Status of Forward Hadron Calorimeter at MPD/NICA

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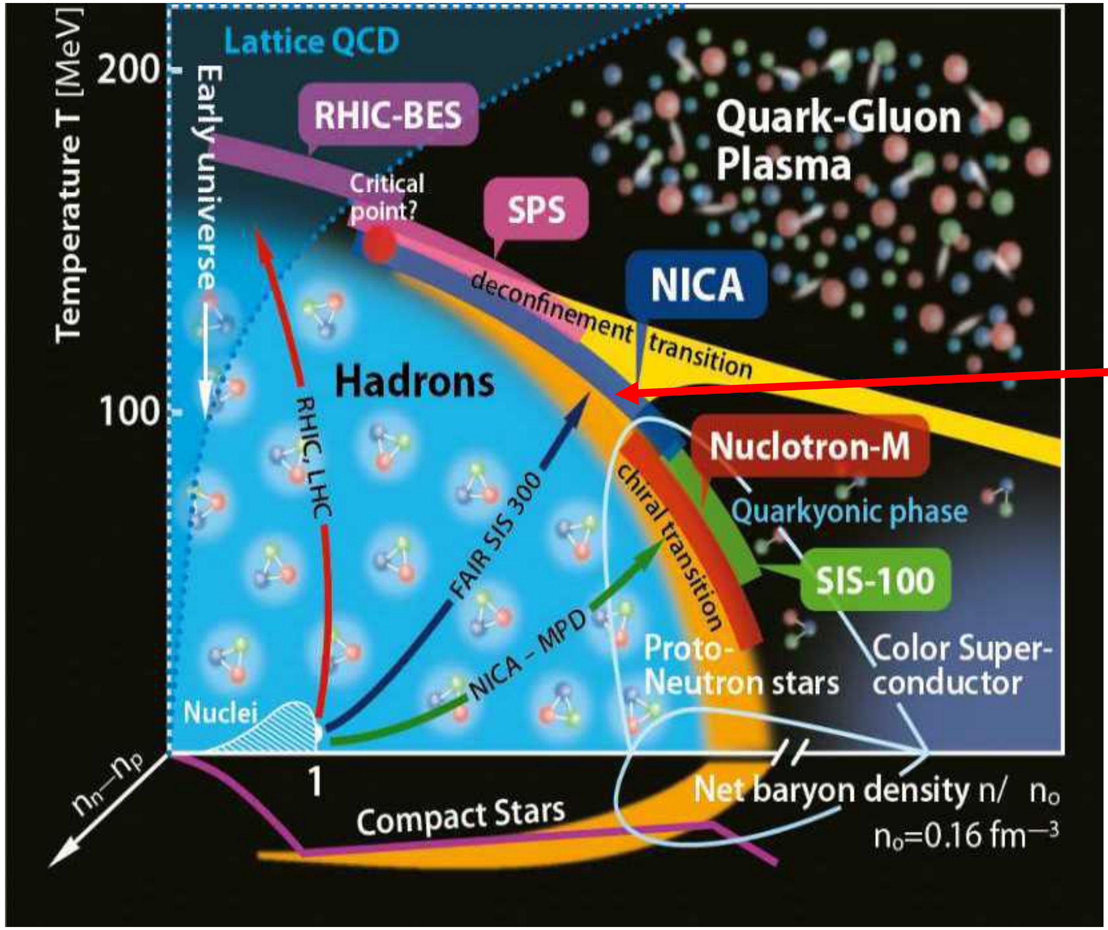
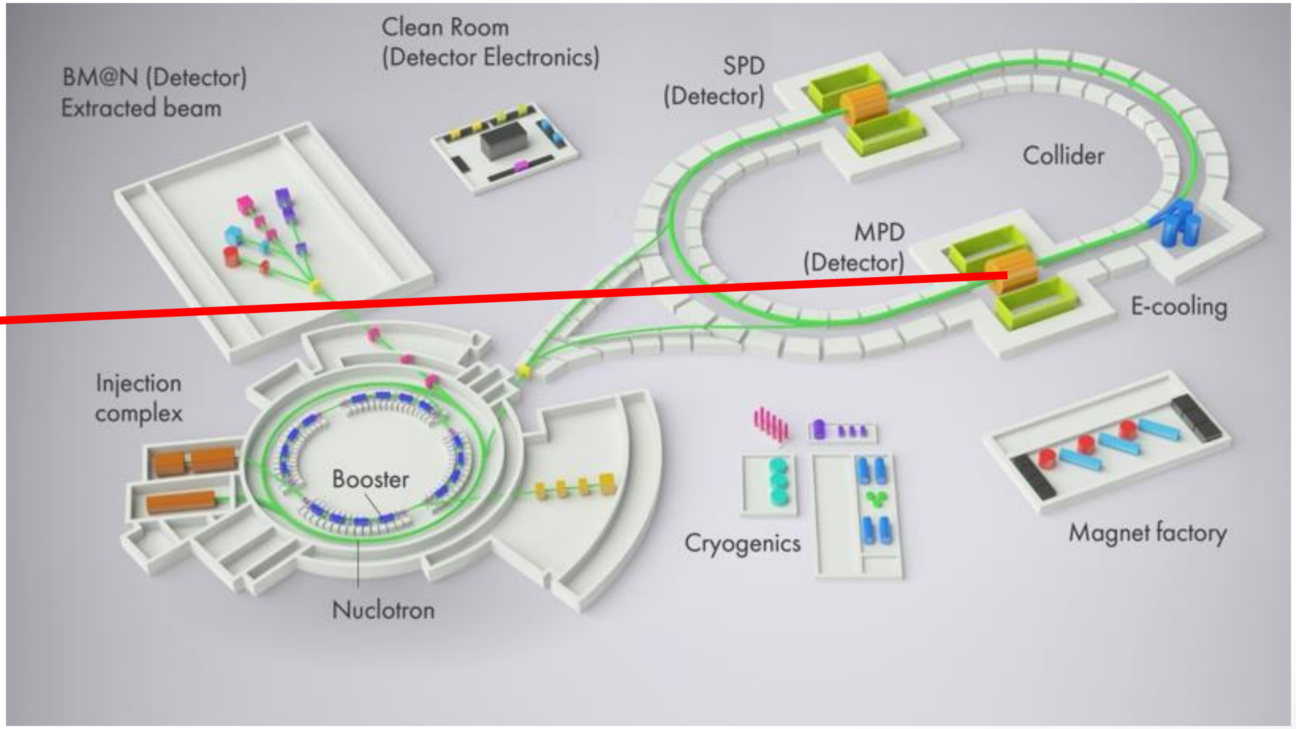
Outline

- Tasks and features of FHCal in MPD experiment
- Structure of FHCal modules
- Integration of FHCal in MPD
- Test bench at INR RAS
- Energy calibration with horizontal muons
- Feasibility of calibration with muons in whole solid angle

Goals of MPD/NICA project

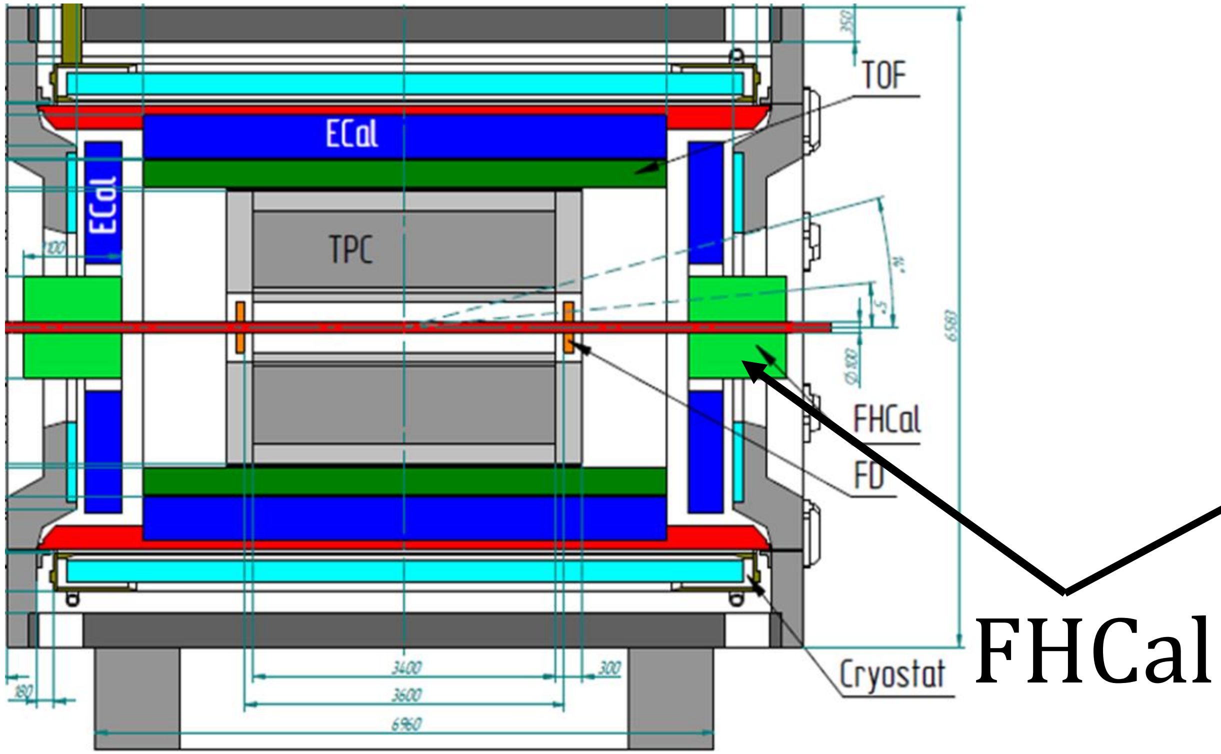


Phase diagram of QCD

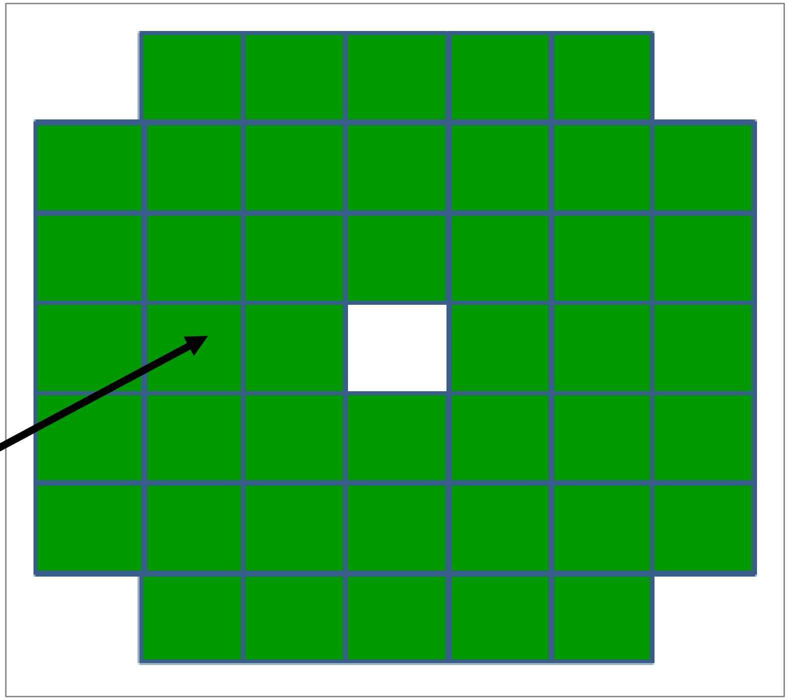


- research of phase transition
- research of mixed phase
- search for a critical point
- equation of state

