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# Commissioning of Collider NICA and formation of first heavy ion beams

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## Contents



**Abstract. This paper discusses the results of Run N 1 of the NICA Accelerator Complex, including beam formation and injection complex equipment upgrades, the technological launch of the Collider systems and its engineering infrastructure, including the launch of the large-scale cryogenic system of the accelerator complex, the technical details of the first beam run at the NICA Collider, and the optimization of xenon beam circulation, as well as the achieved intensities and other measured beam characteristics in the Collider. The first circulation of a xenon beam in the Collider's lower ring was achieved on January 11, 2026. On February 12, simultaneous circulation of colliding xenon beams in the Collider rings was achieved, ensuring the same frequency of particle bunch circulation in each of the Collider rings and synchronization of their passage at the collision point in the MPD detector region.**

**Keywords:** ion collider, superconducting magnets, heavy ion beams

## 1. Introduction

In 2006, Joint Institute for Nuclear Researches (JINR), first discussed a project to carry out experiments with heavy ions bombarding a stationary target with a center-of-mass collision energy of 5–10 GeV/n [1]. Shortly thereafter, the NICA project [2, 3] emerged, aiming to conduct similar experiments, but with both colliding heavy ion beams and beams directed to a target.

This paper presents the results of the first successful beam run with xenon ions at the NICA complex, carried out in 2025–2026. The NICA accelerating complex [1–5] was built at JINR (Dubna). Its primary purpose is to provide ion beams for experimental studies of hot and dense strongly interacting baryonic matter and spin physics. The physics program focuses on searching for possible manifestations of phase transitions and critical phenomena in the energy range where excited baryonic matter with the highest achievable density is formed. The NICA collider [5, 6] will provide heavy ion collisions in the energy range $\sqrt{s_{\mathrm{NN}}} = 4-11$ GeV. At maximum energy, an average luminosity of $L = 1 \times 10^{27}$ cm$^{-2}$ s$^{-1}$ is expected for $^{197}\mathrm{Au}^{79+}$ nuclei. Further development of the accelerator complex will add collisions of polarized protons in the energy range $\sqrt{s_{\mathrm{NN}}} = 12-27$ GeV with a luminosity at maximum energy of $L \geqslant 10^{32}$ cm$^{-2}$ s$^{-1}$.

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## 2. Formation of the first beams of heavy ions in the NICA Collider

On March 5, 2025, Run 1 of the NICA Collider accelerator complex was formally launched at the Laboratory of High Energy Physics (LHEP) of JINR. The launch took place on the sidelines of the session of the Committee of Plenipotentiaries of the JINR Member States in the presence of representatives of 20 JINR Member States, Associate Members and Partners. The NICA accelerator complex [6, 7] includes the Krion-6T electron-string heavy ion source, the SPI polarized ion source, the HiLAC heavy ion linear accelerator, the LU-20 linear accelerator, the Booster superconducting synchrotron, the Nuclotron superconducting synchrotron, two superconducting rings of the NICA Collider with two collision points, beam transport lines between the linear accelerators, synchrotrons, and the Collider, and facilities and channels for applied research.

The goals of the technological part of this run were (1) further development of the NICA injection complex, aimed at generating heavy ion beams for injection into the Collider, and (2) the technological launch of the Collider systems and testing their functionality before injection of heavy ion beams.

To increase the beam intensity injected into the Collider, ion accumulation at the injection energy was implemented in the Booster in 2025 using electron cooling [8–10]. Ions from the ion source are injected into the HILAC linear accelerator, where they are accelerated to an energy of 3.2 MeV/n, and then injected into the Booster at a frequency of 5–10 Hz. Ten injection cycles demonstrated a sevenfold increase in the accumulated beam intensity in the Booster [10]. To transfer heavy ion beams from the Nuclotron to the Collider, a fast extraction system was added, including a Lambertson septum magnet and a fast kicker magnet. The first xenon ion beams were extracted into the beamline in November 2025.

