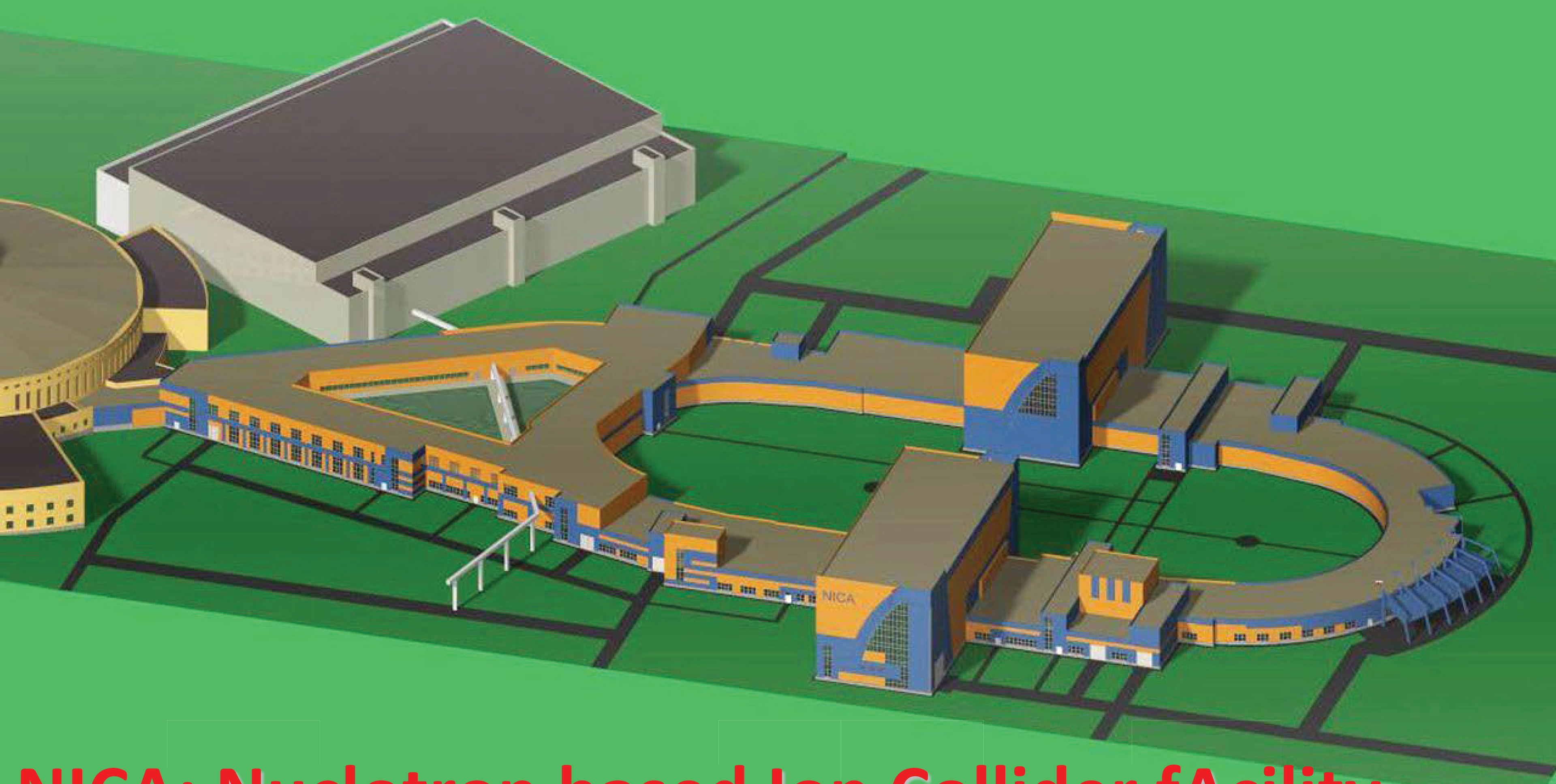
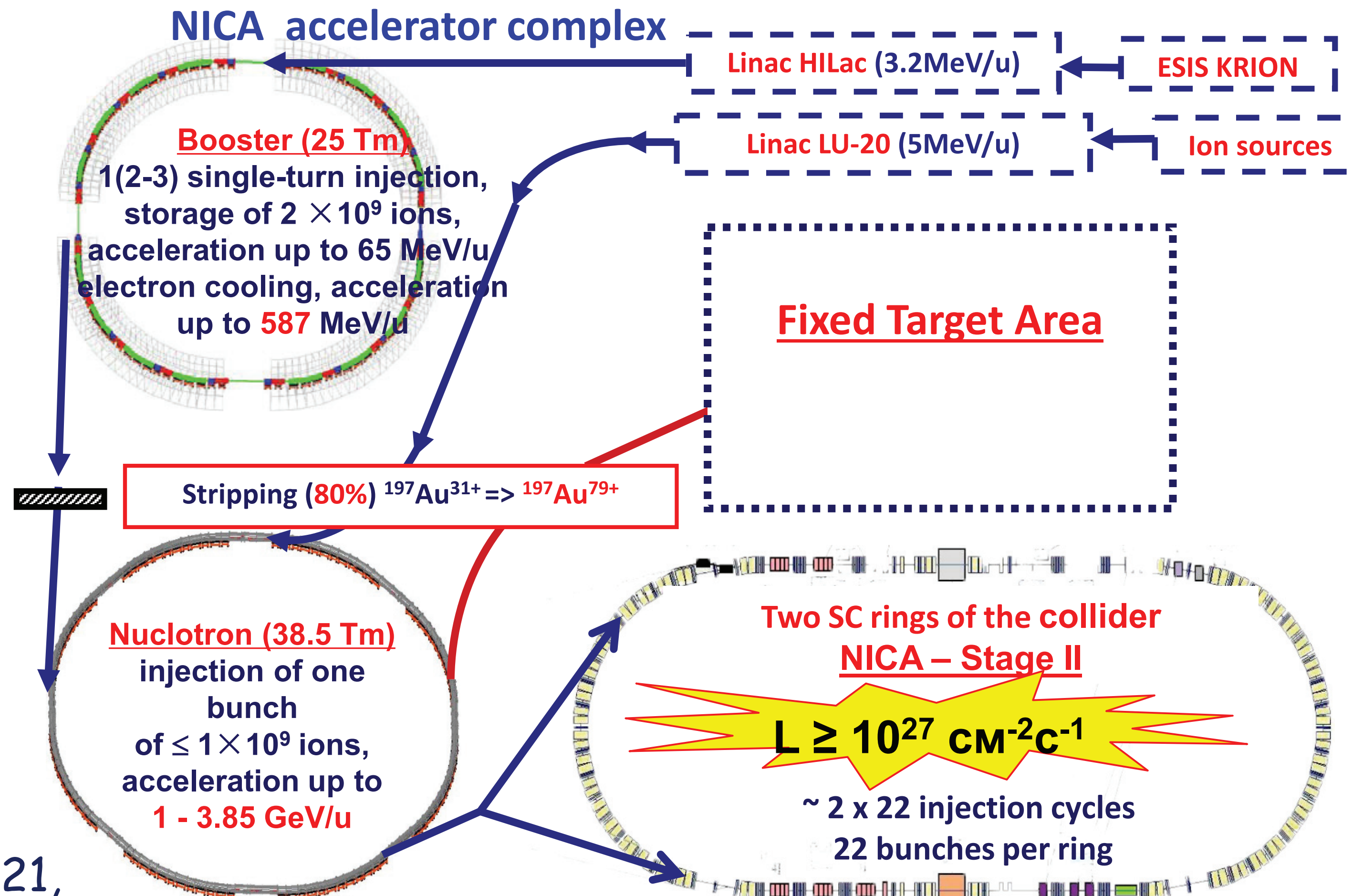
NICA Ion Collider at JINR

Evgeny Syresin on behalf of team
Veksler and Baldin Laboratory for High Energy Physics
Joint Institute for Nuclear Research



NICA: Nuclotron based Ion Collider fAcility



RUPAC 21,
A. Butenko, MOY01

Injector Complex

Heavy ions: ESIS+HILac (Au^{31+} 3.2 MeV/n)+ Booster+Nuclotron

Polarized p↑ and d↑ beams, protons and light ions (z/A>0.3):
SPI (LIS or DP)+ Linac LU-20 (5MeV/n)+ Nuclotron
Construction of new light ion linac (LILAC at 7 MeV/n)+medium energy proton acceleration sections (13 MeV)+ SC sections (20 MeV)

NICA accelerators

Collider

The Collider ring 503.04 m long has a racetrack shape and is based on double-aperture (top-to-bottom) superconducting magnets at maximum dipole field 1.8 T;

The major parameters of the NICA Collider are the following:

- magnetic rigidity = 45 T·m;

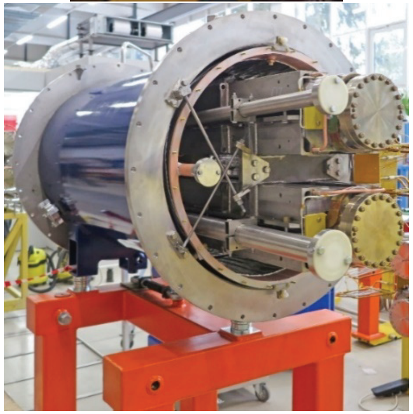
-ion kinetic energy range from 1 GeV/u to 4.5 GeV/u for Au^{79+};

-energy of polarized deuterons is 6 GeV/u, protons – 12 GeV,

- vacuum in a beam chamber: 10^{-11} Torr;

- zero beam crossing angle at IP;

- 9 m space for detector allocations at IP's;



Average luminosity 10^{27} cm^{-2}·s^{-1} for gold ion collisions at $\sqrt{s_{NN}}$ = 9 GeV.

The luminosity in the polarized mode is up to 10^{32} cm^{-2}·s^{-1}.

