Study of the spectator matter in heavy ion collisions at the BM@N experiment

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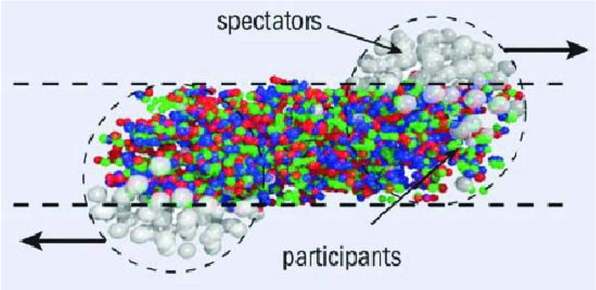
Importance of spectator matter study at the BM@N



- **The pass time of the projectile spectators through the target nucleus is comparable to the fireball lifetime at the BM@N energy range.**
  Sensitivity of spectator matter to fireball matter?

- **Event generators (DCM-QGSM, DCM-SMM etc.) used for BM@N simulations are based on different fragmentation models.**
  Validity of the fragmentation models?

- **Centrality classes determination with forward hadron calorimeters at the BM@N, CBM and MPD experiments also requires correct fragmentation models.**

There are no experimental fragmentation data at energies of few AGeV.

There is a good opportunity for experimental study of fragment spectators properties in nucleus – nucleus collisions at energy range up to 4.5 AGeV at the BM@N.

OUTLINE

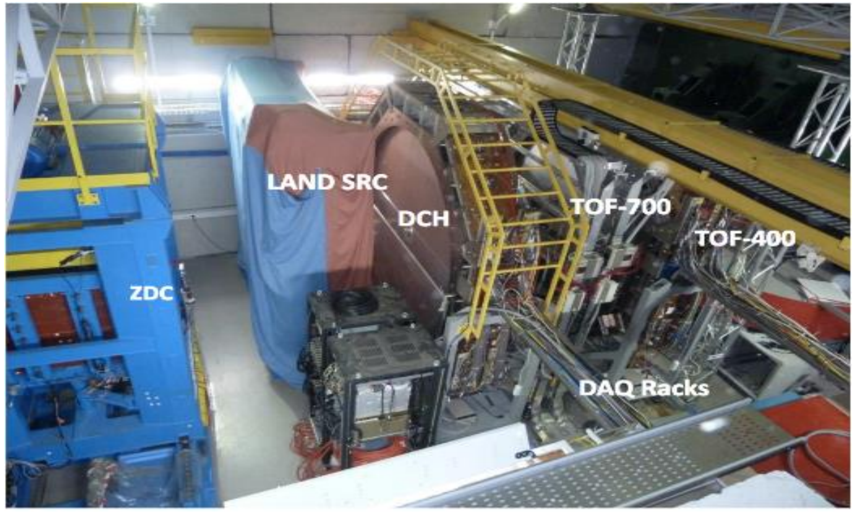
- **Status of the BM@N. Some features of spectators measurements with FHCAL in heavy ions collisions experiments at the BM@N.**

- **Proposed approaches for centrality classes determination at the BM@N.**

- **The possibility of separate measurements of charged fragments and neutron projectile spectators at the BM@N.**

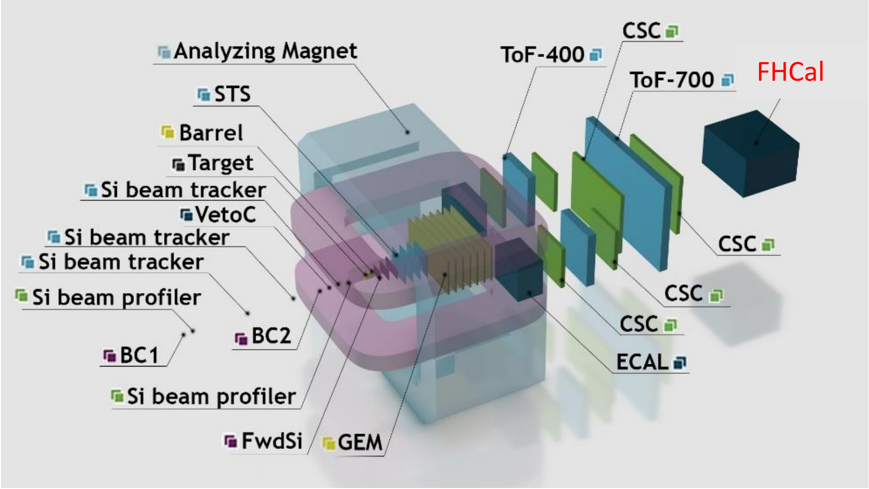
BM@N at Nuclotron

BM@N (Barionic Matter Experiment at Nuclotron)



- Fixed target experiment on the extracted beam from Nuclotron.
- First experiment data obtained in 2016-2018 with d, C, Ar Xe beams.
- ZDC was used for the centrality classes determination
- (see S.Morozov presentation).

BM@N upgrade 2019 -2021

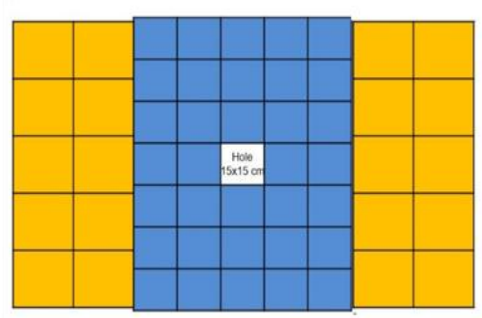


- ➢ Beam vacuum pipe installation
- ➢ Upgrade of all detector systems
- ➢ New FHCal instead of the ZDC

- Fall 2021 - start new experiments with C beams
- 2022+ -start experiments with heavy ions beams with beam rate up to 2x10^6 ions/sec and trigger rate up to 50k.

FHCal status

FHCAL@BM@N



34 inner MPD type + 20 outer CBM modules.
Sampling lead/scintillator modules with sampling ratio 4:1.
The beam hole 15x15 cm^2.

FHCal front view

FHCal back side view

Photodetectors – 438 Hamamatsu MPPC: S12572-010P

FEE – 54 boards

Readout – 8 ADC64, 62.5MS/s boards.

