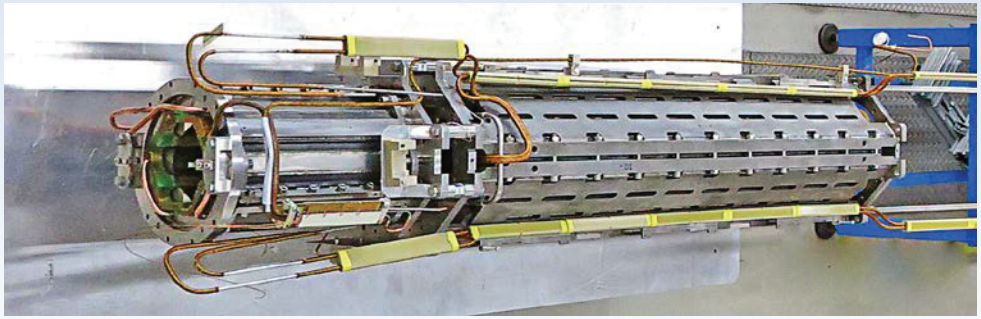
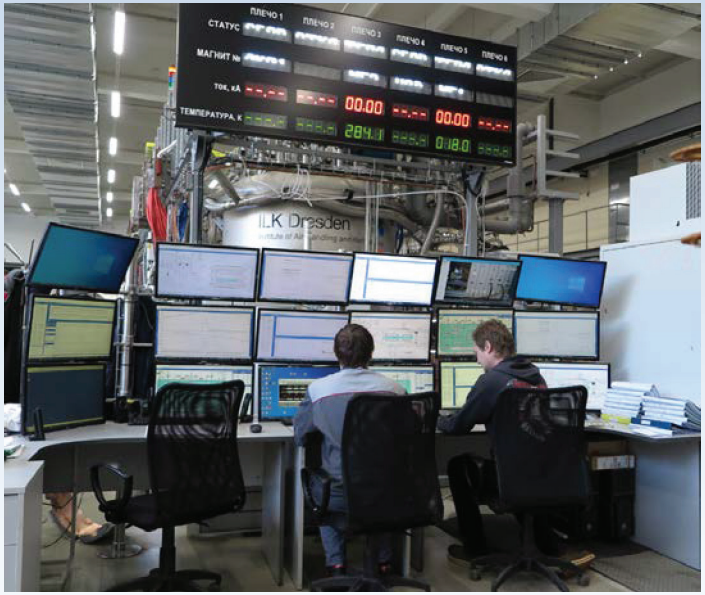
# First Experience of Production and Testing the Superconducting Quadrupole and Corrector Magnets for the SIS100 Heavy Ion Accelerator of FAIR

E. Fischer, Y. Bespalov, V. Borisov, H. Khodzhibagiyan, D. Khramov, D. Nikiforov,
T. Parfylo, M. Petrov, A. Shemchuk, D. Zolotykh
JINR, Dubna, Russia
A. Waldt, A. Bleile, GSI, Darmstadt, Germany

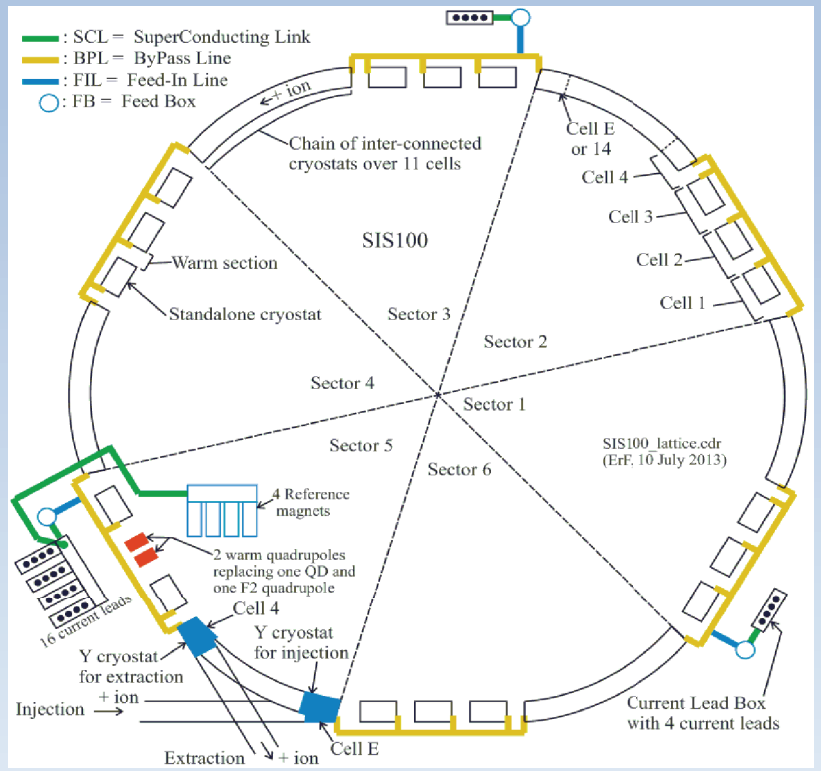
# Outline

1. **The SIS100 Lattice Structure**
   a) Doublet Modules
   b) Quadrupole Units
2. **Main Quadrupoles and Correctors**
   a) Design of the Superconducting Magnets
   b) Status of Series Production
   c) Test Results and Reproducibility
3. **Summary**

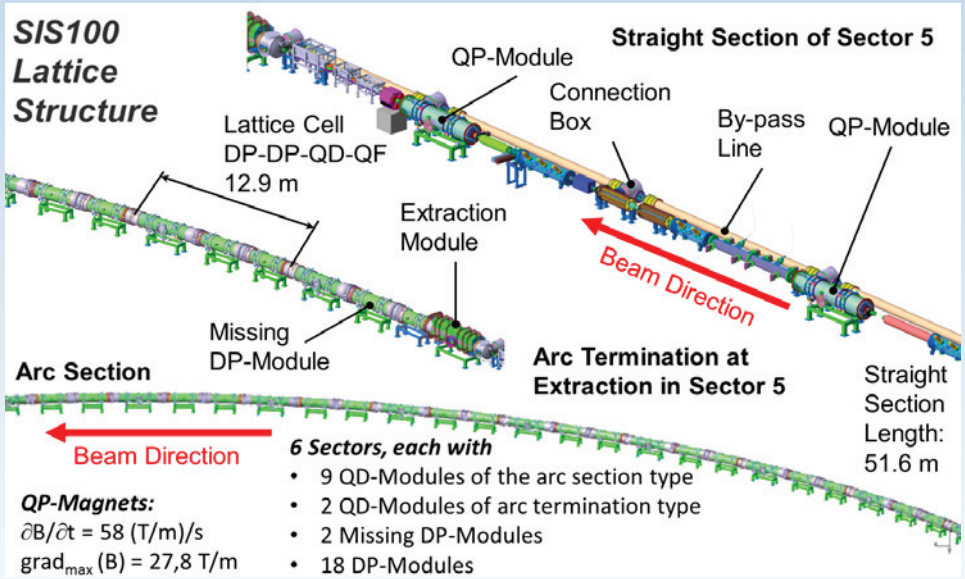




# SIS100 Lattice Structure

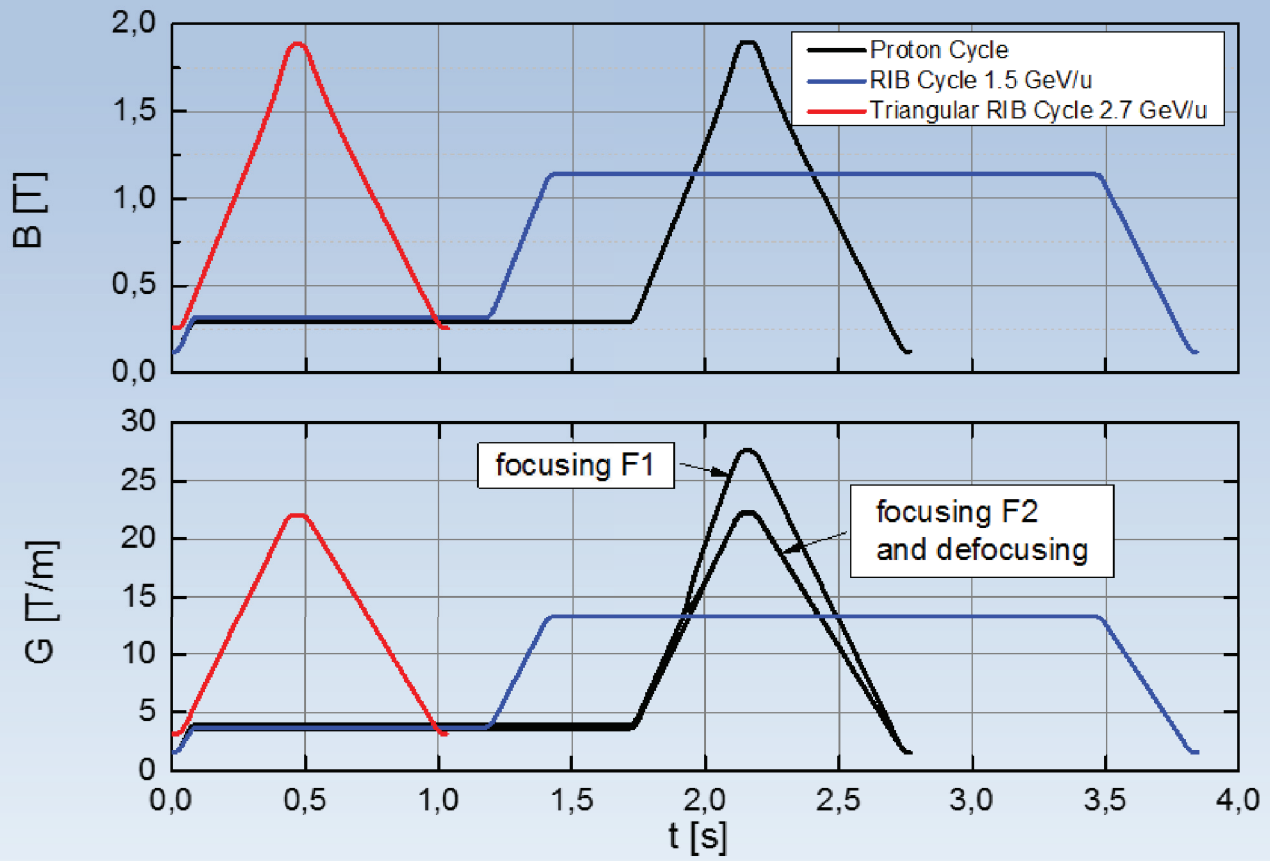



◄ The six sections of the synchrotron ring with its Bypass Lines, the cryogenic and electrical supply systems.




