Analysis of BM@N Run8 experimental data from forward detectors of spectator fragments

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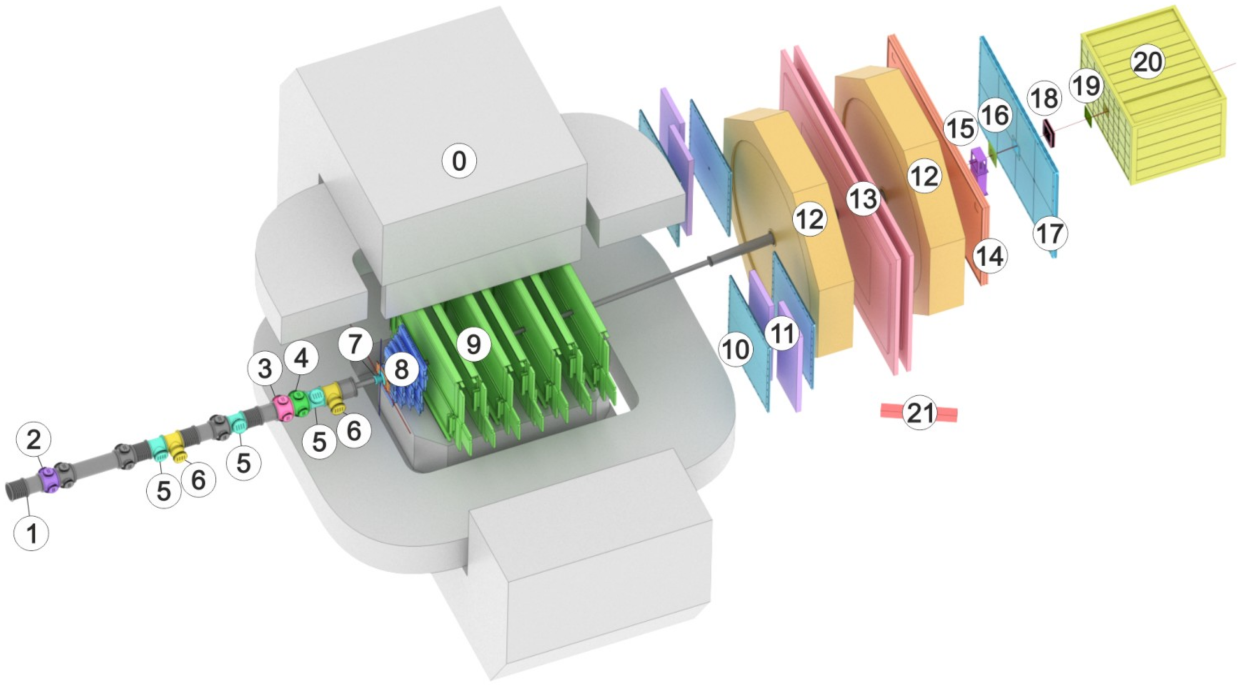
on behalf of the INR RAS team

Analysis and Detector Meeting of the BM@N Experiment
12-13 March 2024 LHEP JINR

Overview

- BM@N forward detectors of spectator fragments: ScWall, 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
- Fragments measured by ScWall in comparison with DCM-QGSM-SMM and PHQMD
- Conclusions and future plans

BM@N Setup
Run8



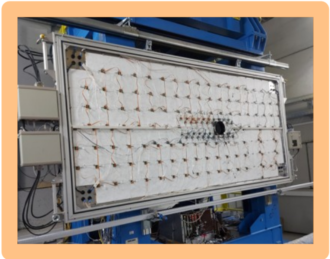
- Magnet SP-41 (0)
- Vacuum Beam Pipe (1)
- BC1, VC, BC2 (2-4)
- SiBT, SiProf (5, 6)
- Triggers: BD + SiMD (7)
- FSD, GEM (8, 9)
- CSC 1x1 m^2 (10)
- TOF 400 (11)
- DCH (12)
- TOF 700 (13)
- ScWall (14)
- FD (15)
- Small GEM (16)
- CSC 2x1.5 m^2 (17)
- Beam Profilometer (18)
- FQH (19)
- FHCal (20)
- HGN (21)

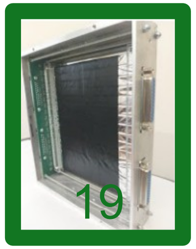
Forward spectators detectors in BM@N

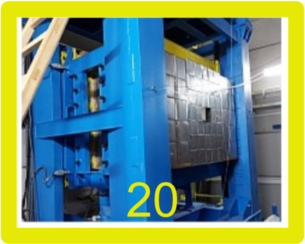
- Scintillation Wall (ScWall)
- Forward Quarz Hodoscope (Hodo)
- Forward Hadron Calorimeter (FHCal)

Tasks:

- charge distributions of spectator fragments
- centrality determination
- reaction plane orientation



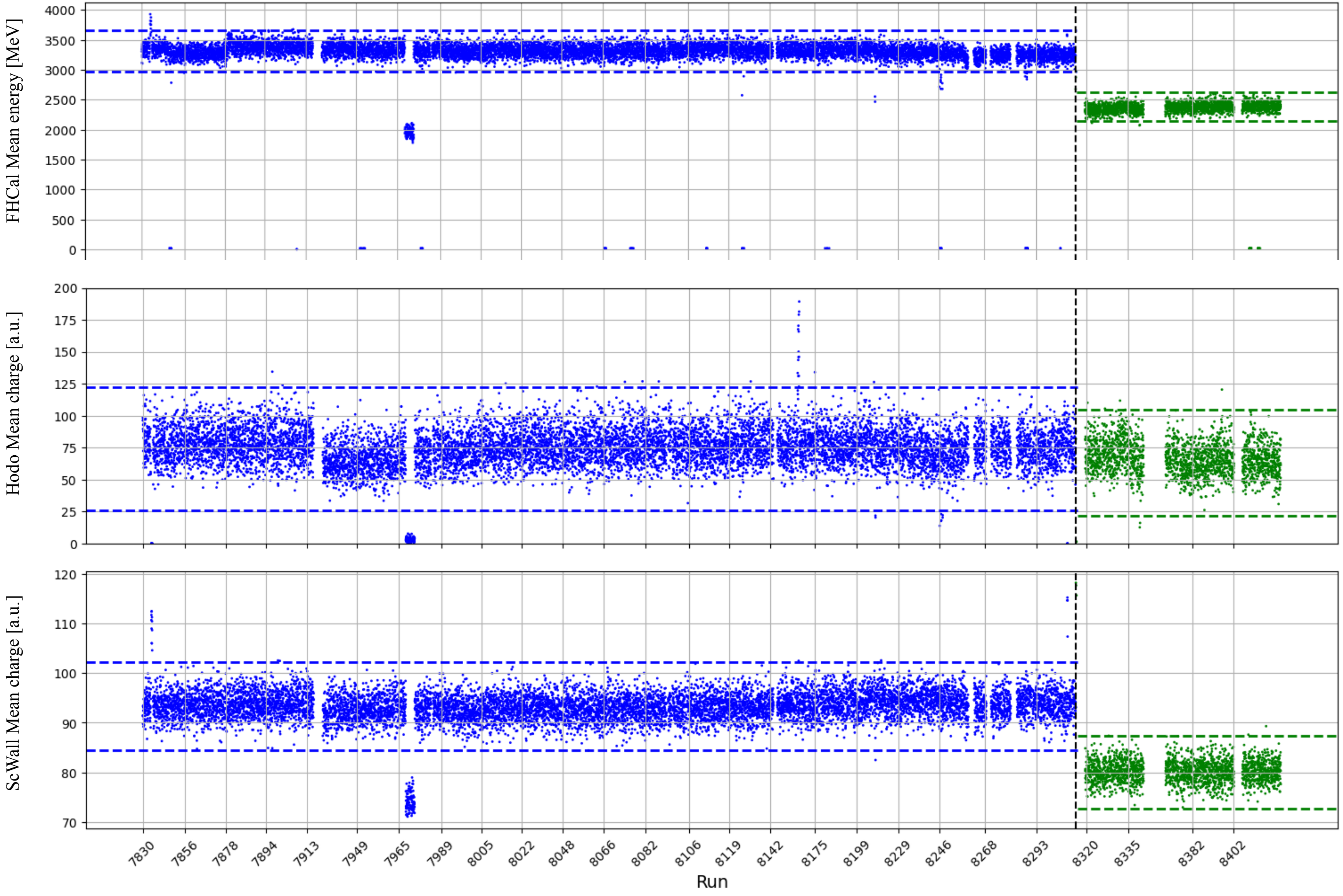




Quality Assessment. Run 8
XeCsI 3.8A GeV and 3.0A GeV

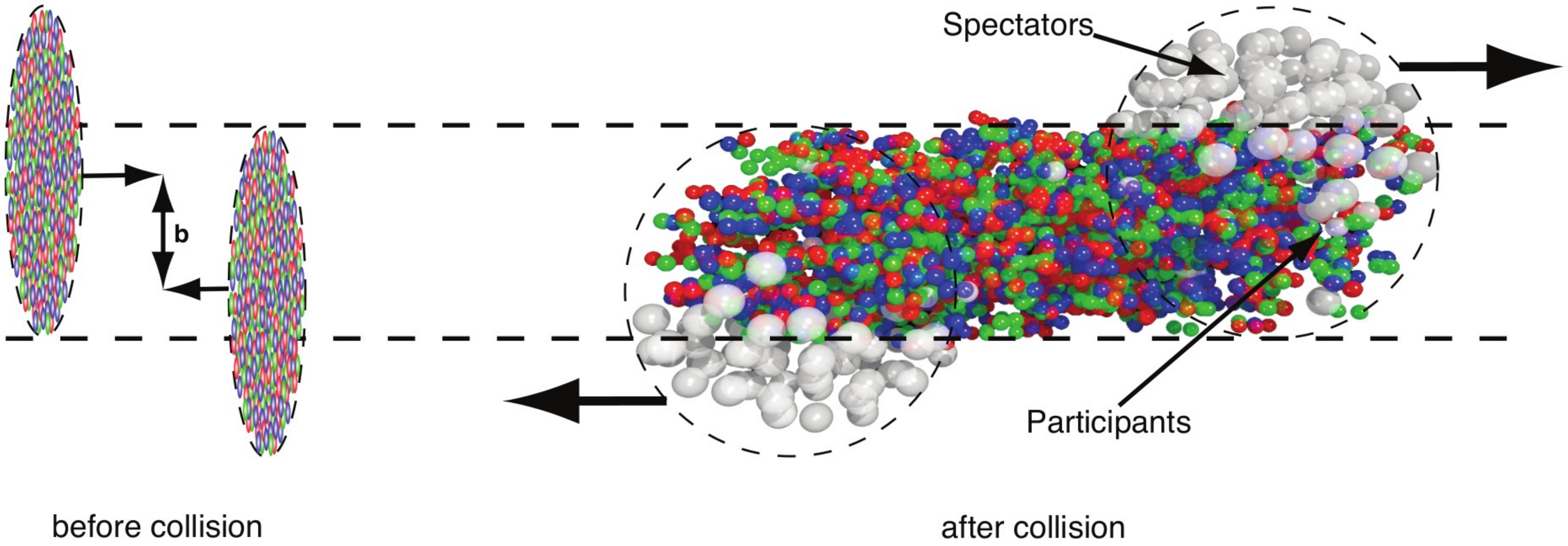
More than 1 track in vertex reconstruction
1 Xe ion by BC1S integral
Vertex position (-1.5 < Z <1.5)

- 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

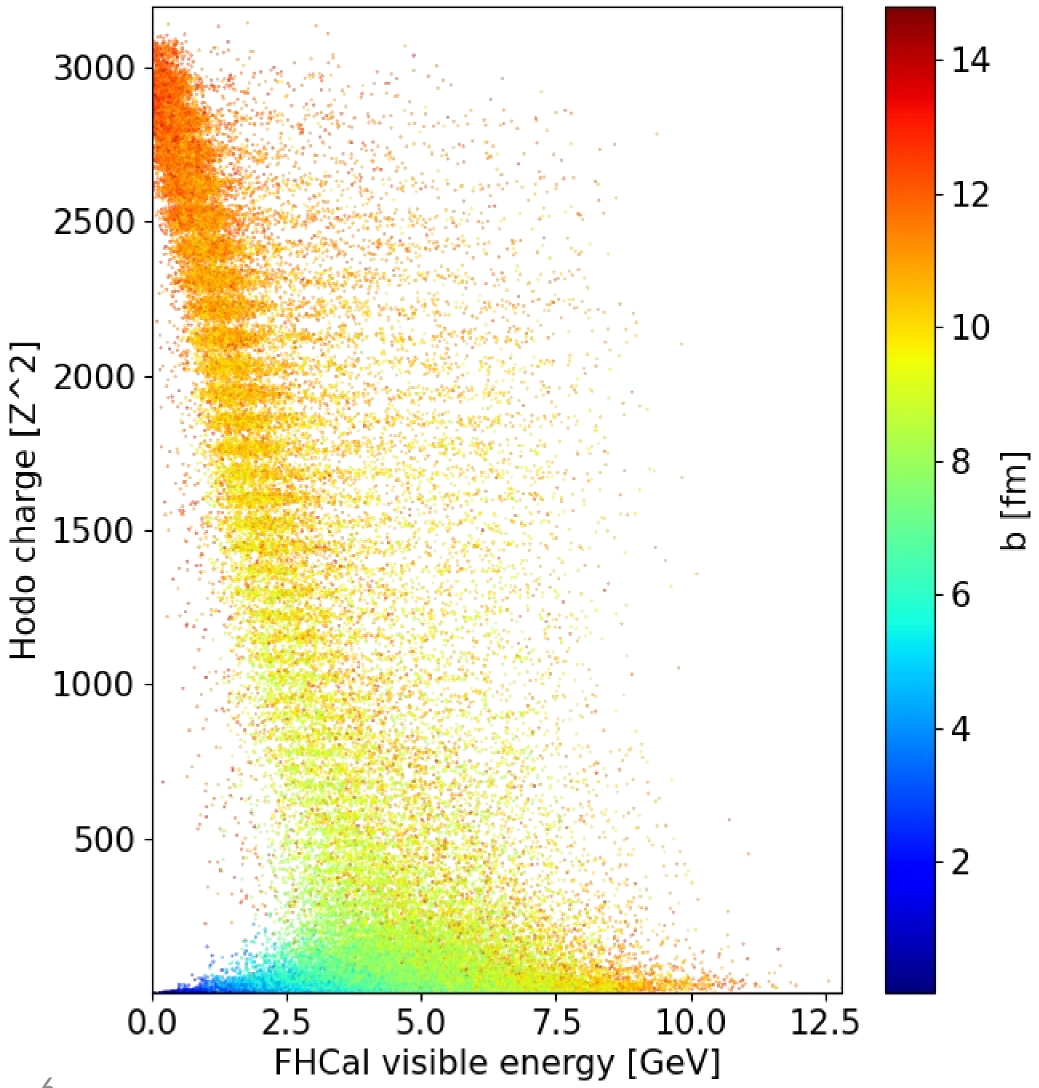
Collision centrality



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

Event characterisation: FQH&FHCal correlation

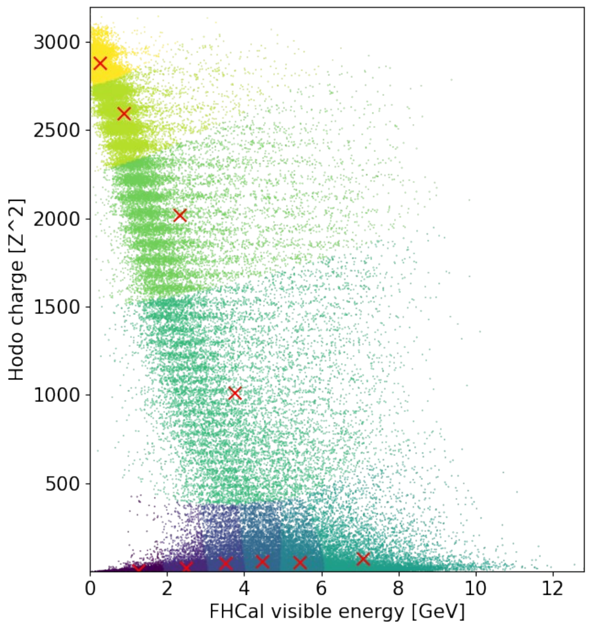
*XeCs@**3.8A GeV**. DCM-QGSM-SMM 100k minbias*

