BNG Industrial experience on Superconducting Undulators

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Short history of BNG in SC undulators

2007 ***Nb_3Sn short prototype built for KIT and tested at CERN***

2007 ***Collaboration with KIT on SCUs and SCU15 contract***

2008 ***SCU15 demonstrator***

2009 ***SCUW prototype: design and fabrication based on KIT concept with test by KIT***

2010 ***SCU15 1.5m long coils completed and tested by KIT at CERN***

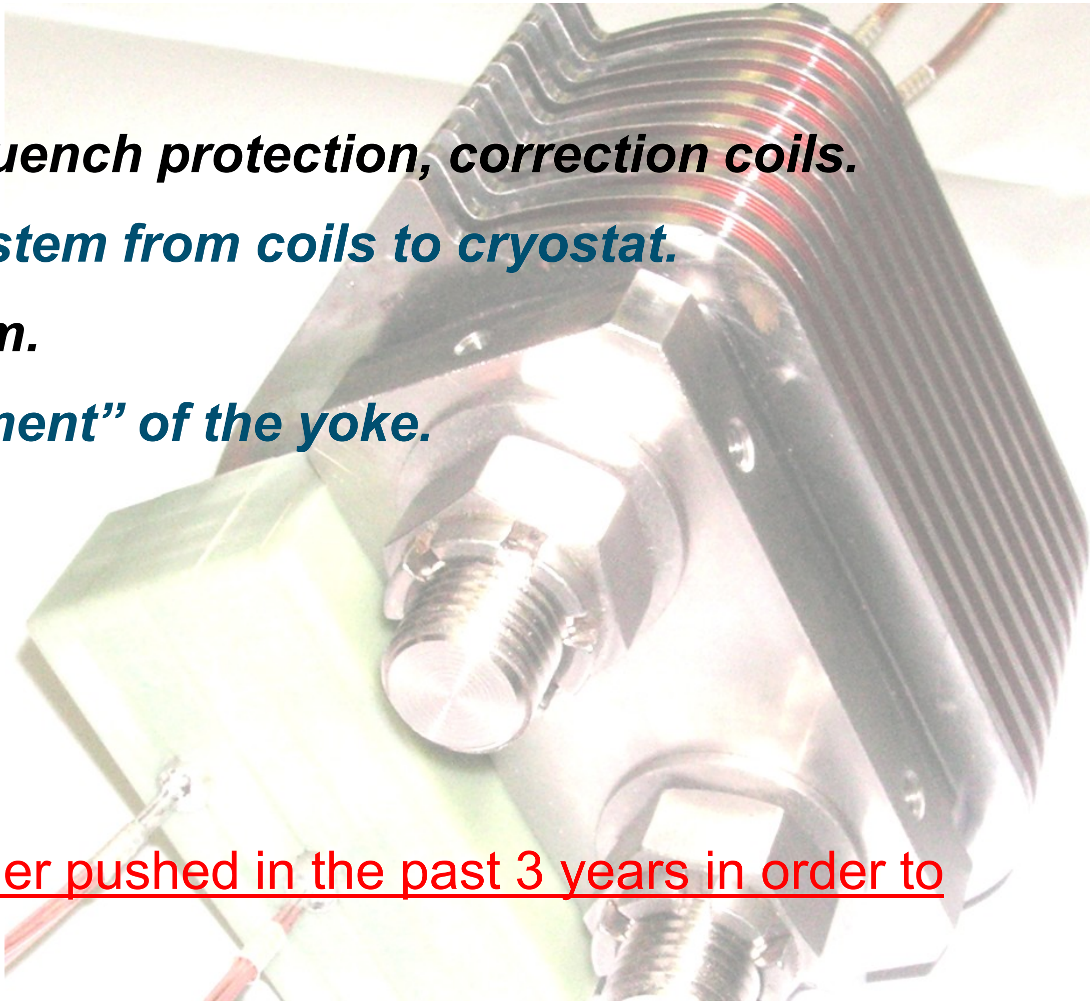
2010 ***First HTS SCU prototype: design and fabrication with test by KIT***

SCU15: 15mm period undulator

SCUW : tripling period 15mm/45mm switchable device undulator/wiggler

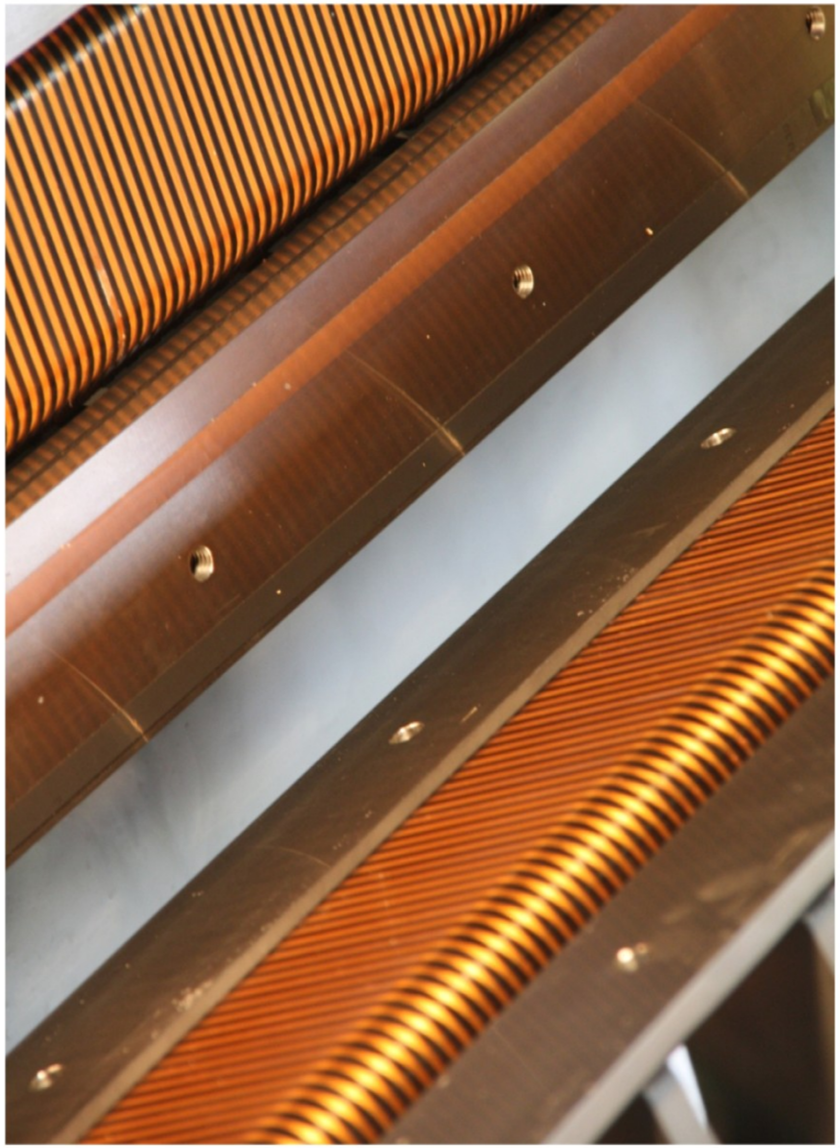
BNG knowhow on SCUs

- ***Magnetic design: coil configuration, quench protection, correction coils.***
- ***Mechanical design of the complete system from coils to cryostat.***
- ***Cryogenic design: cryogen free system.***
- ***Fabrication and high precision "alignment" of the yoke.***
- ***Winding process.***
- ***Vacuum-pressure impregnation.***
- ***Assembly of the complete system.***