Position and design of FHCal



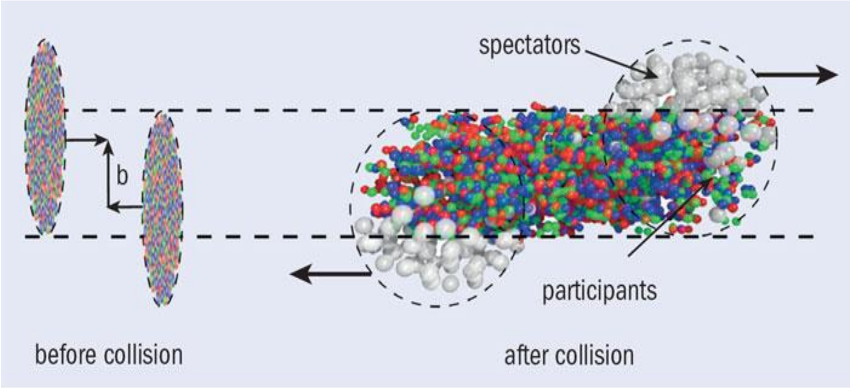
MPD structure

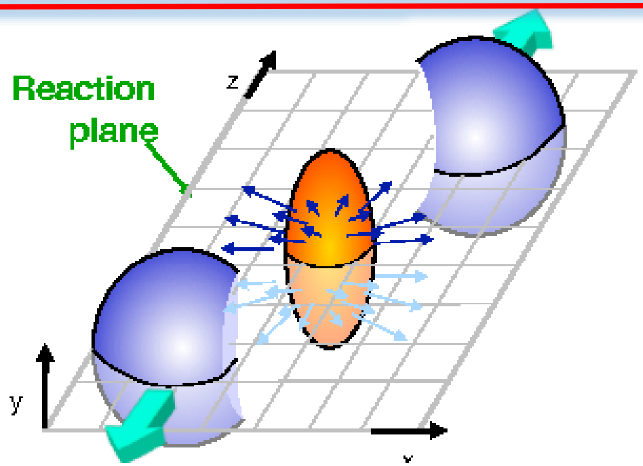


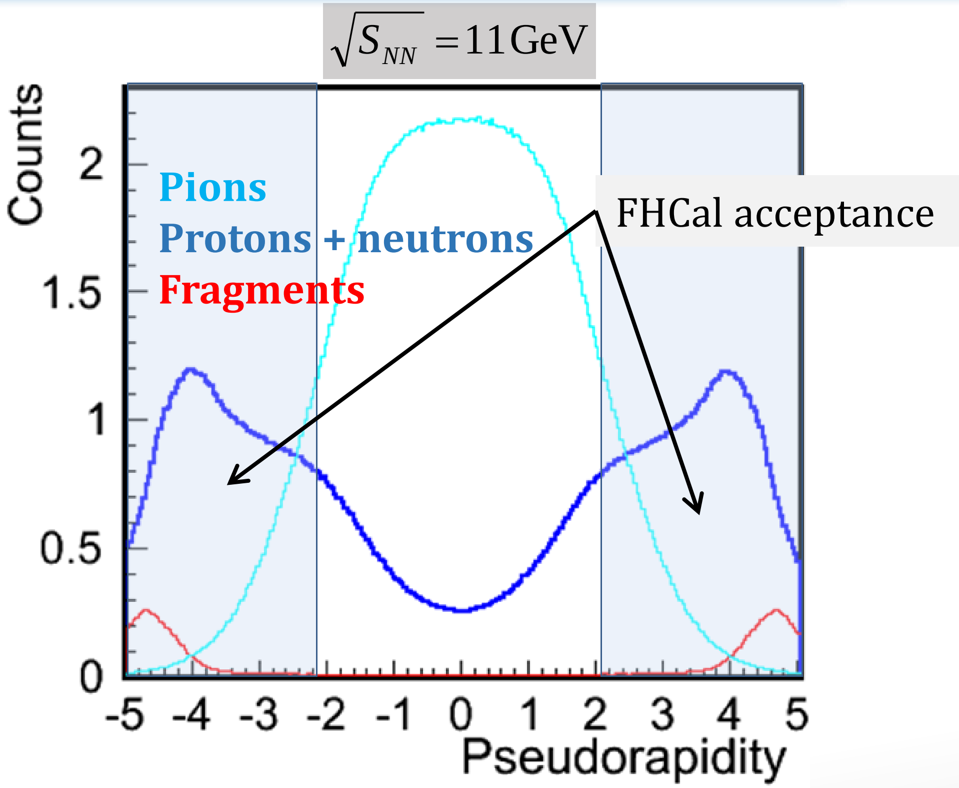
transversal cut of FHCal arm

- **FHCal consists of two arms of 44 modules;**
- **Each arm is positioned at 3,2 m from collision point;**
- **Transversal size of FHCal ~1.1x1.1 m^2;**
- **Beam hole in the centre**
- **Expected energy resolution** $\frac{\sigma_E}{E} = \frac{57\%}{\sqrt{E[GeV]}}$

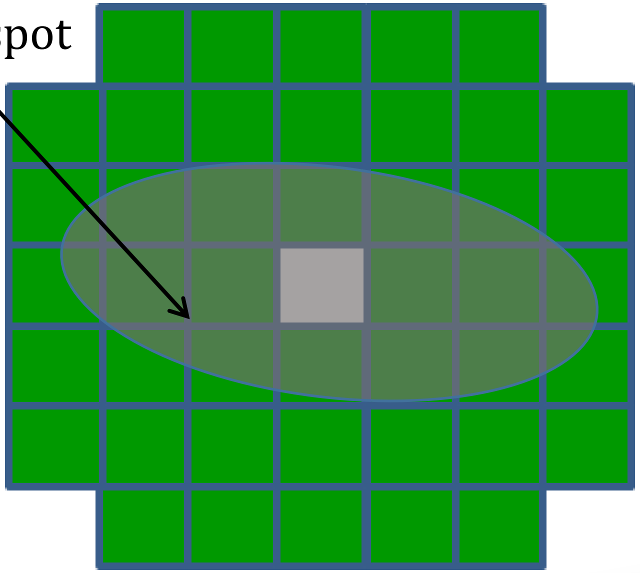
FHCal features







Spectator spot



FHCal detects

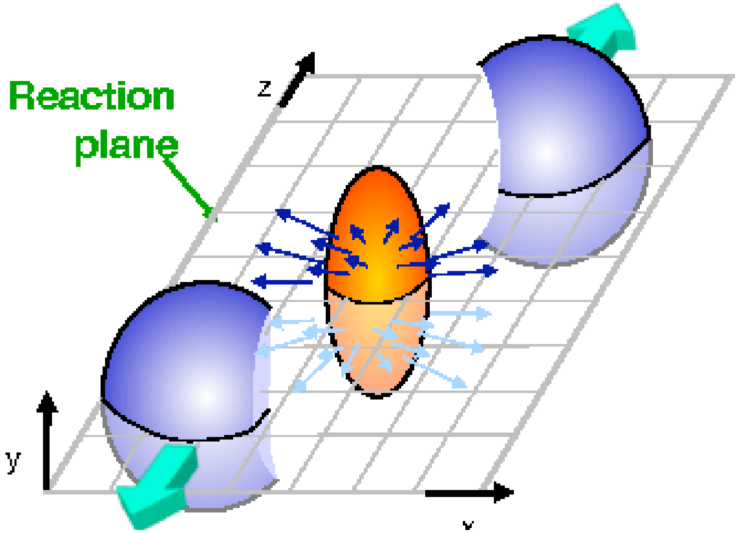
- ✓ **the energy of spectators;**
- ✓ **the space distribution of the spectators;**

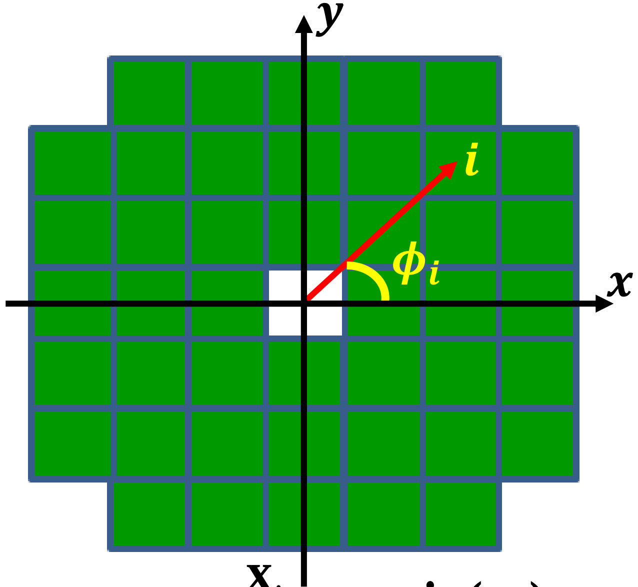
To measure centrality and reaction plane of collision

- **Since FHCal has a beam hole, most of the <u>bound spectators</u> leak in this hole.**
- **Mainly, <u>free spectators</u> (protons and neutrons) deposit energy in FHCal.**

Task 1: Reconstruction of the event plane with spectators

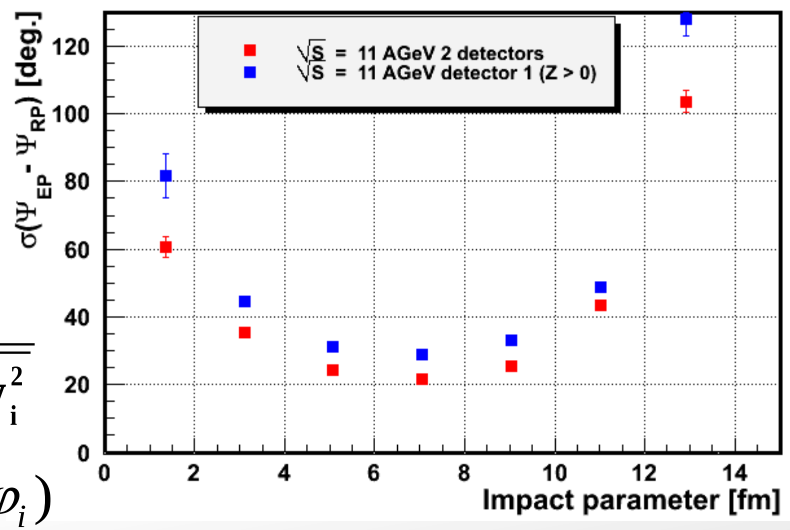
From energy and space distribution of spectators one can determine the <u>event plane</u> as an experimental estimate of the reaction plane.





$$\cos(\varphi_i) = \frac{x_i}{\sqrt{x_i^2 + y_i^2}} \qquad \sin(\varphi_i) = \frac{y_i}{\sqrt{x_i^2 + y_i^2}}$$

Resolution: difference between true reaction plane and reconstructed event plane.



Event plane in first FHCal part: $\Psi_{1,EP} = acrtg \frac{\sum E_i \sin(\varphi_i)}{\sum E_i \cos(\varphi_i)}$

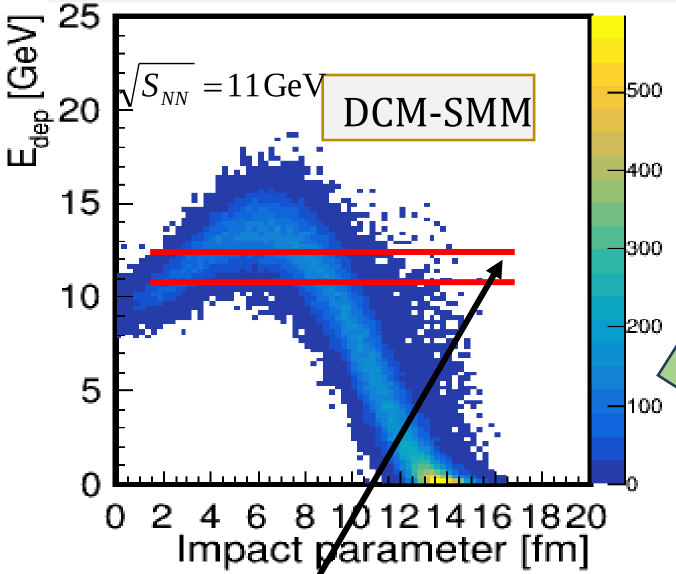
Event plane in both FHCal parts: $\Psi_{EP} = \Psi_{1,EP} + (\Psi_{2,EP} + \pi)$

Detection of all types of the spectators (protons, neutrons) for both colliding nuclei would ensure the outstanding $\approx 20^{\circ}$ angular resolution of the event plane!

Task 2: Solving ambiguity in centrality determination

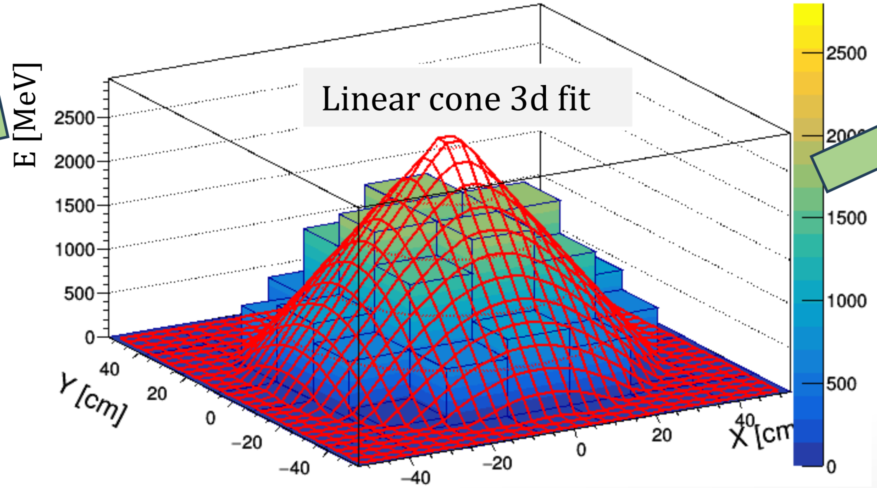
- For hermetical calorimeter the energy deposition of spectators has monotonic dependence on impact parameter.
- It is not true in real situation.