Cryomagnetic components in sector 5 ►

# Examples of the SIS100 Operation Cycles




main dipoles

three families of quadrupole magnets F1, F2, QD

See also E. Fischer et al.
Start of the Series Production for the Cryogenic Magnet Corrector Modules of FAIR
https://jacow.org/ipac2019/papers/THPTS010.pdf

# SIS100 Lattice Structure

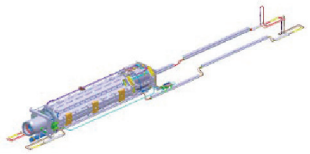
## Quadrupole Units and Doublet Modules

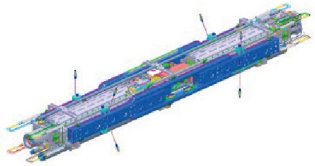
| *Unit Configuration* | | | *Doublet Configuration* | | |
|---|---|---|---|---|---|
| **Upstream** | **Centre** | **Downstream** | **Joined Name** | **Short Name** | **Quantity** |
| QDB | -TRP- | SF2 | QDB-TRP-SF2 | 2.123 | 15 |
| QDBs | -TRP- | SF2s | QDBs-TRP-SF2s | 2.13s | 2 |
| QDBb | -T- | SF2Mb | QDBb-T-SF2Mb | 2.4 | 5 |
| QDBx | -T- | SF2Mx | QDBx-T-SF2Mx | 2.4x | 1 |
| **VQD** | **-CR-** | **SF2B** | **VQD-CR-SF2B** | **2.5** | **6** |
| BQD | -C- | SF1H | BQD-C-SF1H | 1.6A | 12 |
| VQD | -CR- | SF1B | VQD-CR-SF1B | 1.7B | 12 |
| BQD | -C- | SF2H | BQD-C-SF2H | 2.8C | 12 |
| BQD | -CR- | SF2J | BQD-CR-SF2J | 2.9D | 12 |
| MQDb | -C- | SF1Bb | MQDb-C-SF1Bb | 1.E | 5 |
| MQDi | -C- | SF1Bi | MQDi-C-SF1Bi | 1.Ei | 1 |
| | | | **Total** | | **83** |

| **Abbreviations** | |
|---|---|
| QD | Defocusing quadrupole |
| F1 | Focusing quad. 1 |
| F2 | Focusing quad. 2 |
| B | Beam position monitor |
| V | Vertical chrom. sextupole |
| H | Horizontal chrom. sextupole |
| S | Steering magnet |
| M | Multipole corrector magnet |
| C | Cryo-ion-catcher (collimator) |
| T | Drift tube |
| b | modified busbars |
| i | injection Y cryostat |
| x | extraction Y cryostat |
| s | Star shape chamber |
| P | Cryo-sorption-pump |
| R | Roughing pump with CWT |

**Example: Type 2.5**

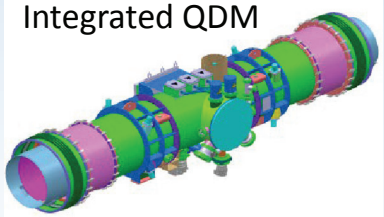
Unit (type SF2B)



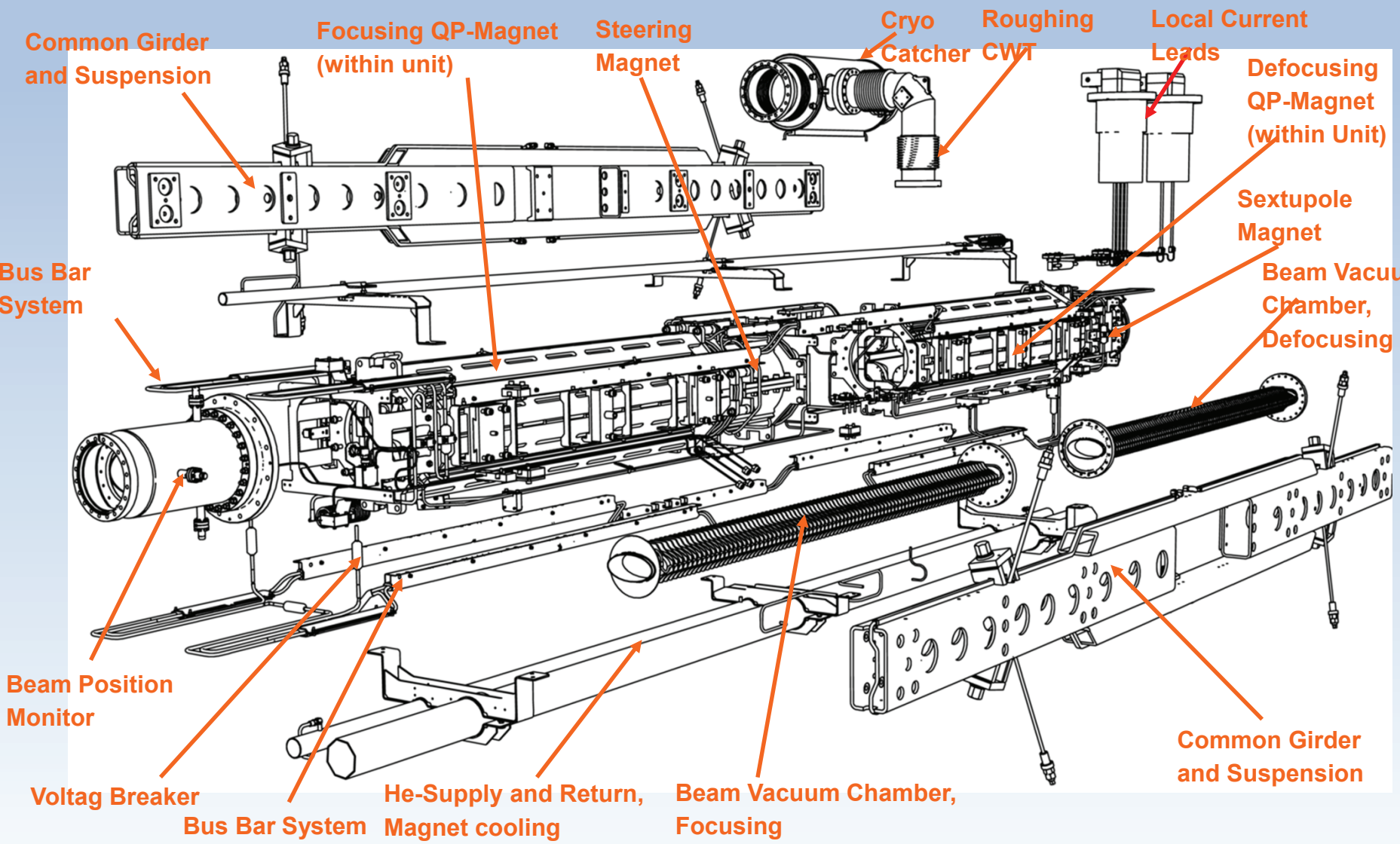


Doublet (cold mass)

Integrated QDM



# QP Units and Doublet Modules



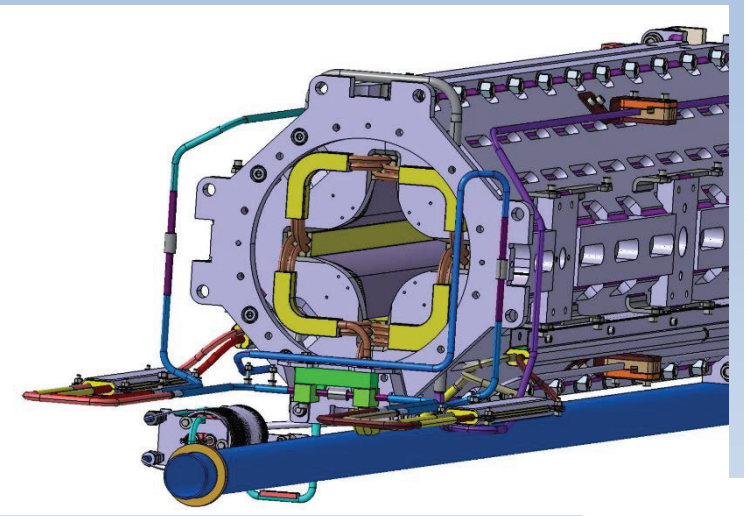
# Main Quadrupoles and Correctors

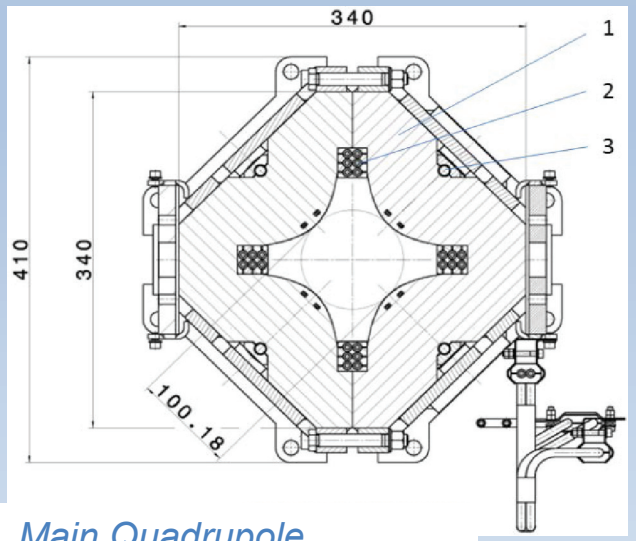
All SIS100 lattice quadrupole and corrector magnets have to be made in JINR, Dubna. The Nuclotron-type design, based on a cold, window-frame iron yoke and a winding of the hollow superconductor, was chosen for the SIS100 magnets.

**Characteristics of the magnets**

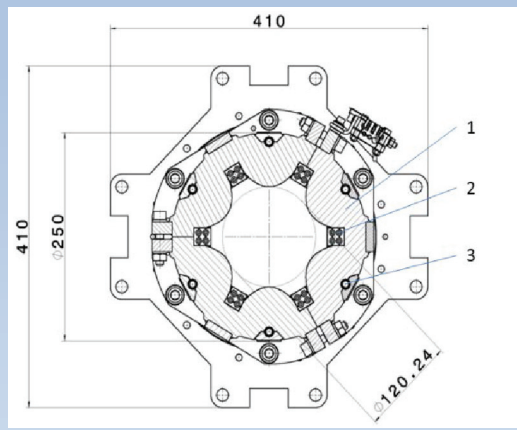
| Characteristic | Lattice Quadrupole | Corrector magnet | | |
|---|---|---|---|---|
| | | Multipole (Q/S/O) | Steerer | Chrom. Sextupole |
| Number of magnets | 166 | 12 | 84 | 42 |
| Max. field strength, $T/m^{n-1}$ | 27.77 | 0.75/25/333,3 | 0.37 | 232 |
| Effective magnetic length, m | 1.264 | 0.75 | 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 |

