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ELEMENTARY PARTICLES AND FIELDS
Experiment

Status of the Time-of-Flight System of the MPD Experiment at the NICA Collider

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Abstract—New NICA accelerator complex at JINR (Dubna), based on the existing upgraded Nuclotron accelerator, will allow conducting all types of research in the field of high-energy physics. The main tasks of this project are study of the properties of the deconfinement phase transition, experimental investigation on medium modification of vector mesons, and search for the QCD critical end point. Thus, two interaction points are foreseen in the NICA collider: one for studying the collision of heavy ions on the Multipurpose detector MPD, the other for polarized beams for the experiment on the SPD installation. The ambitious physical goals of MPD require excellent particle identification at the maximum possible range of phase space. Identification of charged hadrons is achieved by combining time-of-flight measurements and dE/dx energy loss measurements from the time-projection camera TPC. The Time-of-Flight system is based on multigap resistive plate chambers (MRPC), which are successfully used to identify particles in similar experiments around the world. A production site has been organized at the Laboratory of High Energy Physics of JINR for serial production of TOF MPD modules including 10 MRPCs. This site includes the entire cycle of work from preparing materials for the assembly of detectors to testing the assembled modules on cosmic radiation. This report presents the structure of the TOF system, its main parameters, the current state and the results of decoding and processing data obtained at the module testing facility.

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1. INTRODUCTION

The NICA [1] will make it possible to accelerate and collide heavy ions, up to gold ions, at an average luminosity of $L = 10^{27}$ cm^{-2} s^{-1} (for Au^{79+}) in the centre-of-mass energy range $\sqrt{S_{NN}} = 4$–11 GeV. The two interaction points are foreseen at the collider, one of which is designed to study the collision of heavy ions with the multipurpose detector Multipurpose detector (MPD) [2, 3].

The MPD is capable of detecting charged hadrons, electrons and photons in heavy-ion collisions in the energy range of the NICA collider. The detector includes a precise 3-D tracking system and a high-performance particle identification (PID) system. The principal tracker is the time-projection chamber (TPC). The MPD has two main identification subsystems. The first subsystem is high performance Time-of-Flight (TOF) detector [4, 5]. The TOF together with the TPC must be able to identify charged hadrons and nuclear clusters in the broad rapidity range and up to total momentum of 3 GeV/c. The second PID system is the electromagnetic calorimeter. Its main goal is to identify electrons, photons and measure their energy with high precision. The general layout of the MPD apparatus is shown in Fig. 1.

The TOF is located in the MPD between the time-projection chamber and the electromagnetic calorimeter. The active surface of the Time-of-Flight system covers a large range of pseudorapidity and $\sim 330°$ in φ angle. The TOF [6, 7] is segmented into 14 sectors with the length of ~ 5.9 m. One sector contains two independent modules. The module consists of two separate volumes: the inner gas box which contains 10 multigap resistive plate chambers (MRPCs) [6, 7]; the outer box contains front-end electronics (FEE) cards, cables, high voltage and gas plugs. The main parameters of the TOF detector are presented in Table 1. The time resolution of the TOF system can be considered equal to 80 ps [8].

