Study on the Performance of FoCal Pixel Layers

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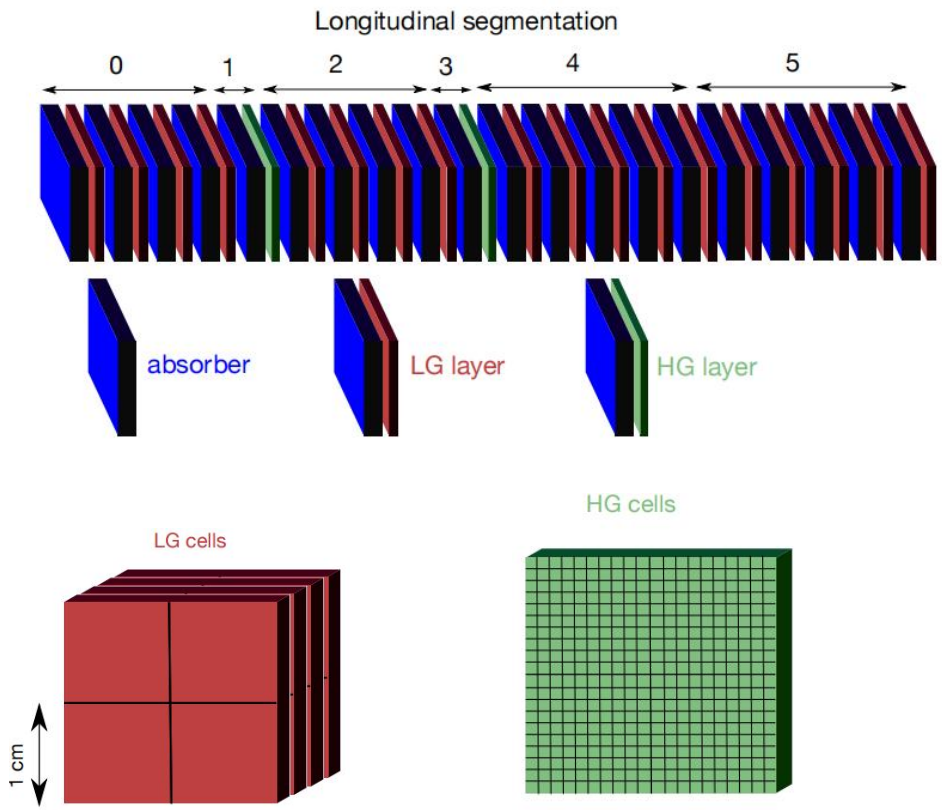
Outline

- FoCal-E detector
- Local averaging method and the results
- DBScan Algorithm and the results
- summary

FoCal-E

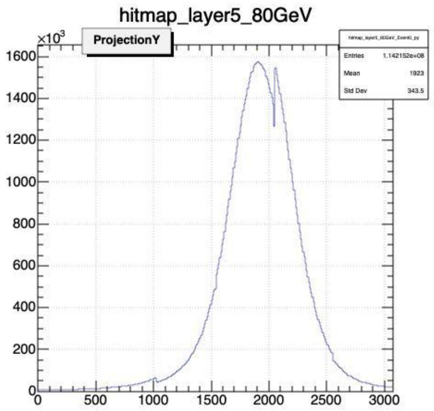


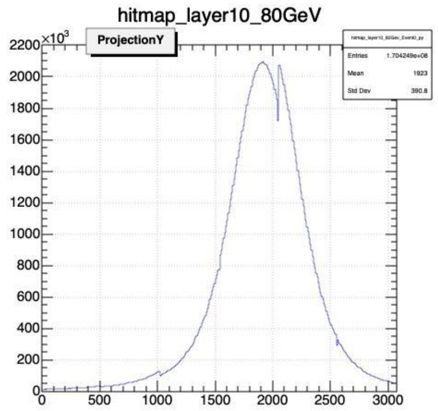
- All layers will consist of W sheets of ≈ 1 X_0 followed by silicon sensors.
- 18 pad layers and 2 pixel layers (5th layer and 10th layer).
- Pad layers, with transverse cell sizes of ≈ 1 cm^2.
- Pixel layers, with digital readout and a cell size of ≈ 30 × 30 μm^2.

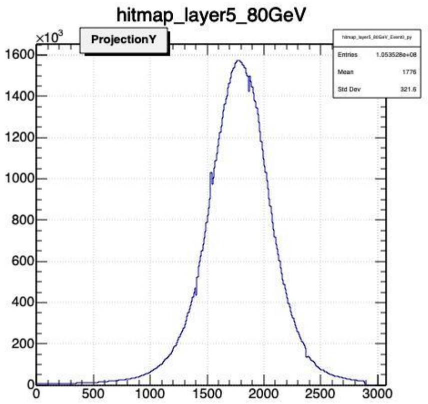
Motivation

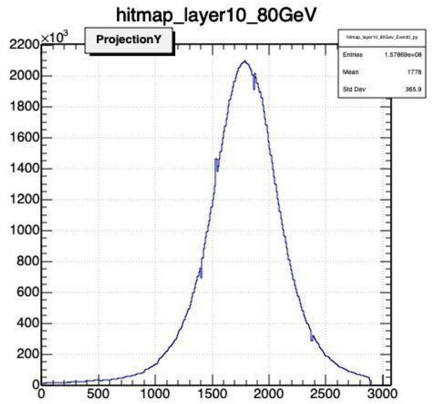
- Pixel layers of FoCal-E has a very small transverse cell size,make it possible to resolve the structure of particle showers on the sub-millimeter scale.
- Single photon shower events will be discriminated against background two-shower events from pi0 decays.
- One of the key parameters for the shower separation is the transverse shower profile.
- One of the keys to accurately reconstructing a shower is finding the correct center.

Local averaging method---Data preprocessing



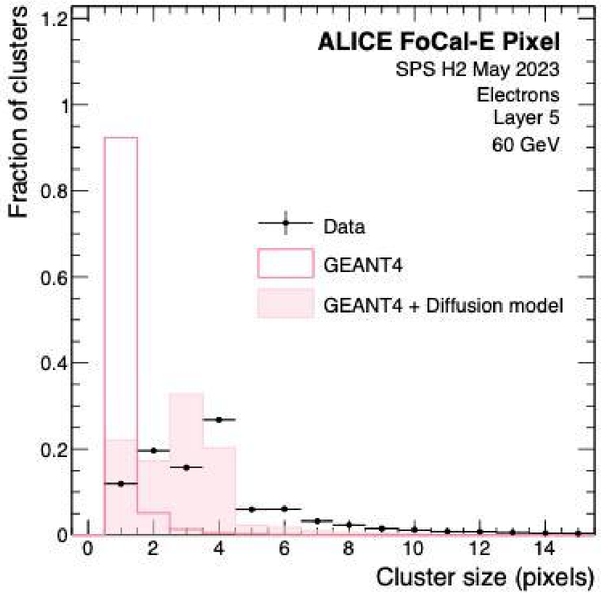


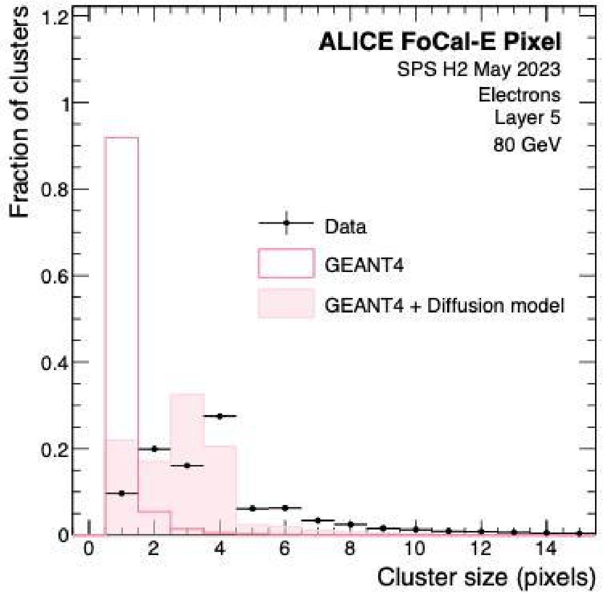




Overlap correction

The detector has an overlap in the y-axis direction.



