

# Correction of Hadron Shower Energy Response Using Autoencoders

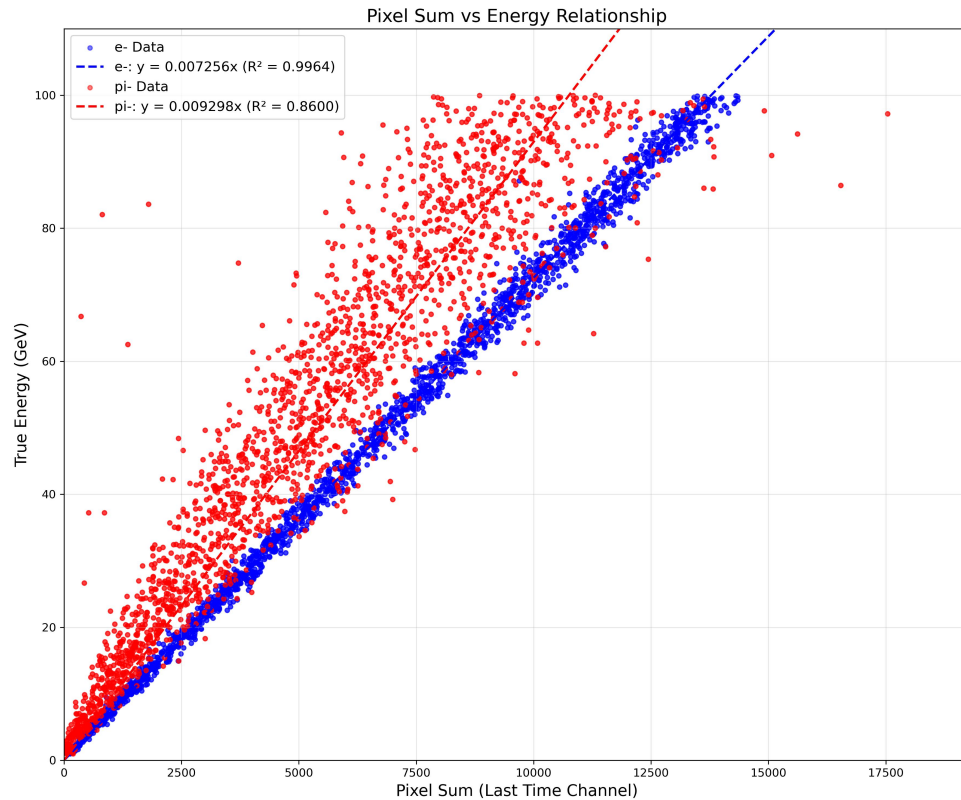
Detector Performance

Liangyu Wu, Ariel Schwartzman

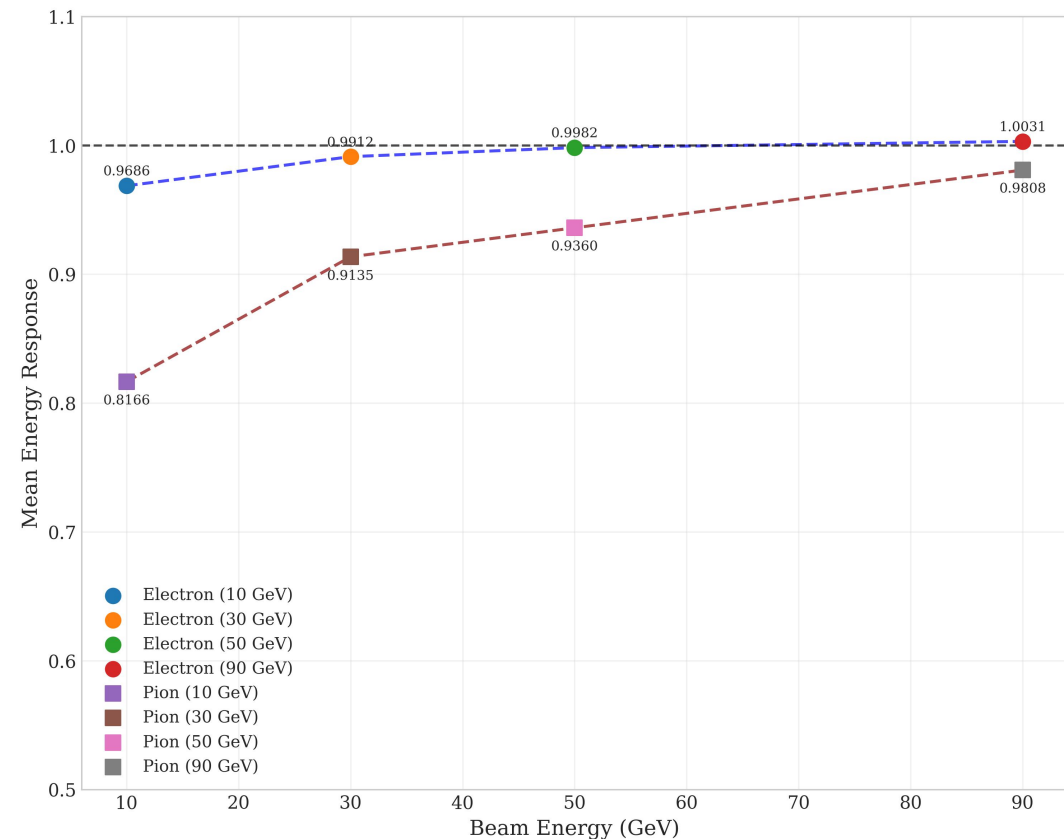
25 June 2025

# Conversion from Photon Count to Energy

- For 1-100 GeV  $e^-$  and  $\pi^-$  data, perform linear calibration
- The energy is calculated by multiplying the total final photon count by the slope



- Response of test data  
(10, 30, 50, 90 GeV  $e^-/\pi^-$ , 1,000 events for each)



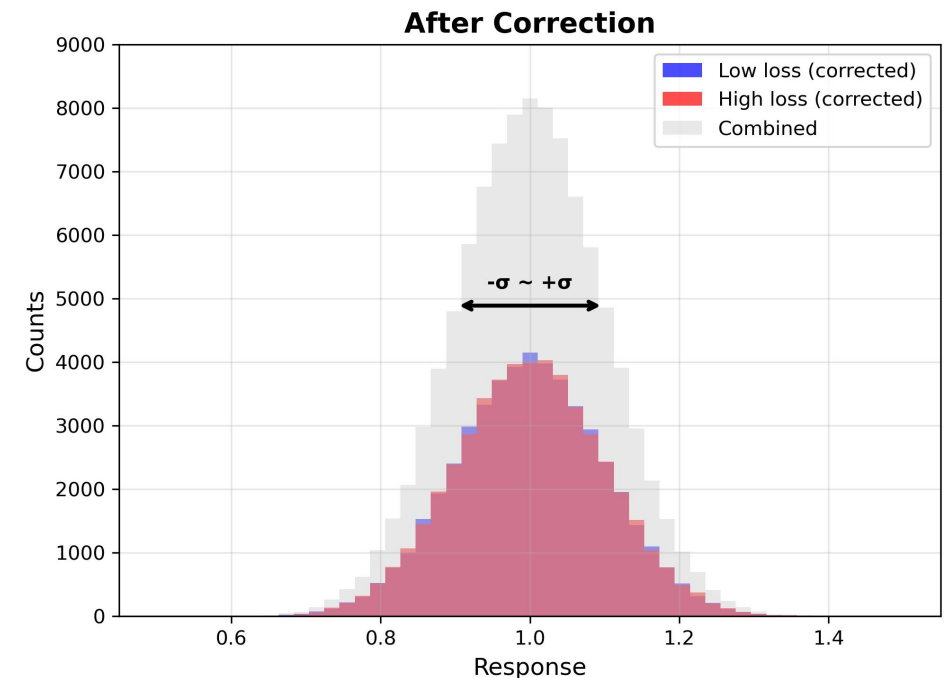
# Autoencoder-Based Shower Characterization

- Use autoencoder to learn shower development characterized by a single value (loss)
- Investigate if the loss captures response differences due to varying shower topologies
- Apply AE loss to reduce sources of energy fluctuation



Apply loss  
correction

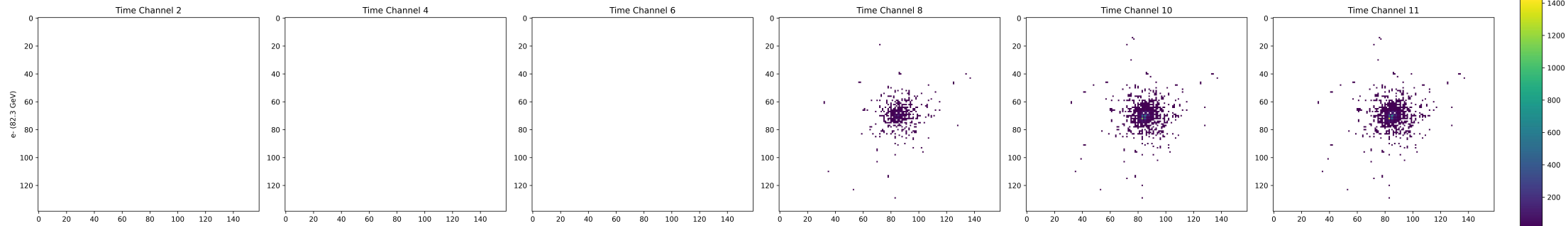
Toy example



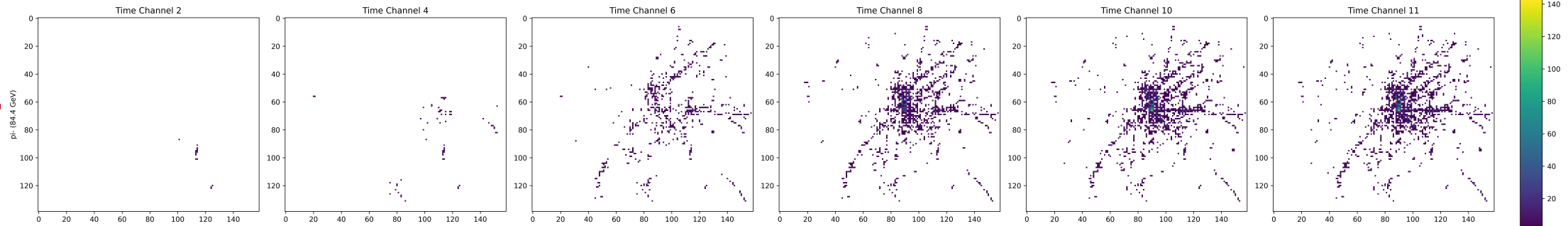
# Input Display

- Photon distribution at the end of the detector with 0.1 ns time slices (~135 images per event)
- Each pixel stands for the information within a rod (~0.4 cm x 0.4 cm)

82.3 GeV  $e^-$



84.4 GeV  $\pi^-$



  
As time progresses

# Preliminary Autoencoder Model

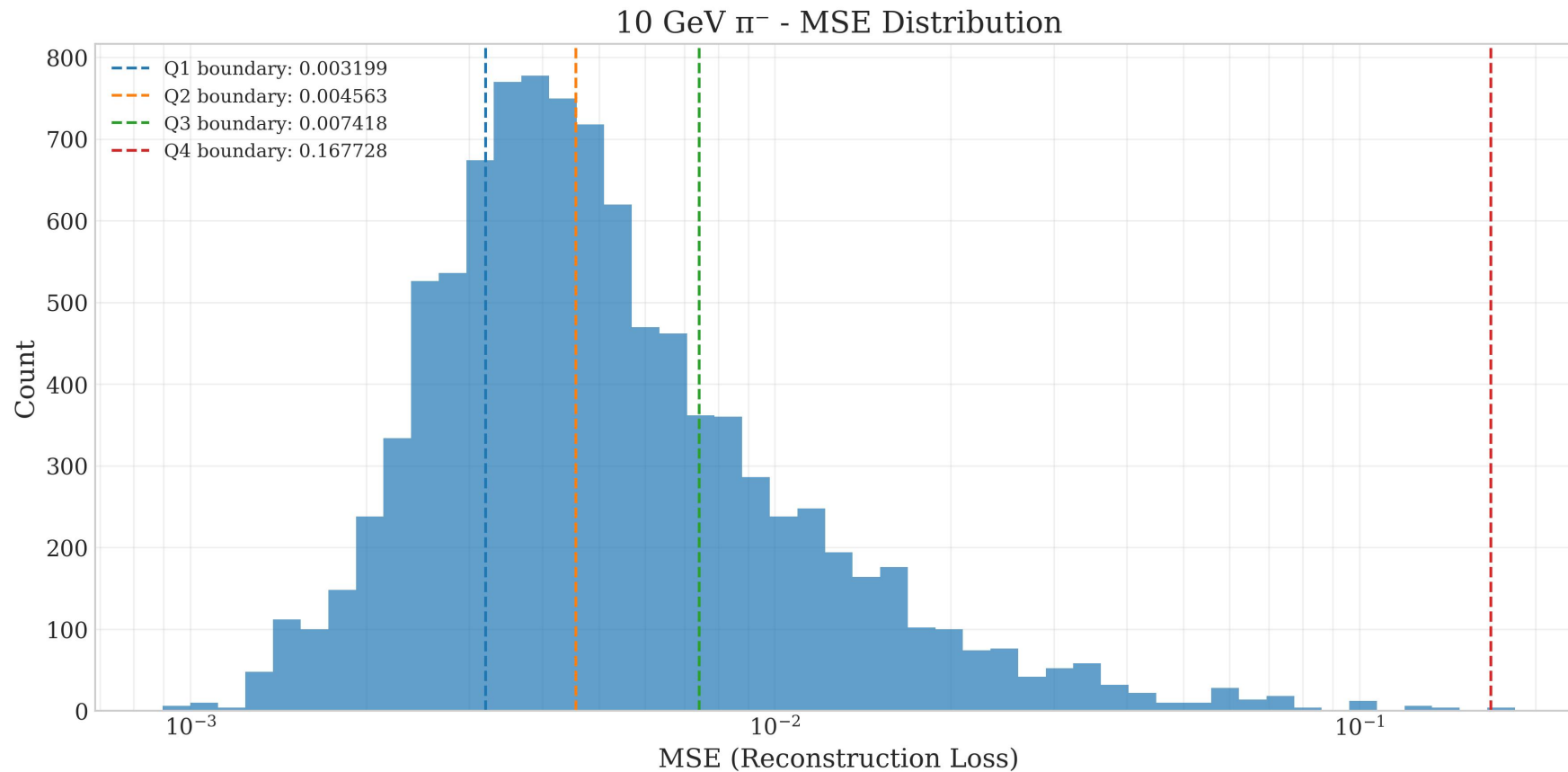
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- Function:  
Transforming one set of time evolution images to another set of the same dimensions
- Training the model with 1-100 GeV  $e^-$  and  $\pi^-$  data (4000 events for each)
- Train/val/test split of 7/2/1
- Loss: “mse”

Layers
# Encoder
InputLayer(input shape=(height, width, time channels))
Conv2D(32, (3, 3), padding='same')
Conv2D(16, (3, 3), padding='same')
Conv2D(8, (3, 3), padding='same')
Conv2D(4, (3, 3), padding='same', name='bottleneck')
Conv2D(8, (3, 3), padding='same')
Conv2D(16, (3, 3), padding='same')
Conv2D(32, (3, 3), padding='same')
Conv2D(time channels, (3, 3), activation='relu', padding='same', name='decoded')
# Decoder

