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The Multi-Purpose Detector for JINR heavy-ion collider

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ABSTRACT: The Multi-Purpose Detector (MPD) is designed to study heavy-ion collisions at the Nuclotron-based heavy Ion Collider fAcility (NICA) at JINR, Dubna. The detector will comprise a superconducting solenoid equipped with three dimensional tracking system composed of a silicon microstrip vertex detector followed by a large volume time-projection chamber and a particle identification system based on time-of flight measurements and calorimetry. In this paper a few parts of apparatus are described and their tracking and particle identification parameters are discussed in some detail.

KEYWORDS: Time projection Chambers (TPC); Photon detectors for UV, visible and IR photons (vacuum) (photomultipliers, HPDs, others); Calorimeter methods

[1]On behalf of the MPD group.

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1 Introduction

A new scientific program on heavy-ion physics launched recently at JINR is devoted to study of in-medium properties of hadrons and nuclear matter equation of state including a search for signals of deconfinement phase transition and the critical point [1]. Investigation will be performed by a careful energy and system-size scan with species ranging from protons to Au^{79+} over the energy range $4 < \sqrt{s_{NN}} < 11$ GeV. The future accelerator facility NICA will operate at luminosity of Au^{79+} up to 10^{27} cm^{-2}s^{-1}.

Following physics perspectives of the heavy-ion program at NICA [2] the main aspects for the conceptual design of the MPD are:

(i) to probe deconfinement phase transition very precise measurements of hadron yields including multi-strange baryons are of great importance;

(ii) search of fluctuation and correlation patterns requires a detector with a solid angle coverage close to 4π and excellent identification capability;

(iii) to study in-medium modifications of hadron properties, the invariant mass spectra of dielectrons should be measured up to ~ 1 GeV/c^2 values in a variety of colliding systems;

(iv) a detector has to be functional at high interaction rates in high track multiplicity environment and provide good event characterization capability.

2 Detector overview

The MPD is design as a 4π spectrometer capable to detect charge hadrons, electrons and photons in heavy-ion collisions in the energy range of the NICA collider. To reach this goal, the detector will comprise a precise 3D tracking system and a high-performance particle identification system based on the time-of-flight (TOF) measurements and calorimetry. At the design luminosity, the event rate in the MPD interaction region is about 7 kHz and the total charge particle multiplicity exceeds 1000 in the most central Au+Au collisions. As the average transverse momentum of the particles produced in an ion collision at NICA energies is below 500 MeV/c, the detector design requires a very low transverse material budget. The general description of the MPD apparatus is presented in [3, 4]. In this report the Central Detector (barrel part) of MPD in its start up configuration is overviewed. The cross-sectional view of MPD Central Detector (CD) is shown in figure 1. The whole CD will be a 9 m long cylinder of about 6 m in diameter and will cover interval $|\eta| \leqslant 2$ in pseudorapidity.

