PROCEEDINGS OF SCIENCE

Status of the NICA Project at JINR

V.Kekelidze, [1] **A.Kovalenko, R.Lednicky, V.Matveev, I.Meshkov, A.Sorin, G.Trubnikov** (for NICA Collaboration)

Joint Institute for Nuclear Research, 141980 Dubna, Russia

E-mail: vladimir.kekelidze@cern.ch, kovalen@dubna.ru, lednicky@fzu.cz, matveev@inr.ac.ru, meshkov@jinr.ru, sorin@theor.jinr.ru, trubnikov@jinr.ru

The NICA (Nuclotron-based Ion Collider fAcility) project is now under active realization at the Joint Institute for Nuclear Research (JINR, Dubna). The main goal of the project is a study of hot and dense strongly interacting matter in heavy ion (up to Au) collisions at the centre-of-mass energies up to 11 GeV per nucleon. Two modes of operation are foreseen, collider mode and extracted beams, with two detectors: MPD and BM@N. The both experiments are in preparation stage. An average luminosity in the collider mode is expected as 10E27 cm-2 s-1 for Au (79+). Extracted beams of various nucleus species with maximum momenta of 13 GeV/c (for protons) will be available. A study of spin physics with extracted and colliding beams of polarized deuterons and protons at the energies up to 27 GeV (for protons) is foreseen with the NICA facility. The proposed program allows one to search for possible signs of phase transitions and critical phenomena as well as to shed light on the problem of the nucleon spin structure.

XII International Baldin Seminar on High Energy Physics Problems
15-20 September 2014
JINR, Dubna, Russia

PoS(Baldin ISHEPP XXII)002

---

[1] Speaker

1 Introduction

The new research facility NICA aimed at study of heavy ion and polarized proton and deuteron collisions has been 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) [2-4]. It is indicated in a series of theoretical works, in particular, in [4] that heavy ion collisions at √sNN ≤ 11 GeV allow attaining the high baryon density. These calculations are illustrated in Fig. 1. The NICA research domain is attractive as being the expected region for searching of new phenomena at the maximum baryon density including possible phase transitions.

The study of the nucleon spin origin ("spin puzzle") and polarization phenomena in light and heavy ion interactions is another target of researches at NICA. The high intensity and high polarization (>50%) of colliding beams could provide unique possibilities for this study.

The NICA construction plan up to 2020 foresees an essential development of the accelerator facility and construction of:

- the new spectrometer Baryonic Matter at Nuclotron (BM@N) in order to start the fixed target experiments with heavy ion beams extracted from the modernized Nuclotron in 2017;
- the MultiPurpose Detector (MPD) at the NICA colliding beams with a primary goal to study heavy ion collisions;
- preparation of the collider detector project "Spin Physics Detector" (SPD) aimed at a primary goal to study spin physics.

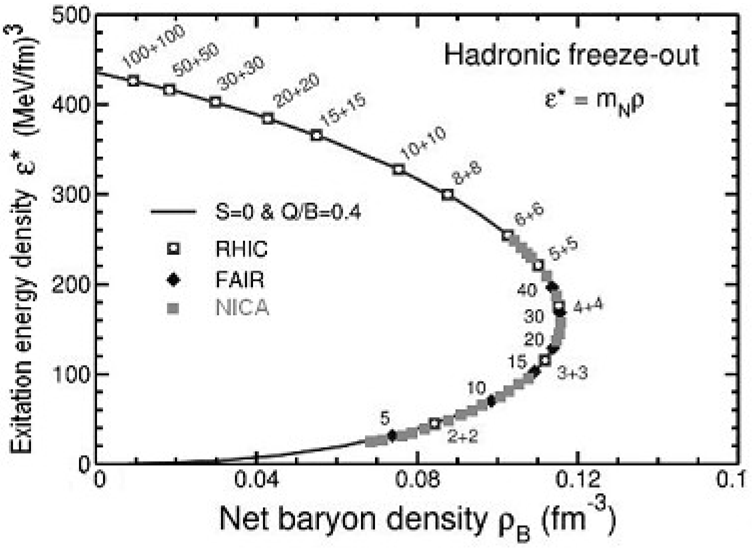

Figure 1: Freeze-out diagram for baryonic matter showing baryon density reachable at different facilities both in collider and fixed target experiments [4].

