SC MAGNETS: Status of fabrication & test results

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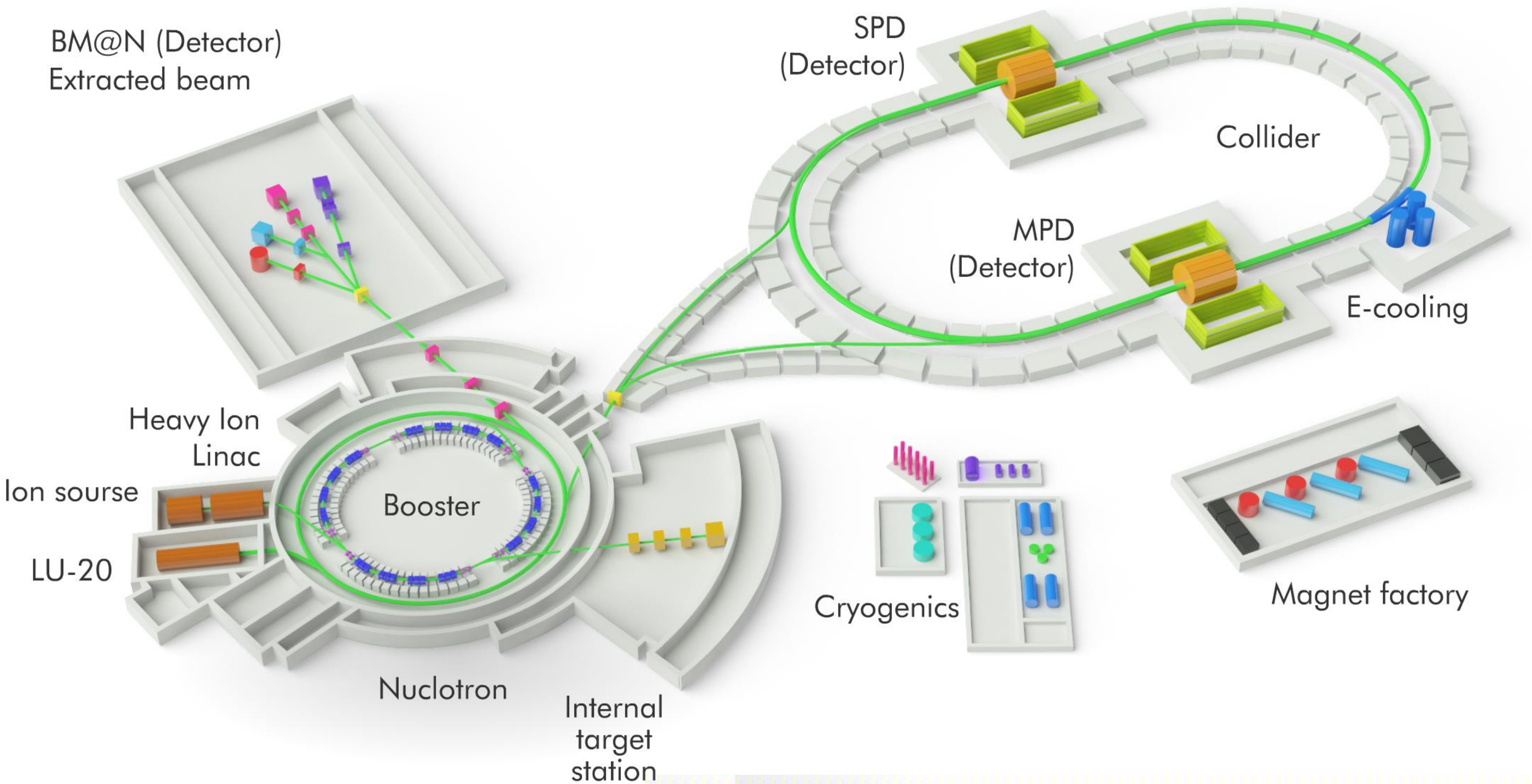
for the NICA team

Outline

- **Introduction, SC magnets in NICA complex**
- **Design of the magnets**
- **Status of magnets manufacturing**
- **SC magnets cryogenic test results**
- **Conclusion**

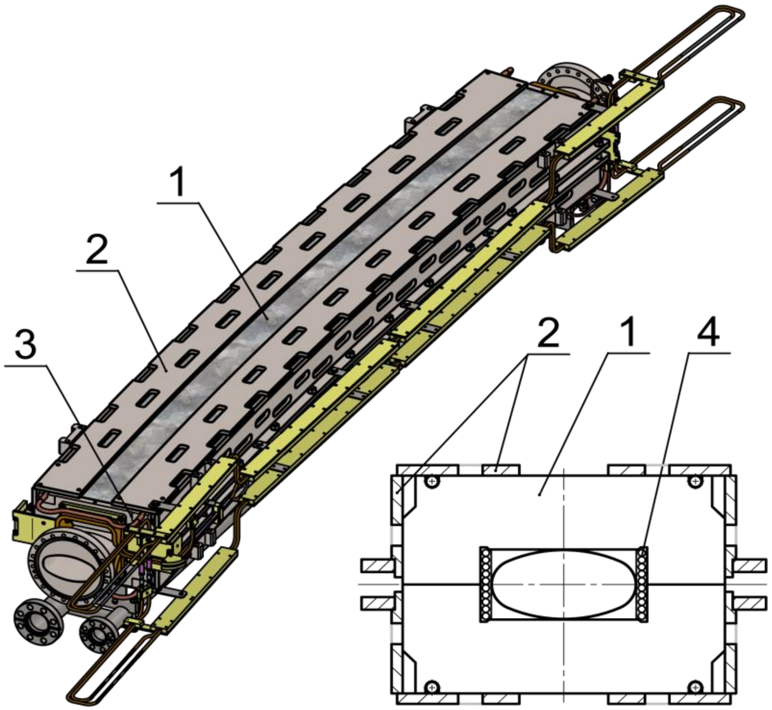
NICA accelerator complex

- two injector chains
- new 600 MeV/u SC booster synchrotron
- upgraded SC synchrotron Nuclotron
- SC collider 503 m in circumference with luminosity up to $1 \cdot 10^{27}$ cm^{-2} s^{-1} for Au^{79+}
- two interaction points with MPD and SPD detectors



