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Status and Perspectives of the NICA Project

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The NICA (Nuclotron-based Ion Collider fAcility) is the new international research facility under construction at the Joint Institute for Nuclear Research (JINR) in Dubna. The main targets of the facility are the following: 1) study of hot and dense baryonic matter at the energy range of the maximum baryonic density; 2) investigation of nucleon spin structure and polarization phenomena; 3) development of JINR accelerator facility for high energy physics research based on the new collider of relativistic ions from protons to gold and polarized protons and deuterons as well with the maximum collision energy of sqrt(s_{NN}) ~11GeV (Au^{79+} +Au^{79+}) and ~ 27 GeV (p+p). An average luminosity of the collider is expected at the level of 10^{27} cm^{-2} s^{-1} for Au (79+) and 10^{32} cm^{-2} s^{-1} for polarized protons at 27 GeV. Two collider detector setups MPD and SPD are under design and construction. The setup BM@N (Baryonic Matter at Nuclotron) was commissioned for data taken at the existing Nuclotron beam fixed target area. The MPD construction process is progressing well. The essential step to the SPD project was made in 2018.

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1. Introduction

The new research facility NICA aimed at the studying of heavy ion and polarized proton and deuteron collisions is under design and construction at the Joint Institute for Nuclear Research (JINR) since 2010 [1]. The 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); phase transition (PT), mixed phase and the critical end-point (CEP); possible local parity violation in strong interactions (LPV) [2-5]. It was indicated that heavy ion collisions at $\sqrt{s_{NN}}\sim$ 11 GeV energy region allow attaining the highest baryon density. Thus, the NICA research domain is attractive as possible domain of phase transitions searching.The study of the nucleon spin content and polarization phenomena in the collisions of polarized protons and light polarized ions introduce a target of the further research at NICA. General scheme of the complex is presented in Fig. 1.

Figure 1. General scheme of the NICA at JINR.

The planned regimes make NICA multifunctional facility providing different operating modes and wide spectra of possible projectiles and target combinations. The NICA construction is progressing step-by-step foresees an essential development of the accelerator facility and construction of the new set-ups for physics research. Spectrometer BM@N has started data taken in fixed target experiments with heavy ion beams extracted from modernized Nuclotron in 2017-2018. Preparation the MPD start version for the commissioning is scheduled for 2021-2022. The reports on NICA design and construction are presented regularly at different international meetings and conferences including the ICNFP [6] and others. Content of this paper is limited to brief description of some new results achieved in 2017- 2018.

2. The NICA accelerator facility

Four types of ion sources are necessary to cover the specified species of particles requested for NICA operation. These are: 1) the KRION-6T - a high pulse current, high charge state heavy ion source; 2) the laser-based light ion source; 3) the SPI - polarized proton and deuteron short pulse, high current source and 4) duoplasmatron type proton and deuteron source for the experiments with unpolarised proton and deuteron beams. The new sources have been commissioned during the past two years. The obtained beam intensities were adequate for the

NICA purposes. An impressive new result was the first acceleration of polarized proton beam in the Nuclotron. The beam energy was limited to 2 GeV (below the predicted dangerous spin resonance). Polarization of coasting beam was measured at energy of 270 MeV by means of polarimeter based on internal target and two - arm particle spectrometer. Extrapolation of the measured data on the asymmetry of elastic pp-scattering at the target to beam polarization degree at different points of injection channel, taking all spin rotating elements into account, gave a level of 90% beam polarization at the source output [7]. Commissioning of heavy ion linac (HILAC) and the new front end part of the old linac LU-20 was completed also.

The Nuclotron total running time in 2016-2017 was at the level of 4000 hours. Beams of deuterons, lithium and carbon ions, and polarized deuterons as well, were used mainly for the tasks connected directly with NICA program, i.e. commissioning the BM@N setup, tests of the MPD detector elements and data taken for current physics projects [8, 9].

The main efforts during the coming two years will be concentrated at completion of the booster system manufacturing, installation, assembling and commissioning.

