Magnetic Field Measurements for the NICA Collider Magnets and FAIR Quadrupole Units

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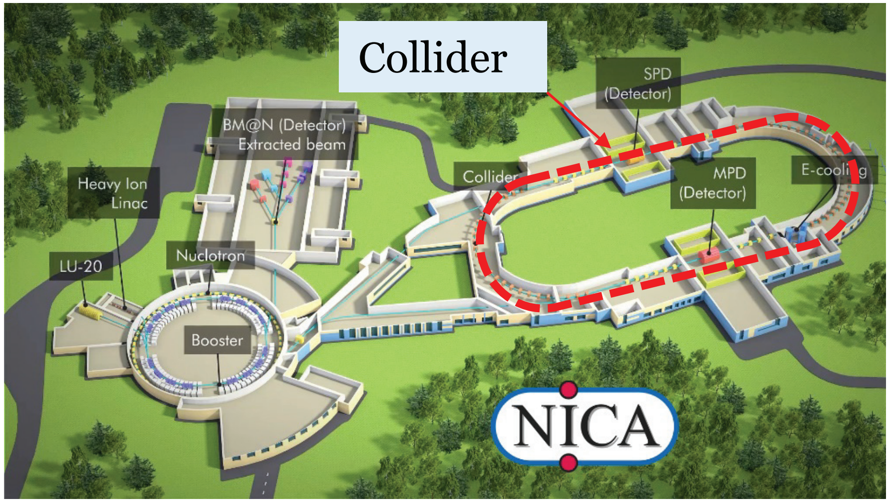
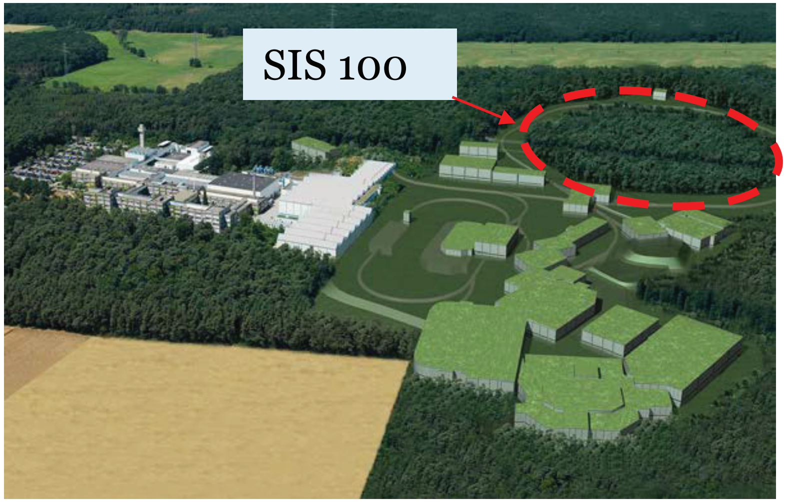


Nuclotron-based Ion Collider fAcility

Dubna, Russia



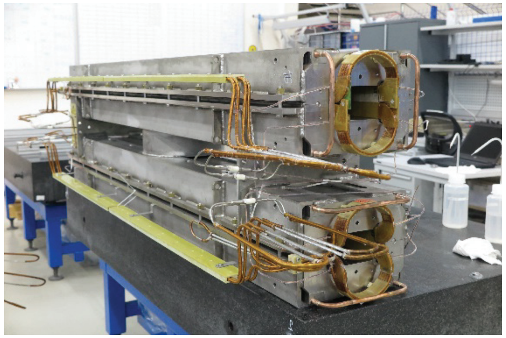
Facility for Antiproton and Ion Research in Europe

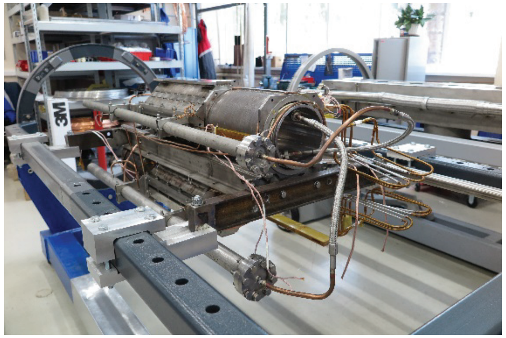
Darmstadt, Germany

Scientific and experemental department of production and testing of superconducting magnets.

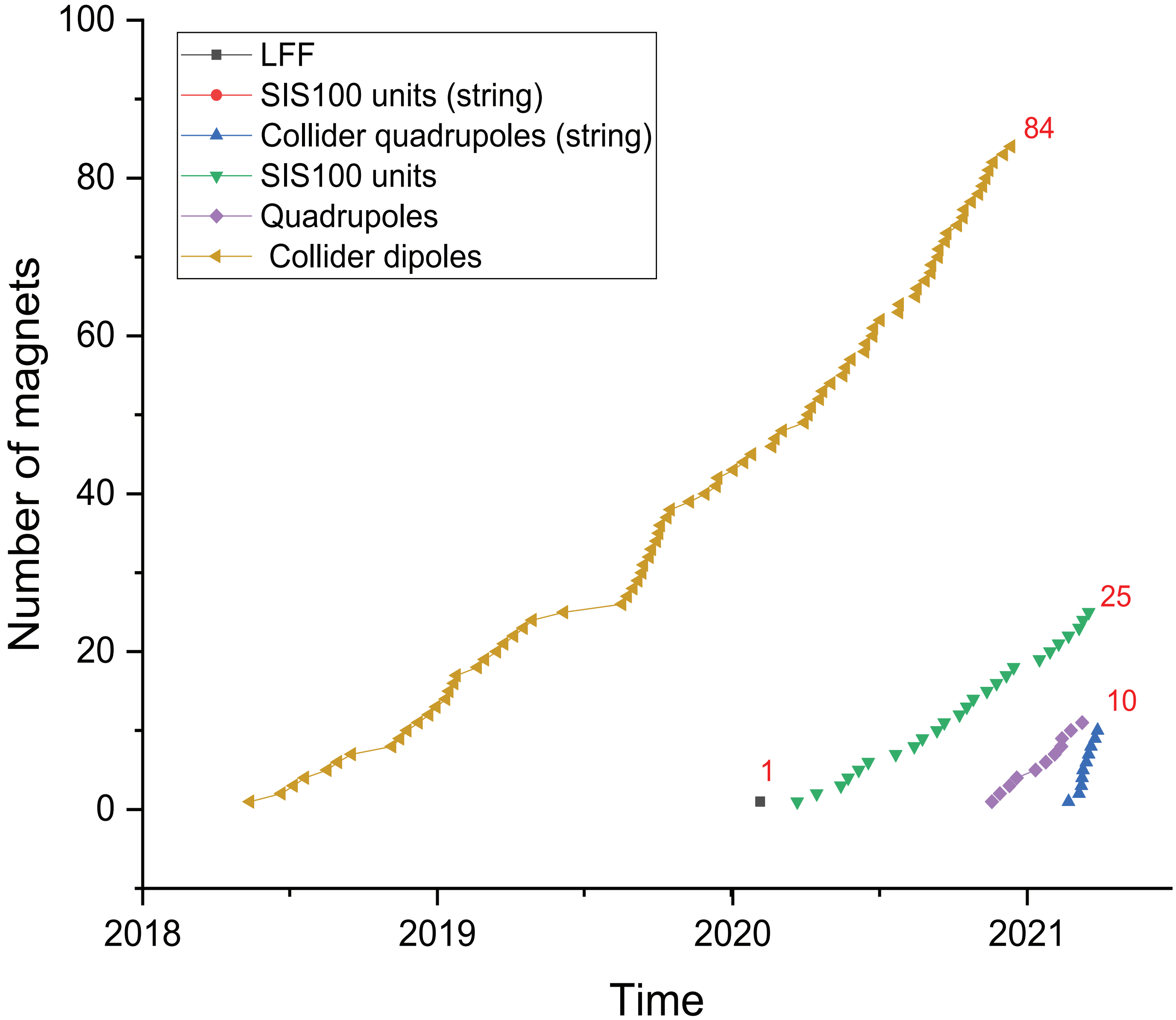
Introduction: NICA and FAIR

-Dipole magnets of NICA collider– 80 pc.
-Quadrupole magnets of NICA collider– 86 pc.
-Quadrupole magnets of SIS-100 (FAIR project) - 175 pc.





Progress of magnetic measurements



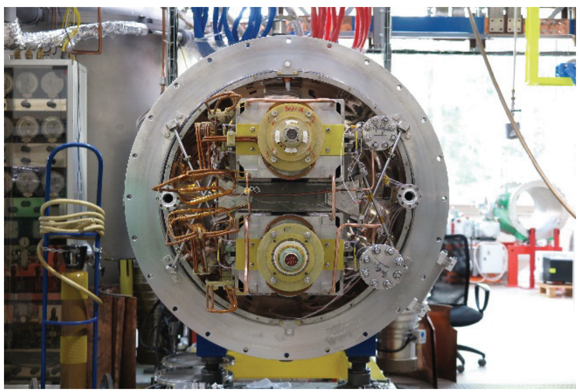
Measurements for the NICA collider magnets: dipoles

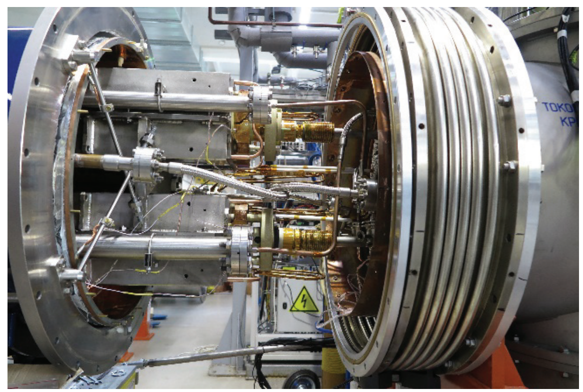
Two measurement modes:

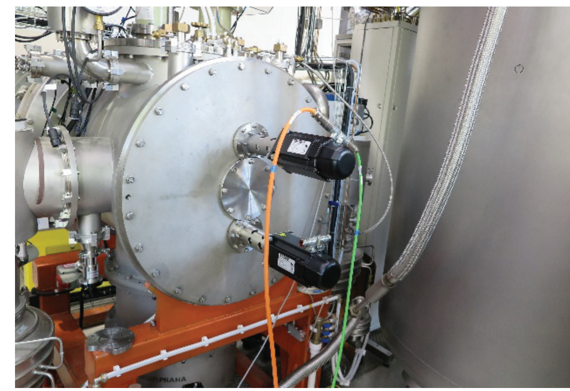
- Step rotation mode (max current of 10500 kA)
- Constant rotation (for 0 A; 2300 A; 6890 A; 10440)

