



SIS 300 R&D activities at GSI

H.Müller, GSI

Outline



- SIS 300 Parameters
- Model Magnets
- Wire R&D
- Cable R&D
- Summary

SIS 300 Dipole Requirements



	Number of Magnets	Usable Aperture (mm)	Eff. Magnet Length (m)	Max. Field	Max. Ramprate
SIS 300					
Dipoles (curved, R= 66.7 m)	48/12	86 (circular) (coil inner diameter: 100mm)	7.757 / 3.879	4.5 T	1 T/s

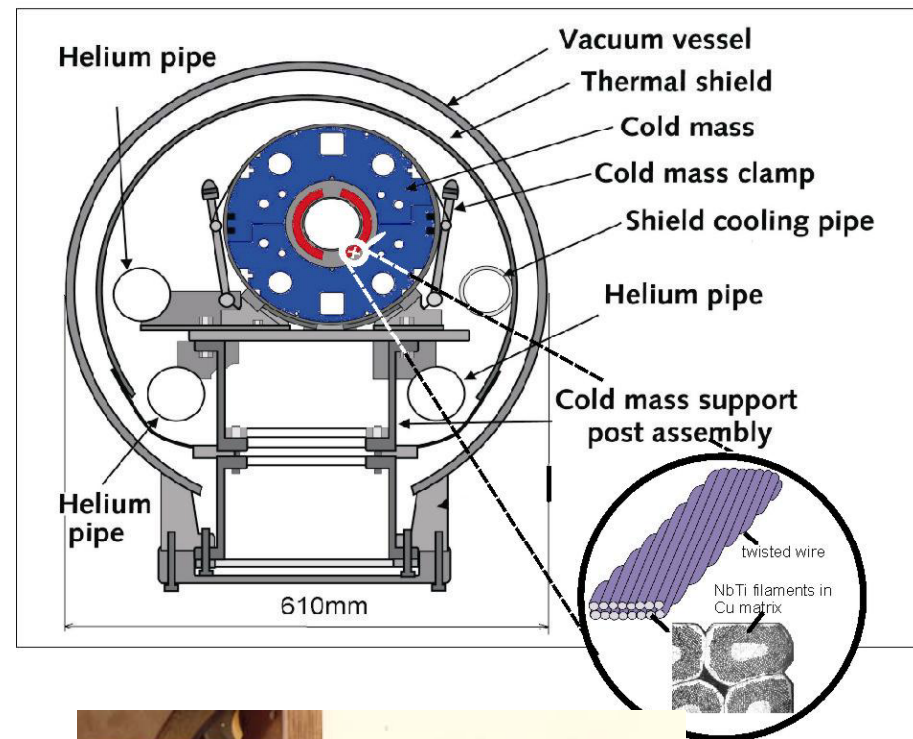
Operation modes

	rigidity (dipole field)	ramp rate	Flat Top time
RIB-operation Stretcher mode	64 Tm (0.96 T) 27 Tm (0.40 T)		
CBM-operation acceleration mode	90 Tm (1.35 T)-300 Tm (4.5 T) 90 Tm (1.35 T)-300 Tm (4.5 T)	1 T/s 1 T/s	10 s 100 s

SIS 200

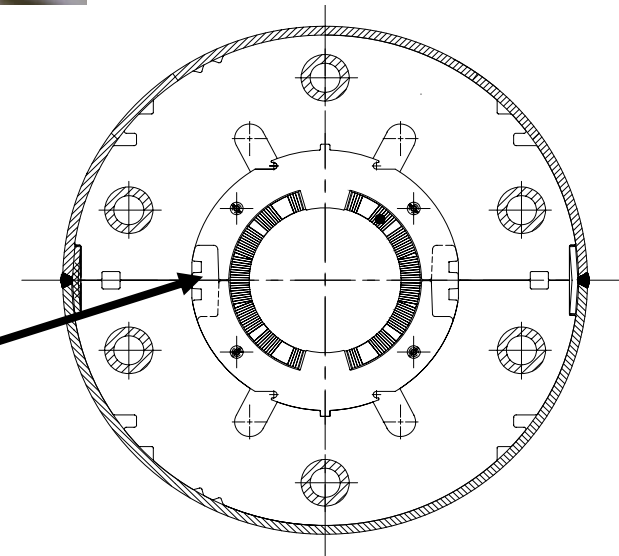
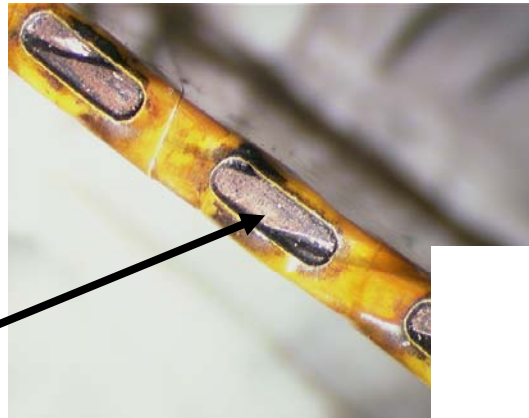
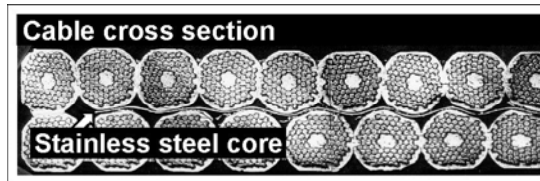


- RHIC dipole
- Collaboration with BNL
- Coil dominated: $\cos\theta$
- Maximum field: 3.5 T \Rightarrow 4 T
- Ramp rate: 70 mT/s \Rightarrow 1 T/s !!!
- Supercond. Rutherford cable
- One-phase helium cooling



SIS 200: R&D goals for GSI 001

- Reduce the effects due to the high ramp rate:
 - lower loss in wire, cable (core) and iron
 - better AC field quality
- Improve the cooling of the Rutherford cable
 - open Kapton insulation with laser cut holes
- Use collars to ensure long-term mechanical stability



Loss Formulas



Loss powers in Conductor
[W/m³]

Filament
hysteresis

$$P_h = \lambda_w \lambda_c \lambda_f \frac{2}{3\pi} J_c(B) d_f \dot{B}$$

→ reduce d_f

interfilament
coupling

$$P_f = \lambda_w \lambda_c \frac{\dot{B}^2}{\rho_t(B)} \left(\frac{p_w}{2\pi} \right)^2$$

→ reduce p_w , enhance ρ_t

interstrand
coupling

$$P_{tc} = \frac{\lambda_c}{120} \cdot \frac{\dot{B}_t}{R_c} \cdot p \cdot N(N-1) \cdot \frac{c}{b}$$

→ reduce R_c (core)
reduce R_a

$$P_{ta} = \frac{\lambda_c}{3} \cdot \frac{\dot{B}_t}{R_a} \cdot p \cdot \frac{c}{b} \cdot \left(1 + \frac{1}{15} \cdot \frac{\dot{G}_t^2 c^2}{\dot{B}_t^2} \right)$$

(but still enable
current redistribution)

$$P_{pa} = \frac{\lambda_c}{8} \cdot \frac{\dot{B}_p^2}{R_a} \cdot p \cdot \frac{b}{c}$$

GSI 001: Means for Loss Reduction



RHIC dipole

Superconducting wire:

NbTi-Cu (1:2.25)
filament diameter 6 mm
twist pitch 13 mm
no coating

Rutherford cable

no core

Coil

phenolic spacer
Cu wedges

Yoke

Hc= 145 A/m
6.35 mm laminations

RHIC type dipole GSI 001

Superconducting wire:

NbTi-Cu (1:2.25)
filament diameter 6 mm
twist pitch 4 mm
Stabrite coating

Rutherford cable

2 x 25 μ m stain-
less steel core
open insulation

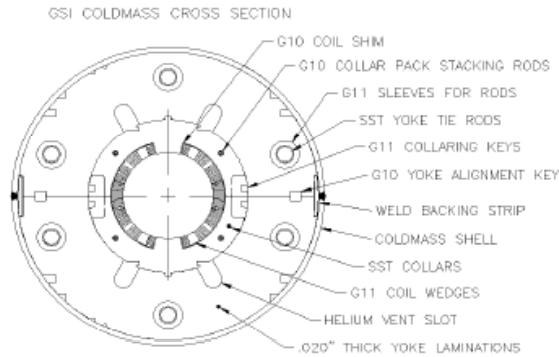
Coil

stainless steel collar (G11 keys)
G11 wedges

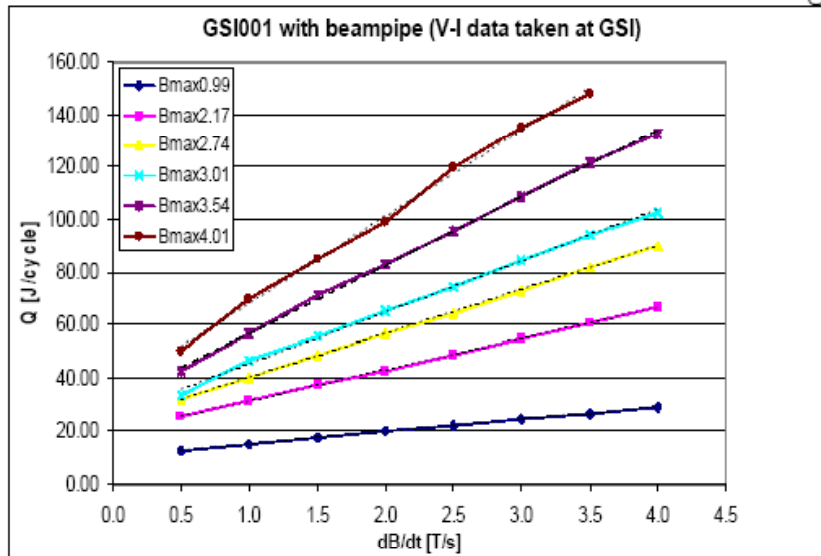
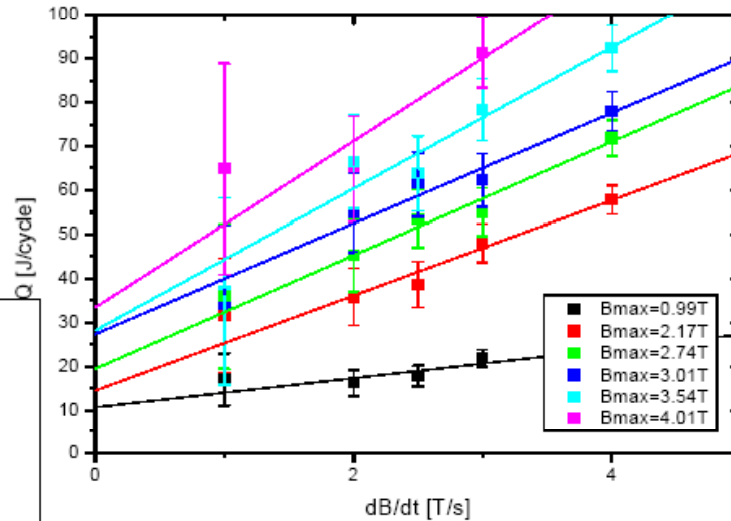
Yoke

Hc= 33 A/m, 3.5% Silicon
0.5 mm laminations, glued

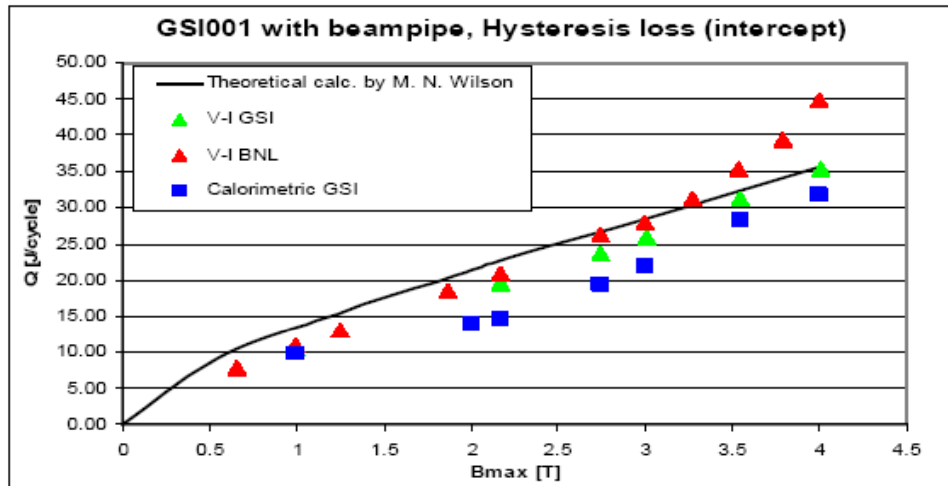
GSI 001:AC-Loss Measurements



GSI001 with beampipe (calorimetric data taken at GSI)



GSI 001: AC-Loss Measurements



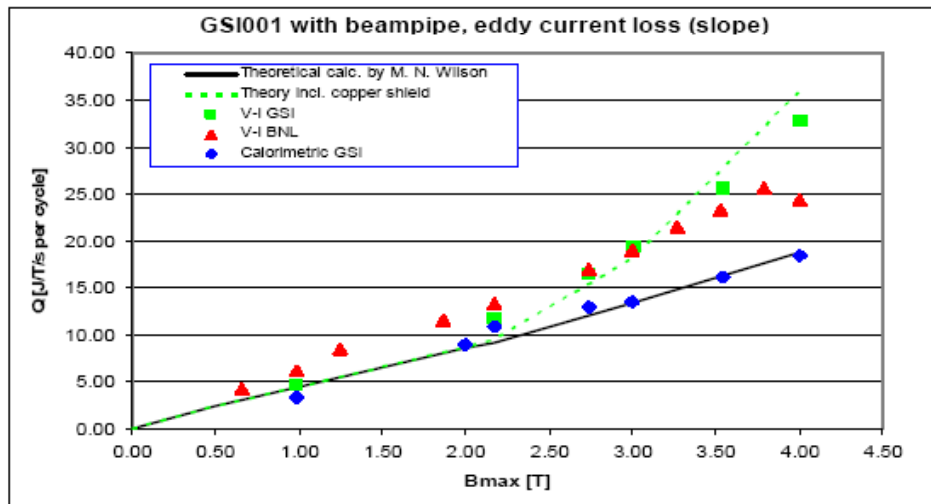
Parameters used for calculation:

$$\rho_{et}(B) = 1.24 \times 10^{-10} + 0.9 \times 10^{-10} B$$

with ρ_{et} in Ωm and B in Tesla.

$$R_c = 62.5 \text{ m}\Omega$$

$$R_a = 64 \mu\Omega$$



Coil loss (triangular cycle)	[%]
Transverse crossover loss (R_c)	0.2
Transverse adjacent loss (R_a)	12.0
Parallel loss (R_a)	0.2
Filament coupling loss (Cu-matrix)	11.9
Hysteresis loss ($d_{fil} = 6 \mu\text{m}$)	69.7

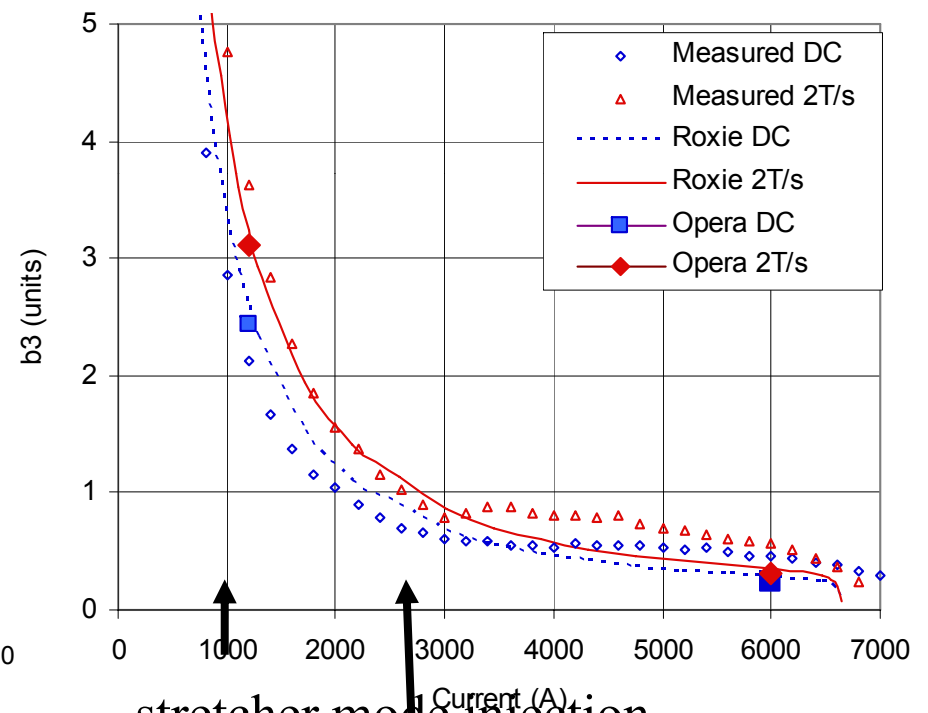
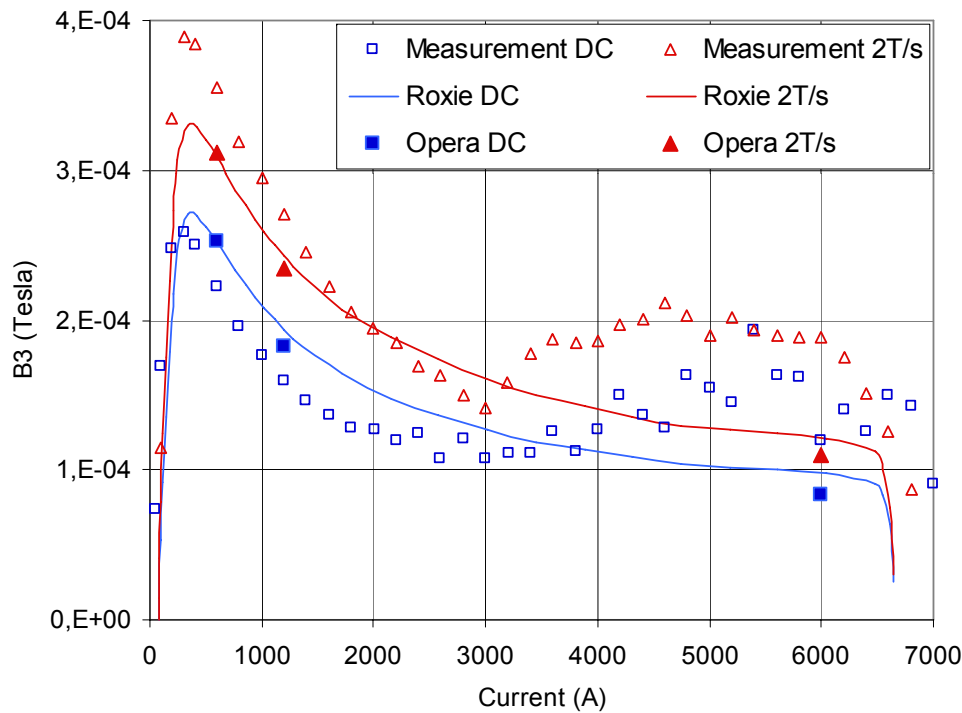
GSI 001: Field quality



