NICA at JINR: New Prospects for Exploration of Quark-Gluon Matter

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A new scientific program is proposed at the Joint Institute for Nuclear Research (JINR) in Dubna aimed at studies of hot and dense baryonic matter in the wide energy range from 2 GeV/u kinetic energy in fixed target experiments to $\sqrt{s_{\rm NN}} = 4$–11 GeV/u in the collider mode. To realize this program the development of the JINR accelerator facility in high energy physics (HEP) has been started. This facility is based on the existing superconducting synchrotron – the Nuclotron. The program foresees both experiments at the beams extracted from the Nuclotron, and the construction of a heavy ion colider – the Nuclotron-based Ion Collider fAcility (NICA) which is designed to reach the required parameters with an average luminosity of $L = 10^{27}$ cm^{-2}s^{-1}.

1. INTRODUCTION

A study of hot and dense baryonic matter should shed light on: in-medium properties of hadrons and the nuclear matter equation of state (EOS); the onset of deconfinement (OD) and/or chiral symmetry restoration (CSR); signals of a phase transition (PT), the mixed phase (see Fig. 1*a*) and the critical end-point (CEP); possible local parity violation in strong interactions (LPV).

It is indicated in a series of theoretical works [1] that heavy ion collisions at $\sqrt{s_{\rm NN}} = 4$–11 GeV/u allow to reach the highest possible baryon density in the lab (see Fig.1*a*).

The realization of the project NICA aimed at studies of hot and dense baryonic matter has been started at the Joint Institute for Nuclear Research (JINR) in Dubna as a flagship

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project in HEP. In addition to beams extracted from the Nuclotron (the existing accelerator of heavy ions) the project foresees the construction of a Nuclotron based Ion Collider fAcility (NICA) and a Multi-Purpose Detector (MPD).

The experimental program aims at investigating hot and dense baryonic matter. The list of the first priority physics tasks to be performed in the experiment includes the measurement of a large variety of signals under systematically changing conditions of collision (energy, centrality, system size):

- bulk observables (hadrons): 4π geometry particle yields (OD, EOS);
- multi-strange hyperon production: yields and spectra (OD, EOS)
- electromagnetic probes (CSR, OD);
- azimuthal charged-particle correlations (LPV);
- event-by-event fluctuation in hadron productions (CEP);
- correlations involving π, K, p, Λ (OD);
- directed and elliptic flows for identified hadron species (EOS,OD).

Reference data (i.e. *pp*) will be taken for the same experimental conditions.

2. ACCELERATOR FACILITY NICA

The Nuclotron is an existing accelerator facility of JINR in HEP put in operation in 1993. It is based on the unique technology of superconducting fast cycling magnets developed at JINR. The Nuclotron provides proton, polarized deuteron and multi-charged ion beams.

The maximum magnetic field of dipole magnets $B = 2.0$ T corresponds to the ion beam energies: 5.81 GeV/u for d (A = 2, Z=1), 3.64 GeV/u for Xe (A=124, Z=42), and 4.56 GeV/u for Au (A=197, Z=79).

The new accelerator facility NICA [2] includes: an injector complex providing wide spectrum of ions up to the heaviest one $^{197}\mathrm{Au}^{32+}$ at the energy 6.2 MeV/u with an intensity 2×10^9; a booster accelerating ions up to 600 MeV/u; the Nuclotron continuing acceleration up to the maximum energy (4.5 GeV/u) and two storage rings with two interaction points (IP). The ions are additionally stripped before the injection into the Nuclotron. The major parameters of the NICA collider are following: $B\rho_{max} = 45$ Tm; vacuum in the beam chamber 10^{-11} Torr; maximum dipole field 2 T; kinetic energy from 1 GeV/u to 4.5 GeV/u for Au^{79+}; zero beam crossing angle at IP; 9 m space for detector allocations at IP's; average luminosity for heavy ions 1×10^{27} cm^{-2}s^{-1} (at 3.5 GeV/u). The required Nuclotron upgrade has started in 2008 and will be fully completed by 2014. A booster and new linac will be put in operation. The overall construction schedule foresees that the storage ring and basic infrastructure facility should be available for the first ion collisions already in 2016 [3].

3. THE BMN EXPERIMENT

The energy of the extracted beams provided by upgraded Nuclotron-NICA will finally reach 5.81 GeV/u for typical values of $A/Z = 2$. A typical variety of possible beams and their intensities provided by the Nuclotron-NICA accelerator complex per cycle (5 s) is presented in Table 1.

To realize the first stage of experiments at extracted beams with a fixed target a new set-up – BMN (Baryonic Matter at Nuclotron) will be constructed using an existing dipole magnet, tracking devices and other necessary parts for particle ID etc. The new silicon vertex detector will be constructed in cooperation with the partners from GSI (Darmstadt).

4. THE MPD EXPERIMENT

The MPD experiment should be competitive and at the same time supplementary to the ones operating at RHIC [4], and those constructed in the framework of the FAIR [5] project.

