Methods and complexes of experimental data processing of the electromagnetic calorimeter (ECal) and the Time-of-Flight detector (TOF) MPD

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Abstract: The Multipurpose Detector (MPD) is one of the main experimental setups at the NICA accelerator complex of JINR. The electromagnetic calorimeter (ECal) and the Time-of-Flight system (TOF) are important components of MPD and are designed to identify particles by measuring energy and time of flight, respectively. Both detectors are complex multicomponent systems containing readout electronics, which, together with the data acquisition system (DAQ), allows digitizing the electrical signals and record data in binary TLV format. The paper presents the results of the development of methods and complexes for experimental data processing of the electromagnetic calorimeter and a Time-of-Flight detector. The main attention is paid to the reconstruction of TOF and ECal data, calibration and correction methods, and online monitoring of the electromagnetic calorimeter.

Introduction

The MPD detector [1] of the NICA [1] complex includes a 3-D tracking system and a particle identification (PID) system. Identification of charged hadrons in a wide range of momentum up to 3 GeV/c is achieved by combining of time-of-flight measurements from the TOF [2,3,4,5] detector and energy loss information (dE/dx) from the TPC. The electromagnetic calorimeter (ECal) [6] of the PID system and its main purpose is to identify electrons, photons and measure their energy.

The TOF is a cylinder system and divided into 14 sectors with a length of 5.9 m. One sector contains two independent modules. Each module consists of sealed gas volume, 10 multigap resistive plate chambers (MRPC) [3,4], on-camera electronics, namely 24-channel preamplifier plate boards based on NINO application-specific integrated circuites (ASIC) [4], amplifier power and signal cables. The MRPC detector consists of three blocks of 5 gas gaps each. The overall dimensions of the MRPC are 650×330×25 mm^3 and correspond to a circuit board with 24 double-sided readout electrodes.

72-channel time-digital converter module in the VME64x standard based on the HPTDC chip are used, which are called TDC72VHL [4,7] are used as read-out electronics. The width of the TDC samples is 23.4 ps. The modules are connected to VME–VXS crates, each of which can accommodate up to 18 TDC72VHL, taking into account the trigger and synchronization module TTVXS [4,7]. Between the crates, time synchronization is carried out using the "White Rabbit" technology, which ensures synchronization accuracy better than 10 ps.