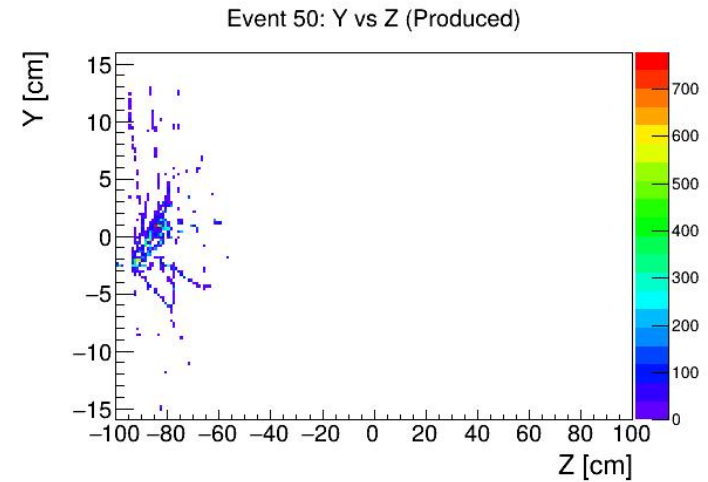
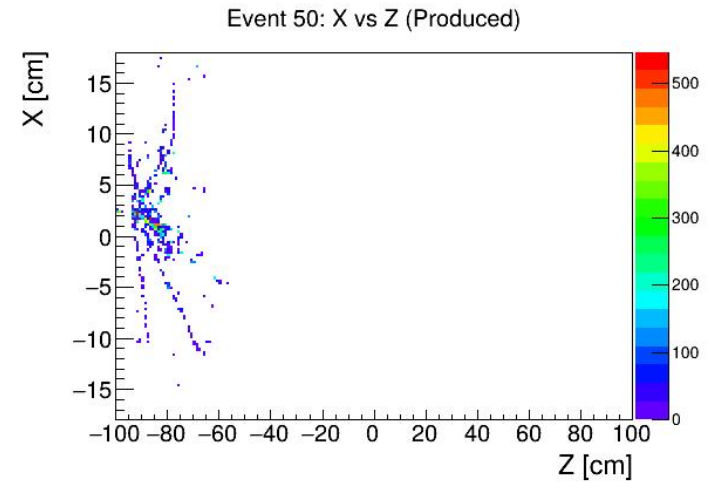
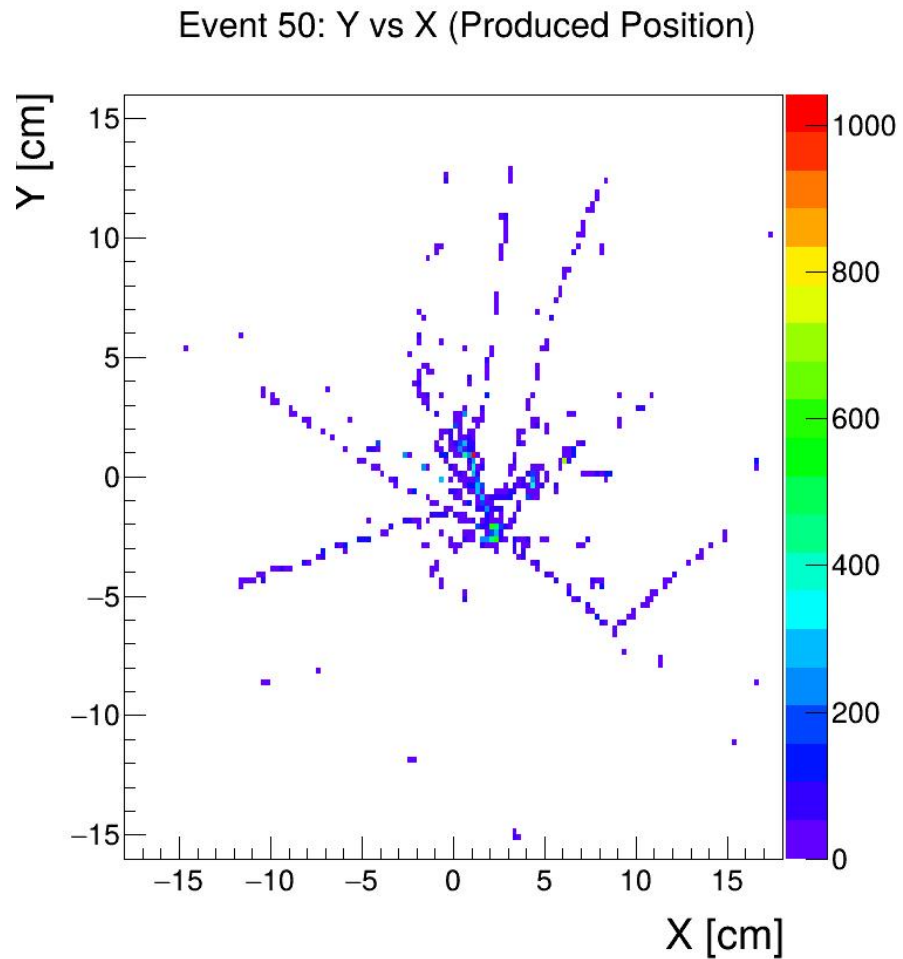
# Loss Distribution of 10 GeV $\pi^-$

- 10,000 events of 10 GeV  $\pi^-$  for test
- Q1-Q4 ordered by increasing loss, with equal #events in each region



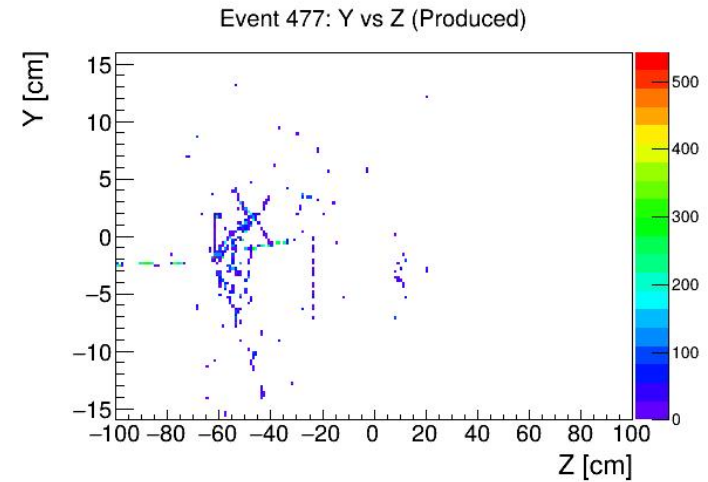
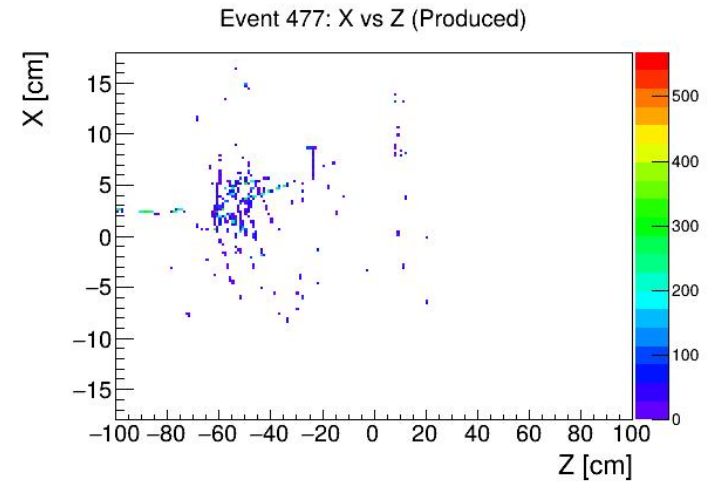
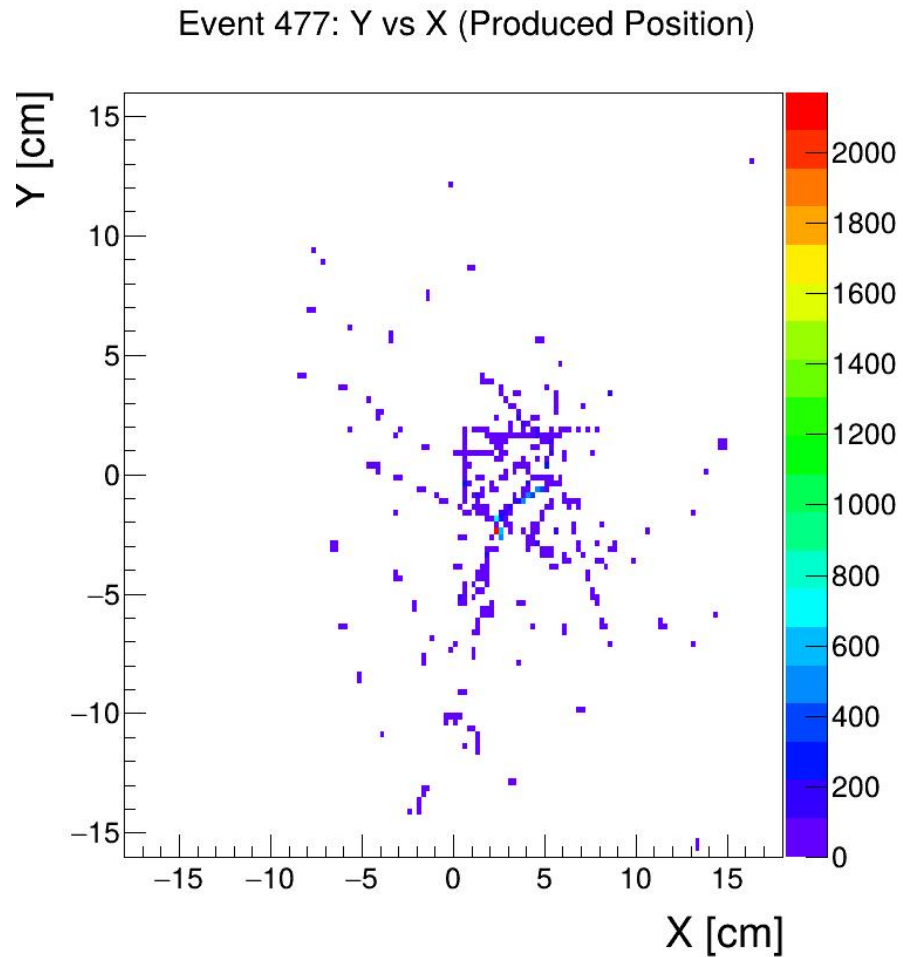
# Event Display for 10 GeV pi-

➤ Q1 Event (lowest loss) 1/3



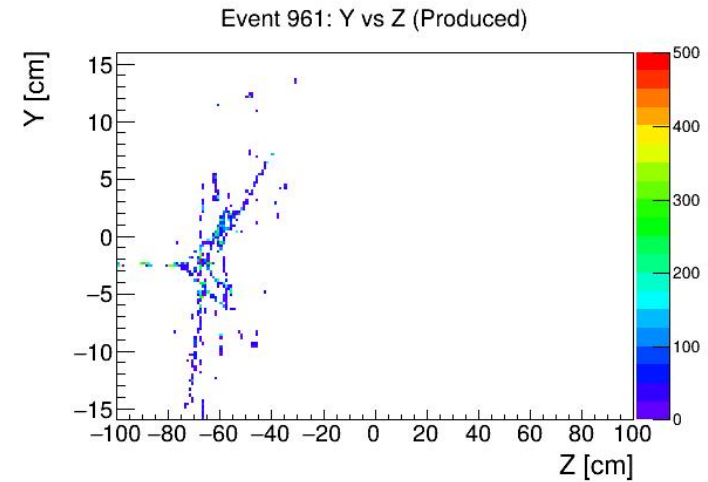
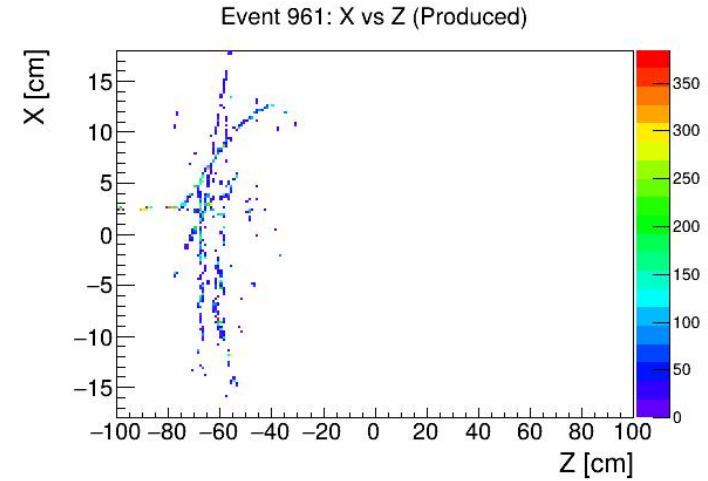
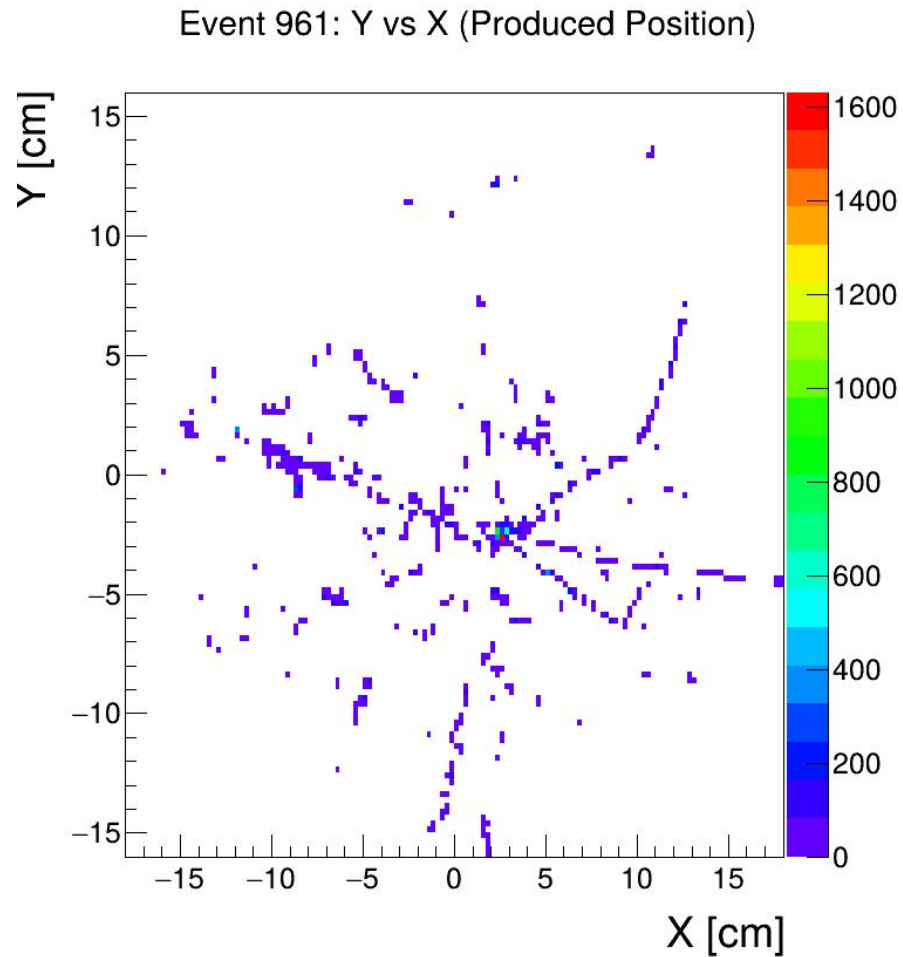
# Event Display for 10 GeV pi-

