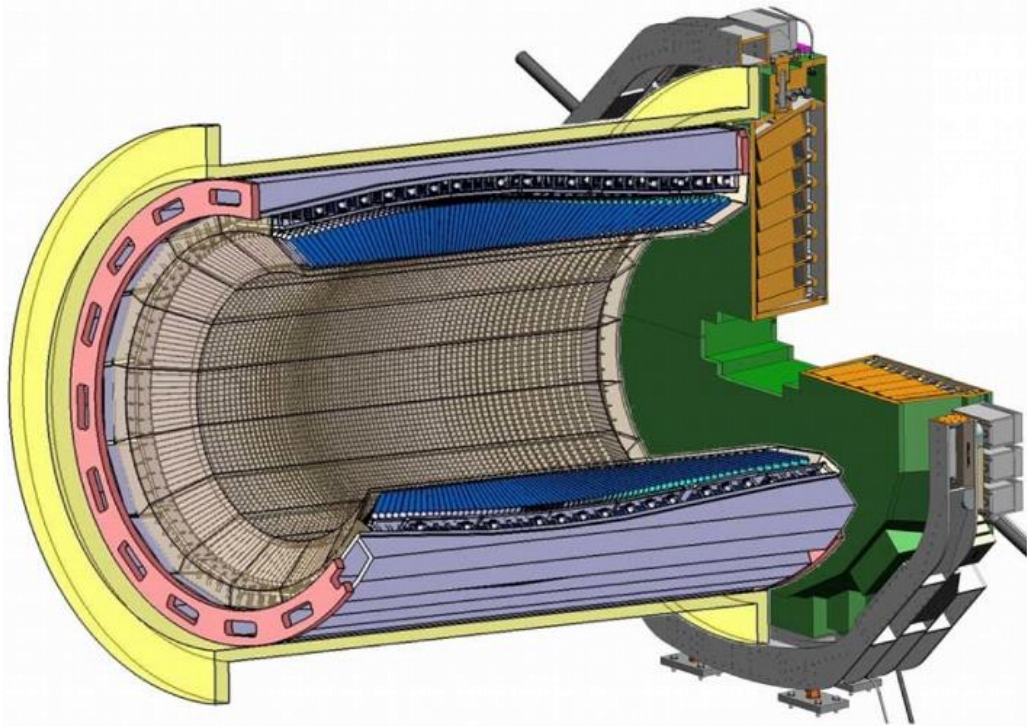
$\bar{\text{P}}$anda Collaboration Meeting

June 13, 2023

Introduction

- ✓ $\bar{P}$ANDA physics
  - Full reconstruction of multi-photon and lepton-pair channels of utmost importance
- ✓ Target Spectrometer
  - Barrel part and two endcaps
  - 15,580 crystals, improved PbWO4
  - X_0 = 0.89 cm, R_M = 2.00 cm
  - For barrel EMC, 11200 crystals, the average lateral size of crystal is 21.3mm
- ✓ Forward Spectrometer
  - Shashlik type sampling calorimeter
- ✓ Good energy and spatial resolution for photons
  - $\leq 1\% \oplus \frac{\leq 2\%}{\sqrt{E/GeV}}$(Target Spectrometer)
  - $\leq 0.5°$(backward), $\leq \mathbf{0.3°}$**(barrel),** $\leq 0.1°$(forward)

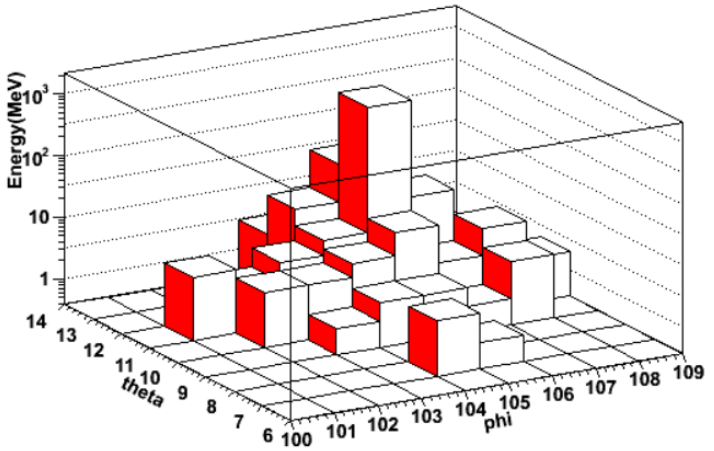


- For barrel EMC :
  - $22^\circ < \theta < 140^\circ$
  - $0^\circ < \phi < 360^\circ$

EMC Reconstruction

✓ Reconstruction

- Cluster Finding
  - Start at the crystal exhibiting the largest energy deposit
  - Find the neighbor crystals with energy deposit greater than a certain threshold until no more crystal fulfills the threshold criterion.



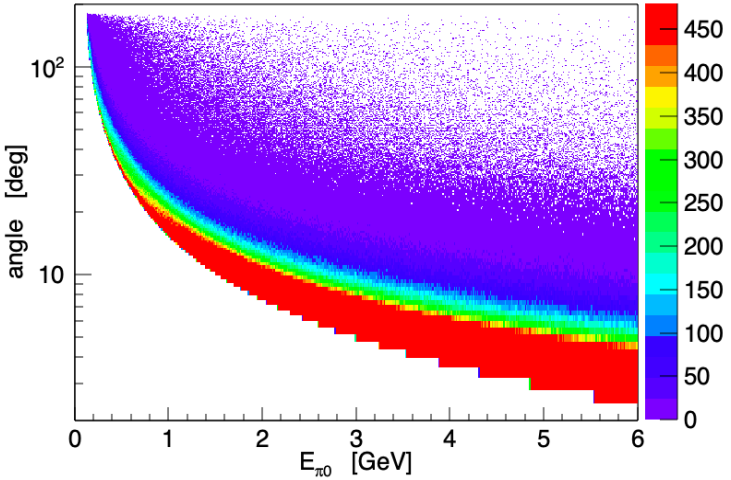
Schematic diagram of 1GeV energy clusters

- Cluster Splitting
  - An energy/position iterative algorithm is used:

$$E_{target} = E_{seed} \cdot \exp(-2.5\, r/R_M)$$

    - Estimate energies and positions of the single showers involved as input parameters
    - Calculate the fraction of energy for each shower deposited in same crystal

- **Cluster position calculation**
  - The spatial position of a cluster is calculated via a center-of-gravity method



Angles between the 2γ from π^0

Position Calculation Formula

✓ Shower position calculation:

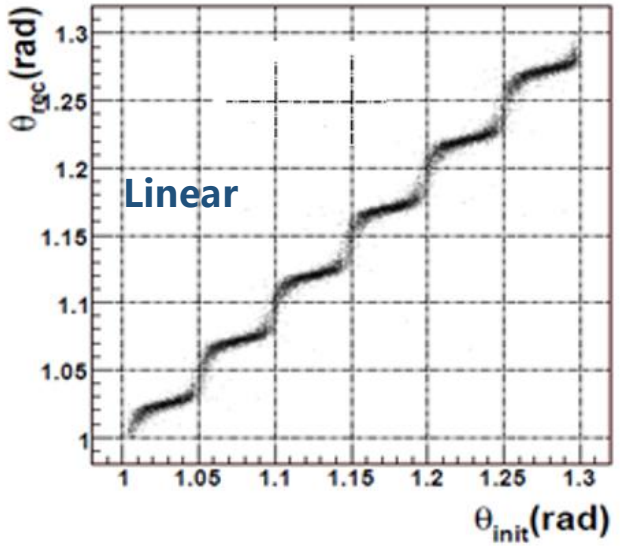
$$x^{rec} = \frac{\sum_j^N w_j \cdot x_j}{\sum_j^N w_j},\ x_j = \theta, \phi$$

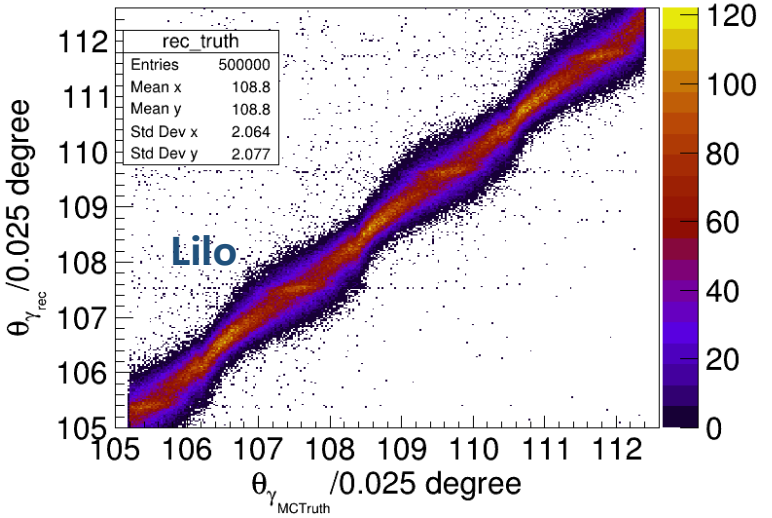
where x^{rec} is the reconstruction position of cluster, and x_j is the depth position of the j-th crystal.

- Weighting function: w_j
  - Linear:
    - $W_j = E_j$
  - Lilo:
    - $W_j = \mathrm{Max}\{0,\ \mathrm{Offset} + ln(E_j) - ln(E_{clus})\}$
      - $\mathrm{Offset} = \mathrm{OffsetParmA} - \mathrm{OffsetParmB} \cdot e^{-\mathrm{OffsetParmC} \cdot E_{clus}^{1.171}} \cdot E_{clus}^{-0.534}$
        - Raw OffsetParmA=4.071
        - Raw OffsetParmB=0.678
        - Raw OffsetParmC=1.000

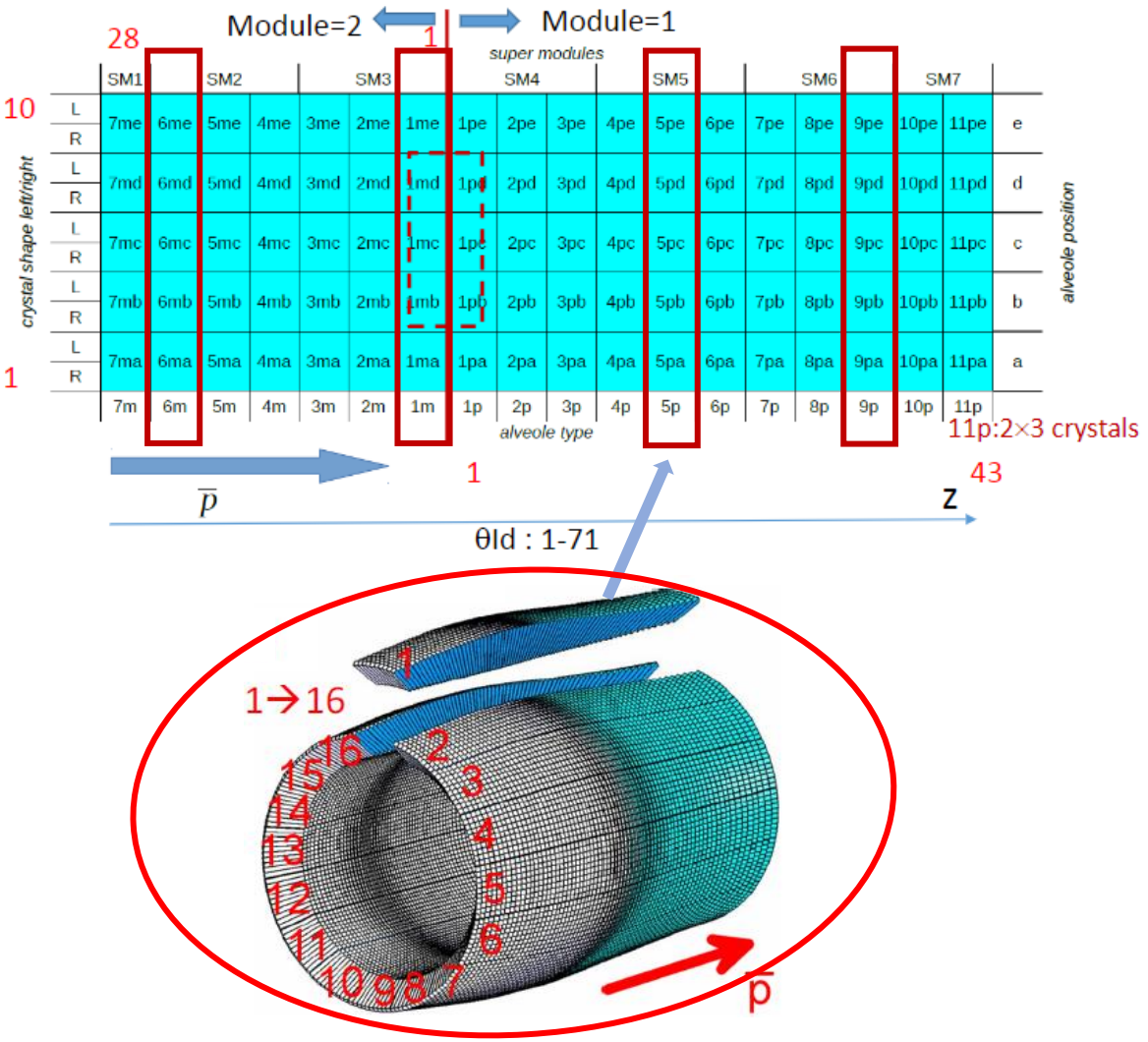
Parameters in PandaRoot Need to be checked

Technical Design Report for $\overline{\mathrm{P}}$ANDA Electromagnetic Calorimeter





Dataset



Barrel EMC Mechanical Structure

- ✓ Data sample
  - Energy: 0.1~6.0GeV
  - Particle: Single Photon
  - θ direction: 4 types of submodules

Location	SM2_6m	SM3_1m	SM5_5p	SM6_9p
Range	(128.4°, 134.8°)	(87.6°, 95.6°)	(48.0°, 54.4°)	(28.4°, 31.6°)

  - ϕ direction: (0°, 360°)
  - Event number: 10000

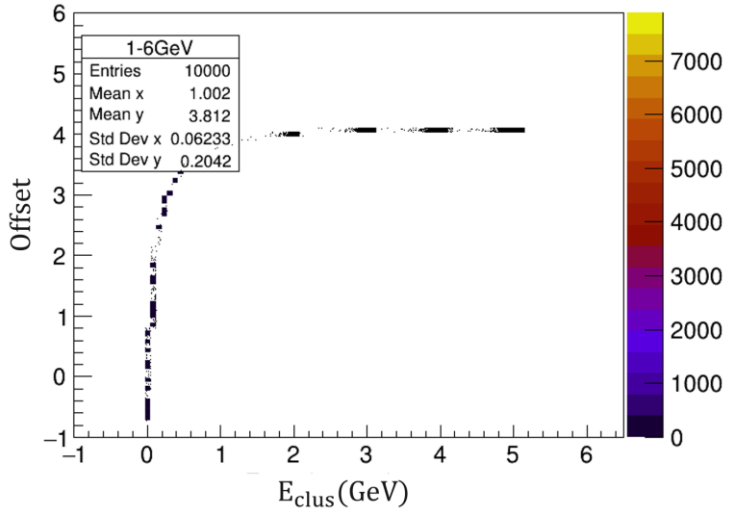
Offset measurements and parameterization

✓ Measure offset by chis-square fit to simulation data:

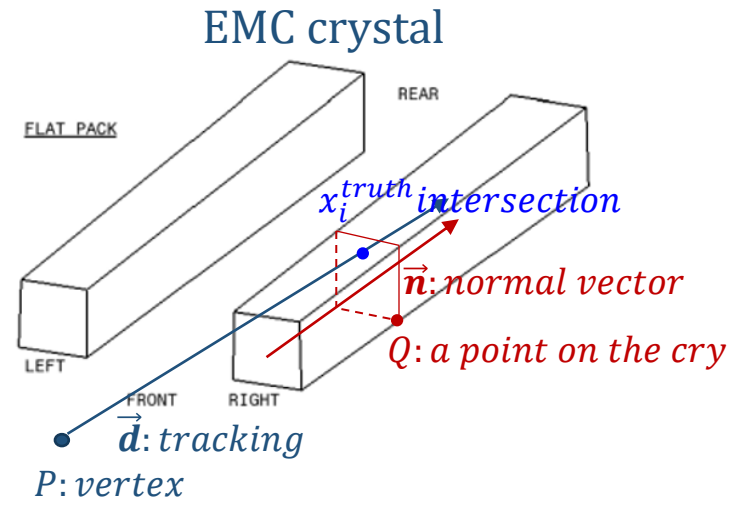
$$\chi^2 = \sum_i^N \frac{(x_i^{rec}(offset) - x_i^{truth})^2}{\sigma_i^2}, x = \theta, \phi$$

where x_i^{rec} and x_i^{truth} are the reconstruction and MCtruth position of the i-th event.

- $x_i^{rec} = \frac{\sum_j^N w_j \cdot x_j}{\sum_j^N w_j}$, $W_j = \mathrm{Max}\{0, \mathrm{Offset} + ln(E_j) - ln(E_{clus})\}$
- MCtruth position(x_i^{truth}) is the intersection of tracking and depth plane:
  - $x_i^{truth} = P + t\vec{d}$, $t = \frac{(P-Q)\cdot\vec{n}}{\vec{d}\cdot\vec{n}}$



The offset curve of the raw offset parameters

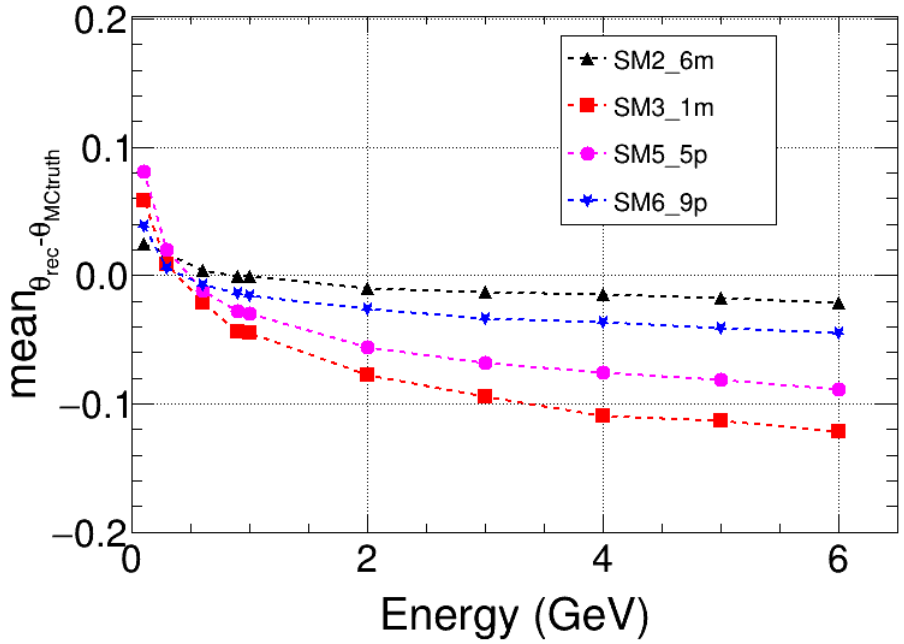


The position calculation schematic of MCTruth

Fit Method

- ✓ Three different chisq fit methods are used
  - Method **A: theta as object**
    - $\chi^2 = \sum_i^N \frac{(\theta_i^{rec} - \theta_i^{truth})^2}{\sigma_i^2}$
  - Method **B: phi as object**
    - $\chi^2 = \sum_i^N \frac{(\phi_i^{rec} - \phi_i^{truth})^2}{\sigma_i^2}$
  - Method **C**: **theta as object with mean correction**
    1. Make a correction of the mean shift
    2. $\chi^2 = \sum_i^N \frac{(\theta_i^{rec} - \theta_i^{truth})^2}{\sigma_i^2}$
- ✓ The theta and phi distribution of three methods are checked.