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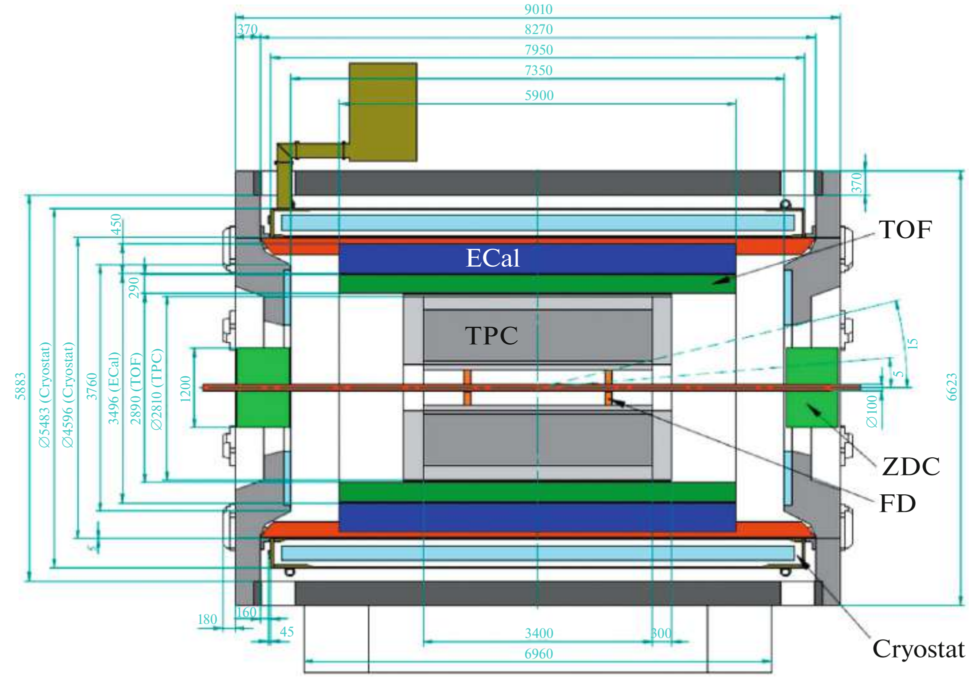

Fig. 1. Structure of the Multipurpose Detector with main dimensions.

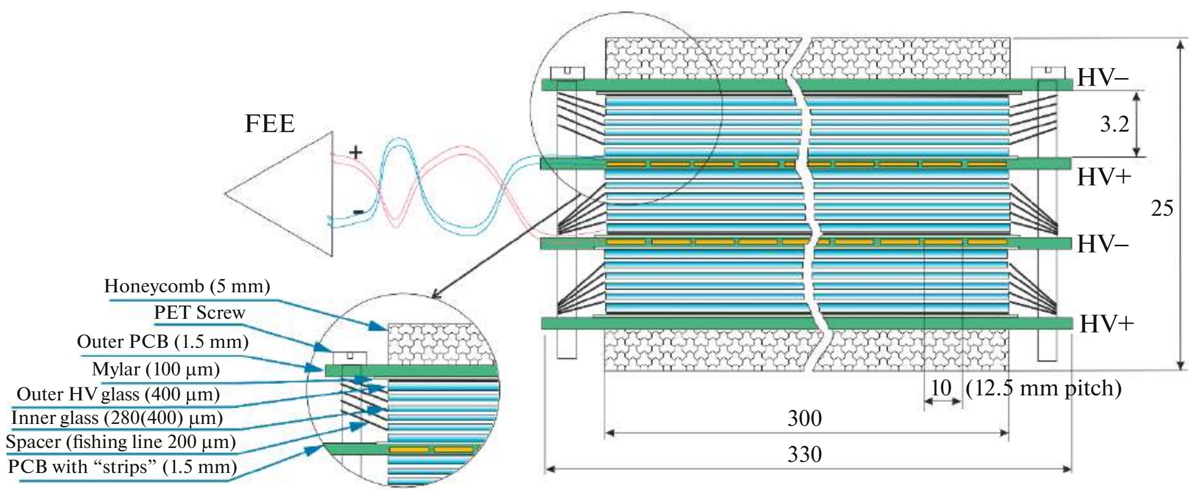

Fig. 2. Structure of the MRPC detector.

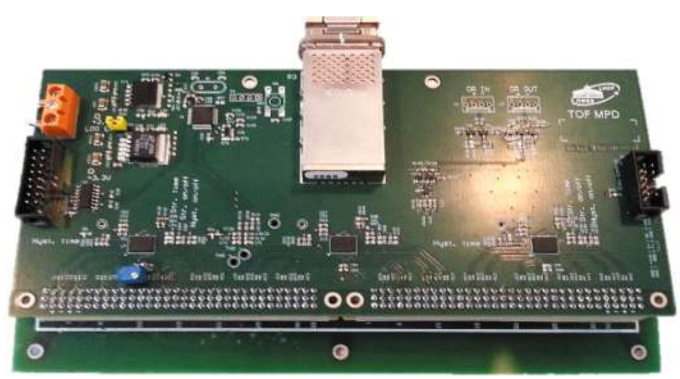

Fig. 3. NINO based 24-channel amplifier-discriminator with the Molex CXP connector.

