28th International Scientific Conference of Young Scientists and Specialists (AYSS-2024)

Reconstruction of cosmic muon tracks inside the half-sector of the ECal MPD/NICA to align the tower responses

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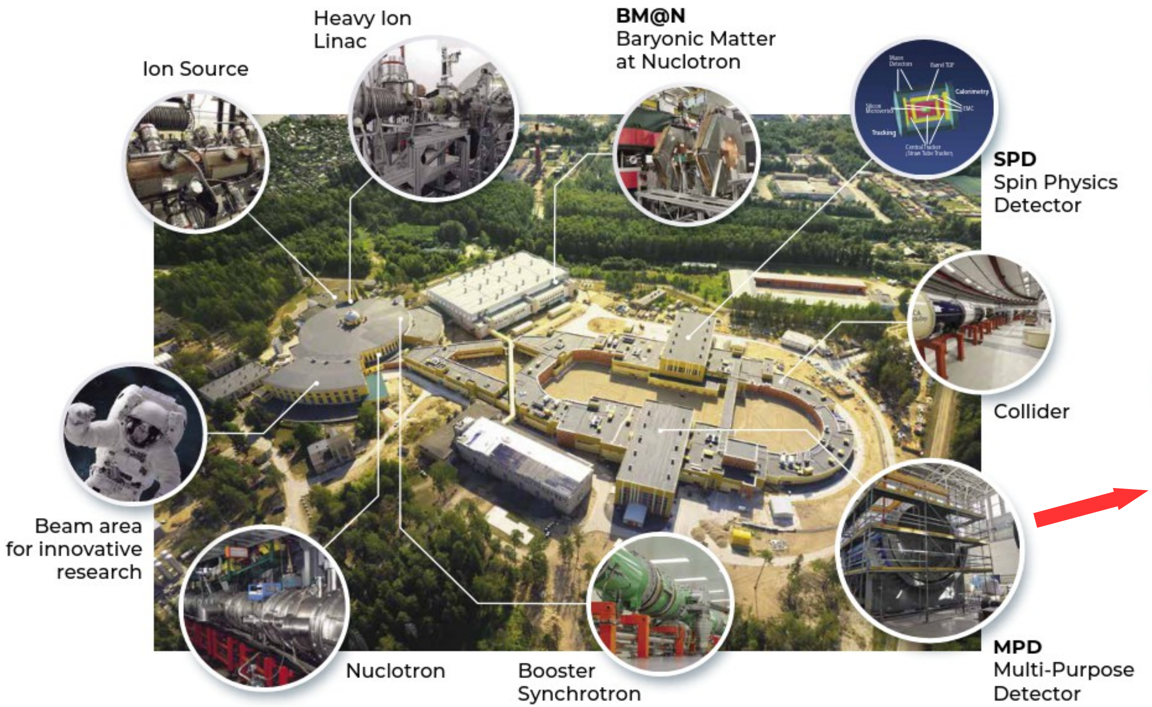
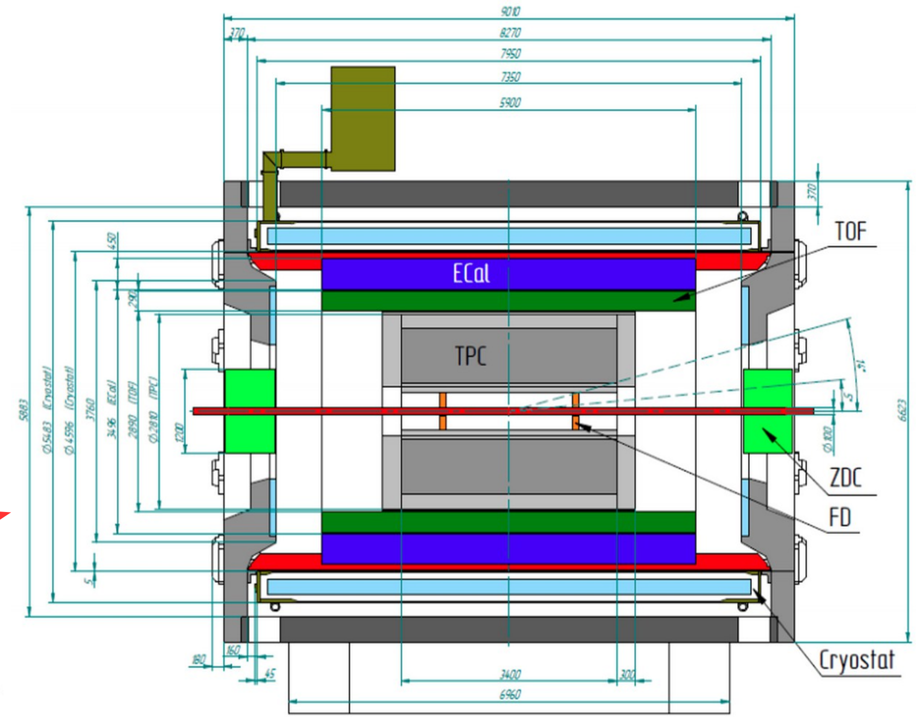
Multi-purpose Detector (MPD) at Nuclotron-based Ion Collider fAcility (NICA)