➤ Q1 Event (lowest loss) 2/3



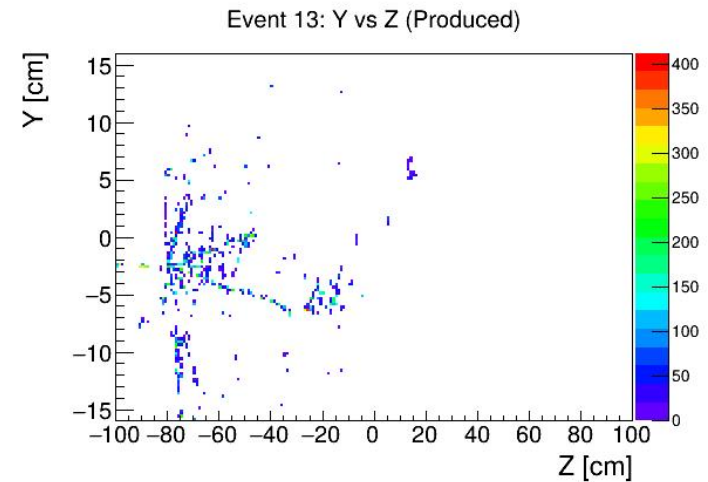
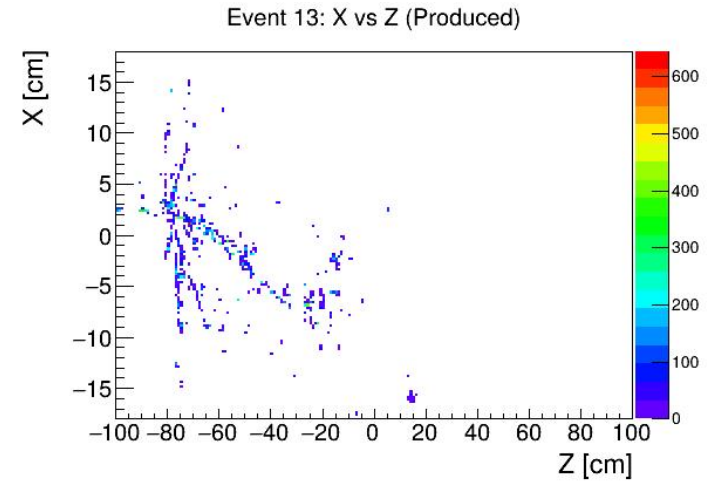
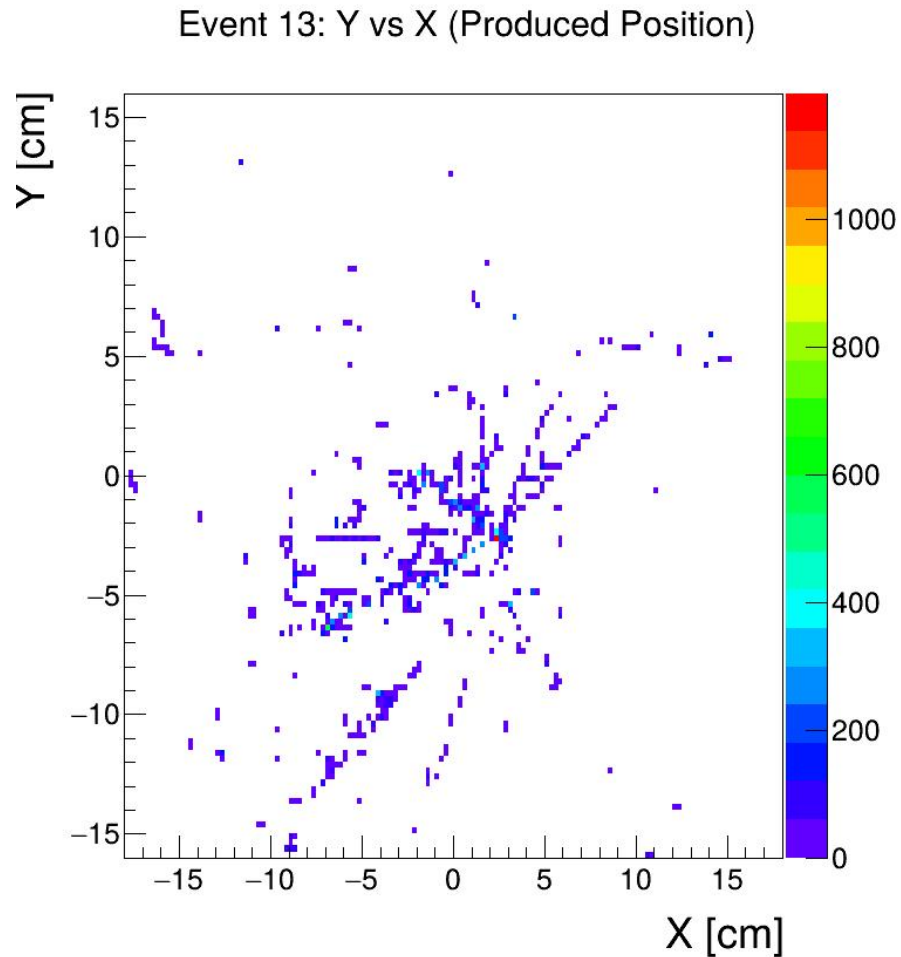
# Event Display for 10 GeV pi-

➤ Q1 Event (lowest loss) 3/3



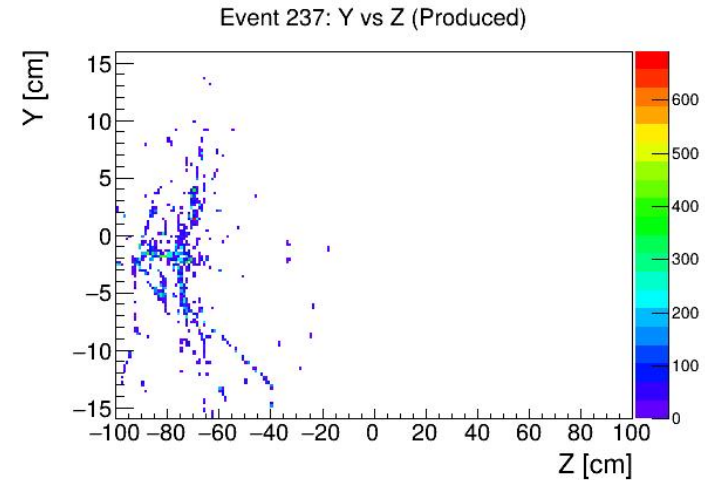
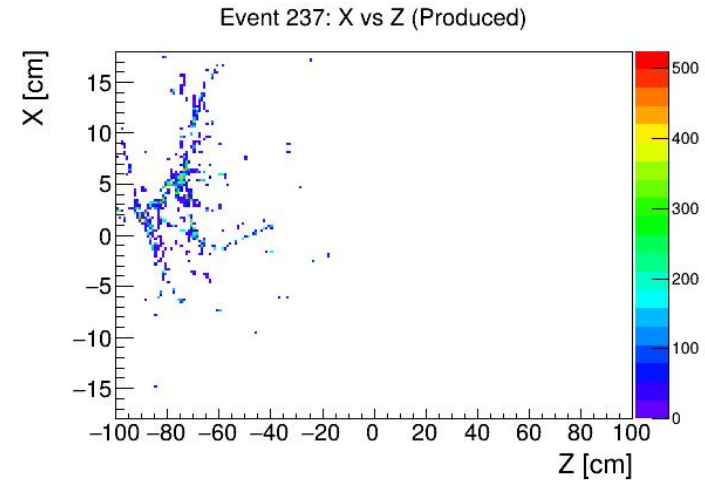
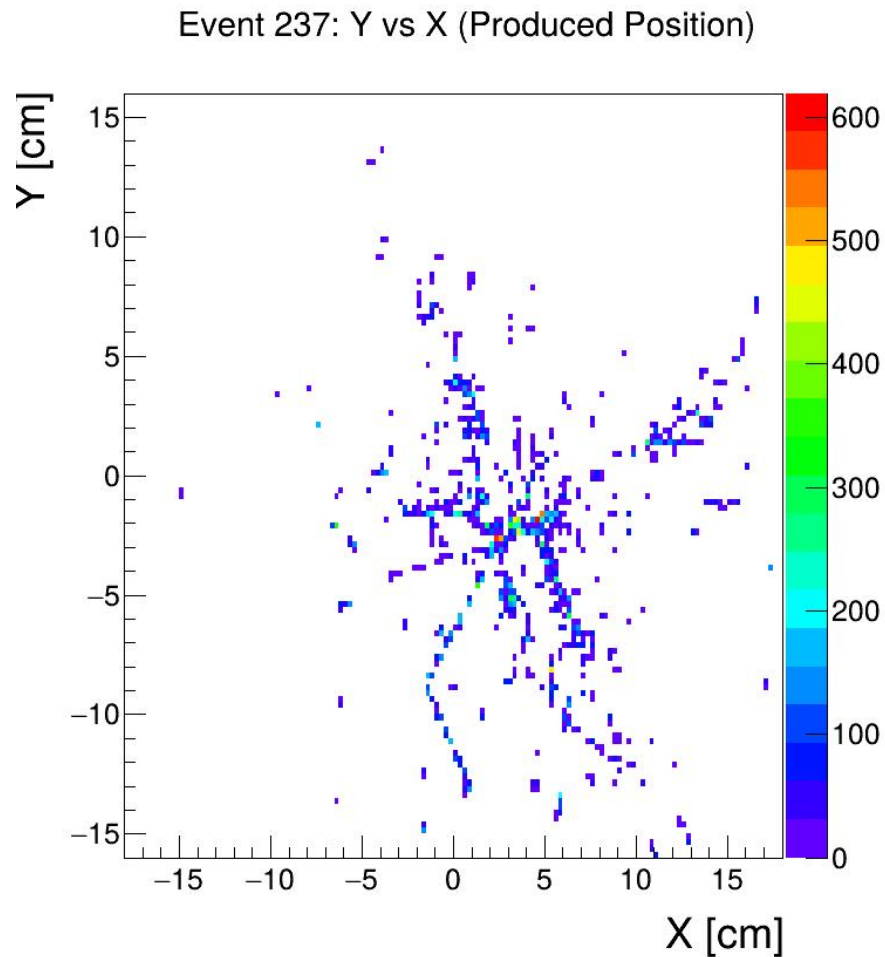
# Event Display for 10 GeV pi-

➤ Q2 Event (2nd lowest loss) 1/3



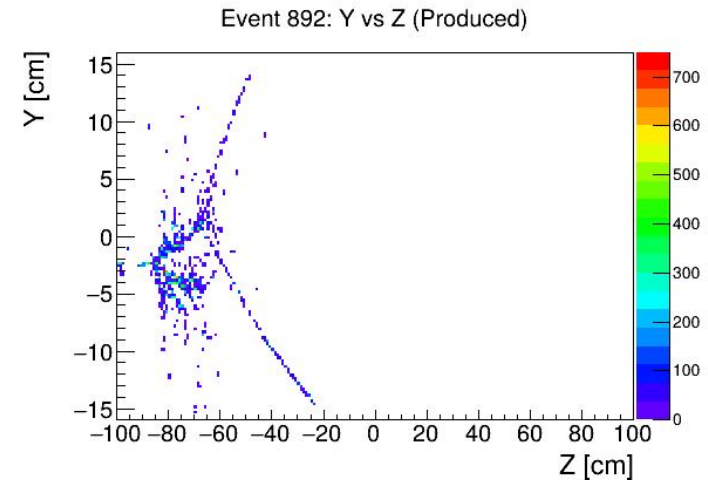
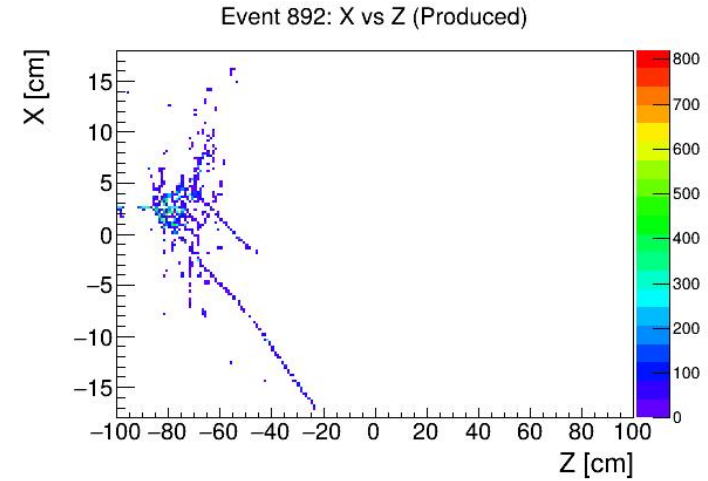
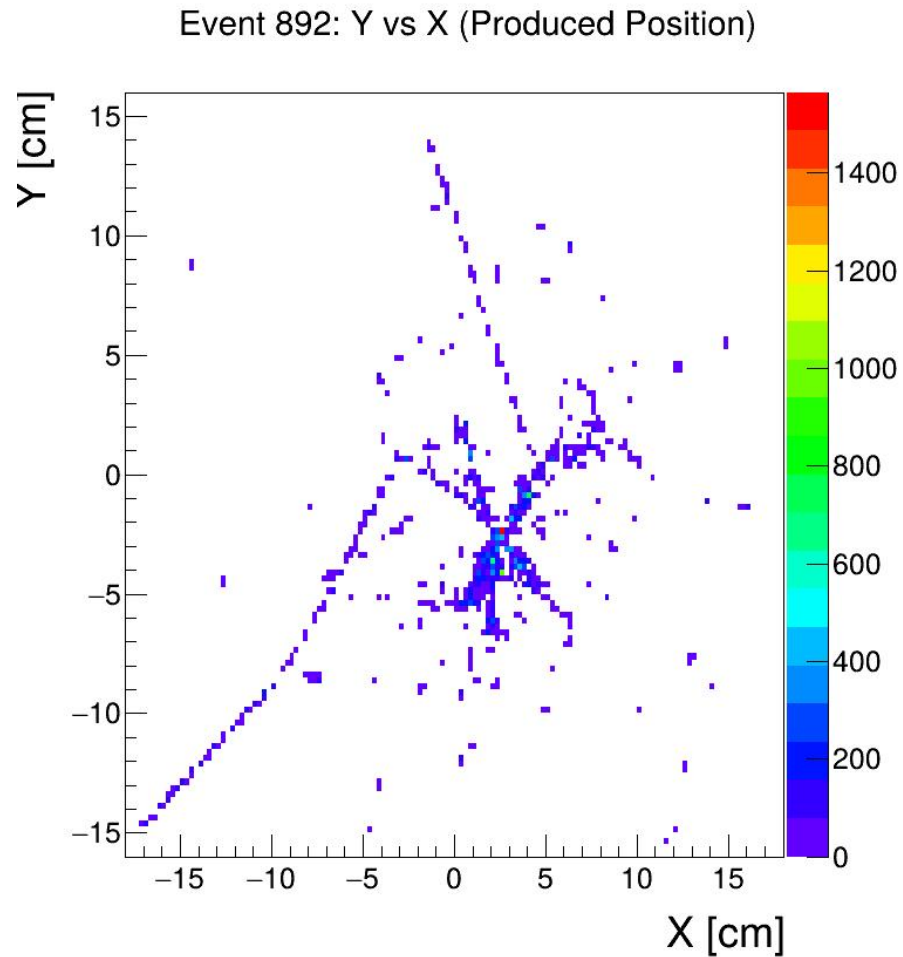
# Event Display for 10 GeV pi-

- Q2 Event (2nd lowest loss) 2/3



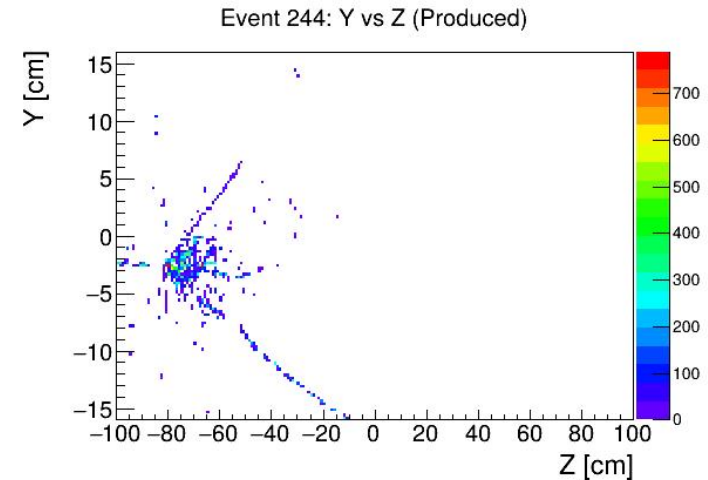
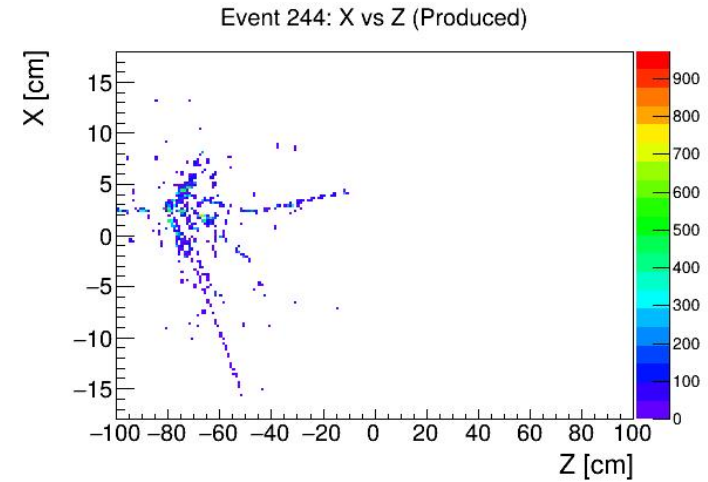
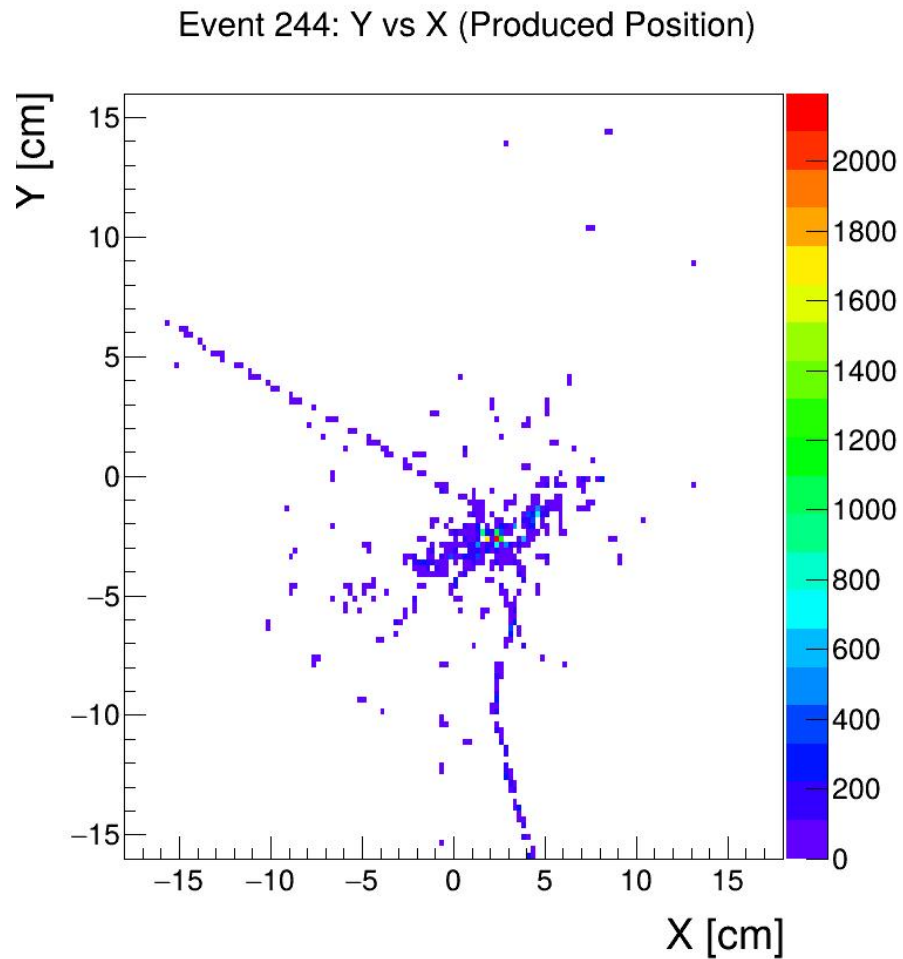
# Event Display for 10 GeV pi-