- Central part – modules with 15x15 cm^2 transverse sizes, L = 4λ_{int}. Longitudinal segmentation - 7 sections.
- Outer part – modules with 20x20 cm^2 transverse sizes.
- L = 5.6λ_{int}. Longitudinal segmentation – 10 sections.
- Total weight – 17t.

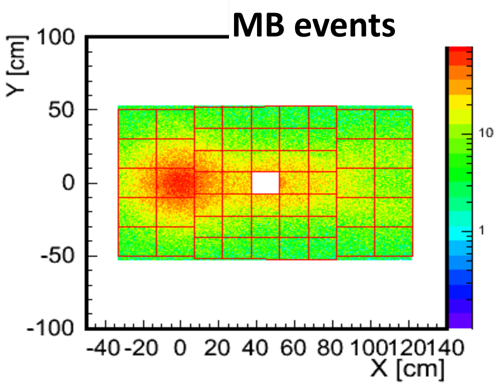
FHCal is already assembled and installed at the BM@N.
Integration into the common BM@N DAQ, calibration on the cosmic muons are in progress.

Features of centrality classes determination with FHCal

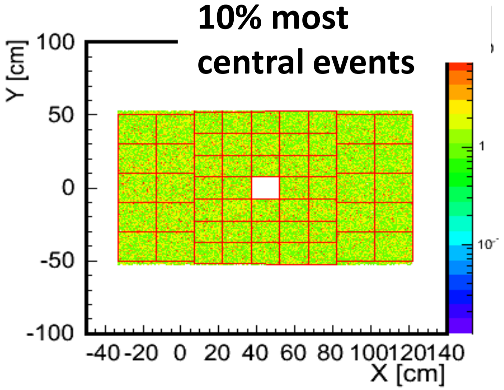
FHCAL BM@N simulation:

Reaction Au+Au@4.5 AGeV

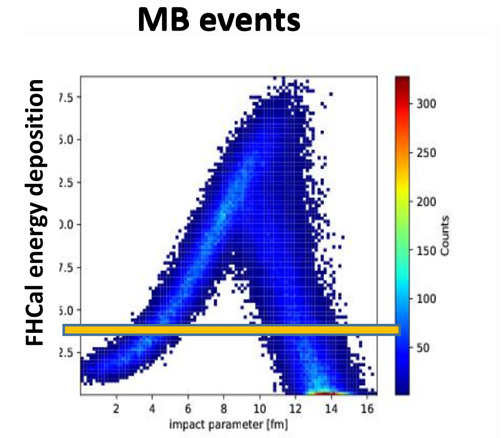
- **Events generators DCM-QGSM and DCM-SMM**
- **Transport code GEANT4 (FTFP_BERT physics list)**
- **bmnroot framework**



50% of particles energy goes through the hole



2% of particles energy goes through the hole

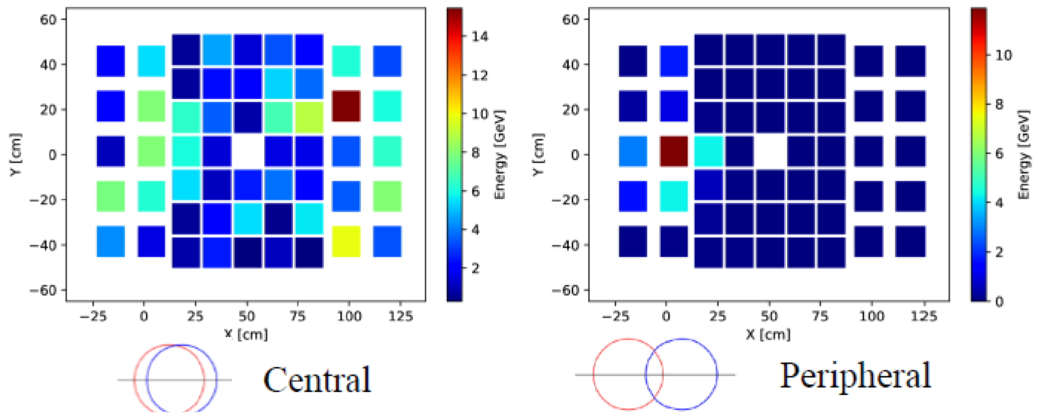


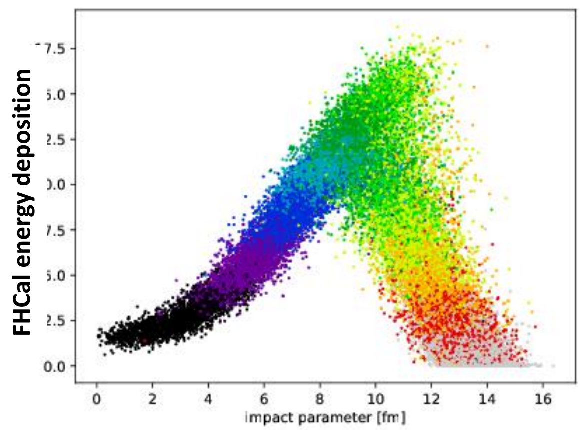
How to resolve the ambiguity in centrality determination?

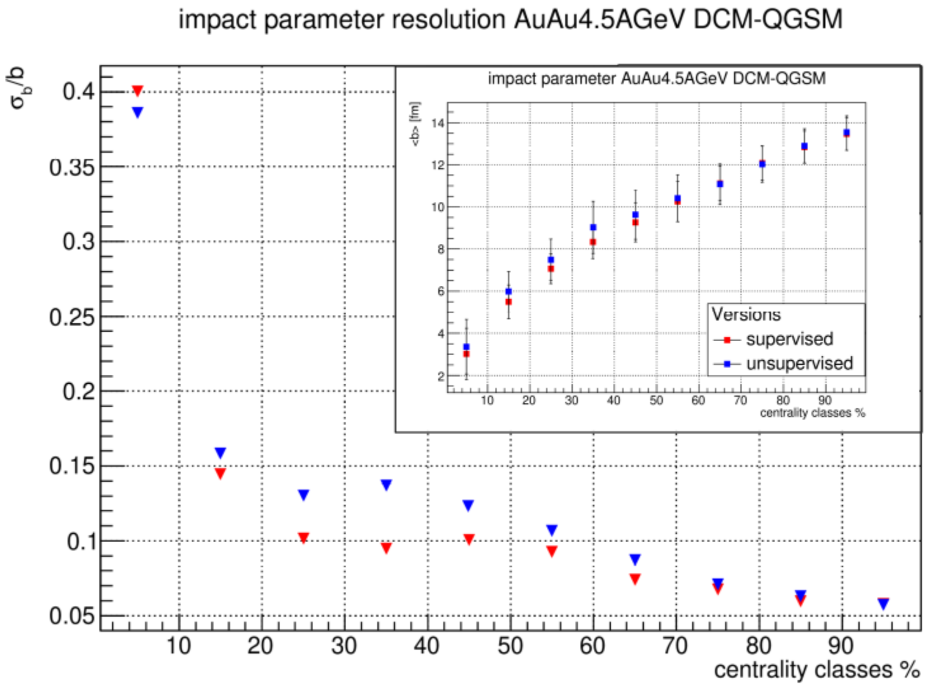
One of the approaches – machine learning (ML) - use of information about energy deposition in each of 54 FHCal modules.

