Performance of FOCAL-E pixel layers

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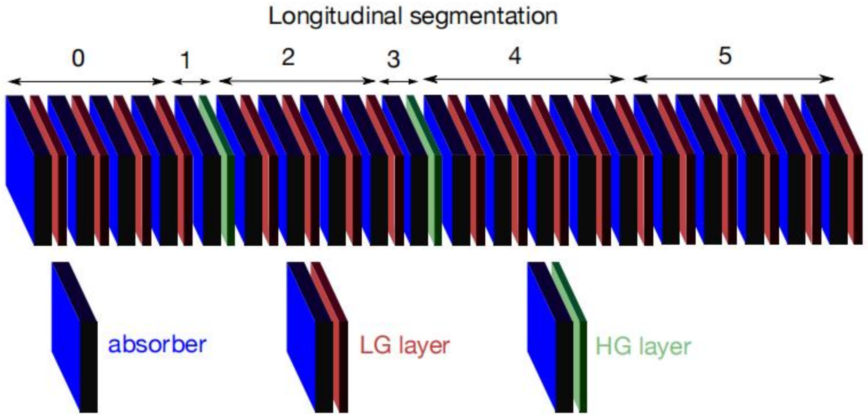
Outline

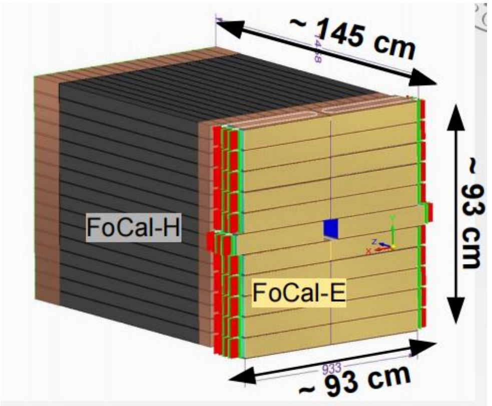
1. FOCAL-E Detector

2. Transverse width of electromagnetic showers

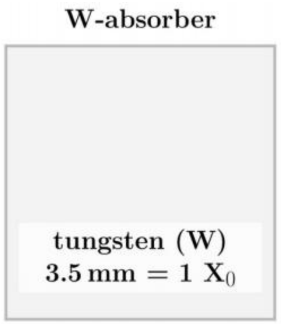
3. Summary

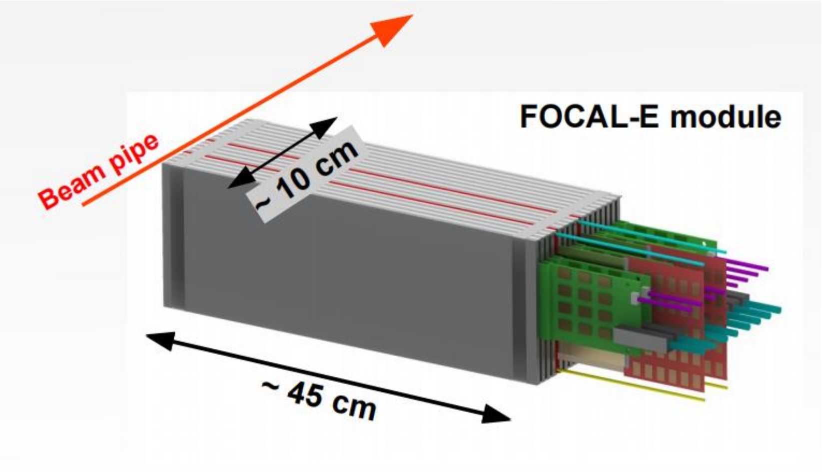
ALICE FoCal-E detector design



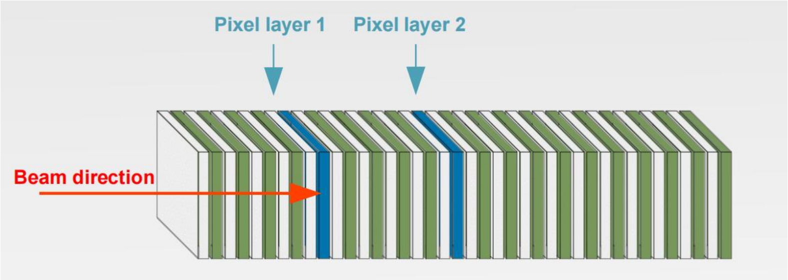


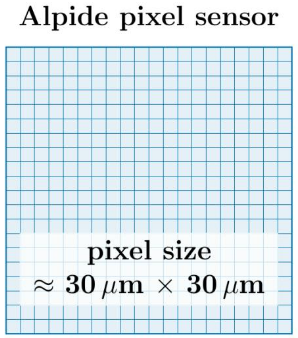
- FOCAL transverse active size ~ 90 cm x 90 cm
- 20 tungsten plates as absorber material
- Atomic number Z = 74
- Density of 19.28 g/cm³
- Thickness of 3.5 mm = 1 X0
- Total radiation length: 20 X0
- Molière radius ~ 1 cm
- Single layer thickness ~ 5 mm



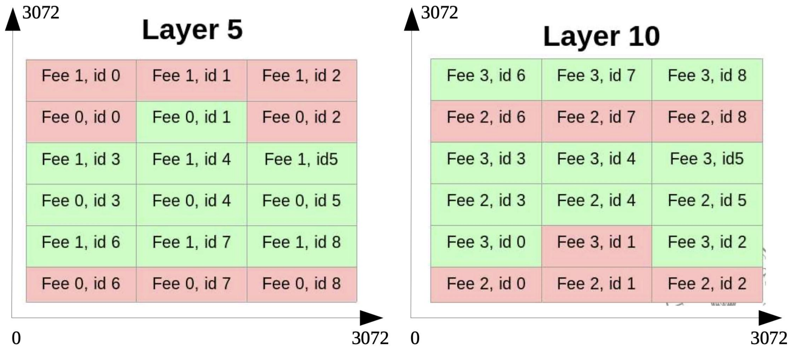


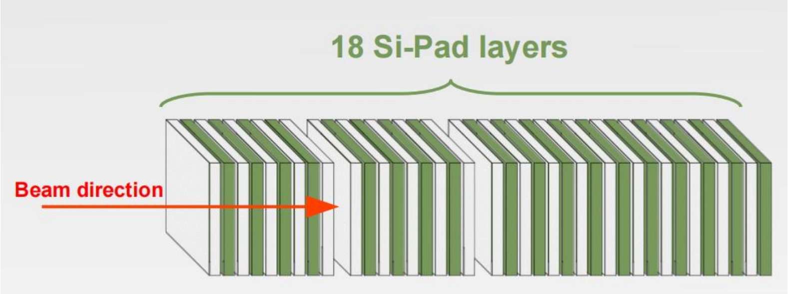
ALICE FoCal-E detector design

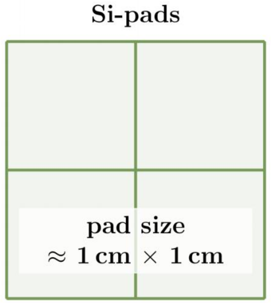




- ALPIDE pixel sensor (ALICE ITS vertex detector pixel sensor)
- Silicon pixel sensor with pixel size of ~30 μm x 30 μm
- 1024 x 512 pixels per chip
- Chip size ~30 mm x 15 mm
- Each pixel layer has 3 x 6 equals 18 chips
- Each pixel layer has 3072 x 3072 pixels