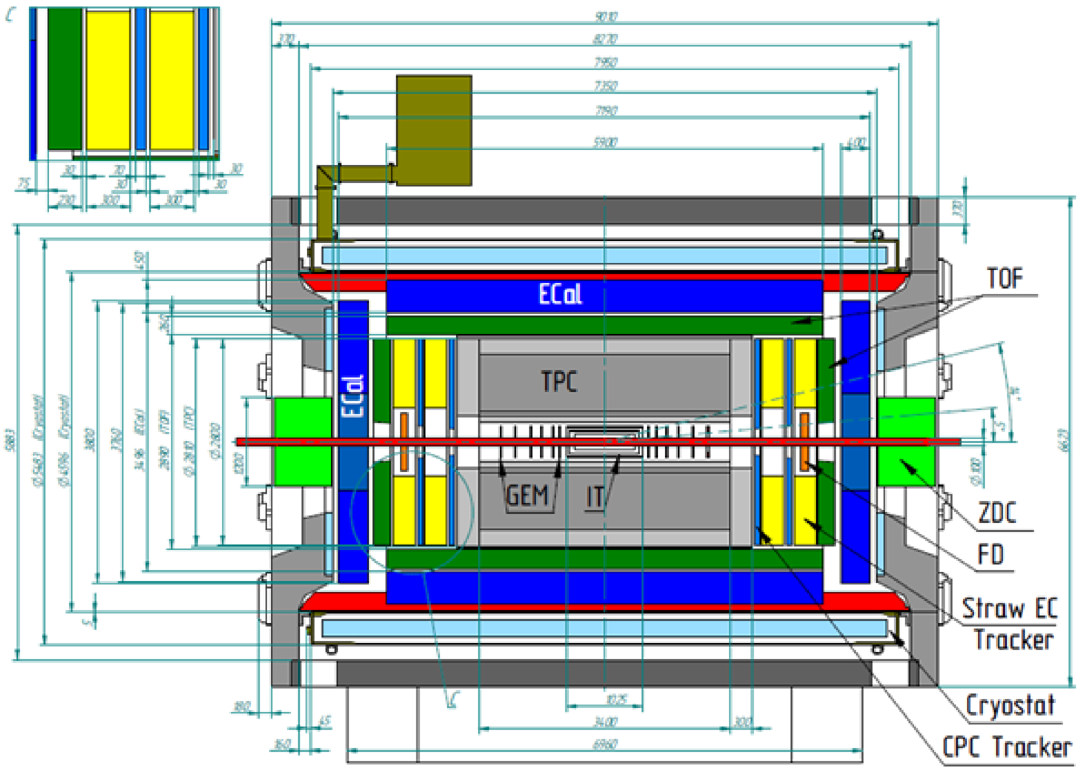

Figure 1. Cross-section of the MPD Central Detector.

2.1 Time-projection chamber

The Time-Projection Chamber (TPC) is the main tracking detector of the MPD. The TPC will provide:

- efficient tracking at pseudorapidities up to $|\eta| \sim 1.2$,
- momentum resolution for charged particles under 3% in the transverse momentum range $0.1 < p_t < 1$ GeV/c,
- two-track resolution of about 1 cm,
- hadron and lepton identification by dE/dx measurements with a resolution better than 8%.

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The brief overview of the TPC design is given in [5]. The TPC design is conventional in the overall structure widely used in other experiments [6, 7]. The lay-out of the TPC is shown schematically in figure 2.

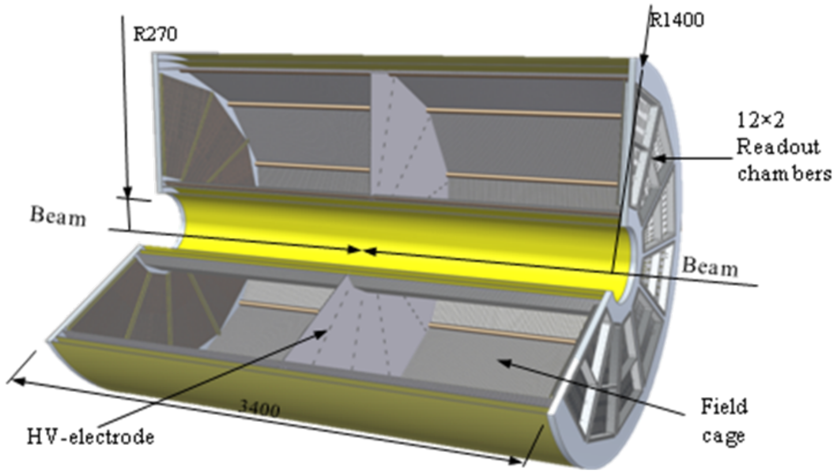

Figure 2. Schematic view of the MPD Time Projection Chamber.