The booster is superconducting strong focusing ion synchrotron 210.96 m perimeter, variable magnetic rigidity from 1.6 to 25.0 Tm aimed at accelerating different ions over a wide range of charge-to-mass ratio (q/A > 0.16). The essential feature of the booster operation is low injection energy (3.2 MeV per nucleon) defined by the HILAC parameters. Due to that, it is necessary to provide proper vacuum conditions inside the beam chamber (the pressure should be less than $1\cdot10^{-11}$ Torr). The peak output energy of Au^{31+} ions (~ 0.6 GeV per nucleon) is reached at the dipole magnetic field of 1.8 T. The booster magnetic ring is mounting inside the window of the Synchrophasotron yoke (see Fig.2a.) The “tunnel” for the magnets installation is prepared except of 3 straight sections connected the arcs of the orbit.

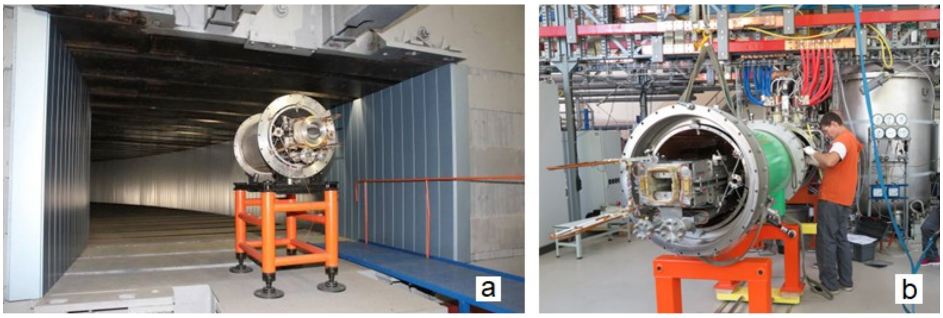

Figure 2. The “tunnel” with the Nuclotron magnet block (a) and the booster dipole magnet at test bench (b).

Manufacturing and tests of the booster magnetic system elements is close to completion, namely: assembling and tests of dipole modules (see Fig.2b.) are completed, yokes and coils for quadrupoles are ready for the assembling. Some delay is exists with the correcting octupole units, nevertheless mounting of the booster magnetic system is scheduled for 2018.

The RF and beam electron cooling systems designed and manufactured at the Budker Nuclear Physics Institute (BINP, Novosibirsk) was delivered to Dubna and the e-cooling system have been installed and commissioned.

The NICA collider consists of two storage rings with two interaction points (IP). Major parameters of the collider are the following: magnetic rigidity $B\rho$ = 45 Tm; vacuum in a beam chamber – 10^{-11} Torr; maximum dipole field 2 T; ion kinetic energy range 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 $L = 10^{27}$ cm^{-2}s^{-1} for gold ion collisions starting from $\sqrt{s_{NN}} \sim 9$ GeV [10]. The

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collider ring 503.04 m long (twice as large as the Nuclotron ring) has a racetrack shape and is based on double-aperture (top-to-bottom) superferric dipoles and quadrupoles. A superconducting NbTi composite hollow-tube cable for the magnets is designed and manufactured at the Laboratory. The first set of full size prototype magnets has been produced and passed all necessary tests. The obtained data of the magnetic field measurements have demonstrated the field distribution acceptable for NICA operation mode. Fabrication of the magnets has to be started in 2018.

The NICA cryogenics will be based on the modernized liquid helium plant that was built in the early 1990s for the Nuclotron. The main goals of the modernization are: increasing of the total refrigerator power from 4000 to 8000 W at 4.5 K, making a new distribution system of liquid helium and ensuring the shortest possible cooldown time. These goals will be achieved by means of an additional 1000 l/h helium liquefier and satellite refrigerators located near the accelerator rings, a nitrogen system that will be used for magnet thermal shield cooling at 77 K and at the first stage of cooling down all three rings of the Nuclotron/NICA with the total length of about 1 km and cold mass of 290 tons. Necessary equipment had been ordered and delivered partially. Work is progressing in accordance with the schedule.