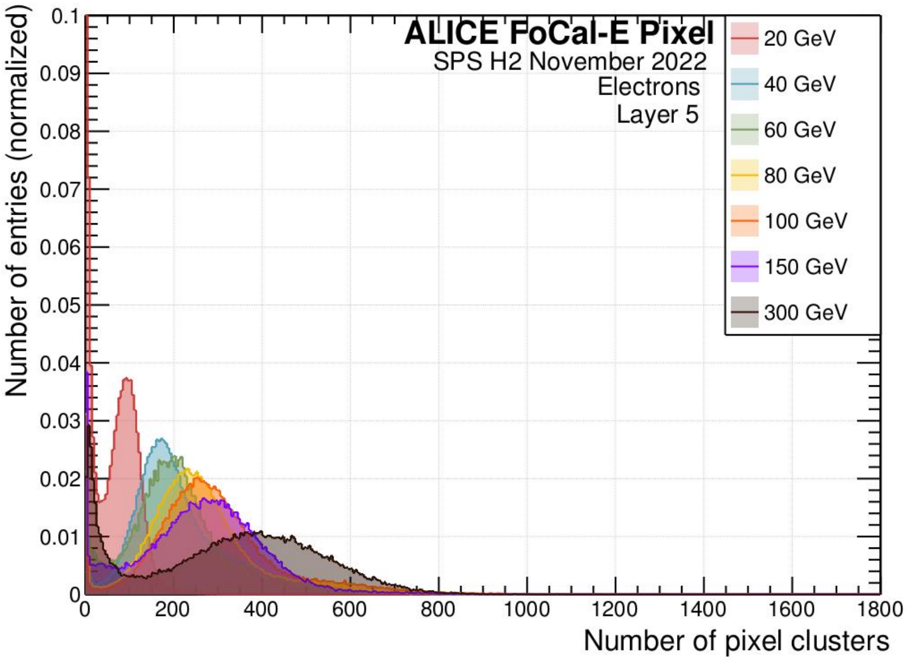
- Silicon sensor with pad size of ~1 cm x 1 cm

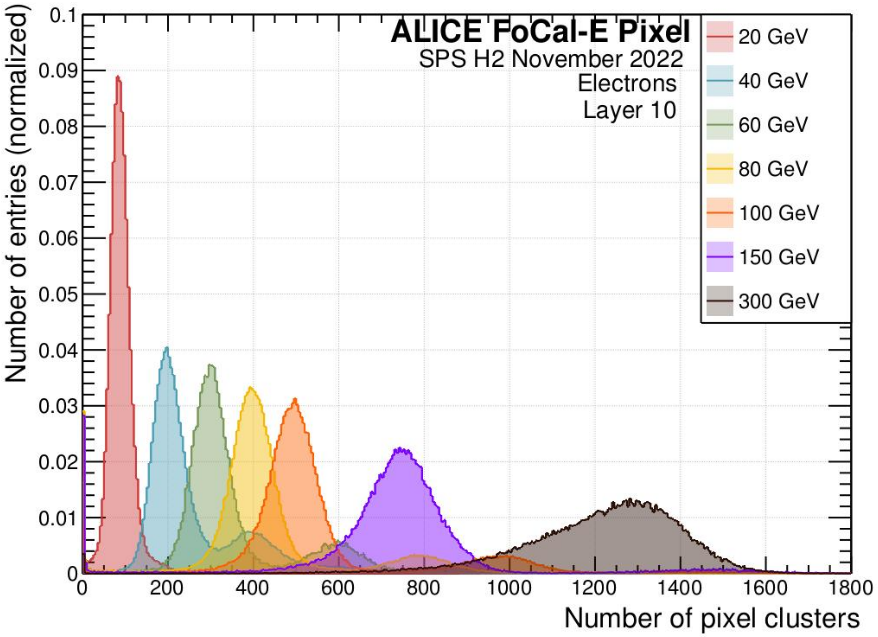
Pixel cluster

● When a particle passes through the detector, not only does a single pixel have a signal, but several pixels around it also produce signals.

● In processing the data, we treat these closely hits as a pixel cluster,the center position of this pixel cluster considered as the point of the incident particle.

● Single pixel cluster contains one or more hit information





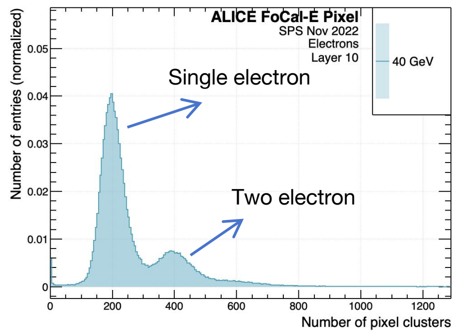
Motivation

● 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**

Single electron event selection

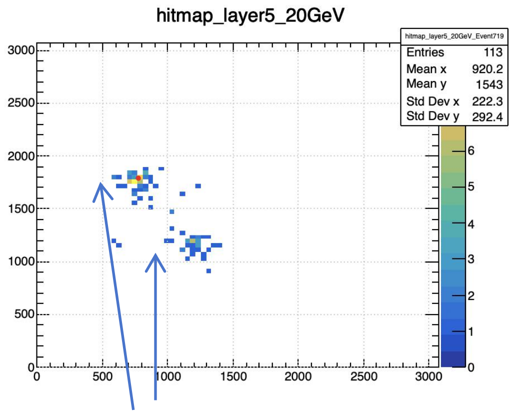


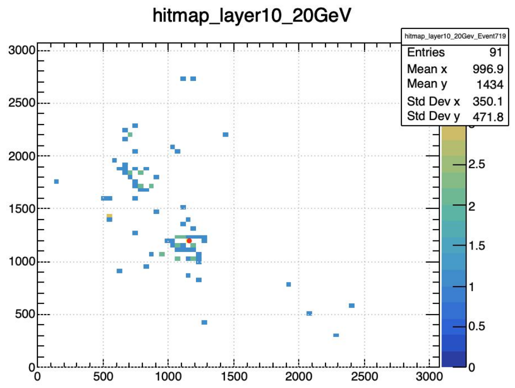
1.Cut on “Number of pixel clusters”

