# Relativistic heavy ion physics at JINR: status of the BM@N and MPD experiments

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The future accelerator facility NICA (JINR, Dubna) will supply ion species ranging from polarized proton to heavy ions with design luminosity of up to $10^{27}$ cm$^{-2}$c$^{-1}$ for Au nuclei in the region of the collider energy up to $\sqrt{s_{NN}} = 11$ GeV. It will complement the existing accelerator Nuclotron, which is being currently upgraded in order to be able to accelerate Au nuclei up to $E_{kin} = 4.65$A GeV ($\sqrt{s_{NN}} = 3.5$ GeV). These machines will host two heavy ion experiments: BM@N (Baryonic Matter at Nuclotron) and MPD (MultiPurpose Detector), which are described in this paper.

## 1 NICA complex

The Nuclotron-based Ion Collider fAcility (NICA) [1], shown in Fig. 1, is a new accelerator complex being constructed at JINR, Dubna, Russia. NICA's aim is to provide collisions of heavy ions over a wide range of atomic masses, from Au+Au collisions at $\sqrt{s} = 4 - 11$A GeV (for Au$^{79+}$) and an average luminosity of L = $10^{27}$ cm$^{-2}$s$^{-1}$ to proton-proton collisions with $\sqrt{s_{pp}} = 20$ GeV and L = $10^{32}$ cm$^{-2}$s$^{-1}$.

Study of heavy ion collisions at the collider with the MultiPurpose Detector (MPD) will be complemented by spin physics research with polarized beams of protons and deuterons with the Spin Physics Detector (SPD) as well as a fixed-target program at center of mass energy from 1 to 4 GeV at the BM@N (Baryonic Matter at Nuclotron) detector.

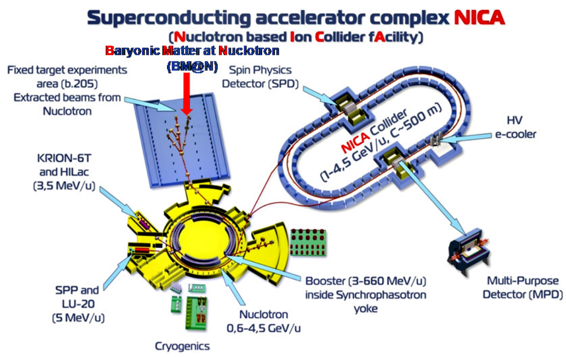


Figure 1: NICA complex.

## 2 MPD experiment

The main goal of the NICA/MPD program [2] is a comprehensive experimental investigation of the properties and dynamics of the hot and dense nuclear matter in a poorly explored region of the QCD phase diagram, with a main emphasis on such QCD subjects as properties of deconfinement phase transition, critical phenomena and chiral symmetry restoration.

The NICA/MPD experimental program includes simultaneous measurements of observables that are presumably sensitive to high nuclear density effects and phase transitions. In the first stage of the project are considered - multiplicity and spectral characteristics of the identified hadrons including strange particles, multi-strange baryons and antibaryons; event-by-event fluctuations in multiplicity, charges and transverse momentum; collective flows (directed, elliptic and higher ones) for observed hadrons. In the second stage the electromagnetic probes (photons and dileptons) will be measured.

The detector for exploring phase diagram of strongly interacting matter in a high track multiplicity environment has to cover a large phase space, be functional at high interaction rates and comprise high efficiency and excellent particle identification capabilities. The MPD detector [3, 4], shown in Fig. 2, matches all these requirements. It consists of a barrel part and two end caps. The barrel part is a set of various subdetectors. The main tracker is the time projection chamber (TPC) supplemented by the inner tracker (IT). IT and TPC have to provide precise tracking, momentum determination and vertex reconstruction. The time of flight (TOF) system must be able to identify charged hadrons and nuclear clusters in a broad pseudorapidity range. The electromagnetic calorimeter (ECAL) should identify electrons, photons and measure their energy with high precision. The zero degree calorimeter (ZDC) should provide event centrality and event plane determination, and also measurement of the energy deposited by spectators. There are also a straw-tube tracker (ECT) and a fast forward detector (FFD).

