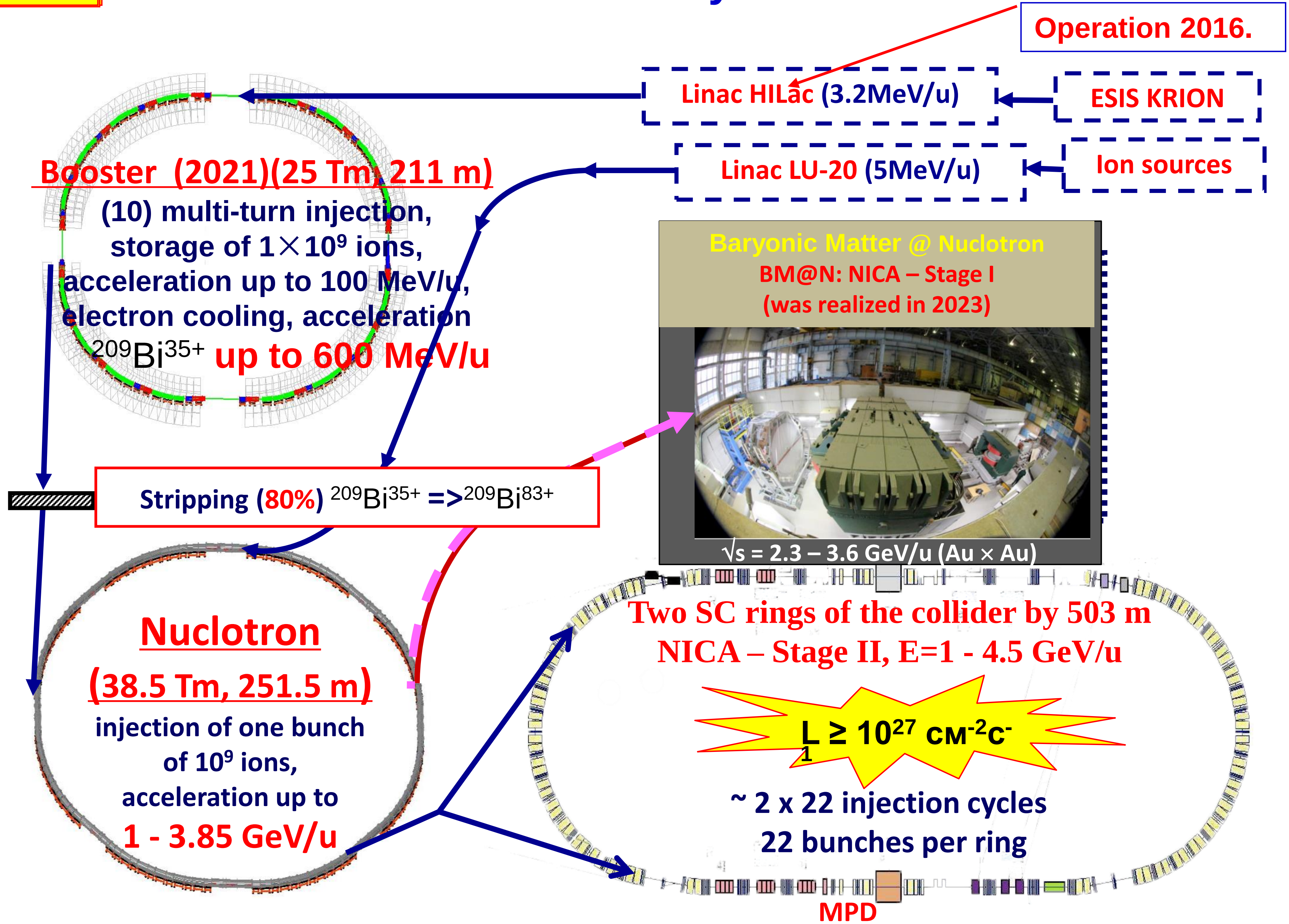
Collider NICA status

Evgeny Syresin on behalf of Accelerator division

NICA: Nuclotron based Ion Collider fAcility

2025

NICA – collisions for Heavy ion mode



NICA Stage II-a (basic configuration):

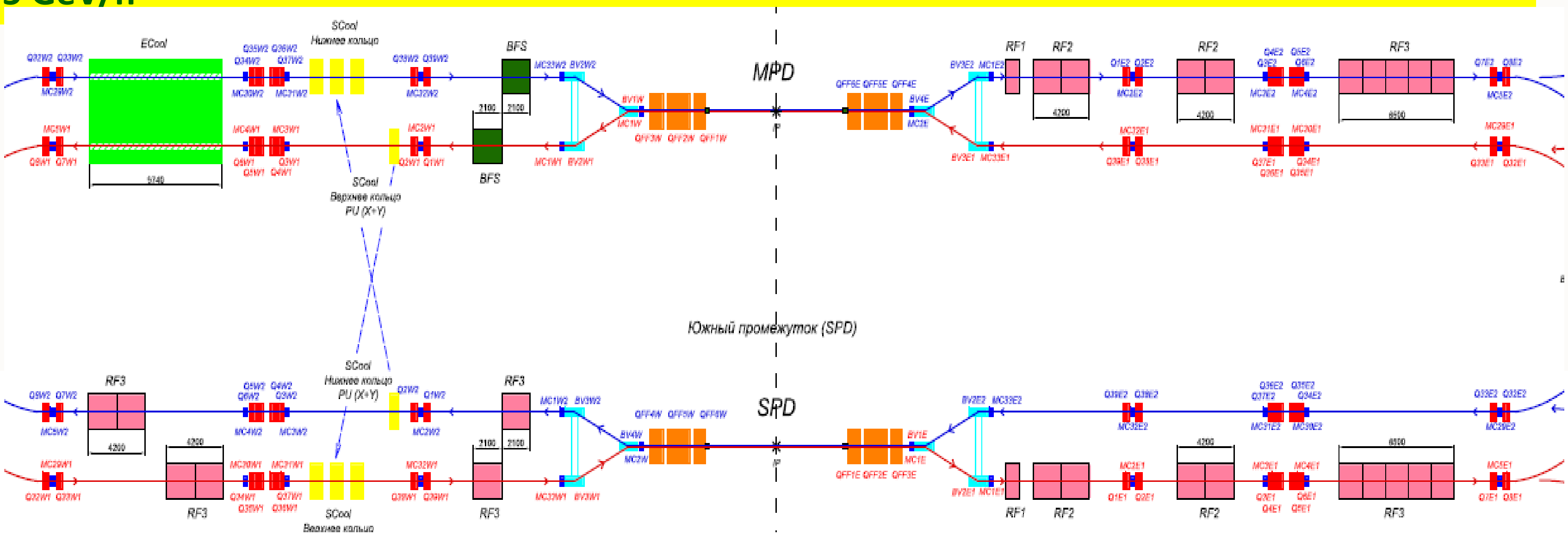
3. Collider equipped with
- RF-1 (barrier voltage system) for ion storage
- RF-2 : 4 cavities per ring instead (100 kV RF amplitude)
- 1 channel of S-cooling per ring (cooling of longitudinal deg. of freedom)

Technological run at cryomagnetic system testing – December 2024

Commissioning – Autumn 2024

First beam run – Spring of 2025

Result: 22 bunches of the length σ ~ 2 m per collider ring that 2e25 $cm^{-2} \cdot s^{-1}$, ion kinetic energy E=2.5 GeV/n



NICA Stage II-b (full configuration):

Collider
+ RF-3 systems in the project version
+ S-cooling (transverse)
+ E-cooling

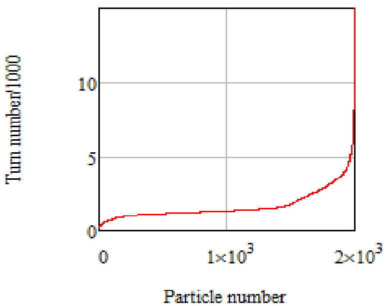
Result: 22 bunches of the length σ ~ 0.6 m per collider ring that 1e27 $cm^{-2} \cdot s^{-1}$, ion kinetic energy E=4.5 GeV/n

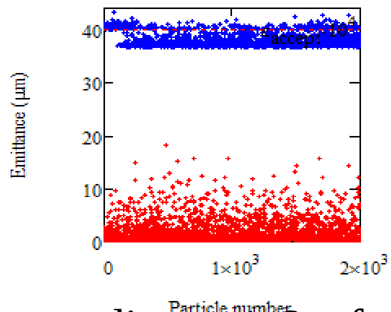
Simulation of beam interaction with internal target in MPD section

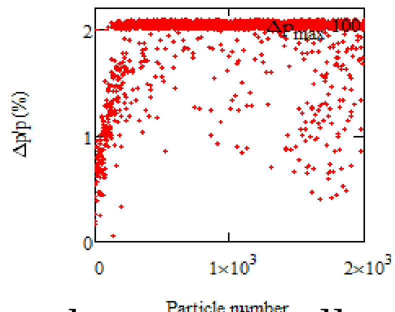
O. Kozlov

Ион	A_0, Z_0	Energy, E_K, ГэВ/н	Target material	A_{targ}, Z_{targ}	Diametr, ø, 10^{-4}см	density, ρ, g/cm³	Radiation length, X_0, g/cm²	minimum energy of ionization, MeV·cm²/g	Termocodactivity, J/mol/K	Maximum energy loss, ΔE_{max}, MeV/n	Max. momentum variation–$\Delta p/p_{max}$, 10^3	Scattering angle, $<\theta_{scat}>_{max, mkrad}$	Probability of nuclear reaction W_{int}, 10^3
Xe	124 54	2.5	W	183 74	50	19.3	6.76	1.742	24.2 7	2.80	0.88	186.5	1.423
			C	12 6	50	2.2	42.7	1.145	8.5	0.48	0.15	20.5	1.753