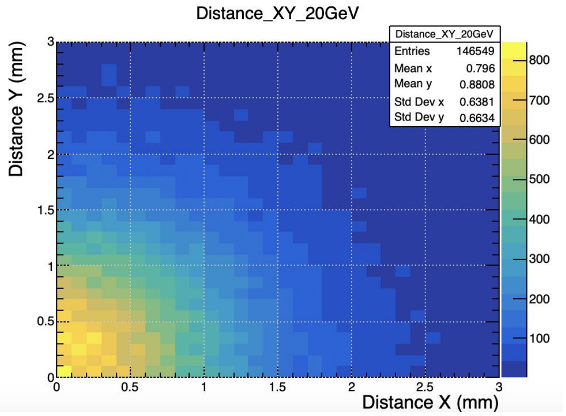
- Reject two-shower events
- Reject events with low number of pixel clusters which might originate from hadrons or non-central electron showers

eg: Layer 5 20GeV’s cut is between 40-160

2.Cut on shower center’s distance between layer 5 and layer 10







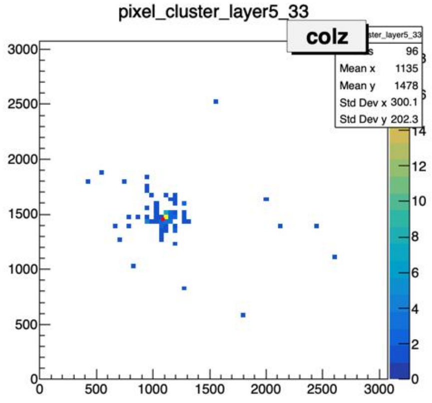
This looks like two electron shower,But the number of hits in this case was small, so my first cut didn't work in this case

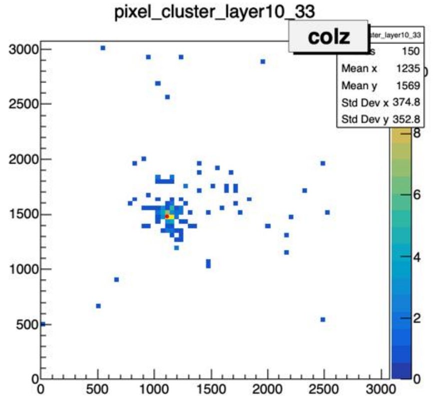
In order to solve this problem,I cut on shower center’s distance:

The events where the x-coordinate or y-coordinate distance between the shower centers of the fifth and tenth layers is greater than 3mm are rejected.

The method I used to calculate the shower width

1.Calculate shower center





My algorithm to find shower center location：

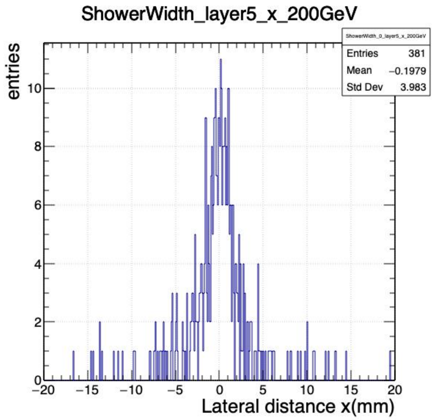
●Plot the coordinates of each pixel cluster's center within a single event on a 2D histogram. BIn size is 1.2mm

●Find the local maxmum, use this coordinate as a seed to find the cluster with a certain radius

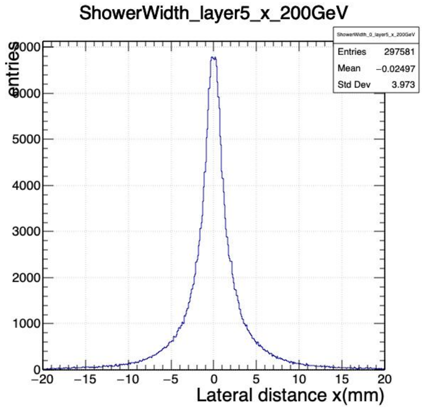
●Use the weighted average method to calculate the shower center

2.Calculate shower width

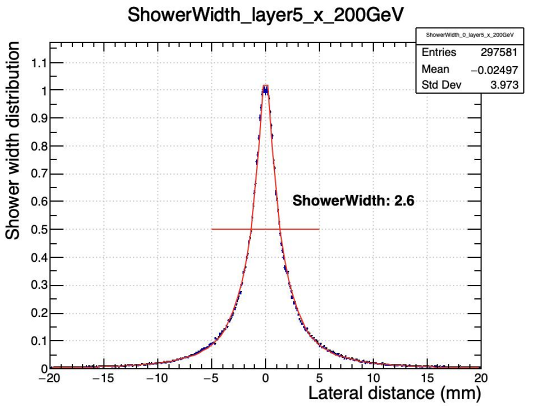
●Calculate the differences between the x or y coordinate of each pixel cluster center and the x or coordinate of the shower center, then fill these differences into an one-dimensional histogram.



Single event



Many events



●I used two methods to fill the one-dimensional histogram:

1.Non-weighted pixel clusters

2.Weighted pixel clusters：Filling the histogram based on the number of hits contained in each pixel cluster

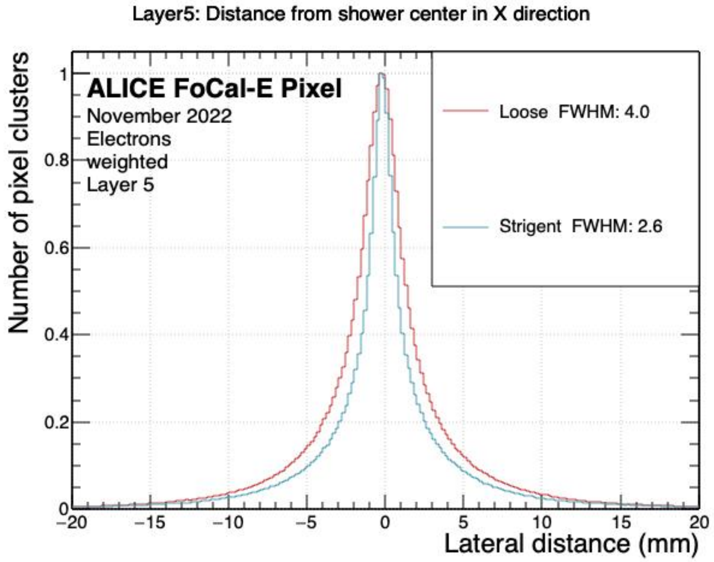
●Fit the plot and use full width halfmaxmum as shower width **(FWHM)**