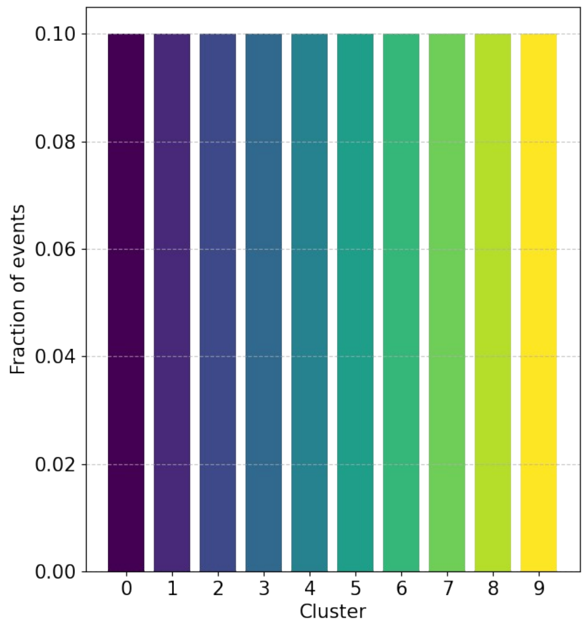


Event class as <u>clusterization</u> task

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

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

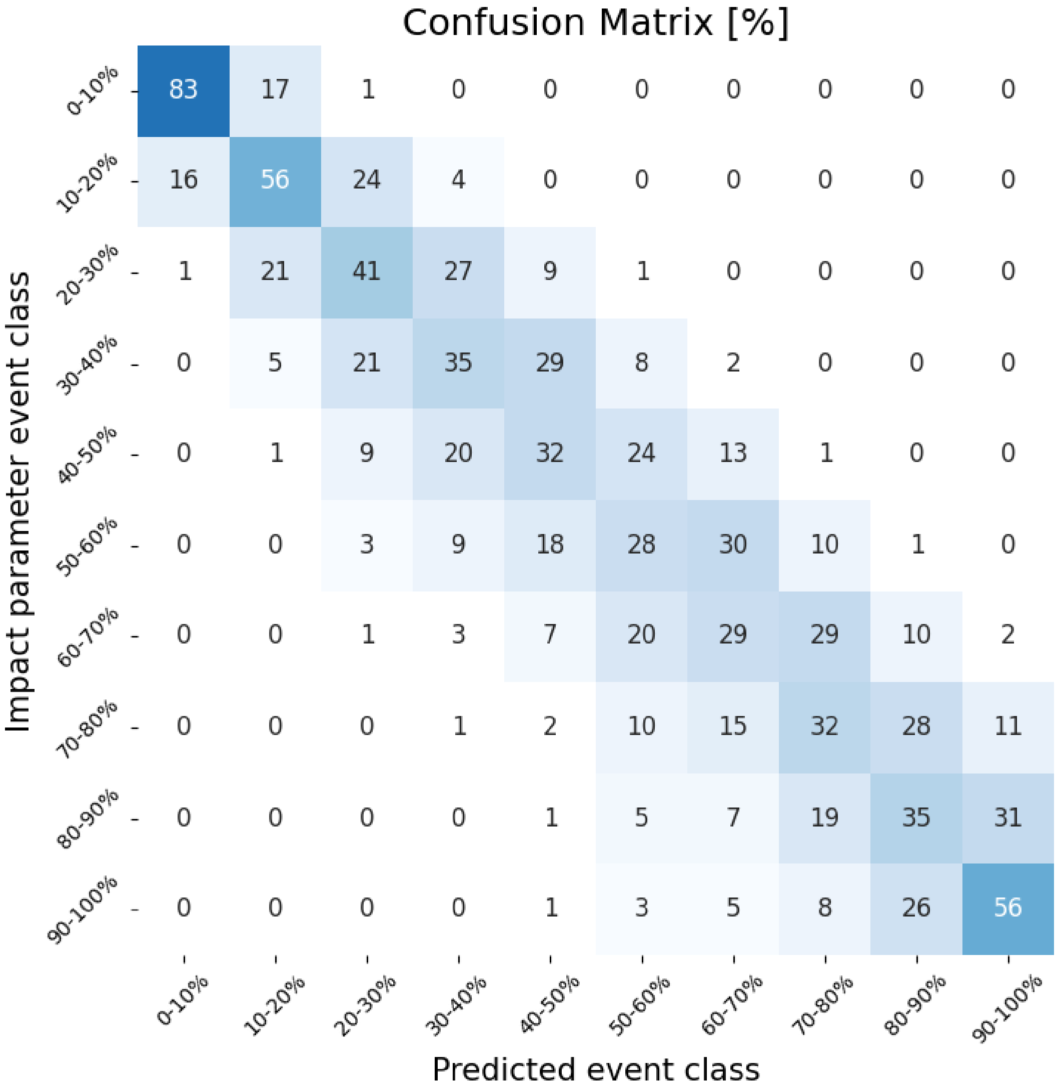




- https://pypi.org/project/k-means-constrained/
- *Bradley, P. S., K. P. Bennett, and Ayhan Demiriz. "Constrained k-means clustering." Microsoft Research, Redmond (2000): 1-8.*
- *With Google's SimpleMinCostFlow C++ implementation*

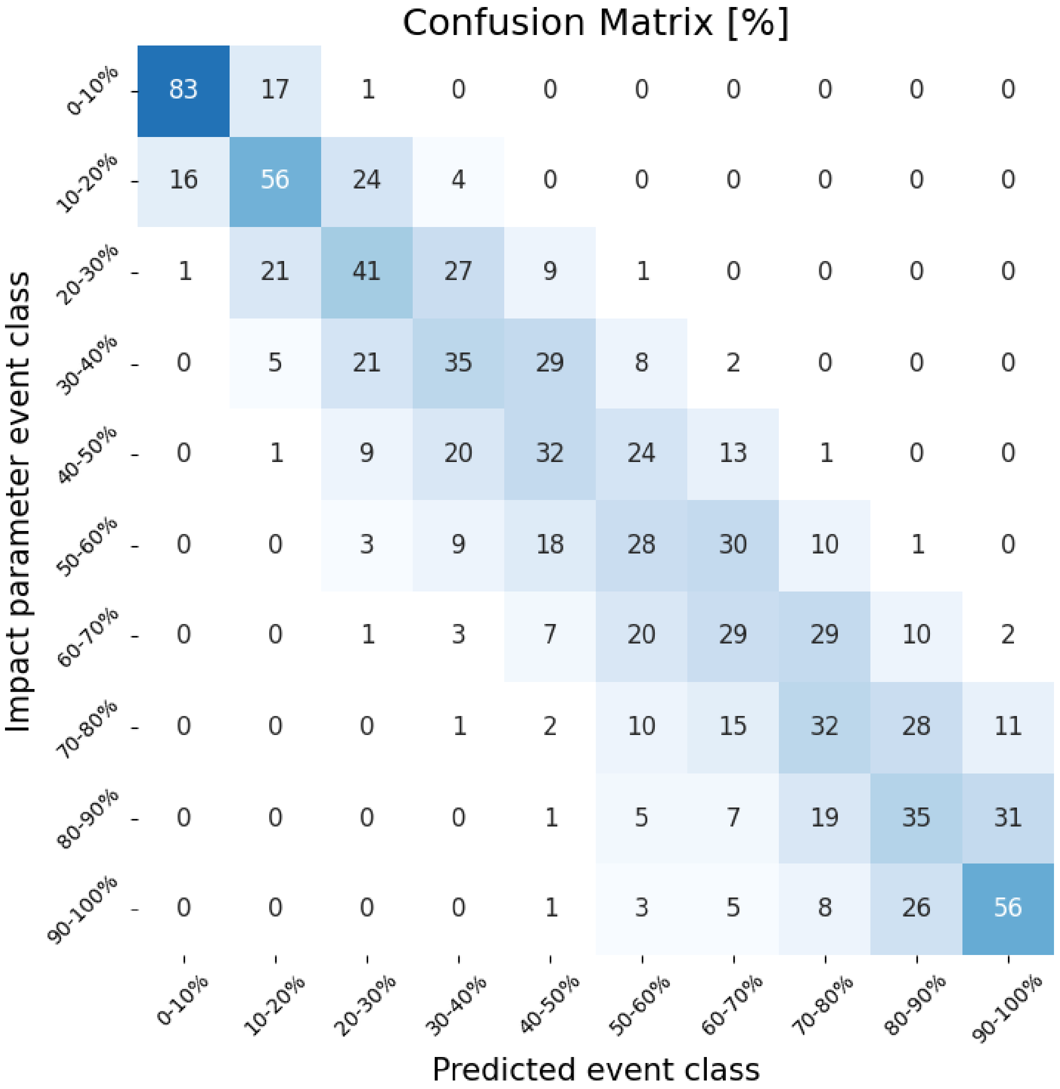
Event characterisation: Cluster information from simulation