Commissioning – 2022

First technological run- end of 2022

NICA collider parameters

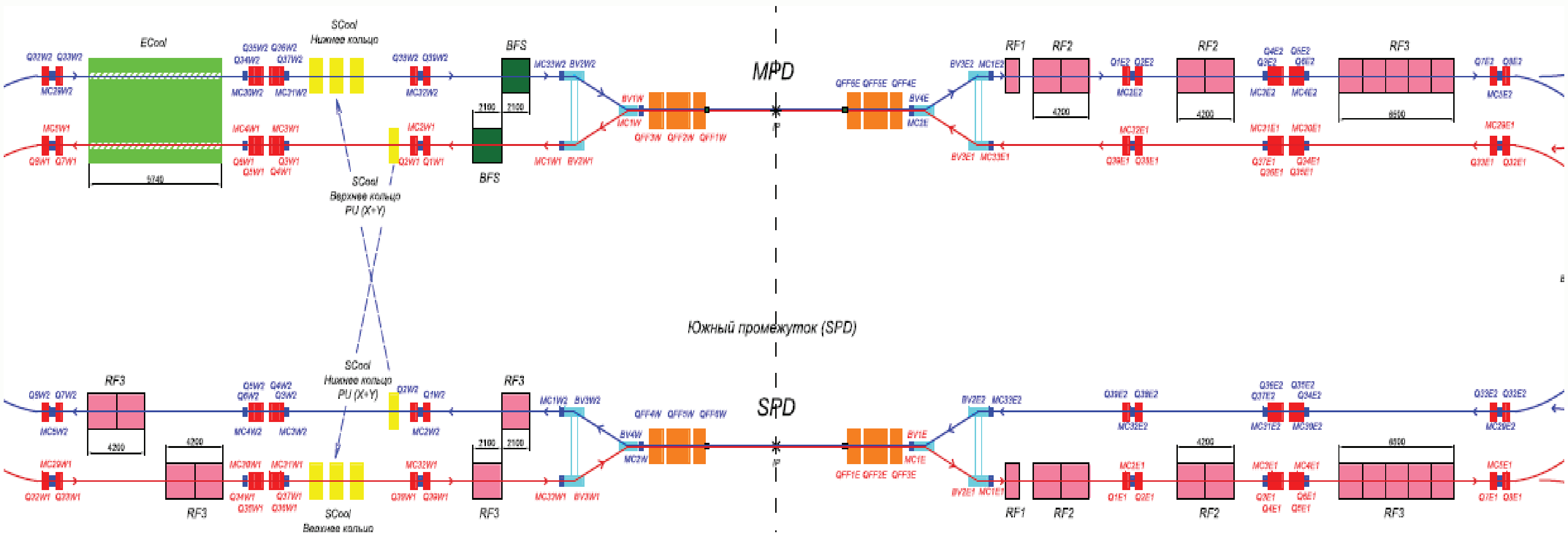
Ring circumference, m	503,04		
Number of bunches	22		
Rms bunch length, m	0.6		
Beta-function in the IP, m	0.6		
Betatron tunes, Qx/Qy	9.44/9.44		
Ring acceptance	40 π·mm·mrad		
Long. acceptance, $\Delta p/p$	±0.010		
Gamma-transition, γ_{tr}	7.088		
Ion energy, GeV/u	1.0	3.0	4.5
Ion number per bunch	$3.2 \cdot 10^8$	$2.9 \cdot 10^9$	$3.1 \cdot 10^9$
Rms dp/p, 10^{-3}	0.7	1.4	1.9
Rms beam emittance, h/v, (unnormalized), π·mm·mrad	1.3/1.3	1.3/1.1	1.3/1.0
Luminosity, $cm^{-2}s^{-1}$	0.8e25	0.8e27	1e27
IBS growthe time, sec	160	460	2000

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 in a reduced version: 2 cavities per ring instead 4 (50 kV RF amplitude instead 100 kV)
- 1 channel of S-cooling per ring (cooling of longitudinal deg. of freedom)

Result: 22 bunches of the length $\sigma \sim 2$ m per collider ring that 5e25 cm$^{-2}\cdot$s^{-1}.



NICA Stage II-b (full configuration):

Collider

\+ RF-2 systems in the project version

\+ RF-3 systems in the project version

\+ S-cooling (transverse)

\+ E-cooling

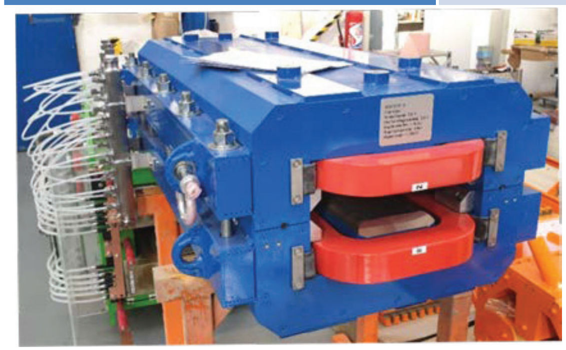
Result: 22 bunches of the length $\sigma \sim 0.6$ m per collider ring that 1e27 cm$^{-2}\cdot$s^{-1}.

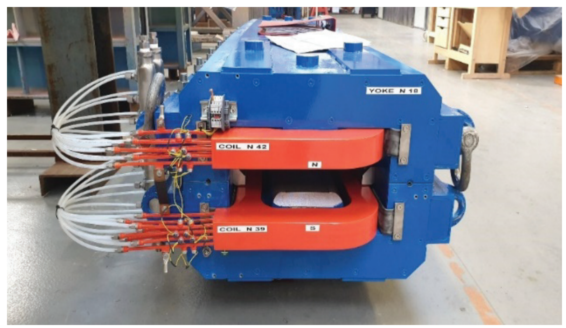
Nuclotron-Collider beam transport channel

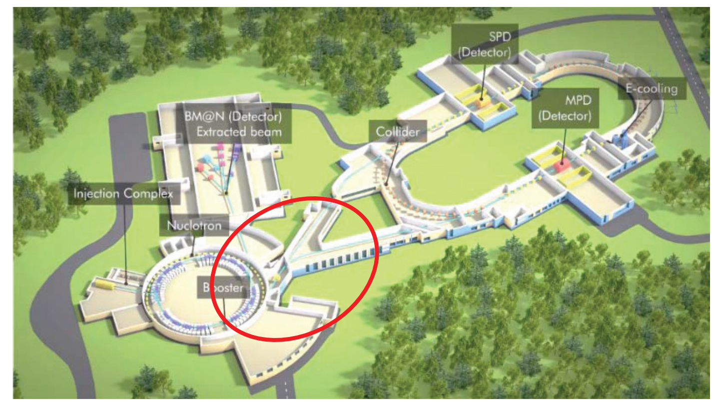
RUPAC 21,
A. Tuzikov
WEA01

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 is under delivery and construction by Sigma Phi

The JINR-SigmaPhi contract schedule:

November 2021 – delivery of first part of power supplies, beam diagnostics, support stands; start of the channel mounting.

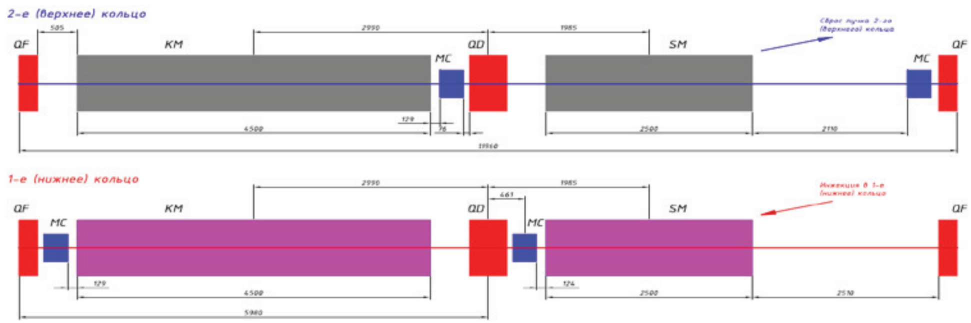
January 2022 – delivery of vacuum equipment.

July 2022 – delivery of second part of power supplies, beam profile monitors, command and control system.

September 2022 – start of commissioning of the channel equipment.

December 2022 – commissioning of the channel with a beam.

Collider beam injection and dump systems



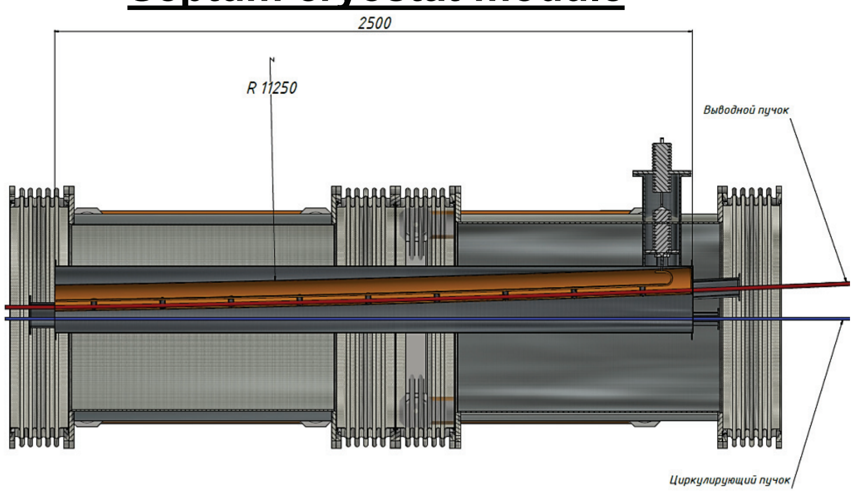
QF, QD – quadrupole; MC – multipole; KM – kicker; SM - septum

Septa

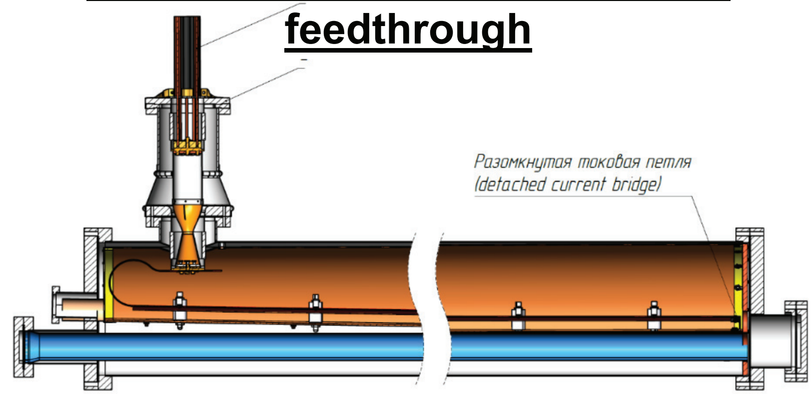
Length, m	2.5
Max magnetic field, T	0.42
Gap, mm	35
Septum thickness, mm	3
Pulse shape	semisinusoidal
Pulse duration, μs	~ 10

- **Technical design development is in progress. The main crucial items are low-inductive feedthroughs for current pulses of order 50 kA.**
- **Power supply based on semi-conducting switches is being developed.**
- **Construction - until October 2022**
- **Installation – November 2022**

