Method of FHCAL calibration with cosmic muons

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4th BM@N Collaboration Meeting
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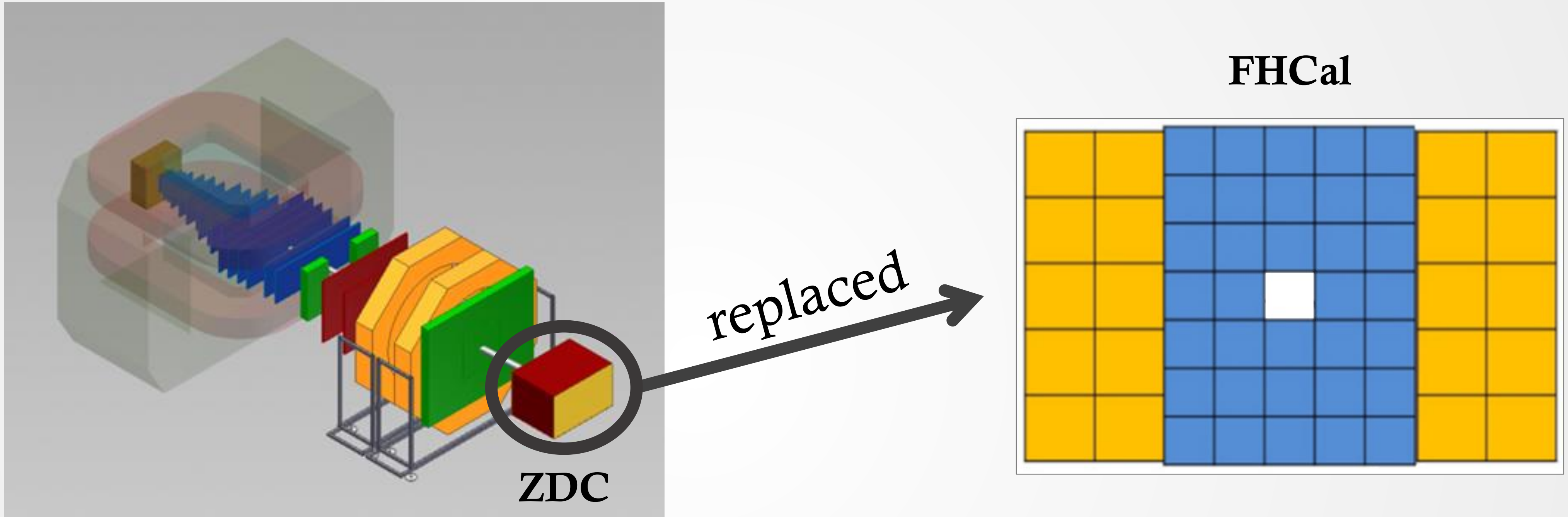
Outline

- New FHCal BM@N calibration task
- Why do we need waveform fitting procedure
- Prony LS method
- Fit quality assessment
- New muon calibration approach

New BM@N FHCal



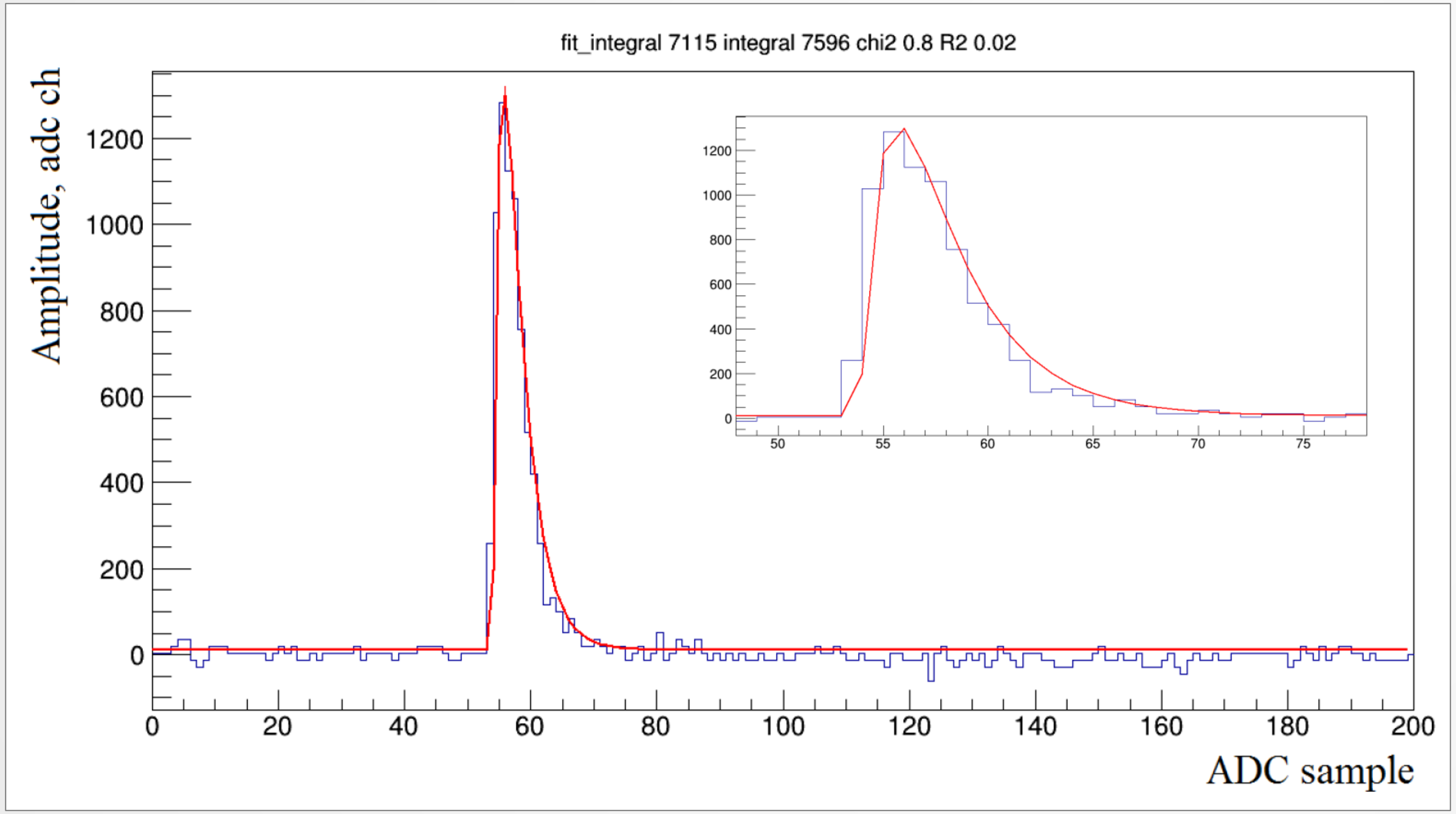
- ❖ Centrality
- ❖ Reaction plane orientation

