Industrial experience
on Superconducting Undulators

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Outline

- Intro to BNG
- SCU15
- HTS SCU prototype

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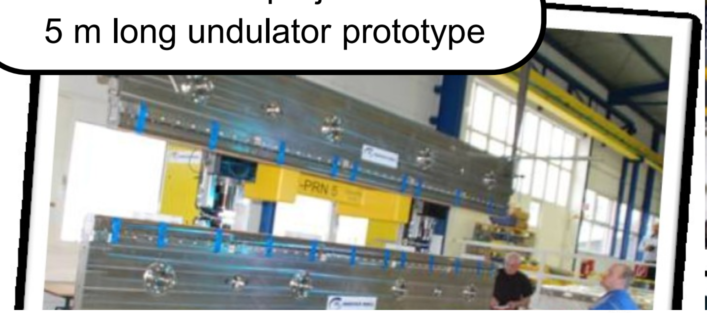
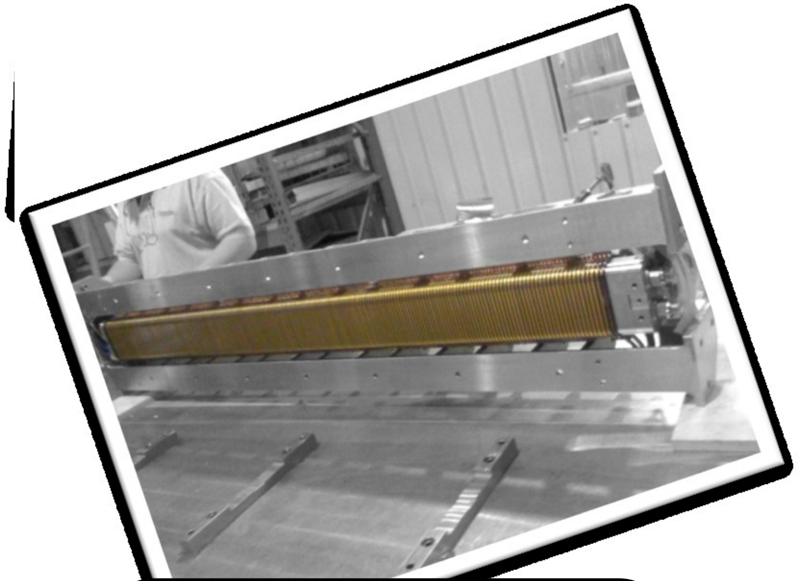
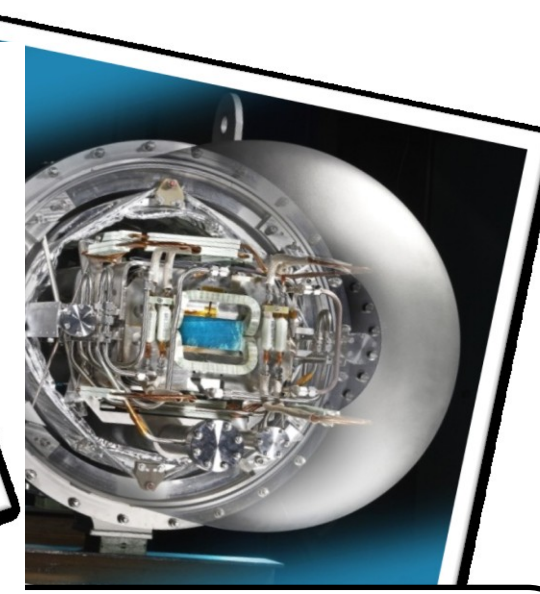
Fabrication of **11 PM Planar Undulators** for Petra III at DESY in **11 months**.

X-FEL project
5 m long undulator prototype





KIT –ANKA
SCU15 SC Undulator



R project Superconducting SIS 100
Dipole Prototype

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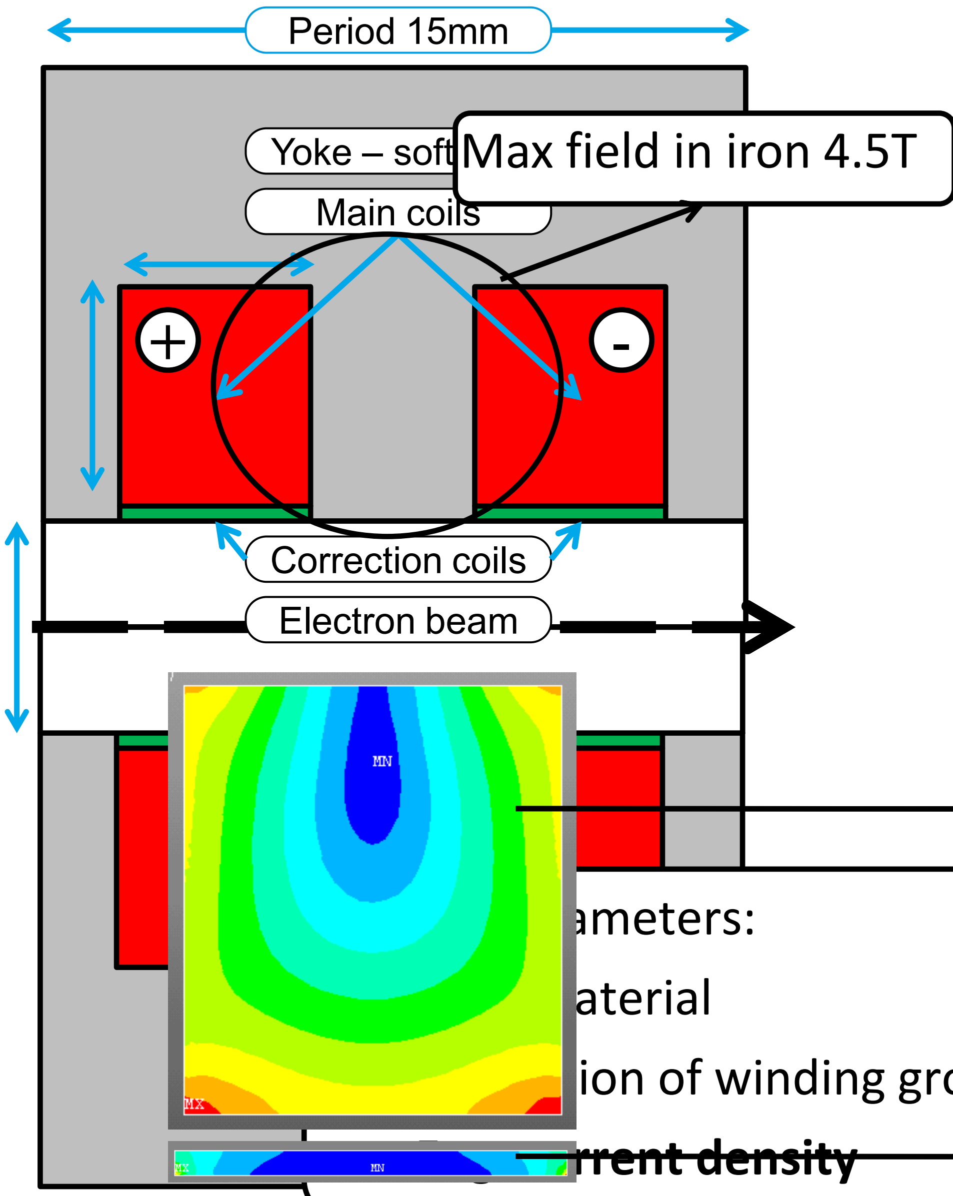
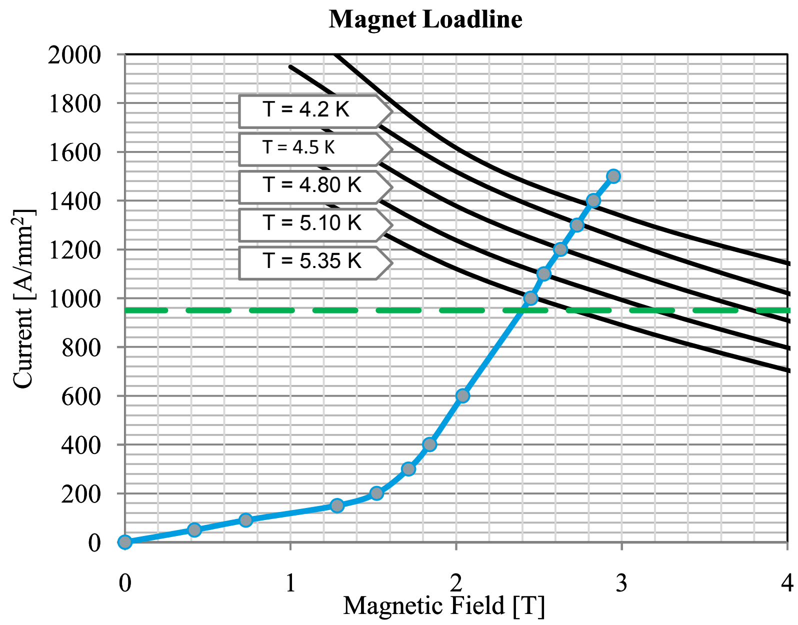
Specifications