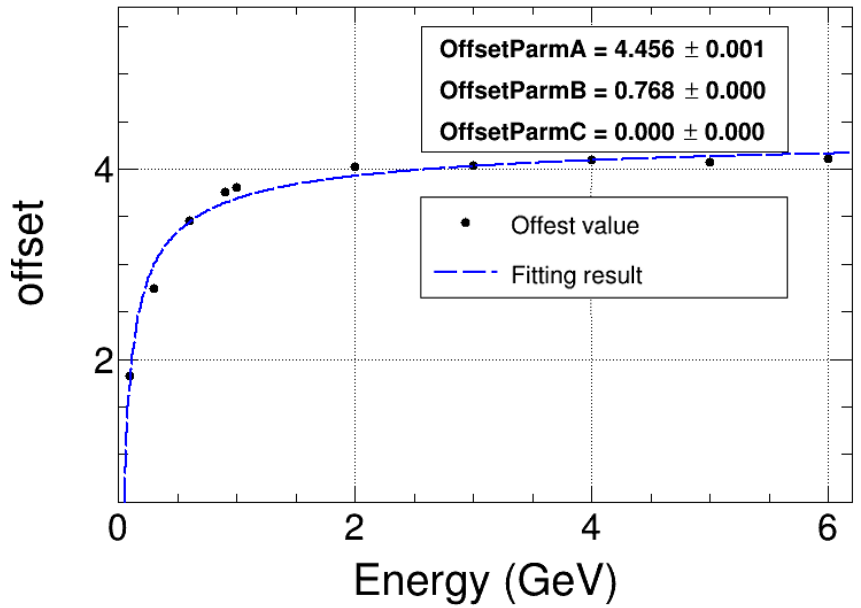
- ✓ Mean shift phenomenon at the fitting result



$\text{mean}_{\theta_{rec}-\theta_{MCTruth}}$ vs. Energy

Fit Method A: theta as object

- ✓ Result of Updated Offset Parameters
  - $\theta = (128.4, 134.8)$
  - $\chi^2 = \sum_i^N \frac{(\theta_i^{rec} - \theta_i^{truth})^2}{\sigma_i^2}$



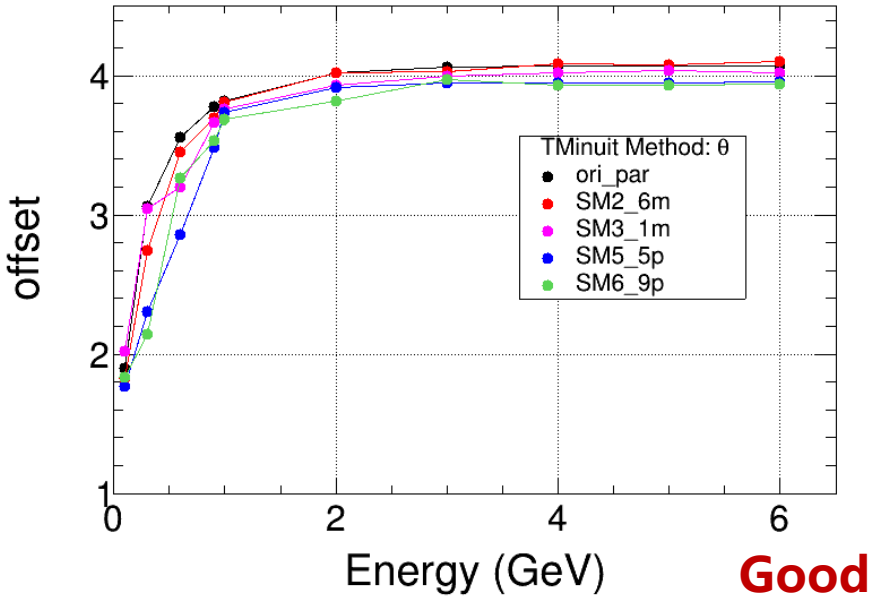
Distribution of offset values at different energy points and fitting result

Fitting :

- $\text{Offset} = \text{OffsetParmA} - \text{OffsetParmB} \cdot e^{-\text{OffsetParmC} \cdot E^{1.171}} \cdot E^{-0.534}$

The result of fit the distribution of offset values at different energy points with different data samples.

Original parameter	SM2_6m $(128.4, 134.8)$	SM3_1m $(87.6, 95.6)$	SM5_5p $(48.0, 54.4)$	SM6_9p $(28.4, 31.6)$
A=4.071 B=0.678 C=1.000	A=4.456 B=0.768 C=0.000	A=4.049 B=0.688 C=0.224	A=3.978 B=0.762 C=0.423	A=4.308 B=0.743 C=0.000

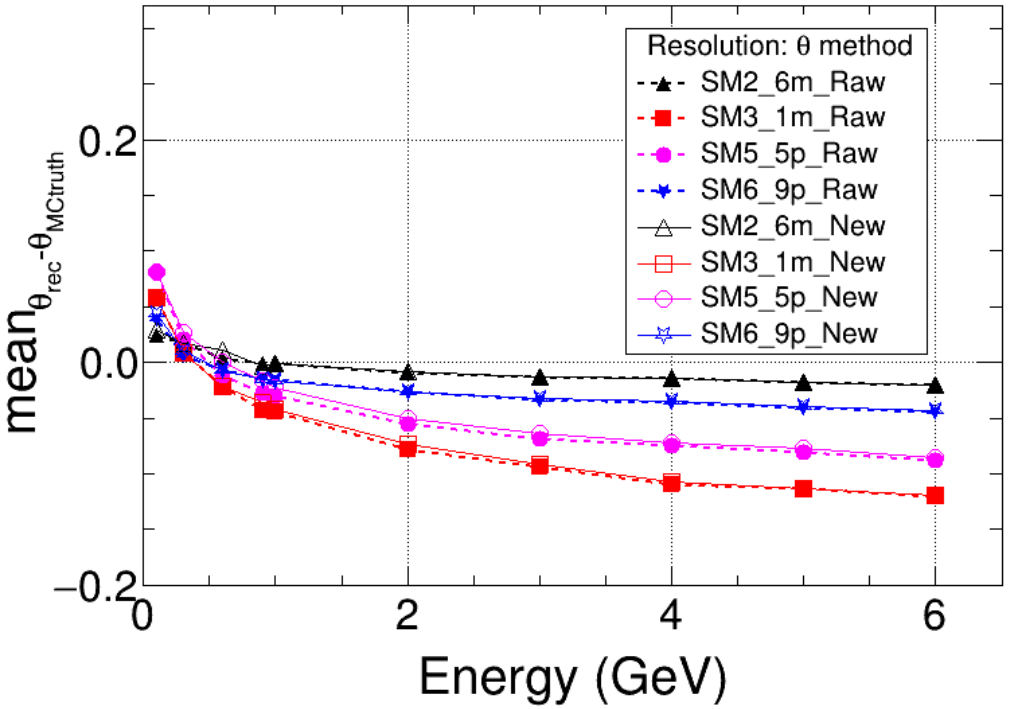


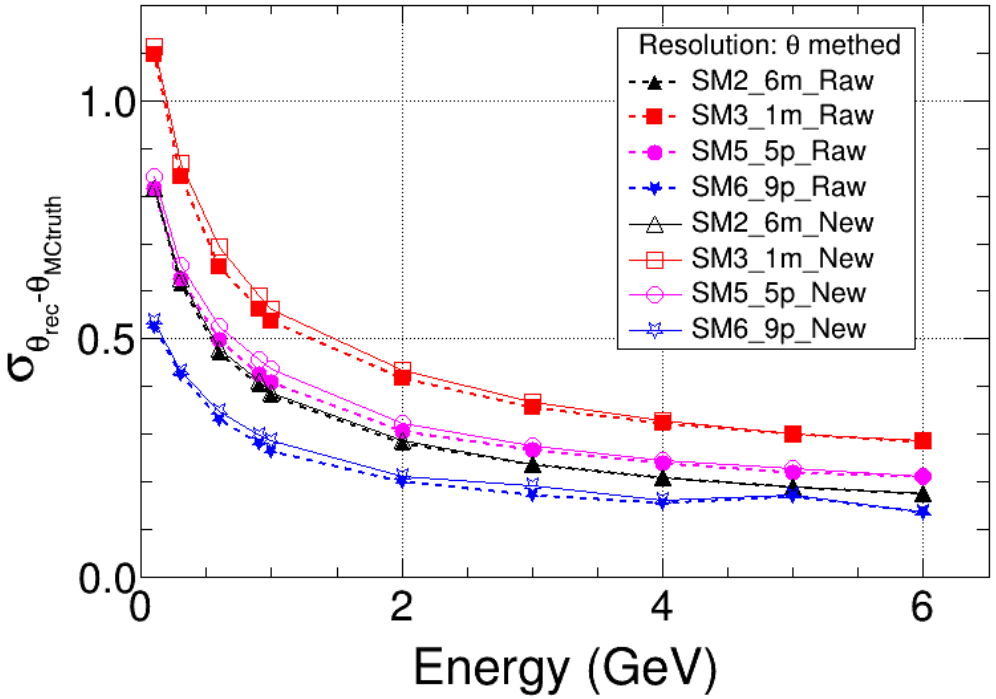
Good consistency

The distribution of offset value at different energy points with different data samples.

Theta check (method A)

- ✓ Theta distribution
  - $\chi^2 = \sum_i^N \frac{(\theta_i^{rec} - \theta_i^{truth})^2}{\sigma_i^2}$
  - SM2_6m, SM3_1m, SM5_5p, and SM6_9p, in range (128.4°, 134.8°), (87.6°, 95.6°), (48.0°, 54.4°), and (28.4°, 31.6°).

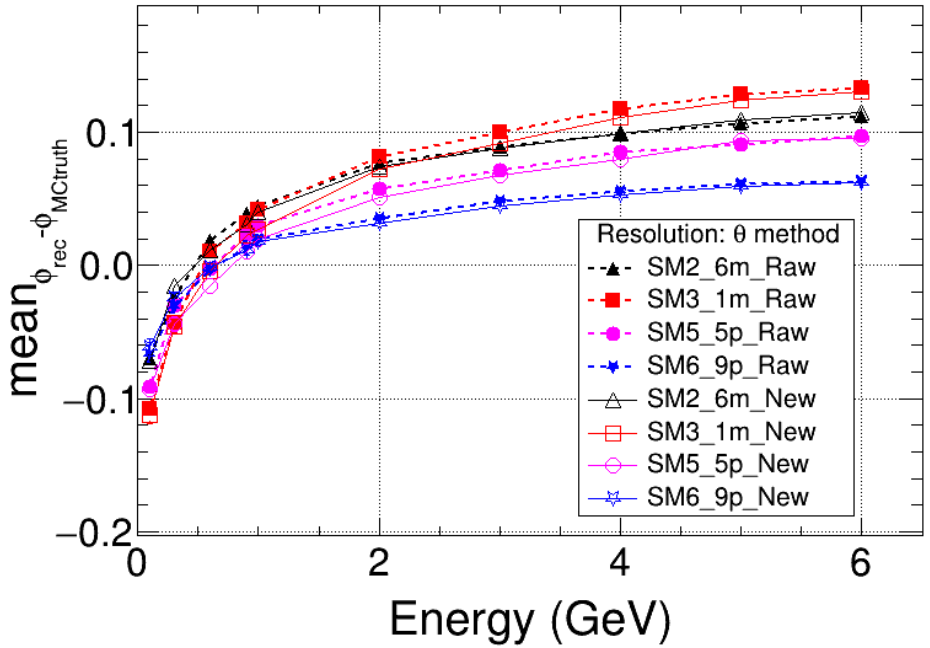


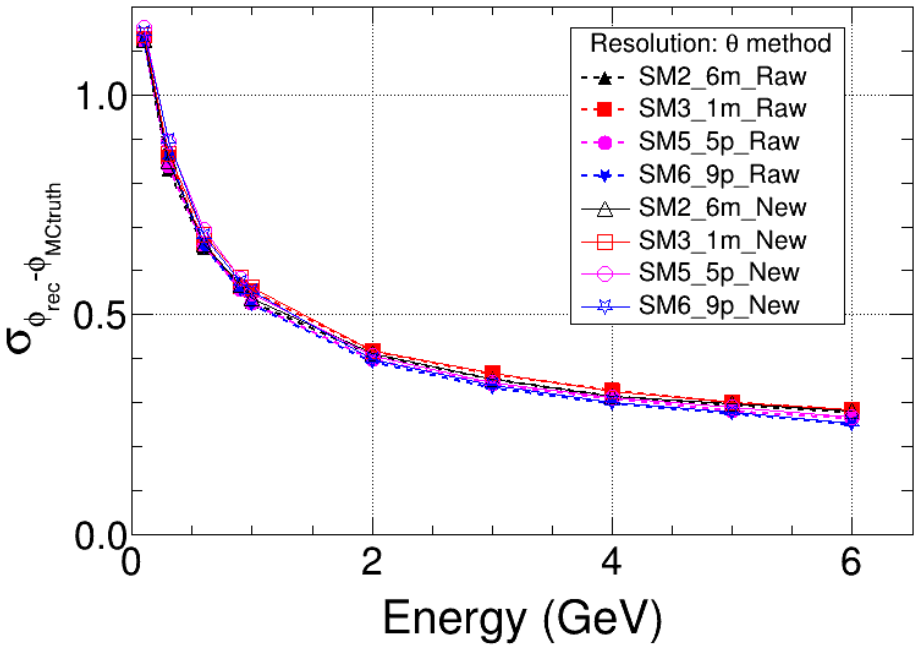


The distribution of origin and updated offset parameter fitting result of $\boldsymbol{\theta_{rec} - \theta_{MCTruth}}$ at different energy points with different data samples.

Phi check (method A)

- ✓ Phi distribution
  - $\chi^2 = \sum_i^N \frac{(\theta_i^{rec} - \theta_i^{truth})^2}{\sigma_i^2}$
  - SM2_6m, SM3_1m, SM5_5p, and SM6_9p, in range (128.4°, 134.8°), (87.6°, 95.6°), (48.0°, 54.4°), and (28.4°, 31.6°).



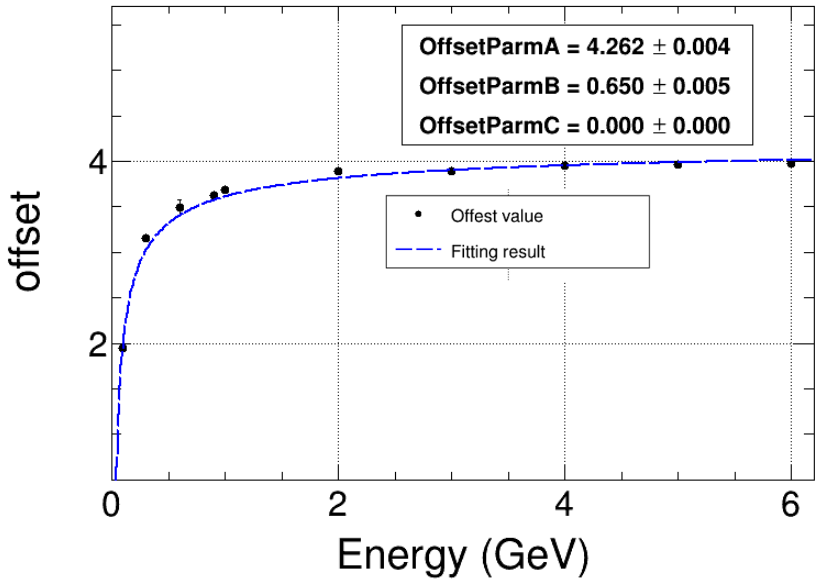


The distribution of origin and updated offset parameter fitting result of $\phi_{rec} - \phi_{MCTruth}$ at different energy points with different data samples.

Good consistency among method A and the PandaRoot values

Fit Method B: phi as object

- ✓ Result of Updated Offset Parameters
  - $\theta = (128.4, 134.8)$
  - $\chi^2 = \sum_i^N \frac{(\phi_i^{rec} - \phi_i^{truth})^2}{\sigma_i^2}$



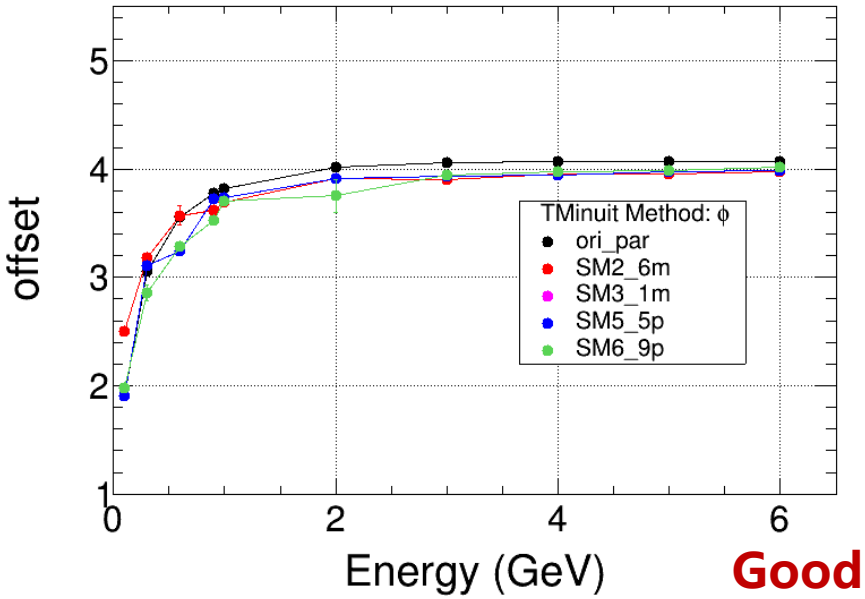
Distribution of offset values at different energy points and fitting result

Fitting :

- $\text{Offset} = \text{OffsetParmA} - \text{OffsetParmB} \cdot e^{-\text{OffsetParmC} \cdot E^{1.171}} \cdot E^{-0.534}$

The result of fit the distribution of offset values at different energy points with different data samples.

