Centrality assessment of Xe+CsI@3.8AGeV collisions using forward detectors at BM@N experiment

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on behalf of the INR RAS team

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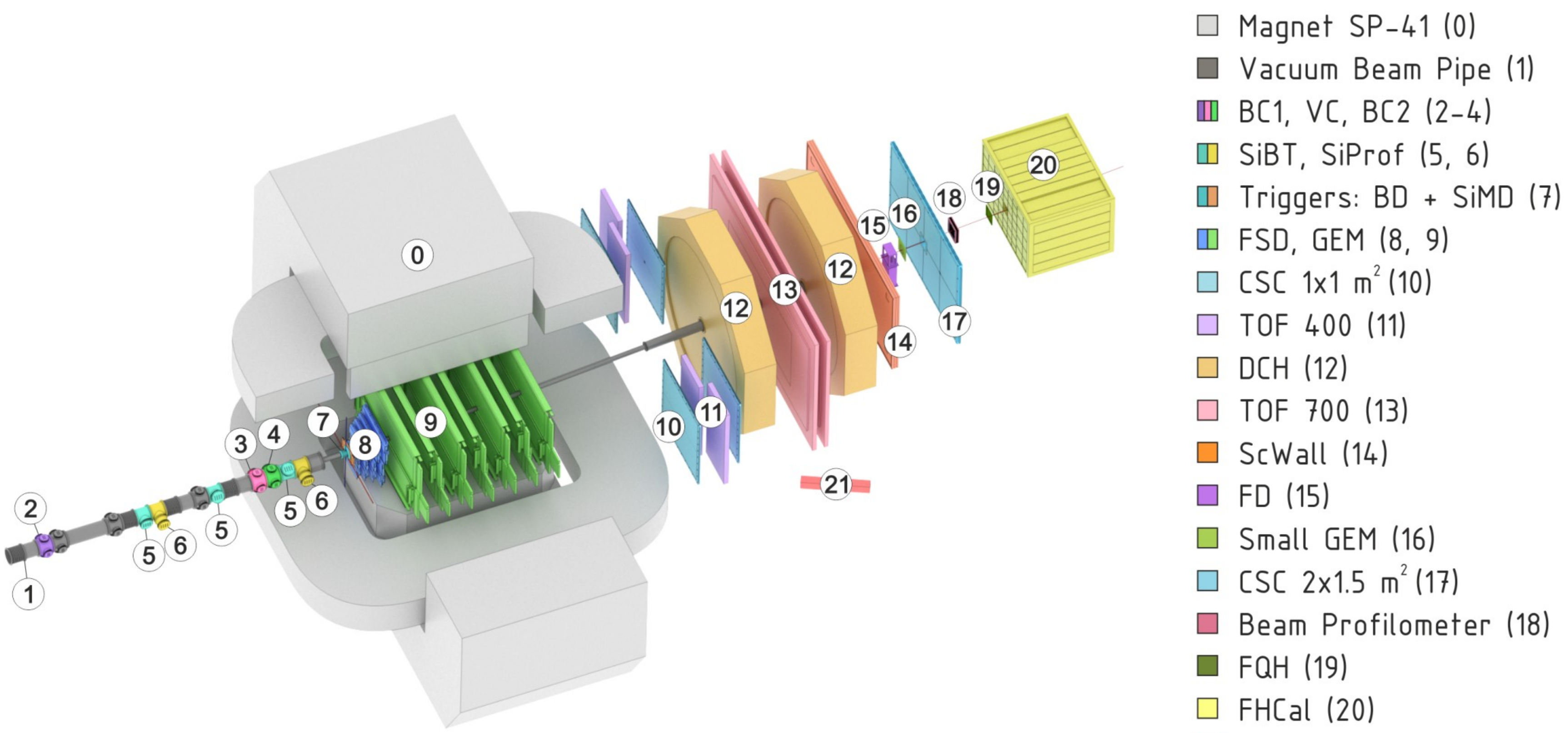
Overview

- BM@N forward detectors of spectator fragments: FQH, FHCal
- Stability of work in the Run 8
- FQH&FHCal correlation for event centrality class determination
  - Simulated data DCM-QGSM-SMM minbias
  - Experimental data Run 8 MBT
- Conclusions and future plans

BM@N Setup
Run8

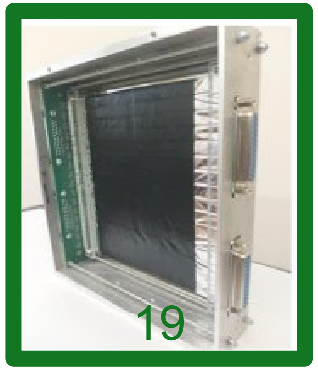


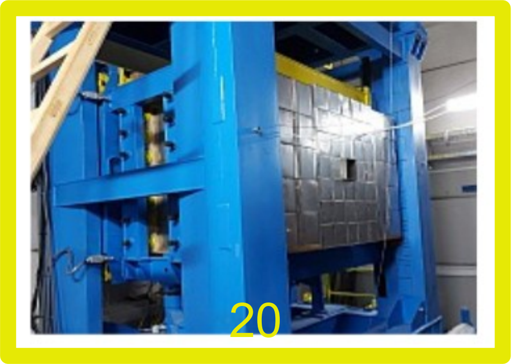
Forward spectators detectors in BM@N

- Forward Quarz Hodoscope (Hodo)
- Forward Hadron Calorimeter (FHCal)

Tasks:

- centrality determination
- reaction plane orientation

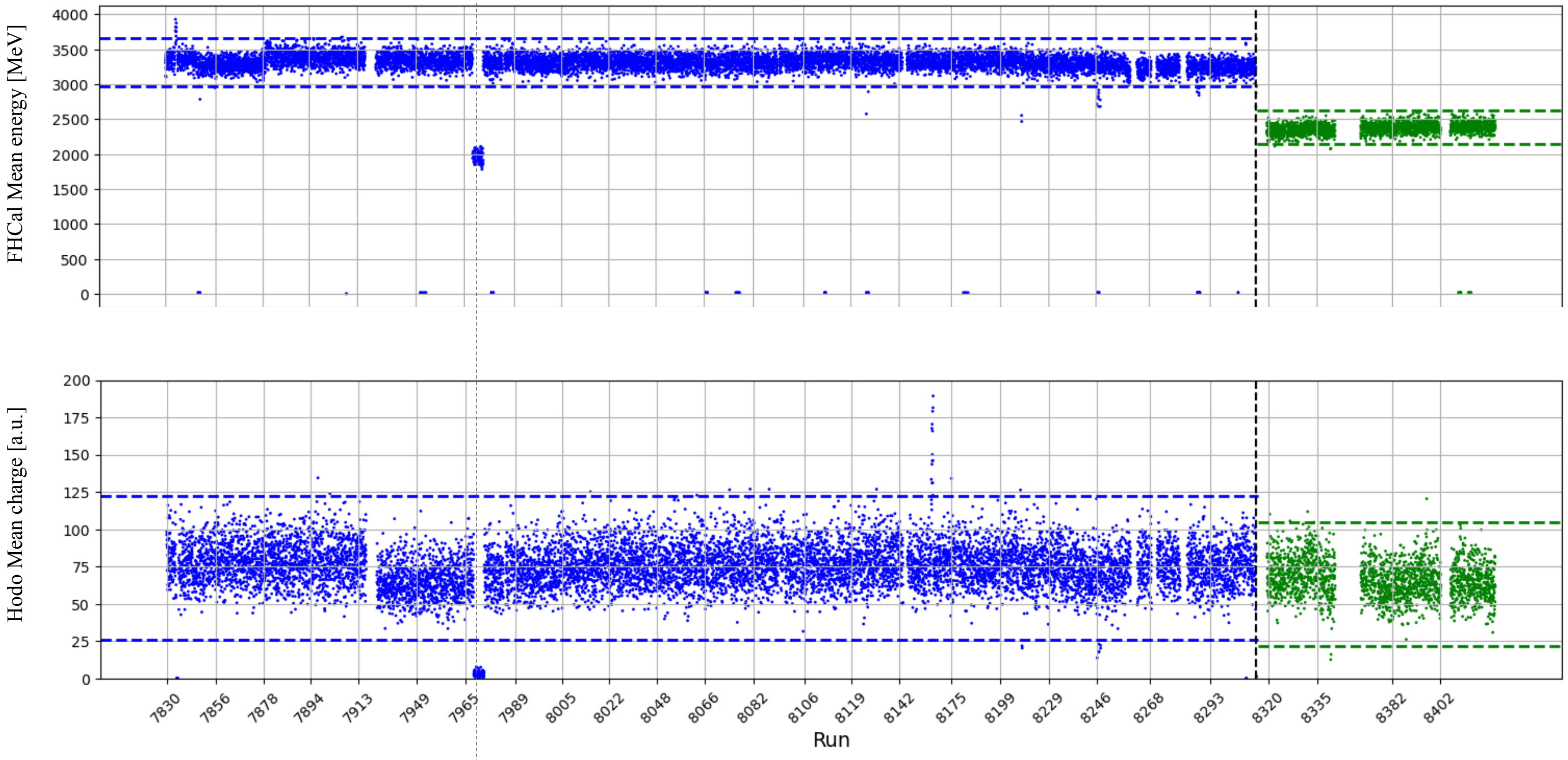




Quality Assessment. Run 8
XeCsI 3.8A GeV and 3.0A GeV

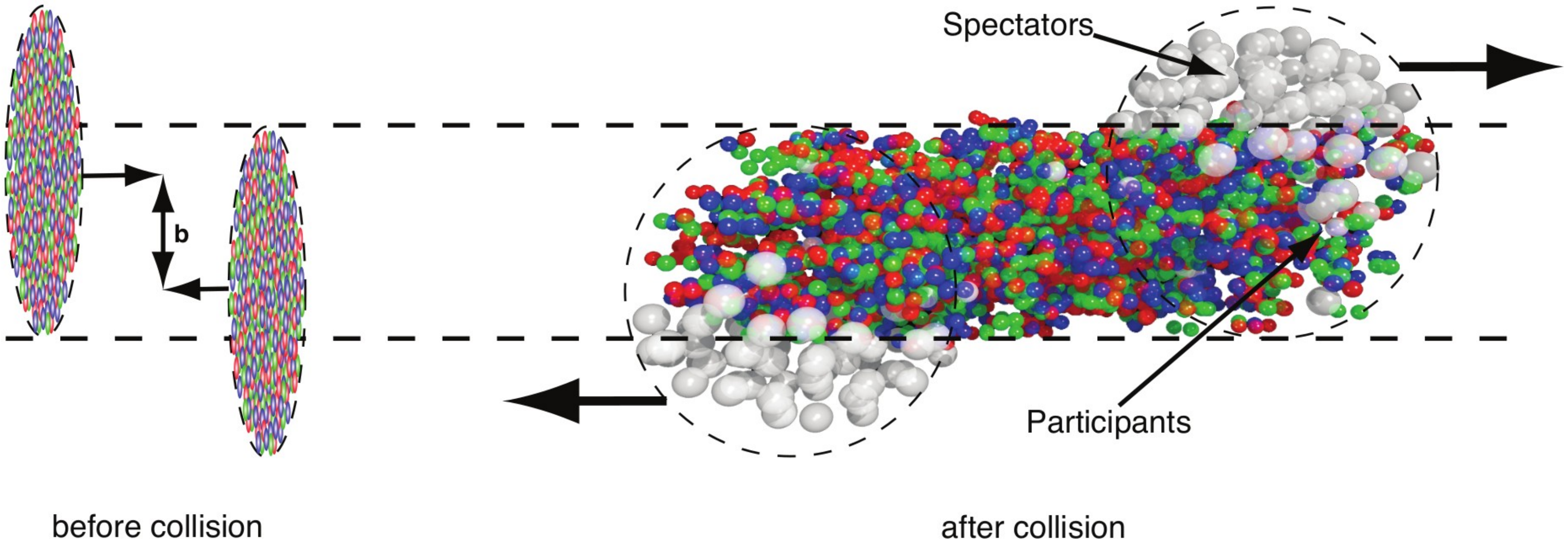
More than 1 track in vertex reconstruction
1 Xe ion by BC1S integral
Vertex position (-1.5 < Z <1.5)

- Forward detectors exhibited stable operation throughout BM@N Run 8.
- The list of problematic runs where the deviation from the mean exceeded 5 sigma is provided at the end of the presentation.