The MPD will be installed at the first IP of NICA. The major sub-detectors of the MPD are (see Fig. 2): a solenoidal superconducting magnet with a magnetic field of 0.5 T (~ 5 m in diameter and ~ 8 m in length); a time projection chamber (TPC); an inner tracker (IT); a time-of-flight (TOF) system; an electromagnetic calorimeter (ECAL); an end cap tracker (ECT); and two forward spectrometers based on toroidal magnets (optional). Three stages are foreseen for putting MPD into operation. The first stage of operation involves magnet, TPC, TOF, ECAL (partially), and IT (partially), and should be ready for the first collision of beams in 2016.

The processes studied with MPD were simulated using the dedicated software framework (MpdRoot). This software is based on the object-oriented framework FairRoot [6] and provides a powerful tool for detector performance studies, development of algorithms for reconstruction and physics analysis of the data. The evaluated rate in AuAu collisions at $\sqrt{s_{\rm NN}} = 7.1$ GeV/u (10% central interactions) taking into account the luminosity of $L = 10^{27}$ cm^{-2}s^{-1} is 7 kHz.

More than ten working groups from 12 institutions are intensively working on sub-detector R&D, and on prototyping of all detector elements. Further detailed information could be found in the corresponding conceptual design report [7].

It has been shown that the MPD is well optimized for the study of in-medium effects caused by high baryon densities, such as: changing particle properties in the hot and dense medium (broadening of spectral functions etc.), event-by-event dynamical fluctuations of strange to non-strange particle ratios, and others. These studies could be done with better precision than the one achieved at presently performed experiments. The simulations of the MPD experiment show that a high statistics of studied events could be accumulated (10^9 minimum bias events and 10^8 central events per week) which provide the best precision for femtoscopy studies with respect to RP correlation of multistrange particles. In ten weeks of running more than $\sim 10^7$ of Ω-hyperon decays will be recorded.

Charged particles are reliably identified using both techniques: by measuring the dE/dx of tracks in the TPC, and by the TOF system. A sufficiently high resolution of vertex reconstruction has been obtained, as illustrated in Fig. 3*a*. Fig. 3*b* also shows the example of an $\Omega \to \Lambda K^-$ decay reconstruction implementing the full chain of simulations: central AuAu collision generation at $\sqrt{s_{\rm NN}} = 7.1$ GeV/u; hyperon productions and decays; decay product detection and their reconstruction using necessary MPD subdetectors.

The MPD performance in general satisfies the required parameters for the proposed experimental program. The further optimization of the MPD element design is continued. The corresponding infrastructure is developed as well at the site in the Veksler and Baldin Laboratory of High Energy Physics (JINR, Dubna).

5. CONCLUSION

The NICA program to study hot and dense baryonic matter is well progressing at JINR Dubna. The conception of all parts of the accelerator facility and the experimental set-up's are completed, R-and-D's for major elements are close to completion. The international collaborations created around this facility involve more than 200 members from 25 institutions of 21 countries. It is permanently growing and new members are welcome !

Acknowledgement

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Table 1. The Nuclotron beams.

beam	p	d	^{7}Li	^{12}C	^{24}Ar	^{56}Fe	^{84}Kr	^{124}Xe	^{197}Au
intensity/s	5×10^{12}	5×10^{12}	5×10^{11}	2×10^{11}	2×10^{11}	5×10^{10}	1×10^{9}	1×10^{9}	1×10^{9}

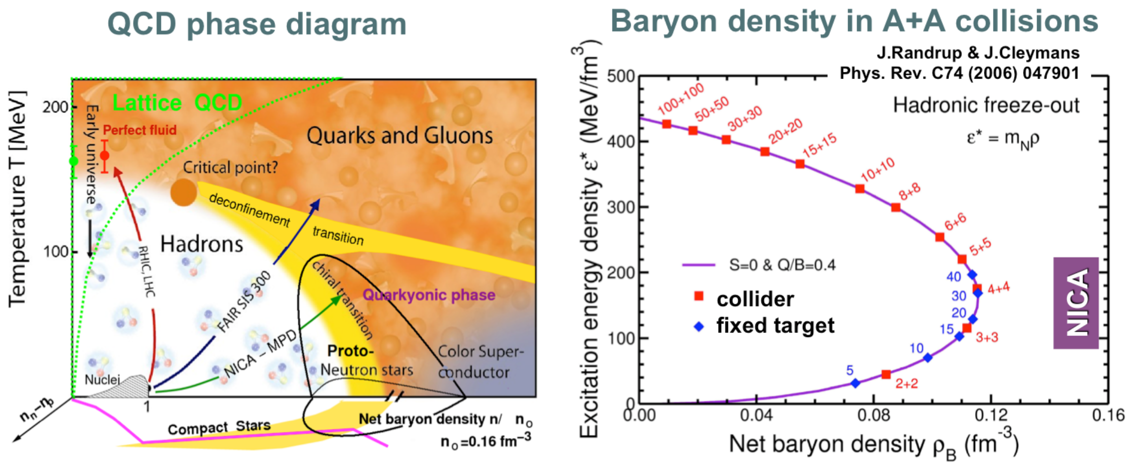

Figure 1. (a) phase diagram for QCD matter (mixed phase is indicated by yellow). (b) hadronic freezout conditions for different energies in fixed target (diamonds) and collider mode (squares).