Sextupole B3 / b3 (half difference between up and down)

in Tesla @ 25 mm radius

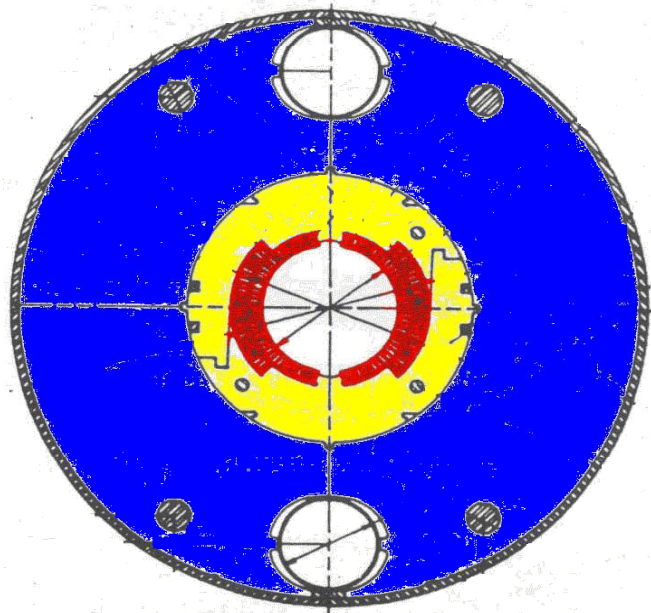
in units @ 25 mm radius (1 unit = 10^{-4})



stretcher mode injection

pulsed mode injection

courtesy of M. Wilson, B. Auchmann, S. Russenschuck



Goal: 6T, 1T/s

UNK Dipole

- 2 layer $\cos\theta$ design
- 80mm bore \Rightarrow 100 mm
- 5.11 T \Rightarrow 6 T
- 0.11 T/s \Rightarrow 1 T/s

Study by Technopark Kurchatov
(Kurchatov Institut Moscow,
IHEP, Protvino): **Such a magnet is
feasible, but needs a lot of R&D !**

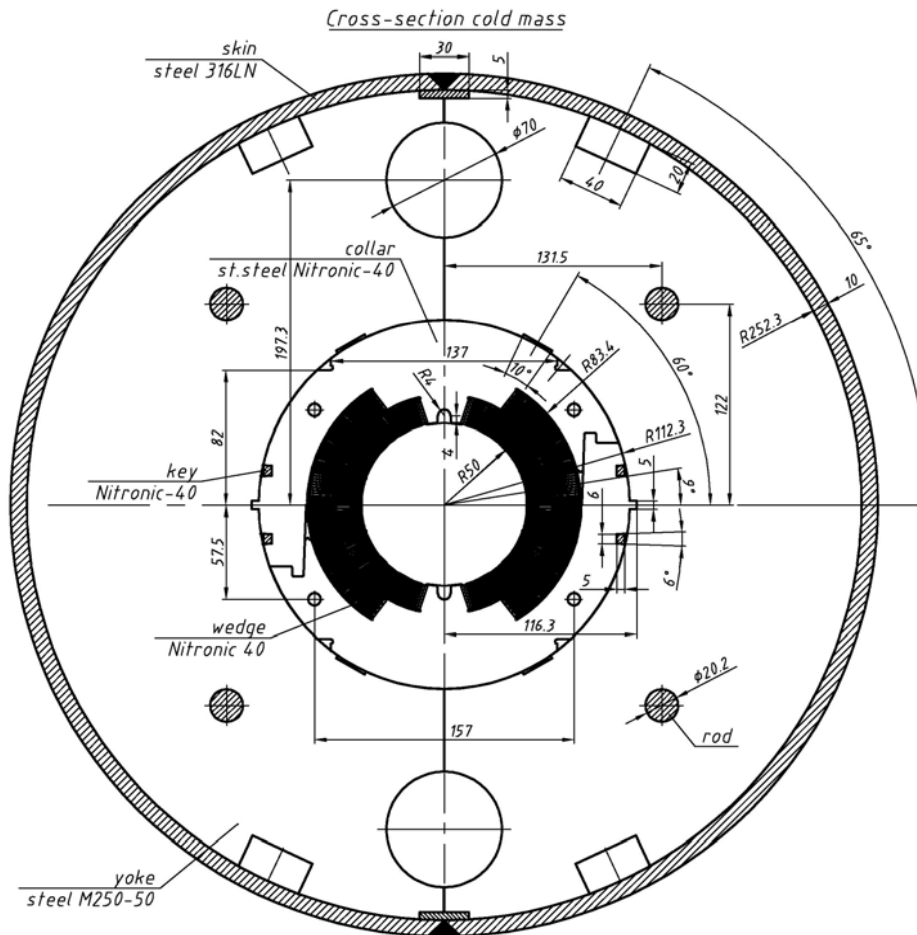
In order to reach 6 T central field with the desired 1 K temperature margin for the conductor, a wider conductor was required.

The dimensions of the CERN LHC dipole outer layer conductor(but with a core inserted for loss reduction) were chosen. The wire size was therefore increased from 0.65 mm to 0.825 mm.

To reduce filament hysteresis loss EAS had already started development of a 0.65 mm wire with 3.5 micron NbTi filaments, 1.8:1 Cu/NbTi ratio for SIS 200.

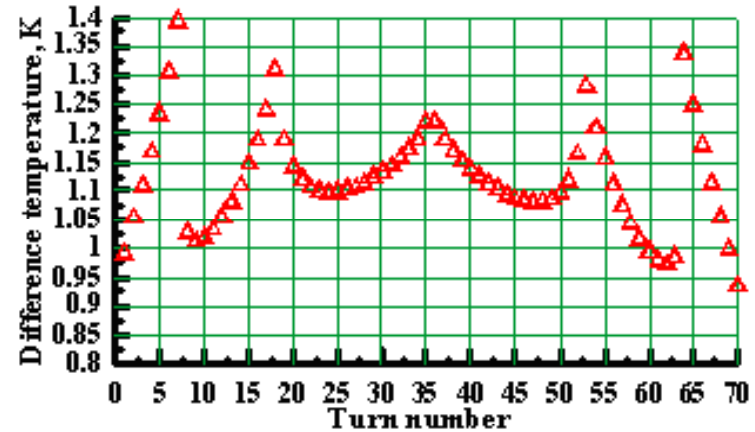
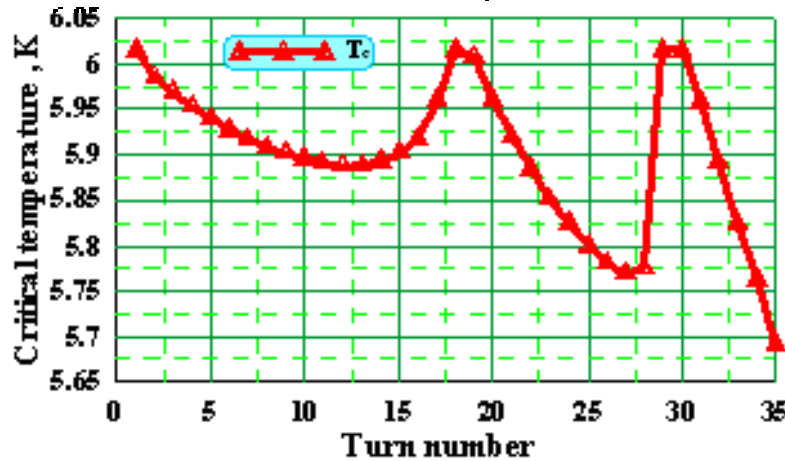
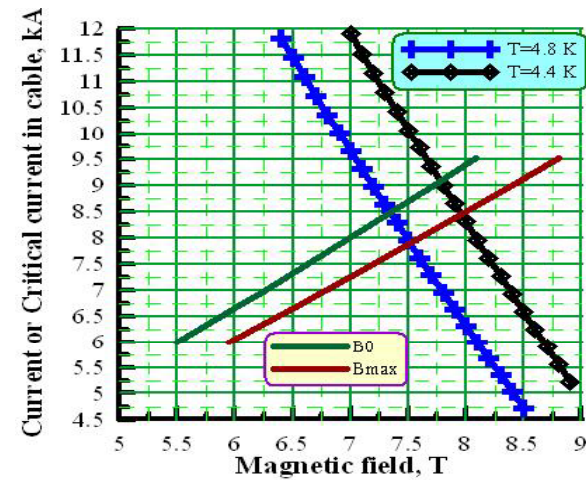
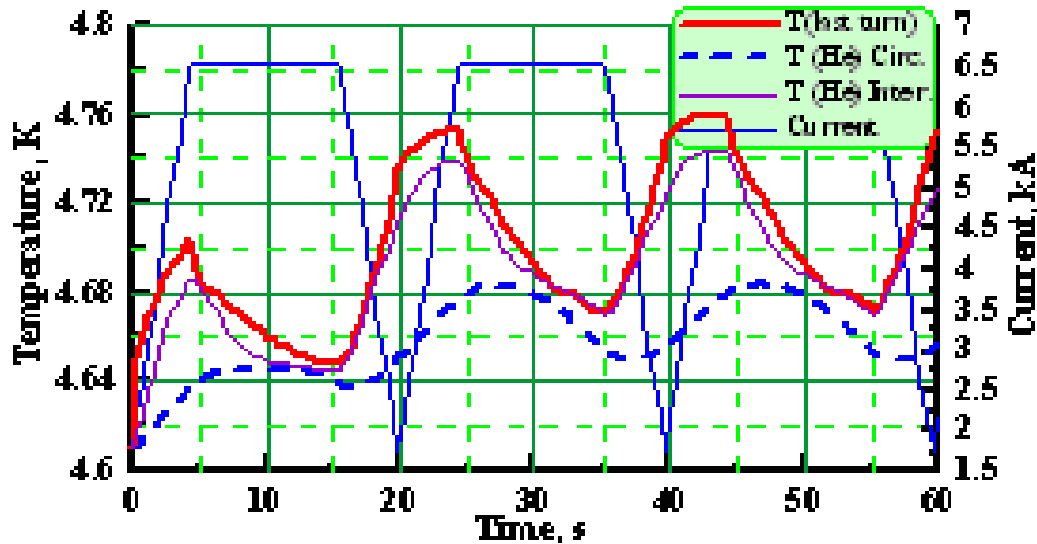
Order has been changed to 0.825 mm wire with 4.3 micron filaments for SIS 300.