$\sqrt{S}$=4–11 GeV/N Energy

Collider ring circumference 503m

nica.jinr.ru

NICA PARAMETERS

Range of nuclei:
from hydrogen to bismuth, including gold

Energy of extracted beams:
up to **4.5 GeV/N**

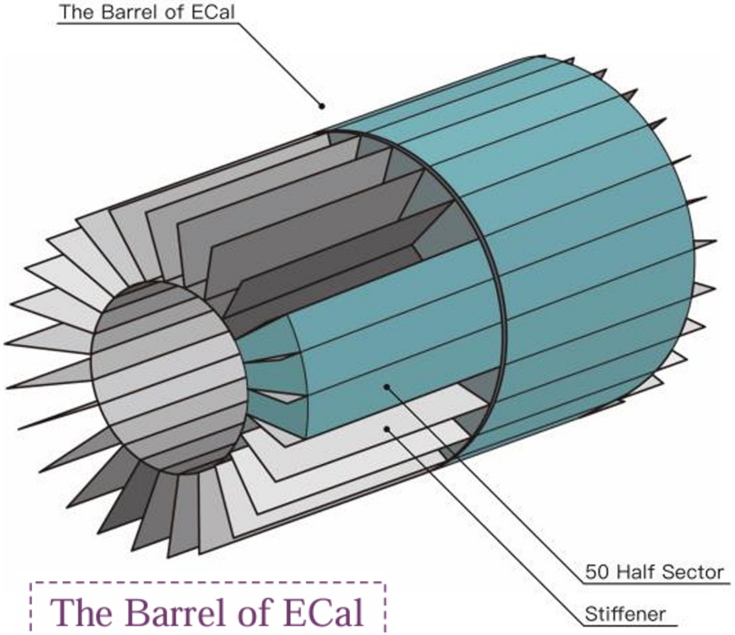
Intensity (per second):
Heavy ions — **$5 \cdot 10^8$**
Protons — **10^{10}**

Designed luminosity:
Heavy ions — **10^{27} cm^{-2}/s^{-1}**

Light nuclei and polarised protons and deuterons — **10^{32} cm^{-2}/s^{-1}**

The MPD is aimed at studying the properties of quark matter. The MPD is capable of detecting charged hadrons, electrons, and photons in heavy-ion collisions and includes a 3-D tracking system and a particle identification (PID) system. The MPD has two main PID subsystems: the first subsystem is a time projection camera TPC and a time-of-flight detector TOF, and the second is an electromagnetic calorimeter ECal.

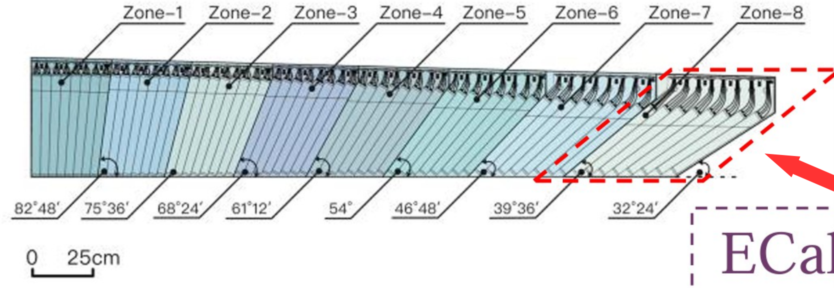
Electromagnetic calorimeter (ECal)



The Barrel of ECal

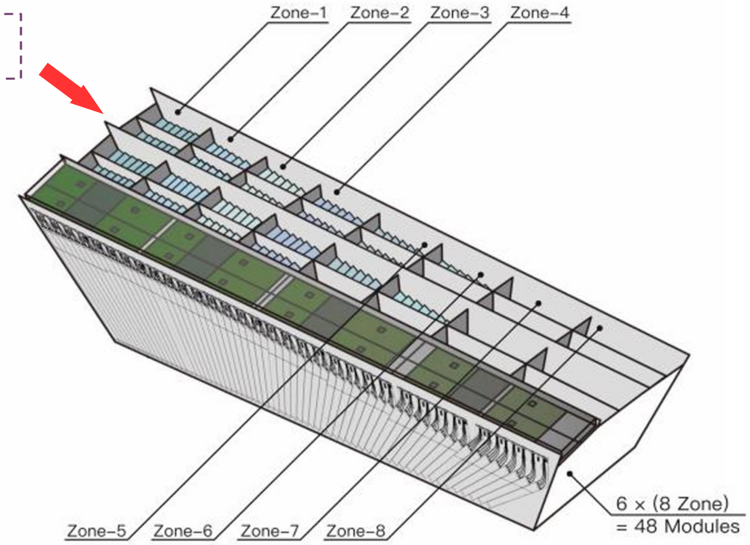
ECal 8-Zone

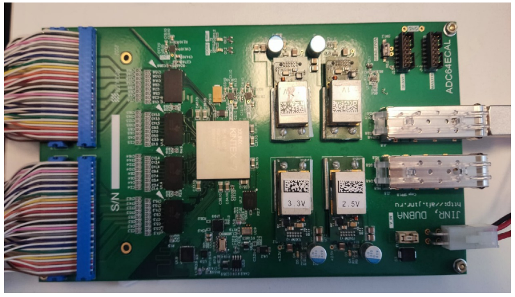
[The progress of ECal production in China // XIV Collaboration Meeting of the MPD Experiment at the NICA Facility]



