The Multi-Purpose Detector for NICA heavy-ion collider at JINR

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on behalf of MPD group

The Multi-Purpose Detector (MPD) is designed to study heavy-ion collisions at the **N**uclotron-based heavy **I**on **C**ollider f**A**cility (NICA) at JINR, Dubna. Its main components located inside a superconducting solenoid are a tracking system composed of a silicon microstrip vertex detector followed by a large volume time-projection chamber, a time-of-flight system for particle identification and a barrel electromagnetic calorimeter. A zero degree hadron calorimeter is designed specifically to measure the energy of spectators. In this paper, all parts of the apparatus are described and their tracking and particle identification parameters are discussed in some detail.

1. INTRODUCTION

A new scientific program on heavy-ion physics launched recently at JINR (Dubna) is devoted to the study of in-medium properties of hadrons and nuclear matter equation of state including a search for the signals of deconfinement phase transition and the critical endpoint [1]. Comprehensive exploration of the QCD phase diagram will be performed by a careful energy and system-size scan with ion 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+} ions up to $L = 10^{27}$ cm^{-2}s^{-1}.

Ref. [2] gives a summary of physics perspectives of the heavy-ion program at NICA, the major physics points that determine the conceptual design of MPD are as follows.

i) To probe the deconfinement phase transition, new very precise measurements of hadron yields including multi-strange baryons are of great importance.

ii) Measure of fluctuation and correlation patterns in the vicinity of the QCD Critical End Point requires a apparatus with a solid angle coverage close to 4π and excellent particle identification capability.

iii) To study in-medium modifications of hadron properties, the invariant mass spectra of dielectrons should be measured up to $M_{e^+e^-} \approx 1$ GeV/c^2 in a variety of colliding systems.

iv) Finally, a detector to study heavy-ion collisions in a high track multiplicity environment has to be functional at high interaction rates; fine granularity of detector elements and good event characterization capability are also required.

2. DETECTOR OVERVIEW

The MPD is designed as a 4π spectrometer capable of detecting of charged 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 measurements and calorimetry. At the design luminosity, the event rate in the MPD interaction region is about 7 kHz; the total charged particle multiplicity exceeds 1000 in the most central AuAu collisions at $\sqrt{s_{NN}} = 11$ GeV. As the average transverse momentum of the particles produced in a collision at NICA energies is below 500 MeV/c, the detector design requires a very low material budget. The general layout of the MPD apparatus is shown in Fig. 1. The detector setup includes Central Detector (CD) covering ± 2 units in pseudorapidity (η) and two forward spectrometers (FS-A,B) for $2 < |\eta| < 3$ (optional). The whole CD will be a 6.5 m long cylinder of about 5 m in diameter. These design parameters are determined by several technical constrains and guided by a trade-off of efficient tracking and particle identification against a reasonable material budget. The cross-sectional view of the MPD Central Detector is shown in Fig. 2 with some major characteristic dimensions of its elements.

A more detailed description of the detector components can be found in Ref. [3].

2.1. Time-projection chamber

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

a) efficient tracking at pseudorapidities up to $|\eta|$=1.2,

b) momentum resolution for charge particles under 3% in the transverse momentum range $0.1 < p_t < 1$ GeV/c,

c) two-track resolution of about 1 cm,

d) hadron and lepton identification by dE/dx measurements made with a resolution better than 8%.

The lay-out of the TPC is shown schematically in Fig. 3. The TPC design is conventional in the overall structure widely used in other experiments [4, 5]. The TPC is 3.4 m long and 2.2 m in diameter. It is filled with gas mixture P10 (90% argon and 10% methane) at 2 mbar above atmospheric pressure. The active gas volume of the TPC is bounded by the coaxial field cage cylinders with the padplane readout structure at both endcaps. The uniform electric field in the active volume required for drift of electrons is created by a thin central electrode at the center of the TPC, concentric field cage cylinders and the readout endcaps. Full plastic cylinders will be used for TPC field cage construction. The TPC readout system is to be based on Multi-Wire Proportional Chambers (MWPCs) with cathode readout pads. Each endcap consists of 12 sectors of MWPCs with the overall area to be instrumented of about 8 m^2. To keep the occupancy as low as possible and ensure the required accuracy of dE/dx and position measurements there will be about 80000 readout pads of two different sizes arranged in two subsectors.

To optimize the overall TPC design for high track reconstruction efficiency and good momentum resolution, Monte-Carlo simulations have been performed with a sample of AuAu events. The calculated relative momentum uncertainty $\Delta p_t/p_t$ is shown in Fig. 4 as a function of p_t. It is seen from the plot that the required resolution of <3% is achieved at $p_t < 1$ GeV/c. The simulations also show that the TPC reconstruction efficiency for charged hadrons exceeds 95% at $p_t > 150$ MeV/c.