Warm
100 A

Cold
10500 A

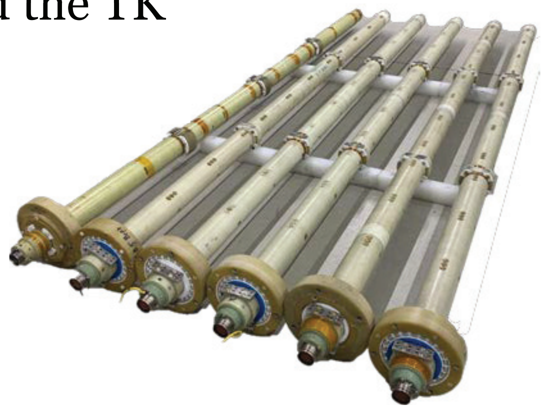




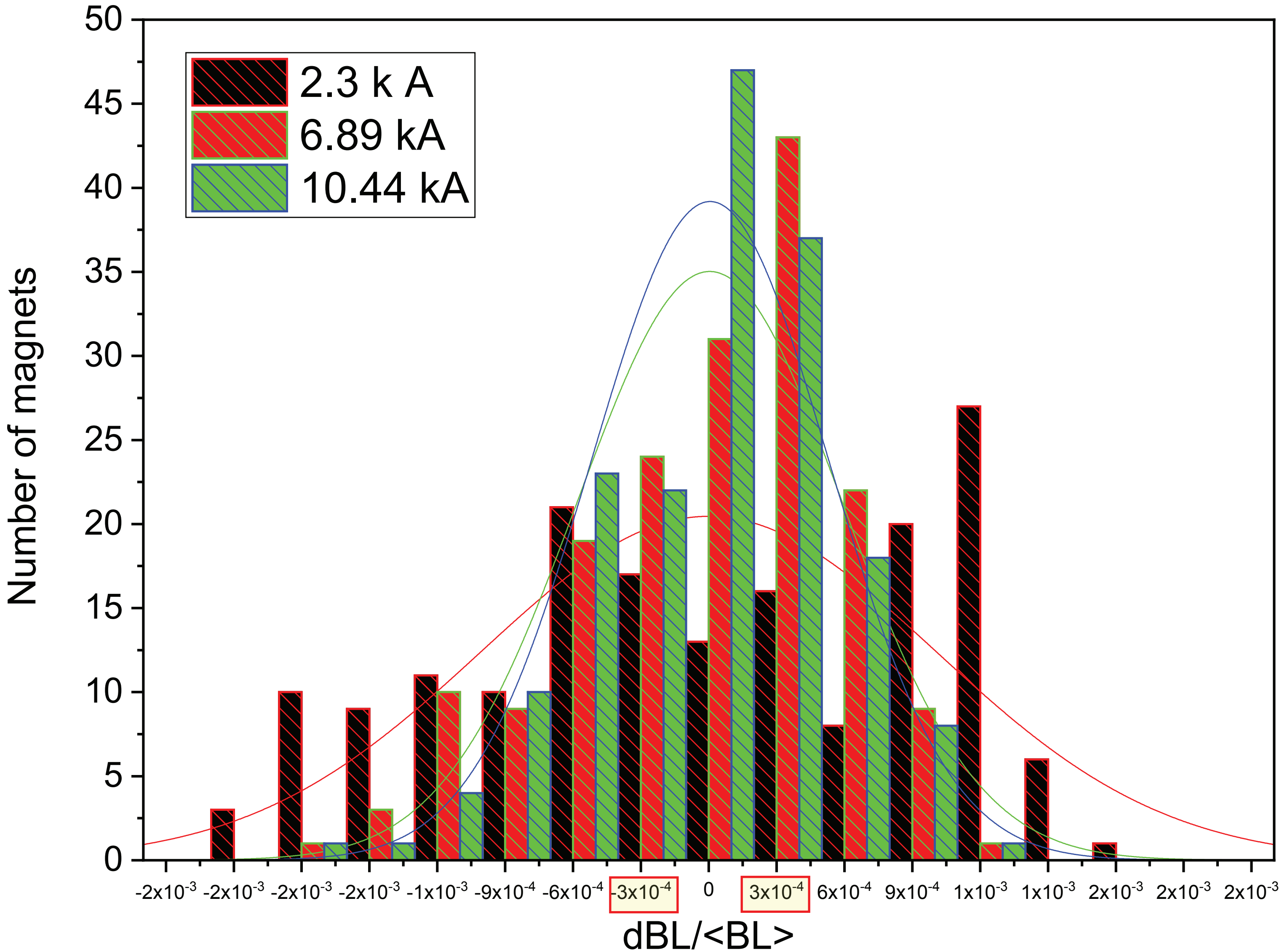


The final number of magnetometers: **6 pc.**

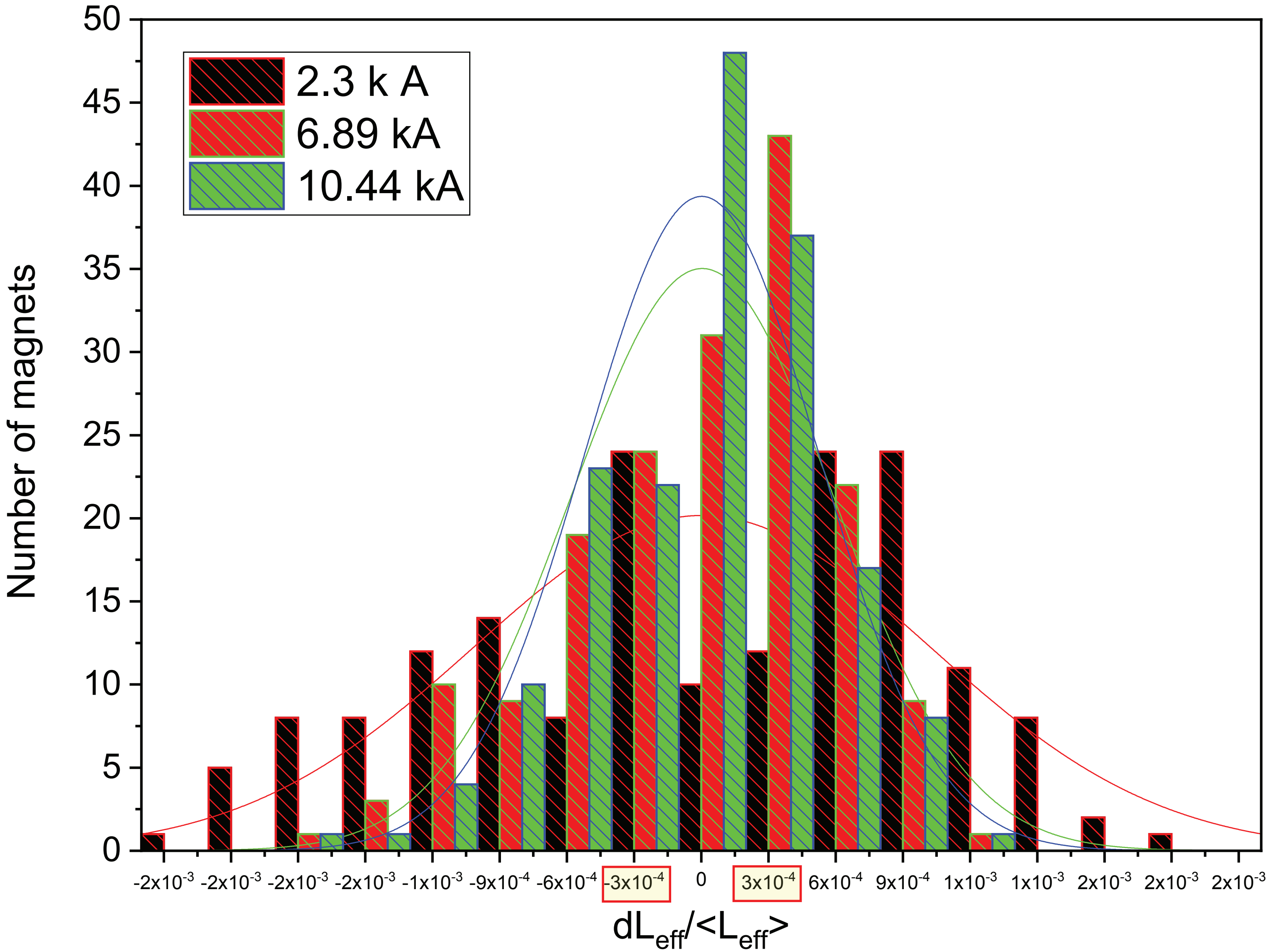
- The production time of 1 magnetometer: **60 days.**
- Each magnetometer is relative calibrated on a reference magnet.
- The assembly is carried out under the control of a control measuring machine (0.050 mm).
- The accuracy of the measuring system does not exceed the TK tolerance.



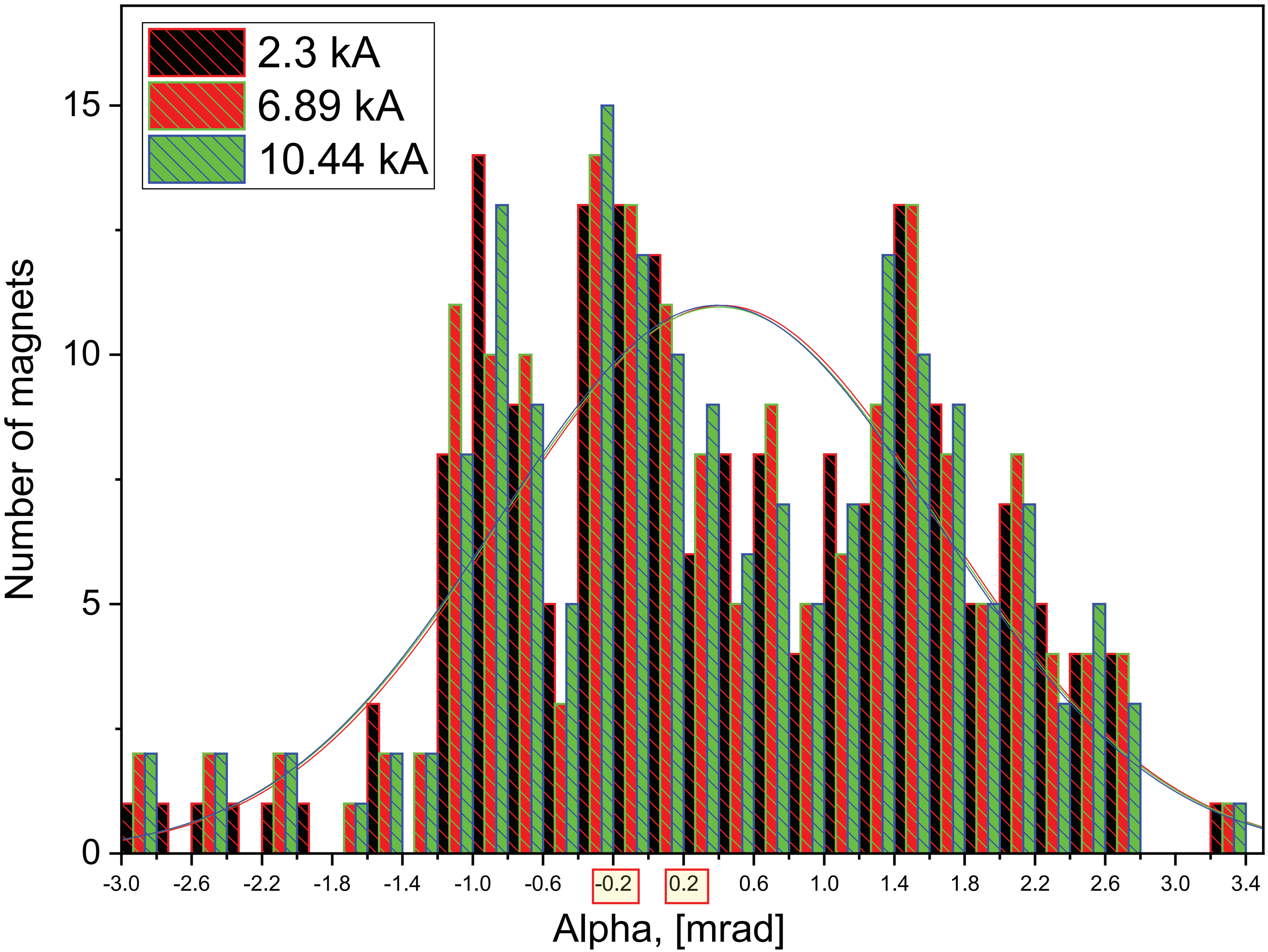
Measurements for the NICA collider magnets: dipoles

