THE NICA PROJECT AT JINR

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Abstract

The physics program and the present status of the project of NICA accelerator complex, which is under construction at JINR (Dubna), are presented. The main goal of the project is to provide ion beams for experimental studies of hot and dense strongly interacting baryonic matter and spin physics. The proposed physics program concentrates on the search for possible manifestations of the phase transitions and critical phenomena in the energy region, where the excited matter is produced with maximal achievable net baryon density, and clarification of the origin of nucleon spin. The NICA collider will provide heavy ion collisions in the energy range of $\sqrt{s_{NN}}$=4÷11 GeV at average luminosity of $L=1\cdot10^{27}cm^{-2}\cdot s^{-1}$ for $^{197}Au^{79+}$ nuclei and polarized proton collisions in energy range of $\sqrt{s_{NN}}$=12÷27 GeV at luminosity of $L \geq 10^{32}cm^{-2}\cdot s^{-1}$. The key issue of the accelerator complex is application of sophisticated beam accumulation schemes and both stochastic and electron cooling methods. Strong space-charge effects in the collider arise a challenge to its optics and application of novel methods of beam stability maintenance.

INTRODUCTION

The NICA (Nuclotron-based Ion Collider fAcility) is accelerator facility which is now under construction at Joint Institute for Nuclear Research (JINR, Dubna) [1]. The facility will implement world-leading long-term programs in relativistic nuclear physics and particle spin physics, radiobiology, applied research and education. It will be unique among accelerator facilities worldwide in its flexibility to support multiple research programs based on particle beams of the frontier parameters. The main goal of the project is a study of hot and dense strongly interacting matter in heavy ion (up to Au) collisions at centre-of-mass energies up to 11 GeV. Two modes of operation are foreseen, collider mode and extracted beams, with two detectors: MPD (MultiPurpose Detector) and BM@N (Baryonic Matter at Nuclotron). An average luminosity in the collider mode is expected as 10^{27} $cm^{-2}\cdot s^{-1}$ for Au^{79+}. Extracted beams of various nuclei 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 to search for possible signs of the phase transitions and critical phenomena as well as to shed light on the problem of nucleon spin structure.

The NICA accelerator facility will provide a range of ion beams of wide parameter spectrum. That allows one to perform both applied and fundamental research in different fields of science and technology. Among them one can point out:
- radiobiology and cosmic medicine;
- beam therapy;
- development of accelerator driven reactors ("energy generation" with subcritical plutonium blankets) and radioactive waste transmutation;
- irradiation tests of electronics.

The facility physics program is suggested to be implemented during three stages:
- At the first stage of the operation it will provide fixed target experiments with heavy and light polarized ions. The heavy ion program at this stage will be realized at BM@N experimental set-up.
- The second stage will be started after completion of the collider construction and dedicated to relativistic nuclear physics researches in heavy ion and light-heavy ion collisions using MPD detector.
- The spin physics program in the collision mode of proton and deuteron beams will be realized at the third stage, when the collider rings will be equipped with required spin control and diagnostic devices.

The NICA will provide the polarized proton and deuteron beams up to the c.m.s. energy of 27 GeV for *pp* collisions with the luminosity higher than $L = 10^{32}$ $cm^{-2}\cdot s^{-1}$. The high intensity and high polarization (> 50%) of the colliding beams open up 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 spin physics program at the collider is under development. It is aimed to study nucleon spin structure exploring the Drell-Yan mechanism with 8 parton distribution functions (PDFs) at leading twist. The Spin Physics Detector (SPD) will be located in the second interaction point of the collider (Fig. 1). Its elaboration is planned during the second phase of the NICA project. The SPD concept is formulated and creation of motivated collaboration has been started in 2015.

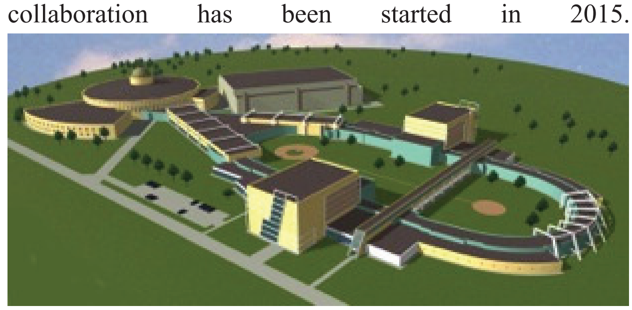

Figure 1: The NICA complex, artistic view.