➤ Q2 Event (2nd lowest loss) 3/3



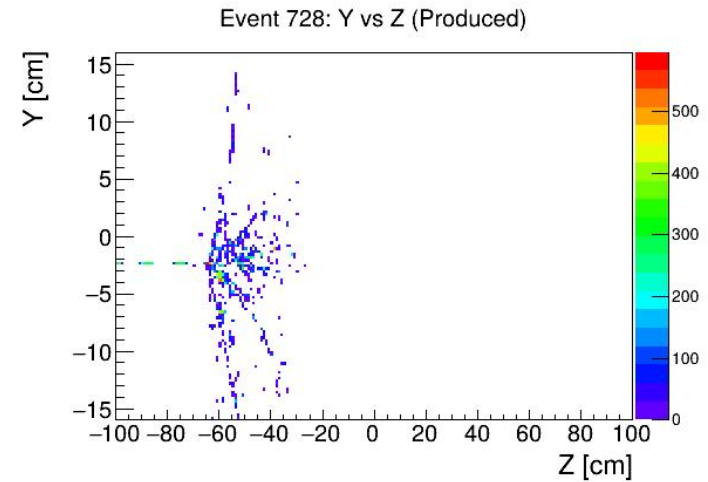
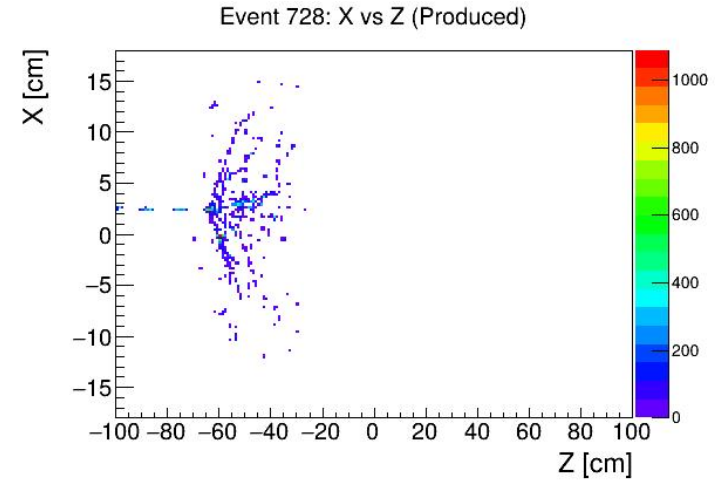
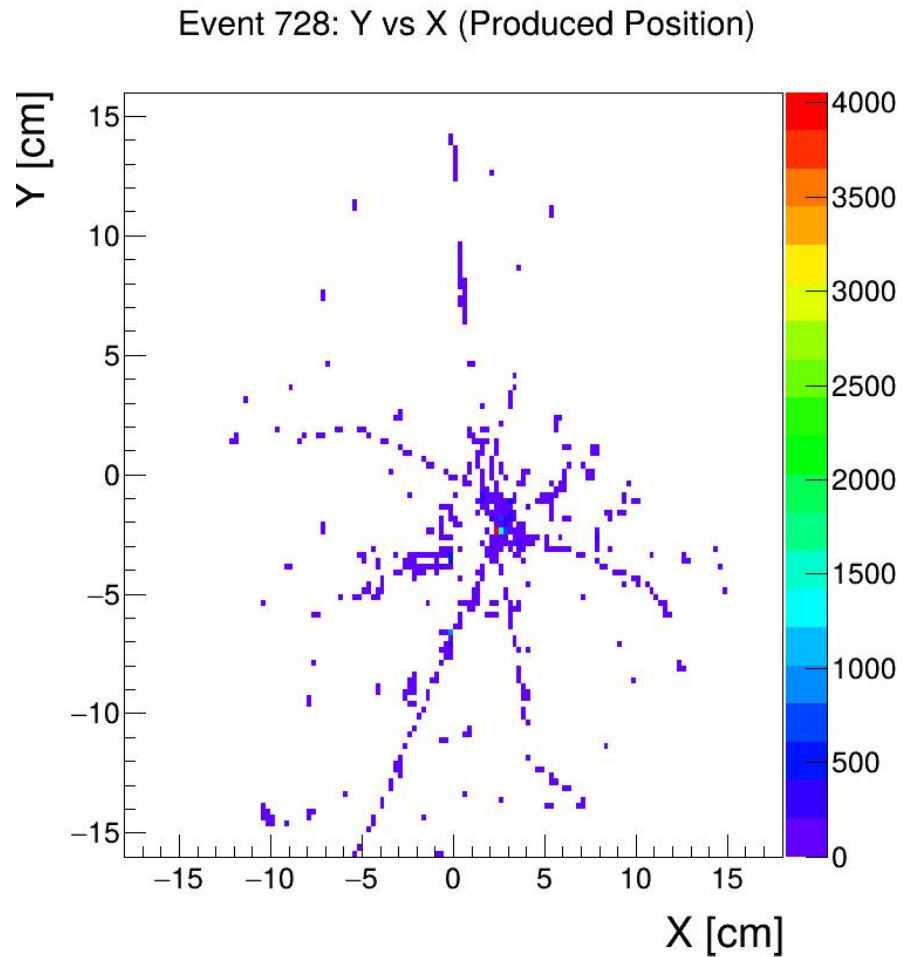
# Event Display for 10 GeV pi-

- Q3 Event (2nd highest loss) 1/3



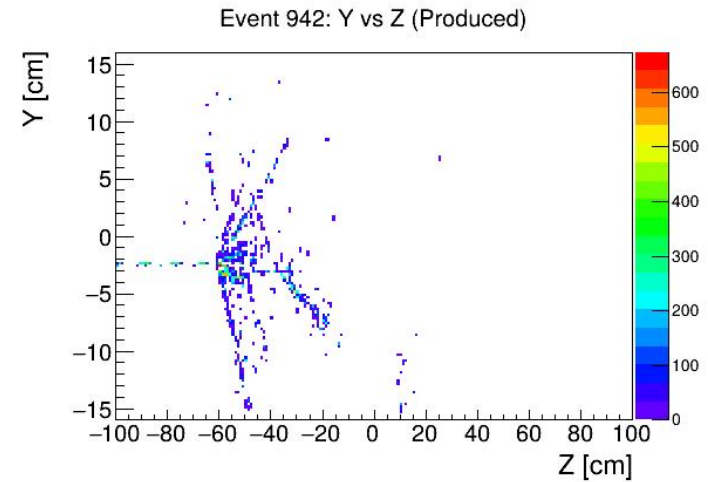
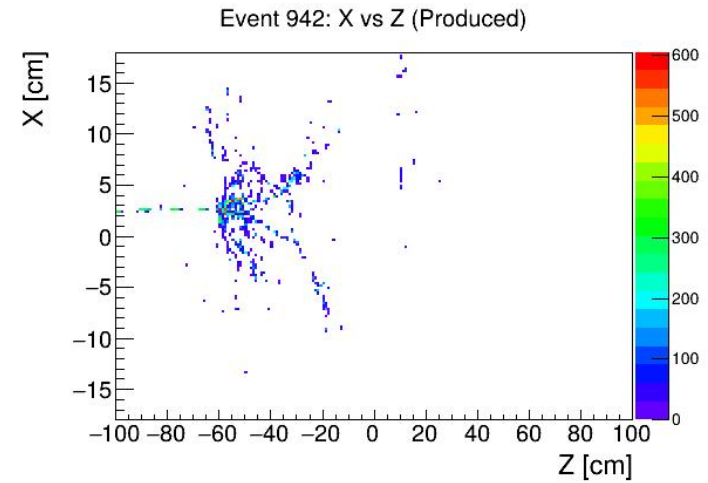
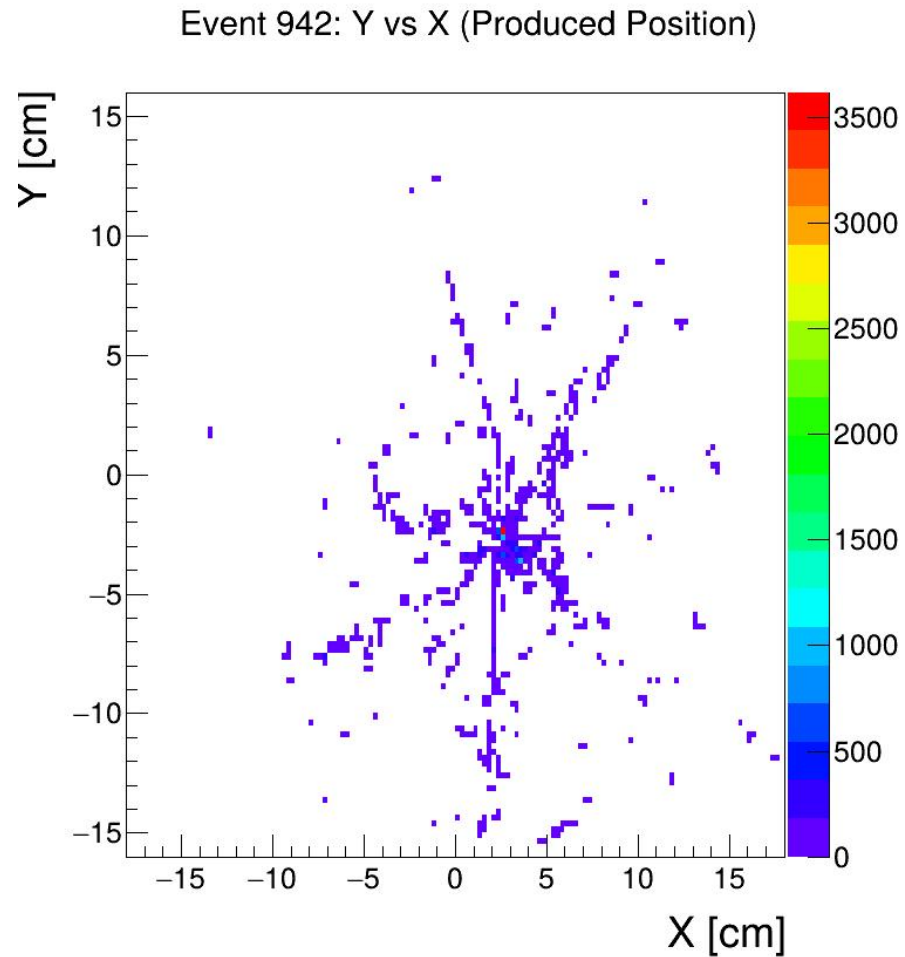
# Event Display for 10 GeV pi-

- Q3 Event (2nd highest loss) 2/3



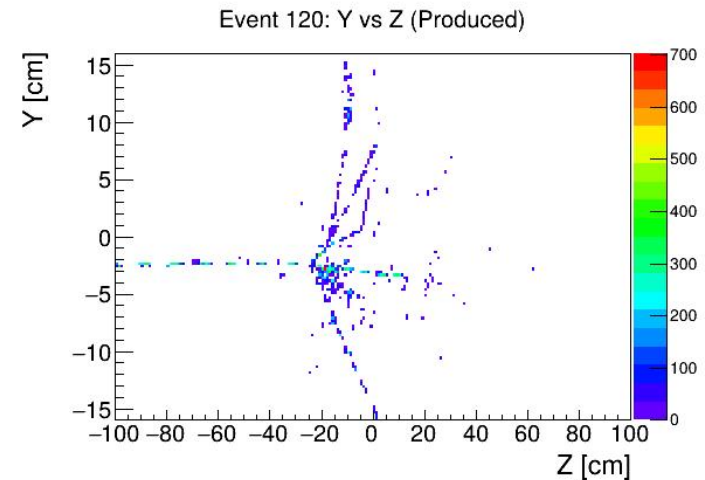
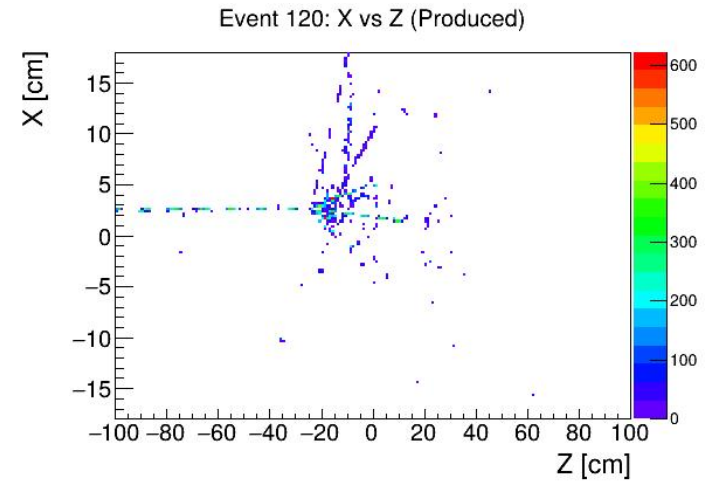
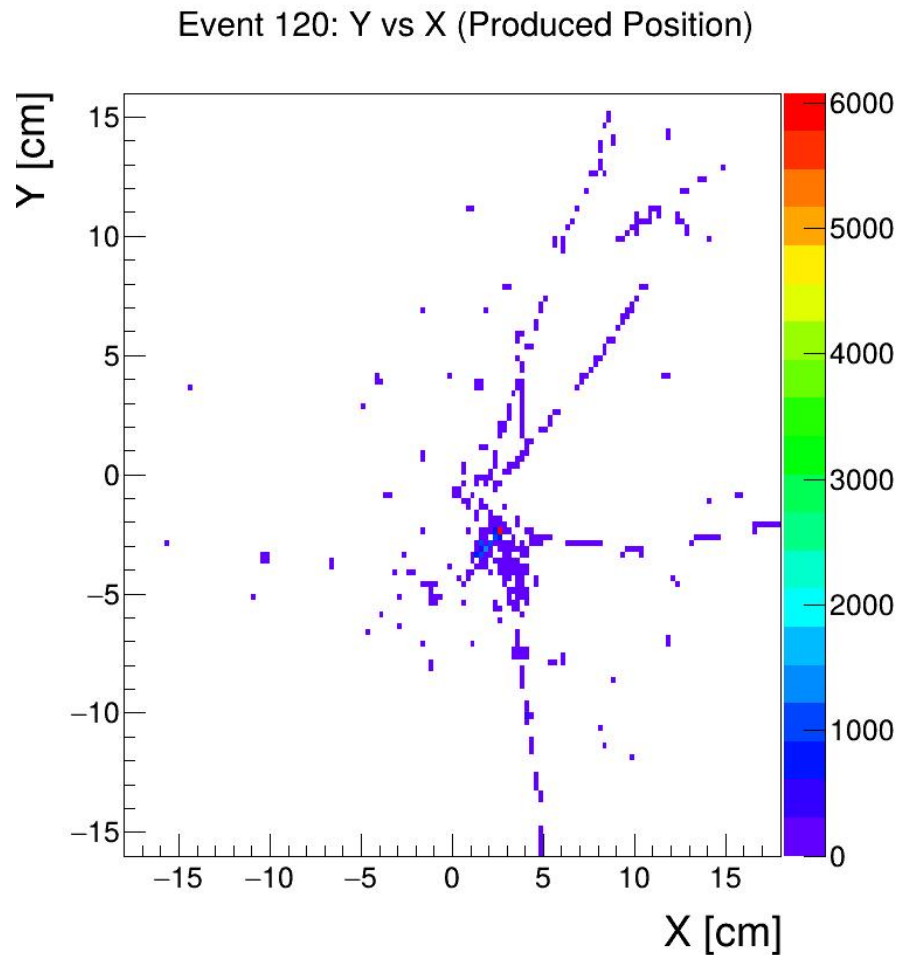
# Event Display for 10 GeV pi-

