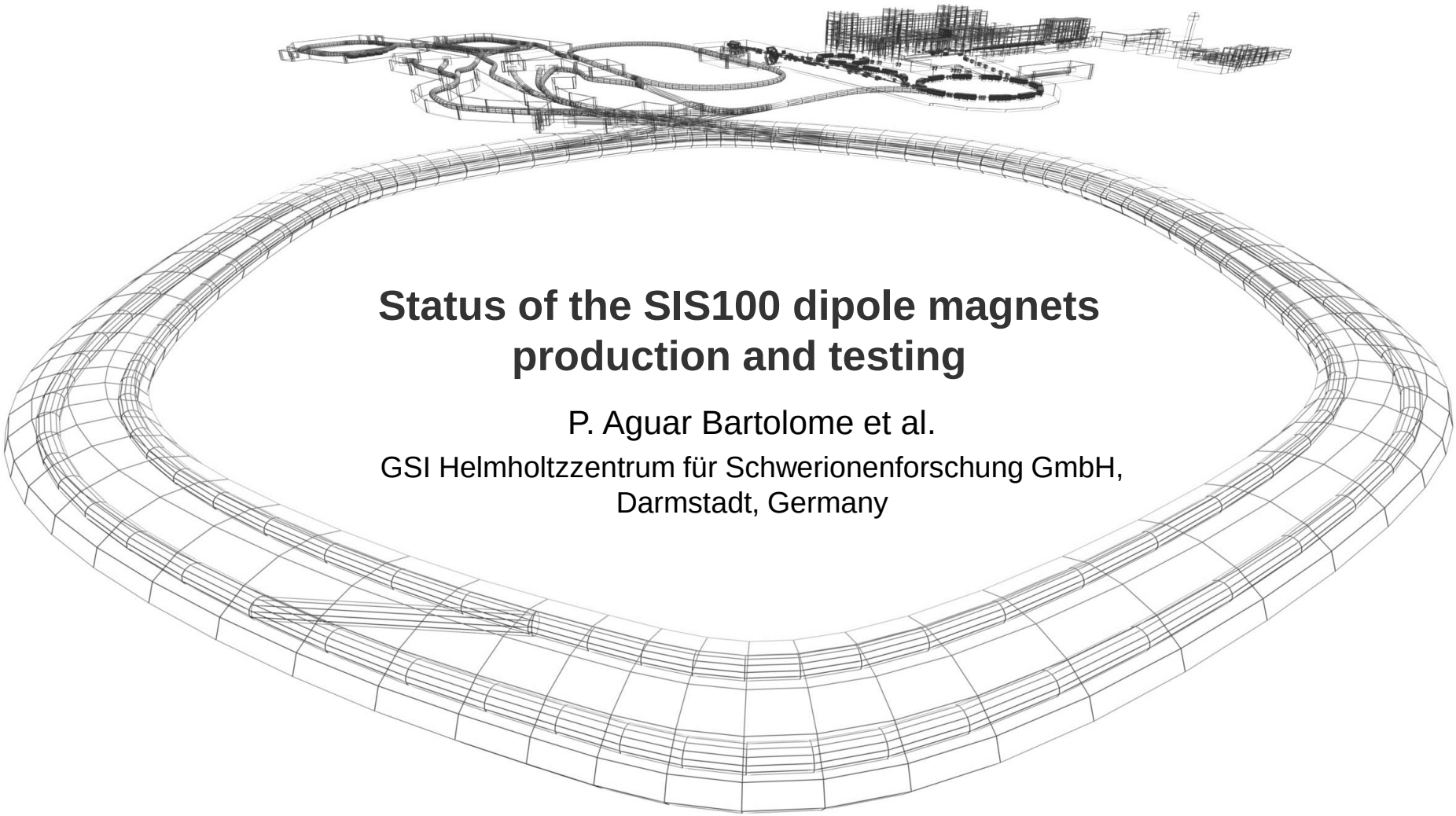

Status of the SIS100 dipole magnets production and testing

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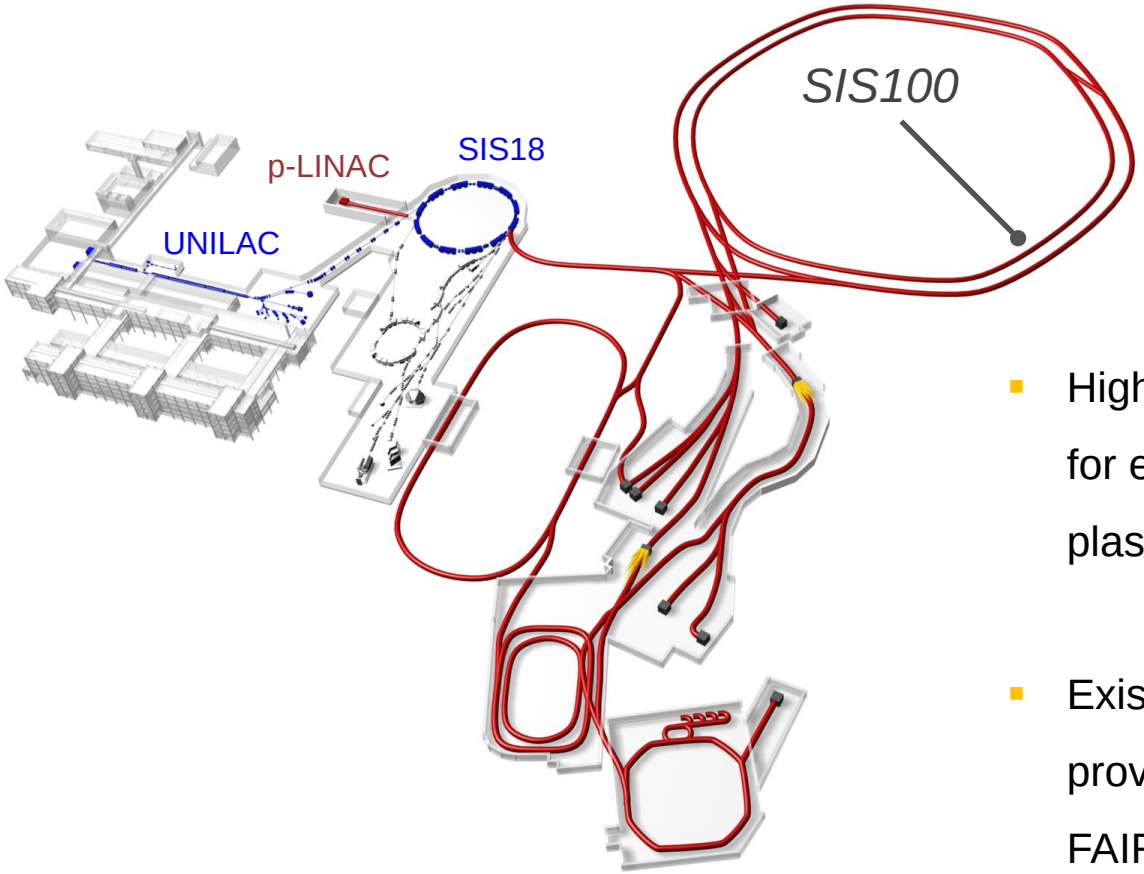
Outline

- Introduction
  - FAIR@GSI
  - Heavy Ion Synchrotron SIS100
- SIS100 Dipole Magnets
  - Design
  - Testing Strategy
- GSI Test Facilities for the SIS100 Magnets
- Testing Measurement Systems
- Test Results for the SIS100 Series Dipoles
- Summary and Outlook