The creation of the NICA accelerator complex necessitated the modernization of its cryogenic infrastructure. The productivity of cryogenic complex at 4.5 K temperature was increased from 4 kW to 10 kW. Russia's largest liquid helium production complex was supplemented by a specially designed helium liquefaction unit with a capacity of 1000 l $h^{-1}$. With the commissioning of the compressor station in September 2025, cooling of the Collider magnets to helium temperatures began, and in October, cryogenic systems for three accelerators — the Booster, Nuclotron, and the Collider — were enabled to operate simultaneously.

Dual-aperture superconducting magnets have been developed for the NICA Collider. The vacuum chambers of the two rings are vertically separated, one above the other. The magnets in the arcs share common yokes, but their design allows for independent field control in each ring. Separation of colliding beams occur in the vertical plane. After passing through the merging section, the bunches of the upper and lower rings have head-on collisions. Beam focusing at the collision points is achieved by shared single-aperture quads, ensuring that both beams are focused at the interaction point. The magnetic structure supports collisions at two interaction points, located in the opposite straight lines of the Collider.

A small factory has been built at the LHEP JINR for the production and testing of superconducting magnets. A total of 428 structural and 304 corrective SP magnets will be manufactured and tested for the Booster, the Collider, and the German synchrotron accelerator SIS100 of the FAIR project (Darmstadt, Germany).

Assembly of the cryomagnetic system for the west arc of the NICA Collider was completed in September 2025. It was followed by cooldown of the arc and its vacuum and cryogenic tests. Assembly of the cryomagnetic system of the east Collider arc and the injection sections located in the arc was completed in mid-November 2025 (Fig. 1).

Upon completion of this work, the east arc (includes magnets of both rings) was cooled to a liquid-helium temperature of 4.5 K. In mid-December the quench protection and energy evacuation systems protecting the magnets were tested and tuned. A 5 kA current, corresponding to a guiding magnetic field of 0.86 T, was introduced into the magnetic system. Also, at this time an installation of the northern branch of the Nuclotron–Collider beam transport lines was completed. It resulted in the first xenon beam injection into the lower ring of the Collider on December 18, 2025. Figure 2 shows an image at the last beam profile monitor in the Nuclotron-Collider transport line aimed to the bottom ring.

Cooling of the Collider's west arc to a temperature of 4.5 K continued until December 24, 2025. By the end of December, test of the east arc quench protection and energy evacuation systems was complete. On December 30, 2025, a current of 5 kA was injected into all Collider magnets. This current corresponds to the bending magnetic field in dipoles of 0.86 T. The maximum current achieved in the magnets of the lower west arcs was 5.6 kA and 8.9 kA into the upper one. That corresponds to a magnetic field of 0.97 T in the lower half-ring, and 1.55 T in the upper half-ring, The maximum current achieved in the magnets of the east arc was the same for the upper and lower half-rings and amounted to 6.5 kA, which corresponds the magnetic field of 1.1 T.

**Figure 1.** Installation of the last magnet of the NICA Collider.

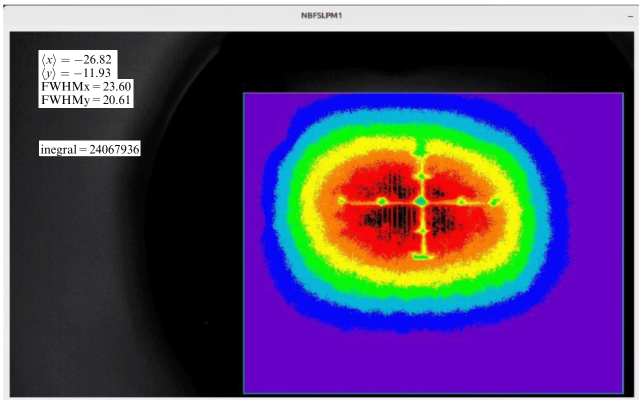


**Figure 2.** Beam profile at the last beam profile monitor of the Nuclotron–Collider transport line.

During the run, a design field of 0.57 T was also obtained in the superconducting solenoid of the MPD detector, which will be moved to one of the Collider's experimental sections later in the year. The solenoid is approximately 7 m in diameter and 9 m in length. At half of the design magnetic field a magnetic field map was measured. It was done in collaboration with the BINP SB RAS. The achieved relative field uniformity of better than $5 \times 10^{-4}$ corresponds to the design requirements.