1. Purity

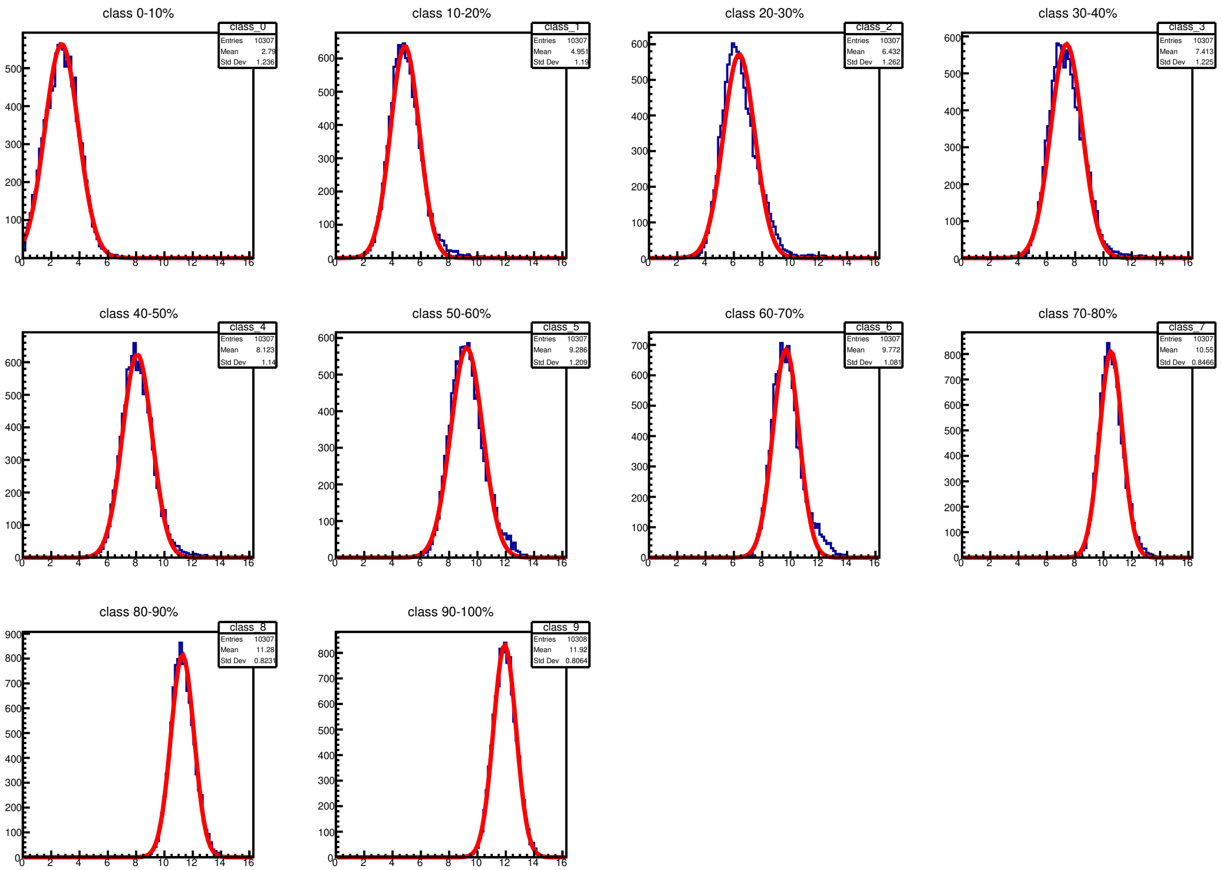


Event characterisation: Cluster information from simulation

1. Purity

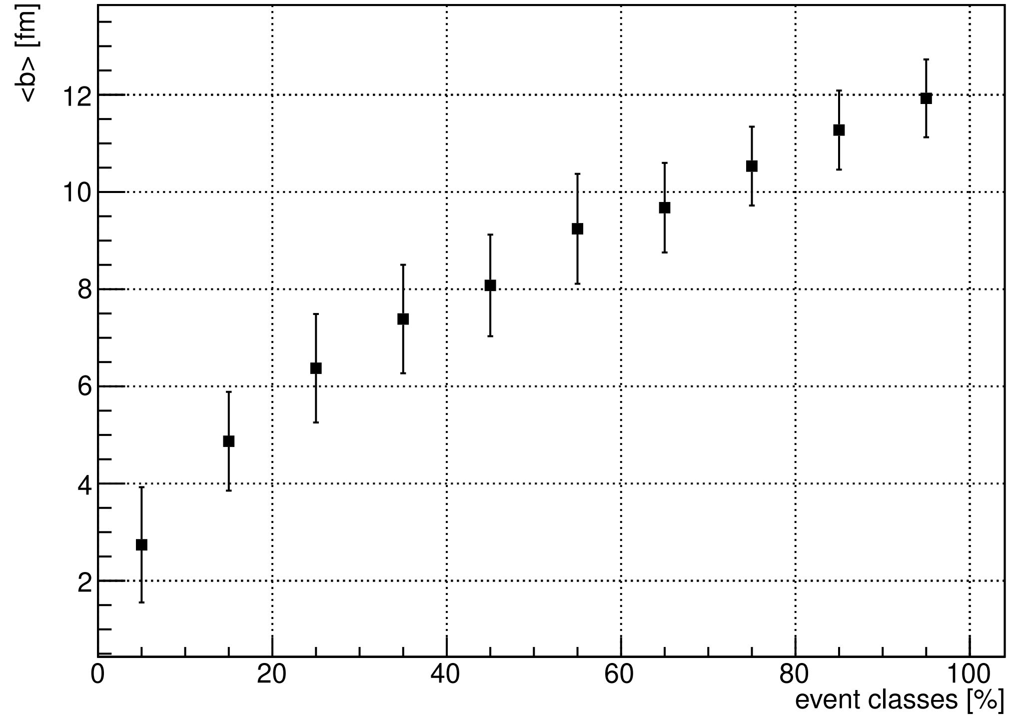


2. Impact parameter distributions

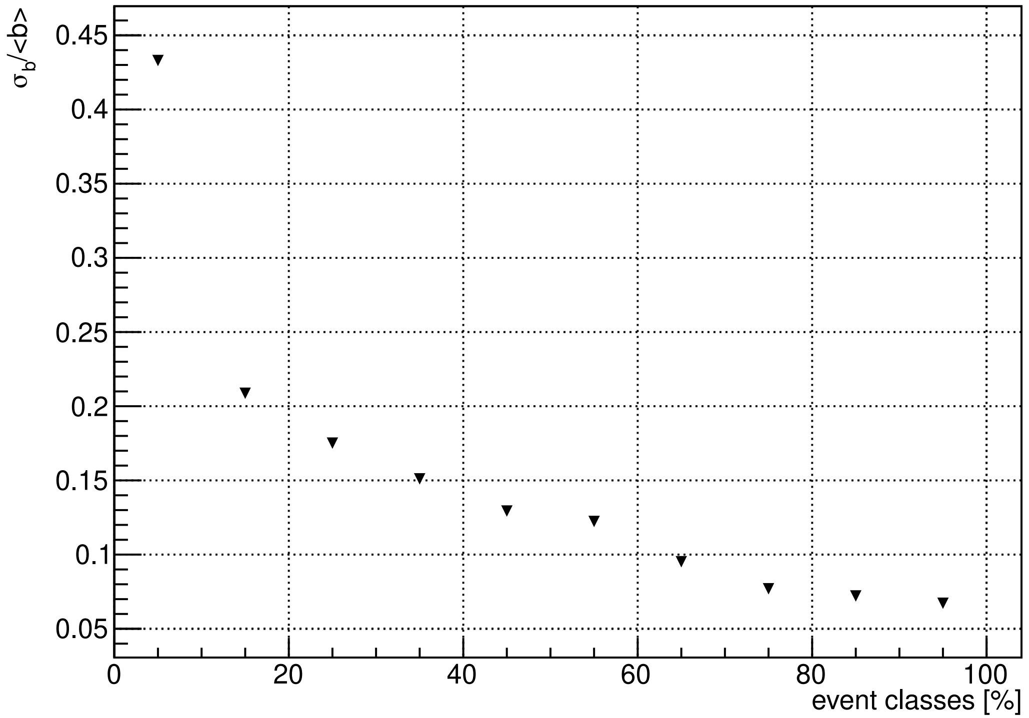


Event characterisation: Cluster information from simulation

2.1 Impact parameter mean



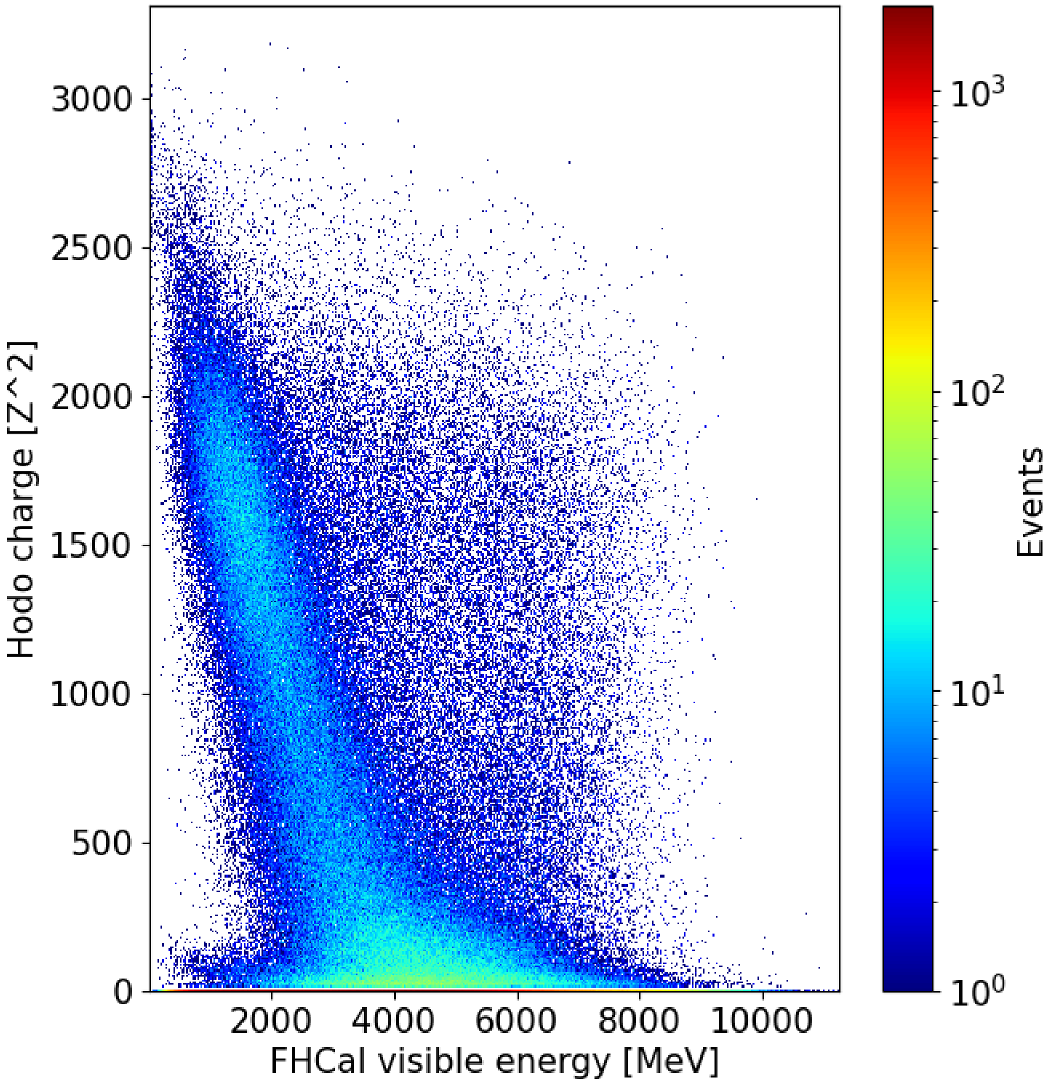
2.2 Impact parameter resolution



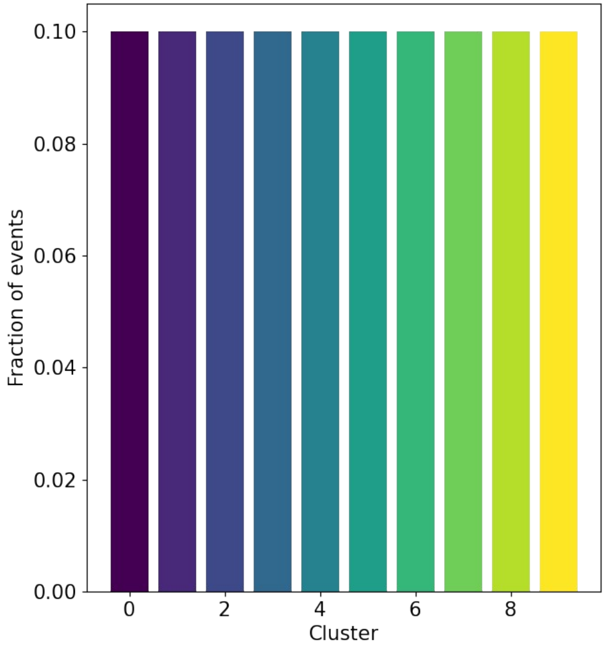
Event characterisation: FQH&FHCal correlation

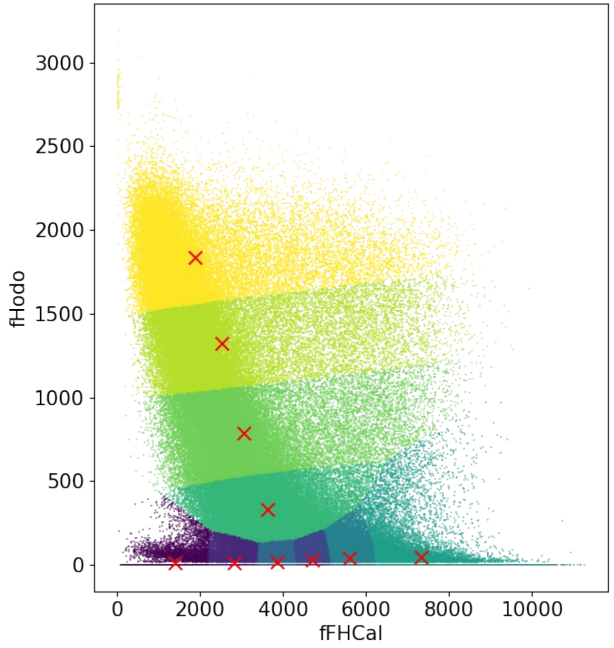
*XeCsI@**3.8A GeV**. MBT 3M runs 7819, 7988, 8097*

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



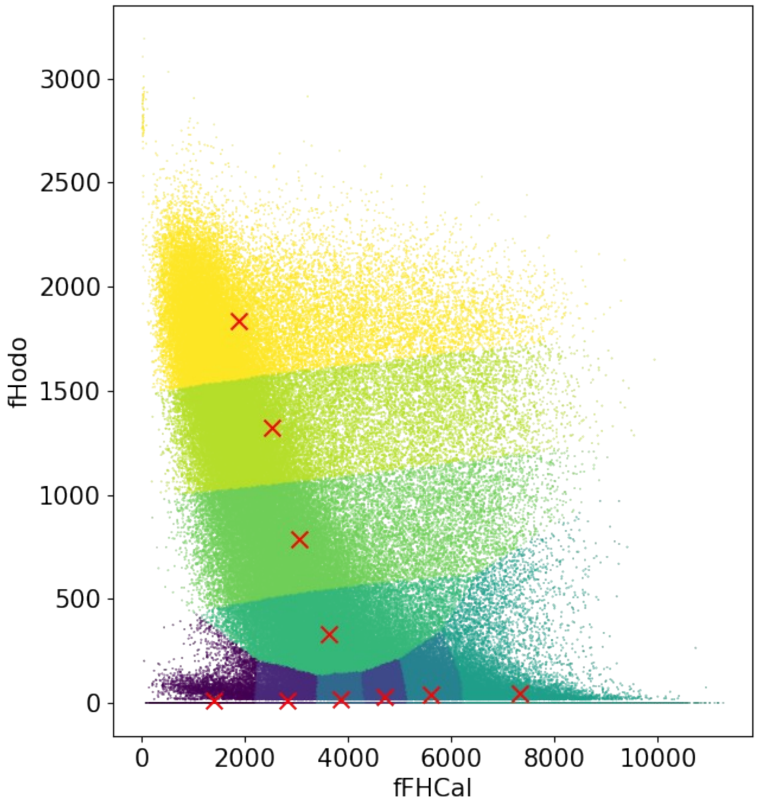
- Apply the same process to experimental MBT data by splitting it into 10 clusters.
- For the time being we do not discuss the trigger efficiency.

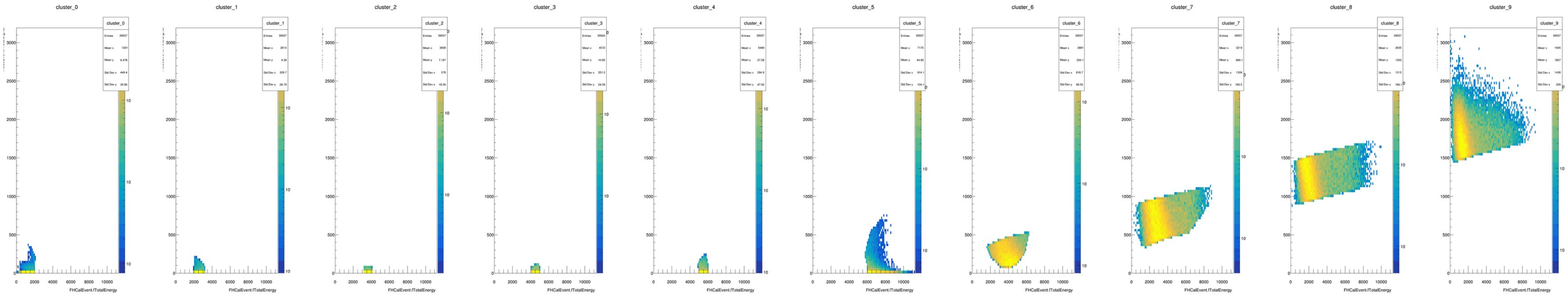




Event characterisation: Software

- 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 (pending commit) and will be accessable from DST files through methods *EventCentrality→GetClass()* and *EventCentrality→GetProbability()*, which return the index and probability of the most likely event class.