Facility for Antiproton and Ion Reseach

Existing GSI facility

FAIR facility

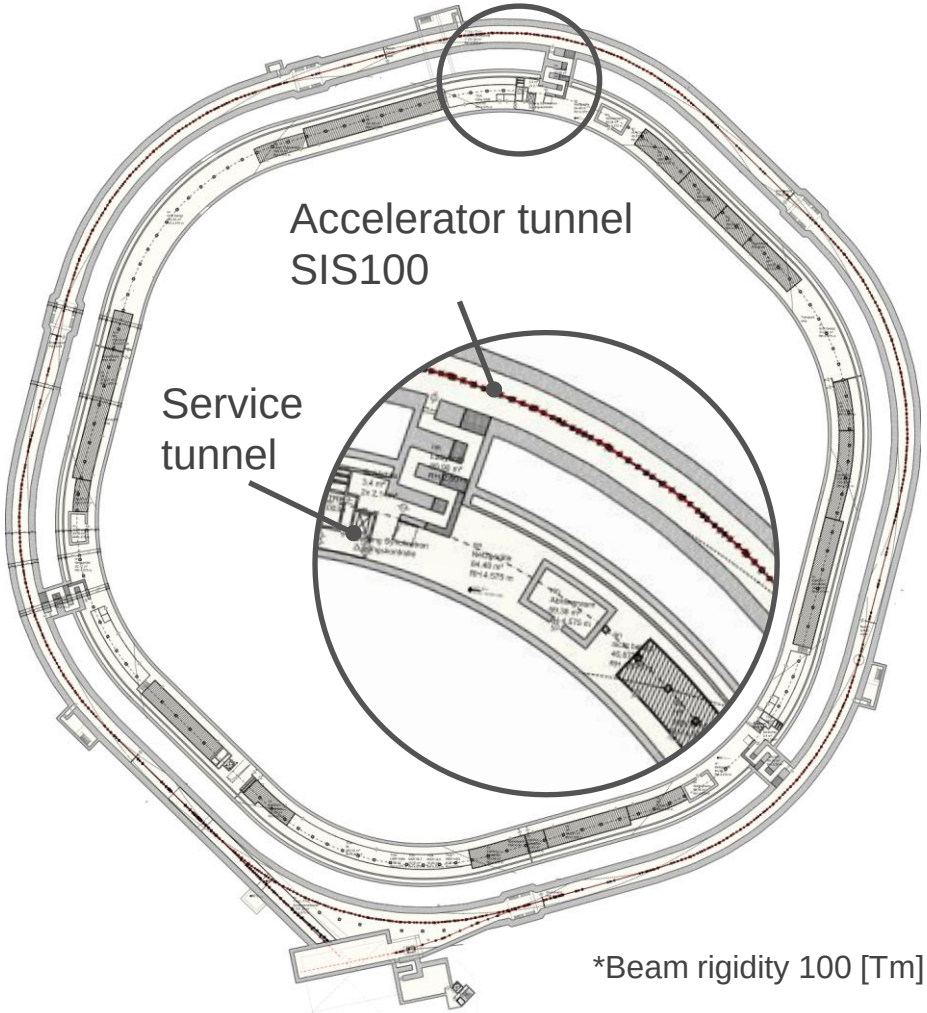


International project

- High intensity ion and antiproton beams for experiments in nuclear, atomic, plasma physics and material science.
- Existing facility UNILAC/SIS18 will provide ion-beam source and injector for FAIR.

Heavy Ion Synchrotron SIS100

SIS100 = **S**chwer**i**onen**s**ynchrotron 100 [Tm] = Heavy ion synchrotron (beam rigidity 100 [Tm]*)

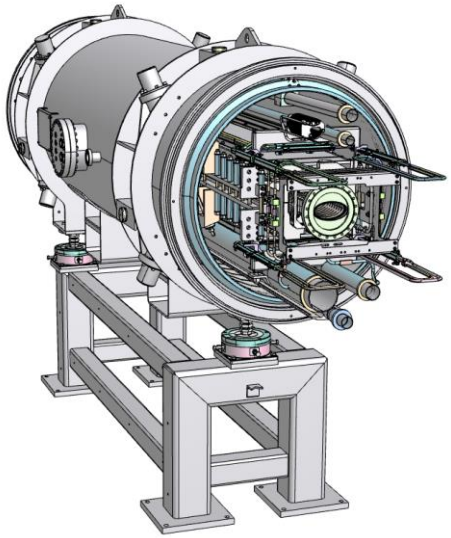


- Hexagonal, circumference 1083.60 m
- Operational modes:
  - ✓ Ultra High Vacuum (10^{-11} mbar)
    - Adsorption by cold vacuum chamber (10 - 15K)
    - Superconducting (magnet) accelerator
  - ✓ Fast-ramp machine ~0.5 sec. to maximum field

*Beam rigidity 100 [Tm] = Bending dipole field 1.9 [T] × Bending radius 52.632 [m]

SIS100 Dipole Magnets: Design

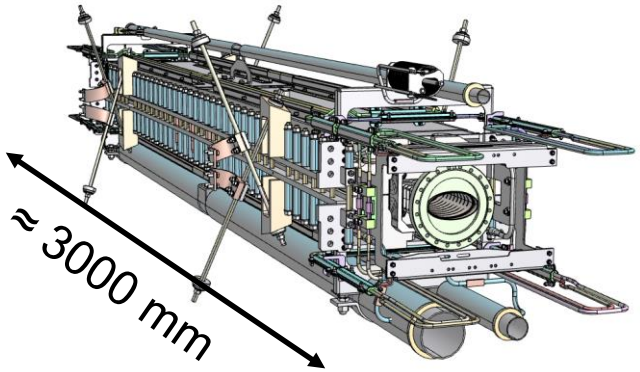
Cryo-dipole module



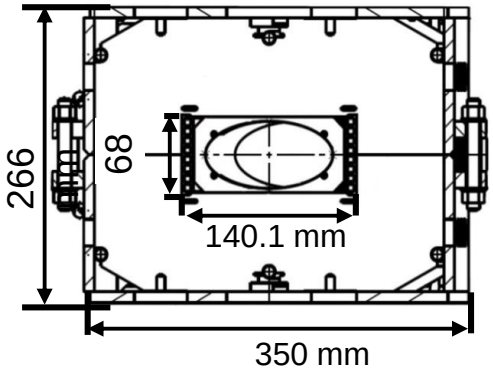