The MRPC detector consists of three stacks of 5 gas gaps each. Overall dimensions of the MRPC are $650 \times 320 \times 25$ mm^3 and it corresponds to the PCB with readout electrodes (Fig. 2). PCB has 24 strips,

Fig. 4. 72-channel time-to-digital converter TDC72VHL v4 with CXP input connector.

Table 1. The main parameters of the TOF system

	Number of detectors	Number of readout strips	Sensitive area, m^2	Number of FEE cards	Number of FEE channels
MRPC	1	24	0.192	2	48
Module	10	240	1.848	20	480
TOF system	280	6720	51.8	560	13 440

10 mm wide and 640 mm long. To reduce crosstalk, the gap between strips is 2.5 mm.

1.1. The Readout Electronics of the Time-of-Flight System

The readout electronics are crucial for the overall time resolution of the TOF system. Therefore, the TOF system uses a 24-channel preamplifier board based on NINO application-specific integrated circuites (ASIC) [5, 9–11]. This electronics board (Fig. 3) includes a transimpedance amplifier and a discriminator. It was developed specifically for reading fast signals for time-of-flight measurements. The distinctive features of the NINO chip [9] are:

- adjustable input impedance;
- the output preamplifier signal is in the LVDS standard;
- the circuit has a low power consumption, which is important for multi-channel detector systems.

Fig. 5. Setup for testing the modules of the TOF system.

The features of the 24-channel preamplifier board based on ASIC NINO are as follows:

• there are capacitors at the inputs of the board, adapted for reading from both sides of the strip;

• the discrimination thresholds monitoring and control;

• the NINO integrated circuit voltage monitoring and control;

• the board and the gas space thermal monitoring.

The VME64x time-to-digital converter TDC72VHL [5, 10, 11] based on the HPTDC chip is also used for the MPD TOF readout (Fig. 4). TDC72VHL is used to digitize the LVDS signals coming from the output of the NINO amplifier. The width of the TDC samples is ∼23.4 ps. This electronics board also includes the core of the White Rabbit node [12]. This will allow you to synchronize all the readout boards.

Fig. 6. Racks with gas system for setup and data acquisition system.