# Design of the superconducting Magnets

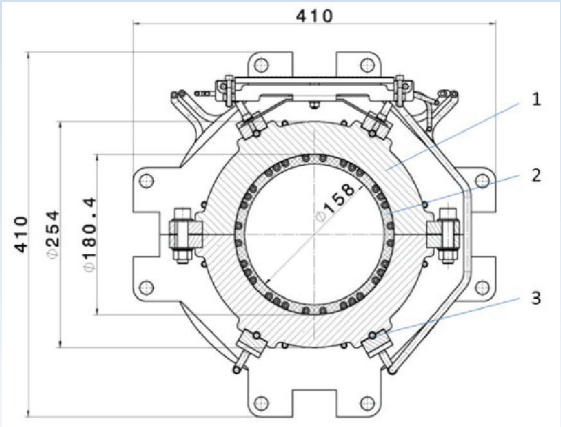




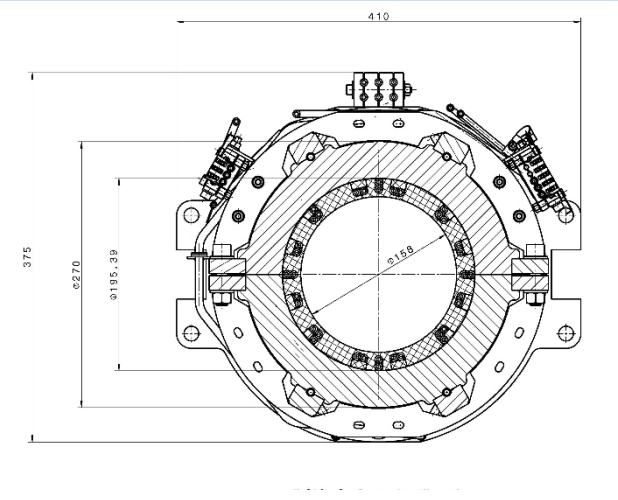

Main Quadrupole



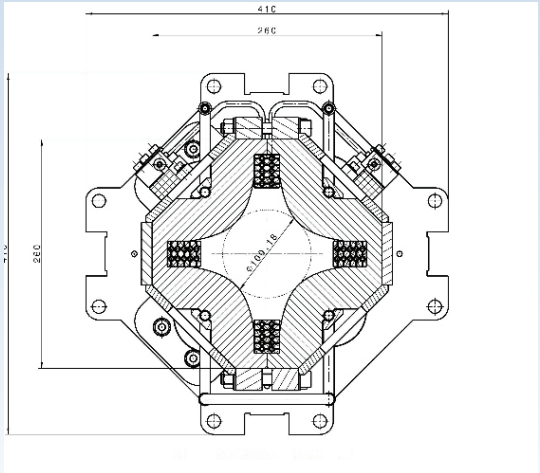

Sextupole




Steerer




Multipole Corrector




Gamma Jump Quadrupole

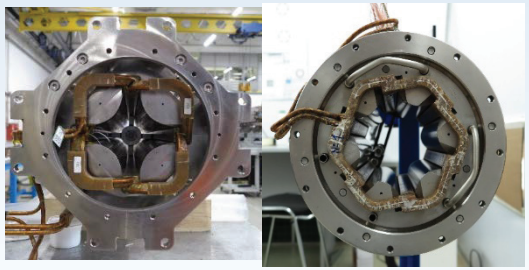
# Status of Series Production

## ❑ Magnet yokes

| Magnet type | at JINR | Completion % | Incoming inspection pass |
|---|---|---|---|
| Quadrupole | 173 | 100 | 173 |
| Sextupole | 85 | 100 | 85 |
| Steerer | 44 | 100 | 44 |

## ❑ Superconducting coils

| Magnet type | Produced at JINR | Completion % | Incoming inspection pass |
|---|---|---|---|
| Quadrupole | 34 | 20 | 34 |
| Sextupole | 21 | 25 | 21 |
| Steerer | 22 | 50 | 22 |



## ❑ Magnet and Unit assembling

| Units | Assembled and delivered | Completion % |
|---|---|---|
| Series 2.5 | 12 | 100 |
| Series 1.7B | 8 | 33 |
| Total | 20 | 12 |

# Test Results and Reproducibility

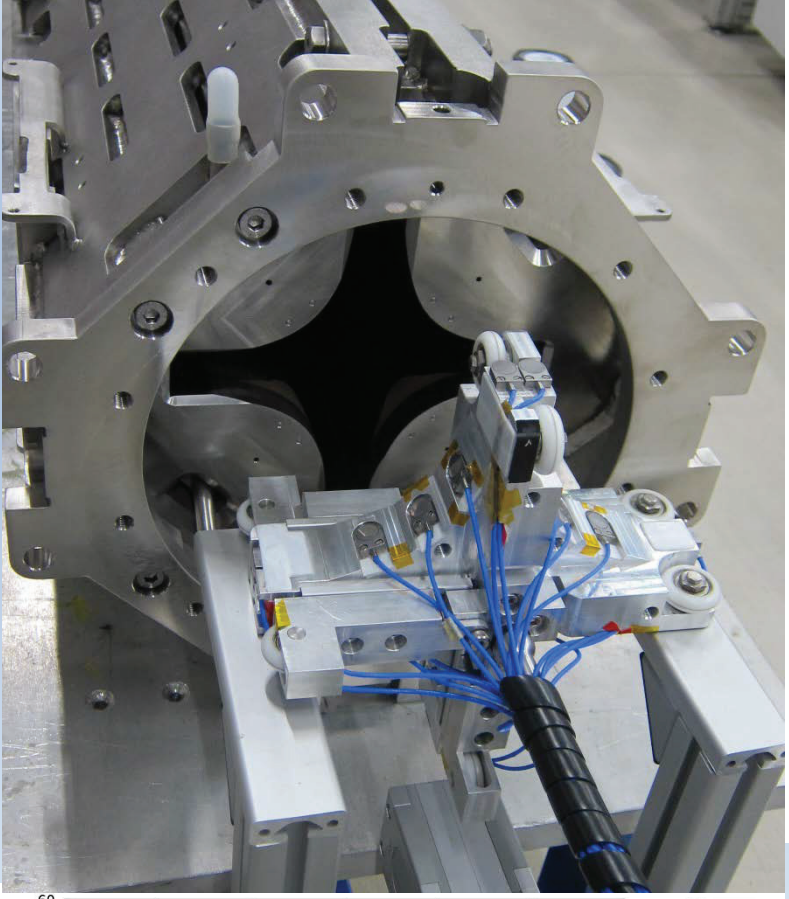
For details of cryogenic procedures and magnetic measurement systems see, e.g.:

V. Borisov et al.
Magnetic Field Performance of the First Serial Quadrupole Units for the SIS100 Synchrotron of FAIR
https://jacow.org/ipac2021/papers/tupab383.pdf

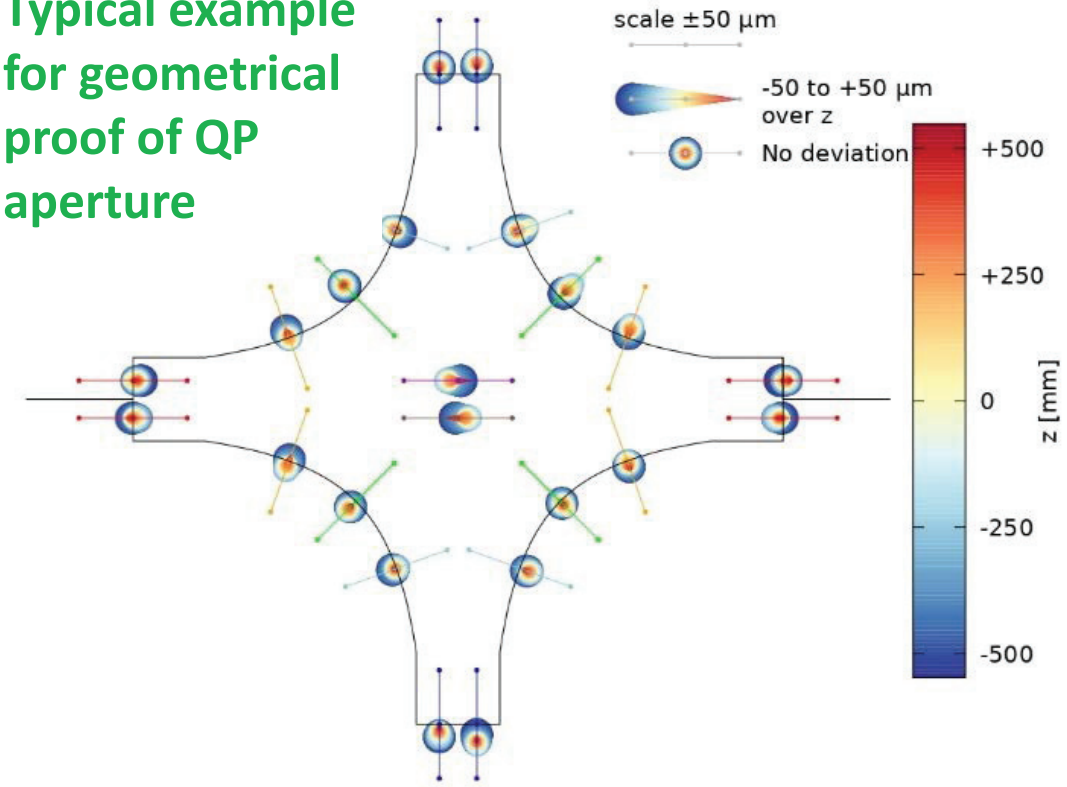
D. Nikiforov et al.
SC Magnets for Project of NICA
RuPAC 2021, WEB01

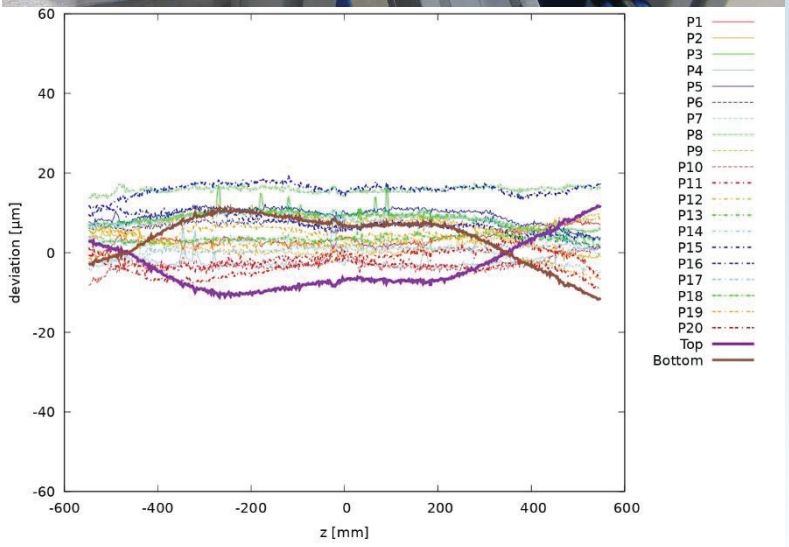
A. Shemchuk et al.
Magnetic Field Measurements for the Collider Magnets and FAIR Quadrupole Units
RuPAC 2021, WEB02

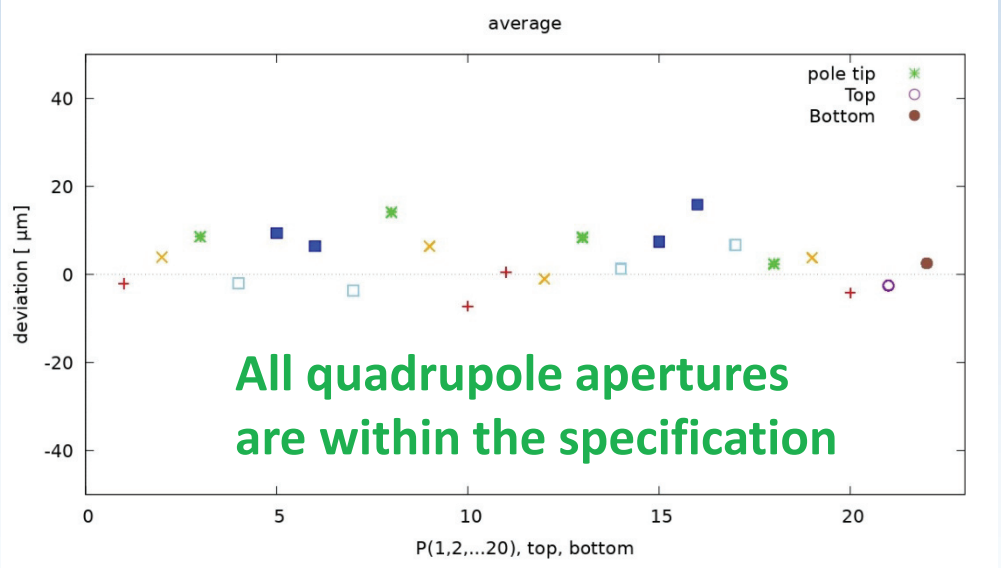
T. Parfylo et al.
Vibrating Wire System for Fiducialization NICA Booster Superconducting Quadrupole Magnets
RuPAC 2021, WEPSC17



