PROCEEDINGS OF SCIENCE

Time-of-Flight particles identification in the MultiPurpose Detector at NICA

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The main goal of the MultiPurpose Detector (MPD) at NICA facility in Dubna is to study hot and dense baryonic matter in ion-ion collisions at energies $\sqrt{s_{NN}} = 4 - 11$ GeV. It is necessary to identify particles produced in interactions with high efficiency for a detailed study of the processes and registration of the slightest fluctuations occurring under these conditions. The time-of-flight identification system (TOF) of the MPD based on the MRPC has characteristics that make it possible to cope with this task as efficiently as possible. The TOF system performance and results of a realistic simulation of hadrons identification are presented in this paper.

European Physical Society Conference on High Energy Physics - EPS-HEP2019 -
10-17 July, 2019
Ghent, Belgium

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PoS(EPS-HEP2019)209

1. Introduction

The experience of creating time-of-flight identification systems for large-scale experiments in high-energy physics has shown that the use of multi-gap resistive plate chambers (MRPC) is the most optimal solution for this task. The decision to use MRPC for the time-of-flight system of the multipurpose detector MPD [1] at the NICA accelerator complex [2] was made quite a long time ago and all this time we have been working to optimize both the detector itself and the system as a whole. Most of the system performances were checked by the GEANT4 simulation. This article summarizes the results of this work.

2. The time-of-flight system design

The process of creating and optimizing the performance of main detecting element of the time-of-flight system, the triple-stack multi-gap RPC, was described in detail and sequentially in several articles [3, 4, 5]. The main features of this detector are a three-stack configuration and two-side readout from the strip. During testing triple-stack MRPC prototypes with a deuteron beam at the "MPD test beam" setup [6], the best time resolution of the detector reached 40 picoseconds with efficiency better than 98% even taking into account the jitter of all the electronics. This result more than satisfies the requirements of the MPD experimental program.

Of course, when testing a single prototype, you can get very good results.Therefore, it is expected that the average time resolution of entire TOF detector which includes more than 13 thousand channels will not exceed 60 ps. Thus, even if the time resolution of the T0 detector is worse than 50 ps, then the total resolution of the system TOF–T0 should be around 80 ps.

The cylindrical part of the TOF MPD is located inside the magnet yoke (Figure 1) between the time-projection chamber (TPC) and the electromagnetic calorimeter (ECal). The TOF barrel length

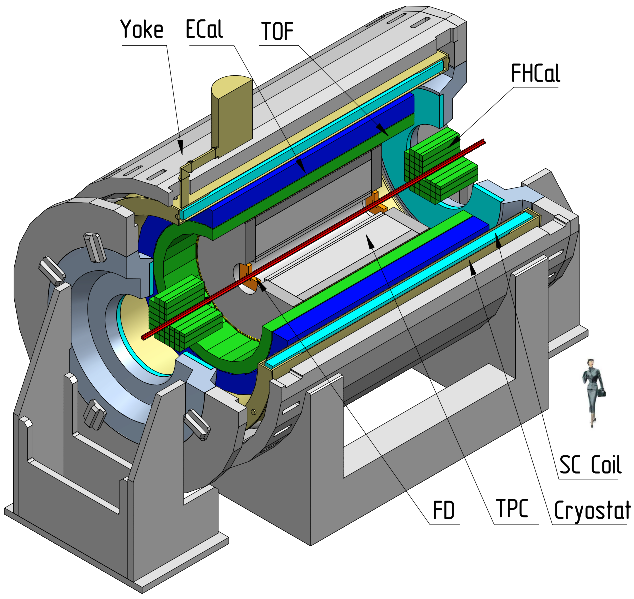

Figure 1: The TOF is green cylinder inside the solenoid yoke.

is 6 meters and internal radius is about 1.5 meters from the beam axis (Figure 2). The active surface of the barrel part of the MPD ToF covers the pseudorapidity range $|\eta| \leq 1.4$. The total surface of the TOF barrel is about 52 m^2. The TOF is organized in a modular way in order to minimize the number of components and cost.

The detector is segmented in the φ direction into 14 pairs of modules of ∼5.9 m length. The maximum distance between two boxes does not exceed 5 mm. The special shape of module minimizes the dead area inside the sector. The dead area between modules along φ direction is due to the limited space along the radius of barrel. This fact does not allow putting modules with overlap azimuthally dire. Wide gaps in the horizontal plane are required for support structures for mounting the TPC.