More detailed information on the NICA experimental program is available at [2].

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STRUCTURE OF THE FACILITY

The first stage of the NICA experimental program will be started at existing accelerator facility which is based on injector comprising set of particle sources (PS) and linac LU-20, that will be equipped with a new RFQ fore-injector. Heaviest ions which were used at the LU-20 are $^{124}Xe^{42+}$. To increase the beam energy and intensity at the exit of the main NICA synchrotron – the existing superconducting Nuclotron - a new injector will be constructed. It consists of ESIS-type ion source providing intensive beam of $^{197}Au^{31+}$ ions, heavy ion linac (HILAc) accelerating ions at A/Z < 6 up to the energy of 3.2 MeV/u, and Booster-synchrotron housed inside the Synchrophasotron yoke. The Booster at circumference of 211 m and magnetic rigidity of 25 T·m will accelerat $^{197}Au^{31+}$ ions up to the energy of 600 MeV/u. To form required phase volume of the beam the Booster is equipped with an electron cooling system. After acceleration in the Booster the ions will be fully striped and injected into the Nuclotron providing acceleration of $^{197}Au^{79+}$ ions up to the energy of 4.5 GeV/u.

The Collider will be constructed in a tunnel with additional buildings for two detectors and HV electron cooler. It will be operated at a fixed energy, also possibility to have slow-rate acceleration of an injected beam is foreseen. To provide required linearity of the field the maximum bending field is chosen to be of 1.8 T. Two collider rings are constructed one above the other and the beam superposition/separation is provided in the vertical plane. The distance between the ring median planes is chosen to be 32 cm. That is achieved with dipole and quadrupole magnets having two apertures in one yoke and a common cryostat (Fig.2).

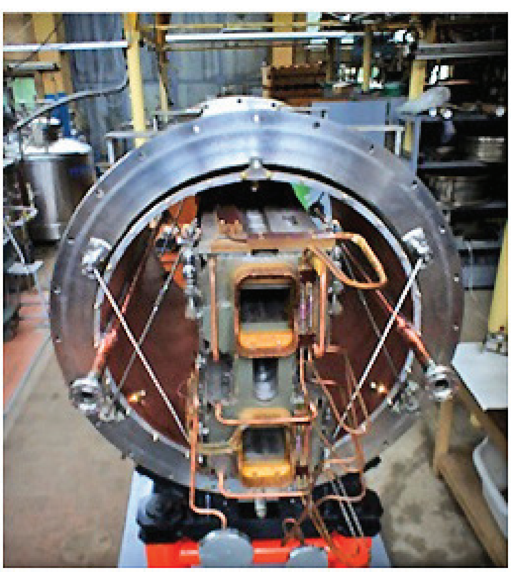

Figure 2: Double-aperture superconducting dipole magnet of the NICA Collider.

The key issue of the NICA collider is application of sophisticated beam accumulation schemes and both stochastic and electron cooling methods during collisions. Strong space-charge effects in the collider arise a challenge to its optics and application of novel methods of beam stability maintenance.

Both new cyclic accelerators of the NICA facility – the Booster and collider will be based on "superferric" superconducting magnets developed at JINR during the Nuclotron construction. To provide injection of the beam from the Nuclotron to collider a new beam transport line of the length of about 335 m will be constructed on the basis of conventional dipole and qudrupole magnets operated in a pulse mode.

HEAVY ION EXPERIMENTAL PROGRAM

The physic program in heavy ion collisions is aimed to explore the QCD phase diagram. The NICA energy covers the region of maximum baryonic density on the phase diagram. The strategy is to perform scan of energy and system size with an emphasis to the production of hadrons and dileptons, event-by-event fluctuations and correlations. The program includes experiments in two operational modes: collider mode with MPD detector [3] and fixed target mode with BM@N detector [4].

The MPD experiment (Fig. 3) is designed as a 4π-spectrometer detecting charged hadrons, leptons and photons in heavy-ion collisions.