Design of the NICA booster magnets

The Nuclotron-type design based on a cold, window-frame iron yoke and a winding of the hollow superconductor was chosen for the NICA Booster.



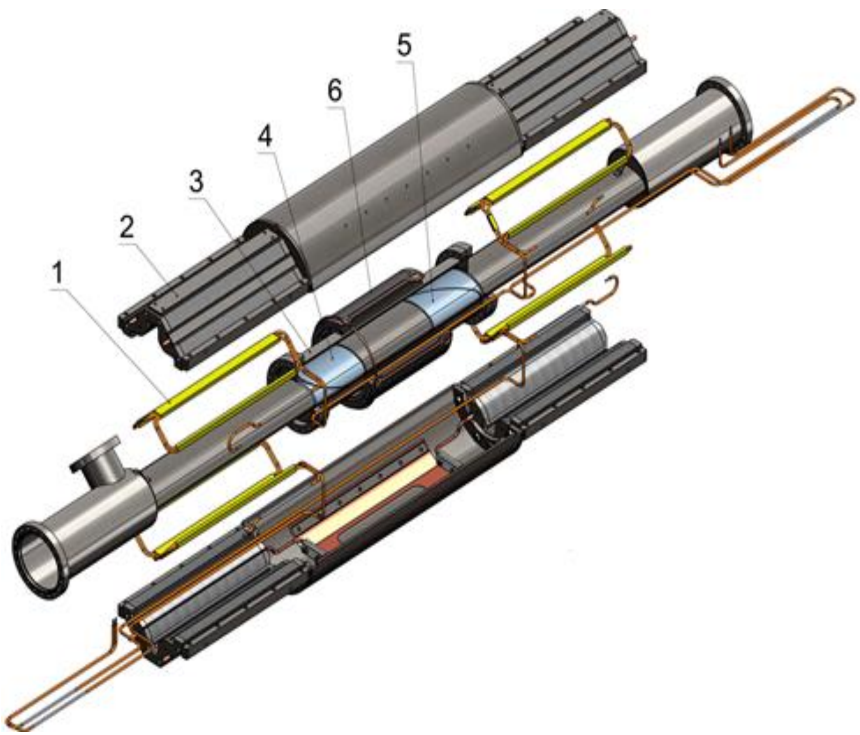
View of the dipole magnet. 1 – lamination, 2 - side plate, 3 - end plate, 4 – SC coil.

The iron yoke consists of two symmetric parts bolted together. The half-yokes are fabricated of laminated isotropic 0.65 mm thick electrical steel M 530. The laminations are compressed with specific pressure of 5 MPa in the direction of the longitudinal axis of the magnet. The side plates, 10 mm thick, are welded with laminations and 20 mm thick stainless steel end plates.

Design of the NICA booster magnets

The Nuclotron-type design based on a cold, window-frame iron yoke and a winding of the hollow superconductor was chosen for the NICA Booster.

Two lattice lenses are connected together using the intermediate cylinder and form a doublet (see Fig. 1). The doublet of about 1.8 m length has a rigid mechanical design. It has a demountable construction that allows splitting the doublet into two horizontal parts to install the beam pipe. The doublet fixed in the cryostat by means of suspension rods and adjusted in space as one unit.



View of the doublet of the lenses. 1 – half-coil, 2 – half-yoke, 3 – beam pipe, 4, 5 – beam position monitors, corrector magnet

SC Cable

Main characteristics of the cable for the SC magnets

Parameter	Booster	Collider	SIS100 QP
Cooling channel diameter, mm	3	3	4.7
Number of strands	18	16	23
SC strand diameter, mm	0.78	0.9	0.8
Superconductor	Nb – Ti		
Cu/SC/CuMn ratio	1.26 / 1 / 0	1.33 / 1 / 0	2.2 / 2.3 / 1
Diameter of SC filaments, μm	7	8	3
Twist pitch of filaments, mm	7	9	7
Cable outer diameter, mm	6.6	7.0	8.38
Operating current (1.8T, 4.65K), kA	9.68	10.4	10.5
Critical current (2.5T, 4.7K), kA	14.2	16.8	21.0

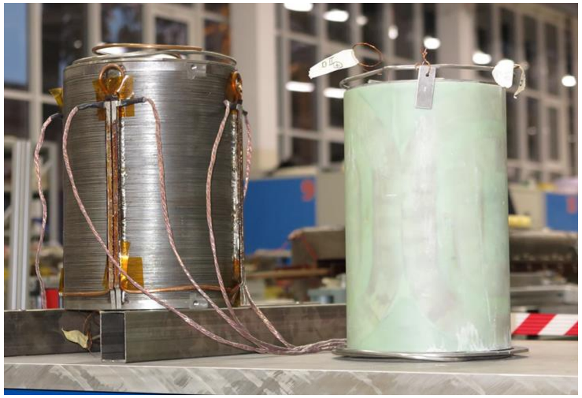
Main Characteristics of the Magnetes for NICA Booster