The TPC is 3.4 m long and 2.8 m in diameter. The active gas volume of the TPC is bounded by coaxial field cage cylinders with the pad-plane readout structure at both end-caps. All four cylinders are produced by Russian industry as monolithic Kevlar composite constructions. Their material budget is less than 2% of X_0. The gas mixture P10 (90% argon and 10% methane) at 2 mbar above atmospheric pressure will be used. The potential degrading network defining the uniform electric field inside the TPC active volume will be realized by means of the aluminized mylar strip system in the same way as it is done in the ALICE [6]. The TPC readout system is to be based on the Multi-Wire Proportional Chambers (MWPCs) with cathode pad readout. Each end-cap readout plane consists of 12 trapezoidal sectors of the readout chambers, each covering 30° in azimuth. To keep the occupancy as low as possible and ensure the required accuracy of *dE/dx* and track resolution there will about 100000 readout pads of two different sizes ($5 \times 12\,\mathrm{mm}^2$ and $5 \times 18\,\mathrm{mm}^2$) arranged in 53 rows parallel to the bases of readout chamber. Figure 3 shows the results of Monte-Carlo simulations of the TPC *dE/dx* capability performed with a sample of Au+Au central collision generated in QGSM model at 9 GeV. The simulations also show that the TPC track reconstruction efficiency for charged hadrons exceeds 95% at transverse momentum above 150 MeV/c and relative momentum resolution of <3% is achieved at $p_t < 1$ GeV/c.

The tracking capability of the TPC in the forward direction for the pseudorapidity $|\eta| > 1.2$ will be enhanced by a forward tracking system.

2.2 Time-of-flight system

The Time-of-Flight system is intended to perform particle identification for total momentum up to 2 GeV/c. The system includes the barrel part and two end-caps and covers the pseudorapidity interval $|\eta| < 2$. The TOF is based on multi-gap Resistive Plate Chambers (mRPC) with high timing properties efficiency in high particle fluxes. The barrel of TOF is about 6 m long and 1.6 m in diameter. It covers the pseudorapidity region $|\eta| < 1.4$. The basic element of TOF is $70\,\mathrm{cm} \times 40\,\mathrm{cm}$

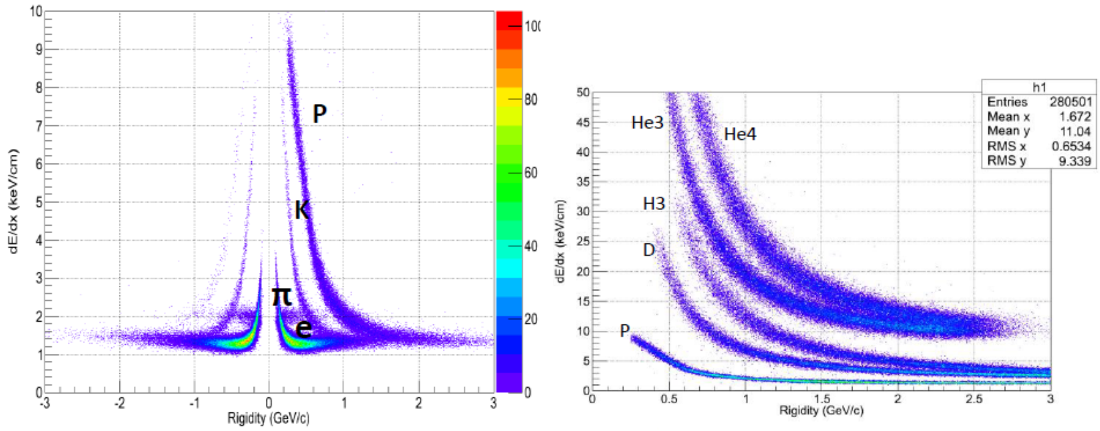

Figure 3. The TPC *dE/dx* capability.

overall size double stack mRPC with active area 60 cm × 30 cm built of 12 glass plates separated by 220 μm thick spacers. All the counters are assembled in 12 azimuthal modules of 1.6 m length providing an overall geometric efficiency of about 95%.

