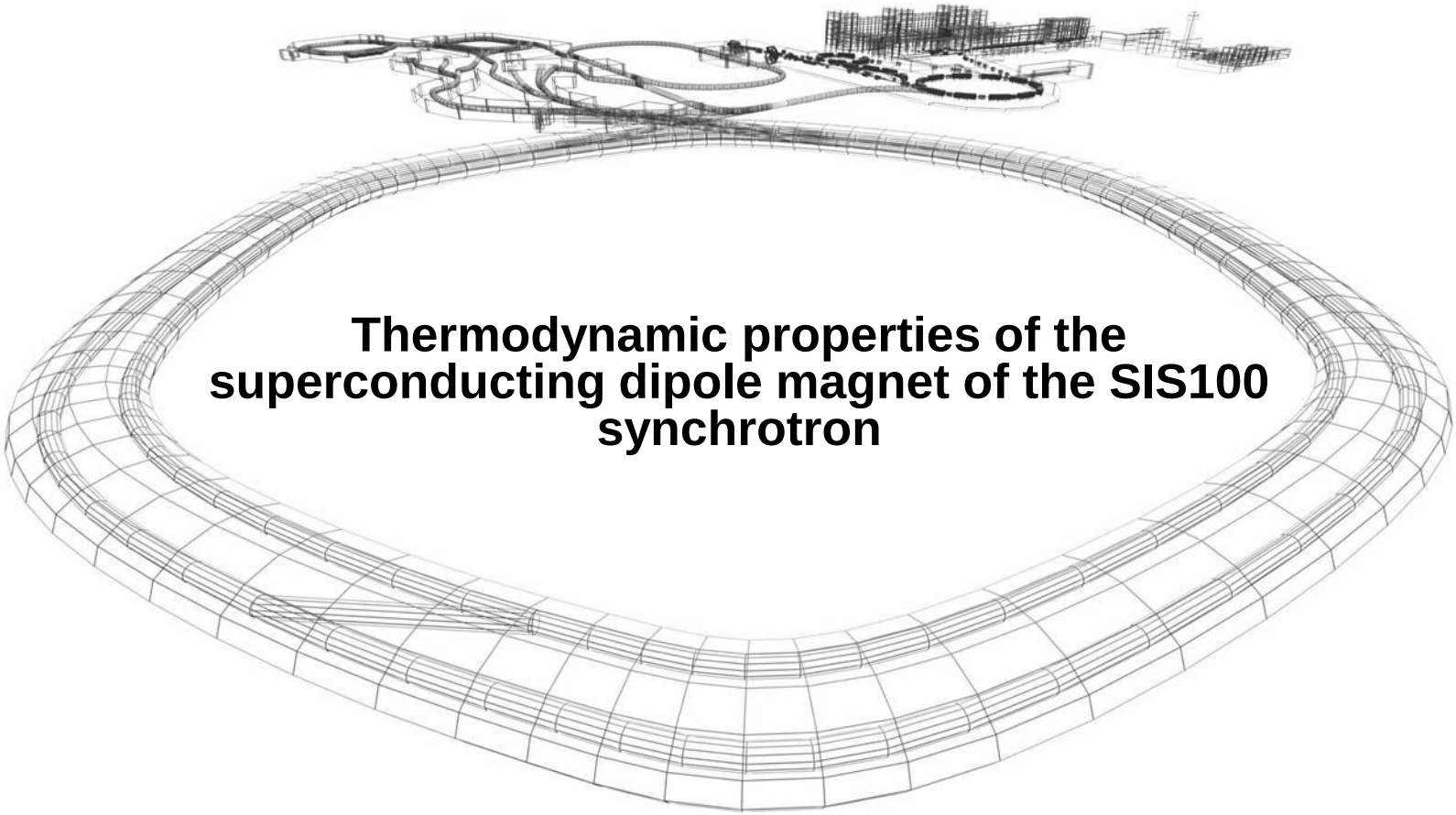


Thermodynamic properties of the superconducting dipole magnet of the SIS100 synchrotron