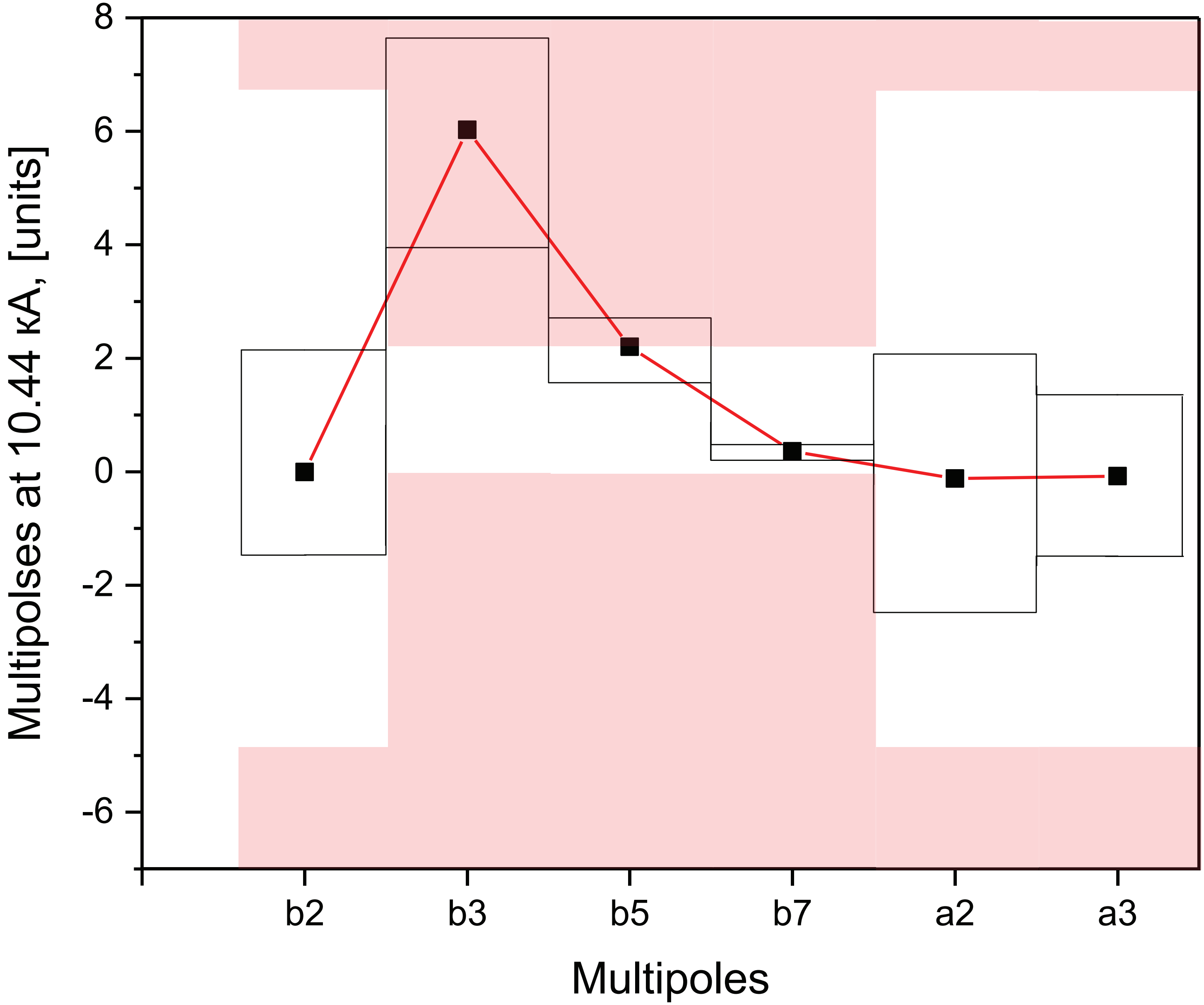


Measurements for the NICA collider magnets: dipoles



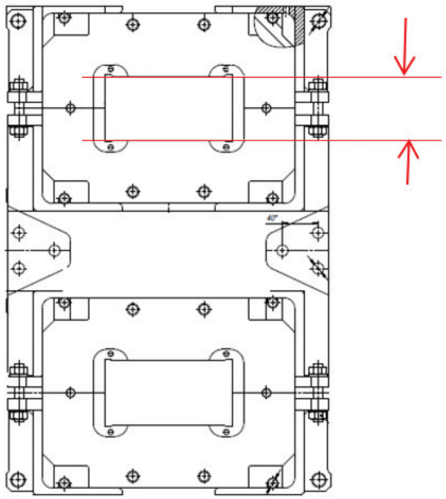
Measurements for the NICA collider magnets: dipoles

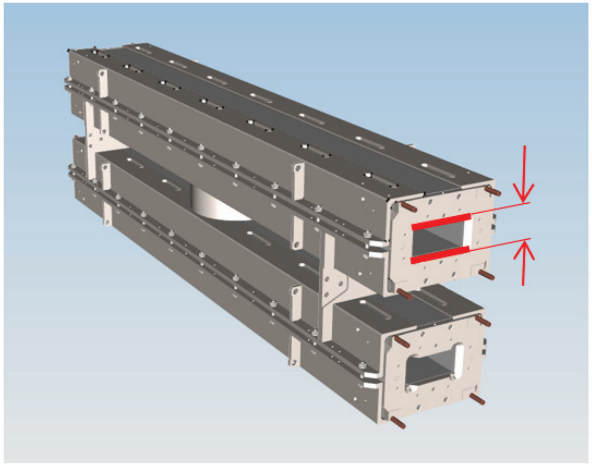




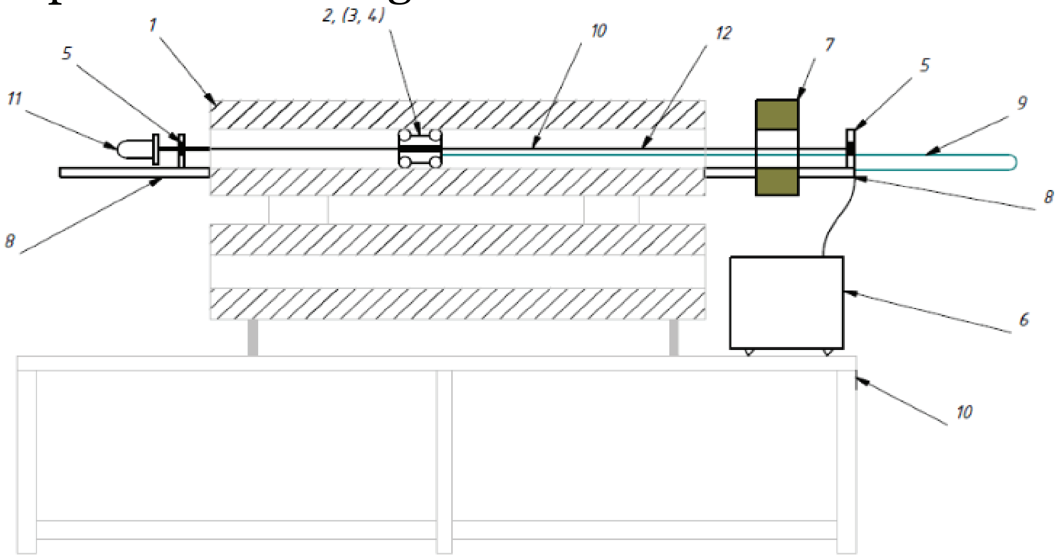
8
6
4
2
0
-2
-4
-6
Multipolses at 10.44 кA, [units]
b2
b3
b5
b7
a2
a3
Multipoles

Measurements for the NICA collider magnets: dipoles



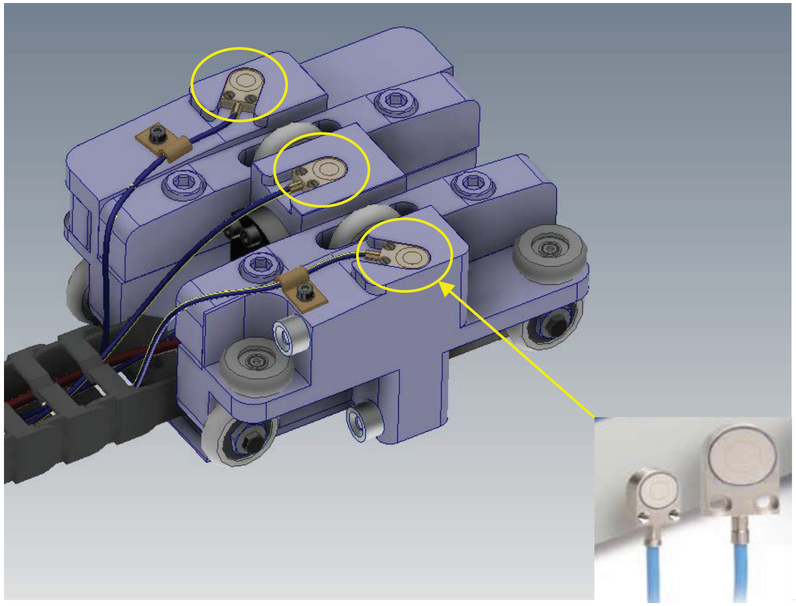


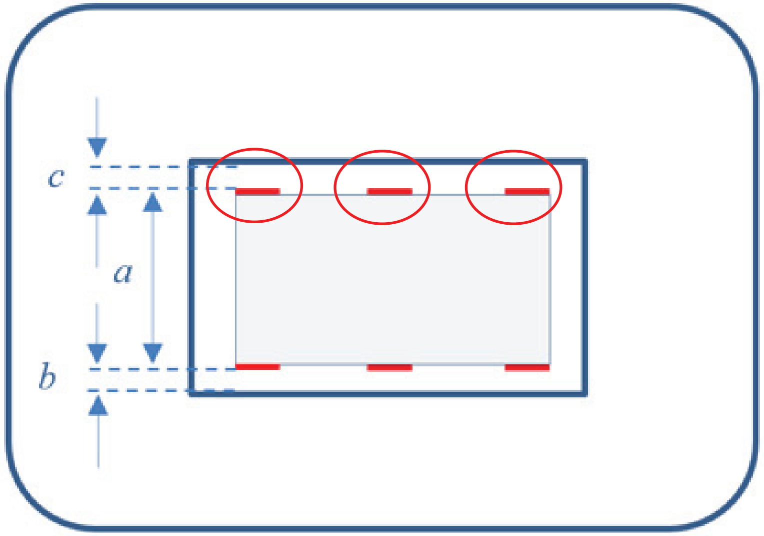
Task: Monitoring the pole gap of a twin aperture dipole collider magnet.