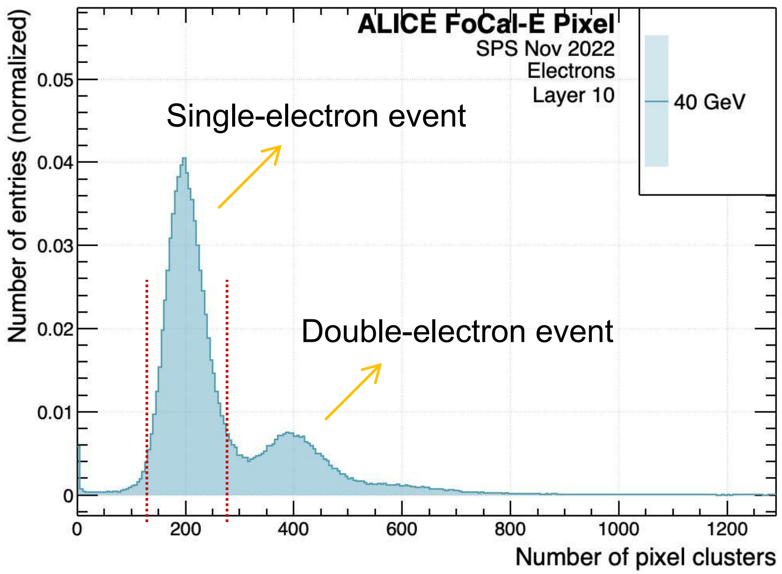


Pixel cluster reconstruction:

1.Group the coordinates of adjacent responsive pixels into a pixel cluster
2.Calculate the pixel cluster's central position using a weighted average method.

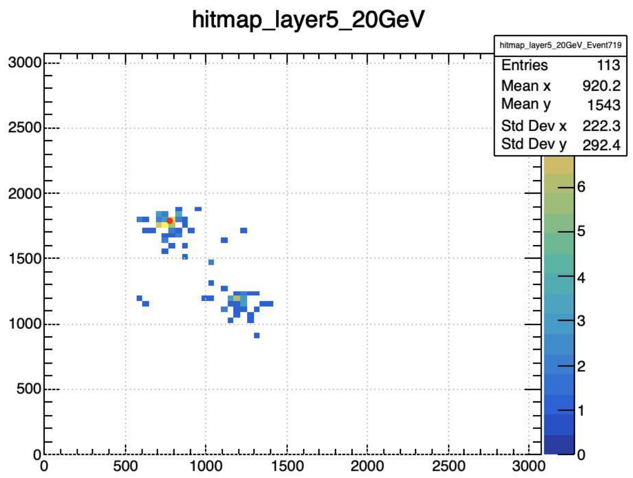
Local averaging method---Single-electron event selection

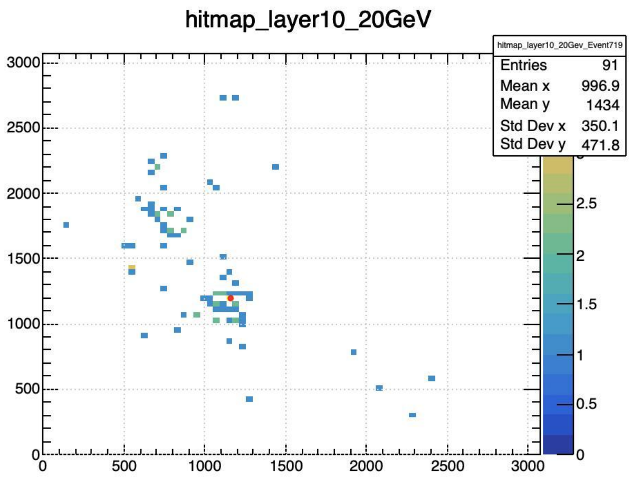
1.Filtering of the number of pixel clusters.



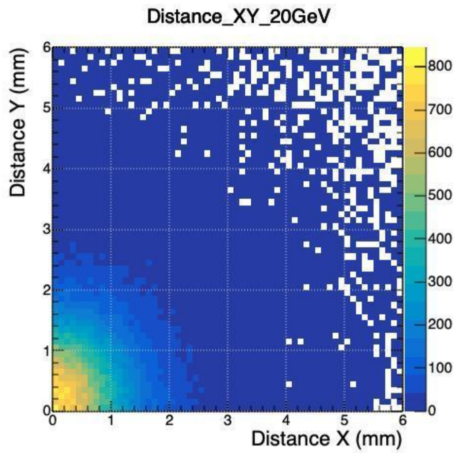
Distribution histogram of the number of pixel clusters.

2.Filtering based on the distance between the cluster center positions in the 5th and 10th layers.