Septum cryostat module



Septum's internal chamber with feedthrough



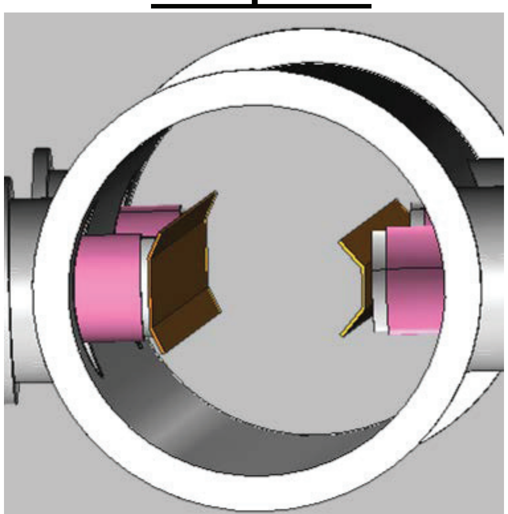
Collider beam injection and dump systems

Kickers

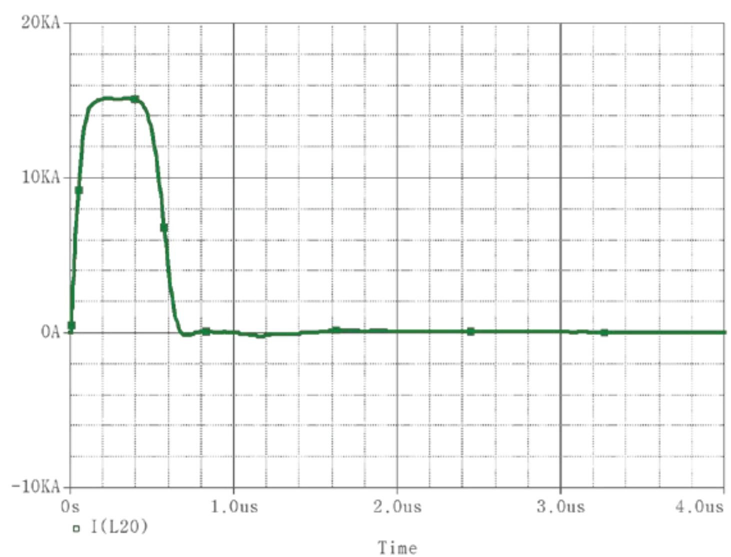
	injection	dump
Length, m	4	4
Max magnetic field, T	0.05	0.11
Pulse duration, ns:		
rise	200	130
plateau	200	1700
fall	200	>10000
After-kick amplitude, plateau level	≤1.5%	-
After-kick duration, ns	≤160	-

- Technical design development is in progress.
- Construction - until October 2022
- Installation –November 2022

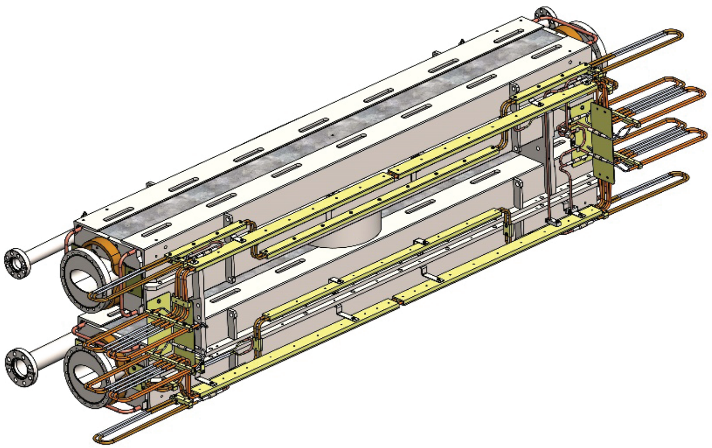
Simplified model of kicker chamber with plates

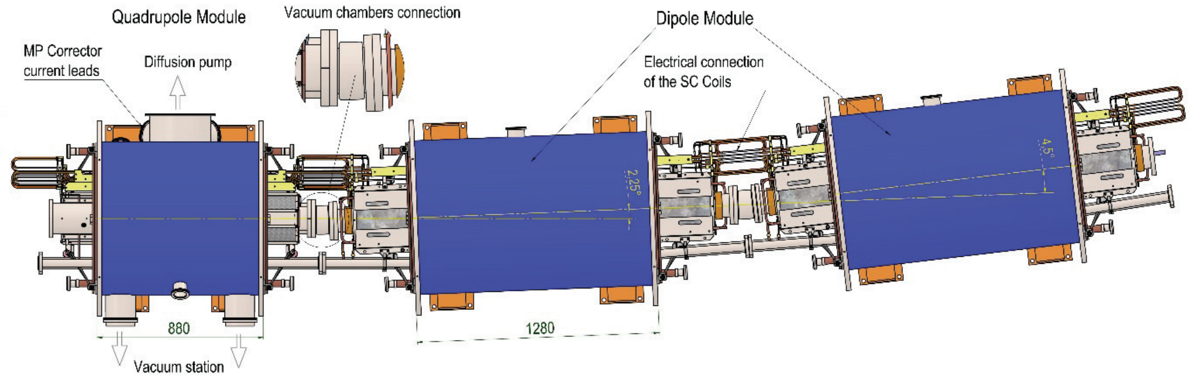


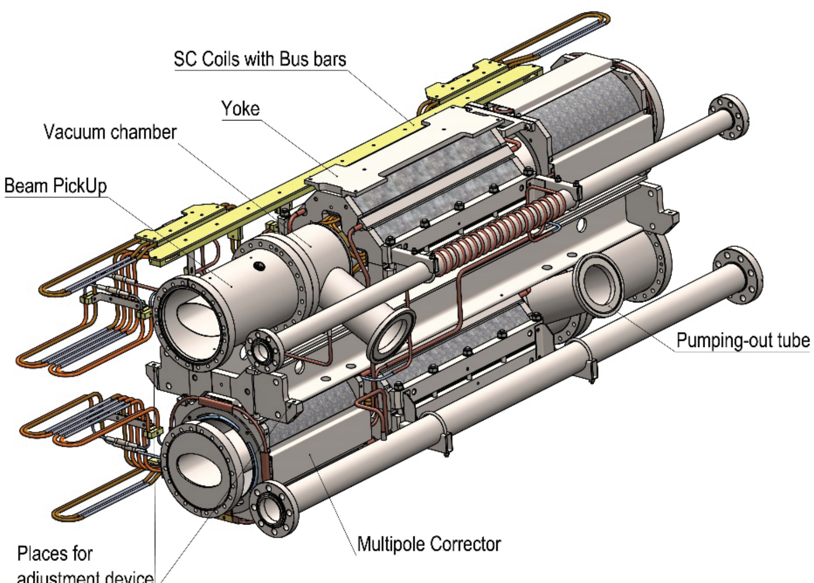
Injection kicker pulse (simulation)



Joining of the magnets







Parameter	**Dipole**	**Lens**
Number of magnets	80+8*	86+12**
Max. magnetic field (gradient)	1.8 T	23.1 T/m
Effective magnetic length	1.94 m	0.47 m
Beam pipe aperture (h/v)	120 mm / 70 mm	
Distance between beams	320 mm	
Overall weight	1670 kg	240 kg

*- the magnets for the vertical movement of the beams

**- the final focus lens.

Construction of magnets and doublet lenses 2018-2022

Commissioning –2022.

NICA

Collider magnets assembly and testing

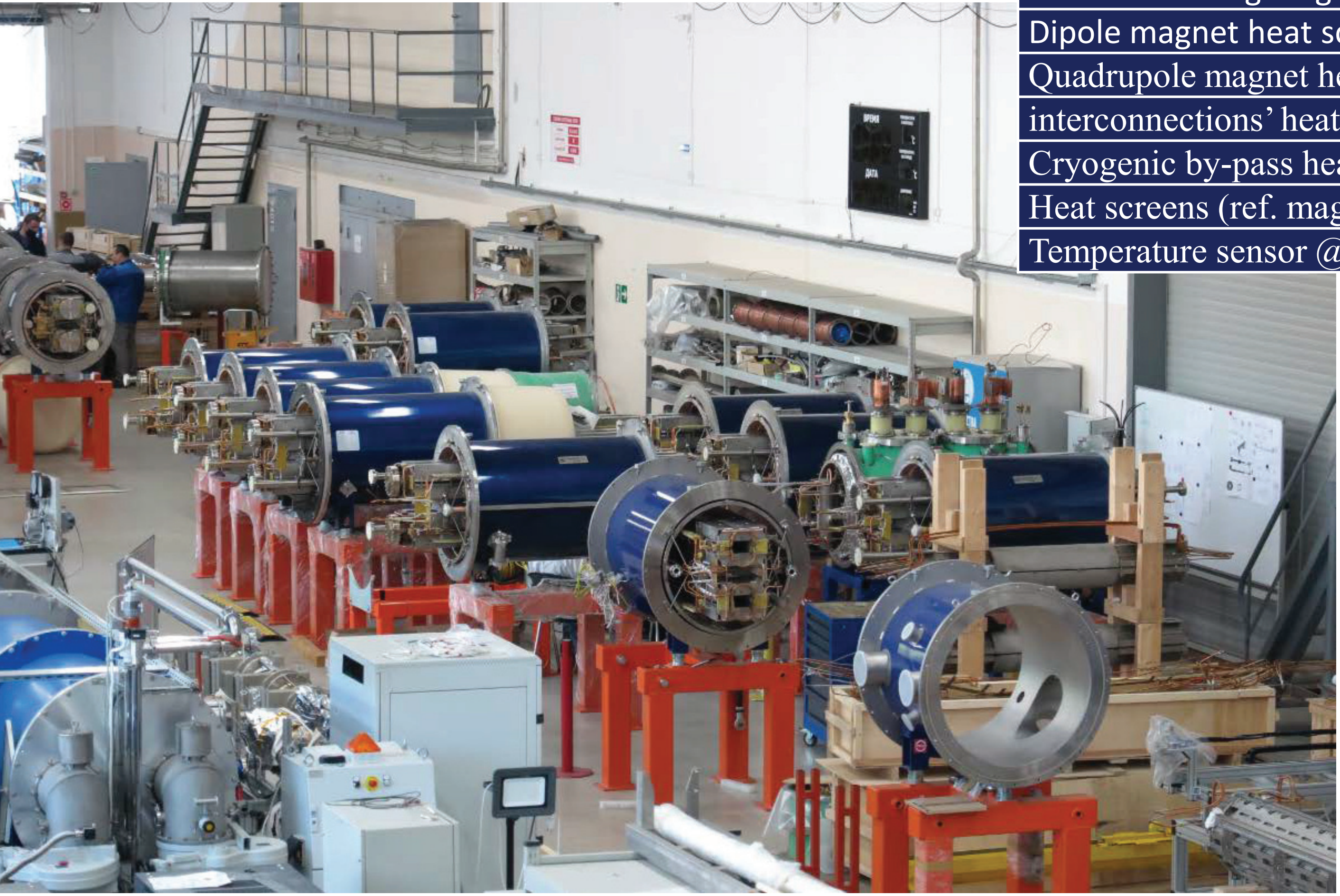
RUPAC 21,
D. Nikiforov
WEB01

Cryogenic-tests per year:

2016	2017	2018	2019	2020	2021
20	60	58	76	72	**150**

Collider dipoles: 100 % tested
Collider quadrupoles: 35% tested

	total	prod. %
Dipole magnet coil	80+1	**100**
Quadrupole magnet coil	46+24	**100**
Corrector magnet coil	124+4	**75**
Final focus quadrupole coil	12	**20**
Vertical bending magnet coil	8	**20**
Dipole magnet heat screen	80+1	**100**
Quadrupole magnet heat screen	46+12	**100**
interconnections' heat screen	181	**50**
Cryogenic by-pass heat screens	2	**20**
Heat screens (ref. mag.& feed b-x)	2	**80**
Temperature sensor @ cold	900	**100**



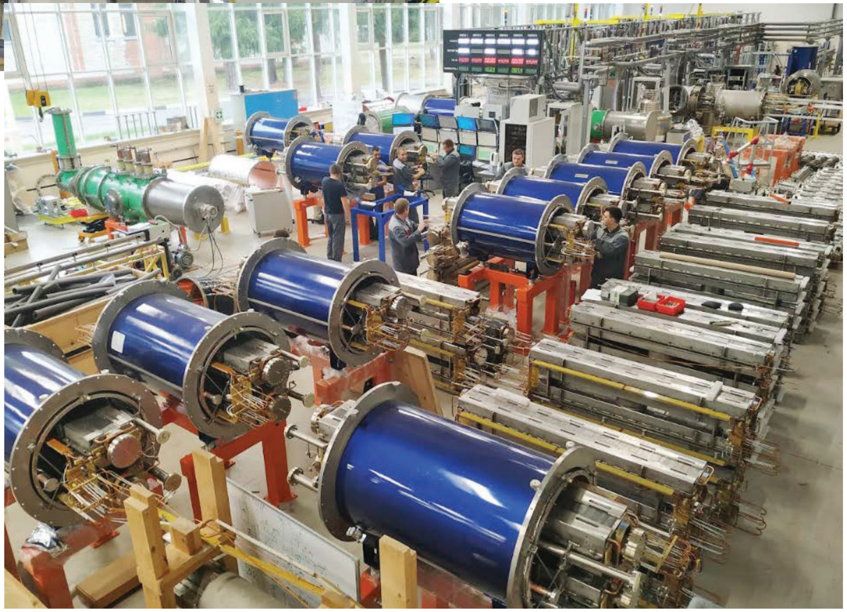
SC-magnets constructed at JINR

Synchrotron booster	Dipole magnets	45
	Quadrupole magnets	56
	Dipole correction magnets	24
	Multipole correction magnets	8
Synchrotron Nuclotron	Commissioned since March 1993	180
Collider	Dipole magnets	85
	Quadrupole magnets (arch)	50 (4)
	Quadrupole magnets (doublet)	30 (0)
	Dipole magnets BV	10
	Quadrupole magnets LFF	16
	Multipole correction magnets	136 (75)
	Total:	**640**

- magnets were produced (green) - magnets are produced (yellow) - designed magnets (blue)

Line for assembling and cryogenic testing of SC-magnets

RUPAC 21,
D. Nikiforov
WEB01



Main production areas:

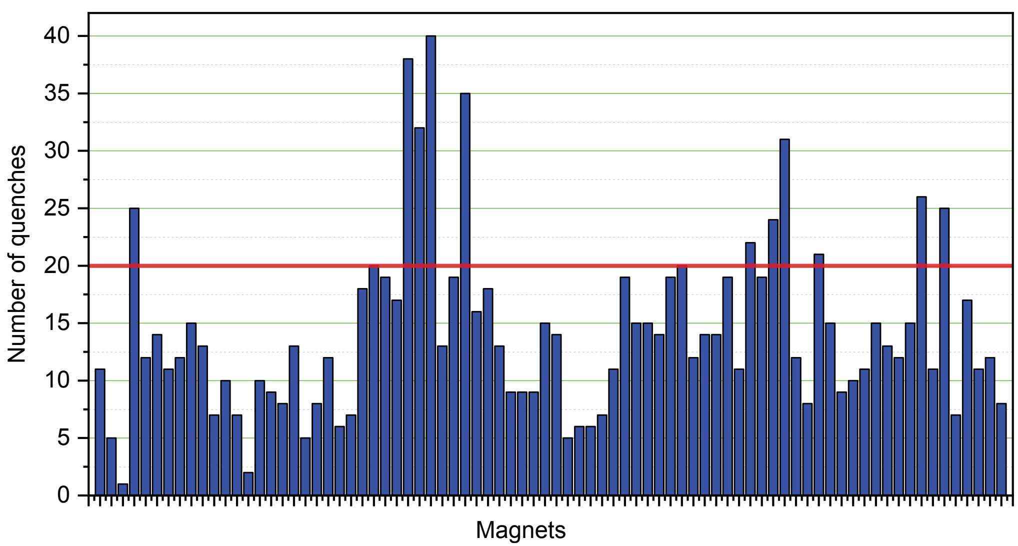
- **Incoming inspection zone**
- **SC cable production hall**
- **SC coils production hall**
- **Area for assembling the magnets**
- **Area for the magnetic measurements under the room temperature**
- **Leakage test area**
- **Area for mounting the SC-magnets inside cryostats**
- **Cryogenic tests bench**

460 magnets for NICA projects

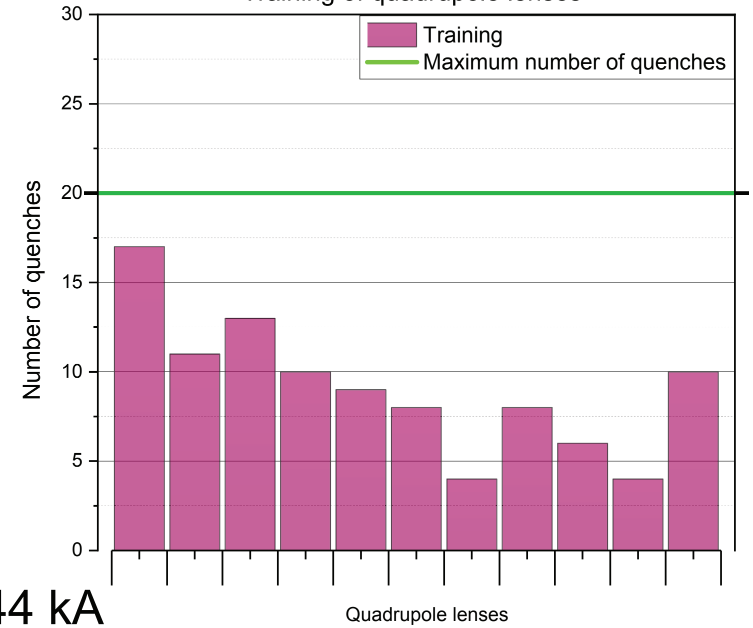
Cryogenic tests of Collider dipole magnets and quadrupole lenses