Test runs 7969-7973

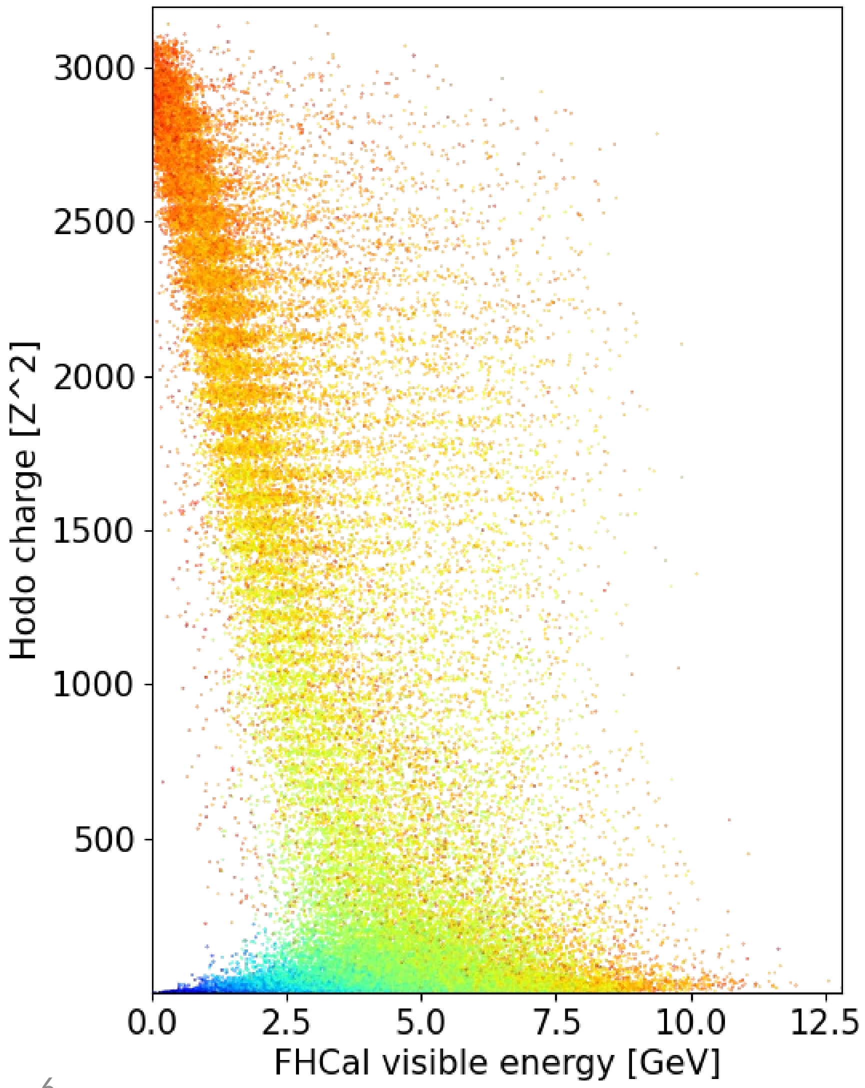
Collision centrality



$$c(b) = \frac{\int_0^b \frac{d\sigma}{db'} db'}{\int_0^\infty \frac{d\sigma}{db'} db'} = \frac{1}{\sigma_{A-A}} \int_0^b \frac{d\sigma}{db'} db'$$

Event characterisation: FQH&FHCal correlation

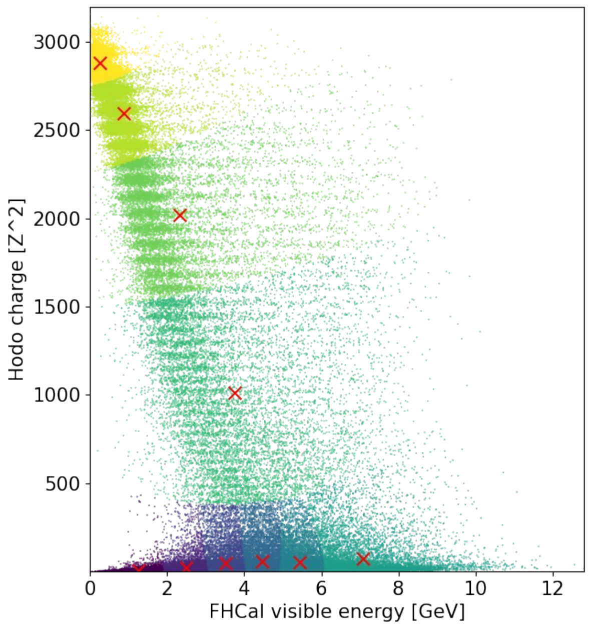
*XeCs@**3.8A GeV**. DCM-QGSM-SMM 100k minbias*

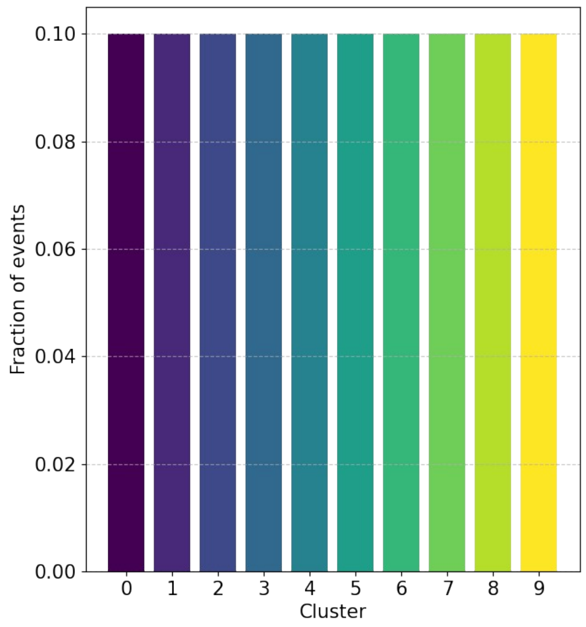


Event class as <u>clusterization</u> task

$$c \approx \frac{1}{\sigma_{A-A}} \int_{\mathbf{X} \in \mathbf{\Omega_k}} \frac{d\sigma}{d\boldsymbol{X}} d\boldsymbol{X}$$

Dividing all available data into clusters of equal sizes with Kmeans constrained method

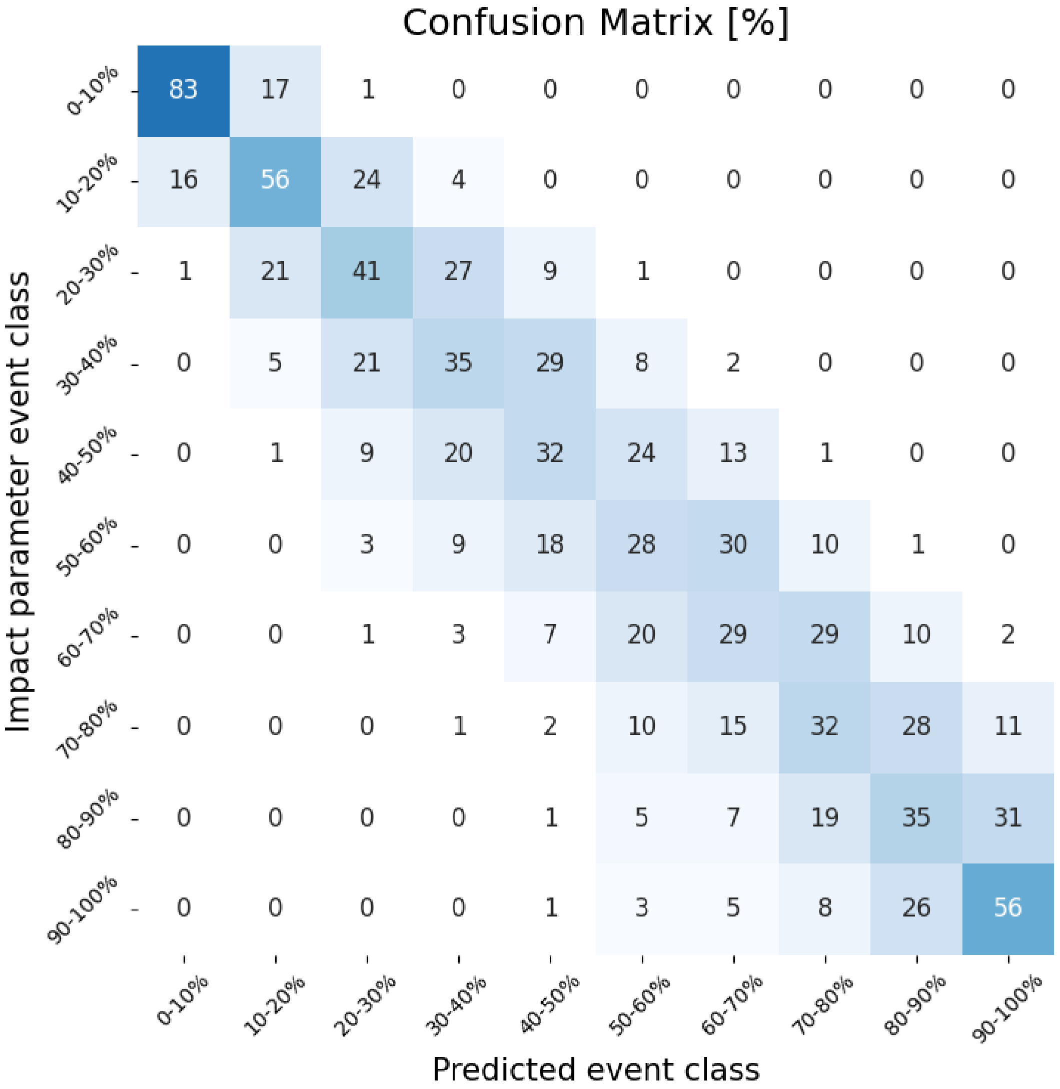




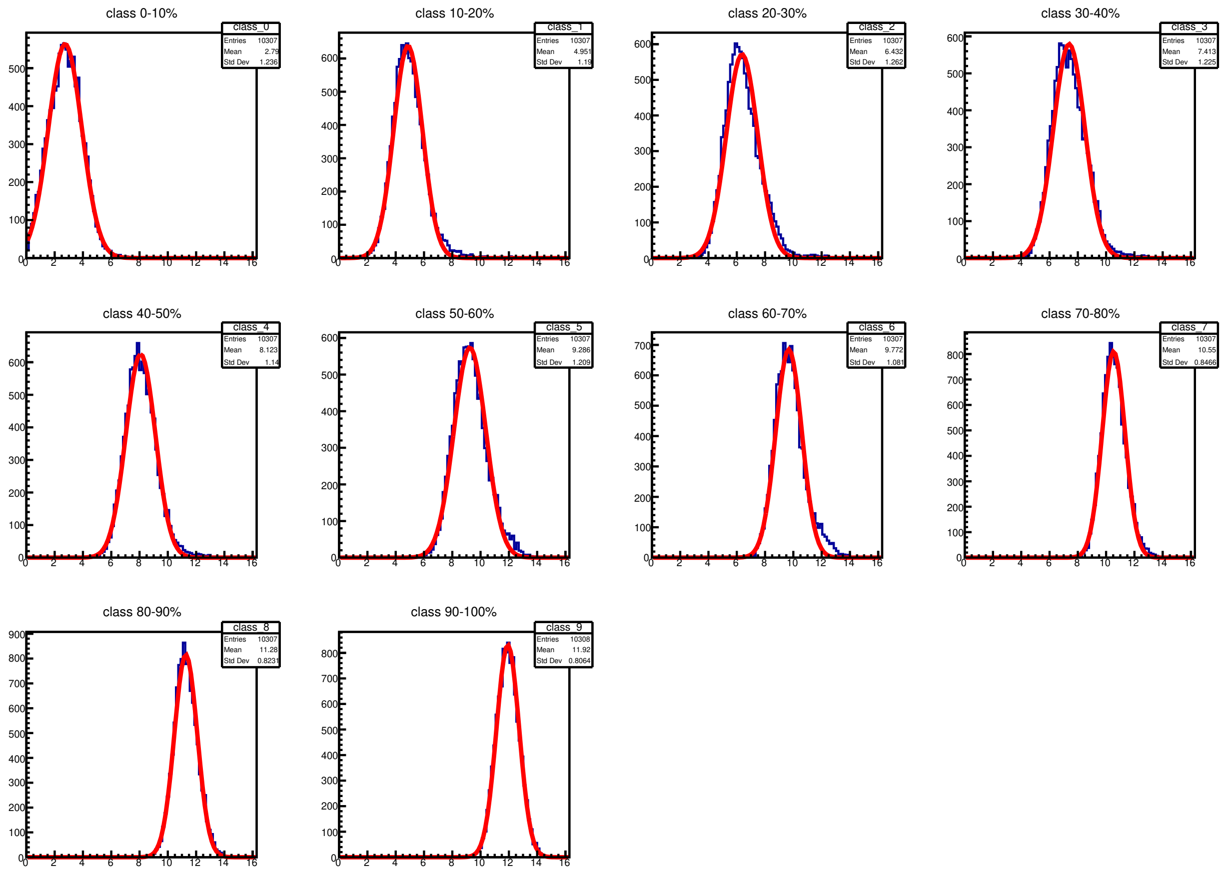
- https://pypi.org/project/k-means-constrained/
- *Bradley, P. S., K. P. Bennett, and Ayhan Demiriz. "Constrained k-means clustering." Microsoft Research, Redmond (2000): 1-8.*
- *With Google's SimpleMinCostFlow C++ implementation*