- For this task, the SIMZ system was created.

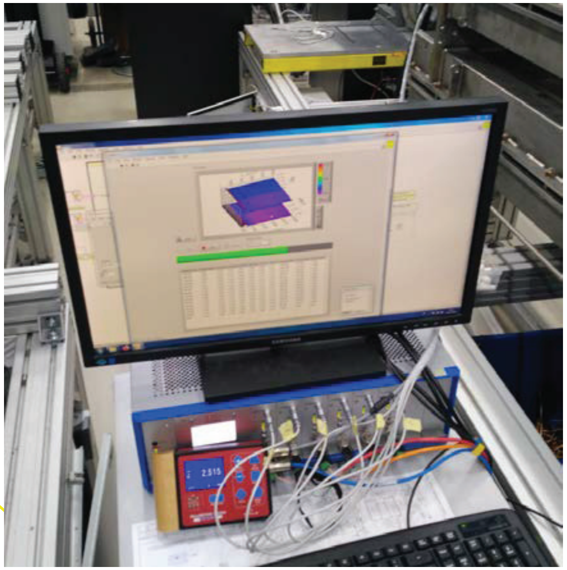
Measurements for the NICA collider magnets: dipoles

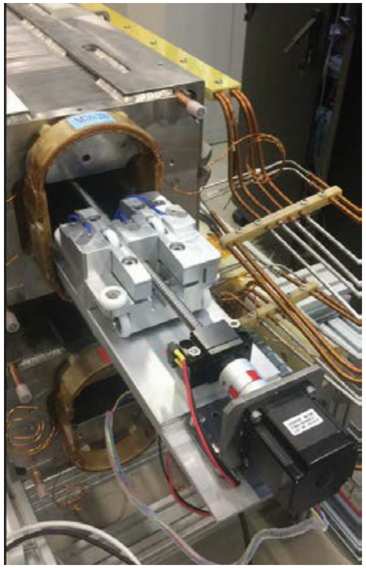




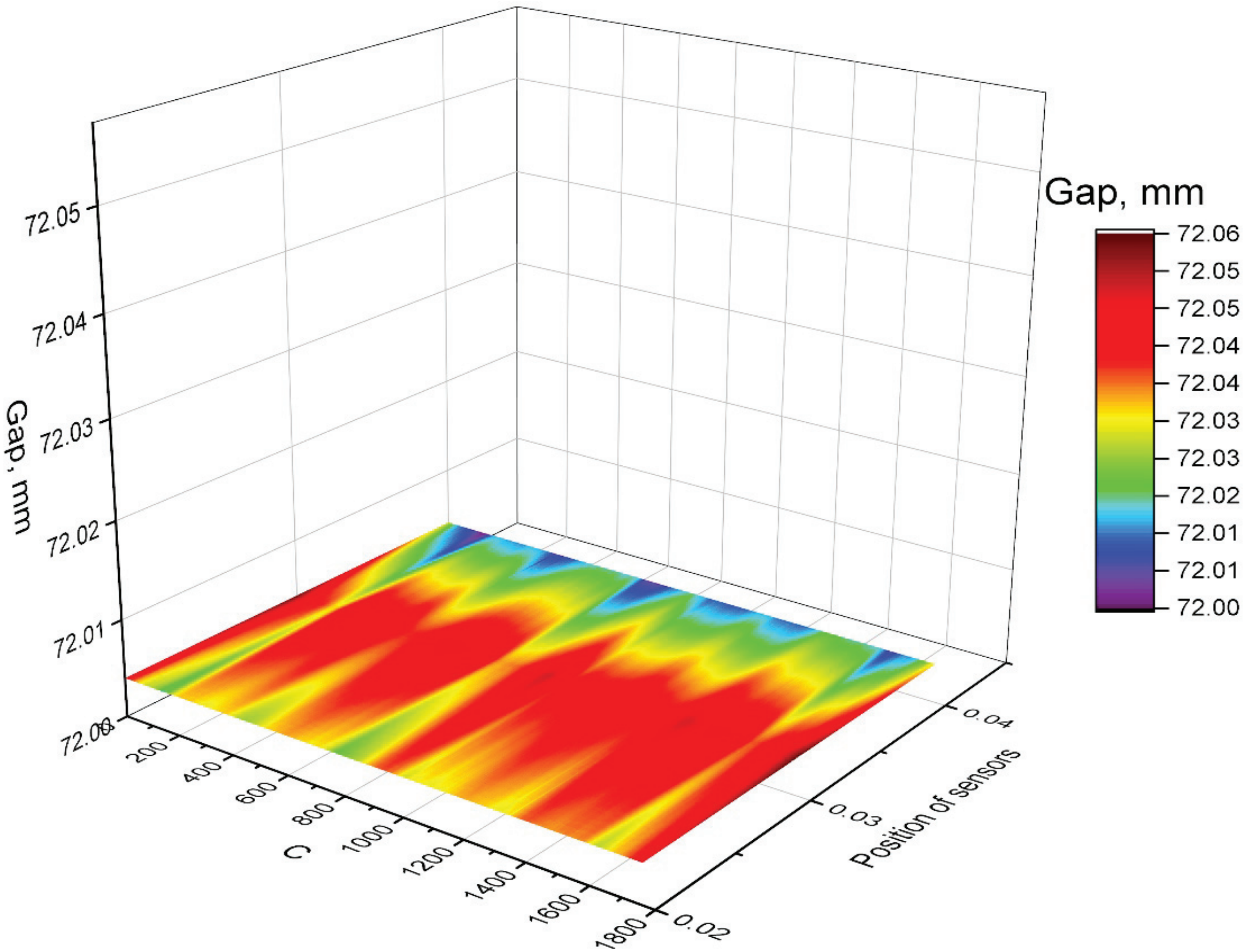
- The main element of the system is capacitive distance sensors micro epsilon. The accuracy of the measuring system is 5 µm.

Measurements for the NICA collider magnets: dipoles



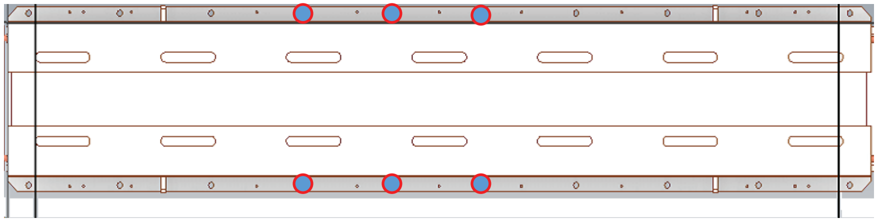


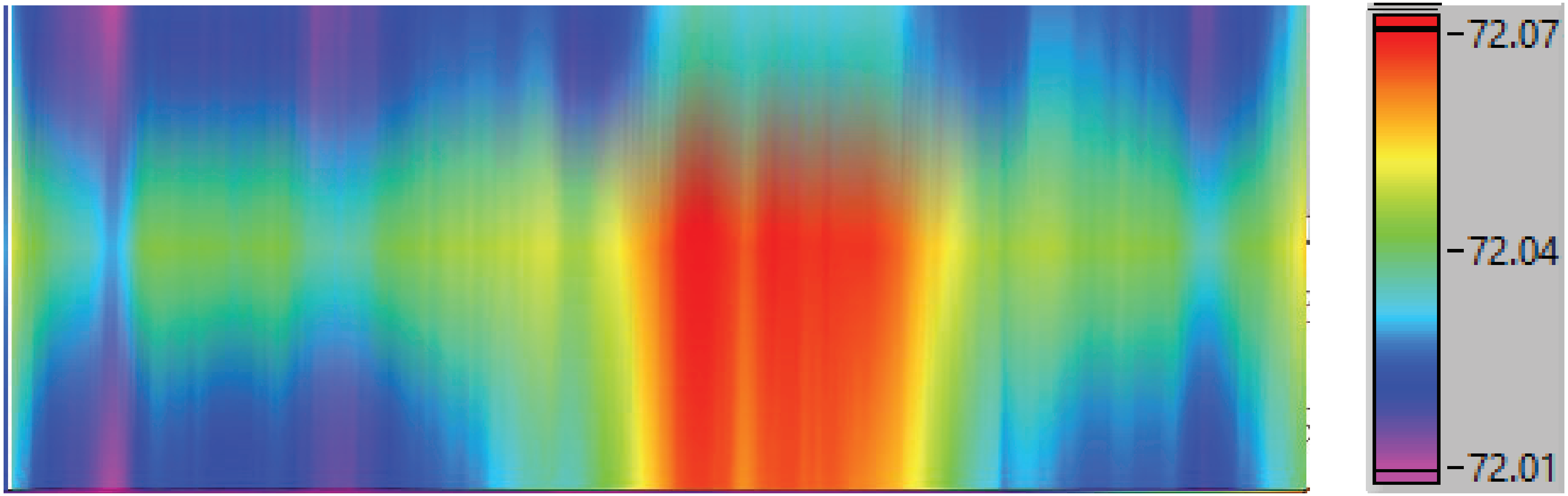
- Measurement time for 2 yokes, taking into account the rearrangement of the system - 3 hours.



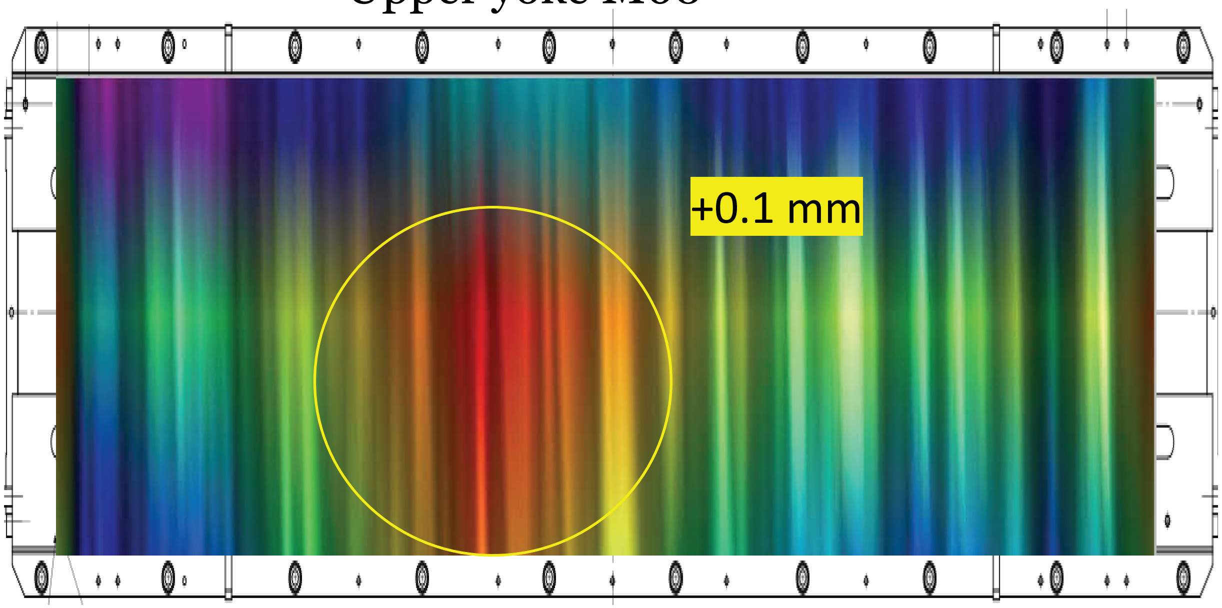
- The system makes it possible to interactively evaluate the value of the gap.