2 The NICA accelerator facility

The Nuclotron at Veksler and Baldin Laboratory of High Energy Physics (VBLHEP) of JINR was put into operation in 1993. It is based on the unique technology of superconducting fast

PoS(Baldin ISHEPP XXII)002

cycling magnets developed at the Laboratory. The NICA facility (Fig. 2) includes: the injection complex, the booster, the upgraded Nuclotron and two storage rings with two interaction points IP1 and IP2 aimed at the MPD and SPD detectors respectively. The injection complex provides a wide set of ion species up to the heaviest one, Au, at an energy of 3.5 MeV/u with an expected intensity of 2·10E9 particles per cycle. The main efforts at the present time are devoted to completion of beam tests of both heavy ion, KRION-6T, and polarized proton and deuteron, SPI, sources aimed at reaching of the specified parameters and to completion of manufacturing of the HILAC and the new RFQ fore-injector that should replace the old high voltage pulsed transformer at the linac LU-20. The design and manufacturing of this new equipment is carried out in collaboration with German and Russian research laboratories and companies [5]. The RFQ of HILAC is under adjustment at Bevatech (Frankfurt). The completion of the injector's manufacturing and its tests at the accelerator together with the ion sources are expected by fall 2015. The facility contains also the source of polarized ions (SPI) with the linac accelerating light ions up to 5 MeV/u that provides direct injection of polarized deuterons and protons (proton beam energy is 20 MeV) into the Nuclotron and then to the collider. The booster synchrotron should accelerate ions up to 600 MeV/u. The magnetic ring of 211 m long is planned to be placed inside the window of the Synchrophasotron yoke. Technical design of the booster systems was performed. The most specific features of the booster are ultrahigh vacuum and the electron cooling system.

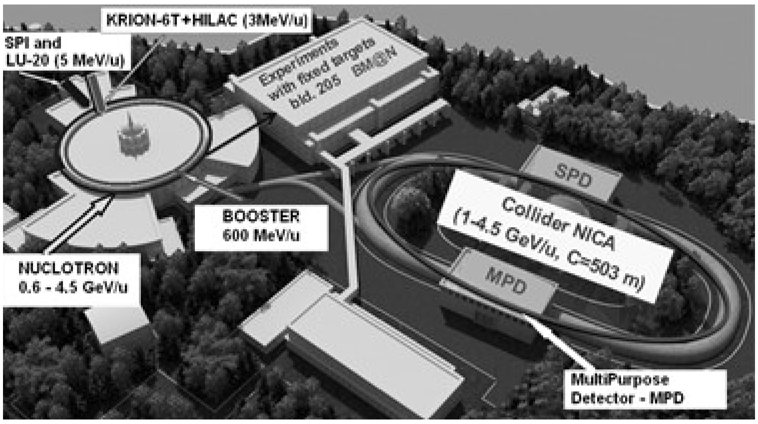

Figure 2: The NICA facility at LHEP JINR.

The upgraded Nuclotron should provide proton, deuteron (including polarized) and multi charged ion beams with the maximum energies: 5.8 GeV/u for (A = 2, Z = l); 3.3 GeV/u for Xe (A = 124, Z = 42); and 4.5 GeV/u for Au (A = 197, Z = 79). The ions are fully stripped before the injection into the Nuclotron.

The two storage rings with two interaction points (IP). The major parameters of the NICA collider are the following: Bρ = 45 Tm; vacuum in a beam chamber – 10E-11 Torr; maximum dipole field 2 T; ion kinetic energy range from 1 GeV/u to 4.5 GeV/u for Au79+; zero beam crossing angle at IP; 9 m space for detector allocations at IP's; average luminosity L = 10E27 cm–2s-1 for gold ion collisions at $\sqrt{s_{NN}}$ = 9 GeV. The 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 magnets – 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 serial fabrication of the magnets for NICA facility will be started at the SC magnet assembly workshop at LHEP in 2016 [6].

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 cool-down 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.

3 The heavy ion accelerator facilities

The NICA place in the landscape of existing and future accelerators is illustrated in Figure 3 [1]. As one could conclude not only the future facilities but the existing ones are targeting at the energy region allowing exploration of baryonic matter at the maximum density.