Event characterisation: Cluster information from simulation

1. Purity

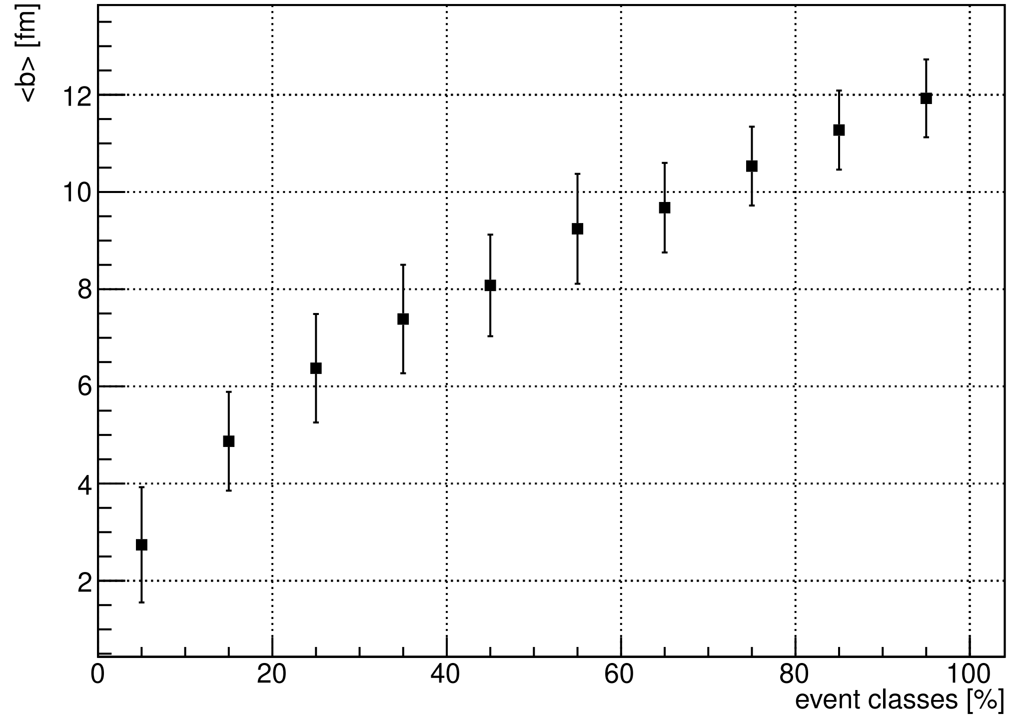


2. Impact parameter distributions

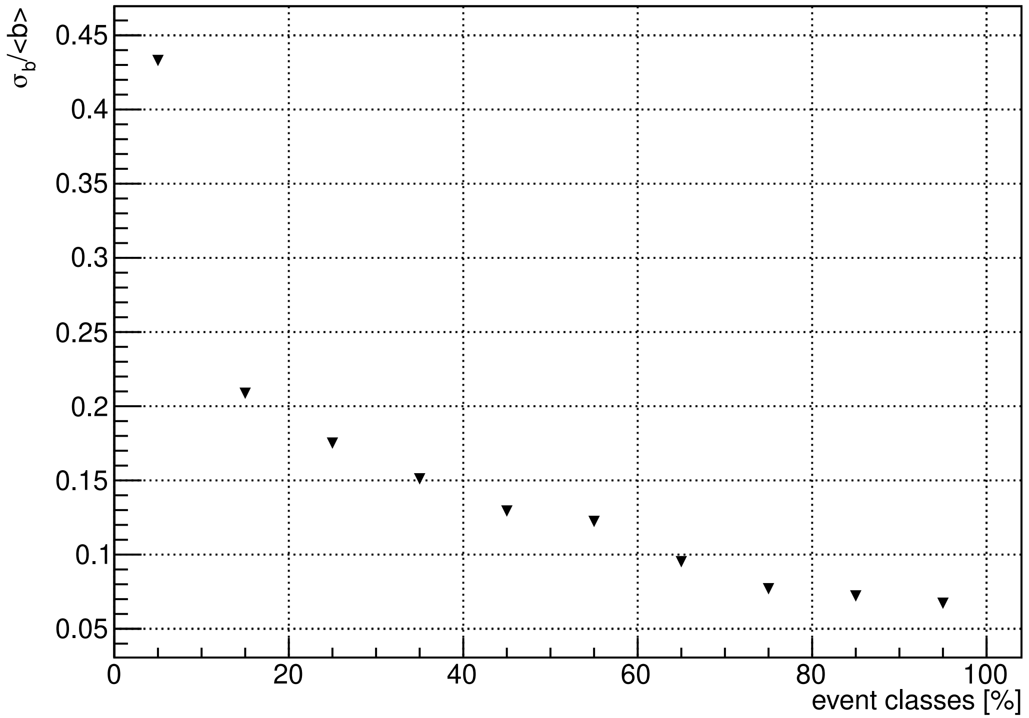


Event characterisation: Cluster information from simulation

2.1 Impact parameter mean



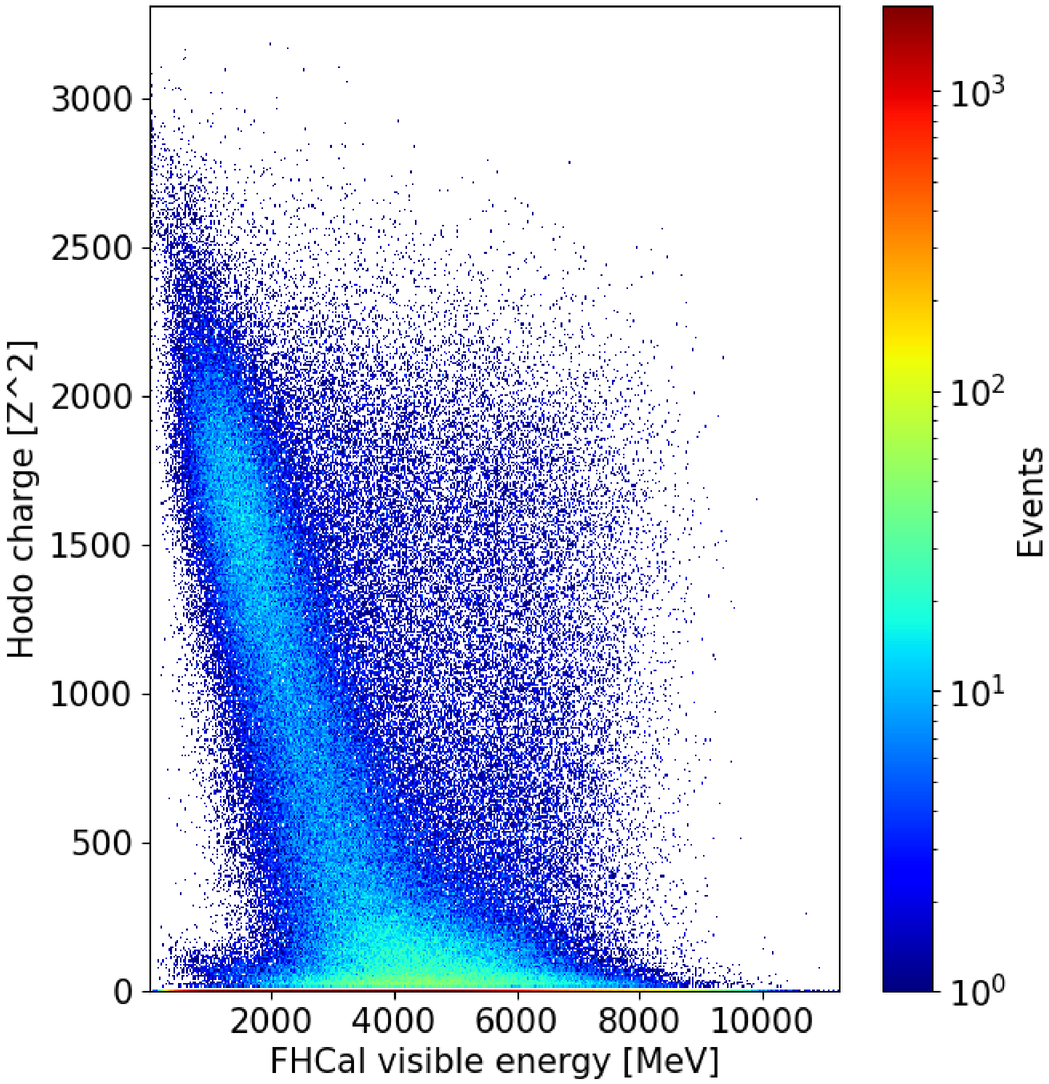
2.2 Impact parameter resolution



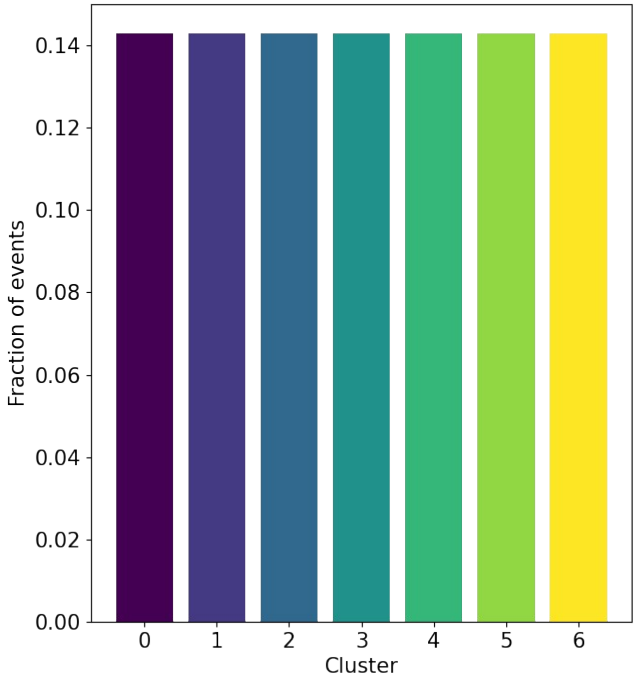
Event characterisation: FQH&FHCal correlation

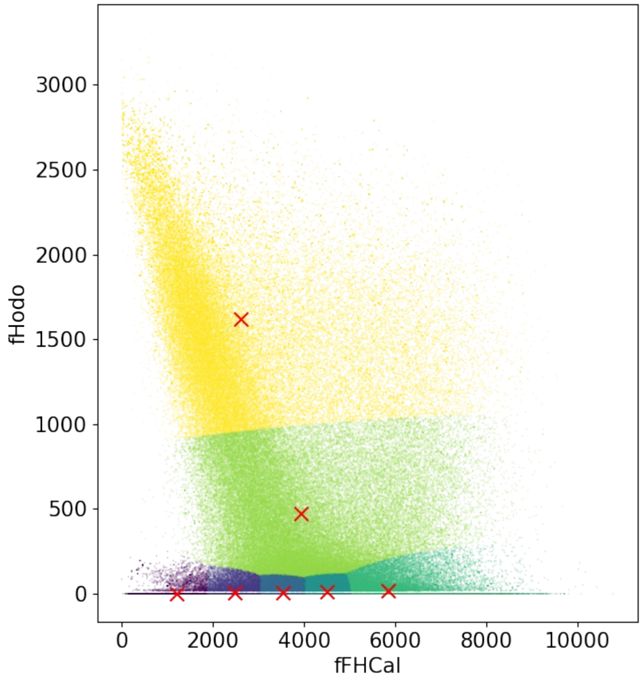
More than 1 track in vertex reconstruction
1 Xe ion by BC1S integral
Vertex position (-1.5 < Z <1.5)

*XeCsI@**3.8A GeV**. MBT 3M runs 7819, 7988, 8097*

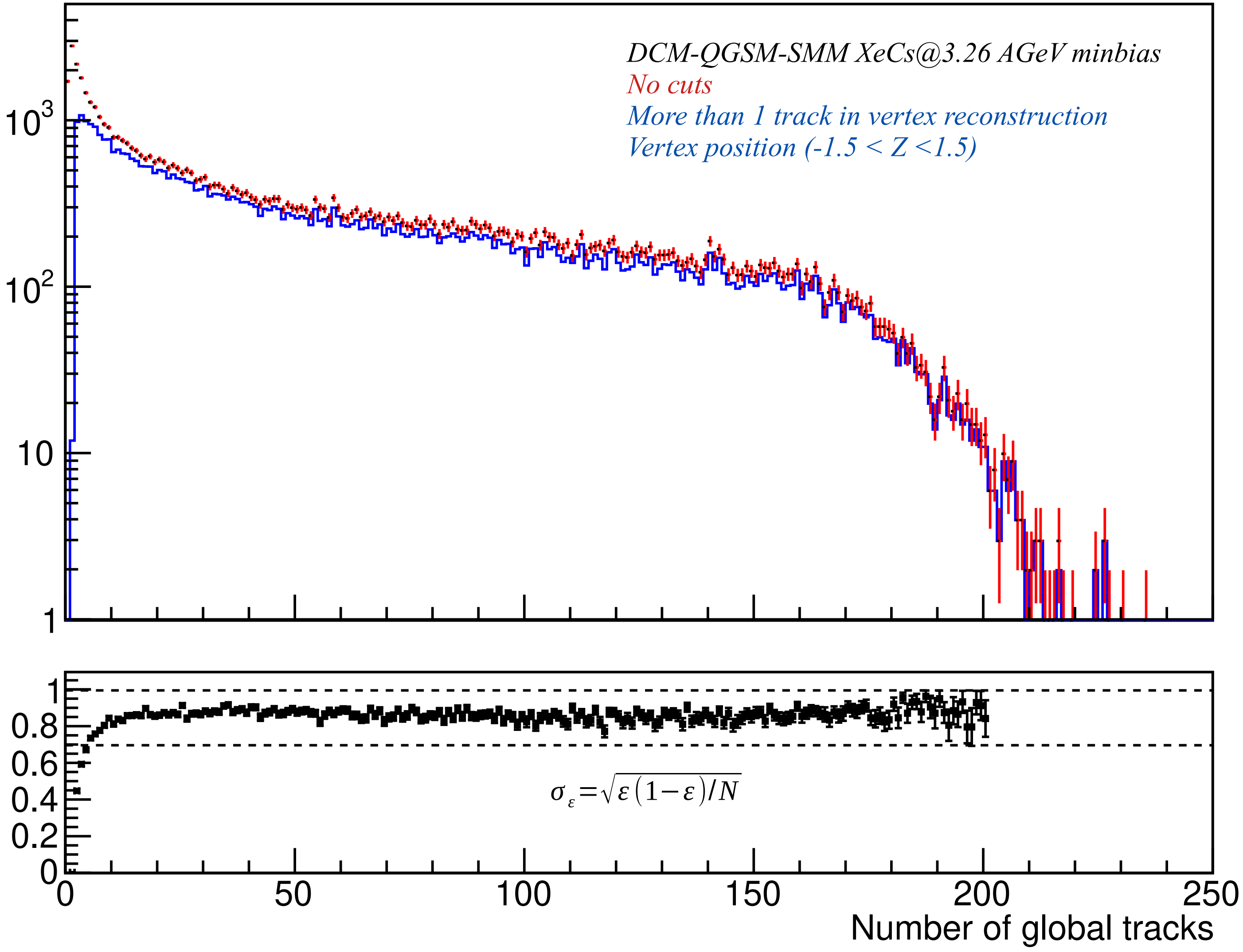


- Apply the same process to experimental MBT data (~70% true minimum bias: *link*) by splitting it into 7 clusters.
- For the time being we do not discuss the trigger efficiency.