Parameter	Dipole	Lens
Number of magnets	40	48
Max. magnetic field (gradient)	1.8 T	21.5 T/m
Effective magnetic length	2.2 m	0.47 m
Beam pipe aperture (h/v)	128 mm/ 65 mm	
Radius of curvature	14.09 m	-
Overall weight	1030 kg	110 kg

NICA

Status of Manufacturing the Magnets for NICA Booster

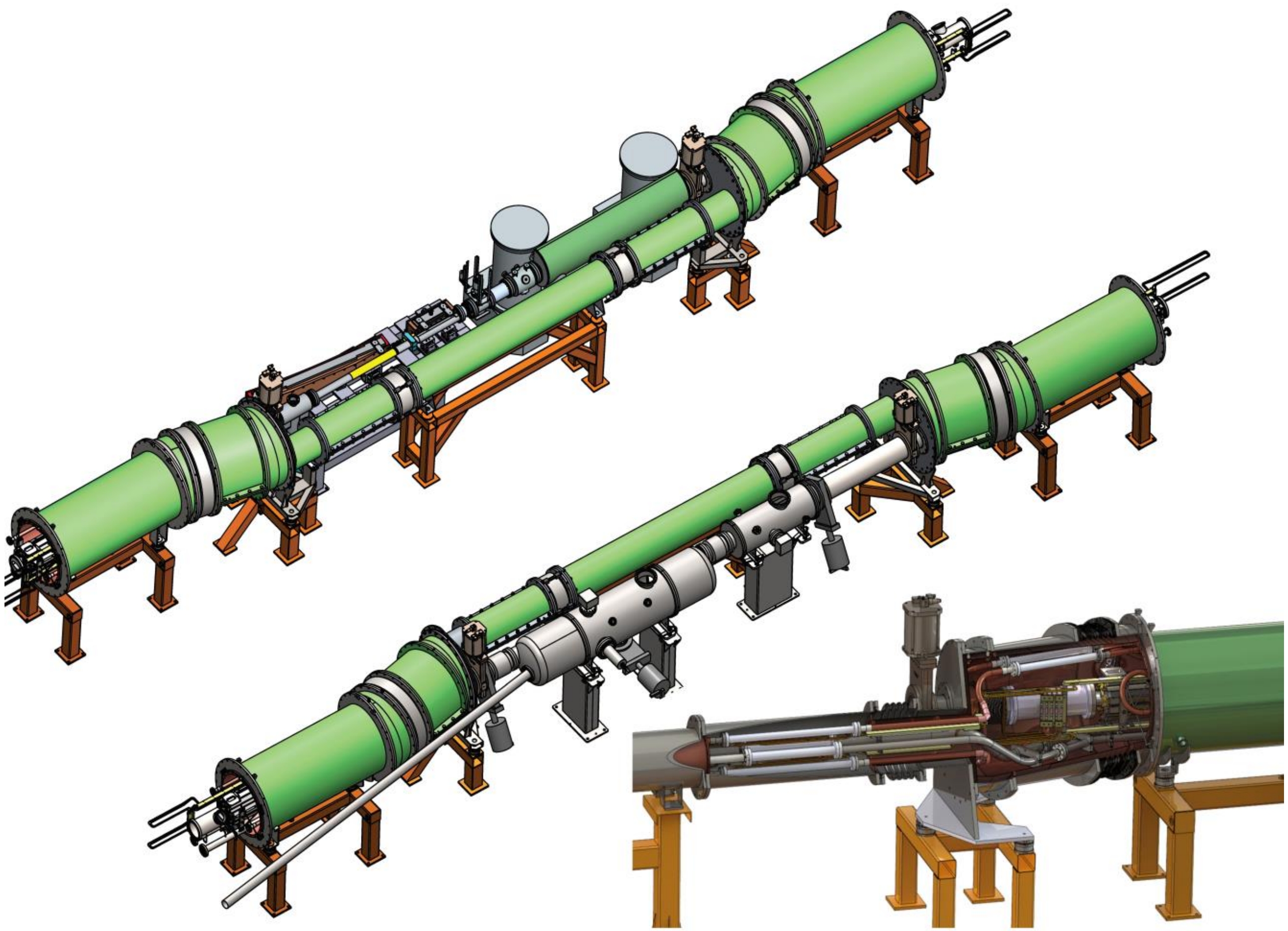
- Yoke of the Dipole Magnets – 40 or 100%
  Coil of the Dipole Magnets - 40 or 100%
- Yoke of the Quadrupole Magnets – 48 or 100%
  Coil of the Quadrupole Magnets - 48 or 100%
- Yoke of the Corrector Magnets – 32 or 100%
  Coil of the Corrector Magnets - 16 or 50%
- Cryostat for magnets – 71 or 100%



Status of Manufacturing the Magnets for NICA Booster

- Supports for the magnets – 71 or 100%
- Bellows for cryostats – 142 or 100%
- HTSC current leads on 10 kA – 10 or 100%
- Beam pipe for dipole magnets – 40 or 100%
  Beam pipe for doublets - 24 or 100%
- Beam position monitor – in manufacturing stage