Work on obtaining the first revolution in the Collider's lower ring began on January 4, 2026. The ion kinetic energy was determined by the readiness of collider system and was chosen to be 1.76 GeV/nucleon. The main difficulties were related to strong EMI (electromagnetic interference) on the BPM (beam position monitor) signals from the pulse generators of the kicker and septum of the collider injection system. After the injected beam passed through the first two superconducting dipoles of the east arc (Fig. 3) and entered the 'warm' straight section, detecting the beam position using the standard BPMs proved being impossible. An original solution was found to address the problem. A short section of the warm straight section was shifted horizontally by approximately 5 cm from the axis. It was possible due long disc-shaped bellows installed in this piece of vacuum chamber. That enabled an installation of compact, multi-wire proportional ionization chamber (MIC) in the beam path without mechanically disassembling the vacuum volume. Due to high energy

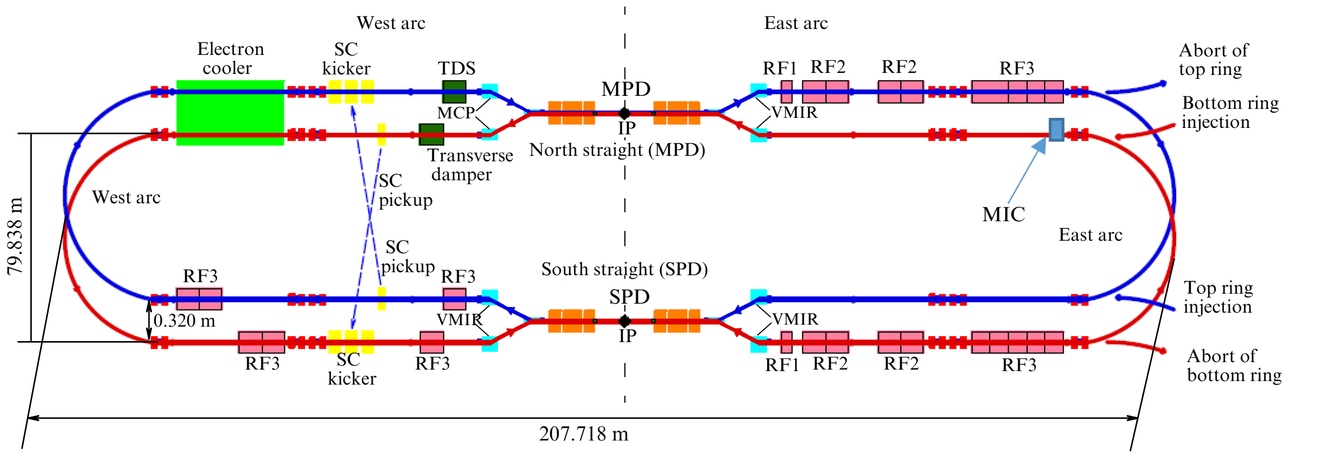


**Figure 3.** Collider layout: top ring — blue line, bottom ring — red line. Shown collider equipment includes [4, 6]: RF systems [6] (RF1 — barrier bucket, RF2 — $h = 22$ and RF3 — $h = 66$), two particle detectors — MPD [4] and SPD [11] around two interaction points (IP), TDS — transverse damper system [6], SCS — stochastic cooling systems with SC kickers and SC pickups [9], SEC — system of electron cooling [9], vertical magnets of interaction regions (VMIR) — 8 blue rectangles, orange rectangles — superconducting lenses of straight section, MIC — multi-wire proportional ionization chamber, blue rectangle with arrow.

the beam easily penetrated through walls of the displaced section of the chamber with effective thickness of approximately 7 mm. That enabled step-by-step beam steering through few warm periods between location of injection and vertical magnets of interaction region.