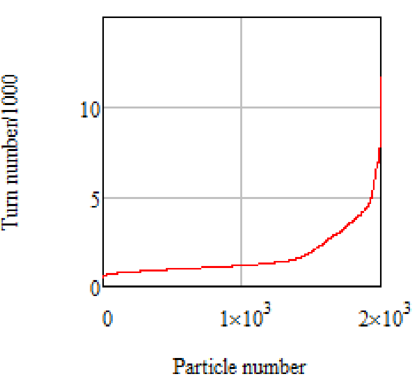
6σ, yw=8.144mm hits=27.875
Npart=2000 Nmax=20000
Nturn=17933 F=3.125kHz

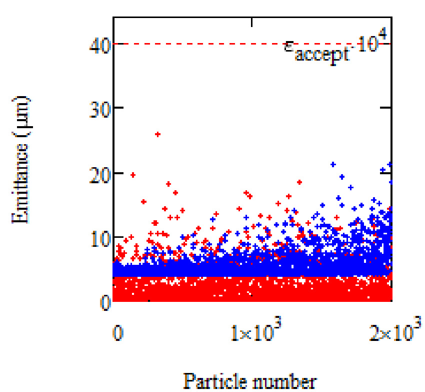


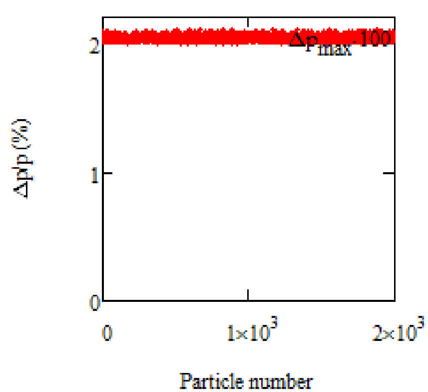




wire target is placed on distance 6σ from beam axis, all nucleus are loosed at chamber aperture due to momentum spread.

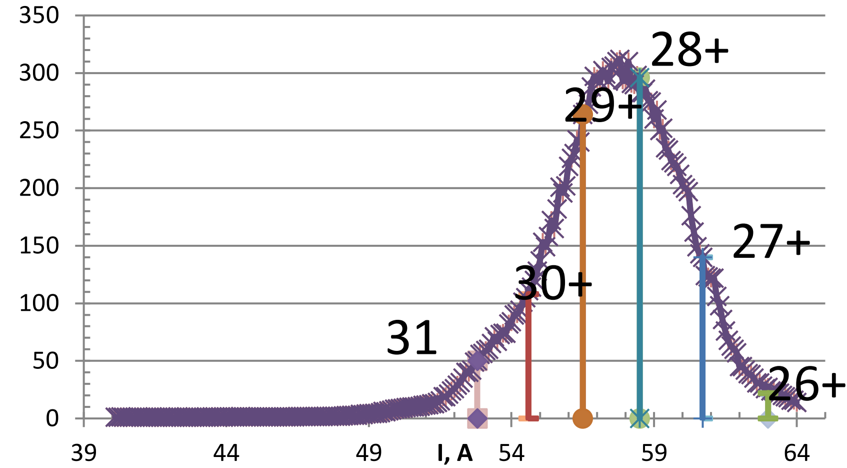






3σ, yw=4.072mm Npart=2000
Nmax=20000 Nlost=2000
Nturn=10632 hits=29.686
F=5.6kHz

Ion source KRION-6T



Xe ion charge distribution at KRION exit

Project ion intensity 2·10^9 Bi^{35+} per pulse

Достигнутые величины

Ar^{16+} - 5·10^8 ions per pulse

Xe^{28+} - 2·10^8 ions per pulse

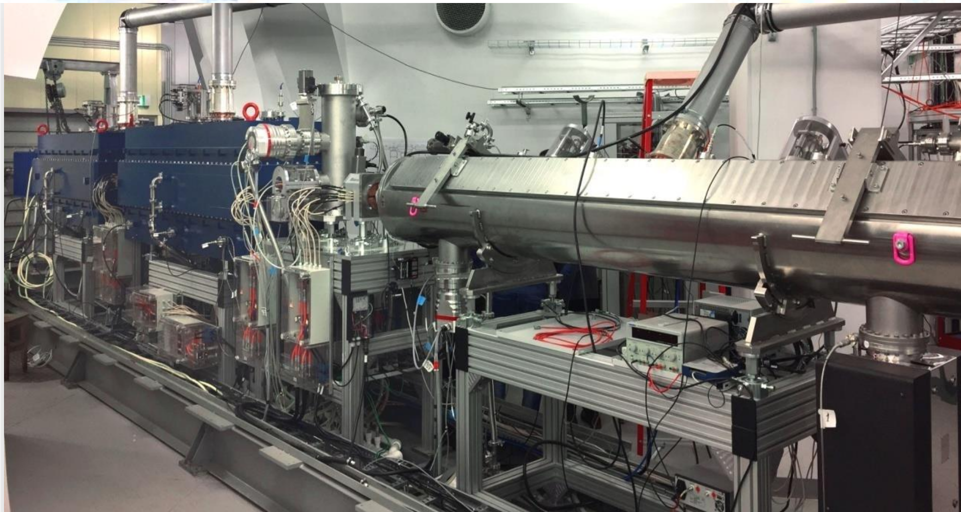
Bi^{35+} - 2·10^8 ions per pulse

First Collider beam run is planed with Xe^{28+} и Bi^{35+} ions

Further development and upgrade of KRION-6T during April-May 2024 beam run with Kr, Xe and Bi ions at injection rate 10 Hz and injection pulse duration 410-^{6} s.

HILAc status

Stable and safe HILAC operation during with Ar^{13+} and Xe^{28+} beams

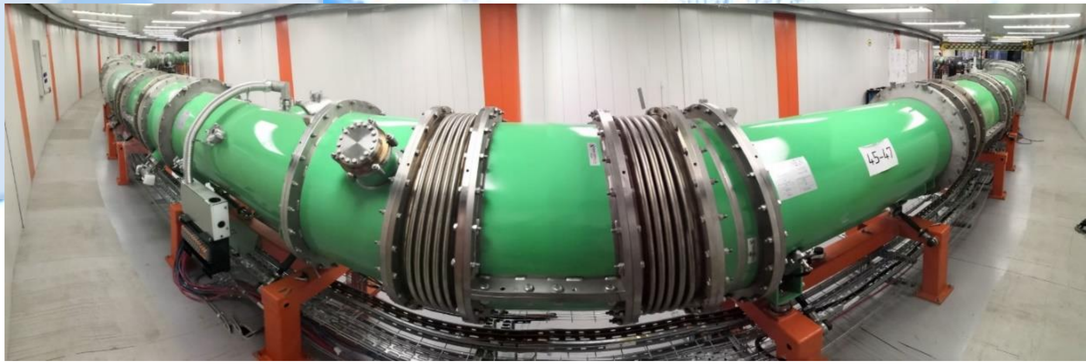


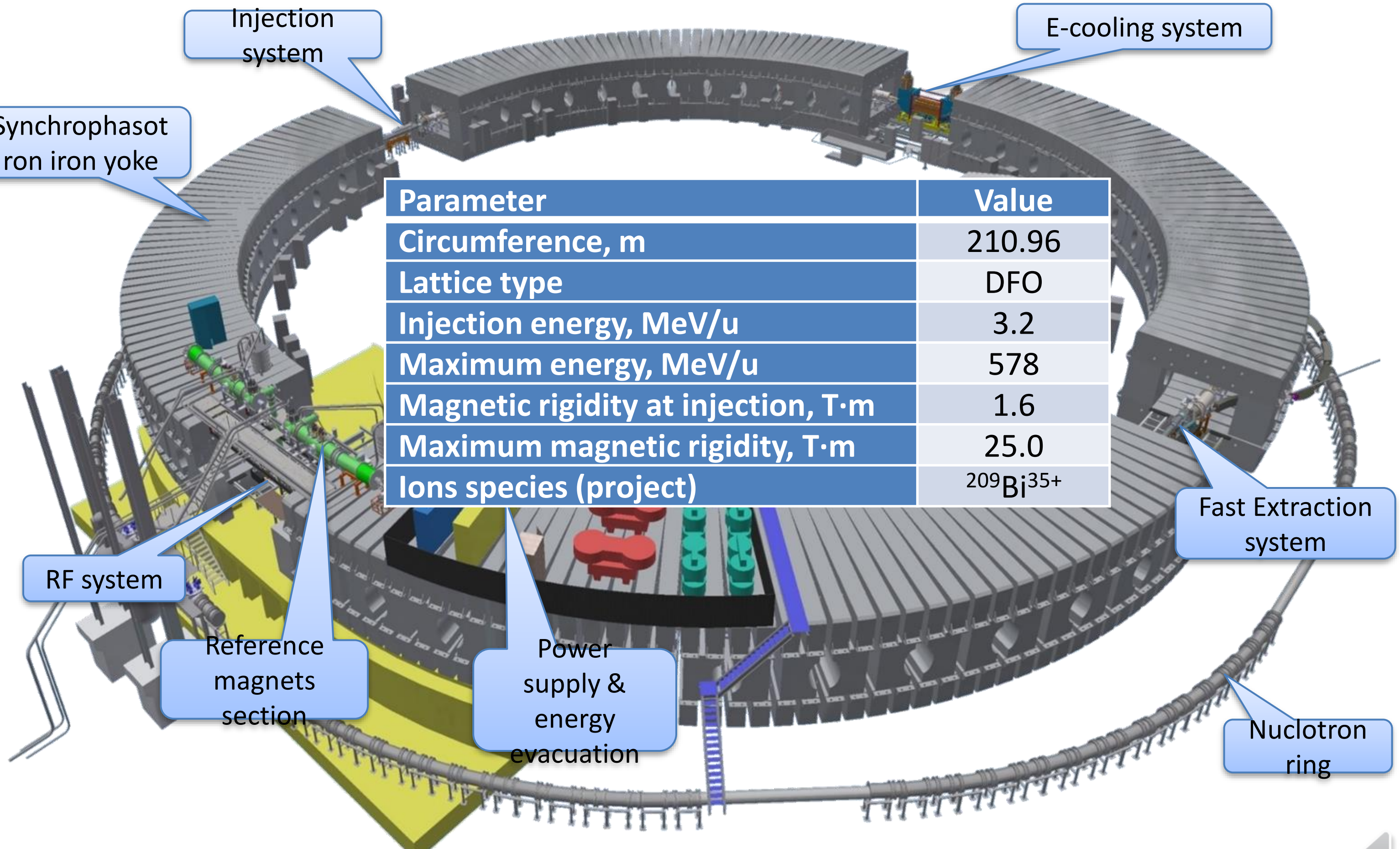
At RFQ exit I=100 μA (yellow line). At HILAC exit I=65 μA at ion pulse duration 22 μs (red line), about 70% at this pulse of target ions $^{124}Xe^{28+}$. **Number of ions accelerated in HILAC at energy 3,2 MeV/n is about 1×10^{8}.**

Project HILAC intensity $^{209}Bi^{35+}$ at energy 3,2 MeV/n is about 1.8×10^{9} per pulse.