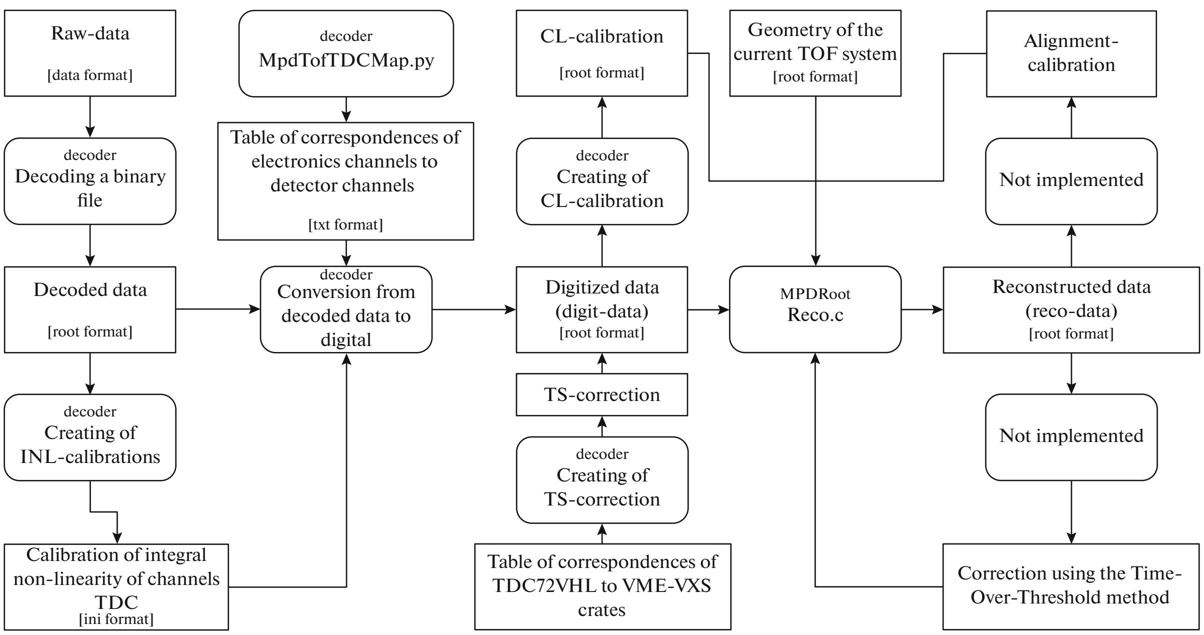

Fig. 7. The scheme of the software for decoding and reconstructing data from the TOF system.

2. SETUP FOR TESTING MODULES OF THE TOF SYSTEM

It is practically impossible to check the modules of the TOF system on the particle beam of the accelerator, since long-term scanning of their all area is required. Therefore, a special setup [5] for testing TOF modules on cosmic radiation was organized. It includes a support structure on which up to 8 modules can be placed, service systems and a data collection system (see Figs. 5 and 6). The main tasks of the setup:

1. check of the performance of all channels of detectors and electronics;

2. check of the long-term stability of the operating parameters of the modules;

3. measurement of the efficiency of all channels of detectors and electronics;

4. pre-calibration of detectors and electronics and measurement of some system parameters.

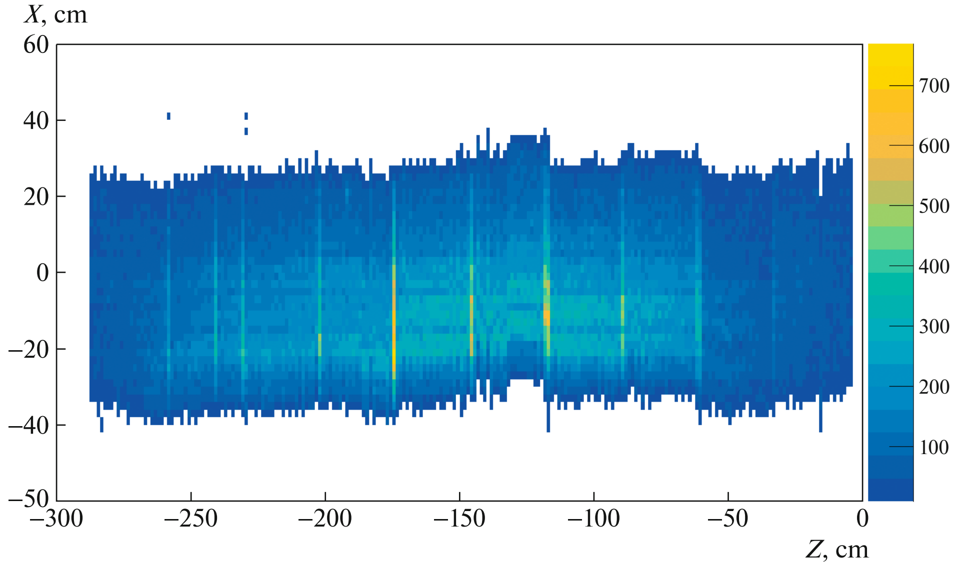

Fig. 8. Histogram of charged particles' hits in the detectors of one module of the Time-of-Flight system without local CL-calibration.

