Results of the AHCAL Fast Simulation Algorithm with a Distance Based Sorting for Calorimeter Tiles

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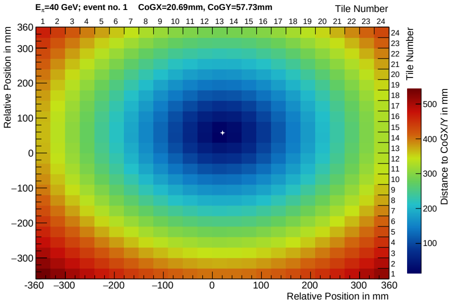
Distance Ordering

- Pion test beam data (2018) with $E_\pi = 40\,\mathrm{GeV}$
- 100000 events for data; 10000 events for simulation
- **Calculate distance of 24 $\times$ 24 to event's centre of gravity (CoG)**
- $\mathrm{CoG}_i = \frac{1}{E_\mathrm{total}} \sum_\mathrm{hits} E_\mathrm{hit} \cdot i_\mathrm{hit}$ with $i \in [x, y, z]$
- **Distance** $\boldsymbol{d = \sqrt{(I - \mathrm{CoGX})^2 + (J - \mathrm{CoGY})^2}}$
- Sort the tiles from smallest to largest distance to CoG
- First tile is first energy in PDF

23	19	18	21	24
16	7	6	10	20
11	2	*	4	14
12	3	1	5	15
17	9	8	13	22



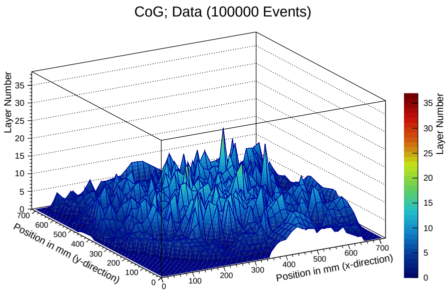
Simulation

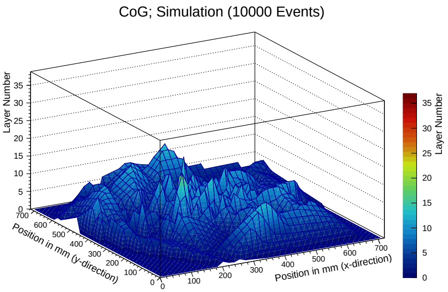
→ PDF for given dataset is created based on KDEs

→ Generate 10000 events from the estimated PDF with $h = 0.01$

→ Each event: $24 \times 24 \times 20$ simulated energies

1. Calculate distance of tiles to the simulated CoGX/CoGY tile
2. Simulate energies based on the sorted energies → sorted simulated energies
3. Assign simulated sorted energies to the tiles sorted by distance

