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STATUS OF NICA COMPLEX AT JINR

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New scientific programme is proposed at the Joint Institute for Nuclear Research (JINR) in Dubna aimed at the study of hot and dense baryonic matter in the wide energy region from 2 GeV/amu to $\sqrt{s_{NN}} = 11$ GeV, and investigation of nucleon spin structure with polarized protons and deuterons maximum energy in the c.m. 27 GeV (for protons). To realize this programme, the development of JINR accelerator facility in high-energy physics has started. This facility is based on the existing superconducting synchrotron — Nuclotron. The programme foresees both experiments at the beams extracted from the Nuclotron and construction of ion collider — the Nuclotron-based Ion Collider fAcility (NICA).

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INTRODUCTION

As an introduction it is a pleasure to notice that this year is the 105th jubilee year of Academician V. I. Veksler who conceived the principle of phase stability in 1944. He was the first director of our Laboratory and was the leader of the Synchrophasotron design and construction. The accelerator was put into operation 55 years ago and at that time it has reached the record energy of 10 GeV for accelerated protons.

Three years ago, the 7-years plan of the Joint Institute for Nuclear Research (JINR) has been approved for 2010–2016 years. In accordance with this plan, the project named «Nuclotron-based Ion Collider fAcility» (NICA) aimed at the study of hot and dense baryonic matter and spin physics is realizing at JINR as a flagship project in high-energy physics (HEP).

The study of hot and dense baryonic matter should shed light on: in-medium properties of hadrons and nuclear matter equation of state (EOS); onset of deconfinement (OD) and/or chiral symmetry restoration (CSR); phase transition (PT); mixed phase (see Fig. 1, *a*) and critical end-point (CEP); possible local parity violation in strong interactions (LPV) [1–4]. It is indicated in series of theoretical works, in particular, in [3] that heavy-ion collisions at $\sqrt{s_{NN}} \leqslant 11$ GeV allow one to reach the highest possible baryon density in the lab (Fig. 1, *b*).

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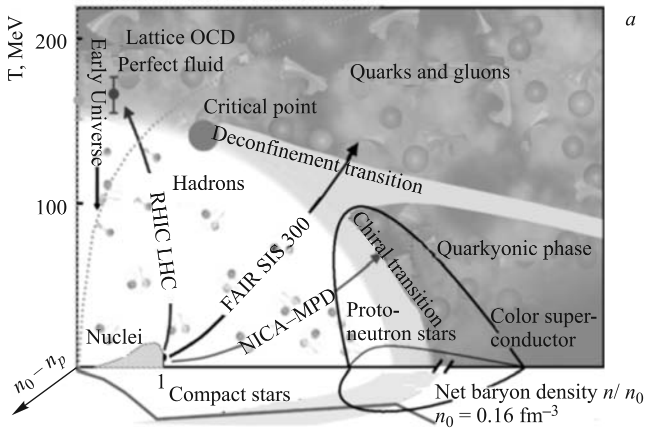

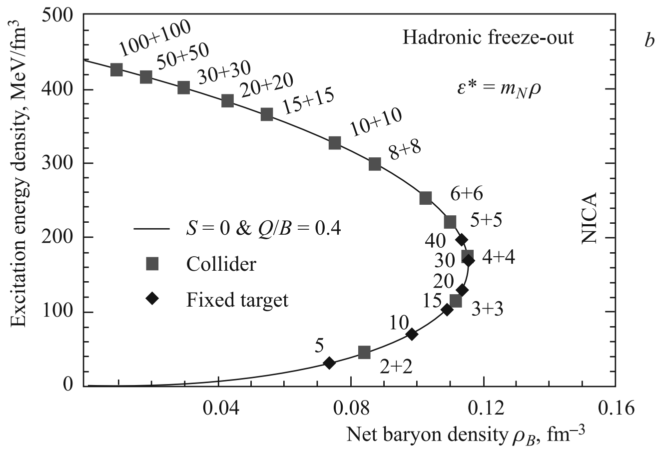

Fig. 1. (Color online) *a*) Phase diagram for QCD matter (mixed phase is indicated by yellow); *b*) freeze-out diagrams for baryonic matter indicating baryon density reachable at different energies in collider and fixed target experiments (CR) (the region covered by the NICA experiments is indicated)

The high intensity and high polarization ($> 50\%$) of colliding beams could provide a unique possibility for spin physics research, which is of crucial importance for the solution of the nucleon spin problem («spin puzzle») — one of the main tasks of the modern hadron physics.