About shower center

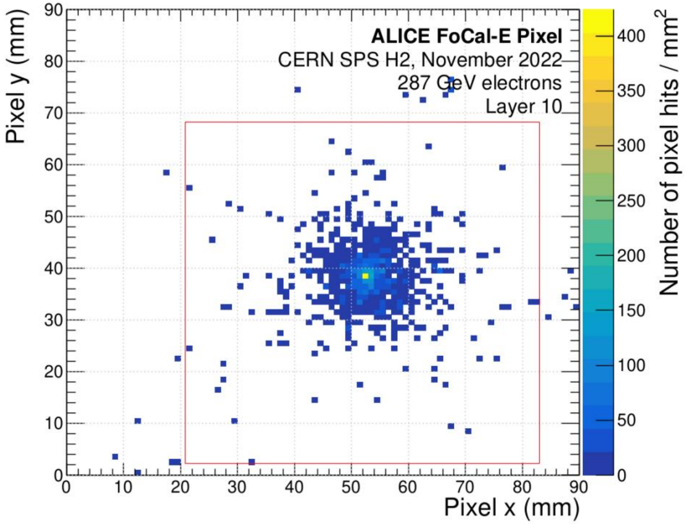
1) The pixel plane's one bin has a width of ~ 40 x 30 μm = 1.2mm
2) The maximum bin is found
3) The shower center is calculated from the weighted mean of bins

Loose
- within a distance of 30 bins (MaxRadius < 3.6cm)
- with number of pixel clusters > 0 (NHits > 0)

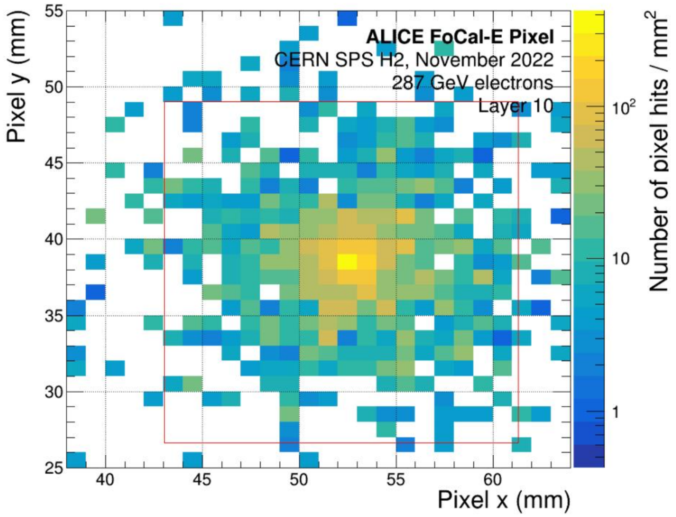
Stringent
- within a distance of 10 bins (MaxRadius < 1.2cm)
- with number of pixel clusters > 3 (NHits > 3)



Loose

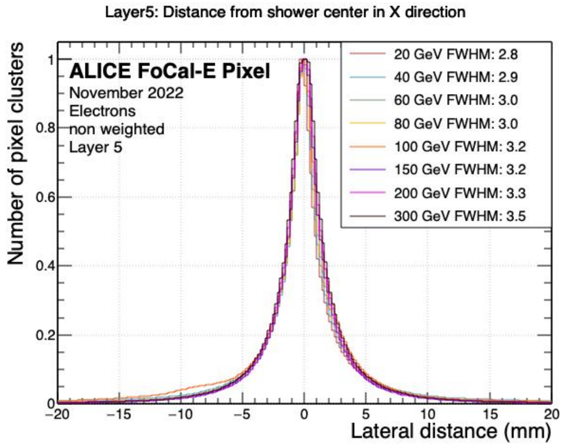


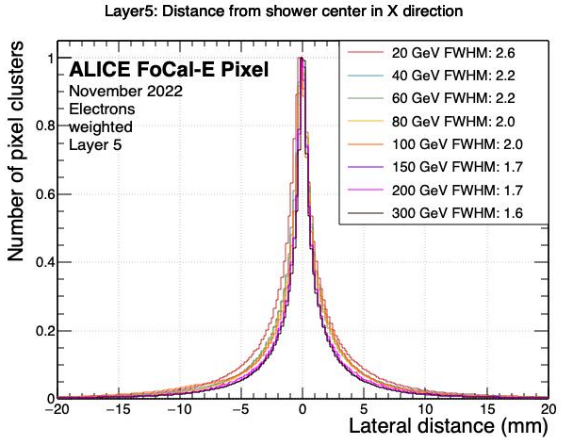
Stringent

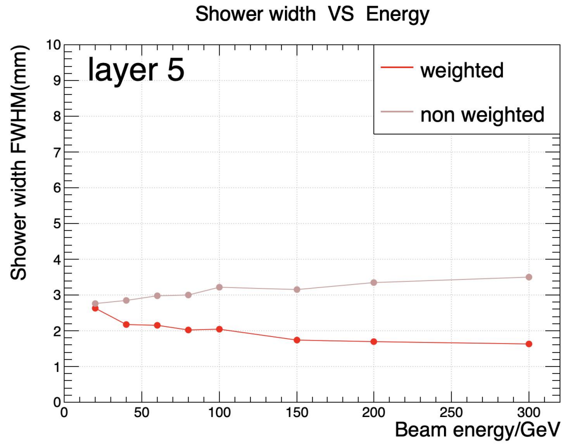


Shower width (CERN SPS Nov 2022 Not weighted VS weighted)