IHEP 6T Dipole



- Central field: 6 T
- Ramp rate: 1 T/s
- Length: 1 m
- Inner coil diameter: 100 mm
- Two layers: inner: 4 blocks/outer: 3 blocks
- Cooling: supercritical helium
- Interlayer cooling channel
- No holes in Kapton
- Optimized end parts
- Appropriate Ra of about $200 \mu\Omega$
- Ready at the end of 2008

IHEP 6T dipole: thermal analysis



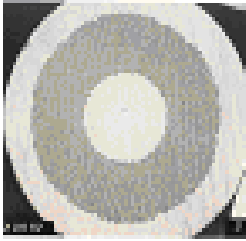
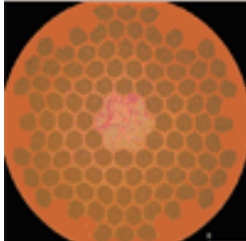
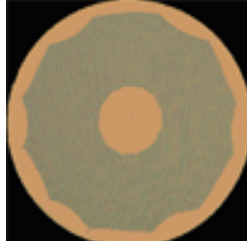
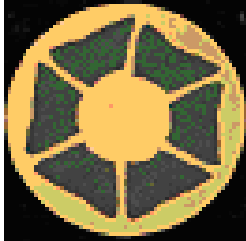

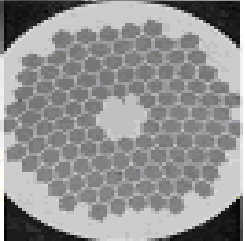
SIS 300 lattice change



- To increase the acceptance a curved dipole option was chosen
- Change to FODO lattice
- Prototype development by INFN

Wire Development, Tested Wires



Wire ID	RHIC	2A12	3N7	K2 001T4	G2 001T6	B944-2 (SSC)
						
Wire diam.	0.641 mm	0.53 mm	0.42 mm	0.665 mm	0.845 mm	0.648 mm
Jct (5 T, 4.2 K) [A/mm ²]	3029	2558	2831	2759	2773	2511
Ratio Jcm/Jct	0.92	1.40	0.94	1.15	1.10	1.23
Filament diam.	5.71 μm	3.4 μm	3.4 μm	3.4 μm	4.3 μm	2.6 μm
ρ_{et} (10 ⁻¹⁰ Ω-m)	(1.24+0.9B)			(0.58+0.89B)	(0.82+0.46B)	(4.15+1.9B)
RRR	198			173	166	102
	single stacked	double stacked	single stacked	double stacked	double stacked	triple extruded, double stacked

CuMn-wire: INTAS Project



Research and development of new design superconducting NbTi wire with low AC losses intended for use in magnet systems of SIS 100 and SIS 300 synchrotrons of FAIR Accelerator Facility

Open Questions to be resolved

- single stacking vs. double stacking (Filament distortion)
- minimum twist pitch before degradation of J_c starts
- optimum heat treatment (RRR)

INTAS Wires and Cables



Two Approaches: Hot Double Stacking
Hot Single Stacking + Cold Bonding

Produced will be the following lengths

type	ca. length
1. Wire with diameter of 0.5 mm	400 m
2. Wire with diameter of 0.825 mm	250 m
3. Wire with diameter of 0.8 mm	250 m
4. Cable for SIS 100 2L coil (OD of CuNi-tube: 5.0 mm)	6 m
5. Cable for SIS 100 SL coil (OD of CuNi-tube: 5.7 mm)	6 m

Actual Status: Wire production nearly finished
Measurements has started
Cable production has started

Cable: R_a and R_c



High R_a and R_c :

- low losses and no influence on field quality
- without core: $R_a = 8R_c$
- reduced stability due to reduced current redistribution

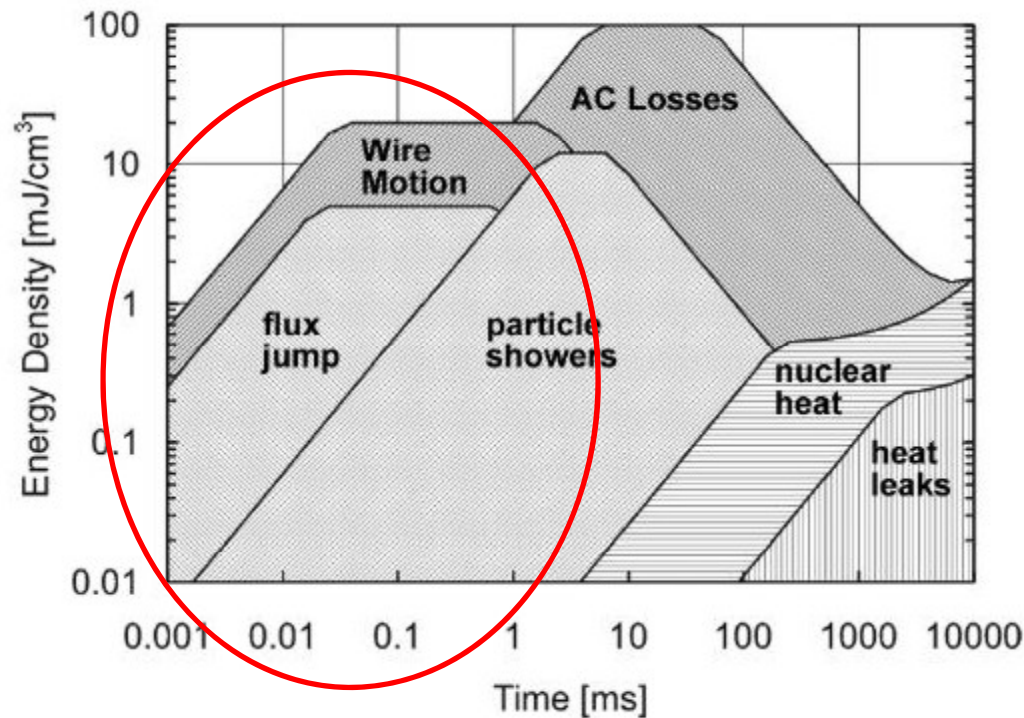
Cored cable and strands with SnAg coating

- High R_c ($m\Omega$) → significant loss reduction
- R_a → can be adjusted so that losses and influence on field quality is reduced but current redistribution is still possible

R&D to find optimum R_a

- MQE-measurements for stability
- Heat treatment and curing cycles of coated cables

Cable Stability:MQE



Disturbance energy spectra for LTS magnets

Typical disturbances of interest this research: Wire motion.
(Training quenches)

Disturbance duration < 1 ms.
Affected volume: 1 strand.

Luca Bottura in (Iwasa, Y, "Stability and protection of superconducting magnets – a discussion", IEEE. Trans. Appl. Supercond., Vol. 15, 2, pp 1615.)

