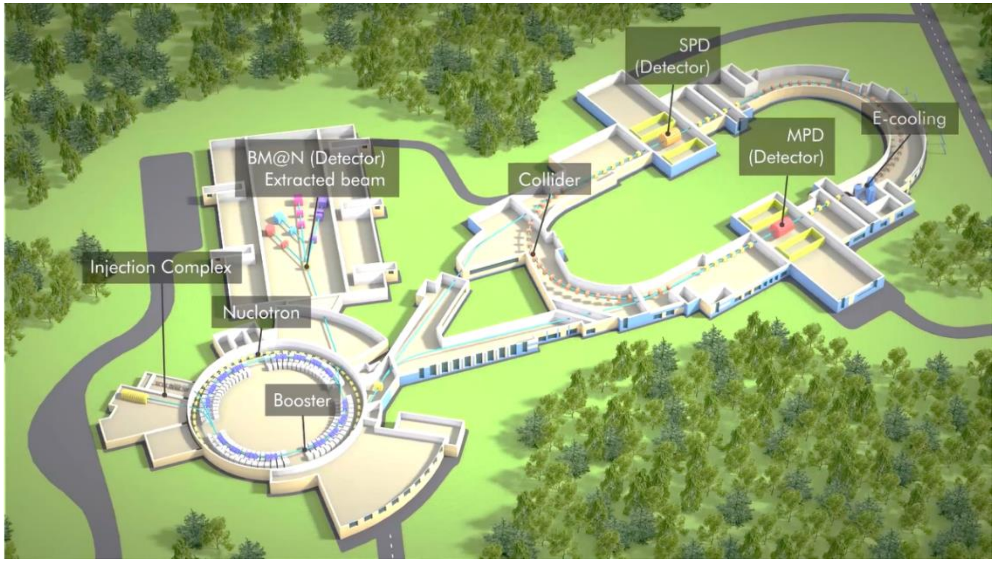
Status of complex NICA

Evgeny Syresin on behalf of Accelerator division

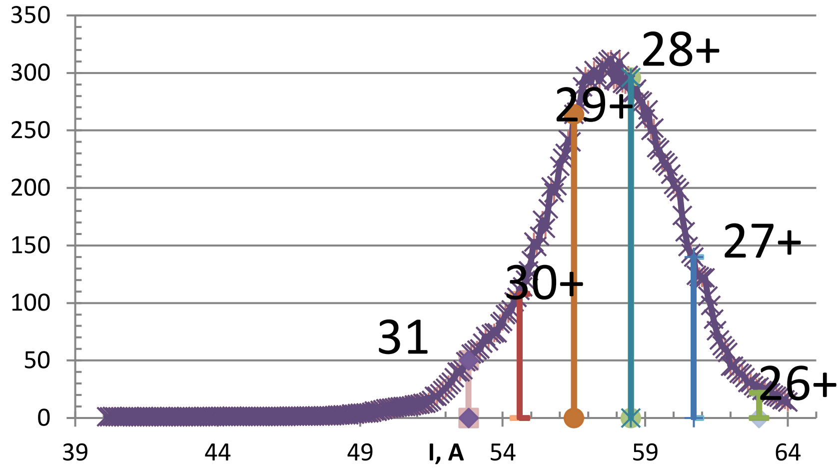
Booster-Nuclotron-Collider beam injection/extraction systems



Beam Parameters

	Booster injection	Booster extraction	Nuclotron injection	Nuclotron extraction	Collider injection
Ions	Au^{31+}	Au^{31+} / Au^{79+} (stripping)	Au^{79+}	Au^{79+}	Au^{79+}
Energy of ions, MeV/u	3.2	578	572	1000 ÷ 3800	1000 ÷ 3800
Maximum magnetic rigidity, T·m	1.64	25	10	14 ÷ 38.5	14 ÷ 38.5
Ion number	$2 \cdot 10^9$	$1.5 \cdot 10^9$	$1.3 \cdot 10^9$	$1 \cdot 10^9$	$1 \cdot 10^9$

Ion source KRION-6T



Xe ion charge distribution at KRION exit

Project ion intensity $2 \cdot 10^9$ Bi^{35+} per pulse

Достигнутые величины

Ar^{16+} - $5 \cdot 10^8$ ions per pulse

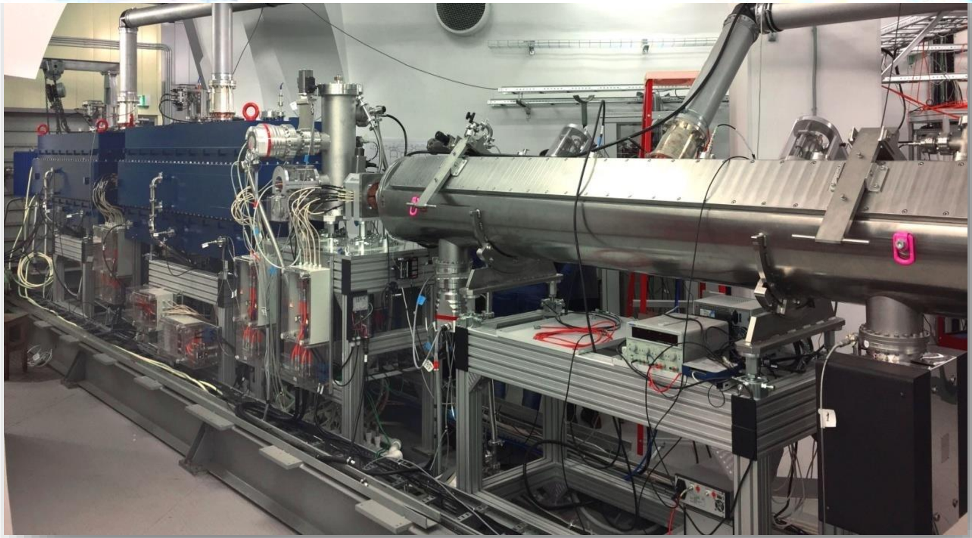
Xe^{28+} - $2 \cdot 10^8$ ions per pulse

Bi^{35+} - $2 \cdot 10^8$ ions per pulse

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

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.

Further development

Realization of multy cycle injection and upgrade of KRION-6T

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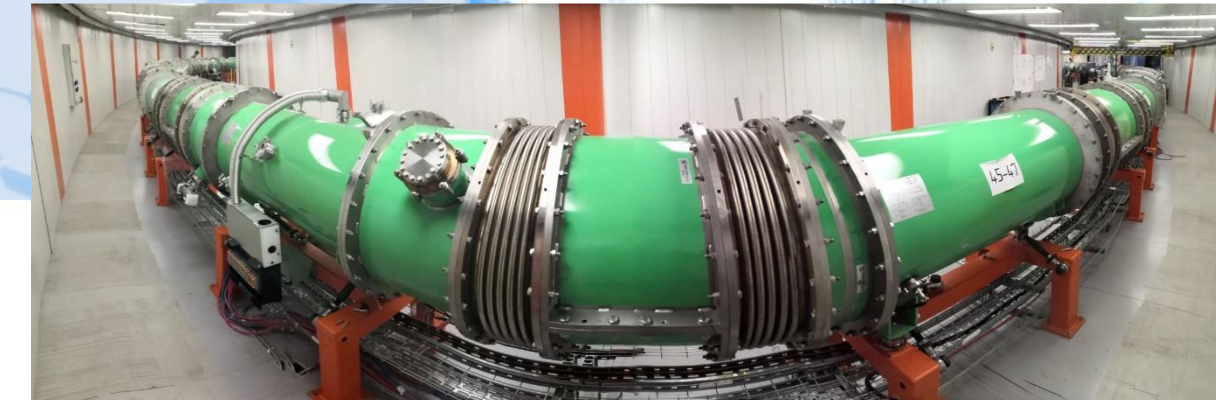
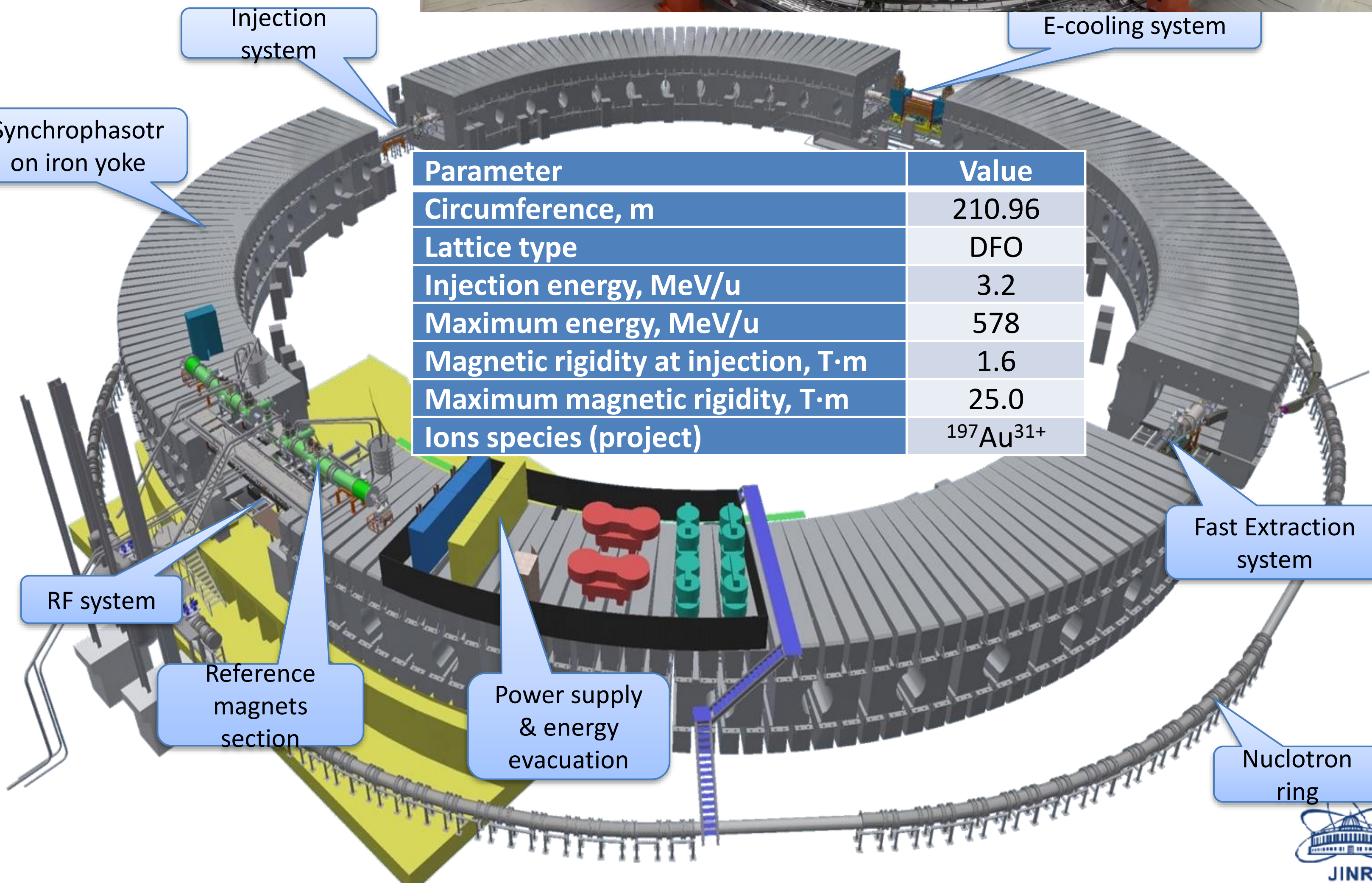
Booster ring layout (2021)