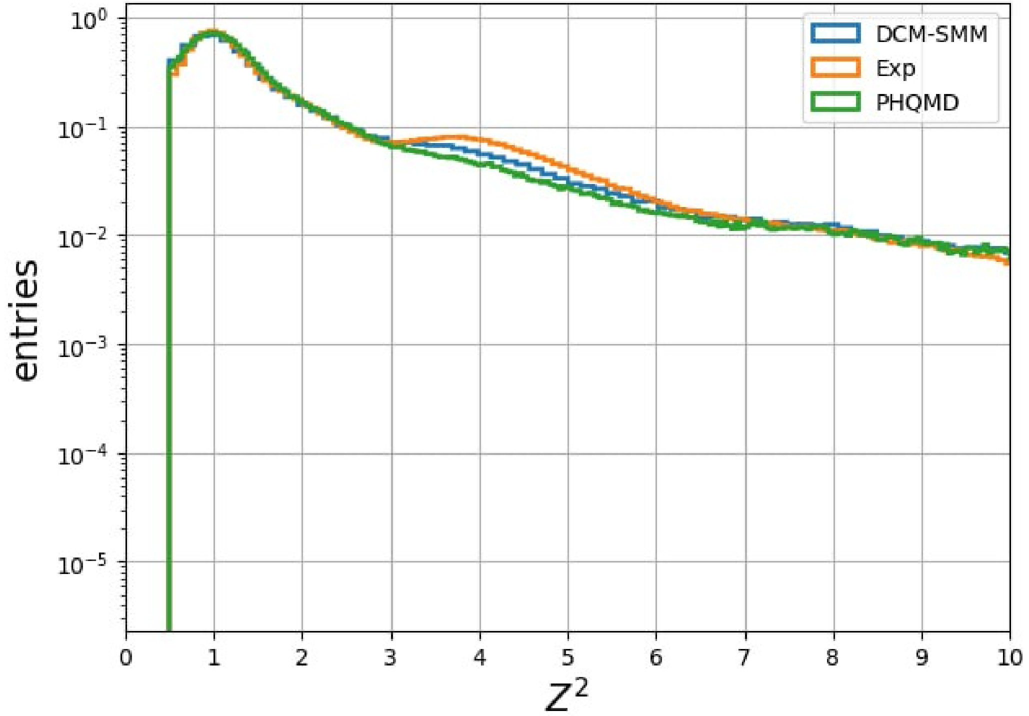


2D normalised joint PDF are stored in a configuration file

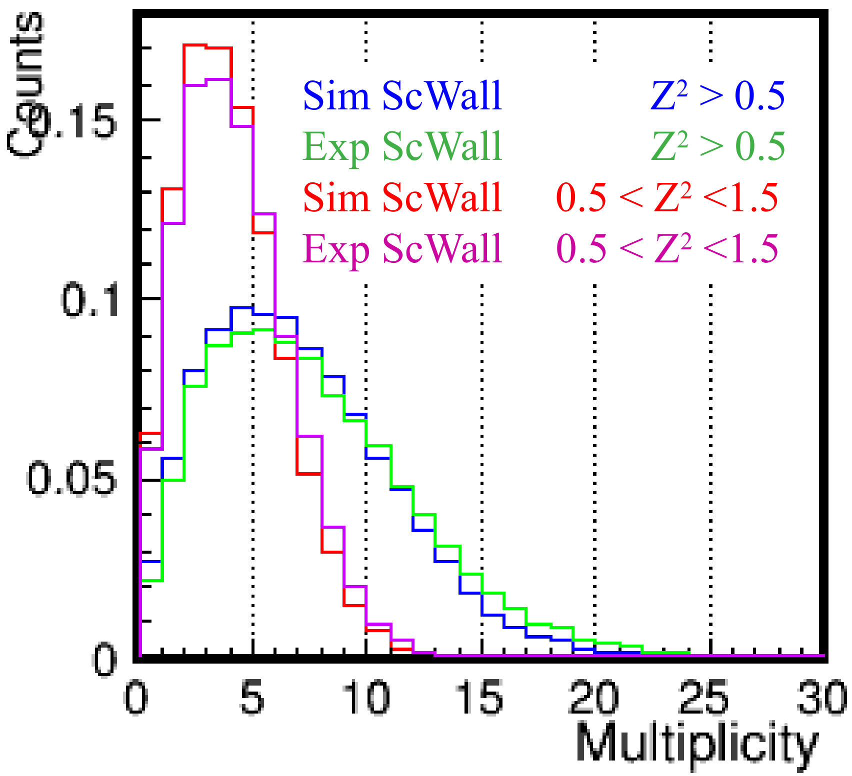
Charged fragments in ScWall

More than 1 track in vertex reconstruction
Vertex position (-1.5 < Z <1.5)
Exp: 1 Xe ion by BC1S integral
Only small cells (central part)

Exp: XeCsI@3.8A GeV Runs 7830 – 7885 CCT2 360k ev
Sim: XeCs@3.8A GeV DCM-QGSM-SMM b < 10 fm
Sim: XeCs@3.8A GeV PHQMD b < 9 fm



Exp: XeCsI@3.8A GeV MBT
Sim: XeCs@3.8A GeV DCM-QGSM-SMM b < 10 fm



- Both the DCM-QGSM-SMM and PHQMD models exhibit a shortage in yields of fragments with charge $Z^2 = 4$ compared to experimental observations.
- The DCM-QGSM-SMM model effectively captures the multiplicity distribution. PHQMD falls short in this aspect even with impact parameter selection criteria (b < 9 fm) – not shown.

Conclusions and future plans

- Forward detectors exhibited stable operation throughout BM@N Run 8.
  See bad runs list on next slide.
- Clusterization method for event class determination by FQH&FHCal data is developped.
  Method is implemented into the bmnroot as a reconstruction task (not pushed yet).
- The next step involves defining the trigger efficiency – the fraction of true minimum bias events captured by the MBT trigger. After that is will become possible to align event classes with centrality classes.
- Yield of the charged fragments with $Z^2 = 4$ in ScWall is underestimated by DCM-QGSM-SMM and PHQMD models. The multiplicity distribution is fairly well described by DCM-QGSM-SMM.

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

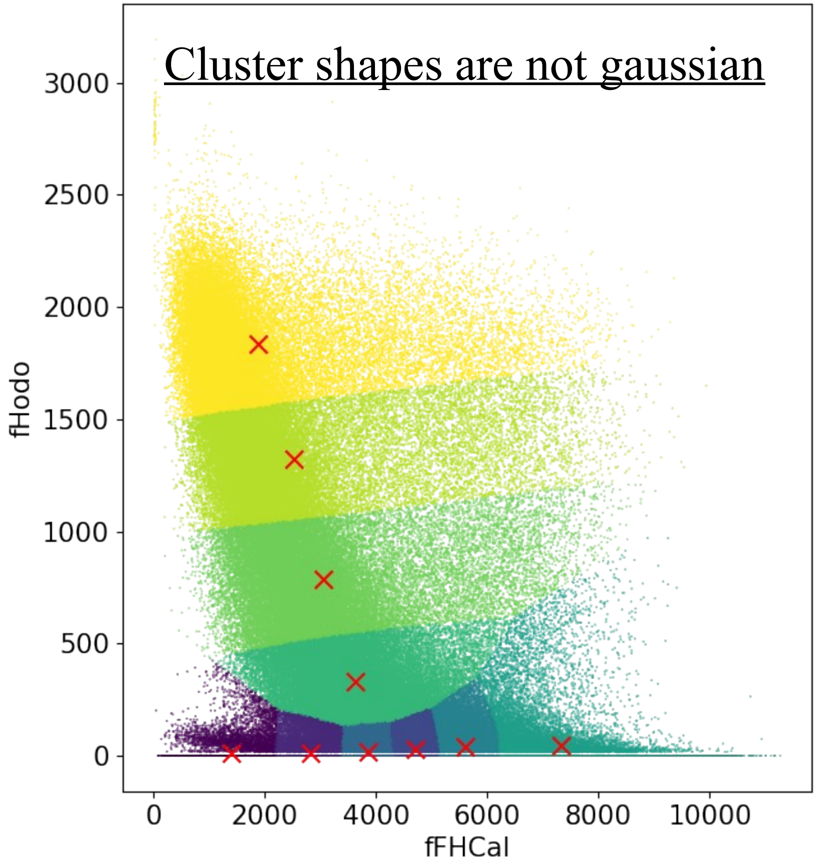
By V.Volkov

BACKUP

Relating clusters to impact parameter

Inversed Bayes

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



https://arxiv.org/abs/2201.12586

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

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

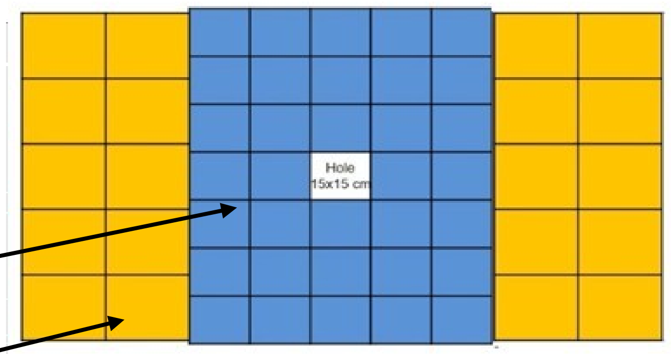
The mean values $\overline{\mathbf{X}}$ and the elements of the covariance matrix Σ_{ij} are smooth positive functions of c_b, and are expressed as the exponential of a polynomial as in Ref. [23],

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

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

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.

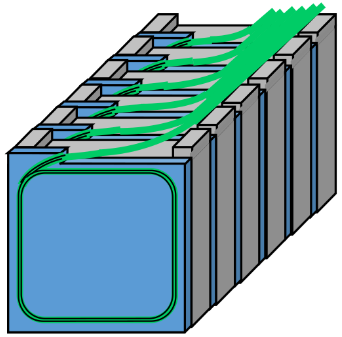
FHCal (Forward **H**adron **Cal**orimeter)
(for centrality and reaction plane reconstruction)



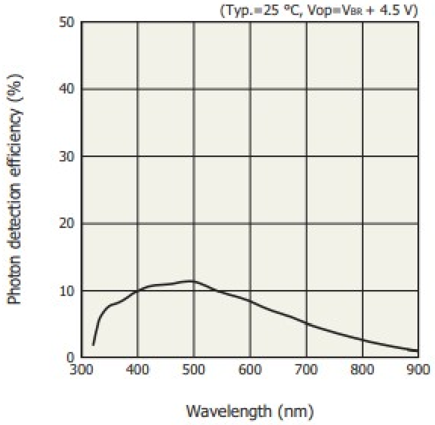
BM@N FHCal

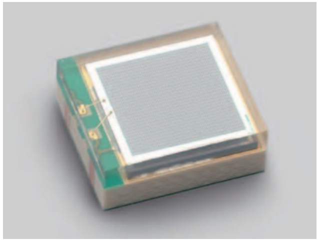
CBM PSD
module production

- 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



one section

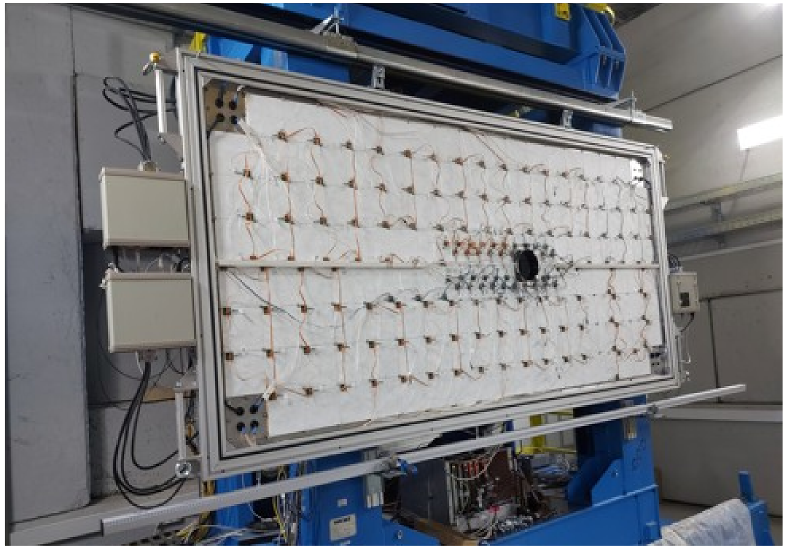




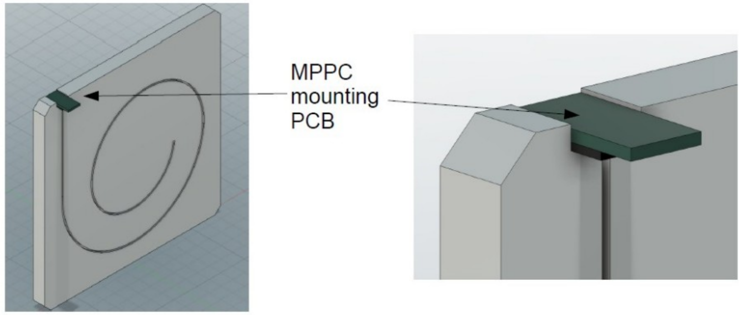
Hamamatsu MPPC S12572-010P 3*3mm^2
Number of pixels: 90000
Gain: 1.35*10^5
PDE: 12%

ScWall (**Sc**intillation **Wall**)

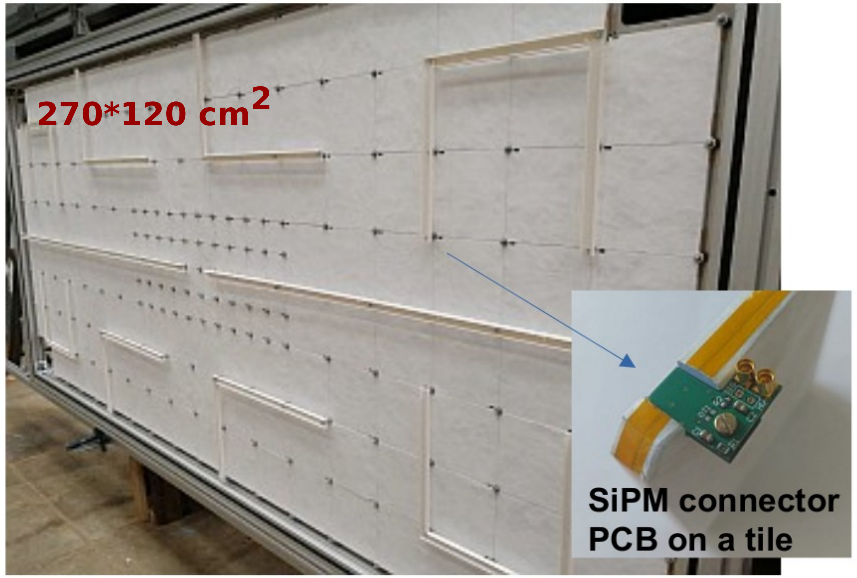
(for fragments charge measurements and reaction plane estimation)