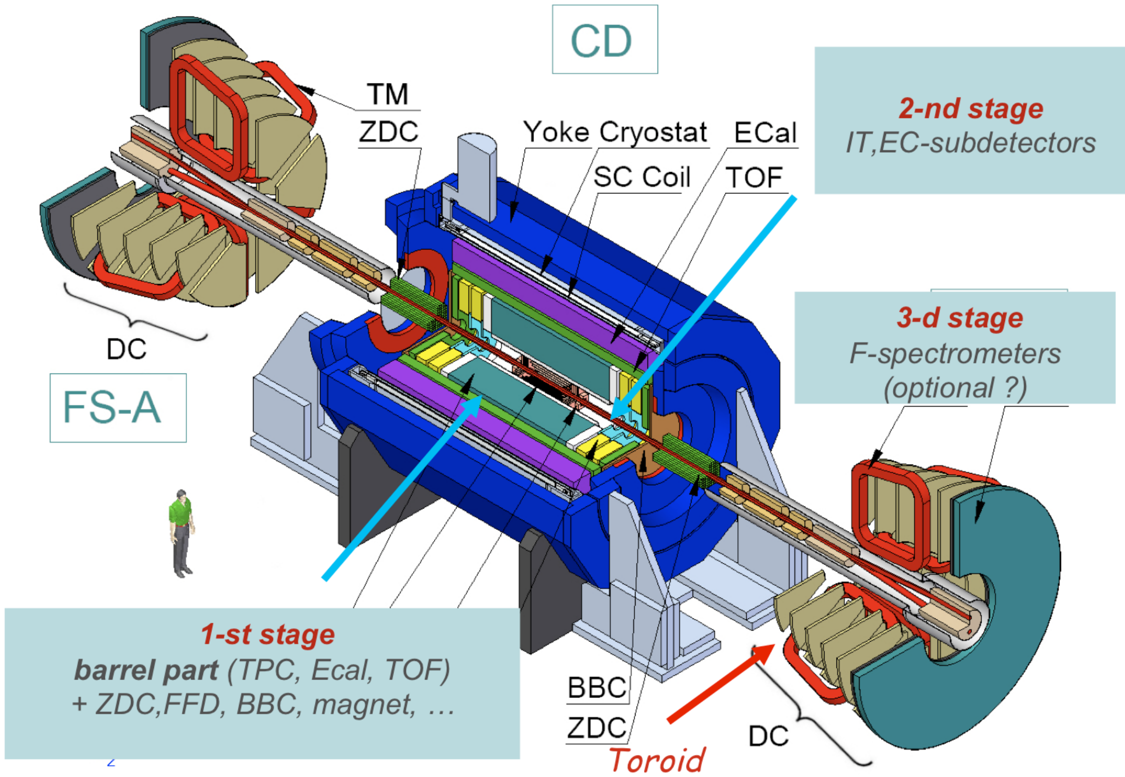

Figure 2. General view of the MPD, and sets of sub-detectors to be put in operation at different stages.

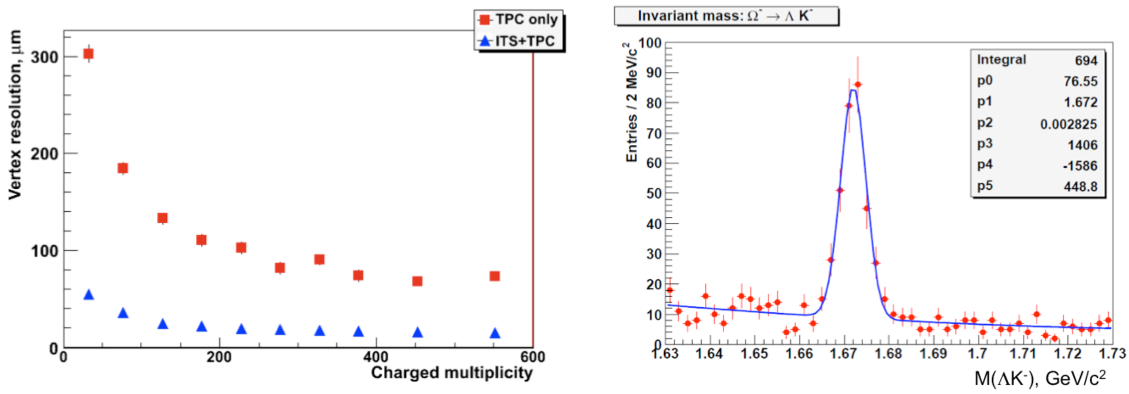

Figure 3. (a) vertex resolutions versus multiplicity for events reconstructed with TPC only (squares), and for events reconstructed using both sub-detectors - TPC and IT (triangles). (b) reconstructed invariant mass of Ω decay products (vertex reconstruction with TPC and IT, and particle ID with TPC and RPC).

FIGURE CAPTIONS

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