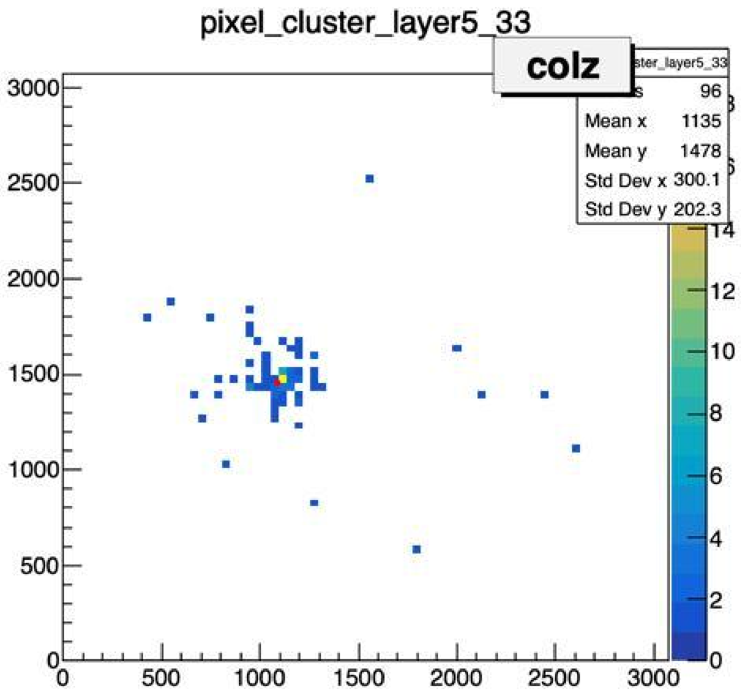


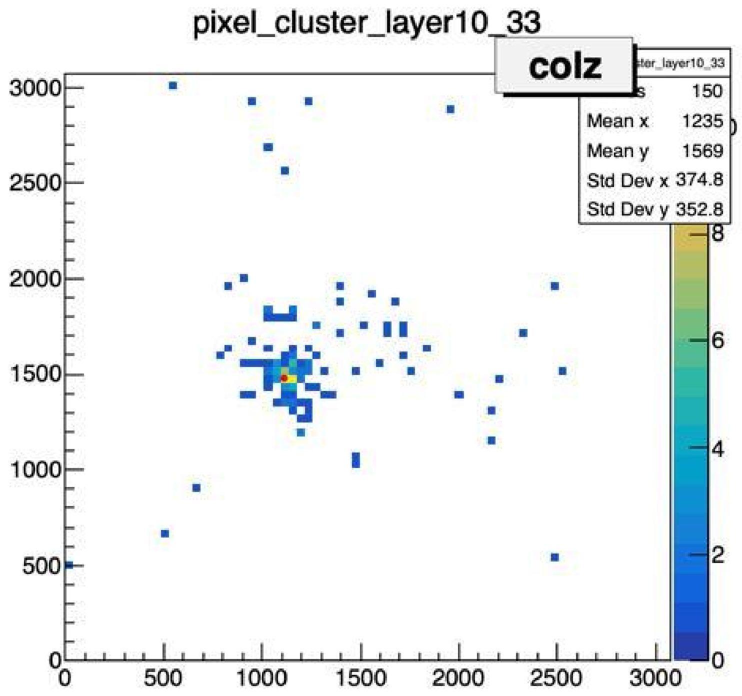


The number of pixel clusters in the above event falls within the filtering range, but it is clearly a double-electron shower event.



Local averaging method---Cluster center position determination

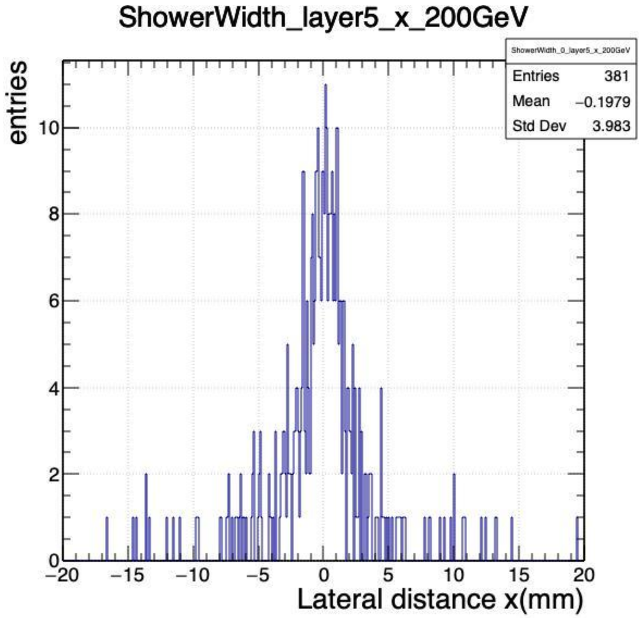




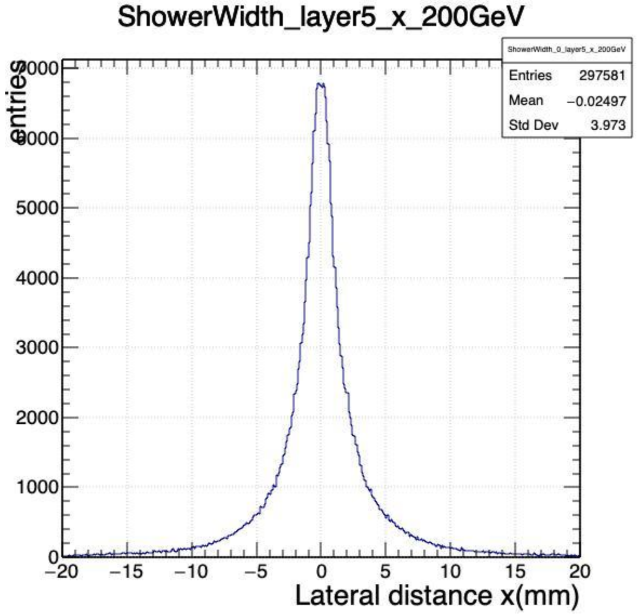
Algorithm:

Plot all the information of a single event on a 2D histogram, find the bin with the maximum number of pixel clusters. Use this bin as the center and perform a weighted average of the pixel cluster coordinate information within a certain range around this bin.