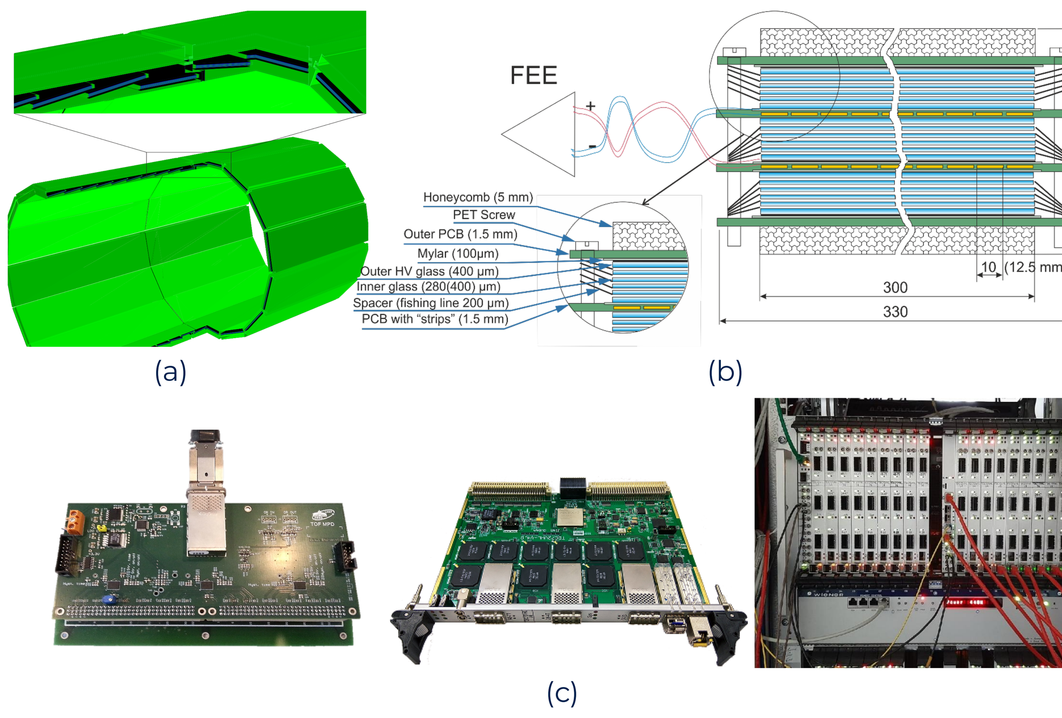

Fig. (1) : (a) - structure of the TOF detector. (b) - structure of the MRPC. (c) - NINO based 24-channel amplifier-discriminator with the Molex CXP connector; 72-channel time-to-digital converter TDC72VHL v4 with CXP input connectors; VME-VXS crate with TDCs and TTVXS modules are shown from left to right.

The electromagnetic calorimeter of the MPD is designed to measure the coordinates and energy of electrons and photons produced in the collision of heavy ions in the central region of pseudorapidity $|\eta| \leq 1.2|$. ECal is a modular cylindrical system of 50 half-sectors, each of which includes readout electronics, a cooling system and 48 modules of various geometries. The module consists of two rows glued together of 8 towers, have a projective geometry [8], in which the axis of each tower is directed at the point of collision of the beams.

The tower is a "shashlik" type calorimeter made of 210 alternating 1.5 mm thick scintillator plates and 0.3 mm thick lead plates. The plates are strung with 16 wave length shifting fibers (WLS) to collect light onto a silicon photomultiplier (SiPM), namely Hamamatsu S13360-6025 [6], which scans its tower. The SiPMs are installed on the HV boards [7] in the amount of 16 pieces per one. For the operation of the high-voltage subsystem, multi channel high-voltage power supply systems from HVSys [9] are used. Specialized 64-channel analog-to-digital converters ADC64ECAL [7] are used as read-out electronics, which can operate in self-trigger mode. ADC64ECAL board allows to be integrated to the White Rabbit system. White Rabbit provides sub-nanosecond accuracy.

An LED source L7113PBC-A [6] of short bright light signals, a fiber -optic split system, SOF-2 side glow fibers inside polycarbonate tubes stretched along each half-sectors let to monitor the stability of the installation over time, monitor the operation of electronics and photodetectors, and check the build quality.