The tracking capability of the TPC for the pseudorapidity $|\eta| > 1.2$ will be enhanced by an endcap tracking system. The straw tube EndCap Tracker (ECT) located between the TPC and endcap TOF is considered as an option. The ECT consists of 2×60 layers of 60 cm long straw tubes and covers the pseudorapidity region $1 < |\eta| < 2.5$.

2.2. Time-of-flight system

The Time-Of-Flight (TOF) system is intended to perform particle identification with total momenta up to 2 GeV/c. The system includes the barrel part and two endcaps and covers the pseudorapidity interval $|\eta| < 2$. The TOF is based on Multigap Resistive Plate Counters (mRPC) with satisfactory timing properties and efficiency in particle fluxes up to

10^3 cm^{-2}s^{-1} [4]. The 2.5 m diameter barrel of TOF has a length of 500 cm to cover the pseudorapidity region $|\eta| < 1.4$. The basic element of TOF is a 7×62 cm mRPC build of 12 glass plates separated by 220 μm thick spacers forming 10 equal gas gaps. All the counters are assembled in 12 azimuthal modules providing the overall geometric efficiency of about 95%.

Two options of the signal readout geometry are still considered. One is a pad structure with lateral dimensions of 3×3.5 cm, the other makes use of 3 cm-wide strips with readout from both sides of strips. The endcap TOF system consists of two discs situated at both sides of the TOF barrel. The inner diameter of the discs is 40 cm, the outer one is 250 cm resulting in pseudorapidity coverage $1.5 < |\eta| < 2$.

The Fast Forward Detectors (FFD) will provide TOF with the start signal. FFD consists of two identical arrays of granulated Cherenkov counters situated symmetrically about the interaction point. FFD covers the pseudorapidity range of $2.5 \leq |\eta| \leq 3.2$. Each FFD counter consists of a lead plate for conversion of high energy photons to electrons and a Cherenkov radiator. The readout will be performed by a multianode MicroChannel Plate PhotoMultiplier (MCP-PMT). It is expected that high energy photons from decays of π^0-mesons provide time resolution of the FFD system $\sigma < 50$ ps which results in the overall TOF resolution better than 100 ps.

MPD identification power obtained for charged hadrons with combined mass-squared (from TOF) and dE/dx (from TPC) information has been simulated with results shown in Fig. 6.

2.3. Inner tracker system

The Inner Tracking System (ITS) located between the beam pipe and the TPC is designed for precise finding of primary collision vertices and reconstruction of decay vertices of strange particles. The energy loss (dE/dx) measurements provided by ITS will enhance particle identification capability in the low momentum region. The ITS concept inherits the best of technical advances of the vertex detectors of the ALICE and D0 experiments [6, 7]. The system covering the region of $|\eta| < 3.5$ comprises four coaxial cylindrical layers of double-sided silicon microstrip detectors with a strip pitch of 90 μm and silicon discs assembled from wedge-shaped double-sided microstrip detectors situated at the ends of the cylinders.

The 1.1 m long ITS cylinder part has a diameter of between 20 cm for the inner layer surrounding the beam pipe to about 50 cm. The material budget of 0.8% radiation length per layer includes the active sensors and the supporting construction. Fig. 5 demonstrates first results of simulations of reconstructing of the primary collision vertex with and without the ITS detector installed. As is easy to see, a considerable improvement in the resolving power of vertices reconstruction is achieved with the combined TPC and ITS reconstruction.

2.4. Electromagnetic calorimeter

The main goal of the ElectroMagnetic Calorimeter (EMC) is to identify electrons, photons and neutral hadrons and measure their energy and position. High multiplicity environment of heavy-ion collisions implies the fine EMC segmentation. In order to provide π^0-γ discrimination the transverse size of the cell should be of the order of the Moli'ere 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 Pb-scintillator sampling calorimeter of the shashlyk-type which can provide energy resolution better than 6% at $E_\gamma > 200$ MeV. The EMC is proposed to be built of towers as basic building elements (e.g., 3 cm squared). Each Pb-scintillator-based tower contains sampling cells consisting of 250 alternating tiles of Pb (0.275 mm) and plastic scintillator (1.5 mm). The module with a 18 radiation length thickness will be approximately 40 cm long. The cells of each tower are optically combined by 9 longitudinally penetrating WaveLength Shifting fibers (WLS) for light collection. The light collected with 9 fibers is read out by Microstrip Avalanche Photodiod (MAPD) units with 3×3 mm^2 sensitive areas. The towers, mechanically grouped together, make a trapezium-shape module.