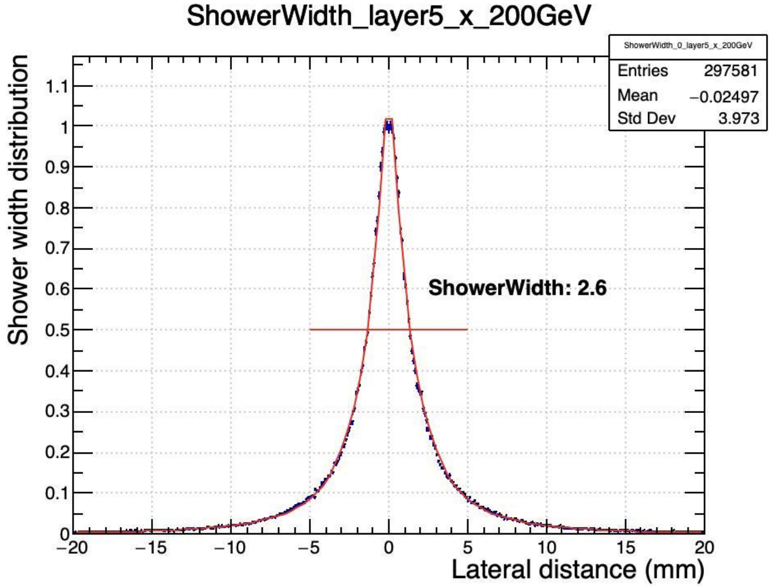
Local averaging method---Shower width



Single event



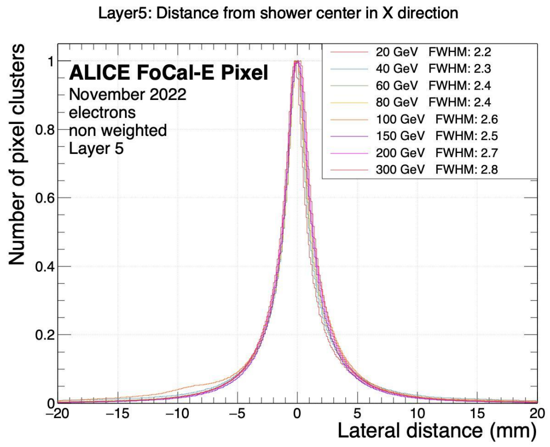
Many events

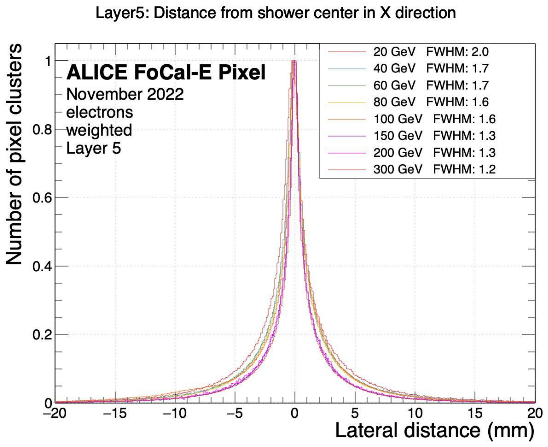


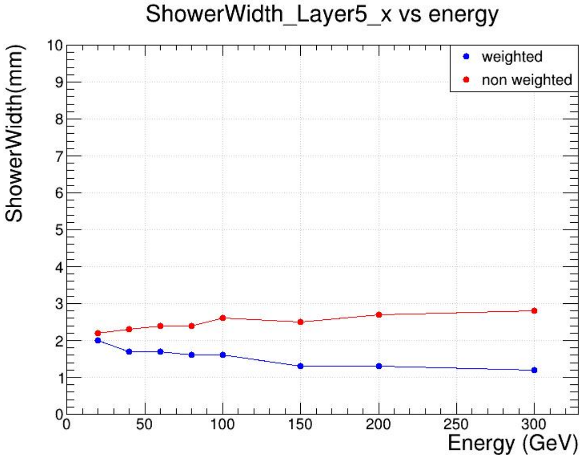
Two methods of filling the histogram: non-weighted，weighted

Fit the histogram and use the width at half of the histogram's maximum height as the shower width FWHM（Full Width at Half Maximum）.

Local averaging method---Shower width

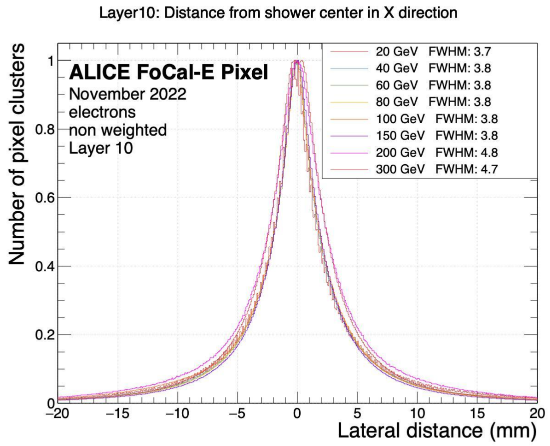


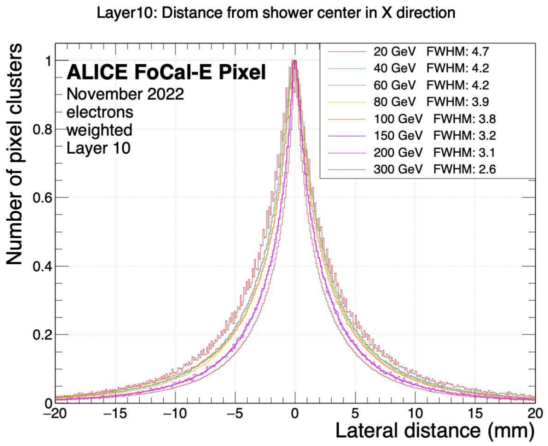


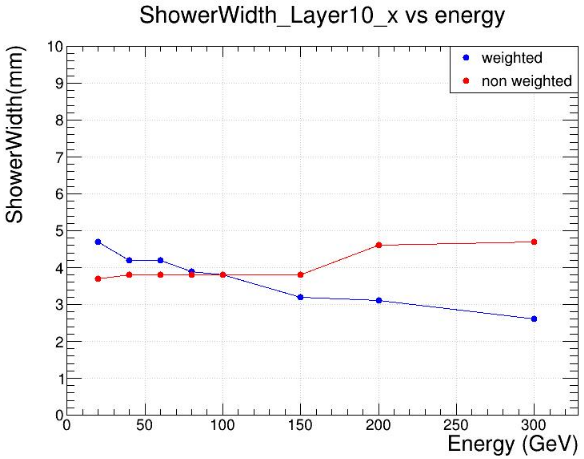


In the non-weighted case, the FWHM increases with increasing energy.

In the weighted case, the FWHM decreases with increasing energy.



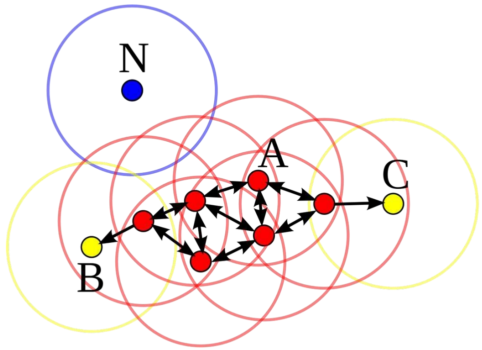




In the weighted case, the influence of the number of responsive pixels within each pixel cluster is taken into account.

DBScan Algorithm

Parameters： Distance parameter ε and minimum number of points MinPoints

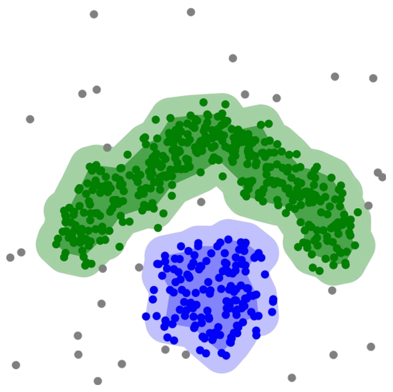


Point Categories

- Core Point: A point with at least MinPoints within its neighborhood radius ε.
- Boundary Point: A non-core point that lies within the neighborhood of a core point.
- Noise Point: A point that is neither a core point nor within the neighborhood of any core point.

Density Relations

- Directly Density-Reachable: If P is a core point and Q lies within P’s neighborhood, Q is directly density-reachable from P (one-way).
- Density-Reachable: If there exists a sequence of points starting from core point P_1 to Q, where each point is directly density-reachable from the previous one, then Q is density-reachable from P_1(one-way).
- Density-Connected: If there exists a core point S such that both P and Q are density-reachable from S, then P and Q are density-connected (two-way, same cluster).



DBScan Algorithm

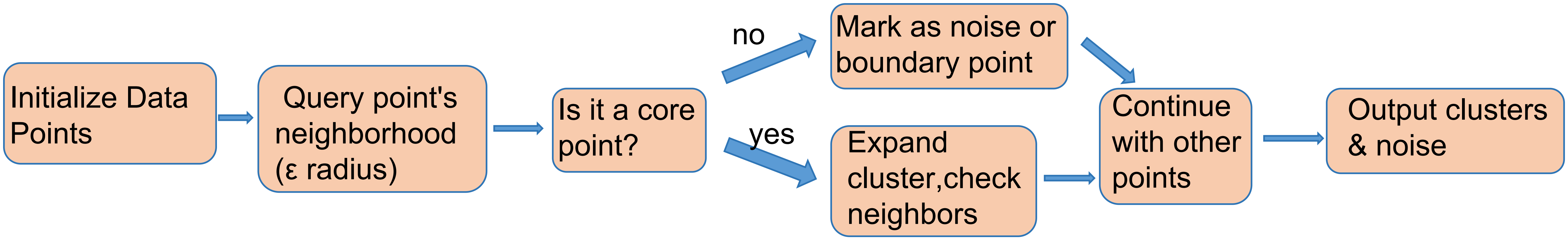
DBScan Algorithm Steps

1.Identify Core Points and Form Temporary Clusters

Scan all points. If a point has at least MinPoints within its radius ε, it is labeled as a core point and forms a temporary cluster with its density-reachable points.