Most of our existing knowhow had to be further pushed in the past 3 years in order to design and fabricate SCU15

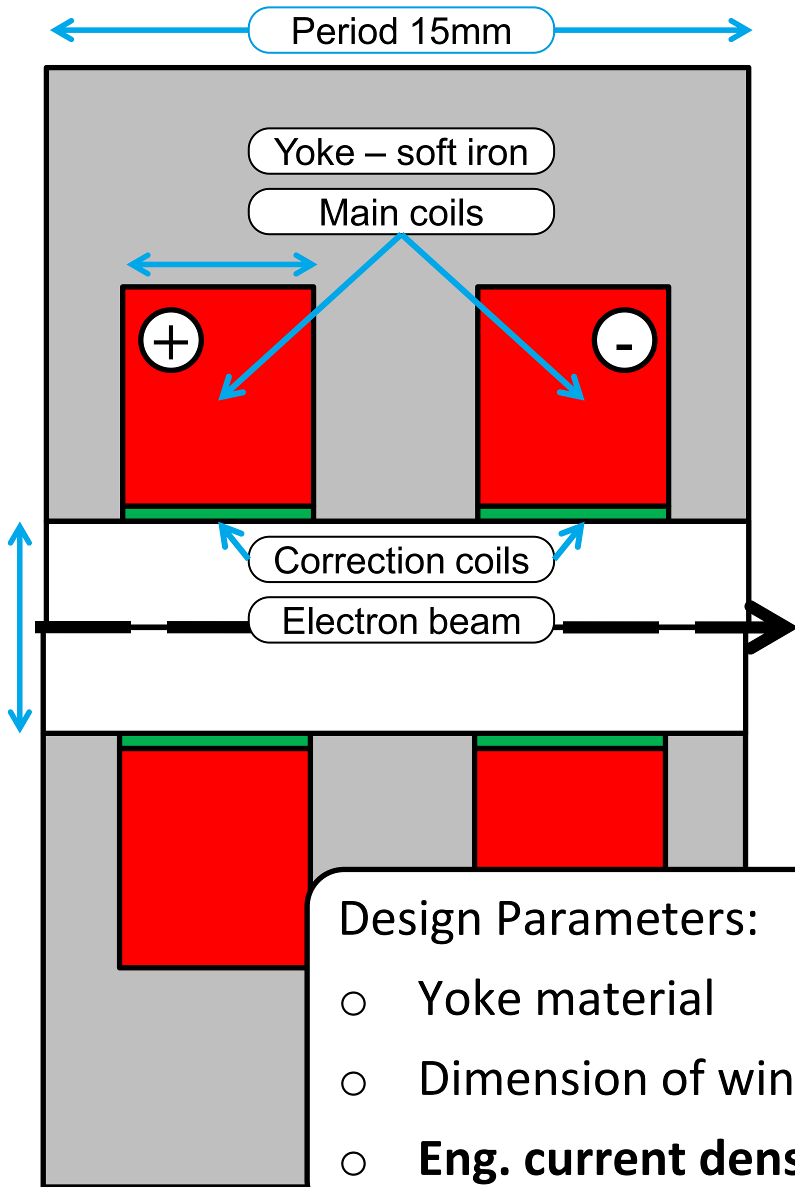
Specifications

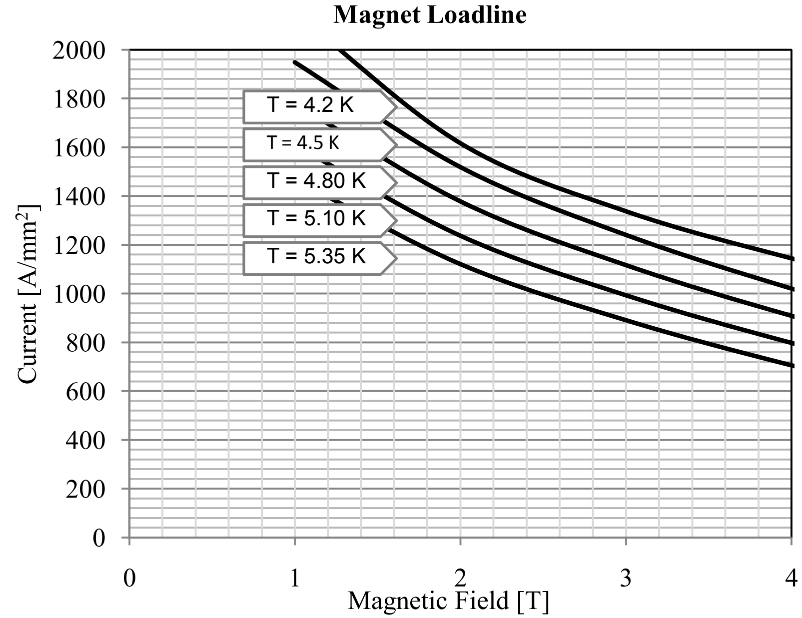


	Units	Value
Period length	mm	15
Number of full periods	-	100.5
Max field on axis with 8 mm magnetic gap	**T**	**0.77**
Max field in the coils	T	2.4
Minimum magnetic gap	mm	5.4
Operating magnetic gap	mm	8
Gap at beam injection	mm	16
K value at 5 mm gap	-	>2
Design beam heat load	**W**	**4**
Phase error r.m.s.	**°**	**3.5**

- High eng. Current density -> magnetic design
- Tolerate beam heat loads -> cryogenic design
- High mechanical accuracy -> fabrication technology