Original parameter	SM2_6m $(128.4, 134.8)$	SM3_1m $(87.6, 95.6)$	SM5_5p $(48.0, 54.4)$	SM6_9p $(28.4, 31.6)$
A=4.071 B=0.678 C=1.000	A=4.262 B=0.650 C=0.000	A=4.287 B=0.643 C=0.000	A=4.287 B=0.691 C=0.000	A=4.184 B=0.649 C=0.071

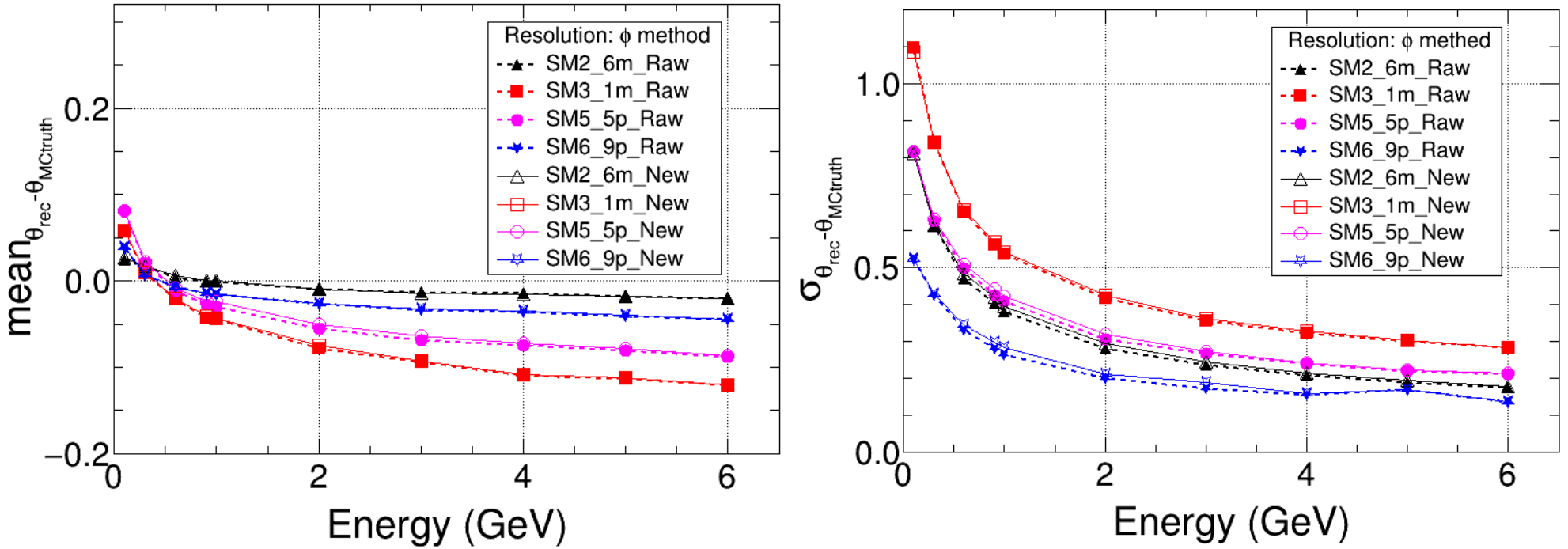


Good consistency

The distribution of offset value at different energy points with different data samples.

Theta check (method B)

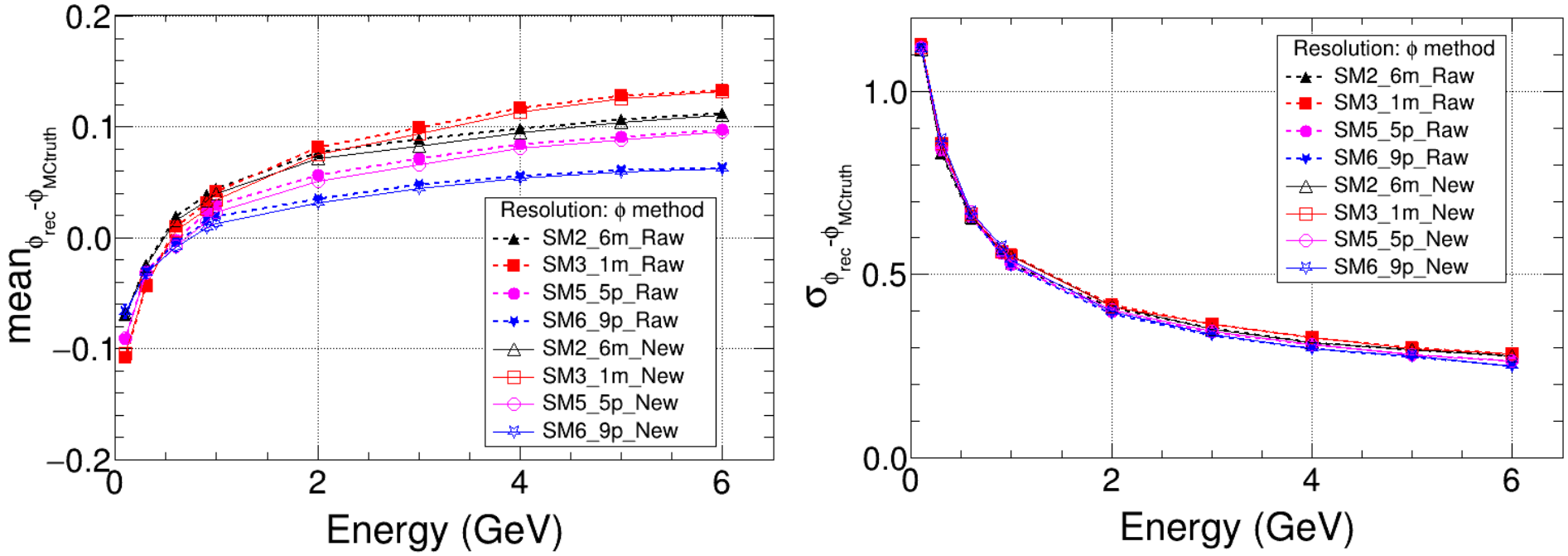
- ✓ Theta distribution
  - $\chi^2 = \sum_i^N \frac{(\phi_i^{rec} - \phi_i^{truth})^2}{\sigma_i^2}$
  - SM2_6m, SM3_1m, SM5_5p, and SM6_9p, in range (128.4°, 134.8°), (87.6°, 95.6°), (48.0°, 54.4°), and (28.4°, 31.6°).



The distribution of origin and updated offset parameter fitting result of $\theta_{rec} - \theta_{MCTruth}$ at different energy points with different data samples.

Phi check (method B)

- ✓ Phi distribution
  - $\chi^2 = \sum_i^N \frac{(\phi_i^{rec} - \phi_i^{truth})^2}{\sigma_i^2}$
  - SM2_6m, SM3_1m, SM5_5p, and SM6_9p, in range (128.4°, 134.8°), (87.6°, 95.6°), (48.0°, 54.4°), and (28.4°, 31.6°).



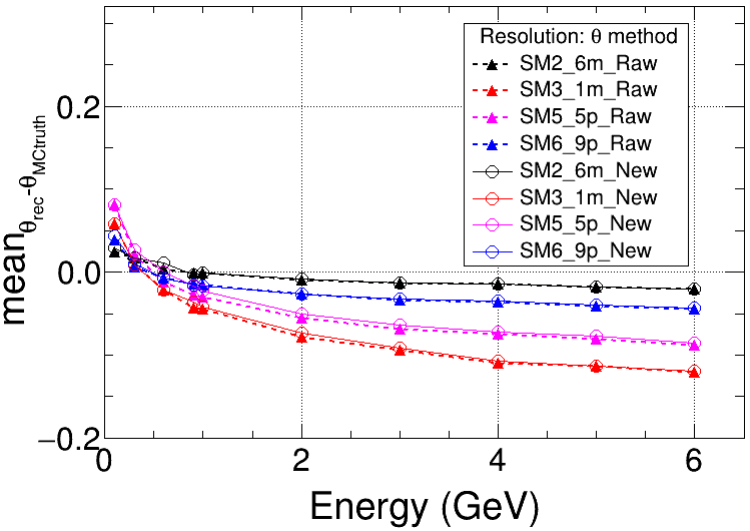
The distribution of origin and updated offset parameter fitting result of $\phi_{rec} - \phi_{MCTruth}$ at different energy points with different data samples.

Good consistency among method B and the PandaRoot values

Fit Method C: theta as object with mean correction

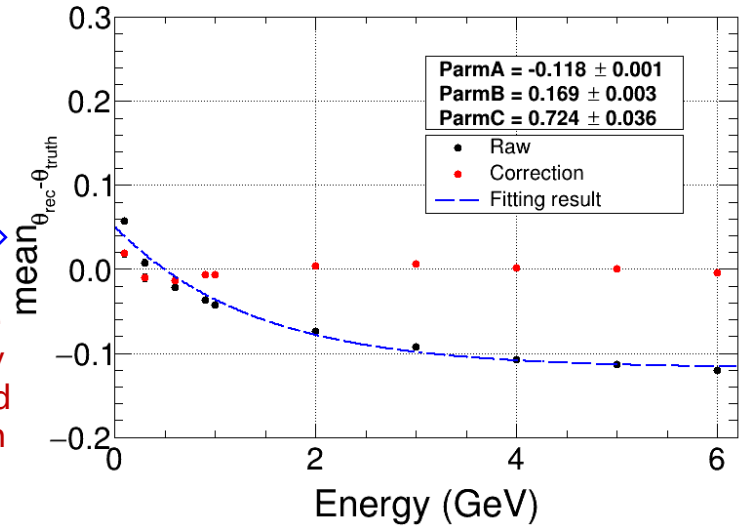
✓ Mean shift phenomenon at the fitting result

- $\theta = (87.6, 95.6),\ \chi^2 = \sum_i^N \frac{(\theta_i^{rec} - \theta_i^{truth})^2}{\sigma_i^2}$



$\text{mean}_{\theta_{rec}-\theta_{MCTruth}}$ vs. Energy

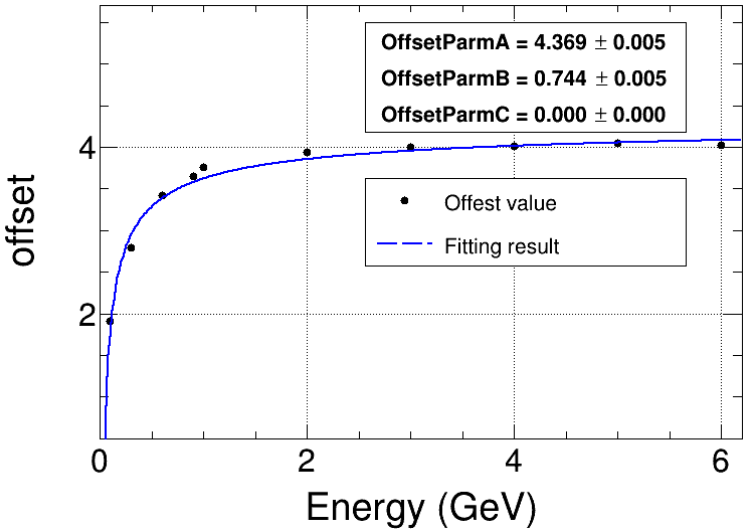
Correcting the mean curve by the constructed fitting function



$mean_{\theta_{rec}-\theta_{MCTruth}}$ vs. Energy

Fitting:

$$\text{Mean} = \text{ParmA} + \text{ParmB} \cdot e^{-\text{E}\cdot\text{ParmC}}$$



offset vs. Energy

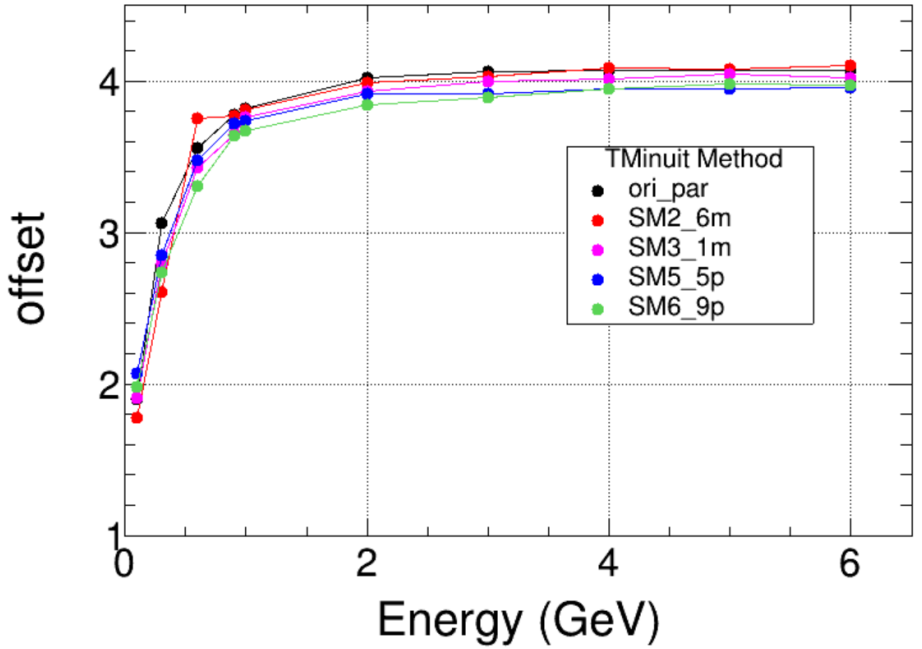
Fitting :

$$\text{Offset} = \text{OffsetParmA} - \text{OffsetParmB} \cdot e^{-\text{OffsetParmC}\cdot E^{1.171}} \cdot E^{-0.534}$$

- Chi2 is biased because of the mean shift, so we make a correction
- The shift is removed after the correction
- Re-perform the chisq fit

Fit Method C: theta as object with mean correction

Original parameter	SM2_6m (128.4, 134.8)	SM3_1m (87.6, 95.6)	SM5_5p (48.0, 54.4)	SM6_9p (28.4, 31.6)
A=4.071 B=0.678 C=1.000	A=4.463 B=0.725 C=0.000	A=4.369 B=0.744 C=0.224	A=4.298 B=0.657 C=0.000	A=3.955 B=0.611 C=0.474

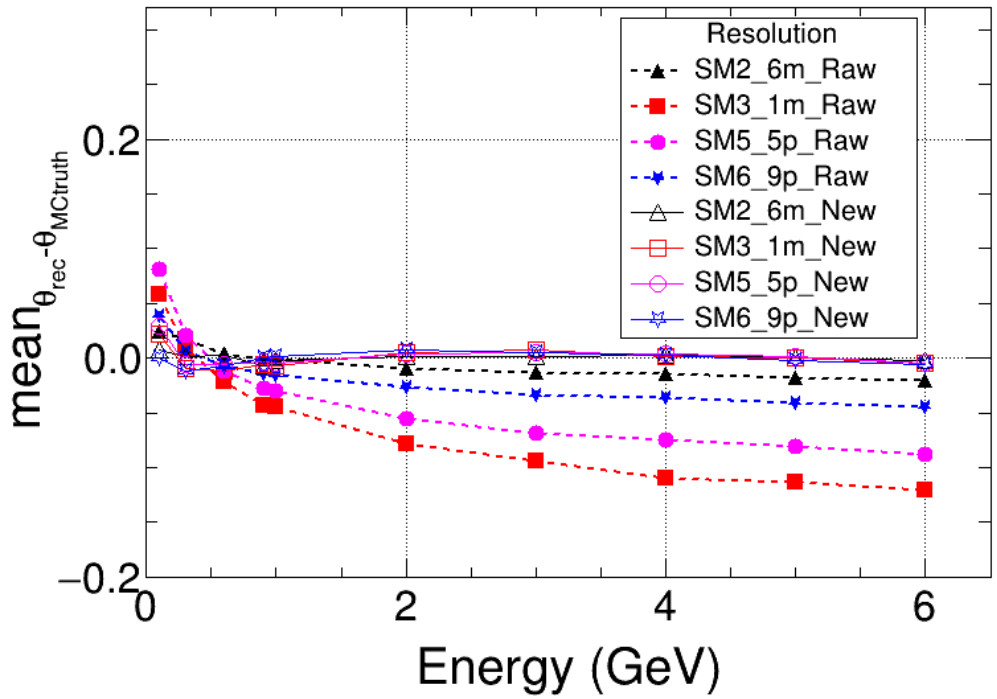


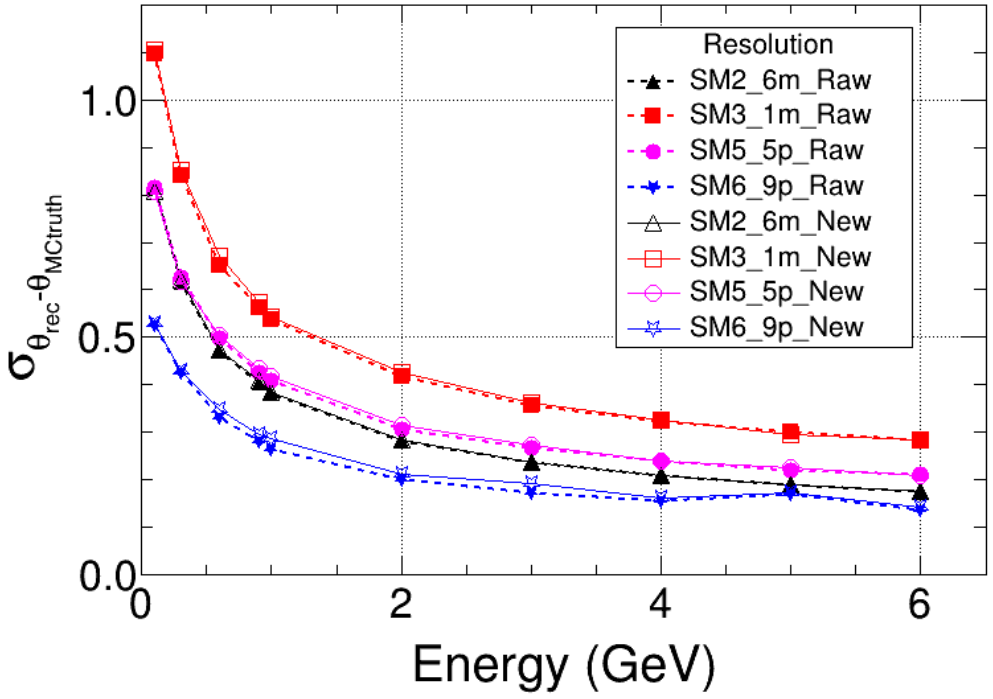
Good consistency

The distribution of offset value at different energy points with different data samples.

Theta check (method C)

✓ Theta distribution
- SM2_6m, SM3_1m, SM5_5p, and SM6_9p, in range (128.4°, 134.8°), (87.6°, 95.6°), (48.0°, 54.4°), and (28.4°, 31.6°).