20 mJ/cm³

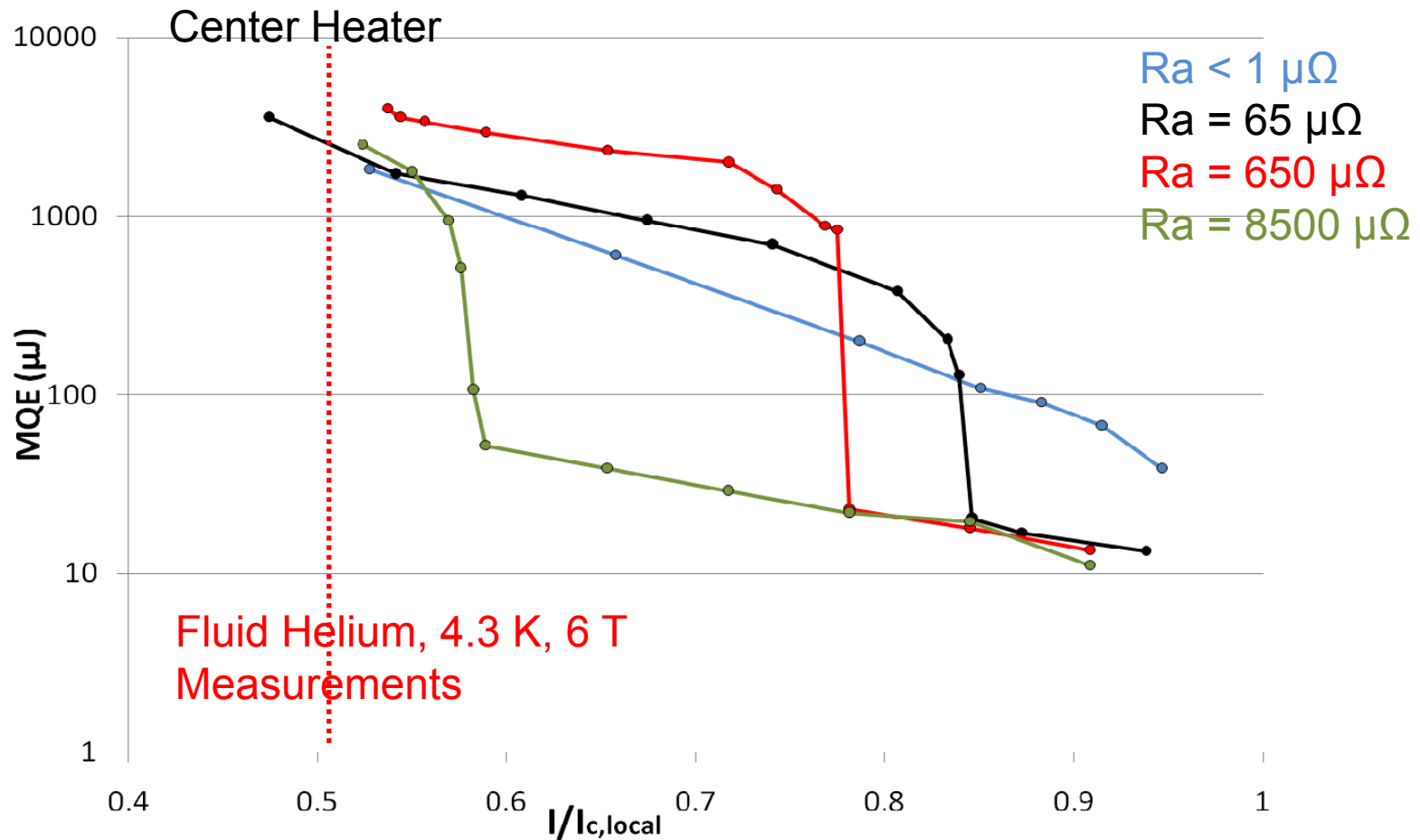
Normally half a twist pitch can move

Total energy dissipated

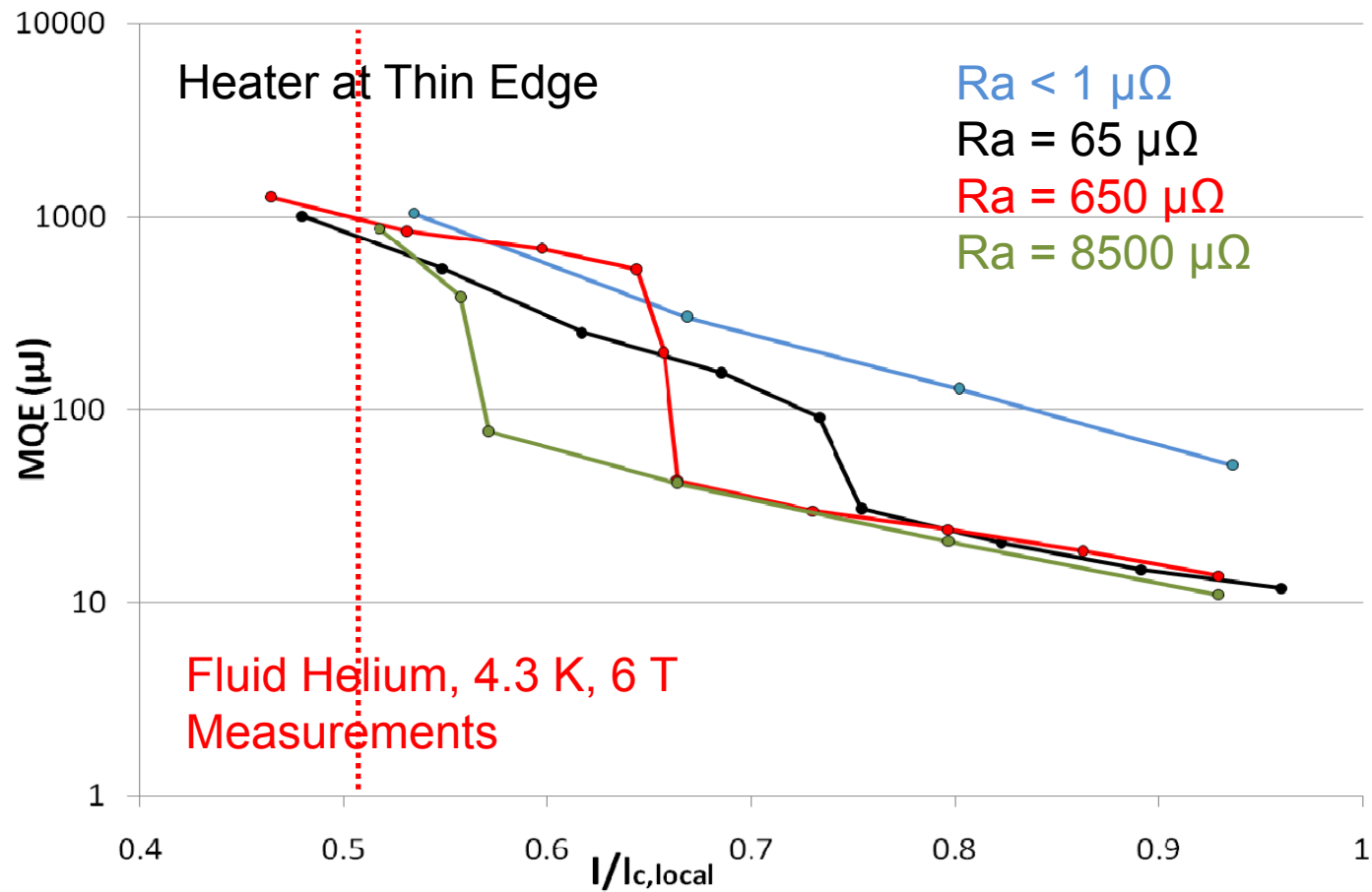
LHC type I $\approx 100 \mu\text{J}$

LHC type II (SIS 300) $\approx 50 \mu\text{J}$

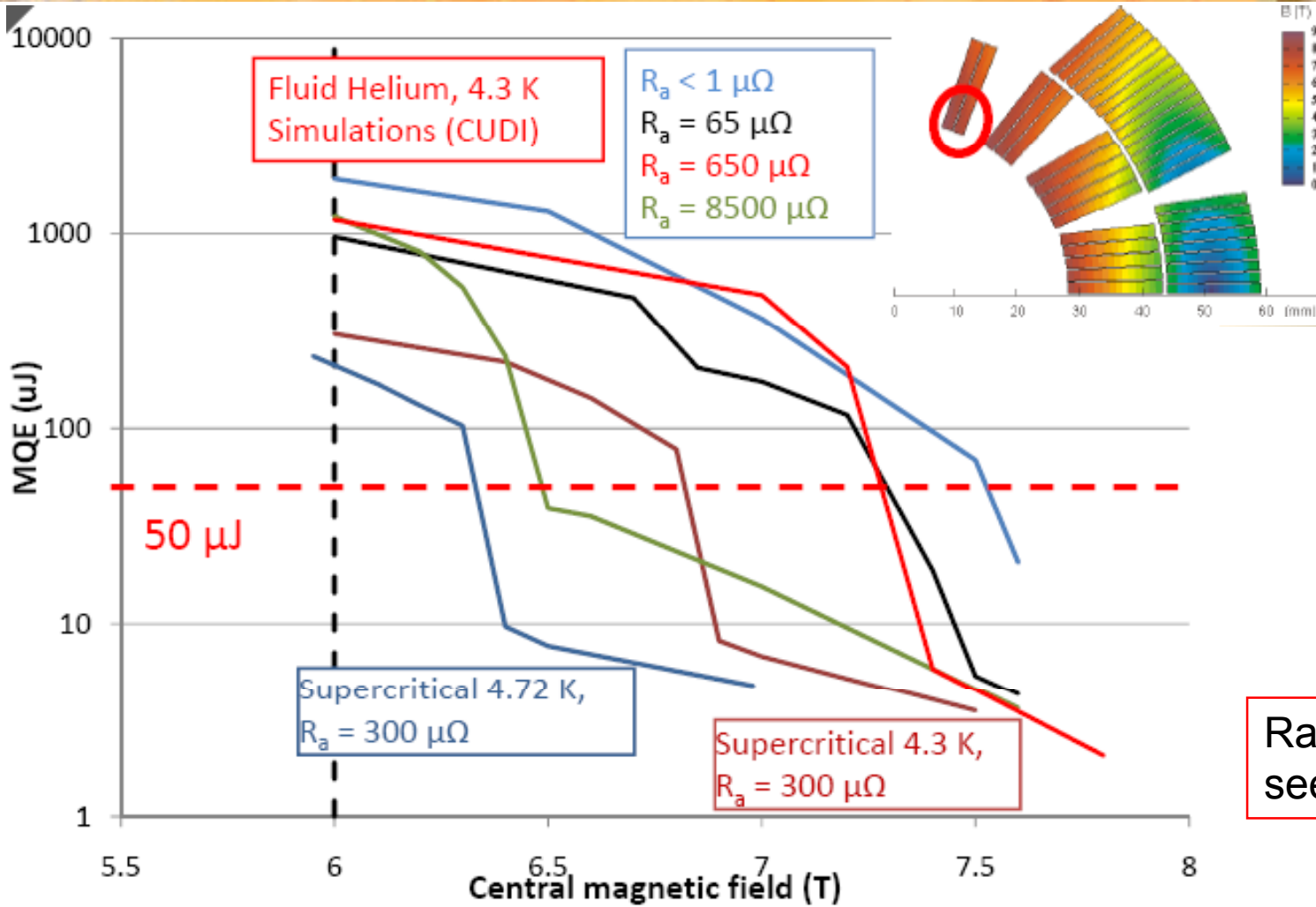
Cable Stability: MQE



Cable Stability: MQE



MQE: Supercritical Helium



$R_a = 200-300 \mu\Omega$
seems ok

Ra-Measurements



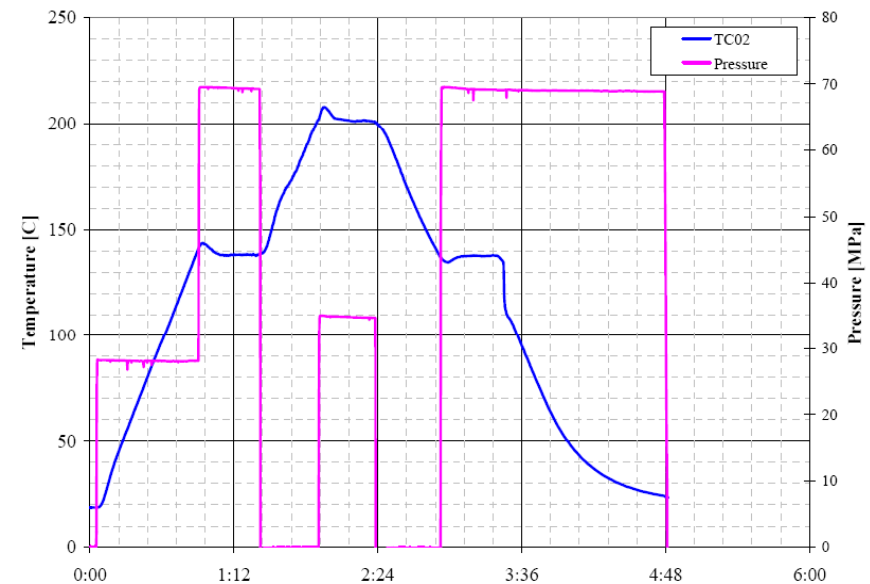
Cure Cycle



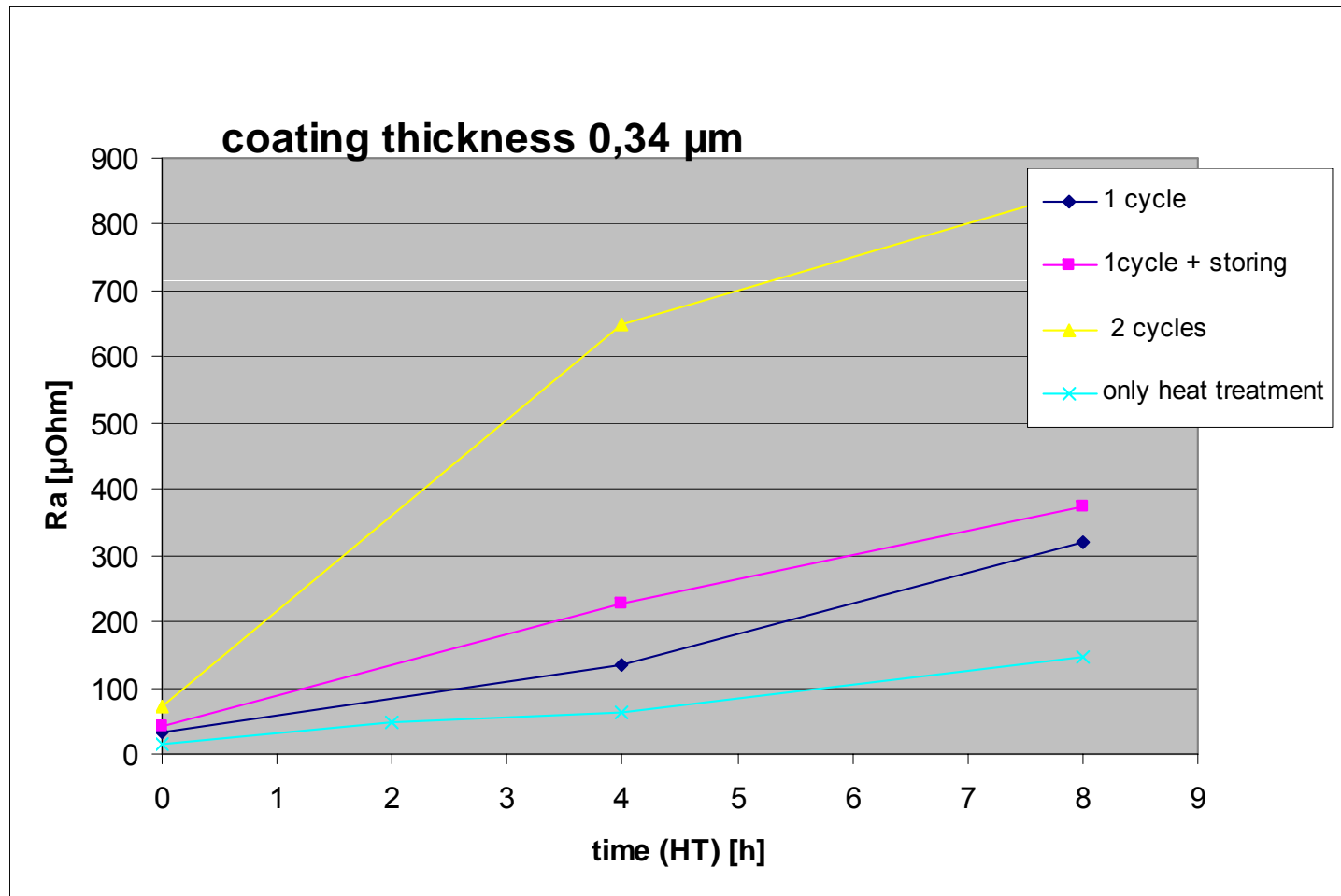