- Q3 Event (2nd highest loss) 3/3



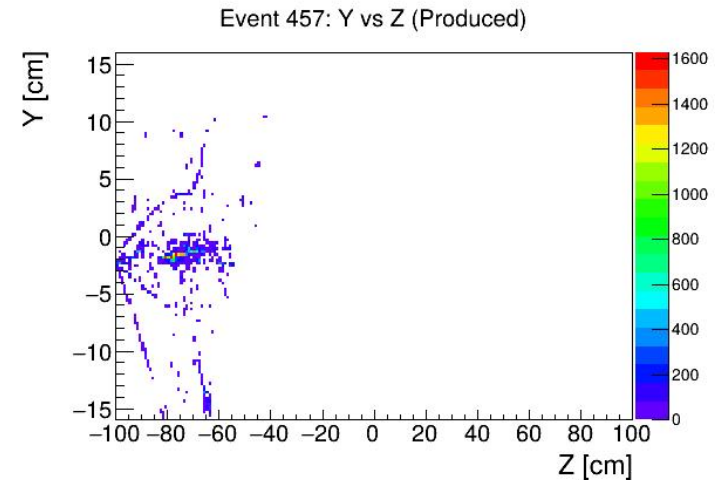
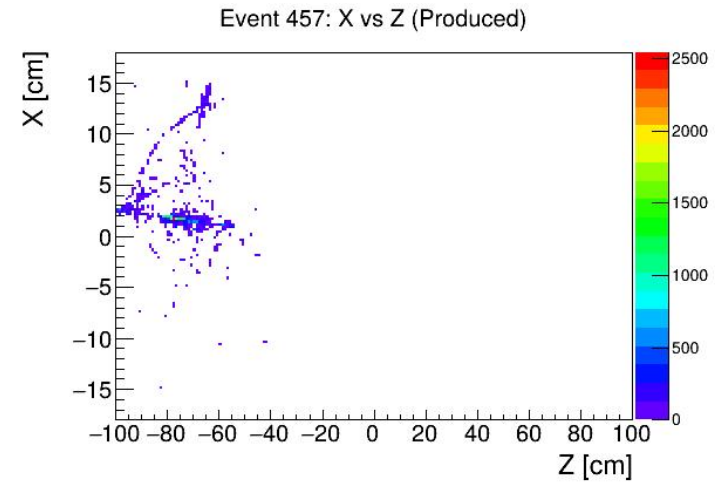
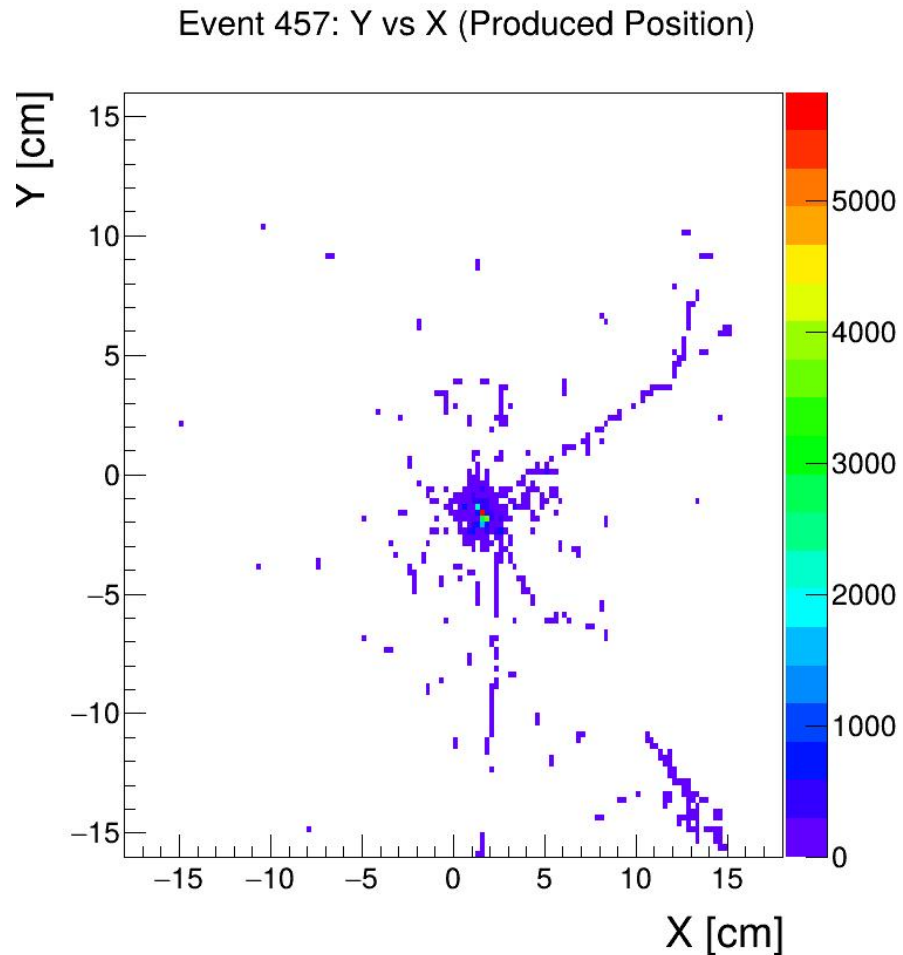
# Event Display for 10 GeV pi-

➤ Q4 Event (highest loss) 1/3



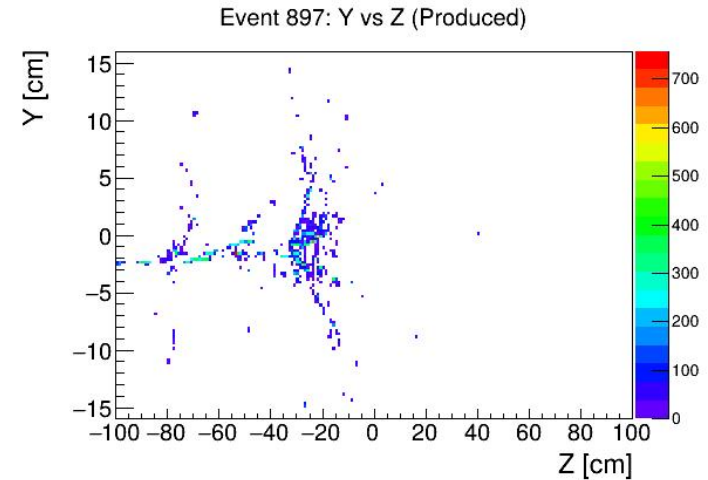
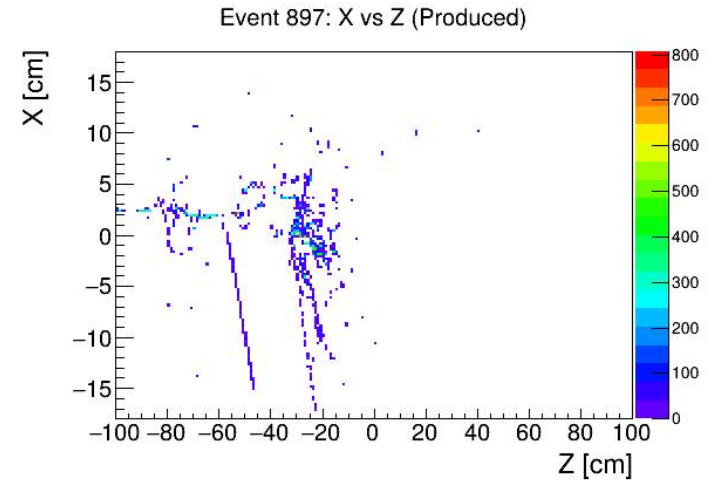
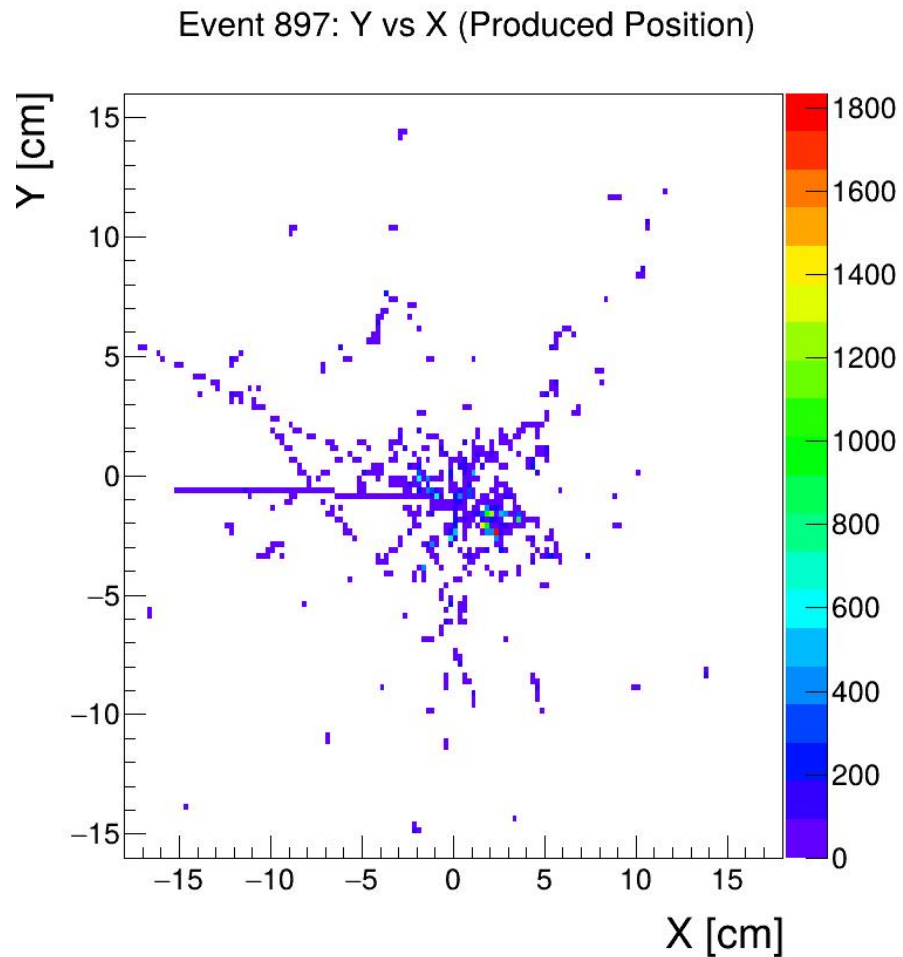
# Event Display for 10 GeV pi-