Design – Magnetic field calculation I



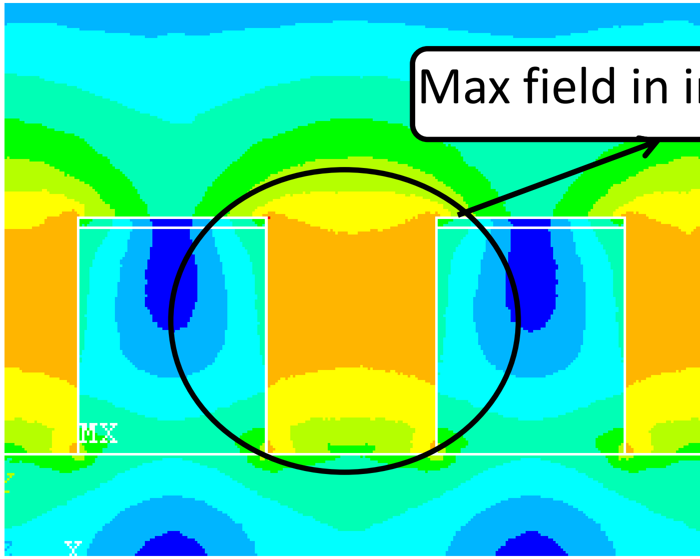


Material.. NbTi
Insulation.. varnish
Geometry.. rectangular
Height..0.34
Width (mm)...0,54
Design critical current density* (A/mm2).......................1000
Design operating temperature** (K)................................4,2
Design magnetic field (T)***...4
Cu/Sc ration...1.2-1.5
RRR...>60
Filament diameter (um)...<40
Twist pitch (mm)..<50

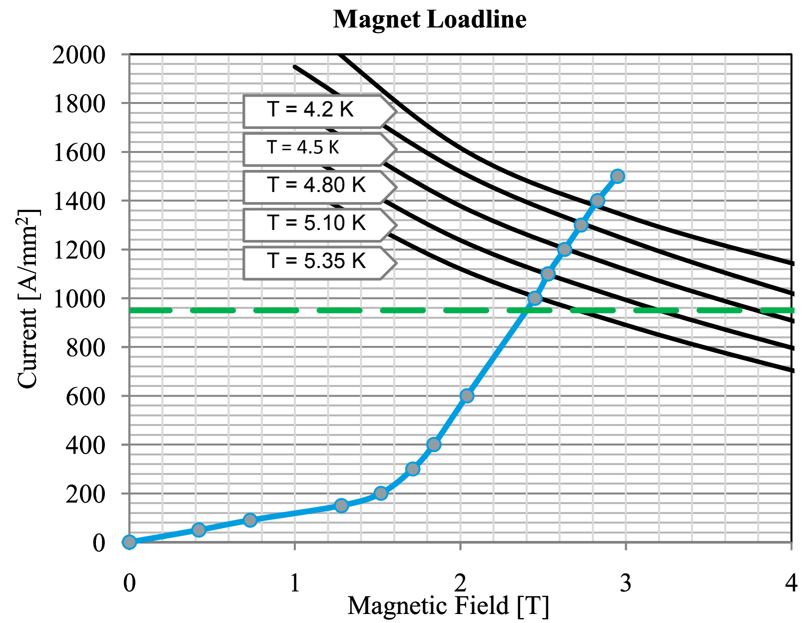
Design Parameters:

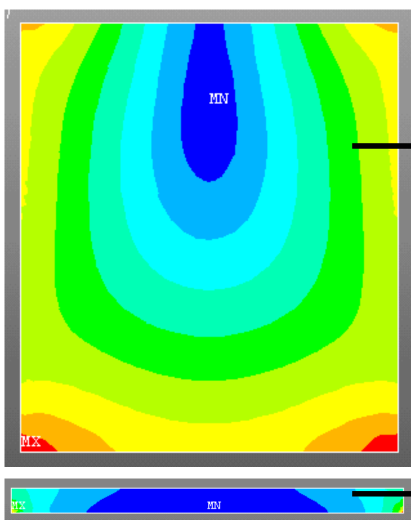
- Yoke material
- Dimension of winding groove
- **Eng. current density**

Design – Magnetic field calculation II



Max field in iron 4.5T





Max field in main coils 2.4T
Max J_{eng} 950 A/mm^2 (175A)

Max field in correction coils 3.8T
Max current 5A
Use 0.15 mm diameter insul. wire

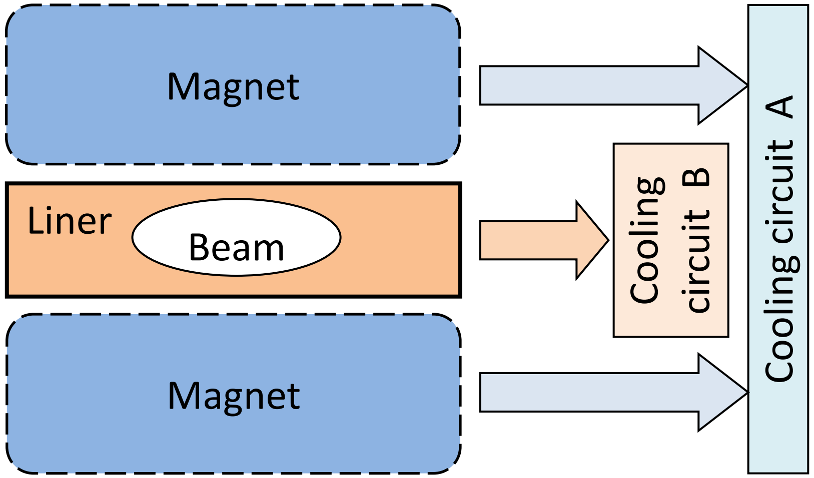
Design – Cryogenic circuit

Main concepts:

○ Two separate circuits for magnet and beam liner.

○ Two base temperatures: 4K for the magnet and 10K for the beam liner.

○ Minimization of gradients between cold head and most distant point in the magnet.



