STATUS OF THE NICA PROJECT AT JINR

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Abstract

Nuclotron-based Ion Collider fAcility (NICA) is the new accelerator complex being constructed in Joint Institute for Nuclear Research. General goal of the project is to provide experimental study of hot and dense strongly interacting QCD matter [1]. The development of NICA injection complex is actively performed. Construction of new 3.2 MeV/u heavy-ion linear accelerator (HILac) is now under way in Germany. Construction of Booster synchrotron has been started. New experimental results in stochastic cooling experiments achieved at Nuclotron are of great practical interest for NICA collider operation. Dedicated Test Facility for superconducting magnets assembly and cold testing is under commissioning now at Dubna. Civil construction had been started in 2014. In this report the present status of the NICA accelerator complex is presented.

NICA PROJECT

The NICA[2] consists of the following elements (Fig.1):

– *"SPP and LU-20" injector*: source of polarized protons and deuterons and Alvarez-type linac LU-20.

– *"KRION-6+HILAC" injector* (under construction): ESIS-type ion source KRION that provides $^{197}Au^{32+}$ ions of the intensity of $2{\cdot}10^9$ ions per pulse of about 7 μs duration at repetition rate of 10 Hz and linear accelerator consisting of RFQ and RFQ Drift Tube Linac (RFQ DTL) sections. The linac accelerates the ions at $A/Z \leq 8$ up to the energy of 3 MeV/u at efficiency not less than 80 % (A, Z are ion mass and charge numbers).

– Inside Synchrophasotron yoke is housed the *Booster-synchrotron*. It has 211 m circumference superconducting (SC) ring with magnetic system that provides $B\rho_{max}$=25 T·m. It is equipped with electron cooling system that allows to provide cooling of the ion beam in the energy range from injection energy up to 100 MeV/u. The maximum energy of $^{197}Au^{31+}$ ions accelerated in the Booster is of 600 MeV/u. *Stripping foil* placed in the transfer beam line from the Booster to the Nuclotron provides the stripping efficiency at the maximum Booster energy not less than 80 % bare nuclei. The Booster elements are under manufacturing and the machine itself is planned to be commissioned in 2015.

– *Nuclotron* - SC hadron synchrotron has maximum magnetic rigidity of 45 T·m and the circumference of 251.52 m. It provides acceleration of completely stripped $^{197}Au^{79+}$ ions up to the experiment energy in the range of 1÷4.5 GeV/u and protons up to maximum energy of 12.6 GeV. It is used presently for fixed target experiments at extracted beams and experiments with internal target. The program includes experimental studies on relativistic nuclear physics, spin physics in few body nuclear systems (with polarized deuterons) and physics of flavours. Besides, the Nuclotron beams are used for research in radiobiology and applied research.

– *Two transfer lines* transport particle beams extracted from Booster and Nuclotron to research area (b.205), where fixed target experiments both for fundamental and applied research will be placed.

– *Transfer channel* will transport the beam from Nuclotron to Collider rings. The line is at design stage.

– *Two SC collider rings* of racetrack shape have maximum magnetic rigidity of 45 T·m and the circumference of 503 m. The maximum field of SC dipole magnets is of 1.8 T. For luminosity preservation both electron and stochastic cooling systems will be constructed. The collider design is in progress, Nuclotron-type dipole and quadrupole magnet prototypes have been fabricated and tested in 2012-2014.

– *Two detectors* — MultiPurpose Detector (*MPD*) and Spin Physics Detector (*SPD*) are located in opposite straight sections of the racetrack rings. The MPD is being designed presently, prototypes of subdetectors are under construction and testing.

– *Electron cooler* of electron energy of 0.5÷2.5 MeV will be placed in special building at collider tunnel. Cryogenics and auxiliary equipment supply facility with *LHe*, LN_2, electric power and cooling water.

The NICA parameters allow us to reach desired luminosity. 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: so-called Space Charge and IntraBeam Scattering dominated regimes at low and high ion energy, correspondingly [3].

