NICA PROJECT AT JINR

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Abstract

The project of Nuclotron-based Ion Collider fAcility NICA/MPD (MultiPurpose Detector) under development at JINR (Dubna) is presented. The general goals of the project are providing of colliding beams for experimental studies of both hot and dense strongly interacting baryonic matter and spin physics (in collisions of polarized protons and deuterons). The first program requires providing of heavy ion collisions in the energy range of $\sqrt{s_{NN}} = 4\div11$ GeV at average luminosity of $L = 1\cdot10^{27}$ cm$^{-2}\cdot$s^{-1} for ^{197}Au^{79+} nuclei. The polarized beams mode is proposed to be used in energy range of $\sqrt{s_{NN}} = 12\div27$ GeV (protons) at luminosity up to $1\cdot10^{32}$ cm$^{-2}\cdot$s^{-1}. The report contains description of the facility scheme and characteristics in heavy ion operation mode, status and plans of the project development.

NICA PROJECT

The **N**uclotron-based **I**on **C**ollider f**A**cility (NICA) [1] is new accelerator complex (Fig. 1) being constructed at JINR. It is aimed to provide collider experiments with

- heavy ions ^{197}Au^{79+} at $\sqrt{s_{NN}} = 4\div11$ GeV (1÷4.5 GeV/u ion kinetic energy) at average luminosity of $1\cdot10^{27}$ cm$^{-2}\cdot$s^{-1} (at $\sqrt{s_{NN}} = 9$ GeV);
- light-heavy ions colliding beams of the same energy range and luminosity;
- polarized beams of protons $\sqrt{s} = 12\div27$ GeV (5÷12.6 GeV kinetic energy) and deuterons $\sqrt{s_{NN}} = 4\div13.2$ GeV (2÷5.6 GeV/u ion kinetic energy) at average luminosity $\geq 1\cdot10^{31}$ cm$^{-2}\cdot$s^{-1}.

The NICA parameters (Table 1) allow us to reach the goals of the project formulated above. The collider design has to provide the project luminosity and its maintenance during a long time necessary for an experiment performance. That requires formation of ion beams of high intensity with sufficiently low emittance and long ion beam life time. The scenario of collider operation had been developed and approved: so-called Space Charge and IBS (intrabeam scattering) dominated regimes at low and high ion energy, correspondingly [2].

As the first step in the realization of the NICA heavy-ion program, Baryonic Matter at Nuclotron (BM@N) - a new fixed-target experiment developed in cooperation with GSI, Darmstadt - has been approved by JINR's Program Advisory Comittee and Scientific Council and is now under construction [3].

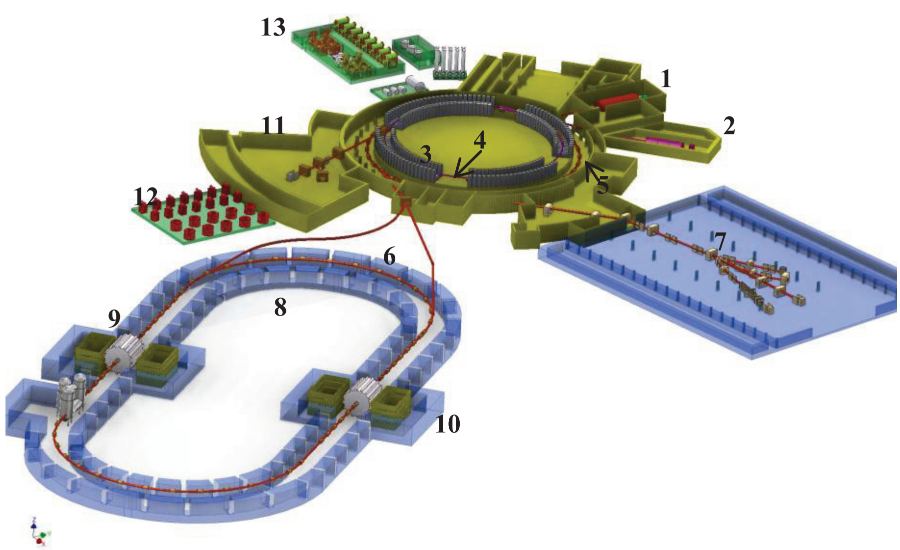

Figure 1: Scheme of NICA facility: 1 – light and polarized ion sources and "old" Alvarez-type linac; 2 – ESIS source and new RFQ linac for ions at $A/q \leq 6$, and energy up to 3 MeV/u; 3 – Synchrophasotron yoke; 4 – Superconducting synchrotron Booster (E_{inj} = 3 MeV/u, E_{max} = 600 MeV/u) equipped with electron cooling system; 5 – Nuclotron; 6 – beam transfer lines; 7 – Nuclotron beam lines and fixed target experiments; 8 – two superconducting rings of the Collider; 9 – MPD detector; 10 – Spin Physics Detector (SPD); 11 – new research area, 12 – auxiliary equipment, 13-cryogenics.