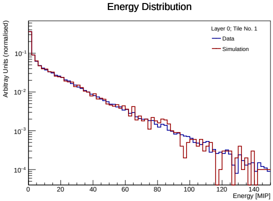




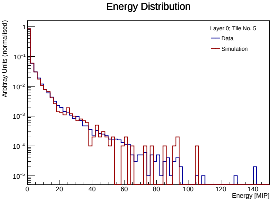
Energy Distribution per Tile

- Layer 0

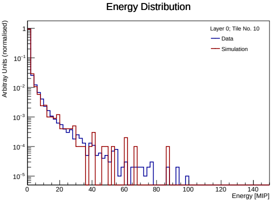
Tile No. 1



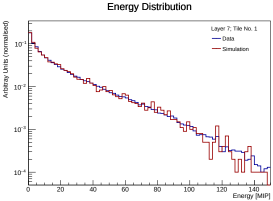
Tile No. 5

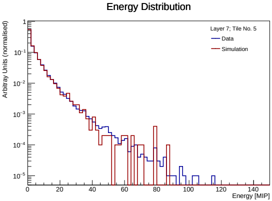


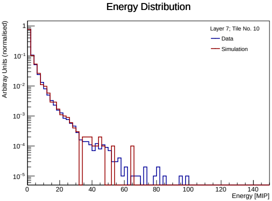
Tile No. 10



- Layer 7

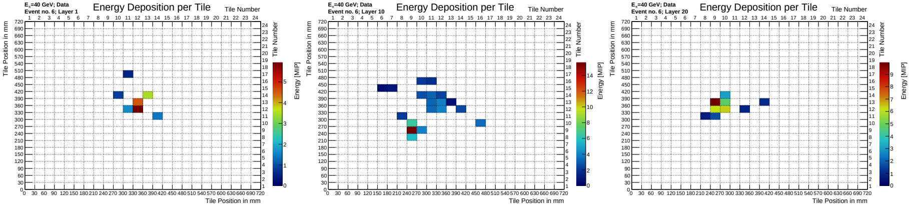




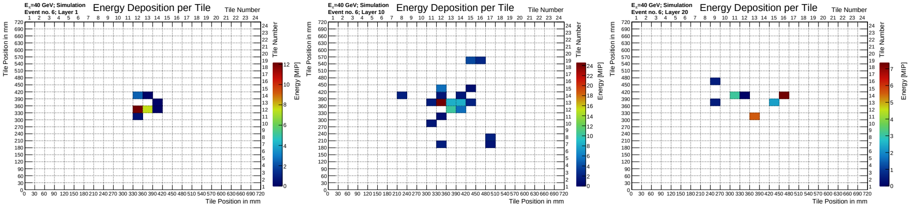


Energy per Tile per Layer (Event 6)

- Data:



- Simulation (simulated energies $< 0.05\,\mathrm{MIP}$ set to 0):



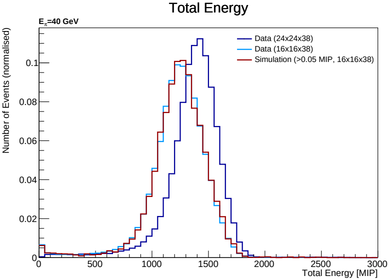
Kinematic Variables

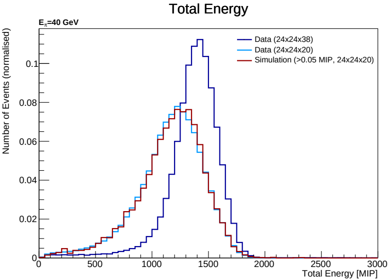
- Full dataset: 24×24 tiles per layer; 38 layer in total $\rightarrow$ 21888 energies per event
- PDF estimation with KDE cannot consider all energies per event

$\rightarrow$ Reduce total tile number and neglect outer layers:

1. Full dataset: **$24 \times 24 \times 38$**
2. **$16 \times 16 \times 38$**
3. $20 \times 20 \times 25$
4. $20 \times 20 \times 30$
5. **$24 \times 24 \times 20$**

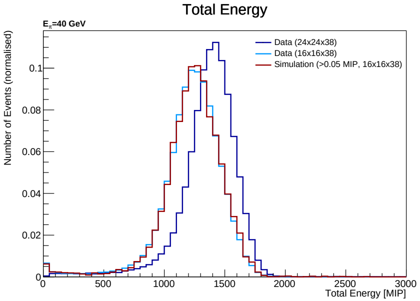
- Reduced **dataset** **simulated**
- No total agreement expected with full dataset
- Include Gaussian noise later

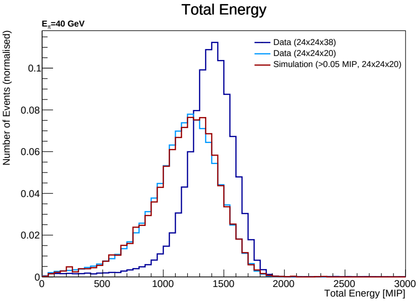




Total Energy

- Total Energy: $E_{\mathrm{total}} = \sum_{\mathrm{hits}} E_{\mathrm{hit}}$
- Simulated energy distribution agrees with reduced data
- More deposited energy in outer layers than outer tiles