RUPAC 21,
A. Shemchuk
WEB02

Training of dipole magnet

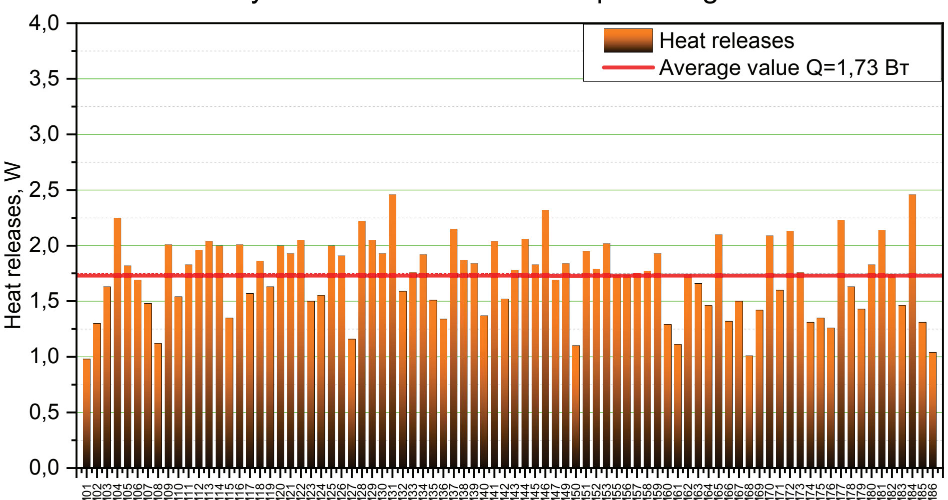


Training of quadrupole lenses

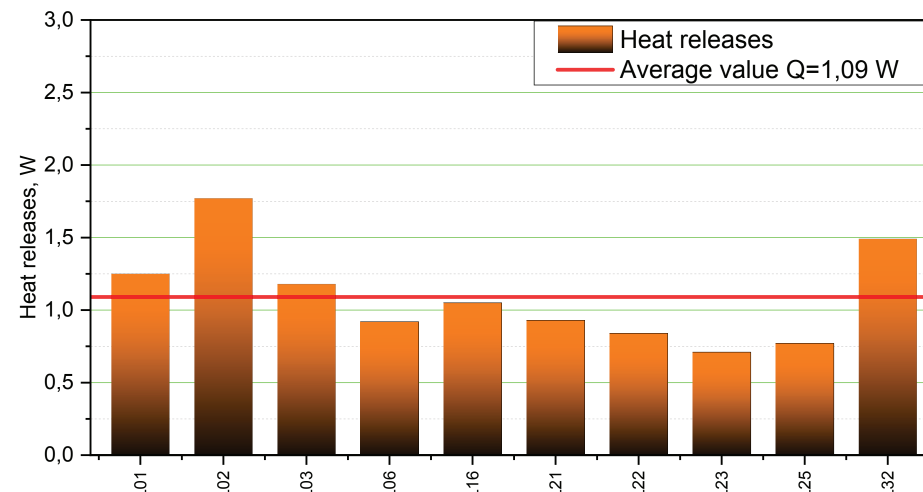


I=const=10.44 kA

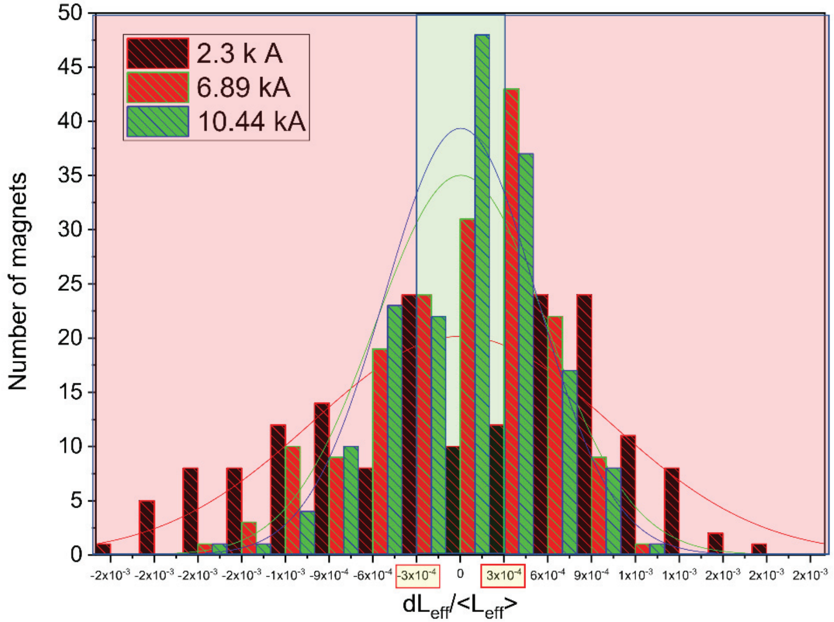
Dynamic heat releases of dipole magnets

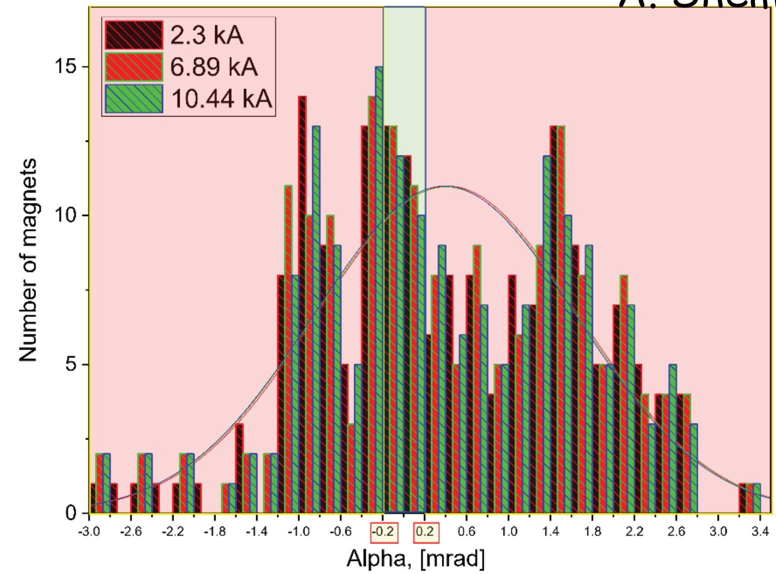


Dynamic heat releases of quadrupole lenses



Measurements for the NICA collider magnets: dipoles

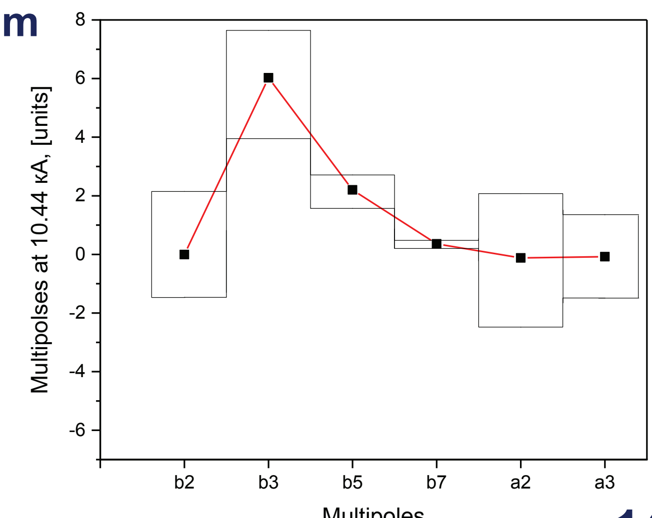




At prilaminary measurement interpretation the angle between median plane and magnet axis is by 5 time larger than project value.
It became to an increase COD from 2-5 mm to 5-10 mm

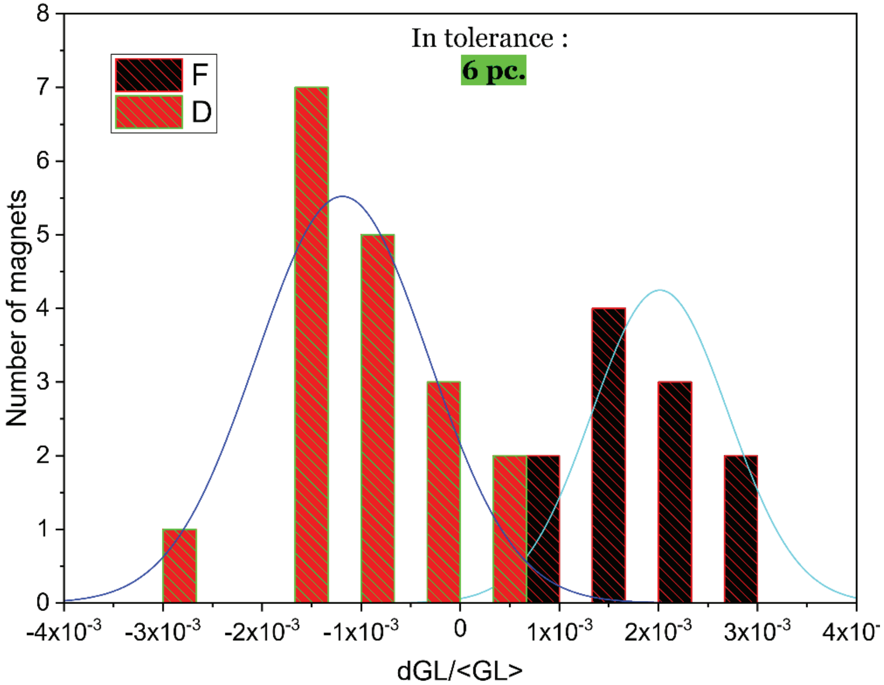
Parameter	2.3 kA	6.89 kA	10.44 kA
L_{eff}	26	55	92
BL	27	55	75
α	25	24	22
b_2	172	172	172
b_3	160	58	172
b_5	172	172	34
b_7	172	172	172
a_2	171	172	172
a_3	172	172	172

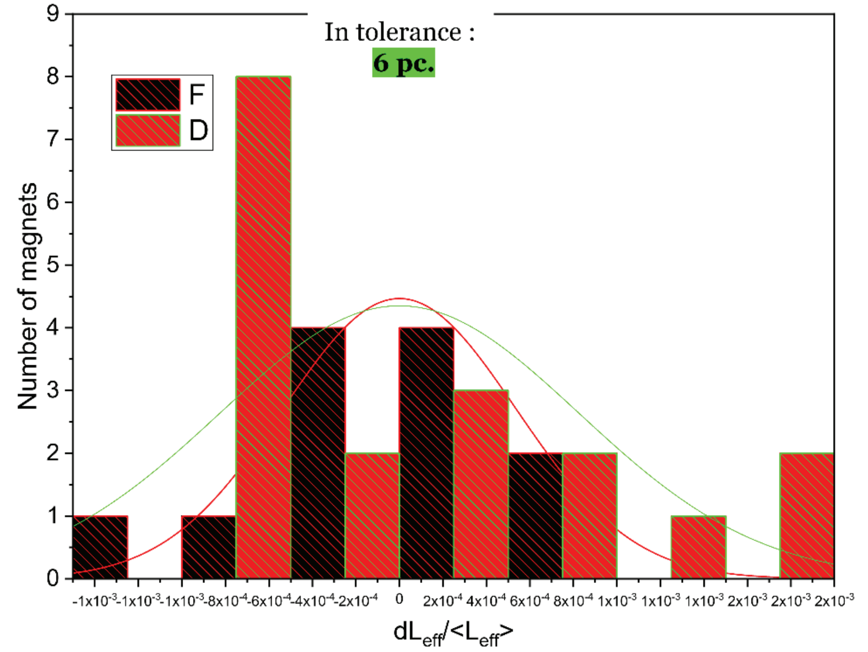
Number of dipole magnets with parameters less than in specification

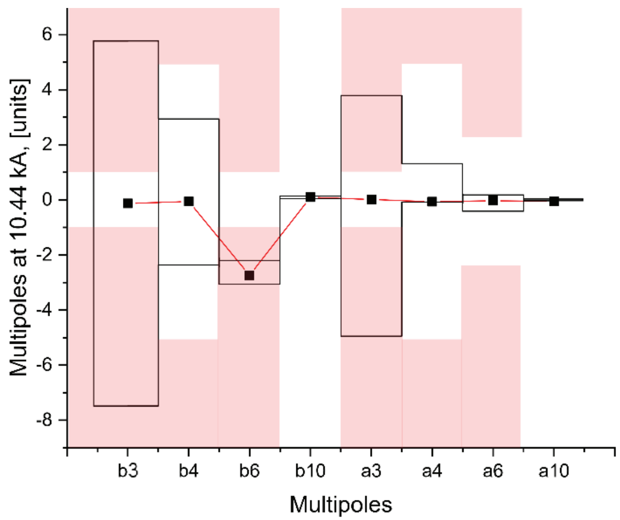


Values of harmonic

Measurements for the NICA collider magnets: quadrupoles







Collider power supply system

RUPAC 21,
V. Karpinsky
WEC01

Power supplies:

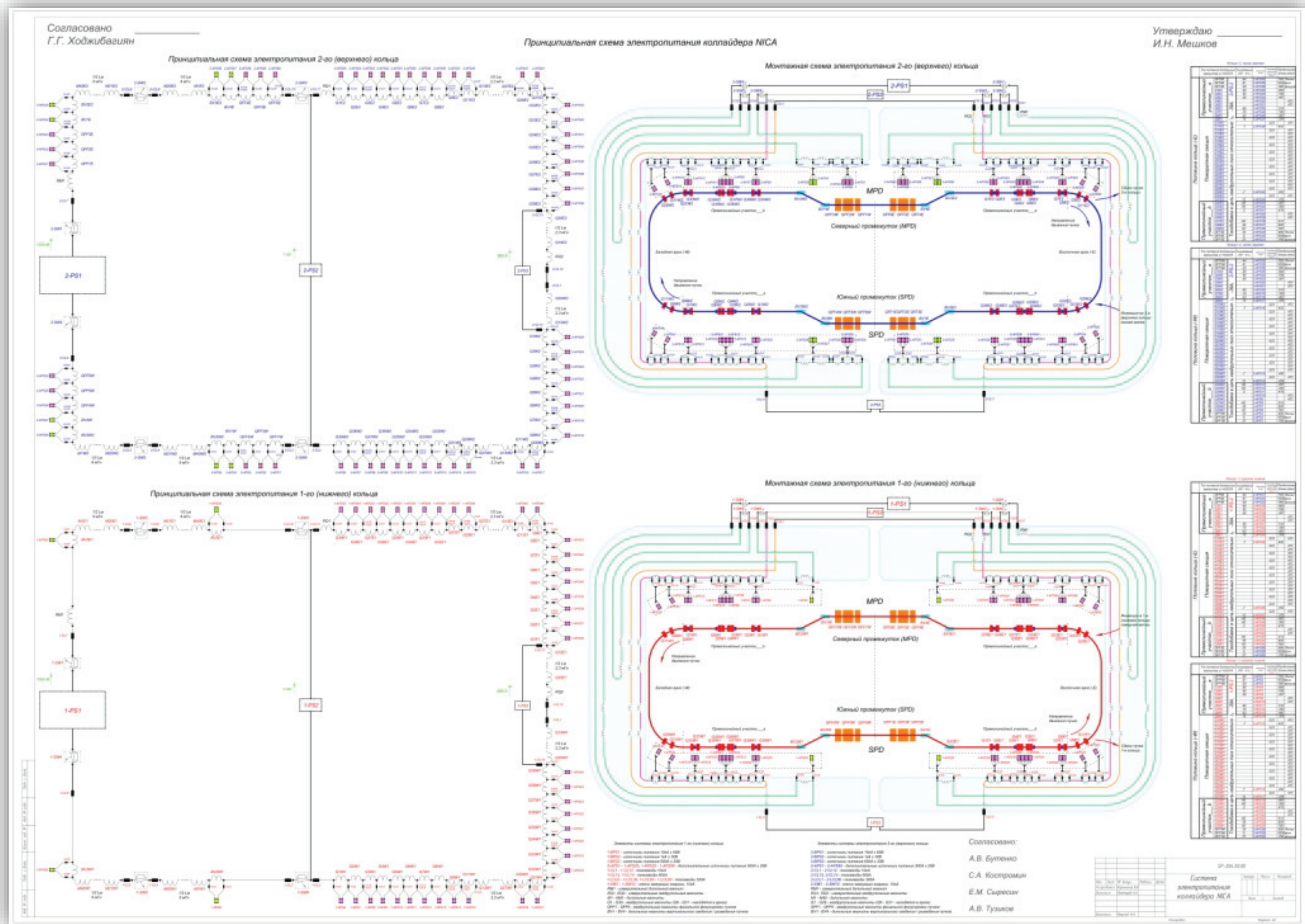
1. **Main power supplies - 2 completes with 3 power supplies**

2. **Additional power supplies (10V x 300A) - 88.**

3. **Energy evacuation keys -12**

4. **High power commutation equipment**

5. **Transformers 6/0,4 kV – 2.**



Collider power supply sustem

Three main power supplies

Constructed by LM Invertor (Moscow)
Delivery to JINR

Energy evacuation keys

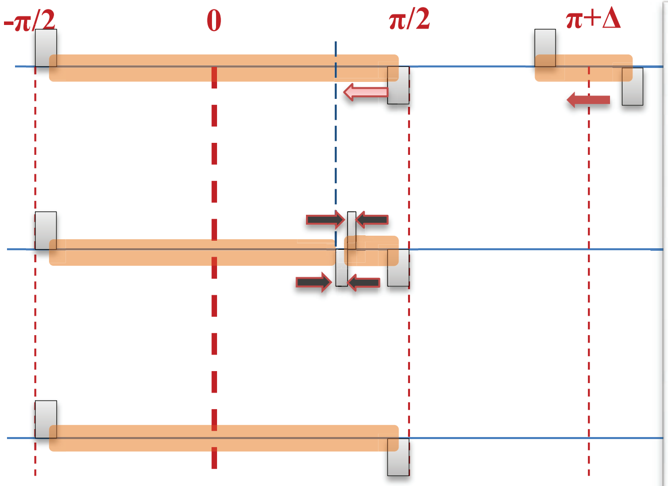
Prototype was constructed and tested

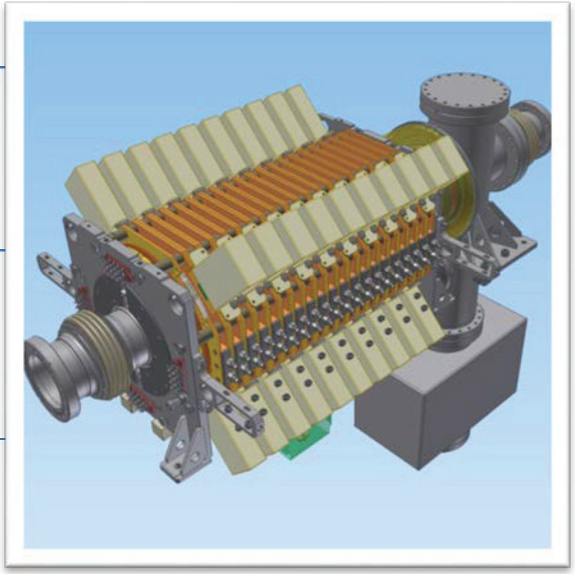
Additional power supplies (10B x 300A)

2 prototypes from 3 were constructed and tested

Storage of ion beams in RF bucket

Ion Beam dynamics
in NICA collider,
S.Kostromin
TUB01





Maximal voltage – 5 kV

Two rectangular barriers each with phase length- π/12

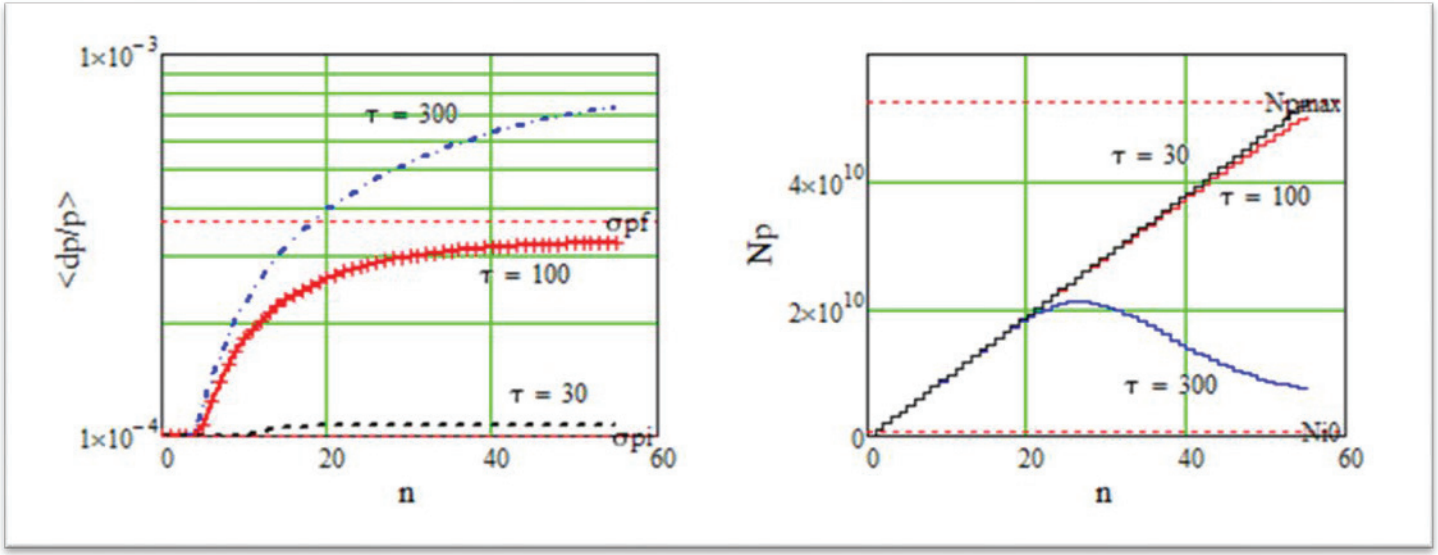
Stack phase zone– π.

Kicker fronts (2 x 200 ns) 0.54π

Kicker plato -200 ns=0.27 π

Injection zone = kicker fronts+ kicker plato=0.81 π=203.7m

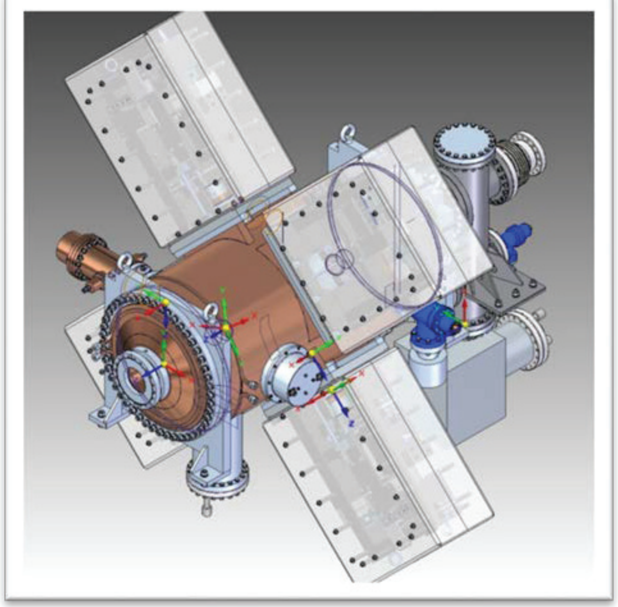
E=3 GeV/n, σ_p=1E-4, σ_l=10 m **3 D model of RF1 station**



Dependence of momentum spread and ion intensity on number of injection cycles.