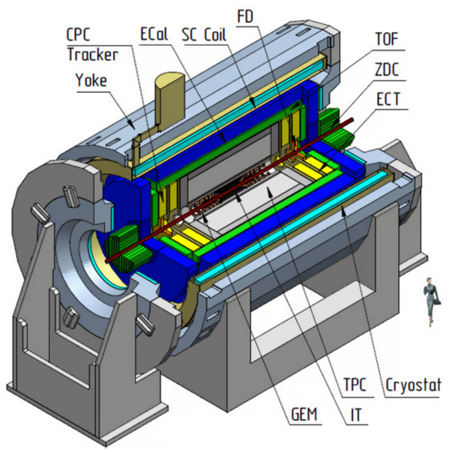


Figure 2: MPD detector.

The magnet of MPD is a solenoid with a thin superconducting NbTi winding and a flux return iron yoke. The magnet should provide a homogeneous magnetic field of 0.5 T. The field inhomogeneity in the tracker area of the detector is about 0.1%.

The MPD time projection chamber (TPC) is the main tracking detector that has to provide charged particles momentum measurement with sufficient resolution (about 2% at $p_t = 300$ MeV/$c$), two track separation (with a resolution <1 cm), vertex determination and dE/dx measurement (dE/dx resolution better than 8%) at pseudorapidities $|\eta| < 2.0$ and $p_t > 100$ MeV/$c$. TPC readout system is based on Multi-Wire Proportional Chambers (MWPC) with cathode readout pads.

The identification of charged hadrons (PID) at intermediate momentum ($0.1 - 3$ GeV/c) is achieved by the time-of-flight (TOF) measurements which are complemented by the energy loss ($dE/dx$) information from the TPC and IT detector systems. TOF system should provide a large phase space coverage $|\eta| < 3.0$, high combined geometrical and detection efficiency (better than 80%), identification of pions and kaons with $0.1 < p_t < 2$ GeV/$c$ and (anti)protons with $0.3 < p_t < 3$ GeV/$c$. The choice for the TOF system is multigap Resistive Plate Counters (mRPC) which have good time resolution of $\sigma < 70$ ps. The barrel covers the pseudorapidity region $|\eta| < 1.5$ with the average efficiency above 90%. The end cap system covers the pseudorapidity region $1.5 < |\eta| < 3.0$.

Currently, the MPD physics program is under careful evaluation through the extensive feasibility studies. As they show, the MPD detector will provide good conditions for the strangeness measurements in heavy ion collisions, both in the hyperon [6] and hypernuclei sectors (Fig. 3 left panel).

Electromagnetic probes (electron-positron pairs) will also be accessible (Fig. 3 right panel) [7] for studies, e.g., of the low-mass dilepton enhancement in heavy ion collisions.

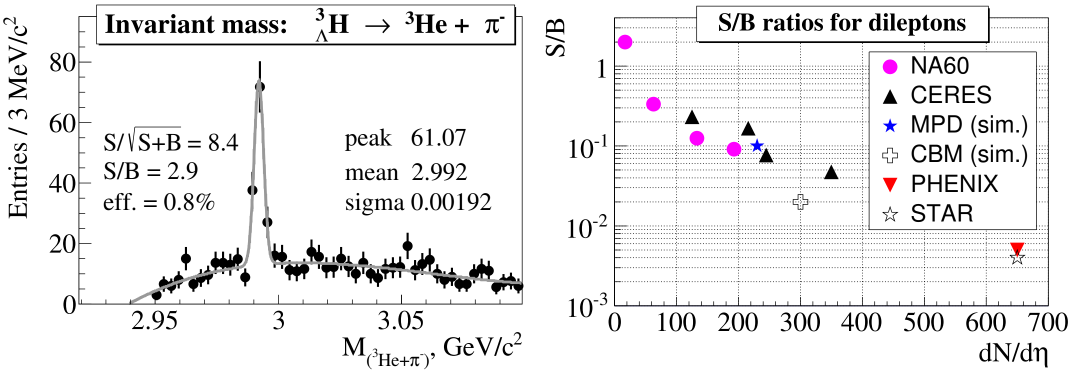


Figure 3: Some results from MPD feasibility studies: left - reconstructed invariant mass of $^3$He and $\pi^-$; right - signal-to-background ratios obtained in different experiments for low-invariant mass region of lepton pairs versus charged particle density.