3. Physics program at NICA

Basic physics objective that NICA research can contribute to are the following: 1) bulk properties, EOS - particle yields & spectra, ratios, femtoscopy, flow; 2) in-medium modification of hadron properties -onset of low-mass dilepton enhancement; 3) deconfinement (chiral) phase transition at high baryon density - enhanced strangeness production; 4) QCD critical point - event-by-event fluctuations & correlations;5) chiral magnetic (vortical) effect, Λ-polarization; 6) γN interactions in dense nuclear matter – hypernuclei. NICA domain at QCD PD corresponds to the density frontier (Fig.3).

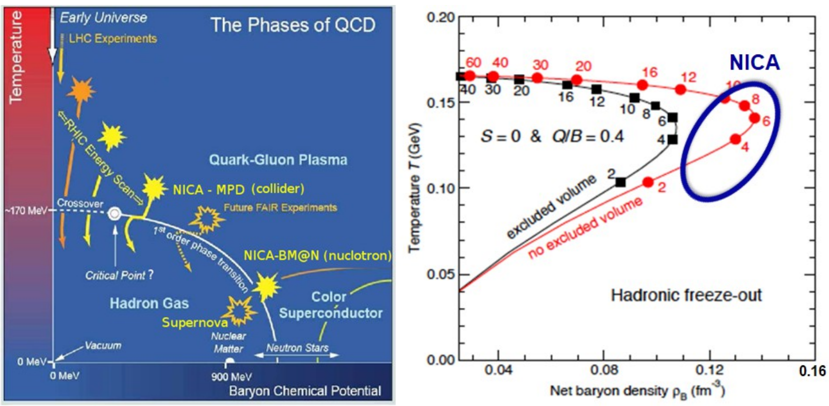

Figure 3. NICA domain at QCD diagram.

NICA "White Book" was enriched by the new proposals, the number of groups and organizations involved in heavy ion interactions research at the collision energies of 4-11 GeV are increased.

4. The BM@N setup

The goals of BM@N setup have been commissioned at the extracted Nuclotron beam channel are the following:

1. Study of the properties of dense nuclear (dominantly baryonic) matter with strangeness in heavy ion (A+A) collisions in particular:
   - production mechanisms and modifications of hadron properties in dense nuclear matter (“in-medium effects”) using different probes, namely: strange mesons, strange and multi-strange baryons; vector mesons via hadronic or dilepton/photon mode).
   - study of the EoS with strangeness;
   - hyper-matter production: search for light hypernuclei and multi-strange objects.
2. Study of elementary reactions: pp, pn(d) as “reference” to pin down nuclear effects
3. Search for ‘cold‘ nuclear matter in p-A collisions.

The energy range of the BM@N and MPD set-up operation is shown in Fig.4.

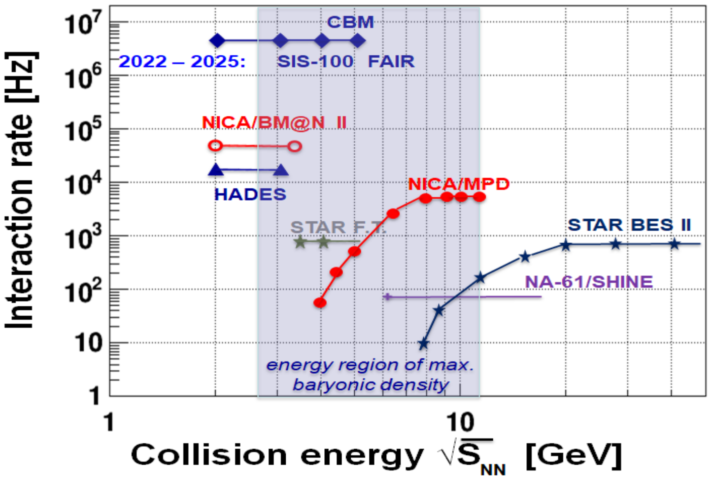

Figure 4. Current and planned experiments and setups aimed at the studying of relativistic ion collisions.