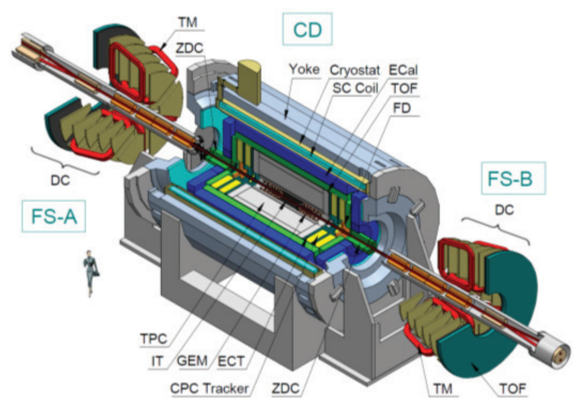

Figure 3: The MPD experimental set-up view.

The setup provides a precise 3D tracking and high performance particle identification. The event rate of minimum bias interactions is ~ 7 kHz, and charged particle multiplicity exceed 1000 in central Au+Au collisions at $\sqrt{s_{NN}}$ =11 GeV. The setup includes Central Detector (CD) covering interval $|\eta|<2$ and two forward spectrometers (FSA, B) for $2 < |\eta| < 3$ (optional). The CD is a typical collider detector based on the solenoidal superconducting magnet with a magnetic field of 0.66 T (6.623 m in diameter and 9.010 m in length) and will be constructed in two stages. At the first stage (2019) MPD will comprise a superconducting solenoid, Time-Projection Chamber (TPC), barrel Time-Of-Flight system (TOF), Electromagnetic Calorimeter (ECal), Zero-Degree Calorimeter (ZDC) and Fast Forward Detector (FFD). Feasibility study was performed using the MPDRoot comprising interfaces to event generators, Geant, detector response simulation and reconstruction algorithms.

The BM@N set-up (Fig. 5) combines high precision track measurements (12 planes of GEMs, 2 drift chambers and 4 planes of silicon strip detectors at the second stage) with time-of-flight information (two sets of RPC's) for particle identification and total energy measurements (ZDC) for the centrality definition. The T0 detector will provide a start signal for the RPC's and trigger.

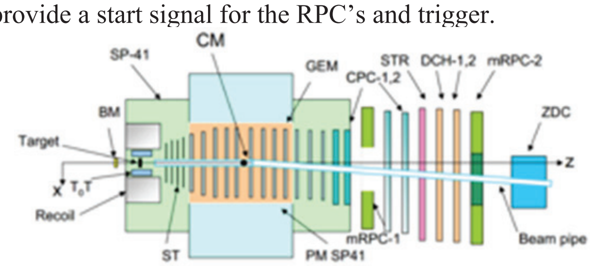

Figure 4: The BM@N experimental set-up.

Heavy ions beams will be available for the BM@N experiment in 2017 while the Au beam with intensity of 10^7 per pulse is planned in 2019. The first technical run of the BM@N had been performed with deuteron and carbon beams in 2015 (Fig. 4).

Figure 5: BM@N detector in experimental hall.

THE PROJECT STATUS

Project NICA/MPD is a part of the 7-years JINR Roadmap for 2009-2016 and for the new RoadMap 2017-2023. It had been approved by Inetrnational Scientific Council of JINR and The Committee of Plenipotentiaries of JINR in 2009. That is a flagship project of JINR presently.

The NICA project has a special status in Russian Federation and had been included to list of so called "Megascience projects". This is one of two from the list, which is already supported by State and is under active realization. JINR has made important efforts to reach beyond its traditional community. The construction of NICA and the FAIR/GSI accelerators is in fact tightly linked via a strong collaboration between Germany and JINR on the FAIR project and there is potential for similar close detector collaboration (MPD/SPD/BM@N). The synergy and complementarity of the NICA and of the ESFRI Landmark FAIR and to some extent of the ESFRI Landmark SPIRAL2 make it very desirable to develop a joint coordinated effort for identifying a strong programme and for offering the best opportunities to international nuclear experimental physics. To this end ESFRI encourages these Research Infrastructure both to work closely together and to pay special attention to developing NICA as a Global Research Infrastructure concept.

Now 16 Institutions from Russia and 79 Institutions from 24 foreign countries officially participate in the NICA project. In December 2015 China joined the project with signing Protocol of understanding with JINR concerning China participation in NICA.