- Super ferric, window frame magnets
- Curved magnet
- SC coil (4 turn per pole)
- Nuclotron type cable
- Cooling with 2-phase He @ 4.5K

Main parameters		
Number of the magnets in SIS100	108	
Effective length L_{eff}	3.062	m
Usable aperture	60 x 120	mm x mm
Bending angle	3 1/3	deg.
Bending radius	52.632	m
Nominal Field	1.9	T
Ramp rate	4 @1Hz	T/s

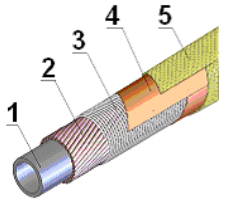
Cold mass with beam chamber



Magnet cross section



Nuclotron cable



1 - Cooling tube CuNi
2 - SC wire NbTi
3 - CrNi wire
4 - Kapton tape

SIS100 Dipole Magnets: Testing Strategy

Series dipoles are manufactured at Bilfinger Noell GmbH, Germany

At contractor site:

- Factory Acceptance Test (FAT)
  - ✓ quality inspections on different production steps (e.g., yoke geometry for half yokes before and after welding, after assembly with the coil)
  - ✓ functionality tests @ 300K (components of assembly, assembled magnet…)
  - ✓ measurement protocols
  - ✓ quality certificate (summary of single tests)