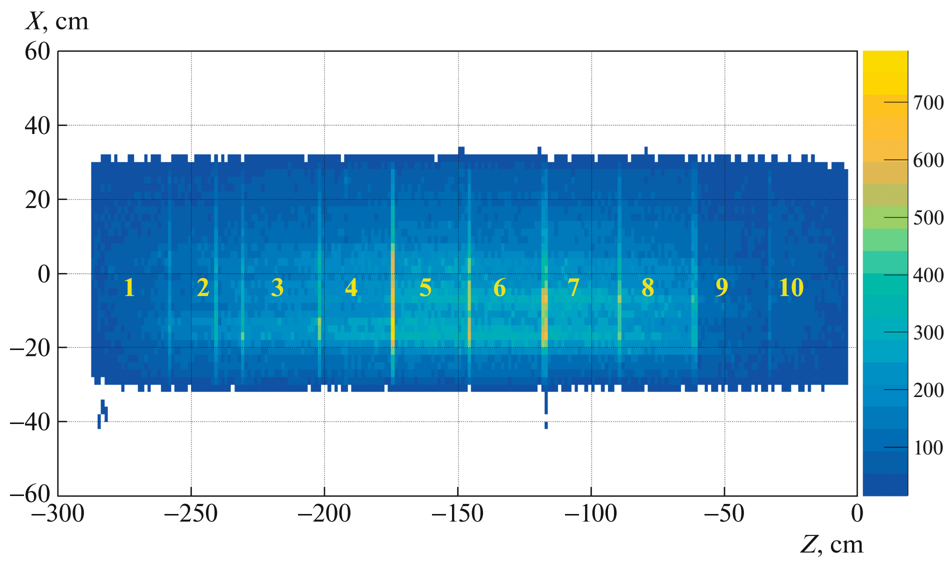

Fig. 9. Histogram of charged particles' hits in the detectors of one module of the Time-of-Flight system with local CL-calibration.

A distinctive feature of this facility is that all devices used on it are completely identical to those that will be used in the Time-of-Flight system of the MPD experiment. Thus, all the functionality of the future system is checked.

The service systems and data acquisition system occupy six standard 19-inch rack. Three of them are occupied by a complex gas system with a closed loop of recirculation and filtration of the working gas mixture.

One of the six racks is occupied by low and high voltage power supplies, logic trigger electronics, and slow control system devices. The remaining two racks are fully used for the data acquisition system and include 6 VME—VXS crates, each of which contains 16 time-to-digital converters TDC72VHL. Each of the VME—VXS crates records the first response time for each of the TDC72VHL in the raw data. In total, the data acquisition system for testing modules contains about 7000 read-out channels.

3. TYPES OF CALIBRATIONS AND CORRECTIONS OF THE TOF SYSTEM

The important factors affecting the quality and accuracy of time measurements of the TOF system are