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Table 1: Parameters of NICA Accelerator Complex

	Booster (project)	Nuclotron		Collider (project)
		Project	Status 2013	
Circumference, m	211.2	251.5		503.0
Maximum magnetic field, T	1.8	2.0	2.0	1.8
Magnetic rigidity, T·m	25.0	45	45	45
Cycle duration, s	4.02	4.02	7 - 1000.0	≥ 2000
Magnetic field ramp rate, T/s	1.2	2.0	0.8	< 0.5
Accelerated/stored particles	p-$^{197}Au^{79+}$, p↑, d↑		p-Xe, d↑	p ÷ $^{197}Au^{79+}$, p↑, d↑
Maximum energy, GeV/u				
Protons	–	12.6	–	12.6
Deuterons	–	5.87	5.1	5.87
Ions, GeV/u	$^{197}Au^{31+}$, 0.6	$^{197}Au^{79+}$, 4.5	$^{124}Xe^{42+}$, 1.5	$^{197}Au^{79+}$, 4.5
Intensity, ion number per cycle (bunch)				
protons	$1{\cdot}10^{11}$	$2{\cdot}10^{11}$	$5{\cdot}10^{10}$	$2{\cdot}10^{11}$
deuterons	$1{\cdot}10^{11}$	$1{\cdot}10^{11}$	$4{\cdot}10^{10}$	$1{\cdot}10^{11}$
$^{197}Au^{79+}$	$1.5{\cdot}10^{9}$	$1{\cdot}10^{9}$	$1{\cdot}10^{4}$ ($^{124}Xe^{42+}$)	$1{\cdot}10^{9}$

NUCLOTRON AS TEST FACILITY FOR NICA

The superconducting synchrotron Nuclotron (Fig. 1, pos. 5) is used presently for fixed target experiments at extracted beams and experiments with internal target. This program is planned to be developed further and will be complementary to that one to be performed at Collider in heavy ions beam mode operation. The program includes experimental studies on relativistic nuclear physics, spin physics in few body nuclear systems (with polarized deuterons) and physics of flavours. At the same time, the Nuclotron beams are used for research in radiobiology and applied research.

In addition to the implementation of the current physics program the Nuclotron having the same magnetic rigidity as the future NICA collider and based on the same type of the magnetic system is the best facility for testing of the collider equipment and operational regimes [4]. Development works for NICA performed during recent Nuclotron runs include the testing of elements and prototypes for the MPD using extracted deuteron beams; the transportation of the extracted beam (C^{6+} ions at 3.5 GeV/u and deuterons at 4 GeV/u) to the point of the future BM@N detector location; operational tests of the automatic control system based on the TANGO platform, which has been chosen for the NICA facility. Simulation of the collider magnetic system operational conditions was performed at the Nuclotron during runs #45-47 (in years 2012-2013). This presumed test of the Nuclotron systems in the operational mode with long plateau of the magnetic field. In the run #45 the circulation of accelerated up to 3.5 GeV/u deuteron beam during 1000 seconds was demonstrated. During the runs #46 and #47 such a regime was used for test of stochastic cooling at the Nuclotron, which is an important phase of the NICA collider cooling system design. Application of the beam cooling methods (electron and stochastic) in the collider rings has the purposes of beam accumulation using cooling-stacking procedure and luminosity preservation during experiments. During 2011-2013 the elements of the stochastic cooling system for test at the Nuclotron were designed, constructed and installed at the ring. Main parameters of the system are the following: bandwidth 2-4 GHz, optimal beam kinetic energy 3.5 GeV/u, system (and notch filter) delay accuracy 1 ps, N_{ion}~1e9. This work performed in close collaboration with the Forschungszentrum Jülich (FZJ) is also important to IKP FZJ for testing elements of the stochastic cooling system designed for the High-Energy Storage Ring (HESR, FAIR) [5]. In March 2013 the effect of the longitudinal stochastic cooling using notch-filter method had been demonstrated at the Nuclotron for the first time (Fig.2). Characteristic cooling time experimentally obtained for deuteron beam is in good agreement with simulation results. We plan to investigate, step by step, longitudinal and transverse cooling of coasting and bunched beams.

