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The MPD Experiment and JINR: construction status and physics performance

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Abstract

The Multi-Purpose Detector is under construction at the Joint Institute for Nuclear Research, as part of the NICA Accelerator Complex. It aims to study the phase diagram of QCD matter at maximum baryonic density, determine the nature of the phase transition between the deconfined and hadronic matter and search for the critical point. The current status of the production of MPD subdetectors will be reported on, as well as progress in preparations of the software and computing infrastructure.

The general characteristics of the designed physics performance of the detector components will be discussed. Potential for the measurement of the spectra of identified hadrons, including hyperons and hypernuclei, as well as directed and elliptic flow determination will be discussed. Characteristics needed for the event-by-event fluctuations and femtoscopic measurements will be given. Electromagnetic calorimeter working in conjunction with the tracking system for the di-lepton measurements will be described. In summary, all the main components of the physics program of the MPD Collaboration will be enumerated.

Keywords:

NICA, JINR, MPD Experiment, Heavy-ion collisions

1. NICA Accelerator Complex

The Nuclotron-based Ion Collider fAcility (NICA) is under construction at the Joint Institute for Nuclear Research in Dubna. The left panel of Figure 1 shows the general overview of the facility. The Nuclotron accelerator is already existing and in operation after significant upgrade in 2013. New injection complexes have been recently installed and commissioned. The dedicated ion sources as well as the LU-20 linac deliver protons and light-ions. The KRION source in cooperation with the HILac linac will deliver up to maximum design intensity heavy-ion beams. The light ions are injected into Nuclotron directly, where they can already be accelerated to full energy. The beams can also be extracted and delivered to the

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Fig. 1. (left) The general overview of the NICA Accelerator Complex. (right) The schematic view of the MPD detector in Stage 1.

Fixed-Target Experimental area, where the Baryonic Matter at Nuclotron (BM@N) experiment is operating. Recently data has been taken with BM@N using the carbon beam at 4 AGeV. The heavy-ion beam requires pre-acceleration before being injected into Nuclotron. This will be achieved in the Booster support accelerator which is currently being installed in close proximity to Nuclotron. The tandem of accelerators will be able to deliver Au beams with total momentum per nucleon of up to 3.8 GeV. They can be extracted and delivered to the Fixed Target Area.

The last stage of the facility preparation will be the construction of the NICA storage ring, together with the Nuclotron-NICA beam transfer lines. The civil construction for this part of the complex is expected to continue in 2020. NICA will deliver collisions of a variety of ion types, including Au ions at $\sqrt{s_{NN}}$ in the range of 4-11 AGeV. They will occur in two collision points. Around one of them the Multi-Purpose Detector (MPD) will be constructed. MPD will be housed inside the MPD Experimental Hall. Civil construction for the hall is expected to conclude in the first half of 2020, when first stages of MPD construction and assembly may begin.

2. The MPD setup

MPD is operated as an international scientific collaboration. It currently has 38 collaborating institutes from 11 countries (including JINR member states, as well as countries with are not JINR members) with more than 470 physicists on the author list. The MPD and its subsystems is under construction in JINR and in the collaborating institutions. The right panel of Fig. 1 shows the expected setup of the detector components in the first stage of data-taking (so-called “Stage 1”). The structural support will be provided by the outer magnet yoke, which has already been produced and delivered to Dubna. It is now awaiting assembly in the MPD Hall. The magnetic field of up to 0.5 T, uniform and directed along the beam axis in the central part of the setup, will be produced by the superconducting coil. It is already manufactured and is under tests at the manufacturer’s site. Inside the magnetic field, closest to the beam the Time Projection Chamber will be installed. It is a large gaseous ionization chamber. Readout electronics will be placed on two end-caps and the central electrode will create a uniform electric field in the TPC volume. The structural elements of the TPC cage have been manufactured and await assembly. The read-out chambers are also in production. The TPC will measure the particle spatial trajectories and their specific ionization. This will allow for momentum determination, as well as contribution to the particle identification. The Time-of-Flight detector (TOF) will form a barrel surrounding the TPC. It is based on MRPC modules, which are currently in production. They will provide information on the time of flight of the particles produced in the collision. Together with tracking information from the TPC this will allow particle identification for particle with momenta higher than 0.5 GeV/c, where the identification with TPC is no longer reliable. The Electromagnetic Calorimeter (ECAL) will occupy a space between TOF and the magnet. It will be constructed in projective geometry and will consist of approximately 39 000 shashlyk-style modules with plastic scintillator and lead absorber,

Fig. 2. (left) The schematic view of the QCD Phase diagram. (right) The collision energies and expected interaction rates of currently ongoing and planned experimental programs.

with light transported via optic fibers to read-out MAPSs. The ECAL modules and their support structure is under construction. ECAL will provide measurement of total energy deposited by electrons and photons registered in the collision. In the forward direction the Forward Detector will provide fast timing signal for triggering and TOF reference. The Forward Hadronic Calorimeter (FHCAL) is composed of 88 modules, which are already manufactured. It will provide information on collision centrality as well as reaction plane orientation. The overall commissioning of the MPD subsystems is planned for 2021.