## Typical example for geometrical proof of QP aperture

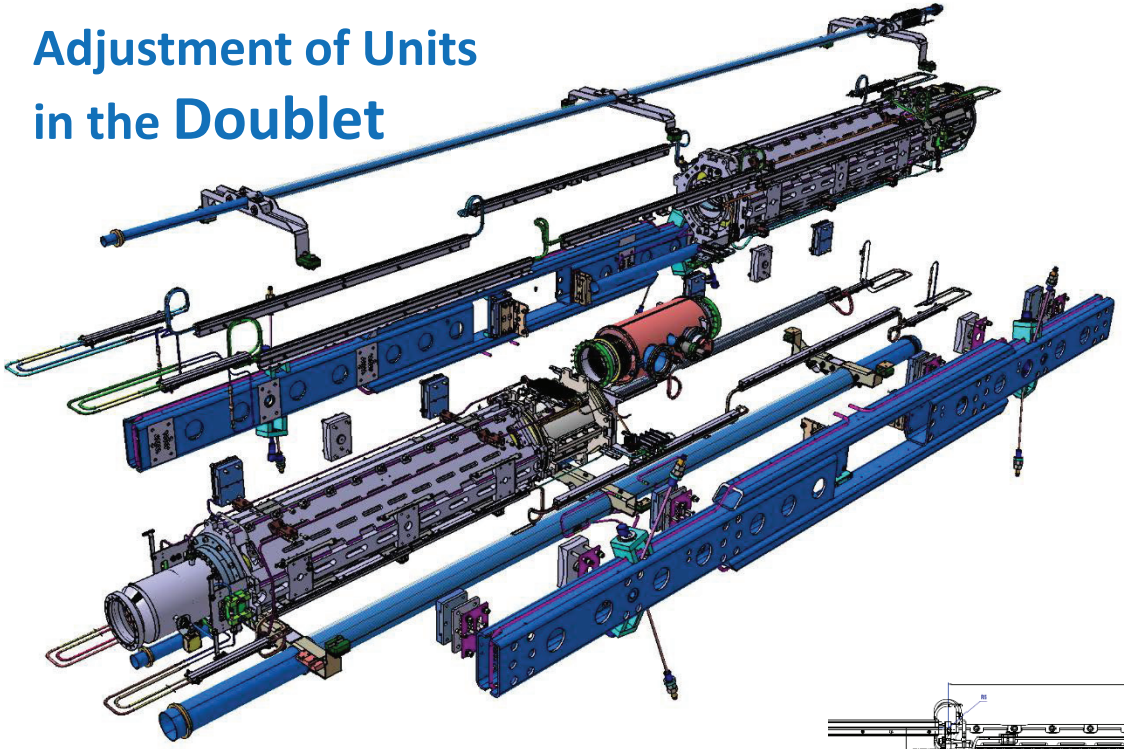


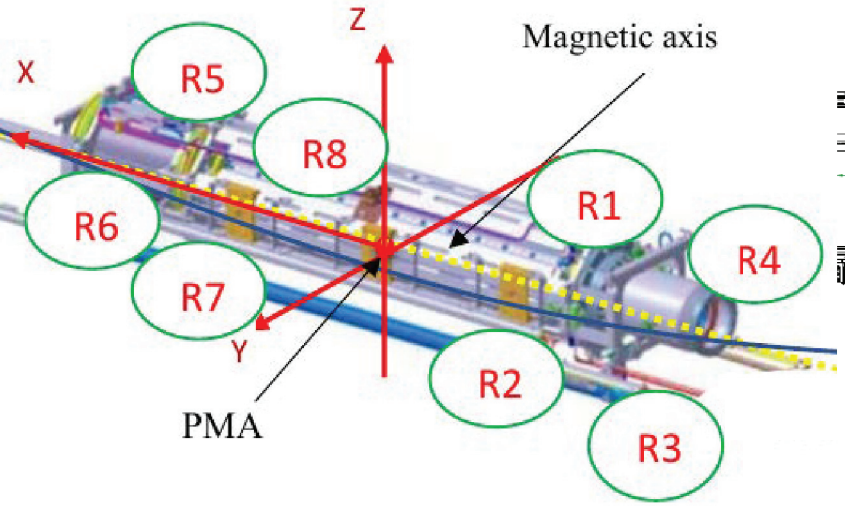

**All quadrupole apertures are within the specification**

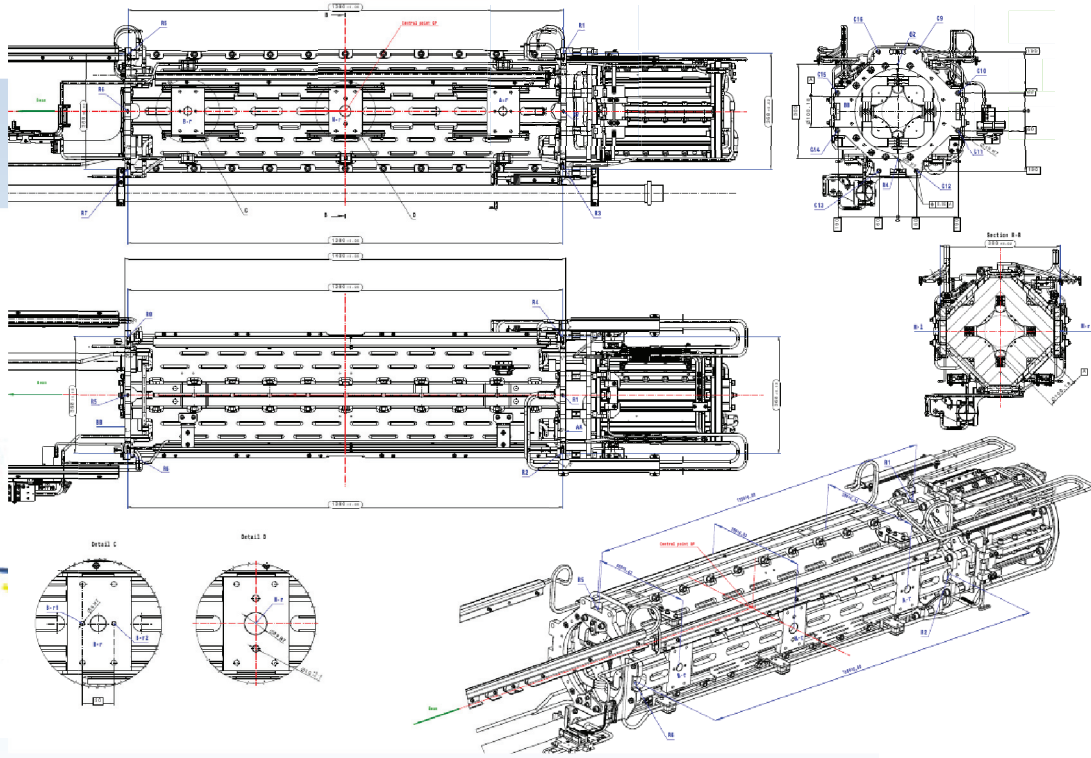
# Adjustment of Units in the Doublet



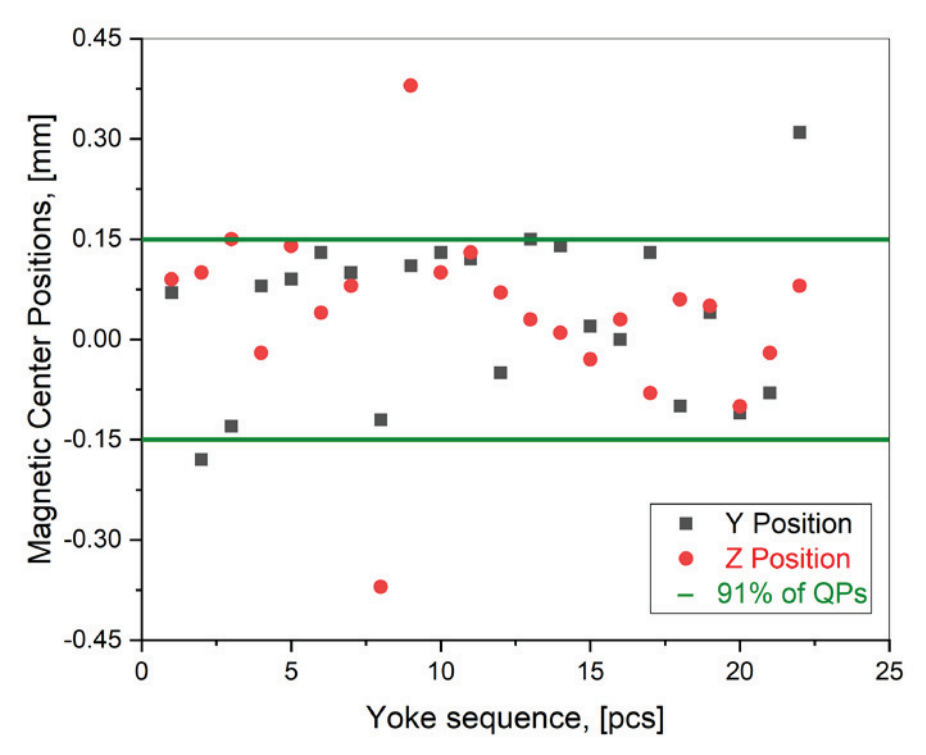
| Description | Drawing size, mm | Real size, mm | Δ, mm |
|---|---|---|---|
| AA-BB | 1400±0,05 | 1400.03 | 0.03 |
| R1-R5 | 1380±0,05 | 1380.05 | 0.05 |
| R2-R6 | | 1380.05 | 0.05 |
| R3-R7 | | 1380.04 | 0.04 |
| R4-R8 | | 1380.05 | 0.05 |
| R1-R3 | 368 ±0,02 | 368.02 | 0.02 |
| R2-R4 | | 368.02 | 0.02 |
| R5-R7 | | 368.02 | 0.01 |
| R6-R8 | | 368.02 | 0.02 |
| A-l – A-r | | 379.99 | -0.01 |
| A-l – A-r | | 0.02 | 0.00 |
| M-l – M-r | | 379.99 | -0.01 |

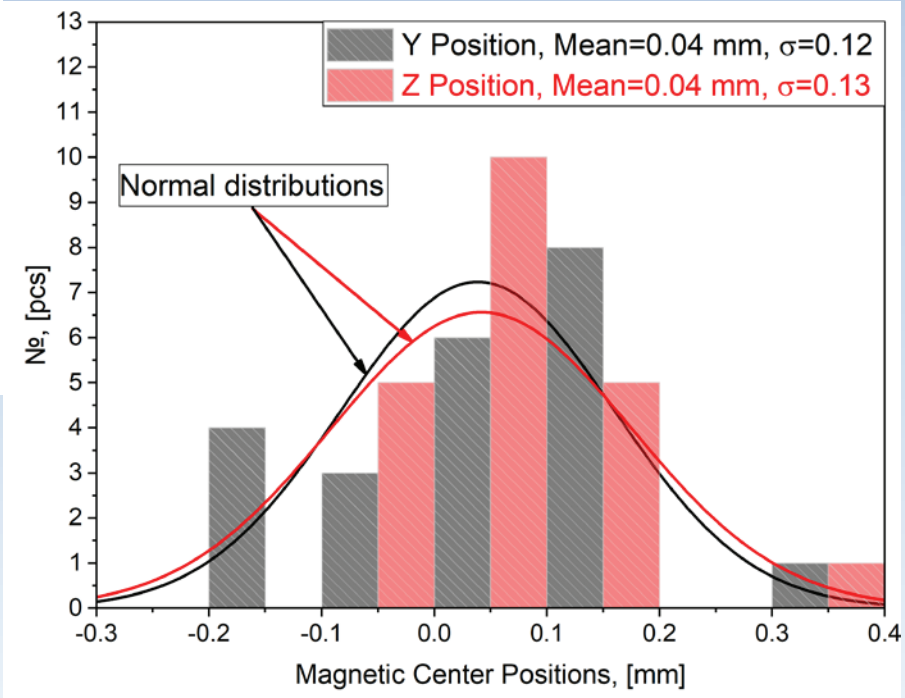
## Geometrical measurements to the reference points of the MM