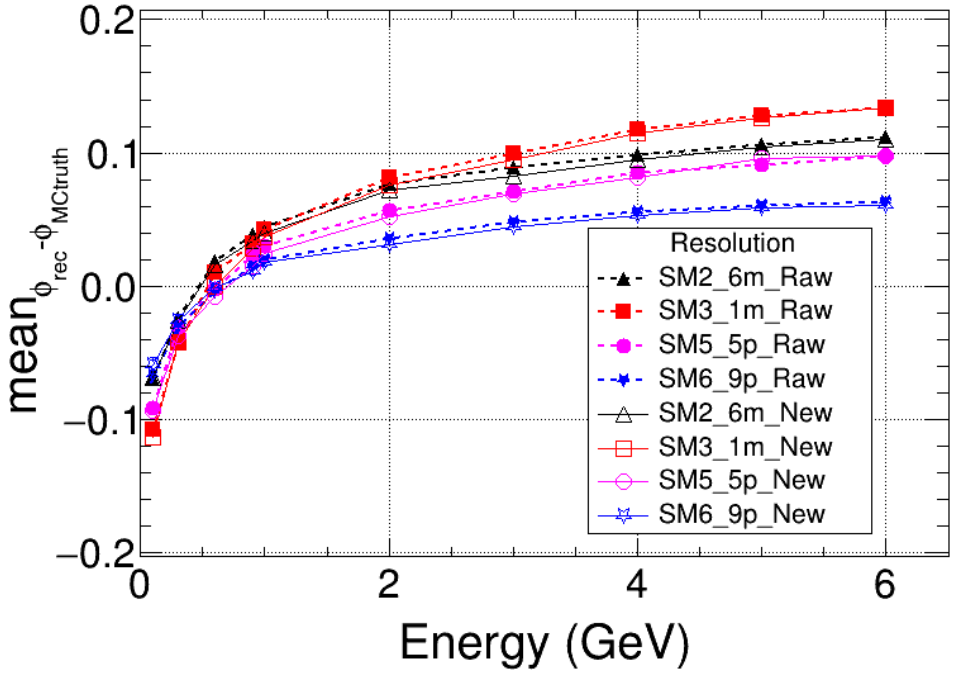


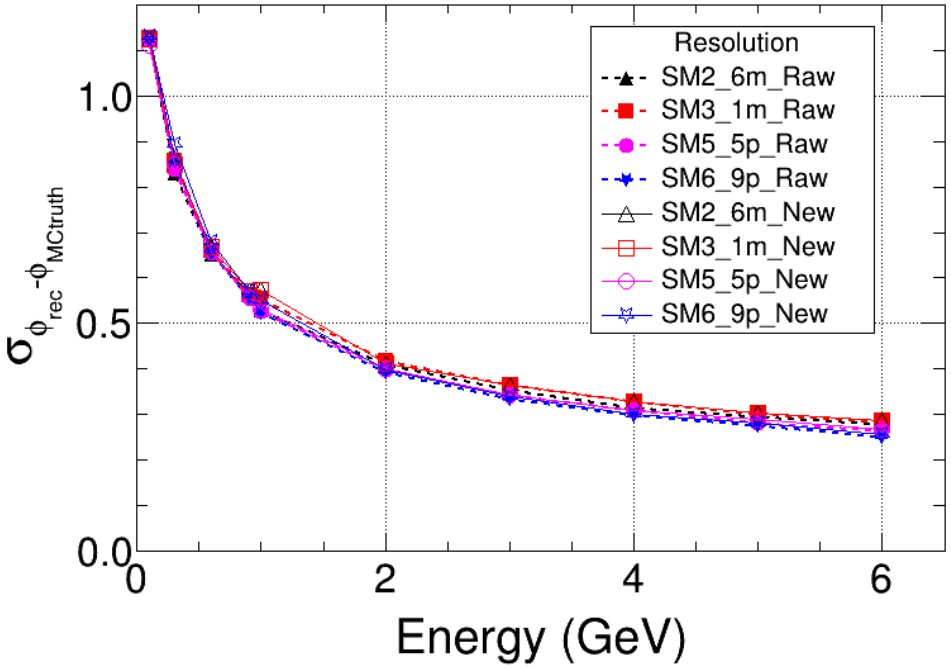


The distribution of origin and updated offset parameter fitting result of $\boldsymbol{\theta_{rec} - \theta_{MCTruth}}$ at different energy points with different data samples.

Phi check (method C)

- ✓ Phi distribution
  - SM2_6m, SM3_1m, SM5_5p, and SM6_9p, in range (128.4°, 134.8°), (87.6°, 95.6°), (48.0°, 54.4°), and (28.4°, 31.6°).





The distribution of origin and updated offset parameter fitting result of $\phi_{rec} - \phi_{MCTruth}$ at different energy points with different data samples.

Good consistency among method C and the PandaRoot values

Summary

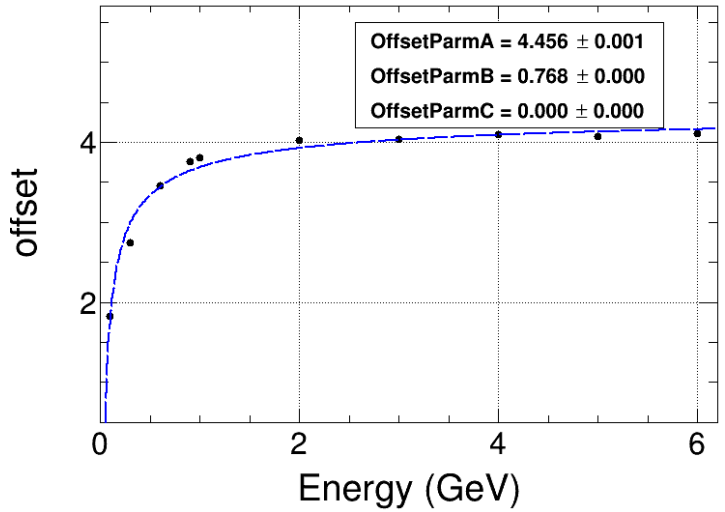
- Check and measure the offset in weighting function of EMC position calculation formula
  - use the intersection of tracking and depth plane as mctruth
  - use data sets with different theta’ s
- Using 3 different chisq fit methods, preliminary results show good consistency among the 3 methods and the PandaRoot values.
- Will further check the position reconstruction and perform position corrections to improve the position resolution

THANKS!

Back up

Update OffsetParm

- Sample:
  - $\theta = (128.4, 134.8)$
  - $\phi = (0, 360)$
  - $E = 0.1 - 6\mathrm{GeV}$
  - $\mathrm{Event} = 10000$
  - $\chi^2 = \sum_i^N \frac{(\theta_i^{rec} - \theta_i^{truth})^2}{\sigma_i^2}$

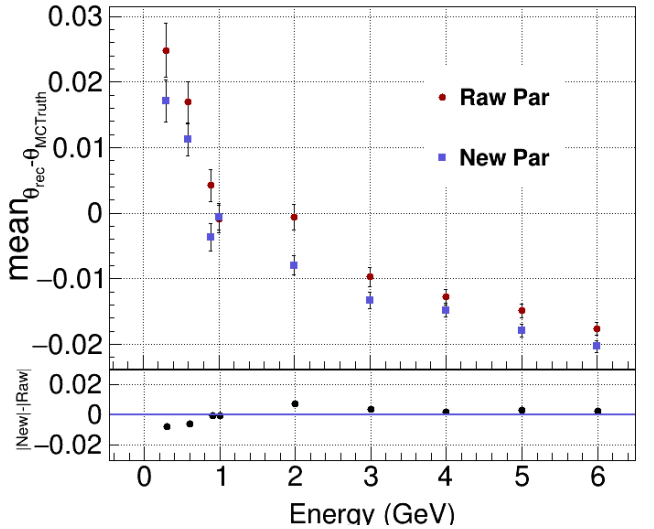


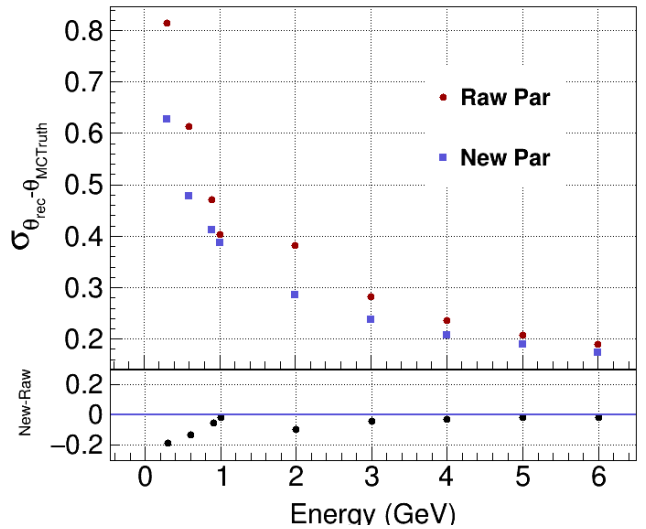
Distribution of offset values at different energy points and fitting result

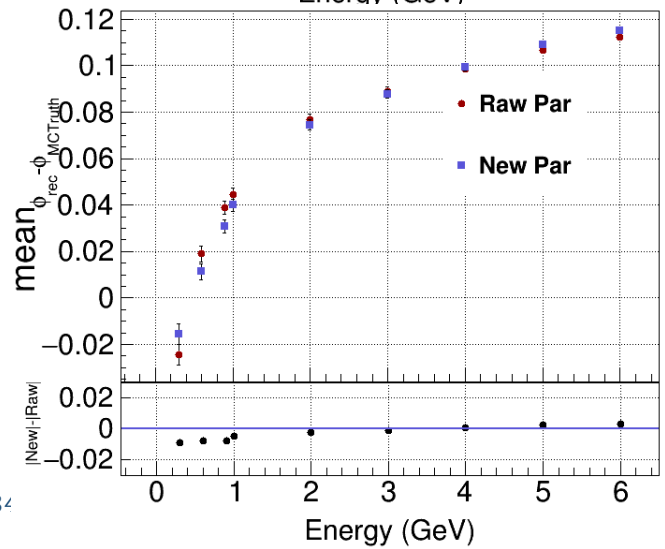
Fitting :

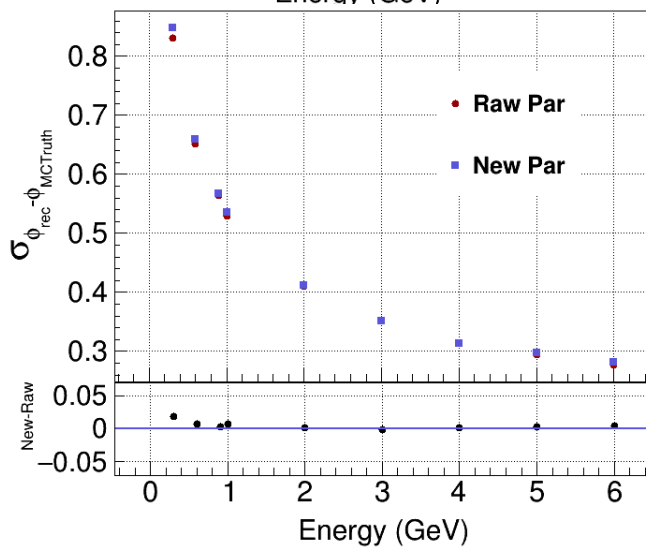
- $\mathrm{Offset} = \mathrm{OffsetParmA} - \mathrm{OffsetParmB} \cdot e^{-\mathrm{OffsetParmC} \cdot E^{1.171}} \cdot E^{-0.534}$

The fitting results of $\theta_{rec} - \theta_{MCTruth}(\phi_{rec} - \phi_{MCTruth})$



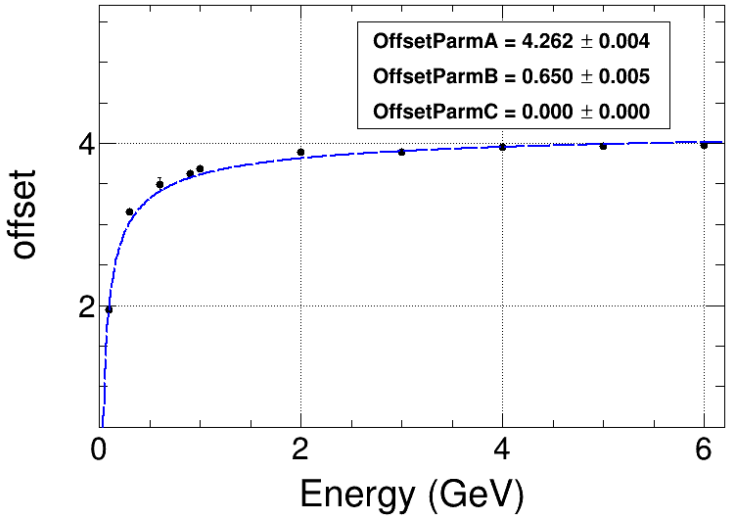






Update OffsetParm

- Sample:
  - $\theta = (128.4, 134.8)$
  - $\phi = (0, 360)$
  - $E = 0.1 - 6\mathrm{GeV}$
  - $\mathrm{Event} = 10000$
  - $\chi^2 = \sum_i^N \frac{(\phi_i^{rec} - \phi_i^{truth})^2}{\sigma_i^2}$

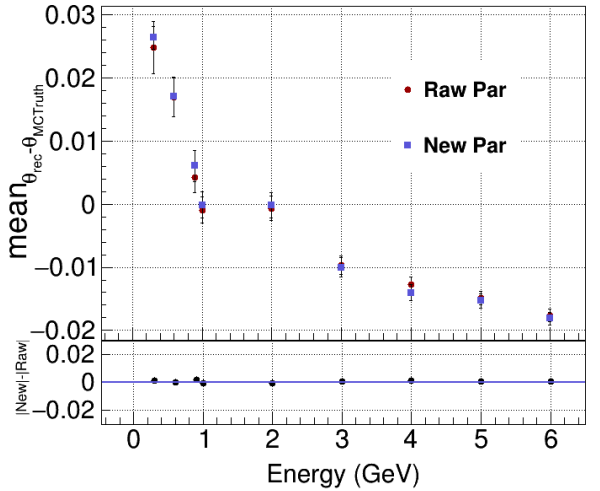


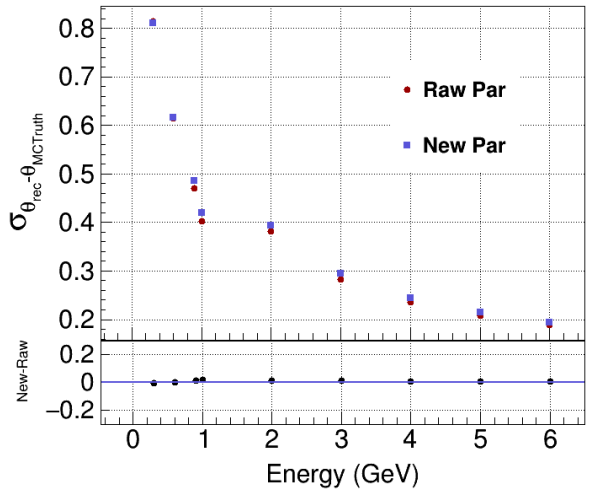
Distribution of offset values at different energy points and fitting result

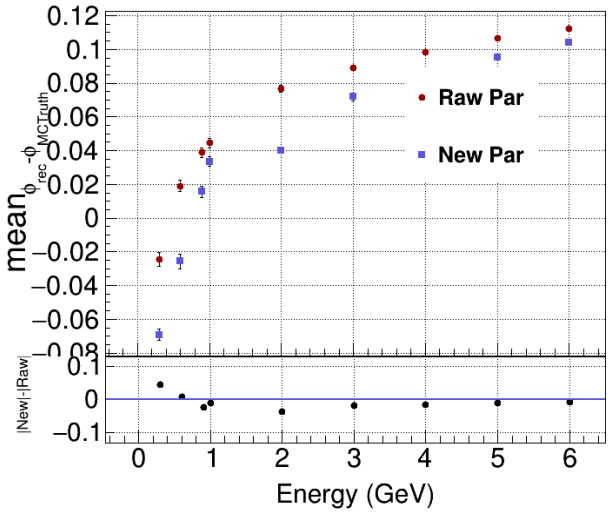
Fitting :

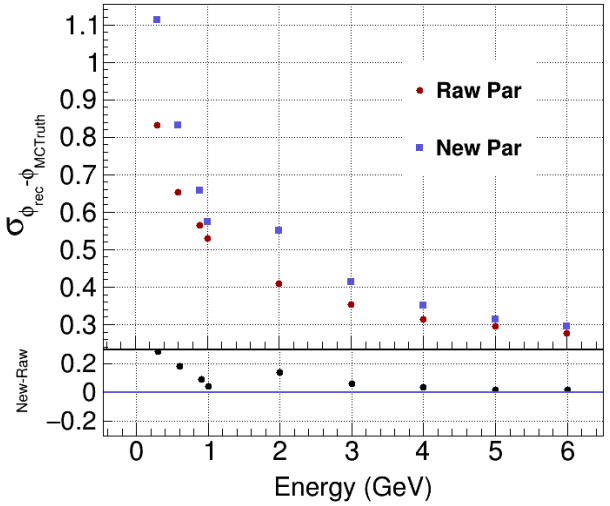
- $\mathrm{Offset} = \mathrm{OffsetParmA} - \mathrm{OffsetParmB} \cdot e^{-\mathrm{OffsetParmC} \cdot E^{1.171}} \cdot E^{-0.534}$

The fitting results of $\theta_{rec} - \theta_{MCTruth}(\phi_{rec} - \phi_{MCTruth})$



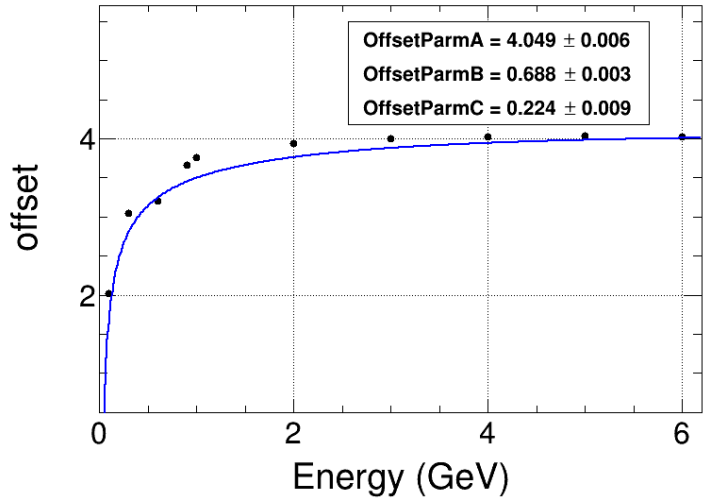






Update OffsetParm

- Sample:
  - $\theta = (87.6, 95.6)$
  - $\phi = (0, 360)$
  - $E = 0.1 - 6\mathrm{GeV}$
  - $\mathrm{Event} = 10000$
  - $\chi^2 = \sum_i^N \frac{(\theta_i^{rec} - \theta_i^{truth})^2}{\sigma_i^2}$