20 CBM PSD and 34 MPD FHCal modules, Beam hole in the center.

Assembled September 2019

Why do we need waveform fitting

No muon beam at BM@N ➔ Calibration by cosmic muons ➔ Large amount of noise in data



Advantages of the fitting procedure:

- ❖ Working with small signals near the noise level
- ❖ More correct determination of amplitude and charge
- ❖ Identification of pick-up noise and signal pile-ups
- ❖ True signal recovery

Prony Least Squares method

Allows to estimate a set of complex data samples x[n] using the p-term model of exponential components:

$$\hat{x}[n] = \sum_{k=1}^{p} A_k \exp[(\alpha_k + j2\pi f_k)(n-1)T + j\theta_k] = \sum_{k=1}^{p} h_k z_k^{n-1}$$

$n = 1, 2, \ldots, N$, $j^2 = -1$, T – sampling interval. $\boldsymbol{h_k} = A_k \exp(j\theta_k)$, $\boldsymbol{z_k} = \exp[(\alpha_k + j2\pi f_k)\mathrm{T}]$.

Objects of estimation are: amplitudes of complex exponentials $\boldsymbol{A_k}$, attenuation parameters $\boldsymbol{\alpha_k}$, harmonic frequencies $\boldsymbol{f_k}$ and phases $\boldsymbol{\theta_k}$.

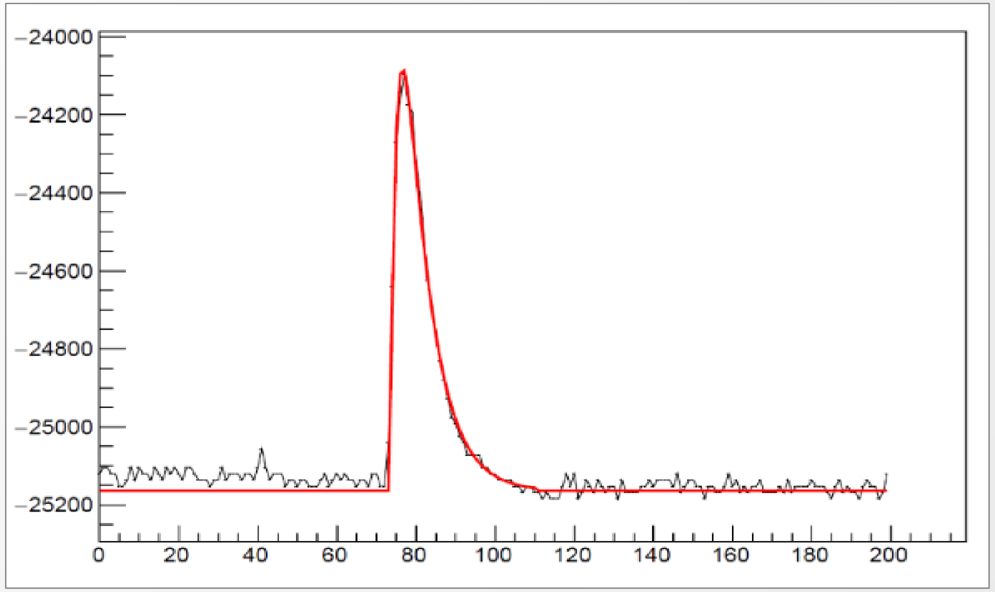
3 algorithm steps:

1. Composing and solving SLE p×p
2. Polynomial factorization

$\left.\begin{array}{l}1.\\2.\end{array}\right\} \boldsymbol{z_k}$

3. Composing and solving SLE (p+1)×(p+1) $\longrightarrow \boldsymbol{h_k}$

3 orders of magnitude faster than MINUIT

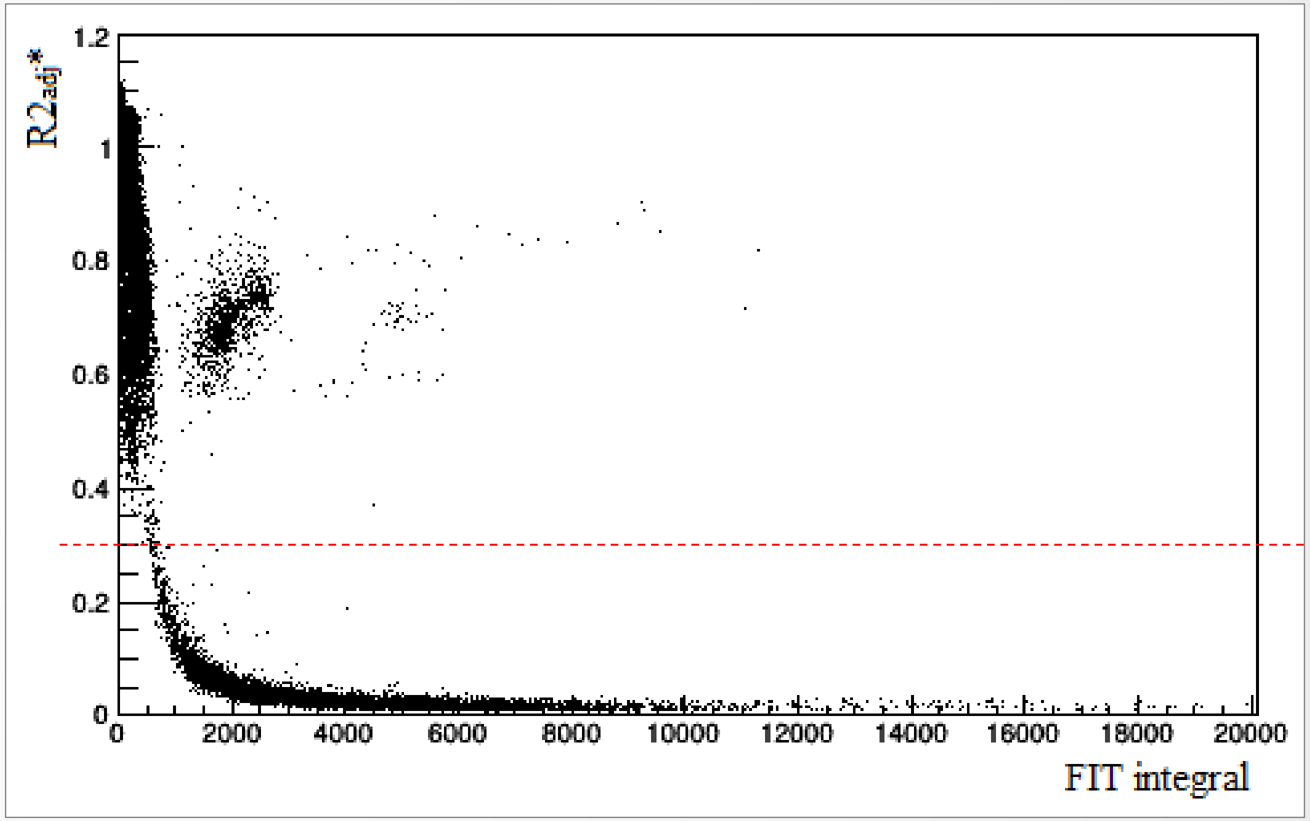


Fit quality assessment

Coefficient of determination*

$$R^2 = \frac{\sum_{n=1}^{N}(x[n] - \hat{x}[n])^2}{\sum_{n=1}^{N}(x[n] - \overline{x})^2}$$

$x[n]$ and $\hat{x}[n]$ are the experimental and model values of the variable, respectively. $\overline{x}$ is the experimental values average.



Adjusted coefficient of determination*

$$R_{adj}^2 = R^2 \frac{N-1}{N-\lambda}$$

N is the number of measurements, λ is the number of model parameters.

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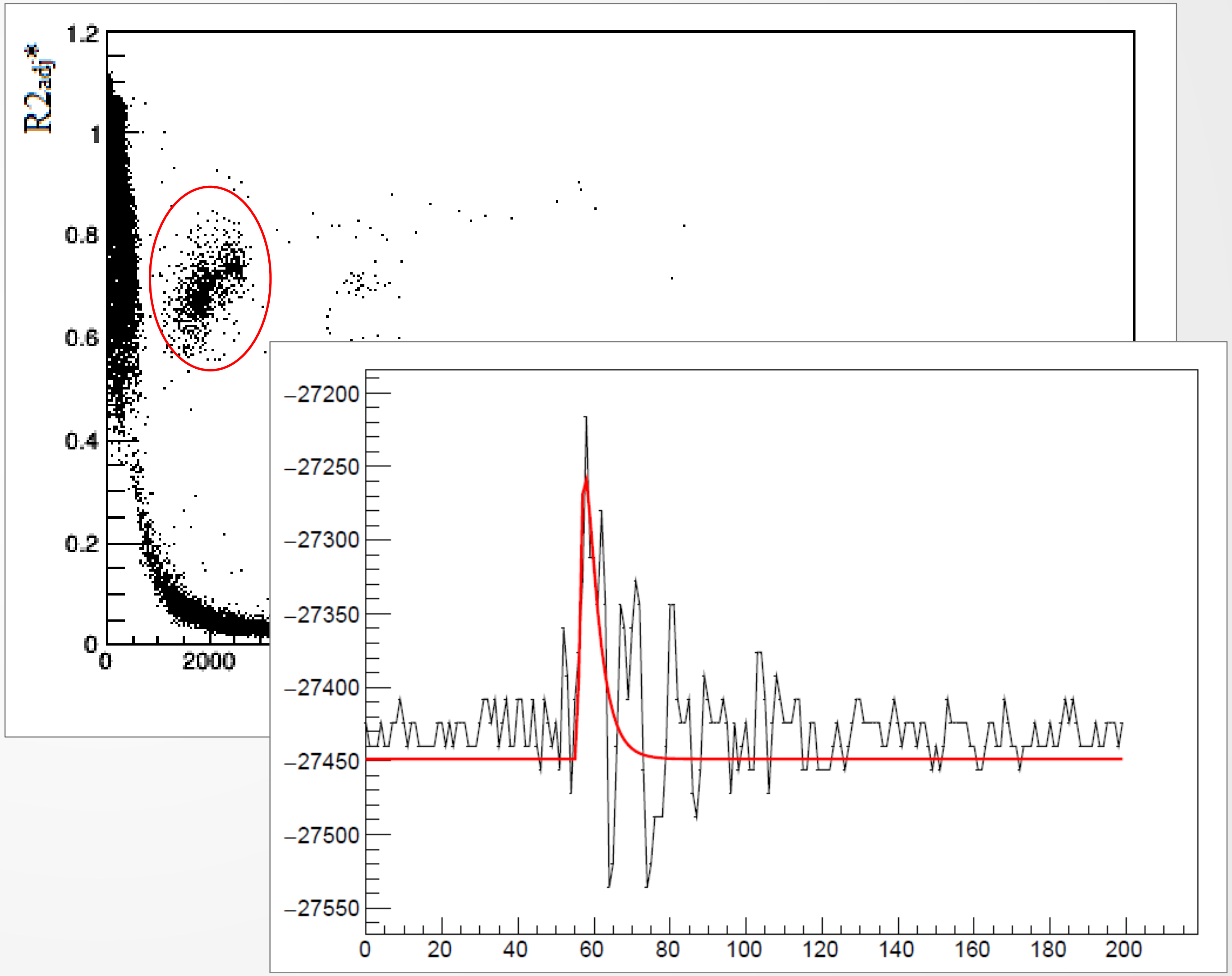
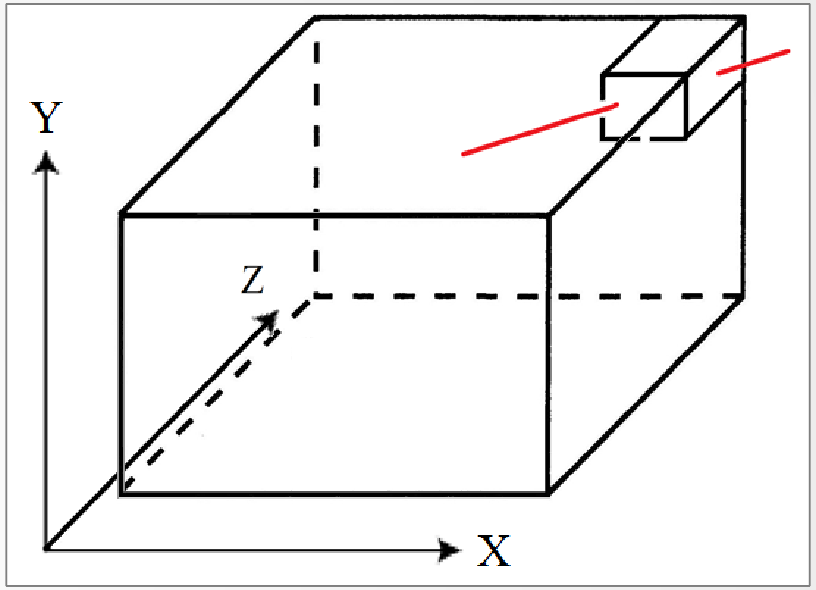