	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





Max field in main coils 2.4T

Max J_{eng} 950 A/mm^2 (175A)

ameters:

aterial

ion of winding groov

rrent density

... NbTi

varnish

angular

.....0.34

Width (mm).....0,54

Design critical current density* (A/mm2).....1000

Design operating temperature** (K).....4,2

Design magnetic field (T)***.....4

.2-1.5

...>60

....<40

....<50

Max field in correction coils 3.8T

Max current 5A

Use 0.15 mm diameter insul. wire

Design – Cryogenic circuit

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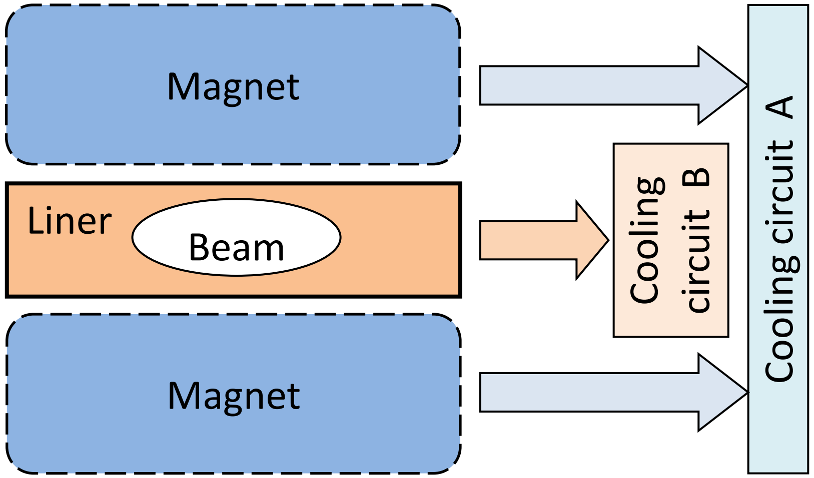
Main concepts:

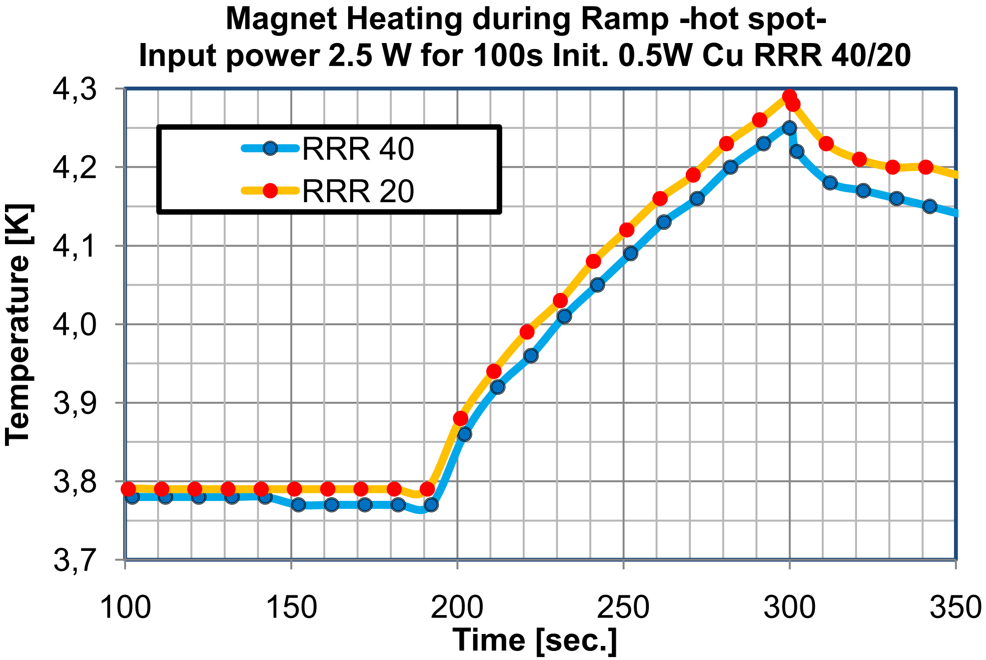
○ Two separate circuits for magnet and beam liner.