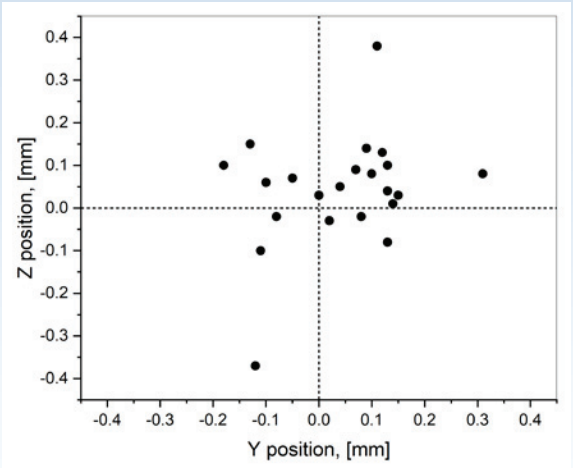


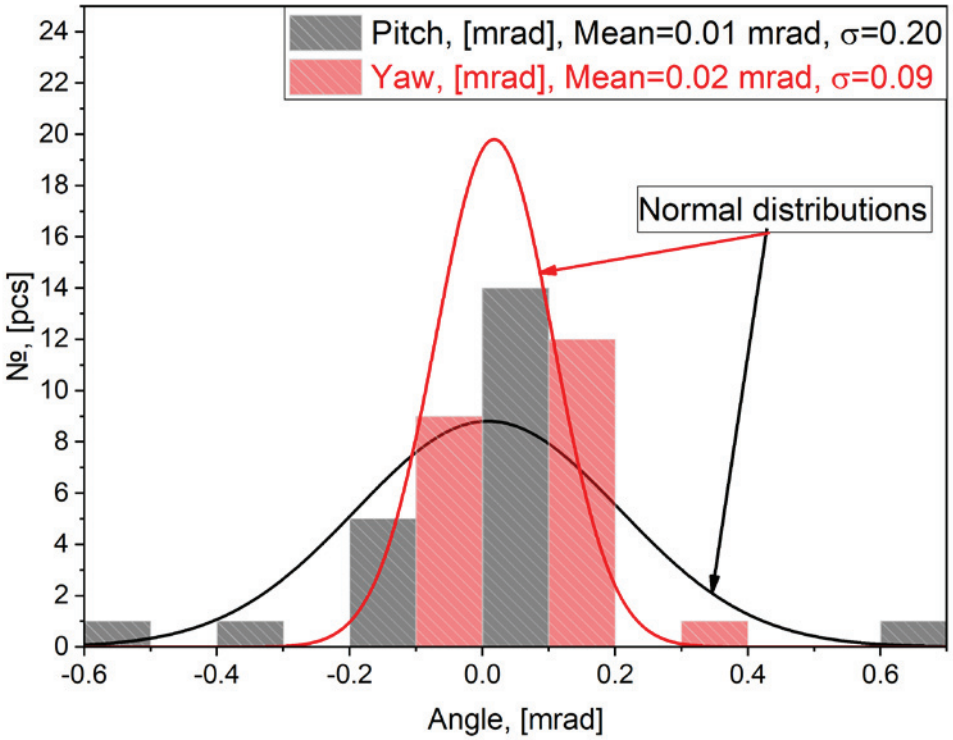
# Magnetic Axis Measurements @ RT using vibrating wire technique