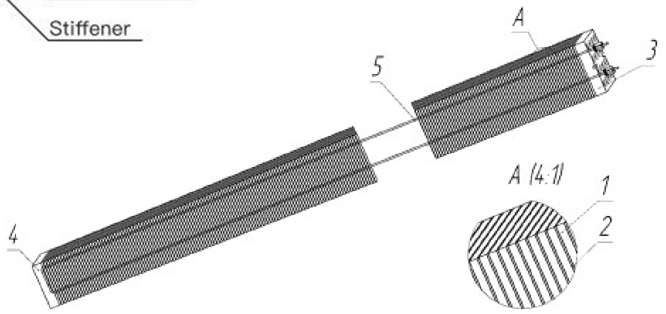
ECal Module

ECal Half-Sector





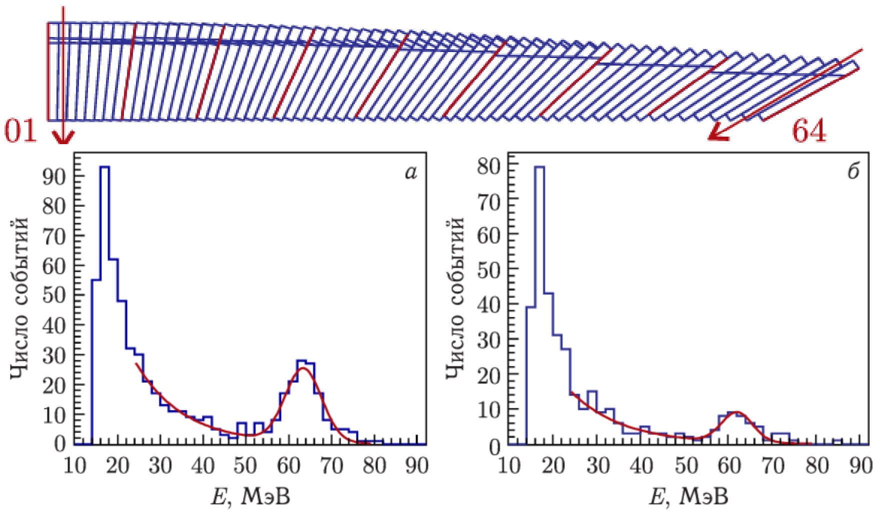
ADC64ECAL board



The design of the tower without WLS: 1 - scintillator plate, 2 - lead plate, 3 and 4 - plastic end plates, 5 - mounting.

Align the tower's responses by using cosmic muons (minimum ionization particles «MIPs»)

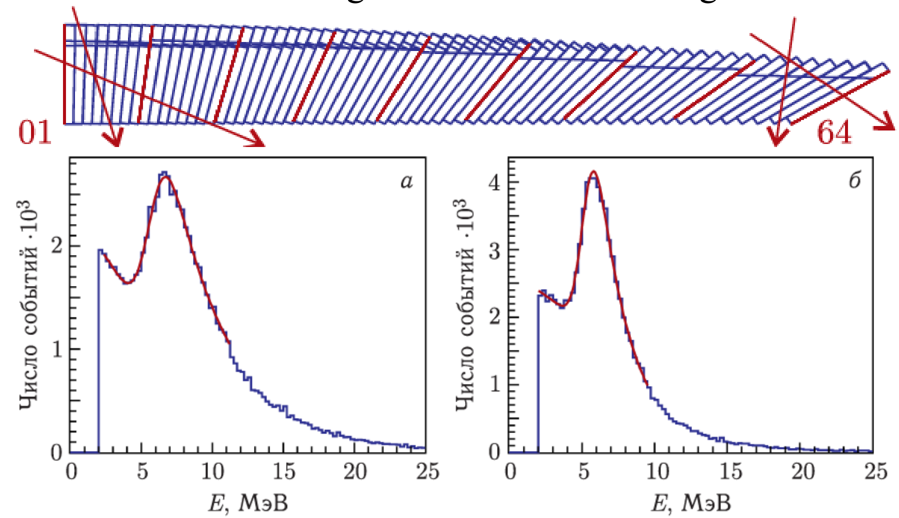
A simple calibration method is to use muons of cosmic rays passing along the axes of the towers.



Simulation. The response of the half-sector towers by longitudinal muons «M1». Horizontally positioned half-sector.

However, in our case, this method is very time-consuming because the transverse dimensions of the towers are small and the statistics are very small. In addition, for rotated half-sectors, the statistics will be even less. This problem can be solved if the towers are calibrated in a horizontal position.

An approach based on selection by **hit multiplicity (M)** of triggered towers was considered: **M = 1, «M1»** - selection of "**longitudinal**" muons passing along the axes of the towers; **M >= 4, «M4»** – selection of muons crossing the towers at some angle to their axis.



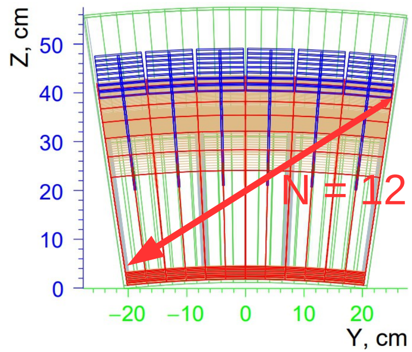
Simulation. The response of the half-sector towers by cosmic muons when multiplicity hit «M4».

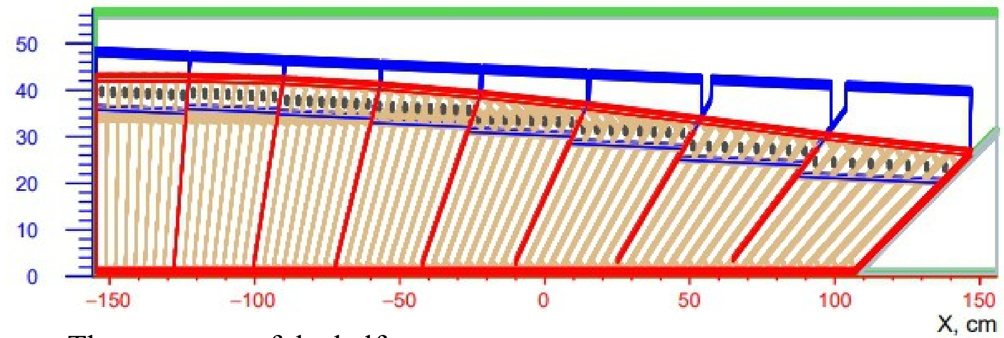
This method is in good agreement with experimental results and simulation results and allows calibration with high accuracy of ~ 2-4% for a horizontally positioned half-sector.