New muon calibration approach

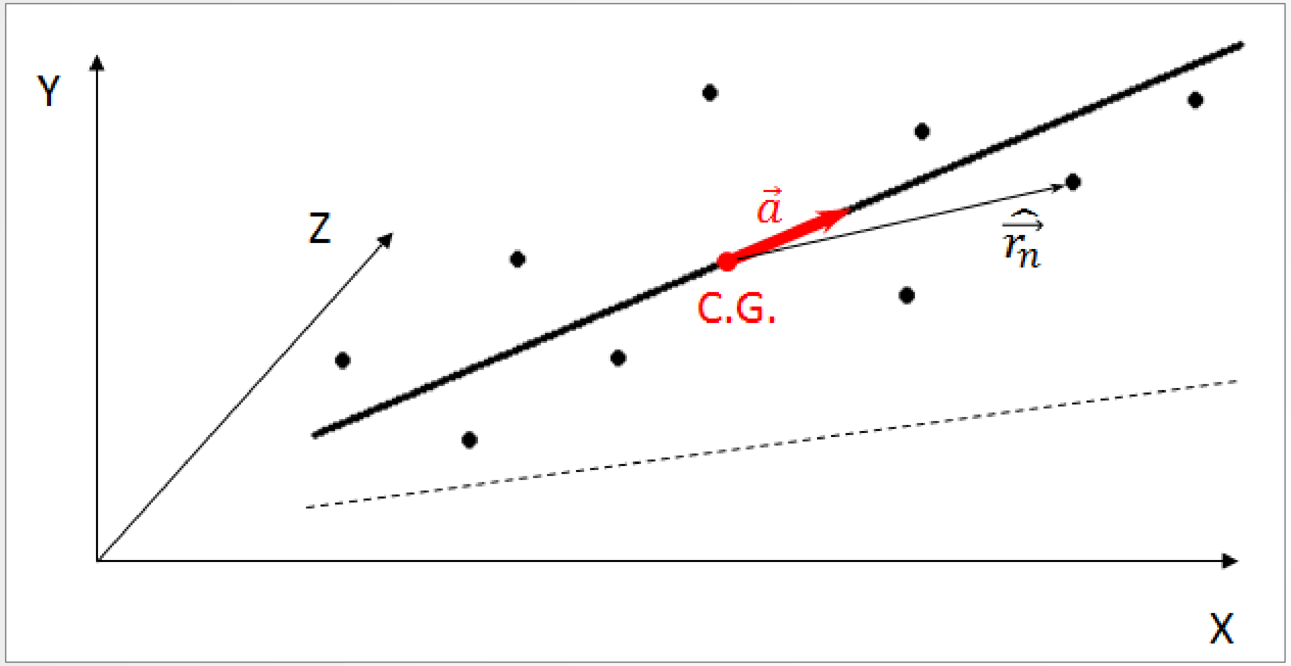
Cosmic muons deposit different amounts of energy in the calorimeter sections depending on the position and direction of the particle track. This should be taken into account when conducting a muon calibration.