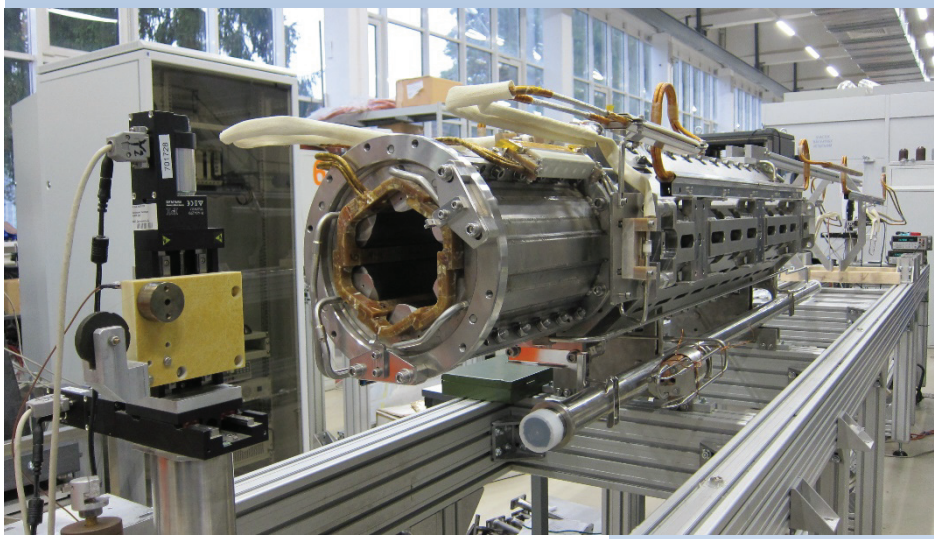


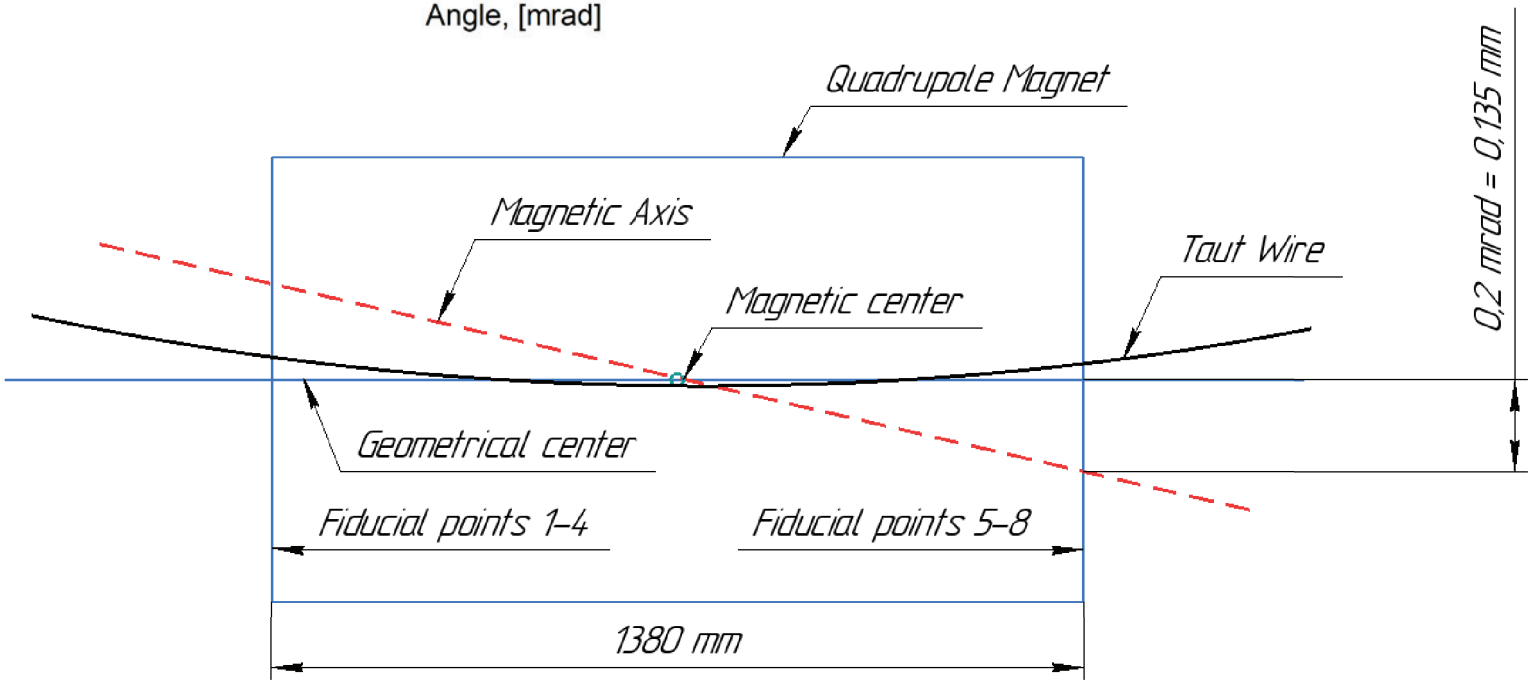



# Angle of the QPs Magnetic Axis

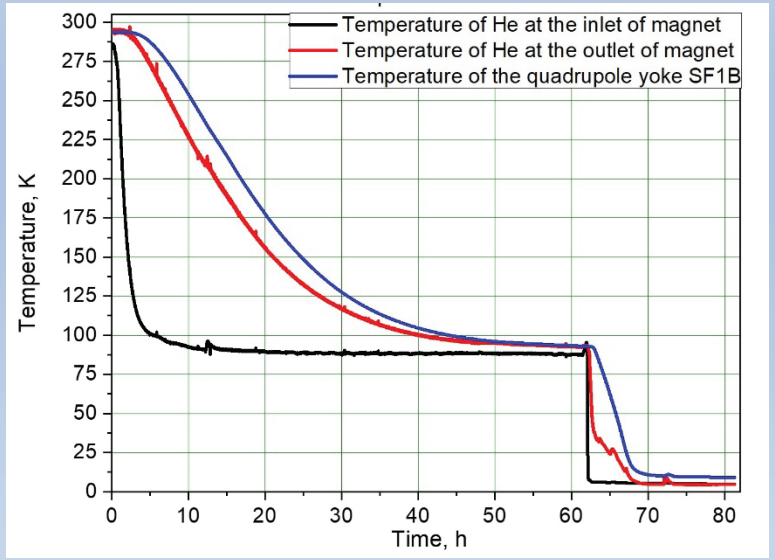


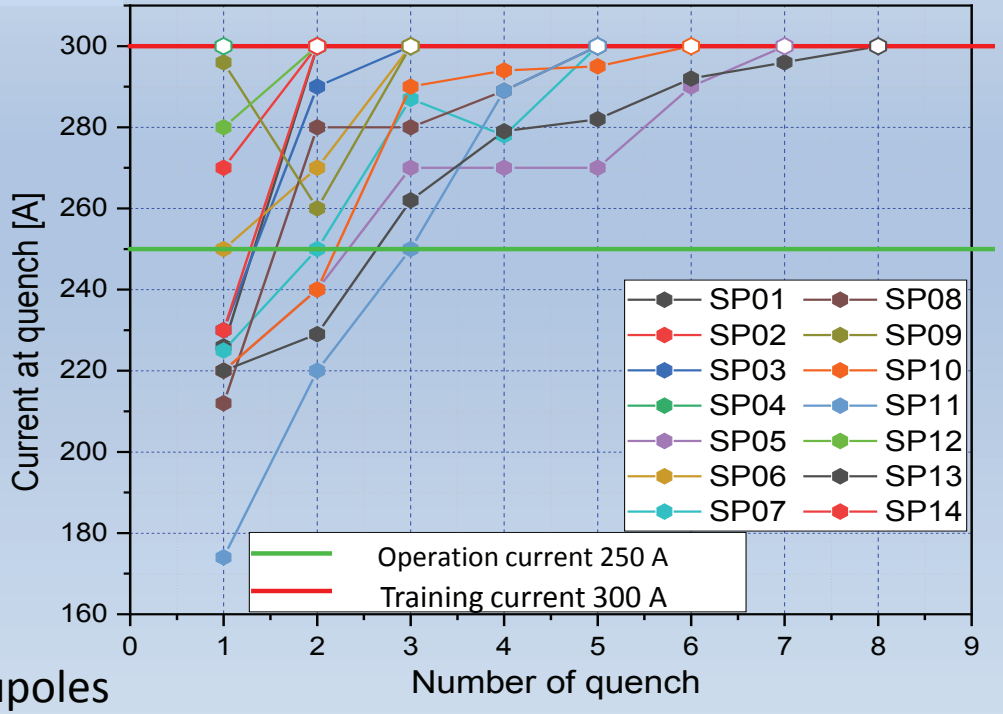


# Cold Tests

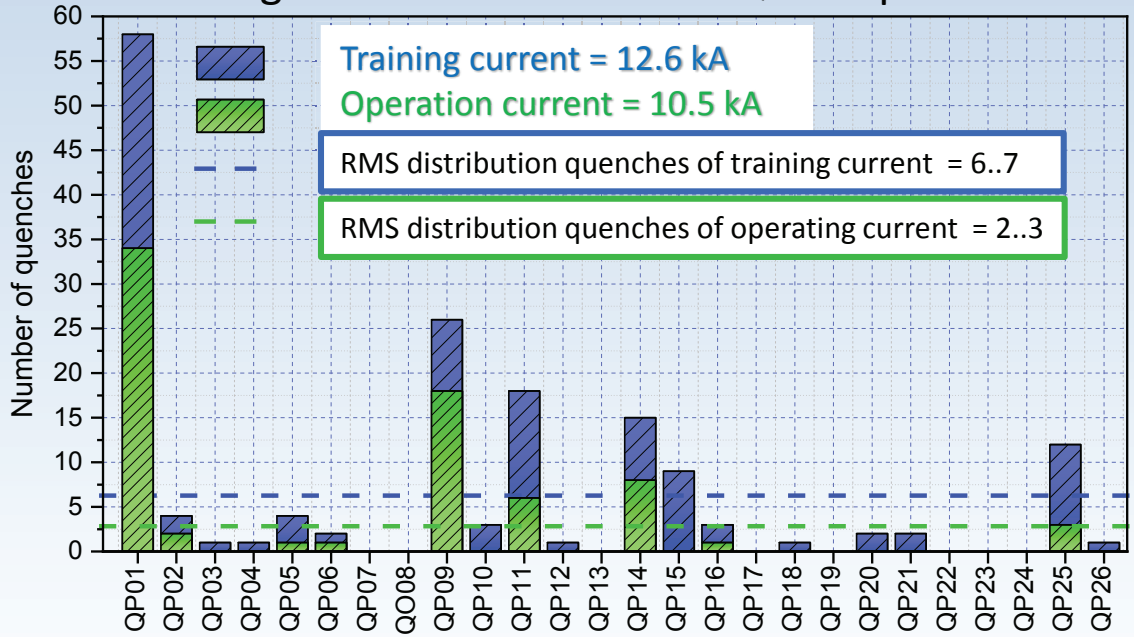
## Typical cooldown scenario for QPUs

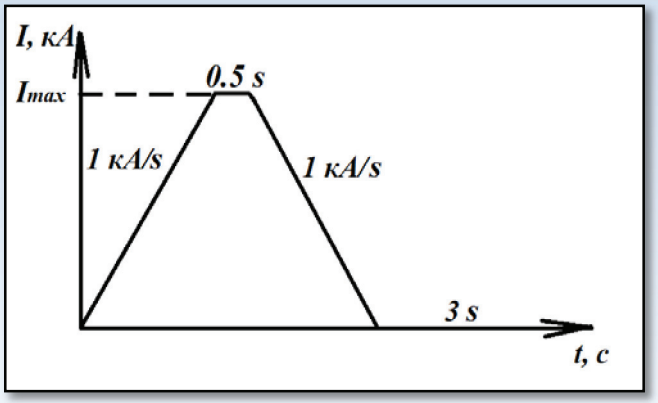



## Training of the sextupole magnets




## Training Statistics of the Series Quadrupoles

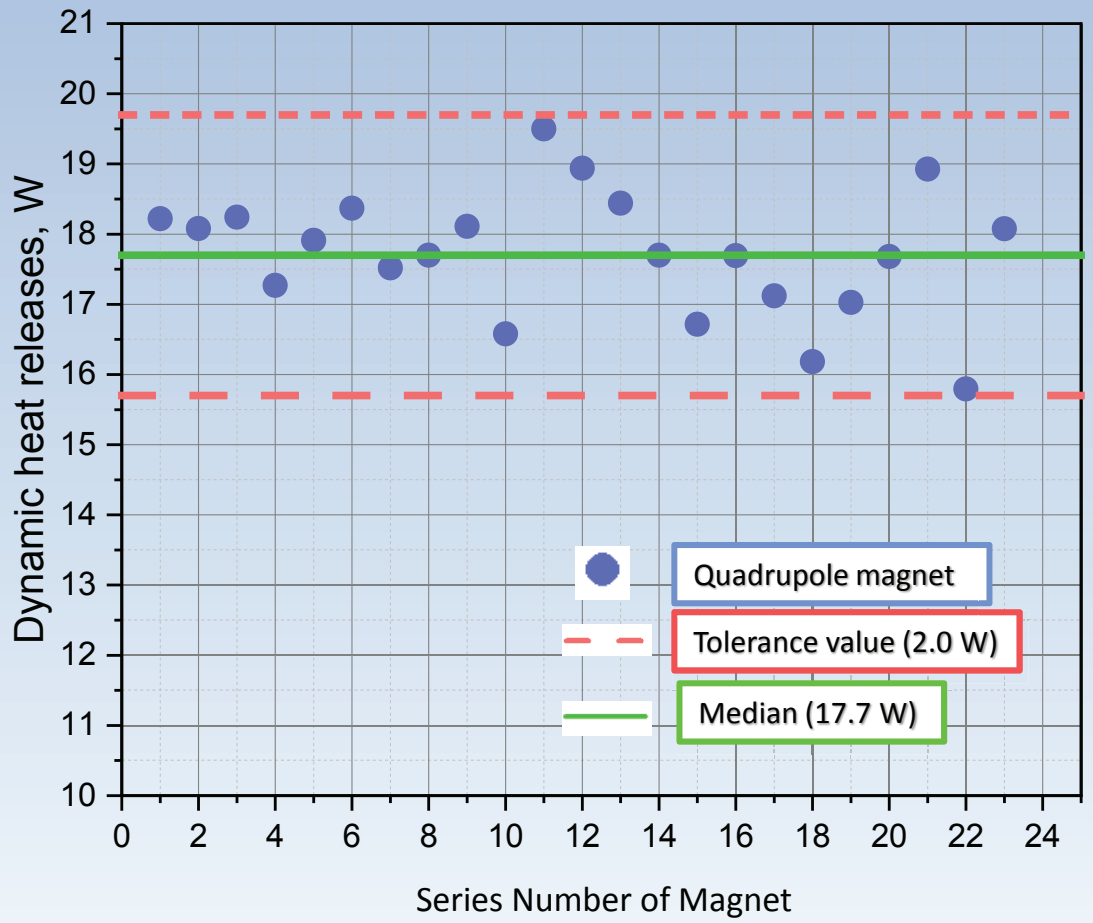


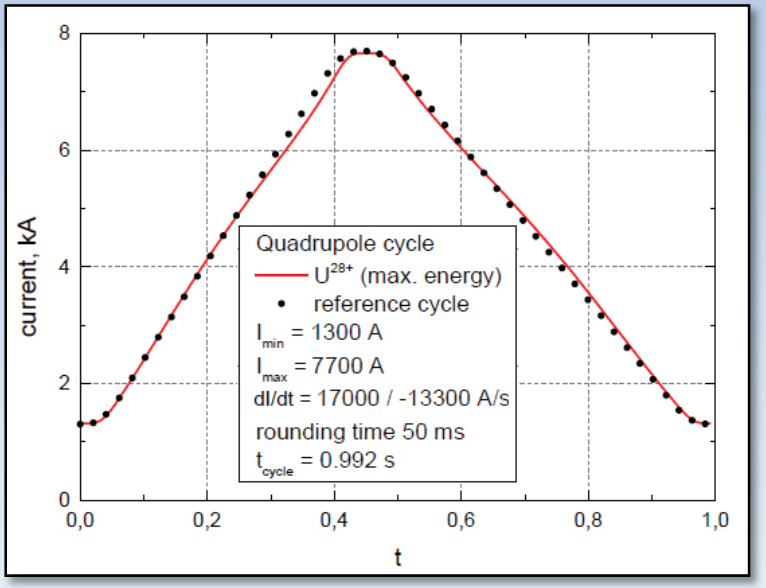

Current cycle for magnet training