➤ Q4 Event (highest loss) 2/3



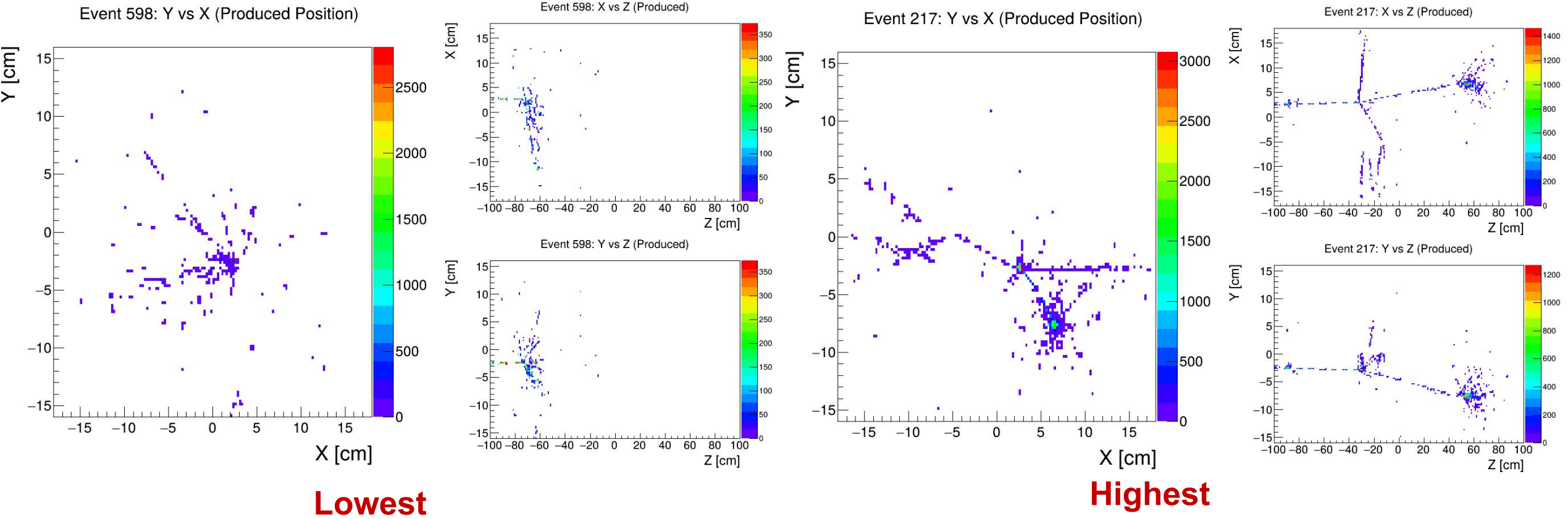
# Event Display for 10 GeV pi-

➤ Q4 Event (highest loss) 3/3



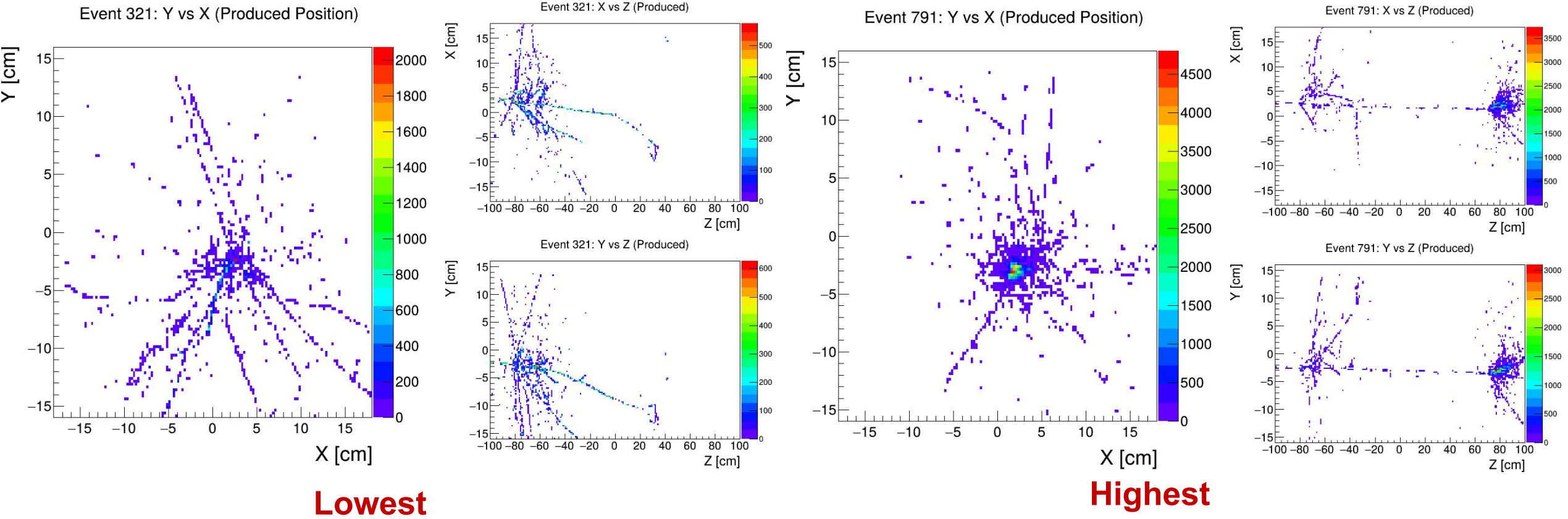
# Event Display for 10 GeV pi-

➤ Lowest loss vs Highest loss event



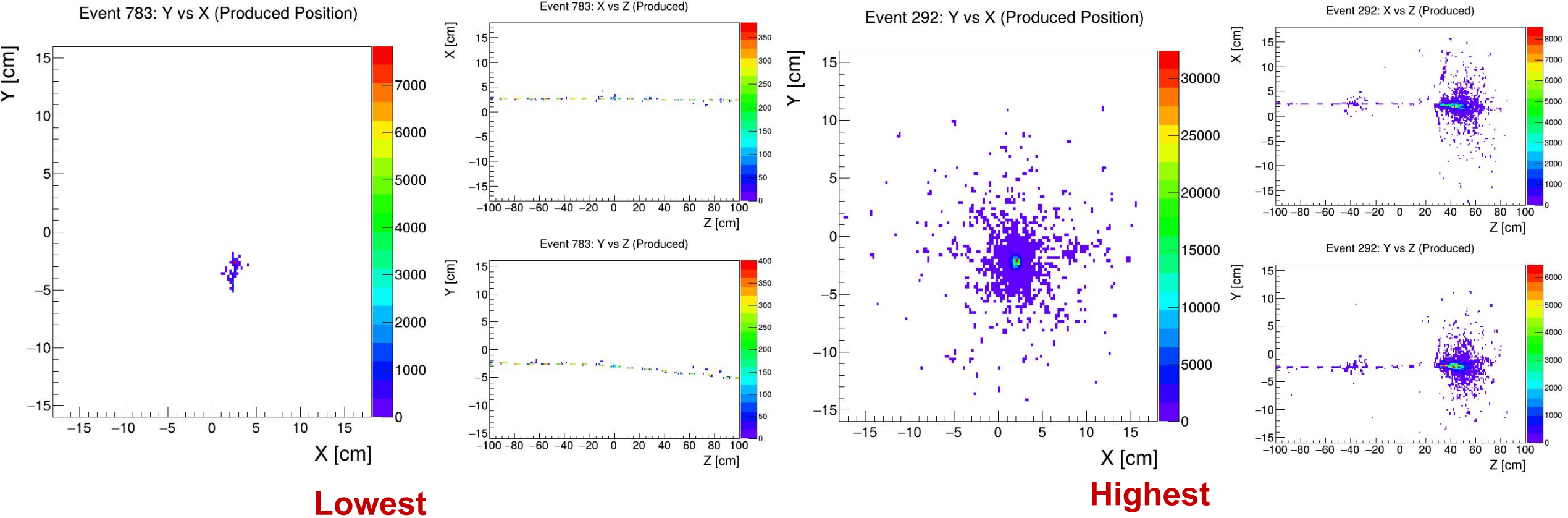
# Event Display for 30 GeV pi-

➤ Lowest loss vs Highest loss event



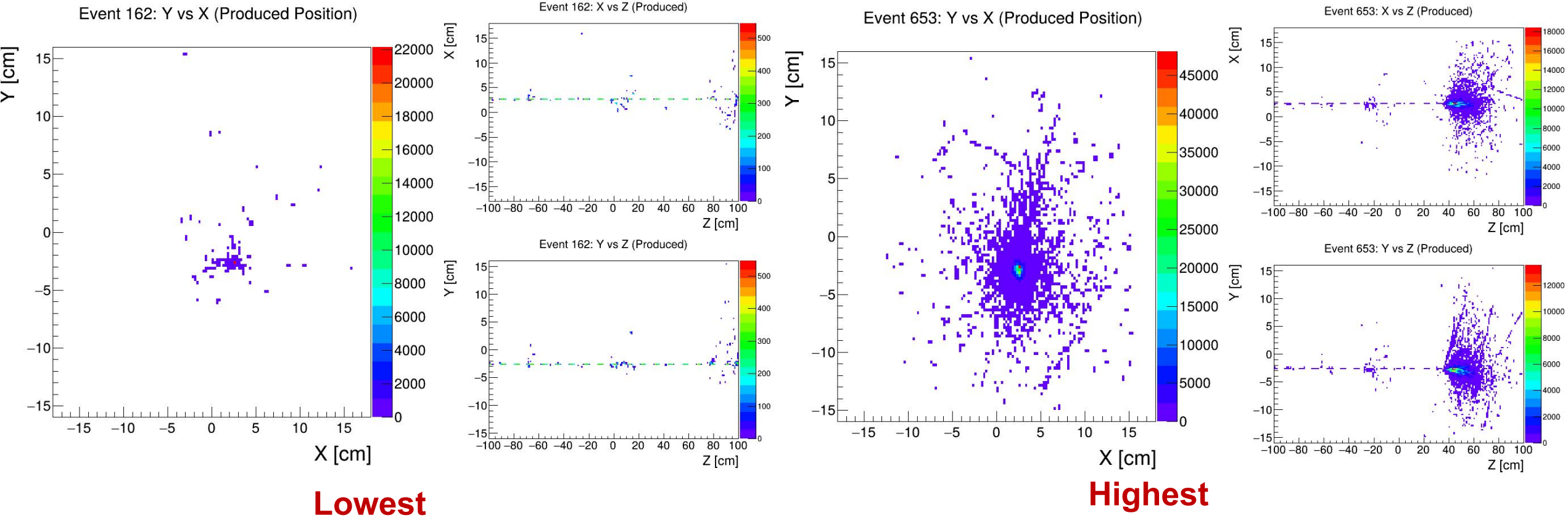
# Event Display for 50 GeV pi-

➤ Lowest loss vs Highest loss event



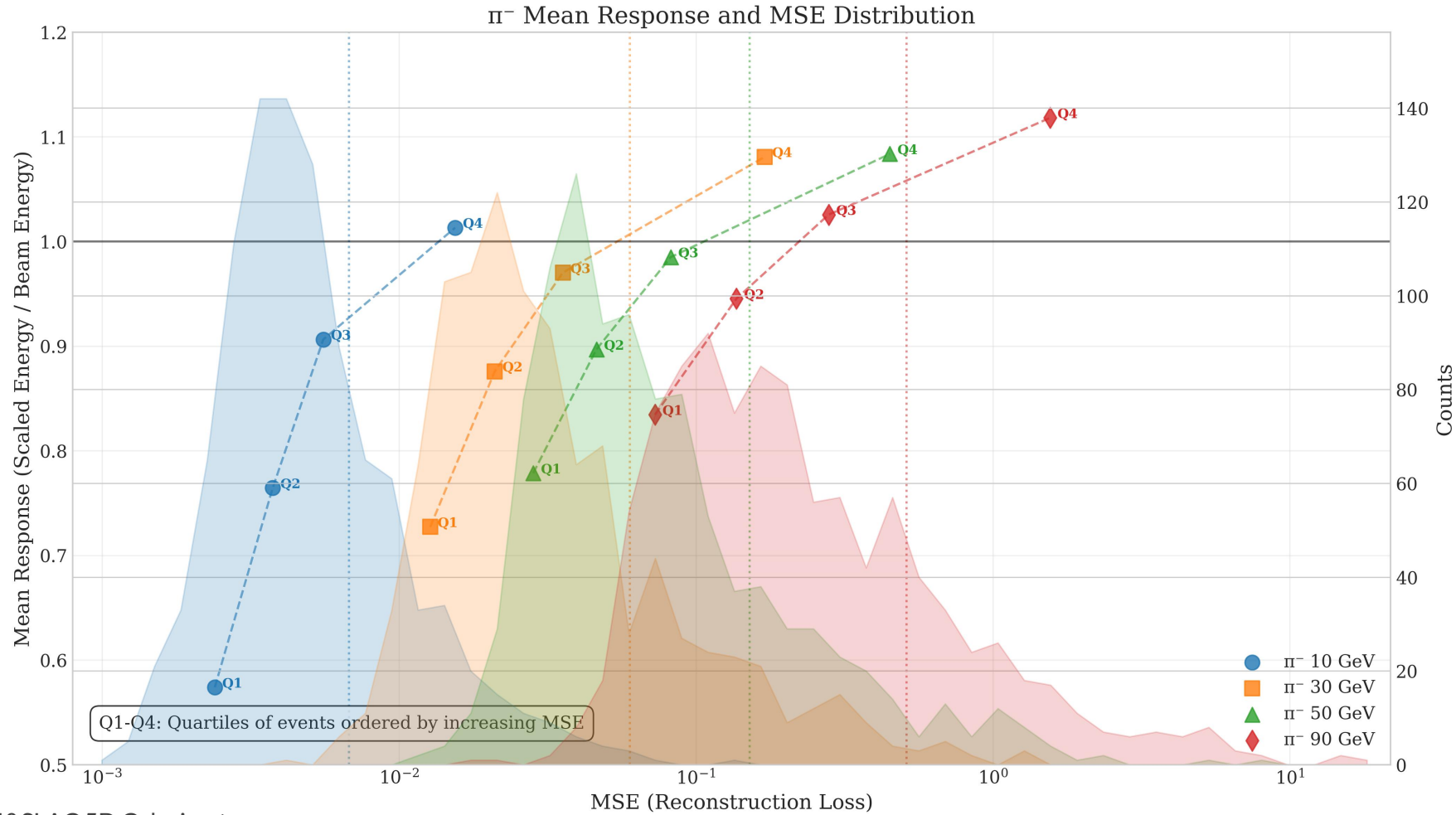
# Event Display for 90 GeV pi-

➤ Lowest loss vs Highest loss event

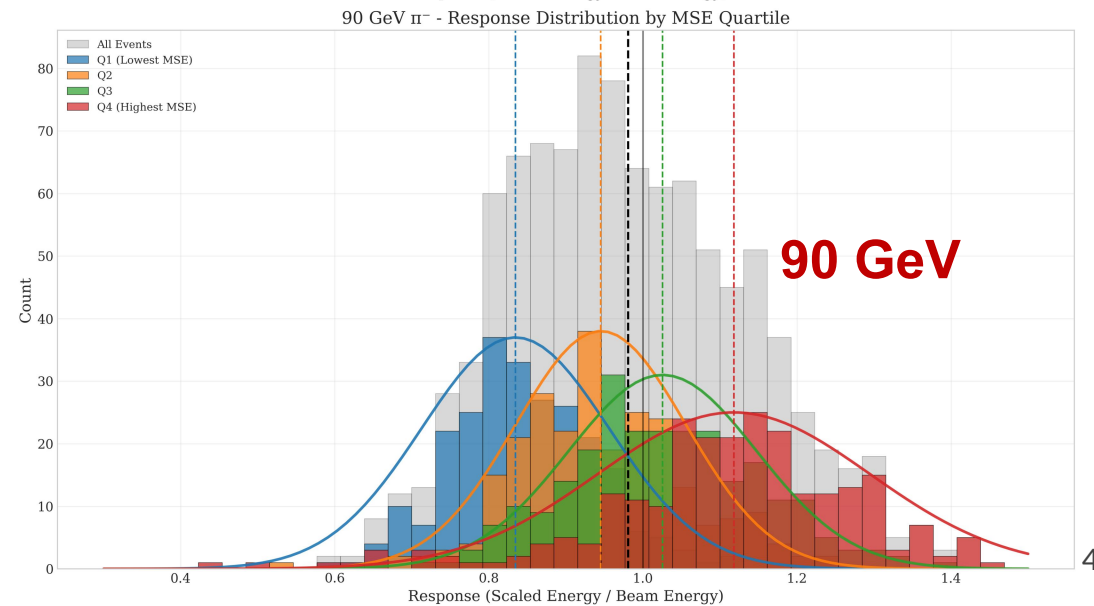
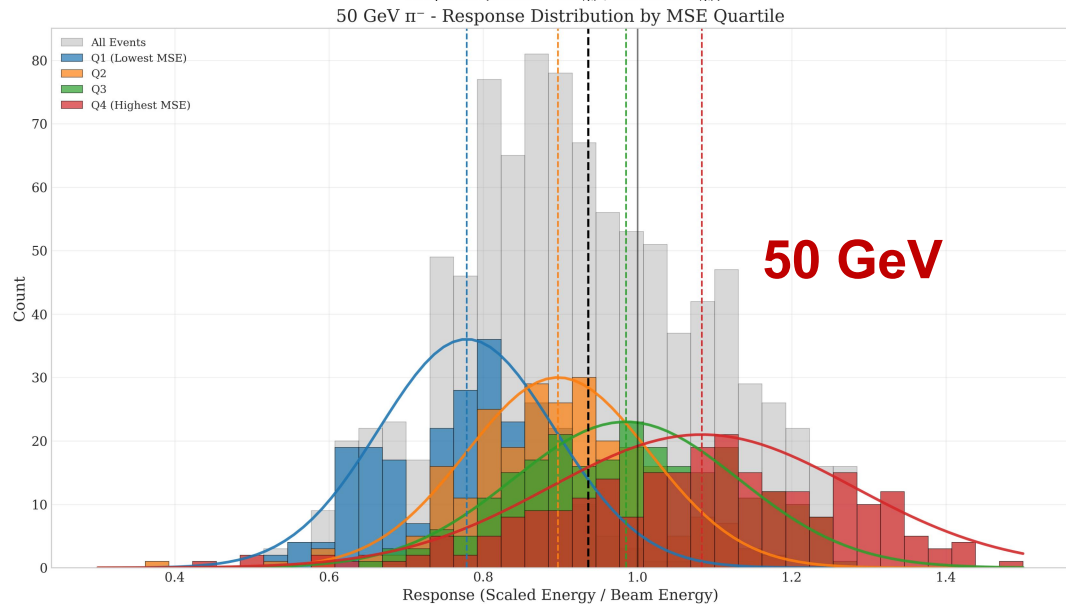
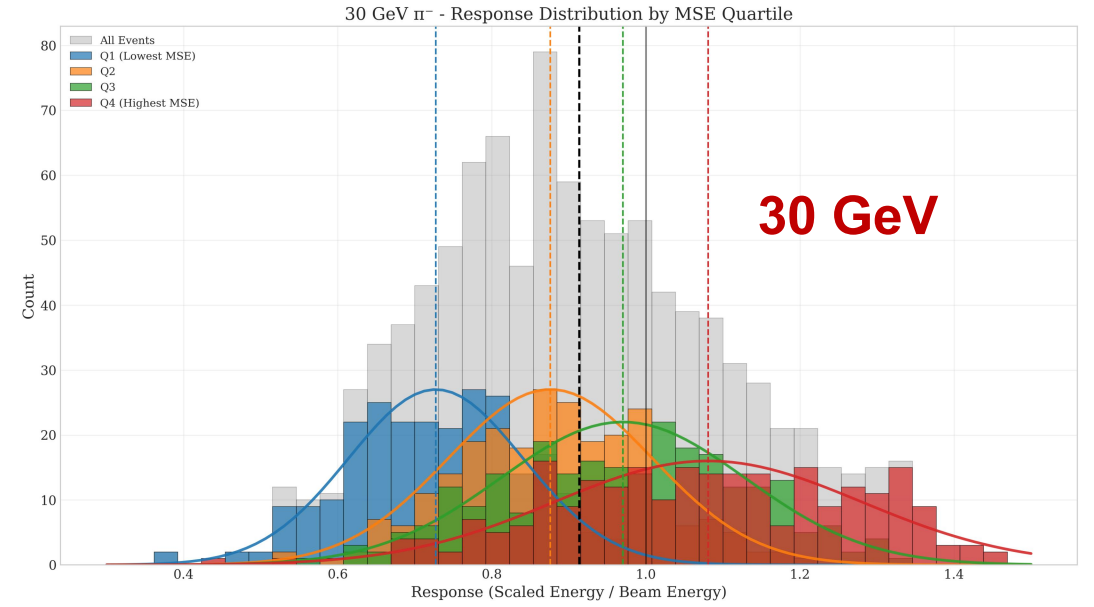
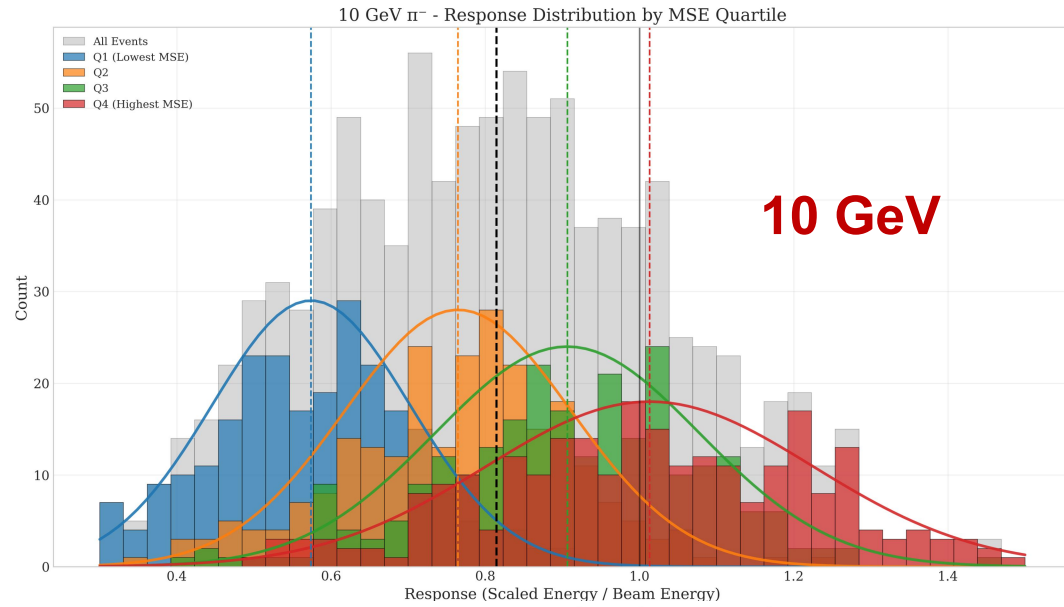