[МЕТОДЫ КАЛИБРОВКИ ПОЛУСЕКТОРОВ ЭЛЕКТРОМАГНИТНОГО КАЛОРИМЕТРА MPD/NICA НА МЮОНАХ КОСМИЧЕСКИХ ЛУЧЕЙ // ФИЗИКА ЭЛЕМЕНТАРНЫХ ЧАСТИЦ И АТОМНОГО ЯДРА. 2024. Т.55, вып.4. С.957–965]

An approach to improve calibration accuracy by using tracks cosmic muons

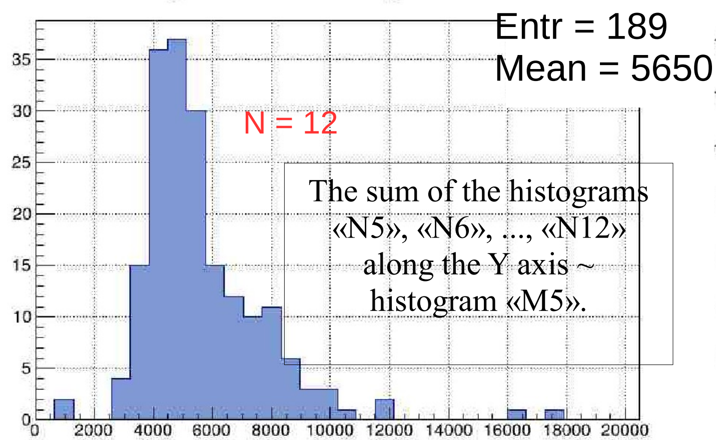
One of the possibilities to improve the calibration accuracy is to select by multiplicity M >= 4 along the axes of the half-sector (X and Y). Thus, we fix one of the directions. But by reconstructing the tracks of cosmic muons in the XY plane and selecting tracks containing **N hits** along one line (X and Y), we will be able to partially fix another direction.



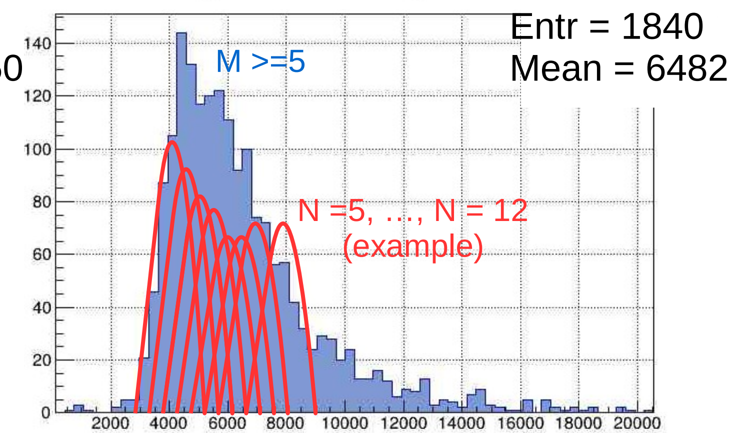


The geometry of the half-sector.

To increase statistics, **"slanting" tracks** in the XY plane of the half-sector can are used. Then there is a problem that is associated with a broadening of the distribution, since the slanting tracks in the tower have a different path traveled and, accordingly, emit different energy. Using the dependence of the signal on the traveled path in the tower, obtained under strong restrictions by direction in XY plane, it is possible to correct the distribution.



Experimental. The response of the half-sector one tower in unit ADC when multiplicity hit «N12».



Experimental. The response of the half-sector one tower in unit ADC when multiplicity hit «M5».

The basic algorithm for reconstructing cosmic muon tracks in the XY plane of the half-sector of the calorimeter

The task of track reconstruction consists of two stages: the **search for track candidates** and the **fitting parameters** of the track.

The **global Hough transform method** is used as a method for searching for track candidates, the idea of which is to transform coordinate measurements and then map points to the appropriate space. The selection of track candidates implies the detection of areas with high density in the Hough space.

Straight 2D track can be presented in the form of a line that is described by the vector form **a** + t**b** where $\vec{a}$ point on the line, and **b** = (bx; by) = (cosφ'; sin φ') - direction, while |**b**| = 1. We use other track parameters, which we obtain using a special case of the **Roberts linear representation** for a two-dimensional system. Then a point on a straight line can be given as:

$$\vec{p} = x' \begin{pmatrix} 1 - {b_x}^2 \\ -b_x b_y \end{pmatrix} + y' \begin{pmatrix} -b_x b_y \\ 1 - {b_y}^2 \end{pmatrix}$$

Where $x' = (1 - {b_x}^2)\, p_x - b_x b_y\, p_y$ and $y' = - b_x b_y\, p_x + (1 - {b_y}^2)$.

Before digitization the parameter space of the tracks, it is necessary to center the array of hits relative to the origin of the coordinates

$$\vec{x}_i \rightarrow \vec{x}_i - \vec{c}, \vec{c} = \frac{1}{2}\begin{pmatrix} x_{max} + x_{min} \\ y_{max} + y_{min} \end{pmatrix}$$

New x' и y' are from $-\left\|\vec{d}/2\right\|$ to $+\left\|\vec{d}/2\right\|$, where $\vec{d} = (x_{max} - x_{min}, y_{max} - y_{min})$ is the diagonal of the bounding rectangle of the hit array.