Development at planed realization of multi cycle injection and upgrade of KRION-6T and HILAC regimes during April-May 2024 beam run with Kr, Xe and Bi ions.

Booster ring layout (2021)





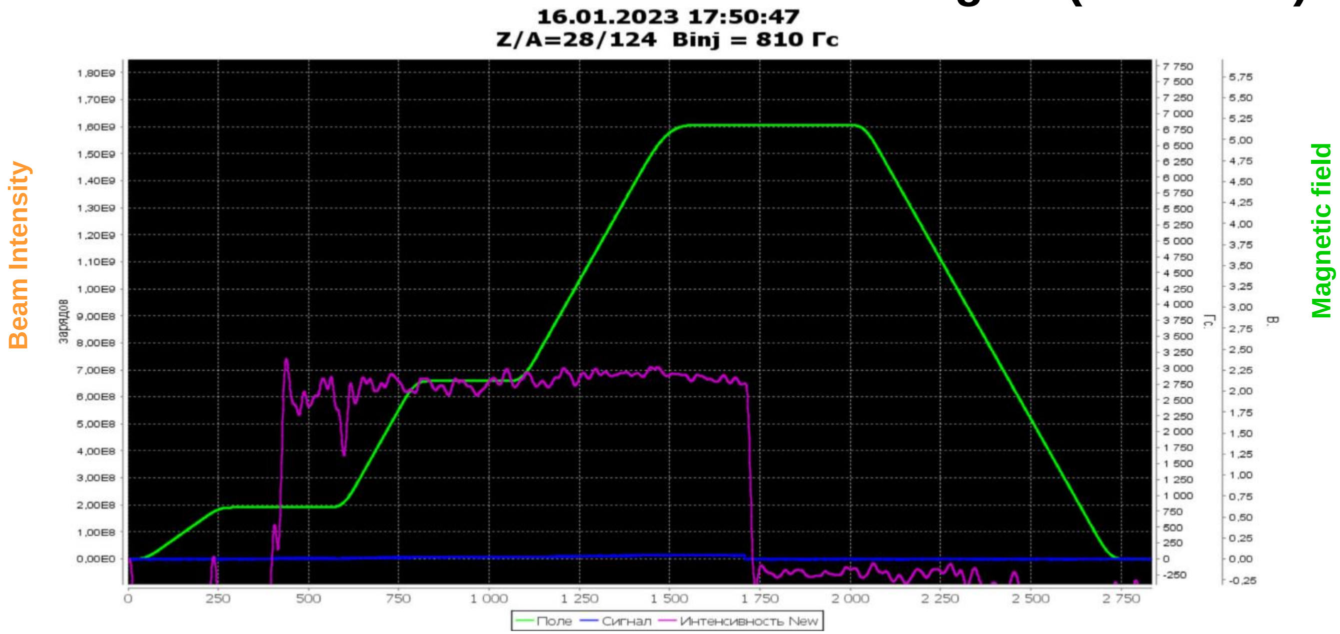
Parameter	Value
Circumference, m	210.96
Lattice type	DFO
Injection energy, MeV/u	3.2
Maximum energy, MeV/u	578
Magnetic rigidity at injection, T·m	1.6
Maximum magnetic rigidity, T·m	25.0
Ions species (project)	$^{209}Bi^{35+}$

Booster run with multi cycle injection and Xe ion accumulation by a factor of 5 is planned in June 2024.

NICA JINR

Booster Beam current

Parametric beam current transformer signal (DC mode)



Booster-Nuclotron run - September 2022 - February 2023 for BM@N baryonic matter researches. Booster acceleration of ions$^{124}Xe^{28+}$ to energy 204,7 MeV/n, where they were stripped up to bare nucleus end extracted in Nuclotron.

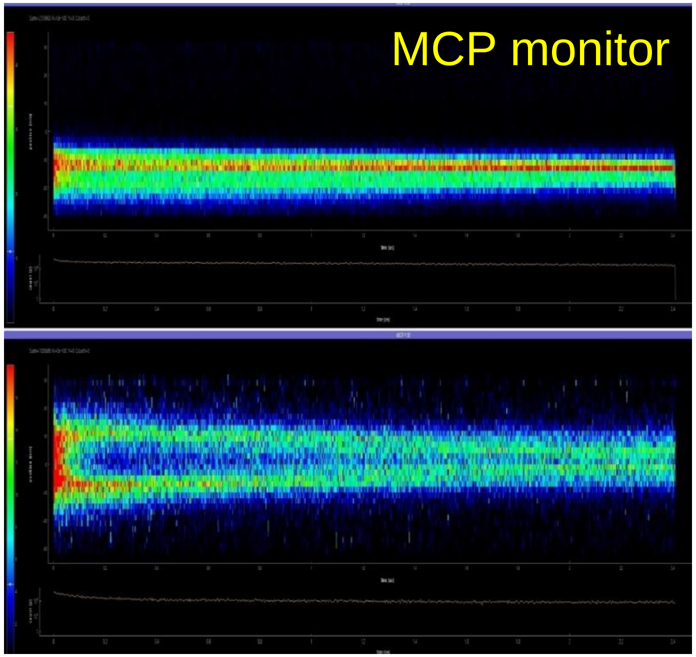
- ✓ ***$6{\cdot}10^{8}$ elementary charges ~ $2.5{\cdot}10^{7}$ of Xe^{28+}***

Electron cooling of Xe beam

$^{124}Xe^{28+}$ at injection energy

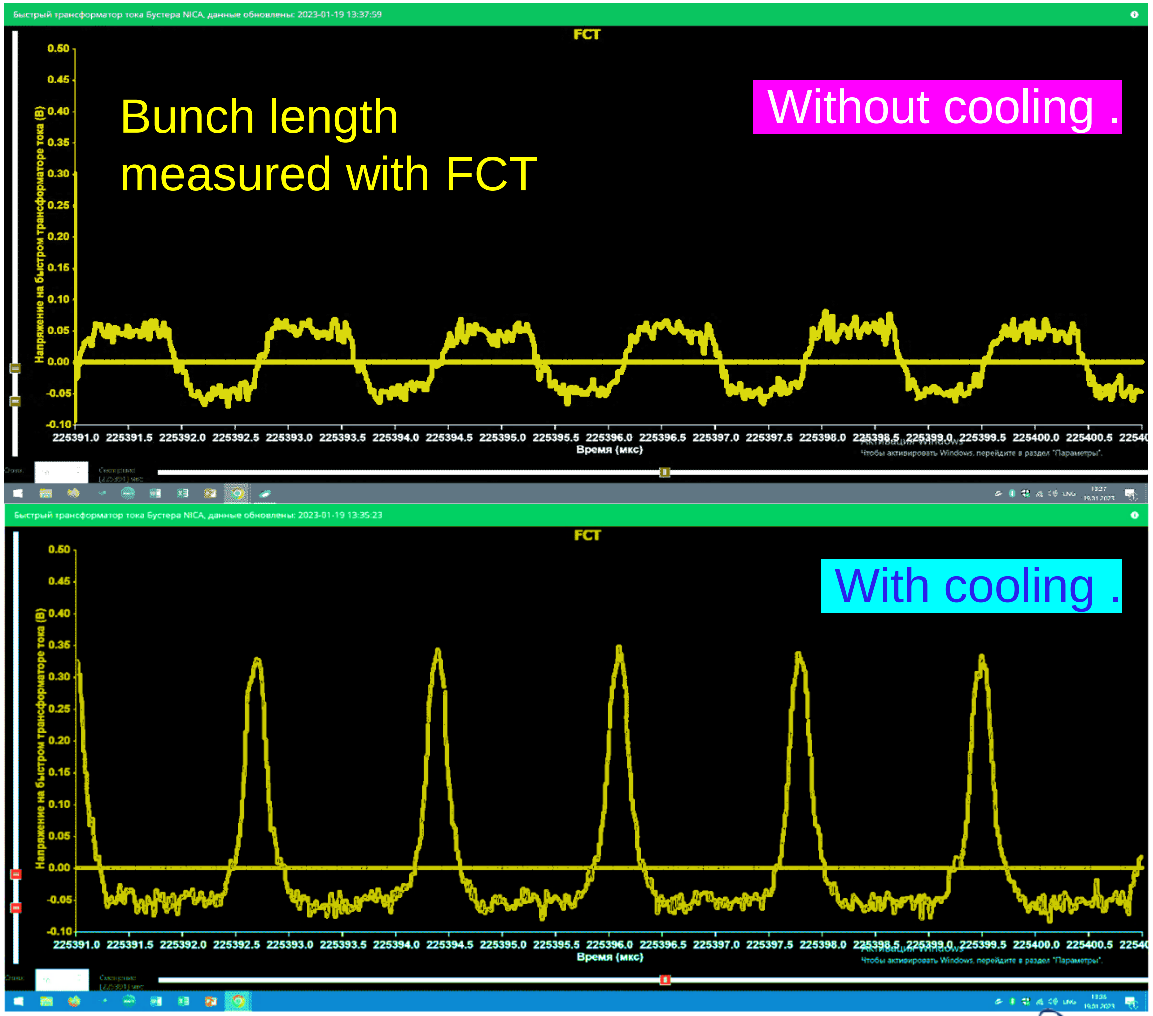
Transverse cooling

Electron energy 1,93 keV
Electron current 150 mA



Signals from Ionization profile monitors during beam circulation

Longitudinal electron cooling



Electron cooling of $^{124}Xe^{28+}$ at electron beam current 50mA and energy 1,830 keV