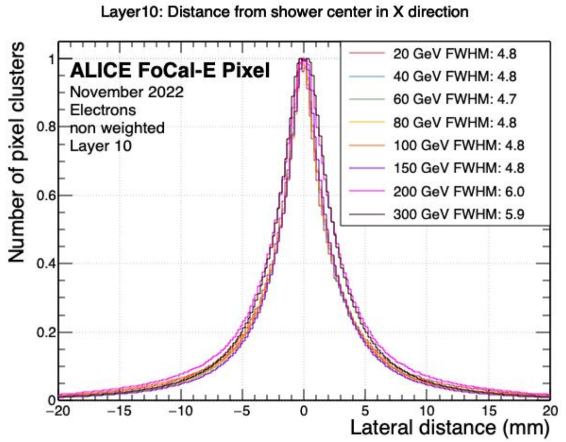
Layer 5

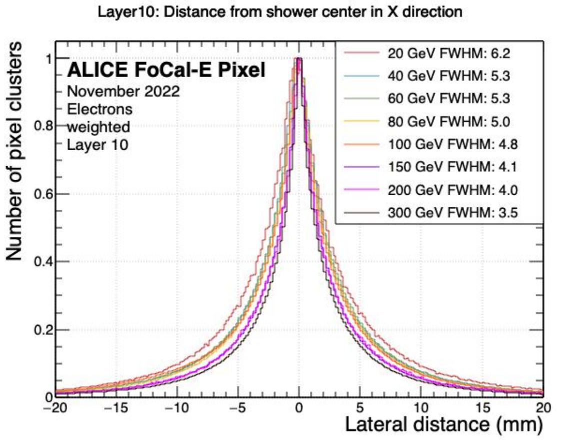


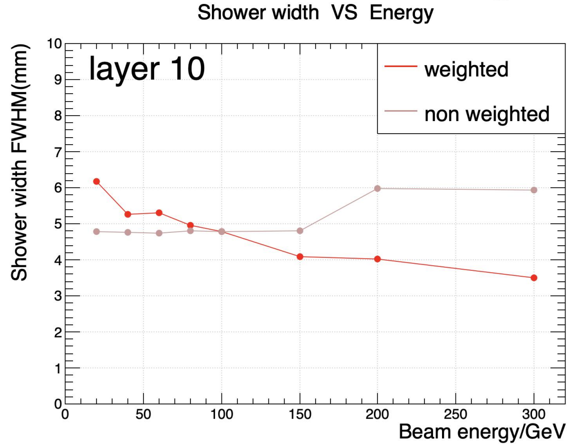




Layer 10



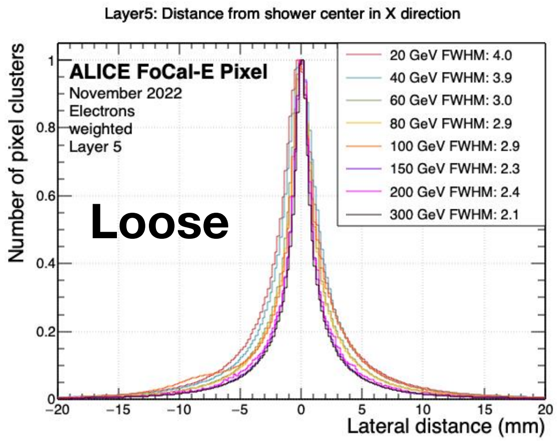


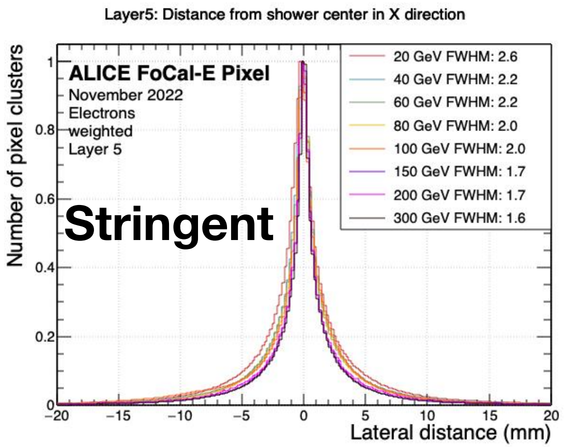


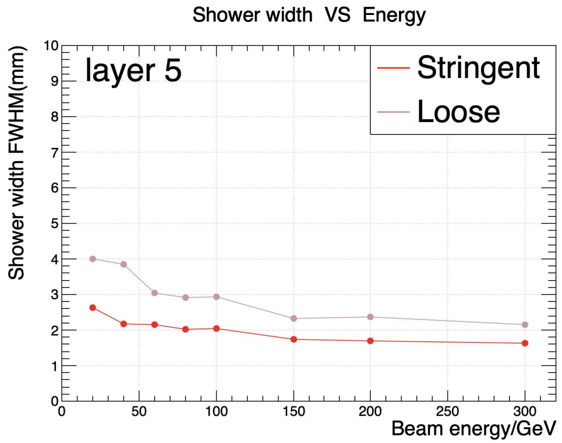
Under the **non-weighted cluster** condition,there is a clear trend of the shower width **increasing as the energy increases**, and under the **weighted cluster** condition, there is a clear trend of the shower width decreasing as the energy increases

Shower width (CERN SPS Nov 2022 Loose VS Stringent)