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

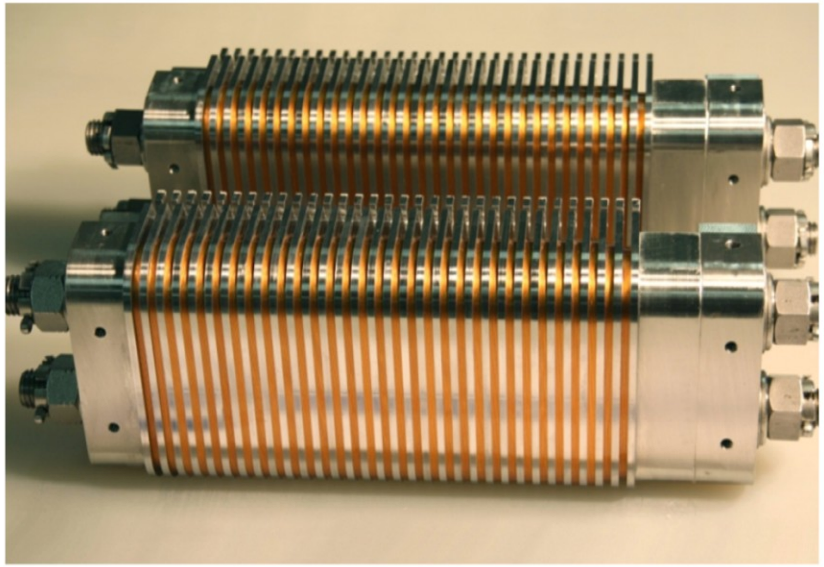
○ Minimization of gradients between cold head and most distant point in the magnet.

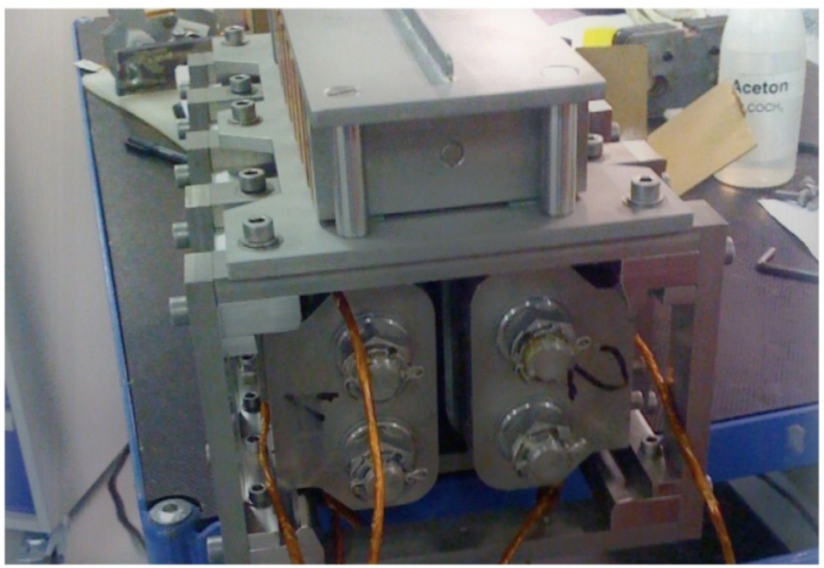


Heta Loads			
	Shield	Circuit B	Circuit A
Radiation	7.93	0.05	
Conduction	21.98	0.53	0.28
Current leads	18.80		0.13
Eddy currents			0.20
Hysteresis			0.14
Coupling SC			1.71
Beam Heat	16	4.00	
TOTAL (W)	64.71	4.58	2.46



Demonstrator – field performance





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

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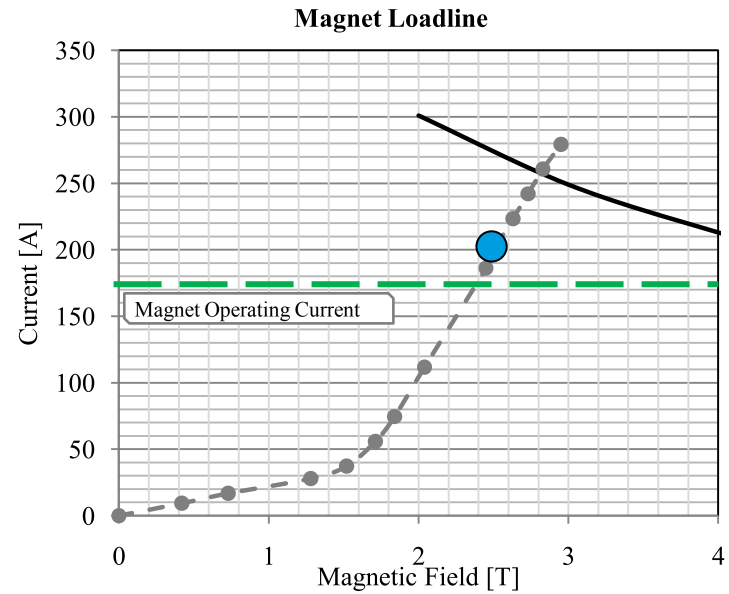
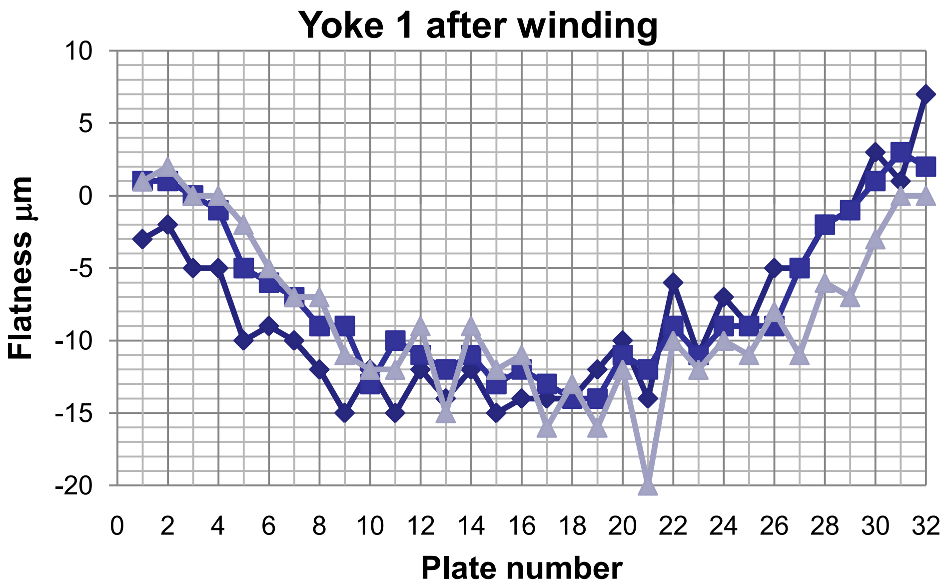
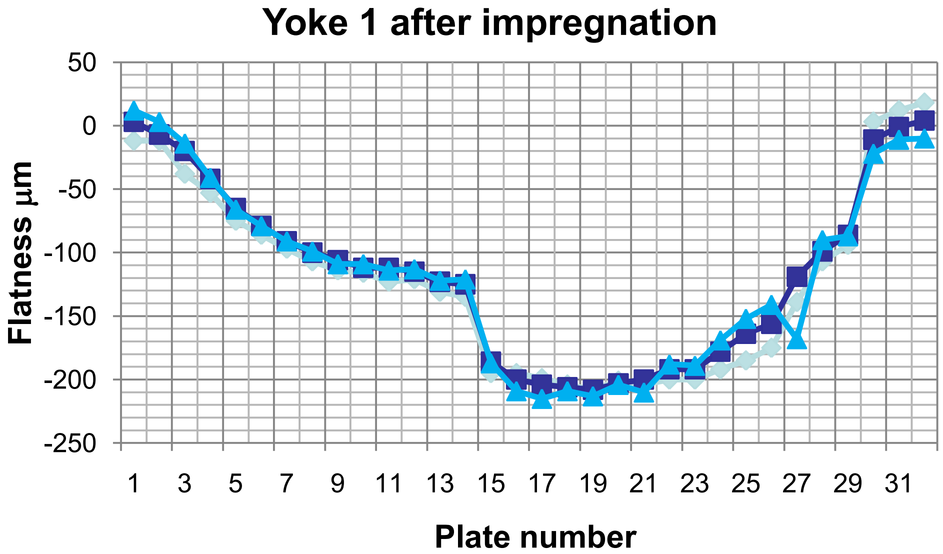