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)	$^{197}Au^{31+}$

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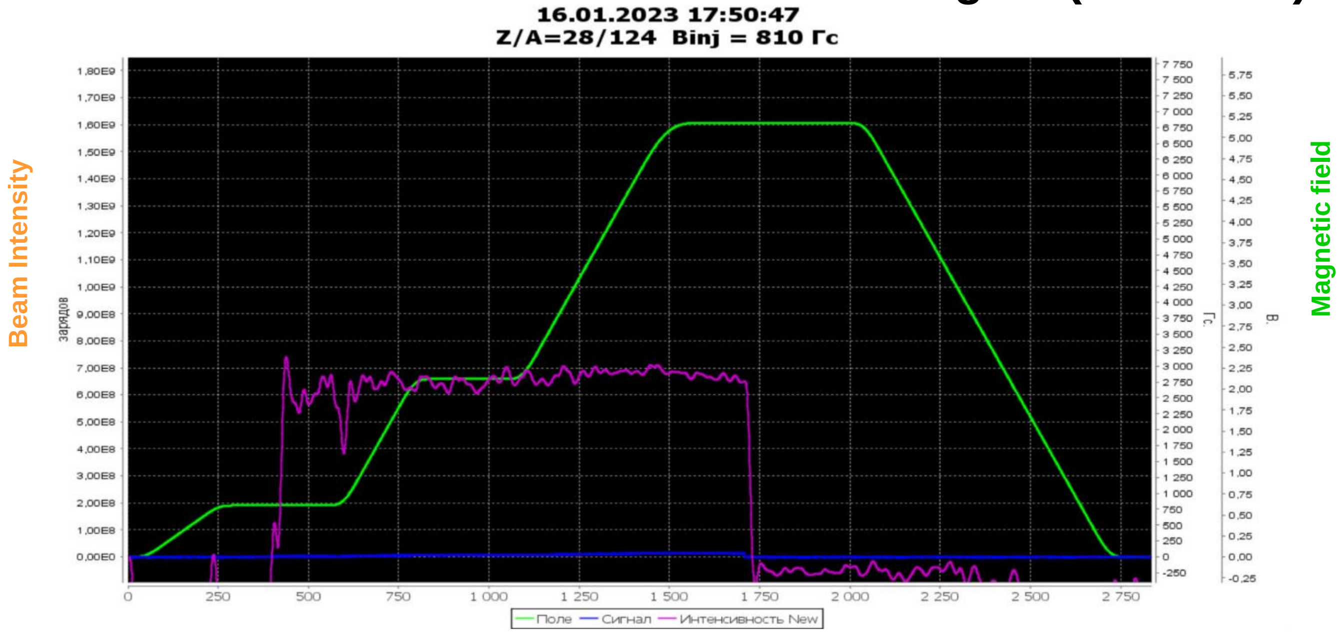
Booster Beam current

Parametric beam current transformer signal (DC mode)

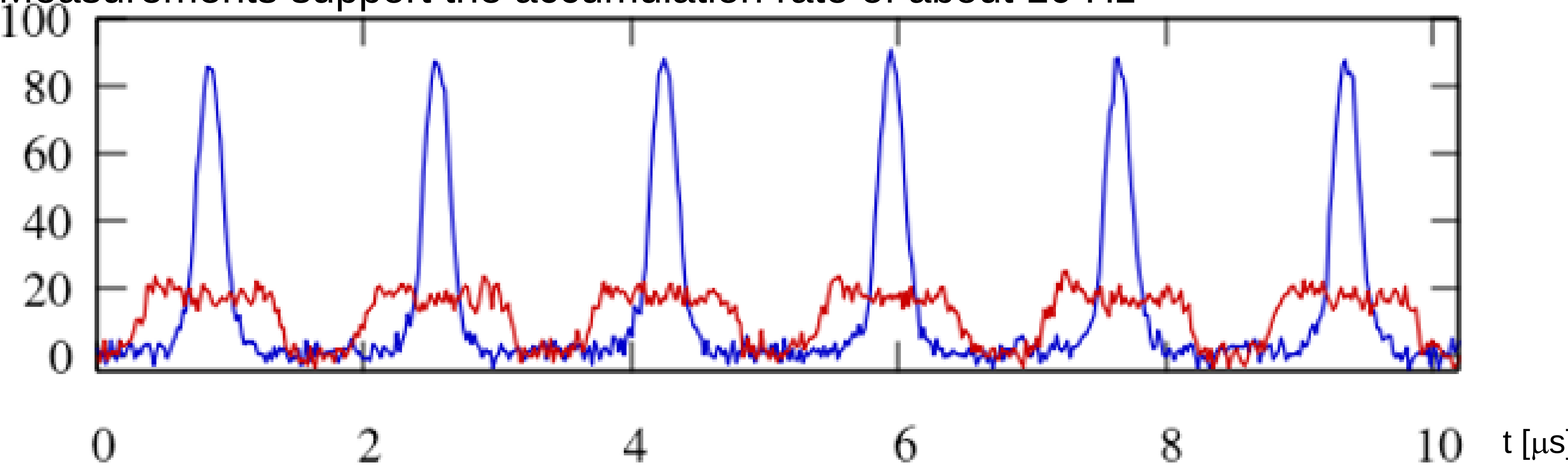


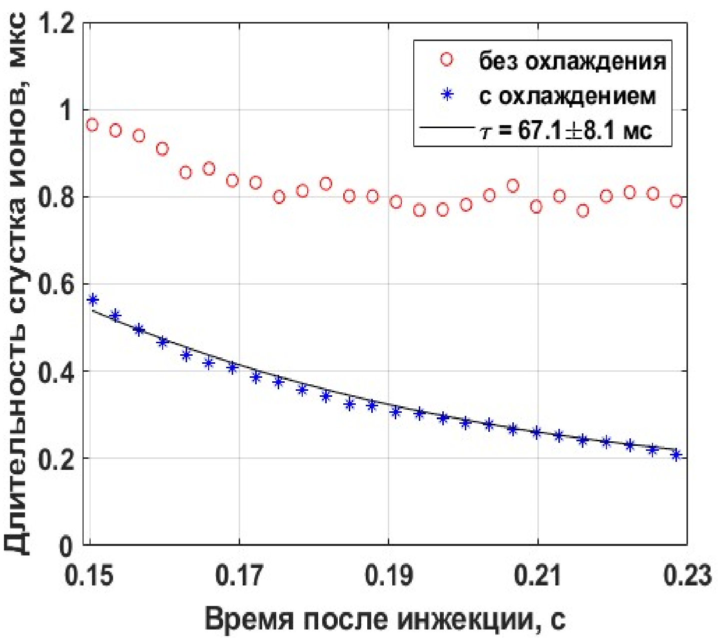
Booster-Nuclotron run - September 2022 - February 2023 for BM@N baryonic matter researches. Booster acceleration of ions $^{124}Xe^{28+}$ to energy 204,7 MeV/n, where they were stripped up to bare nucleus end extracted in Nuclotron.