The MPD is expected to collect data with maximum rate of 6 kHz. It will be able to cope with maximum track density expected in central Au-Au collisions at $\sqrt{s_{NN}} = 11$ GeV. It will provide tracking and particle identification for hadrons and electrons in full azimuth and in $|\eta| < 1$, with efficiency higher than 90%, as well as total energy measurement for photons. The primary vertex position resolution is designed to be below 300 μm for events with more than 100 tracks. The relative momentum resolution will be below 2.5% for particles with relative momentum from 0.15 to 1 GeV/c. MPD will have the ability to distinguish pions from kaons up to p_T of 2.0 GeV/c and kaons from protons up to 3 GeV/c. The energy resolution for electromagnetic probes measured in ECAL is expected to be of the order of 5% at 1 GeV. The timing resolution of the fast forward detector is designed at less than 50 ps.

3. The MPD physics program

The overall physics program of the MPD detector has been summarized in the NICA Whitepaper [1]. The main goal is the investigation of the less-explored area of the QCD phase diagram, shown in the left panel of Fig. 2. Several key features of the diagram can be explored at NICA. The large net baryon density region, which is expected to be probed there, is where the phase transition between the deconfined phase and the hadronic phase is predicted to be of the first-order type. In addition the conjectured critical point of the diagram can be located in this region. The characterization of these phenomena is the key goal of the MPD Physics program.

The investigation of the properties of nuclear matter inside neutron stars is the key goal of modern astrophysics. The recent observation of the neutron star merger both via gravitational waves [2] as well as in the electromagnetic spectrum [3] began the new era of multi-messenger astronomy. Recent model calculations reveal that in the neutron star merger process nuclear matter reaches densities and temperatures expected in the heavy-ion collision in the NICA energy range. Therefore the MPD experiment offers unique opportunity to study such processes in the laboratory. As shown in the right panel of Fig. 2 MPD will

provide unique combination of collision energy and interaction rate, not available in any other research program currently operating or planned in the near future.

The physics program of MPD will encompass a large variety of physics observables in order to meet the challenges mentioned above. Initial running with minimum bias trigger will provide large samples of Au-Au collisions at close to maximum energy. Inclusive p_T spectra for pions, kaons and protons will be measured as a function of collision centrality. The Λ and K_S^0 will also be measured via their decay topology, as well as various hadronic resonances reconstructed via the invariant mass method. This will be enabled by the excellent tracking and PID capabilities of MPD. With the combined dataset the statistical model analysis of baryochemical potential and temperature of the system will reveal the region of the QCD phase diagram being explored. Two-particle femtoscopic correlations for pions, kaons, and protons will determine the size of the system and its basic dynamics. Further study of the radial, directed and elliptic flow and comparison to model calculations will enable a more precise and in-depth investigation of the dynamical and transport properties of the created system.

MPD is also uniquely positioned to study the production of di-lepton pairs and photon spectra, with the combination of the central barrel tracking detectors and the ECAL. It will allow for the direct measurement of the temperature of the system as well as investigation of the chiral symmetry restoration via the measurement of the properties of the produced vector mesons. MPD will also have the capability to measure decays of particles with charm, although they will be much enhanced with the addition of the silicon Inner Tracker in the Stage 2 of MPD operation.

All of the above-mentioned measurements are being currently studied in Monte-Carlo theoretical models, as well as with the full simulation of the detector response, possible in the MPDRoot software package. The computing environment is already being used extensively, based both on the IT resources of JINR as well as the resources of collaborating institutions. The computing capacity is planned to be extensively expanded in time for datataking.

4. Summary

The status of the preparation of the NICA Accelerator Complex has been presented. The Nuclotron is already existing and producing beams, the auxiliary Booster accelerator is being installed at the moment, with the accompanying injection chains already commissioned. The civil construction and magnet production for the NICA accelerator and transfer lines are progressing according to schedule. The production of components for MPD subsystems is advanced and will allow for the assembly of the detector in 2020 and 2021, after the civil construction for the MPD Hall is complete. The commissioning of detector components and support systems will be carried out beginning in 2021.

The main aspects of the design physics performance of the subdetector components as well as the general characteristics of tracking, event reconstruction and particle identification has been presented. It is adequate for the measurement of the physics observables relevant for the main scientific goals. The study of the properties of the less-explored region of the QCD phase diagram at maximum baryonic density, with direct connection to astrophysical phenomena, such as neutron star mergers will be the main focus of the initial investigations in MPD and the NICA Accelerator Complex.

References

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