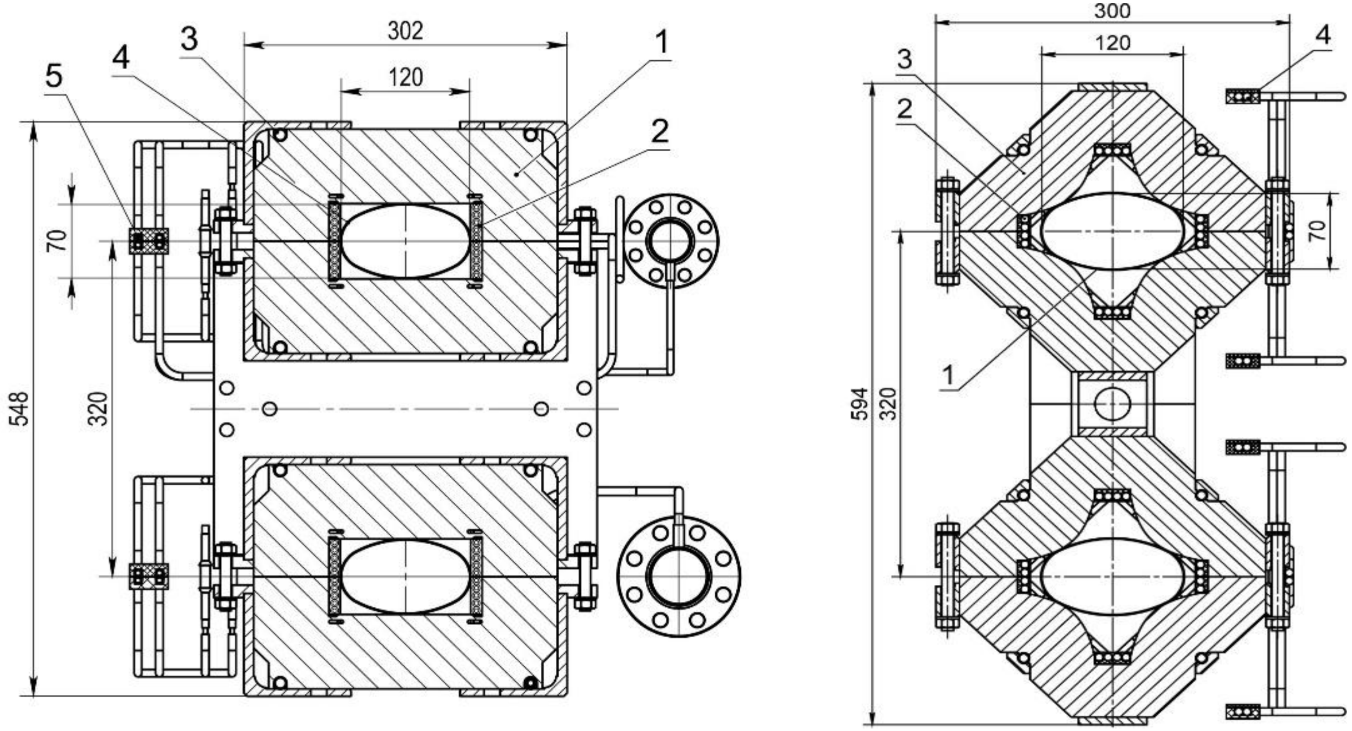
Status of Cryogenic Bypass Lines



There are two bypass lines for injection and extraction of the beam. Vacuum shells and thermal shields are in the manufacturing stage, SC bus bars and helium collectors are in the design stage.

Design of the NICA Collider Magnets

The Nuclotron-type design based on a cold, window-frame iron yoke and a winding of the hollow superconductor was chosen for the NICA Collider.



Cross-section of the collider magnets: Dipole magnet (left): 1 – lamination, 2 – SC coil, 3 – tube for cooling the yoke, 4 – beam pipe, 5 – bus bars; Quadrupole lens (right): 1 – beam pipe, 2 – half-yoke, 3 – lamination, 4 – bus bars. All dimensions in mm.

Main Characteristics of the NICA Collider 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;

Production of the NICA Collider Magnets

- The series production of the collider magnets kicked off in March 2018.
- The series production of the cryostats was launched this spring.
- The manufacturing of 350 bellows for cryostats is completed.
- 300 km of SC wire for all lattice collider magnets was delivered.
- 380 tons of electrical steel for the magnet yokes were manufactured.

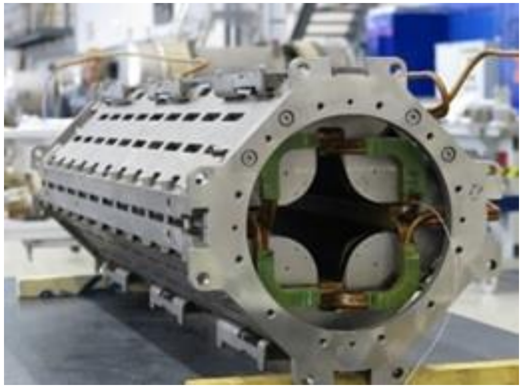
Magnets for the SIS100 Synchrotron

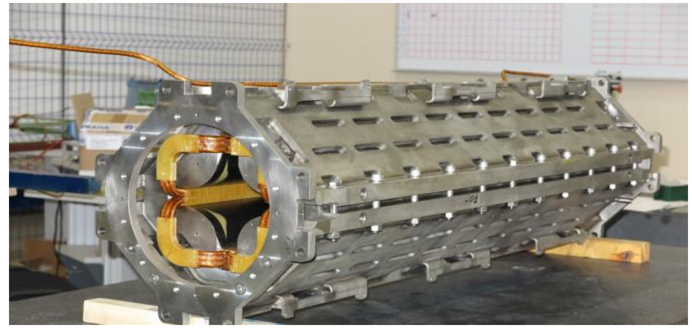
All SIS100 lattice quadrupole and corrector magnets have to be made in JINR, Dubna. The Nuclotron-type design based on a cold, window-frame iron yoke and a winding of the hollow superconductor was chosen for the SIS100 magnets.