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

Electron Cooling in Booster

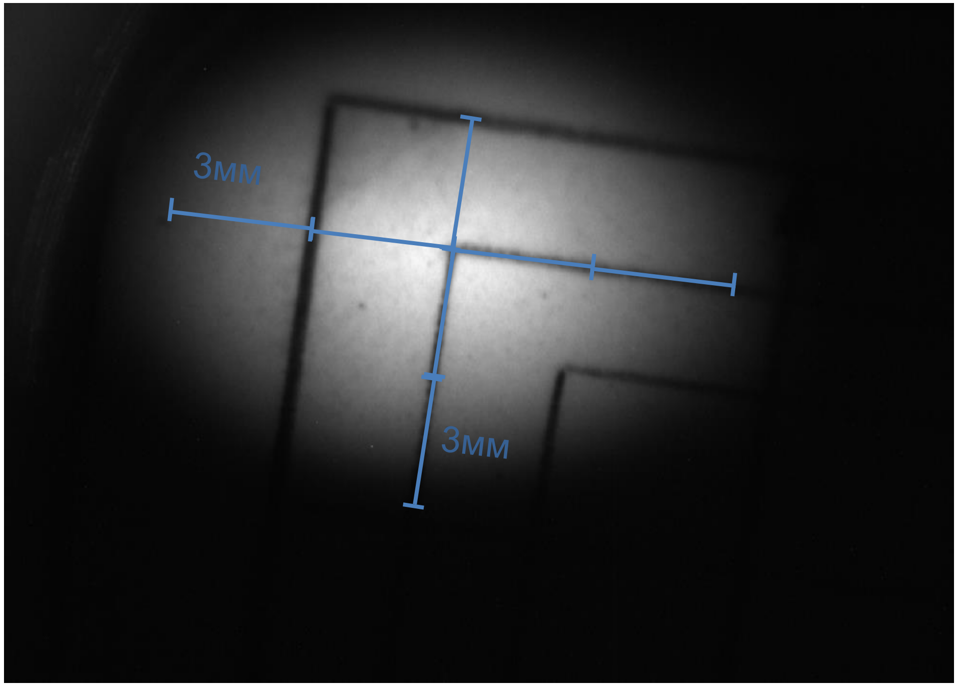
- Electron cooling was demonstrated with the RF voltage present as it is required for beam accumulation
- Measurements support the accumulation rate of about 10 Hz





Beam current dependence on time with and without electron cooling. Rf harmonic number – 5. Cooling cycle duration - 200 ms. Electron beam current 50 mA. Electron beam voltage 1.83 keV

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



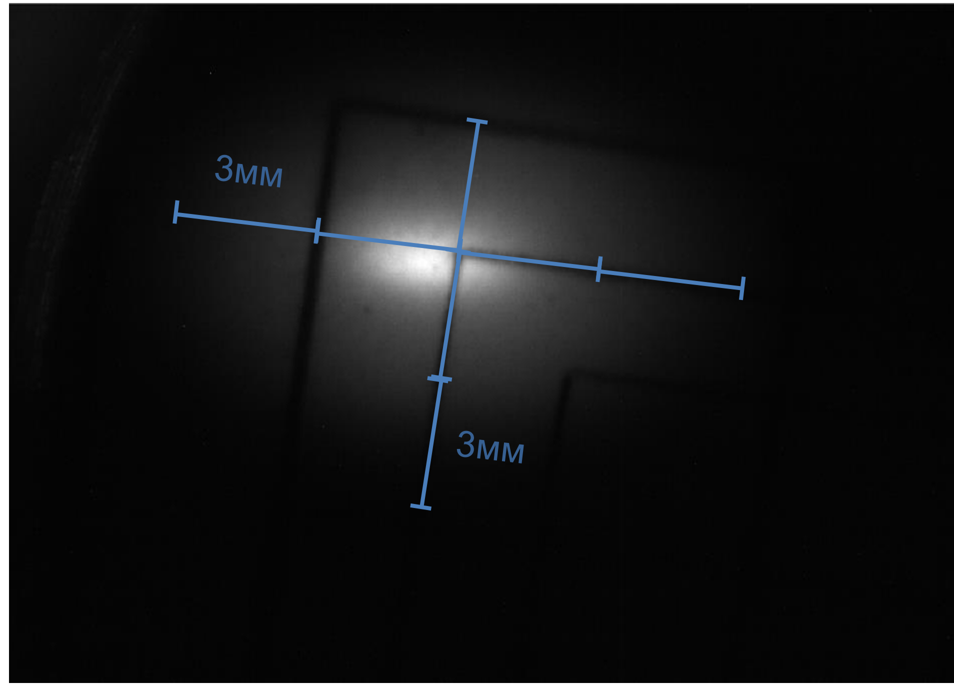
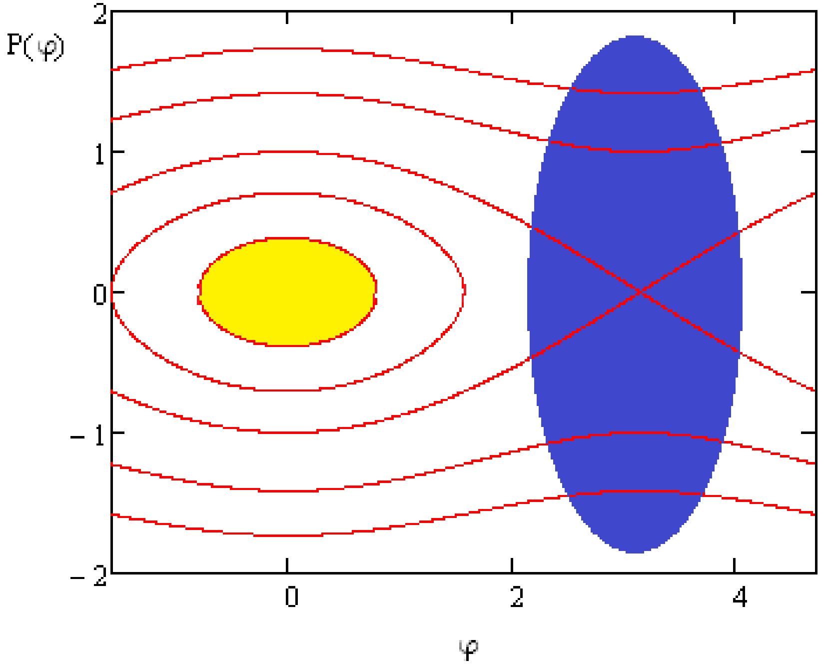


Image of electron beam at Nuclotron entrance without cooling and with cooling.

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 injections will require
  - Total cycle duration ~5 s
- The permanently present 1^{st} 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 Δ*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+}

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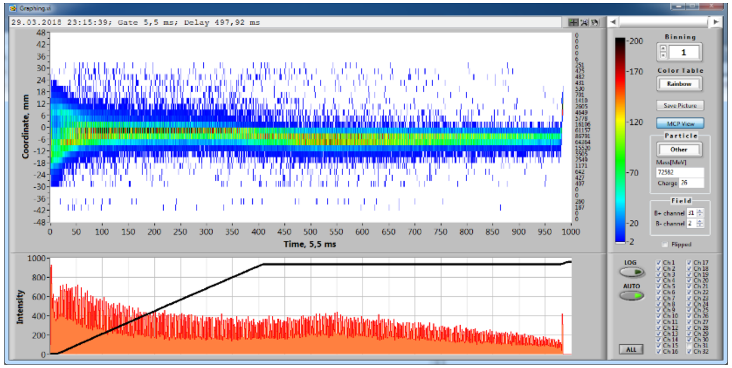
Ion beams in Nuclotron

Parameter	Project	Status (June 2018)
Max. magn. field, T	2	2 (1.7 T routine)
B-field ramp, T/s	1	0.8 (0.7 routine)
Accelerated particles	p–U, d↑	p↑, d↑, p – Xe
Max. energy, GeV/u	12 (p), 5.8 (d) 4.5($^{197}Au^{79+}$)	5.6 (d, ^{12}C), 3.6 ($^{40}Ar^{16+}$)
Intensity, ions/cycle	1E11(p,d), 2E9 (A > 100)	d $4*10^{10}$ ($2*10^{10}$ routine), $^{7}Li^{3+}$ $3*10^{9}$ $^{12}C^{6+}$ $2*10^{9}$ $^{40}Ar^{16+}$ $1*10^{6}$ $^{78}Kr^{26+}$ $2*10^{5}$ $^{124}Xe^{42+}$ $1*10^{4}$