Alexander Bleile
GSI, Darmstadt

Outline

1. Introduction: FAIR / SIS100

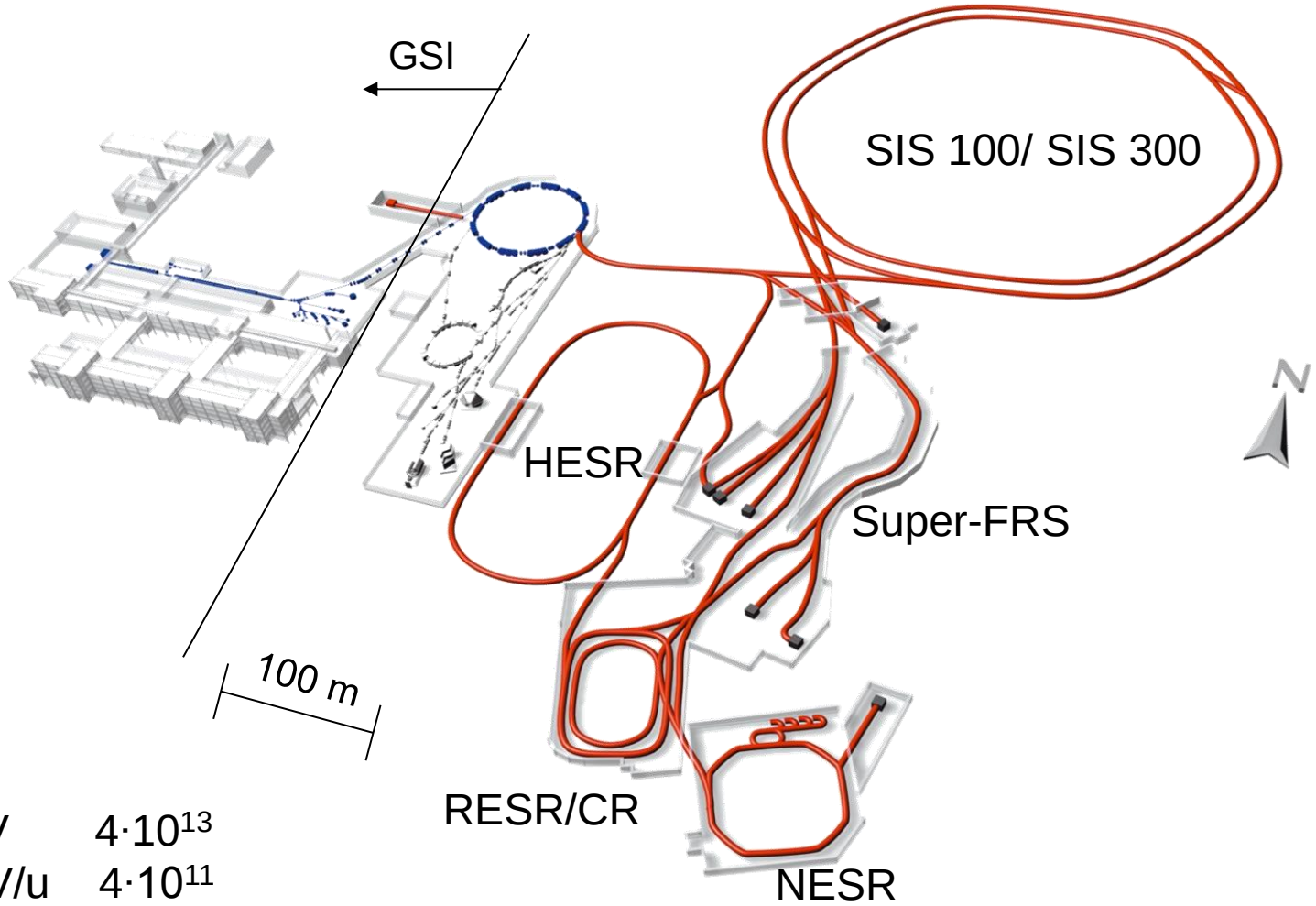
2. Fast ramped superconducting magnets

3. Testing of the First of Series Dipole Magnet

   - Cooling conditions and mass flow rates
   - Dynamic and static heat load

4. Conclusions

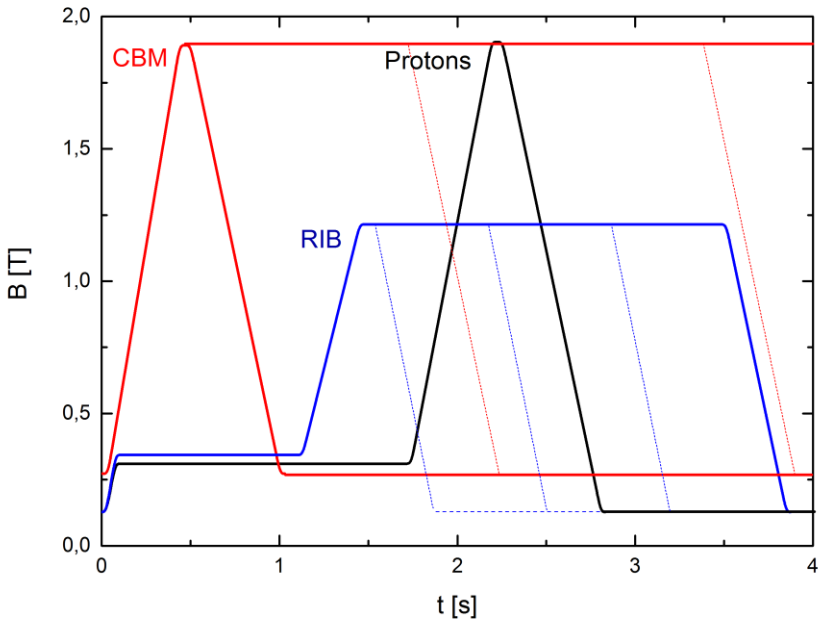
FAIR Project

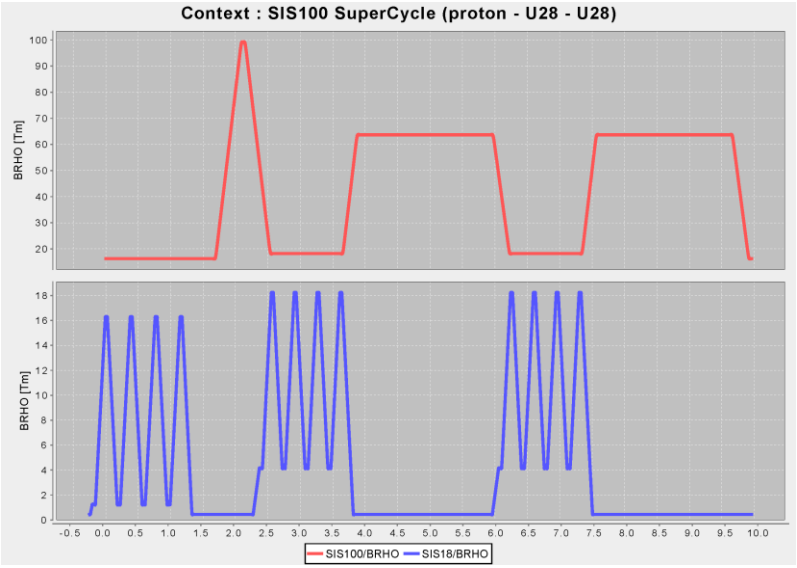


<u>SIS100</u>:

protons:	29 GeV	$4 \cdot 10^{13}$
U^{28+}	2.7 GeV/u	$4 \cdot 10^{11}$

SIS100 Operating Modes





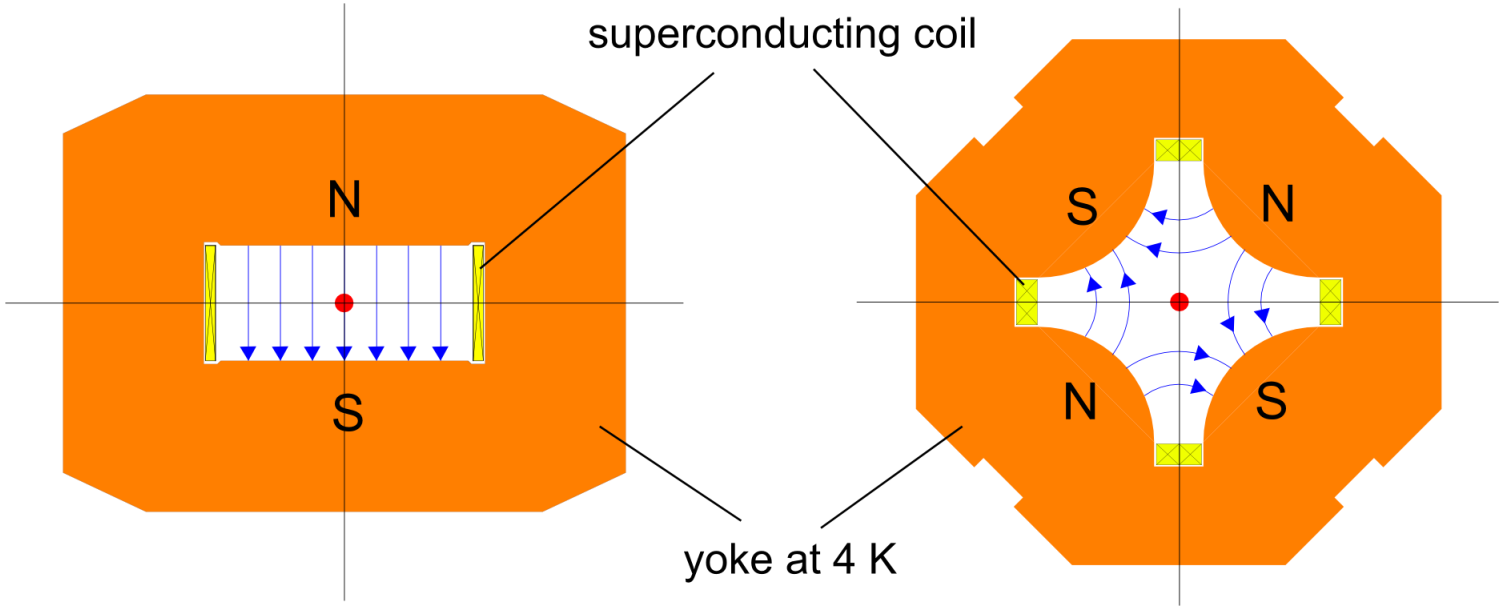
Cycle	B_{max} [T]	B_{min} T]	t_f [s]	t_c [s]
CBM	1.9	0.27	0.1	1...10
RIB	1.2	0.13	3.0	3.88
Protons	1.9	0.13	1.7	2.83
/\	1.9	0	0	0.95

- four injections from SIS18
- acceleration: ramp up at 4 T/s
- extraction (slow or fast)
- ramp down at 4 T/s

Fast Ramped Super-ferric Magnets

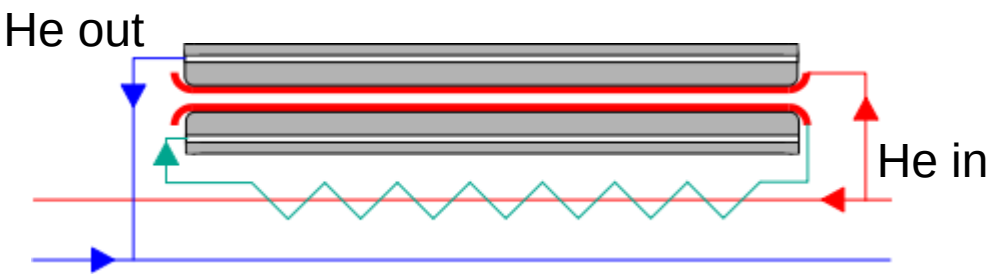
B_{max} = 1.9 T, dB/dt = 4 T/s

G = 33.9 T/m, dG/dt = 67.8 T/(m·s)



- 108 dipole magnets
- 166 quadrupole magnets
- 149 corrector magnets
- beam vacuum chambers

SIS100 Magnet Cooling



Inlet – sub-cooled helium
P_{in} = 1.6 bar, T_{in} = 4.5 K

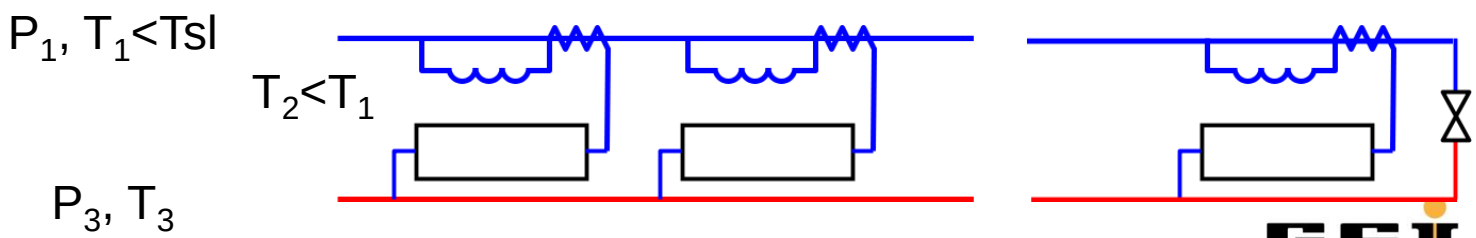
Coil out:
P = 1.2 bar, two-pase (4.3 K)