The basic algorithm for reconstructing cosmic muon tracks in the XY plane of the half-sector of the calorimeter

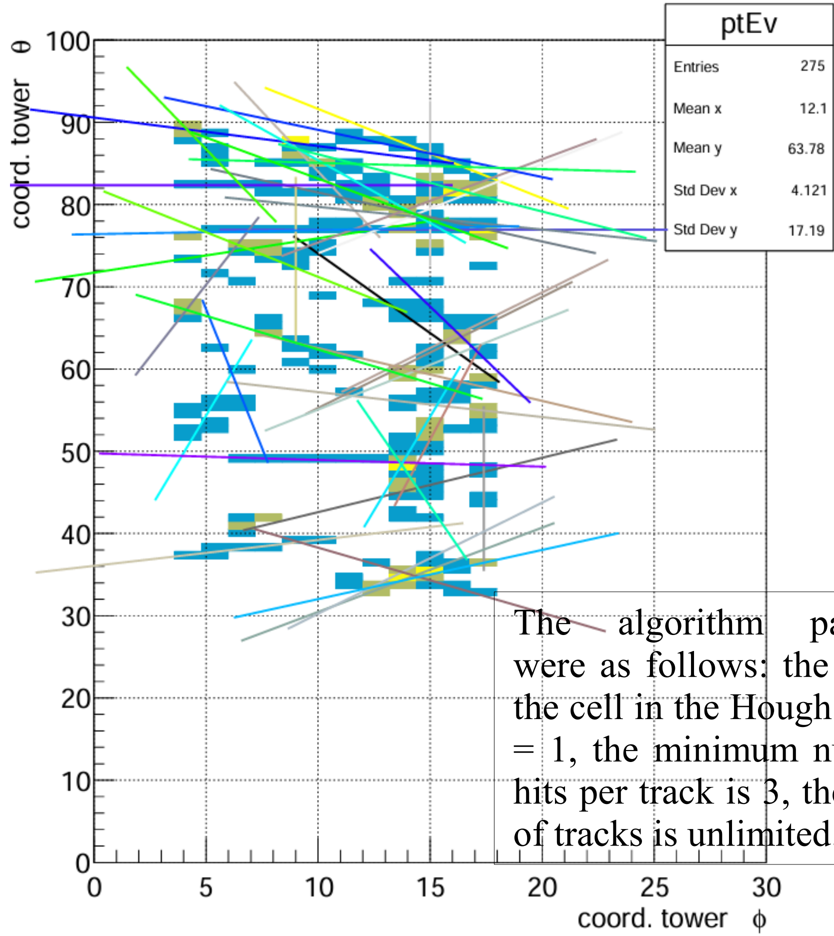
In order to avoid the problems of the classical search for maxima in the Hough space, the points belonging to the corresponding candidate tracks are removed from the original array of points. After that, the Hough transform is applied to the remaining points again. This is how an iterative scheme for searching for track candidates turns out.

We use an optimized scheme, saving a cumulative array between different steps of the search for track candidates. Then the cumulative array will need to be reduced only for remote points. Thus, each hit from the hit array is subjected to the Hough transform only twice: once for the initial creation of the storage array and the second time for its removal from the array.

The criterion for the point x belonging to the line **a** + t**b** is that its distance to the line is less than the width of the cell dx in the Hough space (x', y').

$$\left\|\vec{x} - (\vec{a} + t\vec{b})\right\| \le dx, t = \left\langle \vec{b}, \vec{x} - \vec{a} \right\rangle$$

Next, the resulting candidate track is quoted using the **least squares method**. This allows you to increase the accuracy of the results and at the same time maintain the necessary detail of the processed space.



The algorithm parameters were as follows: the width of the cell in the Hough space dx = 1, the minimum number of hits per track is 3, the number of tracks is unlimited.

Experimental. Cumulative histogram of hits and tracks (with N>= 3) in the half-sector for 100 events.

Track correction algorithm using the maximum likelihood method

The track correction procedure is based on the **maximum likelihood method**, which consists in estimating track parameters based on observed data with a known distribution. This is achieved by maximizing the likelihood function in such a way that, within the bounds of the assumed statistical model, the observed data are the most likely.

When analyzing the results obtained using the selection method for the multiplicity of hits in track N3, ..., N12 along the X and Y lines of the half-sector, the expected energy $\mathbf{E}_{\mathbf{ref,\,i}}$, sigma $\boldsymbol{\sigma}_{\mathbf{ref,\,i}}$ and the reference length of the track in the tower $\mathbf{l}_{\mathbf{ref,\,i}}$ were obtained. Using the assumption of the linearity of the energy release of MIP muons in the tower, it is possible to obtain the expected track length in the tower and its sigma at the current energy:

$$l_{exp,\,i} = \frac{E_i * l_{ref,i}}{E_{ref,i}} \qquad \sigma(l)_{exp,\,i} = \frac{\sigma_{ref,\,i} * \sqrt{l_i/l_{ref,i}}\; l_{ref,i}}{E_{ref,i}}$$

Let a and b be the track **parameters** that need to be **corrected**. Δa is a variation of one of the coordinates of a point on the track and Δb is a variation of the track angle direction. The **maximum likelihood function** will take the form:

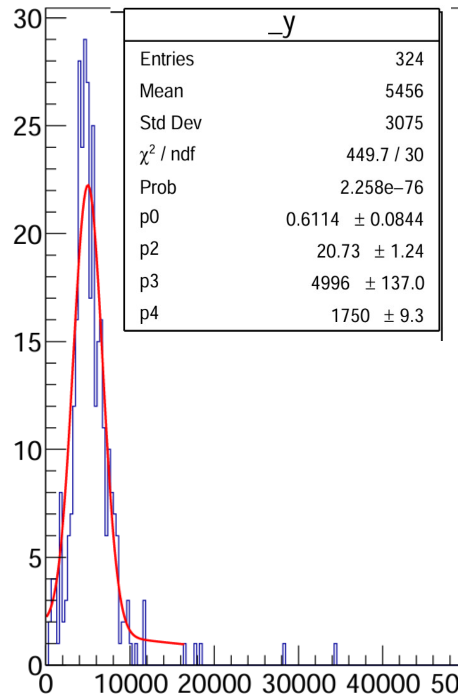
$$L_n(a,b) = \prod_{i=1}^{N} \frac{1}{\sqrt{2\pi}\sigma(l)_{exp,\,i}} * exp\left(- \frac{\frac{1}{2}\sum_{i=1}^{N} \frac{f_i \left[l_i - l_{exp,i}\right]^2}{\sigma(l)_{exp,i}{}^2}}{\sum_{i=1}^{N} f_i} \right)$$

Where $l_i = l_i(a, b)$ is the geometrically calculated **track length** in the i-th tower, and f_i the **densities of the probability function** of the normal distribution of the measured energy E_i are used as weights.