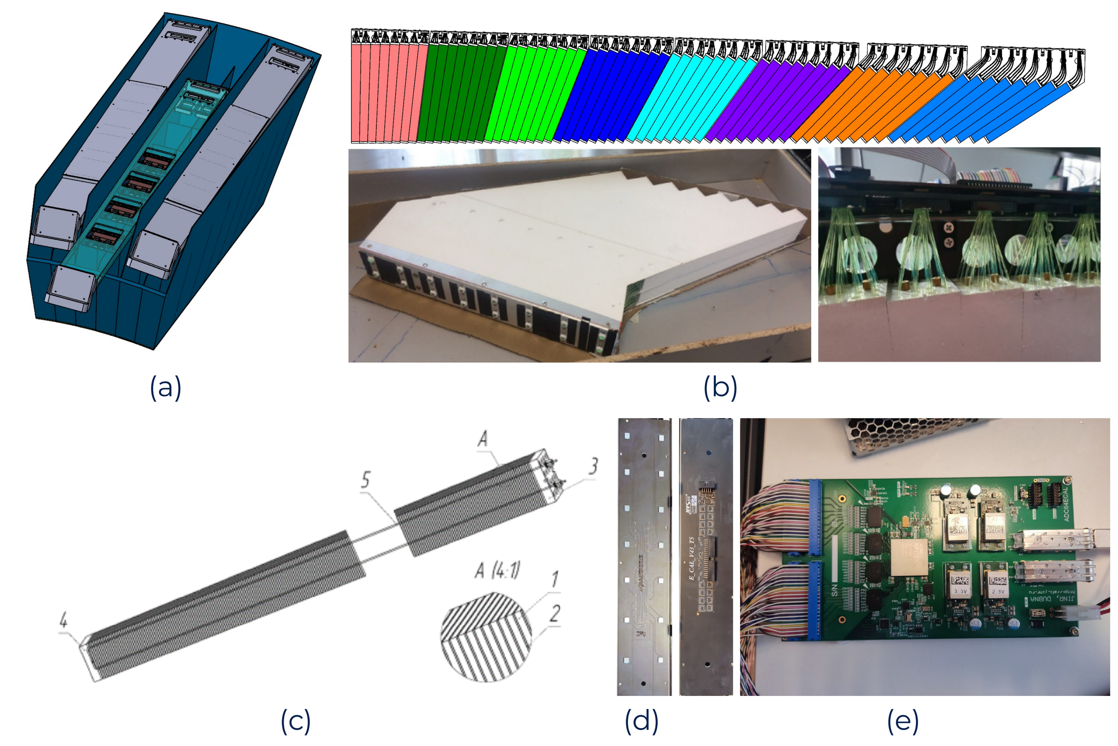

Fig. (2) : (a) - half-sector container (basket) containing 3 boxes with the installed electronics. (b) - top: side view of the half-sector; below: module with SOF-2 fiber inside polycarbonate tube. (c) - the design of the tower without WLS: 1 - scintillator plate, 2 - lead plate, 3 and 4 - plastic end plates, 5 - mounting. (d) - HV board on both sides. (e) - ADC64ECAL board.

Special setups were created in the LHEP JINR to test the TOF [12,13] and ECal elements on cosmic rays. In addition the parts of the calorimeter can be tested with LED source. Each of the installations includes a support structure on which detector systems, service systems and a data acquisition system (DAQ) [10] are placed. The main tasks of the installations: checking the operability of all channels of detectors and electronics; checking the long-term stability of the operating parameters; measuring the efficiency of all detector and electronics channels; preliminary calibration of detectors and electronics and measurement of some system parameters.

Experimental data processing system

The experimental data processing system [12,13,16] based on the MPD-Root [11] software package has a multi-level structure: the raw data of the readout electronics collected according to the selected trigger by the DAQ is converted to ROOT format and converted into digitized detector data; a reconstruction procedure is performed to determine the parameters of the particles interacting with the detectors; physical analysis is being performed. The "raw" data in TLV(Tag-length-value) format is transferred to permanent storage, but some of it can be transmitted via the TCP channel for detector monitoring tasks.

TLV blocks are of different types and contain different information [7]: a complex block (starting/stopping a session/file), a regular block of events, a block of device events, a block of statistics and etc. Special synchronization words are used in the complex block to determine the start/stop of session/file. And to establish the device type, the device identifier is used.

The procedure for converting "raw" binary data into ROOT data, in which the digitized data of the readout electronics of the corresponding detectors is stored in the form of arrays, is called decoding.The decoder has three main functions: initialization, execution, and termination. Depending on the input parameters, the decoder can perform either an offline implementation or an online one. At the moment, processing of a complex, regular block of events and blocks of devices that are used by TOF and ECal detectors is implemented: ADC64ECal, TDC72VXS, TTVXS. The digitized ADC and TDC data are presented as an oscilloscope and a vector of measurements of time and signal amplitude, respectively. Reading and processing are implemented by 3 TLV blocks to correctly stop the decoder in case of file termination or the end of the TCP data stream.