- ○ 16.5 periods
- ○ End field correction ¾ - ¼
- ○ Quench protection with cold diodes
- ○ Local shimming

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

Demonstrator – mechanical accuracies





C. Boffo et al., MT21

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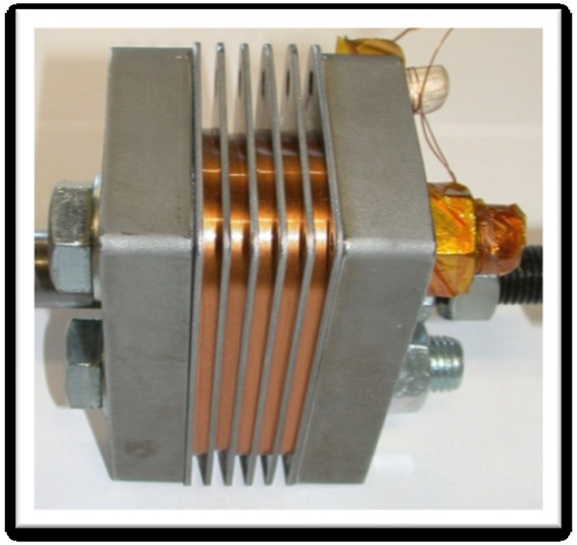
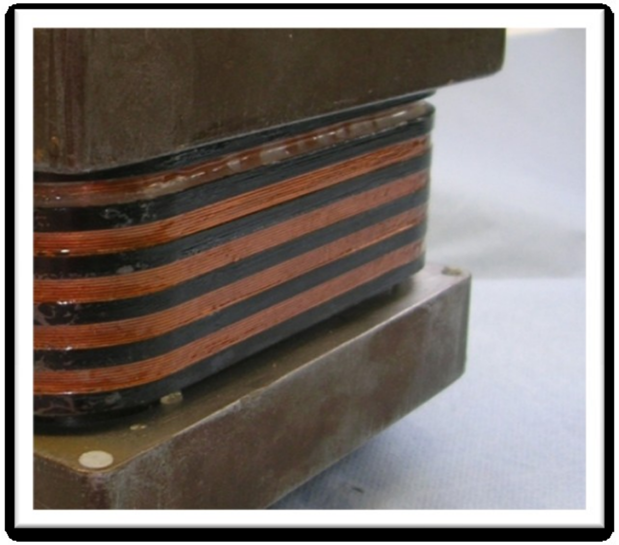
- Yoke flatness measured after winding -> 20 µm.
- Yoke flatness measured after impregnation -> 250 µm.

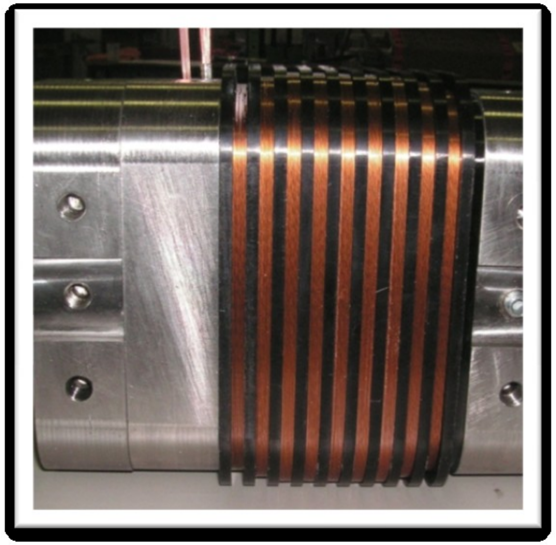
The deformation is the result of the 180 C heating performed during impregnation.

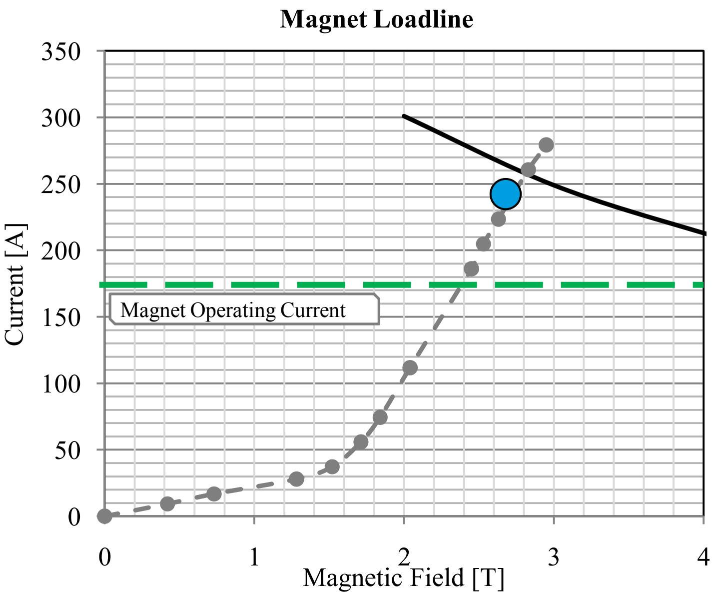
Several mixtures have been tested to eliminate the “high temperature” step while keeping the correct physical properties.