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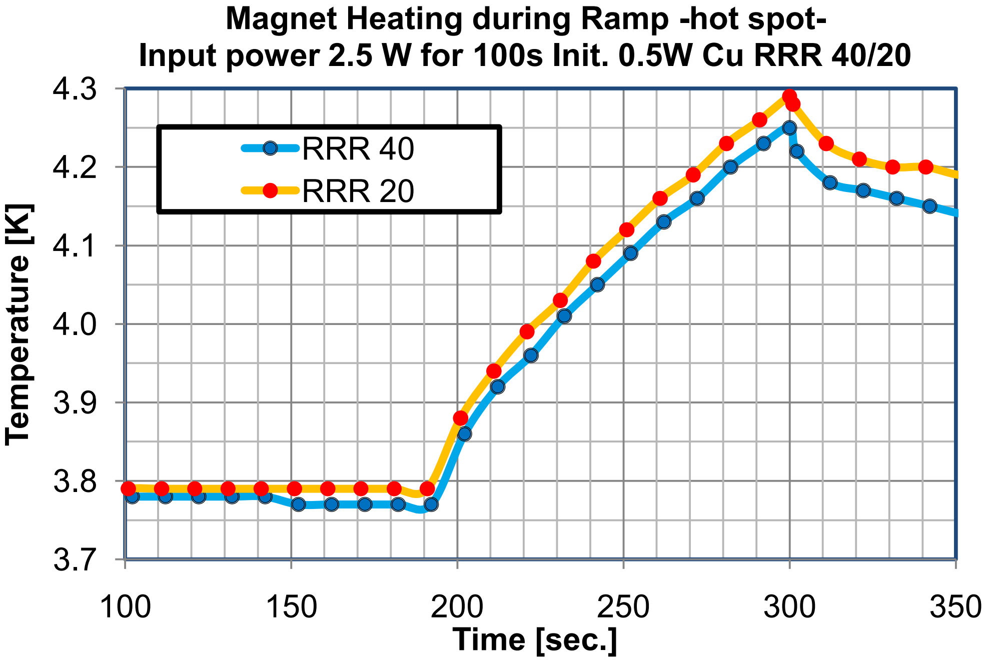
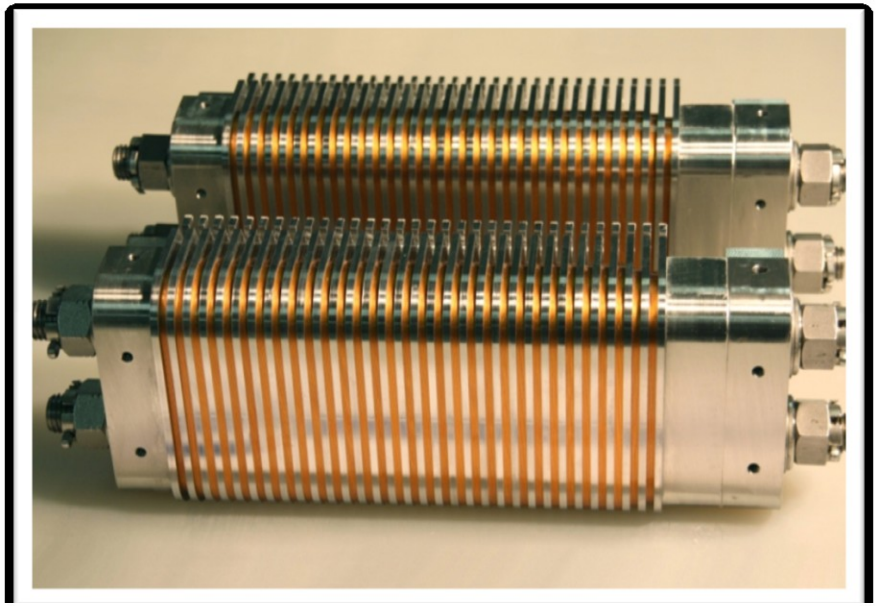
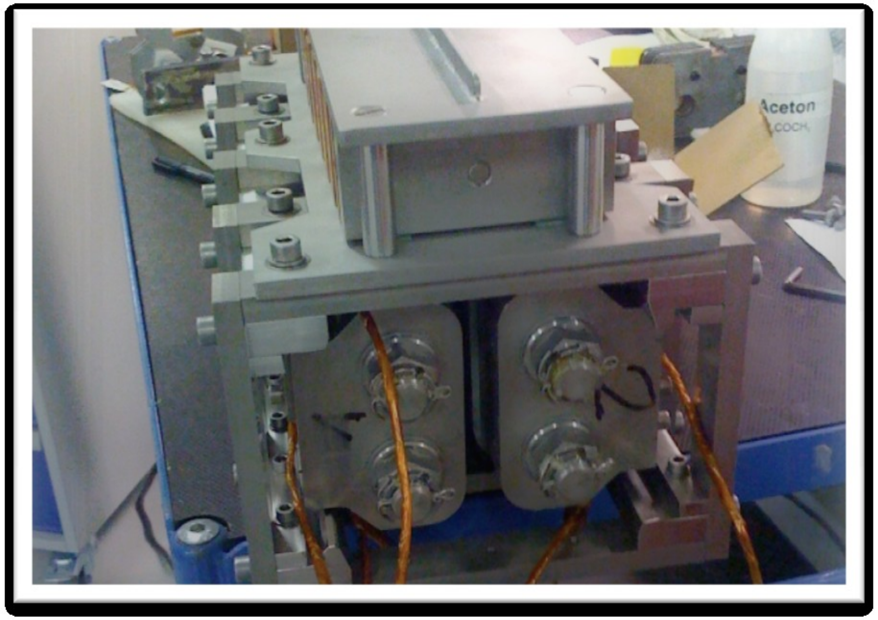
Heta Loads			
	Shield	Circuit B	Circuit A
Radiation	7.93	0.05	
Conduction	21.98	0.53	0.28
Current leads	18.80		0.13
Eddy currents			0.20
Hysteresis			0.14
Coupling SC			1.71
Beam Heat	16	4.00	
TOTAL (W)	64.71	4.58	2.46

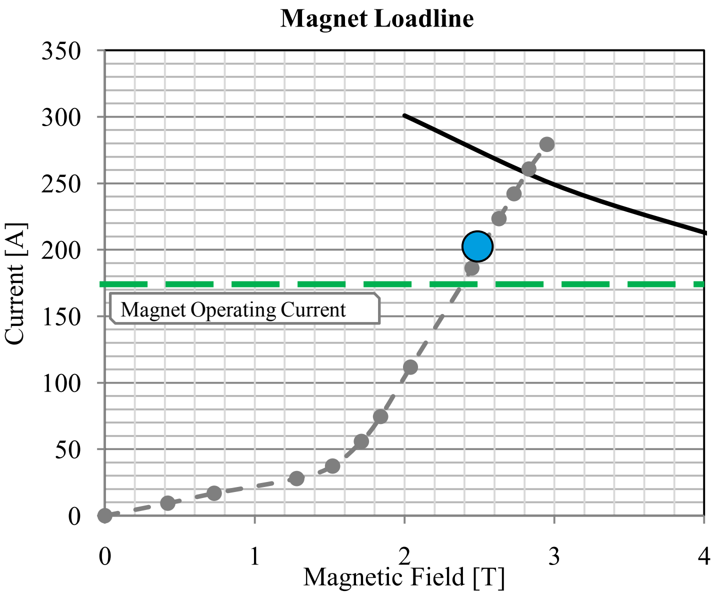


Demonstrator – field performance





Tests by KIT - S. Casalbuoni et al., SRI09



- 16.5 periods
- End field correction ¾ - ¼
- Quench protection with cold diodes
- Local shimming