At GSI site:

- Site Acceptance Test (SAT)
  - ✓ documents control
  - ✓ quality controls
  - ✓ functionality tests @ 300K (after delivery, after cold tests)
  - ✓ functionality tests @ 4.5K (including magnetic field measurements (DC, AC mode))

SIS100 Dipole Magnets: Testing Strategy

Site Acceptance Test (SAT): Scope

Quality assurance (including safety)

- Yoke geometry
  - ✓ aperture height (precise)
  - ✓ sag and twist
  - ✓ positioning
- Process lines
  - ✓ pressure and leak
  - ✓ massflow rate
  - ✓ positioning
- Instrumentation check
- Electrical integrity
  - ✓ HV
  - ✓ continuity
  - ✓ turn-to-turn insulation
- Quench performance
- Static heat load and AC losses

Machine control

- Integral B-field
- Harmonics
- Load line

For each dipole magnet:

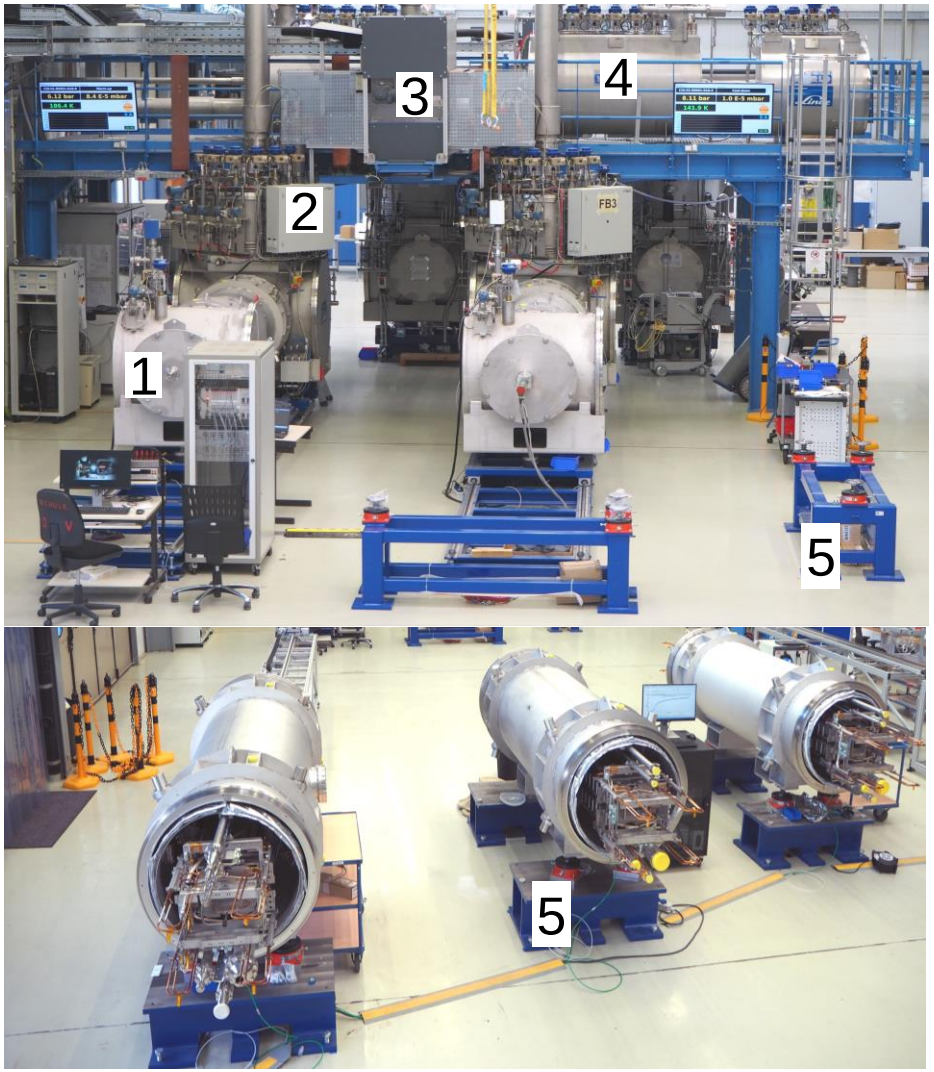
- ➢ About 30 parameters to control
- ➢ Approx. 110 steps to follow
- ➢ Duration ~ 3 weeks

GSI Test Facilities for SIS100 Magnet Testing

Series Test Facility (STF)

- Cryo-plant 1.5 kW – commissioned Q2/2015
- Power converters 2 x 20 kA (66 V) – commissioned Q1 & Q3/2016
- 14 kA DC HTS Current Leads (CL) – commissioning Q3/2015 – Q1/2017
- QD / Magnet protection system
- 687m^2 total area
- 4 test benches for cold tests
- 6 preparation benches
- Calibration chain for MF-probe

Full readiness for operation August 2017



1 - End box, 2 - Feed box, 3 - Distribution box, 4 - Power switch, 5 - Preparation bench