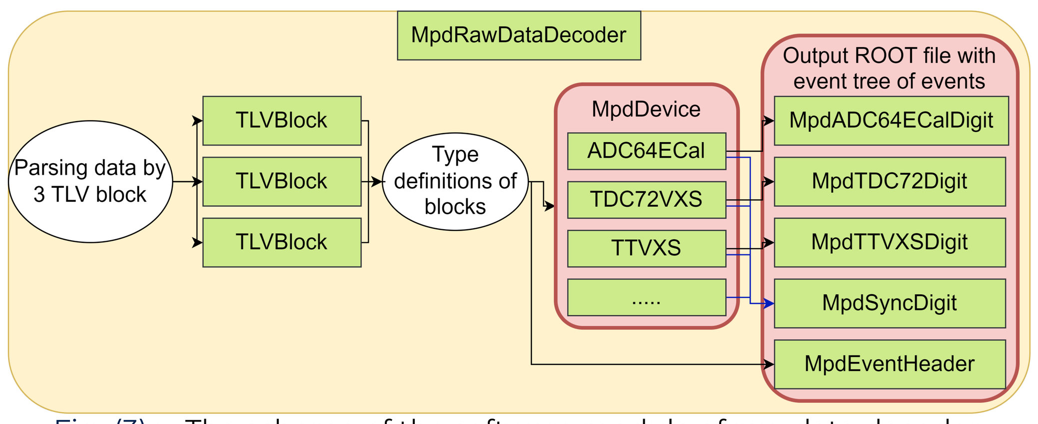

Fig. (3) : The scheme of the software module of raw data decoder.

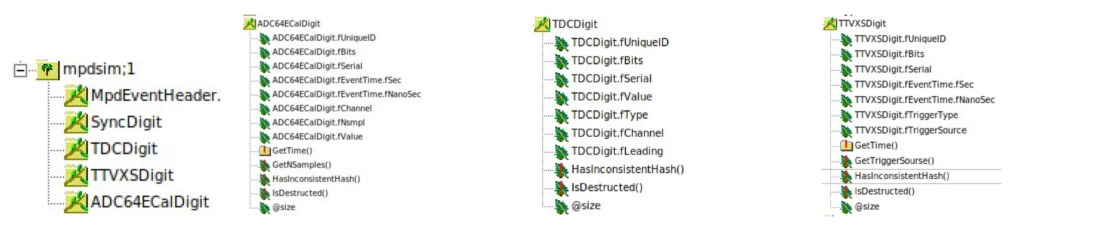

Fig. (4) : Example of tree of events after decoding and branch structure of digitized readout electronics data: ADC64ECal, TDC72VXS, TTVXS.

The stage of converting readout electronics digital data into detector digital data is implemented as separate tasks (software modules) for detector systems separately due to the fact that each detector has its own device map, unique geometry and special data transformations must be performed: for the TOF detector – TDC digital data is searched side-to-side and combined for subsequent processing; for the ECal – an approximation by gaussian function with asymmetry (Eq. 1), called "novosibirsk" function, data is used for the electromagnetic calorimeter. In addition, these data are supplemented with information about the triggered electronics channel. When performing this procedures, it is necessary to use tables of correspondences of electronic channels to detector channels, the geometry of the installation, as well as apply appropriate calibrations and corrections of detectors (Table 1). Hits are reconstructed based on digitized detectors data.

$$f(x; n, \mu, \sigma, \tau) = ne^{-\frac{(\log \xi)^2}{2\omega} - \frac{\omega^2}{2}}; \quad \xi = 1 - \frac{(x-\mu)\tau}{\sigma}; \quad \omega = \frac{sh(\tau\sqrt{\log 4})}{\sqrt{\log 4}} \tag{1}$$

Eq. 1: Gaussian function with asymmetry with parameters: n – the number of points in the peak; τ - asymmetry; σ – standard deviation; μ – the position of the peak vertex.

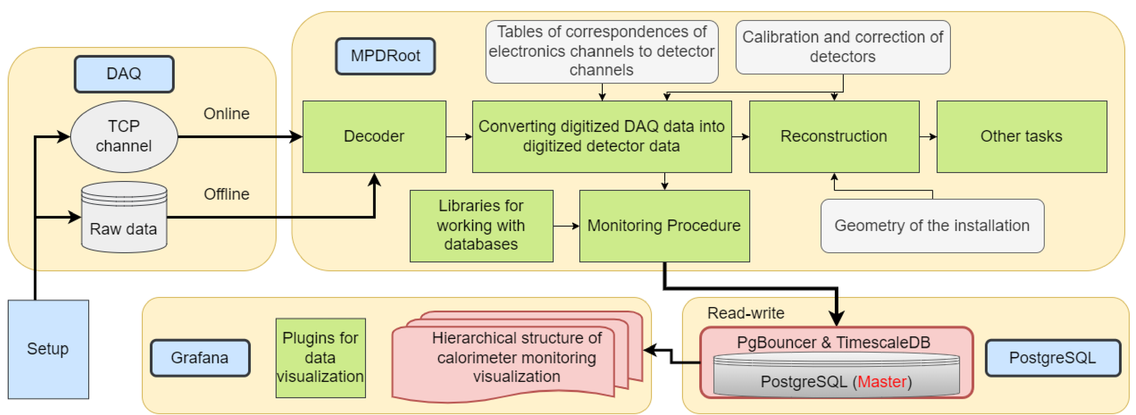

Fig. (5) : Scheme of the ECal and TOF experimental data processing system with online monitoring modules for electromagnetic calorimeter channels.