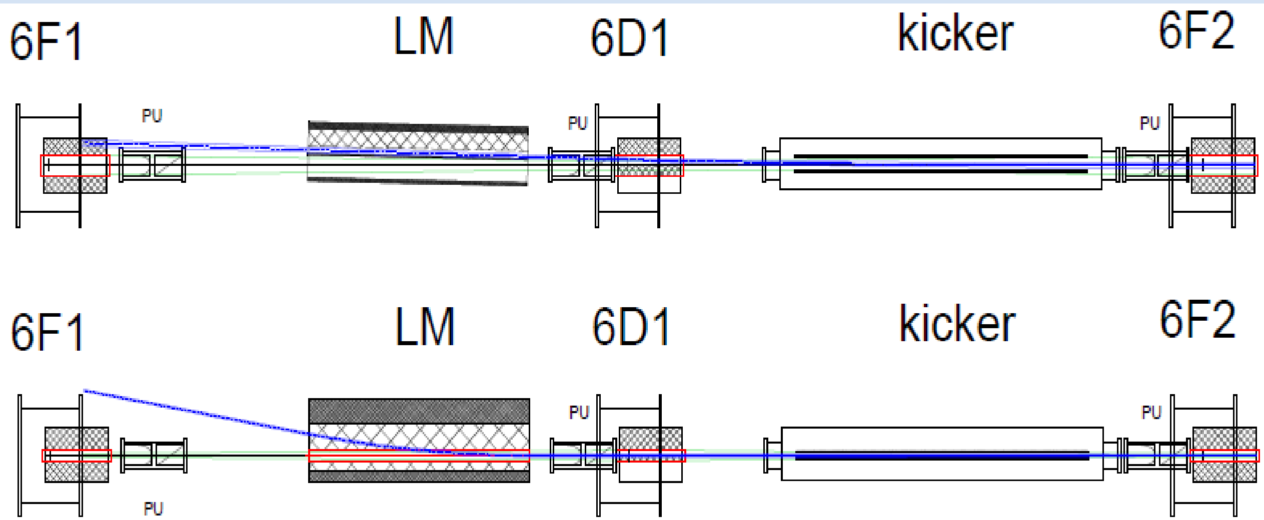
Nuclotron since operation 1993



$^{78}Kr^{+26}$ beam acceleration (3,2 GeV/u)
RUN #55

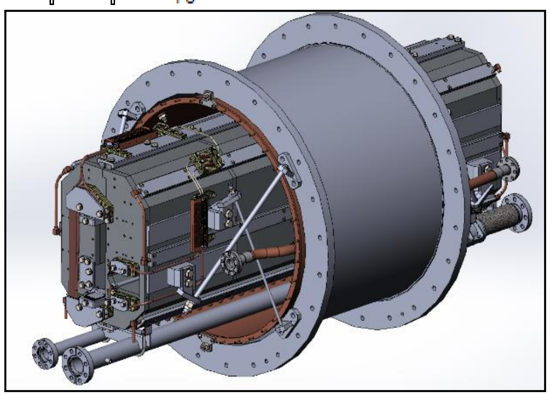
<u>Intensity of xenon ion beam was increased by 3 orders of magnitude at Booster-Nuclotron run 2022-2023</u>

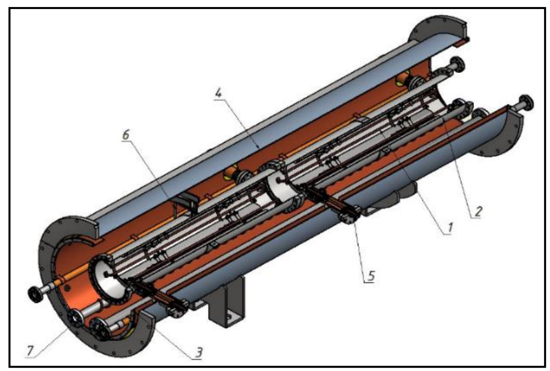
Beam injection system (Nuclotron)

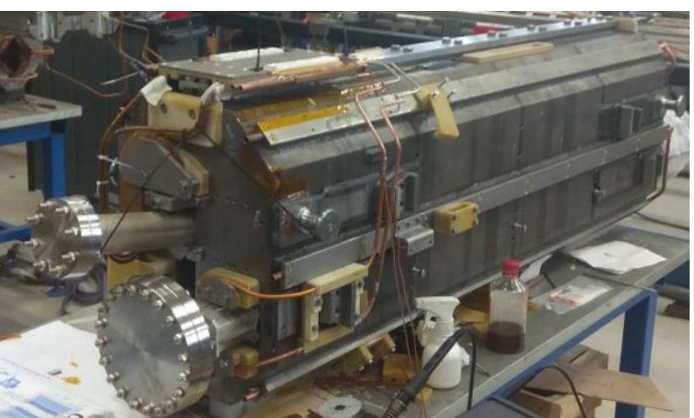


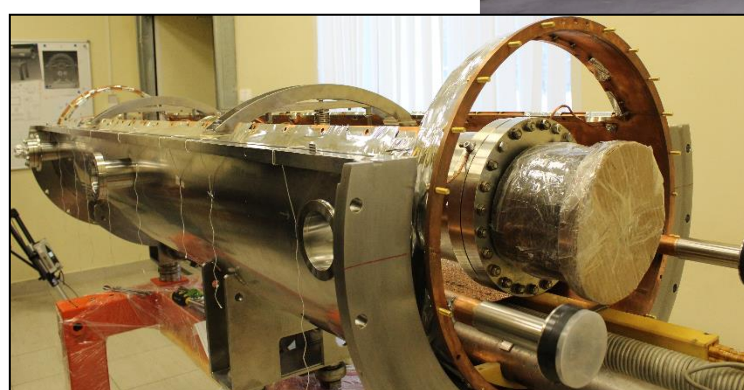
- Lambertson magnet
11.2021
- 4-rod kicker
11.2021
- Testing & mounting
Decem. 2021