Using few correctors we steered beams to the west arc through regions of stochastic and electron cooling. Then the beam was steered through the west arc and north straight which includes RF3, stochastic cooling systems, interaction region of SPD and warm section of RF1 and RF2 systems and finally through the east arc (see Fig. 3).

The settings of vertical magnets of the SPD and MPD interaction regions were symmetric. Finally, January 11 of 2026 the first turns of xenon ions were obtained and then stable circulation was achieved in the bottom collider ring. January 21 was obtained stable circulation of bunched beam supported by RF2 system.

The bunched beam lifetime at the initial stage of circulation was about 10 minutes, which is related to the loss from the bunch particles with large initial synchrotron amplitudes due to the noise in the RF system voltage. These particles were moved to DC and became invisible by the Fast Current Transformer (FCT). After loss of these particles the bunch lifetime was determined by vacuum losses with lifetime of about 1 hour. Later this lifetime was independently confirmed by measurements of the Schottky noise from the detector installed in the Collider's lower ring.

Measurements of the average residual gas density were obtained by analyzing the rate of beam deceleration due to ionization losses in the absence of RF. The measurements reviled that although the vacuum was above the design value (Fig. 4) its value is sufficient to support collider operation. As far as we can judge for now, the multiple scattering at the residual gas was primary mechanism for the losses shown in the right-hand side of Fig. 4. The loss was greatly enhanced by the small value of transverse acceptance determined by large orbit distortions. With obtaining the design value of acceptance and addition of transverse cooling the beam loss is expected to be much smaller. The number of nuclei in the circulating xenon ion beam in the Booster was $6 \times 10^7$, in the Nuclotron before beam extraction it was about $2.5 \times 10^7$, and the number of nuclei injected into the Collider after the first

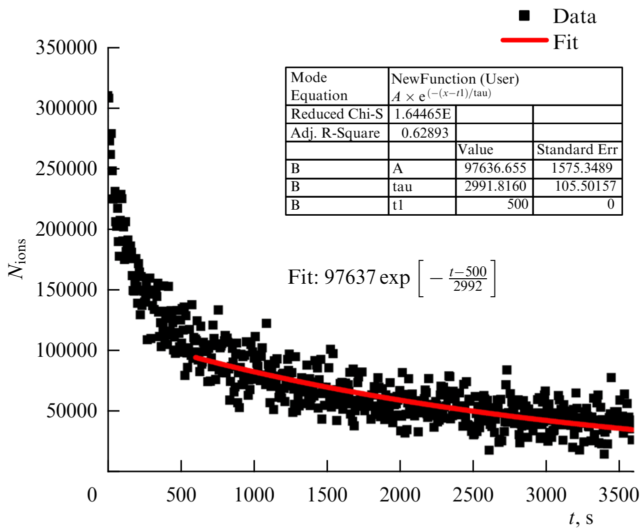


**Figure 4.** Time dependence of the circulating beam intensity of the xenon nuclei in the lower ring of the NICA Collider; black squares are the number of circulating nuclei, the red curve is exponential fitting of beam intensity on time with the lifetime of 2990 s.

revolution did not exceed $2 \times 10^6$. By processing the signals from the beam position monitors in the Collider, its orbit and fractional parts of the betatron frequencies $\nu_x = 0.41$, $\nu_y = 0.478$ were measured; and the frequency of synchrotron oscillations of $\nu_s = 340.72$ Hz was also determined, which value corresponded to the calculated value for the given voltage of the RF system.