# Response Summary for pi-

- Mean Response & histogram of loss for each energy region

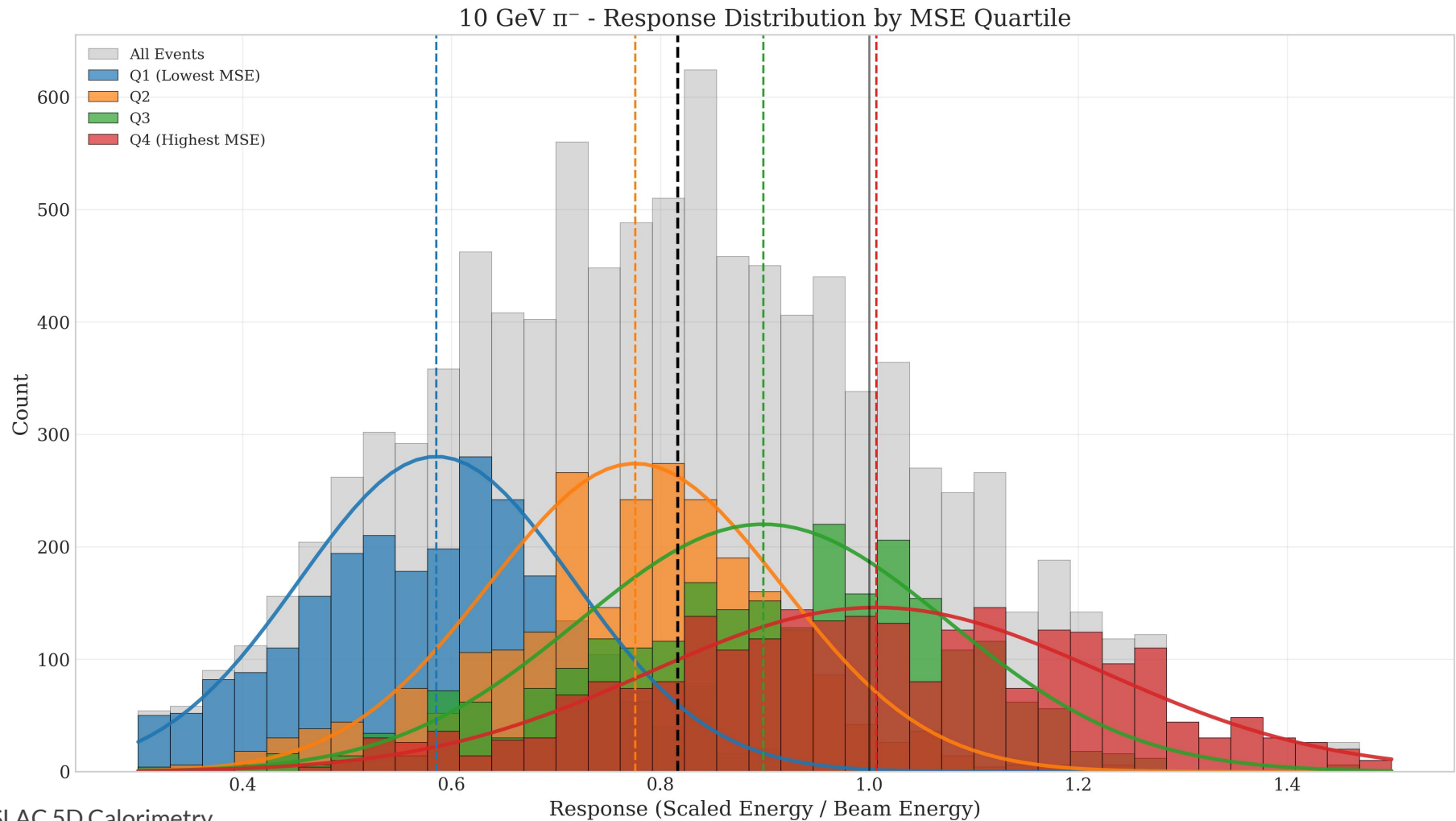


# Response Summary for pi-



# Response Summary for pi-

➤ More stats for 10 GeV pi- (10, 000 events)



# Summary

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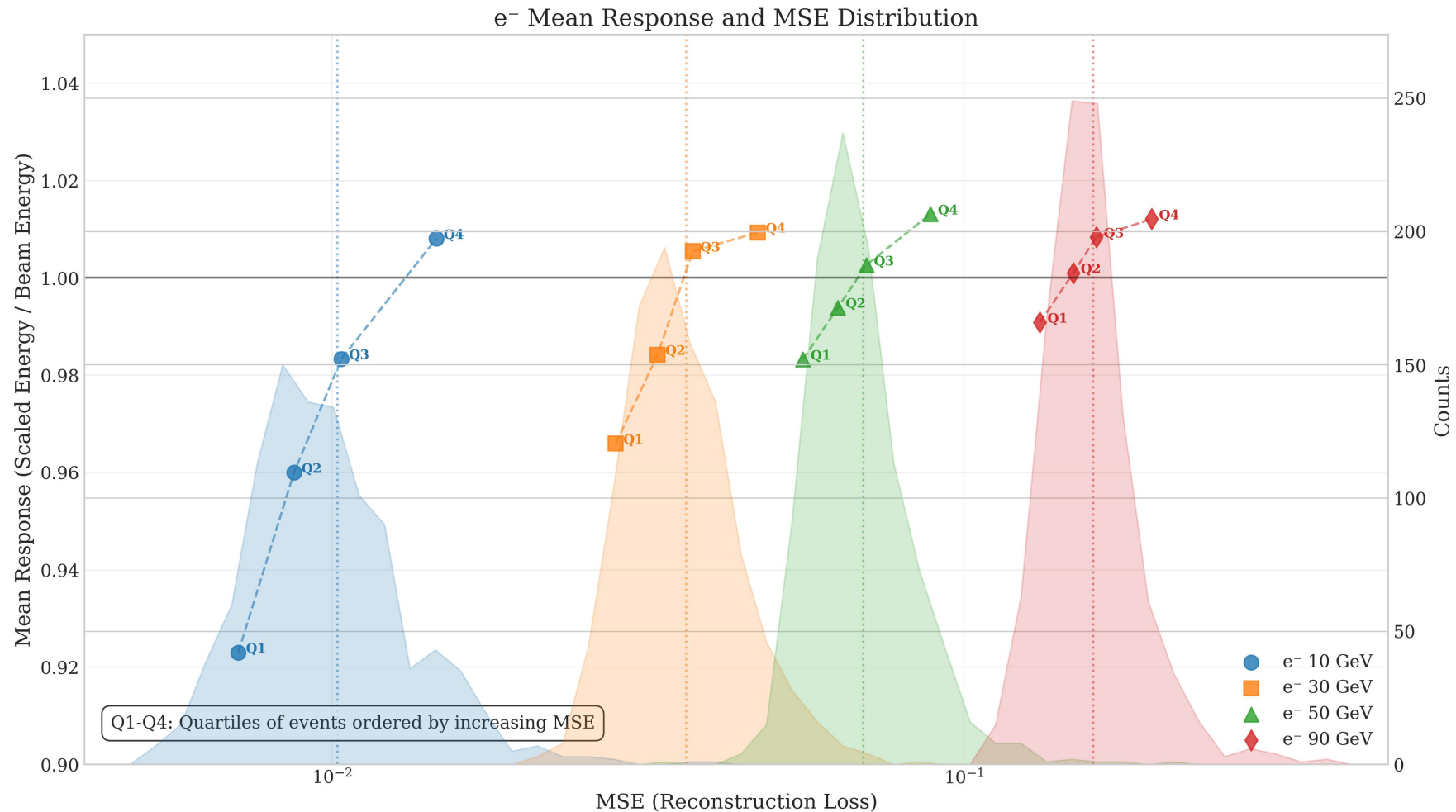
- ❑ Preliminary investigation of using an autoencoder to characterize calorimeter fluctuations
- ❑ Initial results indicate the autoencoder loss is able to capture sources of fluctuations that could be used to improve the jet energy resolution with dedicated corrections
- ❑ Regardless of its potential for improving energy resolution, this approach might be useful to understand various sources of fluctuations and their impact on the energy resolution

# Back ups

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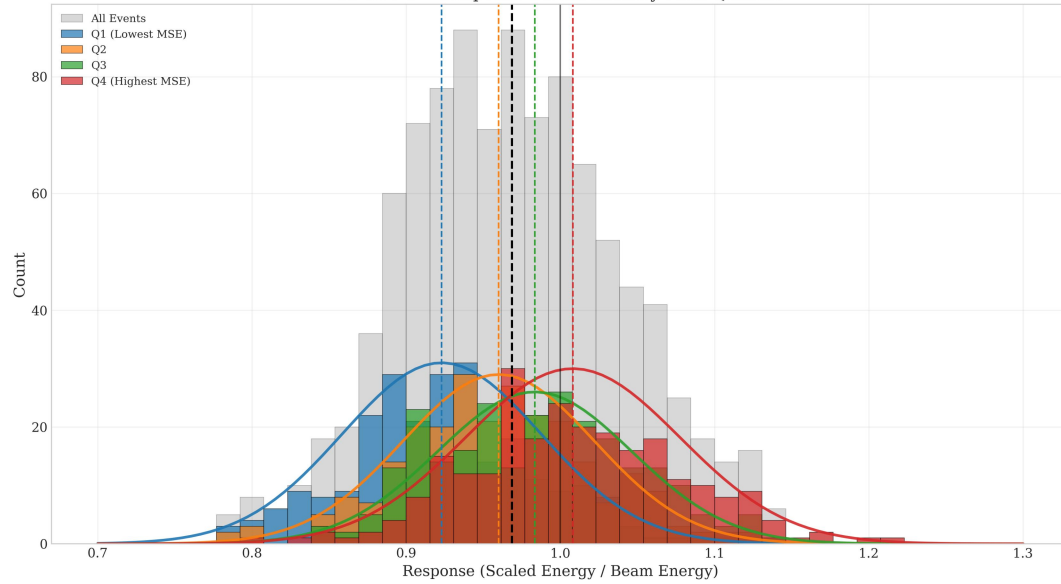
# Response Summary for e-

- Mean Response & histogram of loss for each energy region

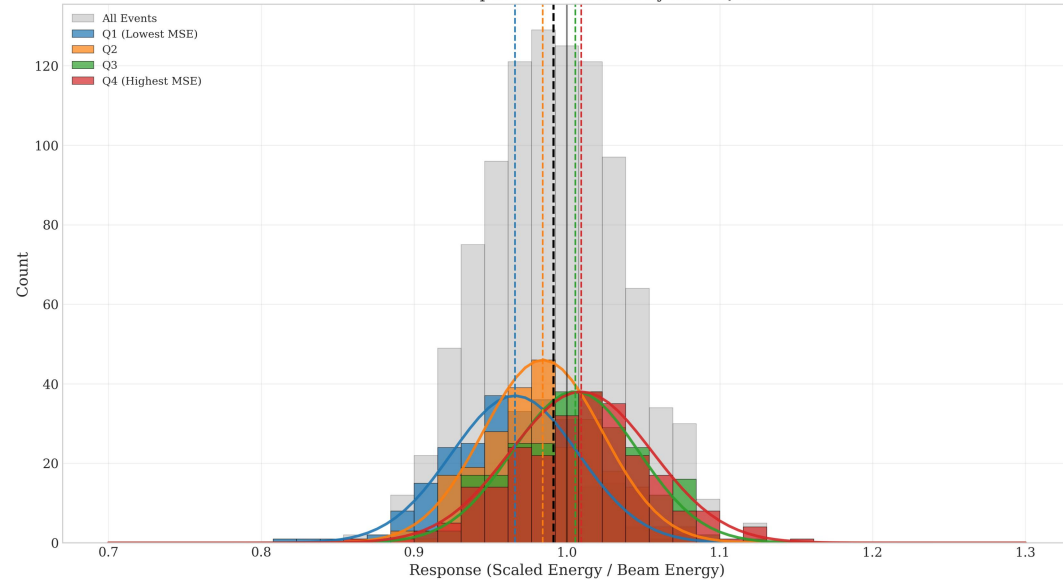


# Response Summary for e<sup>-</sup>

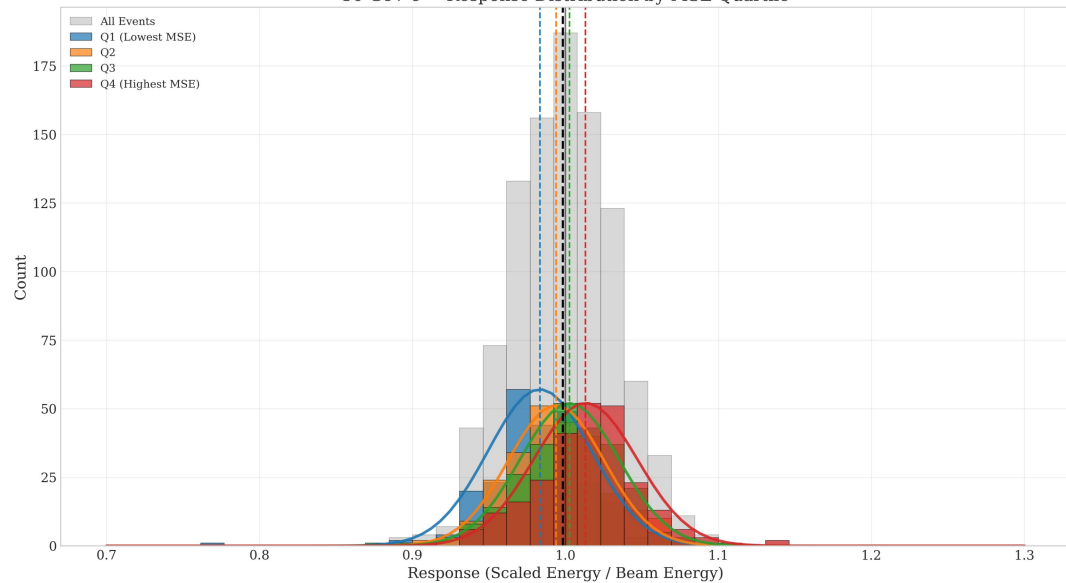
10 GeV e<sup>-</sup> - Response Distribution by MSE Quartile