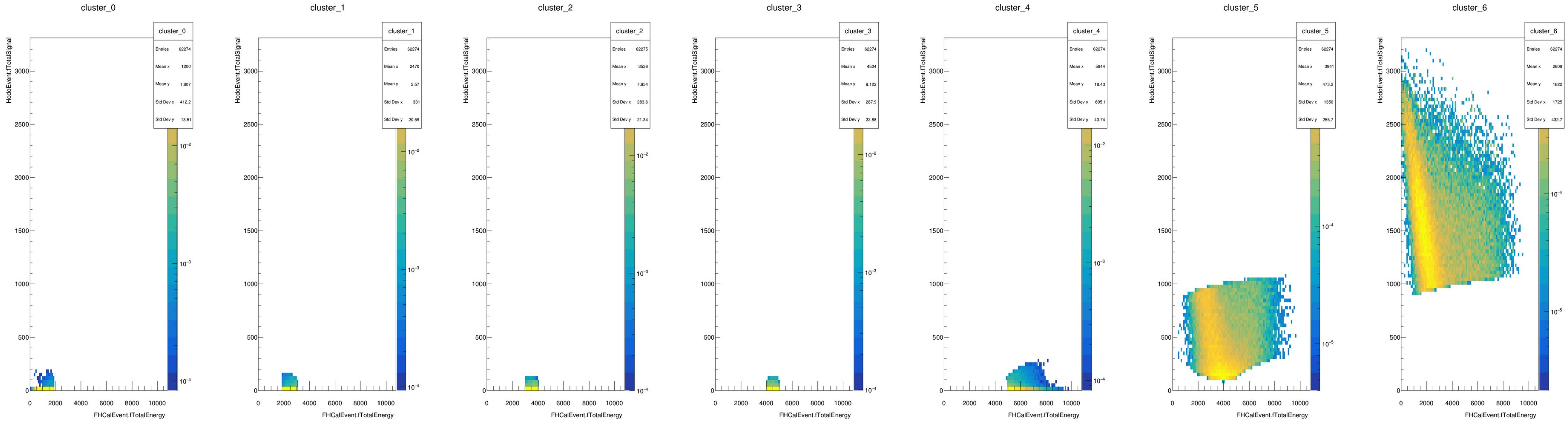


Event characterisation: Taking into account vertex reconstruction efficiency



Event characterisation: Software status

- At the reconstruction stage each event is assigned a soft probability (array) of belonging to each event class.
- At the moment assignment is made unambiguous based on 2D joint probability density functions. If corresponding bin is empty in all pdfs, event is assigned according to nearest centroid while probability is set 0.
- The functionality is integrated into bmnroot and is accessable from DST files through methods *EventCentrality→GetClass()* and *EventCentrality→GetProbability()*, which return the index and probability of the most likely event class.



2D normalised joint PDF are stored in a configuration file

Conclusions

- The forward detectors exhibited stable operation throughout BM@N Run 8.
- A clusterization method for event class determination using FQH and FHCal data has been developed. This method has been implemented into bmnroot as a reconstruction task.
- Vertex reconstruction efficiency is taken into account based on simulated DCM-QGSM-SMM data.

Future plans

- The next step involves defining the trigger efficiency, which is the fraction of true minimum bias events captured by the MBT (or CCT2) trigger.

- A request for centralized simulation with different models (DCM-QGSM-SMM, (+?) UrQMD-SMM, PHQMD) is planned for centrality studies.

- Upgrade: although the unresolved pileup fraction in FQH is made quite small (~4%) with the Richardson-Lucy deconvolution algorithm, we are considering replacing the strips of FQH with thinner strips (1cm → 5mm), which will decrease the fraction of pileups by a factor of 2.

- Investigation into correlations between detector responses and the impact parameter is underway (see *report* by V. Volkov). New algorithm for centrality determination based on Bayesian inversion applied to FQH and FHCal signals is under development by D. Idrisov.

Thank you for your attention!

Bad runs list
(exceeding 5 sigma)

3.8 GeV

FHCal
7839, 7840, 7850, 7856, 7905, 7907, 7950, 7969, 7970, 7972, 7973, 7979, 7997, 8066, 8077, 8111, 8129, 8184, 8186, 8216, 8247, 8289, 8304

Hodo
7839, 7840, 7897, 7901, 7969, 7970, 7972, 7973, 8014, 8063, 8075, 8081, 8088, 8131, 8167, 8175, 8215, 8216, 8247, 8307, 8308

ScWall
7839, 7840, 7900, 7969, 7970, 7972, 7973, 8059, 8167, 8216, 8219, 8307, 8308

3.0 GeV

FHCal
8312, 8323, 8341, 8414, 8419

Hodo
8312, 8321, 8334, 8341, 8395

ScWall
8312, 8421

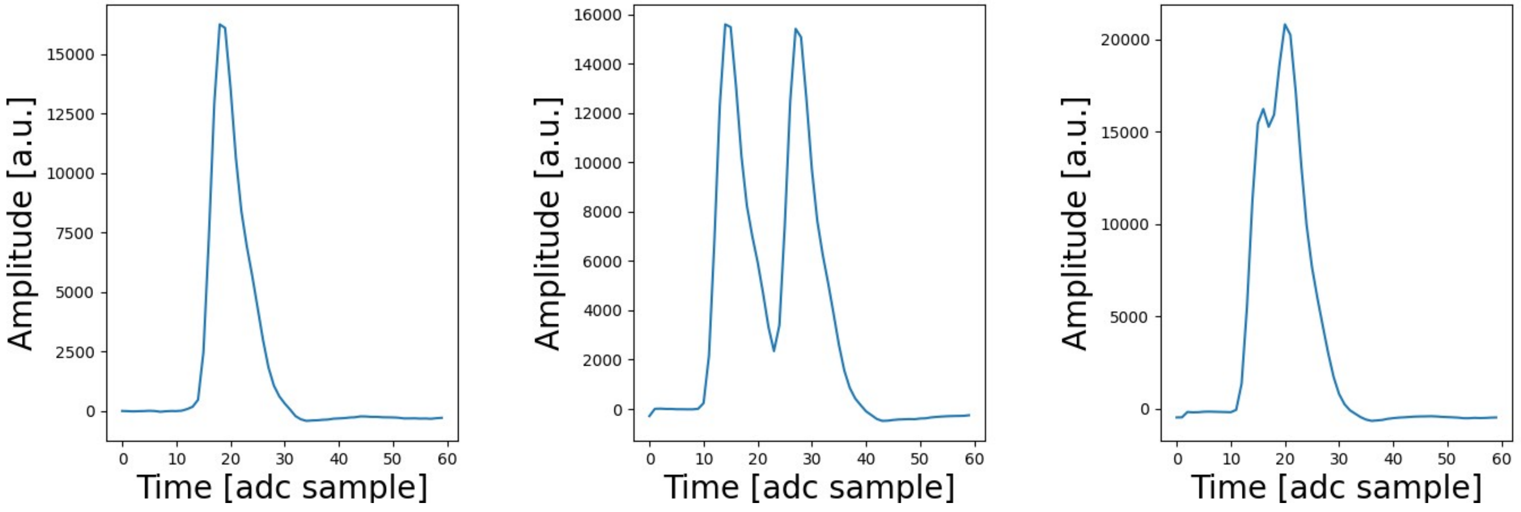
By V.Volkov

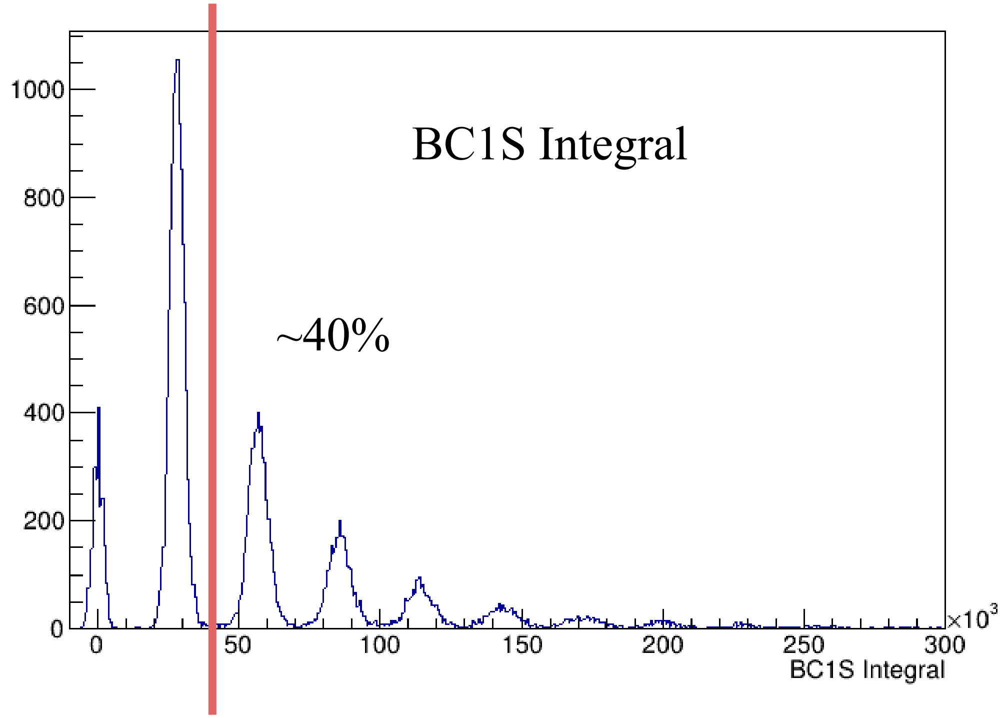
BACKUP

Pileup in FQH

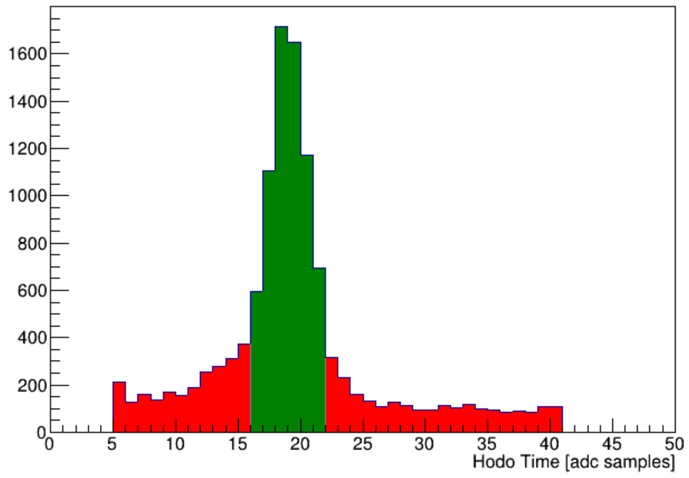
TQDC16VS 125MS/s 12bit

- In the data, **~40%** of BC1S events show **more than one xenon ion**.
- Pileups are visible in FQH. The current algorithm of digitization takes the maximum in a fixed window.





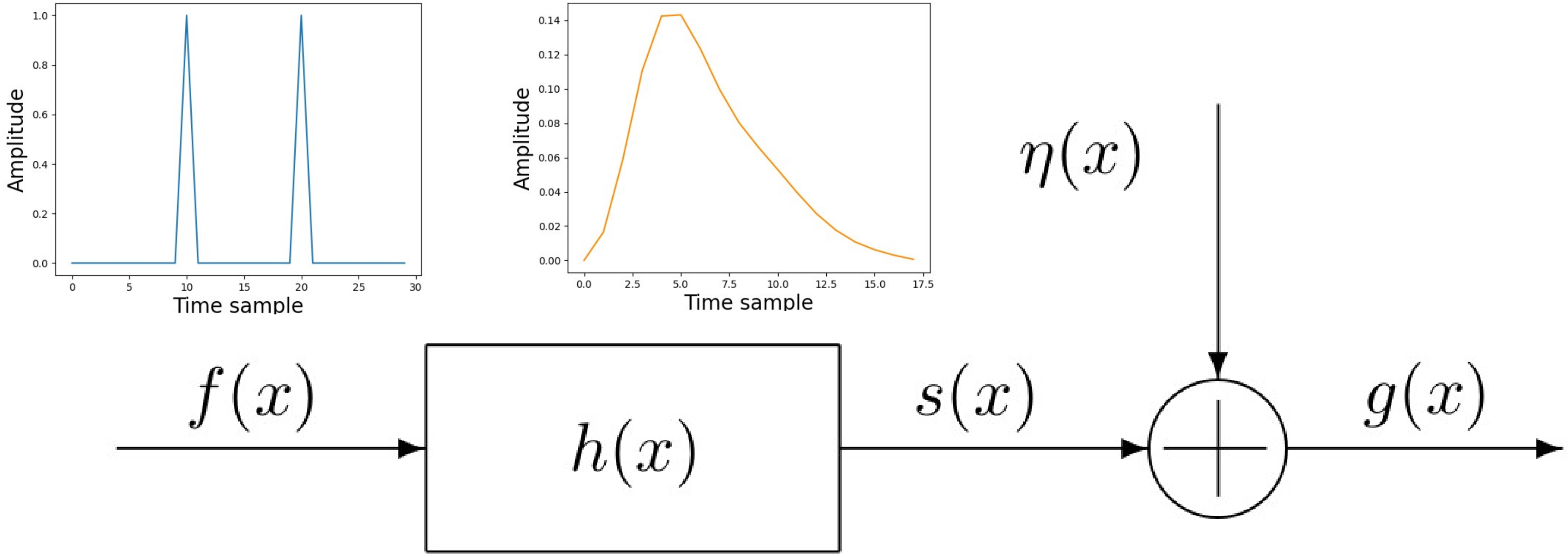
FQH time of maximum

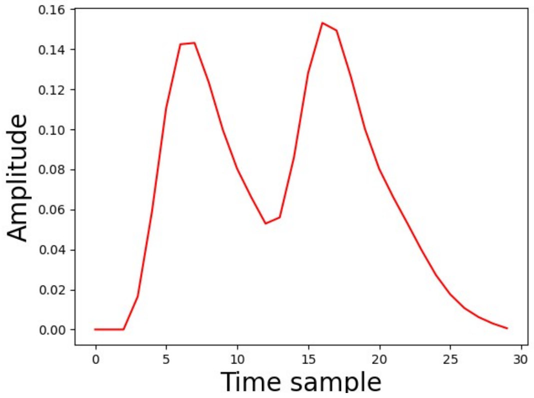


How to improve?

1. Richardson-Lucy Deconvolution
2. Result of processing will be not one peak, but **ALL** found peaks
3. The peak selection will be made at the reconstruction level by e.g. time of the peak, integral
   + Correlation with beam counters, FD, etc.