Distribution of offset values at different energy points and fitting result

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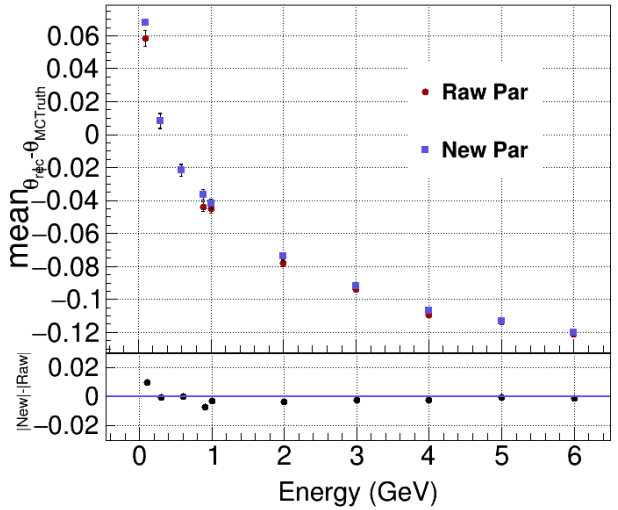
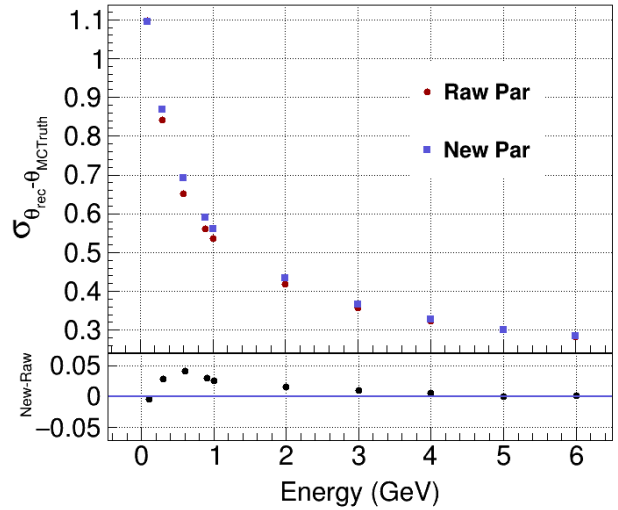
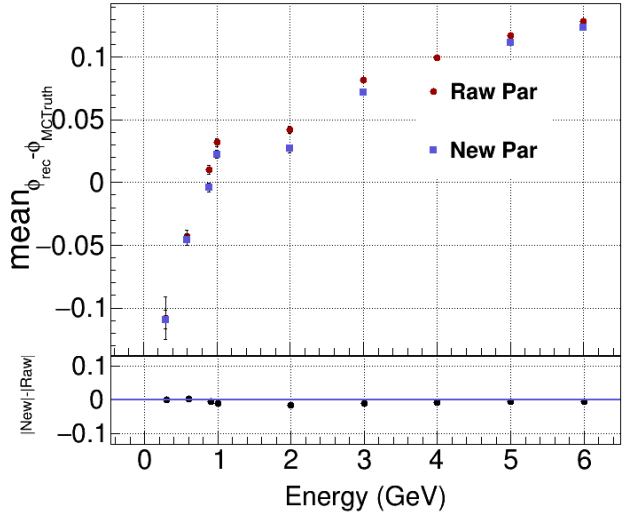
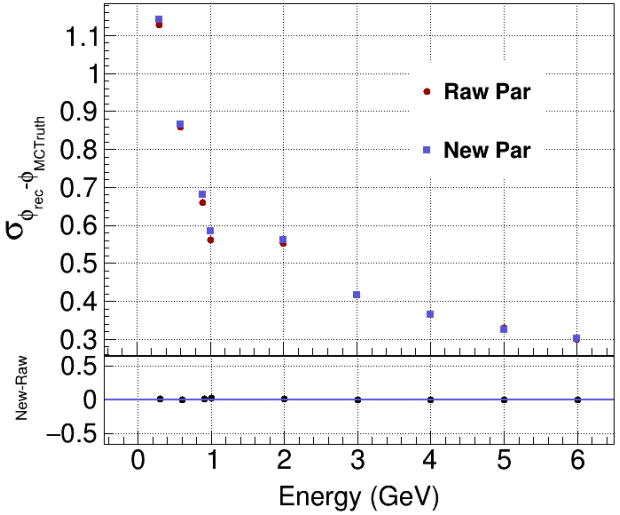


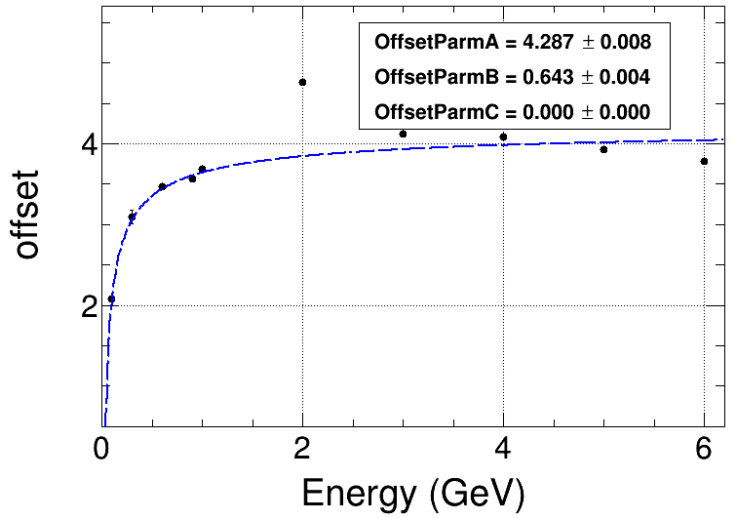






Update OffsetParm

- Sample:
  - $\theta = (87.6, 95.6)$
  - $\phi = (0, 360)$
  - $E = 0.1 - 6\mathrm{GeV}$
  - $\mathrm{Event} = 10000$
  - $\chi^2 = \sum_i^N \frac{(\phi_i^{rec} - \phi_i^{truth})^2}{\sigma_i^2}$

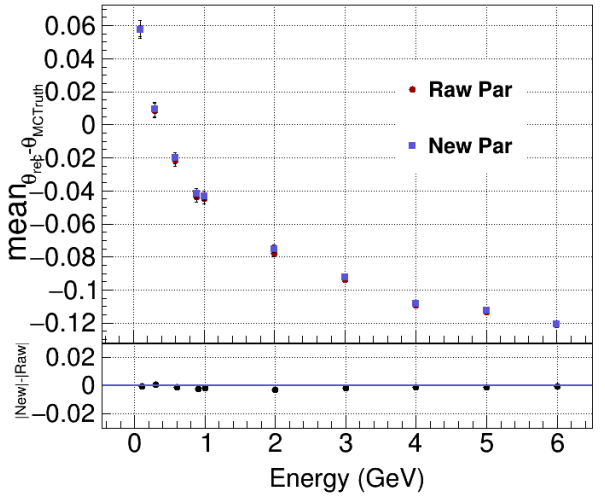


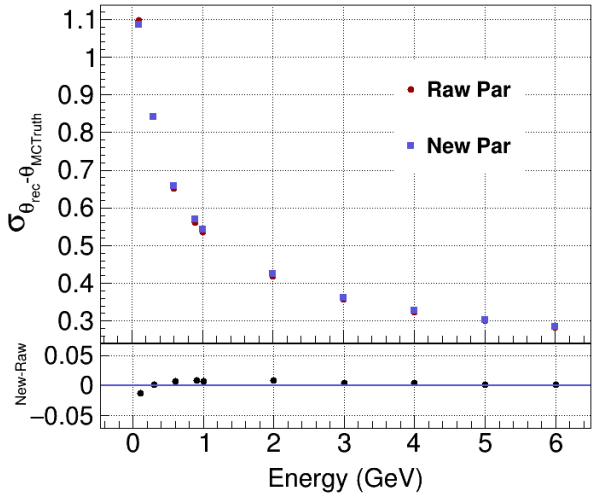
Distribution of offset values at different energy points and fitting result

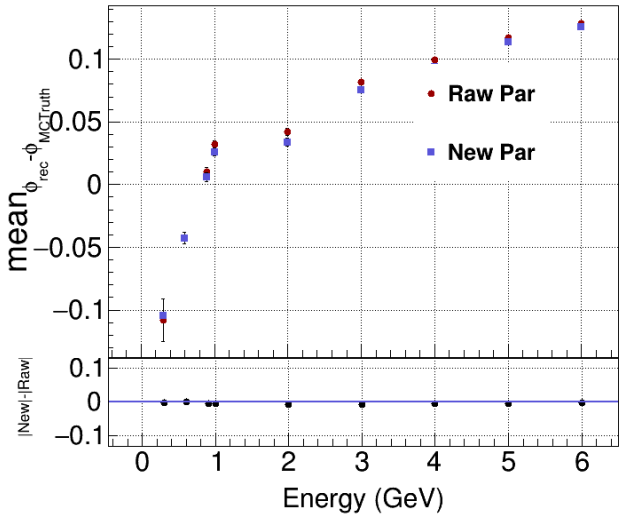
Fitting :

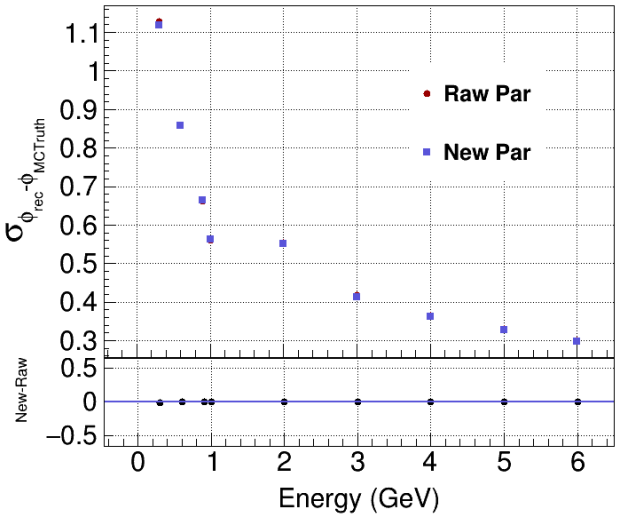
- $\mathrm{Offset} = \mathrm{OffsetParmA} - \mathrm{OffsetParmB} \cdot e^{-\mathrm{OffsetParmC} \cdot E^{1.171}} \cdot E^{-0.534}$

The fitting results of $\theta_{rec} - \theta_{MCTruth}(\phi_{rec} - \phi_{MCTruth})$



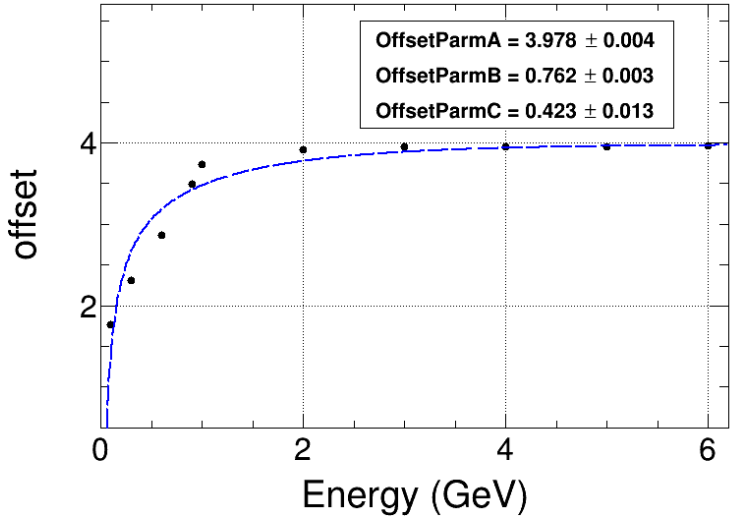






Update OffsetParm

- Sample:
  - $\theta = (48.0, 54.4)$
  - $\phi = (0, 360)$
  - $E = 0.1 - 6\mathrm{GeV}$
  - $\mathrm{Event} = 10000$
  - $\chi^2 = \sum_i^N \frac{(\theta_i^{rec} - \theta_i^{truth})^2}{\sigma_i^2}$



Distribution of offset values at different energy points and fitting result

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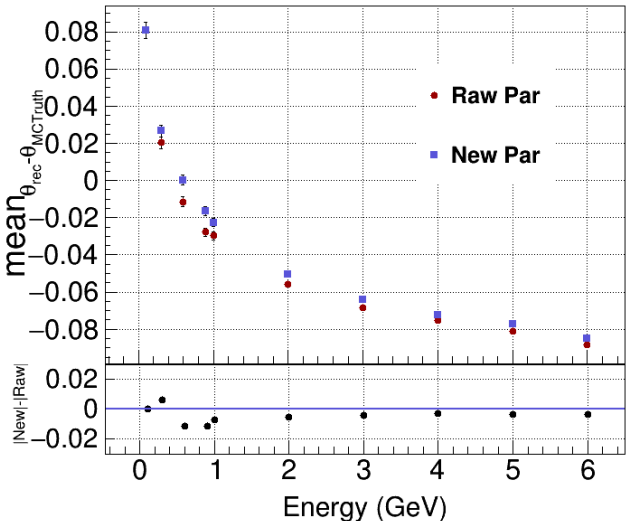
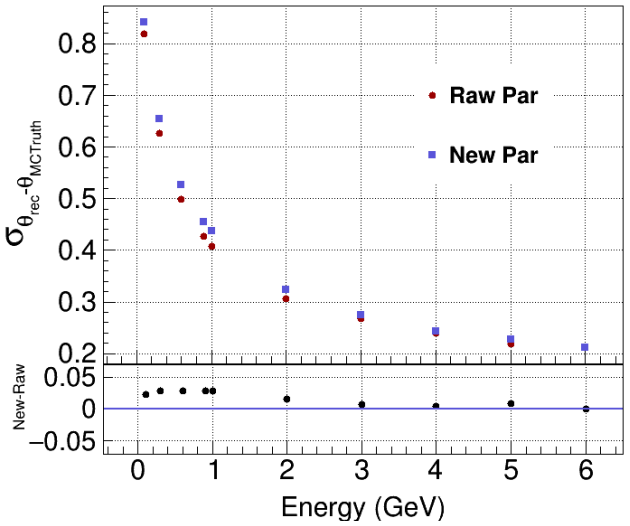
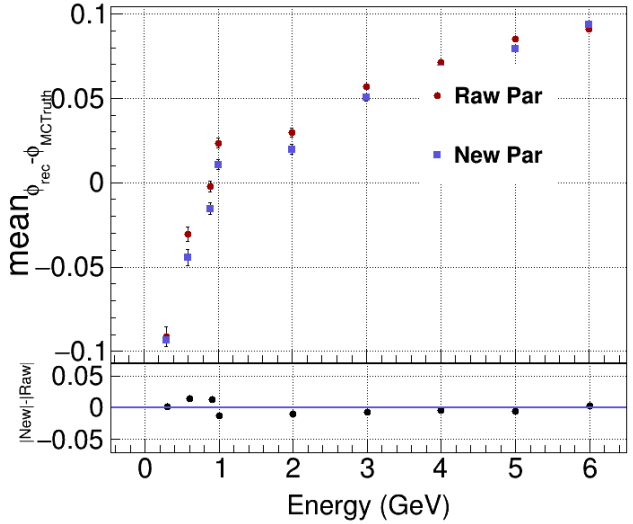
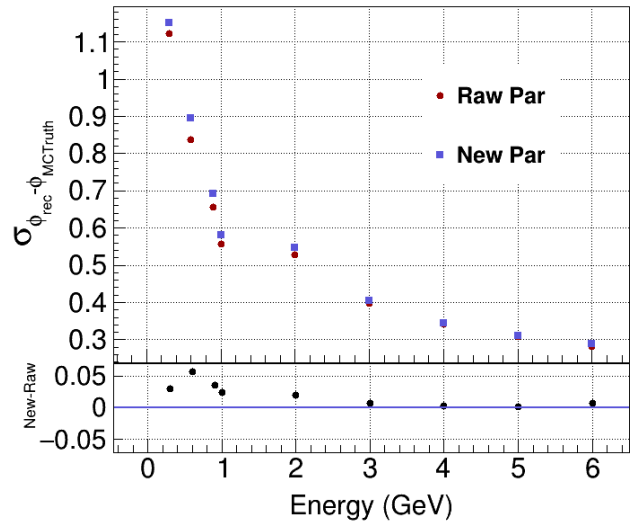
The fitting results of $\theta_{rec} - \theta_{MCTruth}(\phi_{rec} - \phi_{MCTruth})$



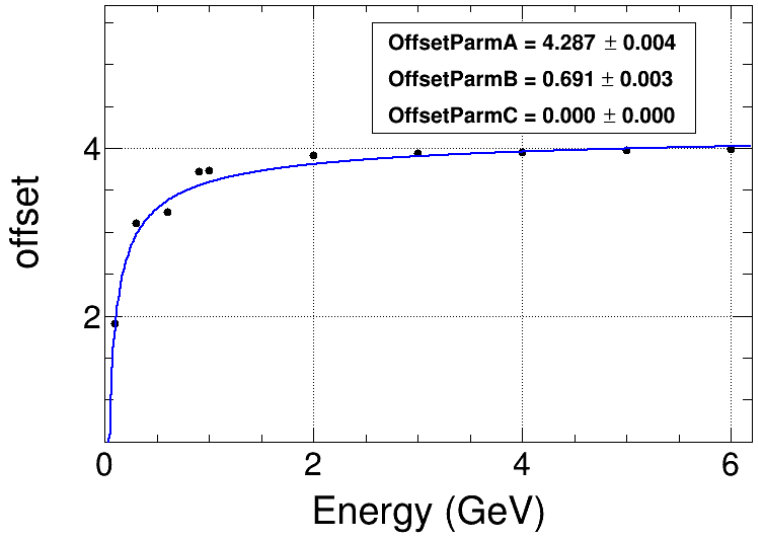






Update OffsetParm

- Sample:
  - $\theta = (48.0, 54.4)$
  - $\phi = (0, 360)$
  - $E = 0.1 - 6\mathrm{GeV}$
  - $\mathrm{Event} = 10000$
  - $\chi^2 = \sum_i^N \frac{(\phi_i^{rec} - \phi_i^{truth})^2}{\sigma_i^2}$

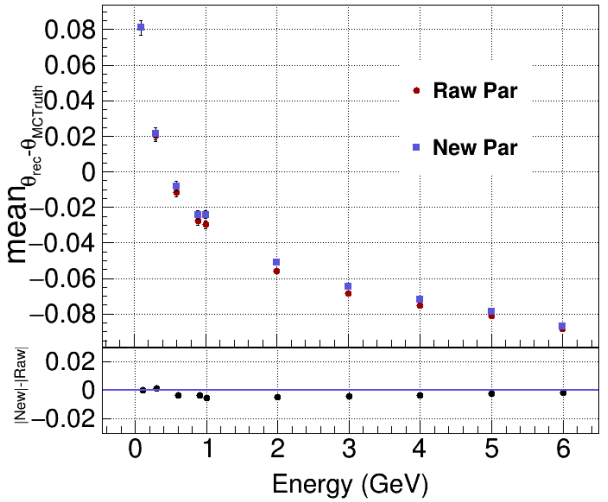


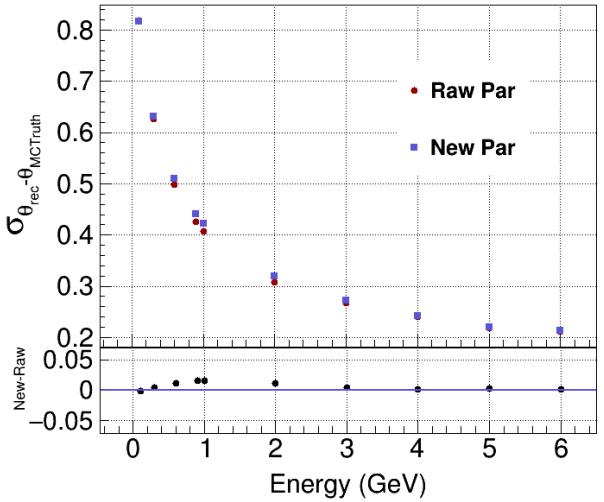
Distribution of offset values at different energy points and fitting result

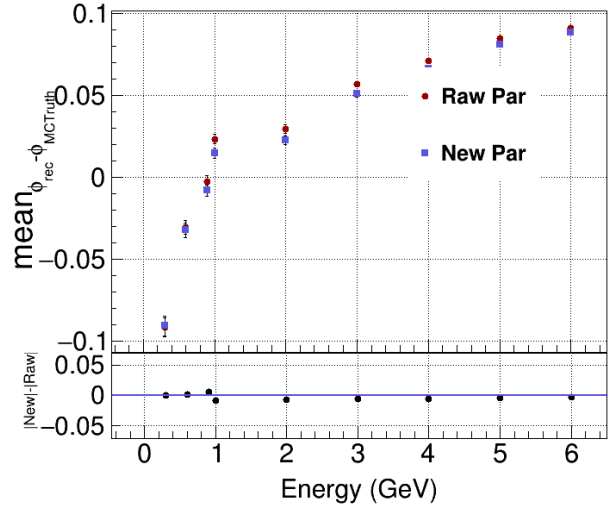
Fitting :