Prototypes









<u>Best test results:</u>

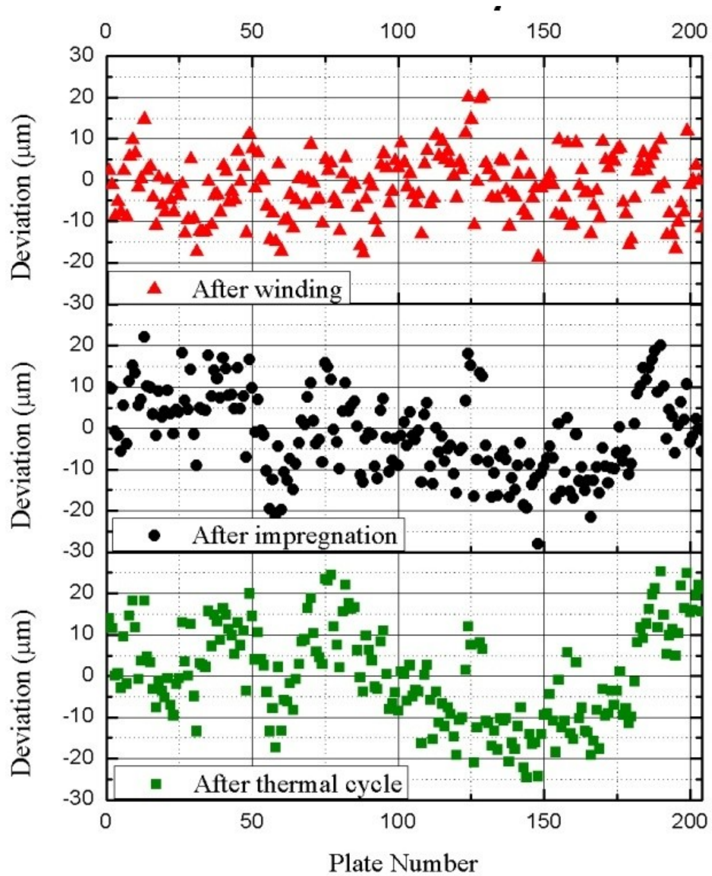
- ○ Max current 240 A
- ○ Max ramp rate 240 A/min
- ○ Max eng. current density above 1300 A/mm^2
- ○ Reached above 90% short sample limit

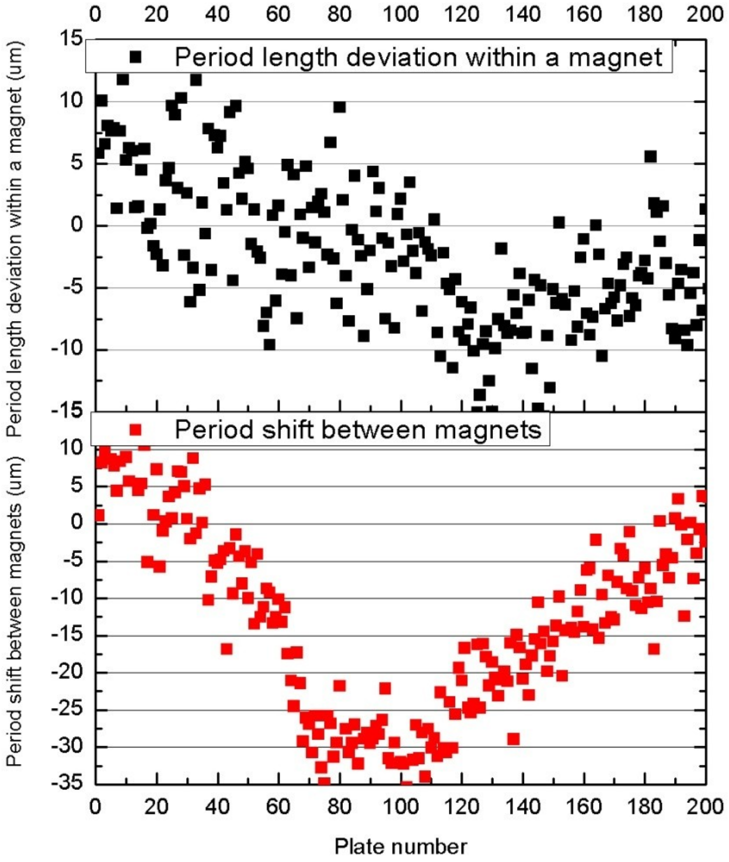
Tests by KIT - S. Casalbuoni et al., IPAC10

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

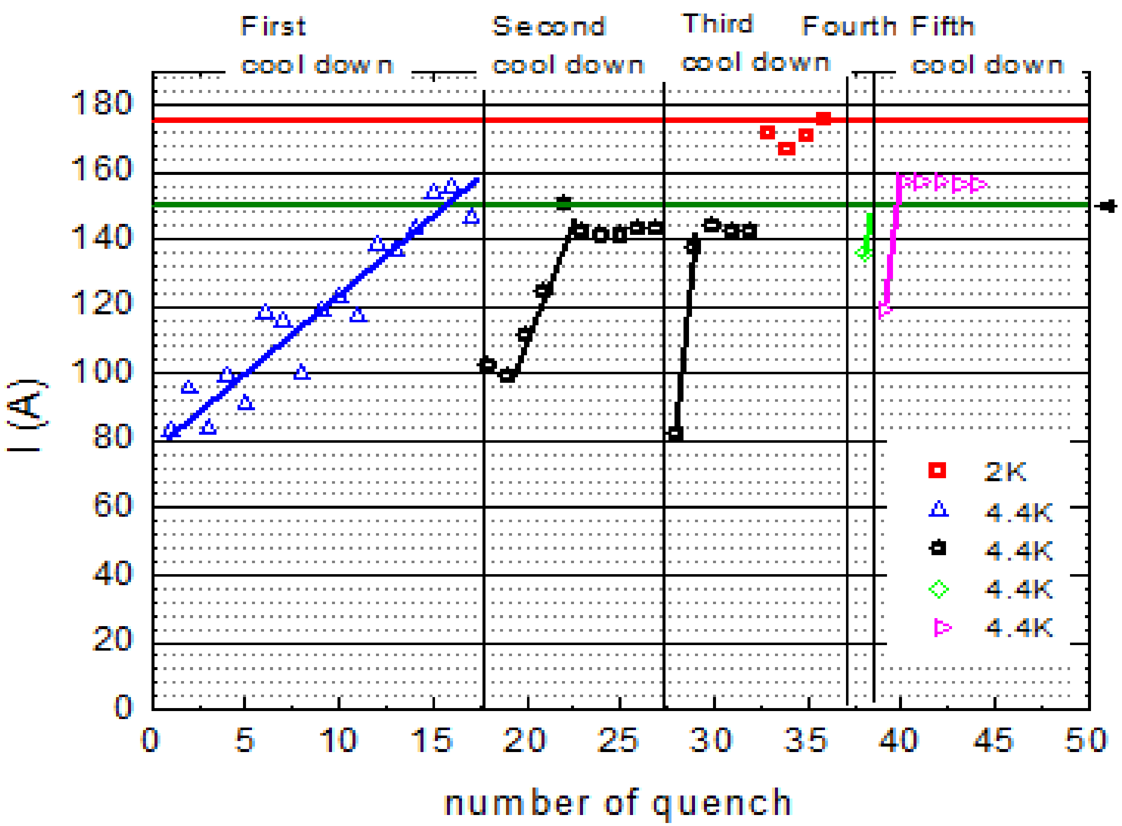




Length difference between magnets:	20 μm
Yoke flatness along 1.5 m:	50 μm
Maximum period length deviation:	30 μm
Maximum deviation of relative position between the magnets:	50 μm