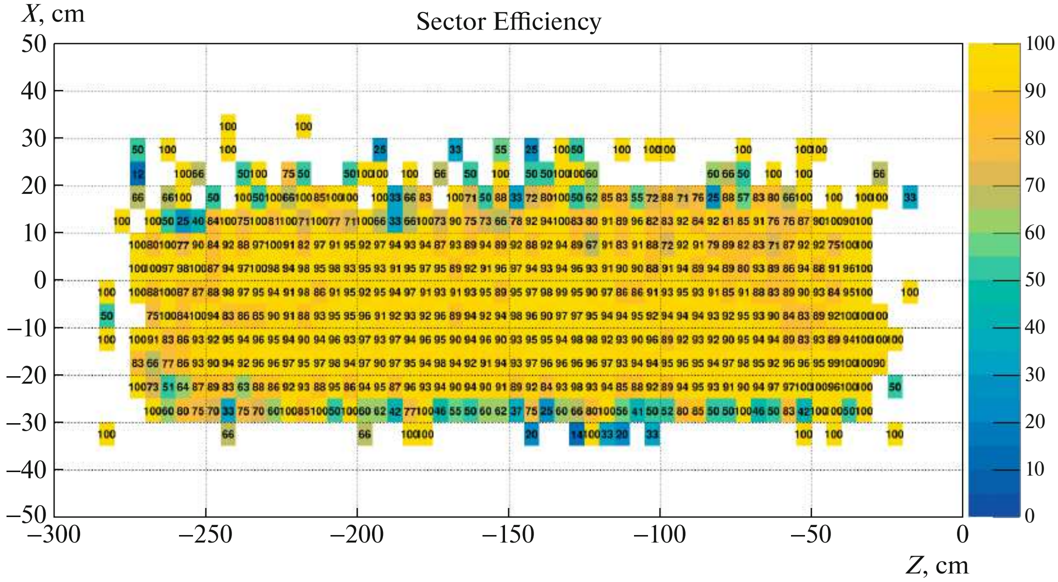

Fig. 10. The average efficiency of one TOF module.

differential and integral nonlinearities of electronics, deviation of the actual geometry of the installation from the reference one. Also it is necessary to take into account the amplitude of the signal, since the NINO circuit pulse width depends on the MRPC pulse height when measuring time of flight. It is also worth noting that the signals from the detectors go through separate cables of different lengths. Thus, in total there are 5 types of calibrations and corrections for our system:

1. INL-calibration — calibration of integral nonlinearity of channels time-to-digital converters VME64x TDC72VHL;

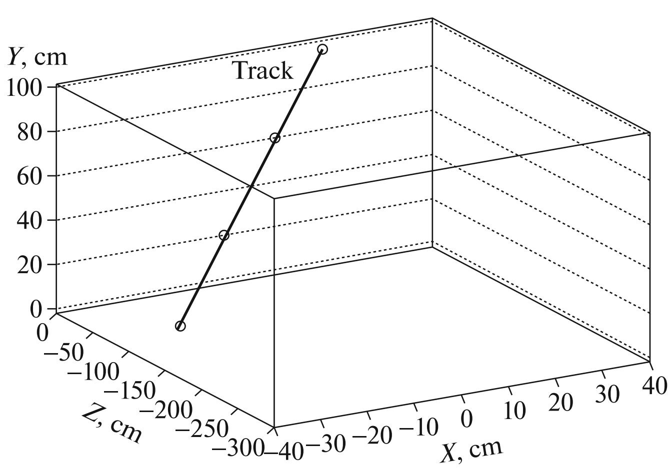

Fig. 11. Track reconstruction based on four hits on different modules of the TOF system.

2. CL-calibration—calibration of individual time delays in each channel;

3. ToT-correction—correction using the Time-Over-Threshold method;

4. TS-correction—time correction during synchronization of the VCP modules;

5. Alignment-calibration—calibration of the geometry of the TOF system.

4. SOFTWARE FOR DECODING AND RECONSTRUCTION OF DATA OBTAINED AT TOF MODULES TESTING SETUP

Software for decoding, reconstruction, processing and physical analysis of data from TOF modules is developed within the MPDRoot [13] package using CVMFS. The following programming languages are used: C++, Python.

The structure of the software is as follows:

- “decoder” software package for data decoding;
- modernized software package “tof” for data reconstruction;
- software package for the analysis of reconstructed data;
- database software package.