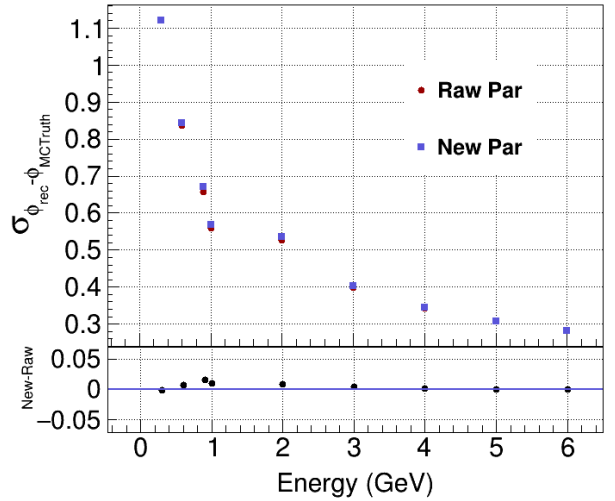
- $\mathrm{Offset} = \mathrm{OffsetParmA} - \mathrm{OffsetParmB} \cdot e^{-\mathrm{OffsetParmC} \cdot E^{1.171}} \cdot E^{-0.534}$

The fitting results of $\theta_{rec} - \theta_{MCTruth}(\phi_{rec} - \phi_{MCTruth})$



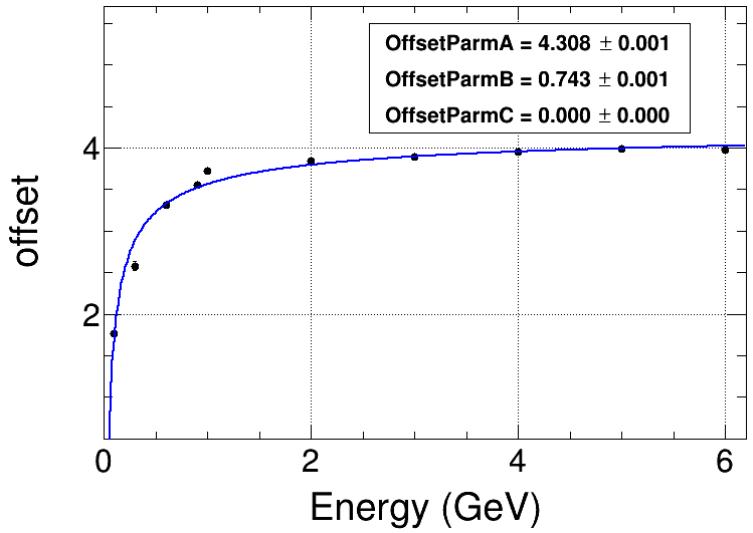






Update OffsetParm

- Sample:
  - $\theta = (28.4, 31.6)$
  - $\phi = (0, 360)$
  - $E = 0.1 - 6\mathrm{GeV}$
  - $\mathrm{Event} = 10000$
  - $\chi^2 = \sum_i^N \frac{(\theta_i^{rec} - \theta_i^{truth})^2}{\sigma_i^2}$



Distribution of offset values at different energy points and fitting result

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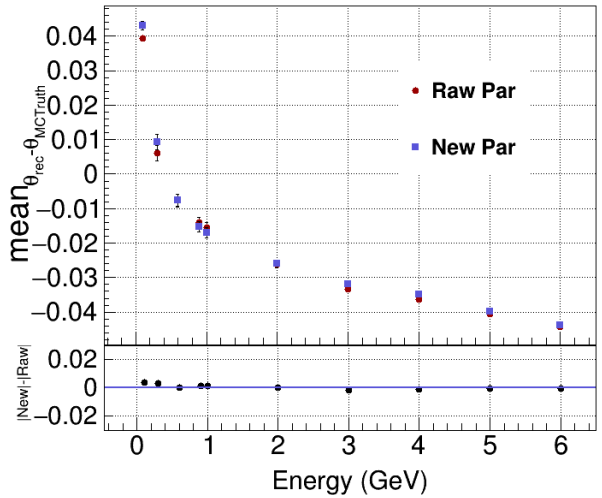
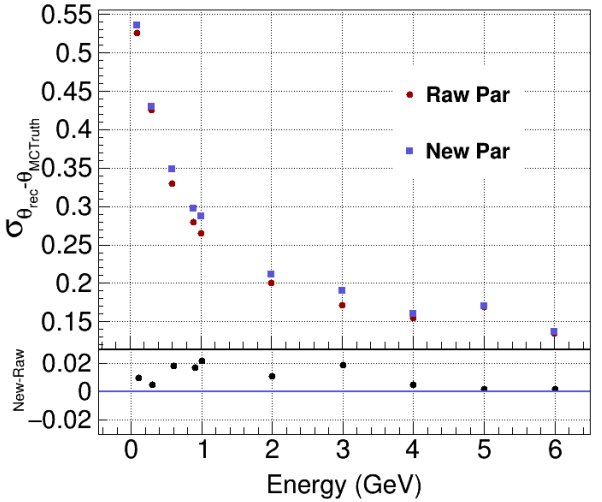
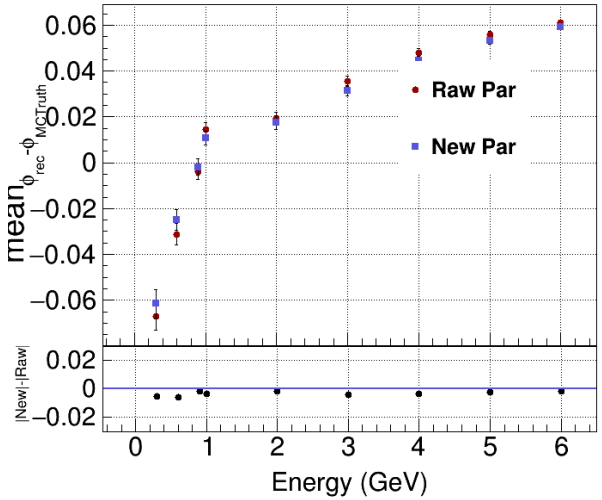
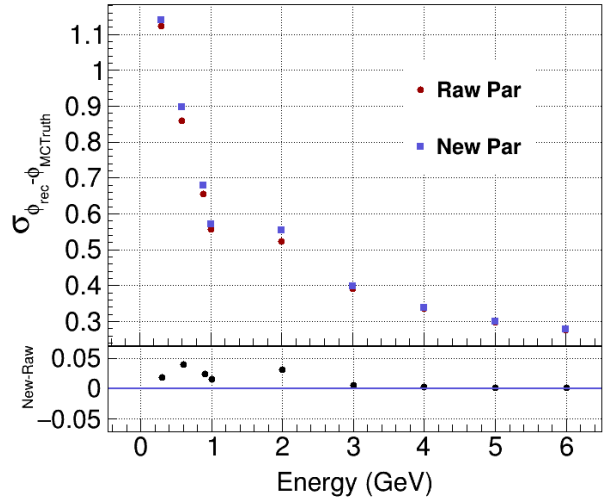
The fitting results of $\theta_{rec} - \theta_{MCTruth}(\phi_{rec} - \phi_{MCTruth})$



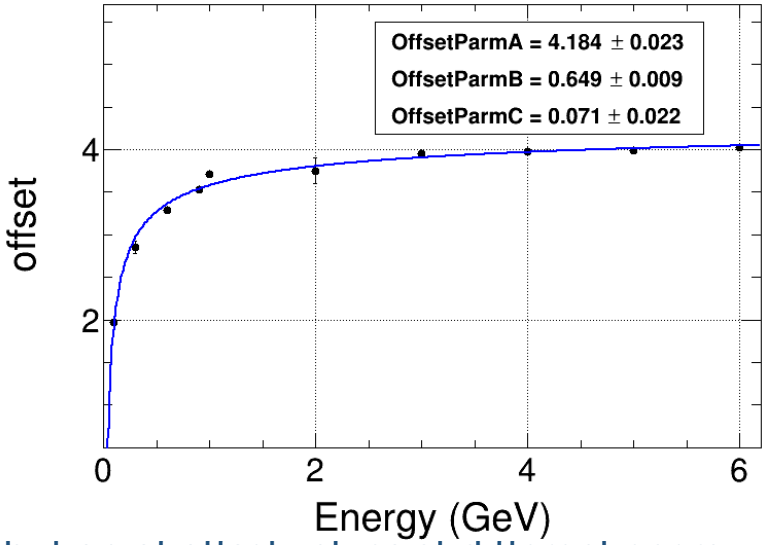






Update OffsetParm

- Sample:
  - $\theta = (28.4, 31.6)$
  - $\phi = (0, 360)$
  - $E = 0.1 - 6\mathrm{GeV}$
  - $\mathrm{Event} = 10000$
  - $\chi^2 = \sum_i^N \frac{(\phi_i^{rec} - \phi_i^{truth})^2}{\sigma_i^2}$



Distribution of offset values at different energy points and fitting result

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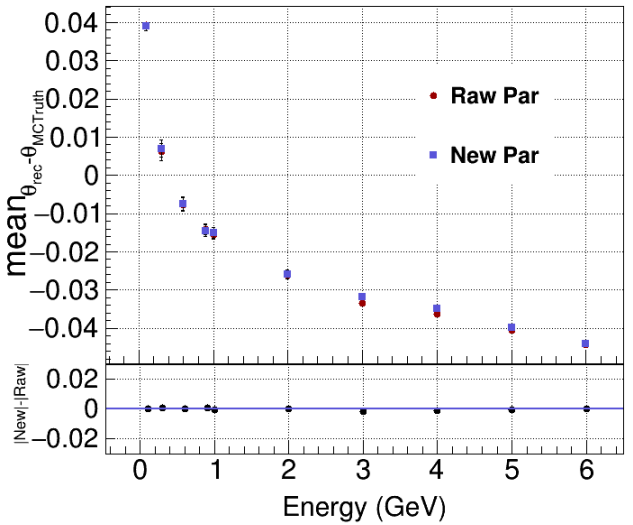
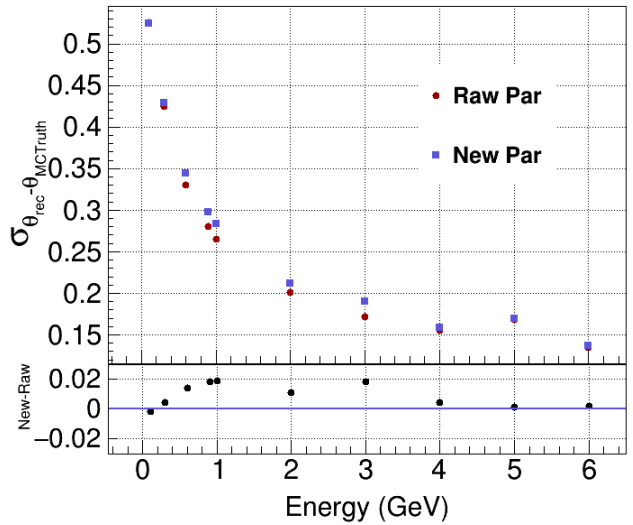
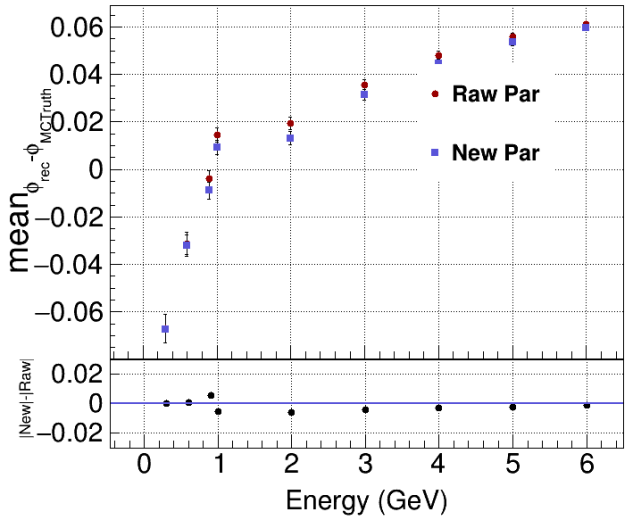
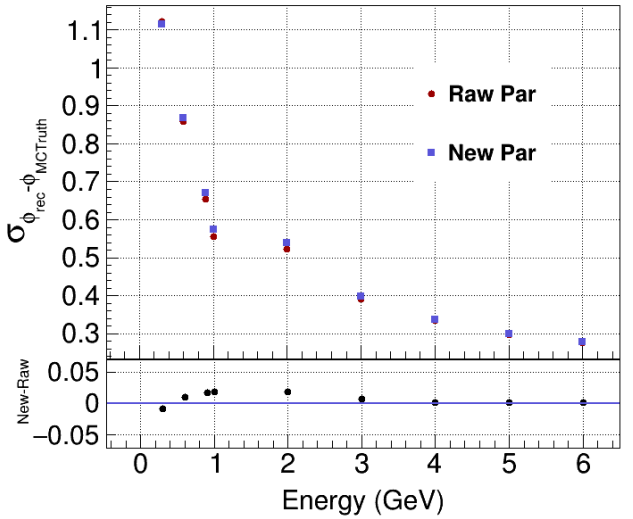
- $\mathrm{Offset} = \mathrm{OffsetParmA} - \mathrm{OffsetParmB} \cdot e^{-\mathrm{OffsetParmC} \cdot E^{1.171}} \cdot E^{-0.5}$

The fitting results of $\theta_{rec} - \theta_{MCTruth}(\phi_{rec} - \phi_{MCTruth})$



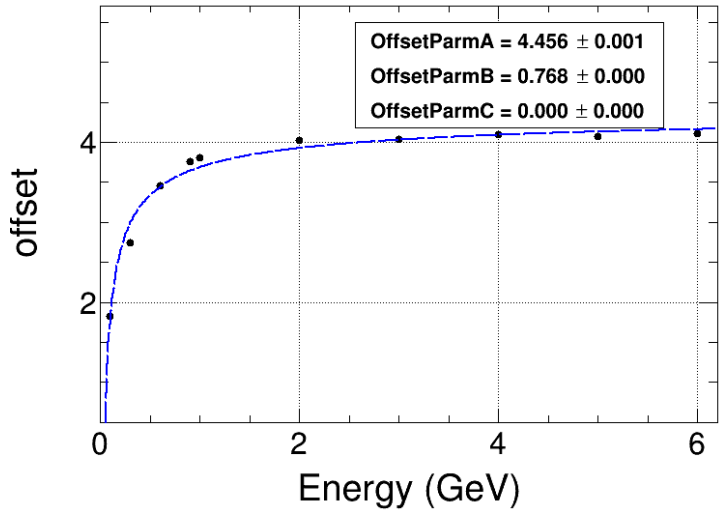






Update OffsetParm

- Sample:
  - $\theta = (128.4, 134.8)$
  - $\phi = (0, 360)$
  - $E = 0.1 - 6\mathrm{GeV}$
  - $\mathrm{Event} = 10000$
  - $\chi^2 = \sum_i^N \frac{(\theta_i^{rec} - \theta_i^{truth})^2}{\sigma_i^2}$



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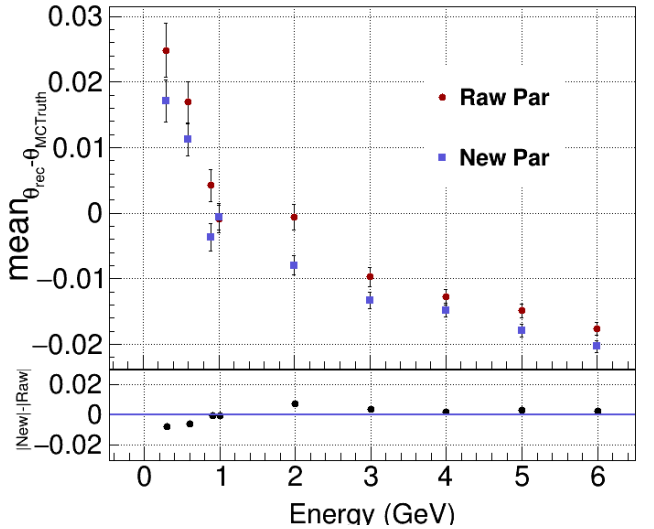
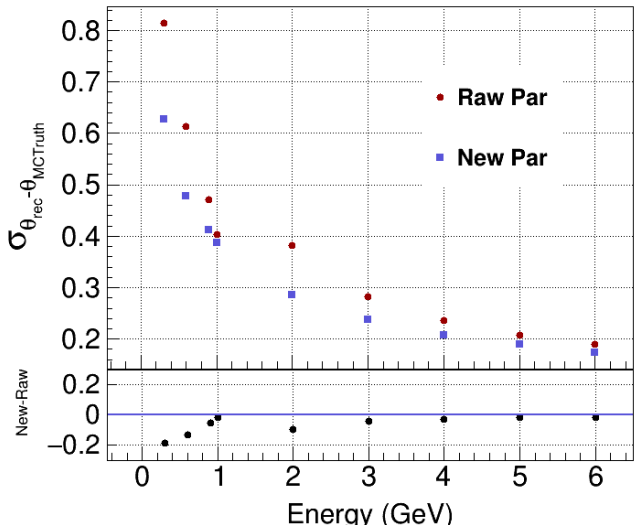
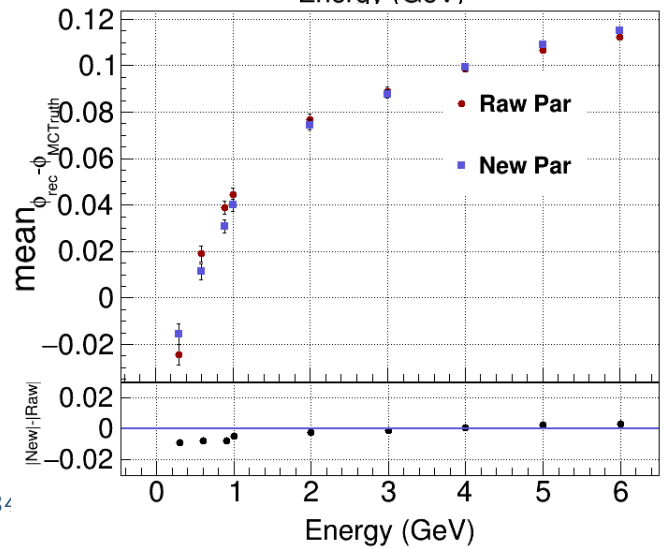
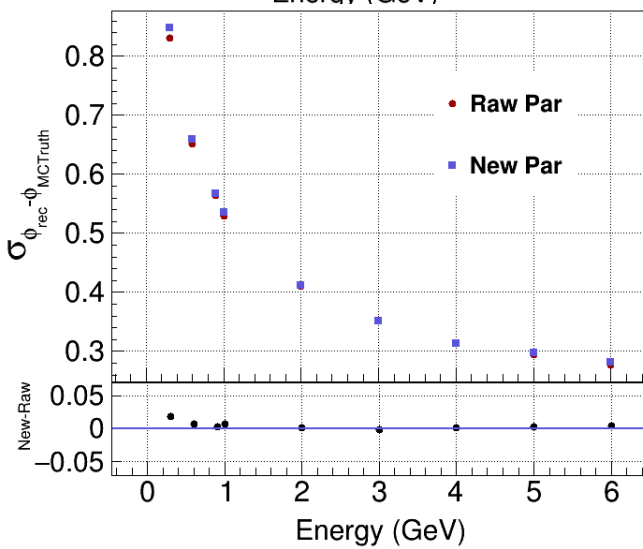