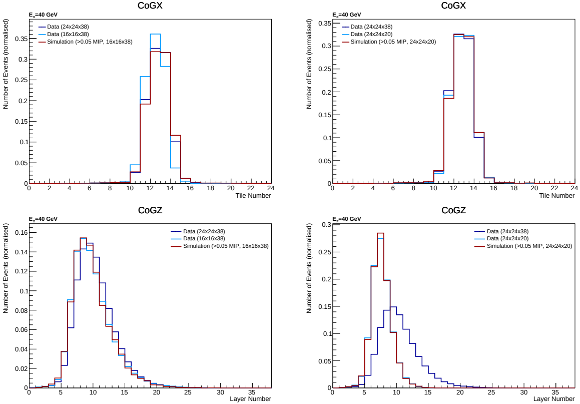




Centre-of-Gravity

Centre-of-Gravity: $\mathrm{CoG}_i = \frac{1}{E_{\mathrm{total}}} \sum_{\mathrm{hits}} E_{\mathrm{hit}} \cdot i_{\mathrm{hit}}$ **with** $i \in [x, y, z]$

- Good agreement between data and simulation with 24 × 24 tiles in x- and y-direction
- Good agreement between data and simulation with all layers in z-direction

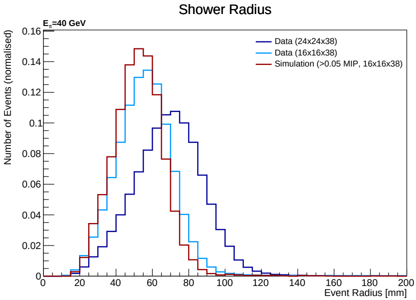


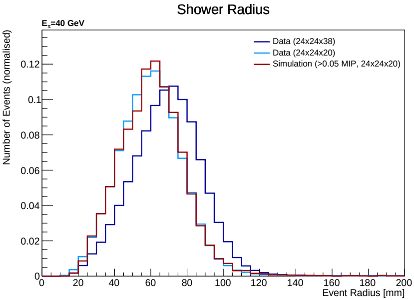
Shower Radius

Shower Radius: $\boldsymbol{R = \frac{1}{E_{\text{total}}} \sum_{\text{hits}} E_{\text{hit}} \cdot r_{\text{hit}}}$ **with**

$$\boldsymbol{r_{\text{hit}} = \sqrt{(i_{\text{hit}} - \text{CoGX}_{\text{hit}})^2 + (j_{\text{hit}} - \text{CoGY}_{\text{hit}})^2}}$$ **and** $\boldsymbol{i_{\text{hit}} \in [x, y, z]}$

- Large influence of outer tiles with deposited energy
- Outer layers register lower-energetic hits → smaller influence for shower radius

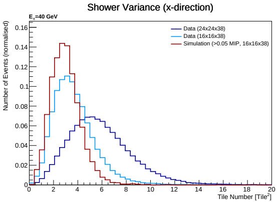


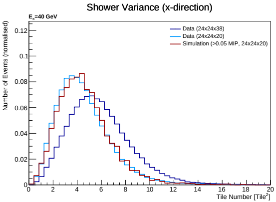


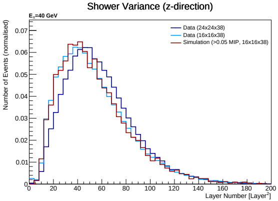
Shower Variance

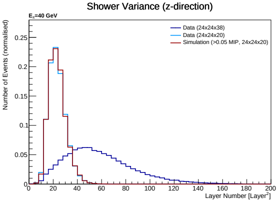
Shower Variance: $\mathrm{Var(i)} = \frac{1}{E_{\text{total}}} \sum_{\text{hits}} E_{\text{hit}} \cdot (i_{\text{hit}} - \mathrm{CoG_i})^2$ **with** $i \in [x, y, z]$

- Large influence of outer tiles with deposited energy
- Outer layers register lower-energetic hits and larger distance to CoGZ $\rightarrow$ smaller influence on shower variance





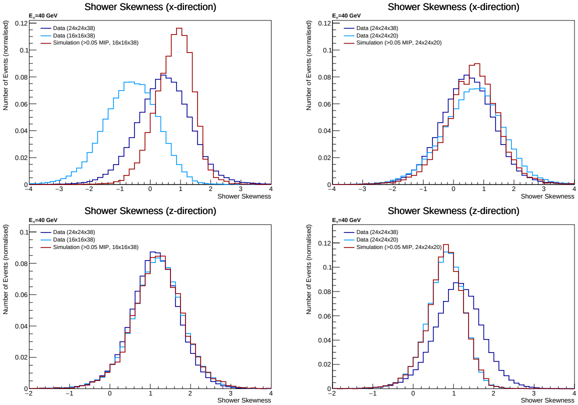




Shower Skewness

Shower Skewness: $\mathrm{Skew}(i) = \frac{1}{E_{\mathrm{total}}} \sum_{\mathrm{hits}} E_{\mathrm{hit}} \cdot \left(\frac{i_{\mathrm{hit}} - \mathrm{CoG_i}}{\sigma_i} \right)^3$ **with** $\sigma_i = \sqrt{\mathrm{Var}(i)}$ **and** $i \in [x, y, z]$