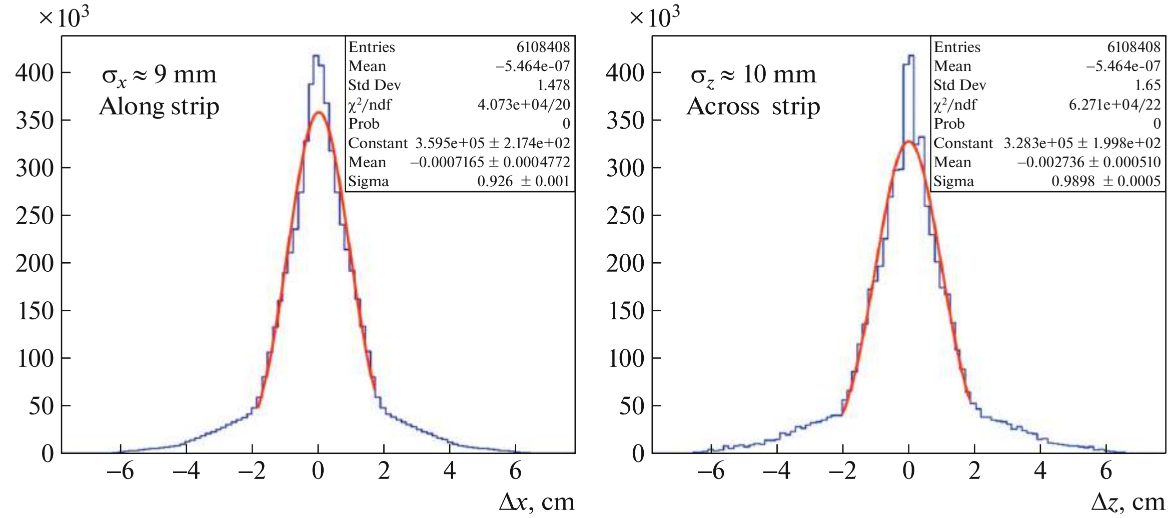

Fig. 12. Deviations of cross points of the reconstructed track and the plane of the corresponding detector from the corresponding hits in this detector.

Figure 7 shows a schematic diagram of the software. First of all, we collect data from TOF modules testing setup, which is called raw-data. These raw-data contain sequentially recorded information about detector signals in the form of sentences that can be conditionally represented as: message start code, message length, useful information, message end code. Second of all, the raw-data are decoded into a deco-file with the “root” extension. This is followed by the stage of converting the deco-file to a digit-file. This is a necessary step for correct reconstruction, based on the commonly used MPDRoot libraries. Finally, we can reconstruct hits in the TOF system.

At the moment, we can calibrate the integral nonlinearity of the TDC channels, individual time delays in each channel and make time correction to synchronize TDC72VHLs in different VCP modules.

5. RESULTS OF DATA PROCESSING FROM THE SETUP OF TOF MODULE TESTING

As a result of de coding and data reconstruction with cable length calibration, the coordinates of the hits in the detectors of the TOF modules aligned. Accordingly, this leads to a more accurate calculation of the time of flight:

$$t' = t + \Delta L/v, \tag{1}$$

where ΔL is displacement of the particle hit position along the strip and v is the signal propagation speed. This is visually demonstrated in Figs. 8 and 9.

The values of the average efficiency of one TOF module containing 10 MRPCs were obtained. The results are shown in Fig. 10.

Within the framework of the developed software package for analyzing the reconstructed data obtained at TOF modules testing setup, an algorithm for conducting tracks on 4 hits was implemented. For this algorithm, hits were clustered in each of the modules according to the position of the hit, its time, amplitude. In each of the clusters, the hits are ordered by signal amplitude. Thus, hits with the highest amplitude from different clusters are used for one track (Fig. 11).

Using different samples the average deviations of the coordinates of charged particle hits from the cross points of the reconstructed track and the plane of the corresponding detector were measured. Thus for vertical tracks the variances are $\sigma_x \approx 0.8$ cm and $\sigma_z \approx 0.6$ cm. For a sample that includes all tracks, the variances are $\sigma_x \approx 0.9$ cm, $\sigma_z \approx 1.0$ cm (Fig. 12).

6. CURRENT STATE OF THE TOF SYSTEM

The production of MRPC detectors has been completed. In total, we have 300 (107%) fully tested MRPC detectors. At the beginning of 2023, $24 + 1$ out of 28 (86%) TOF MPD modules have already been assembled. The software described above is developed for:

1. decoding of TOF system detector signals and their further reconstruction within the MPD-Root software package;

2. creation and automated testing of tables of correspondences of electronics channels to detector channels;

3. creation and automated application of INL-calibration and CL-calibration of the TOF system;

4. creation and automated application of TS-correction based on the VME—VXS crates data of the TOF system;

5. recording calibrations and channel correspondence tables to the database of MPD experiment.

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