Convolution





Richardson-Lucy Deconvolution

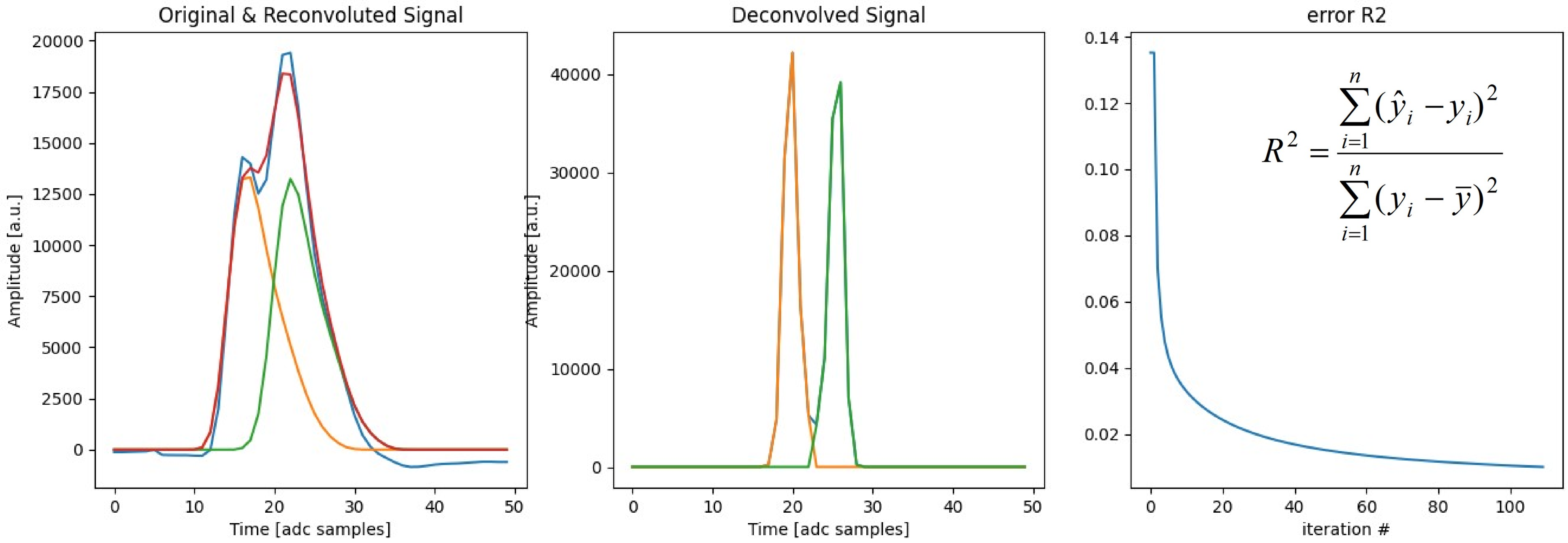
$$u^{(t+1)} = u^{(t)} \left(\frac{g}{u^{(t)} * h} * \widehat{h} \right)$$

$$u^{(0)} = u_{init}$$

This algorithm maximizes the likelihood that the result (**u**), when convolved with the kerhel (**h**), is an instance of the blurred signal (**g**), assuming Poisson noise statistics (**η**).

Richardson W.H., "Bayesian-Based Iterative Method of Image Restoration," J. Opt. Soc. Am. 62, 55-59 (1972)*
Lucy, L.B., "An iterative technique for the rectification of observed distributions", The Astronomical Journal, vol. 79, p. 745, (1974)

Last iteration



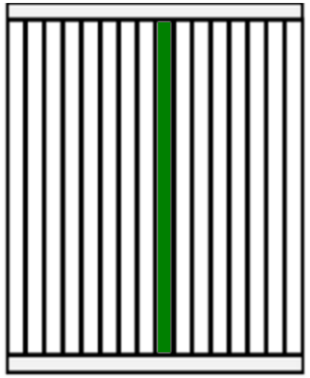
$$R^2 = \frac{\sum_{i=1}^{n} (\hat{y}_i - y_i)^2}{\sum_{i=1}^{n} (y_i - \bar{y})^2}$$

Discussing Limits

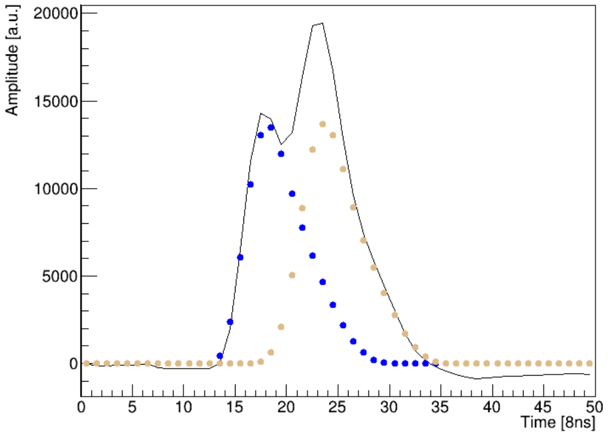
Constraines:

RL deconvolution iterations	100
R2 convergence threshold	0.01
Number of peaks	2

→ Resolving pileups with time difference of 50ns and more

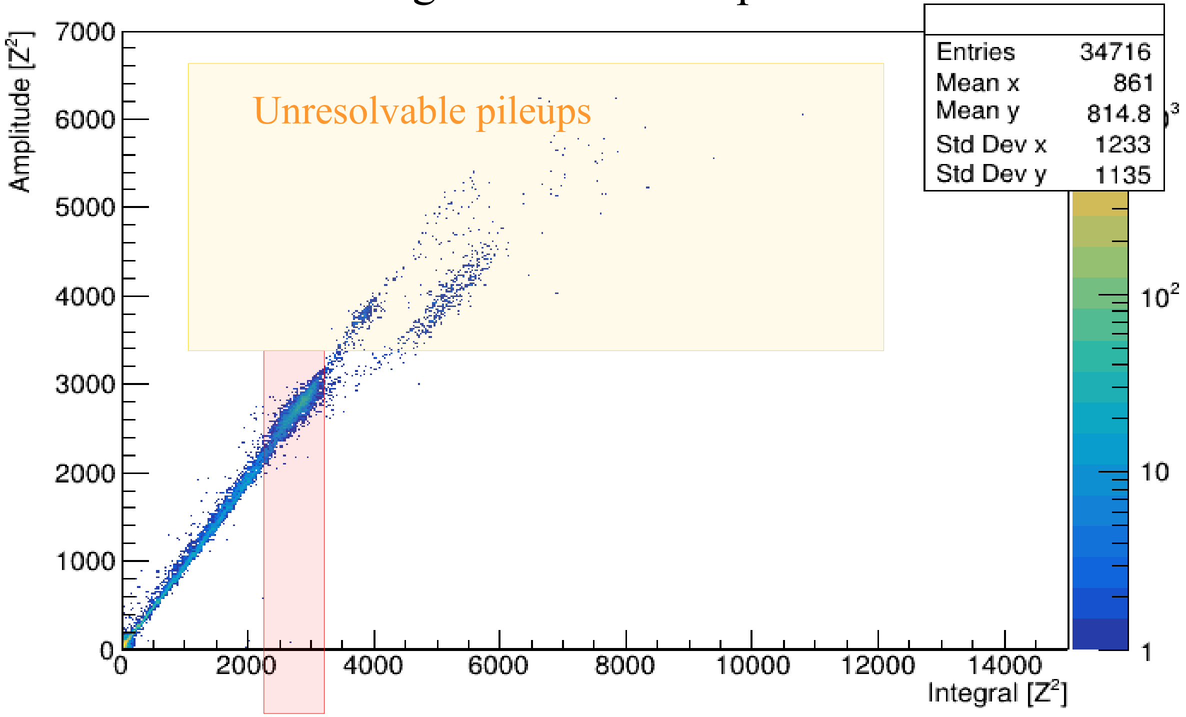


Strip #9



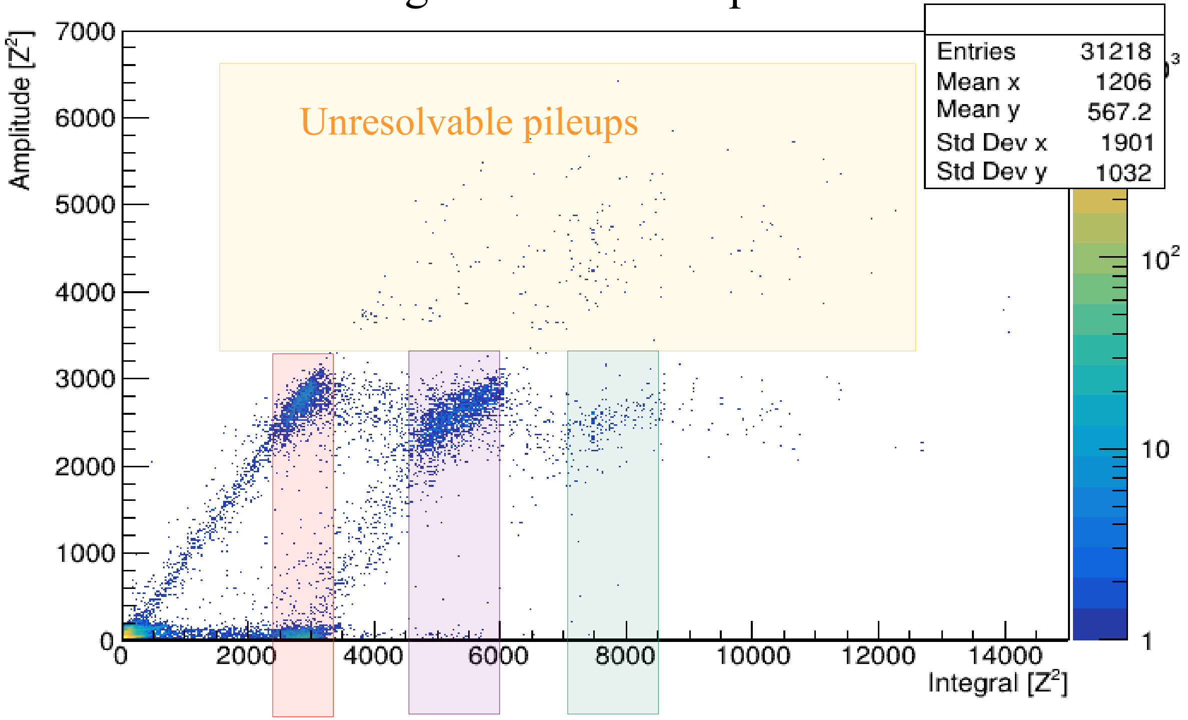
Run 7821 XeCsI 3.8 AgeV MBT no cuts

Algorithm found 1 peak



1 Xe

Algorithm found 2 peaks



1 Xe 2 Xe 3 Xe

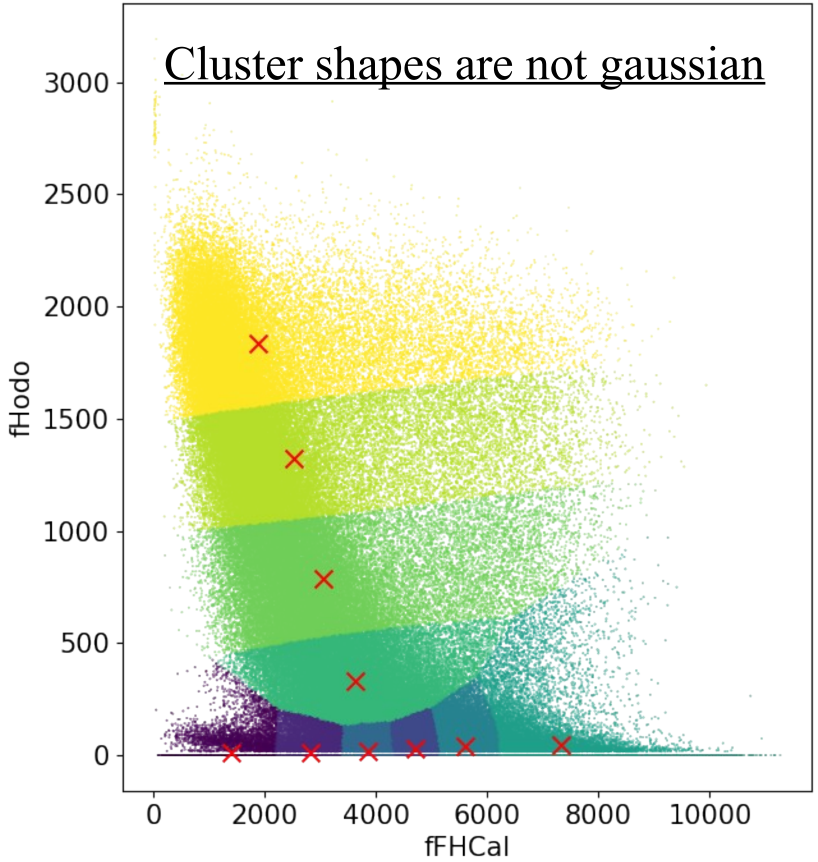
Fraction of unresolvable pileups is ~2%

Relating clusters to impact parameter

https://arxiv.org/abs/2201.12586

Inversed Bayes

$$P(b|\mathbf{X} \in C_k) = \frac{P(b)\int_{\mathbf{X}\in\Omega(C_k)} P(\mathbf{X}|b)d\mathbf{X}}{\int_{\mathbf{X}\in\Omega(C_k)} P(\mathbf{X})d\mathbf{X}}$$



To reconstruct the impact parameter distribution model-independently, we adopt the formula

$$P(\mathbf{X}) = \int_0^1 P(\mathbf{X}|c_b)P(c_b)dc_b = \int_0^1 P(\mathbf{X}|c_b)dc_b, \quad (9)$$

to fit the data of $P(\mathbf{X})$. In our calculations, the form of $P(\mathbf{X}|c_b)$ is assumed to be

$$P(\mathbf{X}|c_b) = \frac{\exp\{-\frac{1}{2}(\mathbf{X}-\overline{\mathbf{X}}(c_b))^T\Sigma^{-1}(c_b)(\mathbf{X}-\overline{\mathbf{X}}(c_b))\}}{2\pi\sqrt{|\Sigma(c_b)|}}. \quad (10)$$

The mean values $\overline{\mathbf{X}}$ and the elements of the covariance matrix Σ_{ij} are smooth positive functions of c_b, and are expressed as the exponential of a polynomial as in Ref. [23],

$$\overline{X}_i(c_b) = \overline{X}_i(0)\exp\left(-\sum_{n=1}^{n_{\max}} a_{i,n}c_b^n\right) \quad (11)$$

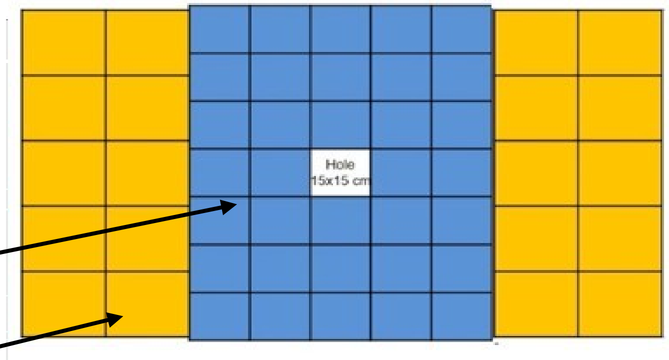
$$\Sigma_{ij}(c_b) = \Sigma_{ij}(0)\exp\left(-\sum_{m=1}^{m_{\max}} A_{ij,m}c_b^m\right) \quad (12)$$

where $\overline{X}_i(0)$, $a_{i,n}$, $\Sigma_{ij}(0)$, $A_{ij,m}$ are free parameters, and $n_{\max}$ and $m_{\max}$ are the degrees of the polynomials used to parametrize the mean and the covariance. These parameters are adjusted to obtain the best fit of $P(\mathbf{X})$ by using the code MINUIT.