Testing Measurement Systems

High precision gap height measurent system

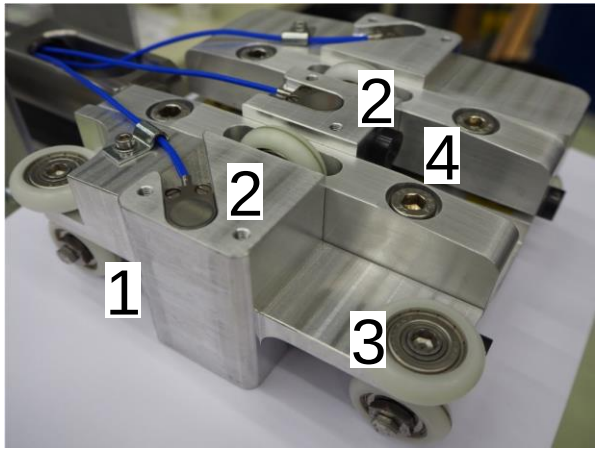
- 6 capacitive sensors CSH1,2FL(20)-CRm 4,0 from Micro - Epsilon GmbH& Co.KG
- Linear encoder WDS-100-P 115-CR from Micro-Epsilon GmbH& Co for reproducible positioning of the carriage along the magnet

Absolute precision 15µm

Relative precision < ± 3µm

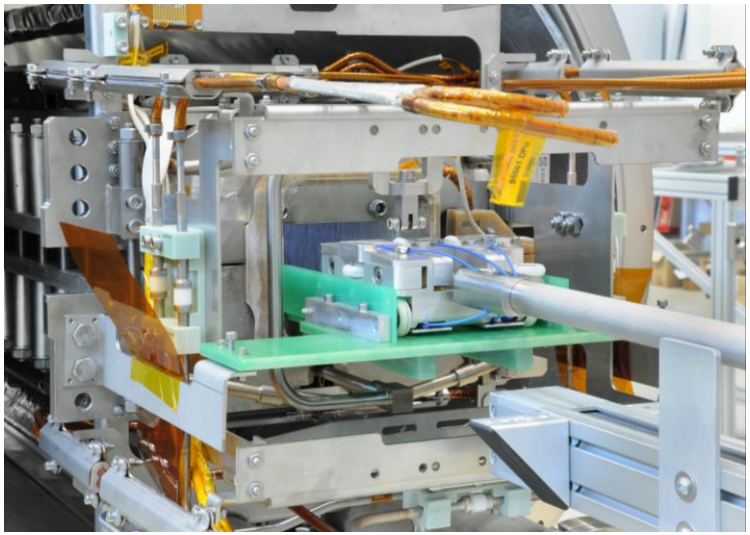
} @ 300K

In combination with a laser tracker, the system provides data regarding the yoke's sag and twist.



1 - Carriage, 2 - Capacitive sensors, 3 - Wheels,

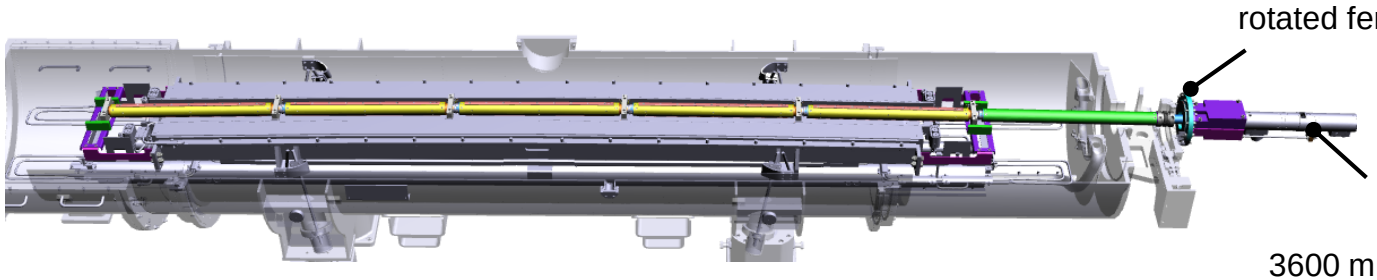
4 - Holder for spherically mounted retroreflectors.



Testing Measurement Systems

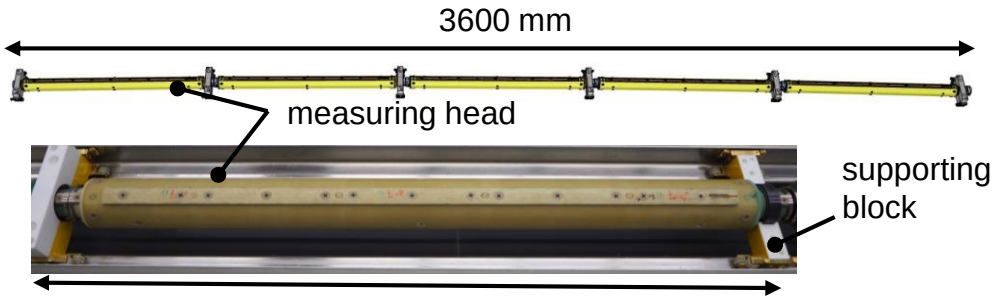
Magnetic field measurent system

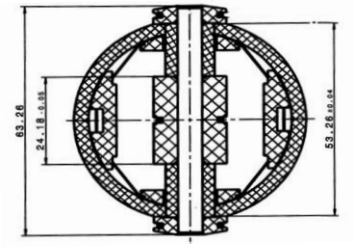
The measuring probe is designed and built in collaboration with CERN