- Single length wire winding
- Vacuum Pressure impregnation (VPI)
- Alignment of coils

Demonstrator – mechanical accuracies

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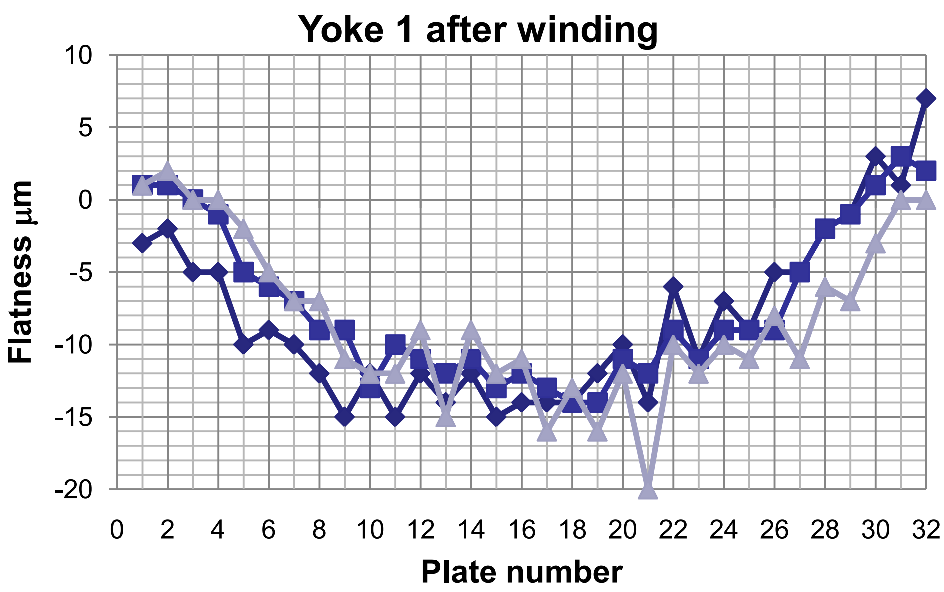

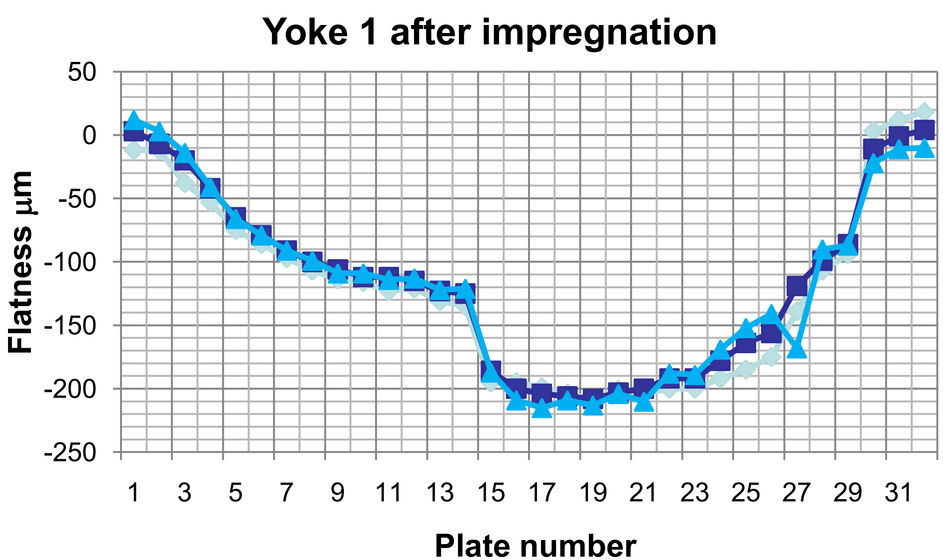

- ○ Yoke flatness measured after winding -> 20 µm.
- ○ Yoke flatness measured after impregnation -> 250 µm.

The deformation is the result of the 180 C heating performed during impregnation.

Several mixtures have been tested to eliminate the “high temperature” step while keeping the correct physical properties.