The project NICA includes:

— an upgrade of the existing superconducting synchrotron Nuclotron to provide variety of ions up to Au with maximum energy of 4.05 GeV/u;

— an experiment Baryonic Matter at Nuclotron (BM@N) in the ion beams extracted from the modernized Nuclotron;

— the construction of NICA collider providing collisions of variety of ions up to Au^{79+} at the energy region up to $\sqrt{s_{NN}} \leqslant 11$ GeV with the luminosity $L = 10^{27}$ cm$^{-2} \cdot$ s^{-1}, and polarized proton and deuteron beams up to the c.m.s. energy of 27 GeV for pp collisions with the luminosity higher than $L = 10^{31}$ cm$^{-2} \cdot$ s^{-1};

— an experiment with the MultiPurpose Detector (MPD) at the first interaction point (IP) of NICA with a primary goal to study heavy-ion collisions;

— an experiment at the second IP of NICA with a primary goal to study spin physics.

1. ACCELERATOR FACILITY NICA

The Nuclotron is an existing synchrotron located at the Veksler and Baldin Laboratory of High-Energy Physics (VBLHEP) of JINR, which has been put in operation in 1993. It is based on the unique technology of superconducting fast cycling magnets developed at VBLHEP. The upgraded Nuclotron will provide proton, polarized deuteron and multicharged ion beams. The magnetic field of dipole magnets $B = 1.8$ T corresponds to the ion beam energies: 5.2 GeV/u for d ($A = 2$, $Z = l$); 3.3 GeV/u for Xe ($A = 124$, $Z = 42$); and 4.05 GeV/u for Pu ($A = 197$, $Z = 79$). The NICA facility (Fig. 2) includes: an injector complex providing wide spectrum of ions up to the heaviest one — Au at the energy of 3.5 MeV/u with an expected intensity $2 \cdot 10^9$; a booster accelerating ions up to 660 MeV/u; the source of polarized ions (protons and deuterons) SPI with the linac accelerating light ions up to 5 MeV/u; the Nuclotron continuing acceleration up to the maximum energy (4.5 GeV/u) and two storage rings with two interaction

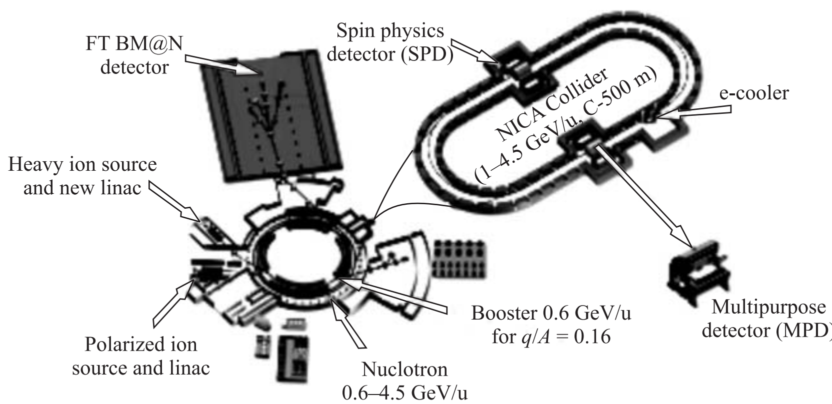

Fig. 2. The new accelerator and experimental facility complex NICA at the VBLHEP

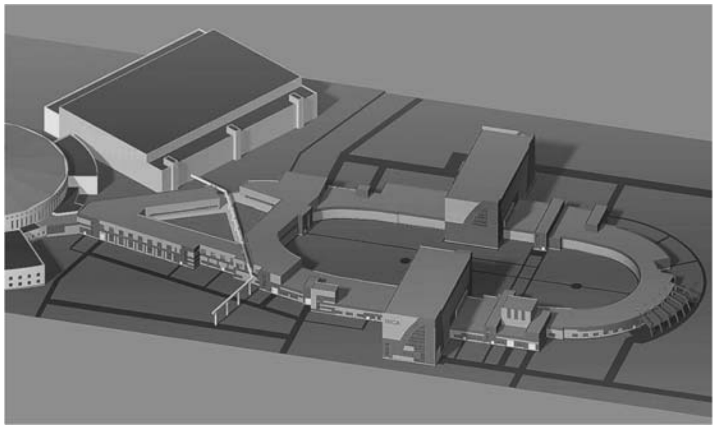

Fig. 3. The architecture design of NICA collider and experimental buildings at two IPs