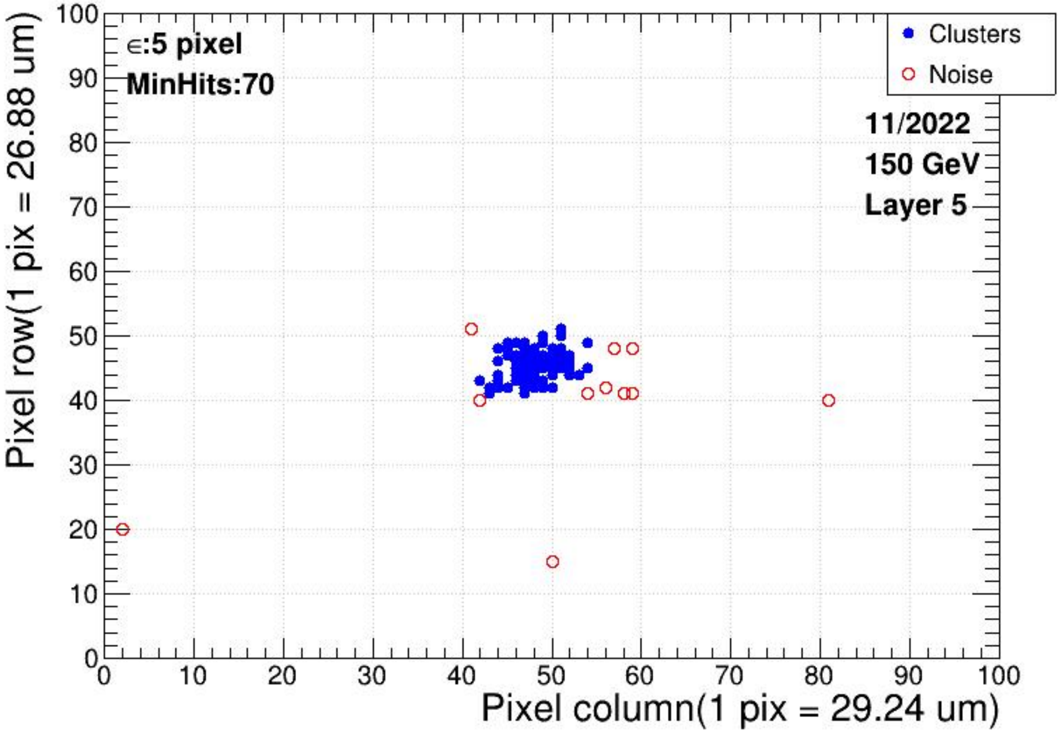
2.Merge Temporary Clusters into Final Clusters

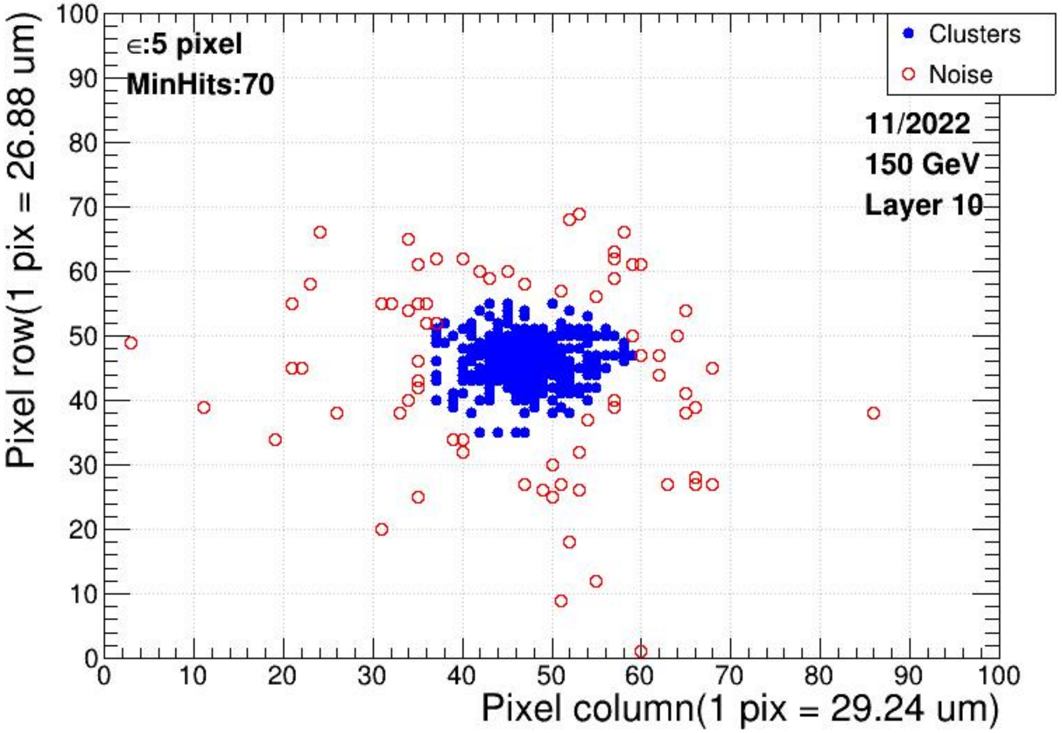
For each temporary cluster, check if any point is a core point. If so, merge the clusters and expand the temporary cluster. Repeat until no further expansion is possible, and the cluster becomes a final cluster. Continue merging remaining temporary clusters until all are processed.