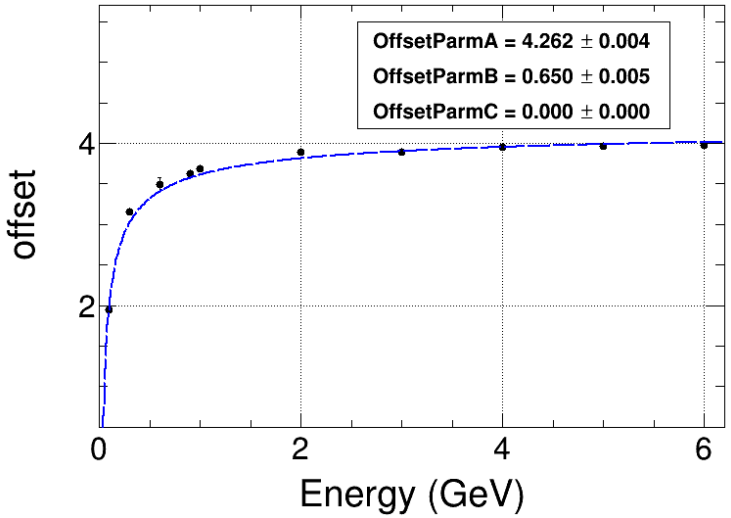






Update OffsetParm

- Sample:
  - $\theta = (128.4, 134.8)$
  - $\phi = (0, 360)$
  - $E = 0.1 - 6\mathrm{GeV}$
  - $\mathrm{Event} = 10000$
  - $\chi^2 = \sum_i^N \frac{(\phi_i^{rec} - \phi_i^{truth})^2}{\sigma_i^2}$



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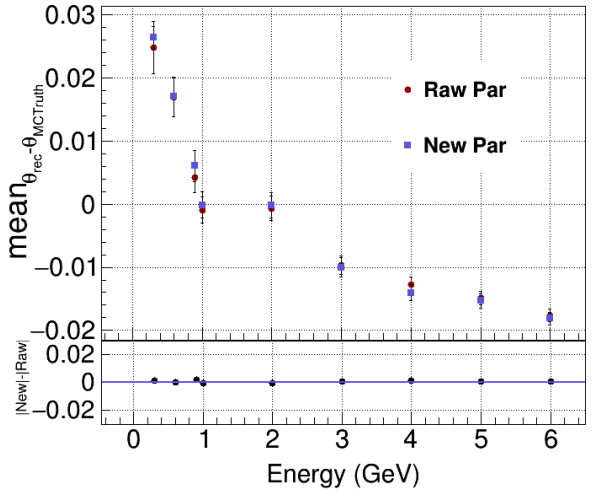
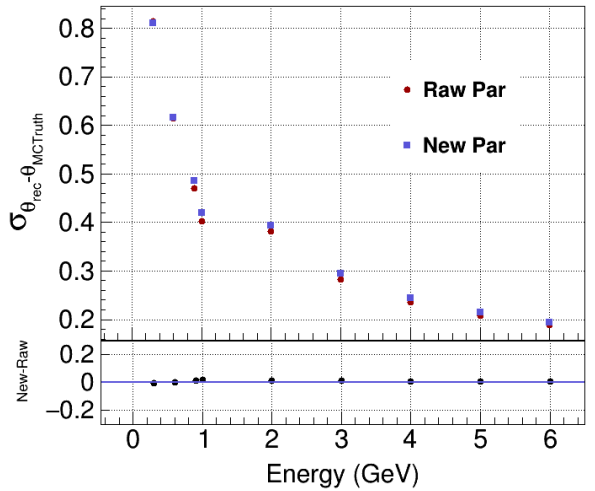
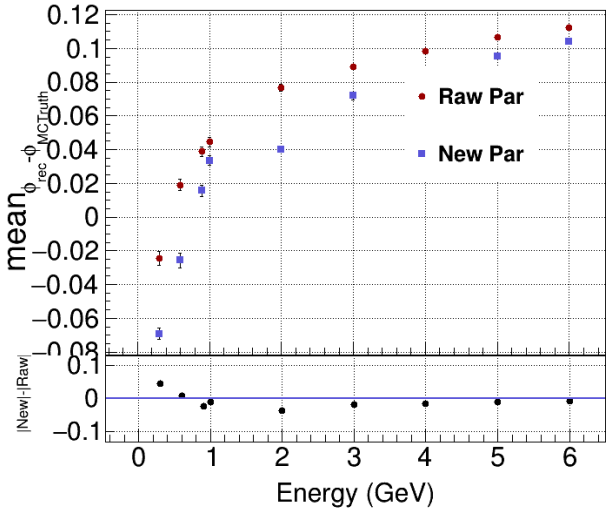
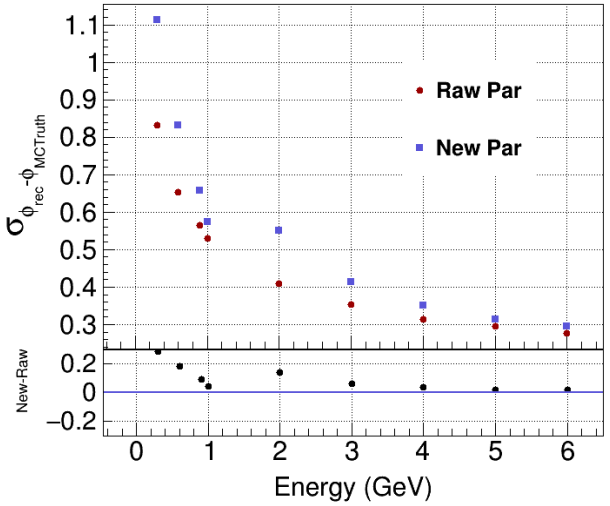


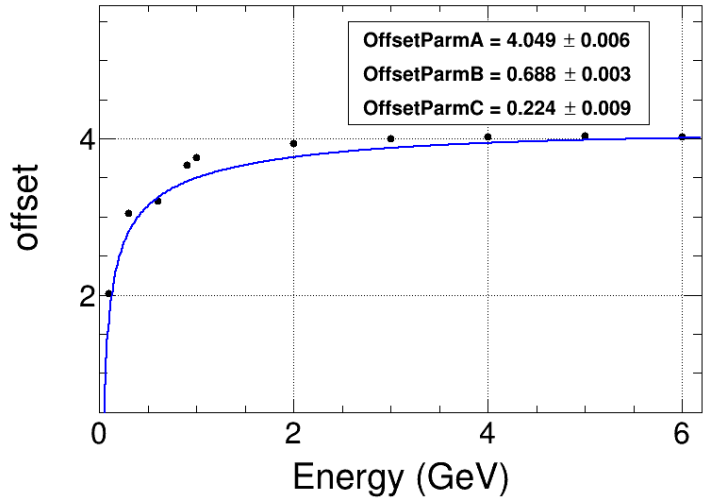






Update OffsetParm

- Sample:
  - $\theta = (87.6, 95.6)$
  - $\phi = (0, 360)$
  - $E = 0.1 - 6\mathrm{GeV}$
  - $\mathrm{Event} = 10000$
  - $\chi^2 = \sum_i^N \frac{(\theta_i^{rec} - \theta_i^{truth})^2}{\sigma_i^2}$



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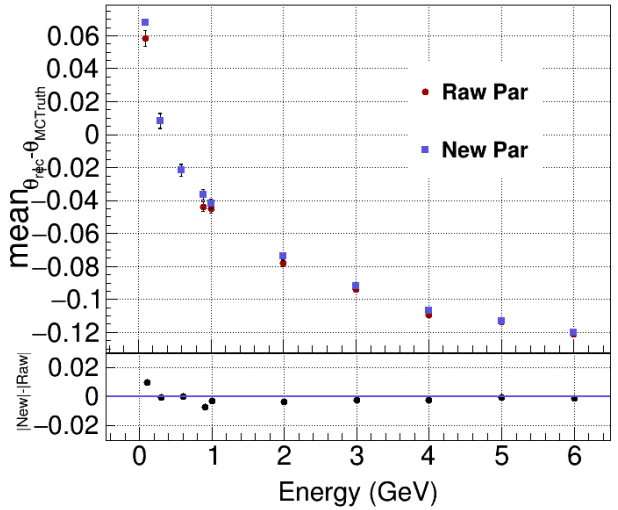
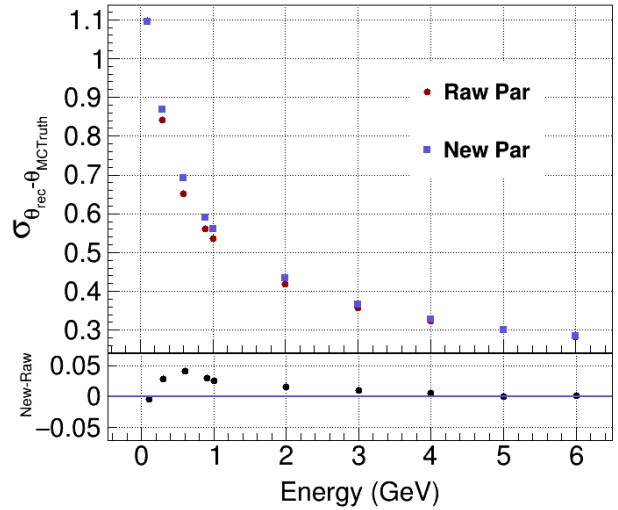
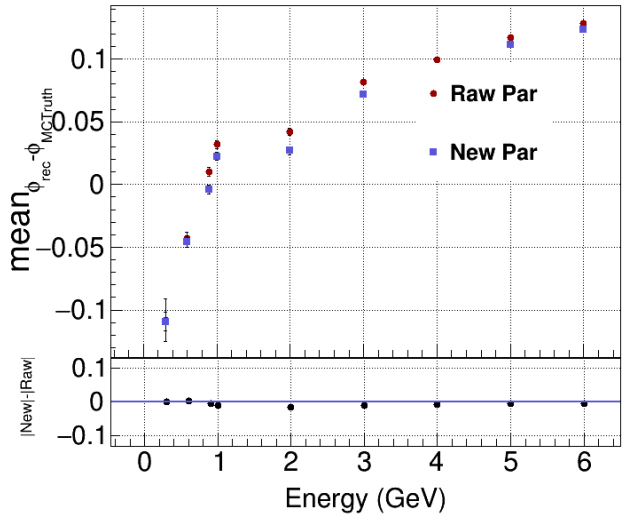
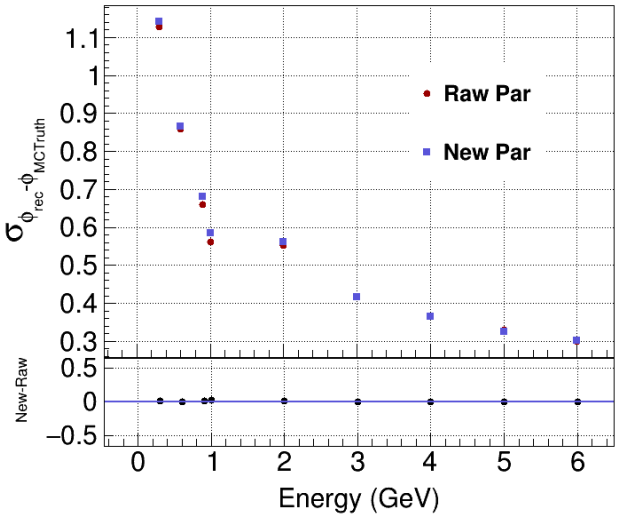
The fitting results of $\theta_{rec} - \theta_{MCTruth}(\phi_{rec} - \phi_{MCTruth})$



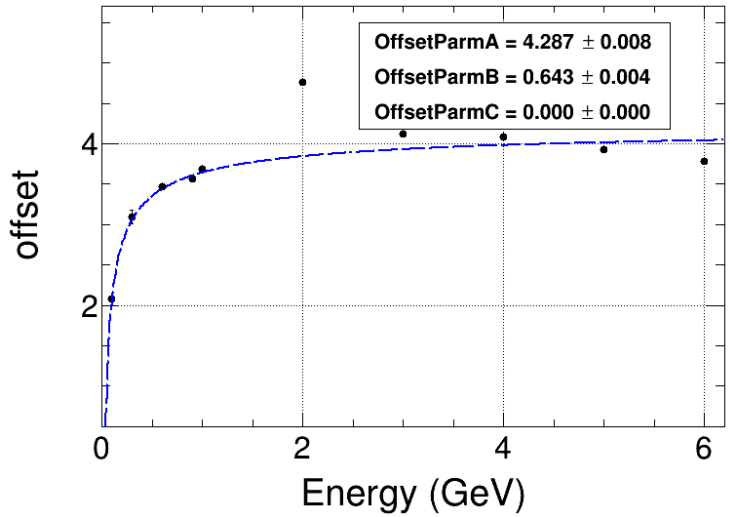






Update OffsetParm

- Sample:
  - $\theta = (87.6, 95.6)$
  - $\phi = (0, 360)$
  - $E = 0.1 - 6\mathrm{GeV}$
  - $\mathrm{Event} = 10000$
  - $\chi^2 = \sum_i^N \frac{(\phi_i^{rec} - \phi_i^{truth})^2}{\sigma_i^2}$

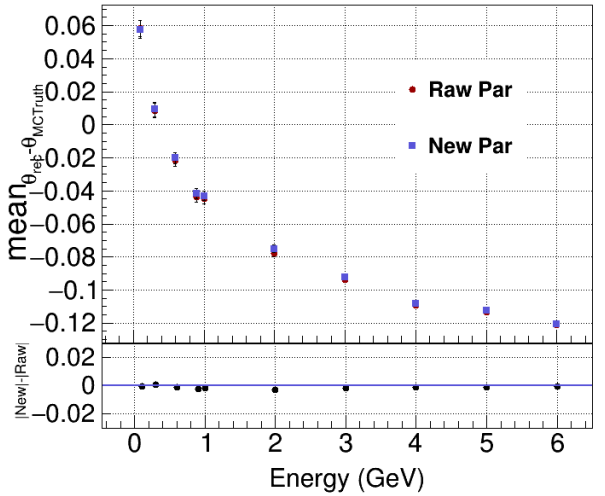


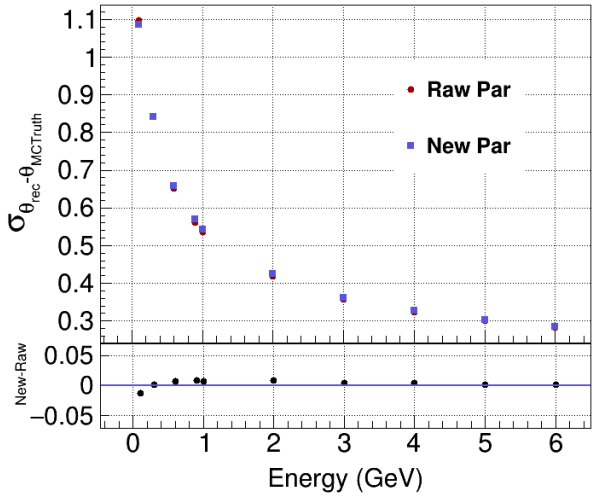
Distribution of offset values at different energy points and fitting result

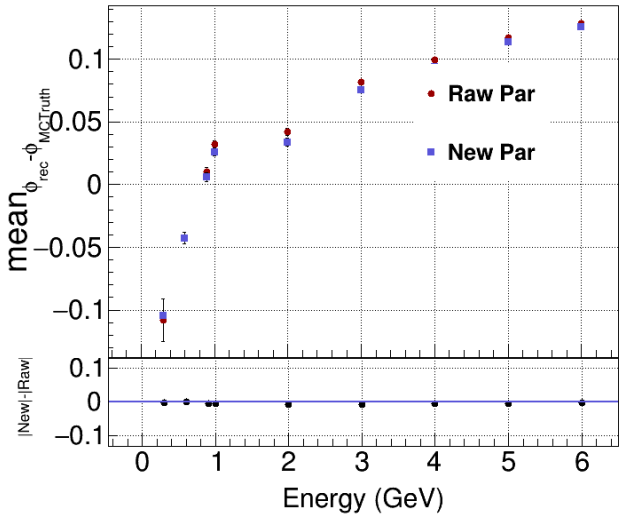
Fitting :

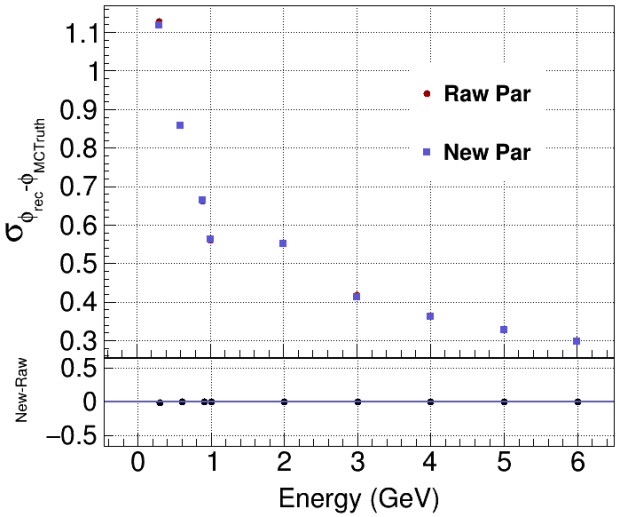
- $\mathrm{Offset} = \mathrm{OffsetParmA} - \mathrm{OffsetParmB} \cdot e^{-\mathrm{OffsetParmC} \cdot E^{1.171}} \cdot E^{-0.534}$

The fitting results of $\theta_{rec} - \theta_{MCTruth}(\phi_{rec} - \phi_{MCTruth})$



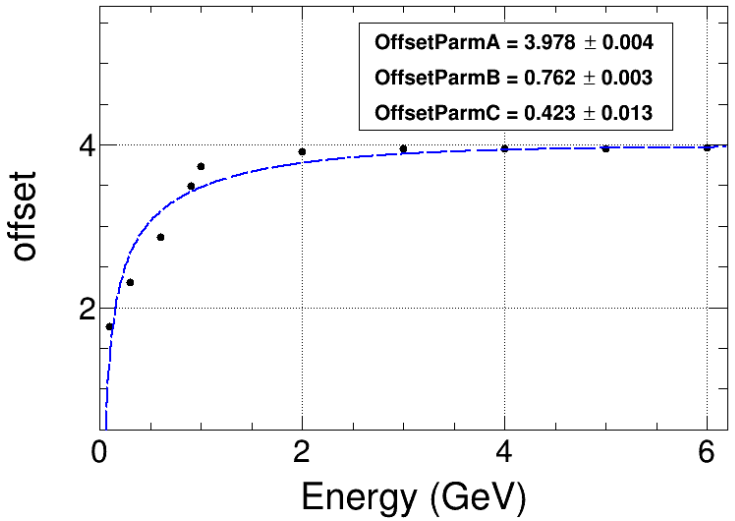






Update OffsetParm

- Sample:
  - $\theta = (48.0, 54.4)$
  - $\phi = (0, 360)$
  - $E = 0.1 - 6\mathrm{GeV}$
  - $\mathrm{Event} = 10000$
  - $\chi^2 = \sum_i^N \frac{(\theta_i^{rec} - \theta_i^{truth})^2}{\sigma_i^2}$