During last 2 years, the following milestones had been achieved while NICA construction:

In September 2015 JINR signed a general Contract for NICA civil construction with Strabag company. Civil construction works began in October 2015 (Fig. 6), the schedule is planned to commission the complex in 2019.

Figure 6: The civil construction site of the NICA.

Prototype of the NICA heavy ion sources Krion-6T (ESIS type) based on superconducting 6 Tesla solenoid had been designed, constructed and commissioned. At a test bench $5 \cdot 10^8$ Au^{31+} ions per pulse had been achieved at 50 Hz repetition rate. In 2014 the source was tested during the Nuclotron Run for Ar ions acceleration (Fig. 7).

Figure 7: Krion-6T ESIS at high-voltage platform of LU-20 fore-injector during the Nuclotron run. June 2014.

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Source for polarized beams had been constructed and commissioned in cooperation with INR RAS (Moscow). The polarized deuteron beam current at the level of 1,5 mA was achieved at test bench. First Nuclotron run dedicated to polarized beam acceleration using the new source is scheduled for 2016.

New linear accelerator (RFQ type) for light ions had been commissioned as fore-injector for LU-20 linac (Fig. 8). This work was performed in cooperation with ITEP NRC KI and MEPhI (Moscow) with participation of INR RAS. Design beam parameters had been achieved (10 mA of the deuteron beam current and 156 keV/u of the energy) [6]. Now the operation of LU-20 and Nuclotron with beam from the new RFQ is under preparation for the first beam run in June 2016.

New heavy ion linear accelerator – the HILAc ($2{\cdot}10^9$ Au ions, 3.2 MeV/u) had been constructed in collaboration with IAP and Bevatech OHG company (Frankfurt, Germany).

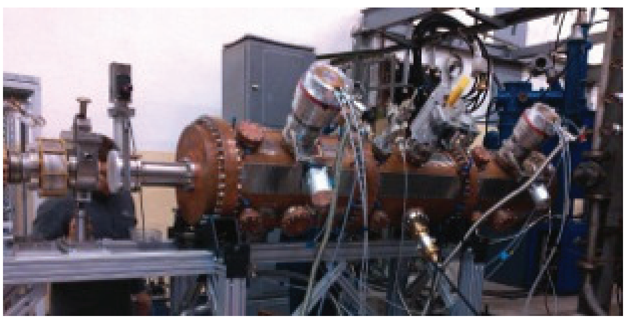

Figure 8: RFQ linac with RF, vacuum components and laser ion source in Nuclotron injector's hall at JINR.

The accelerator and RF power amplifier were transferred to JINR in 2015. The commissioning phase is in active stage now (Fig. 9).

Figure 9: First HILAc section during commissioning.

The Booster commissioning is scheduled for the end of 2017. Construction of its main elements and systems are in the final stage. The Booster RF system was designed and constructed in Budker INP (Novosibirsk). In 2014 it was successfully tested at JINR (Fig. 10).

Figure 10: Commissioning of the Booster RF system at JINR. October 2014.

Construction of the Booster electron cooling system is completed at Budker INP (Fig. 11). The system commissioning at JINR will be provided at the end of 2016.

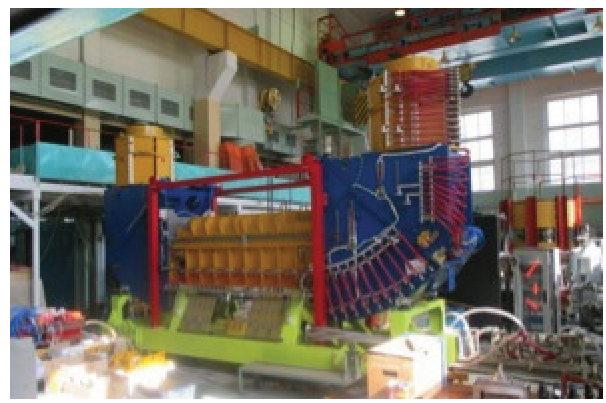

Figure 11. The Booster electron cooling system during assembly in Budker INP (Novosibirsk).

Dedicated large-scale facility for assembly and cold (LHe) tests of superconducting magnets for NICA booster and collider and also for SIS100 (FAIR) quadrupole units had been commissioned. Serial production of all types of magnets had been started in 2016 (Fig. 12). Construction of vacuum chambers, thermal shields, cryostats, pick-up station and other diagnostics is in active phase.