Energy deposition: $\mathbf{E_{dep}}$
Maximum energy: $\mathbf{E_{Max}}$ **– height of cone fit**

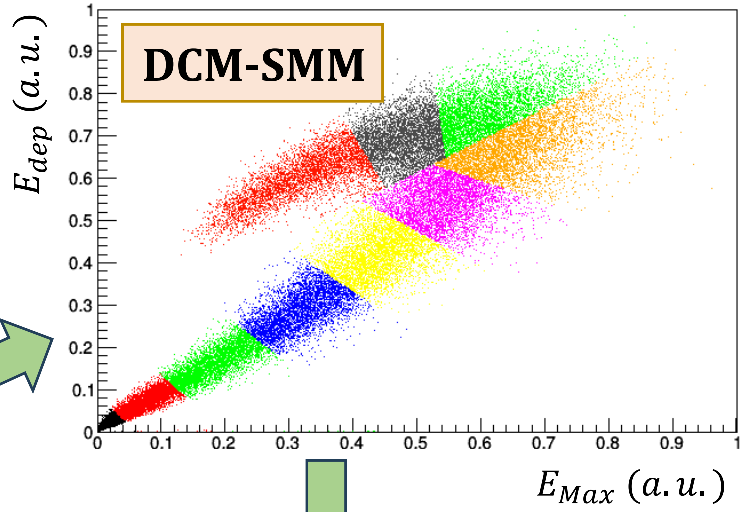


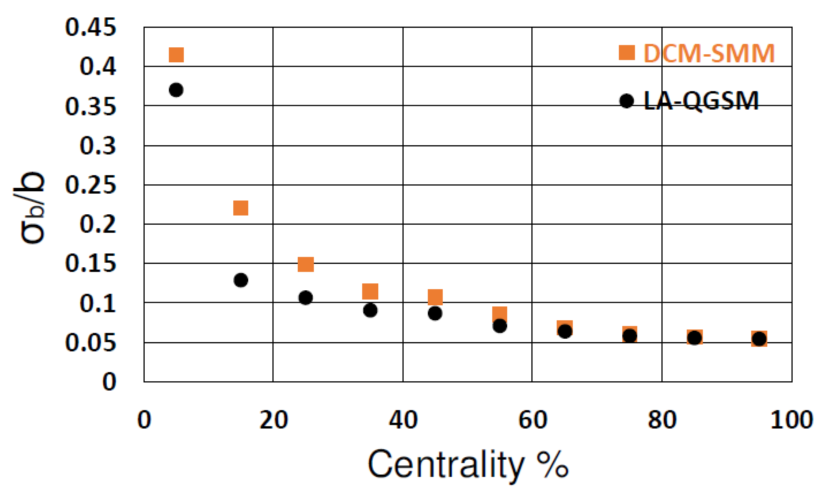
- **Heavy fragments escape into beam hole**
- Ambiguity in centrality reconstruction for central and peripheral events

Energy distribution in FHCal modules in single event

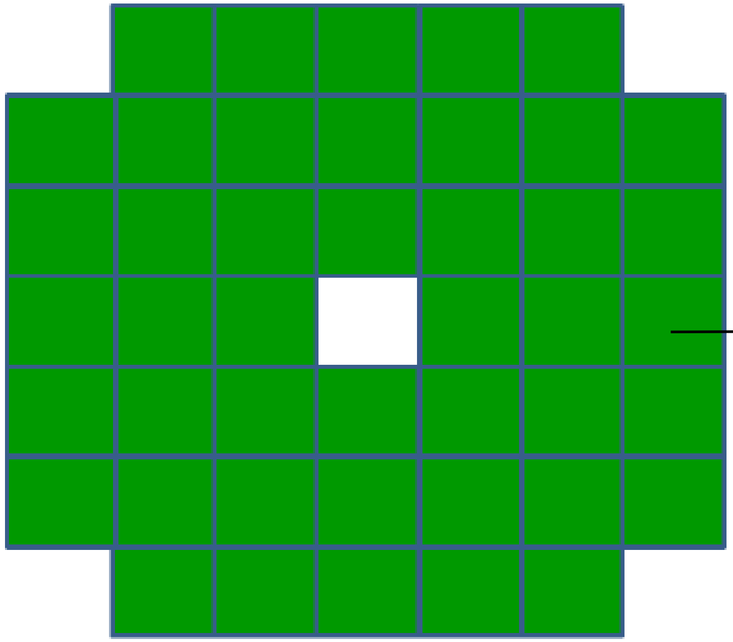


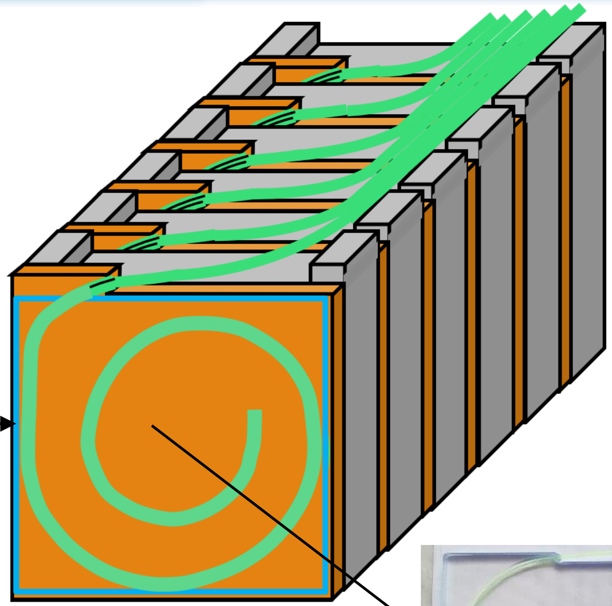
(x, y) coordinates of module center



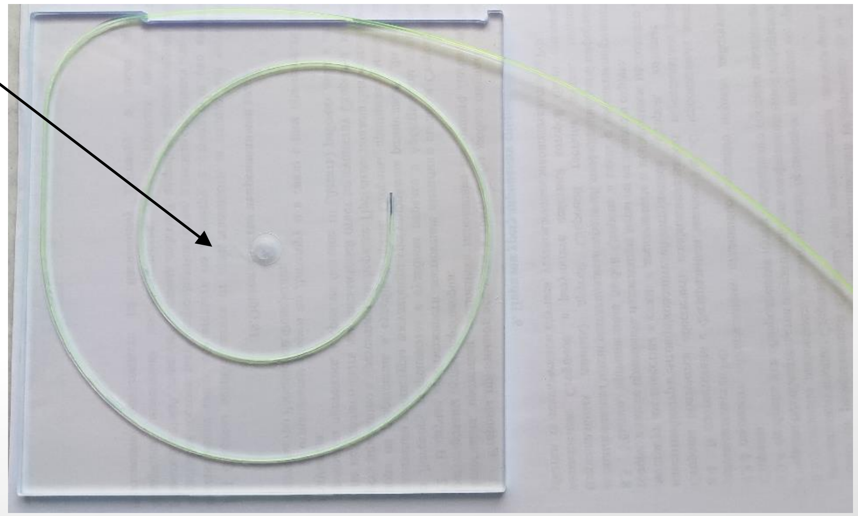


Design of FHCal module





FHCal module



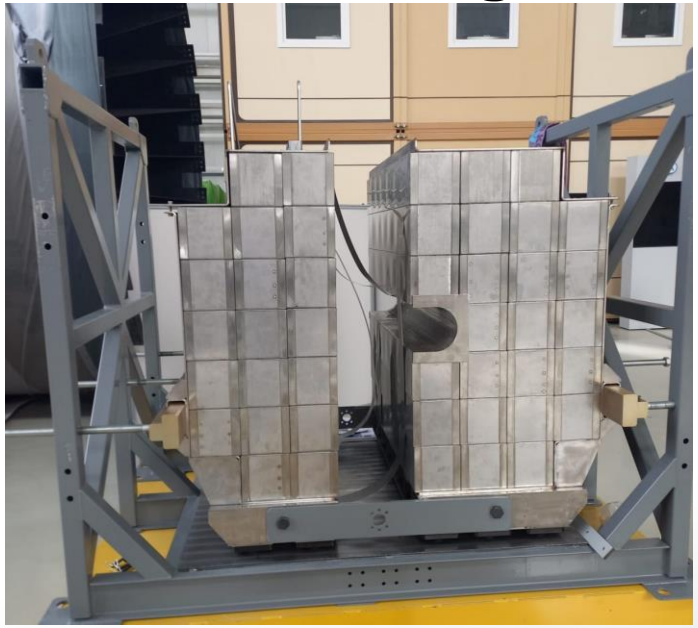
Scintillator plate

- **A module will consist of 42 pairs of lead/scintillator plates (16mm/4mm) having total length of 84cm**
- **Transversal size of FHCal module: $15x15cm^2$;**
- **Module length ~ 4 λ_{int};**
- **Each module consists of 7 equal sections;**

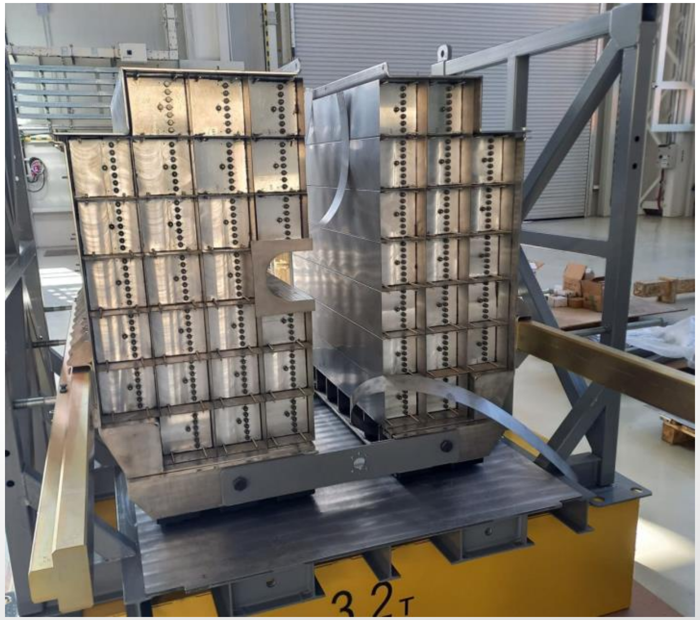
FHCal modules at MPD hall

In Nov'23
90 modules were delivered form INR to MPD hall

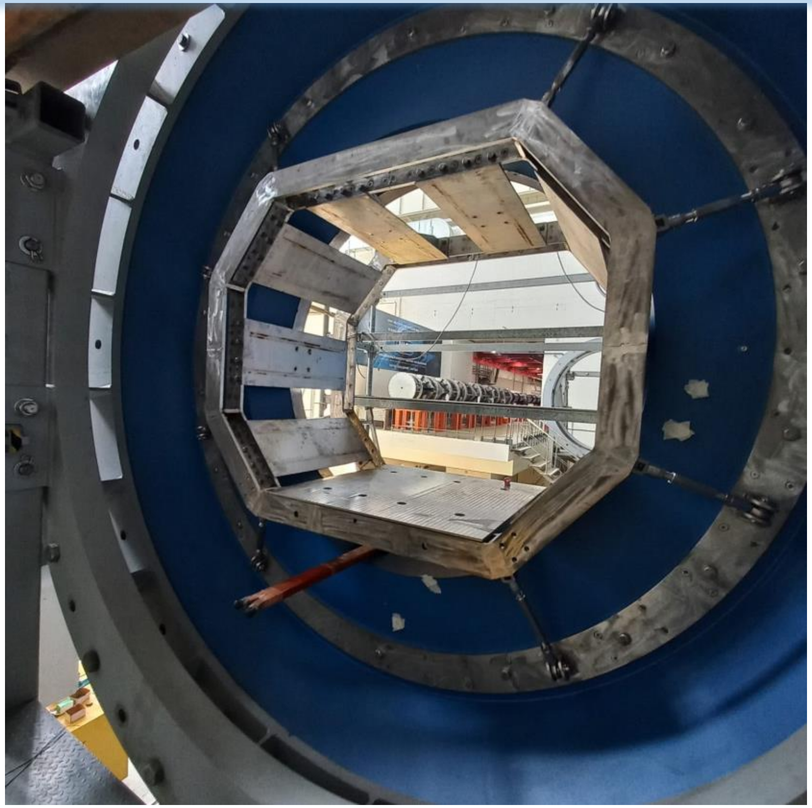
Assembling of FHCal modules in basket at floor:



April'24



FHCal installation into magnet pole (Sept'24)



FHCal support frame in magnet pole

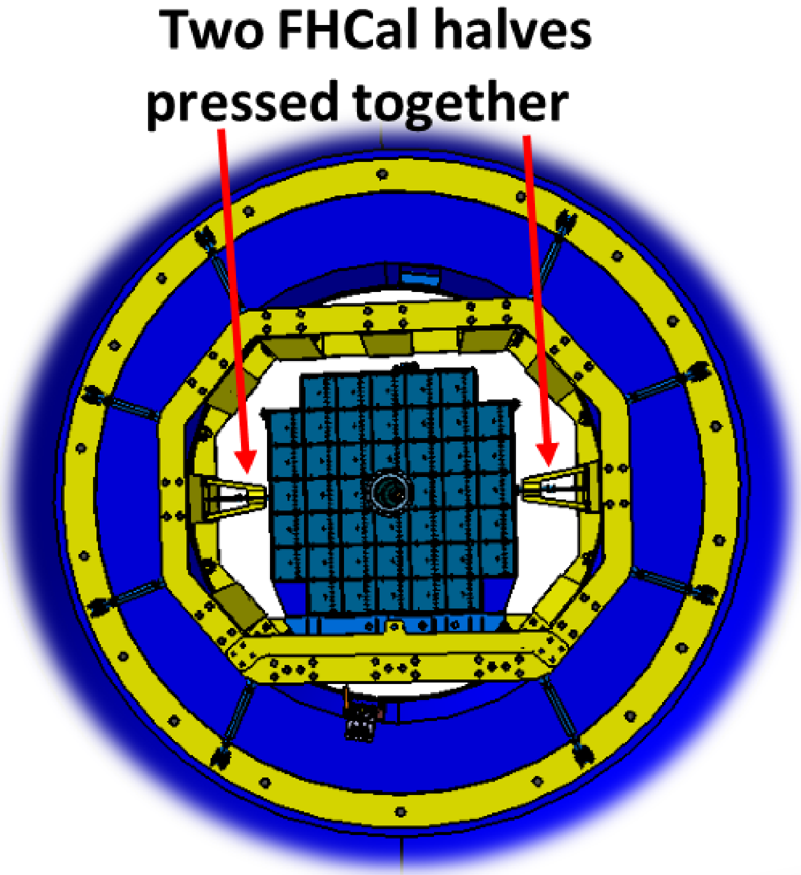
Outer view

Inner (front) view

FHCal arm already moved into magnet pole!

Step 3: Press FHCal parts together

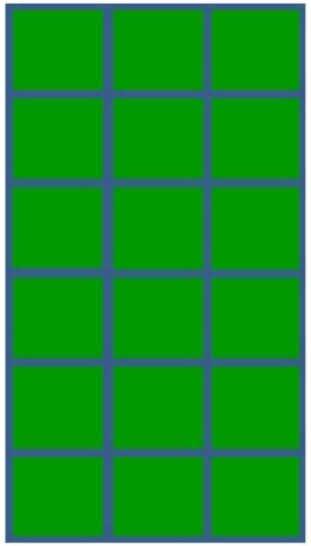
Drawing



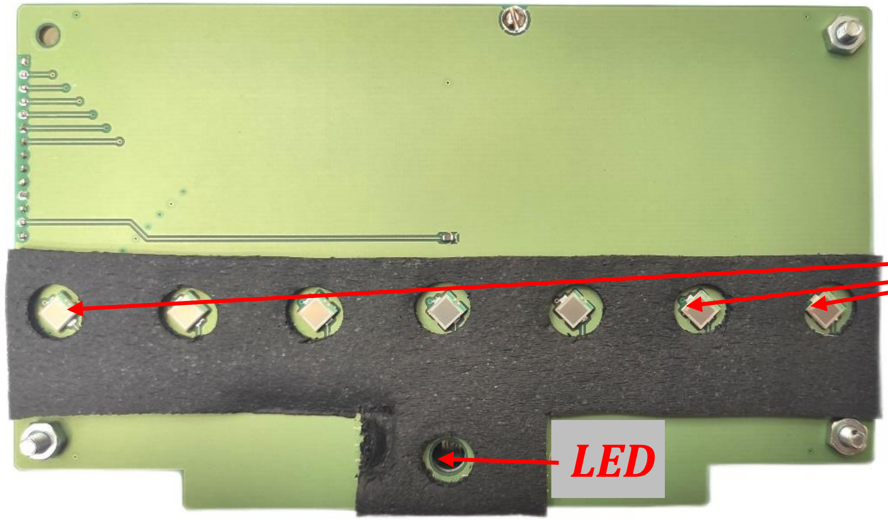
Front End Electronics installed in modules

FHCal parts should be pressed together!
To be done soon!

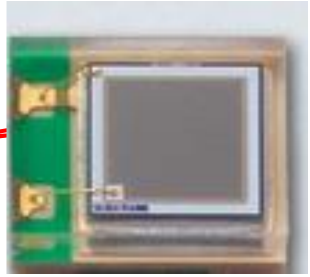
Test bench at INR RAS



Test bench of 18 modules



Front End Electronics (FEE)



Photodetector (SiPM)
Hamamatsu MPPC
S14160-1315PS

Parameters of Hamamatsu MPPC S14160-1310PS

+ high dynamic range (90000 pixels)
+ short recovery time (~10 ns)
+ high count rate
- low photon detection efficiency (< 18%)

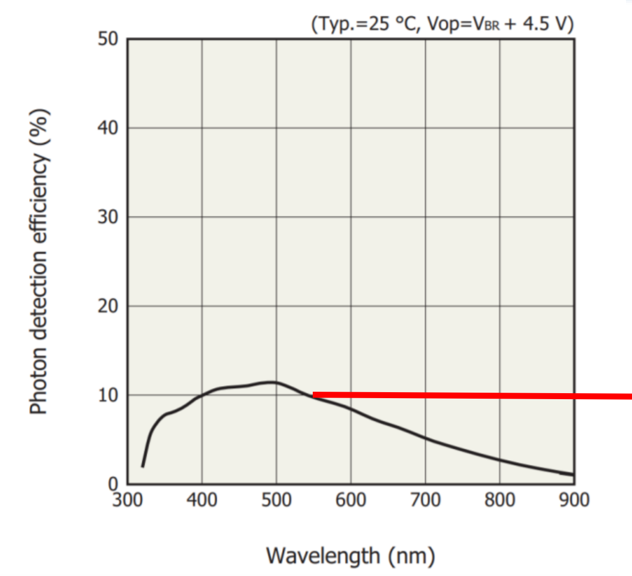
New generation SiPMs allow for more advanced calibration method

Old generation SiPMs:

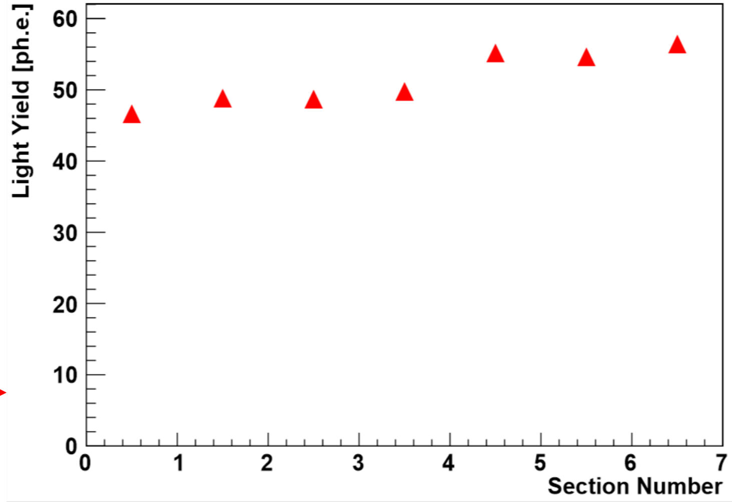
$PDE = 12\%$

$U_{br} \approx 70\ V$

$Gain \sim 10^5$



Hamamatsu MPPC S12572-010C



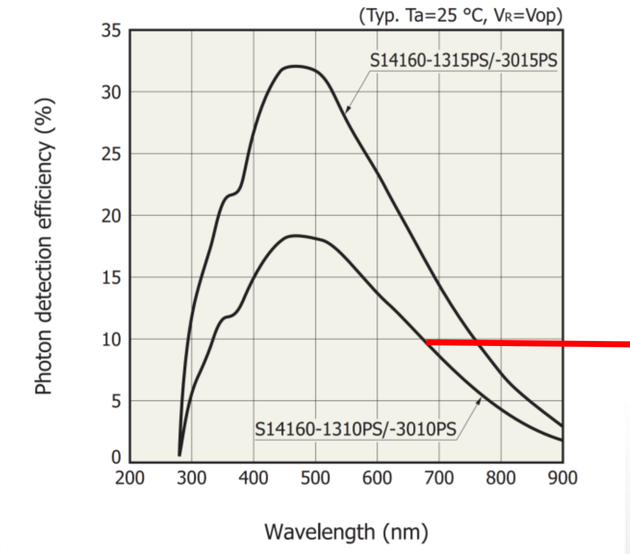
Light yield in sections for old SiPMs

New generation SiPMs:

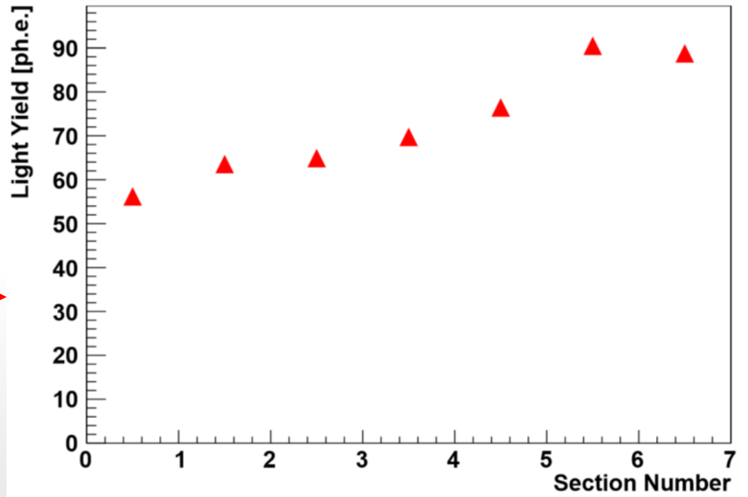
$PDE = 18\%$

$U_{br} \approx 38\ V$

$Gain \sim 1.8 \cdot 10^5$



Hamamatsu MPPC S14160-1310PS

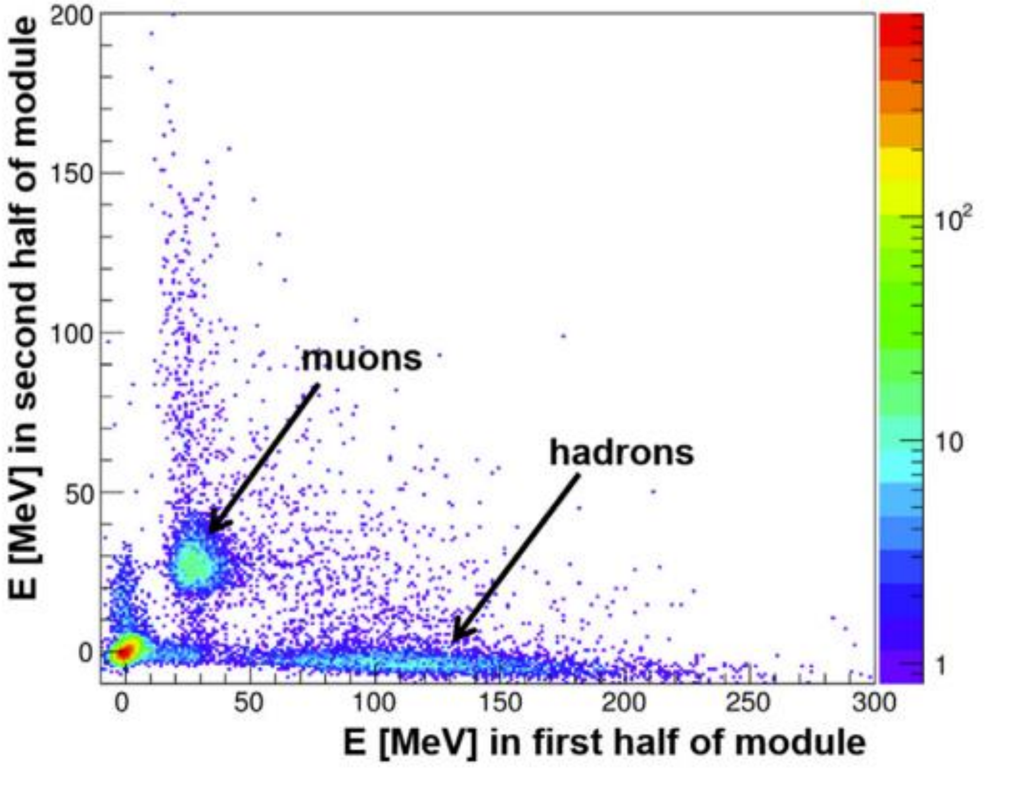


Light yield in sections for new SiPMs

High performance of new SiPMs allows to observe muon peaks above noise

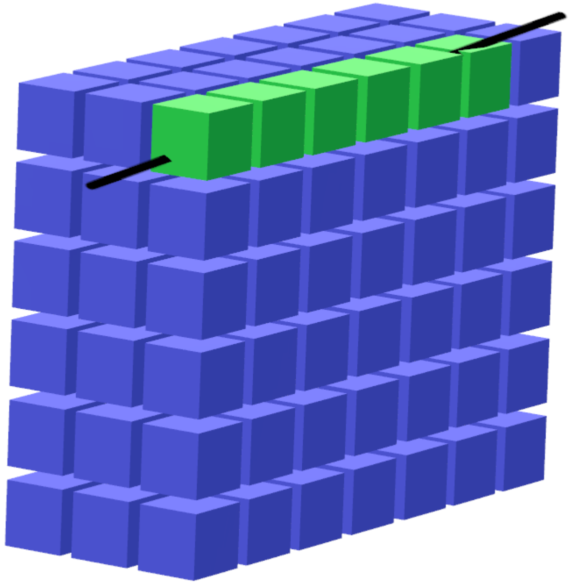
Calibration of FHCal modules with muon beams