For the measurements described below, a RHIC-type cycle labeled GSI-II was used:

1. At 20°C apply 28 MPa
2. 20°C to 135°C ramp up in 50 min under 28 MPa,
3. At 135°C, apply pressure of 70 MPa and hold 30 min
4. Release all pressure and ramp up to 195°C in 30 min.
5. Apply 35 MPa and hold for 30 min.
6. Release pressure and ramp down to 135°C in 30 min.
7. Re-apply 70 MPa and hold for 30 min.
8. Cool down with 70 MPa.

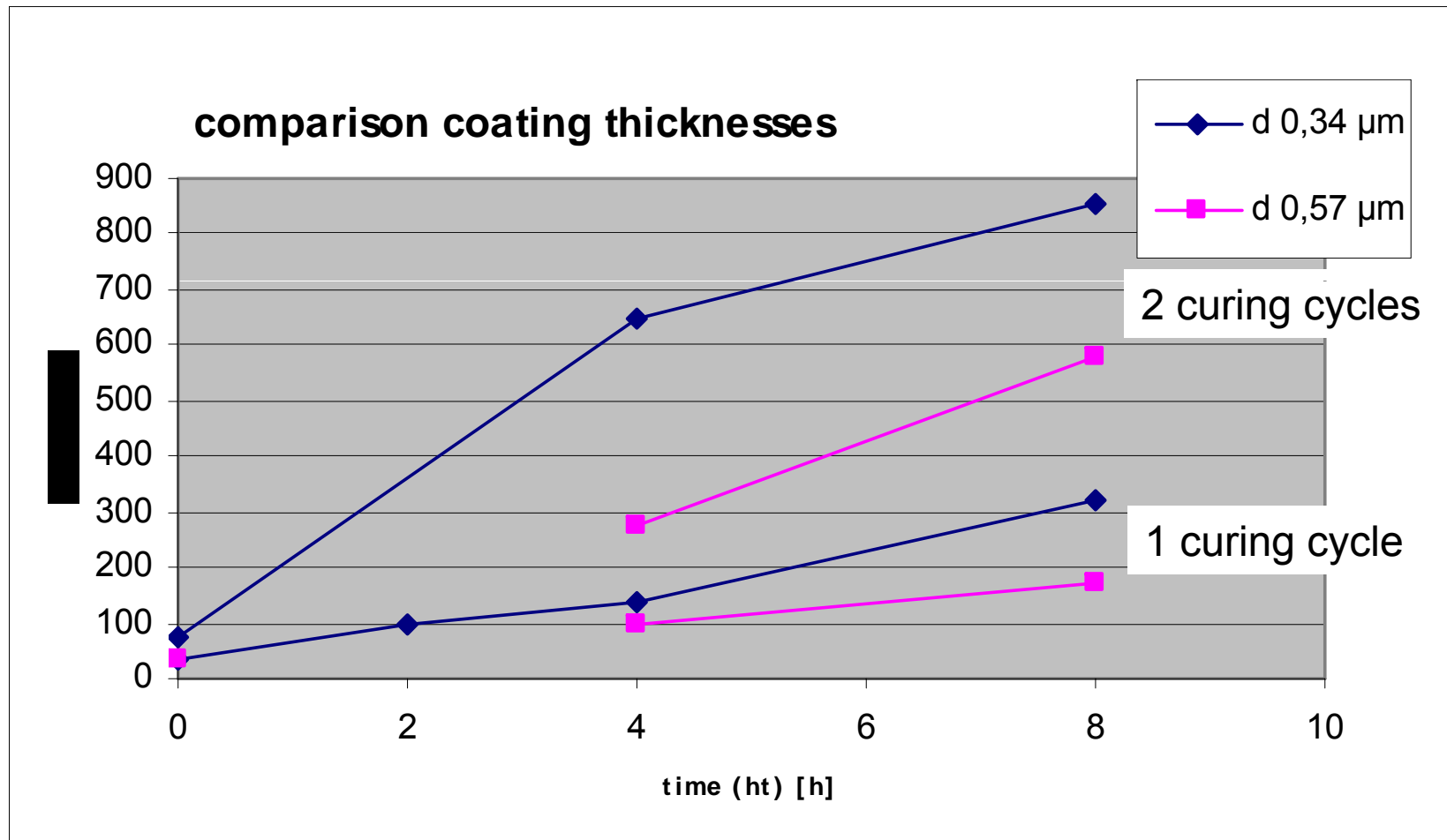
A typical cure cycle is shown in Fig. 2.