points (IP). The ions are fully stripped before the injection into the Nuclotron. The major parameters of NICA collider are the following: $Bp_{\max} = 45$ T $\cdot$ m; vacuum in a beam chamber — 10^{-11} Torr; maximum dipole field 2 T; extracted ion kinetic energy range from 1 to 4.5 GeV/u for Au^{79+}; zero beam crossing angle at IP; 9 m space for detector allocations at IPs: maximum luminosity for ion collisions $L = 10^{30}$ cm$^{-2} \cdot$ s^{-1}. The required Nuclotron upgrade has started in 2008 and will be completed by 2015 including a booster and new linac. The construction of the collider rings and IPs will be started in 2013. The corresponding design project is ready for the Russian State expertise (Fig. 3). The overall construction schedule foresees that the collider storage ring and basic infrastructure facility should be available for the first ion collisions already in 2017 [5].

In the first IP, the MultiPurpose Detector (MPD) will be installed, while a detector for the second IP is not yet designed. A call for the corresponding proposal is announced.

2. The BM@N EXPERIMENT

The energy of the extracted beams provided by upgraded Nuclotron–NICA finally will reach 6 GeV/u for typical values of $A/Z = 2$. Proton and deuteron beams could reach an intensity of $5 \cdot 10^{12}$. A typical variety of other possible beams and their intensities provided by Nuclotron–NICA are presented in Table 1.

To realize the first stage of experiments at extracted beams with a fixed target, a new set-up — BM@N (Baryonic Matter at Nuclotron) will be constructed using existing wide aperture dipole magnet, tracking chambers, time-of-flight (TOF)

Table 1. **The Nuclotron–NICA beams and their intensities (in ppp)**

^{7}Li	^{12}C	^{40}Ar	^{56}Fe	^{84}Kr	^{124}Xe	^{197}Au
$5 \cdot 10^{11}$	$2 \cdot 10^{11}$	$2 \cdot 10^{11}$	$5 \cdot 10^{10}$	$1 \cdot 10^{9}$	$1 \cdot 10^{9}$	$1 \cdot 10^{9}$

system, hadron calorimeter, and fast counter detector providing trigger signal. At the second stage, an upgrade is foreseen to accomplish the set-up with a silicon vertex detector (in cooperation with the partners from GSI, Darmstadt), with the electromagnetic calorimeter, and with the neutron detector (optional).

3. THE MPD EXPERIMENT

The MPD experimental programme is aimed to investigate both: the hot and dense baryonic matter, and the nucleon spin structure and polarization phenomena. A list of the first priority physics tasks to be performed in the experiment includes:

• in heavy-ion programme:

measurement of a large variety of signals at systematically changing conditions of collision (energy, centrality, system size) using as bulk observables the following:

— 4π geometry particle yields (OD, EOS);

— multistrange hyperon 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., $p + p$) will be taken at the same experimental conditions;

• in spin physics:

— a study of hyperon polarization and other polarization phenomena; at the second stage after the MPD upgrade it will be possible to study nucleon spin structure via the Drell–Yan (DY) processes.

The MPD is a typical collider detector based on the solenoidal superconducting magnet. It will be installed in the first IP of NICA. The major subdetectors of the MPD (Fig. 4) are: solenoidal superconducting magnet with a magnetic field of 0.5 T ($\sim$ 5 m in diameter and $\sim$ 8 m in length); time projection chamber (TPC); inner tracker (IT); time-of-flight (TOF) system; electromagnetic calorimeter (ECal); end-cap tracker (ECT); two forward spectrometers based on toroid magnets (optional). There are foreseen three stages of putting MPD into operation. The first stage of operation involves magnet, TPC, TOF, ECal (partially), IT (partially), as well, and should be ready for the first colliding beams in 2017. At the second stage, the end caps of MPD will be fully equipped and some readout