## 3 BM@N experiment

A successful operation of the NICA complex will require the existing machine Nuclotron to be upgraded in order to accelerate Au nuclei. After that, the improved Nuclotron beams will also be used to run a fixed target experiment BM@N [5]. The detector will allow to study A+A collisions by measuring a variety of observables.

Particle yields, ratios, transverse momentum spectra, rapidity and angular distributions, as well as fluctuations and correlations of hadrons will be studied as a function of the collision energy and centrality. A sketch of the proposed experimental set-up is shown in Fig. 4. It combines high precision track measurements with time-of-flight information for particle identification and total energy measurements for event characterization. The charged track multiplicity will be measured with the set of GEM (Gas Electron Multipliers) detectors located downstream of the target inside the analyzing magnet of 0.8 T

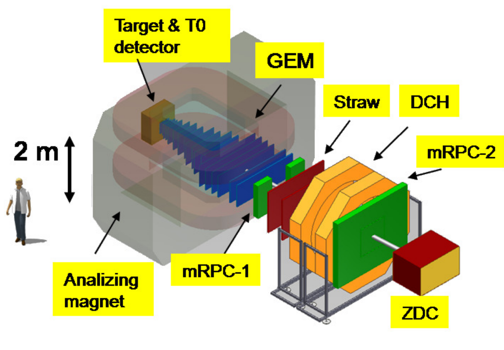


Figure 4: BM@N detector.

and drift chambers (Straw, DCH) situated outside the magnetic field. Design parameters of the time-of-flight detectors based on multigap Resistive Plate Chambers (mRPC-1,-2) with a strip read-out allow efficient discrimination between particle species with momentum up to a few GeV/c. The Zero Degree Calorimeter (ZDC) is designed for the collision centrality analysis by measuring the energy of forward going particles. The Recoil detector, partially covering the backward hemisphere (-1< $\eta$ <1.2) near the target, is planned for the independent analysis of the collision centrality by the measurement of the energy of the target fragments.

The BM@N project is being realized by a Collaboration of more than 100 physicists and engineers from 12 countries. According to the project realization plan, the first elements of the BM@N detector will be installed at the Nuclotron beam line in early 2015 to perform test beam measurement. The physics data taking is planned to start in 2016. At present, an active R&D program and beam line development works are complemented with intensive Monte Carlo simulation studies for optimization of the detector design. Figure 5 illustrates the quality of hyperon reconstruction in the BM@N detector with the GEM tracker. The obtained results indicate that even in high multiplicity central Au+Au collisions the proposed set-up has very good reconstruction capability for strange hyperons.

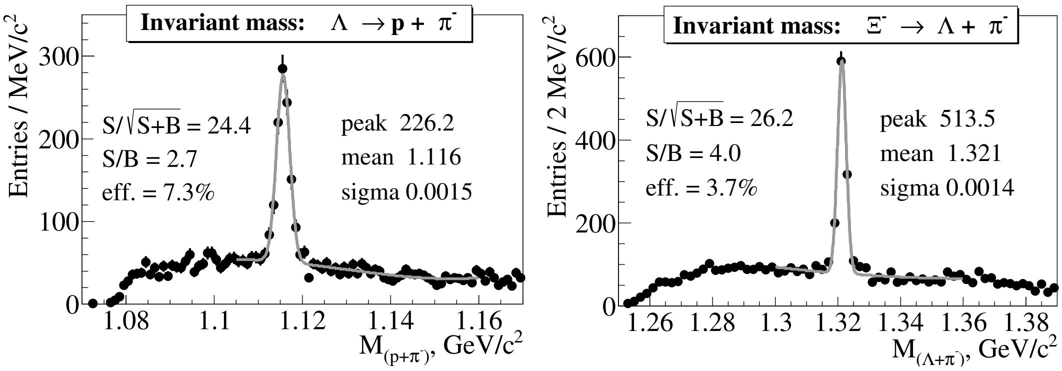


Figure 5: Some results from BM@N feasibility studies: reconstructed $\Lambda$ (left) and $\Xi^-$ (right) hyperon invariant mass peaks.

# References


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