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





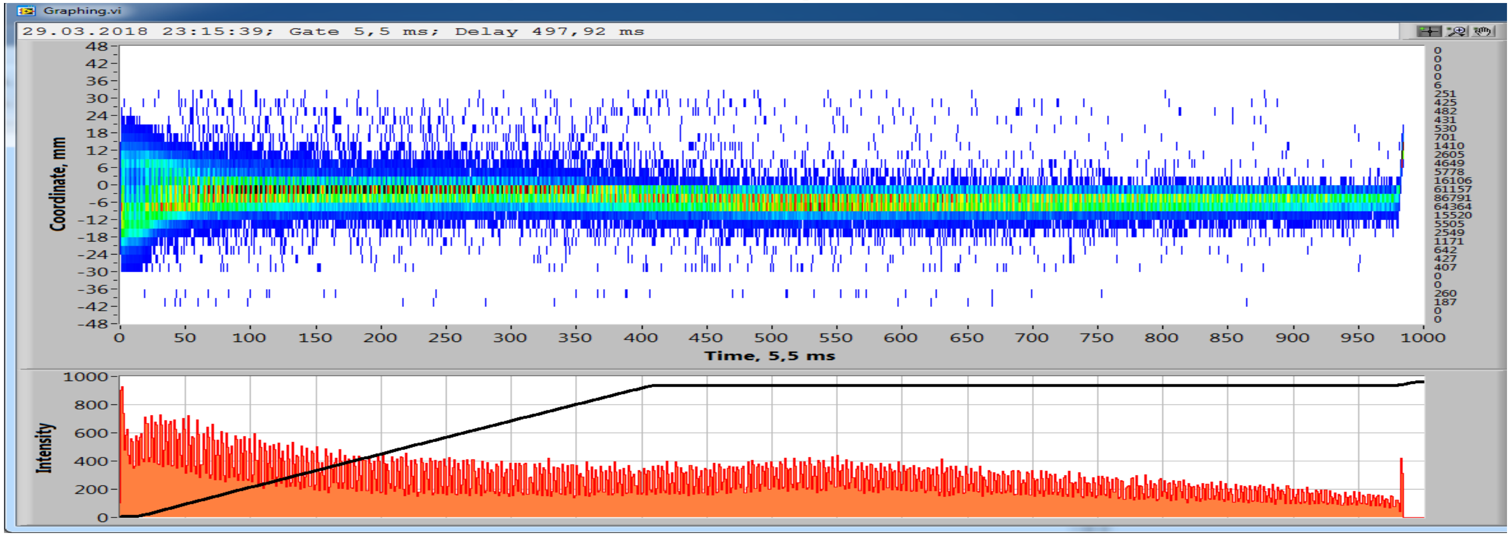


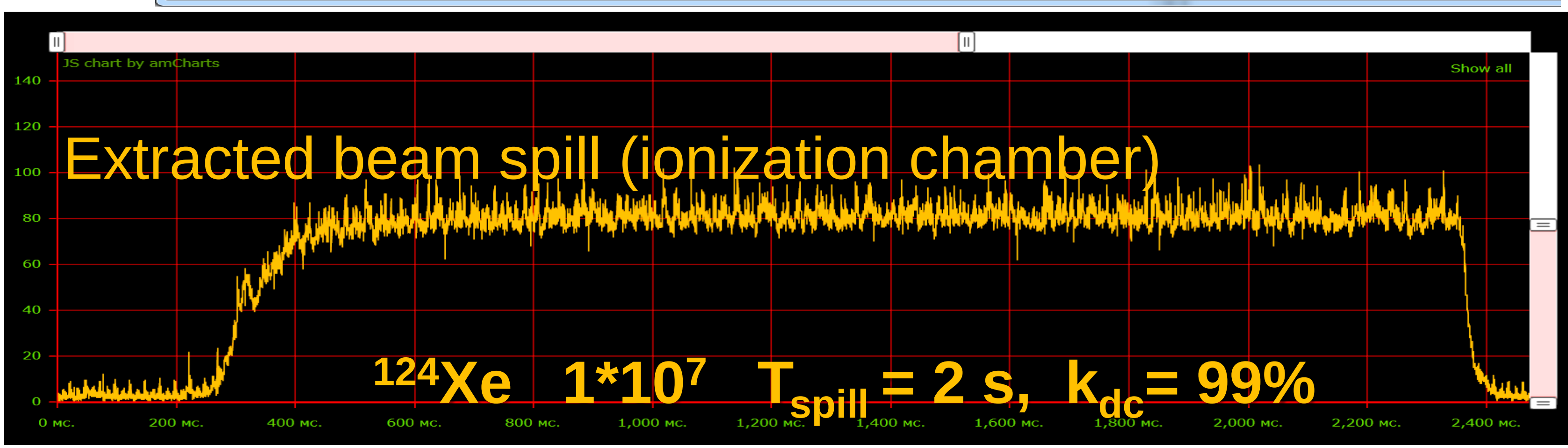


Heavy ion beams acceleration

Jan. 2023

$^{124}Xe^{+54}$ beam extraction (3,9 Gev/u) RUN #4 at NICA complex





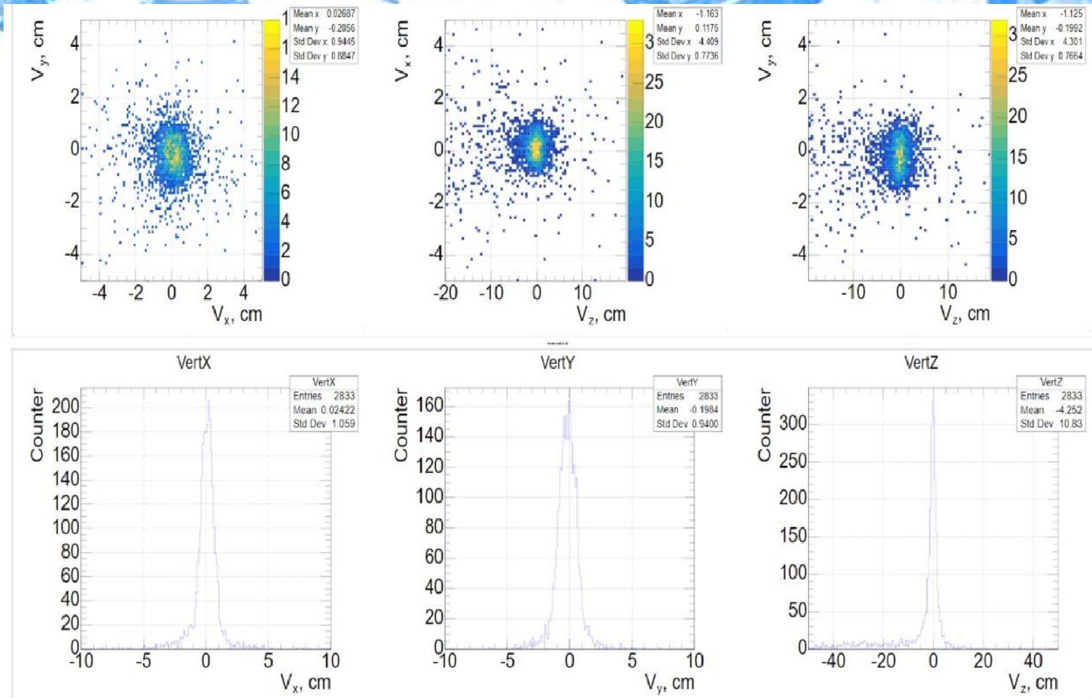
$^{124}Xe^{+54}$ Nuclotron circulated beam intensity of 3*10^{7} nucleus

To reach the Nuclotron project intensity of 1*10^{9} is required multy cycle injection

NICA

JINR

BM@N experiment

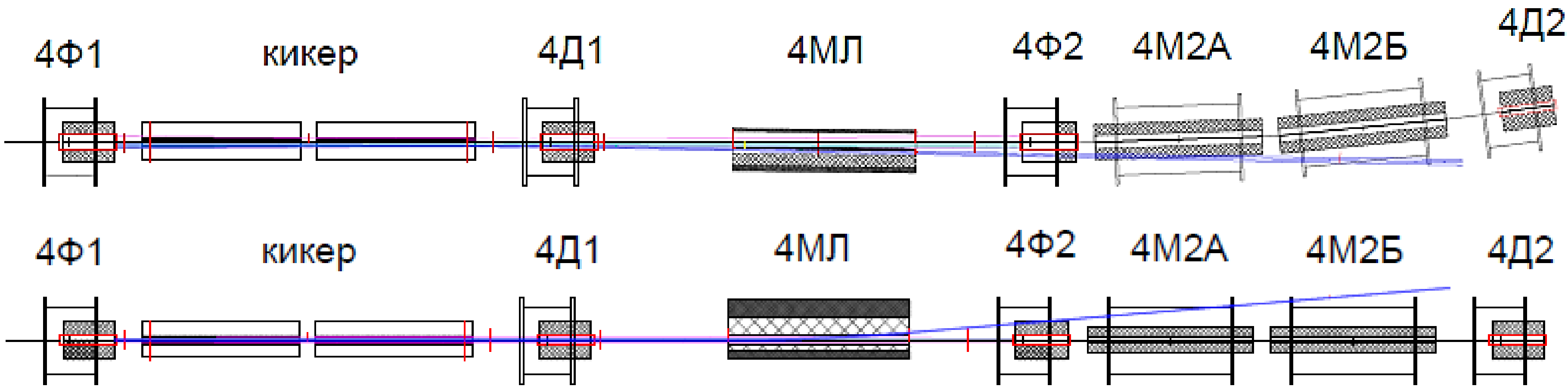


Experiments with BM@N was performed in December 2022 –February 2023. More than 500 millions events were measured at rate of 10^6 Xe^{54+} nucleus per second at energy of 3.9 Gev/n.

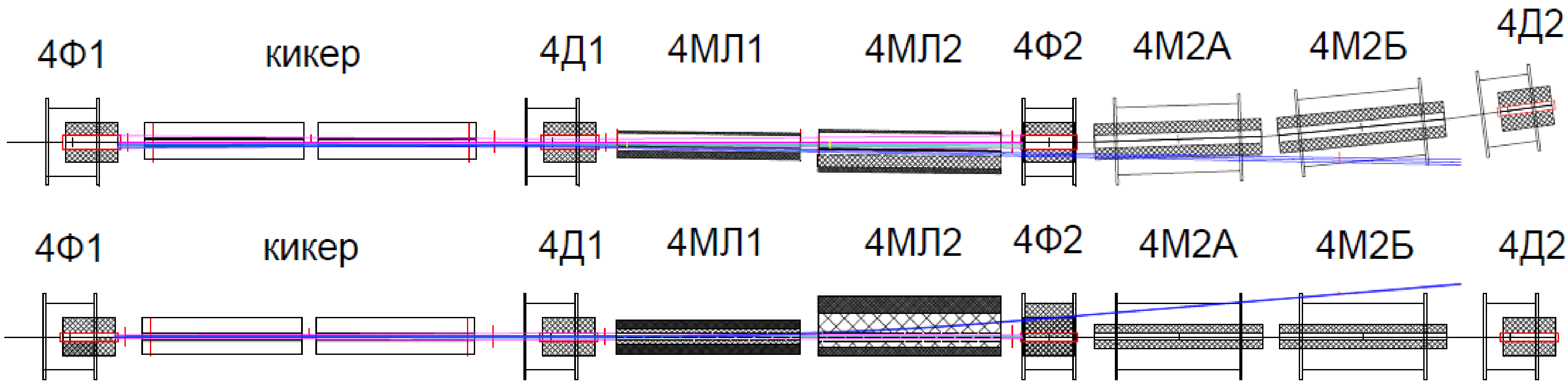
Beam intensity of Xe^{54+}nucleous was increased by 3 orders of magnitude in comparison with 2010 year at xenon acceleration in Nuclotron.