The BM@N setup have started physics data taken at $^{12}C^{6+}$, $^{40}Ar^{18+}$ and $^{89}Kr^{36+}$ in March-April 2018 run (Fig.6), at the beam energies of 3.15, 3.08, 2.57 GeV/u respectively. The accuracy of the extracted ion beam energies was determined based on the measurements of equilibrium RF frequency that provides stable circulation of the accelerated beam in the Nuclotron at the chosen energy point and the known length of the particle equilibrium orbit. It gives the

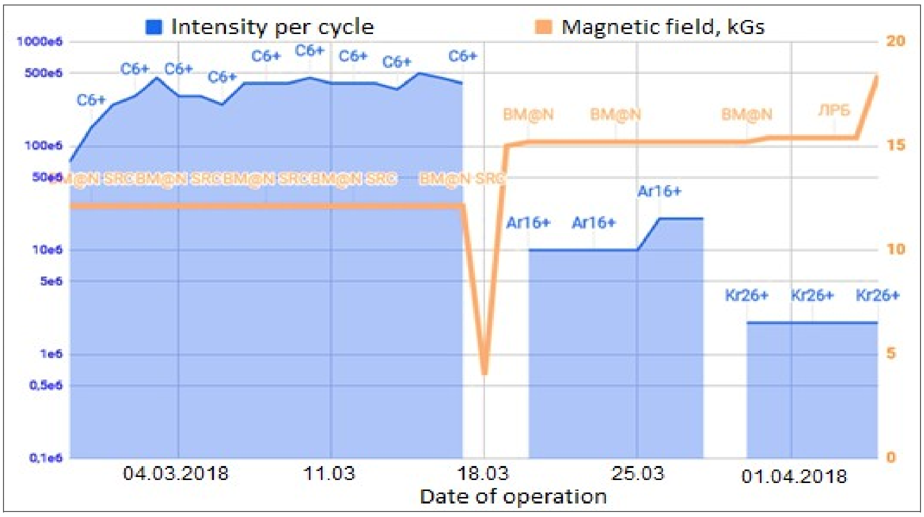

Figure 5. Ion spices, intensities and the Nuclotron run schedule in spring 2018 run.

accuracy of 0.5% of particle energy from the measuring data. Particles are extracted from the accelerator vacuum-cryostat volume through a stainless steel foil of 0.1 mm thickness. This is resulted in the following effects: 1) stripping of the remnant electrons, 2) additional energy loss and the increase of the beam momentum spread. These effects should be taken into account if the needed precision of the beam energy parameter is high. The accelerator running time in the run was of 1100 hours.

Beams of the ions were obtained from the EBIS-type ion source specially prepared for that case (Fig.6a). The source should provide the charge state of the ions (q) high enough to overcome the limitations dictated by the linac LU-20, i.e. q/A > 0.33. Whereas, for the NICA complex the mentioned ratio is supposed to be q/A > 0.16 (say, Au $^{31+}$) and the ions will be further accelerated by the HILAC (Fig. 6b).