The NICA cryogenics is under commissioning. The existing helium liquefier complex and other cryogenics infrastructure had been upgraded cooling power from level of 4kW@4K up to 8 kW@4K to produce more than 2000 lHe l/h.

JINR had signed the contract for design and production of the MPD superconducting solenoid and its cold mass (whole assembly) with European producer. Parameters of the solenoid are very challenging: 0.66 Tesla field on 4.5 m diameter at $5{\cdot}10^{-4}$ field homogeneity.

Dedicated clean rooms and high-tech facility were constructed and commissioned for serial production of microstrip detectors (silicon detectors for Inner Tracker of MPD), time-of-flight detectors and time-projection chambers. Prototyping had been completed. Construction of detectors had been started.

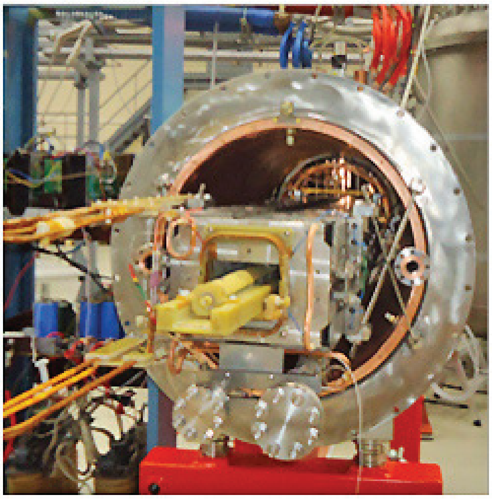

Figure 12: The Booster dipole magnet during the cold tests and magnetic field measurements.

BM@N setup is under commissioning, dedicated beam line and diagnostics had been constructed. 3 new beam lines and dedicated research facilities for innovative tasks are under design and construction.

The NICA construction is provided without termination of the Nuclotron research program. Besides, the Nuclotron beams are used for research in radiobiology and applied research. Moreover, the Nuclotron is very good polygon for testing of the collider equipment and operational regimes, elements and prototypes for the MPD using extracted beams (C^{6+} ions at 3.5 GeV/u and deuterons at 4 GeV/u presently). Particularly, in the run #45 (Feb. 2012) the circulation of 3.5 GeV/u deuteron beam during 1000 seconds was demonstrated. During 2011–2013 the prototype of the NICA stochastic cooling system was designed, constructed and tested at Nuclotron at ion kinetic energy of 3.5 GeV/u with deuteron and carbon ($^{12}C^{+6}$) ion beams. This work was performed in close collaboration with the Forschungszentrum Jülich. The segment of the NICA control system based on Tango platform was successfully tested at the Nuclotron, and presently the system is under active development.

CONCLUSION

The NICA project as a whole has passed the phase of design and is presently in the stage of accelerator elements manufacturing and construction.

The project realization plan foresees a staged construction and commissioning of all major parts and systems of the accelerator complex. The collider commissioning is planned for the end of 2019, beginning of 2020. It is planned to commission so-called NICA start-up version. Nevertheless, this will allow us to start experiments in colliding beams' mode with the test and tuning of the MPD detector and the majority of the accelerators elements at maximum peak luminosity at the level of $5{\cdot}10^{25}$ $cm^{-2}{\cdot}s^{-1}$ at the energy of the $^{197}Au^{79+}$ ions in the range of 3 – 4.5 GeV/u.

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REFERENCES

[1] G. Trubnikov, et.al. Project of the Nuclotron-based ion collider facility (NICA) at JINR, Proc. of EPAC08, Genoa, Italy., Trubnikov, et.al. STATUS OF THE NICA PROJECT AT JINR, Proc. of IPAC2014, Dresden, Germany
[2] http://nica.jinr.ru
[3] V.D. Kekelidze et al., Proc. of ICHEP2012, PoS, p. 411.
[5] BM@N project at JINR, http://nica.jinr.ru/
[6] V.S. Aleksandrov, V.A. Andreev, A.I. Balabin, et.al. Commissioning of New Proton and Light Ion Injector for Nuclotron-NICA, these Proceedings.

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