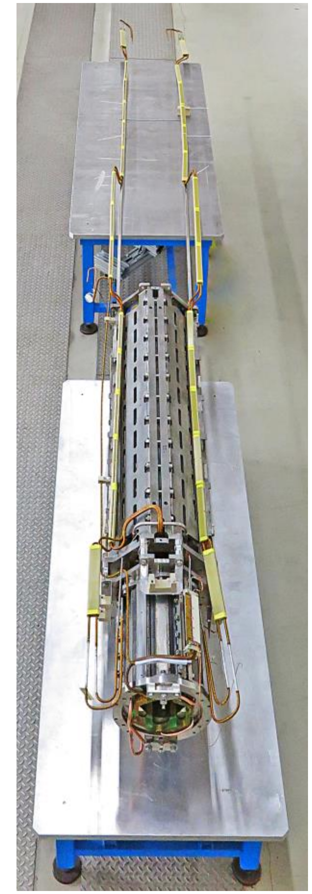
Characteristics of the SIS100 magnets

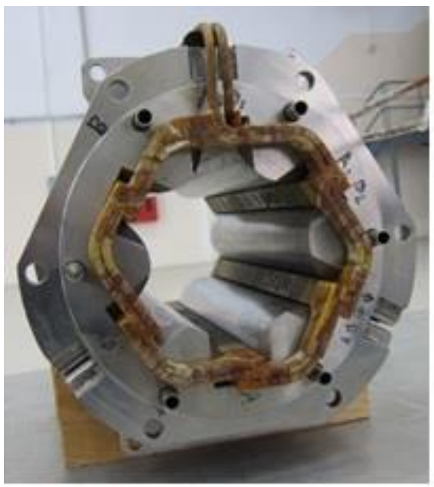
Parameter	Lattice Quadrupole	Corrector magnet		
		Multipole (Q/S/O)	Steerer	Chrom. Sextupole
Number of magnets	166	12	84	42
Max. field strength, T/m^{n-1}	27.77	0.75/25/333,3	0.37	232
Effective magnetic length, m	1.264	0.75	0.403/0.41	0.383
Aperture diameter, mm	100	150	135	120
Operation current	10512	250/246/240	245/241	252
Magnet weight, kg	850	200	120	145

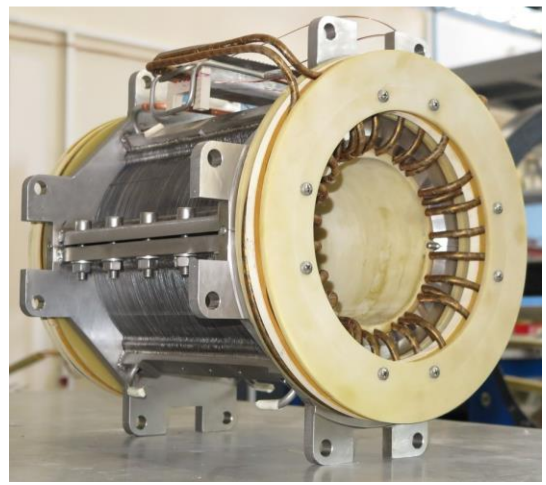
Magnets for the SIS100 Synchrotron









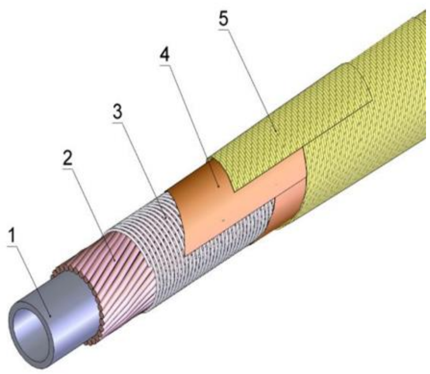


- A sextupole, a steerer and two quadrupole magnets were manufactured.
- Two FoS units of this magnets were assembled and have successfully passed the tests at cryogenic temperature.
- The beginning of the series production of SC magnets for SIS100 in Dubna is scheduled for middle 2018.

Facility for SC Magnets Assembling and Cryogenic Tests

- Test facility in full configuration was commissioned. JINR and FAIR/GSI participate together in funding of this test facility.
- 100% of the dipole magnets and 20% of the doublets for the NICA booster synchrotron have successfully passed the tests up to May 2018.