Joke out:
P = 1.2 bar, two-phase, x = 0.9 – 1.0

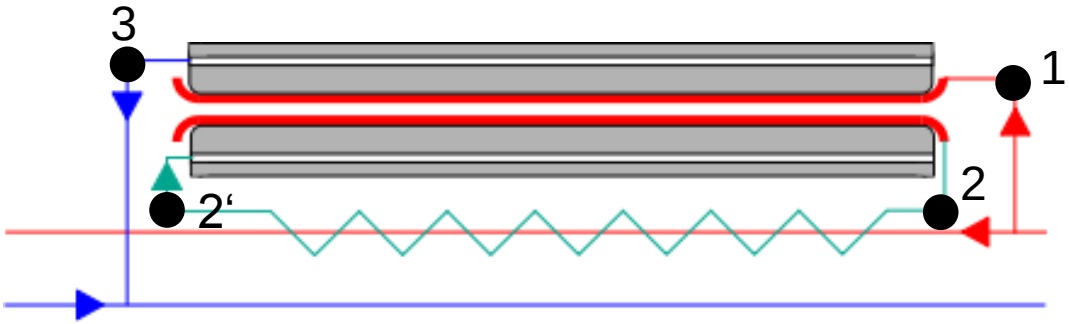
<u>Heat load:</u>

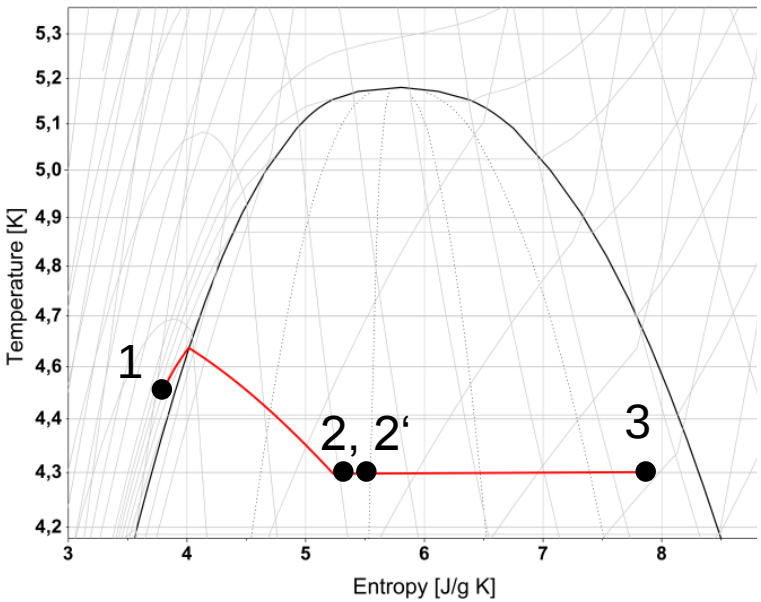
static:	2 W
dynamic:	up to 50 W

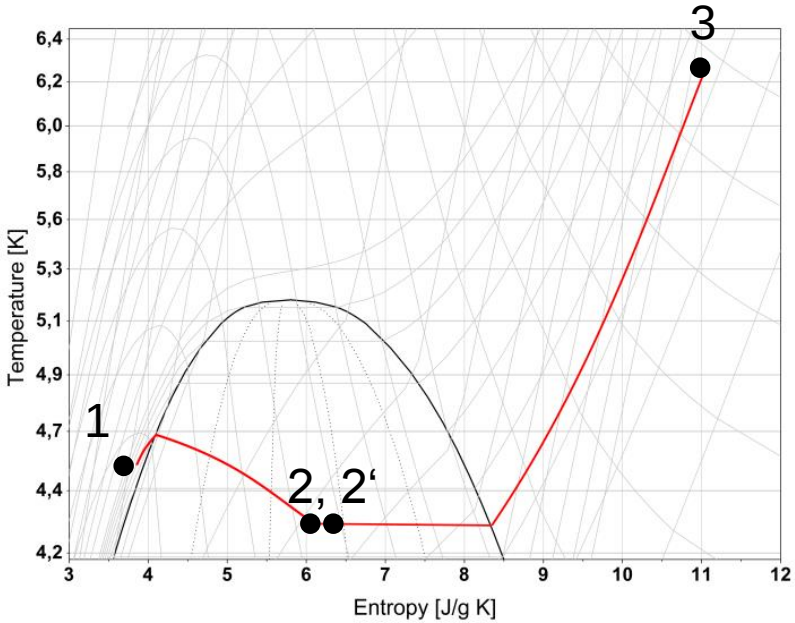
<u>Mass flow</u>: defined by the pressure difference P_{in}-P_{out} and by the total heat load
hydraulic resistance of cooling channels:
cable inner diameter: d = 4.7 mm iron yoke: d = 10 mm
dipole: L = 54 m + 54 m



SIS100 Magnet Cooling







Development of the SIS100 s.c. Magnets

Requirements:

- **Maximal field 1.9 T**
- **Ramp Rate 4 T/s**
- **goog field quality within an elliptical apperture 57.5 x 30 mm**

Magnet design is based on the NUCLOTRON magnets:

- **iron dominated magnets**
- **hollow two-phase cooled s.c. cable**
- **cold iron at 4 K**

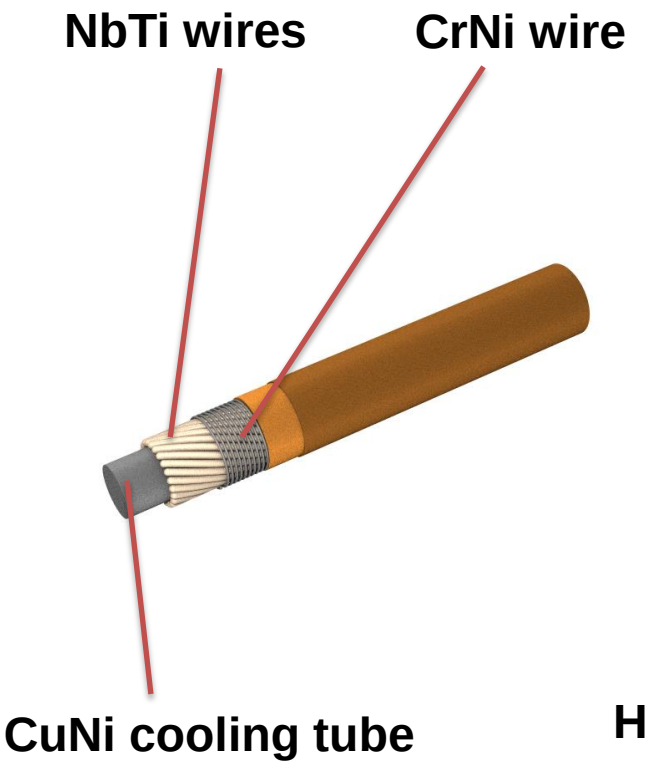
R&D program:

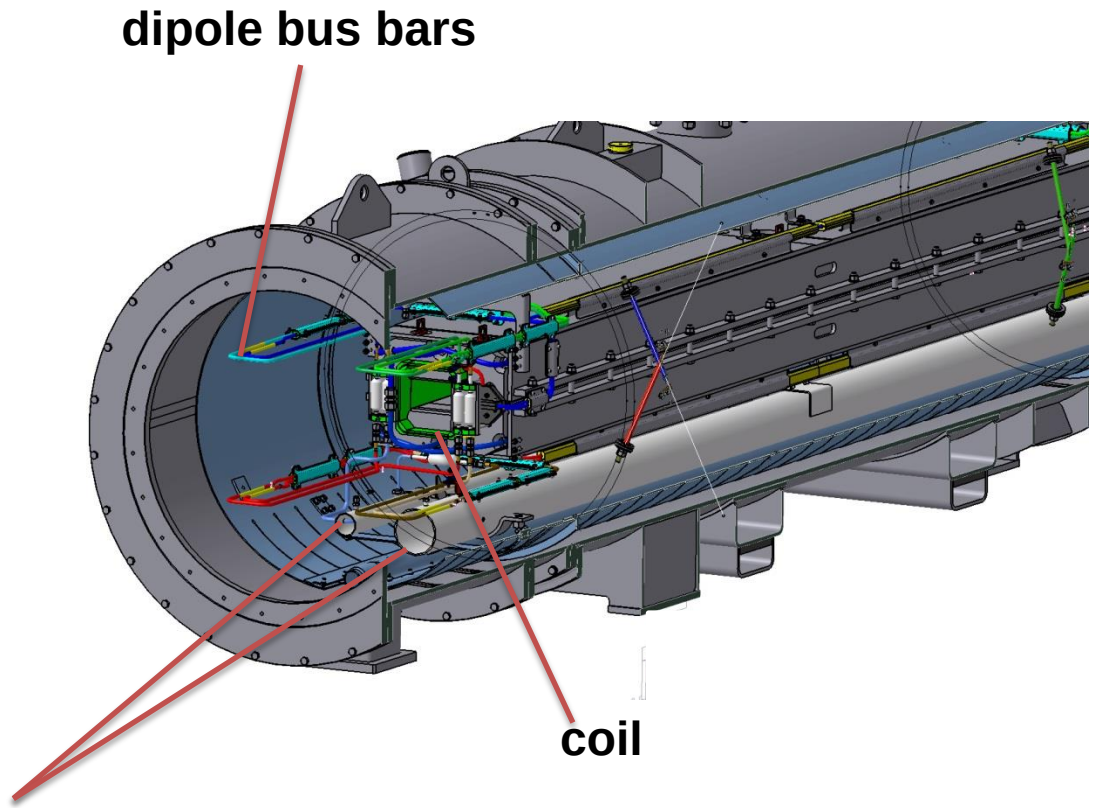
- **reduction of the AC losses**
- **improvement of the DC/AC field quality**
- **long term mechanical stability (> $2 \cdot 10^8$ cycles)**