Two options of the signal readout geometry are still considered: the pad signal readout and the strip readout. At low multiplicity of charge particles it makes sense to use a strip electrode for readout to reduce the number of electronic channels. It will be used for the barrel TOF and for end-caps a combined pad and strip readouts will be used.

Both options have been studied with full-scale mRPC prototypes using the Nuclotron 1GeV/n deuteron beam at JINR. In order to increase the differential signal accepted up from the mRPC's pads or strips a 24-channel amplifier based on ALICE NINO chip was used. This chip has the possibility to adjust input resistance to match it with the mRPC readout electrodes. The output signal from the NINO chip discriminator is LVDS-standard differential signal. 32-channel time-to-digital convertor (TDC32VL) based on HPTDC chip was used for digitization of VLDS signals and data acquisition. The results obtained in test experiments demonstrate the double-stack mRPC with strip as well as with pad readout meet the requirements to the time-of-flight system of the MPD.

The efficiency and the time resolution of mRPC with pad and strip readout is shown in figure 4.

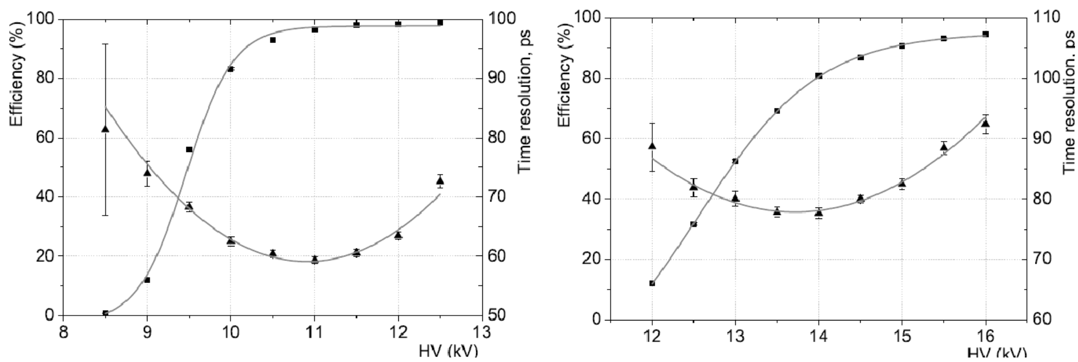

Figure 4. The efficiency and time resolution of mRPC with pad readout (left) and strip readout (right).

2.3 Fast forward detector

The Fast Forward Detector (FFD) will provide high-speed production of signals serving for the L0-trigger system with selection of ion collisions occurring close to interaction point and for generation of precise start pulse to activate the TOF system. The detailed overview of MPD FFD is presented in [8].

At relatively low energies of NICA charge particles produced in ion-ion collision are mostly not relativistic within a large spread of velocities. Therefore, to reach the best time resolution the concept of the FFD for MPD is based on registration of a fraction of high-energy photons from neutral pion decays along the beam line in both directions from interaction point. In the FFD the high-energy photons are registered by their conversion to electrons inside a lead plate of ~ 1.5–$2X_0$ thickness. The electrons pass through a quartz radiator generating the Cherenkov light with excellent time characteristics.

FFD consist of two identical modular arrays of granulated Cherenkov counters and placed symmetrically about interaction point along the beam line. Each array covers the pseudorapidity range of $2.3 \leqslant |\eta| \leqslant 3.1$. The readout is performed by multi-anode Micro Channel Plate Photo-Multiplier (MCP-PMT). The MPC-PMT Planacon XP85012/A1, recently developed by Photonis, is chosen for the FFD counters. It has a matrix 8×8 multi-anode topology, good linearity of output pulses with the 0.6 ns rise time, the transit time spread less than 37 ps and low noise providing picoseconds time resolution of the FFD.