(see presentation of N.Karpushkin)

Example of ML results with supervised/unsupervised approaches



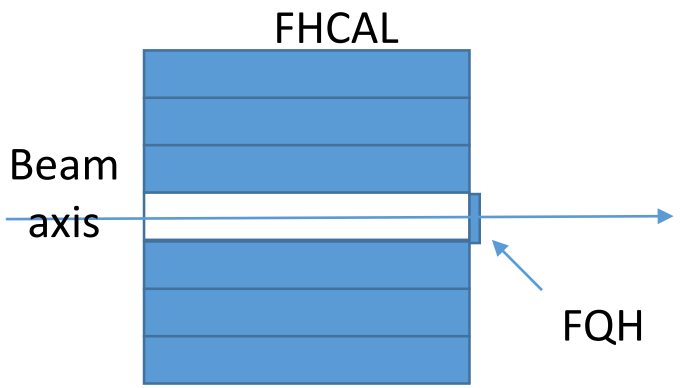




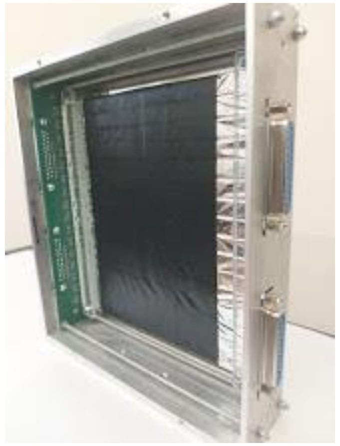
- Difference in impact parameter resolution between supervised and unsupervised approaches for semicentral events is essential.
- ML method can be modified with taken into account not only energy deposition in modules but also the energy depositions in longitudinal sections of the FHCal modules.

Another approach to centrality classes determination

The use of the Forward Quartz Hodoscope (FQH) to measure fragments charges in the FHCal beam hole.

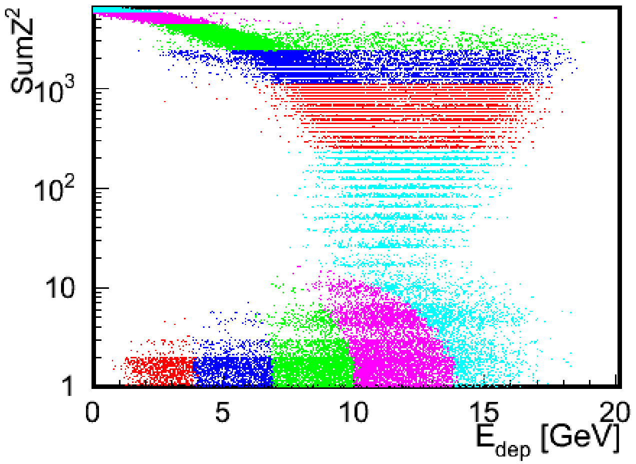


FQH:
- **Fragments charge measurements in the FHCal beam hole.**
- **Alignment of the FHCAL.**
- **To organize MB and centrality trigger.**



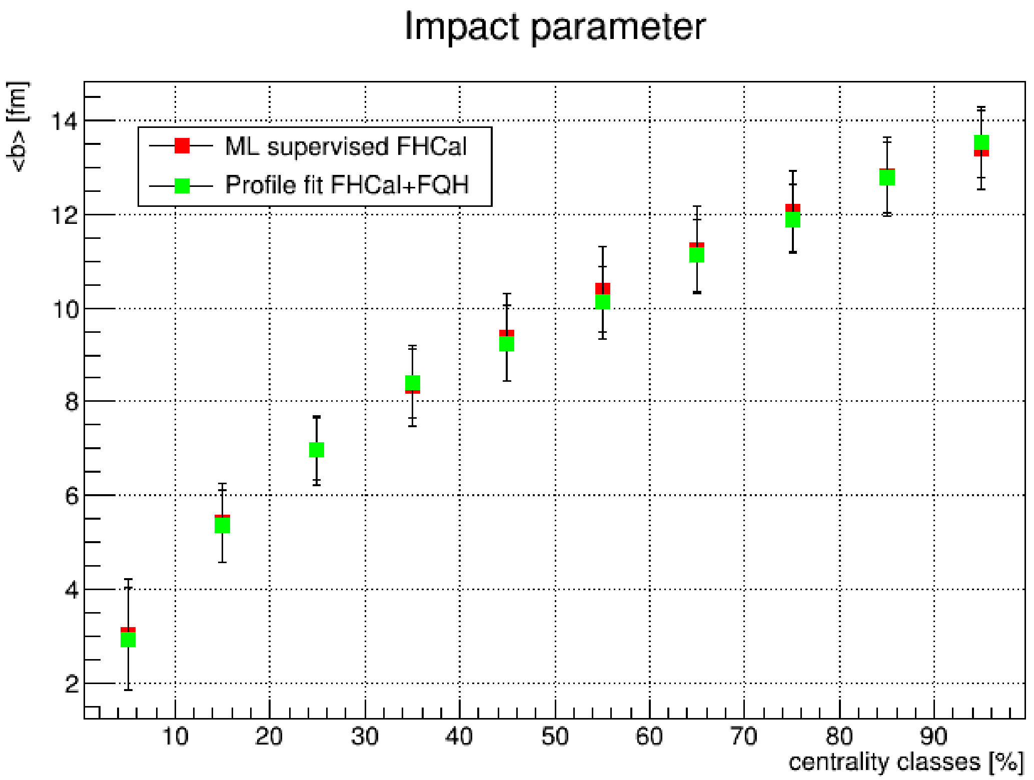
- **16 quartz strips with sizes 10x160x4 mm^3;**
- **Light readout of each strip:**
  2 SiPMs from each strip ends;
- **FQH covers beam hole 15x15 cm^2.**