C. Boffo et al., MT21

Prototypes

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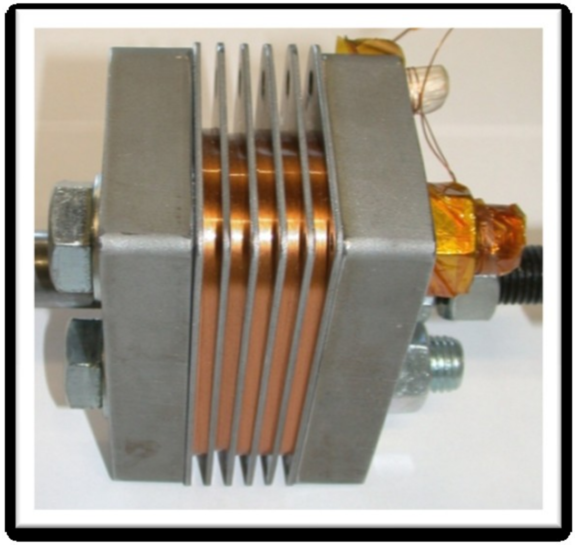
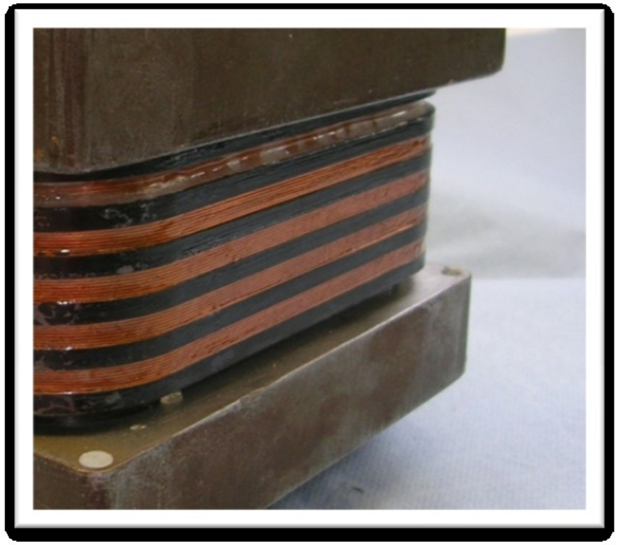
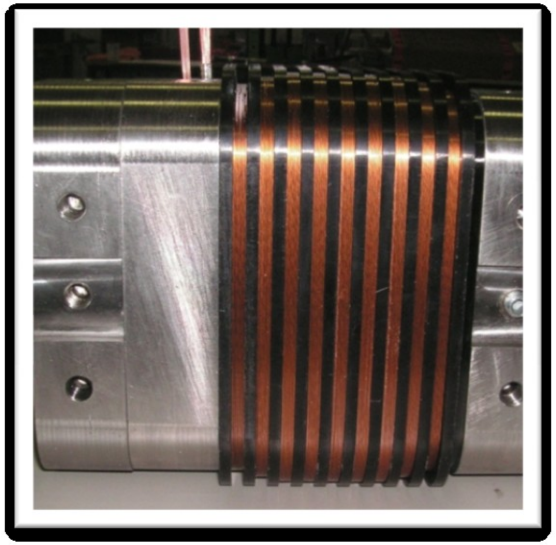
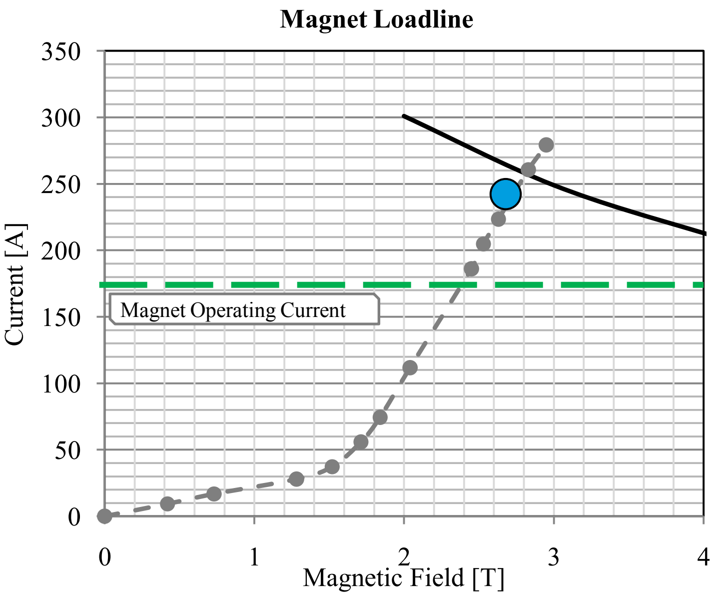






<u>Best test results:</u>

- ○ Max current 240 A
- ○ Max ramp rate 240 A/min
- ○ Max eng. current density above 1300 A/mm^2
- ○ Reached above 90% short sample limit

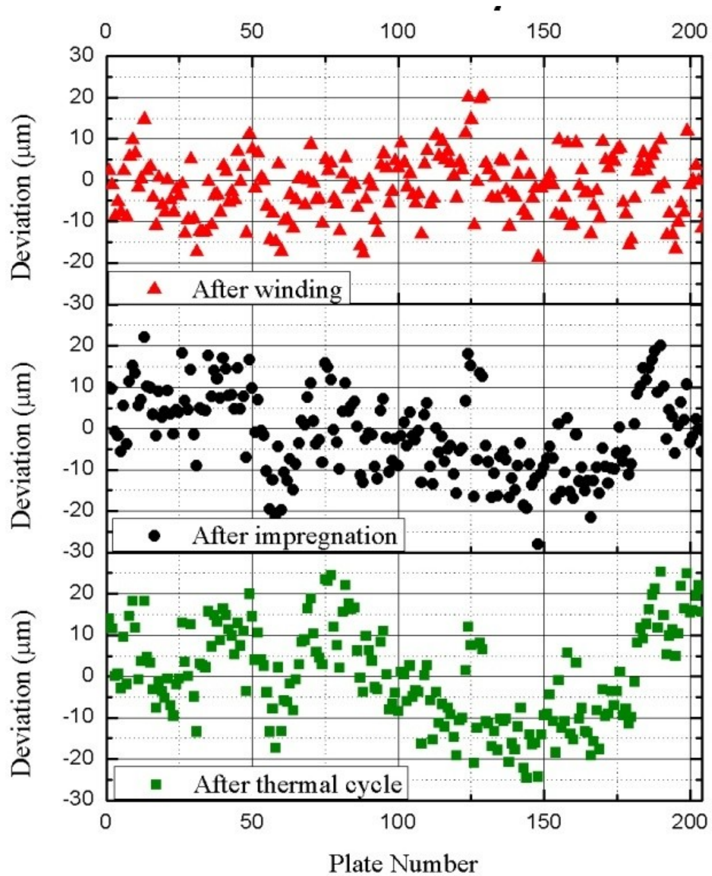


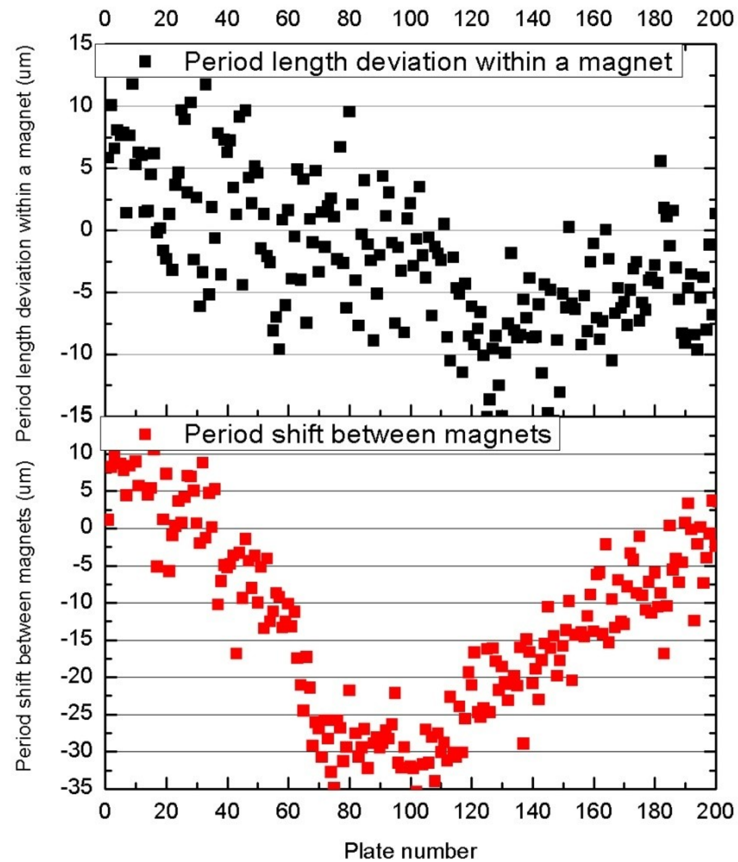
Tests by KIT - S. Casalbuoni et al., IPAC10

Fabrication

- Stapling and alignment of 205 plates for each yoke.
- Plates have been measured and positioned to minimize period length variations.
- Winding with single wire.
- Single joint per magnet at end.
- Impregnation at room temperature.
- Measurement of yoke flatness between fabrication steps.
- Support strongback in stainless steel.