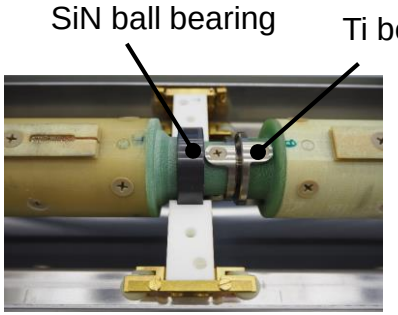
- 5 measuring heads – tangential coils
- 3 pick up coils per head, 600 mm length
- Effective surface 1.67 m^2
- Ti-alloy bellows – interconnection between segments and to align the heads along the beam axis
- SiN ball bearings for rotation motion
- Ceramic supporting blocks for transverse positioning in the gap

Field measurements in vacuum @ 4.5K

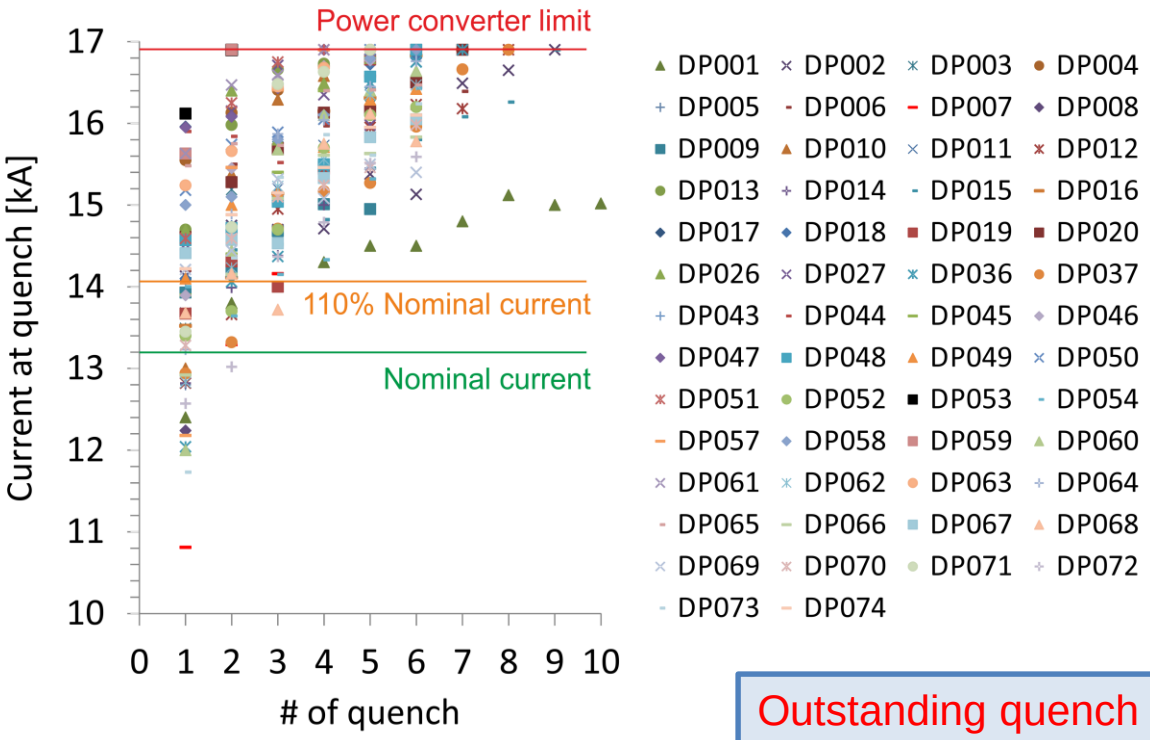




Cross section of the measuring head (3 tangentinal coils)



Test Results for the SIS100 Dipoles: Training



53 magnets tested @ cold

Specifications:

- nominal current (nc) to be reached:
  - at 3rd quench in first cycle
  - at 1st quench in further
- de-training limited to 5 % of nc (compared to previous quench)
- quench current has to stabilize at 110 % of nc at least (14.5 kA)

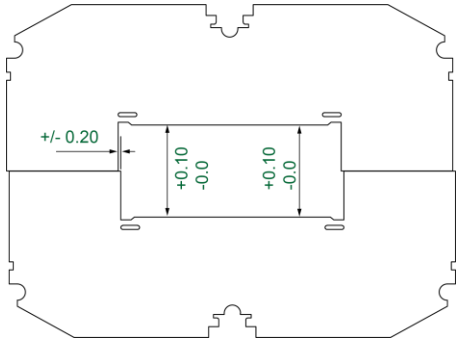
Outstanding quench performance!