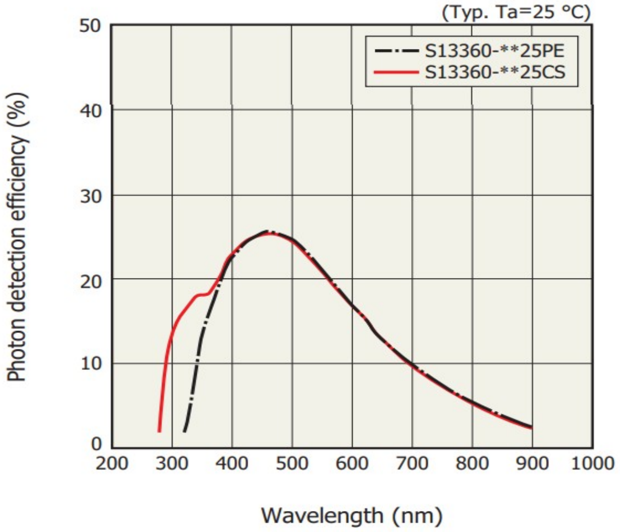


- 36 small inner cells 7.5*7.5*1 cm^3 + 138 big outer cells 15*15*1 cm^3
- light yield for MIP signal – small cells 55 p.e.±2.4%; big cells 32 p.e.± 6%.
- optional beam hole (covered with 4 small cells for the SRC run)
- covered with a light-shielding aluminum plate
- light collection by WLS fibers
-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



light collection from tiles

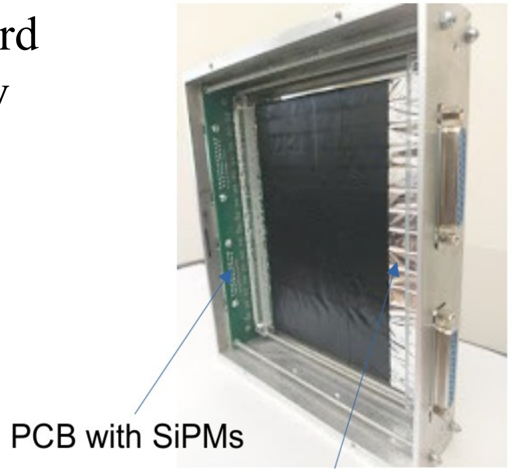




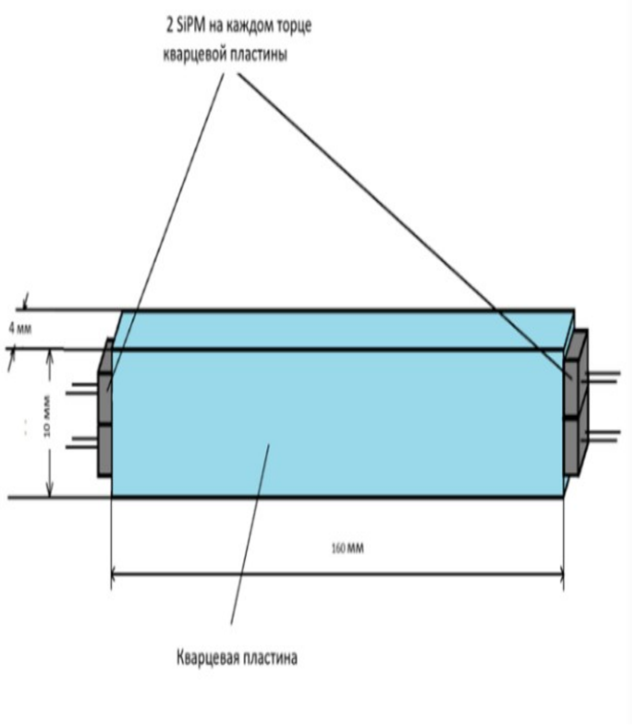
Hamamatsu MPPC S13360-1325CS
1.3*1.3mm^2
Number of pixels: 2668
Gain: 7*10^5
PDE: 25%

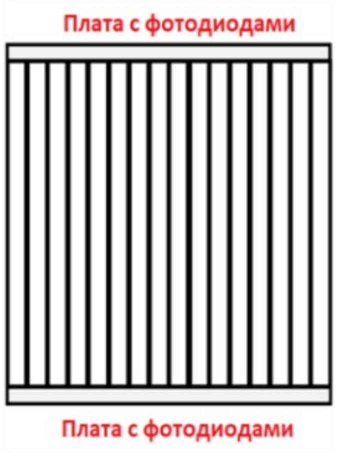
FQH (Forward Quarz Hodoscope)

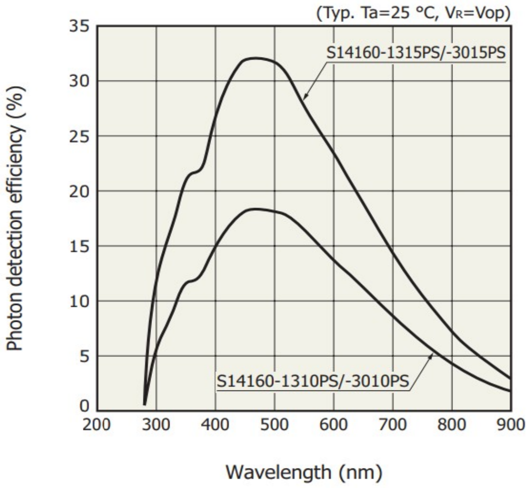
measurement of fragments charge in the FHCal beam hole – very forward rapidity region (for event centrality determination)



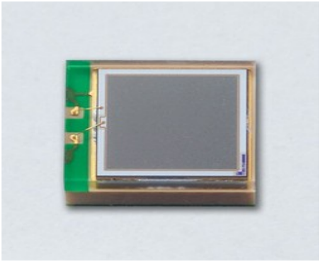
- 16 strips 160*10*4 mm^3 with mylar reflector
- cover beamhole 15*15cm^2
- light readout from both edges of each strip
- 2 SiPMs connected in parallel on each side
- each SiPM pair is read with gains x1 and x4







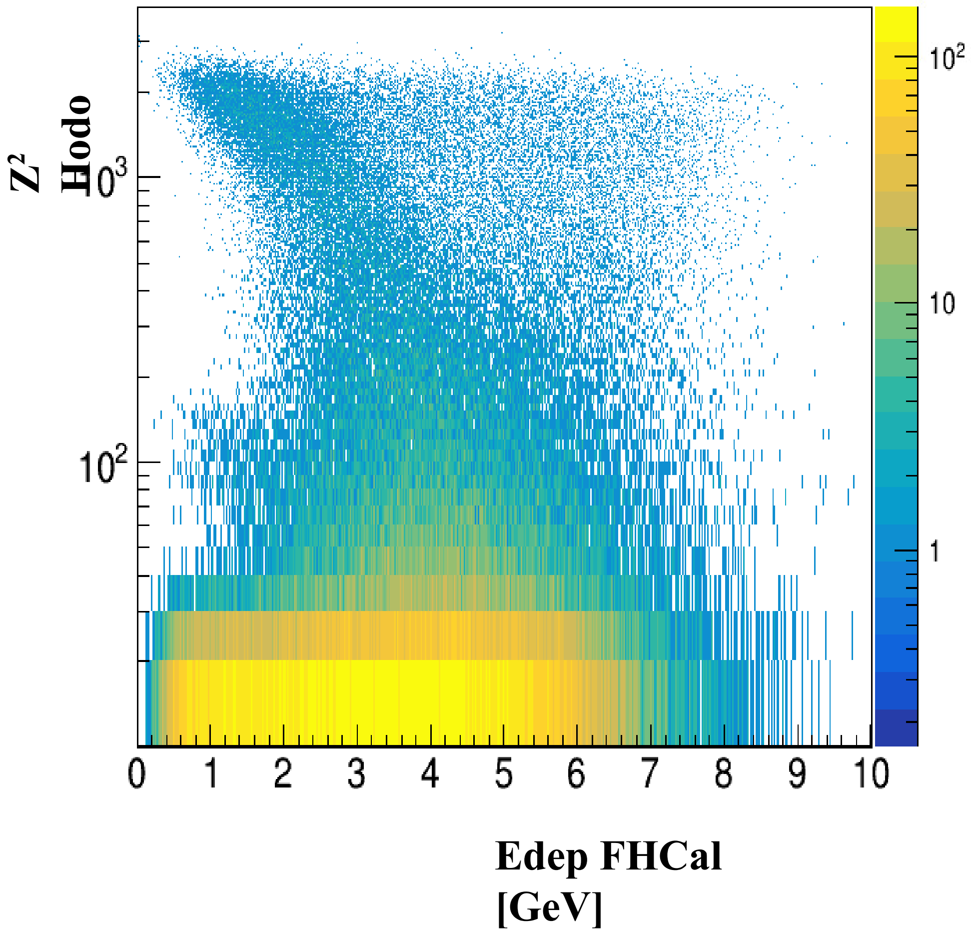
Hamamatsu MPPC S14160-3015PS
3*3mm^2
Number of pixels: 39984
Gain: 3.6*10^5
PDE: 32%



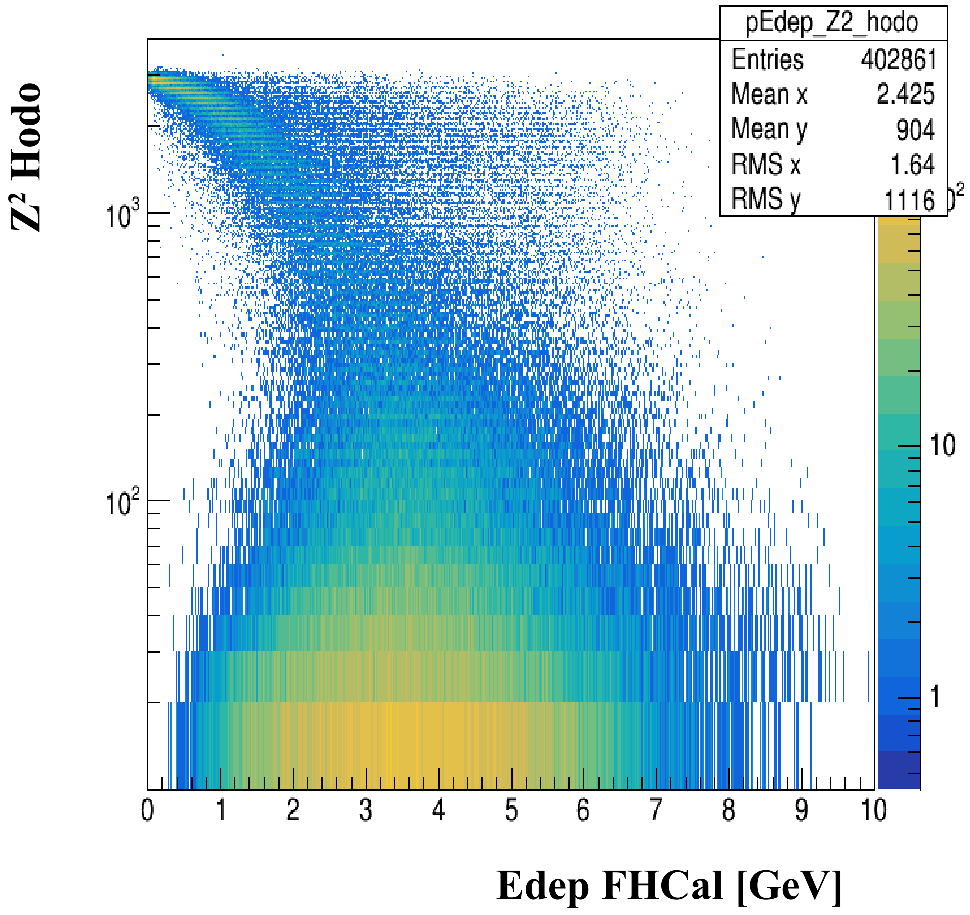
Centrality determination: correlation with FHCal

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.*



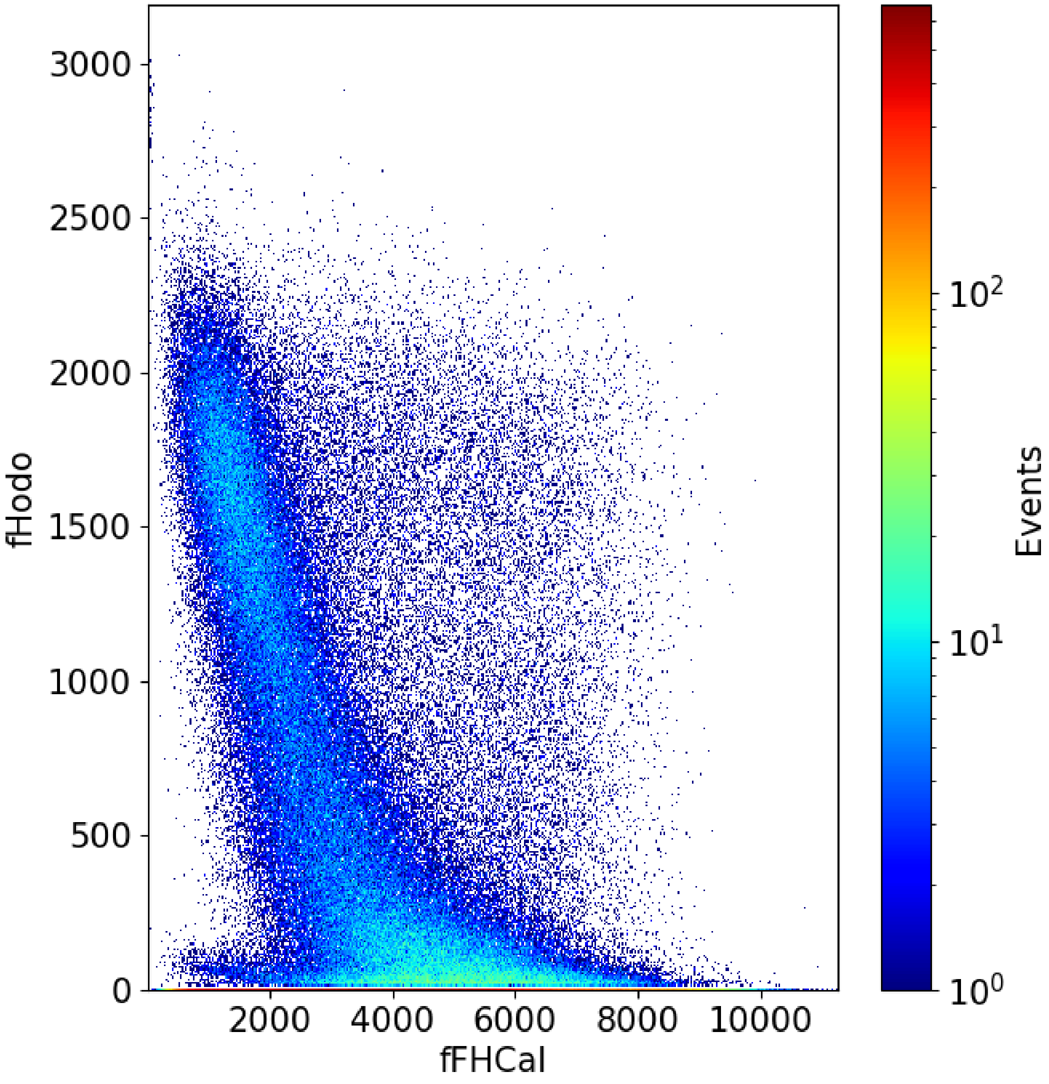
DCM-QGSM-SMM minbias

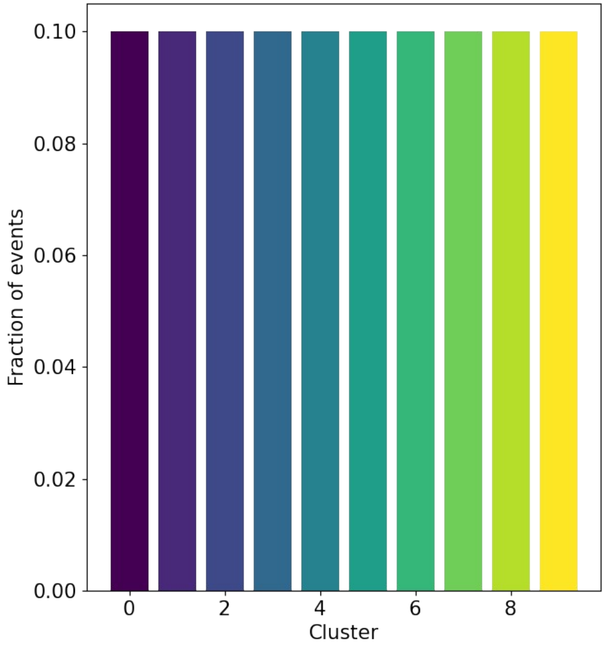


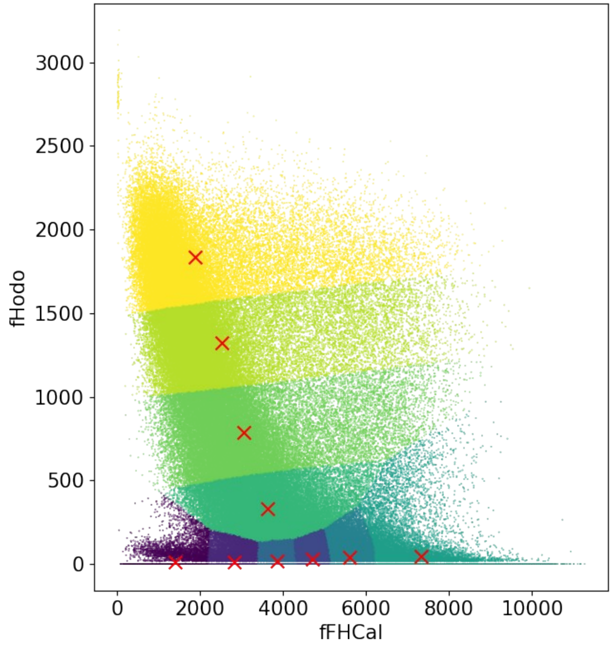
Centrality determination: FQH&FHCal correlation