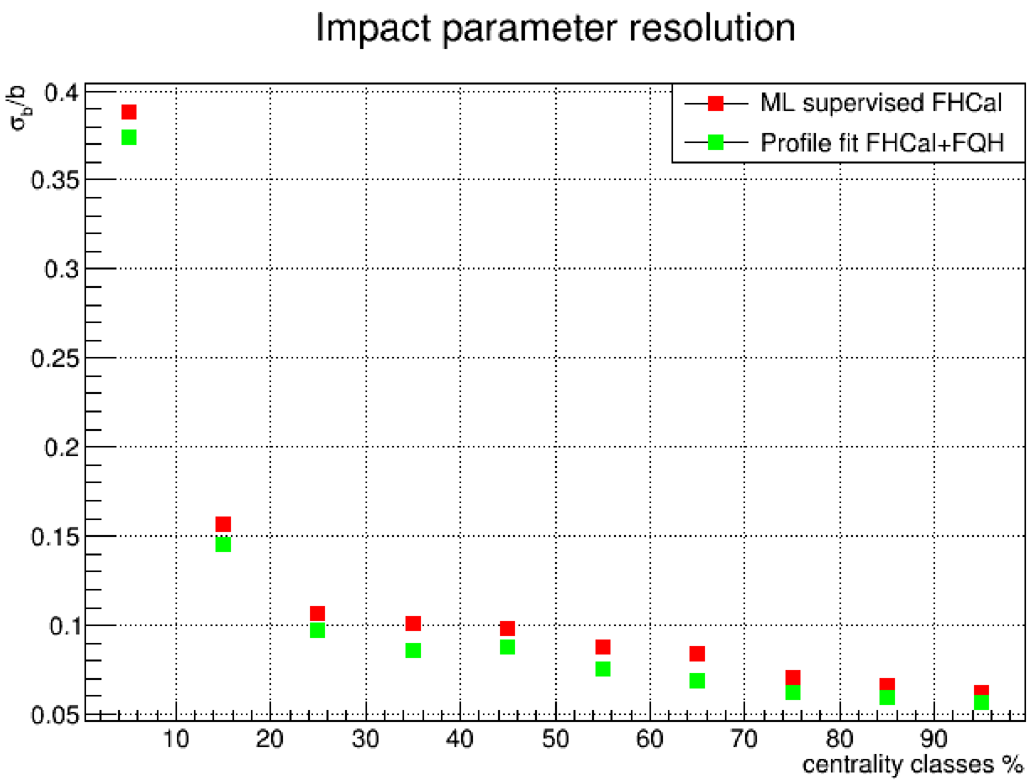
FQH – forward quartz hodoscope with SiPMs light detection was already constructed.



10 centrality classes are defined along the plot envelope.