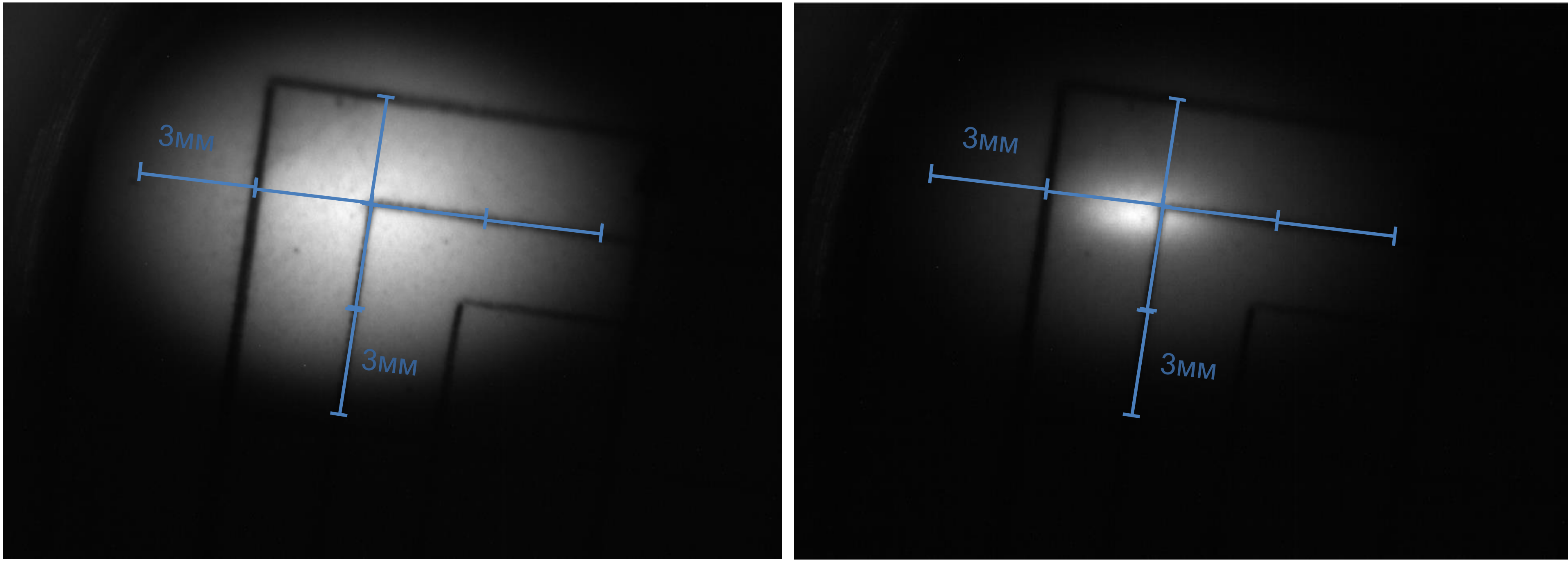
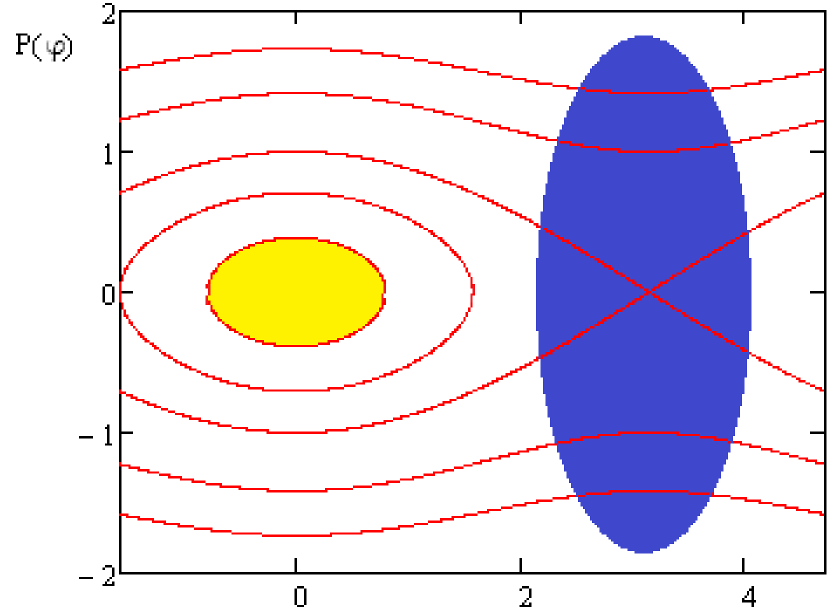


Image of electron beam at Nuclotron entrance without cooling and with cooling.

At electron cooling the rate of events in BM@N *was increased by 2 times*.

Beam Accumulation at electron cooling

- Beam accumulation happens in the longitudinal plane at Booster injection
  - 4 μs bunch – 8 μs revolution time
- Each new injection happens after the previous one is cooled to the core
  - Expected injection rate – 10 Hz
  - 10 – 15 injections will require
  - Total cycle duration ~5 s
- The permanently present 1st RF harmonic weakly affects large amplitude particles
- For small amplitude particles the cooling force will be intentionally reduced to avoid overcooling

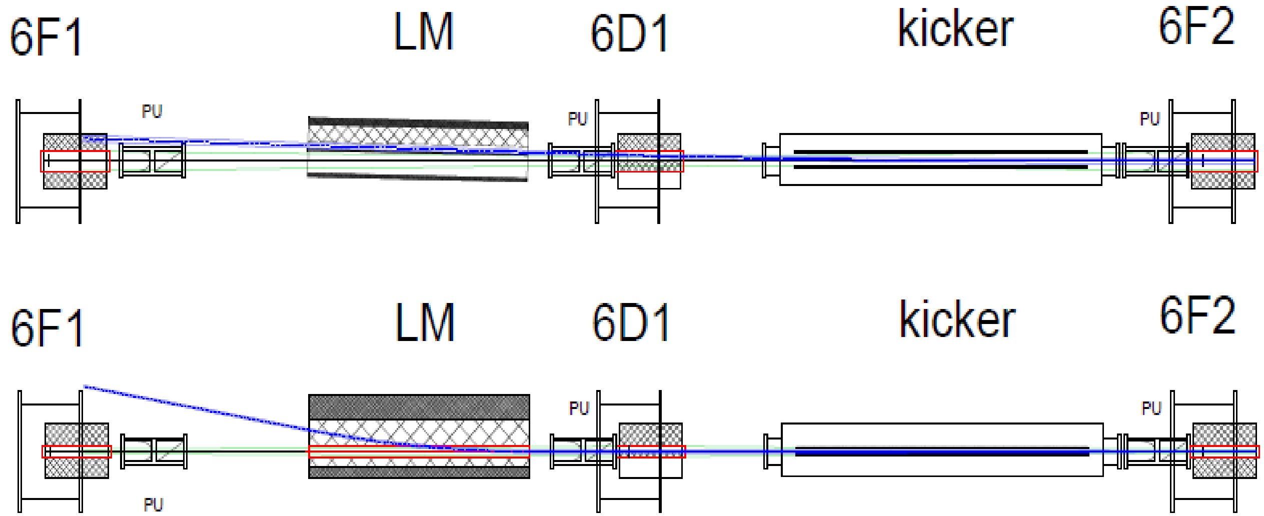


- To avoid anticoolig we need to match well the injection magnetic field and e-beam energy
  - It happens since for large $\Delta p/p$, dF/dt changes sign after reaching the peak

An increase of ion accumulation intensity by a factor of 5 is planned. However application of electron cooling is restricted by ion bunch space charge effects at a level of $\cdot 10^9$ ions of Bi^{35+}

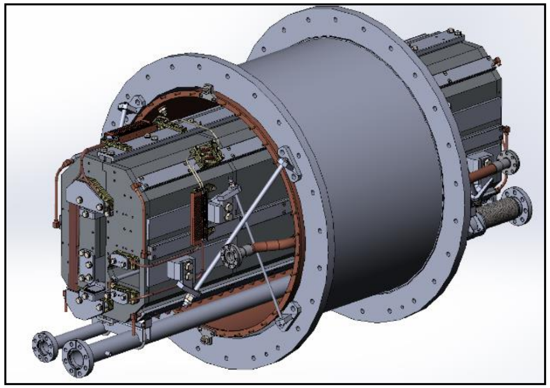
KRION-6T- HILAC -Booster beam run with Xe ions at realization of multi cycle injection, accumulation and electron cooling is planned in June 2024

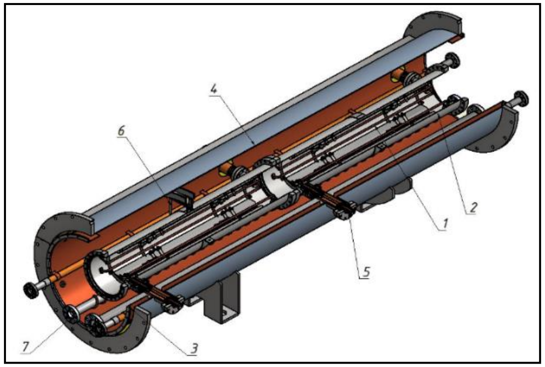
Beam injection system (Nuclotron)