Bunching beam by RF2

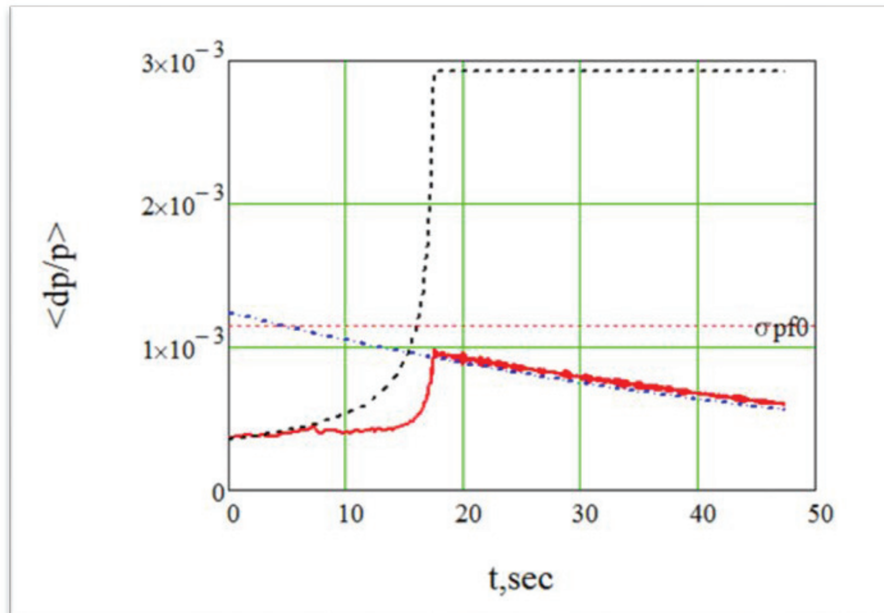
Number of RF2 cavities per ring -4, RF2 voltage -25 kV

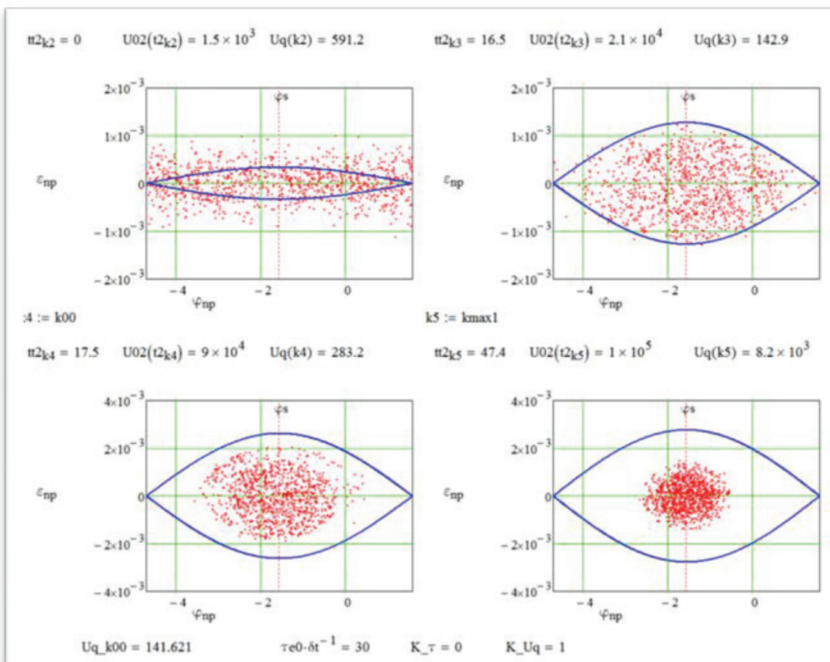


3D model of RF2 station

RF2 bunching at 3 GeV/n

$U0_{Rf2}$=1.5 kV, U_{Rf}=100 kV at RF2 frequency variation 10 kHz/s, cooling time 30 s, for initial σ_p=3.7E-4, at t=17,5 s and additional cooling during 40s

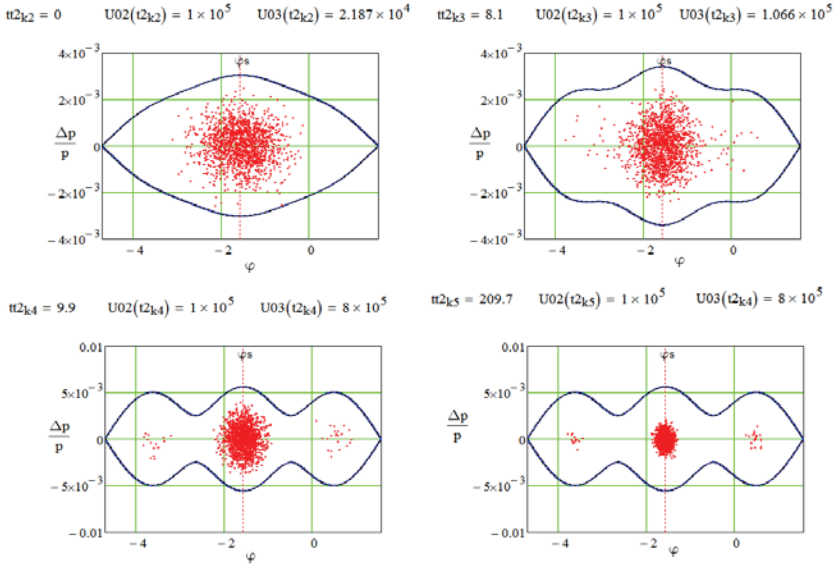


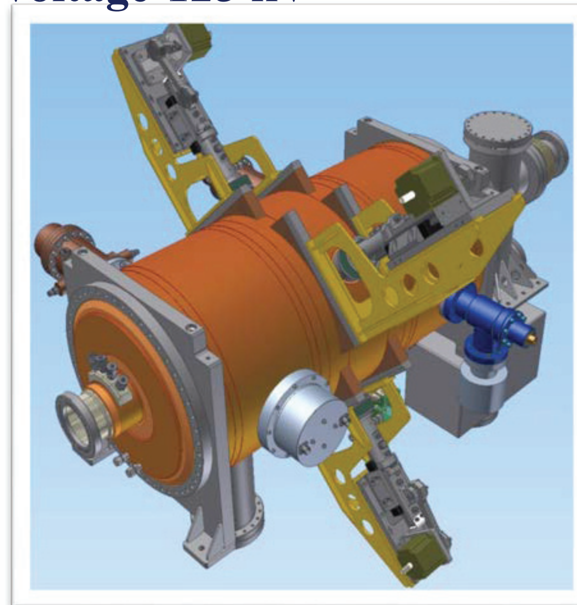


Dependence of momentum spread at adiabatic Rf2 bunching and cooling after 17,5 s.

RF3 Bunching

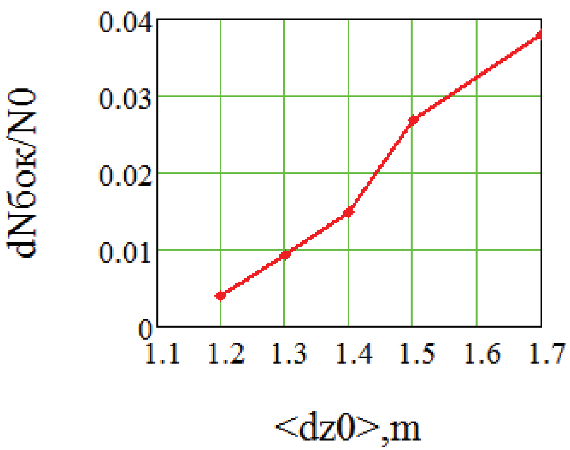
Number of RF3 cavities per ring -8, RF3 voltage-125 kV



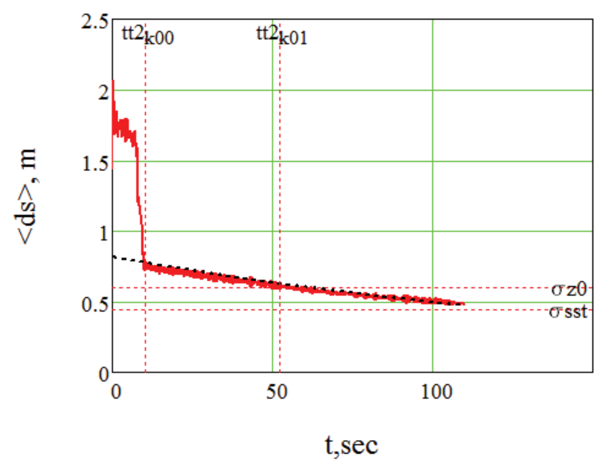


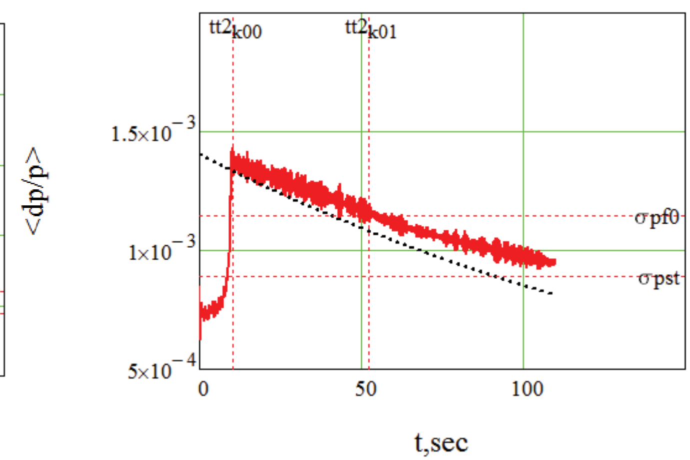
3D model of RF3 station

E= 3GeV/n, U_{Rf2}=100 kV, $U0_{Rf3}$=21.8 kV, U_{Rf3}=800 kV at RF3 frequency variation 25.7 kHz/s cooling time 100 s, for initial rms bunch length σ=1.7 m after R2 bunching



Dependence of ratio of number of ions captured in parasitic separatrix to number of ions captured in central separatrix on rms bunch length.





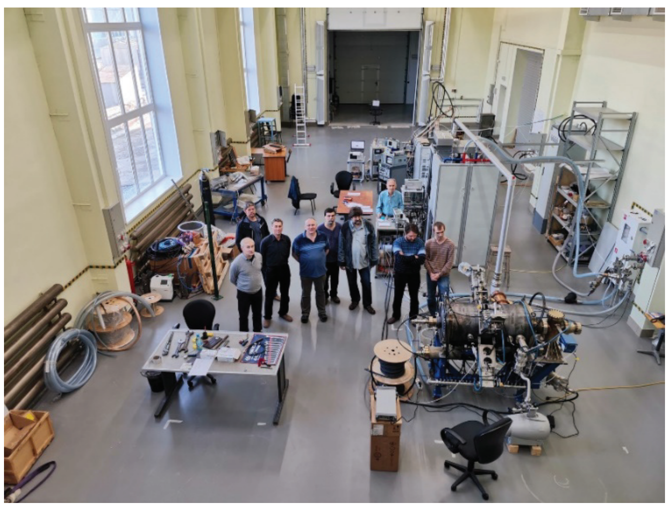
Dependence of bunch length and momentum spread on time at cooling time of 100 s.