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

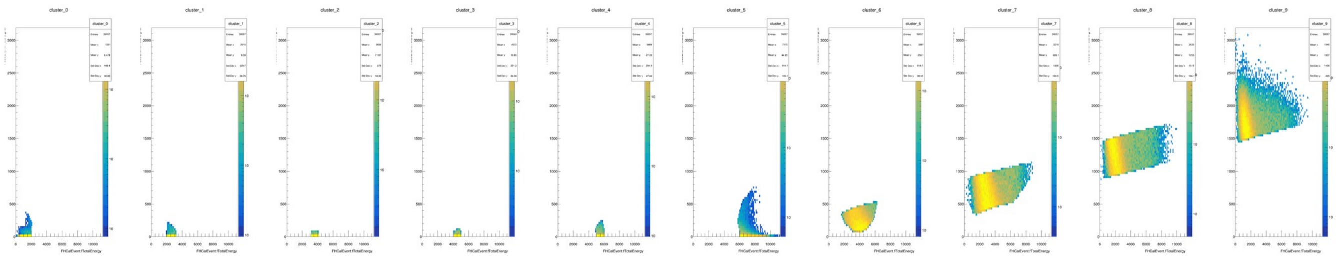
More than 1 track in vertex reconstruction
1 Xe ion by BC1S integral
Vertex position (-1.5 < Z <1.5)





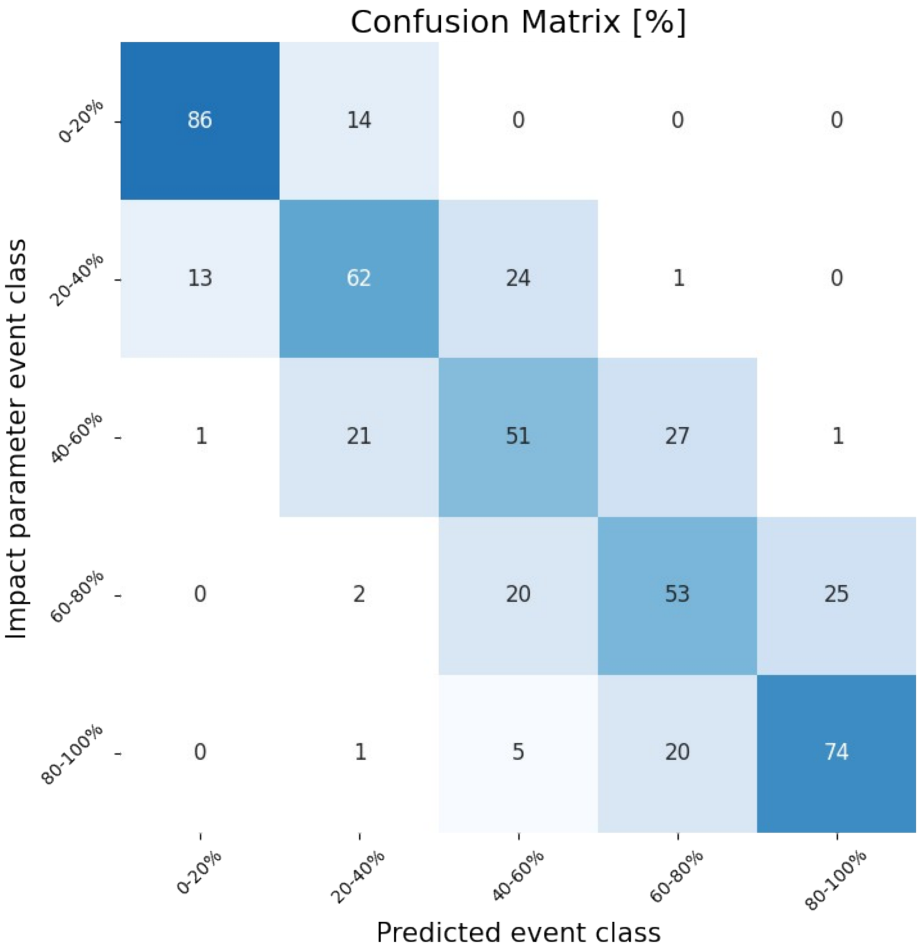


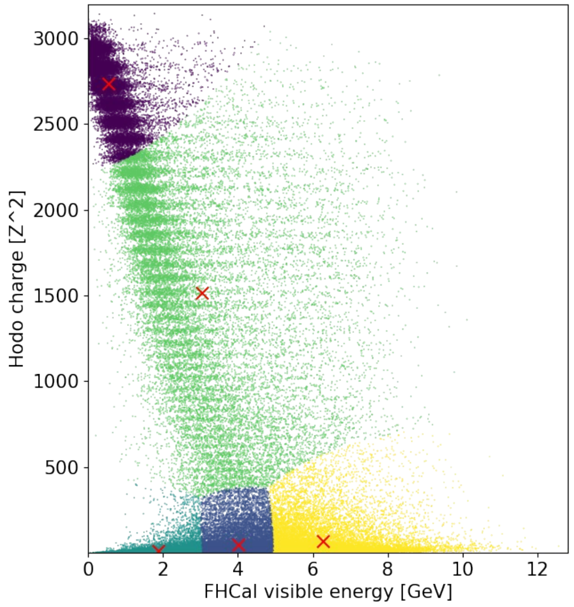
2D normalised joint PDF are stored in a configuration file

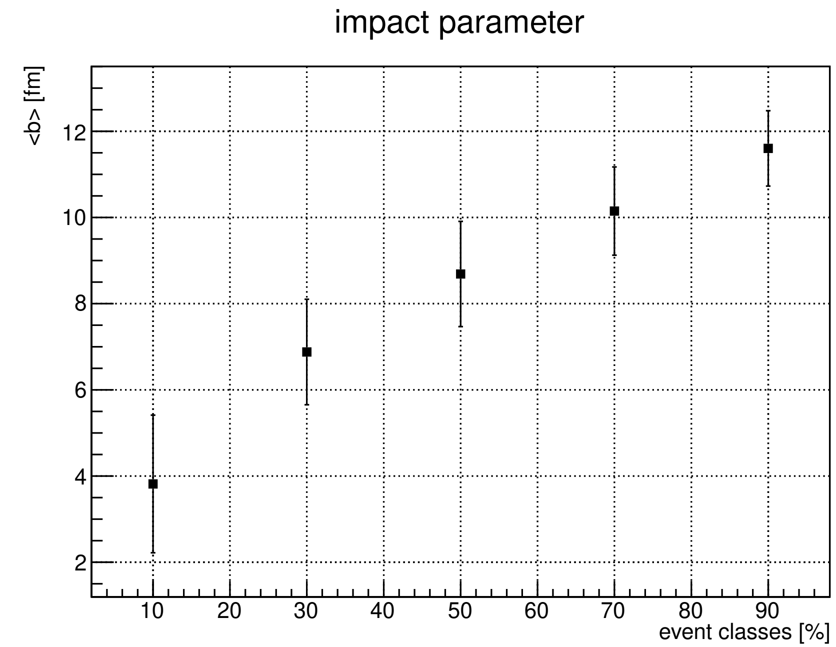


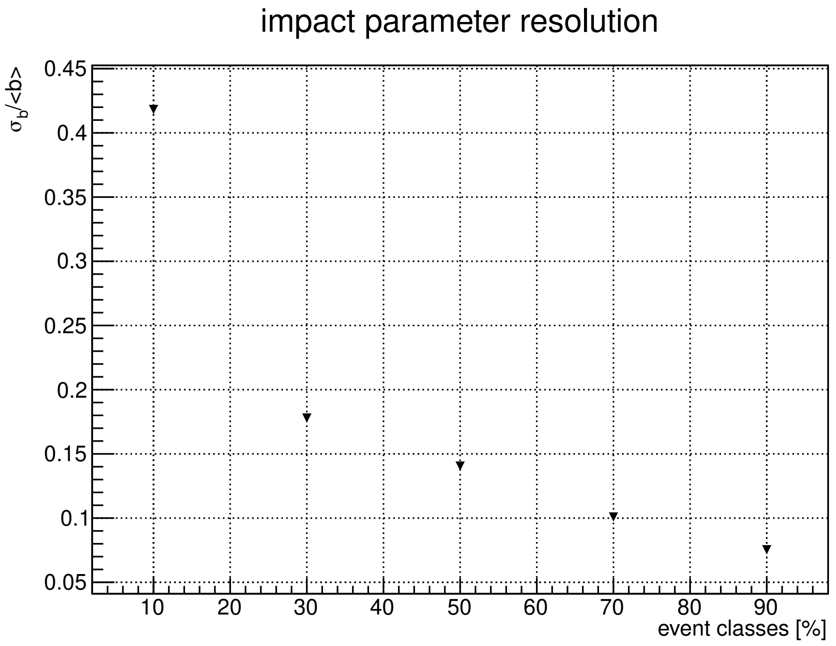
Centrality determination: 5 clusters case

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









XeCs@3.26A GeV, DCM-QGSM-SMM, UNIGEN
Scale 0.929
FHCal 977.8 cm, Xsh=65.3 cm,Ysh=-0.8cm, rotY 1.6 deg
Hodo 970.2 cm, Xsh=64.9 cm, Ysh=-1cm, rotY 1.6 deg
ScWall hole 741.5 cm, Xsh=68.7cm
air in cave, Magnet, **all BMN detectors**
VacZdcWall 200x200cm before nDet 12x12cm 27.3deg
Simul - 58992 ev, RECO – 58804 ev

ScWall Z^2 distributions (Z^2 > 0.5)

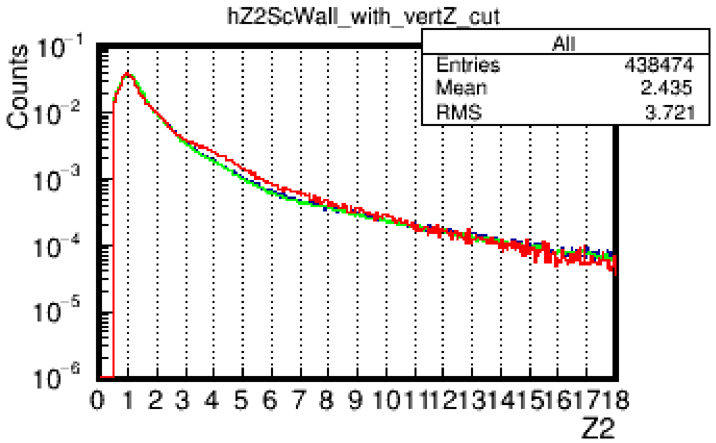
Simulation
after RECO, with reconstructed vertexZ cut
-1.5cm – 1.5 cm
no trigger
DrawNormalized()

Experiment
run 8
XeCsI@3.8 AGeV,
DrawNormalized()
Vadim

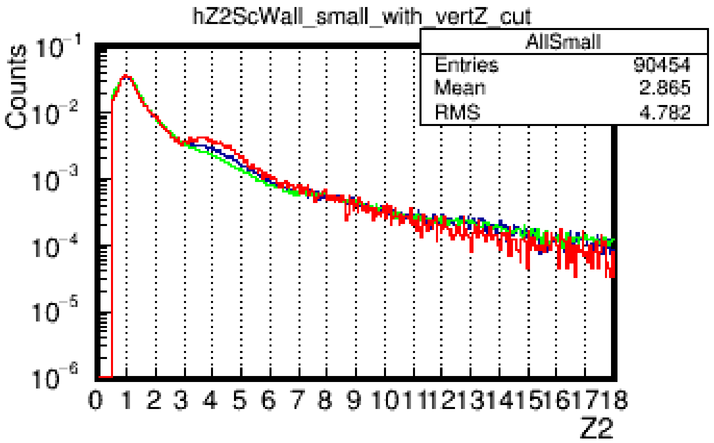
XeCs@3.8A GeV, PHQMD, UNIGEN
Scale 0.929
FHCal 977.8 cm, Xsh=65.3 cm,Ysh=-0.8cm, rotY 1.6 deg
Hodo 970.2 cm, Xsh=64.9 cm, Ysh=-1cm, rotY 1.6 deg
ScWall hole 741.5 cm, Xsh=68.7cm
air in cave, Magnet, **all BMN detectors**
VacZdcWall 200x200cm before nDet 12x12cm 27.3deg
Simul - 281163 ev, RECO – 279140 ev, no etaCut