Calibration approach:

- Reconstruct muon tracks using signals selected with fit QA
- Determine the thickness of the scintillator passed by track in each cell
- Make corrections when calculating energy deposition

Muon track reconstruction



$$\sum_{n=1}^{N}\left(\frac{(\hat{\vec{r}}[n],\vec{a})}{|\vec{a}|}\right)^2 \to \mathrm{max} \qquad \varphi = \sum_{n=1}^{N} \hat{r}_i a_i \hat{r}_j a_j \to max$$

Maximizing the quadratic form φ on the unit vector $\vec{a}$. The quadratic form is maximal on the eigenvector corresponding to the maximal eigenvalue.

- ❖ Selection of triggered sections by fit QA
- ❖ Shift reference system to the center of gravity

$$\vec{R}_{C.G.} = \frac{1}{N}\sum_{n=1}^{N} E[n]\,\vec{r}[n].$$

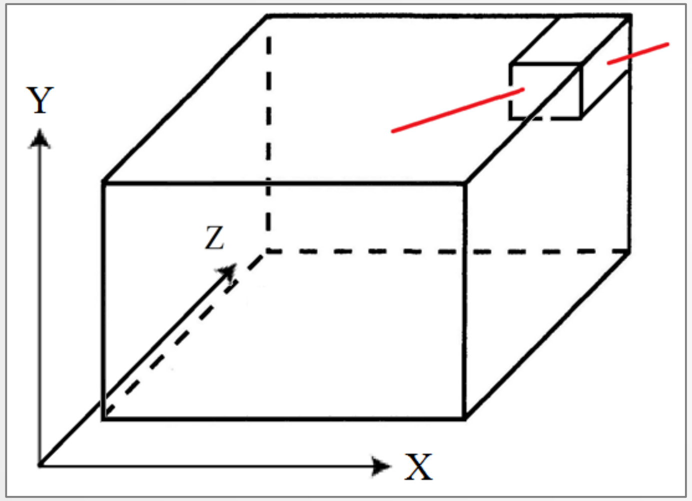
- ❖ Extremum search

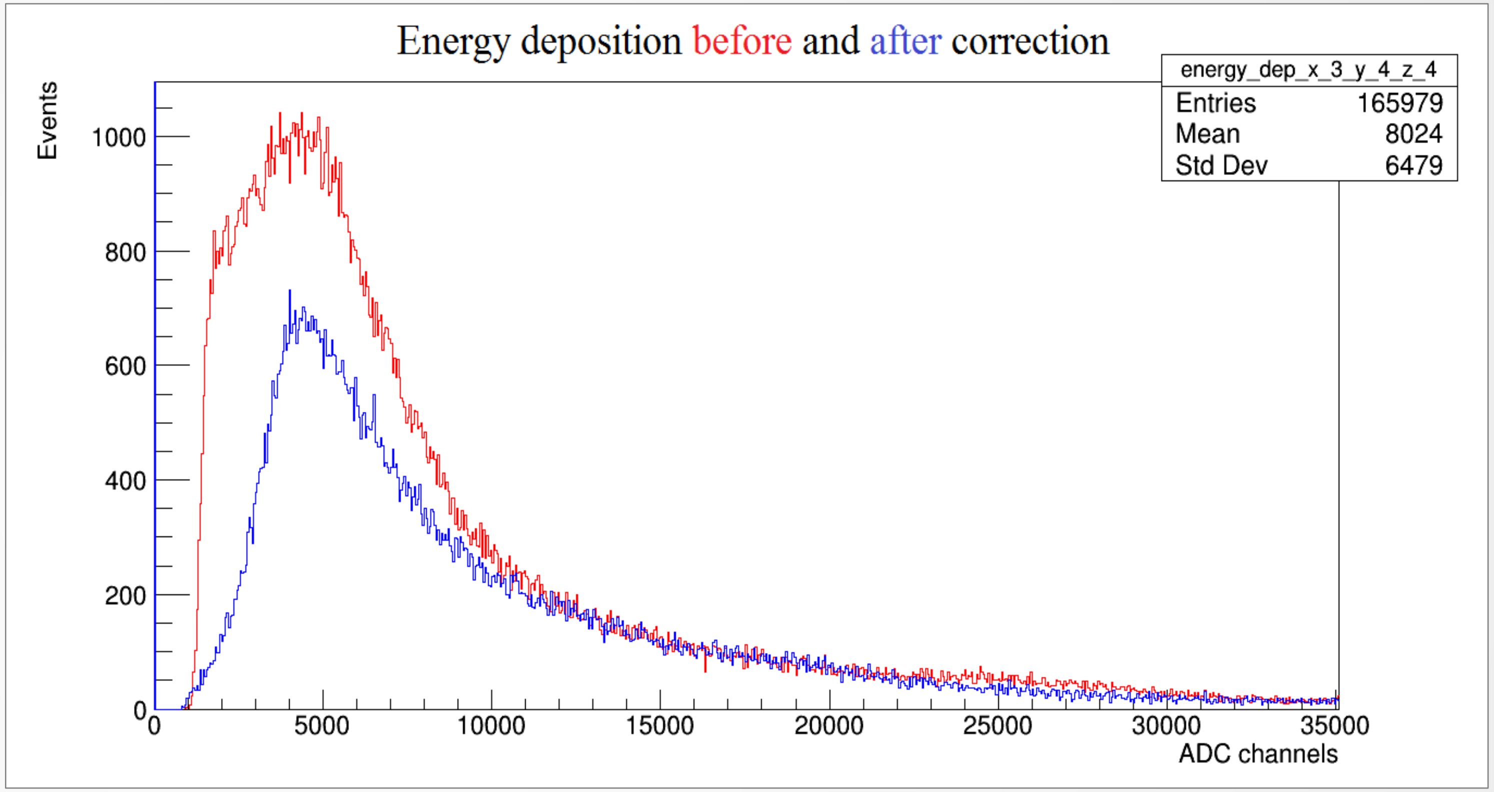
$$\sum_{n=1}^{N}\left(\hat{\vec{r}}^{2}[n] - \left(\frac{(\hat{\vec{r}}[n],\vec{a})}{|\vec{a}|}\right)^2\right) \to min$$