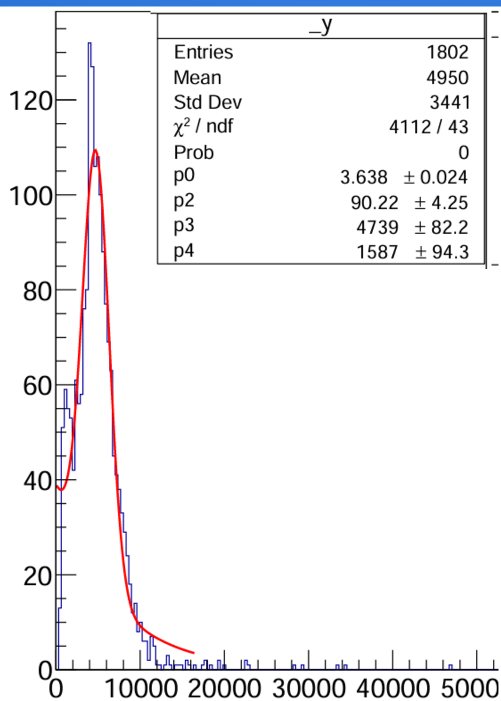
$$f_i = f\left(\frac{\left[E_i - \frac{E_{ref,\,i} * l_i}{l_{ref,\,i}}\right]}{\sigma_{ref,i}\sqrt{l_i/l_{ref,\,i}}};\; \sigma_{ref,\,i}\sqrt{l_i/l_{ref,\,i}} \right)$$

Then
$$(\hat{a}, \hat{b}) = \underset{(a-\Delta a;\, b-\Delta b)<(\hat{a},\, \hat{b})<(a+\Delta a;\, b+\Delta b)}{arg\max} L_n(a,b)$$

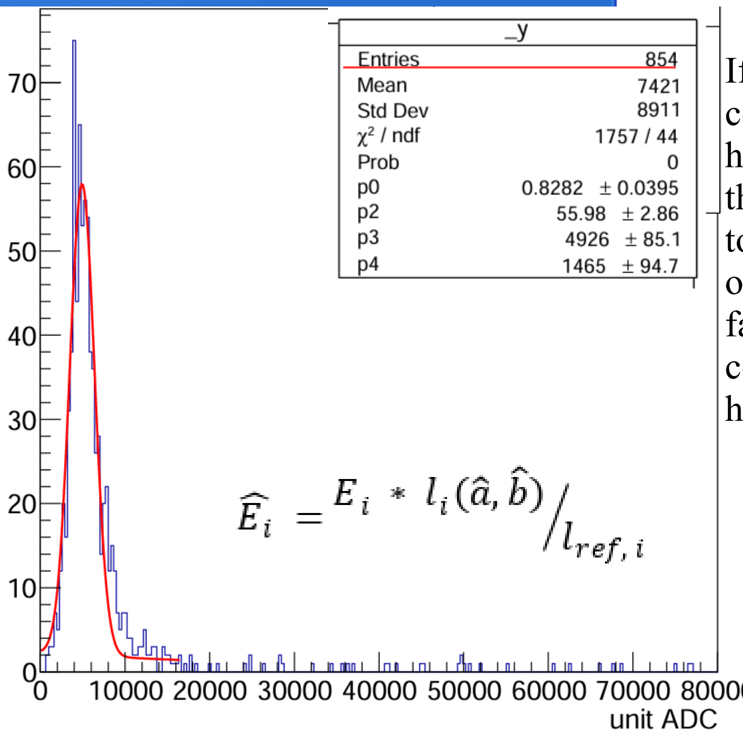
Results of the application of algorithms for reconstruction and correction of muon tracks



Experimental. The energy distribution of MIP muons in tower №0 during the selection of tracks along the X-axis.



Experimental. The energy distribution of MIP muons in tower No. 0 during the selection of slanting tracks, the angle of which was up to 30 degrees with the X-axis.