2.5. Zero degree calorimeter

The energy of the projectile spectator nucleons will be measured by the Zero Degree Calorimeters (ZDCs) located at distances of 2.9 m from the center of the interaction region. The transverse size of the calorimeter ($\approx$ 50 cm) is determined by angular distribution of the spectators. The calorimeter should have an energy resolution for single hadrons $\sigma_E/E < 60\%/\sqrt{E}$ and sufficiently fine granularity needed for the event plane reconstruction.

Each ZDC will be assembled of 84 identical modules. Each 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 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 ($\approx 6\lambda$), the weight of each module is about 120 kg. This particular design yields an energy resolution $\sigma_E/E = 53\%/\sqrt{E}$ which has been demonstrated in the tests measurements with pion beams at CERN [8].

3. CONCLUSION

A conceptual design of the Multi-Purpose Detector to be build for the heavy-ion experimental program at JINR (Dubna) is briefly described. The MPD comprises a tracking system based on TPC and ITS built of double-sided silicon microstrip detectors. Identification of charged hadrons is performed by the time of flight system based on the mRPC technology; electrons and gammas are detected by the shashlyk-type electromagnetic calorimeter.

Acknowledgement

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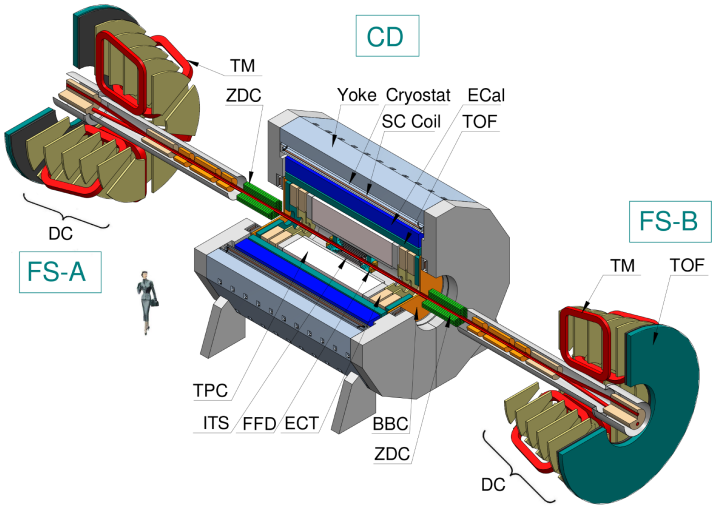

Figure 1. Layout of the MPD detector.

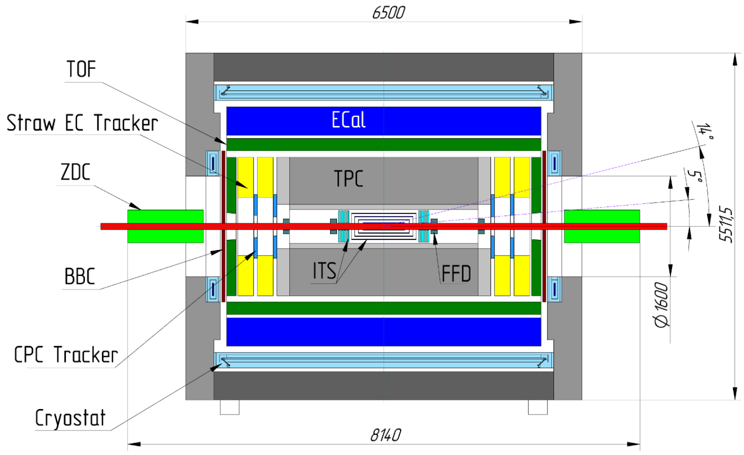

Figure 2. Cross-section of the Central Detector.

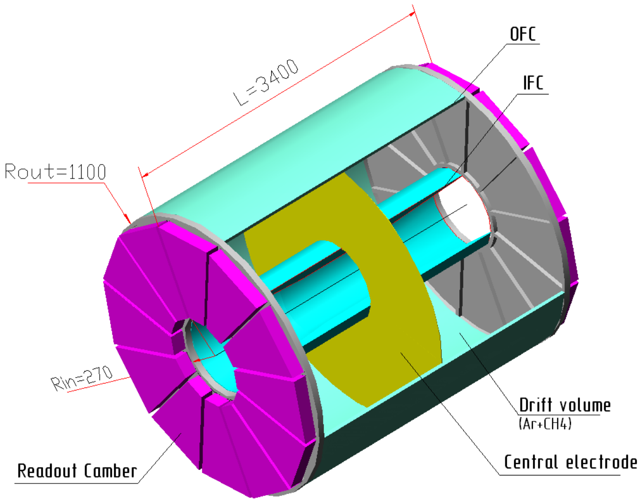

Figure 3. Schematic view of the MPD Time Projection Chamber.