- System tests with intentional geometry distortion



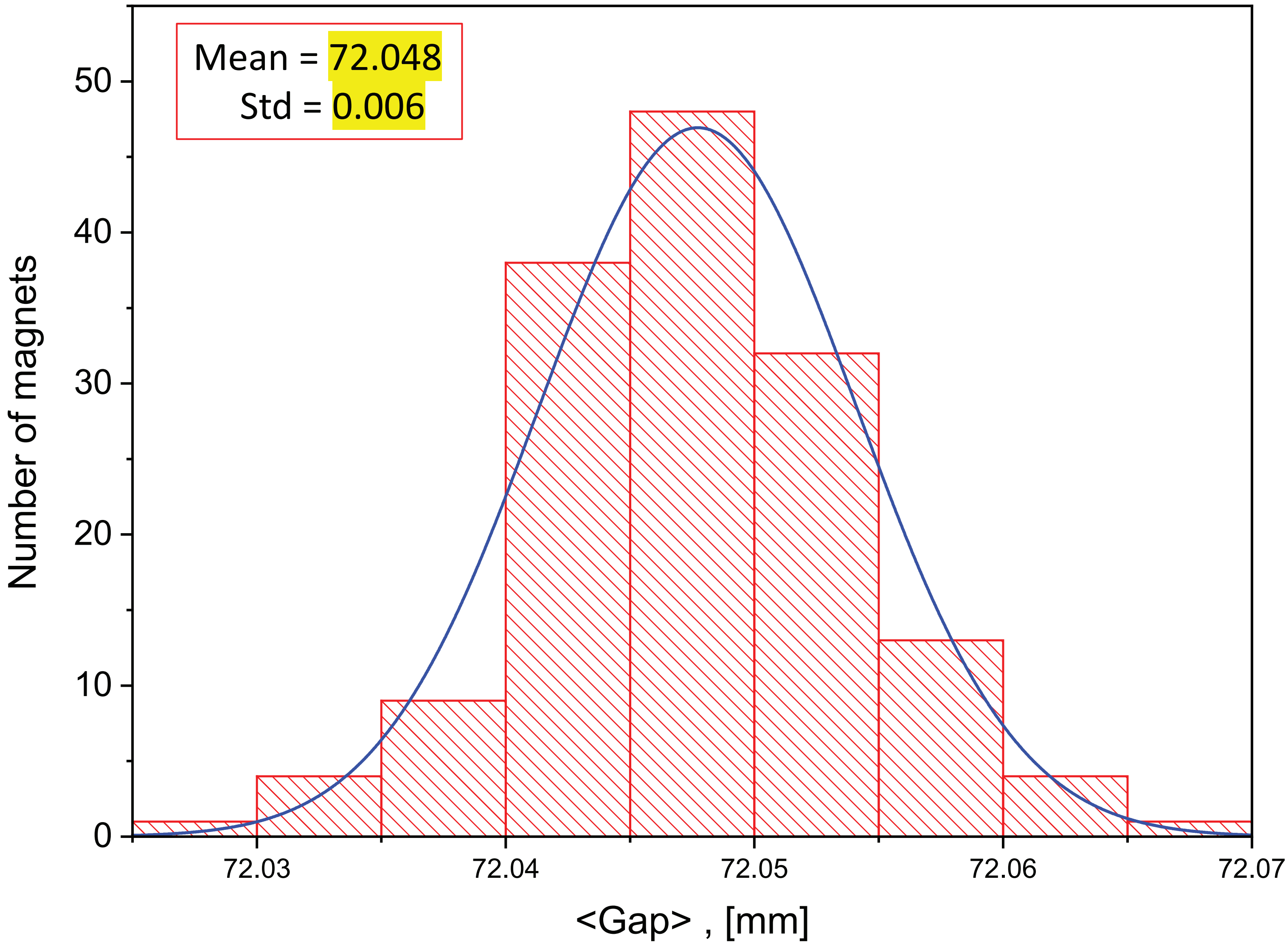


Upper yoke M60



- A case of over-clearance detection. Magnet M60. Torque wrench defective.

Statistics on measurements of the pole gap of the collider dipole magnets

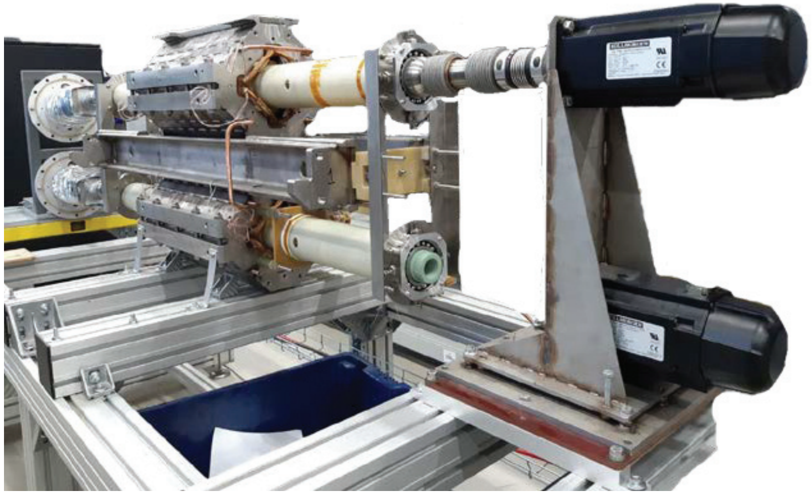


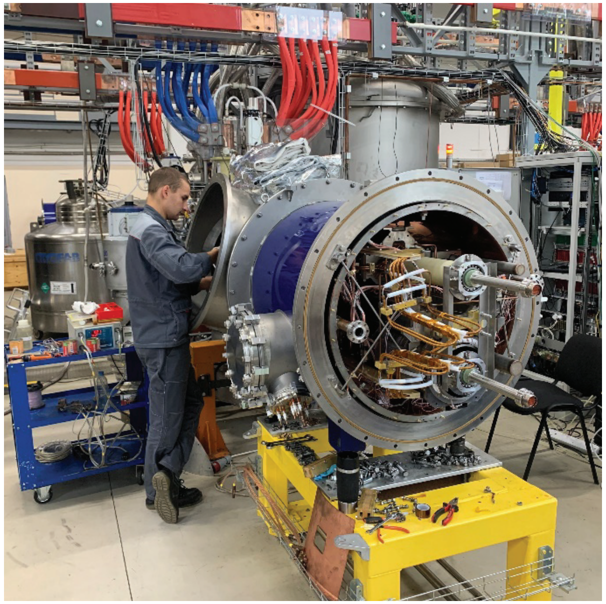
Rotating coil methodic

Warm
100 A (RC)

Warm
50 A

Cold
10500 A (RC)





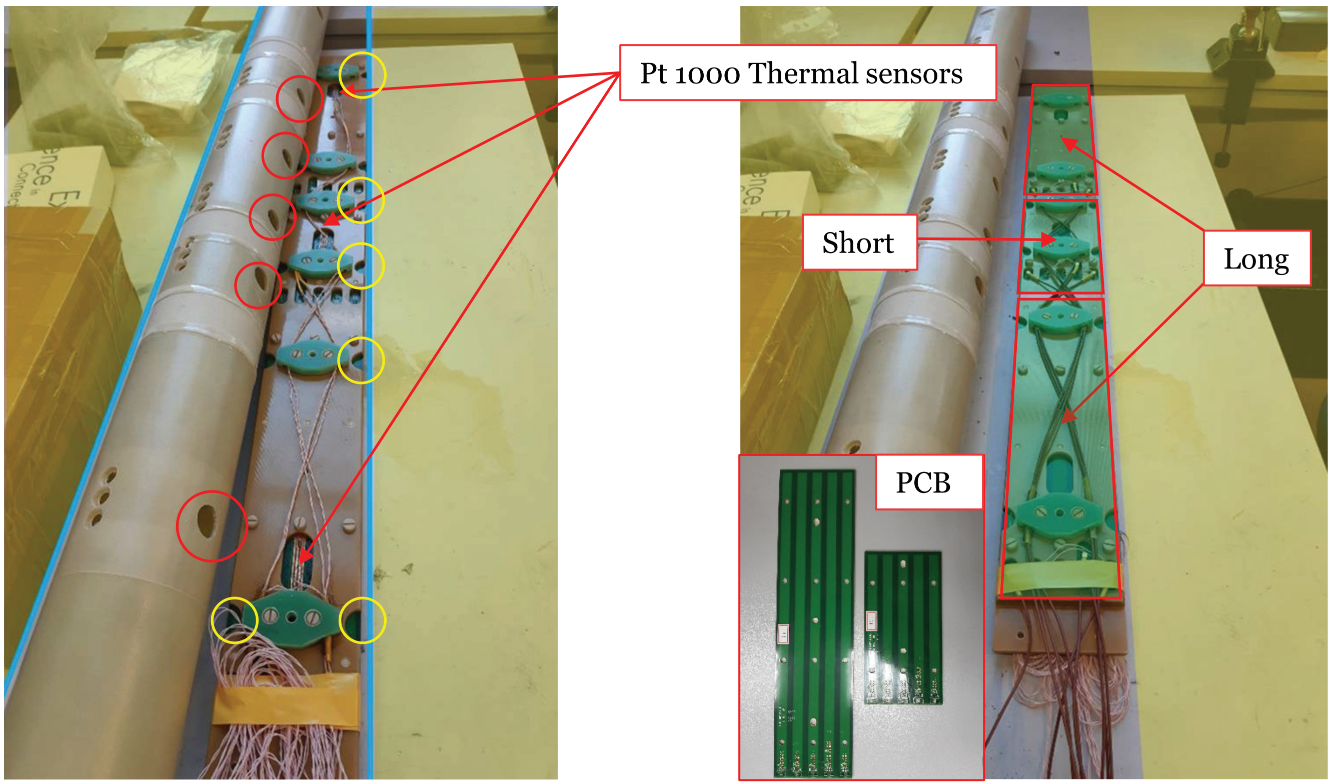
- Step rotation mode (max current of 10500 kA)