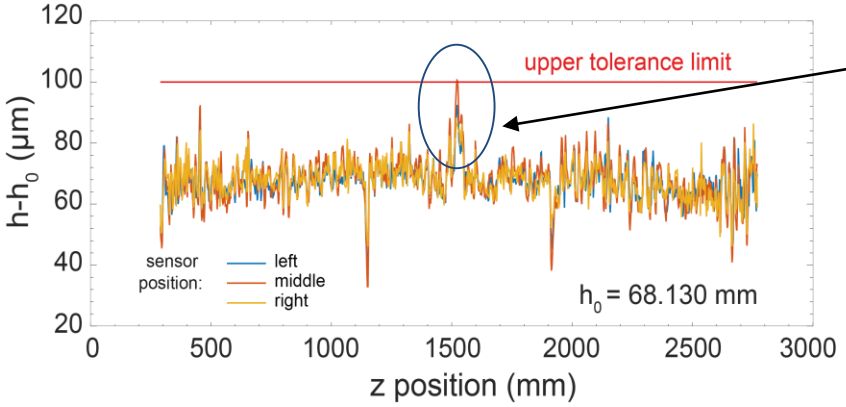
✓ nom. current reached at 2nd quench at least
✓ no significant de-trainig observed

Training close to the short sample limit of the cable (17.8 kA)
⟶ high stability of the coil structure in the yoke

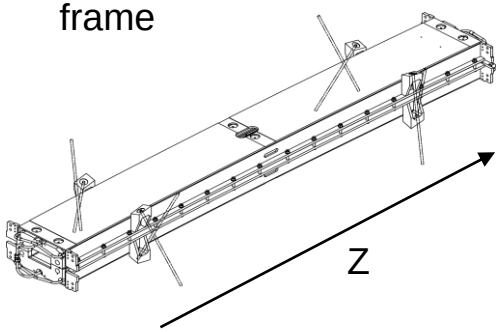
Test Results for the SIS100 Dipoles: Gap Geometry

Required:





spot welding of lamination to outer frame

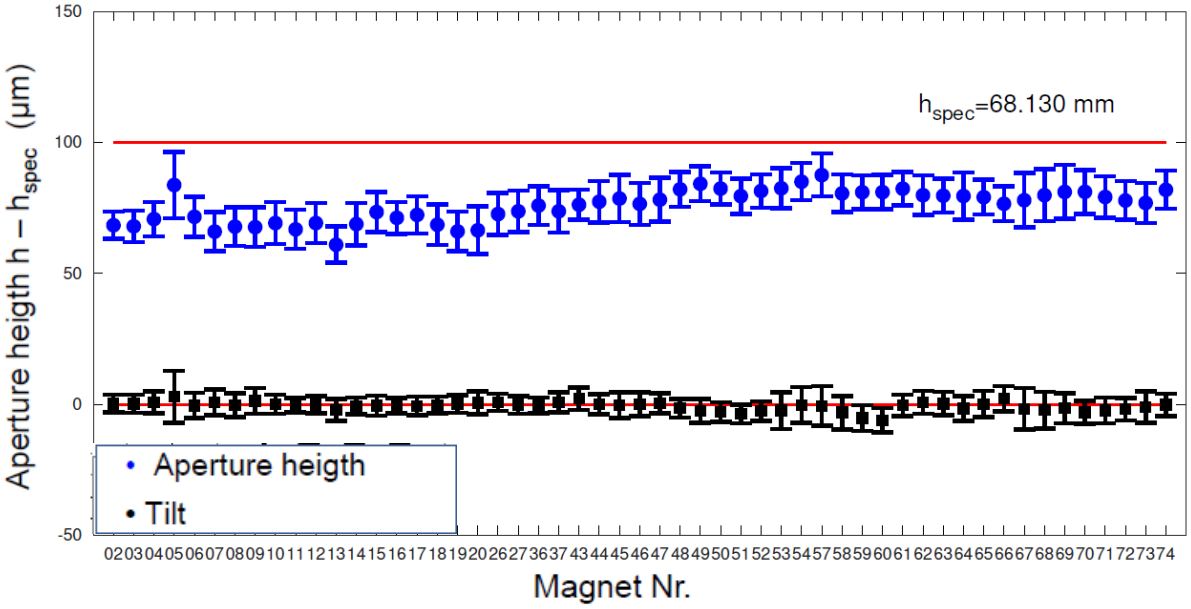


Aperture height (→BL)

- well within specification on average for each magnet
- very good reproducibility

Tilt (→ a_n, b_n)