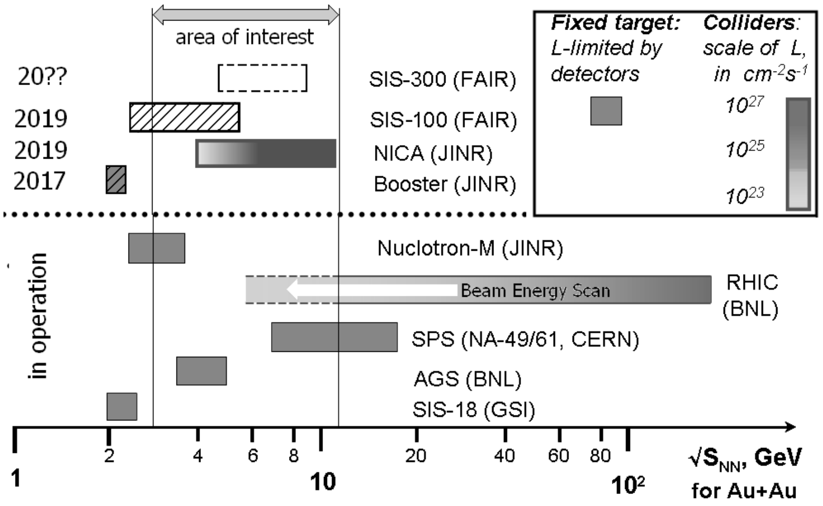

Figure 3: The landscape of present and future HI accelerators.

4 The BM@N experiment

The goals of the experiment at the fixed target setup – BM@N (Baryonic Matter at Nuclotron) are:
1. Heavy-ion collision A+A - study of the properties of dense nuclear (dominantly baryonic) matter with strangeness:
• production mechanisms and modifications of hadron properties in dense nuclear matter ("in-medium effects") using the following probes: 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 metastable objects.
2. Study of elementary reactions: pp, pn(d) as "reference" to pin down nuclear effects
3. Search for ‚cold' nuclear matter with pA – collisions.

BM@N at the first stage can study the in-medium effects on strangeness measuring of a variety of observables for different energies and centralities in heavy-ion collisions in order to find an "anomalous" behaviour in comparison with theory. The observables sensitive to in-medium effects are the following: particle yields and ratios pT -(mT)-spectra, rapidity distributions, angular distributions, collective flow. The measurement of in-medium effects for vector mesons(V = ρ, ω, φ) could be possible in perspectives. An optimal way for that is investigation of the dilepton mode: V → e+e– - or photon mode: ω → γ π0. Possible alternative is φ → K+K^- strong decay.

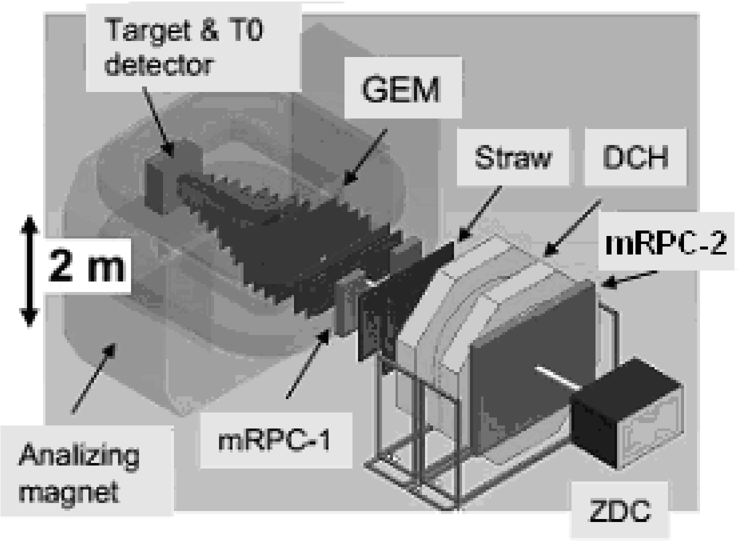

Figure 4: The BM@N setup: GEM – central tracker inside analysing magnet; DCH+Straw – outer tracker behind the magnet; mRPC+T0 – time-of-flight system; ZDC – centrality measurements.

The BM@N setup includes: the existing wide aperture dipole magnet; a tracking system consisting of 12 planes of high resolution gem chambers (GEM) and 8 planes of drift chambers (DCH); a time-of-flight (TOF) system based on the RPC chambers and a fast counter detector providing trigger signal; a zero degree hadron calorimeter (ZDC) for the reaction plane definition and estimation of the impact parameter. The upgrade is foreseen at the second stage to equip the setup with a silicon vertex detector (in cooperation with GSI, Darmstadt), and with an electromagnetic calorimeter. The heavy-ion collision experiments at BM@N located in the fixed-target hall of the Nuclotron will provide competitive research program focused on physics of dense nuclear and strange matter.