The FFD module prototypes have been tested with proton and deuteron beams at JINR Nuclotron. Two modules were placed at the beam line at the distance 2 m between them and the proton time of flight was measured. The lead convertor was removed out of module for these tests. A typical distribution of pulse height measured with the LeCroy oscilloscope for protons of the 1.95 GeV energy is shown in figure 5 (left). The proton time of flight distributions obtained with and without time-amplitude (t-A) correction are shown in figure 5 (right). As a result of the correction, the Gaussian shape indicates $\sigma \sim 42$ ps which corresponds the time resolution $\sigma_t \sim 30$ ps for single detector channel.

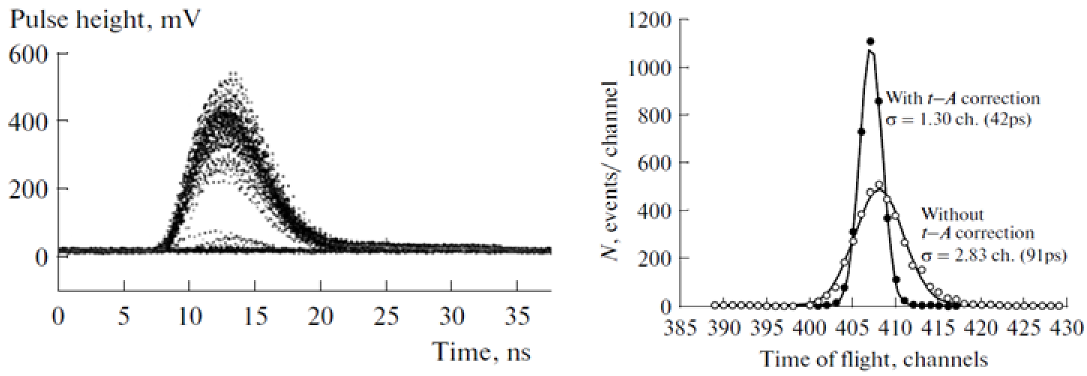

Figure 5. Typical distribution of pulse height measured with the LeCroy oscilloscope (left) and time of flight distributions for the 1.95 GeV protons with and without t-A correction (right).

Further improvement of FFD module characteristics is planned by applying as photodetectors the MPC-PMT XP85012/A1-Q with quartz window to increase the number of photoelectrons.

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2.4 Electromagnetic calorimeter

The main role of the ElectroMagnetic Calorimeter (EMC) is to identify electrons, photons and neutral hadrons and measure their energy and position. At high multiplicity environment of heavy-ion collisions calorimeter has to be fine segmented. In order to provide π^0–γ discrimination the transverse size of the EMC cell should be of the order of the Moliere radius. Moreover, as Monte-Carlo simulations indicate, the EMC occupancy should not exceed 5% to reconstruct photons with high accuracy.

The design of our choice is a shashlyk-type Pb-scintillator sampling calorimeter with Wave-Lenght Shifting (WLS) fibers and Microstrip Avalanche Photodiod (MAPD) readout. This type of EMC can provide energy resolution better than 6% at gamma energies more 200 MeV and fulfills the most of requirements. The basic building element for EMC is 3 cm squared tower. Each tower contains sampling sells consisting of 250 alternating tiles of 0.275 mm thick lead and 1.5 mm thick plastic scintillator and has a thickness of 18 radiation lengths. The module will be about 40 cm long. The cells of each tower are optically combined by 9 longitudinally penetrating WLS fibers to collect light to $3 \times 3\,\text{mm}^2$ MAPD sensitive area. The towers, mechanically grouped together, form a trapezoidal module.

The prototype of the EMC-module have been studied at CERN and DESY. The data presented in figure 6 indicate the shashlyk type EMC module with MAPD readout looks very promising and it can serve as a basis for MPD EMC.