The experimental investigation of stochastic cooling was a complex test of machine performance. During the experiment, the cryogenic and magnetic systems, power supply and quench-protection systems, cycle control and diagnostic equipment were operated stably in a mode in which the circulation time of the accelerated beam at the

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flat-top of the magnetic field was gradually increased from a few tens of seconds up to eight minutes.

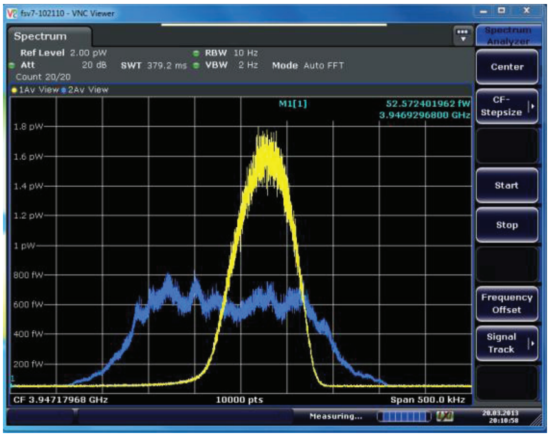

Figure 2: A longitudinal Schottky spectrum of the 3 GeV/u deuteron beam at 3500th harmonics of the revolution frequency, showing the initial spectrum (blue curve) and after 8 minutes of cooling (yellow curve). The beam intensity is $2x10^9$ ions.

The safe operation of the magnetic system was guaranteed by a new quench-detection system commissioned during the run. It permits a prompt change in the number of detectors, uniform work with the group and individual detectors and implementation of the total reservation of the line controlling the energy evacuation system. The system provides monitoring of the status of all of its components, as well as signal-testing of external systems, and also indicates malfunctions.

NICA CONSTRUCTION STATUS

In parallel with the existing accelerator complex development the technical design of the NICA complex had been prepared for the State expertise that is planned for 2013.

The development of NICA injection complex is actively performed [6]. New ESIS heavy ions source KRION-6T with solenoid of 6 Tesla is assembled and is at the stage of commissioning with electron beam now. New source of polarized particles (SPP) had been assembled and tested in 2012, we plan to perform several experimental runs for polarization measurements and test bench operation experience at the source during 2013-2014. Construction of new 3 MeV/u heavy-ion injector with RFQ linac is now under way in cooperation with the BEVATECH Company, its commissioning in Dubna is scheduled for the beginning of 2014.

RF stations for the Booster manufactured at BINP are scheduled for commissioning at Dubna at the end of 2013. Electron cooling systems both for the Booster and the Collider area under development. Construction of the first one will start in 2013 at BINP. The second one passes the stage of preliminary design. The full-scale Nuclotron–type superconducting model dipole and quadrupole magnets for the NICA booster and collider were manufactured during 2010 – 2012 [7]. First magnets for the booster have successfully passed the cryogenic test on the bench. Serial production of the booster magnets is expected start in early 2014. To construct the Booster and collider rings, it is necessary to fabricate more than 250 dipole magnets and lenses during a short period of time. Special Test Facility for the magnet assembly and full-scaled tests required for the magnet commissioning is currently constructed. This Facility is planned to be used also for assembly and cold testing of quadrupole magnets for SIS100 (FAIR project).

The NICA cryogenics [8] will be based on the modernized liquid helium plant that was built in the early 90’s for the Nuclotron. The main goals of the modernization are increasing of the total refrigerator capacity from 4000 W to 8000 W at 4.5 K and construction a new distribution system of liquid helium. These goals are achieving now by construction of a new 1000 l/hour helium liquefier, “satellite” refrigerators located near the accelerator rings, and a liquid nitrogen system that will be used for shield refrigerating at 77 K and at the first stage of cooling down of three accelerator rings with the total length of about 1.5 km and “cold” mass of 220 tons.

ACKNOWLEDGEMENT

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CONCLUSION

The NICA project as a whole has passed the phase of concept and technical formulation and is presently under development of the working project, manufacturing and construction of the complex elements. The project realization plan foresees a staged construction and commissioning of the accelerators that form the facility. The main goal is beginning of the facility commissioning in 2017.

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