DCMSMM
PHQMD
Experiment

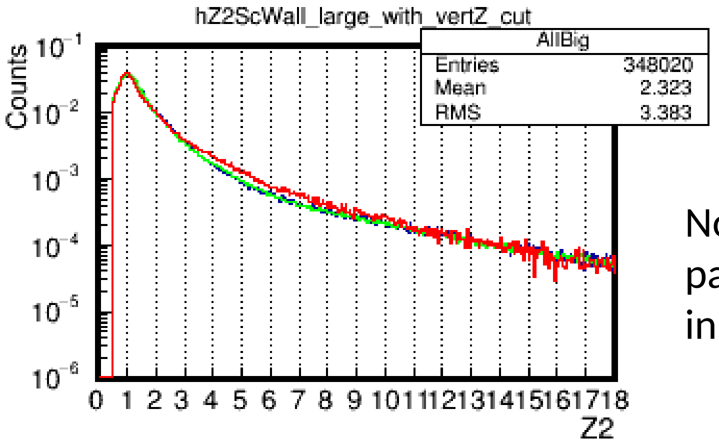
All cells



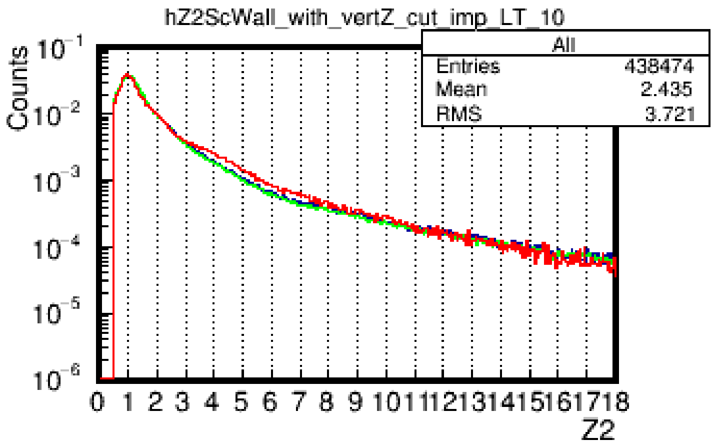
Small cells

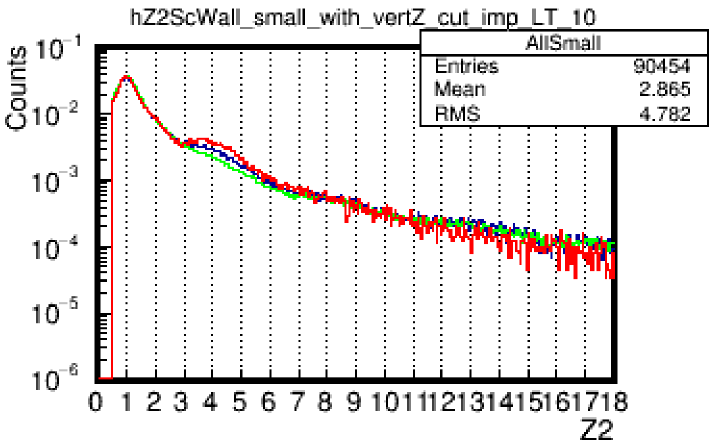


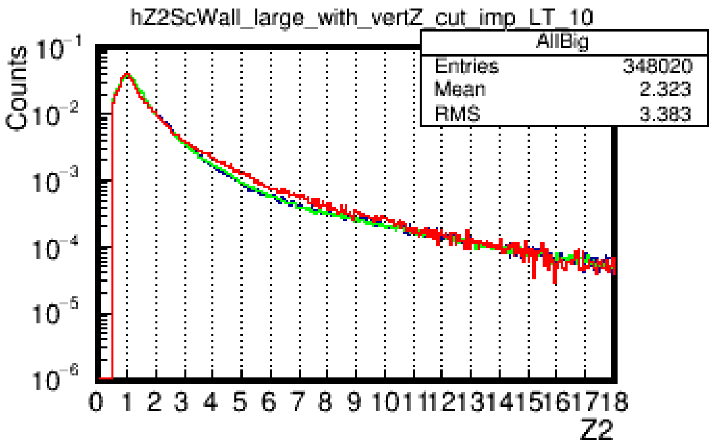
Large cells



No cuts on impact parameter in simulations





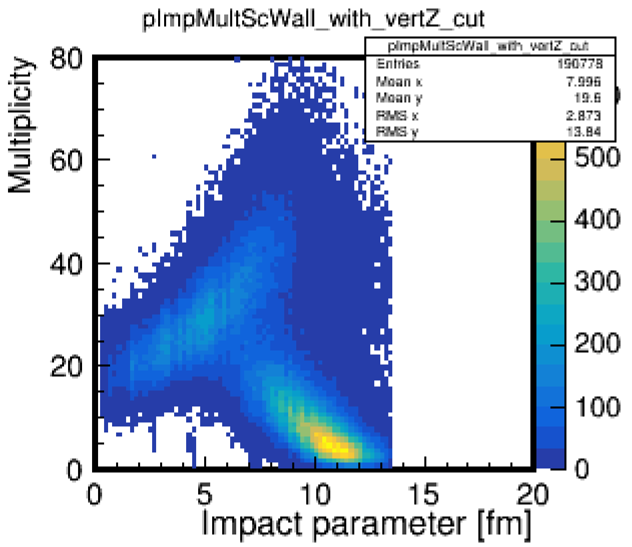


b < 10 fm
b < 9 fm

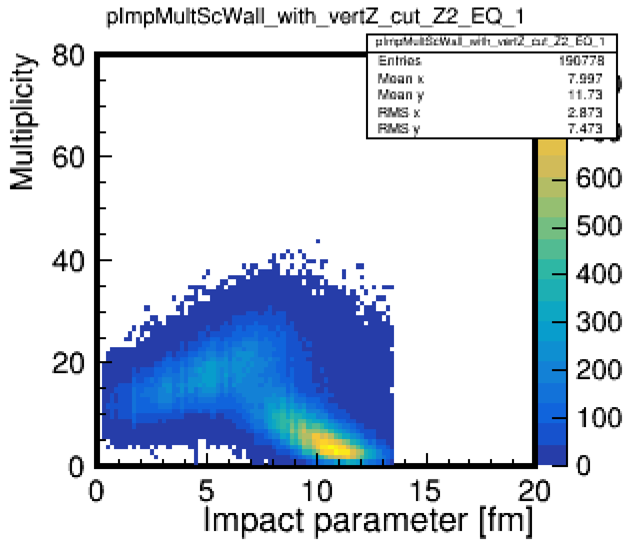
ScWall multiplicities with different impact parameter cuts

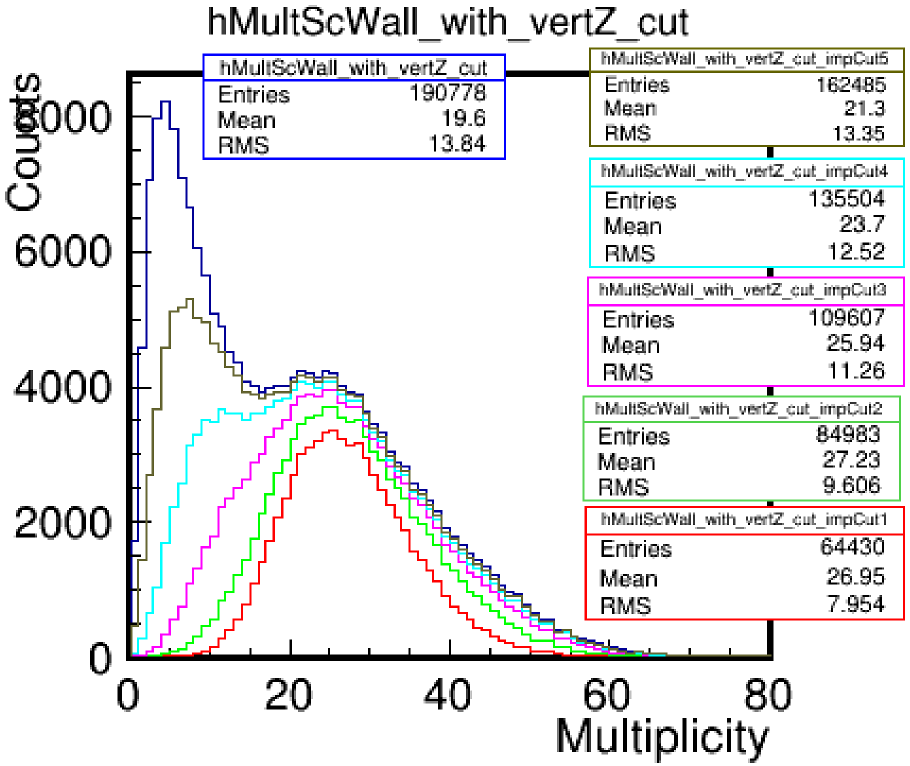
PHQMD

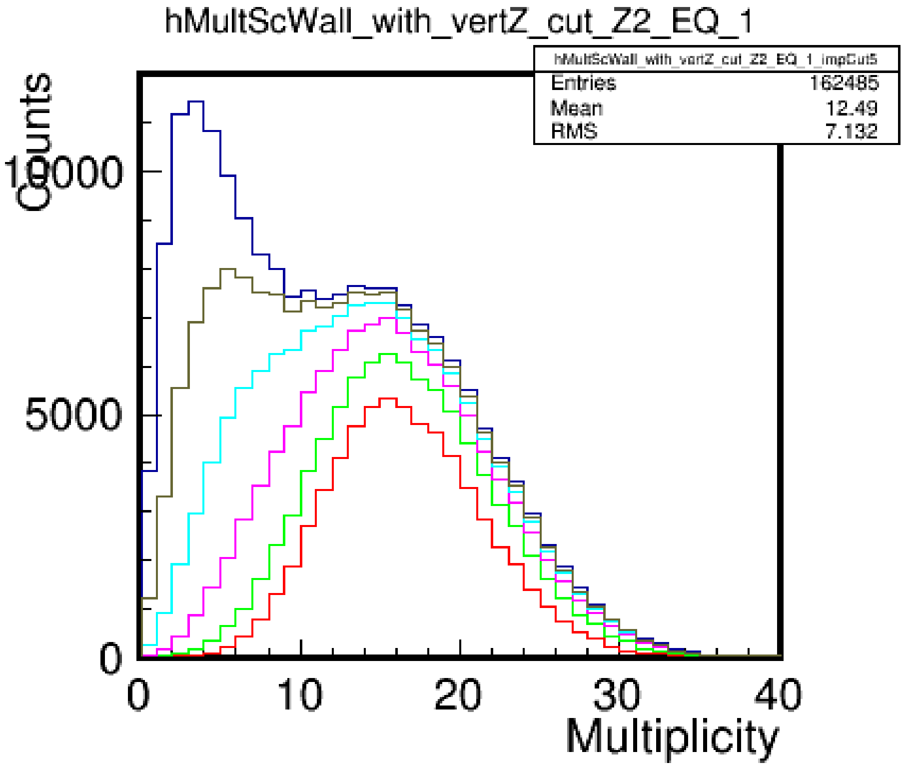
ScWall $Z^2 > 0.5$



ScWall $0.5 < Z^2 < 1.5$







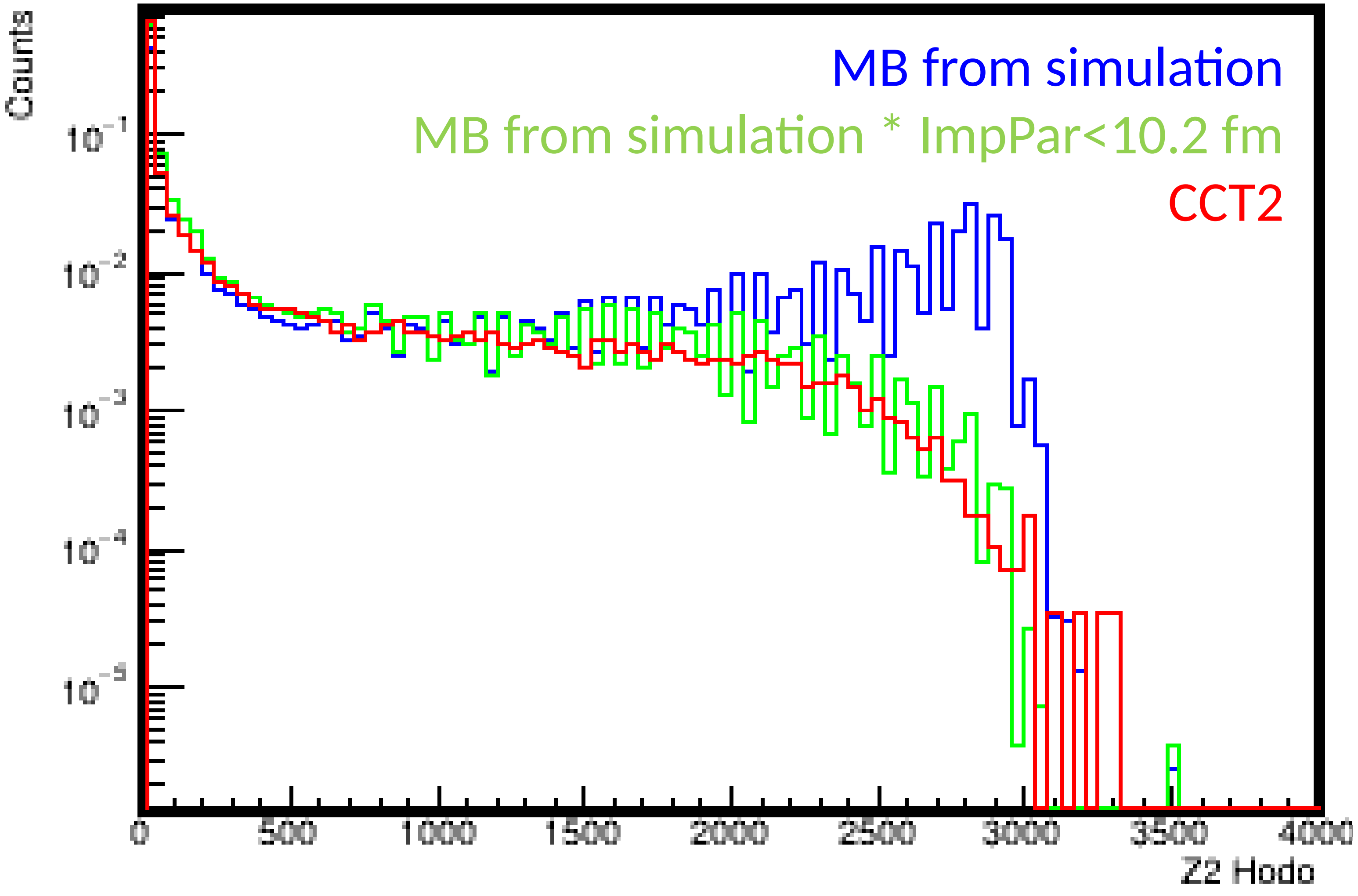
XeCs@3.8A GeV, PHQMD, UNIGEN
Scale 0.929
FHCal 977.8 cm, Xsh=65.3 cm,Ysh=-0.8cm, rotY 1.6 deg
Hodo 970.2 cm, Xsh=64.9 cm, Ysh=-1cm, rotY 1.6 deg
ScWall hole 741.5 cm, Xsh=68.7cm
air in cave, Magnet, **all BMN detectors**
VacZdcWall 200x200cm before nDet 12x12cm 27.3deg
Simul - 281163 ev, RECO – 279140 ev, no etaCut