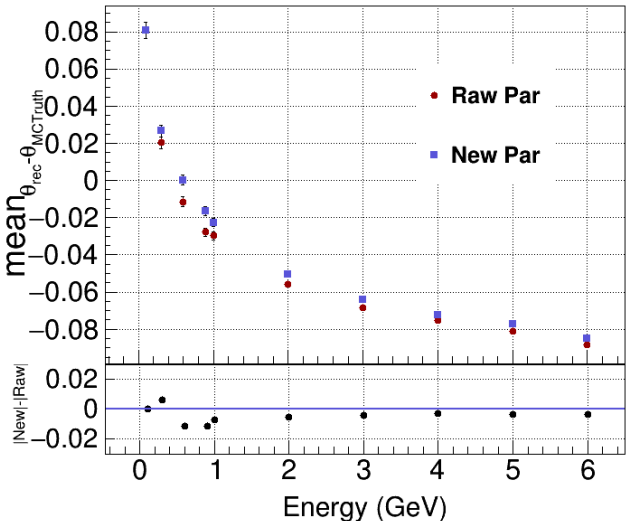


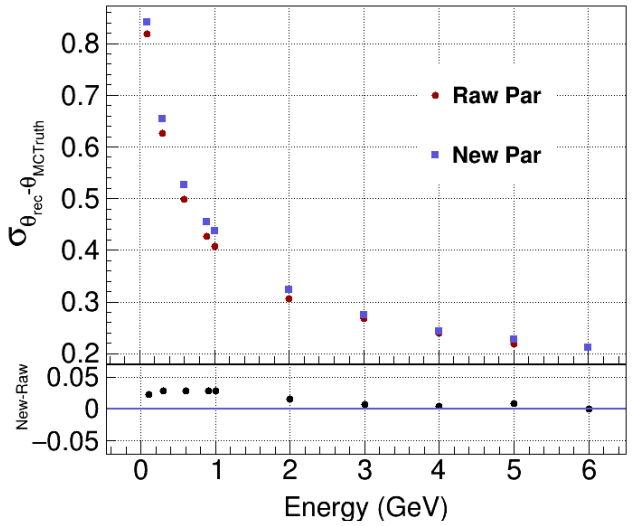
Distribution of offset values at different energy points and fitting result

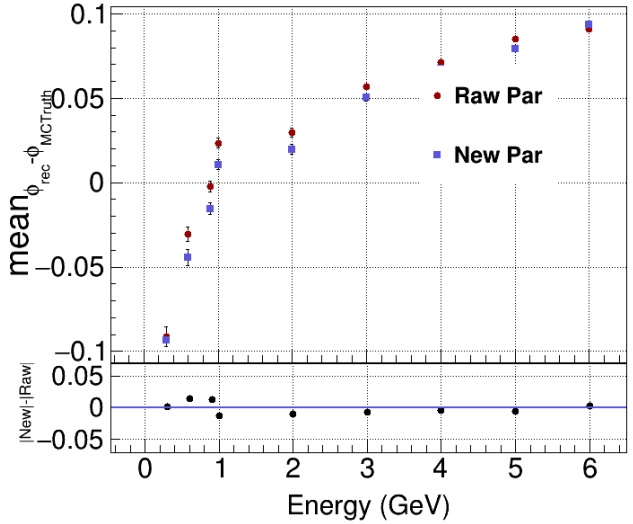
Fitting :

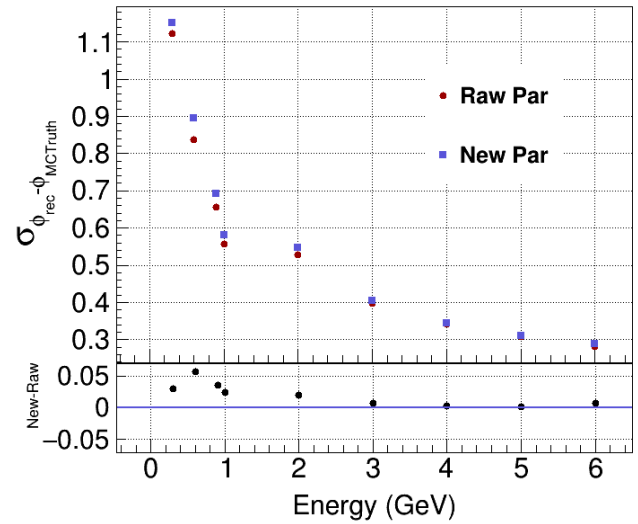
- $\mathrm{Offset} = \mathrm{OffsetParmA} - \mathrm{OffsetParmB} \cdot e^{-\mathrm{OffsetParmC} \cdot E^{1.171}} \cdot E^{-0.534}$

The fitting results of $\theta_{rec} - \theta_{MCTruth}(\phi_{rec} - \phi_{MCTruth})$



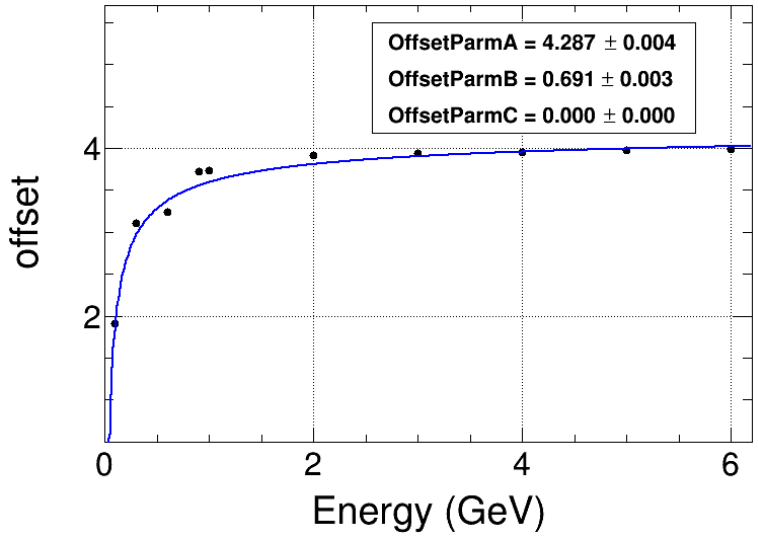






Update OffsetParm

- Sample:
  - $\theta = (48.0, 54.4)$
  - $\phi = (0, 360)$
  - $E = 0.1 - 6\mathrm{GeV}$
  - $\mathrm{Event} = 10000$
  - $\chi^2 = \sum_i^N \frac{(\phi_i^{rec} - \phi_i^{truth})^2}{\sigma_i^2}$

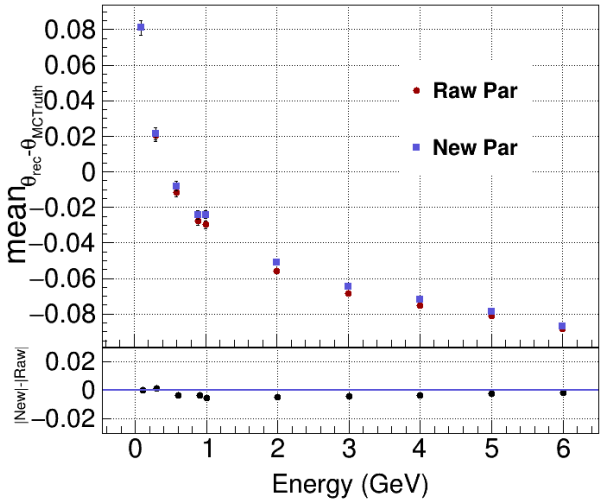


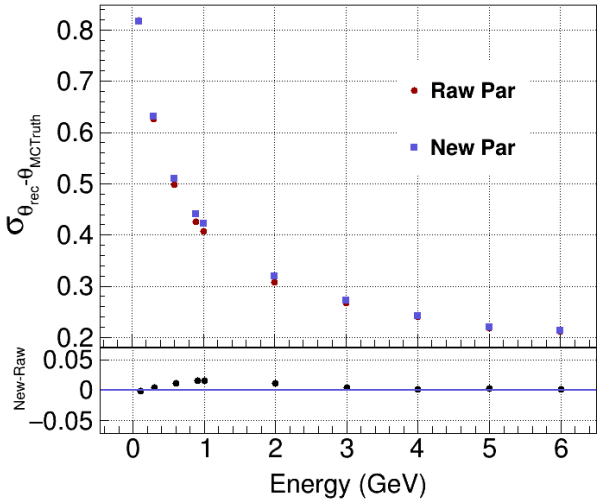
Distribution of offset values at different energy points and fitting result

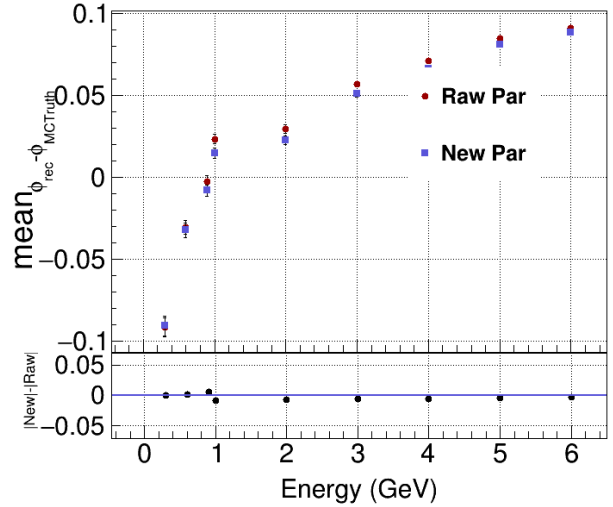
Fitting :

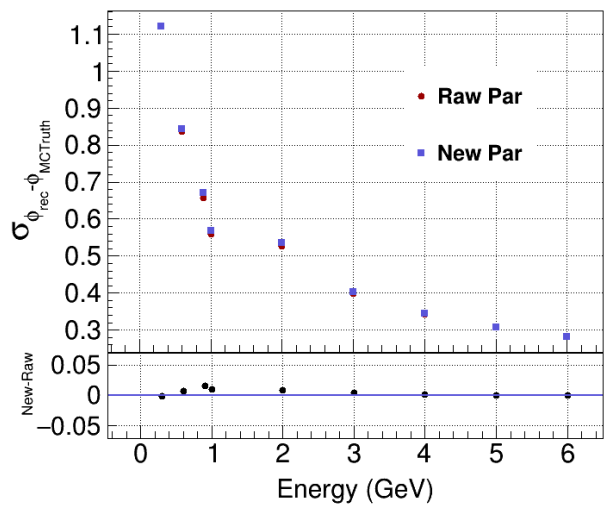
- $\mathrm{Offset} = \mathrm{OffsetParmA} - \mathrm{OffsetParmB} \cdot e^{-\mathrm{OffsetParmC} \cdot E^{1.171}} \cdot E^{-0.534}$

The fitting results of $\theta_{rec} - \theta_{MCTruth}(\phi_{rec} - \phi_{MCTruth})$



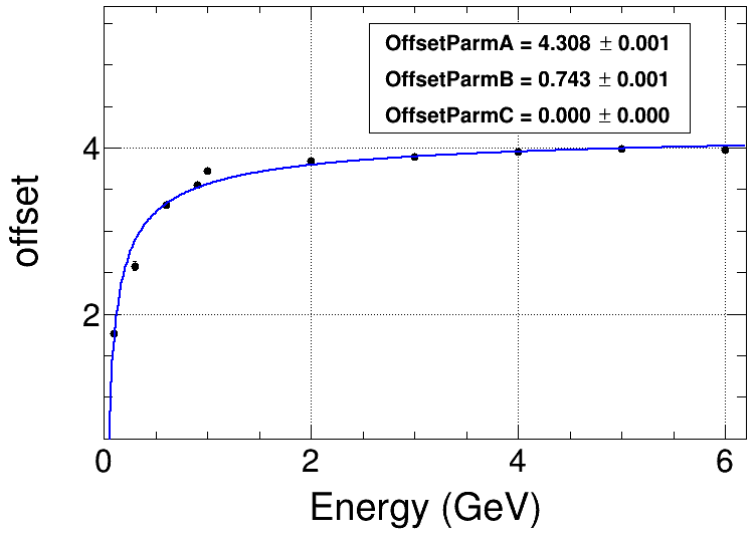






Update OffsetParm

- Sample:
  - $\theta = (28.4, 31.6)$
  - $\phi = (0, 360)$
  - $E = 0.1 - 6\mathrm{GeV}$
  - $\mathrm{Event} = 10000$
  - $\chi^2 = \sum_i^N \frac{(\theta_i^{rec} - \theta_i^{truth})^2}{\sigma_i^2}$

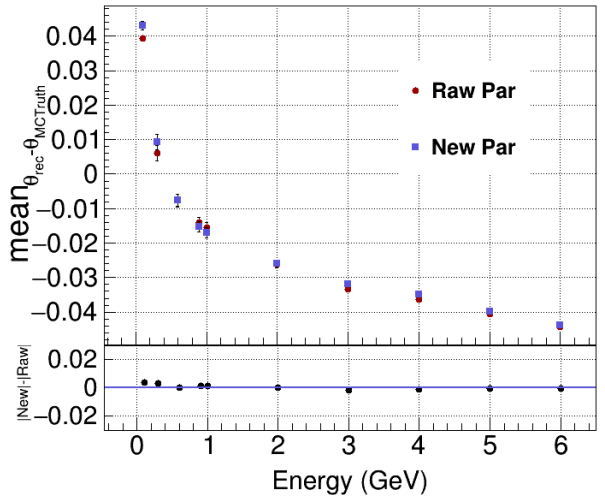


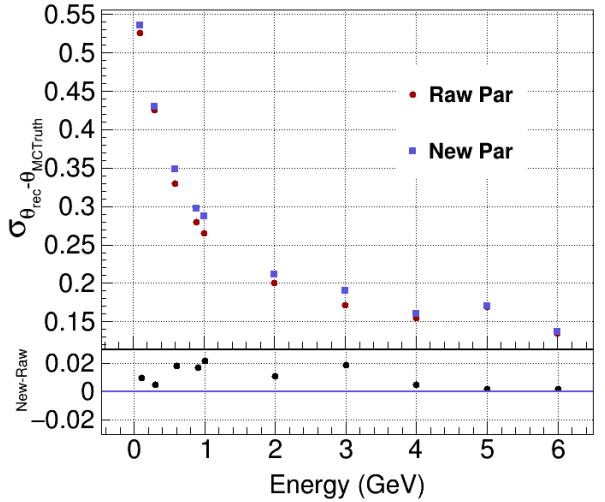
Distribution of offset values at different energy points and fitting result

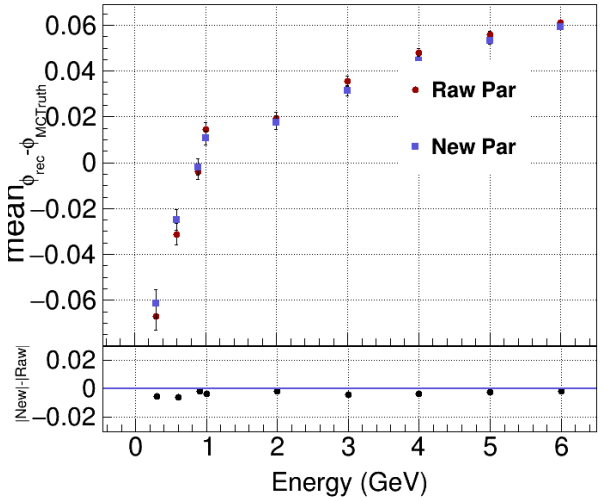
Fitting :

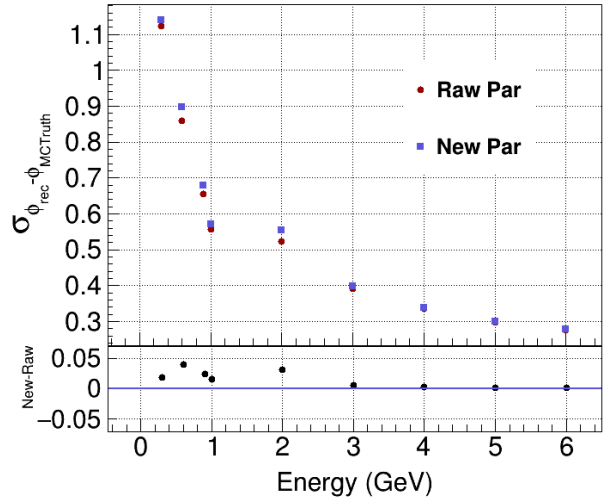
- $\mathrm{Offset} = \mathrm{OffsetParmA} - \mathrm{OffsetParmB} \cdot e^{-\mathrm{OffsetParmC} \cdot E^{1.171}} \cdot E^{-0.534}$

The fitting results of $\theta_{rec} - \theta_{MCTruth}(\phi_{rec} - \phi_{MCTruth})$



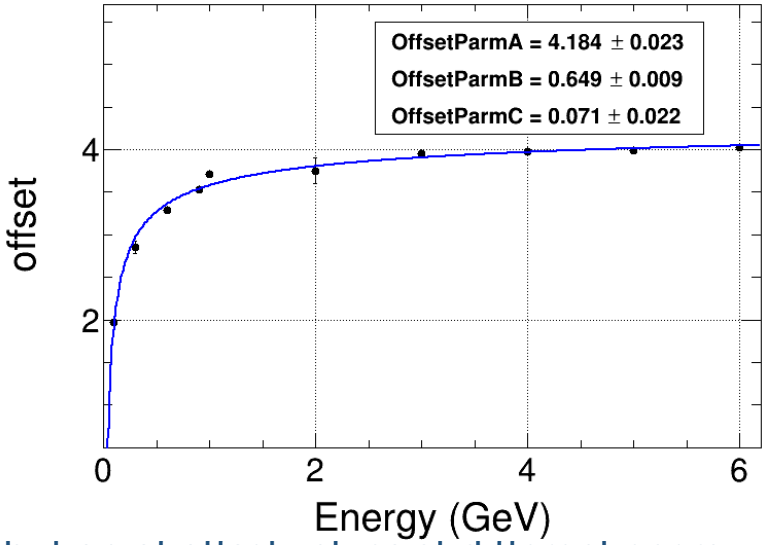






Update OffsetParm

- Sample:
  - $\theta = (28.4, 31.6)$
  - $\phi = (0, 360)$
  - $E = 0.1 - 6\mathrm{GeV}$
  - $\mathrm{Event} = 10000$
  - $\chi^2 = \sum_i^N \frac{(\phi_i^{rec} - \phi_i^{truth})^2}{\sigma_i^2}$



Distribution of offset values at different energy points and fitting result

Fitting :

- $\mathrm{Offset} = \mathrm{OffsetParmA} - \mathrm{OffsetParmB} \cdot e^{-\mathrm{OffsetParmC} \cdot E^{1.171}} \cdot E^{-0.5}$

The fitting results of $\theta_{rec} - \theta_{MCTruth}(\phi_{rec} - \phi_{MCTruth})$