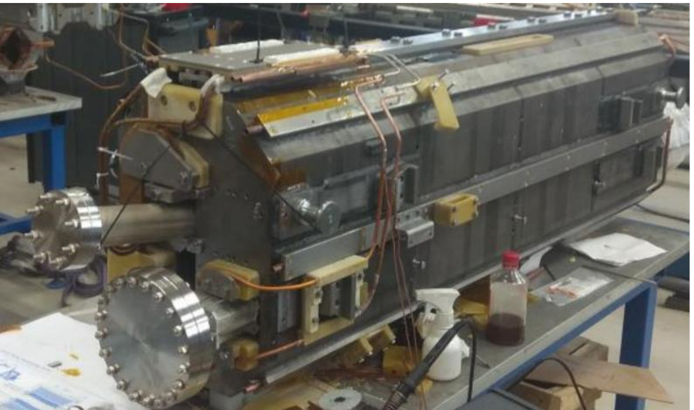


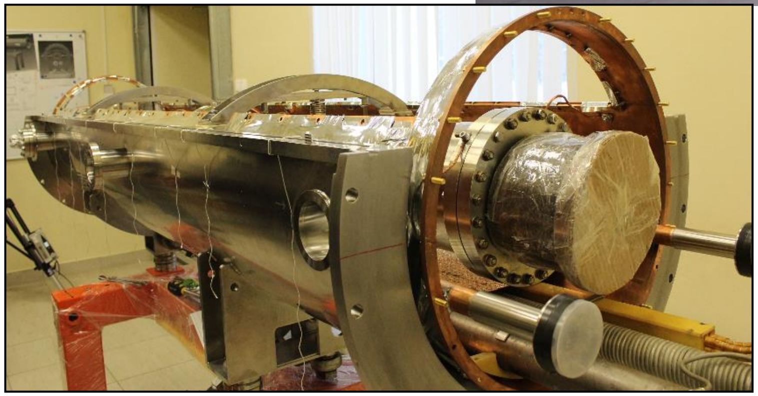
- Lambertson magnet 11.2021
- 4-rod kicker 11.2021
- Testing & mounting Decem. 2021

HILAC-Booster-Nuclotron run - December 2021-January 2022





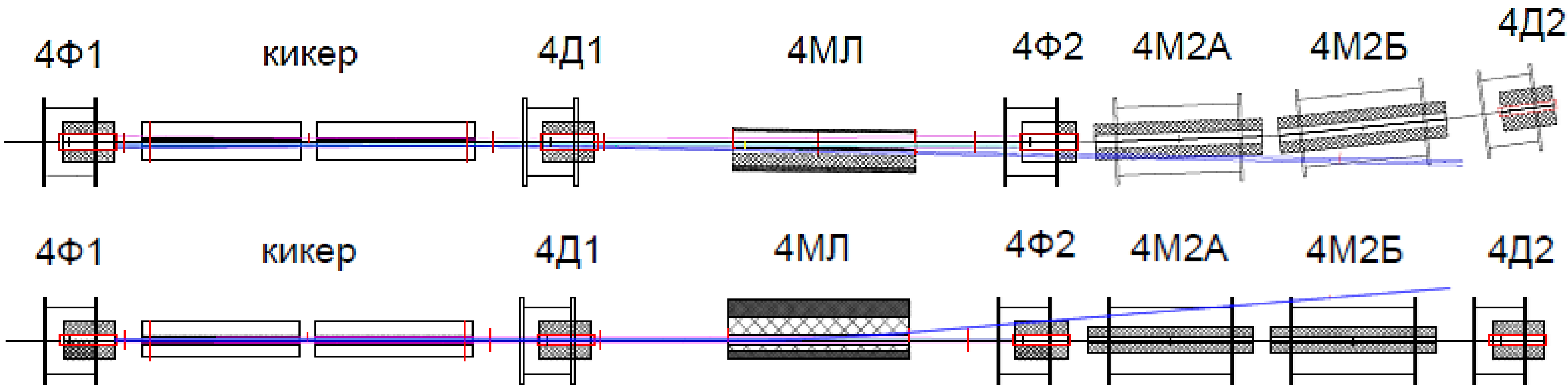




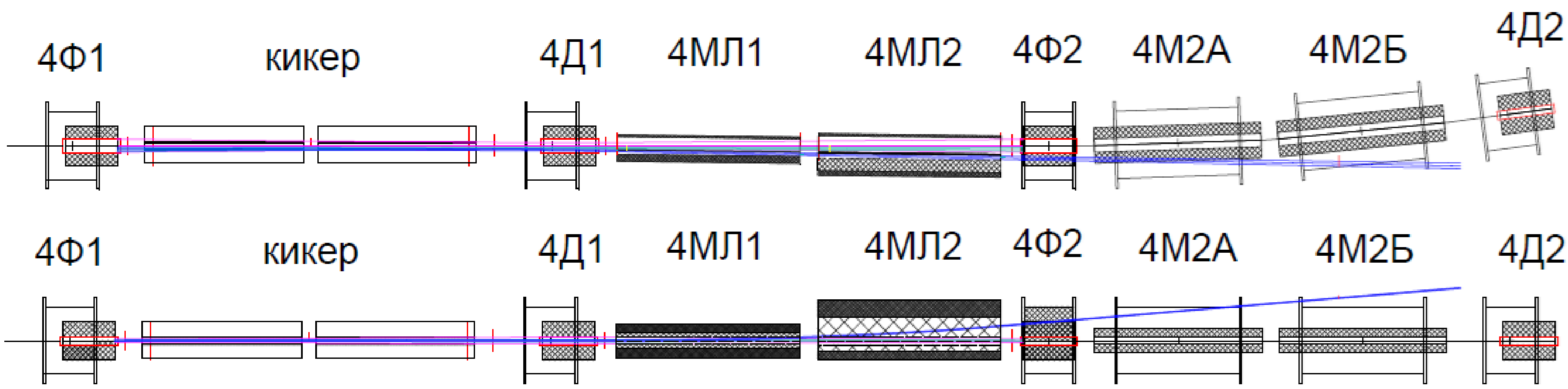
JINR

Nuclotron extraction system

Start configuration (magnetic rigidity up to 29 T·m)



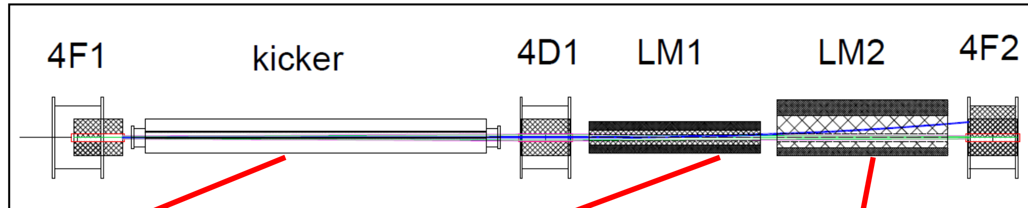
Full configuration (magnetic rigidity up to 38.5 T·m)



Application of one extraction Lambertson magnet permits to reach the maximal kinetic ion energy 2.5 GeV/n in first Collider beam runs

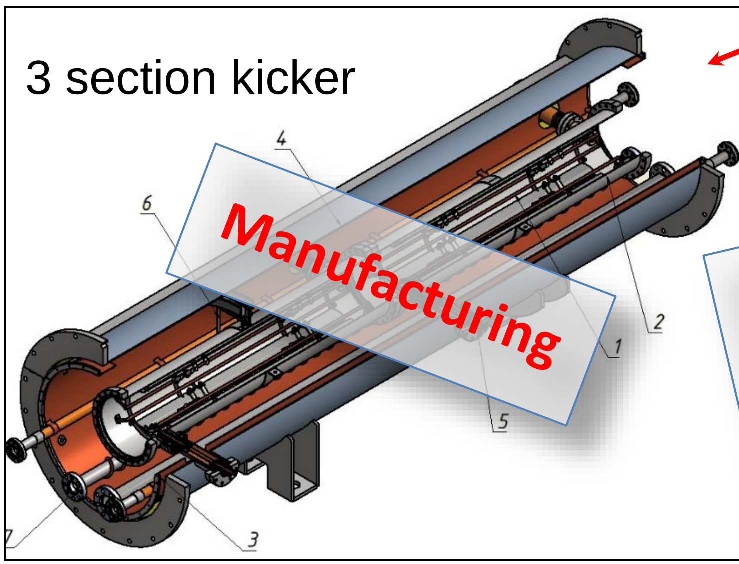
Fast extraction from the Nuclotron

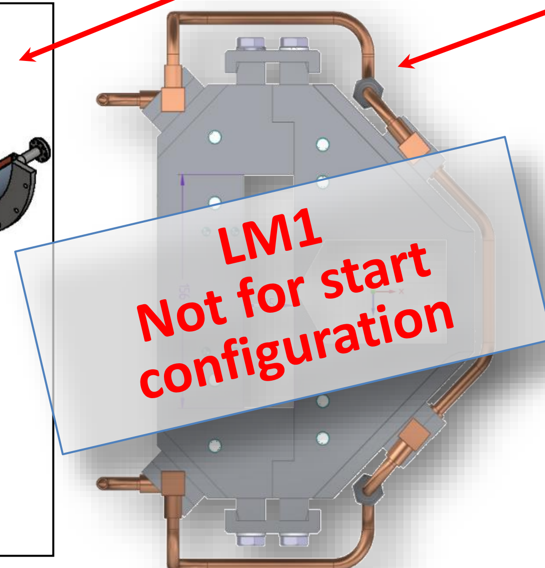
Design was finished, equipment is under construction

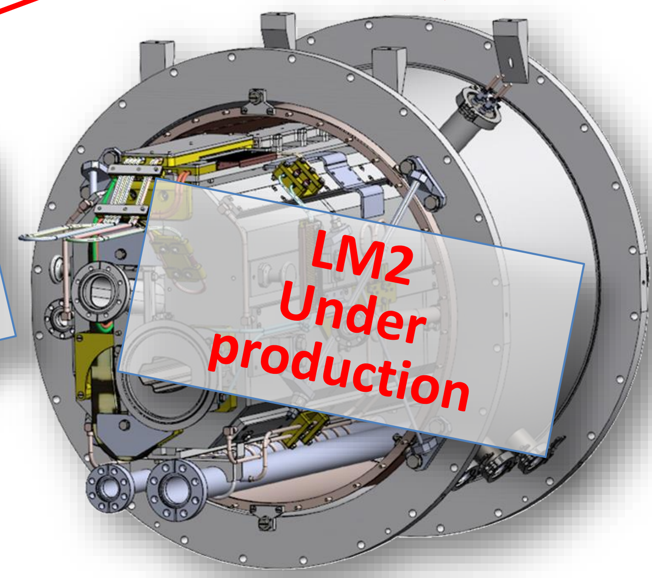


Delays:

- ✓ Due to delays of LM for injection;
- ✓ Due to delays of injection Kicker;





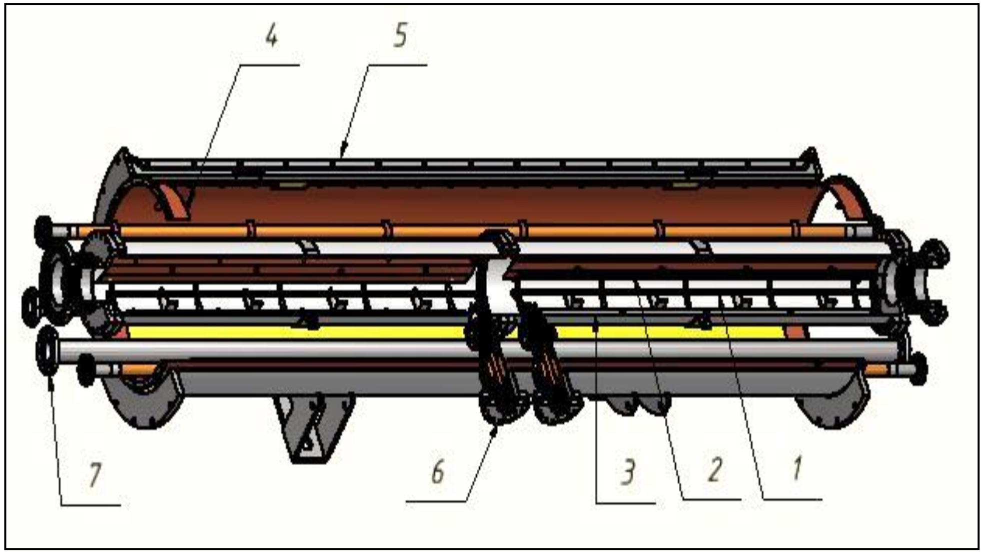


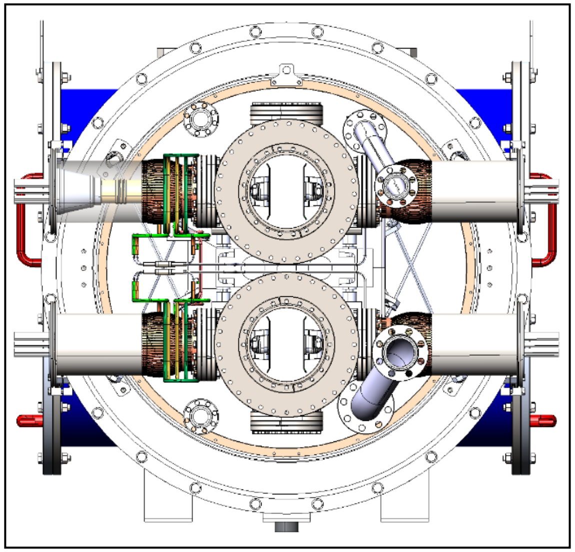
- ✓ Limitation of extracted beam energy by factor 1,6 (~2.5 GeV/u for Bi)
- ✓ Doubling of injection LM with the same design and tooling for higher current;

NICA JINR

Kickers of Nuclotron and Collider

	Extraction from Nuclotron	Injection into Collider
Effective length, m	2×1.3	3×1.3
Max. field, T	0.13	0.055
Bending angle, mrad	8.4	5
Pulse duration, ns:		
rise	550	200
plateau	200	200
fall	600	200
Current amplitude, kA	27	11

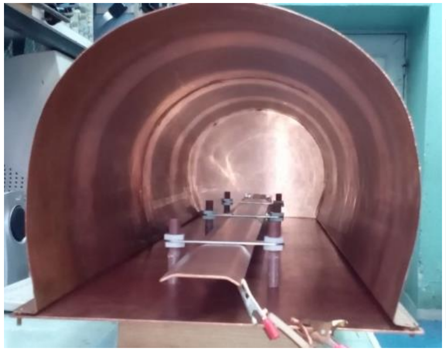


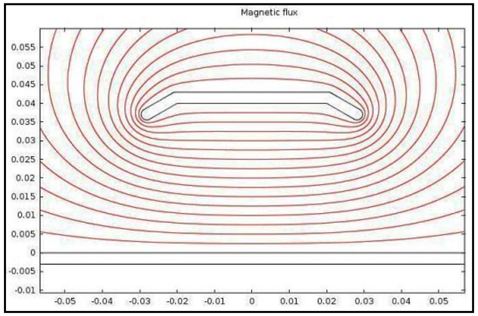


Nuclotron extraction kicker – in production, collider injection kickers – start of fabrication, construction should be finished in beging of 2025

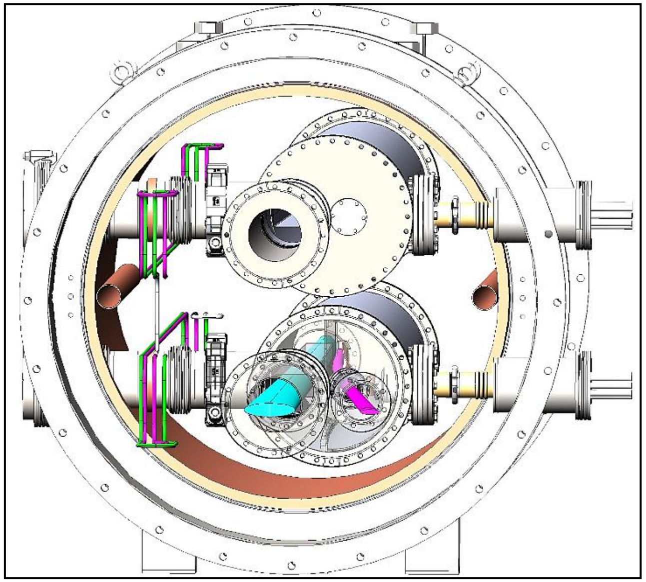
Collider beam injection septa

Effective length, m	2.5
Max. magnetic field, T	0.42
Bending angle, mrad	24
Gap, mm	30
Septum thickness, mm	3
Current, кА	50
Pulse duration, µs	10

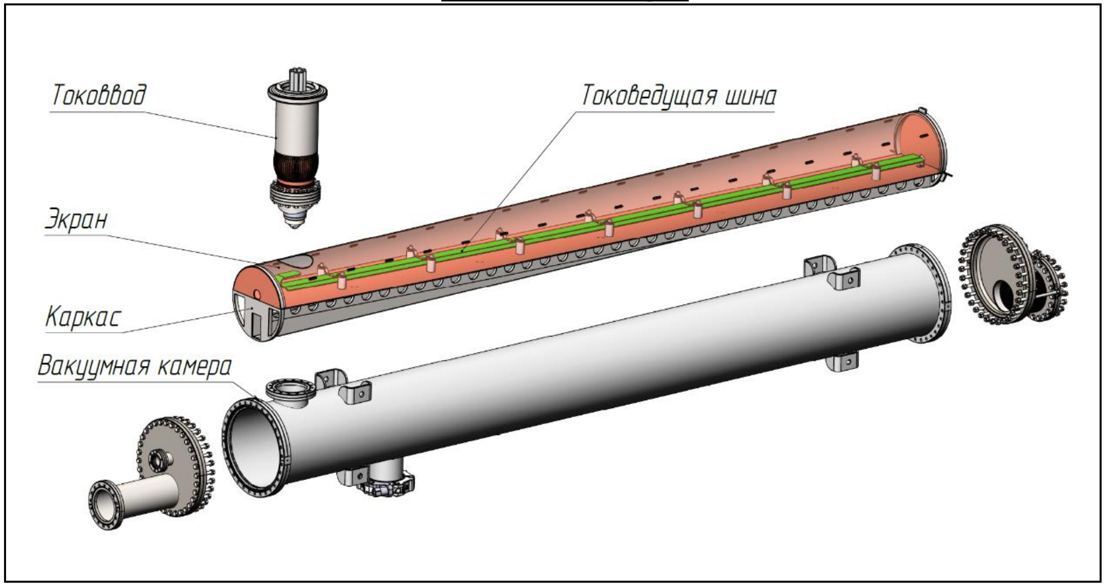




Septum cryostat module



Septum's internal chamber with feedthrough



Nuclotron-Collider beam transport channel

Parameters of pulsed magnet elements

Magnetic element	Number	Effective length, m	Max. magnetic field (gradient), T (T/m)
Long dipole	21	2	1.5
Short dipole	6	1.2	1.5
Quadrupole Q10	22	0.353	31
Quadrupole Q15	6	0.519	31
Steerer	33	0.466	0.114

Magnets delivery in JINR in February 2021

Nuclotron-Collider transfer line was contracted by France firm Sigma Phi

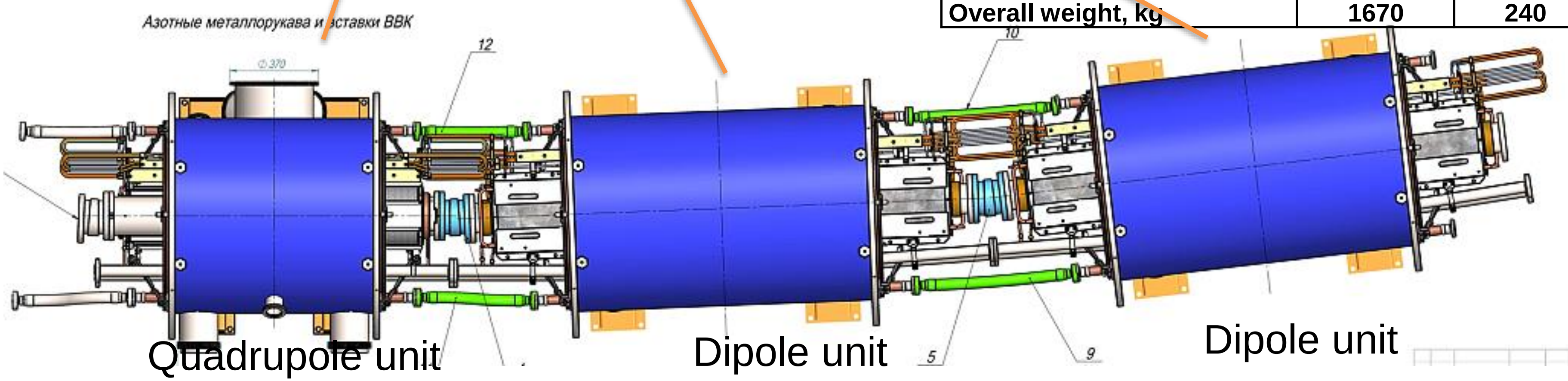
JINR can not obtain part of ready equipment: power supplies, beam diagnostics, vacuum chambers and support stands.