Nuclotron extraction system

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



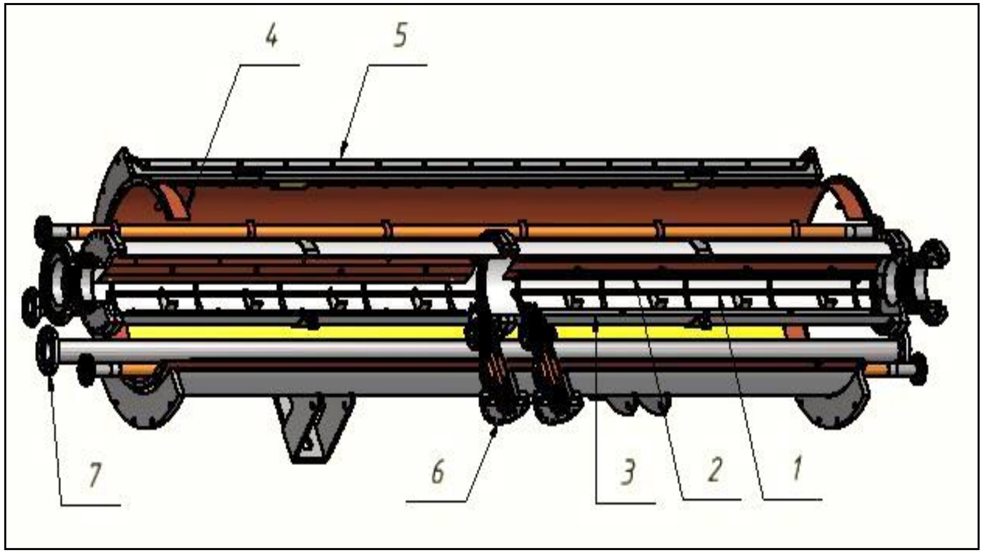
Full configuration (magnetic rigidity up to 38.5 T·m)

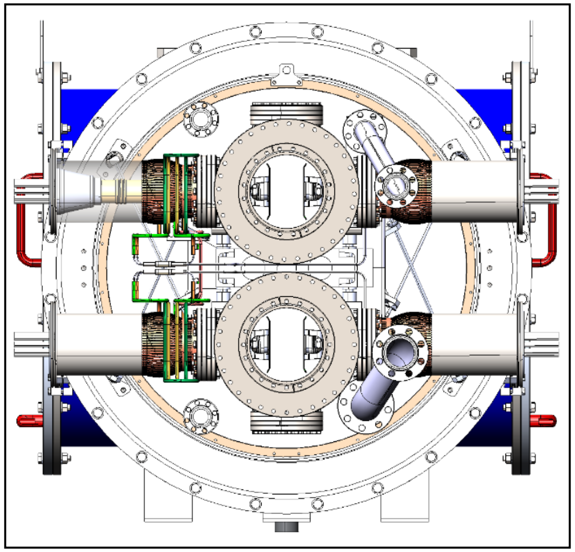


Application of one extraction Lambertson magnet permits to reach the maximal kinetic ion energy 2.5 GeV/n in first Collider beam runs

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

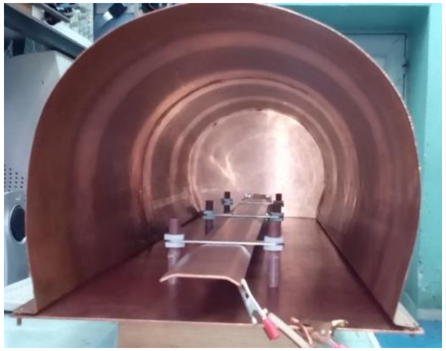


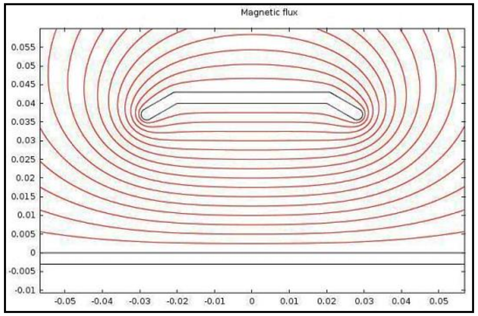


Extraction kicker – in production, injection kickers – start of fabrication, construction should be finished in middle of 2024

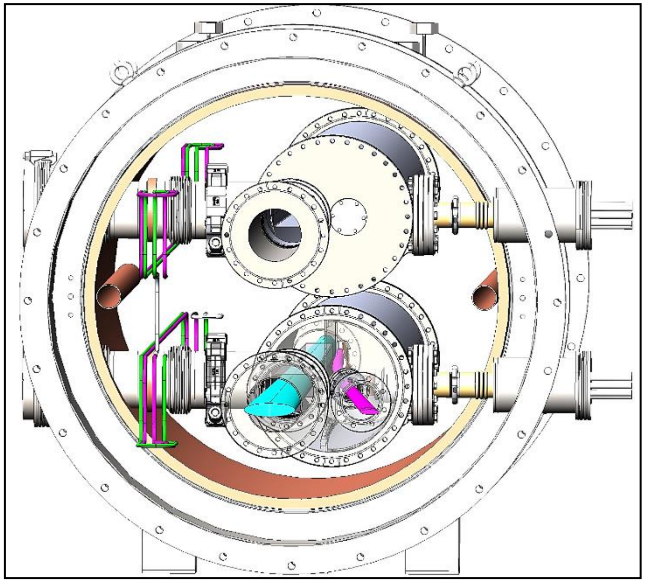
Collider beam injection septa

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

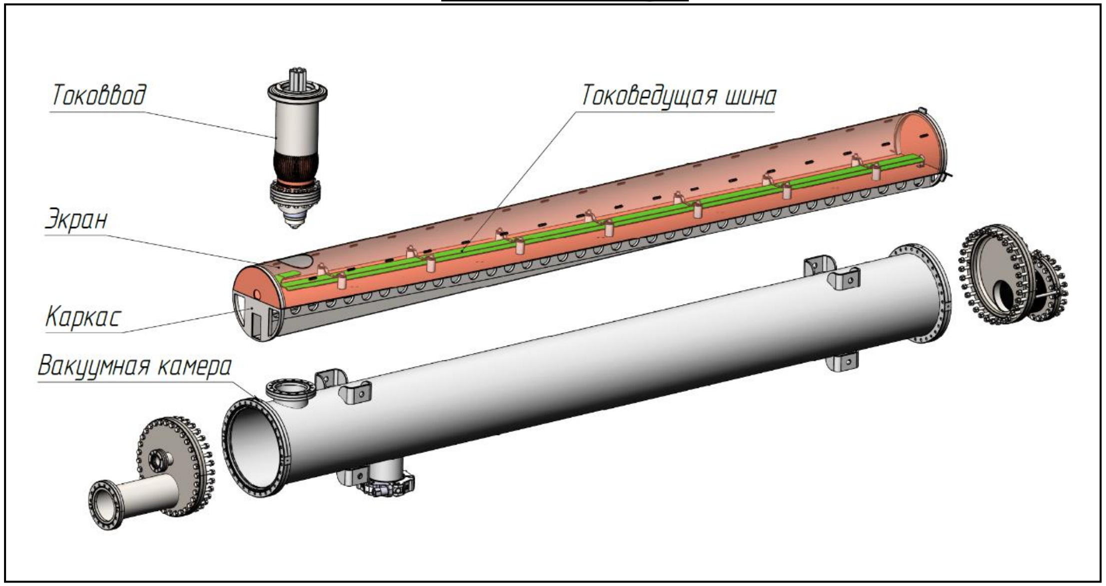




Septum cryostat module



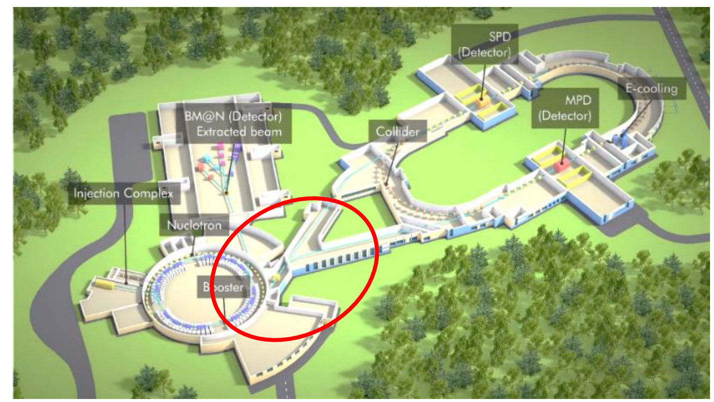
Septum's internal chamber with feedthrough



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



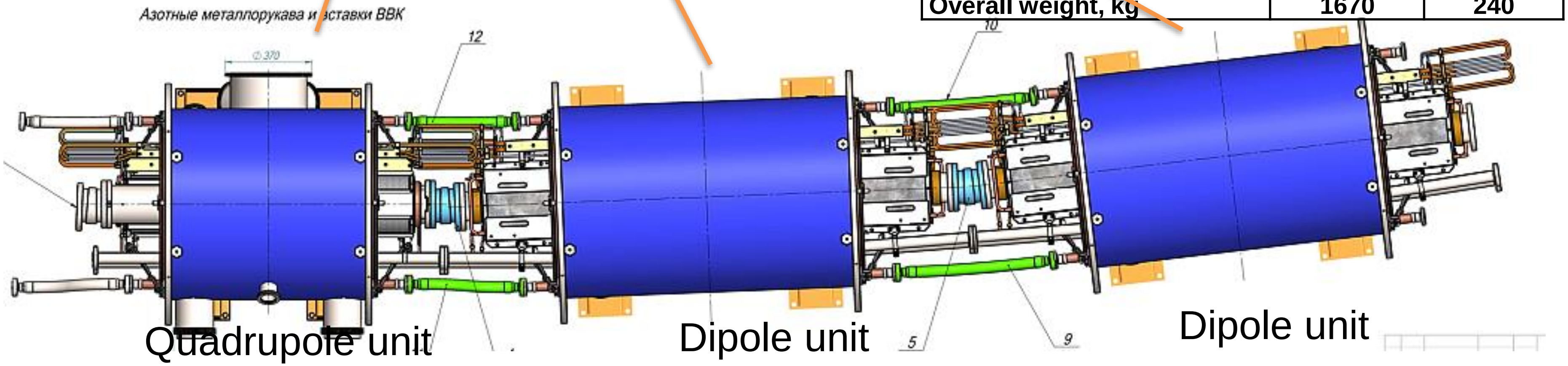
Magnets delivery in JINR in February 2021