Ra: Heat Treatment and Cure Cycle

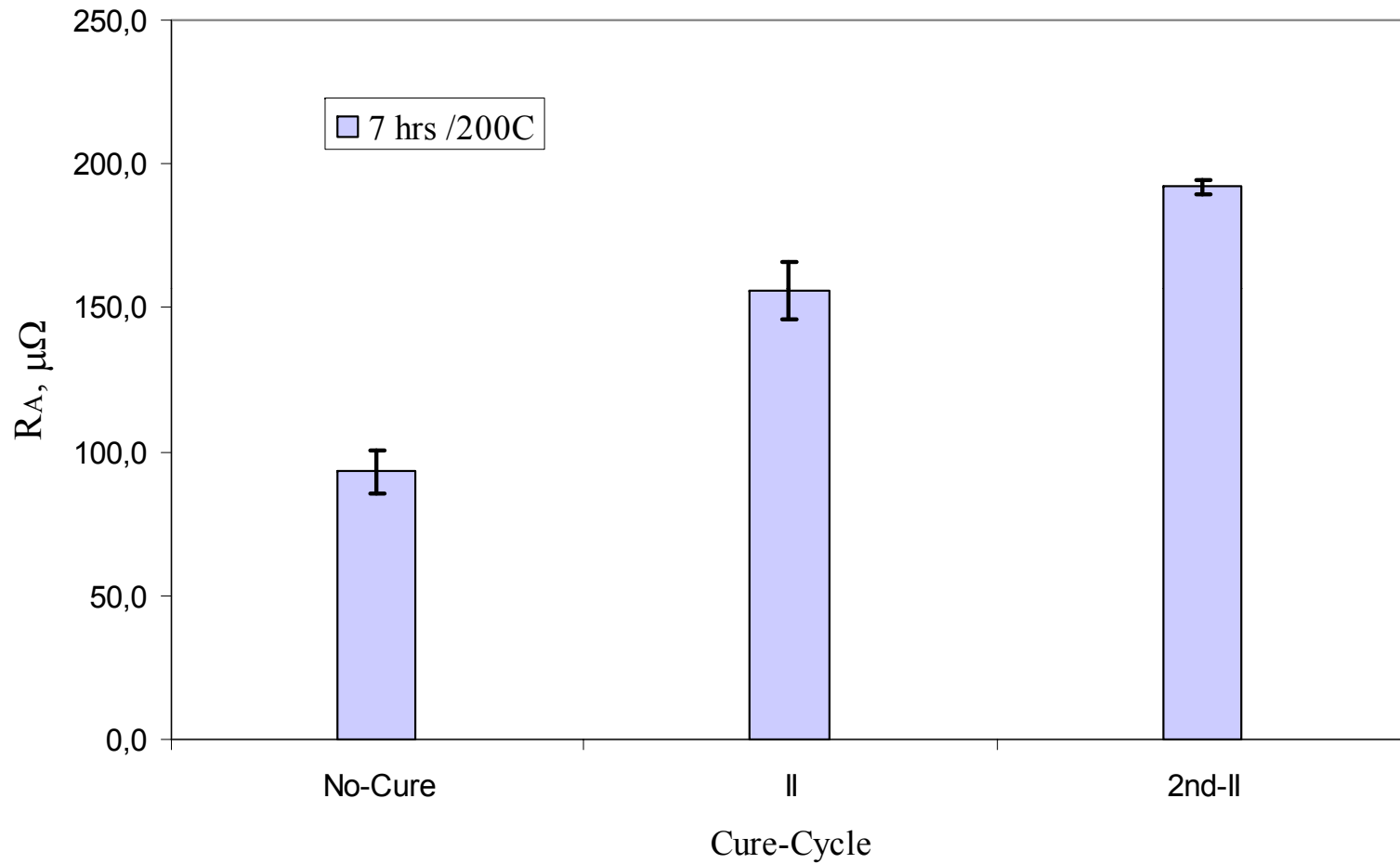


Ra: Coating thickness



Ra: HT for IHEP model dipole

7 hrs /200C



Summary



- SIS 200: Model magnet GSI 001 was built and tested with regards to AC-losses and field quality; the magnet could be ramped up to 4T 4T/s.
- 1m model dipole for SIS 300 doublet lattice was designed and is built at IHEP. Tests of this magnet at GSI in 2009
- Wire R&D: Low loss wires with small filament diameter and reduced twist pitch were developed and used for different model magnets (SIS300 and SIS100)
- Cable R&D: Optimum Ra of 200 $\mu\Omega$ was chosen from MQE measurement results; Heat treatment and curing recipe was established to reach this value.

Thanks to



our colleagues at

BNL (P.Wanderer, A. Jain, A. Gosh, R.Soika)

IHEP (S. Kozub, L. Tkachenko, V.Zubko)

CERN (S. Russenschuck, B. Auchmann, A. Verweij.....)

Twente (A. den Ouden, G. Willering)

Bochvar Inst. (V. Pantsyrnyy,.....)

our consultant

M. Wilson

and INFN

Quench protection



The protection scheme of the SIS300 dipole string will be one of the following:

- dump resistors + cold diodes (on every magnet) + quench heaters (on every magnet) (Fig. 10)
- dump resistors + warm bypass (bypassing 2 to 4 dipoles) + quench heaters (on every magnet)

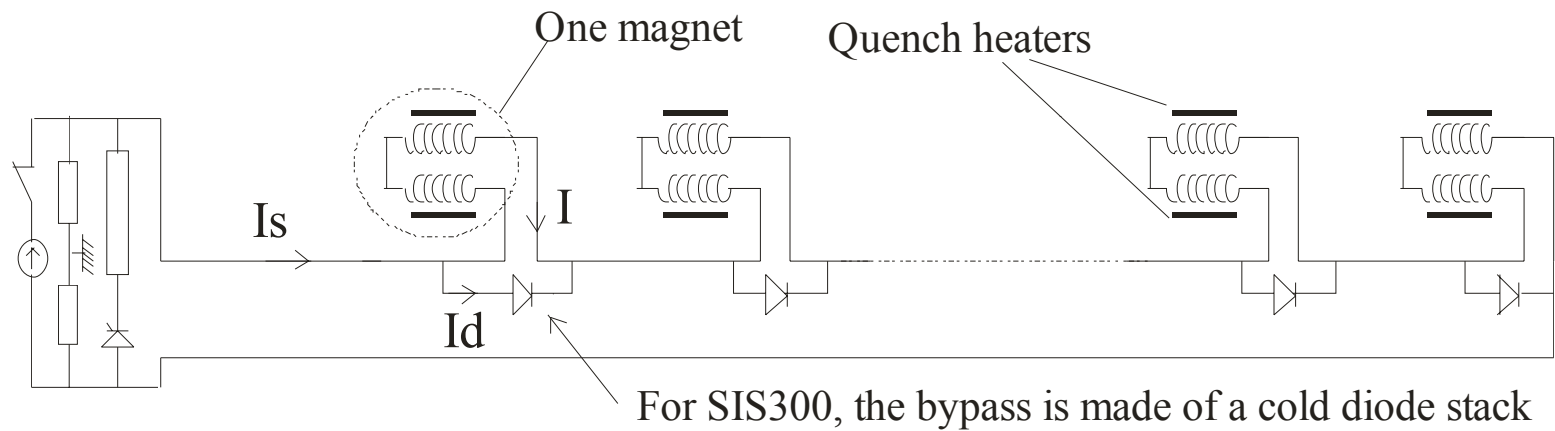


Fig. 9 Protection scheme with dump resistor, cold diodes and quench heaters.