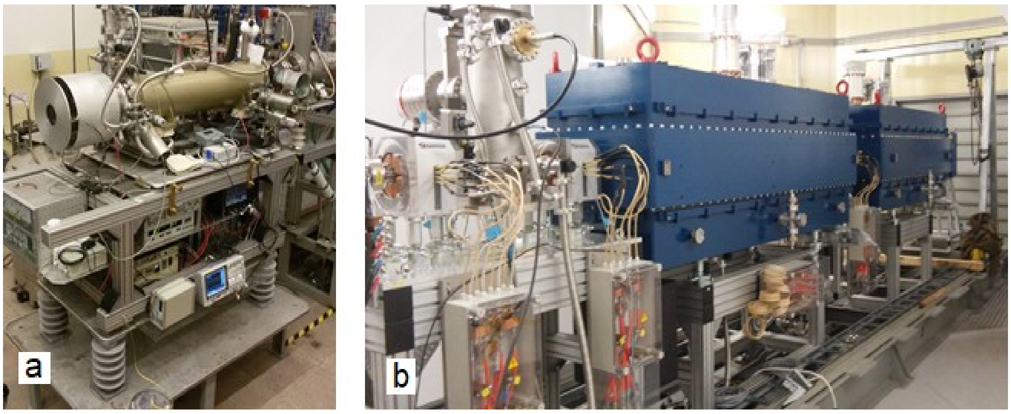

Figure 6. Special ion source prepared for heavy ion run at linac LU-20 and Nuclotron for the BM&N setup data taken (a) and the new linear accelerator HILAC for NICA heavy ion injection chain (b).

5. The MPD status

The MPD experimental program is aimed at investigating both hot and dense baryonic matter and some polarization phenomena. Preliminary list of the first priority physics tasks to be performed includes:

1) measurement of a large variety of signals at systematically changing conditions of collision (energy, centrality, system size) using as bulk observables 4π geometry particle yields (OD, EOS); multi-strange 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;

2) study of hyperon polarization and other polarization phenomena including possible study of the nucleon spin structure via the Drell-Yan (DY) processes after the MPD upgrade.

The MPD is a typical collider setup used a superconducting solenoid. View of the detector is shown in Fig.7. Physics program at MPD have been discussed elsewhere. Information about recently published works are presented at NICA site [11].

Status of the setup preparation: SC-solenoid and heavy metallic support parts under manufacturing whereas the first turn detector elements and systems are at preparation to mass production stage.

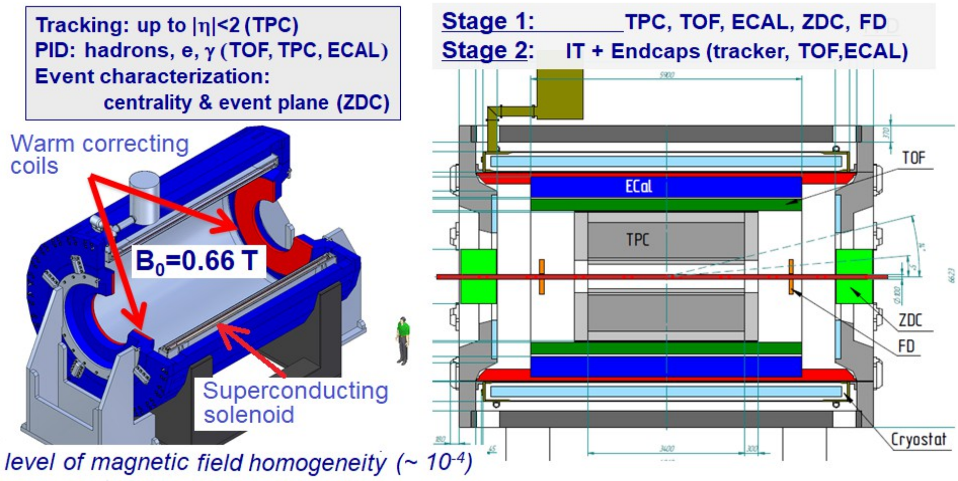

Figure 7. General view of the MPD setup.

General contractor for the SC solenoid is ASG Superconductors Co. (Genova, Italy). The photos (Fig. 8 and Fig. 9) illustrate manufacturing stages of the MPD parts and elements.

Figure 8. Support rings of 6.63 m diameter, 43.7 tons weight each (left part) and poles 4.5 m diameter, 47 tons each (right part).

Figure 9. Manufactured 25 from 28 of yoke plates: 0.35x0.74x8.47, m3; 16 tons each are ready (left part). Two 80 ton cranes for the MPD and SPD halls were prepared and tested (right part).

Preparation of the detector, electronic, data acquisition and other systems aimed at the first phase of the set-up commissioning are progressing well also.