- negligible



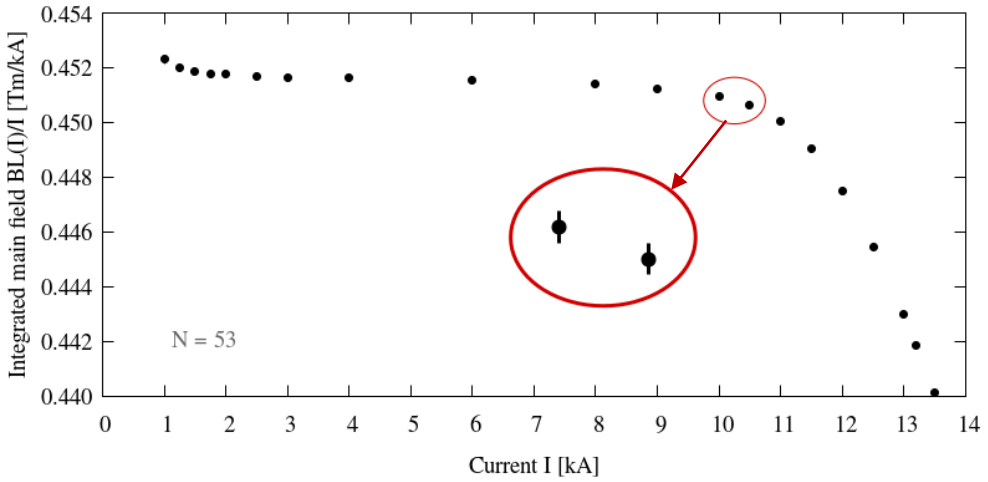
Test Results for the SIS100 Dipoles: Magnetic Field

Integral field

acceptance criteria for SIS100:

$$\Delta BL/_{BL} \leq 4 \times 10^{-3} \quad \text{with } BL = \int B(l)dl$$

measured on 53 magnets: **ΔBL/BL = 2.3 ×10^{-4}**



Field homogeneity

acceptance criteria:

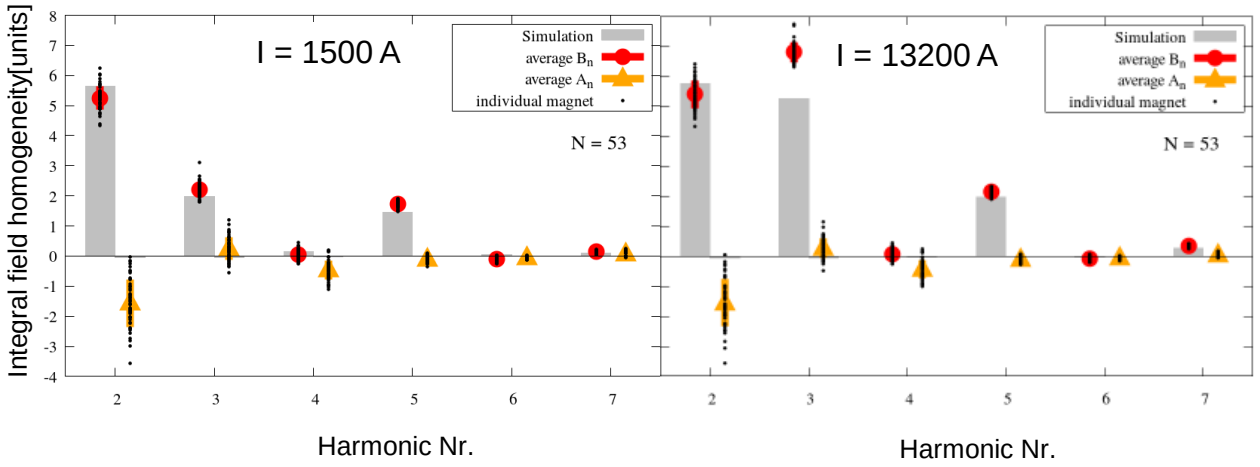
$\sum_n C_n/B_1 <$ ± 6 units @ R_{ref}= 30mm

$$\boldsymbol{B}(z = x + iy) = \sum_n \boldsymbol{C_n} \left(\frac{z}{R_{\text{ref}}}\right)^{n-1} \quad \text{with} \quad \boldsymbol{C_n} = B_n + iA_n$$

measured on 53 magnets:

- ✓ magnet data acceptable for synchrotron operation
- ✓ good agreement with expectation except:
  - b_3 systematic → correctable
  - a_2 under investigation

High reproducibility



Test Status for the SIS100 Dipoles

- The measurement results reveal an excellent performance of the chosen design and high production quality.
- The magnetic field shows very low variation in terms of the field integral and the low harmonic content is satisfactory for the beam physics requirements.
- Quench performance verifies a high stability of the coil structure in the yoke.

Dipole magnets delivered	Dipole magnets tested
62	58

Summary & Outlook

- The series production of the SIS 100 dipole magnets started in August 2016.
- The first series dipole was delivered to GSI at the end of September 2017.
- Quality control and functionality tests at contractor and GSI site are defined .
- High precision measurement systems were developed for magnet evaluation.
- Excellent performance of the chosen design and high production quality.
- More than 50% of the series dipoles successfully tested.
- Dipole series production is ongoing with a delivery rate of approx. one magnet per week.
- Next challenges for magnet testing are the FoS quadrupole module and magnet string tests.

SAT Team

- Test coordinators
- Survey & alignment
- Electrical integrity
- Field measurement
- Quench detection
- Cryoplant operators
- Transport and installation
- Quality assurance
- DAQ, control and software

GSI departments

SCM, QA, TRI, CRY, EN-MG, EPS, VAC, BB, RHV
Support on demand – MEWE, KB, ENG

Thank you for your attention