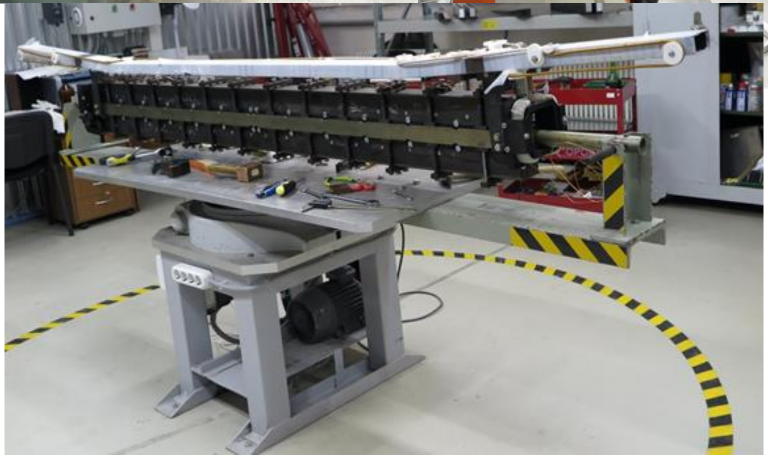
SC Cable Production



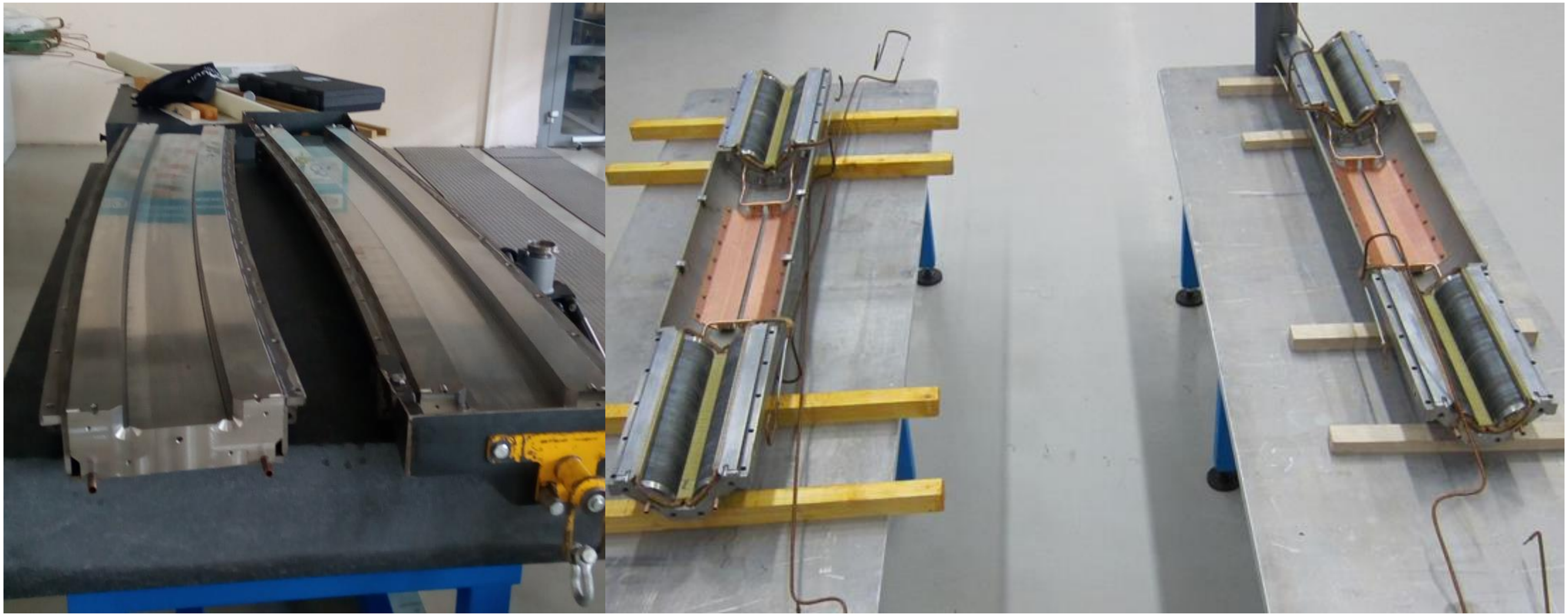
View of Nuclotron-type cable:
1 – cooling tube, 2 – SC wire,
3 – Ni-Cr wire, 4 and 5 - insulation

Machine for production Nuclotron-type superconducting cable with performance of 30 m/h.

Production of SC Coil



Coil with Yoke Assembling



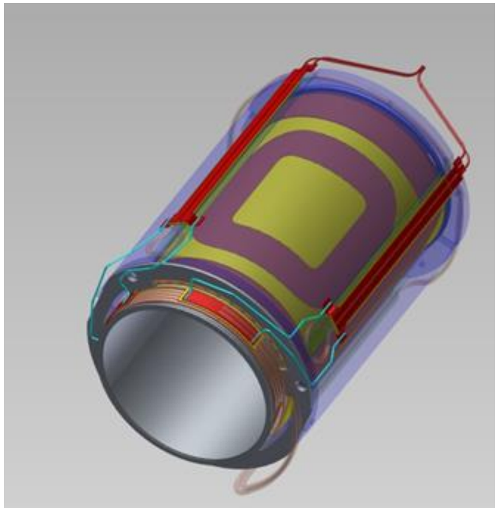
Half-coils assembling with half-yokes for the booster dipole magnet (left) and doublet of the lenses (right)

Production of SC Coil

Check and assembly of the yoke and the coil for the SIS100 quadrupole magnet

Corrector Magnet

24 steering magnets will have two coils each (horizontal and vertical dipole coils) and 8 corrector magnets will contain four coils each (normal and screw sextupole, screw quadrupole and octupole coils).