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 middle of 2024

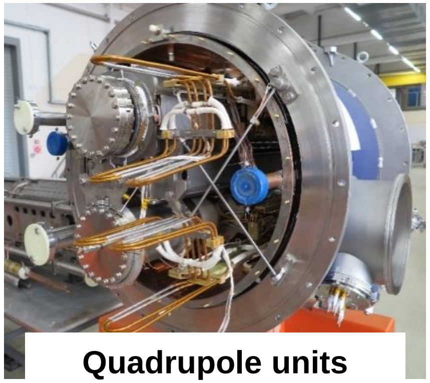
The magnetic system: regular period

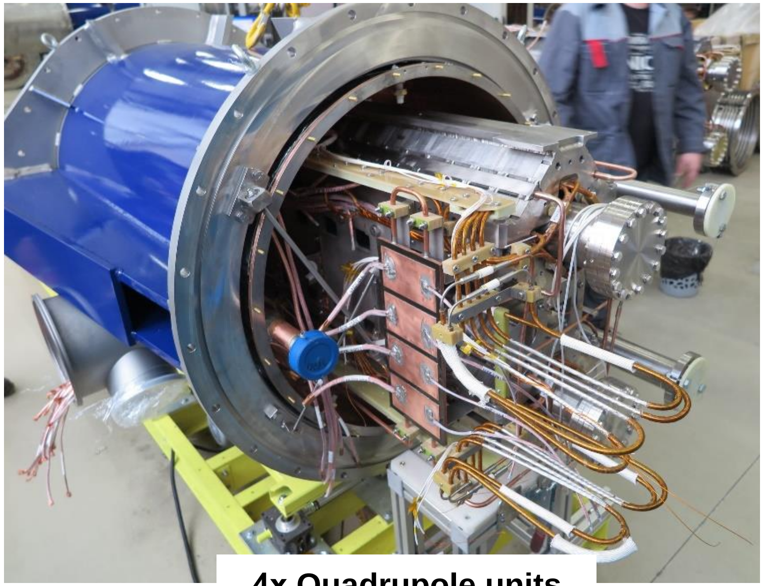
Parameter	Dipole	Lens
Number of magnets (units), pcs	80	46
Max. magnetic field (gradient)	1.8 T	23.1 T/m
Effective magnetic length, m	1.94	0.47
Beam pipe aperture (h/v), mm	120 / 70	
Distance between beams, mm	320	
Overall weight, kg	1670	240