The beam injection into the upper ring through the south branch of the Nuclotron–Collider transport line was carried out at January 14. Beam circulation in the Collider's upper ring was obtained on January 22, 2026. Detailed studies with a circulating bunched beam in the upper ring were carried out on February 12. At the initial stage, the beam lifetime in this ring was also approximately 10 minutes, and the initial intensity of the xenon beam injected into it was equal to $3 \times 10^6$. The fractional parts of the betatron tunes, $\nu_x = 0.189$, $\nu_y = 0.139$, were computed from the turn-by-turn BPM signals.

After successful operation with single beams injected into the Collider's upper or lower ring, and observation of stable

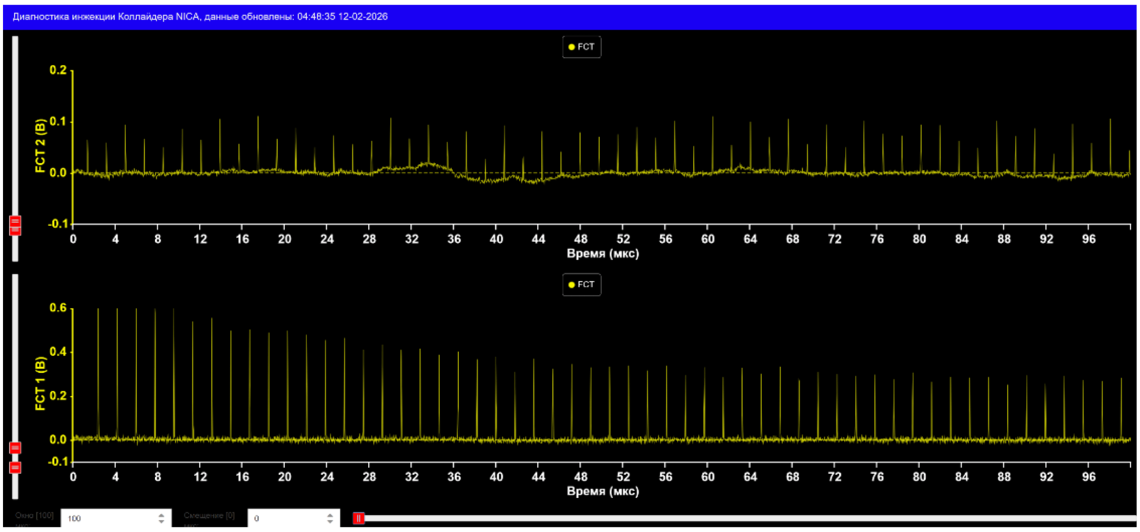


**Figure 5.** Signals from the broadband current transformers of the upper and lower rings of the Collider, generated by the simultaneous circulation of colliding beams of xenon nuclei.

beam circulation for tens of minutes in each, an important milestone was reached on the night of February 12, 2026 — the simultaneous circulation of both colliding beams achieved for the first time (Fig. 5). The following procedure was used. First, an injection of xenon beam into the Collider's upper ring was carried out. Then its injection system was turned off which ensured beam circulation for approximately ten minutes. During this time, a new beam was injected into the Collider's lower ring every 6 seconds. Consequently, a simultaneous circulation of counter propagating beams was achieved in both Collider rings.

The phase lock of both rings RF systems resulted in synchronized beam passage through the both collision points (Fig. 6). This achievement paves the way for obtaining the design parameters of the collider and confirms that the main systems of the Collider meet the technical requirements. Physicists and engineers are now moving on to the next stage, required to carry out physics experiments. Plans for the near future include measuring and correcting the orbits and beam optics of the rings, increasing beam intensity, and, finally, recording the first collisions at the interaction point of the MPD detector.