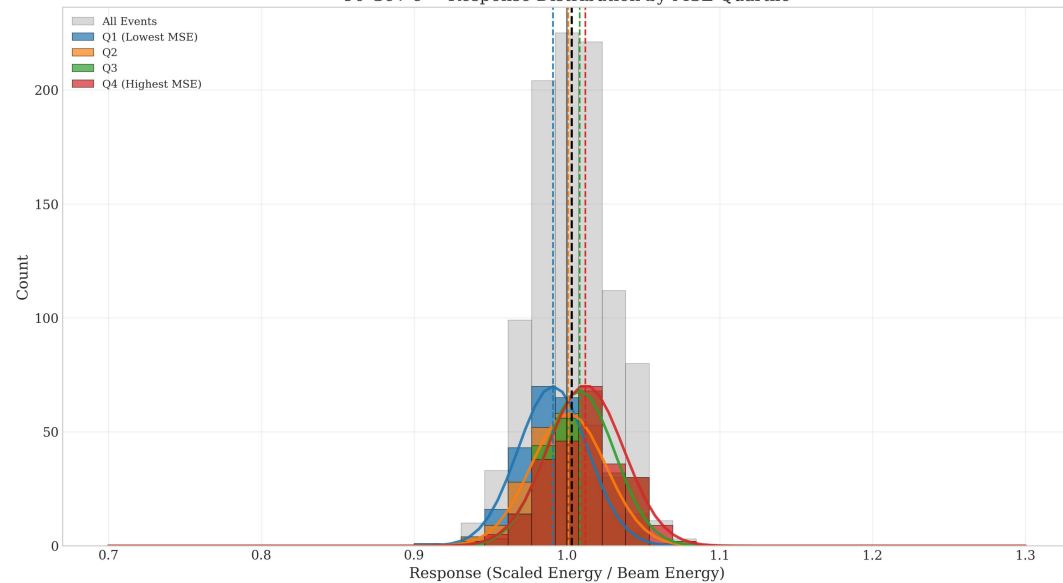
30 GeV e<sup>-</sup> - Response Distribution by MSE Quartile



50 GeV e<sup>-</sup> - Response Distribution by MSE Quartile



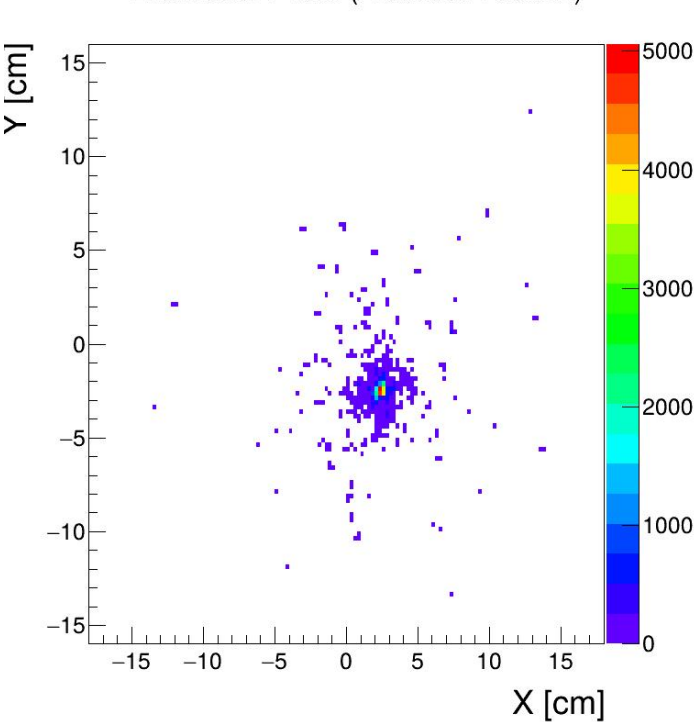
90 GeV e<sup>-</sup> - Response Distribution by MSE Quartile



# Event Display for 10 GeV e-

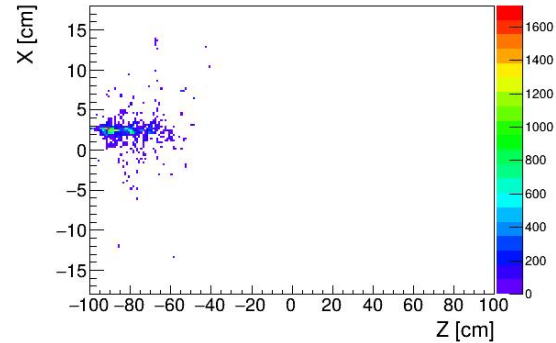
## ➤ Lowest loss vs Highest loss event

Event 566: Y vs X (Produced Position)

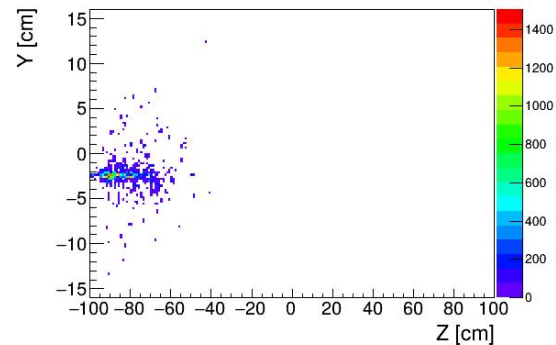


**Lowest**

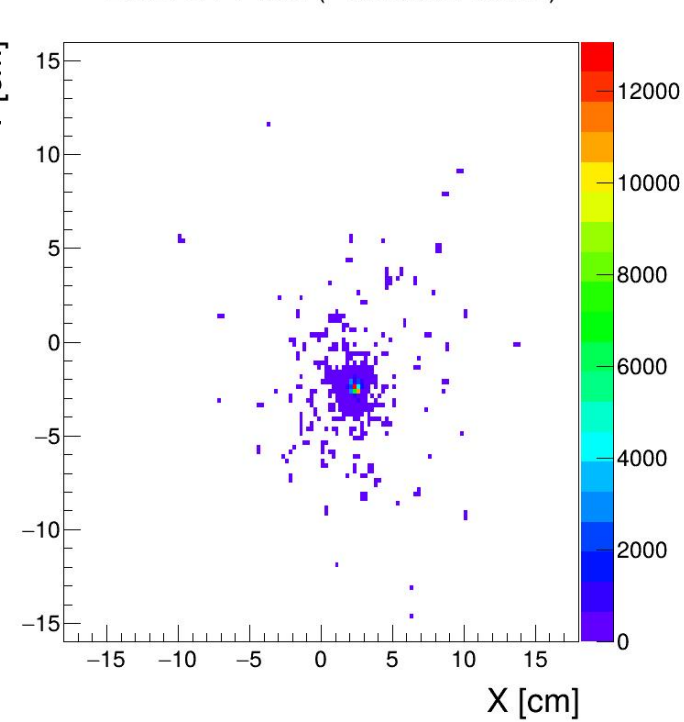
Event 566: X vs Z (Produced)



Event 566: Y vs Z (Produced)

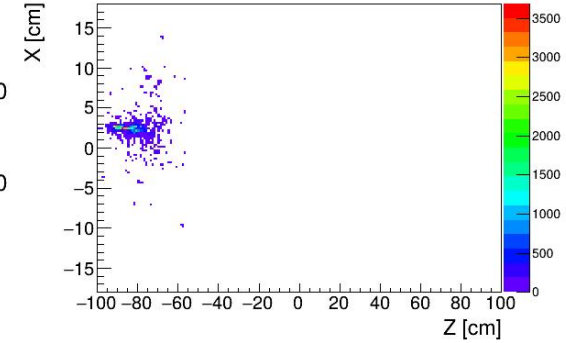


Event 17: Y vs X (Produced Position)

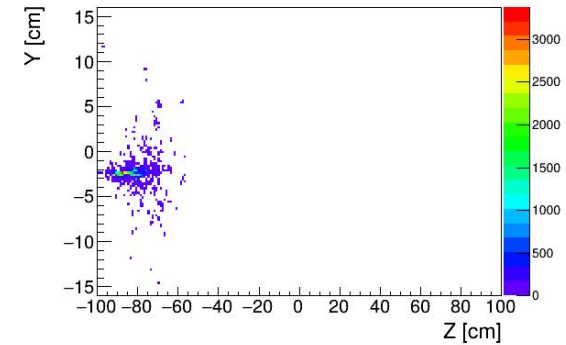


**Highest**

Event 17: X vs Z (Produced)



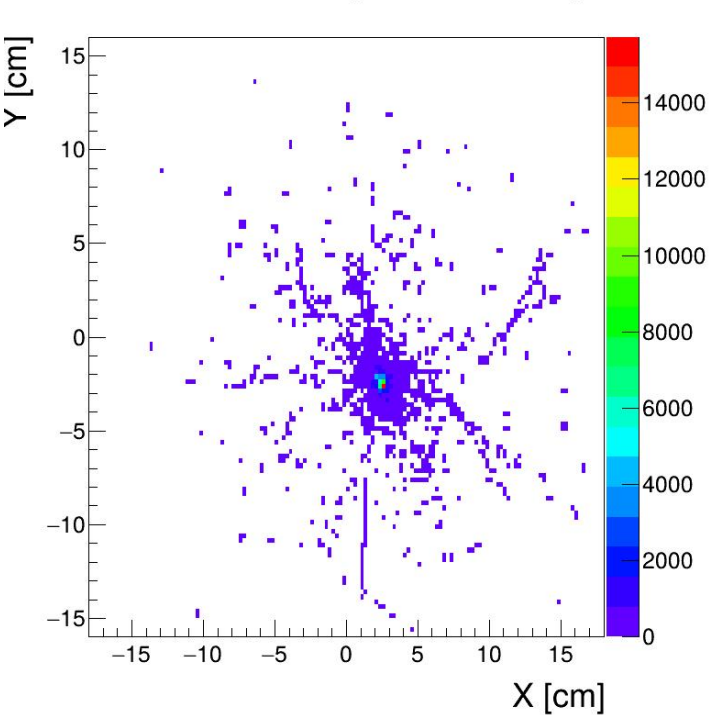
Event 17: Y vs Z (Produced)



# Event Display for 30 GeV e-

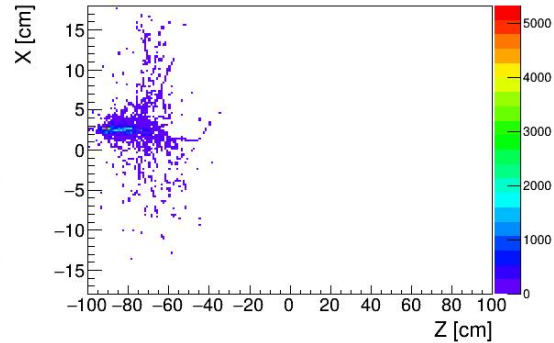
## ➤ Lowest loss vs Highest loss event

Event 534: Y vs X (Produced Position)

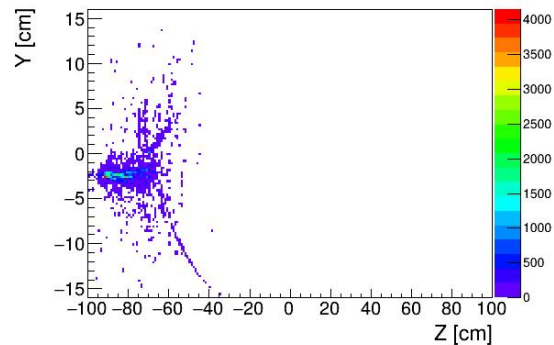


**Lowest**

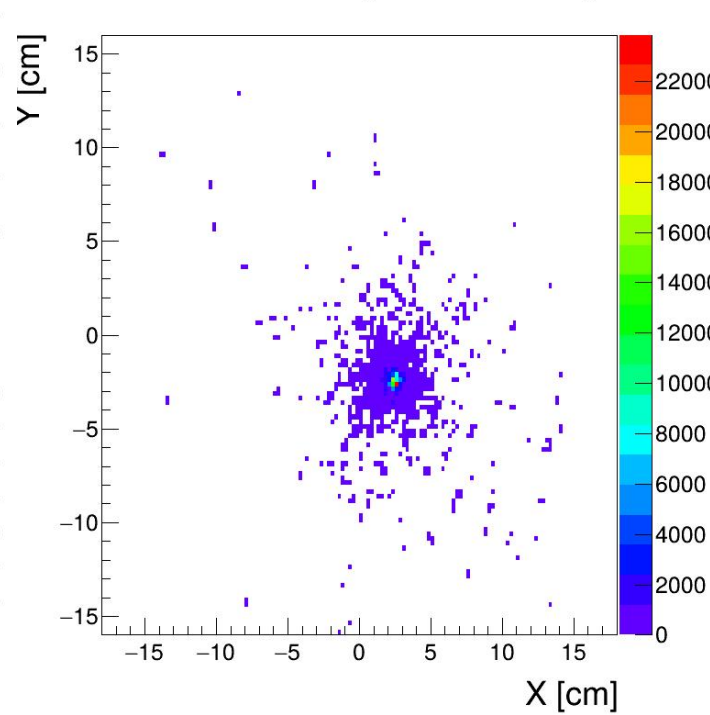
Event 534: X vs Z (Produced)



Event 534: Y vs Z (Produced)

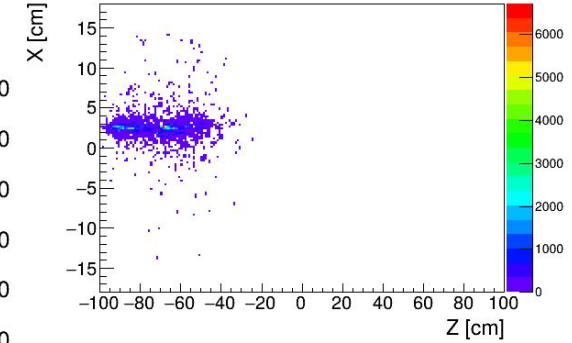


Event 560: Y vs X (Produced Position)

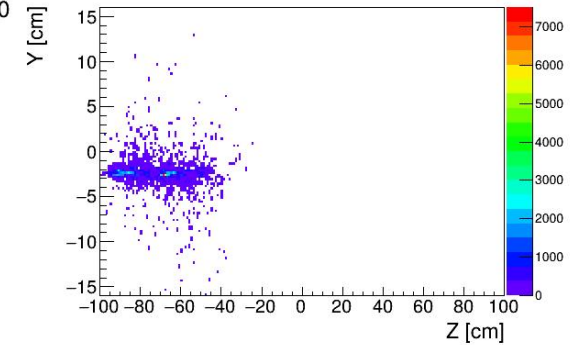


**Highest**

Event 560: X vs Z (Produced)

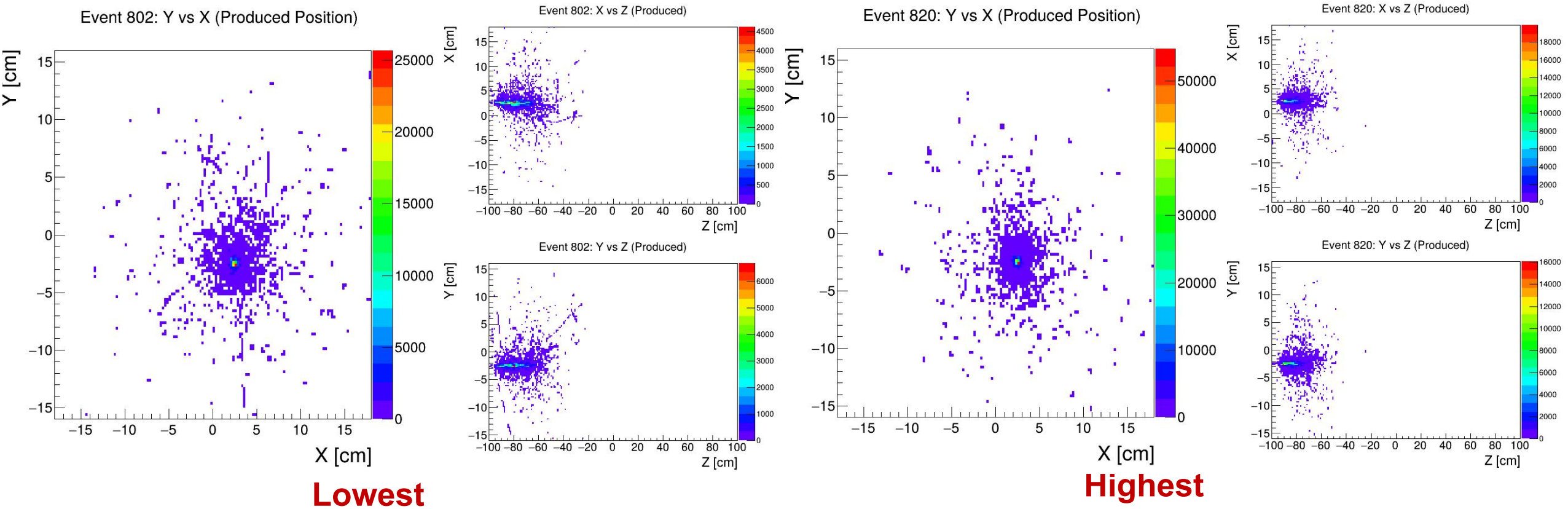


Event 560: Y vs Z (Produced)



# Event Display for 50 GeV e-

## ➤ Lowest loss vs Highest loss event



# Event Display for 90 GeV e-

## ➤ Lowest loss vs Highest loss event