Start-up configuration of the NICA collider has been proposed and approved by NICA MAC. Energy range for first experiments chosen from 3 to 4.5 GeV/u (optimum ~ 3.5 GeV/u), and factor of 1/4 design intensity (5e8 instead of 2e9 ions per bunch). Advantage is that at low beam intensity one can neglect with parasitic collisions in the straight sections. Expected luminosity in the start-up configuration is 1÷7e25cm^{-2}s^{-1}.

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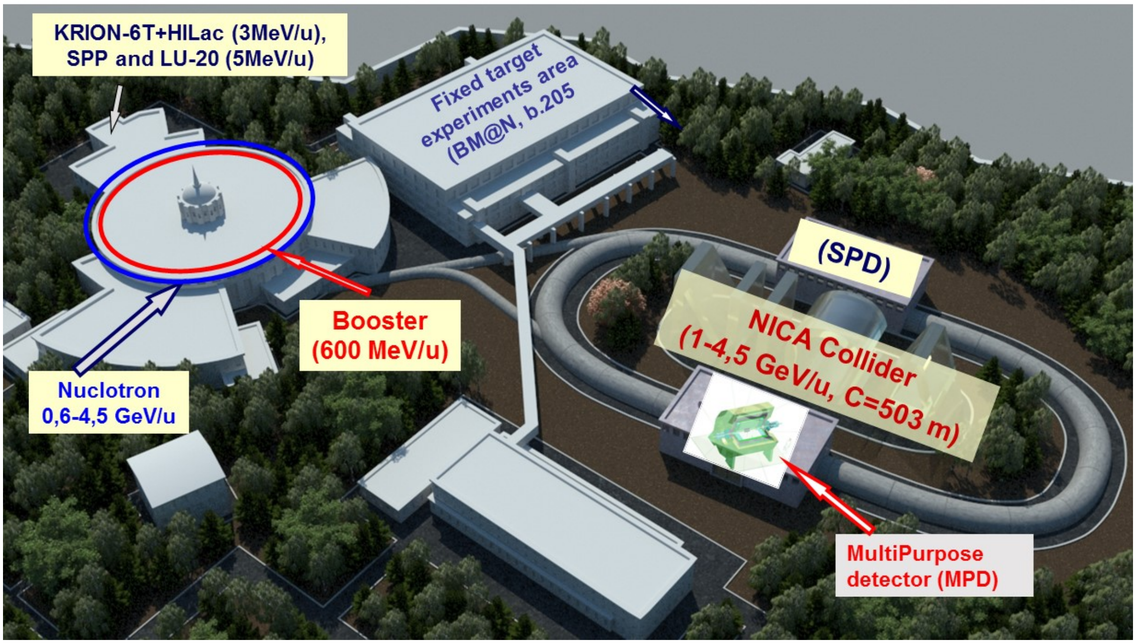

Figure 1: Scheme of NICA facility.

No electron cooling system, reduced (initial) version of stochastic cooling system, reduced version of RF system consisting of barrier bucket (BB) RF system and RF-2 – for beam bunching at h=22. Operation scenario: stacking with BB + stochastic longitudinal cooling. Bunch length is about 1.2 m, instead of 0.6m, momentum spread of 4.2e-4 instead of 1e-3.

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 Committee and Scientific Council and is now under construction [4]. This program is developed 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.

RECENT EXPERIMENTAL RESULTS AT NUCLOTRON COMPLEX

The superconducting synchrotron Nuclotron is used presently for fixed target experiments at extracted beams and experiments with internal target. 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 [5]. 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 first version of 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. Stochastic cooling effect had been successfully demonstrated in December 2013 both for coasting and bunched carbon beams (Fig.2) [6]. Characteristic cooling time experimentally obtained for deuteron beam is in good agreement with simulation results.