Each TOF module consists of two separate volumes. The inner volume is filled of the gas mixture and contains 10 MRPCs. High-voltage cables and gas pipes are supplied to this volume from an external end. The outer one contains the Front End Electronic (FEE) cards, low voltage, signal and trigger cables. Both covers of the volumes are made of the aluminum profile and aluminum honeycomb panels 5 mm thick. The aluminum honeycomb panel with the thickness of 10 mm is located between inner and outer volumes. It has special holes for the interface card, which provides connection of signals from MRPCs to preamplifiers. Most MRPCs are arranged inside the box with an angle of 6° to the axis of the beam as shown in Figure 2.

3. Simulation with detailed MpdRoot geometry of the TOF

Monte Carlo simulation has been performed using the MpdRoot [7] framework based on the CERN ROOT software. The MpdRoot framework has interfaces to several event generators (UrQMD, LAQGSM, HIJING, HSD etc.) and includes all algorithms for MPD reconstruction and analysis, thus providing a complete set of instruments to simulate ion-ion collisions. For the purposes of this simulation we used LAQGSM and PHSD event generators.

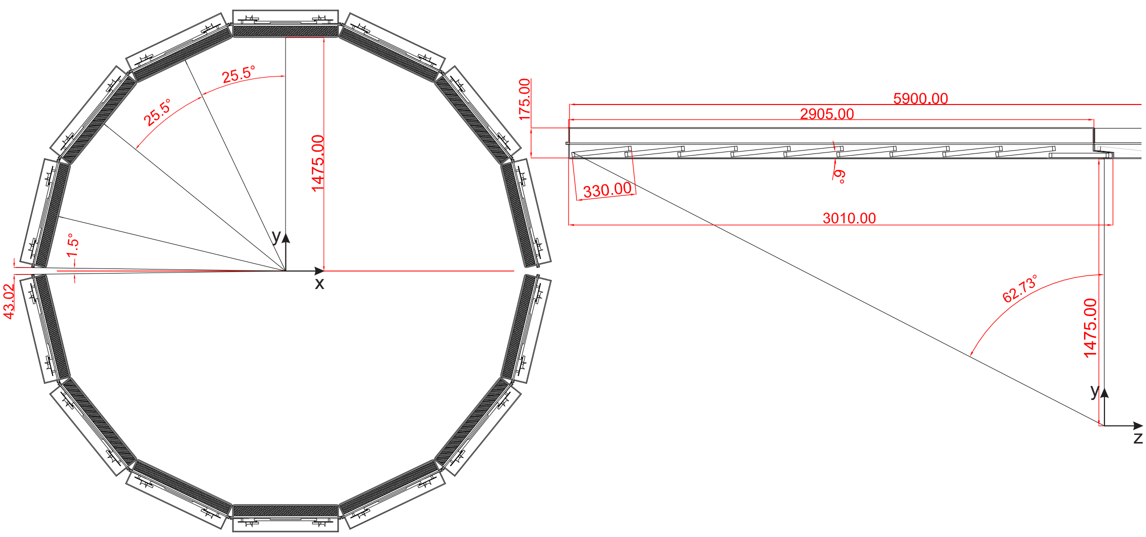

Figure 2: Sections of the TOF barrel in the XY plane (left) and one half of the TOF in ZY plane (right).

To obtain the most reliable simulation results, the most detailed version of geometry of the time-of-flight system was created and implemented in MpdRoot (Figure 3). MRPC detector itself has become more detailed in this version of geometry. Three layers of RPC glass and active gas are placed between PCB plates in accordance with the design of the real detector. The division of active areas into three layers allows running more accurate simulations, compared with previous version of the TOF geometry, where the MRPC contained only one active layer. Honeycomb panels were set as a pair of solid plates, each one has four times less thickness, than original one. Due to limited amount of shapes available in ROOT geometry, the gas boxes were set as several aluminum plates, placed in the shape of box. Inner volume of box is filled with gas. Detectors are placed inside the gas box. Each detector is attached to box with three pairs of mounts, which were also set in geometry.