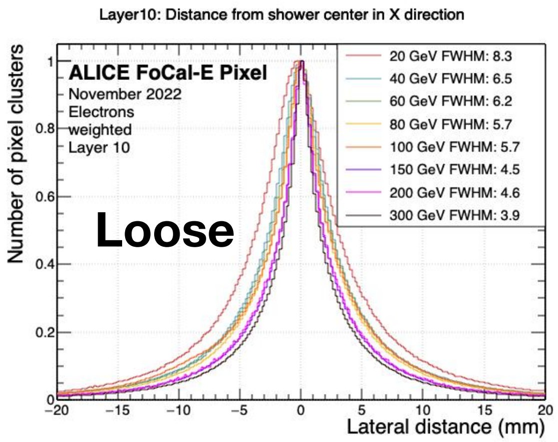
Layer 5

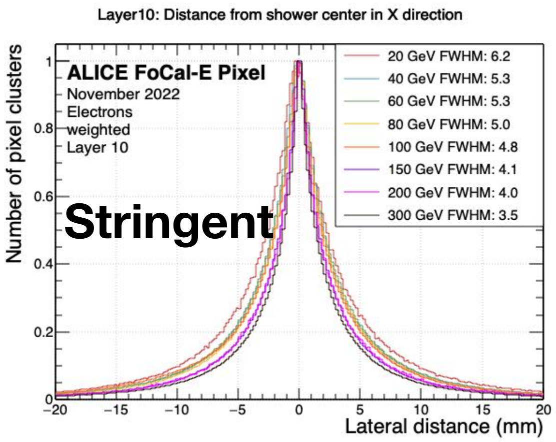


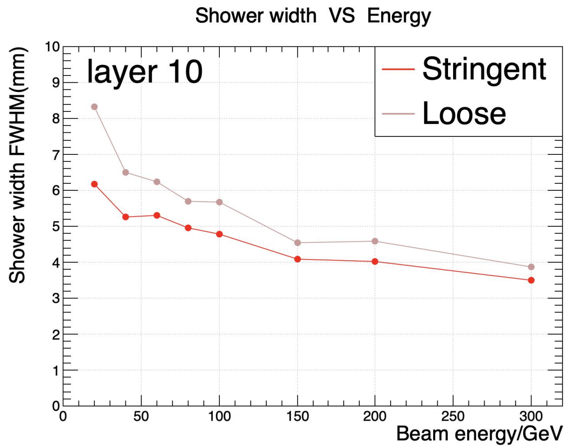




Layer 10



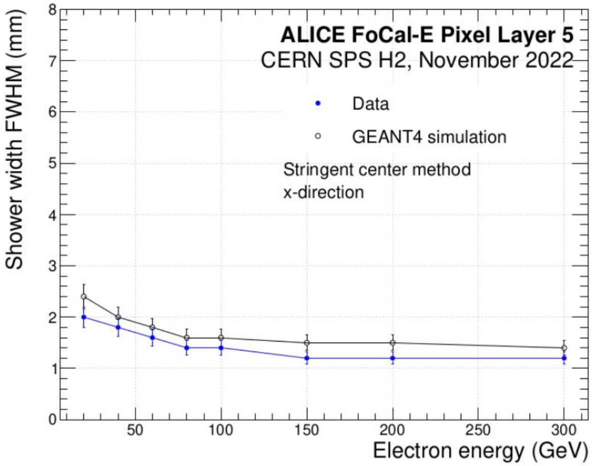


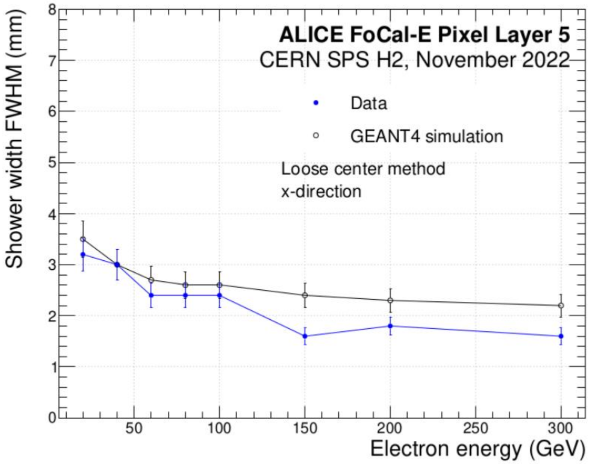


While with the loose method outlier hits or potential noise hits which might influence the calculation of shower center, the stringent method rejects these contributions, emphasizing the high particle density core of the shower.

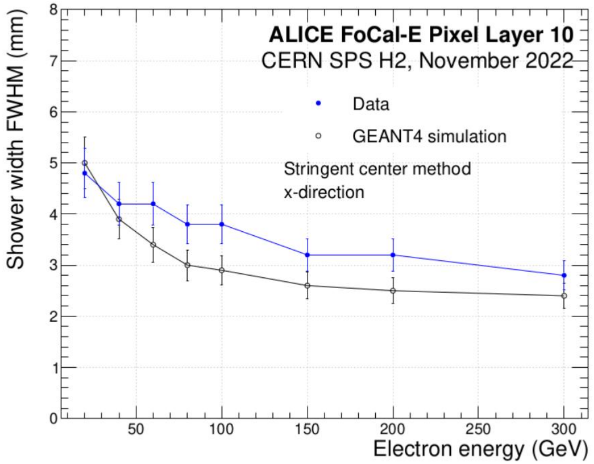
Compare simulation results and beam test data

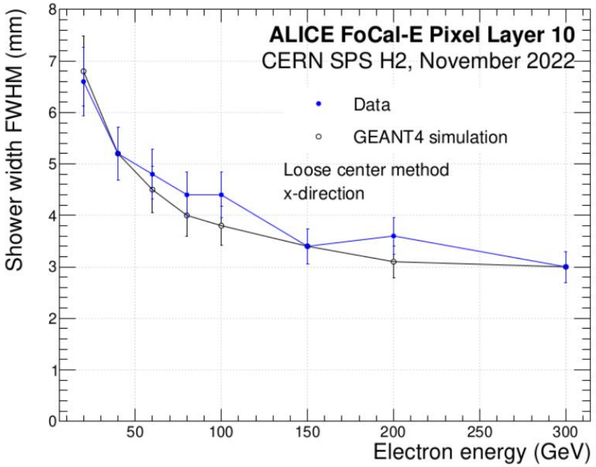
FWHM Layer 5





FWHM Layer 10





FoCal-E Pixel Layer : measured and simulated FWHM for the loose (left) and stringent (right) shower center method. The error bars indicate an uncertainty of 10 %.

Summary and outlook

Results

1. Under the **non-weighted cluster** condition, the shower width **increasing as the energy increases**
2. Under the **weighted cluster** condition, the shower width decreasing as the energy increases
3. The measured and simulated FWHM of the transverse shower widths are in general consistent within 20 %, or better.
4. FOCAL detector's pixel layer performs well. It has the capability to distinguish structures of particle clusters at very small scales, around sub-millimeter

●Next step

1. Use the one-electron transverse shower profile information for shower separation

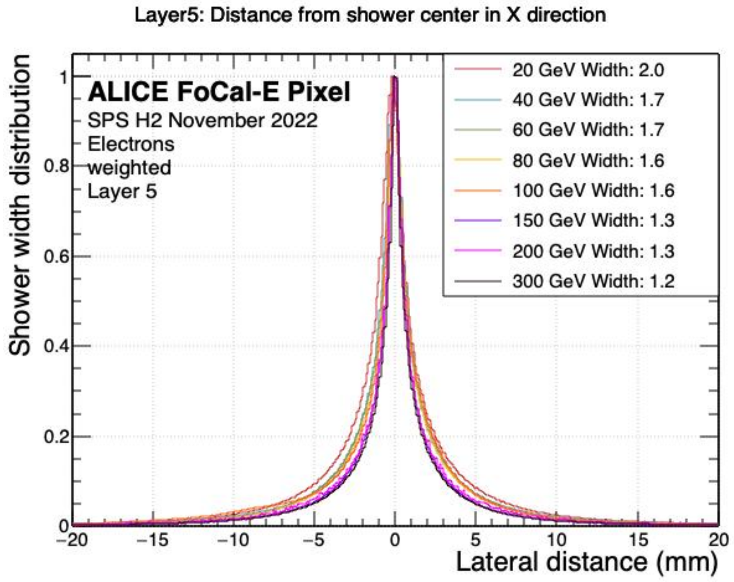
Thanks!