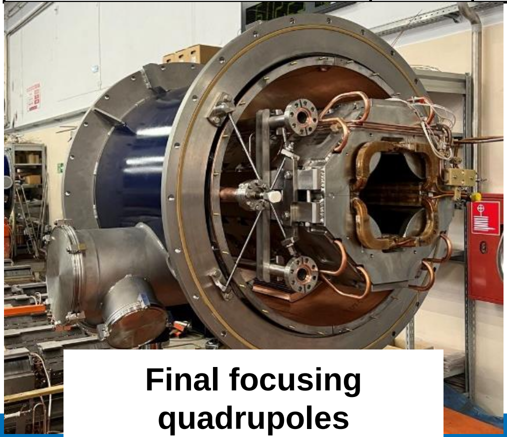


The magnetic system: magnets

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

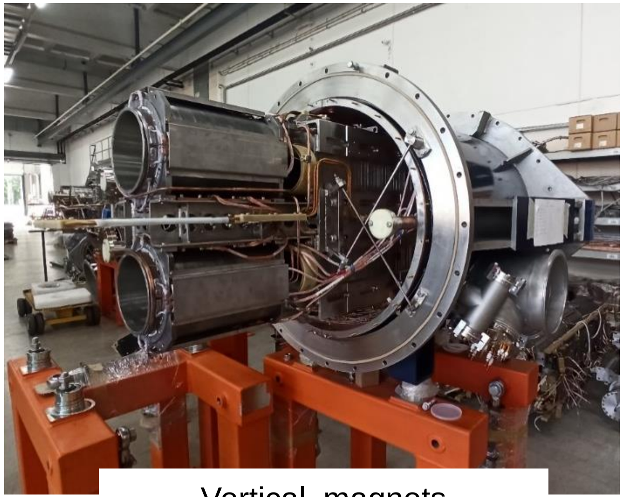

4x Quadrupole units


Final focusing quadrupoles

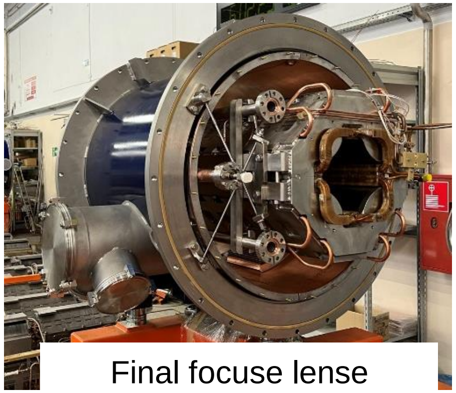

BI vertical 1x dipole units

Straight sections: magnets

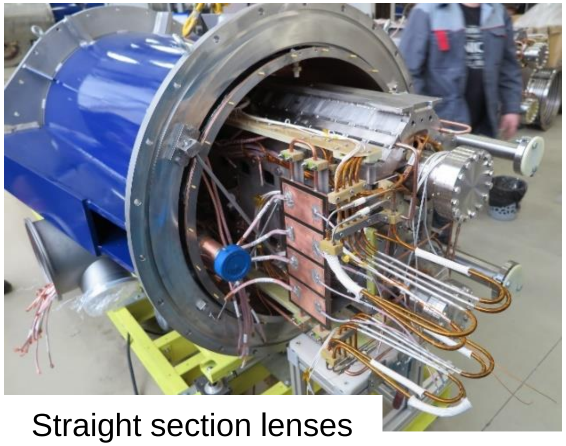
Straight section



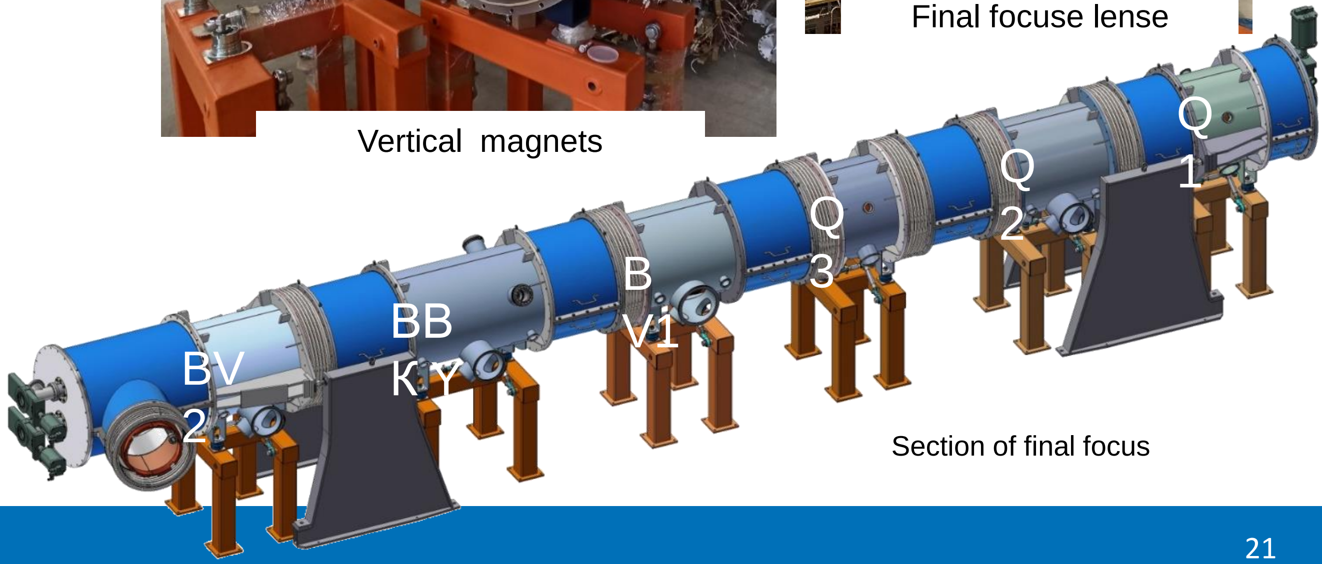
Vertical magnets



Final focuse lense

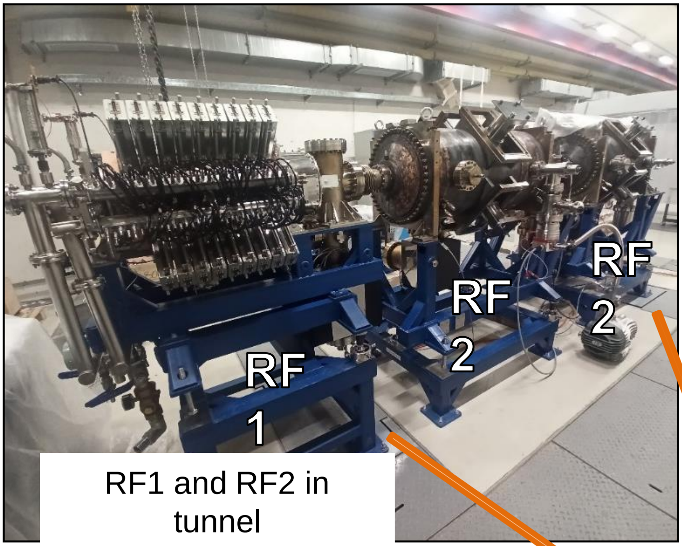


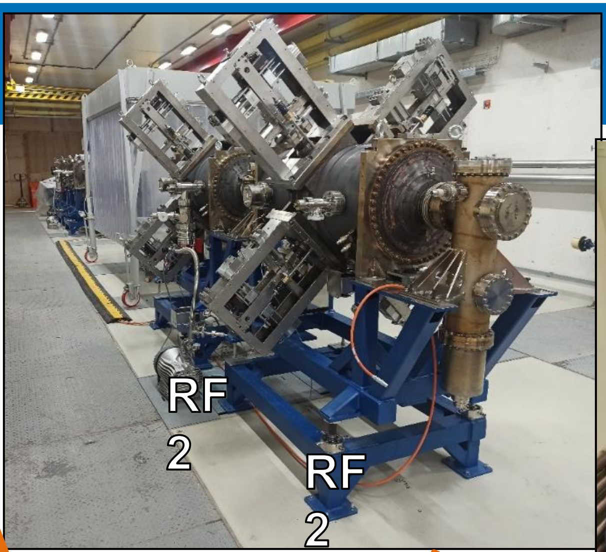
Straight section lenses

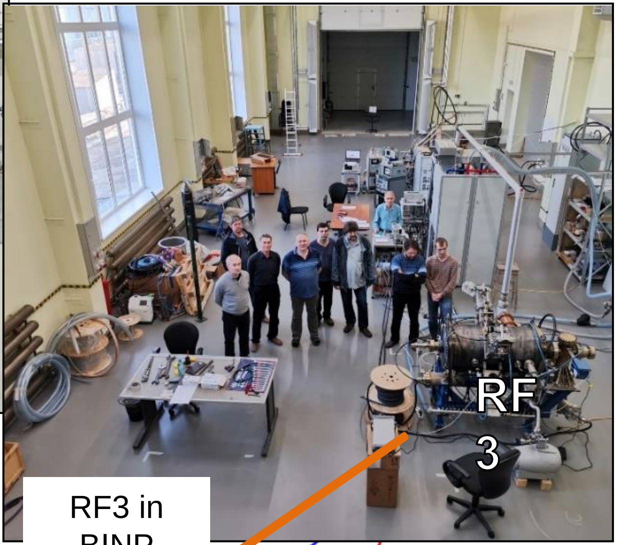


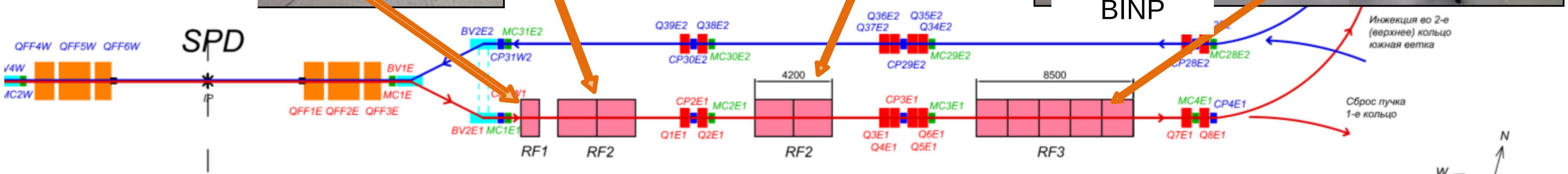
Section of final focus

R









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

Schedules

							2023								2024												2025		
	IV	V	VI	VII	VIII	IX	X	XI	XII	I	II	II	IV	V	VI	VII	VIII	IX	X	XI	XII	I	II	II	IV	V	VI	VII	VIII
Magnets			Production and testing								Assembling																		
Magnetic system			Assembling and testing											Testing															
Cryostat System			Assembling and testing																										
Beam diagnostic system																													
RF system			RF1+RF2 ring's part												RF3 ring's part														
E-Cool			Main solenoid																										
Beam pipe vacuum system																													
Injecting/Dump		Designing								Production					Assembling and mounting														
Magnetic field correction system																													
Main Power Supplies																													
Water cooling system			Circulation part								with cooling																		
Synchronization system																													
Quench protection system																													
S-Cool																													
Additional Power Supplies								Production						Assembling ring part															

Assembling and technological runs

Run without beam

Run with beam (Stage II-a)

Commissioning with beam

Program of the September 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

RISKS AT CREATION OF COLLIDER ENGENIER INFRASTRUCTURE

Electric power supply system

Electric distributed panels for biuding 17enginirieng infrastructure were constructed by Polish firm й Fracoterm

29 electric distributed panels for Collider will be delivered in JINR by Fracoterm in end of Summer 2024

1.JINR starts advance payment

However until autumn of 2023 Fracoterm has problem at selling of Shneider electronic components caused by their absence on Europe market.

The project of 29 electric distributed panel is planned in December 2023

First delivery of electric distributed panel is planned from February 2024.

There is a risk that equipment could not manufactured and delivered from Polland

2. Start discussion with Russian firm TES (Tavrida) about preparation of project 29 electric distributed panels on base of China electronic components and construction of this panels on Russian enterprises (N. Semin)..

Project - March 2024.

- **JINR delivery – September 2024.**

Water cooling system

- **Shtraback subcontractor firm Tracson does not perform schedule of water cooling mounting.**
- **1.It is planned that 3 collider water cooling chains will start operation in end of 2024 г. (N.Semin).**
- **It is proposed to cancel contract with Tracson and conclude new contract with Alstramerija and other firms**
- **High risks are caused by an absence of company which will be ready to finish works before end of 2024.**
- **2.Operation of control water system of cool setups and closed armature will be realized in middle of 2025. (N.Semin) (Firm ATM Technology)**
- **2.1 New TS caused by escape of Shneider electronic from Russian market**
- **2.2. Project –June 2024**
- **2.3 Mounting and start of operation in a manual regime of separate subsistems-September 2024 (N.Semin)**
- **High risks at start of operation of control water system before autumn 2024**

Risks related to engineer collider infrastructure

Cryogenic helium transport lines

1.Cryogenic helium transport lines are planed to constructed by BINP in July 2024.

1.1.Contract of helium short transport line to east ark is under signature with time duration of 8 months (it is planed to finish troug 5 months)

1.2 Second contract of helium long transport line to west ark is planed to sign in 2023. Construction will be finished in July 2024

2.Nitrogen transport lines

2.1 Mounting of nitrogen transport lines to east ark - 4 months

2.2 Finish of mounting of nitrogen transport lines to west ark- July 2024.

Main risks at realization of technological collider run are connected with start of exploitation of engineering systems: water cooling, electric power supply and cryogenic transport lines.

Operation of cryogenic compressor station with nitrogen recondensation is planed in end of April 2024 (A.Кonstantinov).

If at that time we will have problems with realization of technological cryogenic collider run connected with absence of required engineer infrastructure in the end of Spring beginning of Summer we will plan Booster-Nuclotron-BM@N run.

At plan realization of engendering infrastructure and mounting of collider equipment the run Booster-Nuclotron-BM@N do not planned in 2024.

The first Collider run with beam

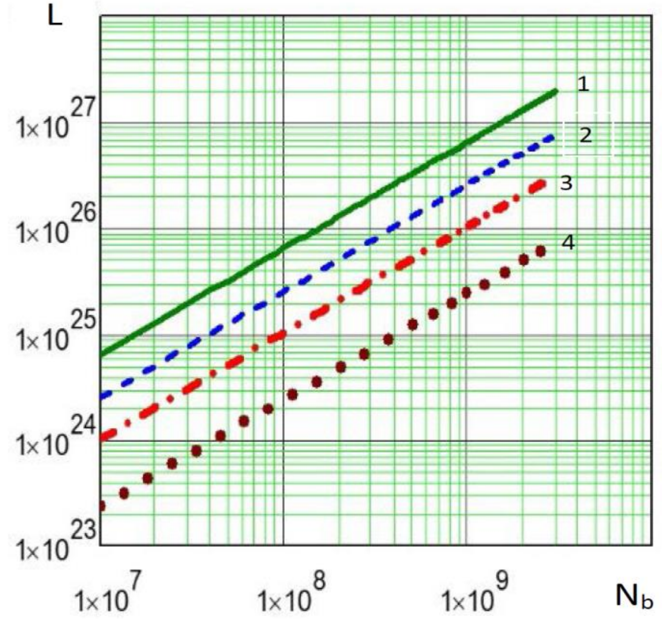
NICA Stage II-a (basic configuration):

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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