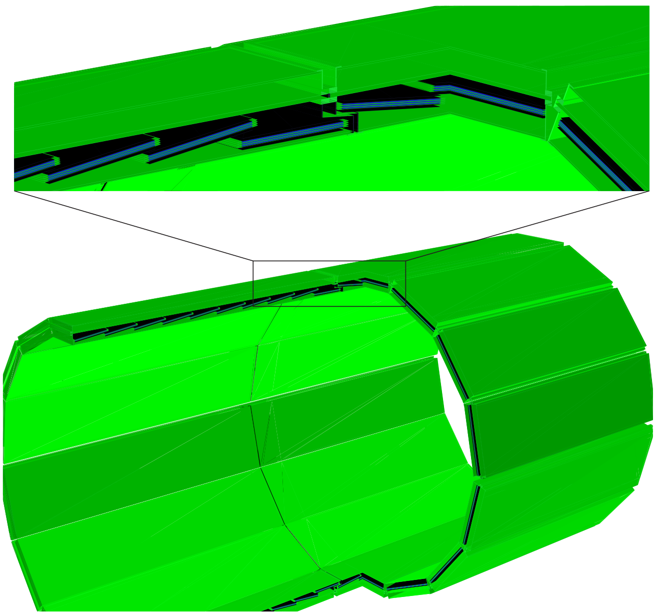

Figure 3: Detailed MpdRoot geometry of the TOF barrel.

The geometrical efficiency depends on the geometry of whole TOF system and arrangement of the MRPCs in the TOF. The efficiency in Figure 4 is differential efficiency ($d\varepsilon/dZ$) along Z direction. It follows from Figure 4 that 93.8% of all particles flying in direction of the TOF fall into the active region of detectors. The others (inefficient) fly through the gaps between the modules.

The procedure of calculation of occupancy is as follow. We calculate the number of TOF hits per each channel (taking into account the experimental data [5] for cluster size in dependence on the particle input angle) from all MC tracks in central (0-3 fm) collision of Au-Au with maximum NICA energy $\sqrt{s_{NN}} = 11$ GeV. As a result, we can get a distribution of the mean number of hits per channel in one central colission. The distribution presented in the Figure 5 is dependence of mean numbers of heats per channel from position of track along the beam. It can be seen that the maximum occupancy is about 14% and mean occupancy less than 12%.

Procedure of matching tracks with hits in the TOF system is to find the appropriate time for each of the reconstructed TPC tracks that have reached the TOF barrel. Number of these tracks

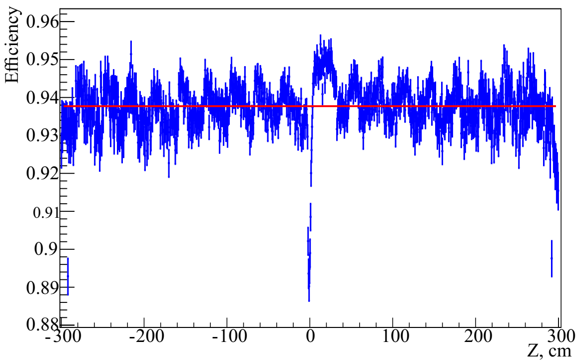

Figure 4: Geometrical efficiency of the TOF barrel for primary particles along Z axis.

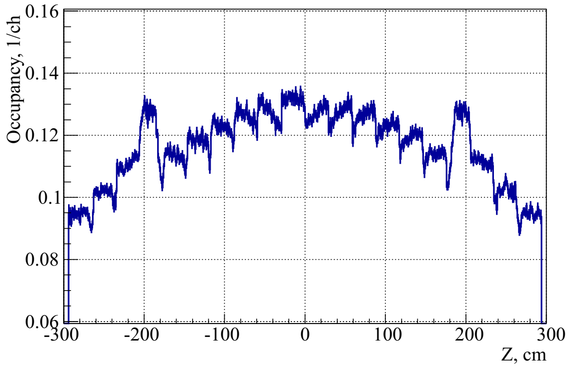

Figure 5: The TOF system occupancy estimation along the beam direction.

is N_{rec_tracks}. For a given TPC track, we have then a set of TOF strips and TOF dead regions crossed by the probe tracks. Each reconstructed TPC track has an extrapolated point with spatial window, determined by the accuracy of the Kalman track extrapolation (3σ). Hits in the TOF – candidates for matching are selected in each track window. Such candidates can be more than one in window. The nearest to the extrapolation point candidate selected as matched with this track. If, as a result of matching, the Kalman track and the MC hit correspond to one particle, then such track is considered to be well matched or true (N_t). If matched Kalman track does not correspond to the correct particle, then such a track is considered wrong-matched (N_w). Therefore, the matching efficiency is calculated as: $eff = (N_t + N_w)/N_{rec\_tracks}$. Contamination means the ratio of wrong-matched to the sum of wrong and true matched pairs: $cont = N_w/(N_t + N_w)$. The momentum dependence of matching efficiency for $\sqrt{s_{NN}} = 11$ GeV is in Figure 6. The average matching efficiency is around 84%. Such a value due to the fact that a large number of particles reaching the system have a momentum of less than 500 MeV. The contamination is around 10%.