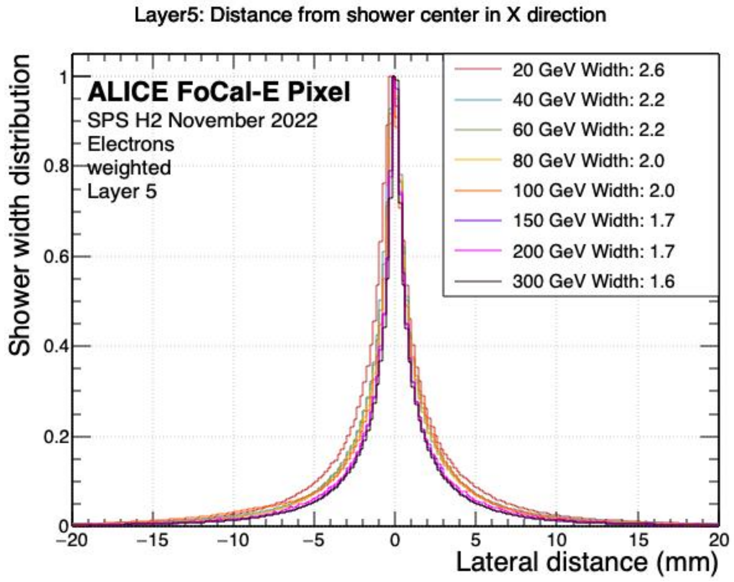
Different bin size

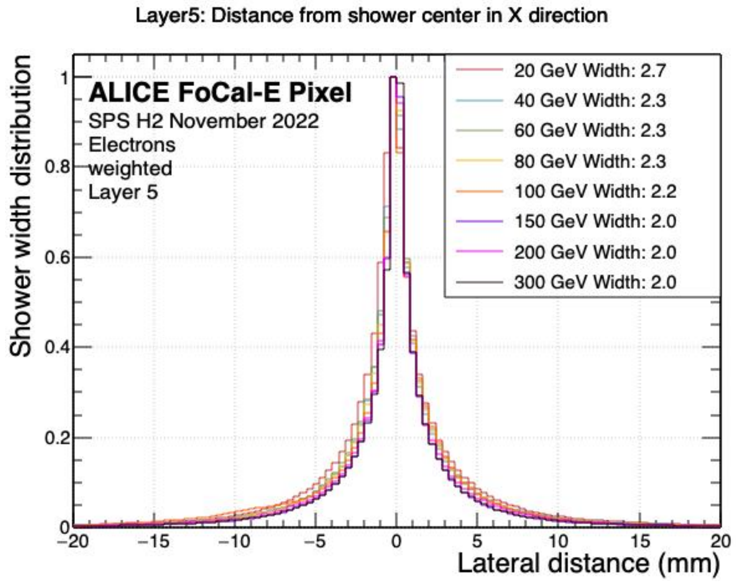
Bin size = 0.1mm

Bin size = 0.2mm

Bin size = 0.4mm







Fit function

$$\frac{d}{dr}N_{\text{hits}}(r) = f(r) = p f_C(r) + (1-p) f_T(r) \tag{7.2}$$

$$= p\frac{2rR_C^2}{(r^2+R_C^2)^2} + (1-p)\frac{2rR_T^2}{(r^2+R_T^2)^2}, \tag{7.3}$$

where $p \in [0, 1]$ denotes the fraction of particles which is carried by the core component of the shower. In order to obtain lateral profiles, i.e. the probability density function along one axis in a cartesian coordinate system, we rewrite Eq. 7.4 with the surface element and assume azimuthal symmetry, thus eliminating the azimuthal angle ϕ:

$$dN_{\text{hits}}(r) = f(r) r dr = s(x_{\parallel})\, x_{\parallel}\, dx_{\parallel} \tag{7.4}$$

If we set $\Delta x = x - x_0 = x_{\parallel}$ and $x_0 = 0$, we can describe the measured shower shapes with the lateral profile

$$s(x) = p\, x\, f_C(x) + (1-p)\, x\, f_T(x) \tag{7.5}$$

$$= p\frac{2x^2R_C^2}{(x^2+R_C^2)^2} + (1-p)\frac{2x^2R_T^2}{(x^2+R_T^2)^2}. \tag{7.6}$$

We describe the event-by-event uncertainty on x_0 by convoluting $s(x)$ with a simple Gaussian function

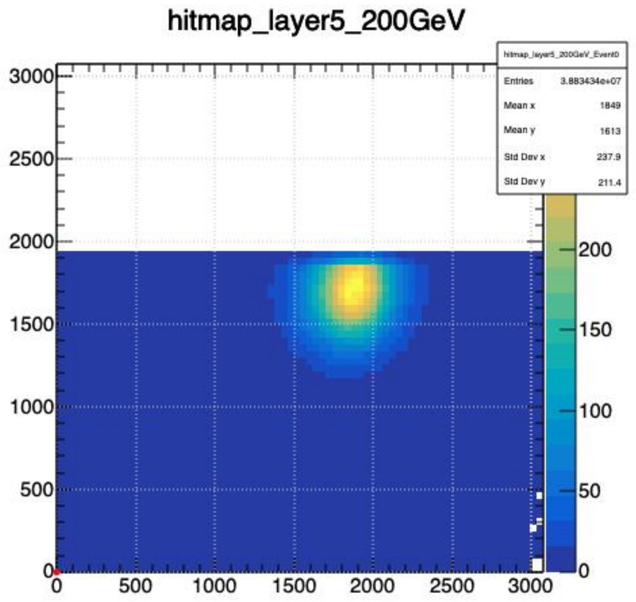
$$\tilde{g}(x) = Ng(x) = N\exp\left(-\frac{(x-x_{\text{sys}})^2}{2\sigma_{x_0}^2}\right), \tag{7.7}$$

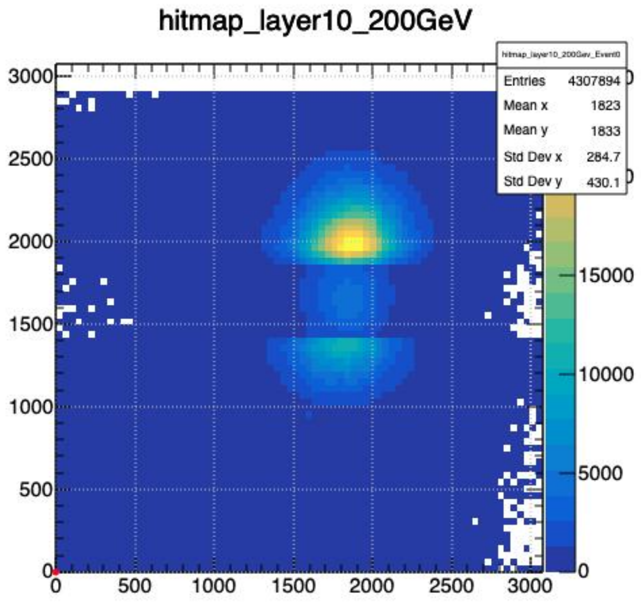
where N is the normalization constant, x_{sys} describes potential systematic errors in the determination of the shower center, and σ_{x_0} accounts for event-by-event uncertainties on the shower center. The fit function, which we implemented numerically, is given by

$$t(x) = Ng(x) * s(x) \tag{7.8}$$

About 200GeV data

There seems to be something wrong with the 200GeV data， layer 5 is normal, layer 10 looks problematic