Quench heaters



Calculations by D. Hagedorn:
 Quench heater should cover 12 turns

- Wires manufacturers give
 - $RRR = R_{300K} / R_{10K}$
- because of CuMn: $RRR_{wire} < RRR_{Cu}$
- we would like to have:
 - R_{10K} , R_{300K} , distance between Voltage taps
 - ρ_{CuMn_bulk} at 4, 77 and 300 K
- With this information, we reconstitute $R_{cable}(T)$

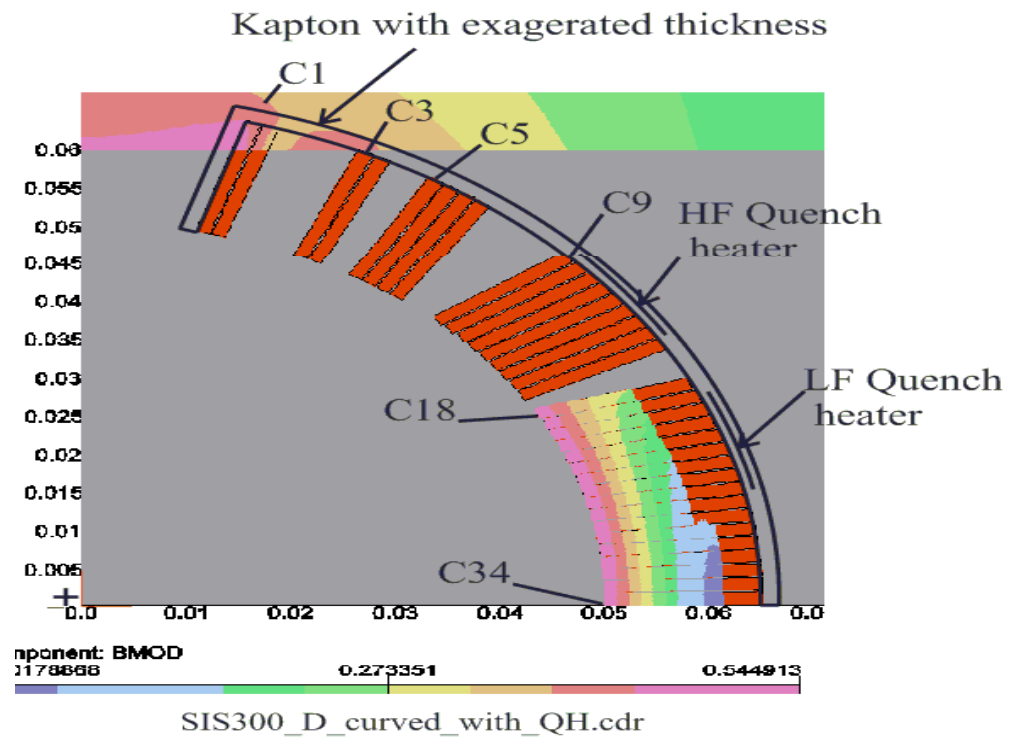


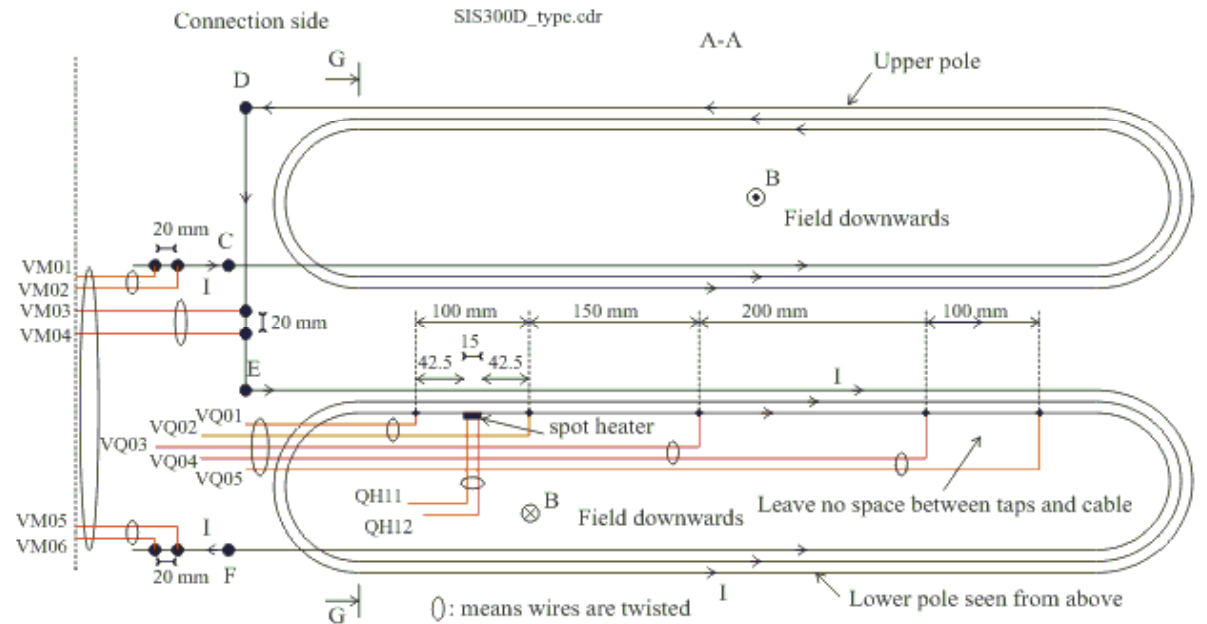
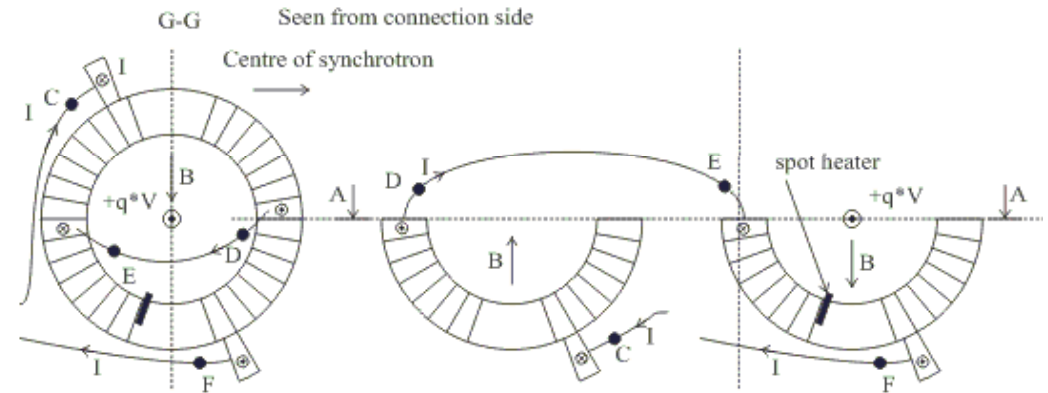
Fig. 12 Proposal to use LHC quench heaters in the 4.5T SIS300 dipole.

Instrumentation for Quench Studies



Quench Studies are needed to compare calculations for a magnet with CuMn wire to measurements.

This requires
 1 spot heater
 11 voltage taps



MQE Core-No Core

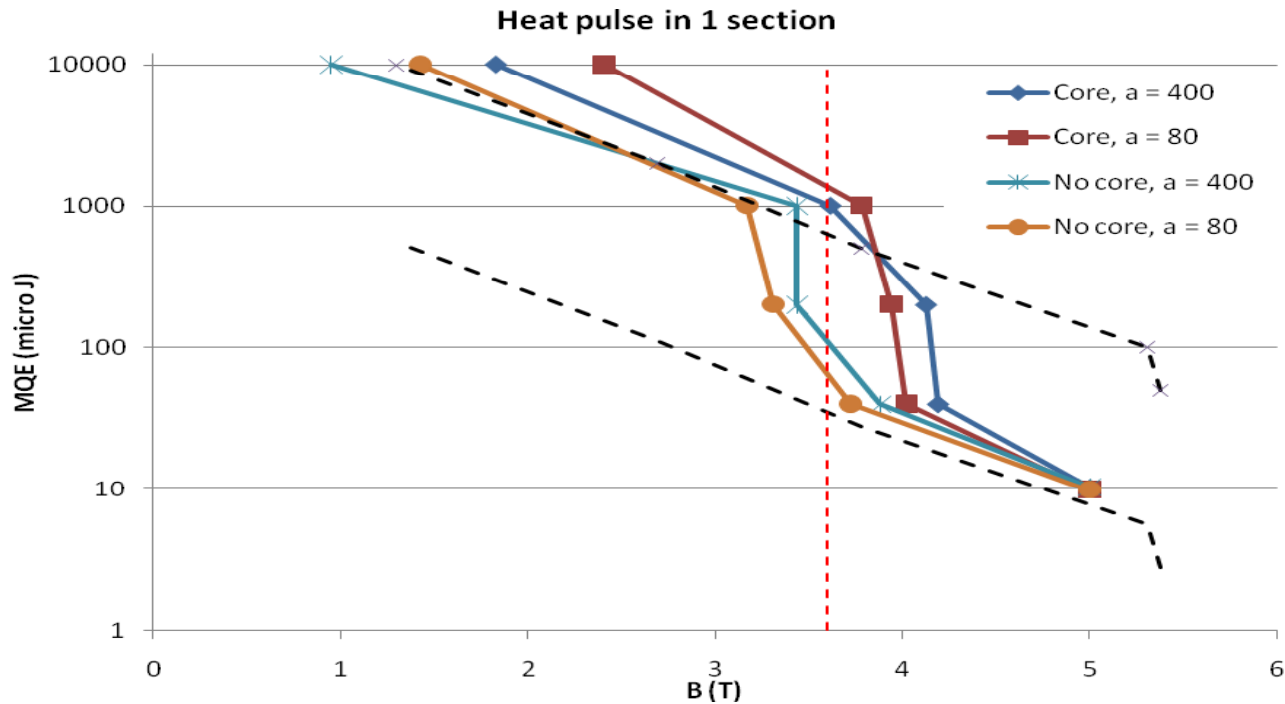


Core: $R_a=300 \mu\Omega$; $R_c=20 \text{ m}\Omega$

No Core: $R_a=10 \text{ m}\Omega$; $R_c=10 \text{ m}\Omega$

Interstrand thermal conductance: $h=a \cdot T^n$ with $n=1.67$

$a=400$ $a=80$



MQE Core-No Core