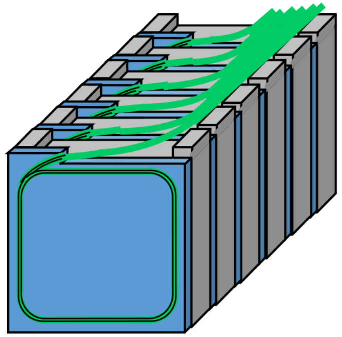
FHCal (Forward **H**adron **Cal**orimeter)
(for centrality and reaction plane reconstruction)

CBM PSD
module production

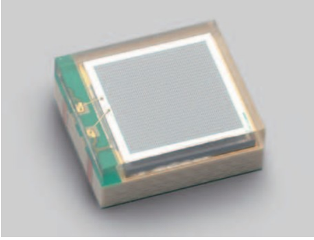
- 34 MPD FHCal modules – 42 Pb/scint samples
  (16mm Pb + 4mm Scint)
- 20 CBM PSD modules – 60 Pb/scint samples
  (16mm Pb + 4mm Scint) – to be replaced after run 8
- Length of the MPD module ~ 4 λ_{int}
  Length of the CBM module ~ 5.6 λ_{int}
- Light collection – 6 WLS fibers from each 6 conseq. scint tiles (one section) combined to one optical connector at the end of module
- Light readout:
  7 MPPCs per MPD module
  10 MPPCs per CBM module
- Weight of MPD module – 200kg
  Weight of CBM module – 500kg

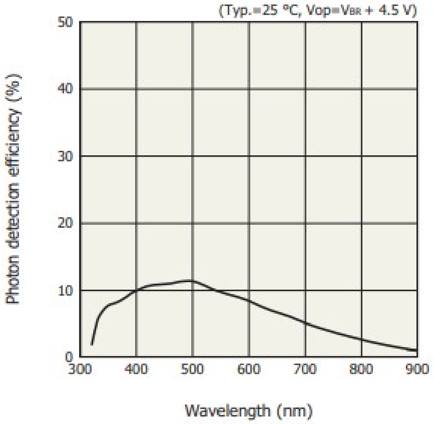


BM@N FHCal



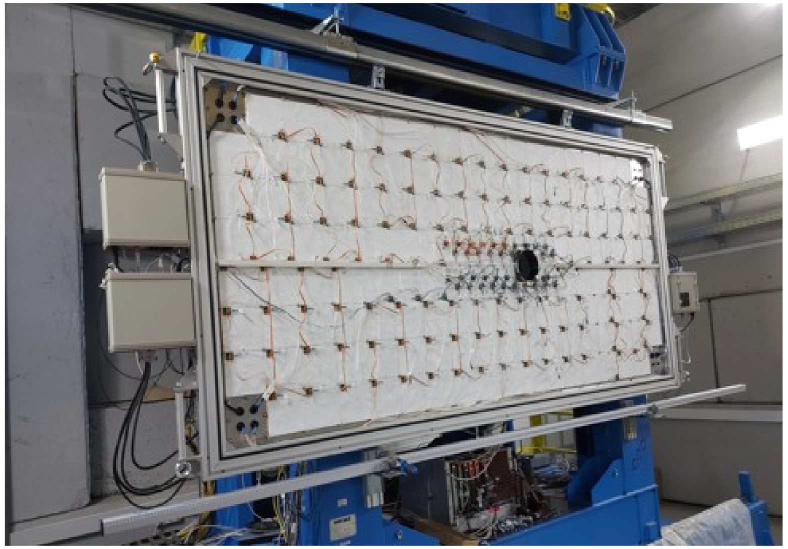
one section



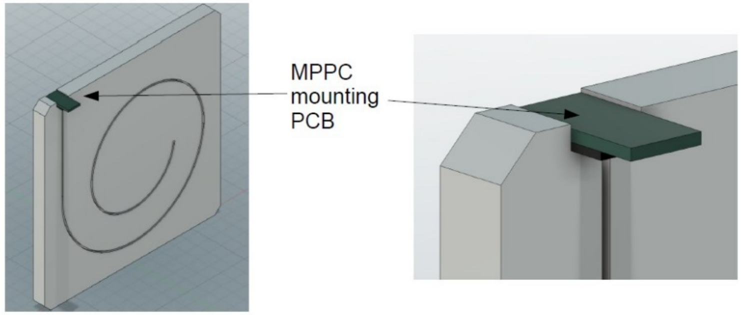


Hamamatsu MPPC S12572-010P 3*3mm^2
Number of pixels: 90000
Gain: 1.35*10^5
PDE: 12%

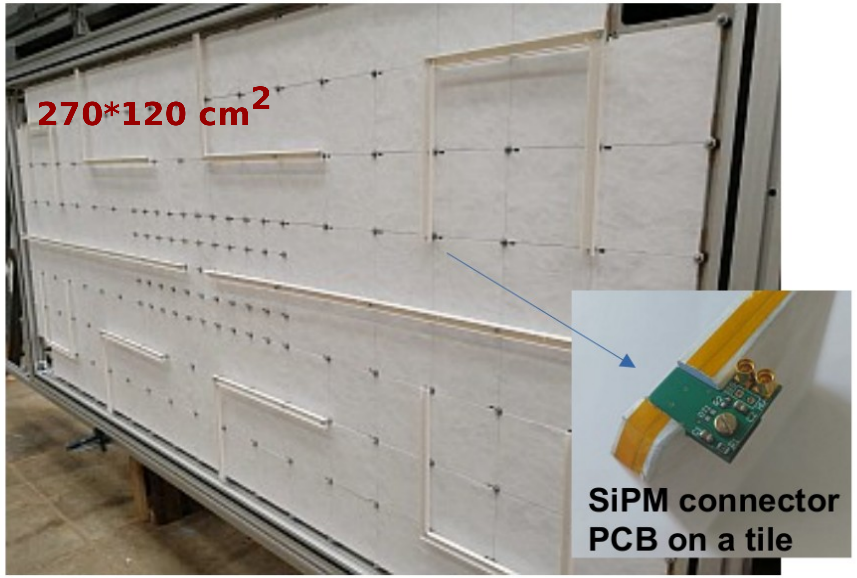
ScWall (Scintillation **Wall)**
(for fragments charge measurements and reaction plane estimation)

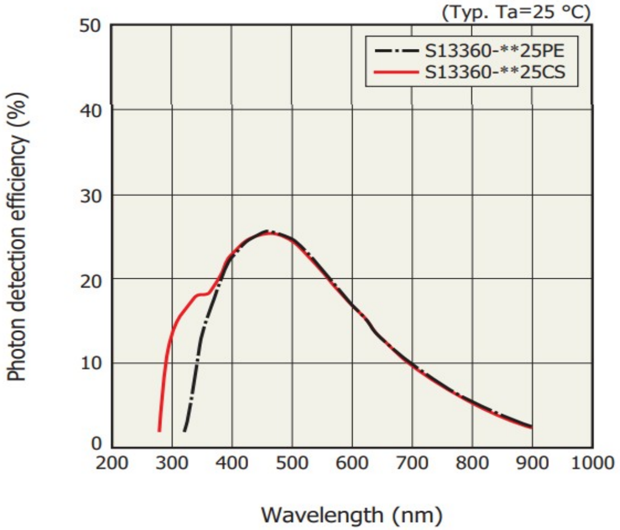


- 36 small inner cells 7.5*7.5*1 cm^3 + 138 big outer cells 15*15*1 cm^3
- light yield for MIP signal – small cells 55 p.e.±2.4%; big cells 32 p.e.± 6%.
- optional beam hole (covered with 4 small cells for the SRC run)
- covered with a light-shielding aluminum plate
- light collection by WLS fibers
- light readout with SiPM mounted on the PCB at each scint. cell



light collection from tiles

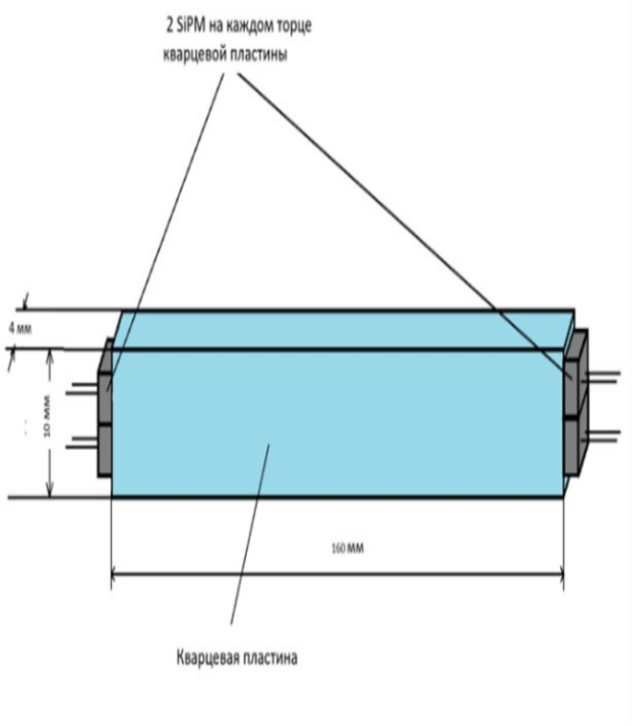




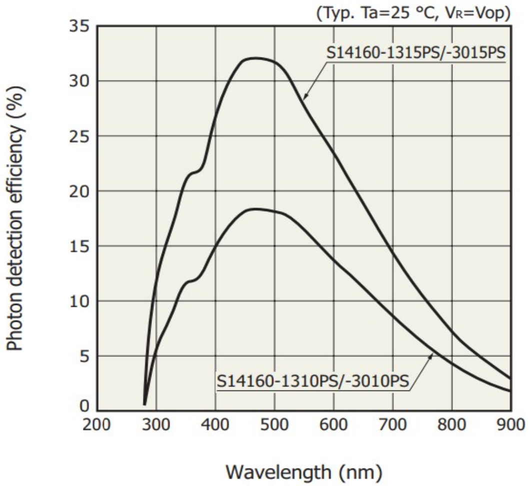
Hamamatsu MPPC S13360-1325CS
1.3*1.3mm^2
Number of pixels: 2668
Gain: 7*10^5
PDE: 25%

FQH (**F**orward **Q**uarz **Hodo**scope)

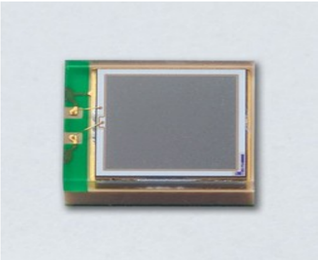
measurement of fragments charge in the FHCal beam hole – very forward rapidity region (for event centrality determination)



- 16 strips 160*10*4 mm^3 with mylar reflector
- cover beamhole 15*15cm^2
- light readout from both edges of each strip
- 2 SiPMs connected in parallel on each side
- each SiPM pair is read with gains x1 and x4



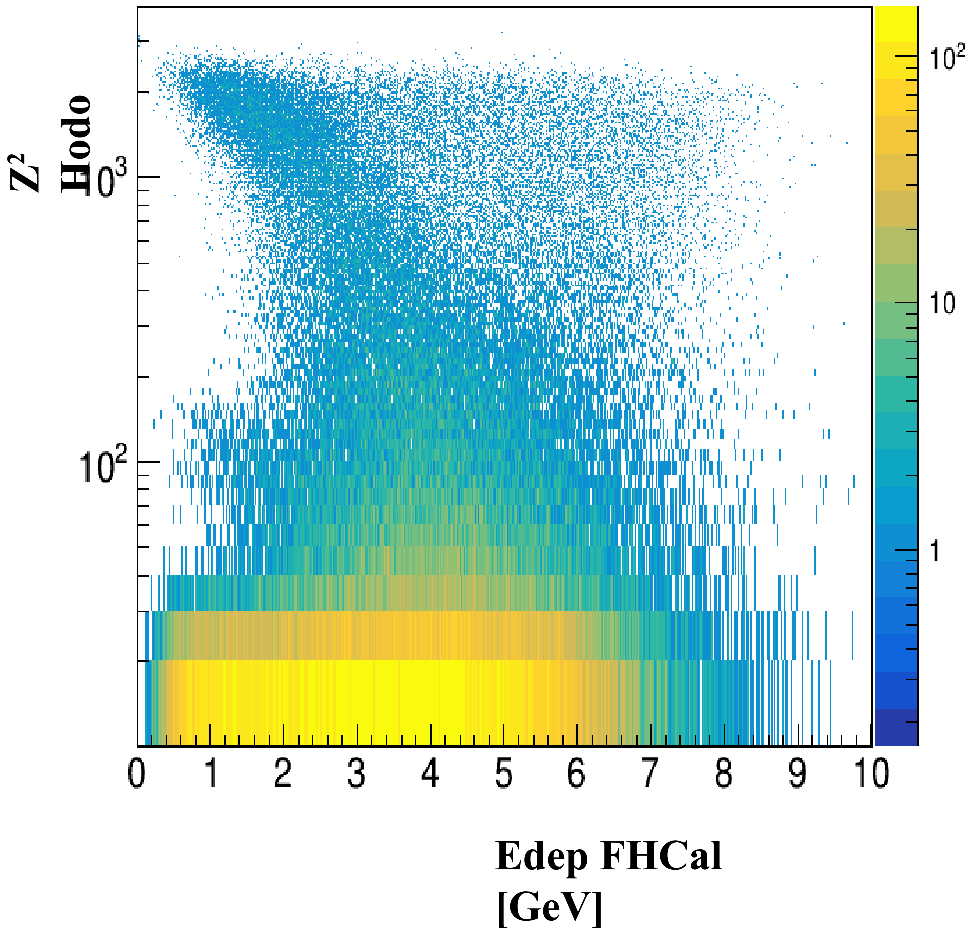
Hamamatsu MPPC S14160-3015PS
3*3mm^2
Number of pixels: 39984
Gain: $3.6*10^5$
PDE: 32%