Comparison of centrality determination with FHCal vs FHCal + FQH

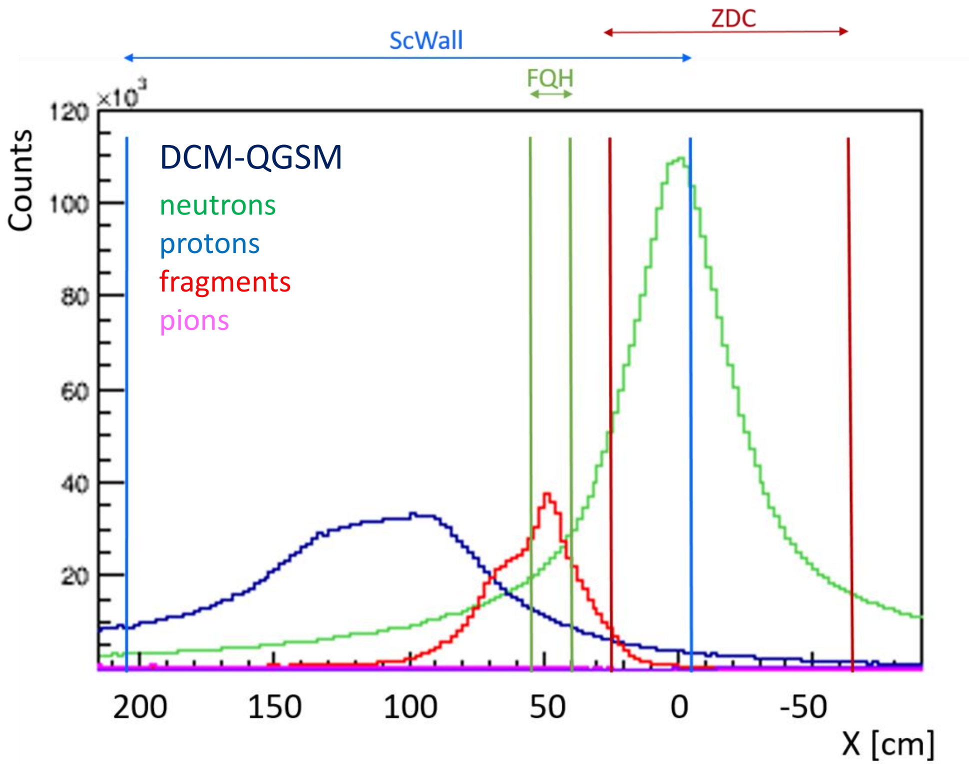


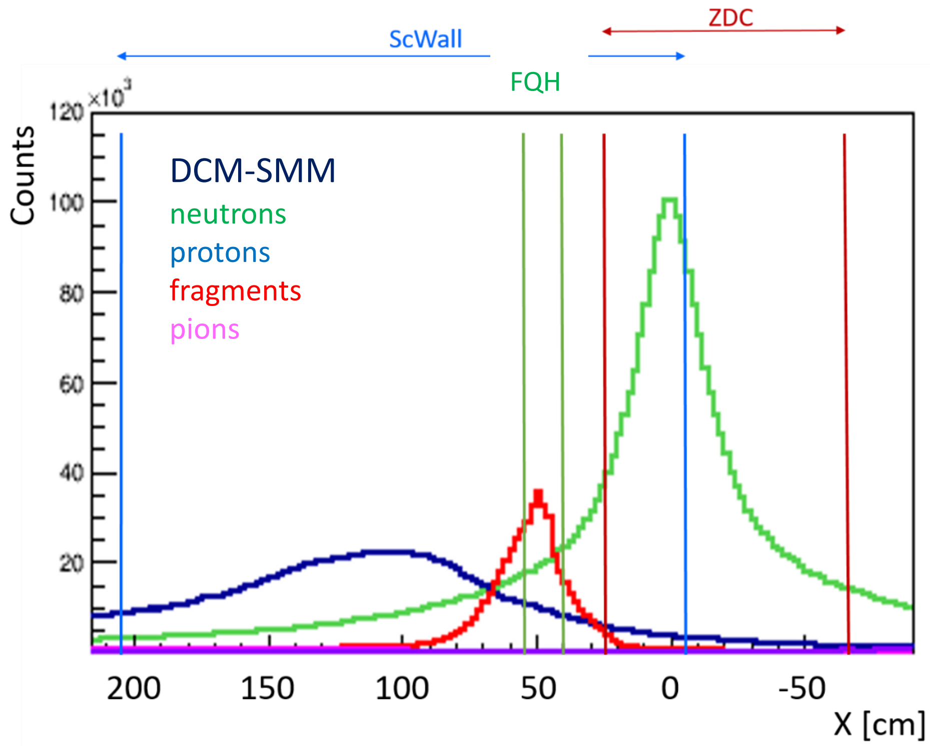


The impact parameter resolution is slightly better when FQH+FHCal detectors are used.

Measurements of proton, neutron spectators and charged fragments at the BM@N

Spatial spectators distributions from Au+Au reaction at 4.5 AGeV with DCM-QGSM and DCM-SMM event generators

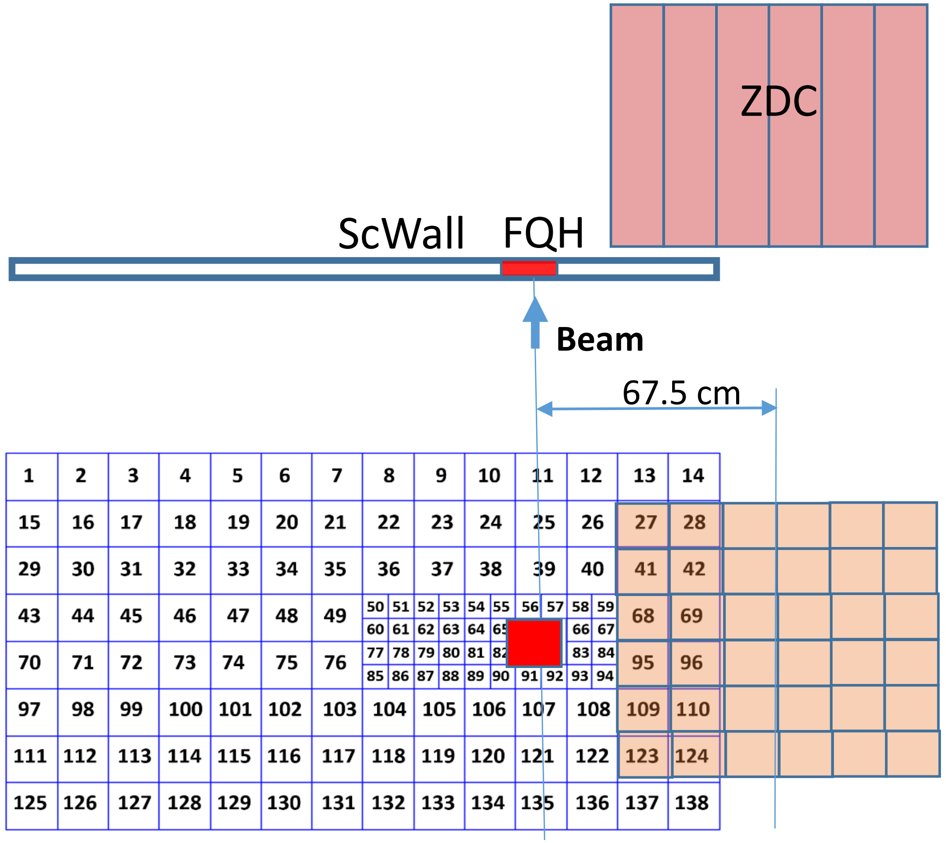




Large spatial separation between the proton and neutron spectators on the plane located at 9m from the target.

Separate measurements of heavy fragments, neutron and proton spectators are possible.

New BM@N forward detector system
proposed for separate measurements of charged spectators and neutrons



ZDC (36 FHCal central modules 15 x 15cm^2)– to measure neutron spectators.

Scintillator Wall (138 cells: 28 cells (75 x 75 x 10 mm^3).
+ 110 cells (150 x 150 x 10 mm^3)
and **FQH (**16 quartz strips 160 x 10 x 4 mm^3) – to measure charged fragments

Separate measurements of the neutron, proton and fragments could be possible with this detector system.