Achieved accuracies





Length difference between magnets:	20 µm
Yoke flatness along 1.5 m:	50 µm
Maximum period length deviation:	30 µm
Maximum deviation of relative position between the magnets:	50 µm

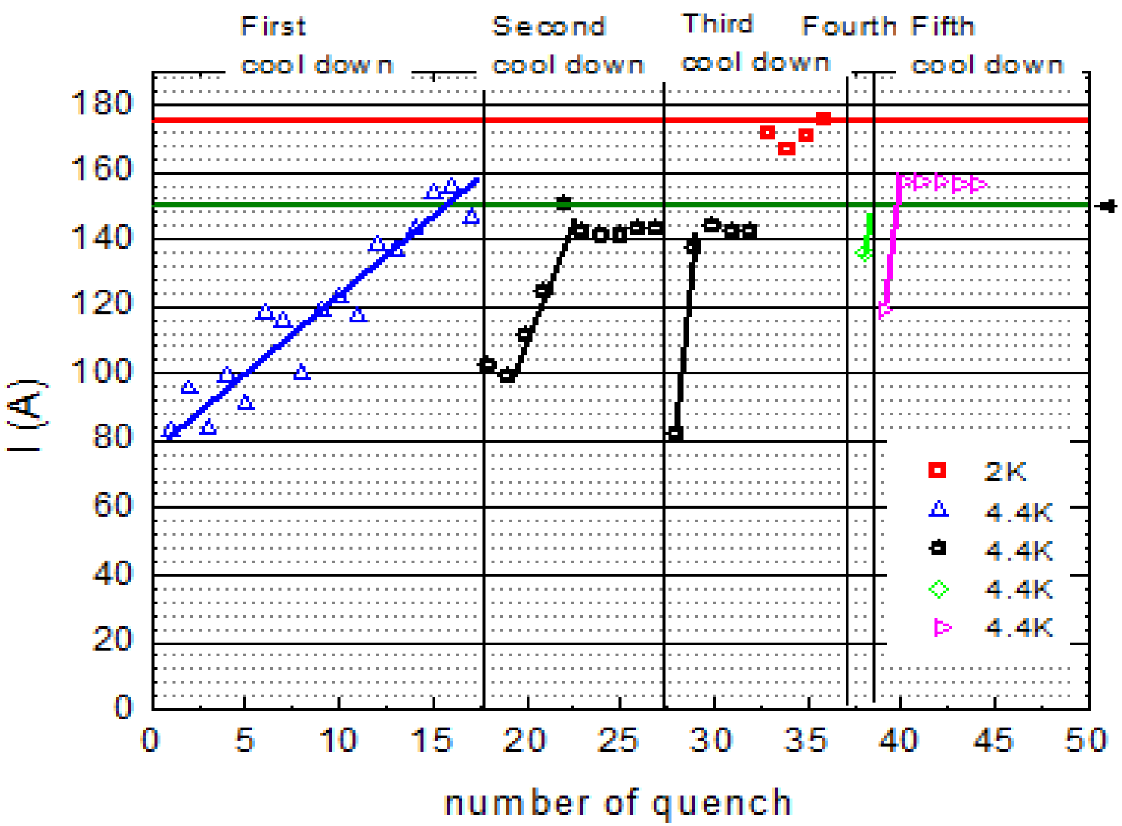
C. Boffo et al., ASC2010

Tests at CERN

- The magnet test was performed at CERN at BLOC4
- Vertical configuration
- Temperature between 4.5 and 2.2K
- Tight quench detection system