# Cold Tests

Dynamic heat releases of quadrupole magnets

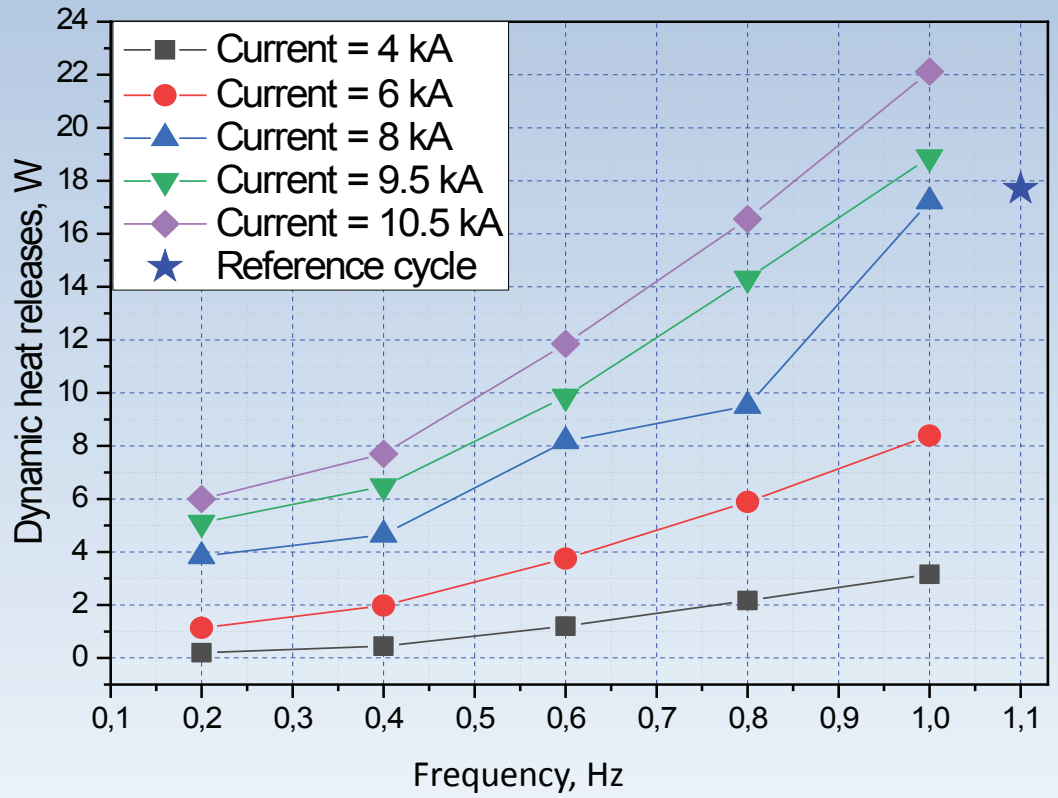



Reference cycle

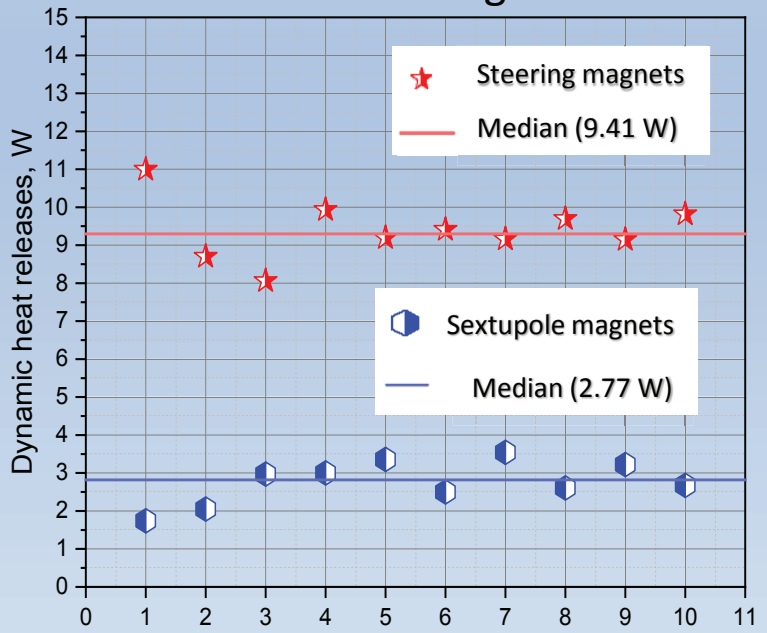


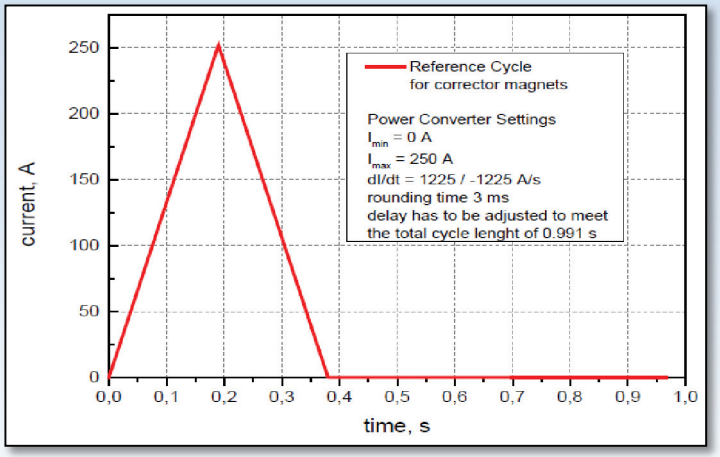
# Cold Tests

## Heat release matrix of the quadrupole

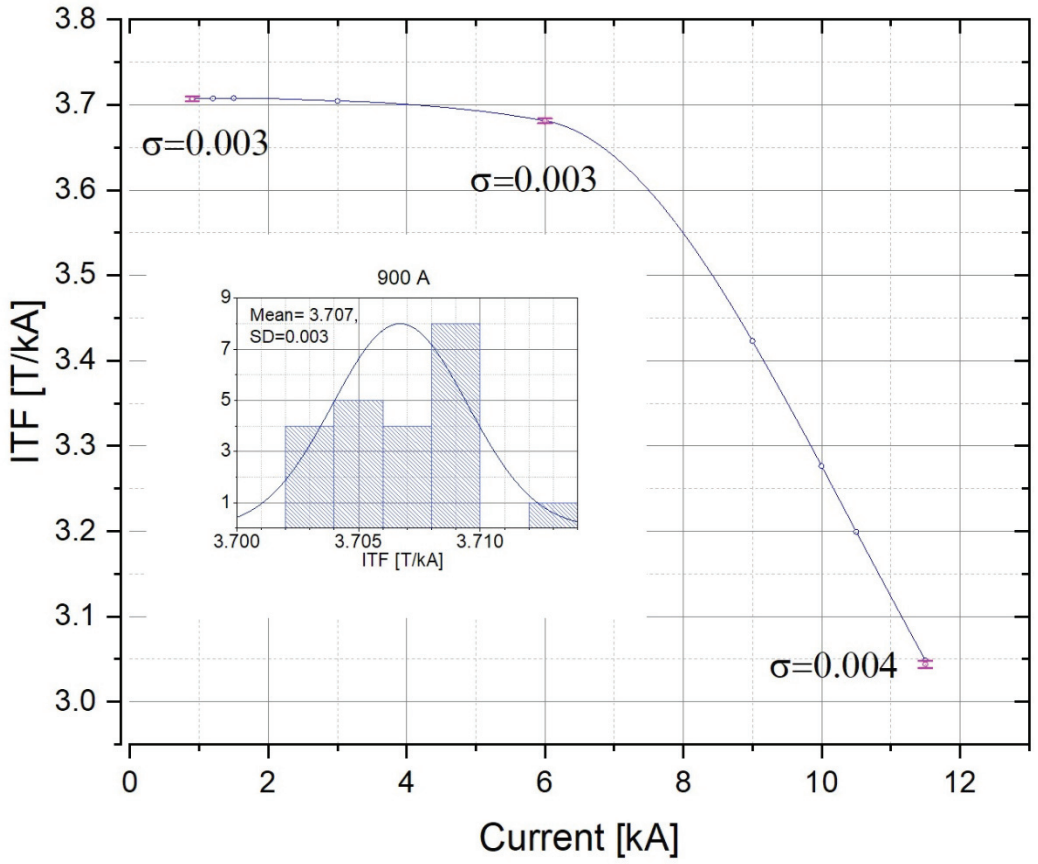


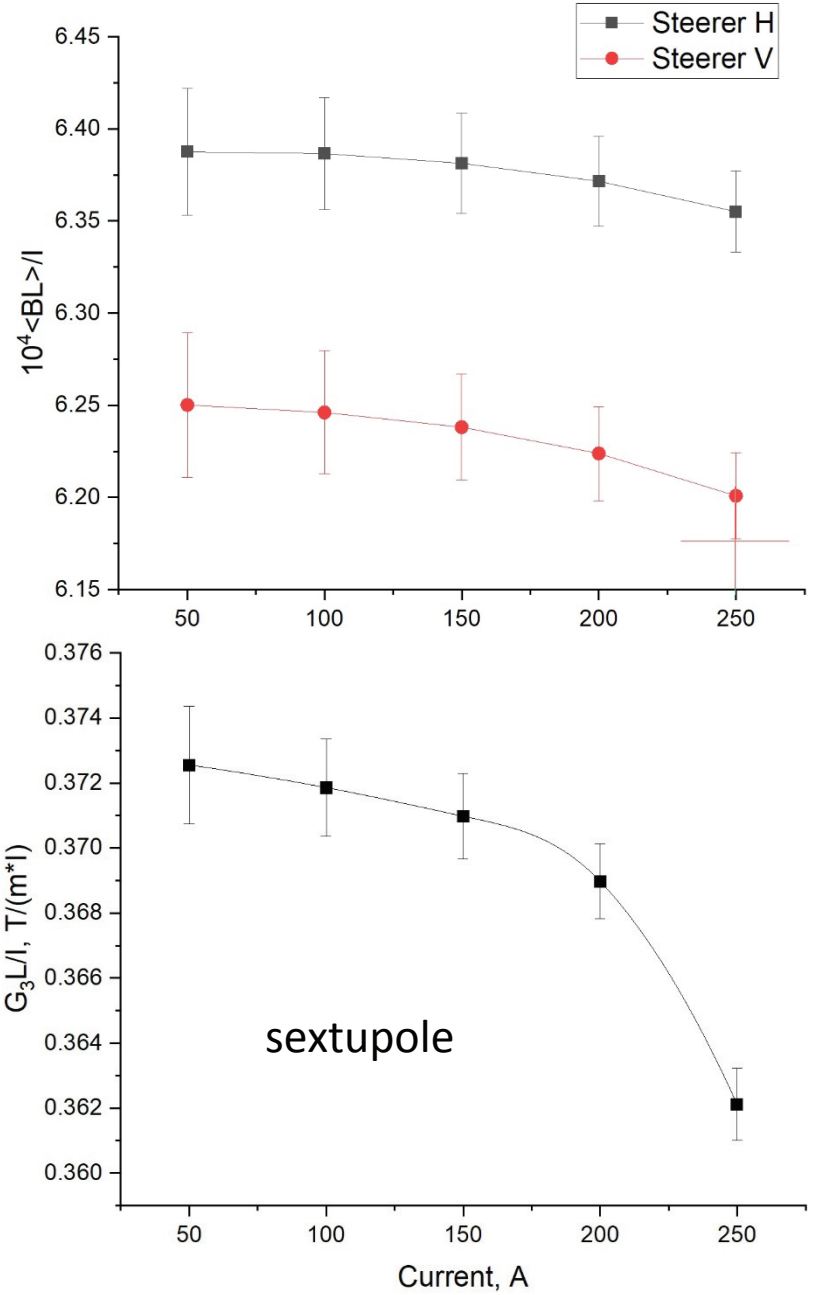

## Dynamic heat releases of the corrector magnets



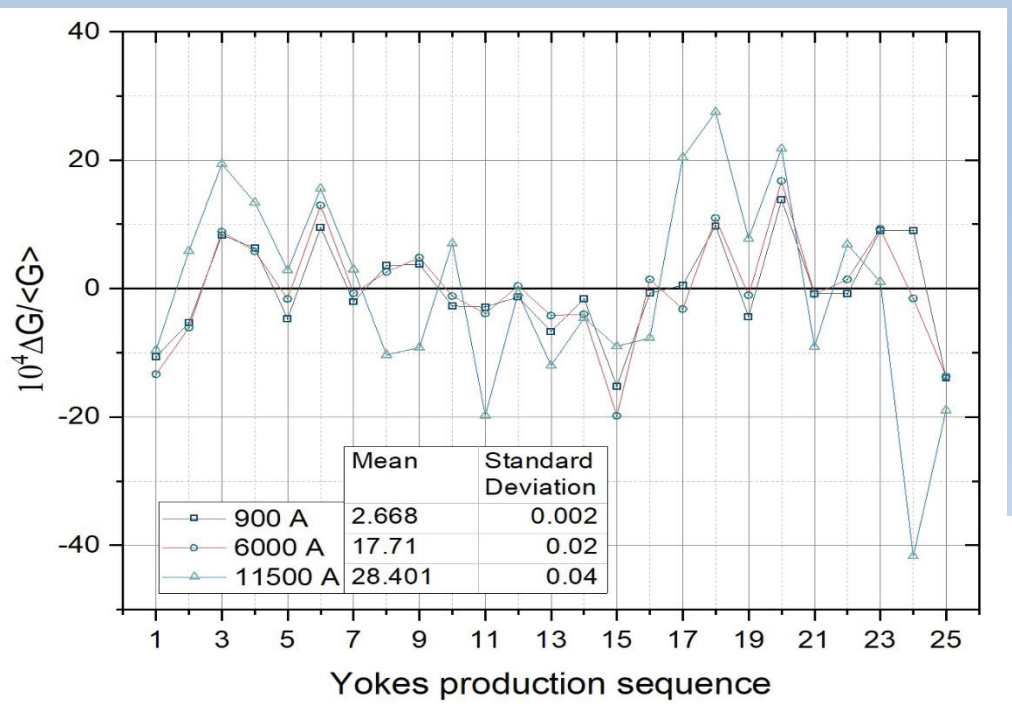



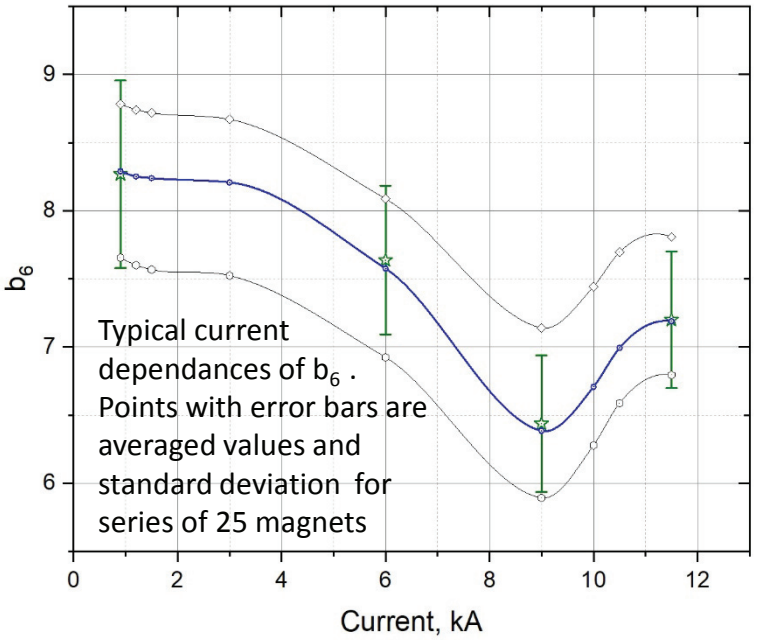
Typical current dependance of Integral transfer functions.
Inset graph: distribution of ITF of 22 series magnets « 900 A.