- Including less tiles lead to discrepancies for skewness in x- and y-direction
- No significant influence of outer layers on skewness in z-direction



Summary and Outlook

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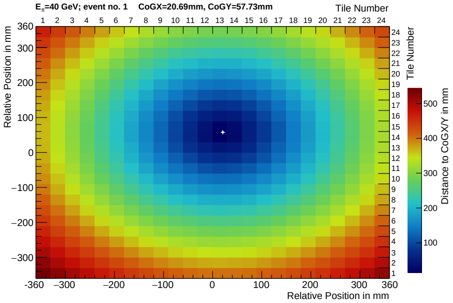
- Distance based sorting and simulation of deposited energies for fast simulation
- Exclude outer tiles and layers to see behaviour of energy distributions
- **Initial results promising; however, not fully optimal**

- Include Gaussian noise
- Investigate behaviour of energy and kinematic variables with tile groups (16×16) and all 38 layers
- Expand to larger energies

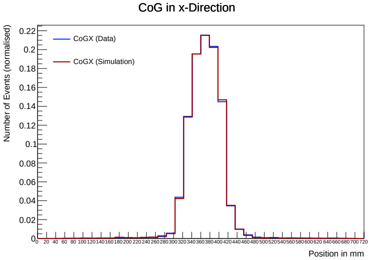


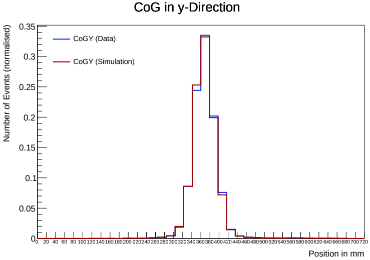
Thank You For Your Attention!