- A test bench of modules was studied in CERN at T9/T10 beamlines
- T9/T10 beam lines provide pion and proton beams in range of 2-6 GeV
- $\pi \rightarrow \mu\nu_{\mu}$ decay in beam line allows using muons for calibration of modules sections
- Energy depositions of muons (unlike hadrons) in sections are close for all sections
- Correlation of total energy deposition of muons inside first and second halves of modules allows to reliably separate muons from hadrons
- According to MC simulation energy deposition of muon in single section to be about ~5 MeV



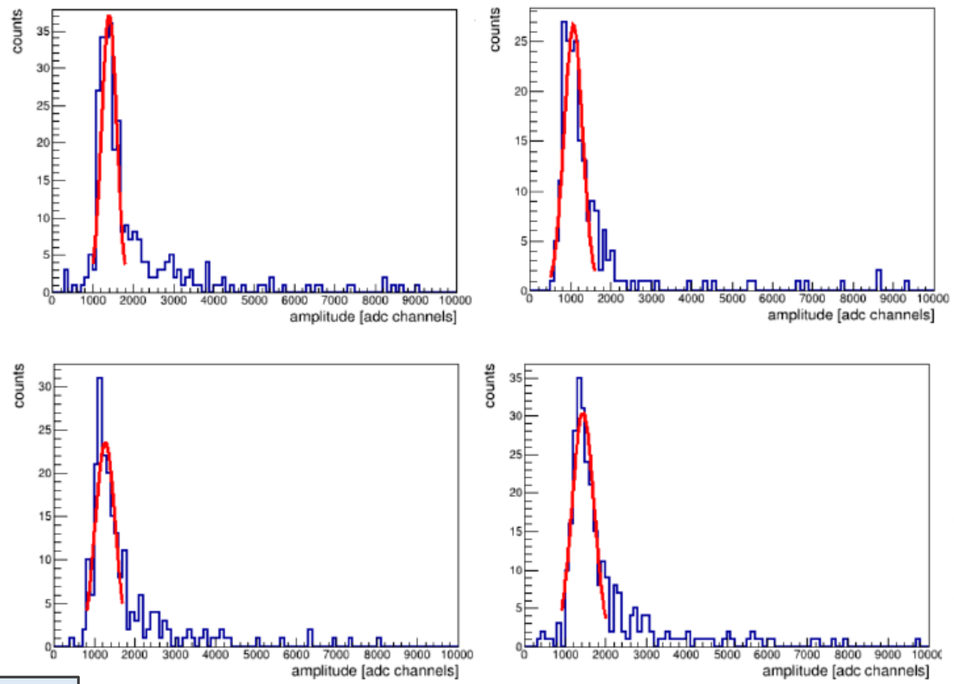
Correlation of energy depositions in first and second halves of modules

Energy calibration with horizontal cosmic muons

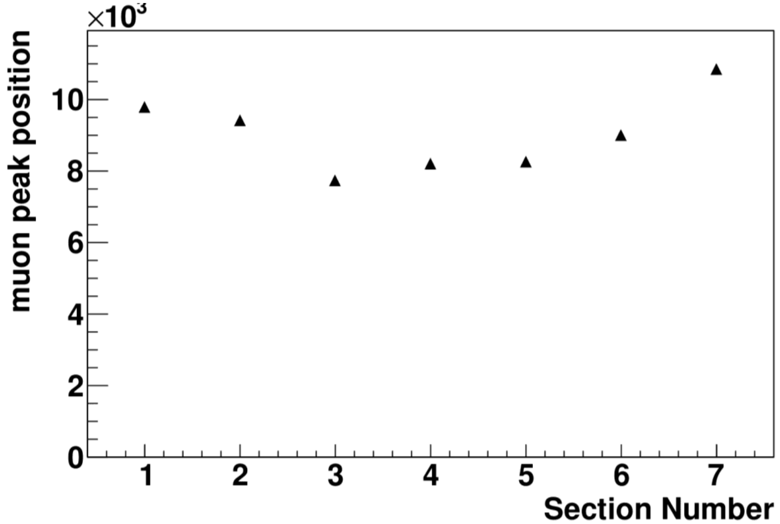


Different muon tracks that are were considered. For example
- ❖ when two neighbor sections signals
- ❖ three neighbor sections signals
- ❖ all sections signals

are compared



Examples of horizontal cosmic muon amplitude spectra for FHCal module sections (one week of data acquisition)

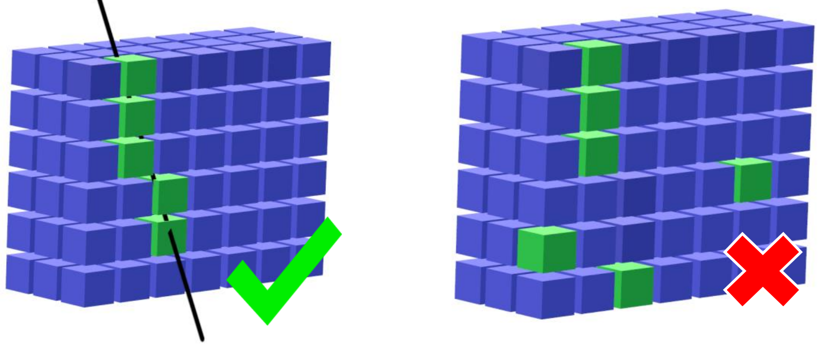


Light yield in module sections for horizontal cosmic muons

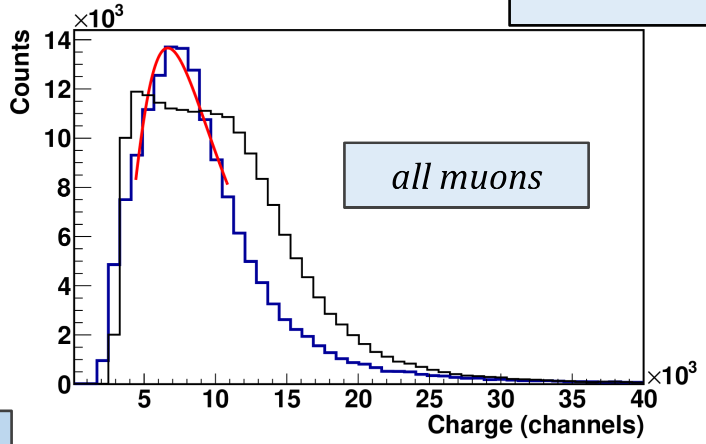
Main con: low statistics horizontal muons! Data acquisition takes 1 week.

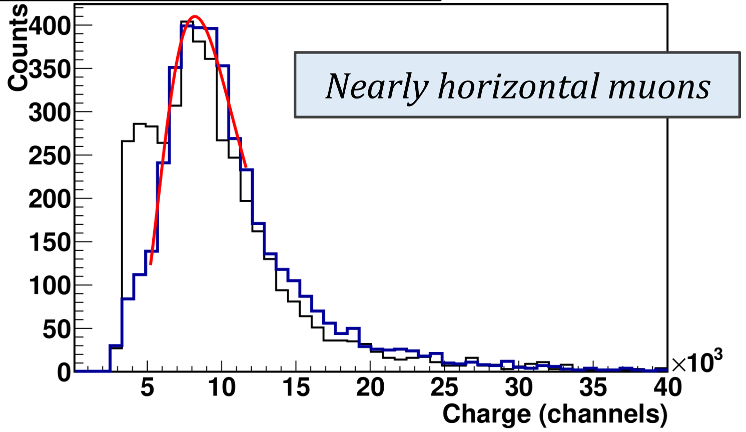
All muons track selection and charge on pass length correction

Izvestnyy, A, et. Al “Calibration of FHCal with cosmic muons at the BM@N experiment.”



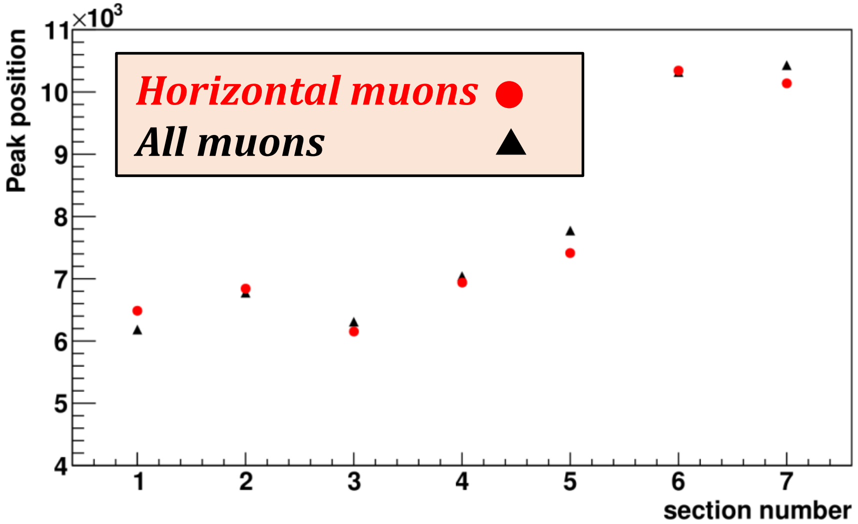
Charge spectra ***without*** *and* ***with*** *track reconstruction*





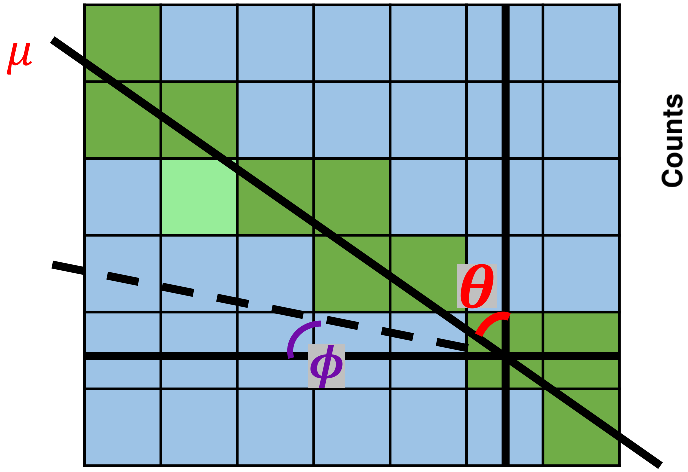
Muon track selection:

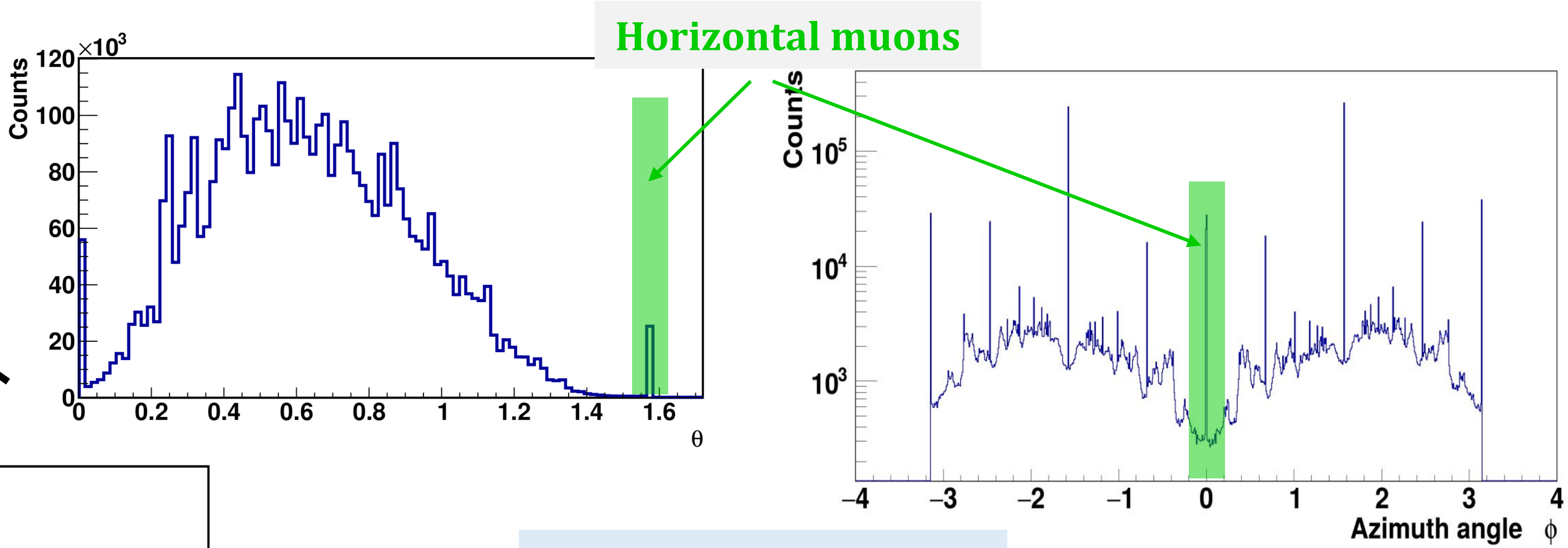
- only adjacent sections tracks are chosen;
- Tracks are reconstructed using deviation minimization procedure with energy deposition as weight coefficients;
- Correction on pass length in scintillator is required.



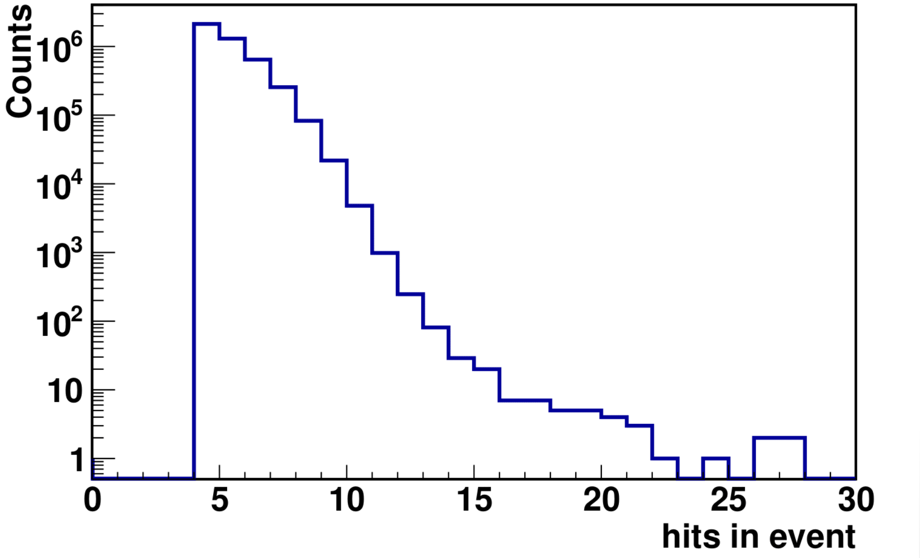
- ❖ 5 MeV peaks correspond to nearly the same charge on both spectra
- ❖ Spectrum for the new calibration technique contains ~50 times more events than horizontal muons spectrum
- ❖ Application of new technique for strictly horizontal muons does not change the 5 MeV peak position

Angular (polar and azimuthal) distribution of muons





Muon track angles



Number of fired sections

Spectra of track angles show several features of the method:

- ❖ Multiple peaks are due to finite number of sections and layer structure.
- ❖ Majority of muon tracks pass with the angle $\theta \approx 34°$ respective to normal axis.

Summary

- FHCal is one of the basic detectors of MPD aimed at the reconstruction of heavy ion collision geometry.

- One arm of FHCal has already been constructed and integrated in MPD.

- Test bench of 18 modules at INR RAS is used for the FHCal electronics development and energy calibration.

- Different approaches in cosmic muon calibration are tested.

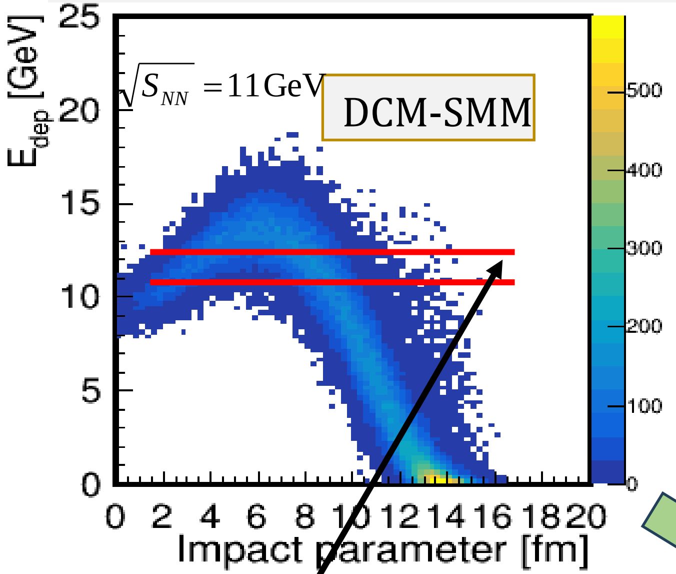
- Calibration with horizontal muons provides a clear detector response with 5 MeV energy deposition in each longitudinal section of FHCal modules. But this method requires one week of data taking.

- Whole solid angle technique is 50 times faster but requires the correction of energy depositions to muon track lengths in FHCal modules.

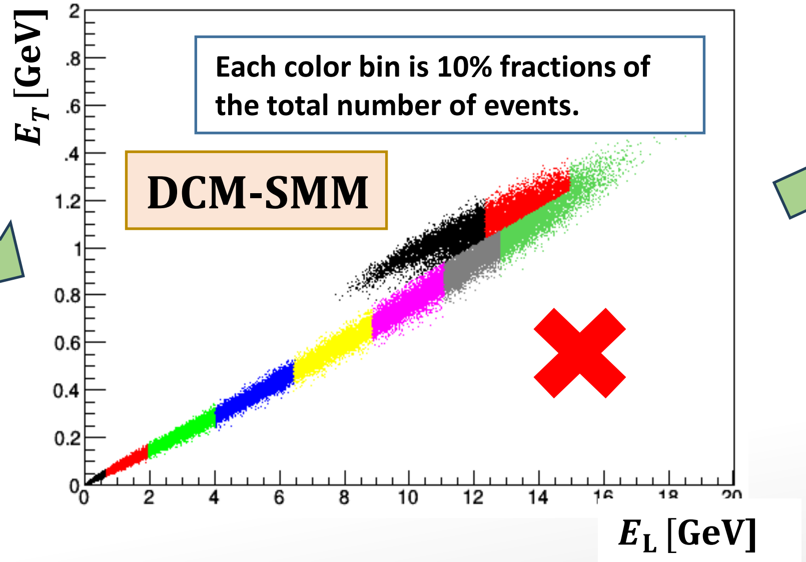
Thank you for your attention

Task 2: Ambiguity in centrality determination

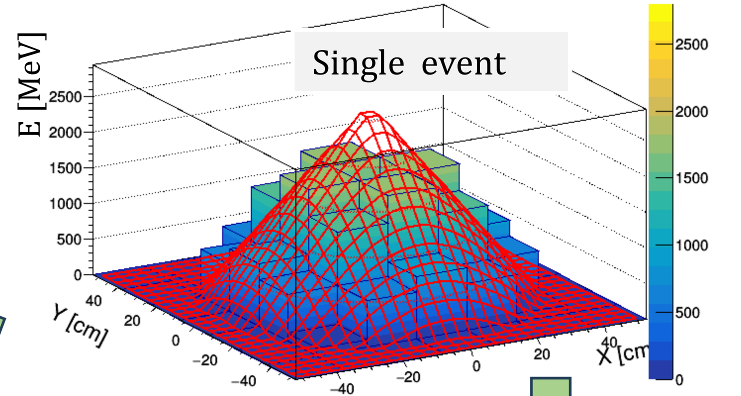
- For hermetical calorimeter the energy deposition of spectators has monotonic dependence on impact parameter.
- It is not true in real situation.

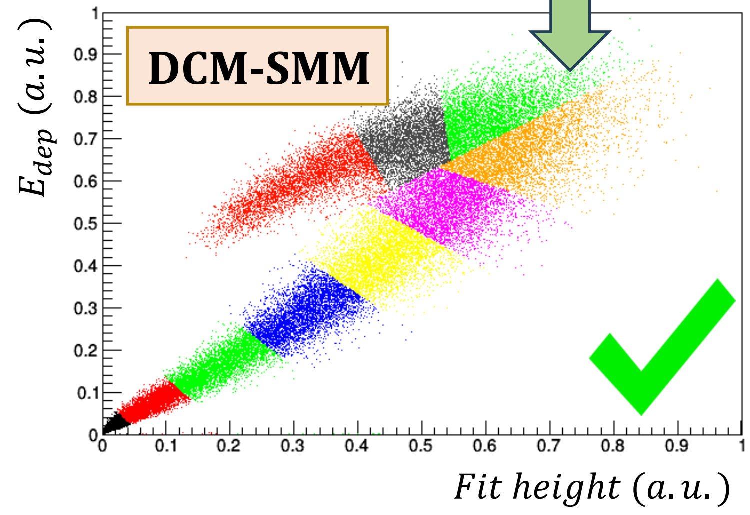


Observables
Transverse energy: $E_T = \sum E_i\, sin\theta_i$
Longitudinal energy: $E_L = \sum E_i\, cos\theta_i$
θ_i **angle of i FHCal module**