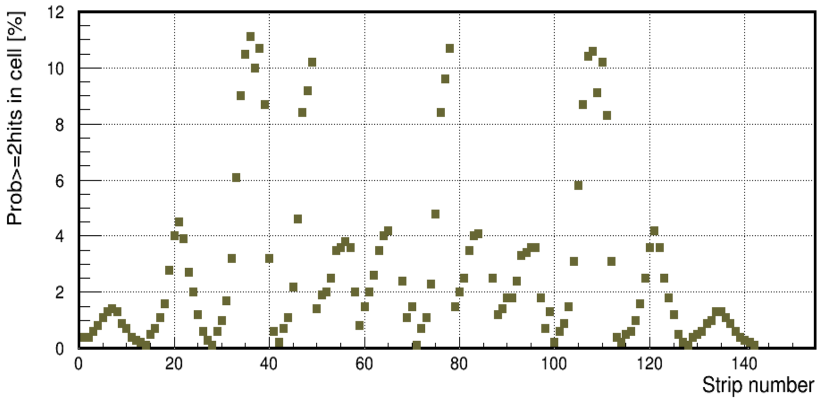
Occupancy of ScWall cells and in FQH strips

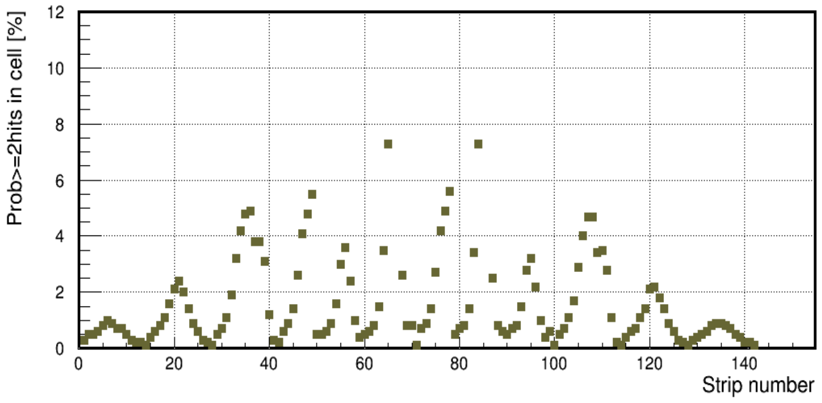
(probability to have >= 2 hits in cell (strip) [%] for charged particles and fragments)