TOF	ECal
Calibration of integral nonlinearity of channels TDCs [12,13]	Correction of the nonlinearity of the electromagnetic calorimeter energy scale
Calibration of individual time delays in each channel [12,13]	Correction of signal attenuation during signal propagation through WLS fibers
Correction response time and charge using the Time-Over-Threshold method [12,13]	Alignment the responses of the electromagnetic calorimeter elements and transformation the signal to deposited energy [15]
Local time synchronization of TDCs in different crates [12,13]	Local time synchronization of ADCs half-sectors
Global time synchronization	
Calibration of the geometry of the detector system	

Table 1: Calibrations and corrections of TOF and ECal.

A module of slow-control system for towers electromagnetic calorimeter has been developed [16]. The architecture of the module is: data processing in MPD-Root, data storage in the PostgreSQL [17] database, visualization and postprocessing in Grafana [18,19]. To speed up the work with the database, various extensions were used, such as TimeScaleDB [20] and PgBouncer [21]. All this is designed for continuous monitoring and control of the parameters of the towers electromagnetic calorimeter. At the moment, two sources are used: cosmic rays and LED signals.

Results

To determine the nonlinearities of the ADC channels, a statistical code density test based on a random event source is used. As a result of decoding the data using INL calibration and further reconstruction with calibration individual time delays in each channel, it was possible to align the coordinates of the TOF hits.

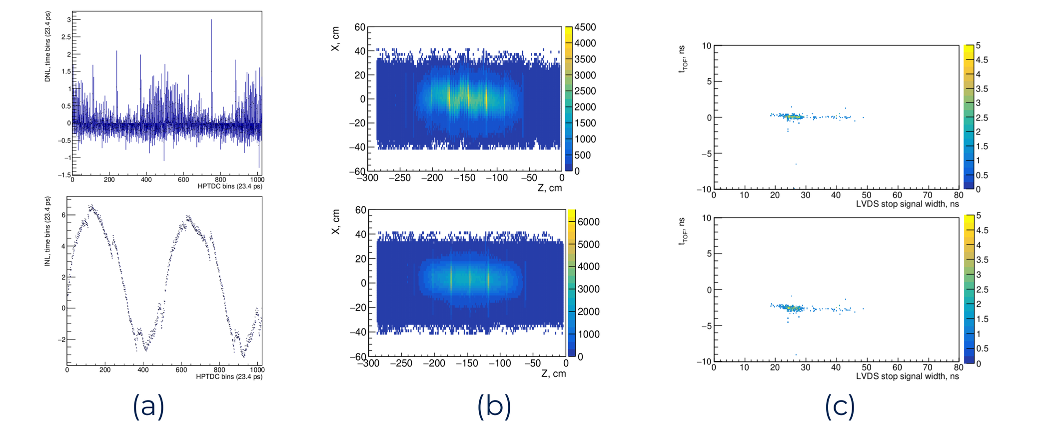

Fig. (6) : (a) - Differential nonlinearity (DNL) (left) and integral nonlinearity (INL) (right) of a single channel (1024 bins) VTSP TDC72VHL. (b) - Histograms of hits TOF-module without calibration individual time delays in each channel and with one. The Z-axis is directed along the module, the X-axis is directed along the strip. (c) - The time of flight distribution from the signal width of before and after correction.