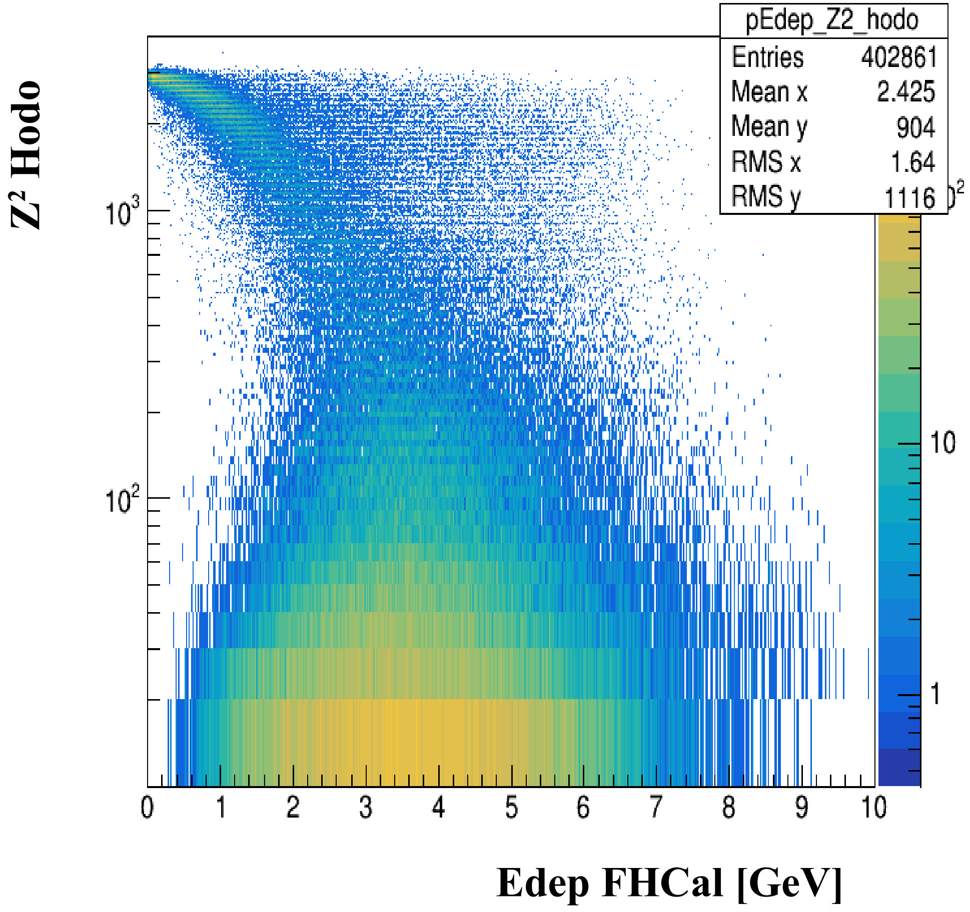
Centrality determination: correlation with FHCal

More than 1 track in vertex reconstruction
1 Xe ion by BC1S integral
Vertex position (-1.5 < Z <1.5)

*XeCsI@**3.8A GeV**. Run 8142 2% CsI target, CCT2.*



DCM-QGSM-SMM minbias



Centrality determination: FQH&FHCal correlation

*XeCsI@**3.8A GeV**. MBT runs 7819, 7988, 8097*

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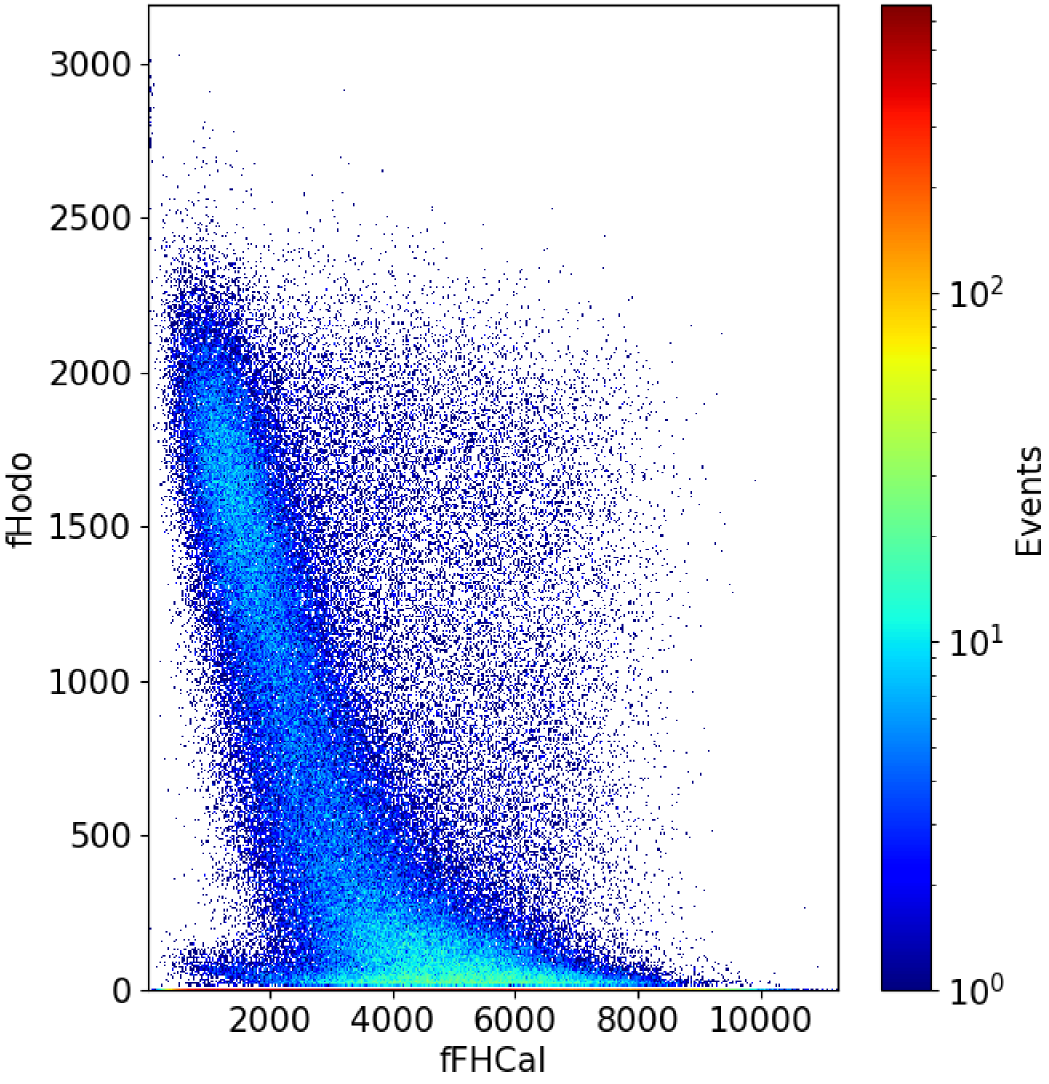
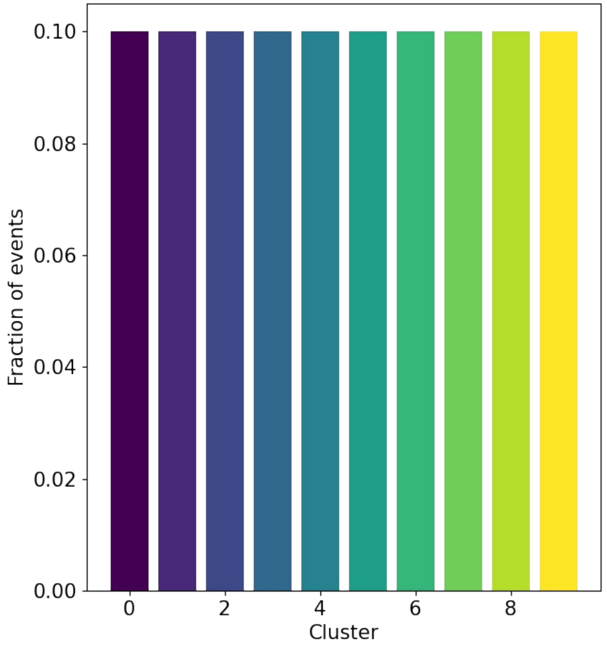
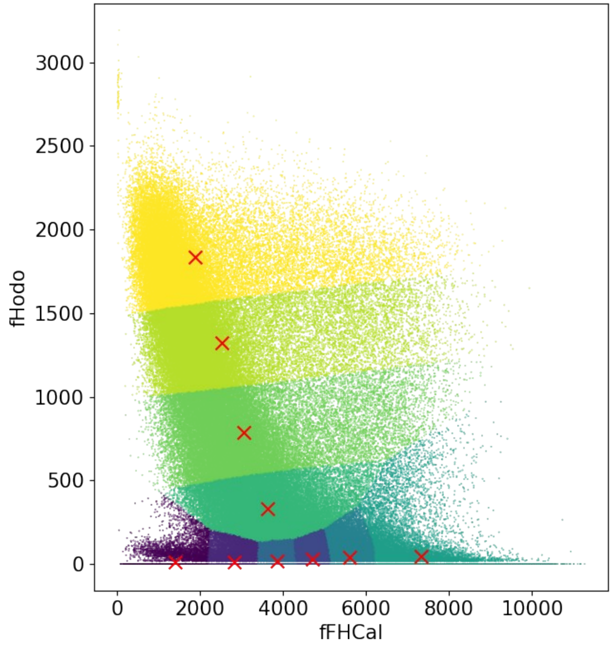
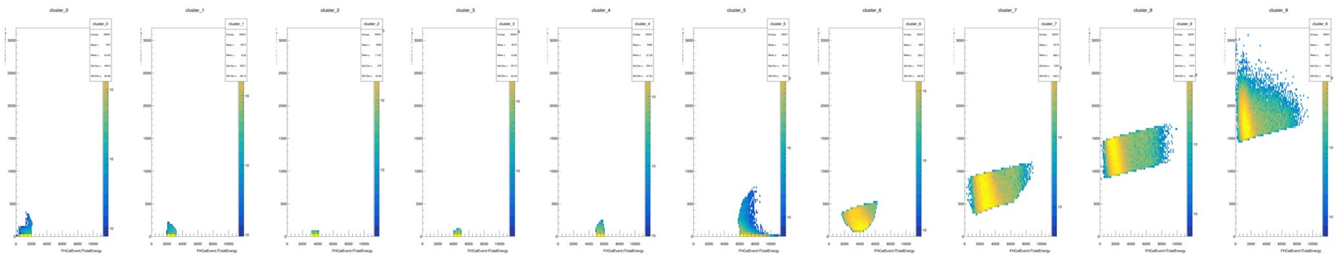






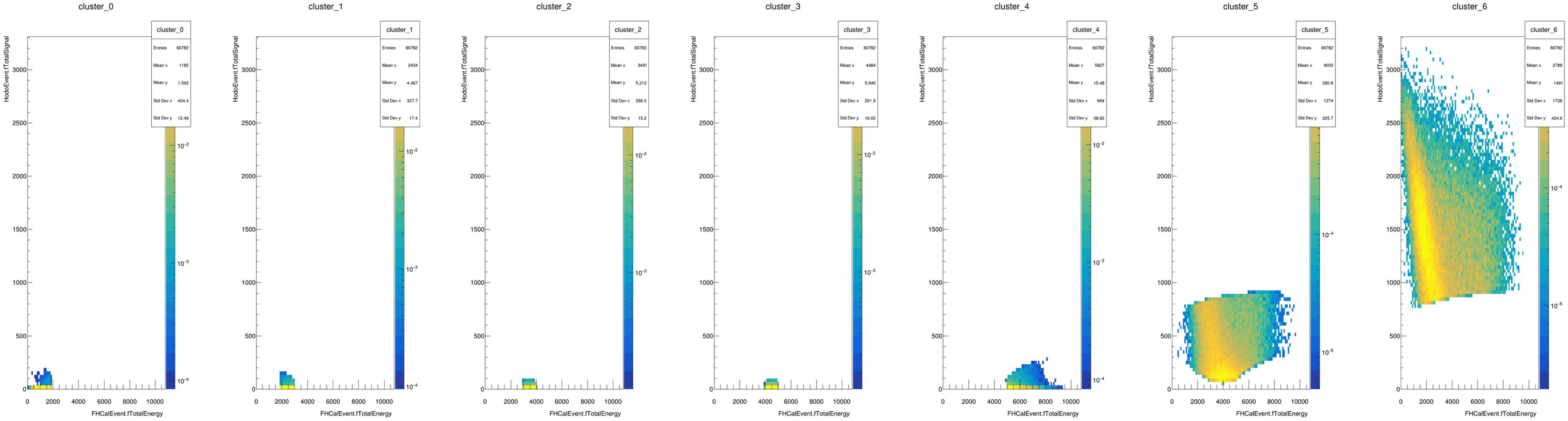
2D normalised joint PDF are stored in a configuration file



Centrality determination: FQH&FHCal correlation

More than 1 track in vertex reconstruction
Vertex position (-1.5 < Z <1.5)
Eff Not Compensated &&
1 Xe ion by BC1S integral