DBScan Cluster

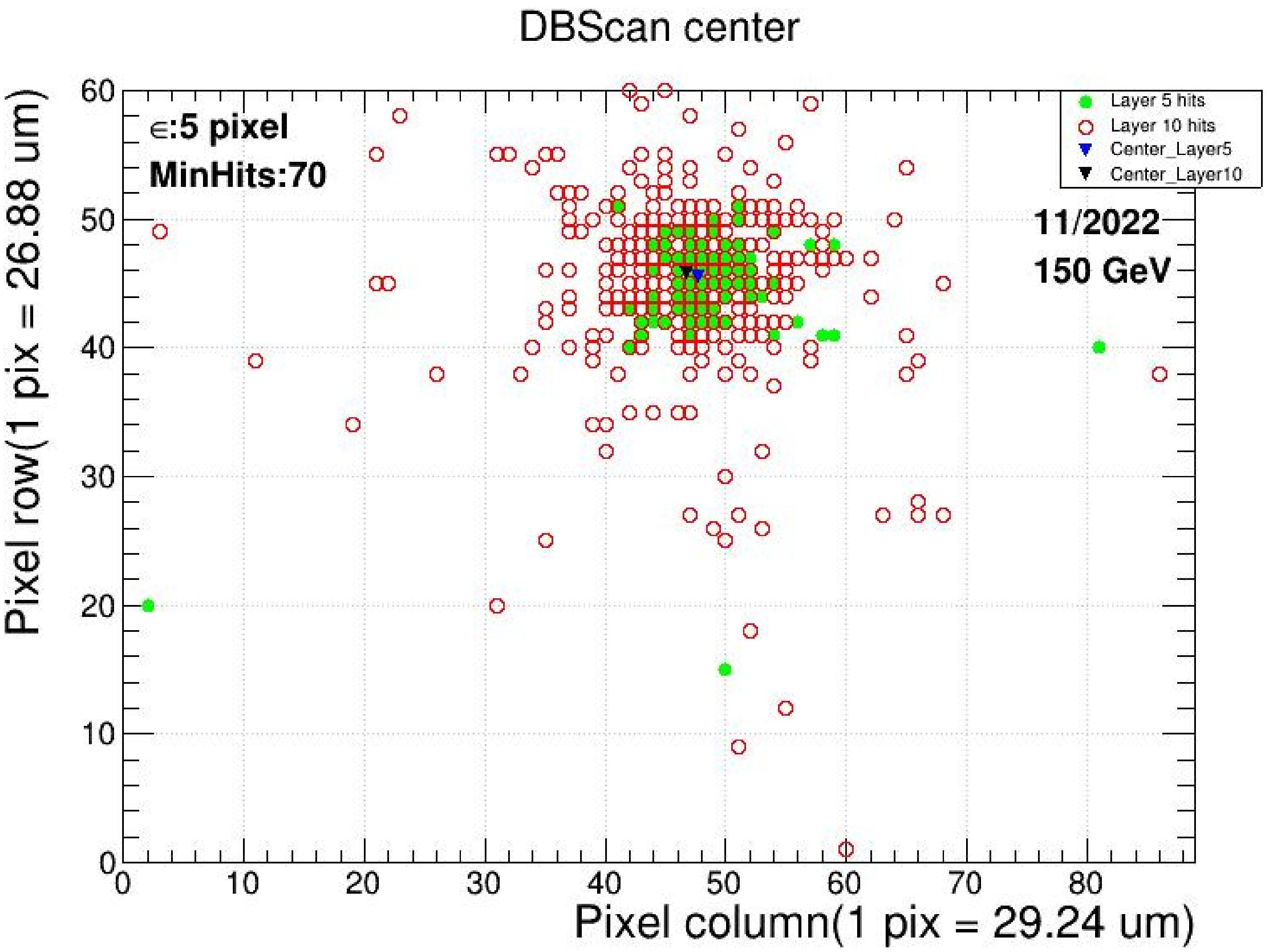
The overlap correction was also applied, but instead of reconstructing pixel clusters, the DBScan algorithm was used to analyze the coordinates of the responsive pixels directly .



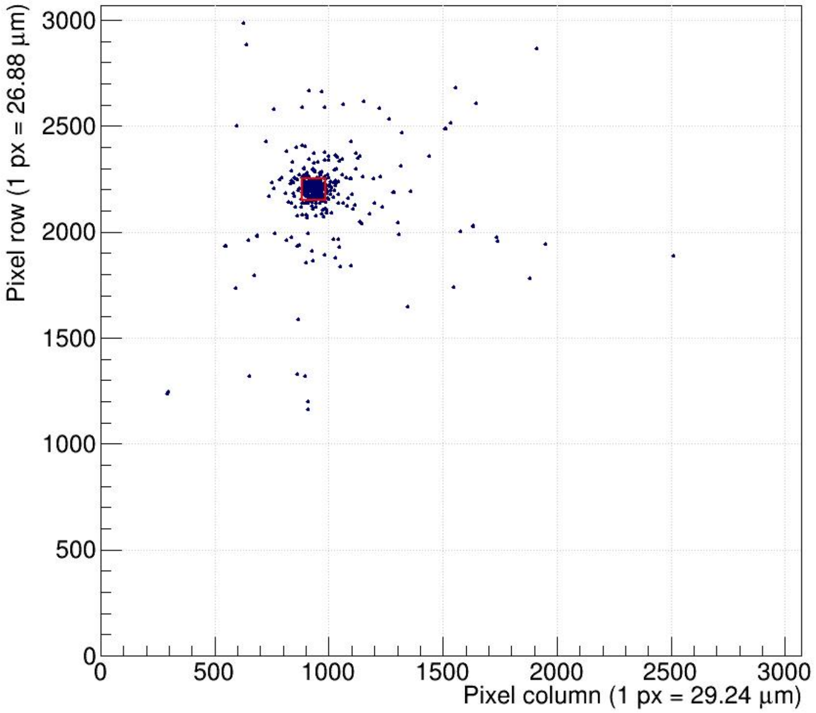


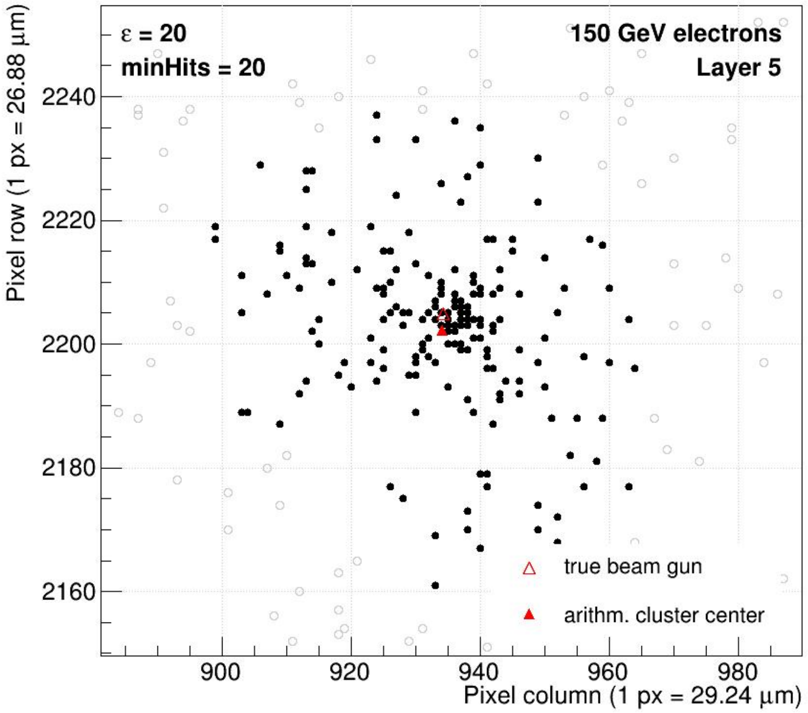
DBScan centers for the fifth and tenth layers.

Use the centroid of the largest DBScanCluster as the center.