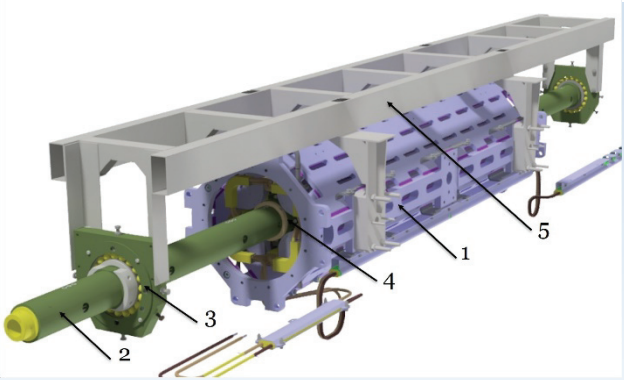
# Relative variations of gradient at the center of quadrupole magnets vs. yokes production sequence



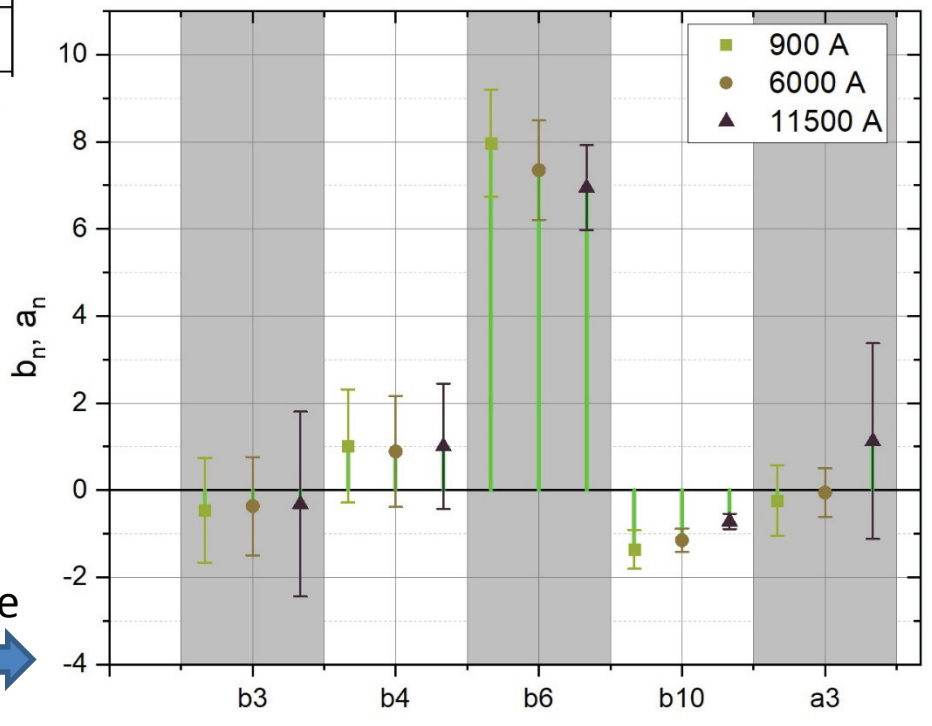




Measuring probe inside the magnet:

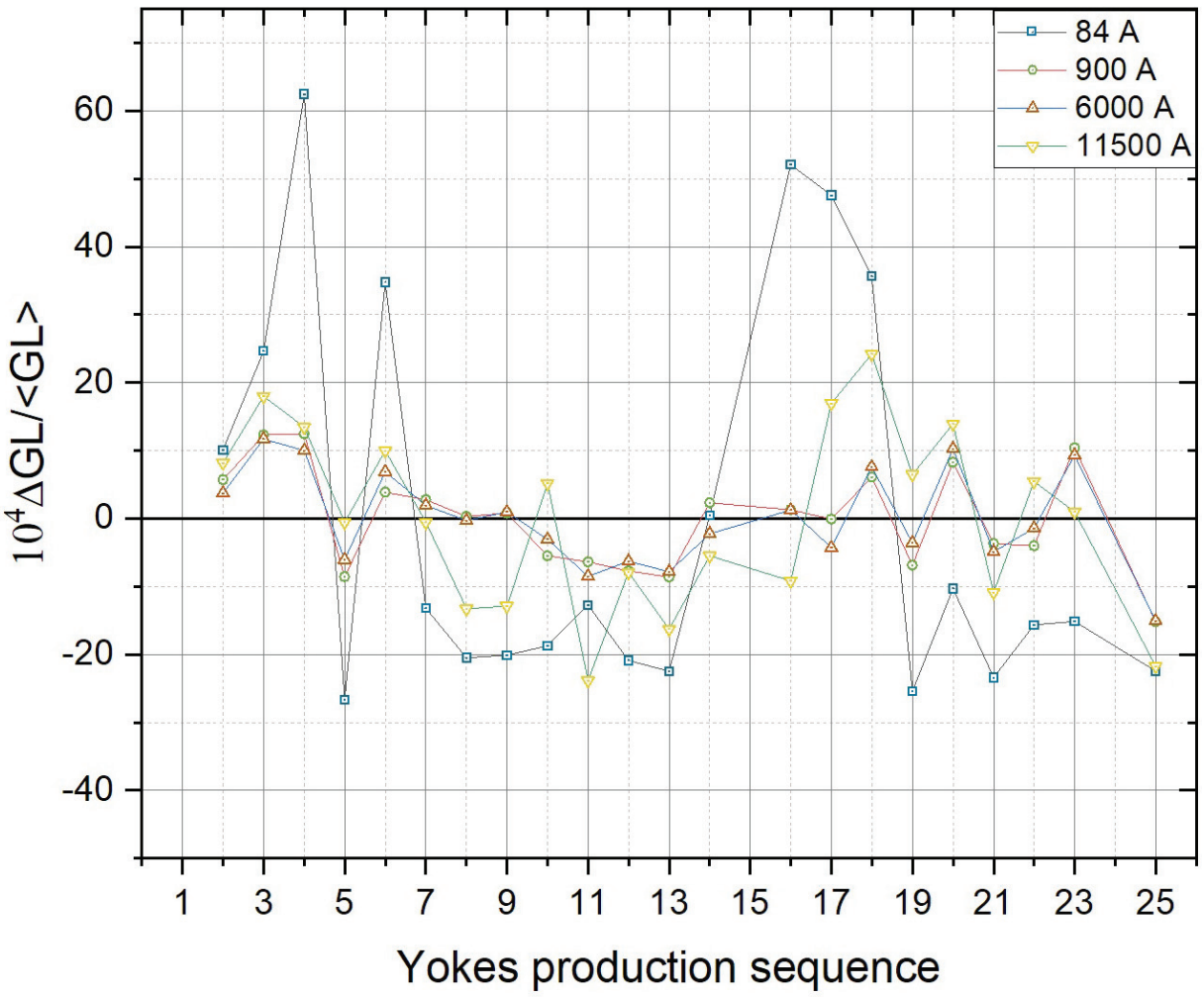
1 - quadrupole
2 - probe
3 - ball bearings and adjustable housings
4 - inside precision ceramic ball bearing
5 - frame



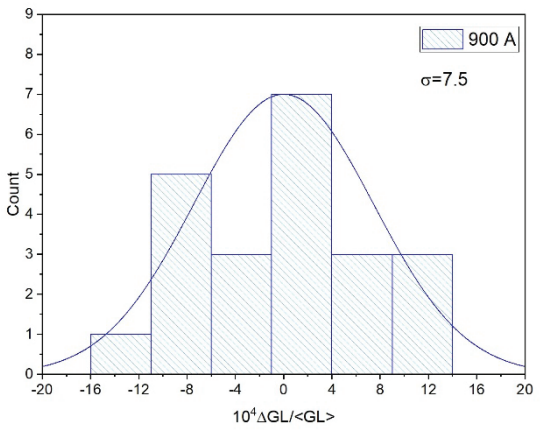

Integral Multipoles of the Quadrupole Magnets .

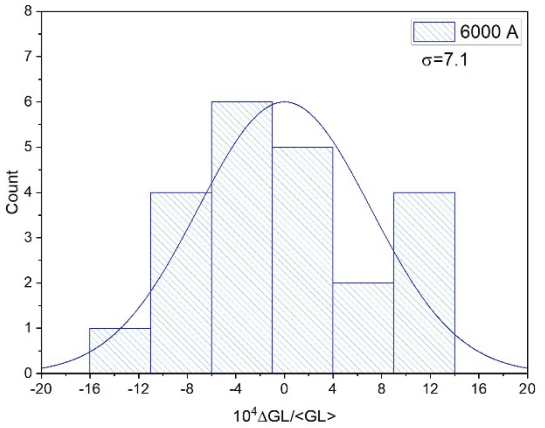


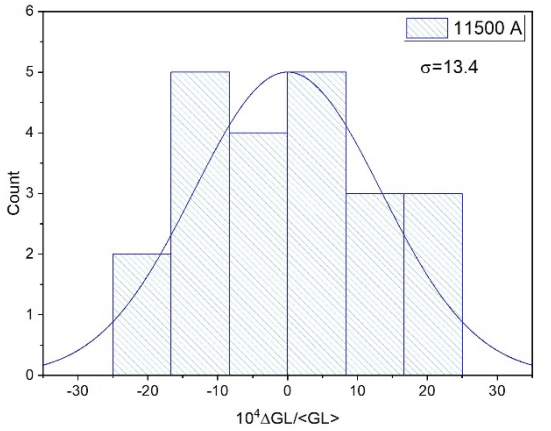
# Relative variations of the integral gradient vs. production sequence of the quadrupole yokes




Distribution of relative variations of the integral gradient



# Summary

- ✓ 100 % of all yokes for QP-unit magnets were already delivered to JINR
- ✓ 20 QP-units are assembled, successfully tested at JINR and were delivered to FAIR
- ✓ Next 8 Units are under preparation for shipment in October 2021
- ✓ The first Unit series 2.5 was completed in March this year, the second series 1.7B will follow in October.
- ✓ JINR had established an effective and stable production and testing scenario for the Quadrupole Units
- ✓ The optimisation of the production technology and detailed methodological adjustment of the measurement techniques resulted in the proven and continuously high quality of the series magnets.

Thank you for your attention !