JINR restarts construction and production of this equipment in Summer 2023. We plan to produce this equipment in begging of 2025.

Critical point is construction of magnet power supplies.

The magnetic system: regular period

Parameter	Dipole	Lens
Number of magnets (units), pcs	80	46
Max. magnetic field (gradient)	1.8 T	23.1 T/m
Effective magnetic length, m	1.94	0.47
Beam pipe aperture (h/v), mm	120 / 70	
Distance between beams, mm	320	
Overall weight, kg	1670	240

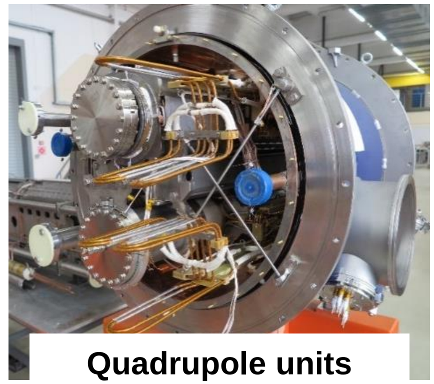


NICA

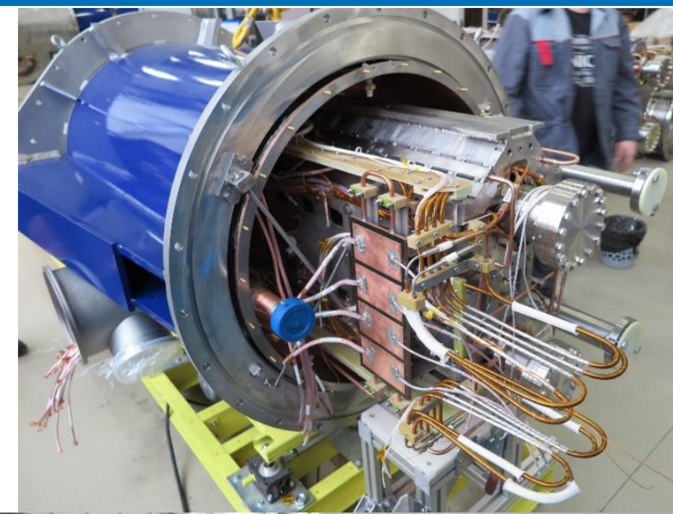
Nuclotron-based
Ion Collider fAcility

The magnetic system: magnets

Title	Nes.	Fin.	Prod. %
2×ap Dipole units	80+1	84	100
2×ap Quadrupole units	46	46	100
4×ap Quadrupole units	12	2	80
BI vertical 1×ap dipole units	4	0	80
BI vertical 2×ap dipole units	4	0	80
Final focusing quadrupoles	12	0	80



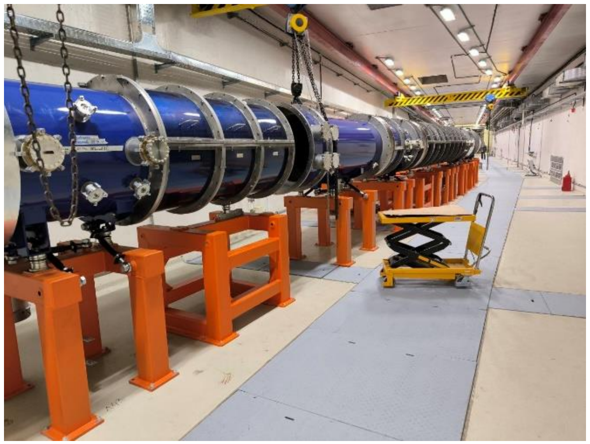
Quadrupole units



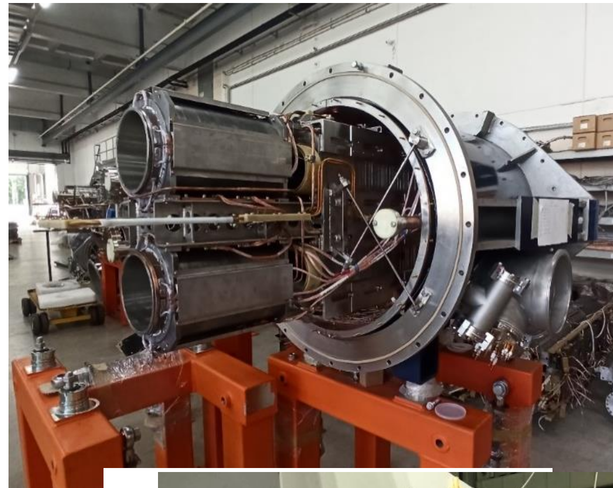
Final focusing quadrupoles

BI vertical 1x dipole units

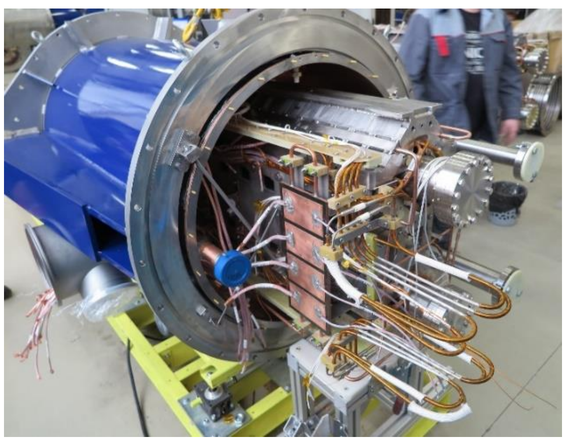
Straight sections: magnets



Straight section



Final focuse lense



Straight section lenses

straight sections and MPD final focus

Collider power supply system

Each collider ring has its own power supply system based on 3 main current sources

2 sets of main PS for both collider rings are manufactured by NPP "LM Inverter" and delivered to JINR.