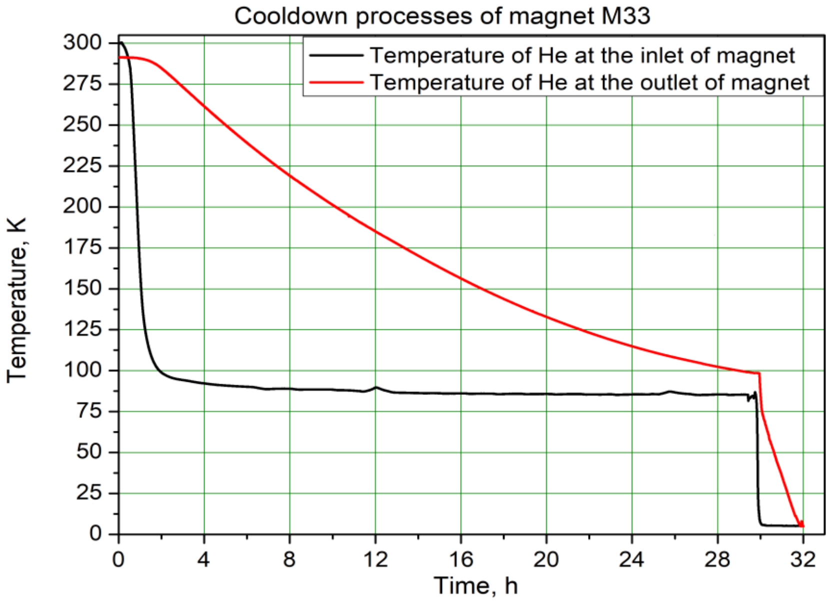


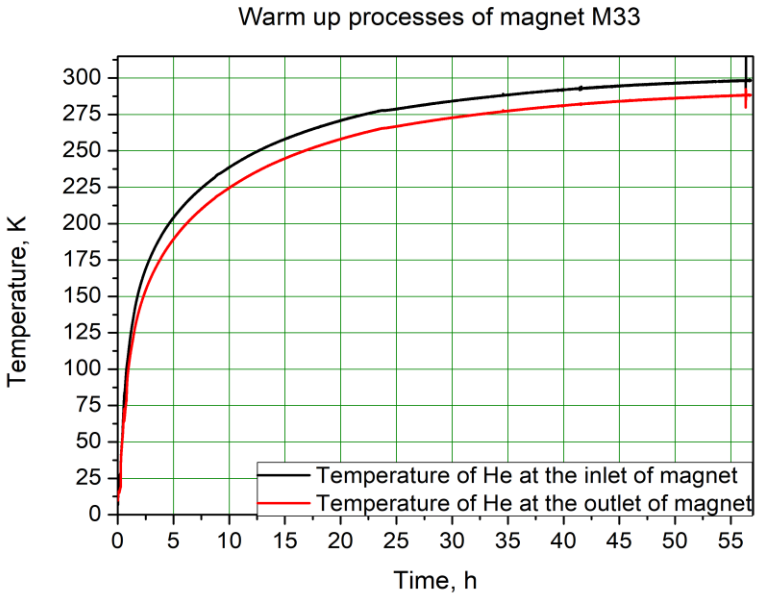
The coil for the NICA booster corrector magnet manufacturing

Series Test of the booster magnets

- All of the dipole magnets for the NICA booster synchrotron was successfully passed cryogenic test and can be installed in the tunnel of the accelerator. Magnetic measurements have good repeatability and their magnitude is within the permissible values.
- The measured value of heat release in a dipole magnet at operating in the project operation cycle was about 13.7 W, of which 4.5 W is static heat flow.
- The measured value of heat release in a doublet of quadrupole lenses at operating in the project operation cycle was about 9.8 W, of which 7.0 W is static heat flow.
- Pressure difference between supply and return helium headers for dipole magnet and doublet of lenses at operating in the project operation cycle is about 0.3 bars.