5 The MPD experiment

The MPD experimental program is aimed to investigate both hot and dense baryonic matter and 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);
2) 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;

3) 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 detector based on a superconducting solenoid with the magnetic field of 0.5 T (~ 5 m in diameter and ~ 8 m in length). It will be installed in the IP-1 of the collider ring. The major sub-detectors of the MPD (Fig. 5) are: a time projection chamber (TPC); an inner tracker (IT) based on the silicon strip detectors; a time-of-flight (TOF) system based on the RPC modules; an electromagnetic calorimeter (ECal); end cap trackers (ECT). There are foreseen three stages of putting the MPD into operation. The first, start-up stage

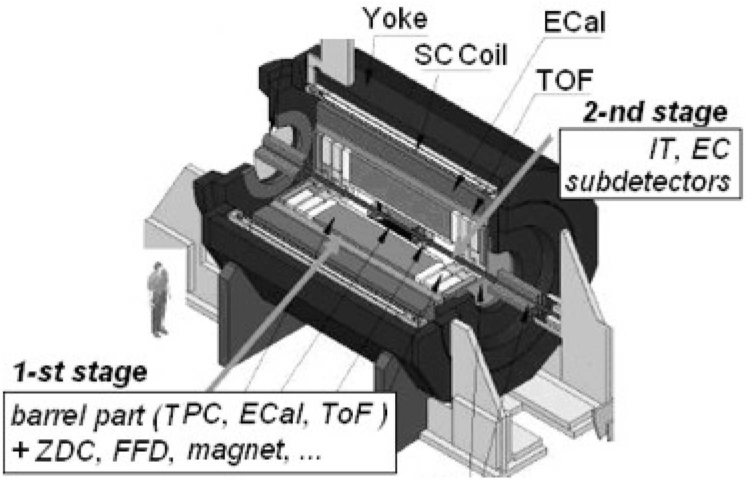

Figure 5: General view of the MPD setup.

involves the magnet, TPC, TOF, ECal (partially), IT (partially). At the second stage the end caps of the MPD will be fully equipped and some readout systems modernized.

The processes studied with the MPD were simulated using the dedicated software framework (MpdRoot). This software is based on the object - oriented framework FairRoot [7] and provides a powerful tool for detector performance studies, development of algorithms for reconstruction and physics analysis of the data. The evaluated rate in Au + Au collisions at the maximum energy (10% central interactions) will be up to 7 kHz taking into account the design luminosity of $L = 1 \cdot 10^{27}$ cm^{-2} s^{-1}. Groups from 12 institutions are working on the sub-detector R&D and on prototyping all detector elements. More detailed information could be found in the conceptual design report [8]. It was shown that the MPD is well optimized for studying in-medium effects caused by high baryon densities, such as: changing particle properties in hot and dense medium (broadening 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 ones performed at the current experiments. The simulation of MPD capabilities shows that high statistics of studied events could be accumulated (10^9 minimum bias events and 10^8 central events per week), which provides a precision femtoscopy study with respect to correlation of multi-strange particles. More than ~ 10^6 of Ω - hyperon decays will be recorded in ten weeks of running.

Charged particles are reliably identified using both techniques: measuring dE/dx of tracks in the TPC and by the TOF system There was obtained sufficiently high resolution of vertex reconstruction, for example $\Omega \rightarrow \Lambda K^-$ decay reconstruction implementing full chain of simulation: central Au+Au collision generation at $\sqrt{s_{NN}} = 7.1$ GeV is at the level of 10 mkm. Special attention was devoted to the simulation of vector meson production and their di-lepton decays. The results confirm reliable identification of these decays.

There are optimal conditions at both BM@N and MPD detectors for observation and study light hypernuclei. The simulations (Fig.7) demonstrates enhanced yields of different single and double Λ light hydrogen and helium nuclei as a function of $\sqrt{s_{NN}}$. There are some novel proposals such as studying vorticity [9], helicity separation in heavy ion collisions [10], and directed flow in asymmetric nuclear collisions [11] that could be studied at NICA.