12 energy evacuation keys was constructed and tested

68 Additional power supplies (10B x 300A)

Busbars system model in b.17

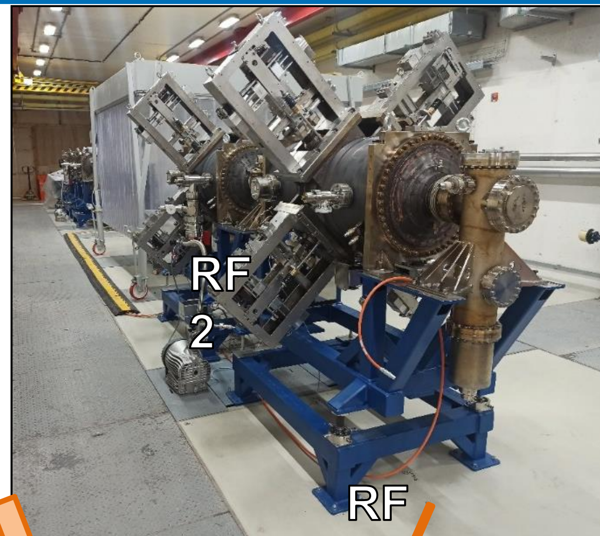
NICA

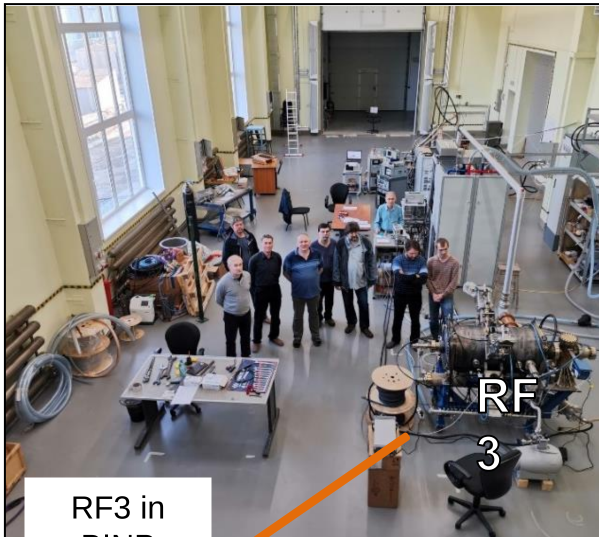
JINR

Nuclotron-based
Ion Collider fAcility

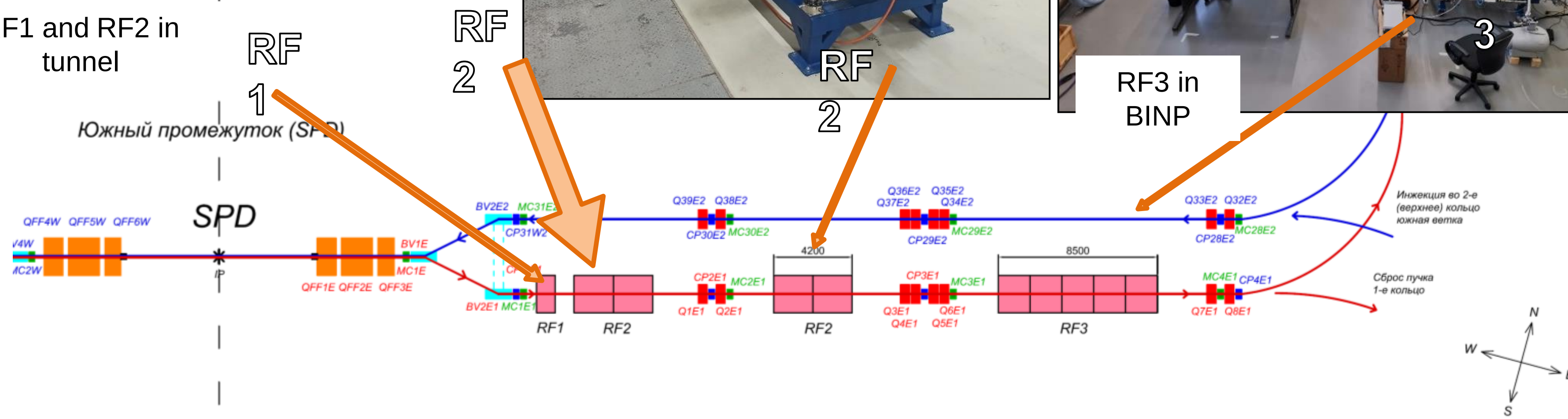
RF system: status RF1 and RF2

RF1 and RF2 in tunnel



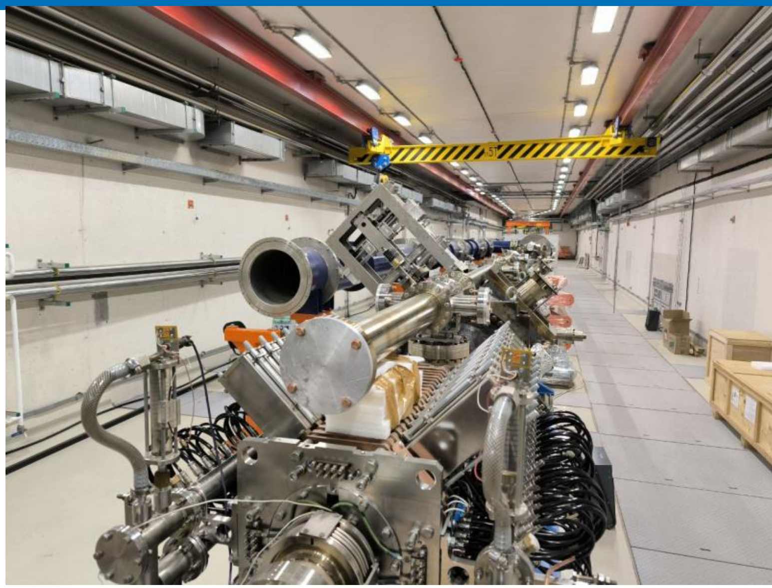


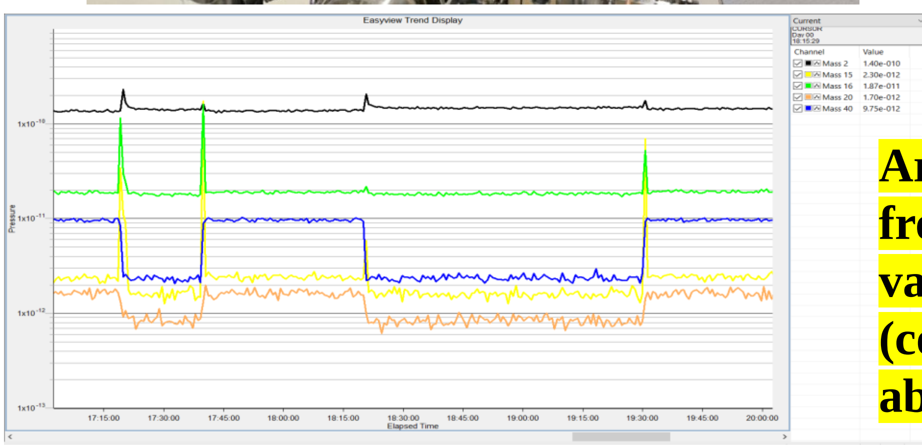
RF3 in BINP



- **All RF1 and RF2 cavity in JINR.**
- **One RF1 and four RF2 cavities were mounted. Other four RF2 were installed in the end of 2023**
- **RF3 cavities and amplifier in BINP. Installation of two RF3 cavities in the summer of 2024**

RF system: status RF1 and RF2



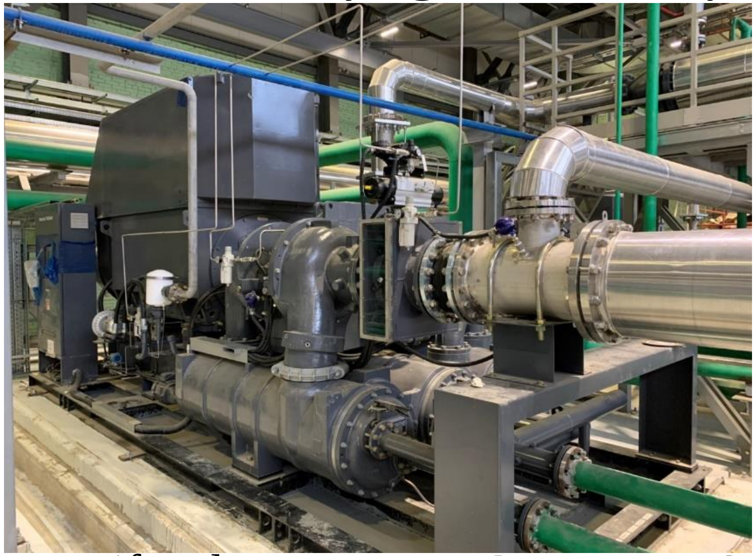


RF1 and RF2 in tunnel

Ar vacuum pressure in RF2 cavity is about 8% from hydrogen pressure. At turbo pumping Ar vacuum pressure is reduced by a factor of 4-4.5 (cost of additional valve and turbo pump is about 50 kE per RF2 cavity).

Status of cryogenic compressor station

Aerocom - 2 179/18



Hanwha Techwin SM5000

Commissioning and tests of nitrogen centrifugal compressor **Aerocom - 2 179/18 and two nitrogen centrifugal compressors Hanwha Techwin SM5000** was done. Compressors pass through 72 hour tests in air medium and they are ready for testing in NICA cryogenic nitrogen system.

Spiral helium compressor

Commissioning and tests of two spiral helium compressors **«Kaskad- 110/30»** was performed in air medium durin 3 hours. There is leakage in oil cooling system. Firm Helijmash provides repair of this system. During May 2024 we plan to finish testing of compressors.

Program of the December 2024 Collider technological run

- I. Collider cryomagnetic tests:
- Tests of Power supplies on an equivalent load
- Tests of energy evacuation switchers
- Vacuum of isolation volume
- High vacuum of beam chamber
- Operation of control system
- Magnet system cryogenic cooling
- Thermometry tests
- Operation of quench protection and evacuation system
- Formation of magnetic cycle, power supplies tuning
- Corrector system tuning

Main risks

Design of helium lines to far from beam transfer line arc –April 2024, BINP
Construction of helium lines - May-November 2024, Cryoservice
Connection and welding of cryogenic loops of magnet coils (10% of performed work)

NICA Nuclotron-based Ion Collider fAcility

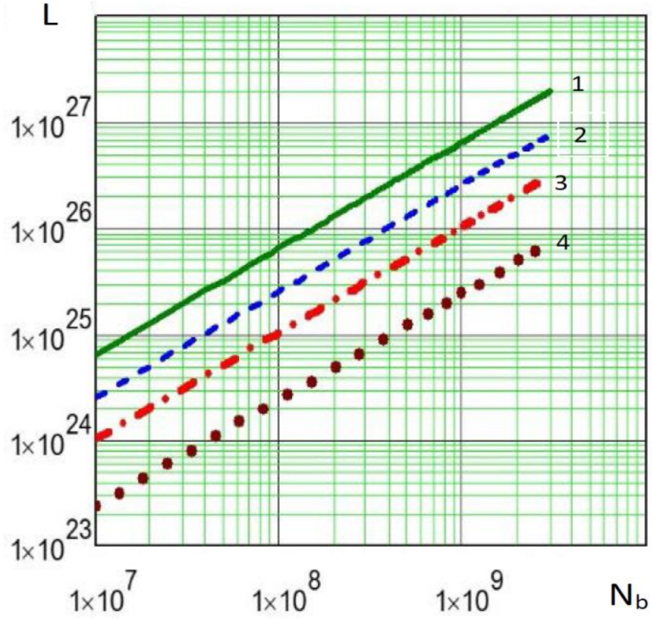
The first Collider run with beam

NICA Stage II-a (basic configuration): April 2025

1. Injector chain: KRION => Booster => BTL BN => Nuclotron
2. BTL Nuclotron => Collider
3. Collider equipped with
- RF-1 - (barrier voltage system) for ion storage
- RF-2 - 4 cavities per ring (100 kV RF amplitude)

Result: 22 bunches of the length σ ~ 2 m per collider ring that 2e25 $cm^{-2} \cdot s^{-1}$. Maximum kinetic ion energy 2.5 GeV/n

	Booster		Nuclotron		Collider
	Injection	Extraction	Injection	Extraction	
E	3,2 MeV/u	530 MeV/u	523 MeV/u	1,5-2,5 GeV/u	1,5-2,5 GeV/u
N	$5 \cdot 10^8$	$3.5*10^8$	$2.5*10^8$	$2*10^8$	$2*10^8$ (at injection) $4*10^9$ (at RF1 accumulation and formation of 22 bunches by RF2)
B_d, Тл	0,1	1,6	0,4	<1,2	<1.2



Dependence of luminosity on number ions per buch at different energies (1) 4.5 GeV/u (2) 3GeV/u, (3) 2 GeV/u, (4) 1 GeV/u.

Thank you for attention

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