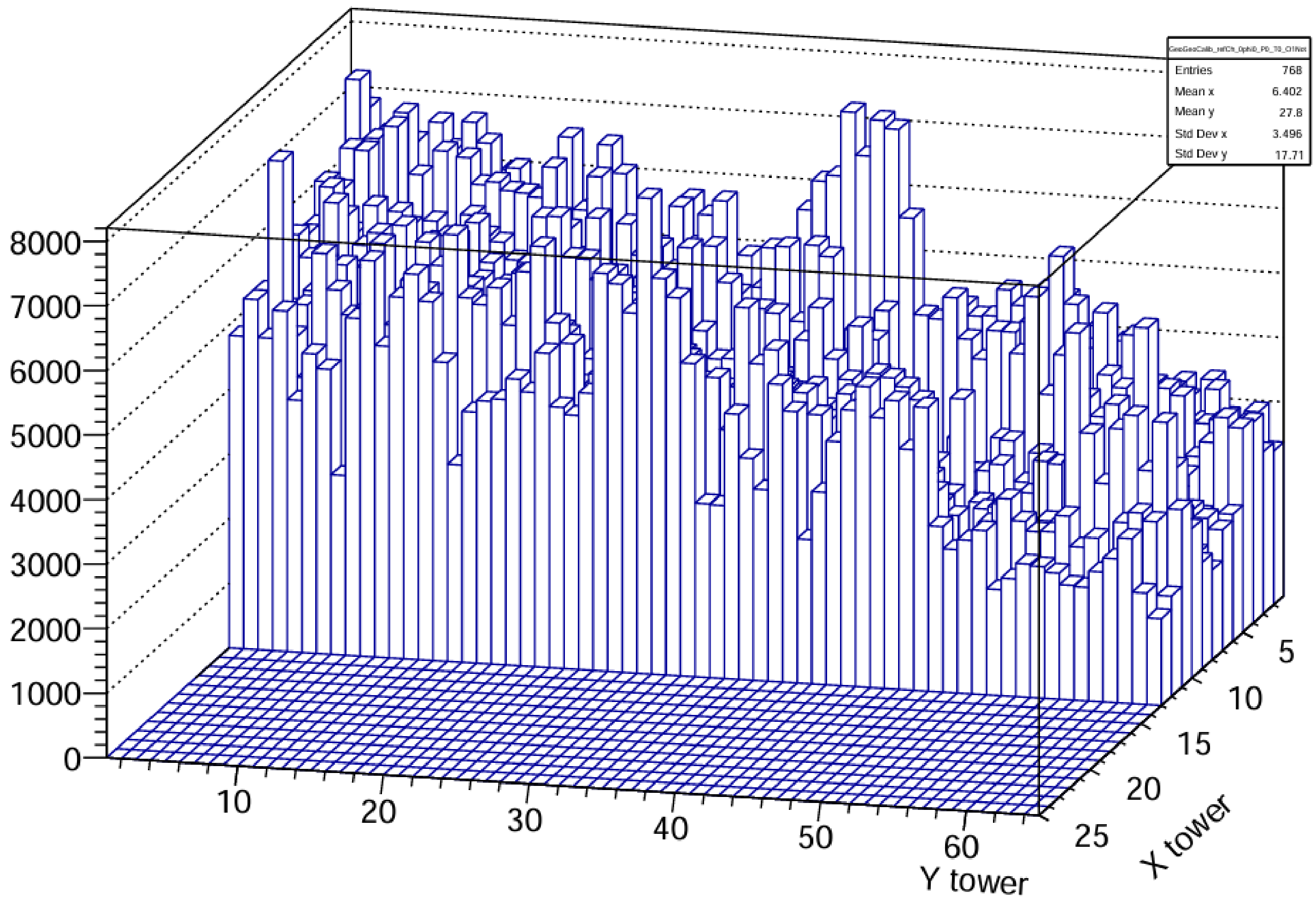


$$\widehat{E_i} = E_i * l_i(\hat{a}, \hat{b}) / l_{ref,\, i}$$

Experimental. The energy distribution of MIP muons in tower No. 0 during the selection of slanting corrected tracks, the angle of which was up to 30 degrees with the X-axis.

If, as a result of track correction, the hypothesis says that there is no hit in some tower, then the energy of such a hit does not fall on the corresponding histogram.

Why calibrate the towers of an electric magnet calorimeter



Experimental. Two-dimensional distribution of tower responses when selecting tracks along the Y axis at N = 5.

CONCLUSION

This work presents the developed algorithms for **two-dimensional track reconstruction** and **track correction** for preliminary calibration of the responses of the towers of the electromagnetic calorimeter ECal of the MPD/NICA.

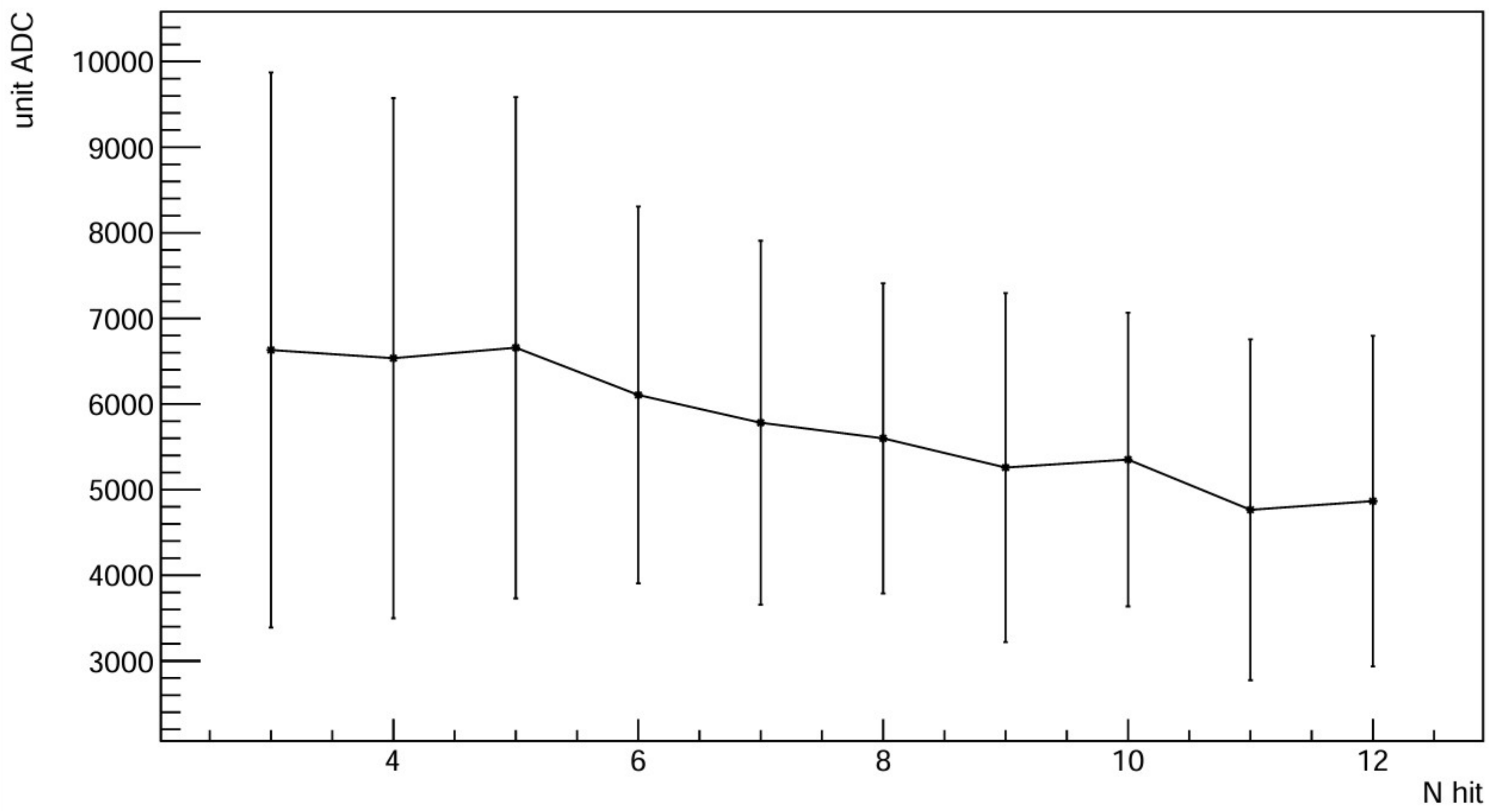
- The basic track reconstruction algorithm consists of two main parts: **iterative search** for candidate tracks in the **Hough space** and **fitting** tracks according to selected hits using the **least squares method**.
- The track correction algorithm uses the **maximum likelihood method** and the **dependence of the released energy on the traversed path in the tower**.