C. Boffo et al., ASC2010

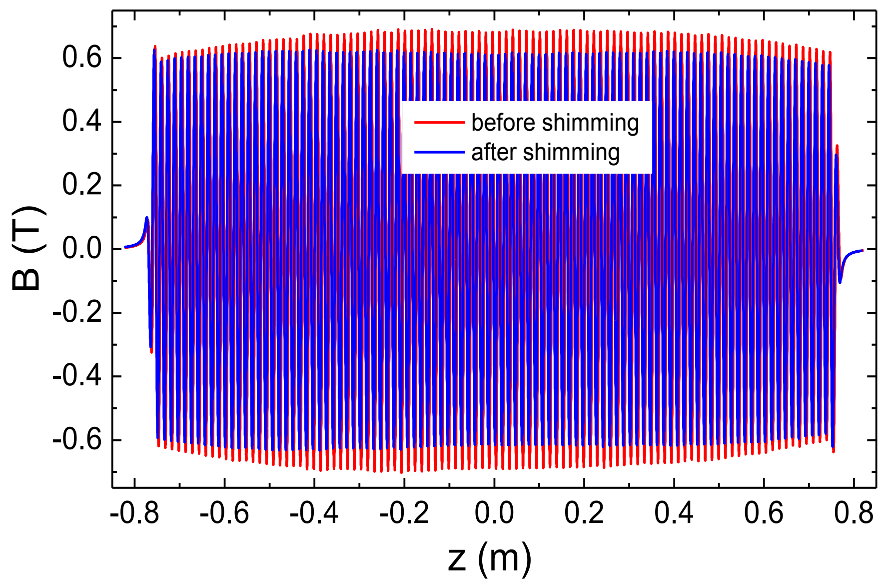
Training and repairs



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.

Deformation after cooldown



- General bending of the coils after cooling dominate the field profile.
- Effect of differential contraction between the support structure and the coils.
- The issue has been partially solved by pre-bending the coils before cooling.
- An appropriate solution has to be found for the installation in the final cryostat.

S. Casalbuoni et al., ASC2010

SCU15 Conclusions and outlook

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

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

- The magnet performance is acceptable and close to specifications.

- After a final test at CERN in middle October, the magnet will be installed in the cryostat

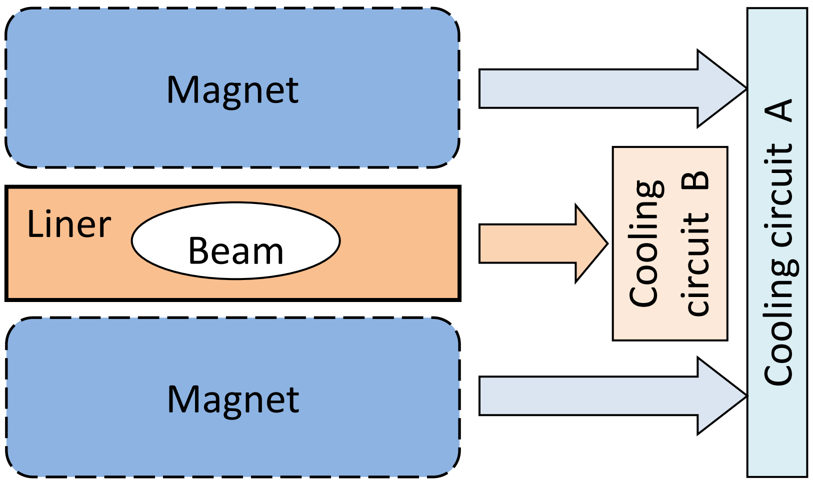
A case for HTS materials

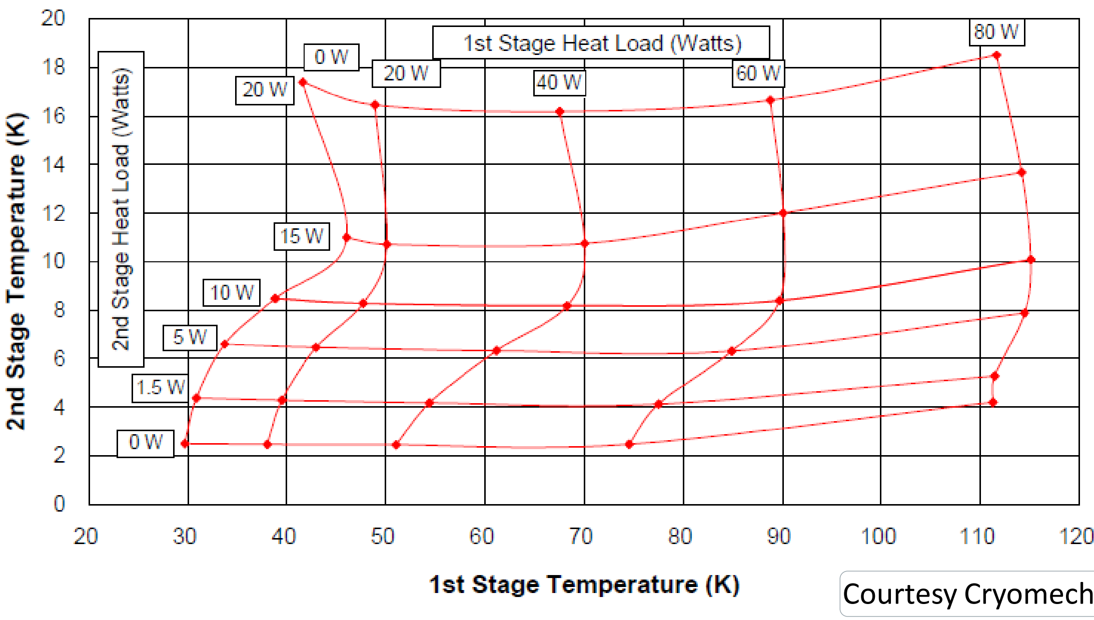
- Need to pack high current densities in a small volume.
- Nb_3Sn requires a 700 C heat treatment and is brittle.
- Temperature margin (beam heat load requirement).