DCM-QGSM

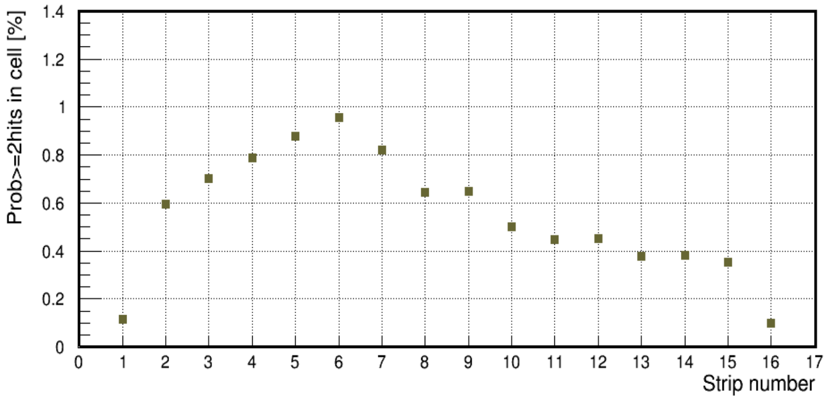
DCM-SMM

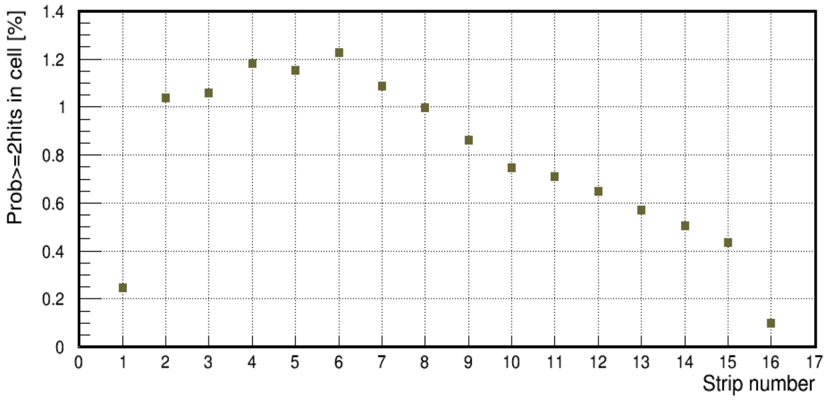
ScWall



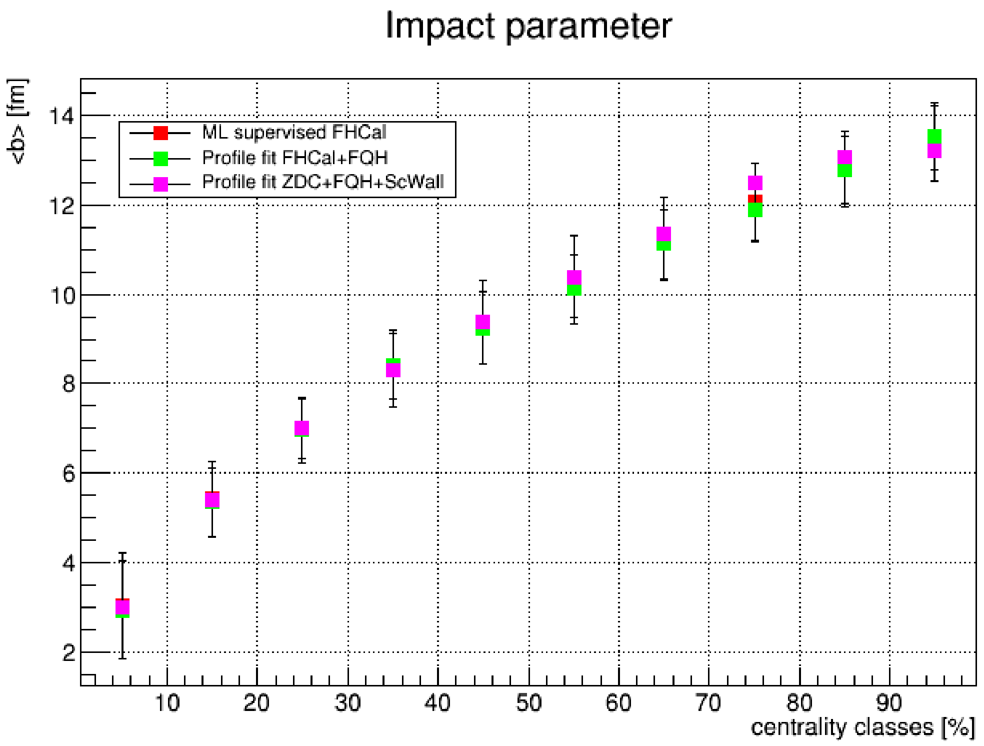


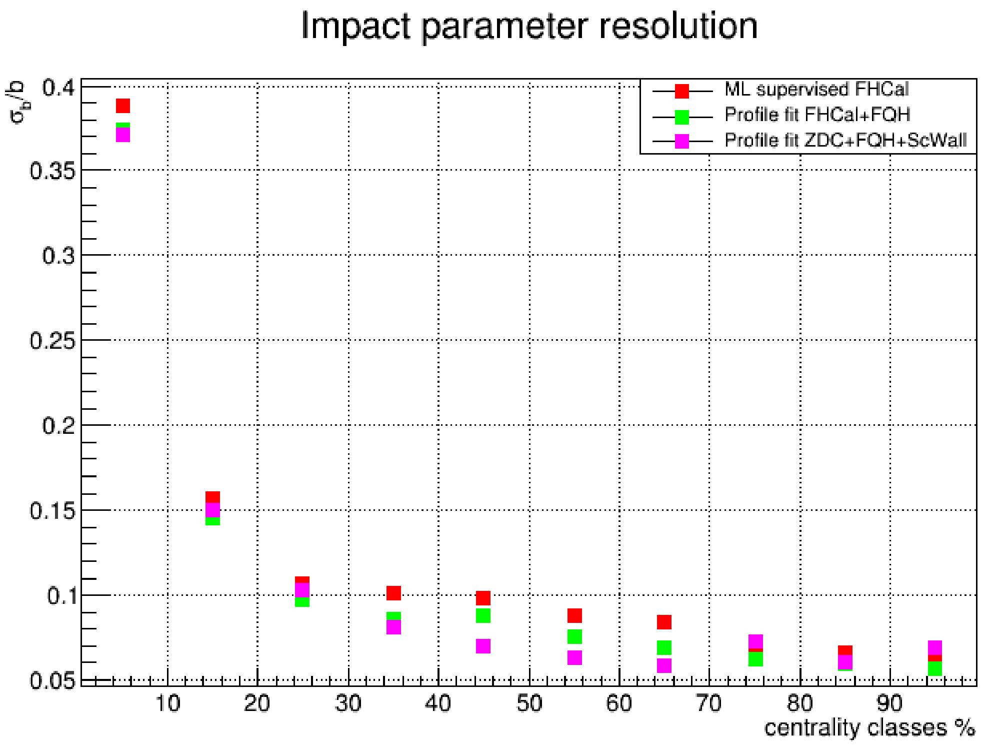
FQH





Comparison of centrality classes determination with different forward detectors

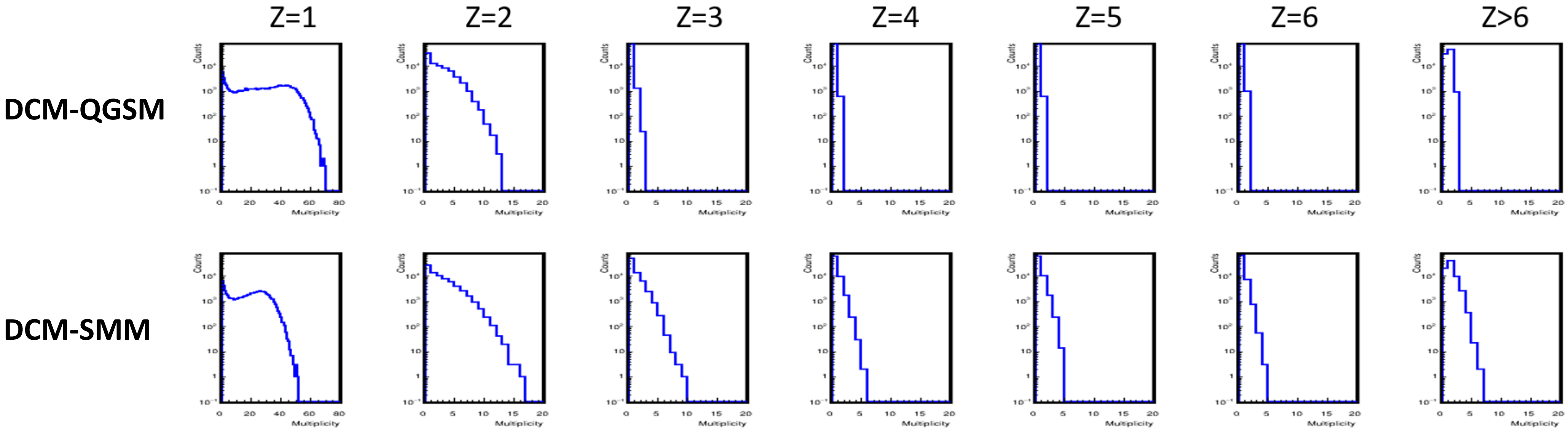




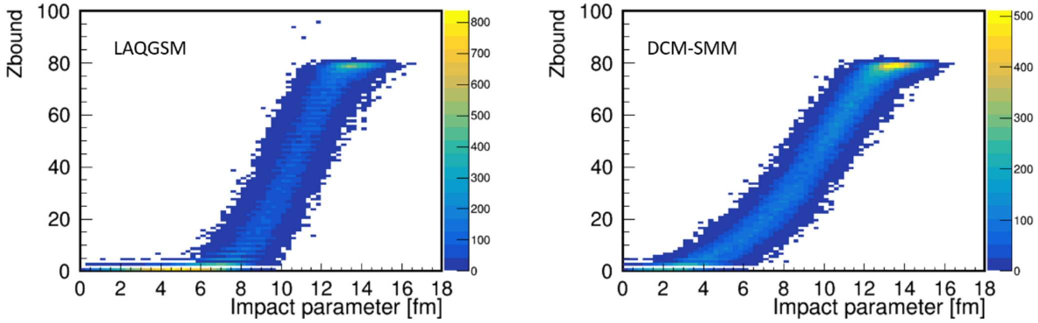
The best result is for combination of detectors ZDC + FQH + ScWall **(magenta points)**