In addition, estimates of the coordinate and time resolution of TOF modules were performed. To do this, an algorithm was implemented for matching 4 hits and 3 hits into one track. Each of the hits belongs to a separate module. 4 modules are located one above the other on one arm of the TOF testing setup. So for the first module, the deviations are $\sigma_x \approx 0.98cm$ and $\sigma_z \approx 0.71cm$ [12,13] using vertical tracks. To obtain an estimate of the time of flight resolution, only vertical tracks with hits belonging to strips with the same number from MRPC with the same number were selected by one MRPC detector. This is done so that the same strip is responsible for the start time. The time resolution of such a system is $\sigma_t \approx 169ps$ without ToT correction and with - $\sigma_t \approx 97ps$. The time resolution of the MRPC together with the electronics is $\frac{97}{\sqrt{2}} \approx 69ps$ [12,13]. This is somewhat worse than the declared characteristics of the TOF system due to experimental data collected using particle of cosmic rays with a wide range of momenta.

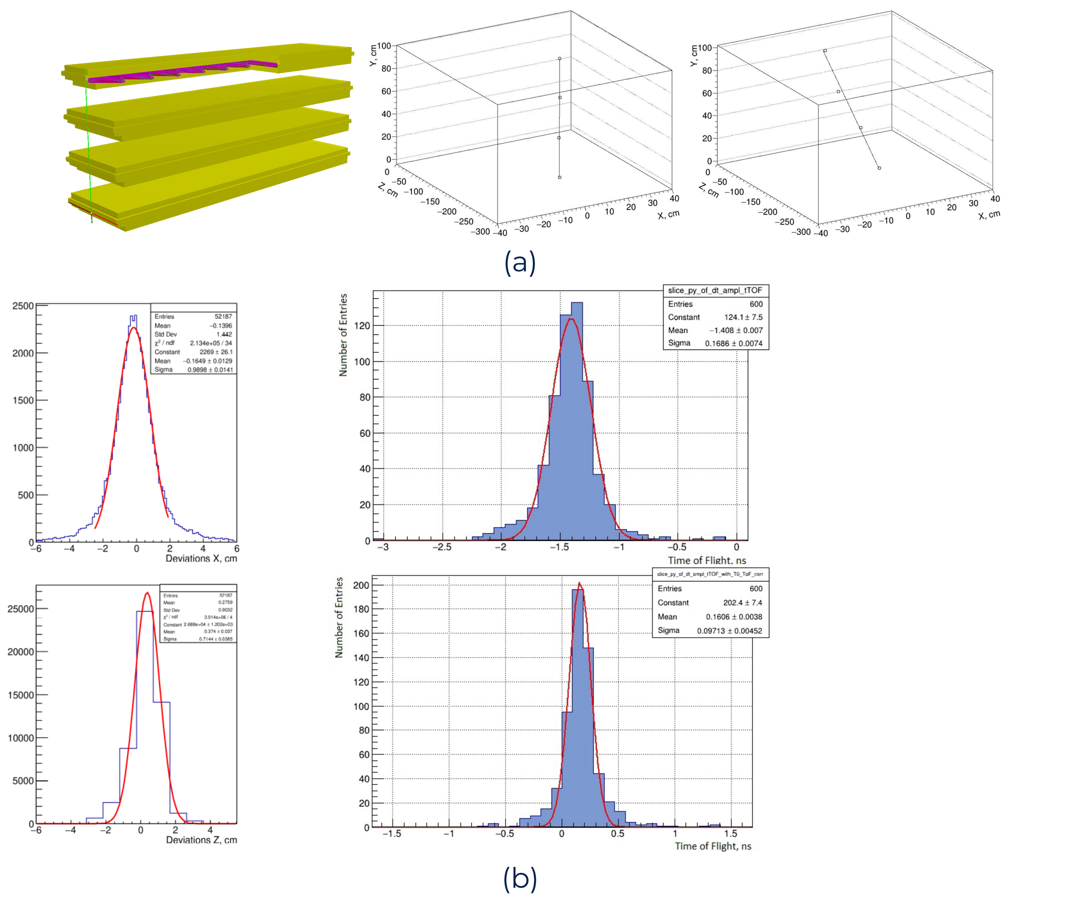

Fig. (7) : (a) - Reconstruction of tracks based on 4 hits from various TOF modules. a) - vertical track, b) — inclined track. (b) - The coordinate resolutions for vertical track selection are shown on the left and the time resolution without and with ToT correction is shown on the right.