Accuracy of center determination

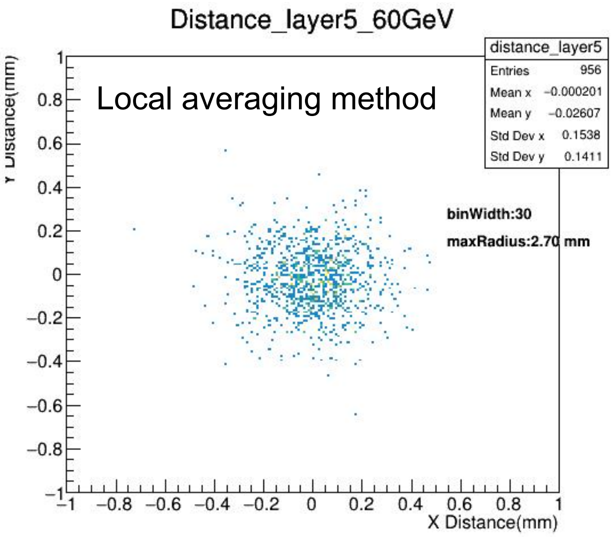


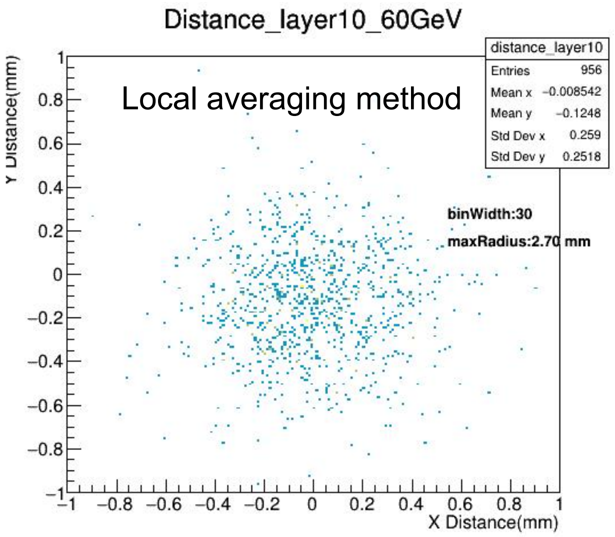


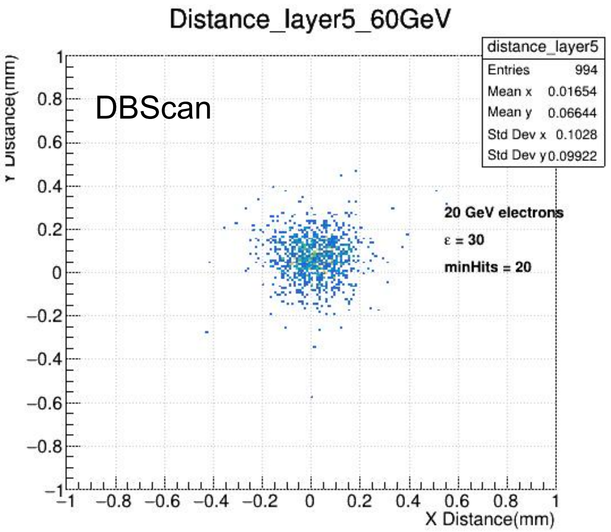
Generate simulated data using GEANT4 and analyze it with DBScan algorithm to identify points that belong to clusters and noise.

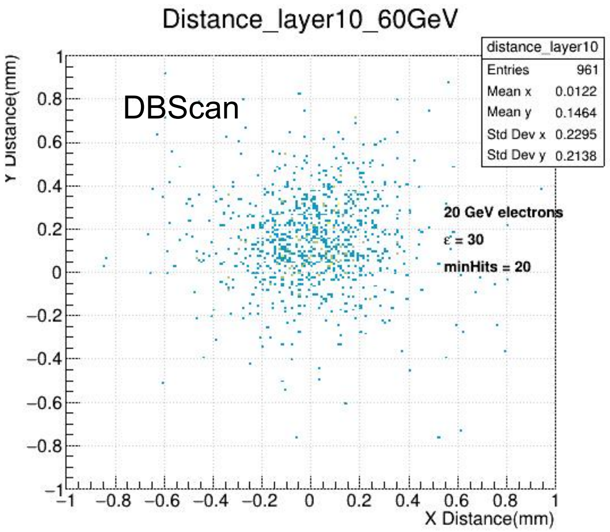
The left graph shows the coordinate information of all the responding pixels in the entire 5th pixel layer, while the right graph shows the local region (the red rectangular section in the left graph) where the points identified as belonging to clusters by the DBScan algorithm are located.