$$M = \begin{pmatrix} \sum_{n=1}^{N} r_n^x\, r_n^x & \sum_{n=1}^{N} r_n^x\, r_n^y & \sum_{n=1}^{N} r_n^x\, r_n^z \\ \sum_{n=1}^{N} r_n^y\, r_n^x & \sum_{n=1}^{N} r_n^y\, r_n^y & \sum_{n=1}^{N} r_n^y\, r_n^z \\ \sum_{n=1}^{N} r_n^x\, r_n^z & \sum_{n=1}^{N} r_n^y\, r_n^z & \sum_{n=1}^{N} r_n^z\, r_n^z \end{pmatrix}$$

Adjusted charge calculation

Calculation of the thickness of scintillator material traversed by the particle track by enumerating 6 faces of each triggered section.





The adjusted charge is considered as if the particle has passed straight through the section, traversing 6×4 mm of the scintillator. In the case when the track did not pass through the section, it is impossible to correct the charge, the adjusted energy deposition is considered to be zero.

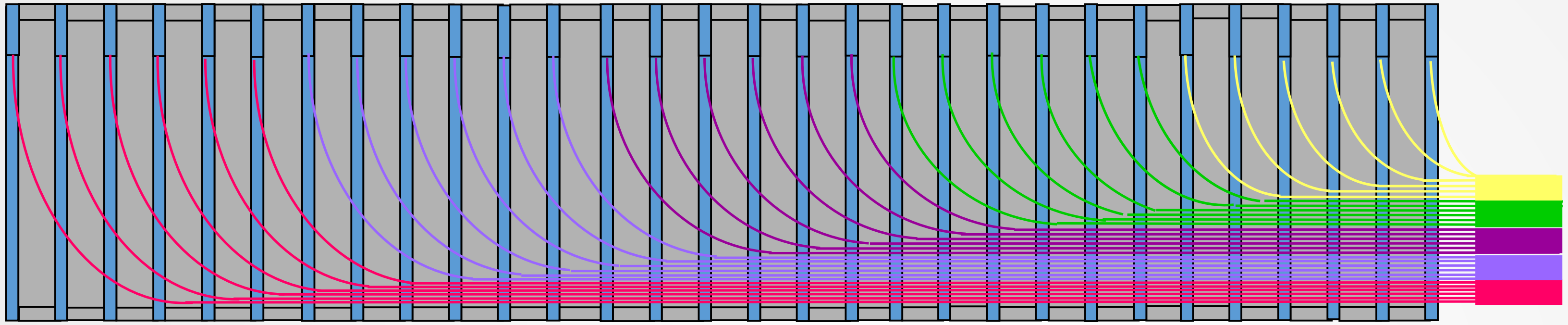
Summary

- A new method for fitting signals is developed
- The application of the fit QA is shown
- New approach to the muon calibration is implemented

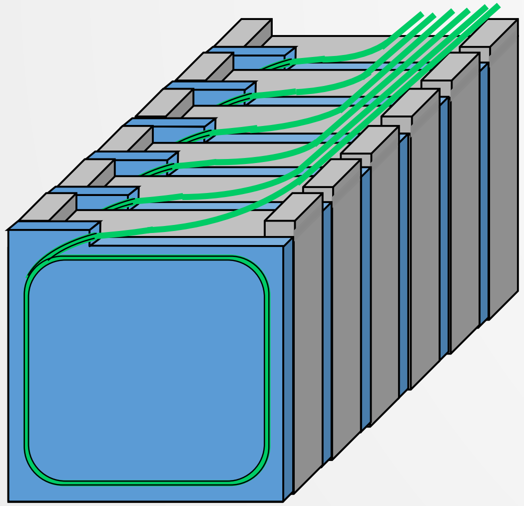
Thank you for your attention

Backup

Structure of calorimeter module



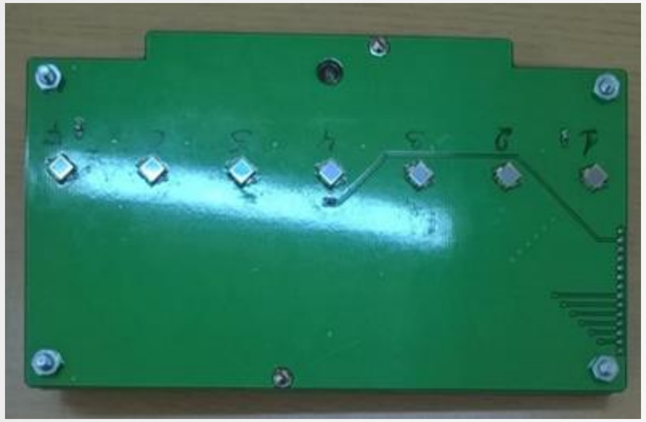
Photodetectors &amplifiers

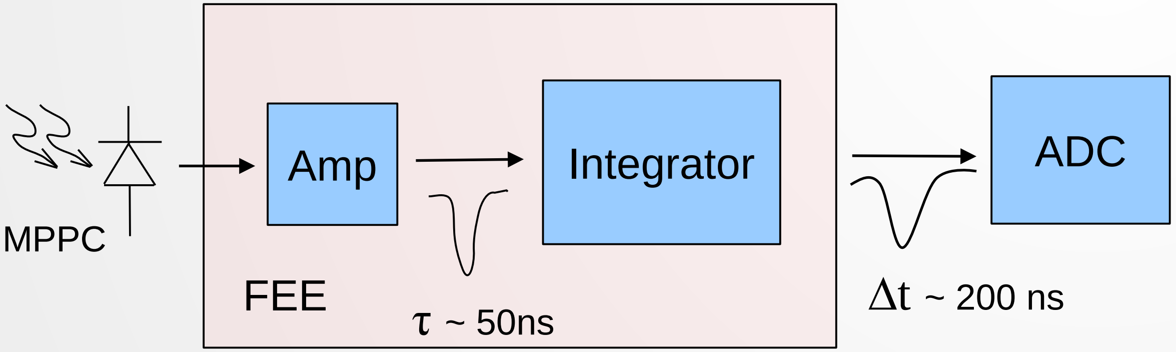


- Transverse size - 15x15cm^2 or 20x20cm^2
- Longitudinal segmentation – 7 or 10 sections
- 7 or 10 photodetectors/module;
- Photodetectors – silicon photomultipliers (SiPM).