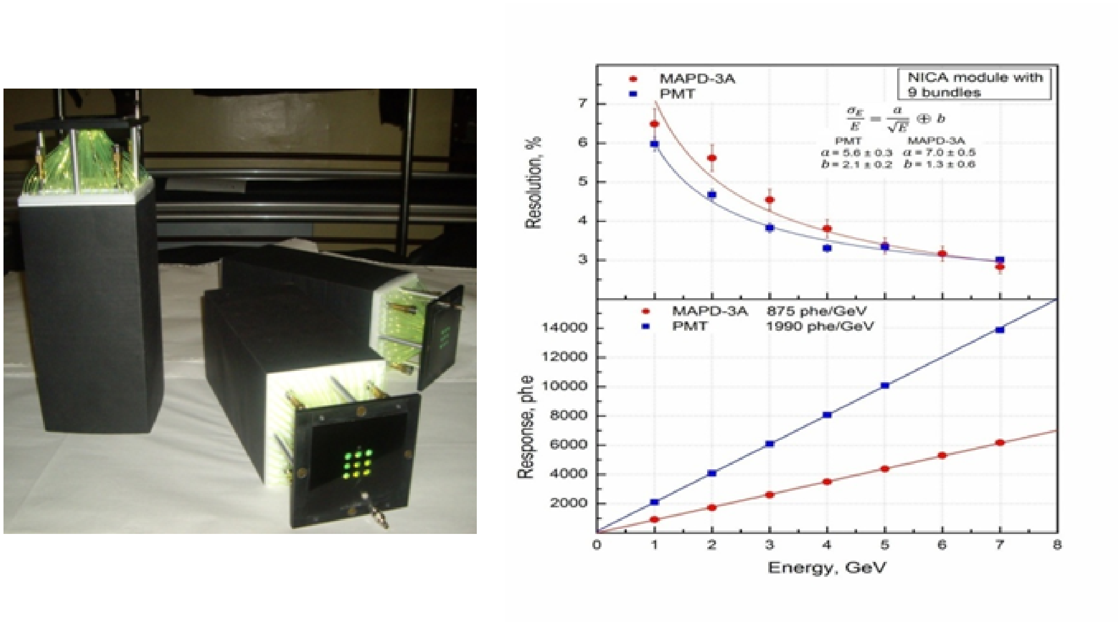

Figure 6. The EMC module prototype (left) and test results of modules with readout by PMT EMI 9814B and MAPD-3A at 15°C versus electron beam energy.

2.5 Zero degree calorimeter

The Zero Degree Calorimeters (ZDCs) are served for determination of the event centrality and reaction plane via registration of the projectile's spectator nucleons.

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ZDCs are located at distances of 2.9 m from the center of the ion interaction region. The transverse size of the calorimeter ($\sim$ 50 cm) is determined by an angular distribution of the spectators. The calorimeter should have an energy resolution for single hadrons better than $60\%/\sqrt{E}$ and fine granularity to measure an asymmetry in azimuth spectator distribution.

Each ZDC will be assembled of 84 identical modules. The module with a lateral size of 5×5 cm consists of sandwiches of 16 mm thick lead and 4 mm thick scintillator tiles with embedded WLS fibers. The fibers from each group of 6 consecutive scintillator tiles are collected together and viewed by a single photodetector at the end of the module. MAPDs are under consideration for the photodetector because of their ability to operate in magnetic field, compactness and high internal gain. The total length of the calorimeter is 120 cm ($\sim 6\lambda$). The module prototype with this design has been tested with pion beams at CERN and the energy resolution $53\%/\sqrt{E}$ was determined [9].

3 Conclusion

The progress in design of Multi-Purpose Detector to be build for the heavy-ion experimental program at JINR (Dubna) is overviewed. The results of R&D and prototyping of the main sub detectors of the MPD Central Detector (barrel) demonstrate the functional parameters of the tracking system and particle identification system are achievable. The MPD compromised with the TPC as a tracking system and calorimeters and TOF based on mRPCs as identification system will be adequate start up configuration to begin experiments at NICA.

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