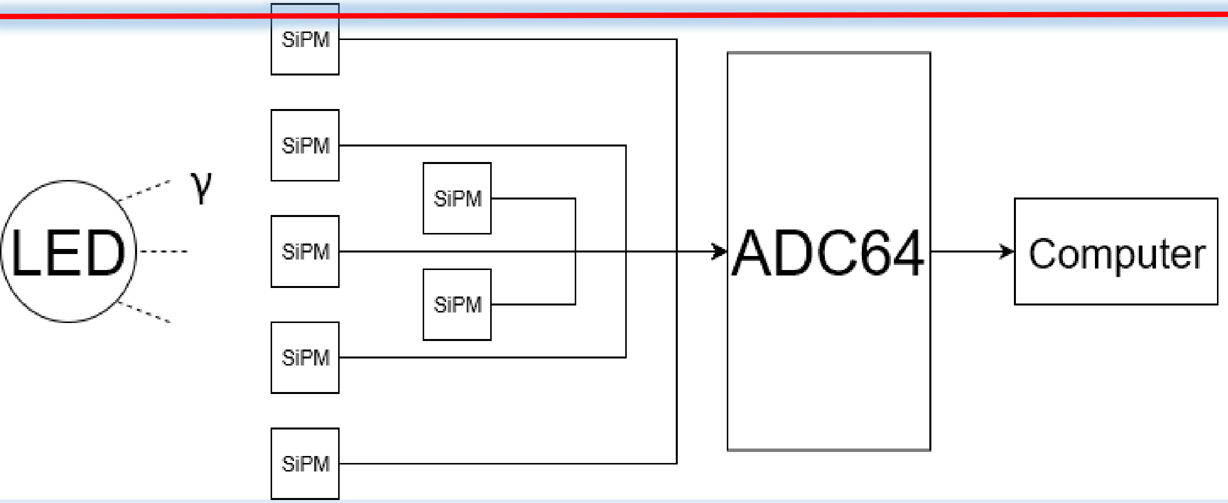
Energy distribution in FHCal modules



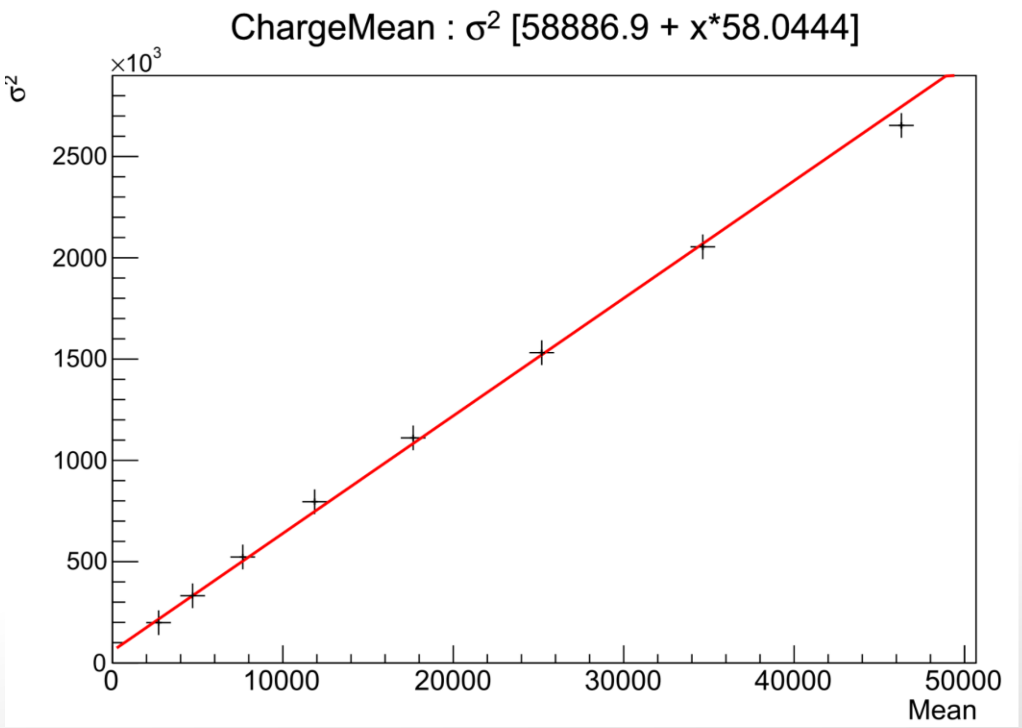


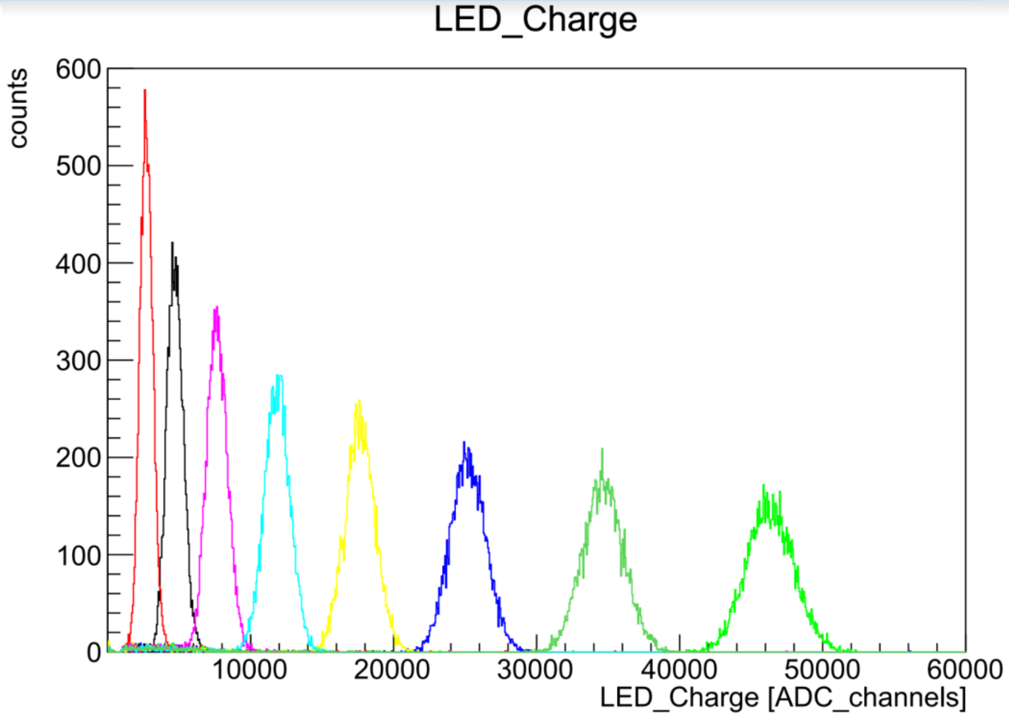
- **Heavy fragments escape into beam hole**
- Ambiguity in centrality reconstruction for central and peripheral events

Absolute calibration



Experimental setup scheme





LEDs amplitude spectrum for a module

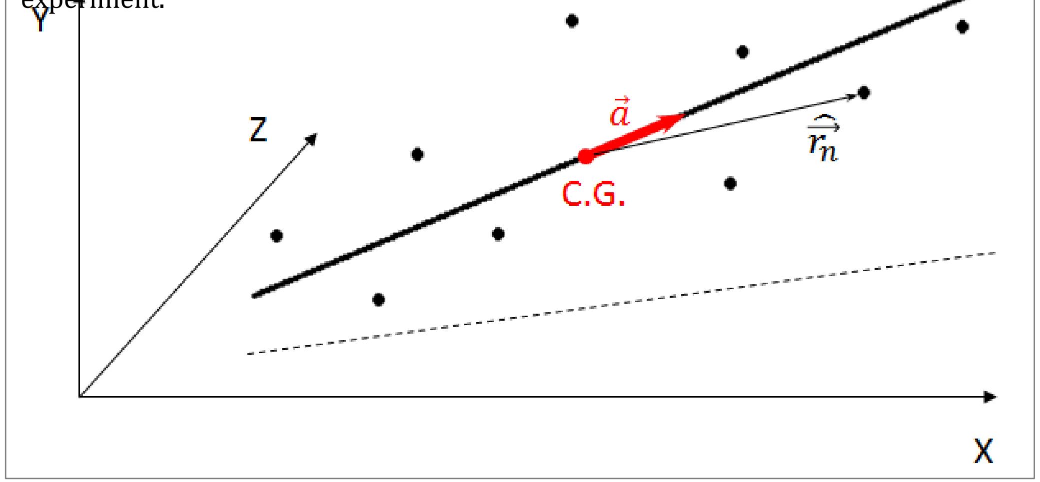
These spectra have Poisson distribution. Poisson distribution has following parameters: $\sigma[\text{ф.э}] = \sqrt{N}$, $Mean[\text{ф.э}] = N$

$$Mean[channels] = calibration\_coefficient \cdot Mean[ph.e];$$

$$\sigma[channels] = calibration\_coefficient \cdot \sigma[ph.e];$$

$$\boldsymbol{N = \left(\frac{Mean}{\sigma}\right)^2 \Rightarrow calibration\_coefficient = \frac{\sigma^2}{Mean}\left[\frac{channel}{photoelectron}\right]}$$

Track selection and charge on pass length correction



Izvestnyy, A, et. Al “Calibration of FHCal with cosmic muons at the BM@N experiment.”

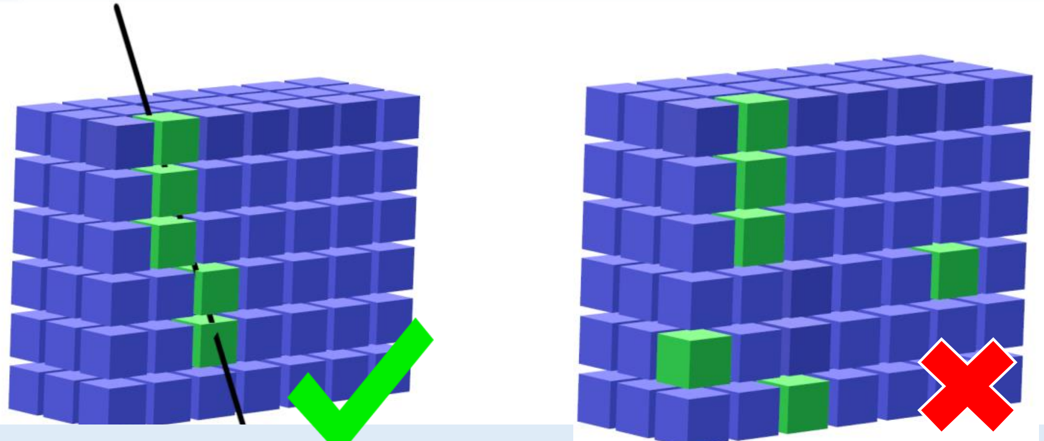
At first, a coordinate of charge center needs to be found:

$$\bar{R} = \frac{\sum_{n=1}^{N} E[n]\,\vec{r}[n]}{\sum_{n=1}^{N} E[n]}$$

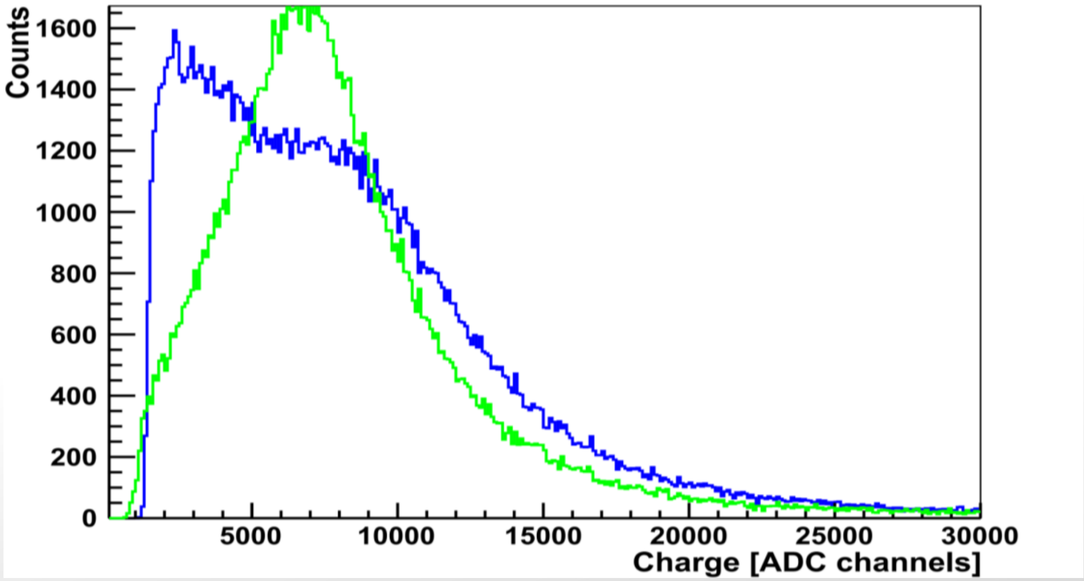
Then distance between centers of fired cells and possible muon track needs to be minimized in order to find right muon track:

$$\sum_{n=1}^{N}\left(\hat{\vec{r}}^{\,2}[n] - \left(\frac{(\hat{\vec{r}}[n],\vec{a})}{|\vec{a}|}\right)^2\right) \to min$$

Finally, corrected charge spectrum (as if all muons go along the axis of FHCal module) can be found