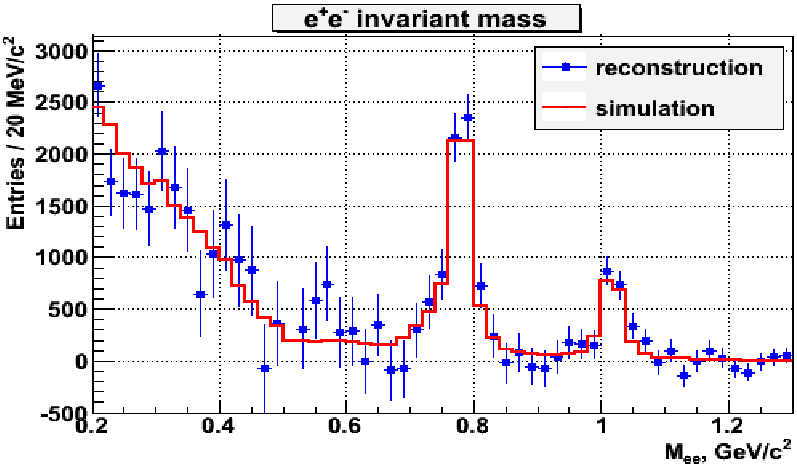

Figure 6: Reconstruction of simulated production of lepton pairs.

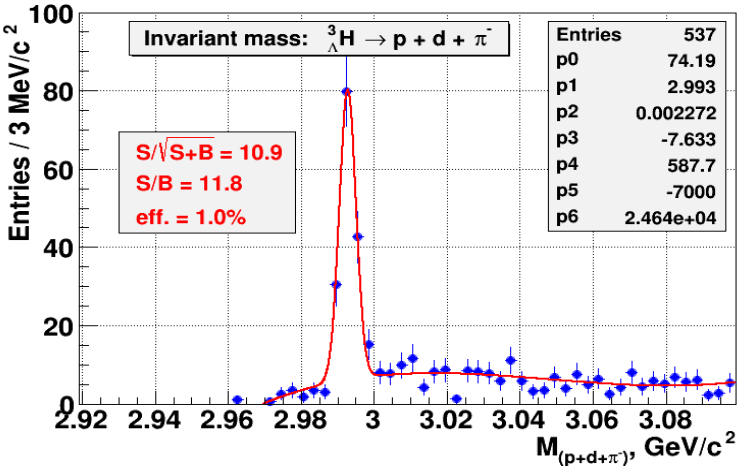

Figure 7: Reconstruction of simulated $^{3}_{\Lambda}$H - hypernuclei yield at the MPD in ^{3}Heπ^- channel.

The tests of the detector prototypes have been carried out at the Nuclotron test beams. The optimization of the MPD elements design is completed. The technical design of the SC solenoid was also completed, the arrangements for its manufacturing are in progress

6 Spin physics at NICA

The NICA program foresees that the SPD detector will be designed and installed in the IP-2 to study spin physics. 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 quakonium with any available decay modes. This can be done in the kinematic energy region not available for other experiments. The formation of the collaboration has been started. The analysis of the accelerator issues related to polarized proton and deuteron beams has been progressing during the last three years. The schemes of the polarization control in the Nuclotron and collider have been proposed [12, 13].

7 Status of the construction and conclusion

The main R&D work on the MPD components and the new accelerator components has been fulfilled by the end of 2014. The mass production of the SC - magnets and different MPD detector elements is planned to start in 2015. The preparation of the area for the collider and the detectors was started in 2013. The technical design project of the NICA collider building, the MPD and SPD halls and engineering infrastructure was completed in 2013. The State expertise review passed in accordance with the Russian regulations.

Figure 8. View of Dubna and the NICA facility place.

The NICA accelerator and experimental complex and the corresponding research program will provide relevant research, which is both competitive and complementary to ones being carried out at other centers and facilities.

References

[1]V.D.Kekelidze et al.,, PoS (ICHEP2012) 411, (2013).

[2]A.Sissakian et al. Part.& Nucl Lett. 5, 1 (2008).

[3]M.Gazdzicki et al. PL., B585, 115 (2004)

[4]J. Cleymans, and J. Randrup, Phys. Rev. C74 (2006) 04791.

[5]A.Butenko et all. IPAC 2014, paper WEPRO067, Dresden, June 2014.

[6]G.Trubnikov et al. ibid, paper TUPRO005, June 2014.

[7]D.Bertini et al., JoP,CS,119, 032011, (2008). http://cbmroot.gsi.de.

[8]MPD CDR v.1.2 (JINR, Dubna, 2010); http://www.nica.ru.

[9]O.Rogachevsky et al, PR, C, v.82, (2010) 054910.

[10]M.Baznat et al., PR, C, v.88, (2013) 061901.

[11]V.D.Toneev. Private communication 2014.

[12]A.D.Kovalenko et al, Part.&Nucl Lett. Vol.45, Issue 1 (2014).

[13]I.A.Savin et al. arXiv:1408.3959 [hep-ex], August (2014).