Warm: **2 pc.**
Cold: **4 pc.**

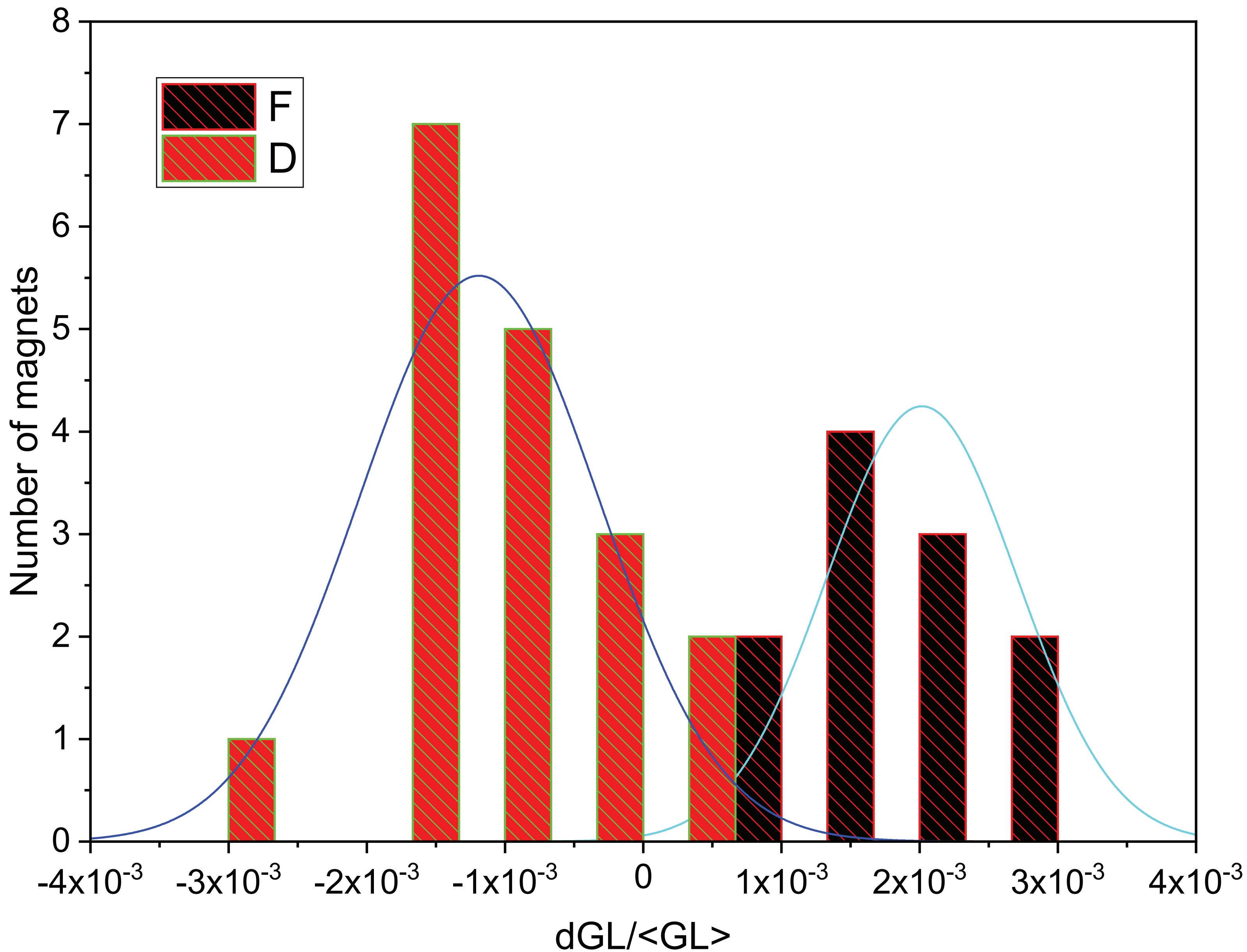
The final number of magnetometers: **6 pc.**

- The production time of 1 magnetometer: **30 days.**
- Each magnetometer is relative calibrated on a reference magnet.
- The assembly is carried out under the control of a control measuring machine (0.050 mm).
- The accuracy of the measuring system does not exceed the TK tolerance.
- A Hall sensor is installed on each magnetometer.

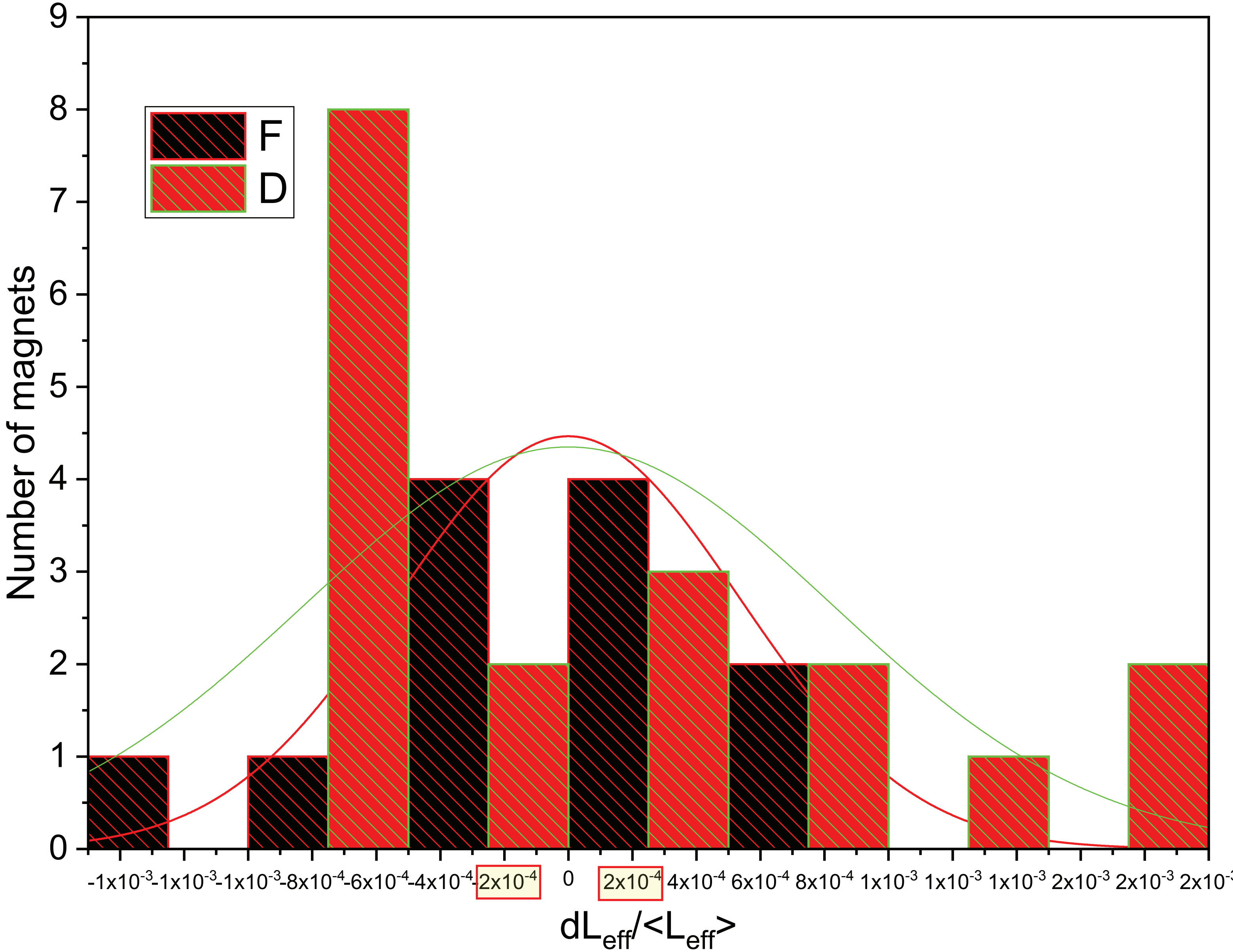
Magnetometer design



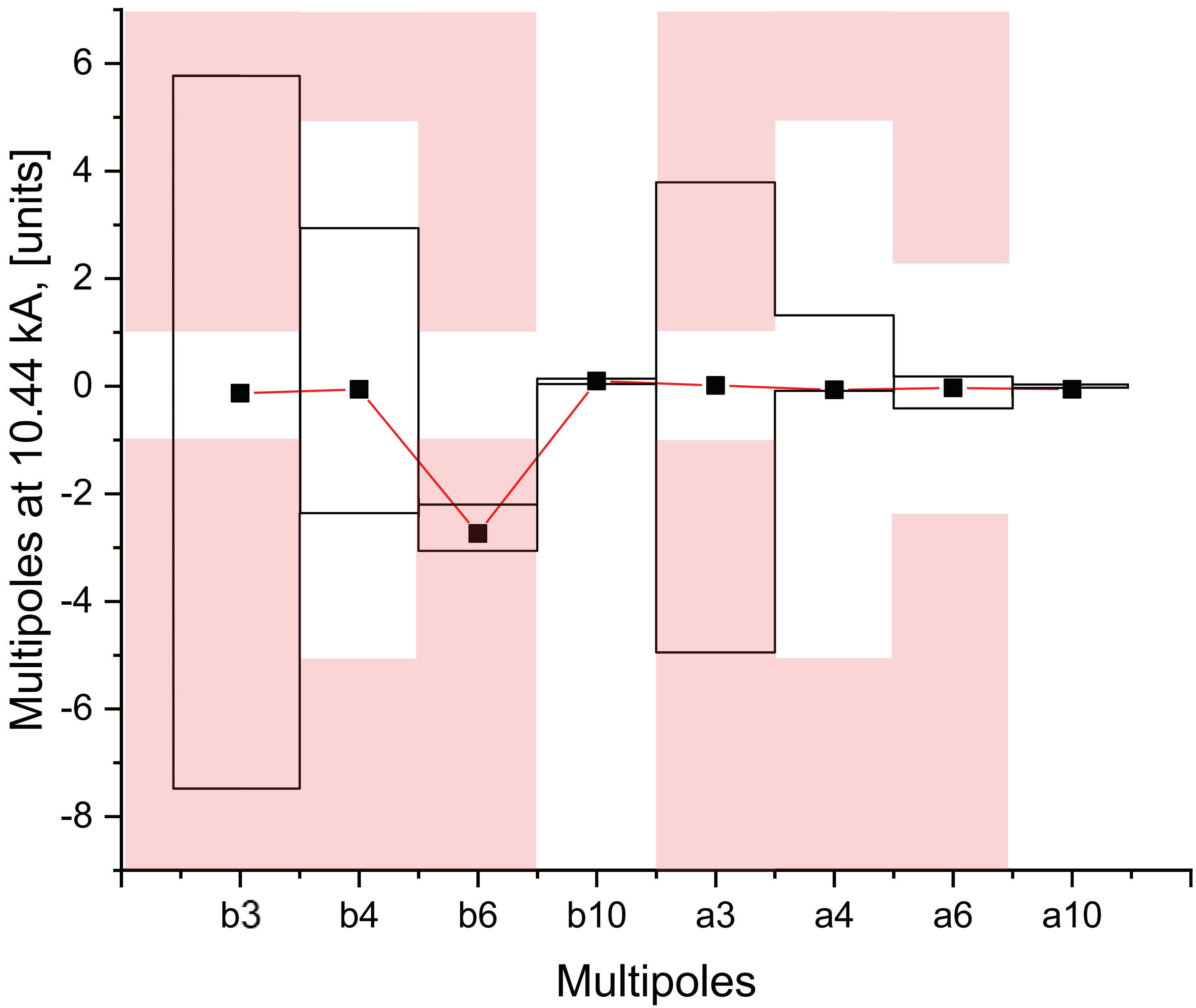
Measurements for the NICA collider magnets: quadrupoles