Full size prototypes

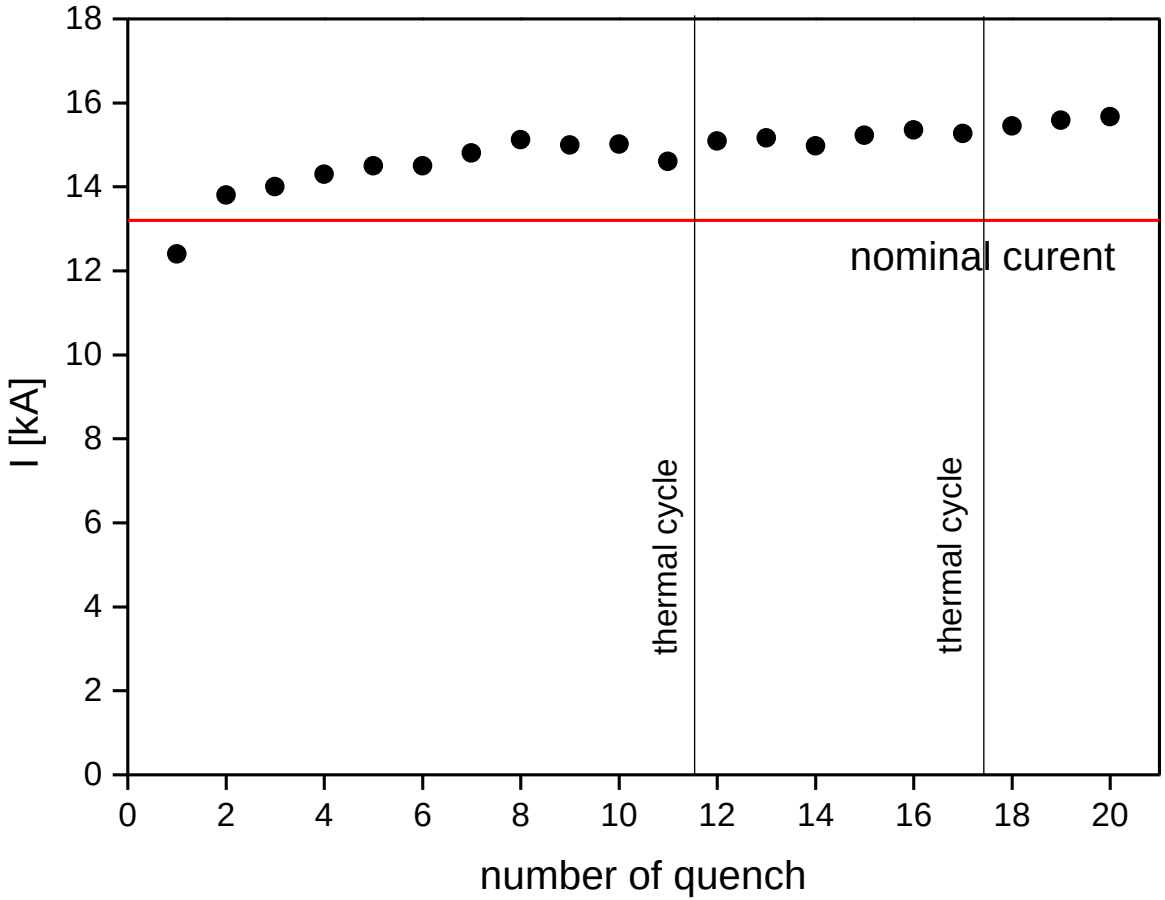
First of Series Magnet: built by BNG in June 2013

SIS100 Series Dipole





Training and powering tests



- nominal current reached after the first quench
- no de-training after thermal cycling

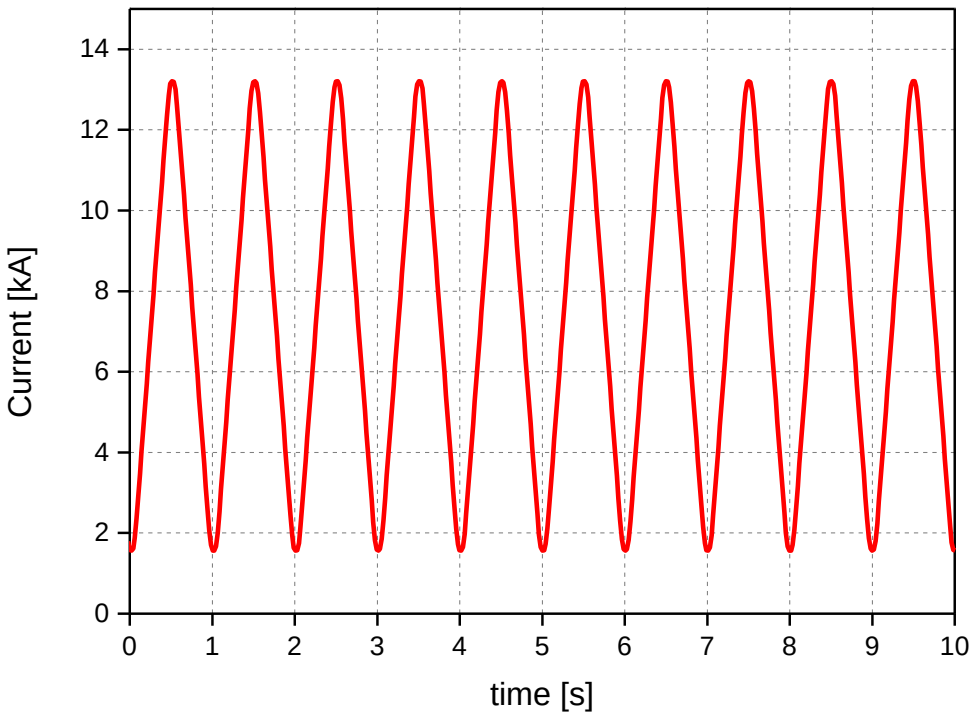
Training and powering tests

AC operation at different modes

continuous cycling with:

B_{min} = 0.23 T
B_{max} = 1.9 T
dB/dt = 4 T/s

1 Hz repetition frequency



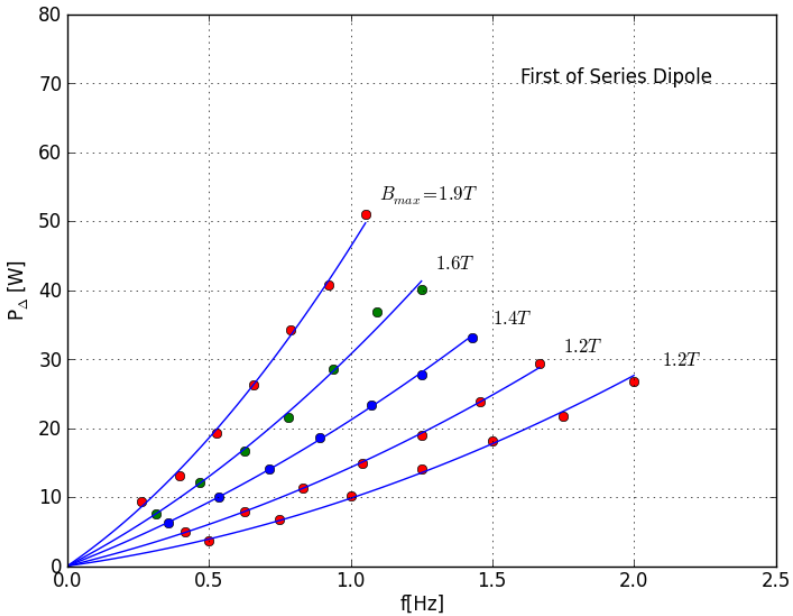
AC losses

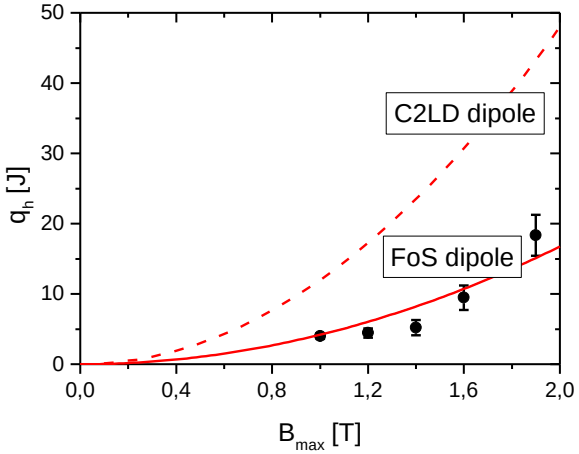
Measured with VI method

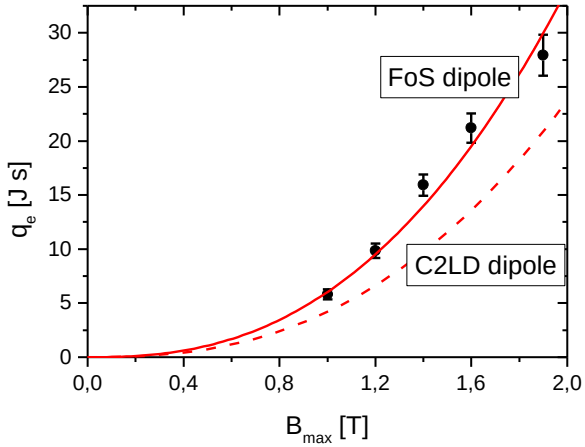
$$P_\Lambda = q_h(B_{max}) \cdot f + q_e(B_{max}) \cdot f^2$$