The main characteristic of a TOF system is its ability to separate various particles. For simulation, we set the time resolution of the TOF system to 80 ps, which is a realistic value. As a result, the distribution of the m^2 of (π, K, p) was obtained in dependence on their momenta (Figure 7).

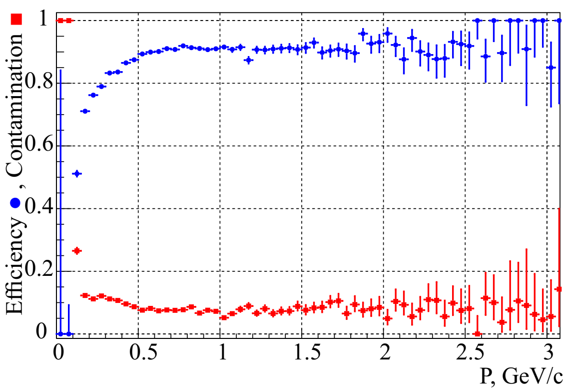

Figure 6: Matching efficiency and contamination for reconstructed tracks that reached the TOF.

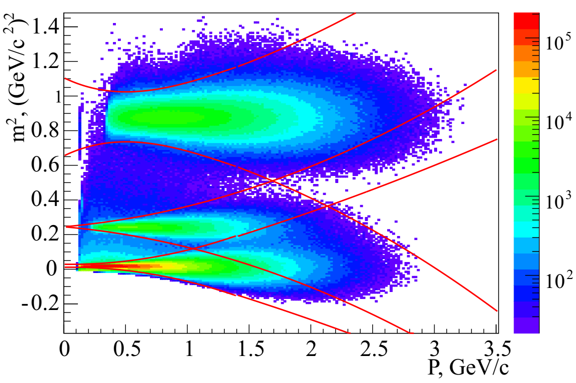

Figure 7: Momentum dependence of m^2 distribution from the TOF (red lines depict 3σ bands).

To evaluate the efficiency of particle identification, the three sigma method was chosen. All particles of the correct sort that fall within their 3σ boundaries are effective. If the type of particle is different, then this is contamination. The momentum dependence of the efficiency and contamination of identification by the only TOF system is shown in Figure 8. For low-momentum particles the efficiency is rather poor with a high percentage of contamination. This problem is successfully solved by the combined identification of TOF and energy losses in the TPC (Figure 9).

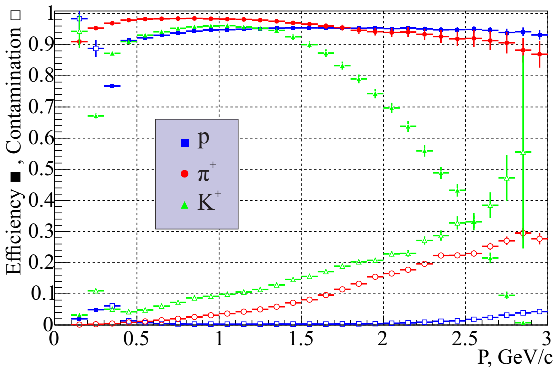

Figure 8: Efficiency and contamination of the MPD PID using only TOF.

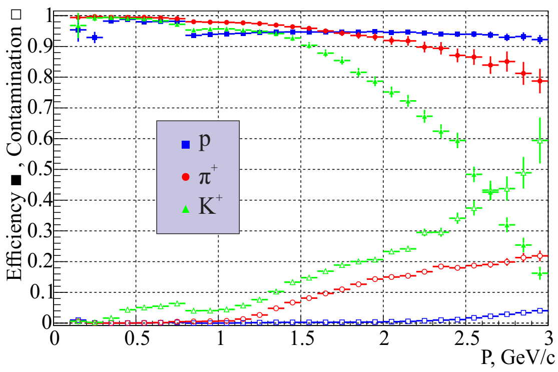

Figure 9: Efficiency and contamination of combined PID using TOF and dE/dX.

4. Conclusions

Simulation results shows that the performance of the MPD TOF system satisfies the experiment requirements. Such results allow us to start mass production of TOF system detectors at the beginning of 2019. The MPD TOF will be commissioned at the end of 2020.

This research is supported by the Russian Foundation for Basic Research: grant 18-02-40051.

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