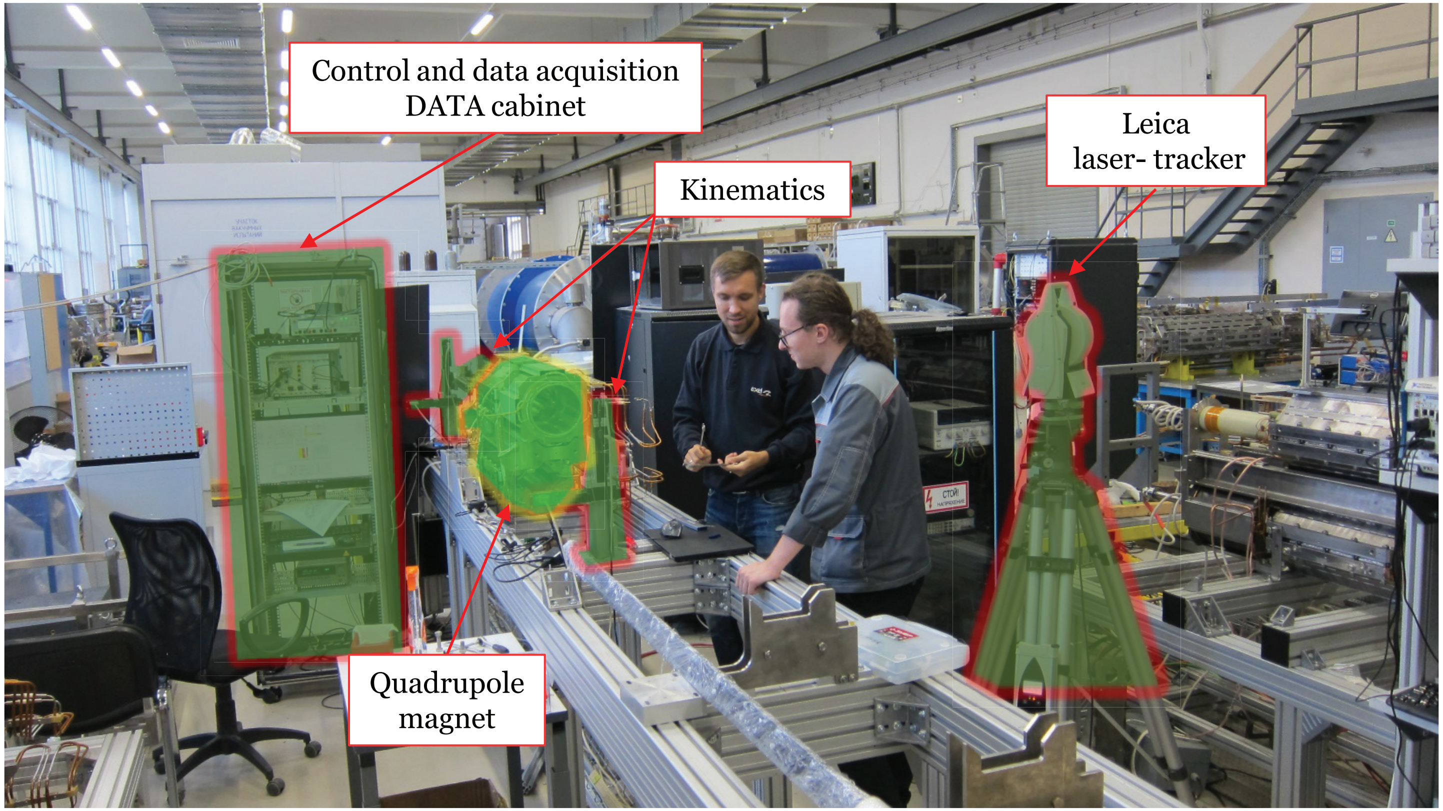
Measurements for the NICA collider magnets: quadrupoles



Measurements for the NICA collider magnets: quadrupoles

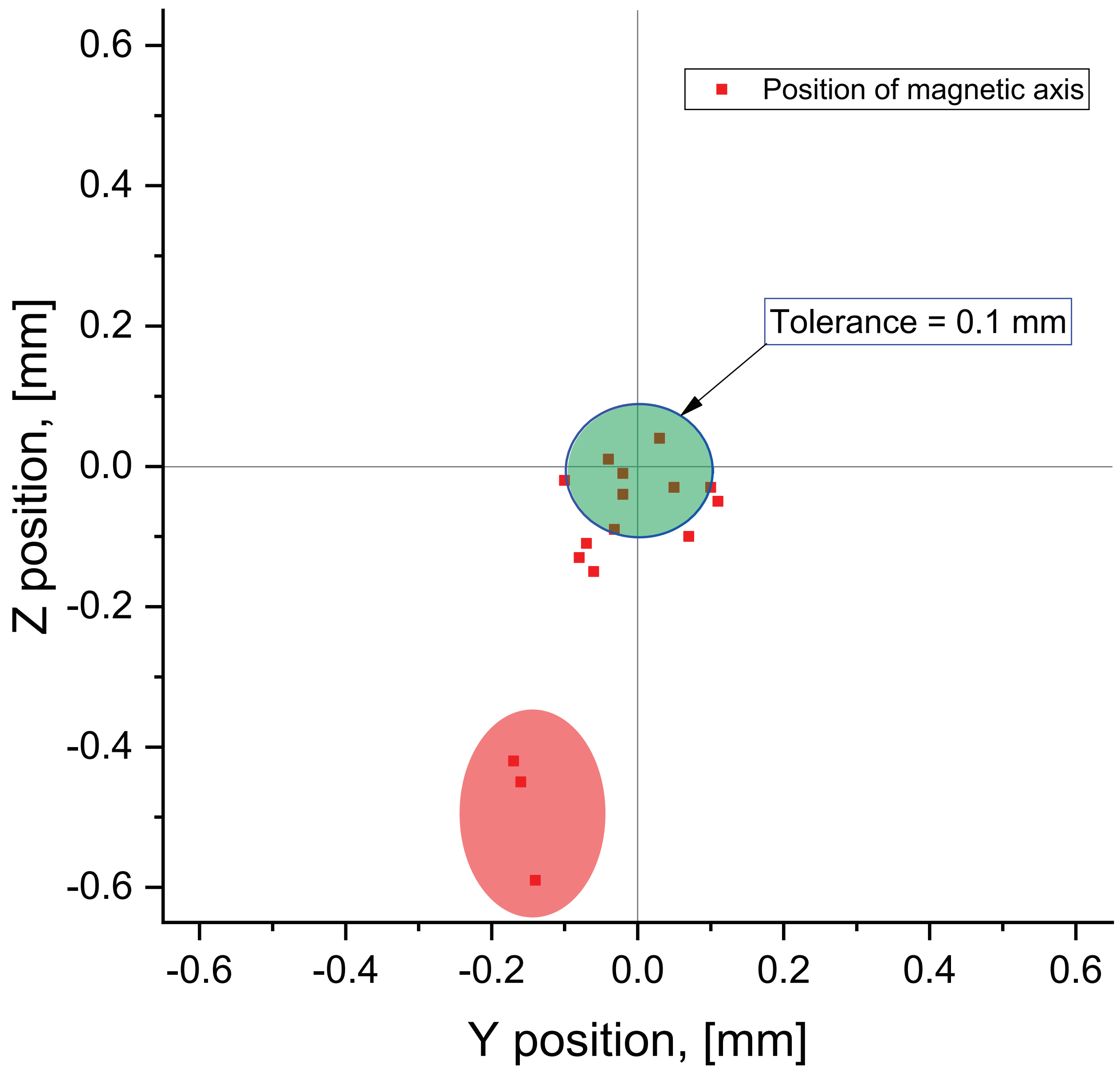


Vibration wire stand



- the main task is to find the magnetic axis relative to the magnet's coordinate system.

Measurements for the NICA collider magnets: quadrupoles



Measurements for the FAIR quadrupole units

Name	Quantity	Main quadrupole magnet	Corrector Magnets				Position in SIS100 ring	Up-/ Down stream	Remarks
			Sextupole magnet	Steering magnet	Multipole corrector	γ_t jump quadrupole			
VQD		QD	✓				arc	U	
BQD		QD					arc	U	
SF1B		F1		✓			arc	D	
SF2B		F2		✓			arc	D	
SF1H		F1	✓	✓			arc	D	
SF2H		F2	✓	✓			arc	D	
SF2J		F2		✓		✓	arc	D	
MQDb		QD			✓		arc termination	U	
MQDi		QD			✓		arc termination	U	Injection module
QDBb		QD					arc termination	U	
QDBx		QD					arc termination	U	Extraction module
SF1Bb		F1		✓			arc termination	D	
SF1Bi		F1		✓			arc termination	D	Injection module
SF2Mb		F2		✓	✓		arc termination	D	
SF2Mx		F2		✓	✓		arc termination	D	Extraction module
QD*B / QD*Bs		QD					straight section	U	
SF1*/SF2*/SF2*s		F2		✓			straight section	D	

Total number of units to be tested: 166

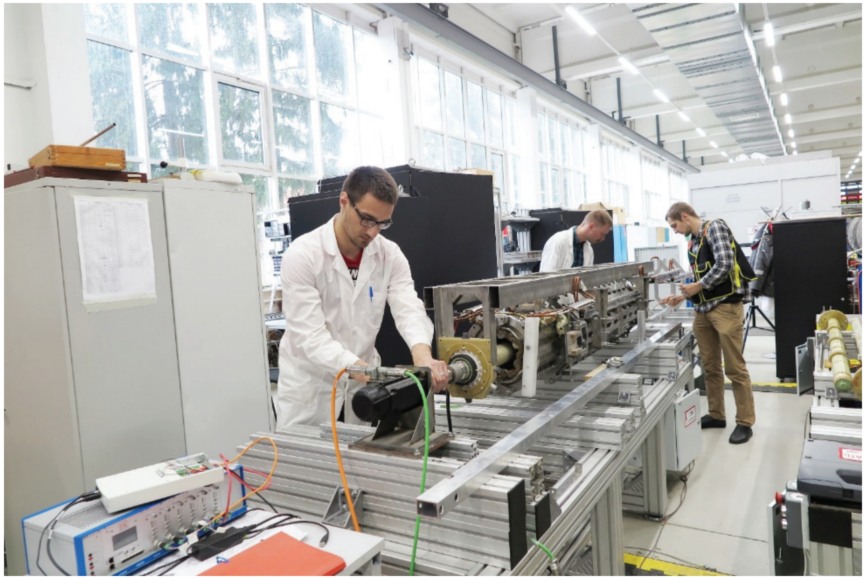
- According to the contract for the production and testing of SC magnets, it is necessary to measure 166 units of the SIS 100, the FAIR project.