NbTi 1300A/mm^2 eng. @ ~100% packing factor

Difficult to maintain accuracies for long units

Possibility to use cryocoolers at higher temperatures

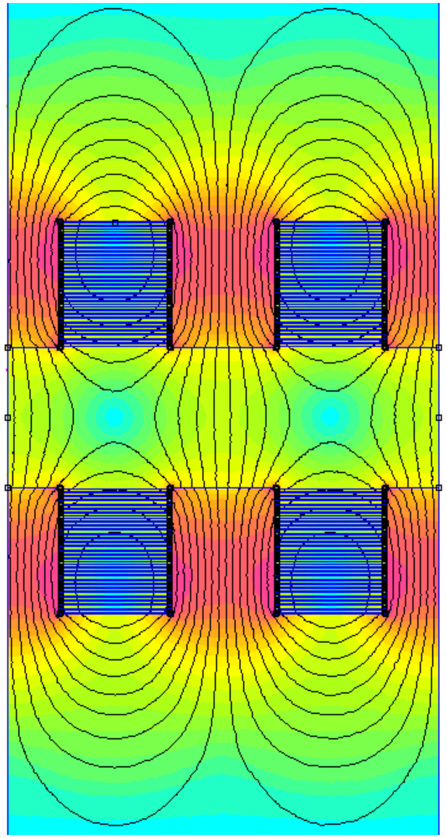




Courtesy Cryomech

Magnetic Design

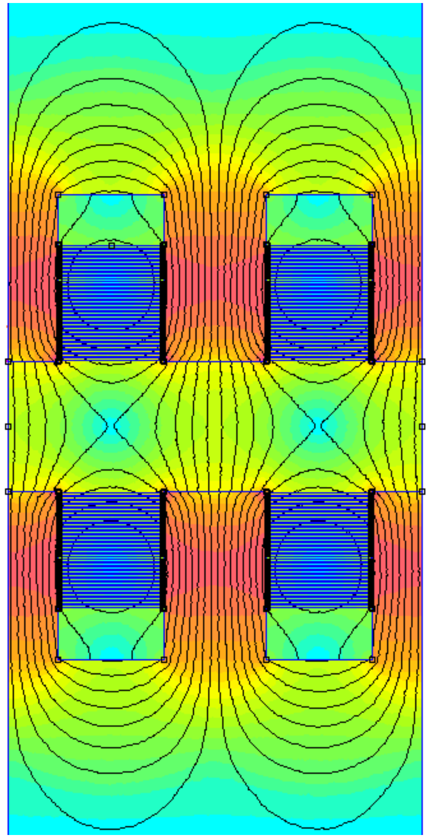
- Goal 1.4 T on axis with a 5 mm gap and 16 mm period (K>2).
- Soft iron (C10e) yoke magnet -> issue with anisotropy of YBCO.
- Minimization of the perpendicular components of field.



Standard Design:

- 4 mm groove
- 30 layers HTS
- Interlayer insulation 50 μm
- Side insulation 50 μm

- Operating current 500A
- Field on axis 1.45 T
- Max field in conductor 2.59T
- Max ortho. Field in conductor **2.25T**

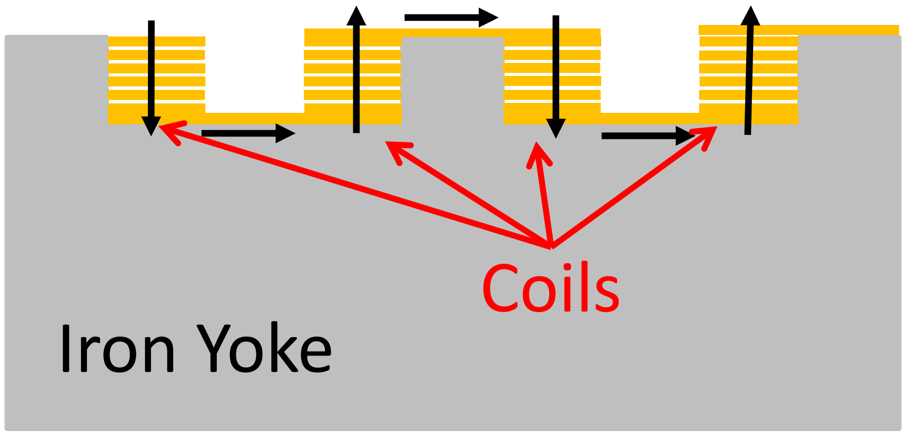


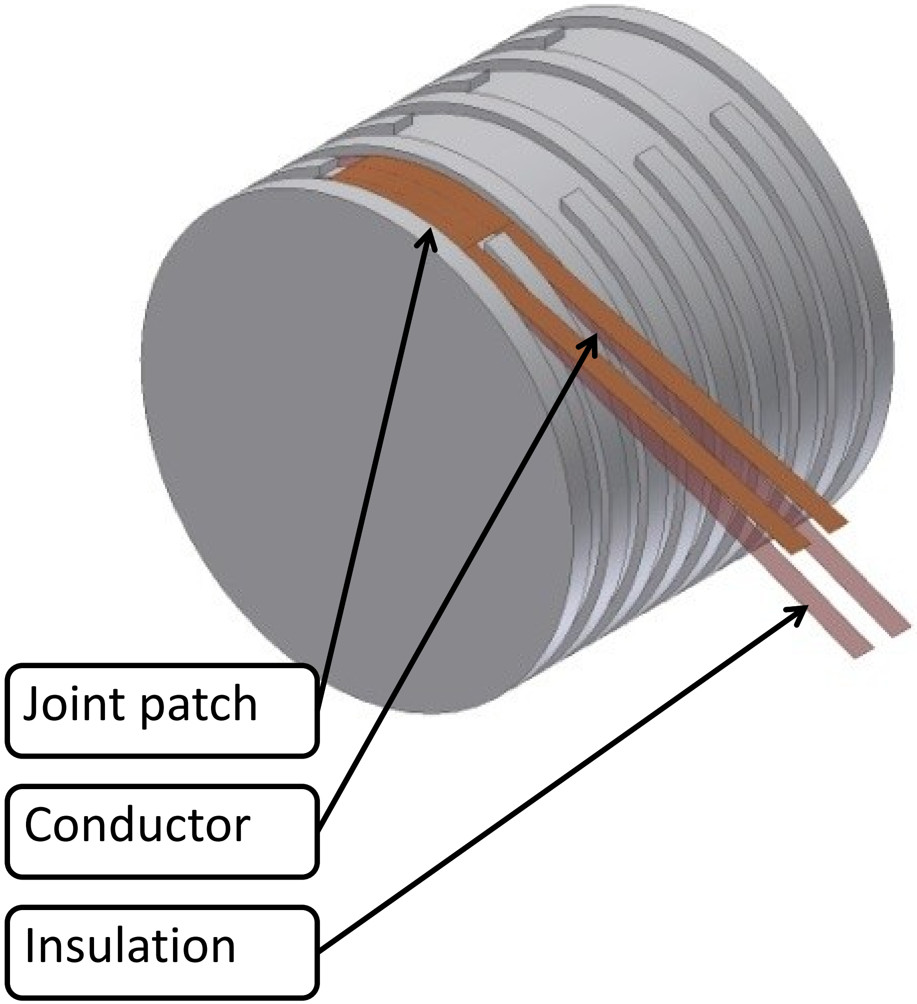
Improved Design:

- 4 mm groove
- 30 layers HTS
- Interlayer insulation 50 μm
- Side insulation 50 μm
- **2 mm non-magnetic bottom layer**

- Operating current 500A
- Field on axis 1.41 T
- Max field in conductor 2.37T
- Max ortho. Field in conductor **1.38 T**

Winding Scheme





Scheme:

- All coils wound in the same direction
- 2 coils wound simultaneously
- 2D scheme – no tape side-bending
- Jointed structure easier to repair
- Use one tape per layer + co-wound insulation