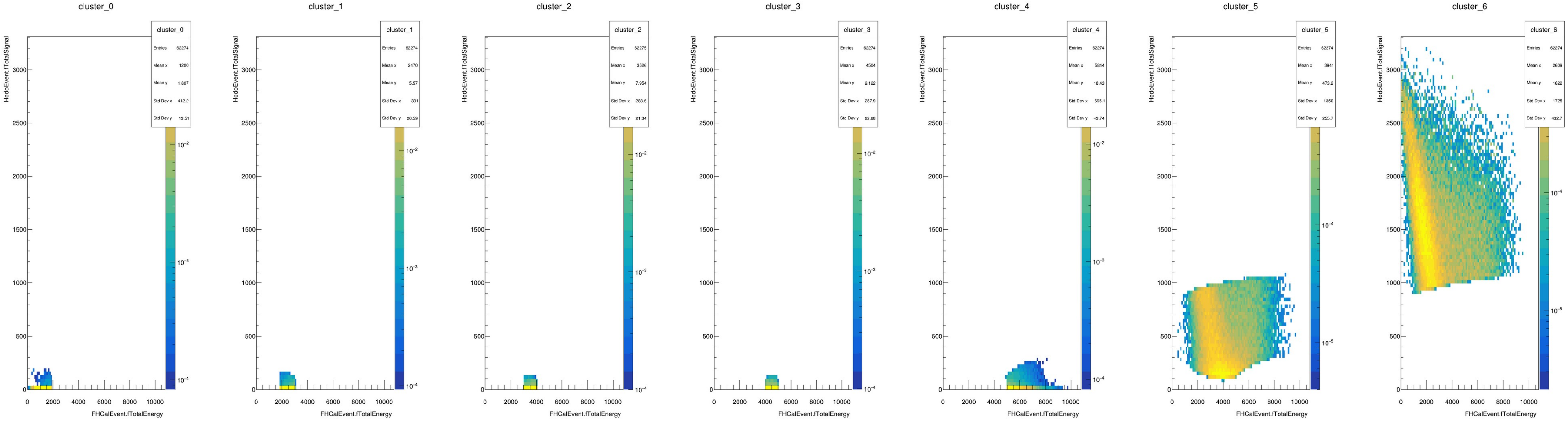
*XeCsI@**3.8A GeV**. MBT runs 7819, 7988, 8097*



Centrality determination: FQH&FHCal correlation

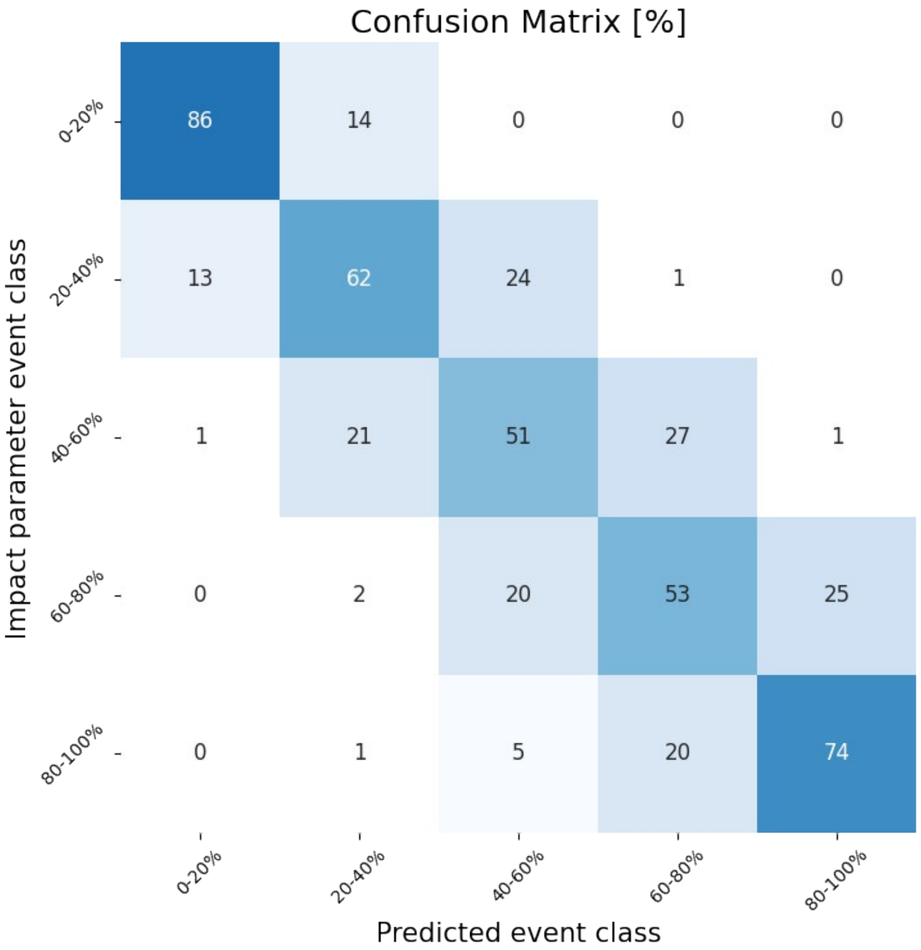
More than 1 track in vertex reconstruction
Vertex position (-1.5 < Z <1.5)
Eff Compensated &&
1 Xe ion by BC1S integral

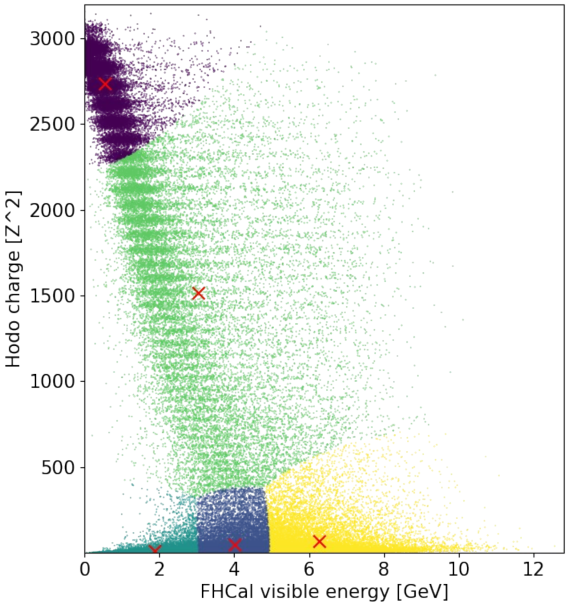
*XeCsI@**3.8A GeV**. MBT runs 7819, 7988, 8097*

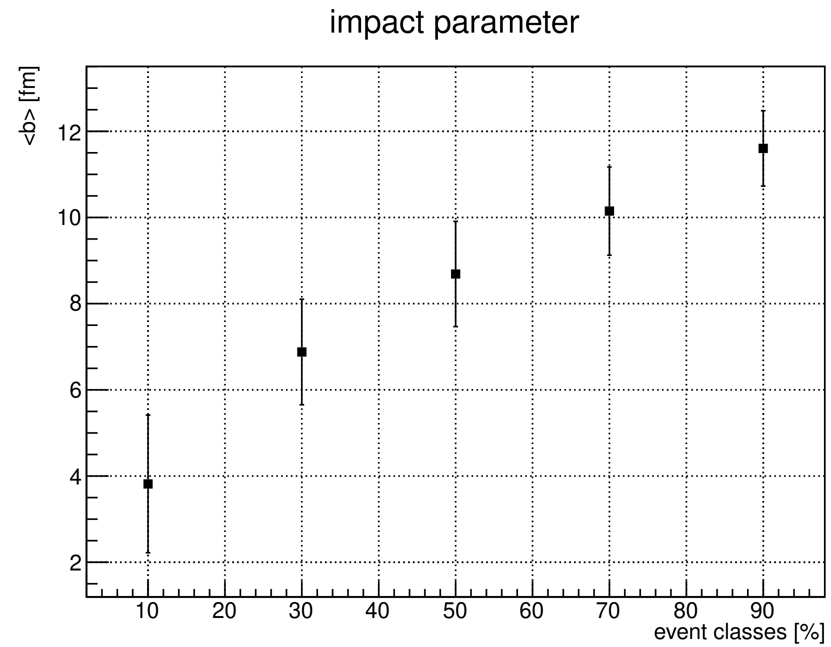


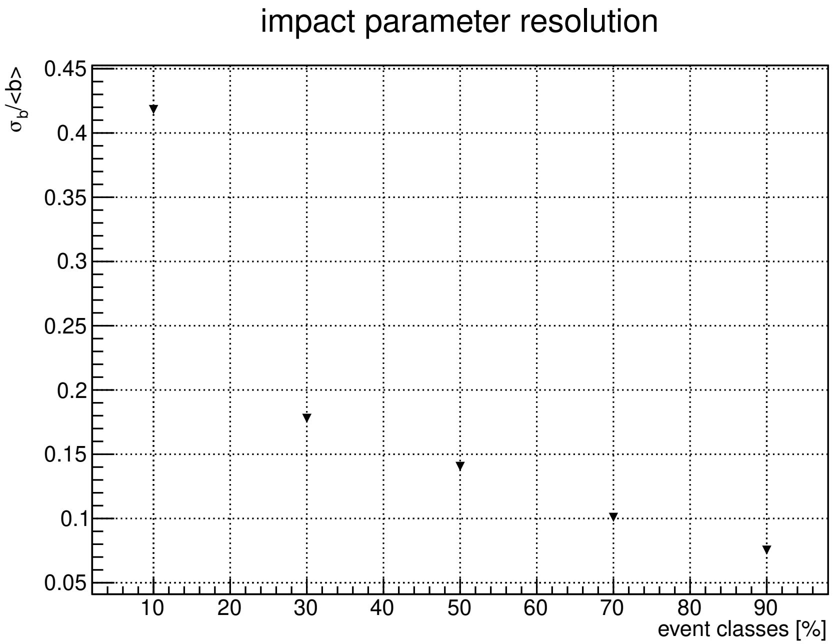
Centrality determination: 5 clusters case

*XeCs@**3.8A GeV**. DCM-QGSM-SMM 100k minbias*



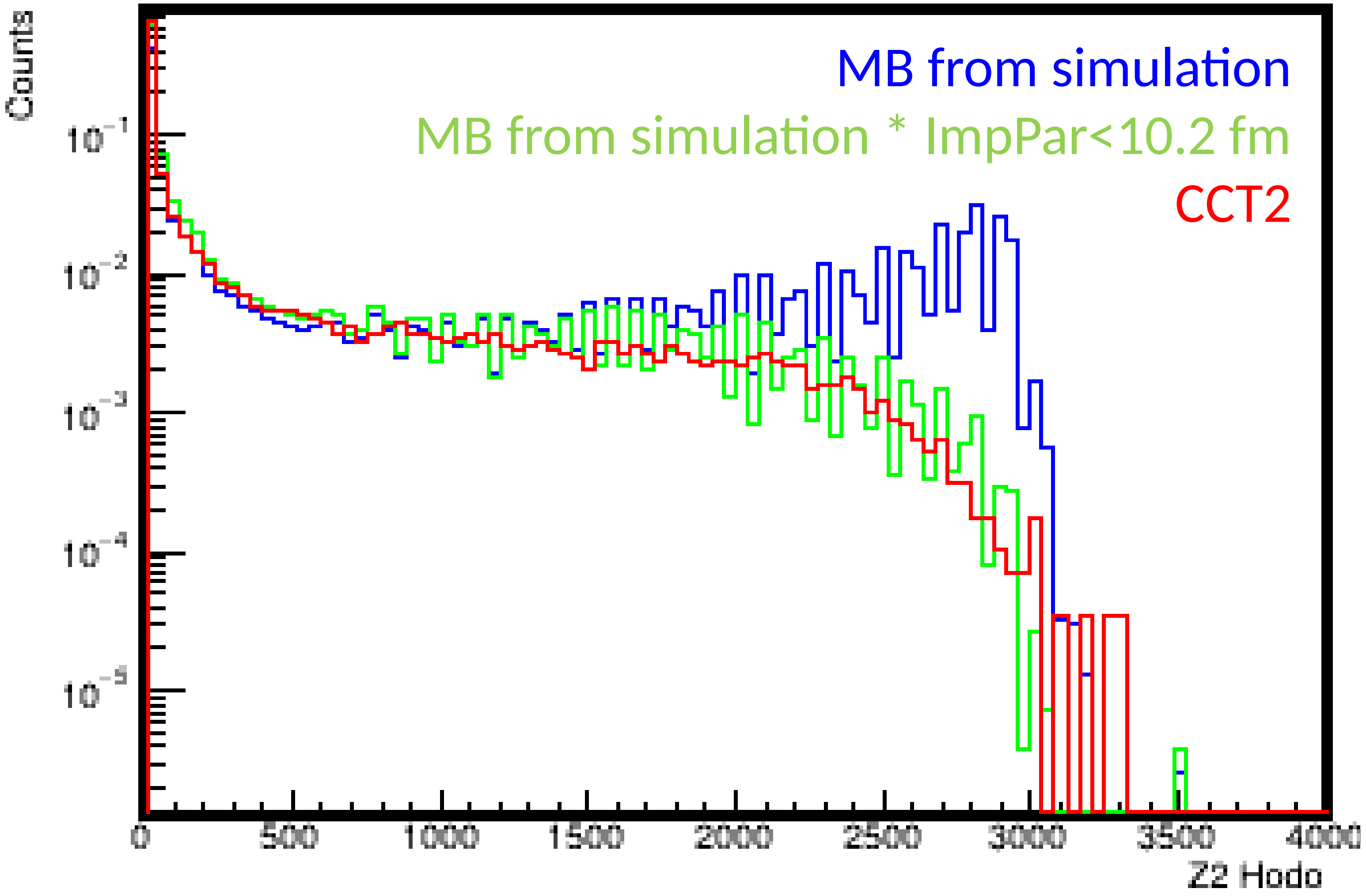






Fragments charge distributions in FQH: Estimating true minimum bias fraction

Preliminary



CCT2 trigger selects up to ~70% of most central events relative to true minimum bias

Impact parameter