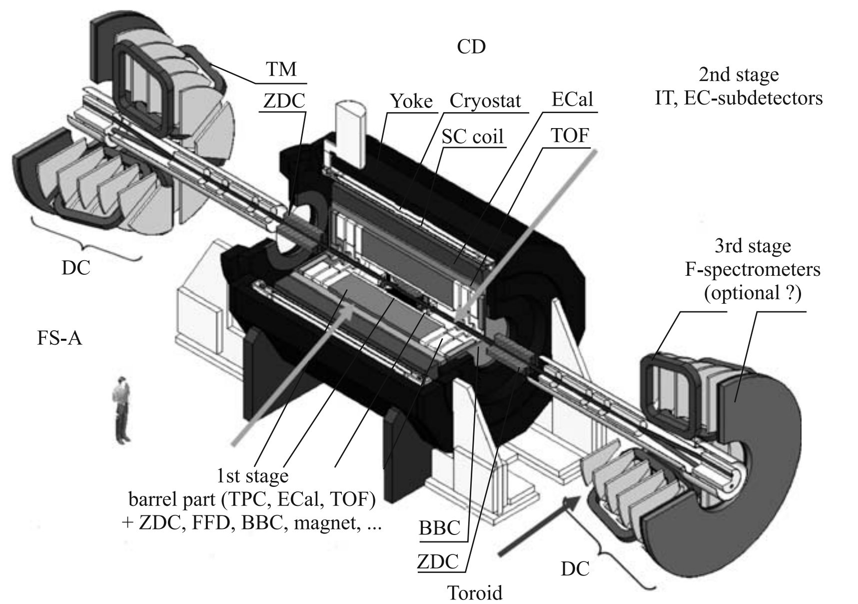

Fig. 4. General view of the MPD, and sets of subdetectors to be put in operation at different stages

system modernized. The third stage related to possible requirement for forward spectrometers and is optional. The MPD experiment should be competitive and at the same time supplementary to ones operated at RHIC [6], and constructed in the framework of FAIR [7] project.

The processes studied with MPD were simulated using the dedicated software framework (MpdRoot). This software is based on the object — oriented framework FairRoot [8] and provides a powerful tool for detector performance studies, development of algorithms for reconstruction and physics analysis of the data. Evaluated rate in Au + Au collisions at $\sqrt{s_{NN}} = 7.1$ GeV (10% central interactions) taking into account the luminosity of $L = 10^{27}$ cm$^{-2} \cdot$ s^{-1} is 7 kHz. The corresponding particle yields are presented in Table 2.

More than ten working groups from 12 institutions are intensively working on subdetector R&D and on prototyping of all detector elements. More detailed information could be found in the conceptual design report [9]. It was shown that MPD is well optimized for the study of in-medium effects caused by high baryon densities, such as: changing particle properties in hot and dense medium (broadening of spectral functions, etc.), event-by-event dynamical fluctuations of strange to nonstrange particle ratios and others. These studies could be done with better precision than ones performed at the world current experiments. The simulations of MPD capabilities show that high statistics of studied events could be

Table 2. **The particle yields in Au + Au collision (central) at $\sqrt{s_{NN}} = 7.1$ GeV**

Particle	Yield/4π	Yield at $y = 0$	Decay mode	ε,%	Yield/10 w
$\pi^{\pm}$	290	100	—	61	$2.6 \cdot 10^{11}$
$K^{\pm}$	60	20	—	60	$4.3 \cdot 10^{10}$
p	140	40	—	60	$1.2 \cdot 10^{11}$
ρ	30	17	e^+e^-	35	$7.3 \cdot 10^5$
ω	20	10	e^+e^-	35	$7.2 \cdot 10^5$
ϕ	2.6	1.2	e^+e^-	35	$1.7 \cdot 10^5$
Ω^-	0.14	0.1	ΛK^-	0.7	$2.7 \cdot 10^6$

accumulated (10^9 minimum bias events and 10^8 central events per week), which provide the best precision for femtoscopy study with respect to RP correlation of multistrange particles. In ten weeks of running more than $\sim 10^6$ of Ω-hyperon decays will be recorded.

Charged particles are reliably identified using both techniques: measuring dE/dx of tracks in TPC and by TOF system (see Fig. 5).