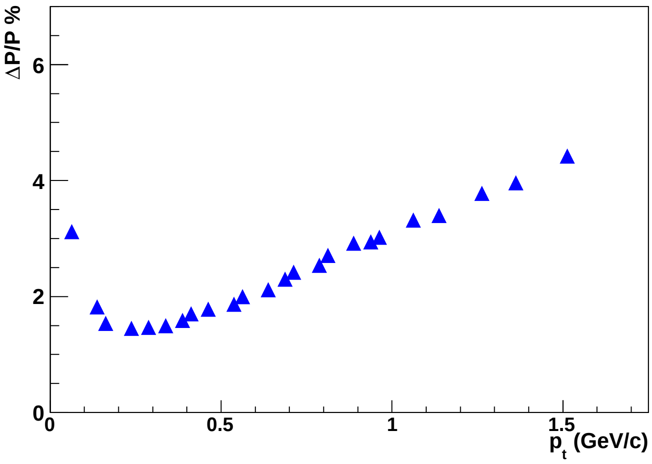

Figure 4. Transverse momentum dependence of $\Delta p_t/p_t$ for charged hadrons reconstructed in TPC.

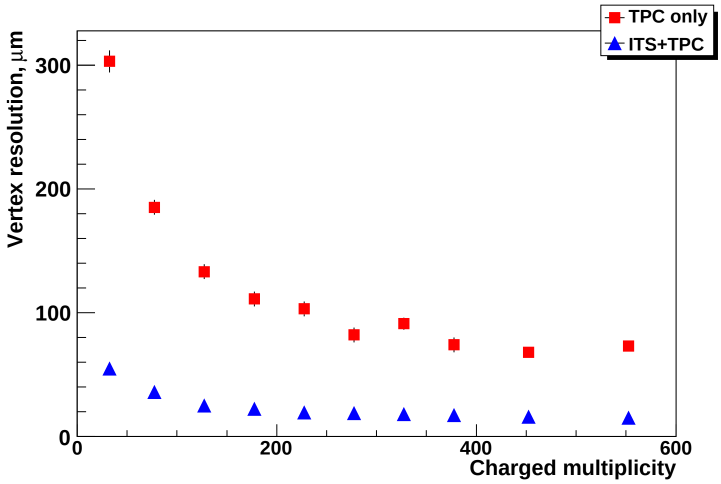

Figure 5. Resolution of the primary vertex reconstruction (σ_z) in AuAu collisions for the stand-alone TPC (squares) and combined TPC+ITS (triangles).

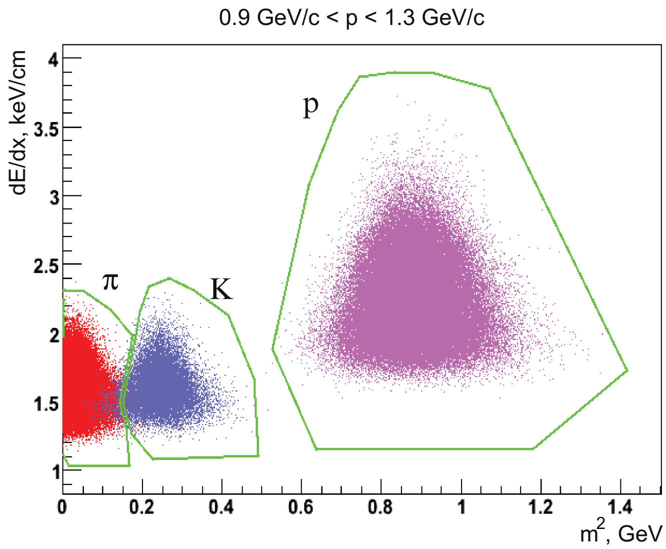

Figure 6. dE/dx (from TPC) versus mass-squared (from TOF) distribution for charged hadron species (π, K, p).

FIGURE CAPTIONS

Fig. 1: Layout of the MPD detector.

Fig. 2: Cross-section of the Central Detector.

Fig. 3: Schematic view of the MPD Time Projection Chamber.

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Fig. 6: Resolution of the primary vertex reconstruction (σ_z) in AuAu collisions for the stand-alone TPC (squares) and combined TPC+ITS (triangles).