6. The SPD status

SPD detector will be installed in the IP-2 to study spin phenomena. The status of the implementation of the NICA spin program was presented at SPIN2016 Conference [12, 13]. Recent progress on the beam parameters and the SPD set-up design was discussed at the NICA-SPIN/Prague workshop [14]. The main results on the implementation of the program in 2017-2018 are the following:

- The new polarized proton and deuteron source SPI was commissioned successfully;
- Polarized deuteron beam parameters are correspond to the specified ones;

- Polarized protons were injected and accelerated in the Nuclotron for the first time;
- The polarimeters for the injected and coasting beam in the Nuclotron were updated;
- The systems of the beam polarization control and monitoring in the Nuclotron and the NICA collider rings were proposed and analysed, new simulation data on the particle spin dynamics were obtained.

More detailed description of recent status of the SPD project preparation is presented in [15]. Basic requirements for the set-up are the following: close to 4π geometrical acceptance; high-precision (~50 μm) and fast vertex detector; high-precision (~100 μm) and fast tracker; good particle identification capabilities; efficient muon range system; good electromagnetic calorimeter; low material budget over the track paths; trigger and DAQ system able to cope with event rates at luminosity of 10^{32} $cm^{-2}\cdot s^{-1}$; modularity and easy access to the detector elements, that makes possible further reconfiguration and upgrade of the facility.

There is a number of processes which could be studied with this detector and with the fixed target detectors at beams extracted from the upgraded Nuclotron, namely: DY processes with longitudinally and transversally polarized p and d beams; extraction of unknown (poorly known) parton distribution functions (PDF); PDFs from J/ψ production processes; spin effects in various exclusive and inclusive reactions; cross sections of diffractive processes; helicity amplitudes and double spin asymmetries (Krisch effect) in elastic reactions; spectroscopy of quarkoniums with any available decay modes. This can be done in the kinematic energy region not available for other experiments. The analysis of the accelerator issues related to polarized proton and deuteron beams has been progressing during the last three years. Feasible schemes of the polarization control in the Nuclotron and collider have been proposed Current status of the SPD systems pre-design stage was reported and discussed at regular meetings of the working group approved by the JINR Directorate. Preparation to the Conceptual project is in progress. Presentation of the proposal to the JINR Program Advisory Council is planned for 2019.

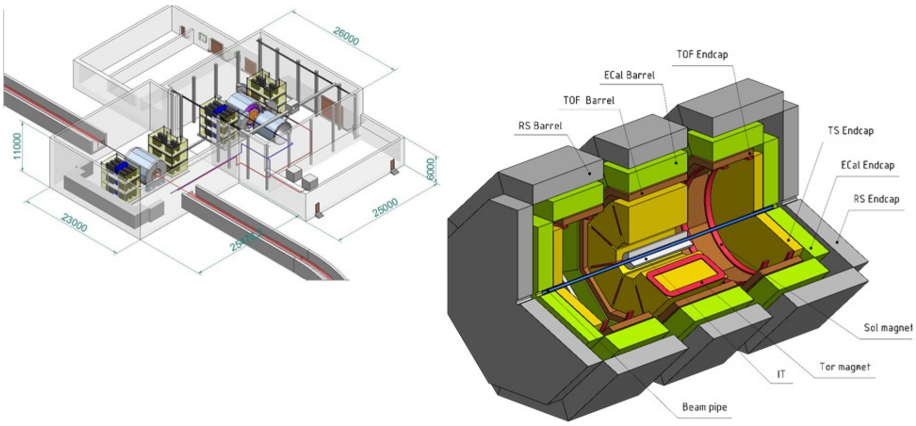

Figure 10. Composition of the SPD setup at parking position in experimental building and at the collider beam line

7. Civil construction and outlook

The civil construction of the complex is progressing . Photos presented in Fig. 11a, b, c, d demonstrate the construction status by summer 2018.

Figure 11. The construction status : **a** - general view of the site; **b** - MPD building; **c** - western part of the collider tunnel; d – cave for the SPD building.

One of the important construction work is connection of the collider building and the Nuclotron tunnel. Construction of the NICA Complex is supported by special grant of the Government of the Russian Federation.

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