Series Test of the magnets

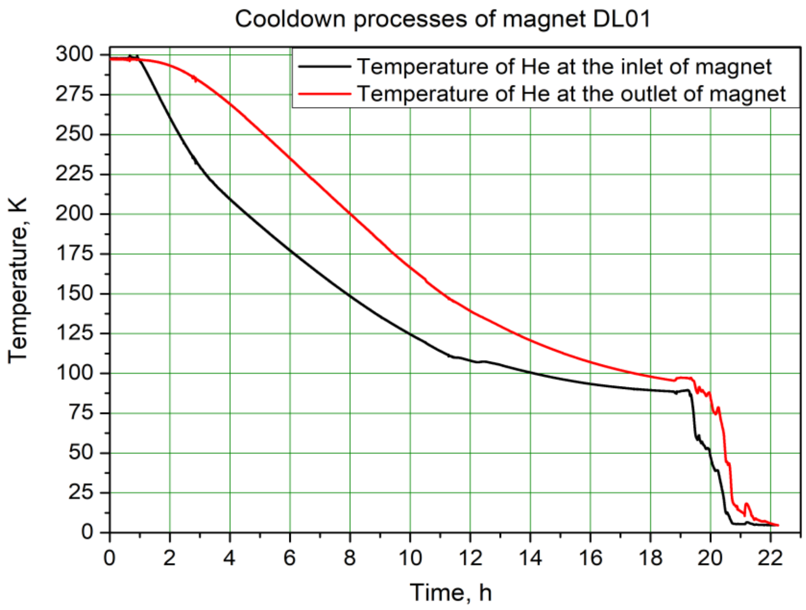


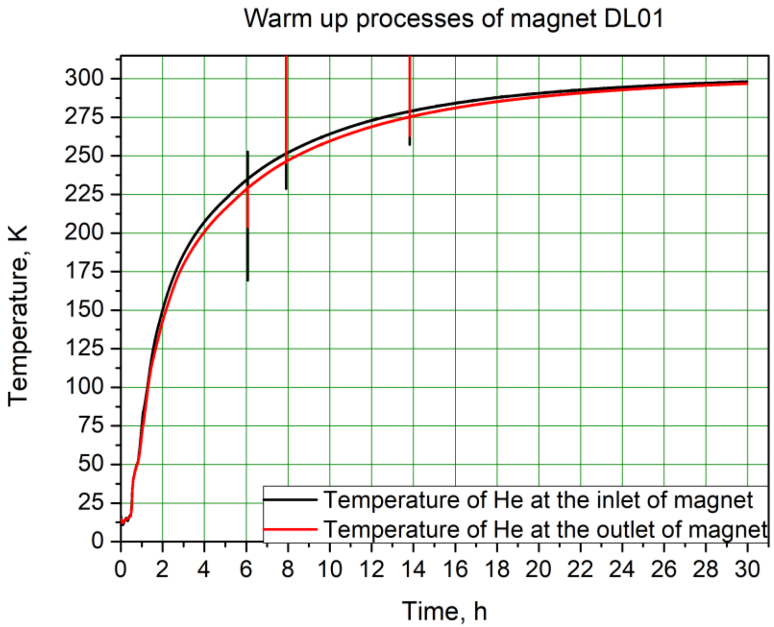


Cooling-down (left) and warm-up (right) of the dipole magnet for the NICA booster. Black line is inlet and red line – outlet of the magnet.

- The total time for mounting on the test bench, cooling-down, vacuum test, carrying out cold tests, warm-up and disassembling the NICA booster dipole magnet is about 140 hours.

Series Test of the magnets

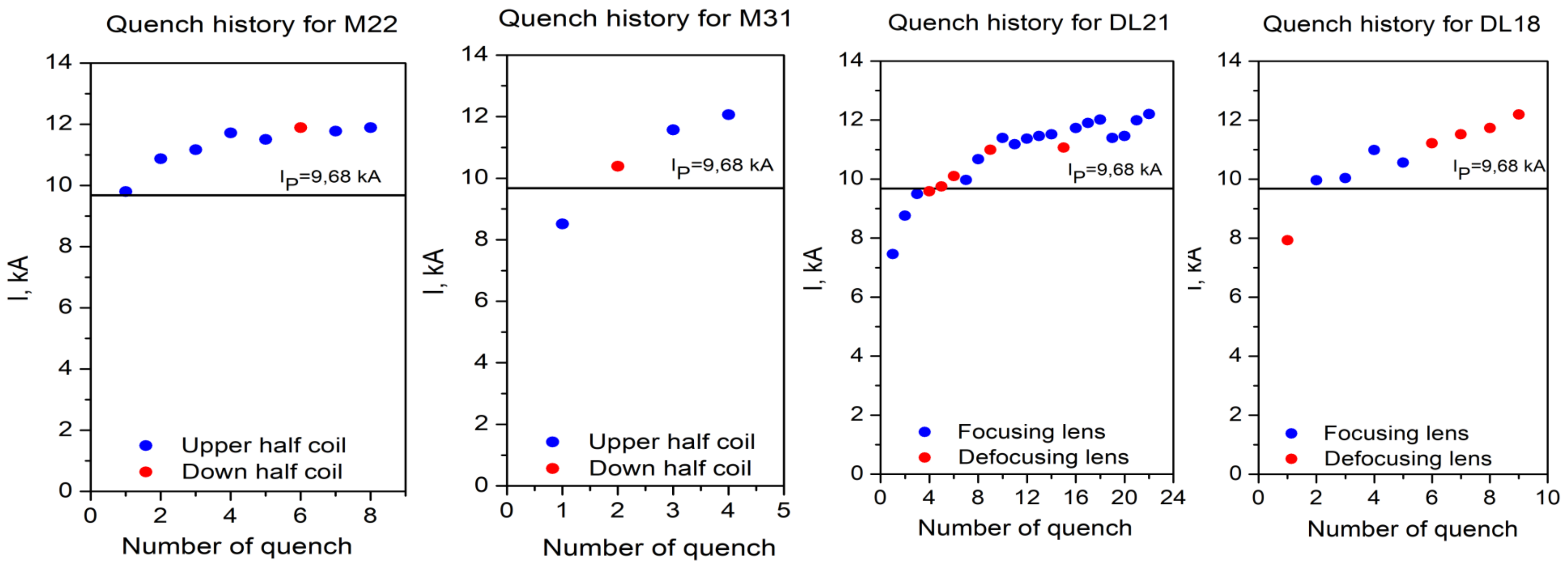




Cooling-down (left) and warm-up (right) of the quadrupole doublet for the NICA booster. Black line is inlet and red line – outlet of the magnet.

The total time for mounting on the test bench, vacuum test, cooling-down, carrying out cold tests, warm-up and disassembling the NICA booster quadrupole doublet is about 110 hours.

Series Test of the magnets



Quench history for the NICA booster magnets.

Series Test of the magnets

Series dipole magnet (left) and doublet (center) for NICA booster, and first of series dipole magnet for NICA collider (right).

Conclusion

- Serial production of the magnets for the NICA booster is completed.
- Facility for assembling and cryogenic tests of the SC magnets for the NICA and FAIR projects was put into operation in full configuration.
- All of the dipole magnets for the NICA booster was successfully passed cryogenic test and can be installed in the tunnel of the accelerator.
- Completing the cold tests and start installation in the tunnel of the magnets for the booster is scheduled for Sept 2018.
- Start of the booster commissioning is scheduled to the end 2018
- The serial production of the collider magnets was start in March 2018. Installation in the tunnel of the collider magnets is scheduled for the second half 2020.
- The beginning of the serial production of SIS100 SC magnets in Dubna is scheduled for July 2018.

Risks and reasons for possible delay in the implementation of the plans

- **Too long time is being spent for preparation of contract with suppliers.**
- **Deficit of staff of necessary qualifications.**
- **Delay in delivery of products by suppliers.**
- **Delay in the delivery of the beam position monitors and the corrector magnets for the booster synchrotron is alarming.**

Thank you for your attention