Accuracy of center determination





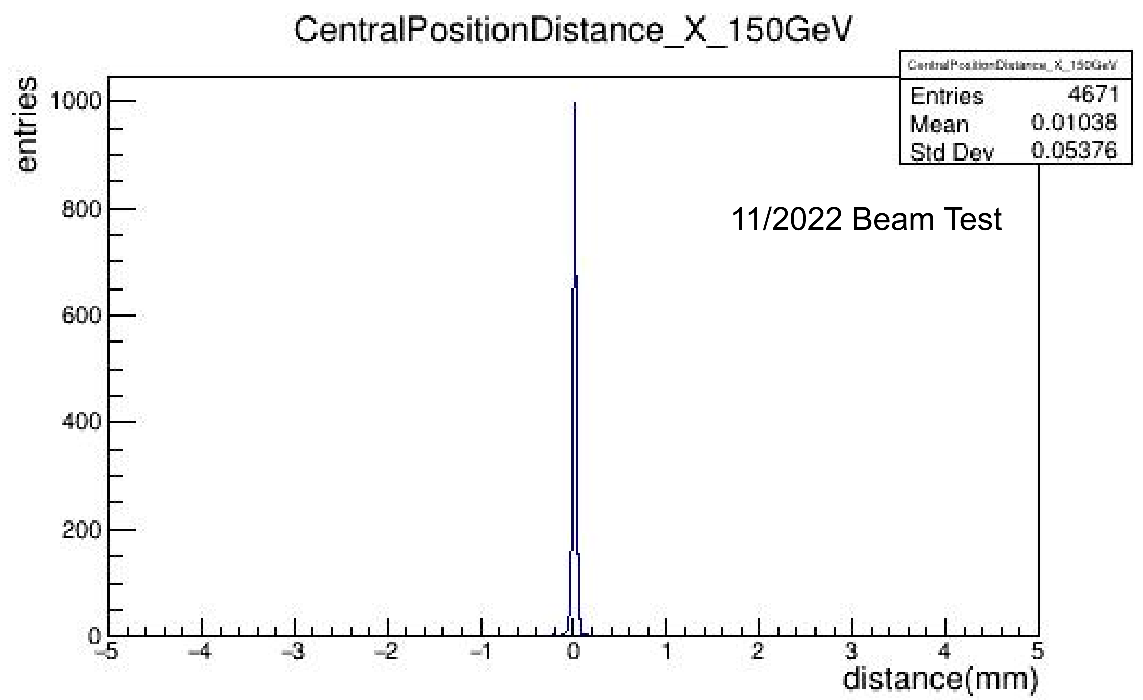


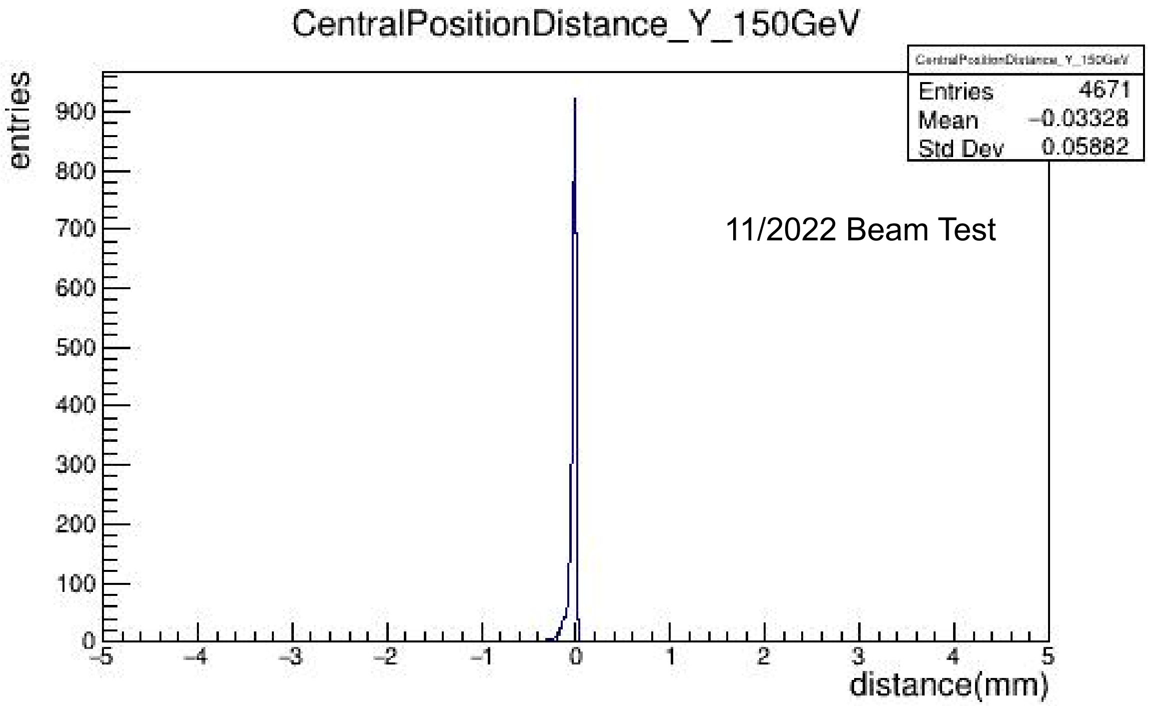


The left histograms show the distribution of the distance between the center we found and the center set in the simulation.

The center found by the DBScan algorithm is more accurate than the one found by the local averaging method.

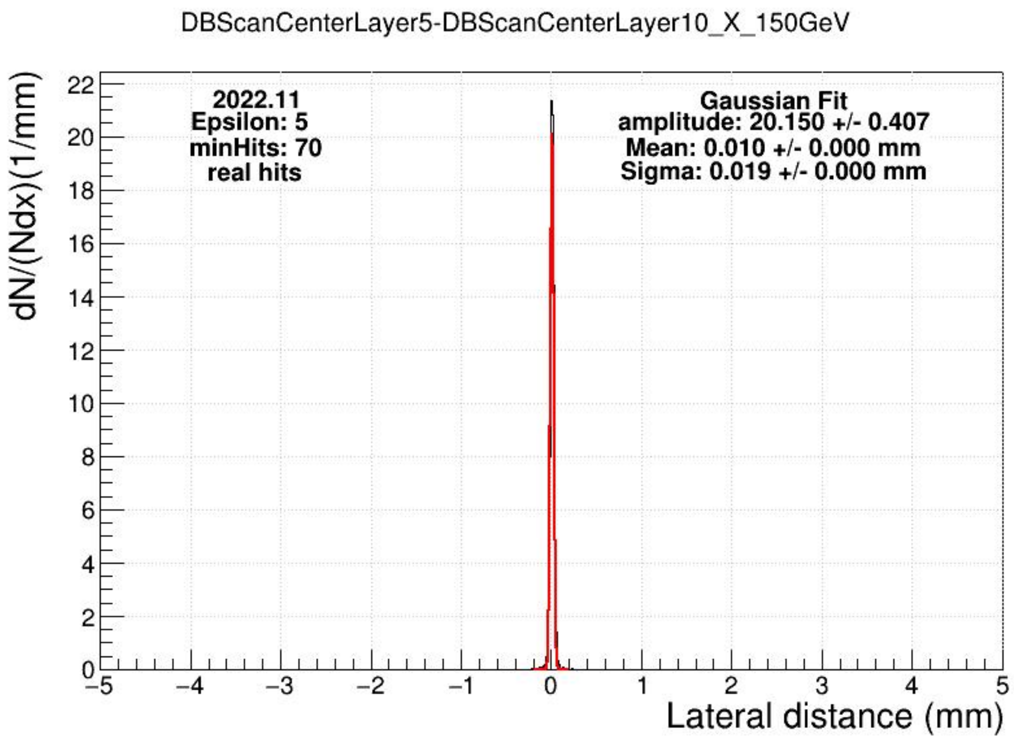
the distance between the DBScanCenter-L5 and the DBScanCenter-L10

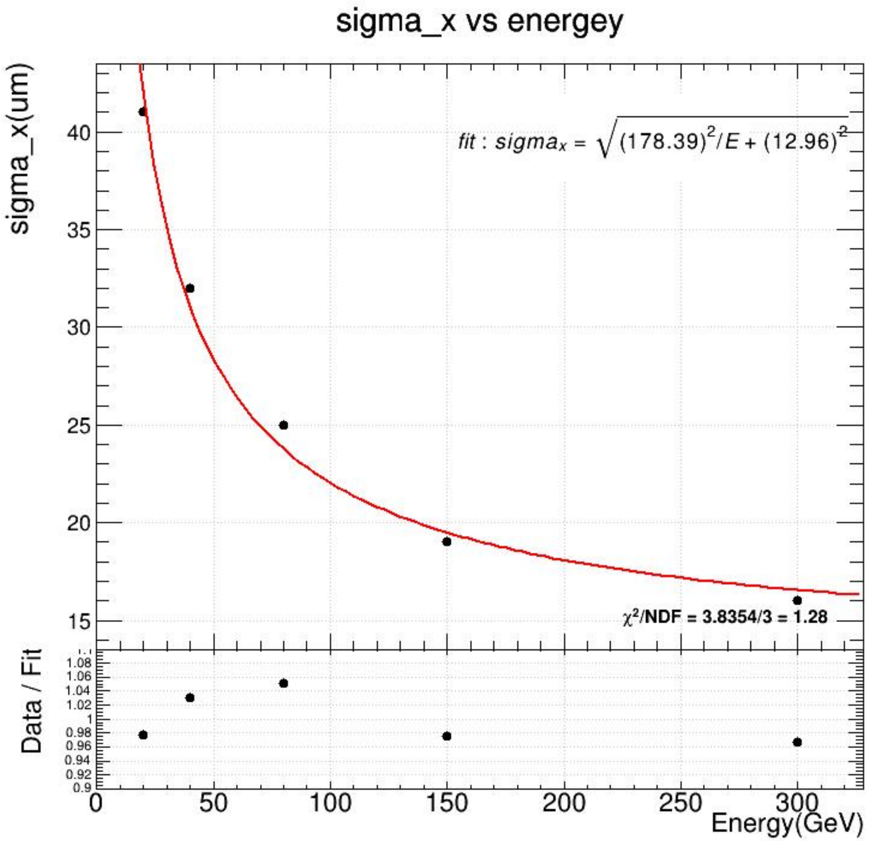




The above histograms show the distribution of the distances in the x and y directions between the centers found by the DBScan algorithm in the 5th and 10th layers.

Position Resolution





Fit using a Gaussian function and consider sigma as the position resolution.

This histogram shows the variation of sigma with energy.

Summary

- After reconstructing the pixel clusters, if the influence of the number of responsive pixels within each cluster is not considered, the shower width increases with increasing energy.
- After reconstructing the pixel clusters, if the influence of the number of responsive pixels within each cluster is considered, the shower width decreases with increasing energy.
- The position resolution of the FoCal-E pixel layers can reach 41 μm at 20 GeV and 16 μm at 300 GeV.

Thanks for your attention!