An electromagnetic calorimeter monitoring system has been developed, which consists of three modules: module of data processing in the MPD-Root package, PostgreSQL database together with the packages TimescaleDB and PgBouncer with materialized view and continuous aggregates for post-processing and visualization module in Grafana. All this is designed to continuously check the stability of elements of the electromagnetic calorimeter.

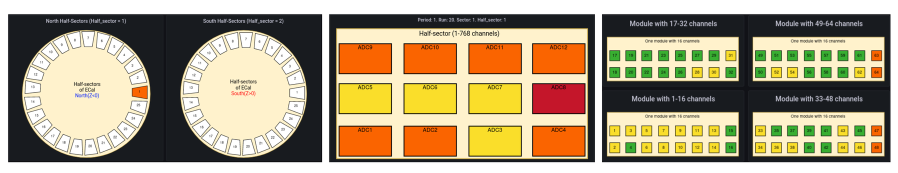

Fig. (8) : ECal monitoring levels [16]: sectors with half-sectors, half-sector, ADC board with 64 channels.

Algorithms for the reconstruction of muon tracks have been developed, consisting of two stages: an iterative search for two-dimensional candidate tracks in the Hough space and their approximation by selected hits using the least squares method. The resulting two-dimensional track is used as part of the initial values of the three-dimensional track; correction of the three-dimensional track parameters is achieved by maximizing the likelihood function based on previous experimental calculations of the reference energy storage and distribution width, as well as current measurements of two-dimensional coordinates and energy. This method works under the assumption that the energy released by a minimally ionizing particle is linearly proportional to the distance traveled. The reference track lengths are determined based on simulation. The results of using this algorithm demonstrate the possibility of improving the preliminary alignment of the ECal MPD tower responses by reducing the width of the energy distributions of cosmic muons in the tower when selecting paths transverse to the tower axis. Thus, compared to the "M5" [15] method of operation, the "N12" selection method, in which the angle of the adjusted tracks was up to 30 degrees relative to the X axis, allowed to reduce the width of the distribution by 1.3 times while reducing the statistics by 2.8 times.

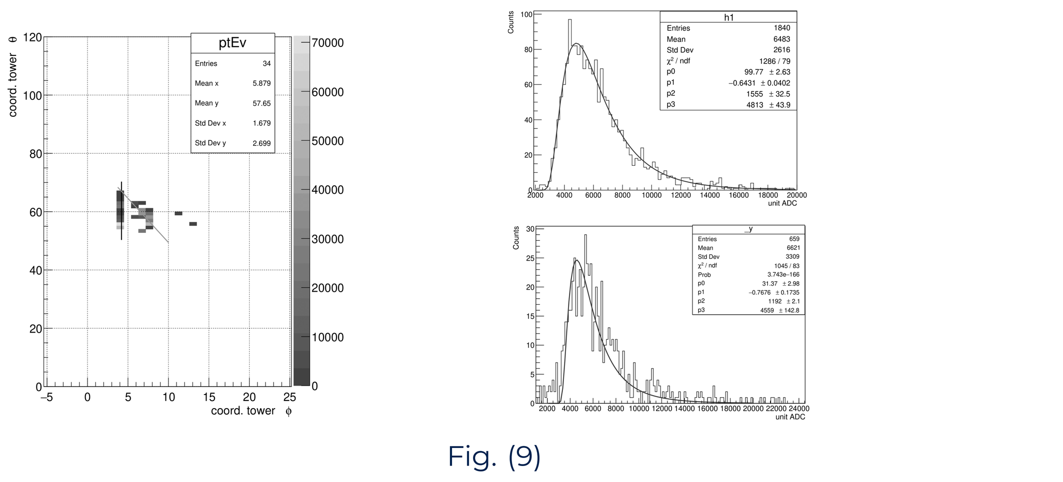

Fig. (9)

On the left is an example of reconstruction of tracks in one event with 34 hits. On the right are the distributions of muon energy release in one tower under different methods: at the top is the selection of "M5" along the X-axis; at the bottom is the selection based on the multiplicity of hits in the adjusted tracks "N12", the angle of which was up to 30° relative to the X-axis.

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