Photodiodes, FEE and readout electronics

Front-End-Electronics:





MPPC

FEE

Amp

Integrator

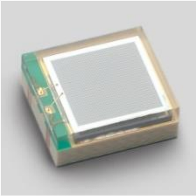
ADC

τ ~ 50ns

Δt ~ 200 ns

7 or 10 channels: two-stage amplifiers; HV channels; LED calibration source.

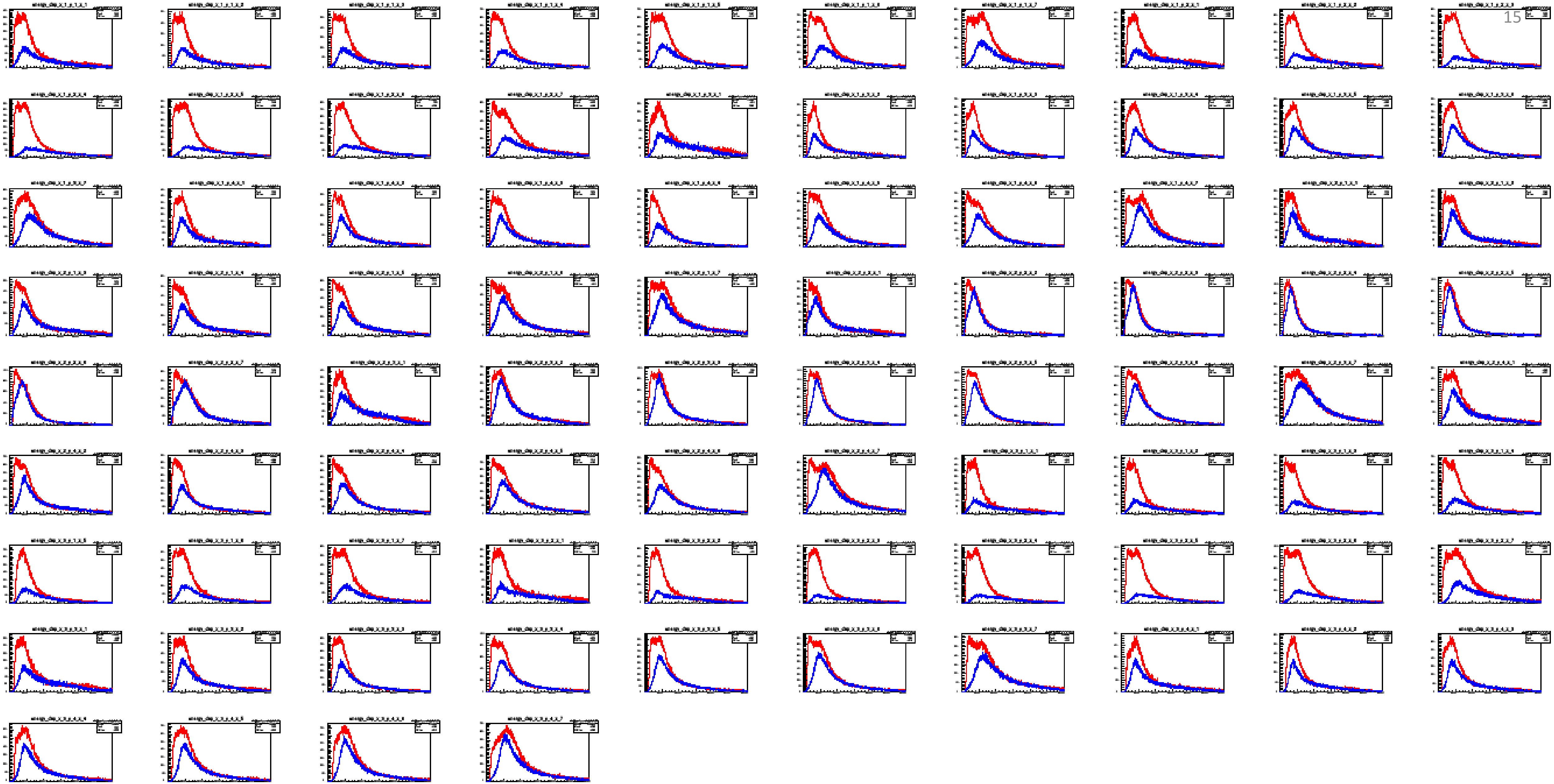
Photodetectors:

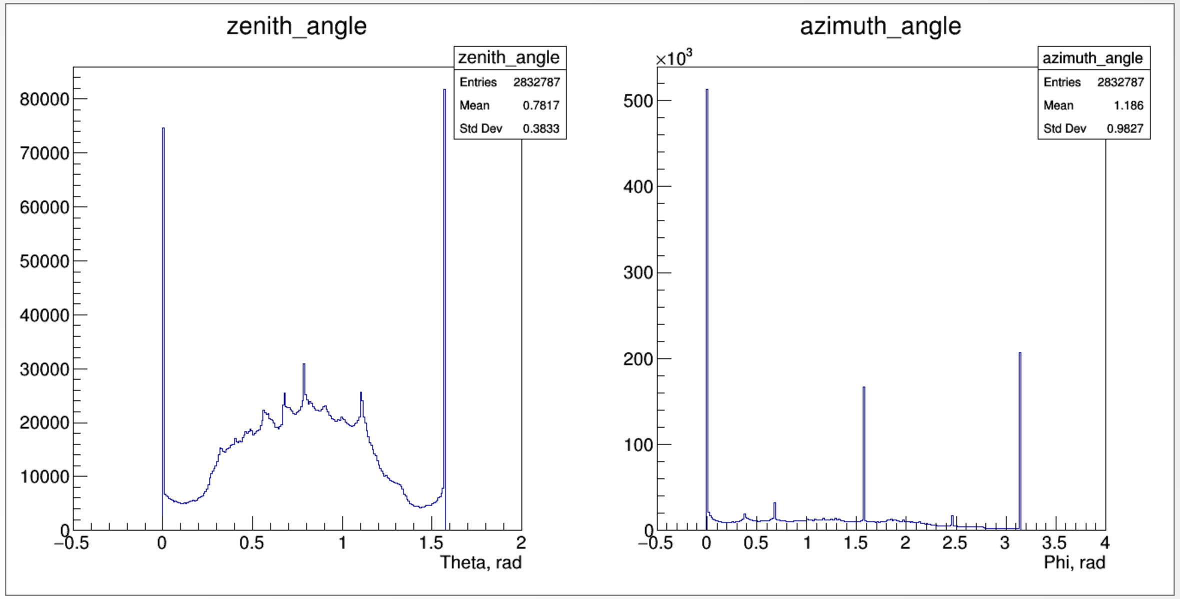


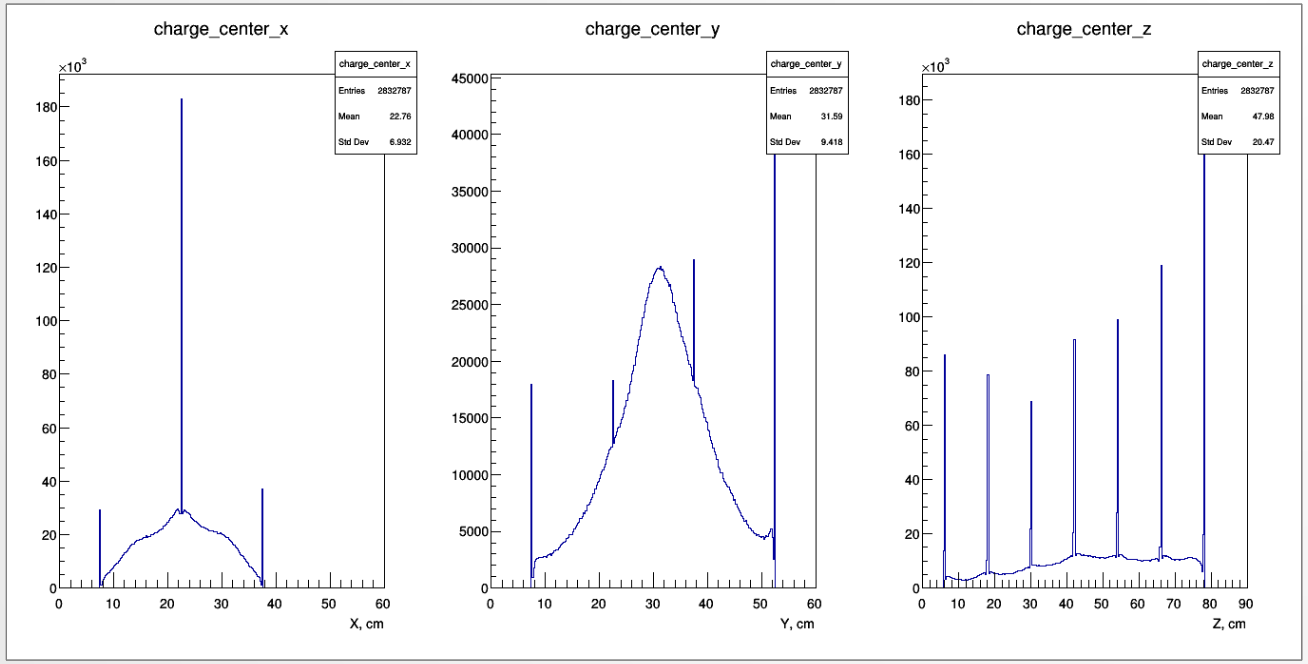
Hamamatsu MPPC:
size – 3x3 mm^2;
pixel -10x10 μm^2;
PDE~12%.

Readout electronics:

FPGA based 64 channel ADC64 board, 62.5MS/s (AFI Electronics, JINR, Dubna).




zenith_angle
zenith_angle
Entries 2832787
Mean 0.7817
Std Dev 0.3833
0
10000
20000
30000
40000
50000
60000
70000
80000
−0.5
0
0.5
1
1.5
2
Theta, rad
azimuth_angle
azimuth_angle
Entries 2832787
Mean 1.186
Std Dev 0.9827
×10³
0
100
200
300
400
500
−0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
Phi, rad


charge_center_x
charge_center_x
Entries 2832787
Mean 22.76
Std Dev 6.932
×10³
0
20
40
60
80
100
120
140
160
180
0
10
20
30
40
50
60
X, cm
charge_center_y
charge_center_y
Entries 2832787
Mean 31.59
Std Dev 9.418
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
0
10
20
30
40
50
60
Y, cm
charge_center_z
charge_center_z
Entries 2832787
Mean 47.98
Std Dev 20.47
×10³
0
20
40
60
80
100
120
140
160
180
0
10
20
30
40
50
60
70
80
90
Z, cm