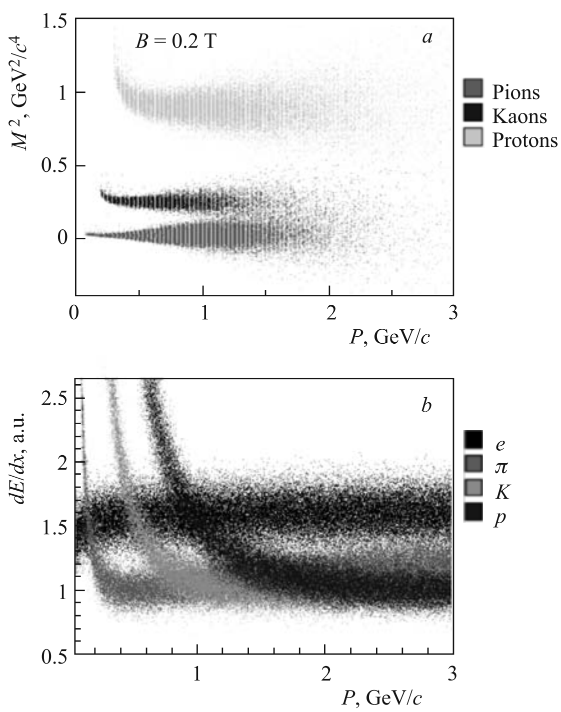

Fig. 5. *a*) Particle ID using TOF system; *b*) particle ID in the TPC by measuring the losses due to the ionization

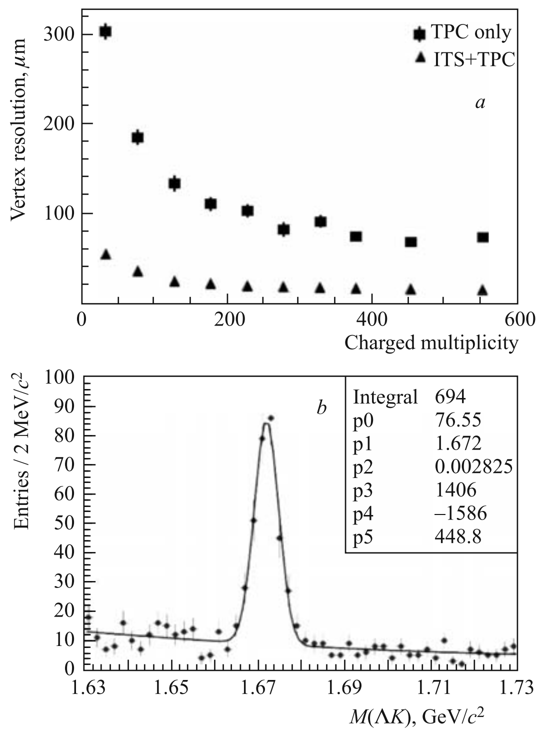

Fig. 6. *a*) Vertex resolutions versus multiplicity for events reconstructed with TPC only (squares), and for events reconstructed using both TPC and IT (triangles). *b*) Reconstructed invariant mass of Ω decay products (vertex reconstruction with TPC and IT, and particle ID with TPC and RPC)

It was obtained sufficiently high resolution of vertices reconstruction illustrated in Fig. 6, *a*. Figure 6, *b* shows as well an example of $\Omega \to \Lambda K^-$ decay reconstruction implementing full chain of simulation: central Au + Au collision generation at $\sqrt{s_{NN}} = 7.1$ GeV; hyperon productions and decays; decay product detection and their reconstruction using necessary MPD subdetectors.

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

4. SPIN PHYSICS AT NICA

The NICA programme foresees that a detector will be designed and installed in the second IP. The physics programme of the related experiment should be dedicated, first of all, to the spin physics. There are number of interesting processes which could be studied with this detector and with the fixed target detectors in the beams extracted from the upgraded Nuclotron, namely: DY processes with longitudinally and transversally polarized p and d beams; extraction of unknown (poor known) parton distribution functions (PDF); PDFs from J/ψ production processes; spin effects in various exclusive and inclusive reactions; diffractive processes cross sections; helicity amplitudes and double spin asymmetries (Krisch effect) in elastic reactions; spectroscopy of quarkoniums with any available decay modes. That can be done in the kinematic region not available for other experiments. The creation of motivated collaboration has started. The proposal could be prepared and presented to the JINR scientific committees. The time scale of this experiment will be defined after the consideration of the proposals. Important part of preparation to the NICA spin physics research programme is adequate development of the infrastructure including the polarization direction control, polarimetery, etc.

CONCLUSION

The accelerator and particle detector complex NICA to be constructed at VBLHEP of JINR, and the related physics programme, will provide relevant researches, on the one hand, competitive, and on the other hand, complementary to the ones being carried out and developing in other centers: RHIC at BNL, SPS and LHC at CERN, SIS18, SIS100 and SIS300 at GSI. The spin physics at NICA has a good perspective to complement experimental research at CERN SPS. And could have the unique possibilities for the experiments at polarized deuterons.

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