The possibility of improving calorimeter calibration by **increasing statistics** and **decreasing sigma** in the energy distributions in the tower for transverse tracks is demonstrated.

The following tasks are:

- Use simulation to accurately determine the reference lengths of tracks in the tower with different track parameters.
- Expand the application of the track correction algorithm to transition into three-dimensional space and compensate for the dependence of the released energy on the number of hits in the track.
- Perform a complete calibration of the electromagnetic calorimeter.

CONCLUSION



Experimental. Dependence of the released energy on the number of hits in the track by X axis.

CONCLUSION

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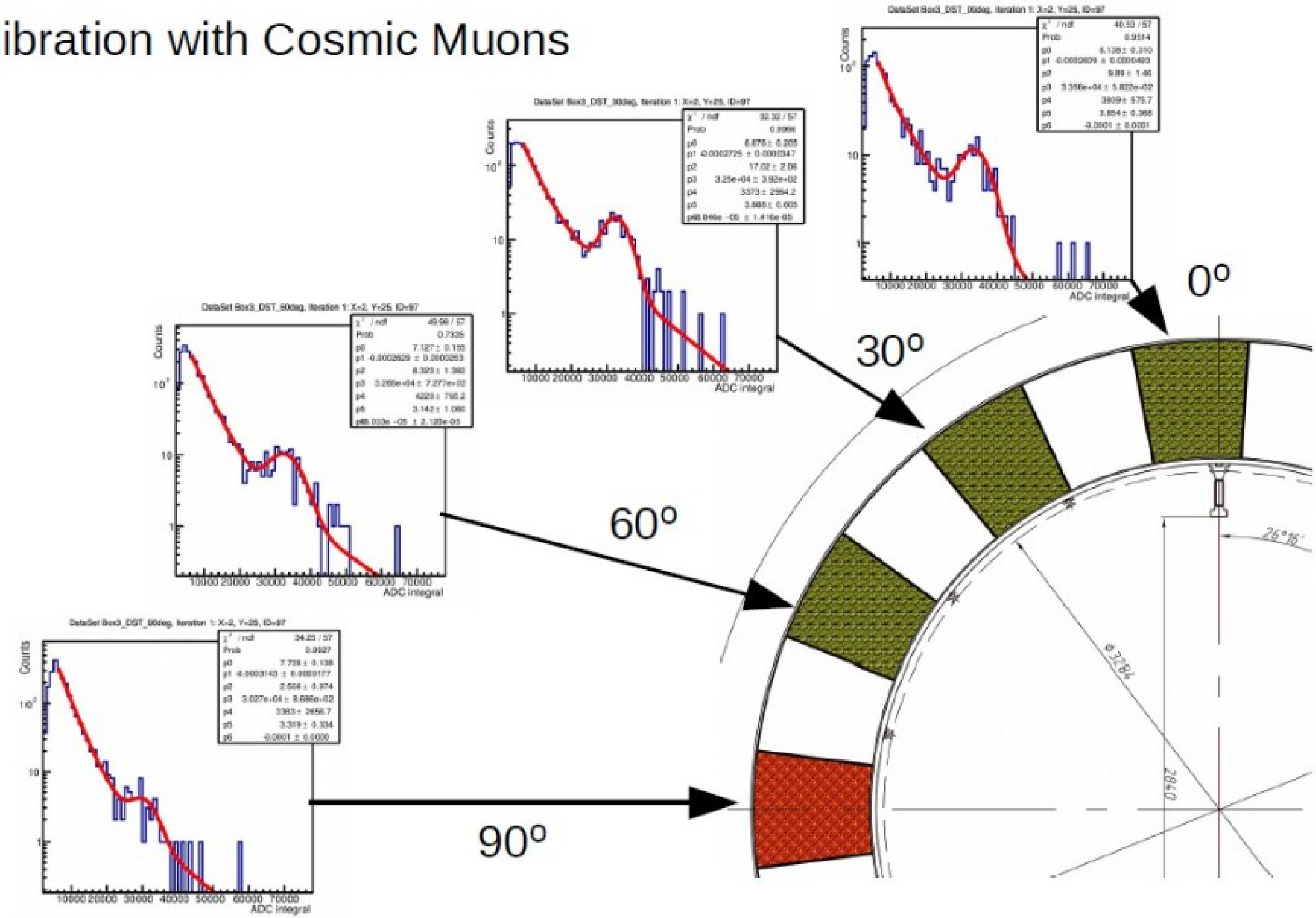
- Perform a complete calibration of the electromagnetic calorimeter.

ECAL Calibration with Cosmic Muons



Problem for the calibration after ECAL assembly: Rotation of the basket on 90 degrees leads to very low statistics in the “longitudinal” muon peak.