Plans for further beam intensity increase in the Collider primarily involve implementing an ion accumulation scheme with the barrier-bucket RF. In March 2026, INP SB RAS and JINR staff plan to complete work on the control electronics and software required for operation of the barrier-bucket RF stations. A reduction in the bunch length will be achieved with addition of four RF2 harmonic resonators ($h = 22$) to the existing four. That will increase the luminosity inside sensitive area of MPD detector. Work on commissioning four additional RF2 cavities will be carried out by JINR and INP SB RAS staff. It is planned to begin in May 2026.

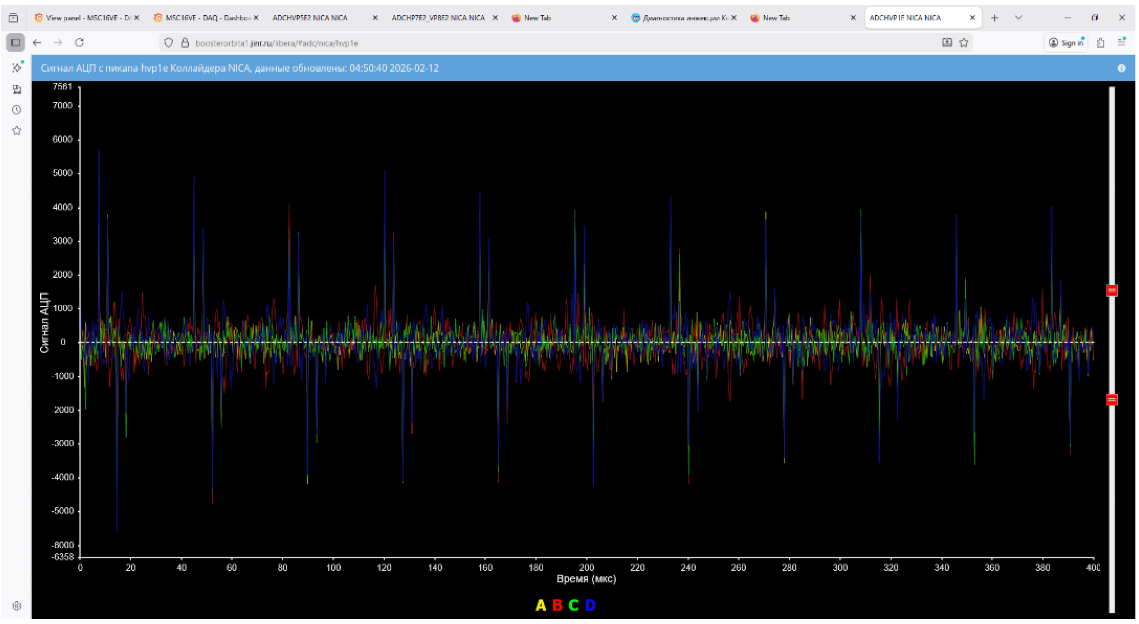


**Figure 6.** Beam position sensor signals at the collision point in the MPD detector region from two xenon beams passing through each other.

## 3. Conclusion

In the next beam run, planned for the fall of 2026, the NICA Collider will be expected to support collisions of $^{124}Xe^{54+}$ nuclei with a center-of-mass energy of $\sqrt{s_{NN}} = 4-7$ GeV with the luminosity of $L = 10^{24}-10^{25}$ cm$^{-2}$ s$^{-1}$. Prior to the run, the MPD detector will be set up to record events from colliding xenon beams. With an average luminosity of $10^{25}$ cm$^{-2}$ s$^{-1}$, the MPD event rate in xenon collisions will be approximately 50 Hz. At this luminosity, the detector can collect approximately 100 million events in approximately three months of NICA operation. Further luminosity increases will be supported by introduction of beam cooling systems. The first stochastic cooling systems out of 12 for each ring are scheduled to be commissioned in late 2026.

The future will tell how significant the Collider's contribution to global science will be, but for now, it's safe to say that the NICA program is establishing JINR as one of world leader in the accelerator and detector technologies.

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