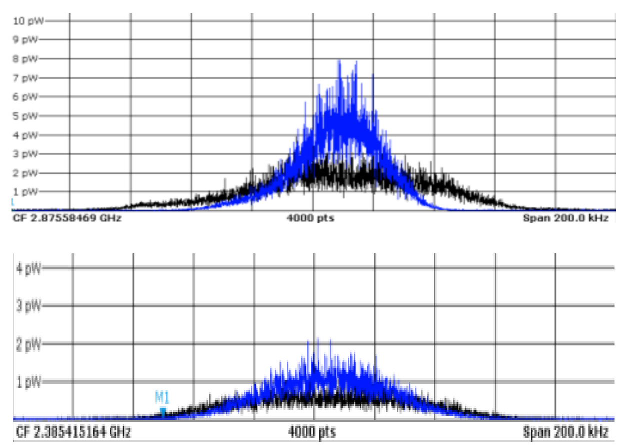

Figure 2: Experimental results of beam stochastic cooling of coasting $^{12}C^{6+}$ and bunched $^{12}C^{6+}$. Schottky beam spectra: black – initial beam, blue – cooled beam. Upper: coasting beam, I~2e9 ions, E=2.5 Gev/u, $dP/P_{initial}$=0.15e-3, dP/P_{final}=0.07e-3, τ_{cool} ~ 27 sec. Below: bunched beam, I~2e9 ions, E=2.5 Gev/u, $dP/P_{initial}$=0.2e-3, dP/P_{final}=0.13e-3, τ_{cool} ~ 64 sec.

New scheme of beam cooling system, which includes ring-slot couplers as pick-up and kicker (designed at FZJ), unique optical notch-filter and a full remote-controlled automation of measurements and adjustments, has been successfully commissioned in 2012. This work was performed in close collaboration with the Forschungszentrum Jülich, the results will be efficiently used also for design of the stochastic cooling system for the High-Energy Storage Ring (HESR, FAIR) [7].

Development works for NICA performed during recent Nuclotron runs included 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 chosen for the NICA facility.

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 and successfully passed it in October 2013. In December 2013 we started civil construction stage: tree cutting, ground works, removal of engineering networks. This stage had been completed in March 2014. In June 2014 first design drawing for civil construction had been issued, this stage will continue for 16 months. In parallel it is planned to start with piling and concrete works in the end of 2014.

The development of NICA injection complex is actively performed [8]. New ESIS heavy ions source KRION-6T with solenoid of 6 Tesla is assembled and commissioned in 2013. Magnetic field in the SC solenoid at B=5.4T reached in a robust regime. Test beams of Au ions have been produced for Au^{30+} ÷ $Au32^{32+}$ with intensity at 6e8 ppp and T_{ioniz}= 20 ms at repetition rate 50 Hz. Also ion beams Au^{51+}÷ Au^{54+} and Tm^{46+} had been generated in a test mode. 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 2014-2015. 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 2014 [8].

The construction of a new test facility for cryogenic testing of superconducting magnets is completed at the LHEP JINR. Premises with an area of 2600 m^2 were prepared for equipment installation. The first phase of the facility construction, including a 15 kA power supply, a satellite helium refrigerator and two benches for magnets testing, was commissioned [9]. The test facility is being created by JINR (Dubna) - GSI/FAIR (Darmstadt) collaboration. It will be duly equipped to provide cold testing superconducting magnets simultaneously on 6 benches for testing NICA (Collider, Booster) and FAIR (SIS100 synchrotron) SC magnets. More than 430 magnets will be tested at 6 benches of the facility in the next 4 years. The first magnets for the NICA booster and collider have successfully passed cryogenic test on the bench. Three pre-serial dipole magnets for the NICA booster will be tested during 2014. Start of the serial production of magnets for the booster is scheduled for the second half of 2014. Serial production of magnets for the NICA collider is scheduled for 2015 [10].

RF stations for the Booster commissioned at BINP. Electron cooling systems both for Booster and Collider are under design and development. Construction of the Booster electron cooler had been started in 2013 at BINP and its commissioning is planned for 2015.

The NICA cryogenics [11] is based on the modernized liquid helium plant that was built in the early 90's for the Nuclotron. Now the modernization is in active phase, its goal is 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 achieved now by commissioning of a new 1000 l/hour helium liquefier (manufactured at HELIIMASH in 2014), "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.

The NICA project as a whole has passed the phase of concept and technical formulation and is presently under development of the working project, and serial production start phase. 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 2019.

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