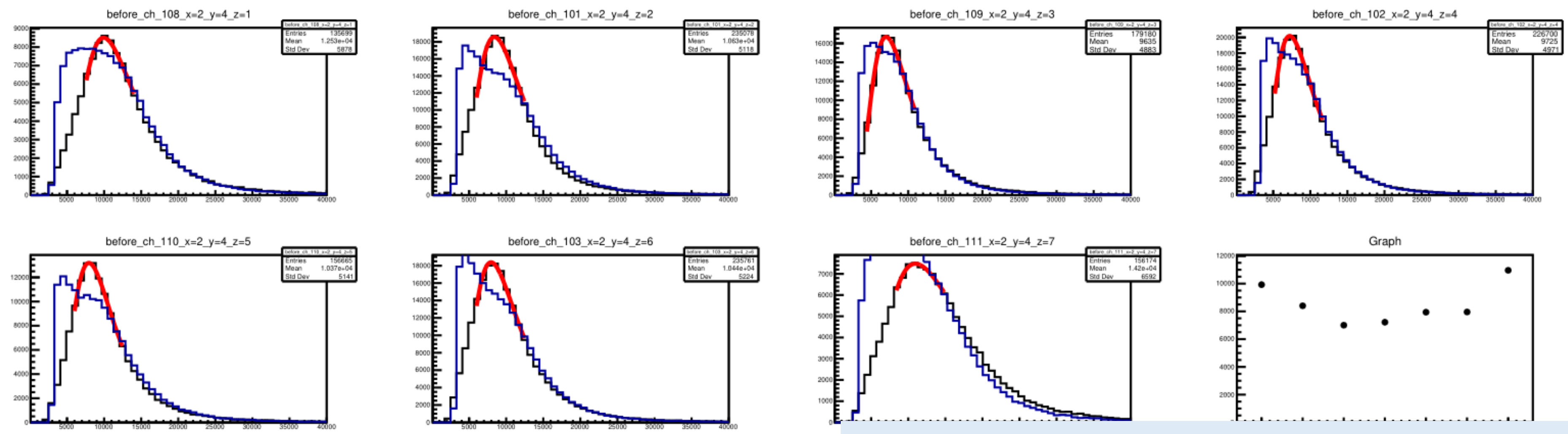


Muon track selection: only adjacent sections tracks are chosen



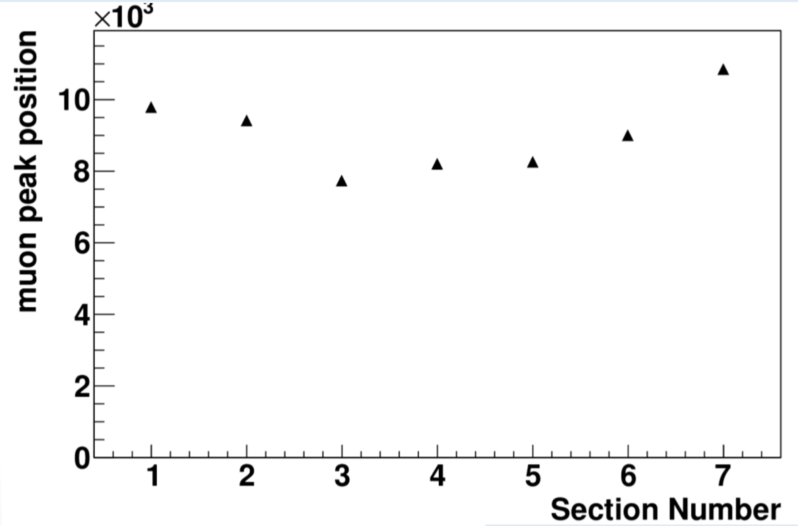
Real charge spectrum of muon and *corrected charge spectrum*

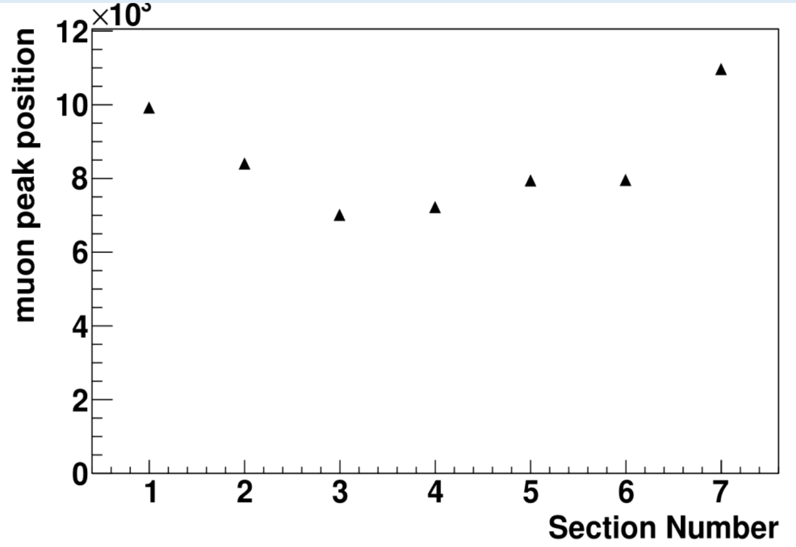
Comparison of both methods for all sections in one module



5 MeV peaks position for all module sections for horizontal muons

5 MeV peaks position for all module sections for all directions muons

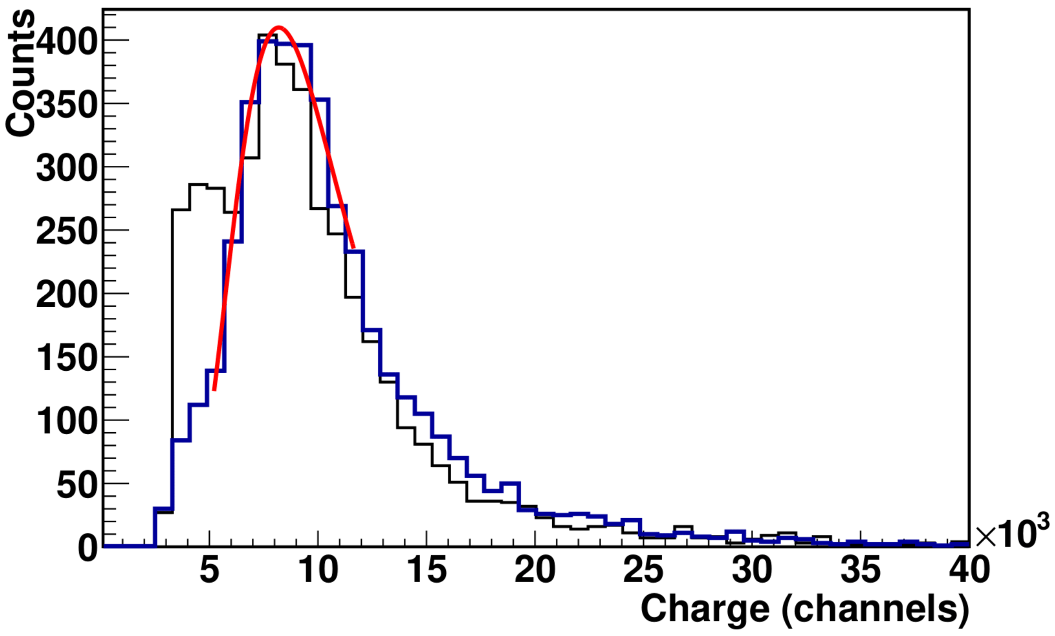




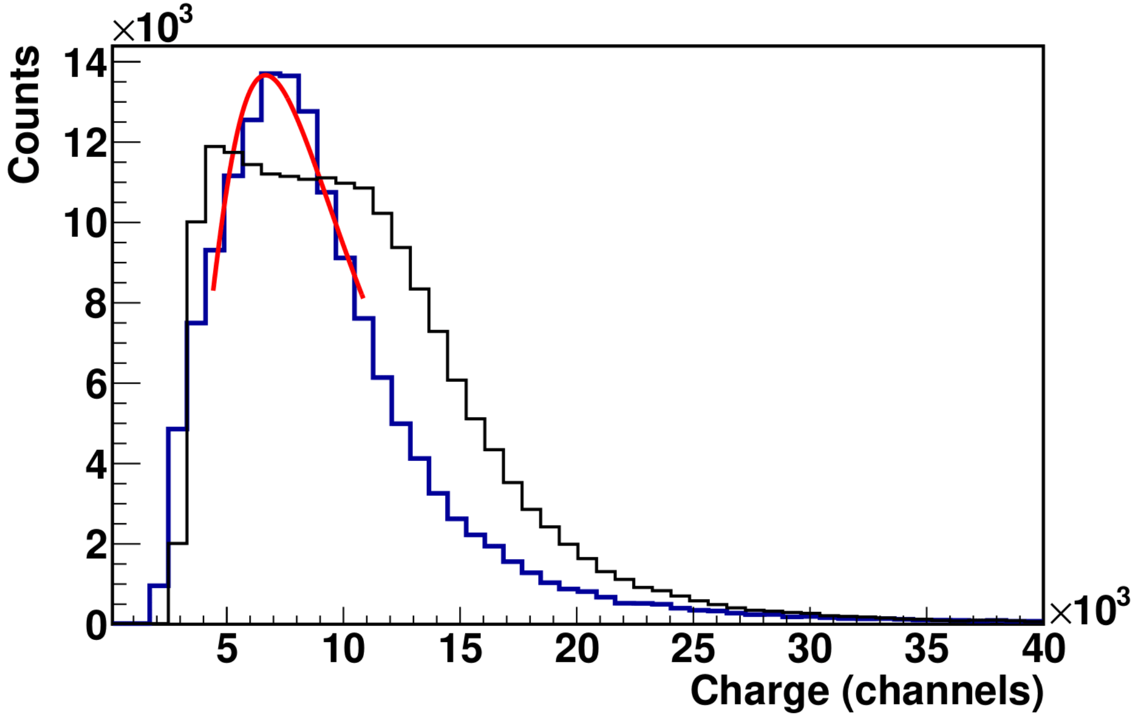
Same results for all module sections

Statistics for horizontal muons vs all muons

Presented results are for 5 days of data acquisition



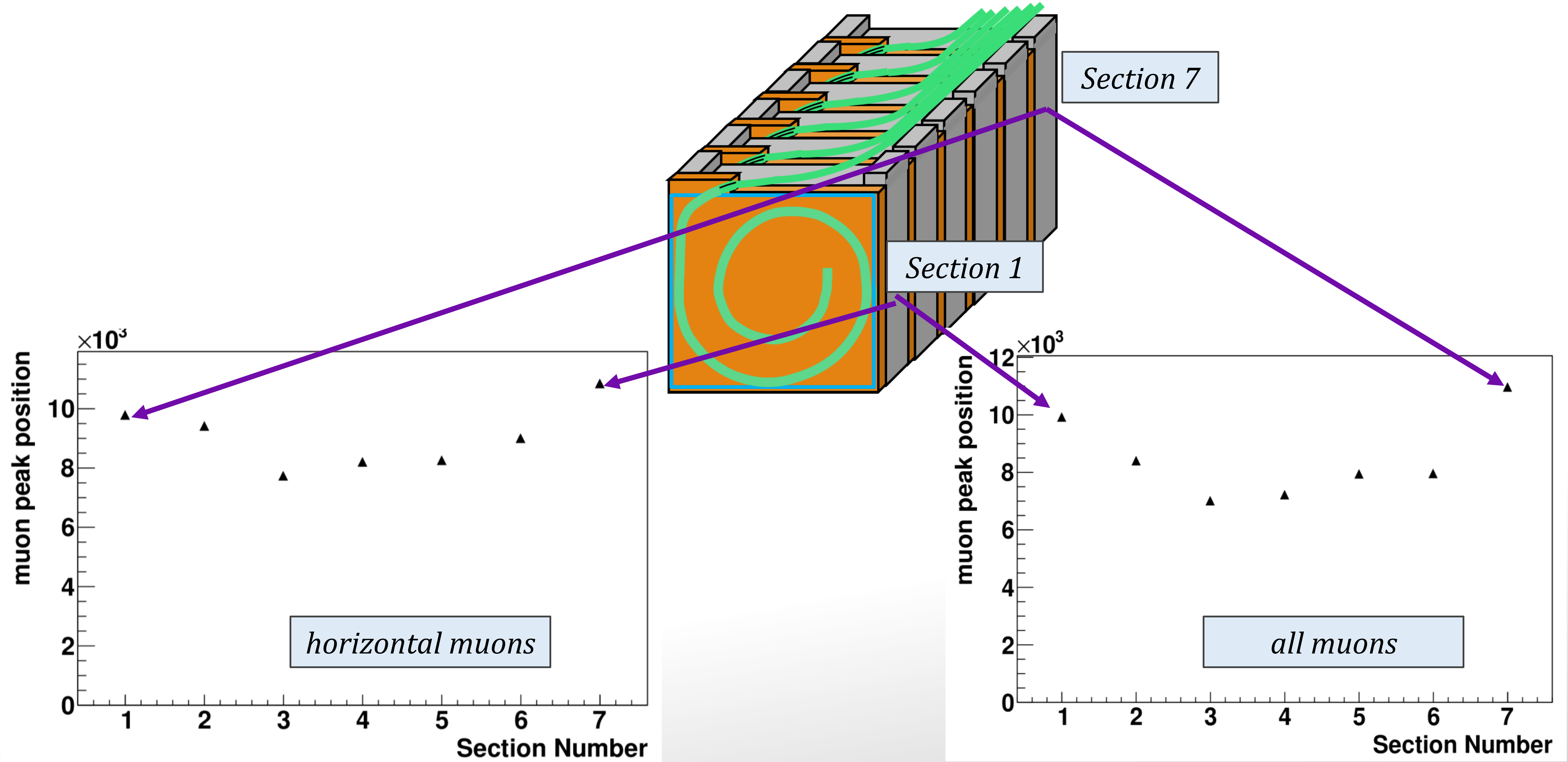
Charge spectra of horizontal muons ***without*** *and* ***with*** *track reconstruction.*



Charge spectrum for muons of all directions

- ❖ 5 MeV peaks correspond to nearly the same charge on both spectra
- ❖ Spectrum for the new calibration technique contains ~50 times more events than horizontal muons spectrum
- ❖ Application of new technique for strictly horizontal muons does not change the 5 MeV peak position

Comparison of both methods for all sections in one module



Results are similar for both methods