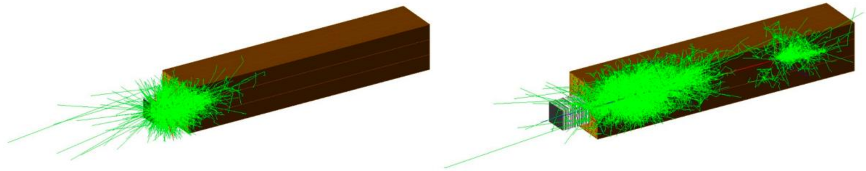




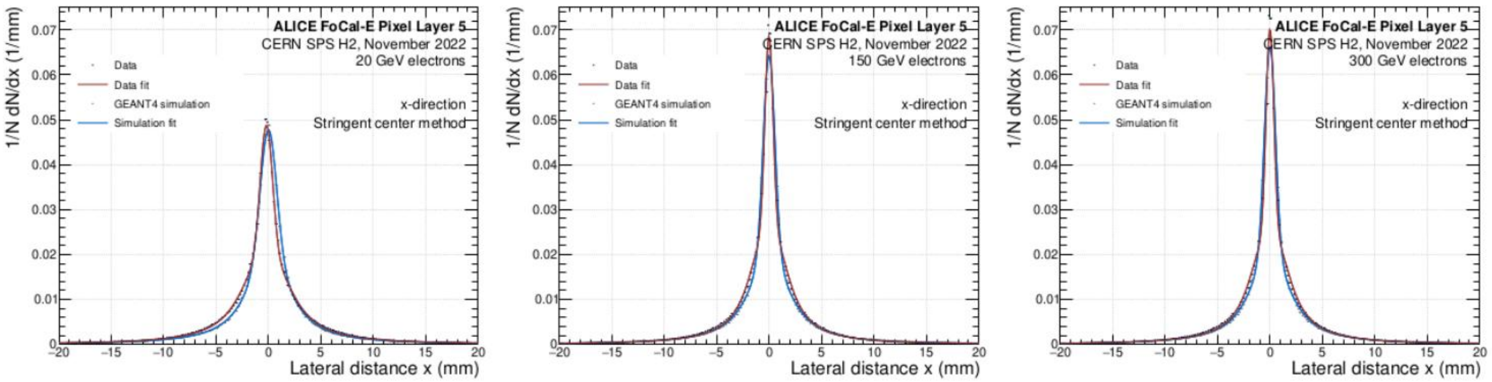
As a result, under the effect of these two cuts, there are only about 2,000 events left in the 200GeV data

Simulation setup

- Software is GEANT 4.10.7
- 20 layers with a 1.2 mm air gap between the layers
- Each layer comprises a 3.5 mm thick tungsten alloy absorber and a silicon sensor
- 20 silicon sensors, 18 are pad sensors, two pixel sensors



Geant4 simulation of the FoCal prototype detectors. The left panel shows a shower created by a 100 GeV electron. The right panel shows a shower created by a 100 GeV pion.



Measured and simulated lateral shower profiles for the Stringent shower center method

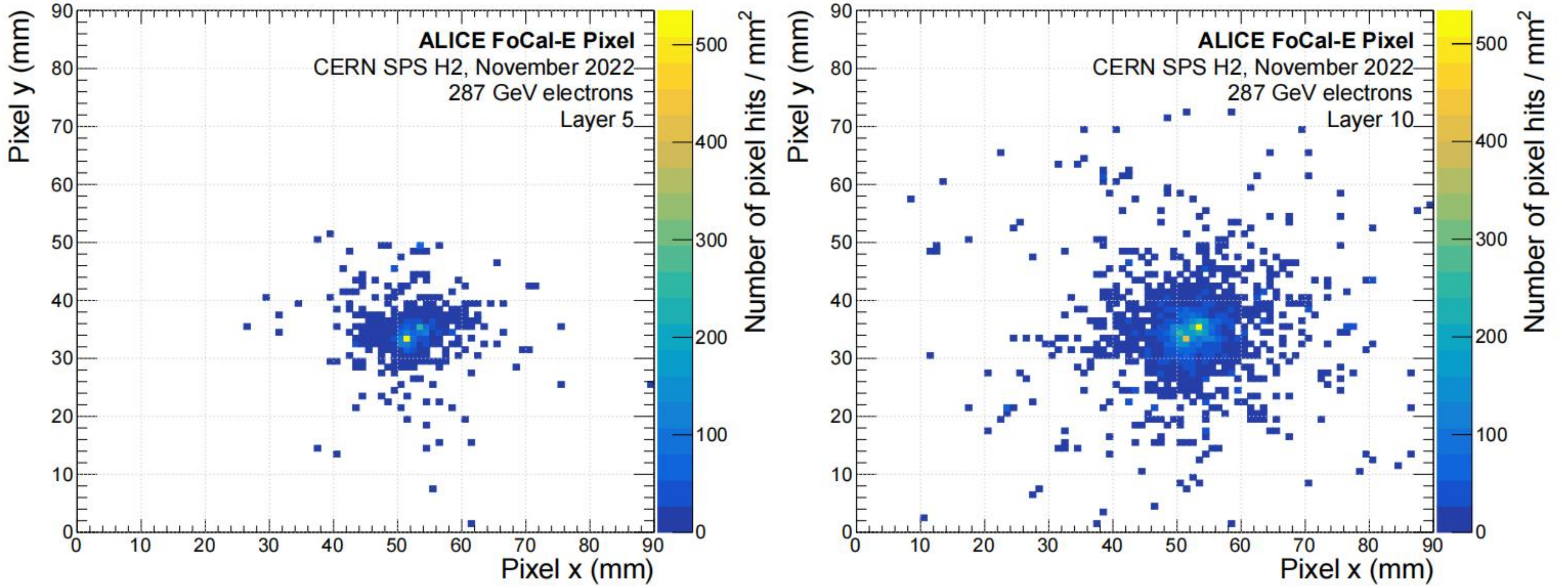


Figure 31. FoCal-E pixel event display of a 287 GeVtwo-electron shower in layer 5 (left) and layer 10 (right).