Rotating coil methodic

Vibration wire
35 A

Warm
100/0.3 A

Cold
10500/250 A



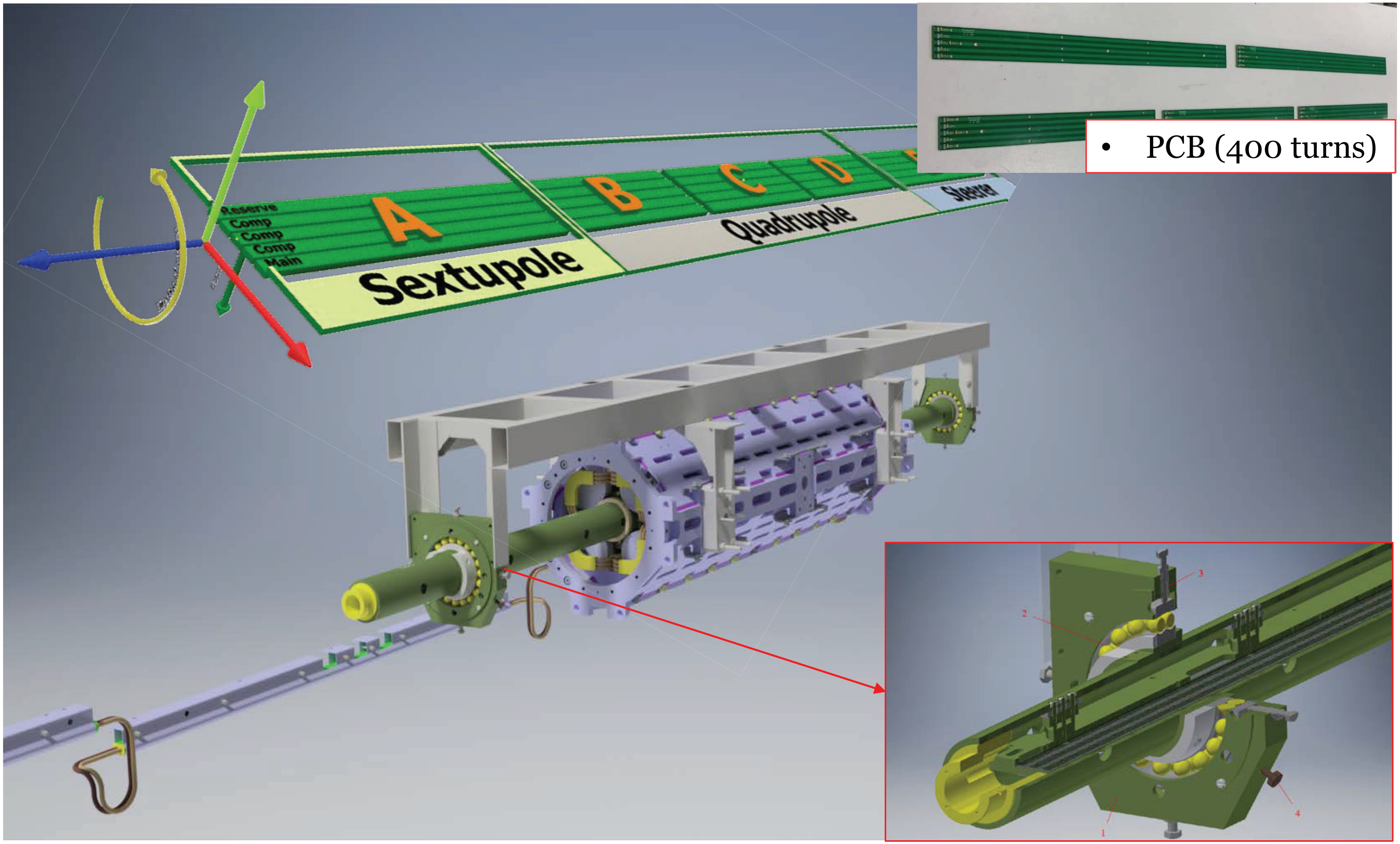
Two measurement modes:

- Step rotation mode (max current of 10500 kA)
- Constant rotation (for 0 A; 10500 A) (only on cold)

The final number of magnetometers: **4(5) pc.**

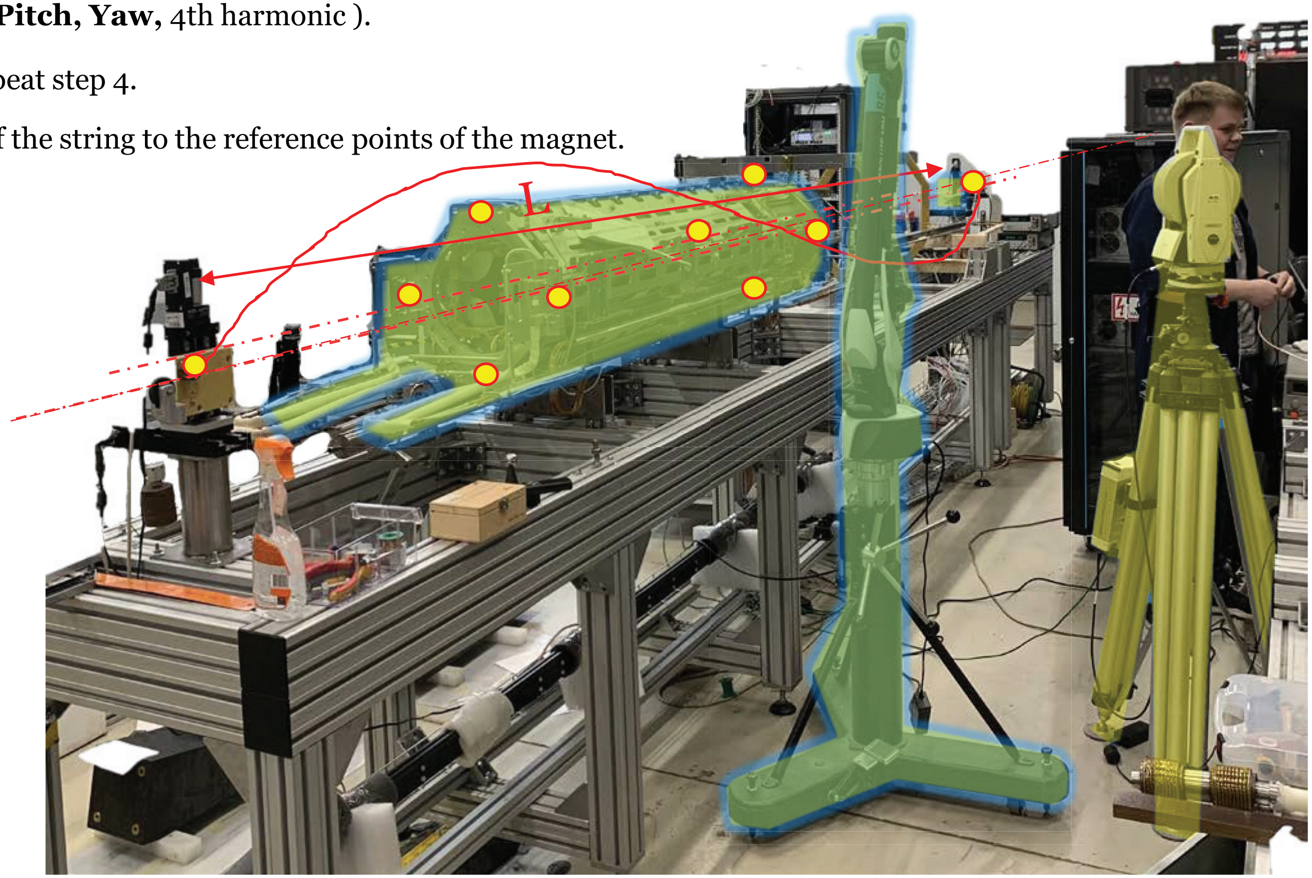
- The production time of 1 magnetometer: **90 days.**
- The accuracy of the measuring system does not exceed the TK tolerance.
- The magnetometer is equipped with a system for monitoring the position of the axis of rotation.

Measurements for the FAIR quadrupole units



Vibrating wire technique

1. Magnet installation (1/2L).
2. Current connection: magnet (35 A), string (100 mA).
3. Automatic search for the resonant frequency of a string. (20-30 Hz).
4. Automatic search for amplitude minimum from optical sensors. Search **dy, dz**.
5. Finding the angle of the string (**Pitch, Yaw,** 4th harmonic).
6. Checking the magnetic axis. Repeat step 4.
7. Geodesy. Binding the position of the string to the reference points of the magnet.
7. Protocol.



- integral of the fundamental field component $GL = \int_{-\infty}^{\infty} G_y(s)ds$
- effective length $L_{eff} = \frac{\int_{-\infty}^{\infty} G_y(s)ds}{G_y(0)}$
- roll angle $\alpha = \frac{\int_{-\infty}^{\infty} \frac{\partial B_x(s)}{\partial x} ds}{2 * \int_{-\infty}^{\infty} \frac{\partial B_y(s)}{\partial x} ds} = \frac{a_2^*}{2b_2^*}$
- multipoles $b_n = \frac{1}{(n-1)!} \frac{r_{ref}^{n-1}}{B_{ref}} \frac{\partial^{n-1} B_y}{\partial x^{n-1}}$

  $a_n = \frac{1}{(n-1)!} \frac{r_{ref}^{n-1}}{B_{ref}} \frac{\partial^{n-1} B_x}{\partial x^{n-1}}$

- Magnetic axis ***dz,dy***

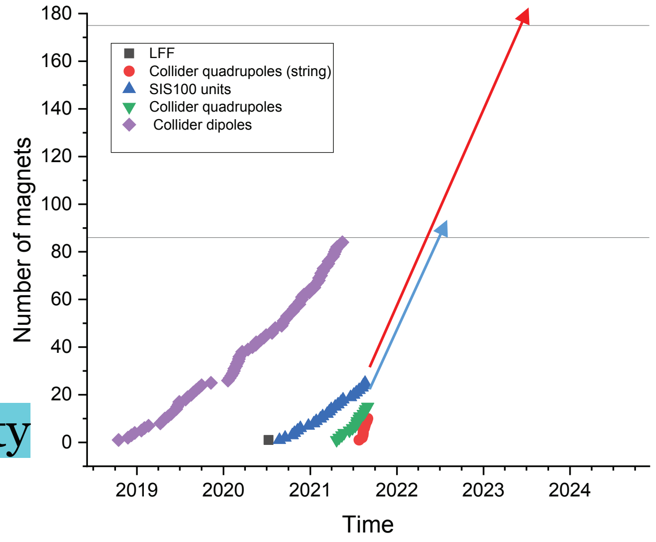
Requiements on the multipoles measurement precision

Multipole	Relative systematic error	Absolute random error, $[T \cdot m]$ @ $R_{ref} = 40mm$
Dipole	0.03%	10^{-5}
Quadrupole	0.03%	7×10^{-5}
Sextupole	0.5%	2×10^{-4}
Octupole	1%	3×10^{-4}
Higher order multipoles	10%	10^{-3}

Conclusion and future plans

- Magnetic measurements performed :
  - ✓ 100 % collider dipole magnets
  - ✓ 35 % collider quadrupole magnets
  - ✓ 15 % SIS100 quadrupole units
- Total created magnetometers:
  - ✓ 16 serial magnetometers of various configurations
- Measuring stands put into operation:
  - ✓ 6 stands for measuring magnetic field parameters
  - ✓ 2 stands for measuring the geometry of magnets

Conclusion and future plans



- Measure 100 % of magnets
- Continue measuring. Increased productivity
- Creation 6 magnetometers for new types of magnets
- Commissioning of 2 stands for measuring the parameters of the magnetic field.