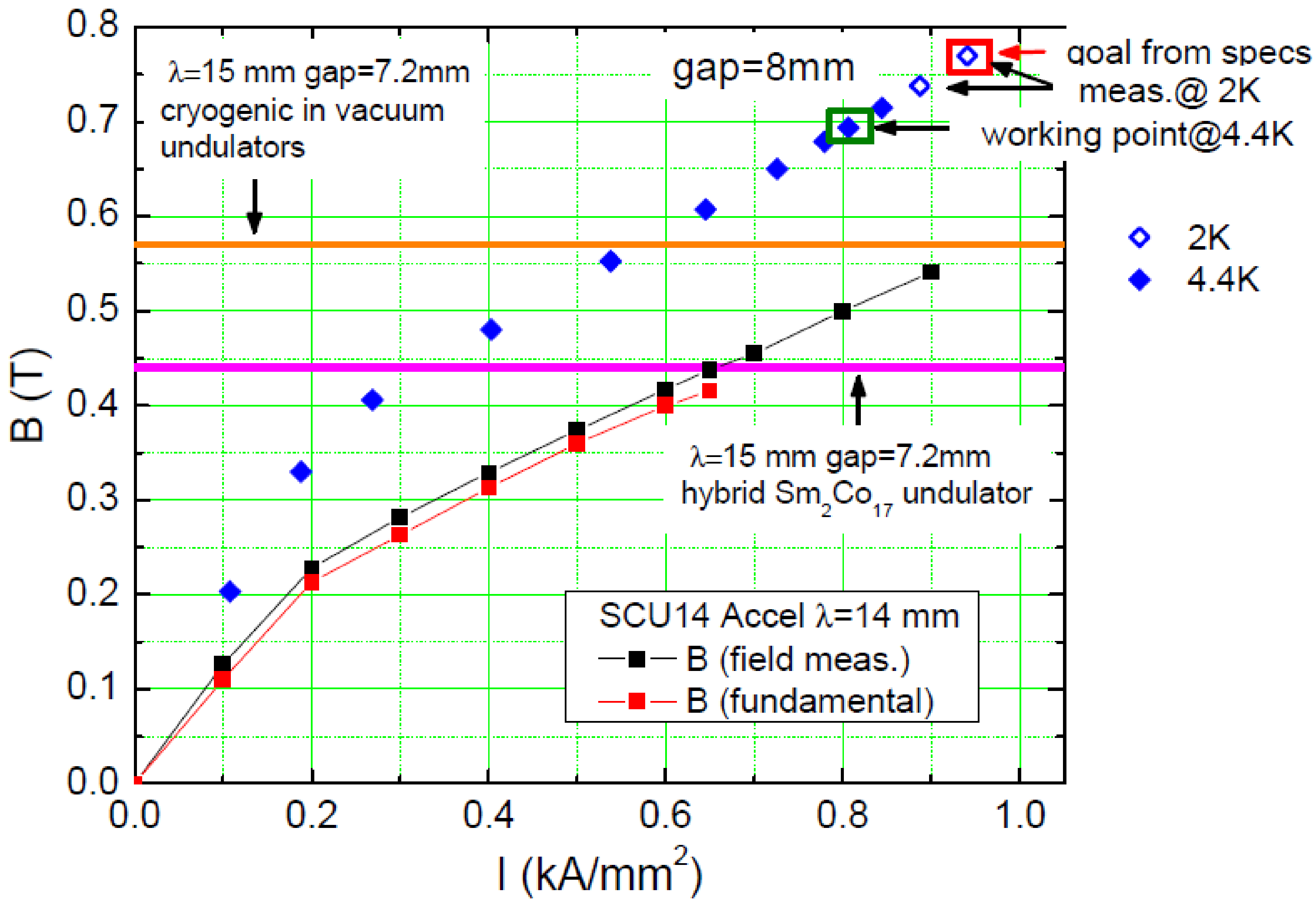
Training and repairs



S. Casalbuoni et al., ASC2010

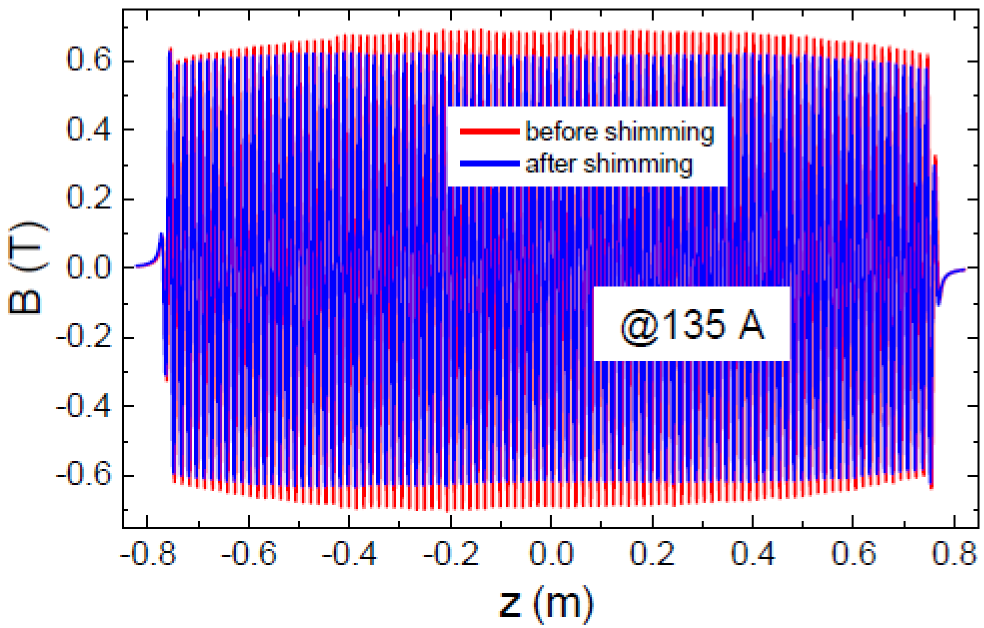
- The weakest point in the magnet system is in the thin wire.
  - Difficult to wind
  - Easy to over bend
  - Sensible on yoke defects
  - BUT small filaments and high packing factor
- Three repairs have been performed.
- A special technique has been developed to remove the impregnation and repair single coils.
- Uncertainty on the joints in conduction cooling.

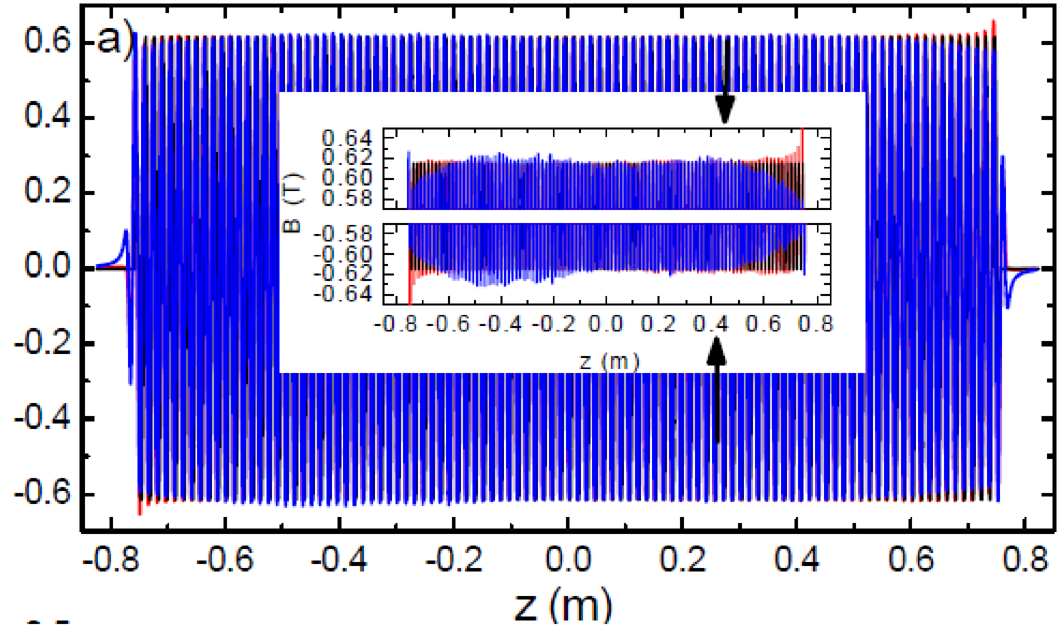
Field performance -1



S. Casalbuoni et al., ASC2010

Field performance -2





Phase error of 7.4 degrees over a length of 0.79 m obtained by application of mechanical shims in the support device

Good agreement between measurement and simulations performed at KIT taking into account the mechanical accuracies

S. Casalbuoni et al., ASC2010

Conclusions

- After three years of close collaboration between KIT and BNG a new 1.5 m long undulator has been fabricated.

- The specifications of the system are such that the technology for the fabrication of SC magnets had to be pushed over the envelope to meet the requirements.

- The magnet performs very satisfactory, close to the envisages specs defined at the start of the R&D.

- The coils are being installed in the cryostat as we speak.

- BNG has a demonstrated knowhow in SCUs design and fabrication.