Simulation

(after RECO,
with reconstructed vertex
Z cut -1.5cm – 1.5 cm

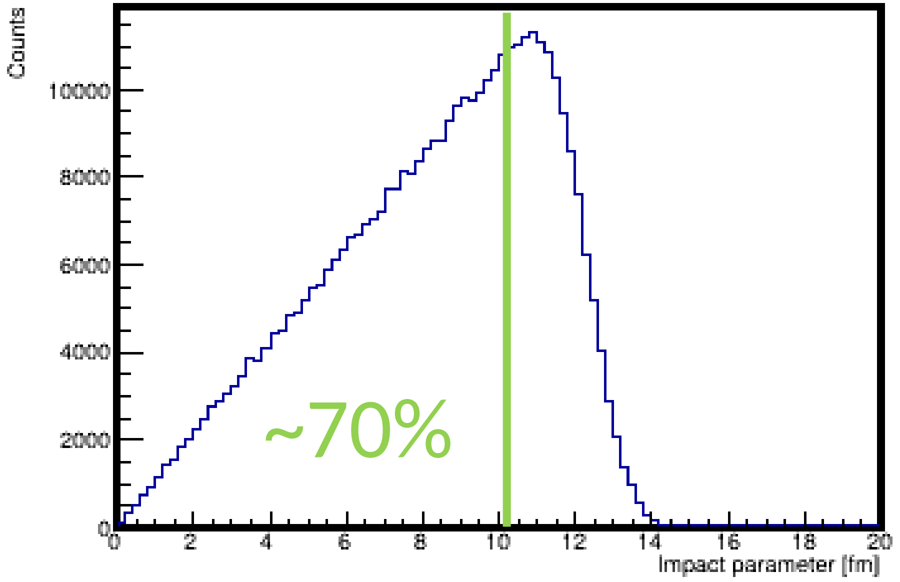
W/o impact parameter cut
Impact parameter < 11 fm
Impact parameter < 10 fm
Impact parameter < 9 fm
Impact parameter < 8 fm
Impact parameter < 7 fm

Fragments charge distributions in FQH: Estimating true minimum bias fraction



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

Impact parameter



XeCs@3.26A GeV, DCM-QGSM-SMM, UNIGEN
Scale 0.929
FHCal 977.8 cm, Xsh=65.3 cm,Ysh=-0.8cm, rotY 1.6 deg
Hodo 970.2 cm, Xsh=64.9 cm, Ysh=-1cm, rotY 1.6 deg
ScWall hole 741.5 cm, Xsh=68.7cm
air in cave, Magnet, **all BMN detectors**
VacZdcWall 200x200cm before nDet 12x12cm 27.3deg
Simul - 58992 ev, RECO – 58804 ev

Simulation and experiment comparison (ScWall multiplicity)

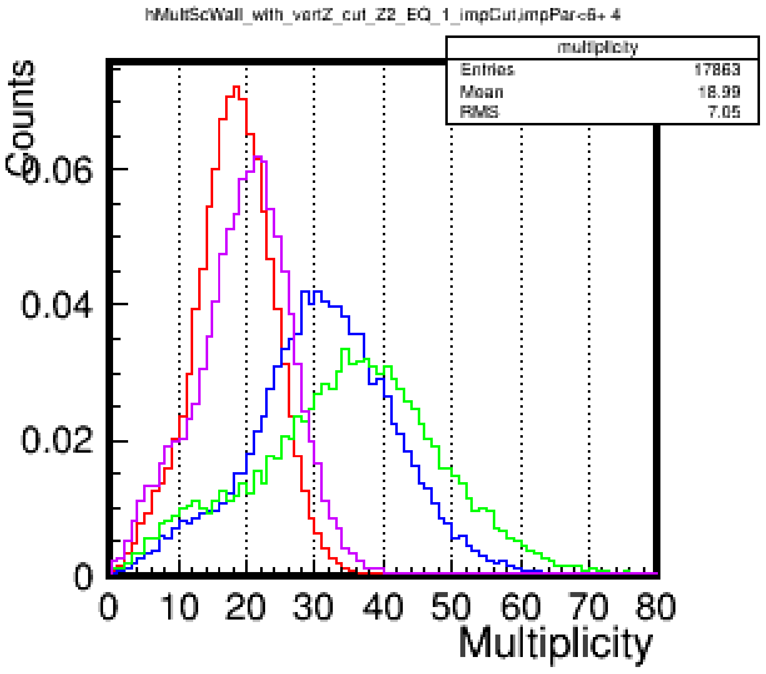
Simulation
(after RECO, with reconstructed vertexZ cut
-1.5cm – 1.5 cm
no trigger cut, MB
DrawNormalized()
With impact parameter < 10 fm

Experiment
(run 8
XeCsI@3.8 AGeV,
MBT trigger
DrawNormalized()
Vadim)

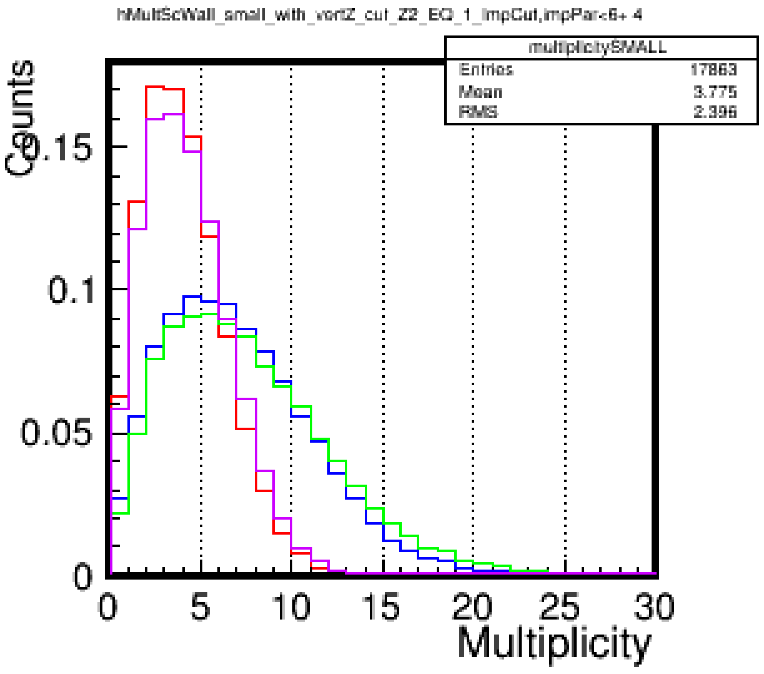
ScWall $Z^2 > 0.5$
ScWall $0.5 < Z^2 < 1.5$

ScWall $Z^2 > 0.5$
ScWall $0.5 < Z^2 < 1.5$

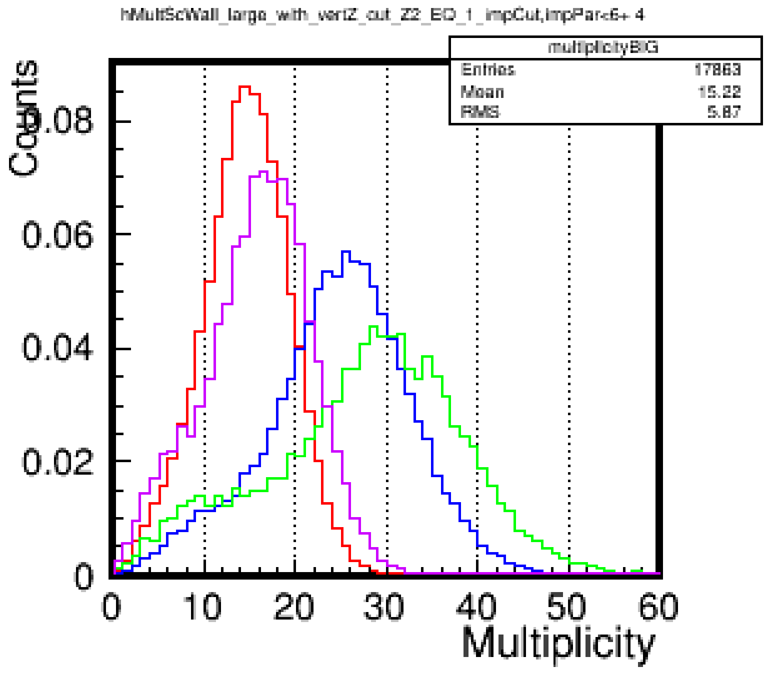
All cells



Small cells



Large cells



Simulation and experiment comparison (ScWall multiplicity)

XeCs@3.26A GeV, DCM-QGSM-SMM, UNIGEN
Scale 0.929
FHCal 977.8 cm, Xsh=65.3 cm,Ysh=-0.8cm, rotY 1.6 deg
Hodo 970.2 cm, Xsh=64.9 cm, Ysh=-1cm, rotY 1.6 deg
ScWall hole 741.5 cm, Xsh=68.7cm
air in cave, Magnet, **all BMN detectors**
VacZdcWall 200x200cm before nDet 12x12cm 27.3deg
Simul - 58992 ev, RECO – 58804 ev

XeCs@3.8A GeV, PHQMD, UNIGEN
Scale 0.929
FHCal 977.8 cm, Xsh=65.3 cm,Ysh=-0.8cm, rotY 1.6 deg
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air in cave, Magnet, **all BMN detectors**
VacZdcWall 200x200cm before nDet 12x12cm 27.3deg
Simul - 281163 ev, RECO – 279140 ev, no etaCut

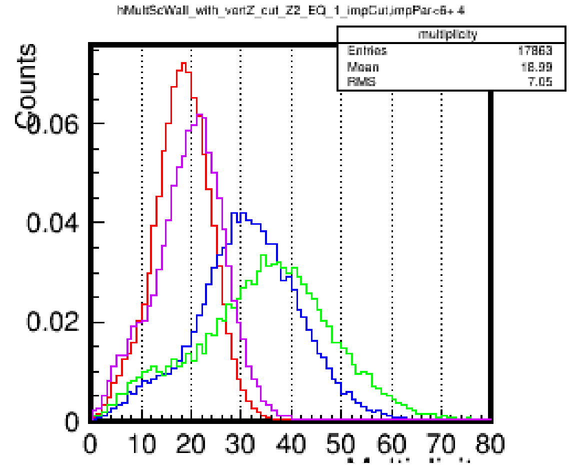
Simulation
(after RECO, with reconstructed vertexZ cut
-1.5cm – 1.5 cm
no trigger cut, MB
DrawNormalized()

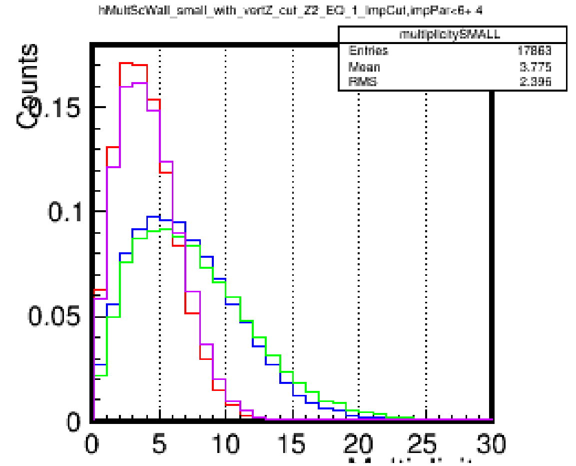
ScWall Z^2 > 0.5
ScWall   0.5 < Z^2 <1.5

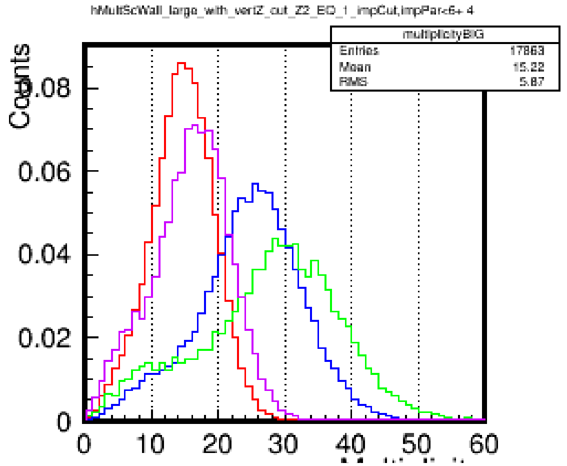
Experiment
(run 8
XeCsI@3.8 AGeV,
MBT trigger
DrawNormalized() Vadim)

ScWall Z^2 > 0.5
ScWall   0.5 < Z^2 <1.5

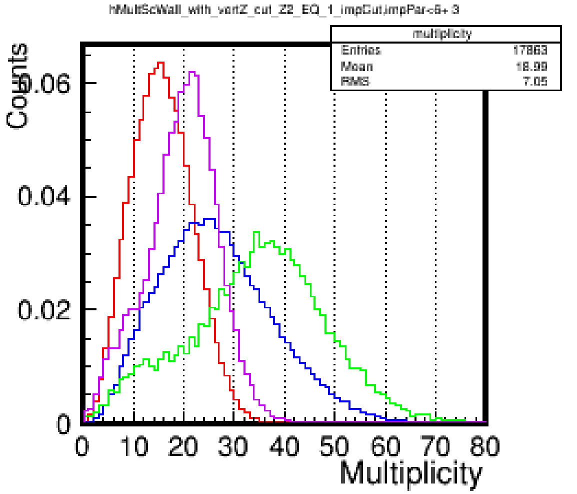
All cells | Small cells | Large cells

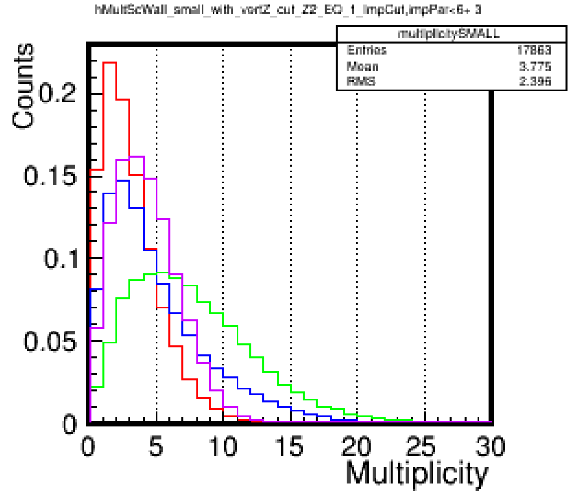


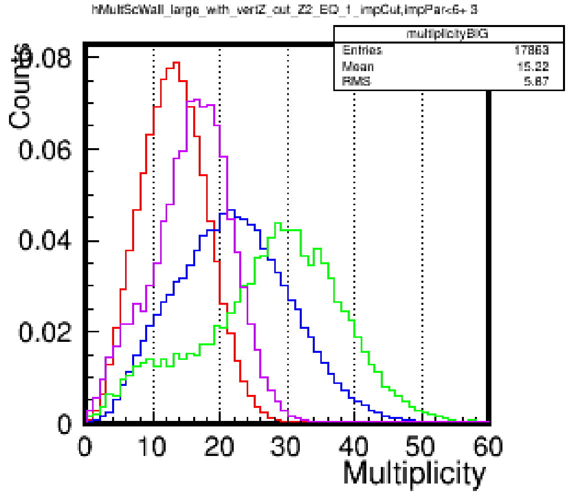




DCMSMM (b < 10 fm) & experiment







PHQMD (b < 9 fm) & experiment