$$q_h = h\, B_{max}{}^2$$

$$q_e = e\, B_{max}{}^{2.5}$$



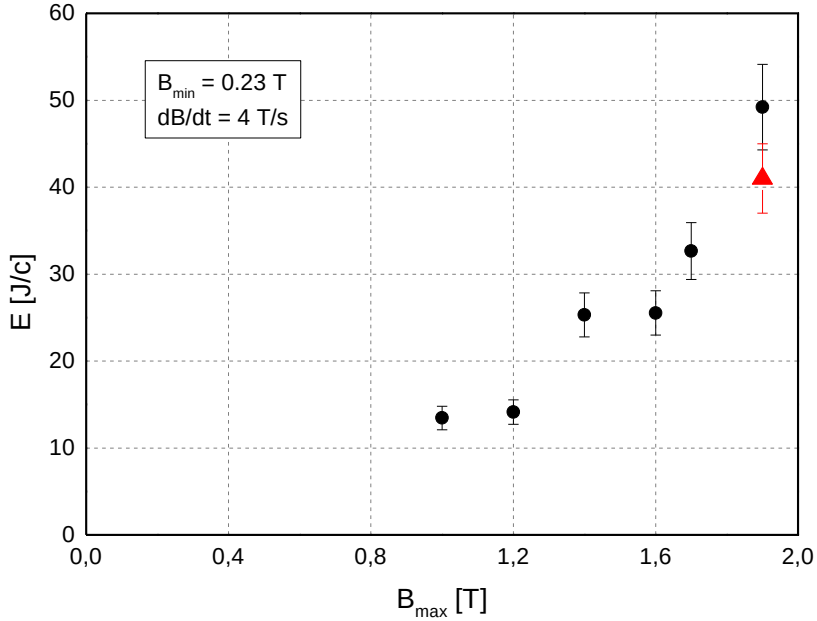


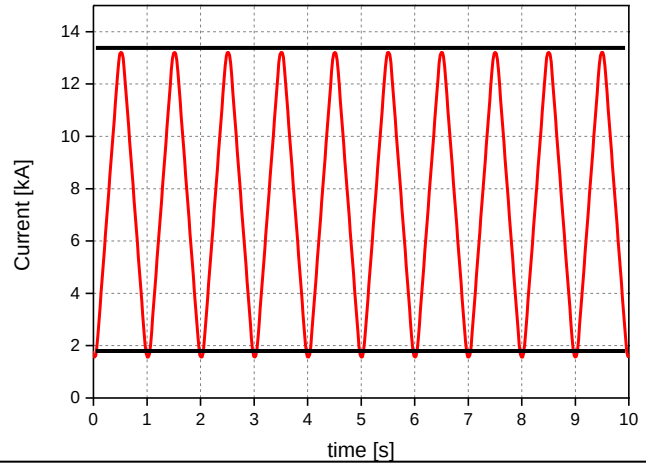


$q_h = 4.2 \pm 0.5$ J

$q_e = 6.0 \pm 0.2$ J·s

AC losses





B_{max}

B_{min} = 0.23 T

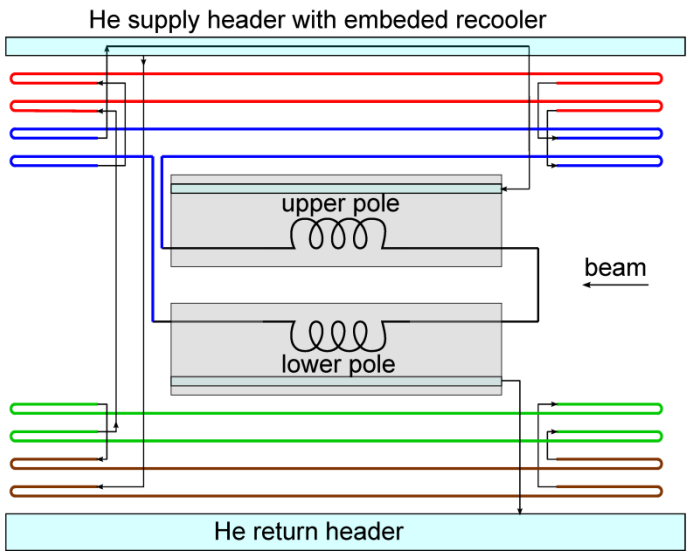
<u>Triangular cycle</u>:
B_{max} = 1.9 T
f = 1 Hz

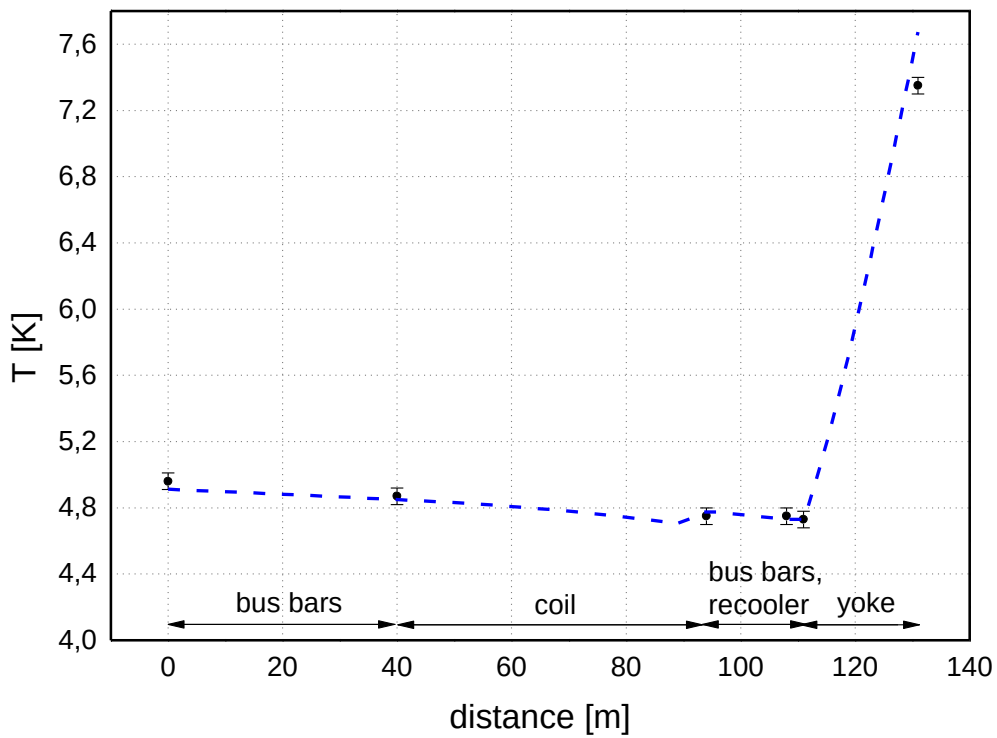
VI method: 49 ± 5 W
calorimetric: 41 ± 4 W

<u>static losses:</u>

12 – 14 W
caused by anty-cryostat
and by optical windows

Temperature profile and mass flow rates





dipole:

input bus bars	40 m
coil	54 m
output bus bar	14 m
inner diameter	4.7 mm

mass flow rate: 1.9 – 1.6 g/s

<u>calculated temperature profile</u>:

for P_{in} = 1.83 bar, P_{out} = 1.40 bar, x_{in} = 0.1

Q_{stat} = 12 W, Q_{dyn} = 45 W (60% in the yoke)

m = 1.61 g/s (1.57 ± 0.2 g/s measured)

Conclusions

- the first of series dipole magnet for the SIS100 synchrotron was build and is being tested at the prototype test facility at GSI
- The nominal field of 1.9 T was reached after one training quench
- The magnet was tested in AC mode including continuous cycling at 1 Hz repetition frequency
- the maximal dynamic heat release is 45 ± 4 W
- the mass flow rates under testing conditions vary between1.9 g/s without current and 1.6 g/s in the triangular cycle
- the measurements will be continued in the next cold runs