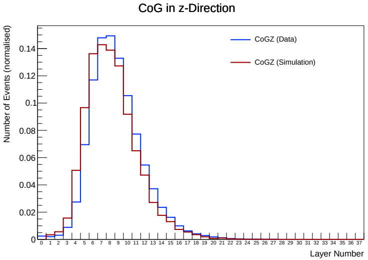
BACKUP

Centre-of-Gravity

- Simulation of CoGs in all three directions with KDE





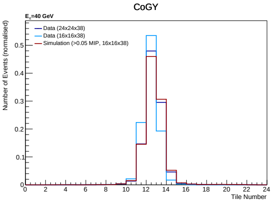


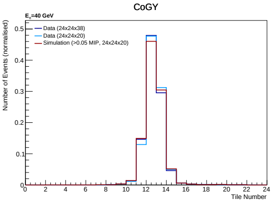
Kinematic Variables

- Centre-of-Gravity: $\mathrm{CoG}_i = \frac{1}{E_{\mathrm{total}}} \sum_{\mathrm{hits}} E_{\mathrm{hit}} \cdot i_{\mathrm{hit}}$ with $i \in [x, y, z]$
- Total Energy: $E_{\mathrm{total}} = \sum_{\mathrm{hits}} E_{\mathrm{hit}}$
- Shower Radius: $R = \frac{1}{E_{\mathrm{total}}} \sum_{\mathrm{hits}} E_{\mathrm{hit}} \cdot r_{\mathrm{hit}}$ with $r_{\mathrm{hit}} = \sqrt{(i_{\mathrm{hit}} - \mathrm{CoGX_{hit}})^2 + (j_{\mathrm{hit}} - \mathrm{CoGY_{hit}})^2}$ and $i_{\mathrm{hit}} \in [x, y, z]$
- Central Fraction: $F_{\mathrm{central}} = \frac{1}{E_{\mathrm{total}}} \sum_{\mathrm{hits}} E_{\mathrm{hit}}$ if $r_{\mathrm{hit}} < 30\,\mathrm{mm}$
- Shower Variance: $\mathrm{Var}(i) = \frac{1}{E_{\mathrm{total}}} \sum_{\mathrm{hits}} E_{\mathrm{hit}} \cdot (i_{\mathrm{hit}} - \mathrm{CoG_i})^2$ with $i \in [x, y, z]$
- Shower Skewness: $\mathrm{Skew}(i) = \frac{1}{E_{\mathrm{total}}} \sum_{\mathrm{hits}} E_{\mathrm{hit}} \cdot \left(\frac{i_{\mathrm{hit}} - \mathrm{CoG_i}}{\sigma_i}\right)^3$ with $\sigma_i = \sqrt{\mathrm{Var}(i)}$ and $i \in [x, y, z]$
- Shower Kurtosis: $\mathrm{Kurt}(i) = \frac{1}{E_{\mathrm{total}}} \sum_{\mathrm{hits}} E_{\mathrm{hit}} \cdot \left(\frac{i_{\mathrm{hit}} - \mathrm{CoG_i}}{\sigma_i}\right)^4$ with $\sigma_i = \sqrt{\mathrm{Var}(i)}$ and $i \in [x, y, z]$

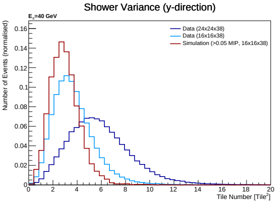
y-Direction

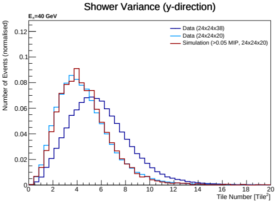
CoGY



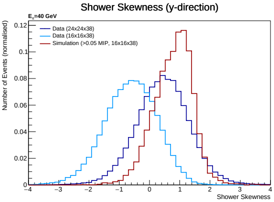


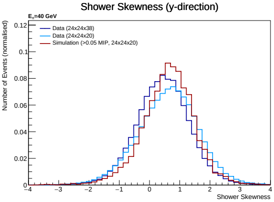
Shower Variance





Shower Skewness

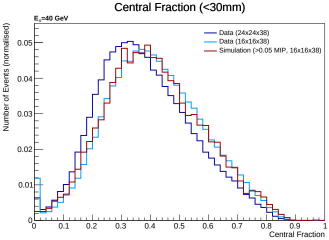


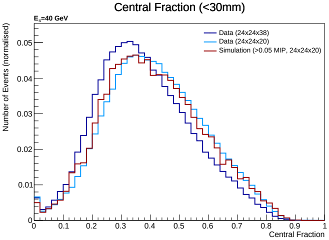


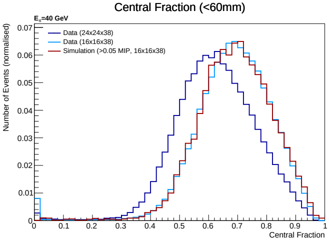
Central Fraction

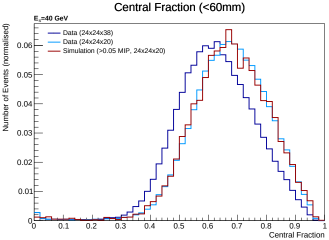
Central Fraction: $F_{\mathrm{central}} = \frac{1}{E_{\mathrm{total}}} \sum_{\mathrm{hits}} E_{\mathrm{hit}}$ **if** $r_{\mathrm{hit}} < 30\ (60)\ \mathrm{mm}$

- Simulation of energy fraction in a radius of 30 mm and 60 mm agrees with data









Shower Kurtosis

Shower Kurtosis: $\mathbf{Kurt}(\boldsymbol{i})$

$$= \frac{1}{E_{\text{total}}} \sum_{\text{hits}} E_{\text{hit}} \cdot \left(\frac{i_{\text{hit}} - \text{CoG}_{\text{i}}}{\sigma_i} \right)^4$$

with $\sigma_i = \sqrt{\text{Var}(i)}$ **and** $i \in [x, y, z]$

- Including less tiles lead to discrepancies for kurtosis in x- and y-direction

- No significant influence of outer layers on kurtosis in z-direction