Comparison of fragments distributions in DCM-QGSM and DCM-SMM models

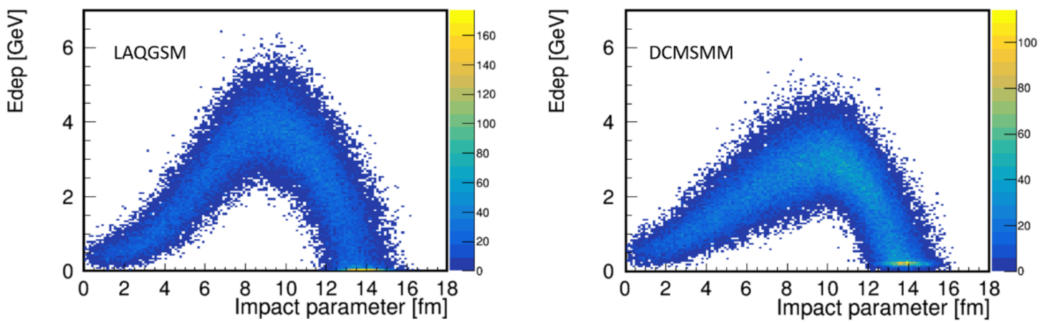
Charged particles multiplicity in ScWall + FQH



Z_{bound} distributions in ScWall+FQH



Neutron energy distributions in ZDC



Summary

- Two methods for centrality classes determination in nucleus-nucleus collisions using new FHCal and FQH detectors for projectile spectators measurements have been developed:

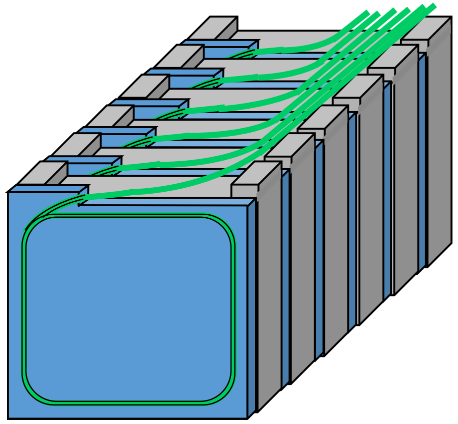
  - ML approach for FHCal
  - Correlation of Z^2 vs E_{dep} - (FQH +FHCal)

- New forward detector system – ZDC + ScWall +FQH was proposed for separate measurements of neutrons and charged spectators at the BM@N.

Thanks for your attention

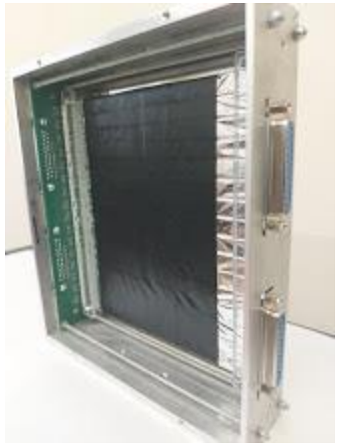
Structure of FHCAL modules

The FHCAL has transverse and longitudinal segmented structure and consists of separate modules.



- 20 CBM PSD module - 60 Pb/scint. samples. - (Pb(16mm), Scint(4mm)
  34 MPD FHCAL module - 42 Pb/scint. samples - (Pb(16mm), Scint(4mm)
- Length pf the MPD module – 4 λ_{int}, CBM module – 5.6 λ_{int}
- Light collections – 6 WLS fibers from 6 sequentially scint. tiles (one section) are combined in one optical connector at the end of module.
- Light readout: 10 MPPC (3x3 mm^2) per CBM module and 7 MPPC per MPD module.
- Weight of the CBM PSD module – 500 kg.
  Weight of the MPD FHCAL module – 200 kg.

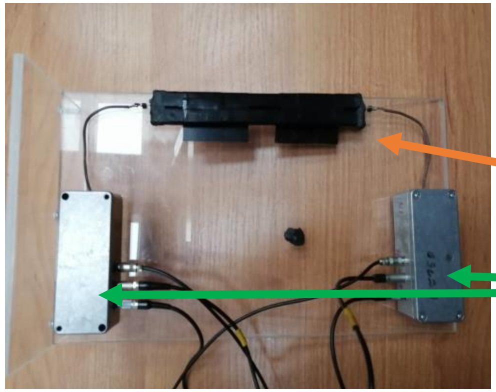
Status of development of Forward Hodoscopes



Quartz/scintillator hodoscopes have been constructed and tested in October at Synchrotron "PAKHRA"

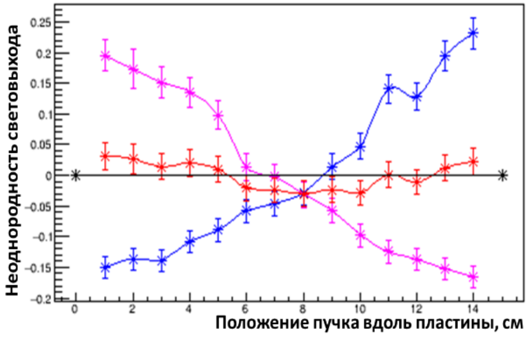
January 2020. Beam tests at Synchrotron "PAKHRA", LPI RAS, Troitsk, Moscow.

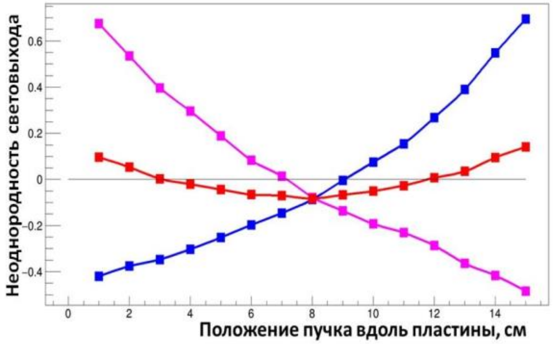
Energy E_e=700 MeV, Count rate ~ 50 Hz.



One quartz and one scint. strips

amplifiers





Non homogeneity of the light yield along the length in the quartz plate (±6%), left, and in scintillator strip (±10%), right, with SiPMs light collection from both strip sides . The average light yield from the two ends of the quartz plate is about 5 ph.el.