Barrier bucket RF1 and harmonic RF2-RF3 cavities

RF1 cavity in BINP

Two RF1 cavities delivered in JINR in 2019

RF1 cavity in JINR



RF3 cavity and amplifier in BINP

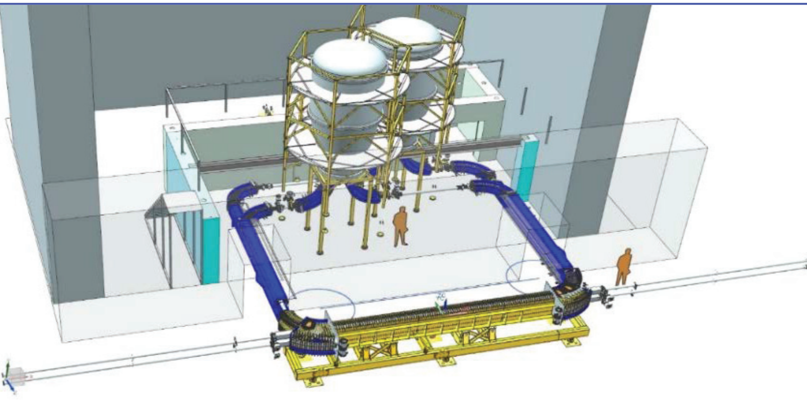
(16 RF3 cavities for extension configuration,
Installation in end of 2022)

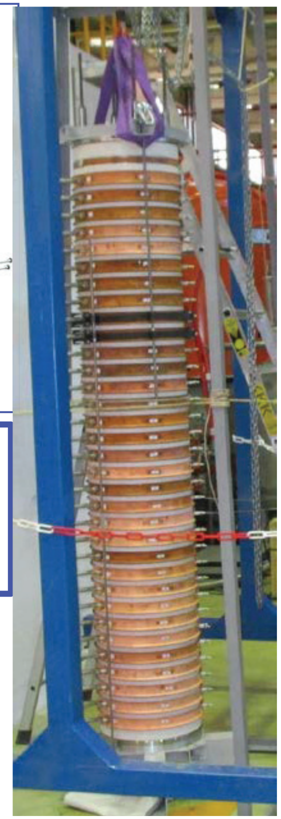
RF2 cavity and amplifier in BINP

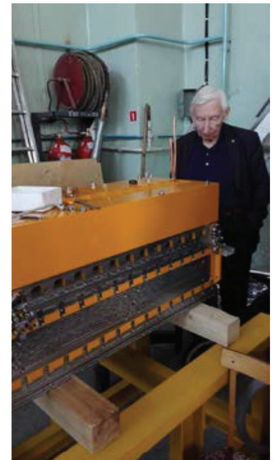
(4 RF2 cavities for base configuration 2022
4RF2 cavities for extension configuration, installation in 2022)

Electron Cooling System of NICA Collider, Ions $^{197}Au^{79+}$

RUPAC 21,
M. Bryzgunov
TUB04

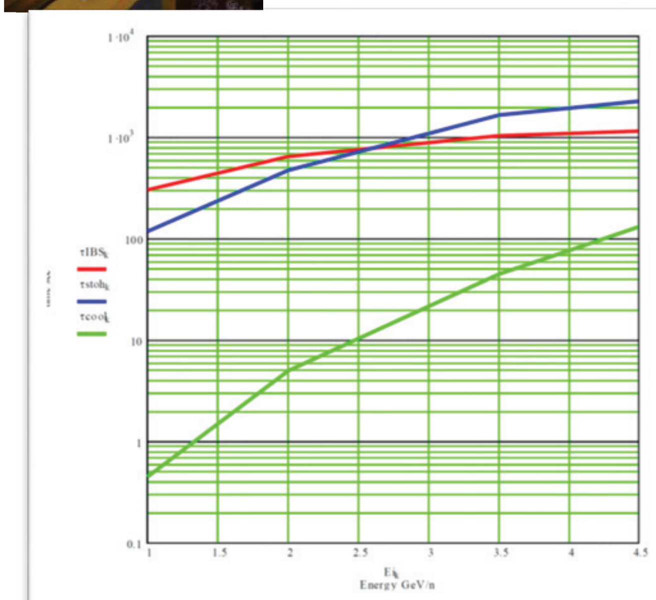




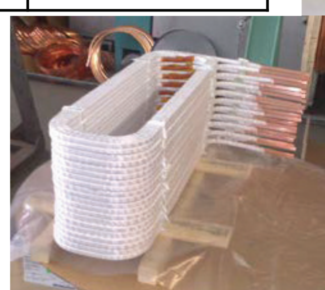


HV Electron Cooler for NICA Collider
Design and construction at BINP
Installation at NICA in 2022

Parameter	Value
Electron energy, MeV Energy instability, ΔE/E	0.2 – 2.5 $\leq 1 \cdot 10^{-4}$
Electron beam current, A	0.1 – 1.0
Cooling section length, m	6.0
Solenoid magnetic field, T Field inhomogeneity, ΔB/B	0.05 – 0.2 $\leq 1 \cdot 10^{-5}$



Dependence of cooling time and IBS on ion energy



Start of mounting – January of 2022
First beam tests – Spring 2023

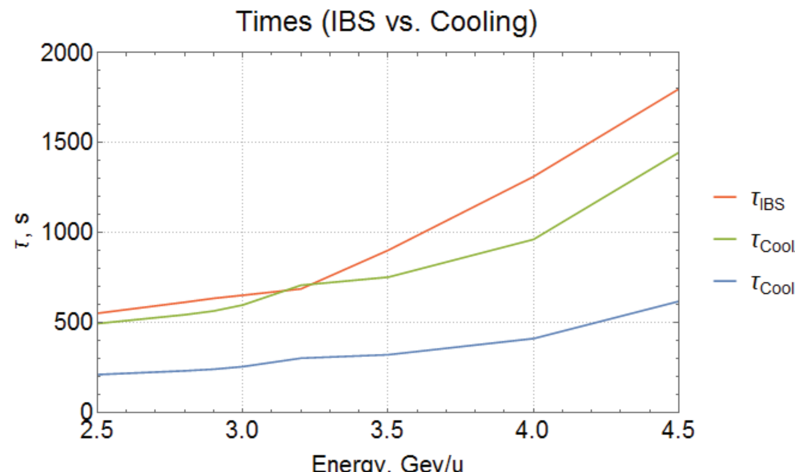
NICA Stochastic Cooling

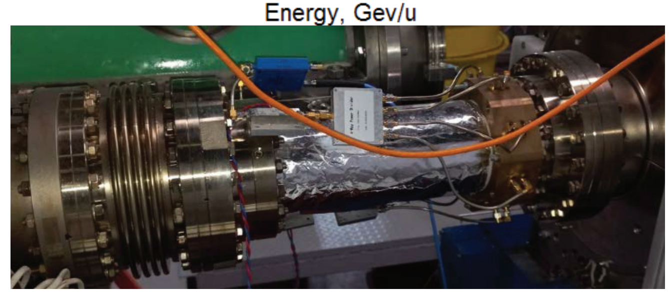
RUPAC 21,
I. Gorelyshev
TUB06

- Beam accumulation
- Longitudinal emittance reduction during the bunching
- Luminosity preservation (IBS counteraction)

SCS Parameters

Longitudinal cooling method	Filter
Passband, GHz	0,7 – 3,2
Beam distance from pickup to kicker, m	183,5-191,5
Phase advance from pickup to kicker, deg	1340-1360
Ion Energy $^{197}Au^{79+}$, GeV/u	3,0
Slip-factor from pickup to kicker	0.0294
Revolution slip-factor	0.0362
Pickup/kicker coupling impedance, Ω	200/800
Gain, dB	75 – 79
Peak power at kicker, W	3×200
Pickup/noise temperature, K	300/40



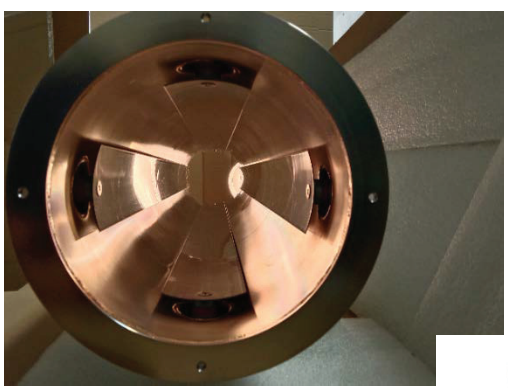


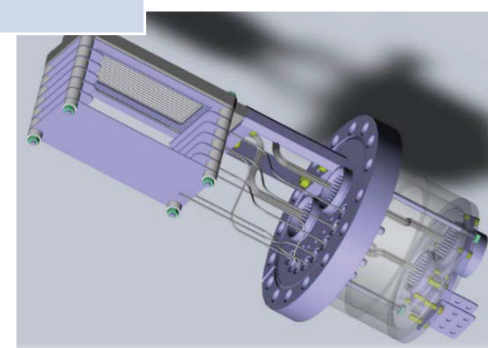
Start of mounting – Spring of 2022
First beam tests – Autumn 2022

Collider diagnostics

Total number of diagnostic devices in one ring (2 arcs + 2 straight sections):

Pick-up near F lenses (X)	24
Pick-up near D lenses (Z)	24
Pick-up in straight sections (X/Z)	20
Parametric current transformer (Bergoz)	1
Fast current transformer (Bergoz)	2
Betatron tune measurements (Q-meter)	1
Ionization profile monitor	3
Strip pick-up monitor	2
Schottky-pick-up	1
Beam loss monitors (for both rings)	68





Start of mounting – Winter of 2022
First beam tests – Autumn 2022

Collider building

Improvement of accelerator and detector equipment parameters during project development after 2013 required increasing power consumption , power of water cooling system, sizes of Collider building and essential increasing of quantity of engineering equipment. **As a result the collider power consumption was increased from 4 to 9 MW, water cooling power from 2.9 up 5.6 MW, building square from 19900 to 30800 m^2.**

Installation of arc magnets is planed to start in October-November 2021

Thank you for your attention!