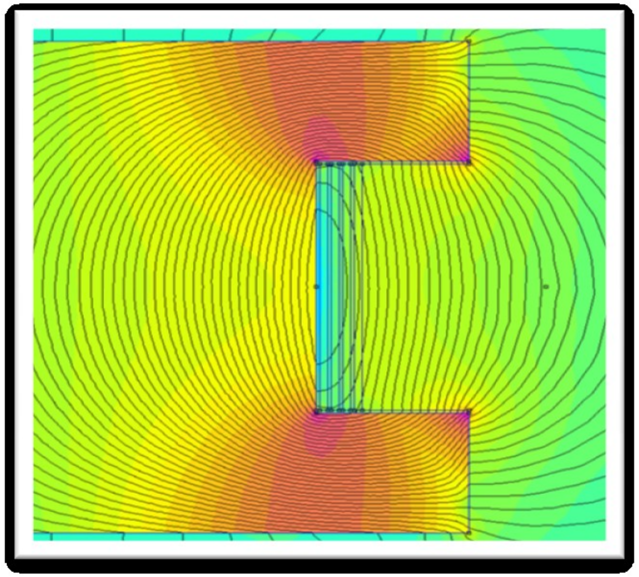
Technology Qualification

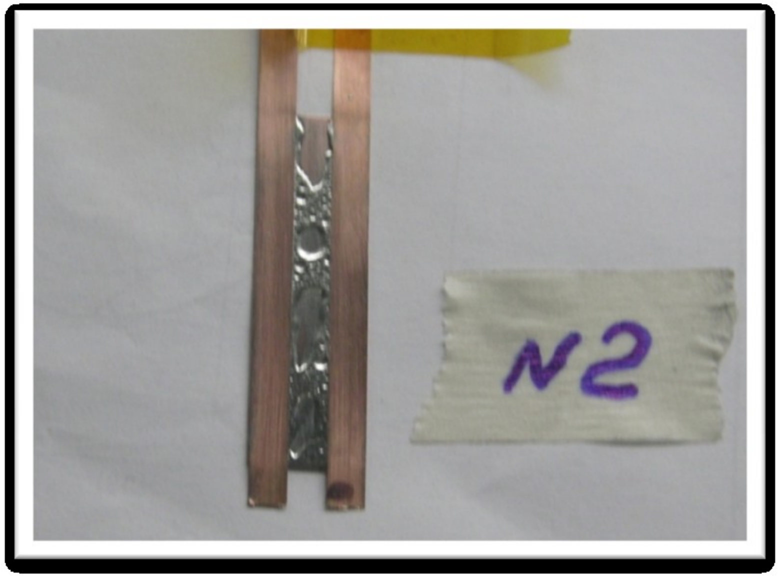
Main goals were:

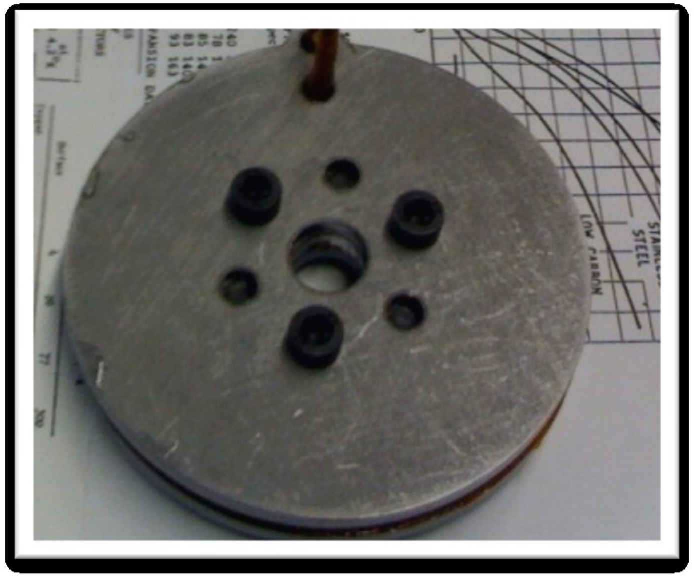
- Familiarization with material (QC/QA process).
- Evaluation of properties at 4K.
- Joint technique.

Prototype solenoids tested at KIT:

- Max current of 640A reached (expected >700A) after several trials, main issue was temperature control during soldering of joints.







Prototype Fabrication

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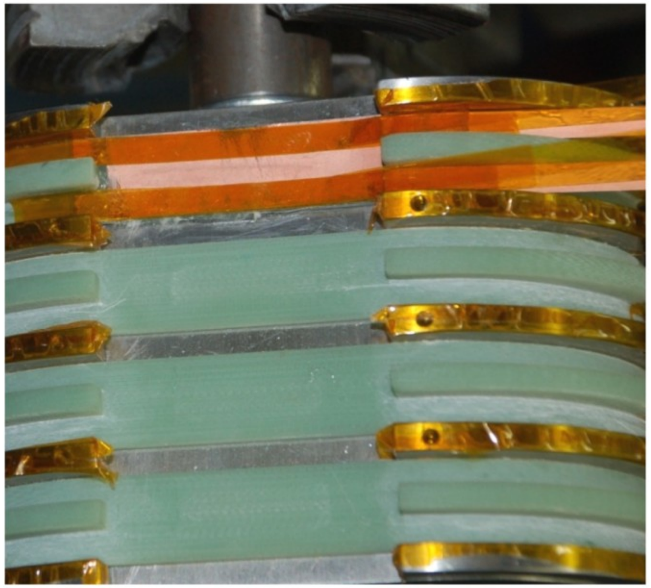
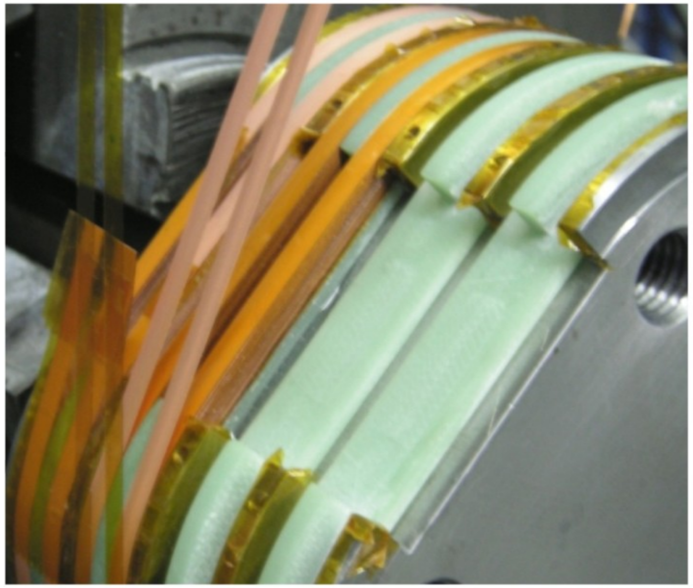
Yoke made of a single block (68 mm long):

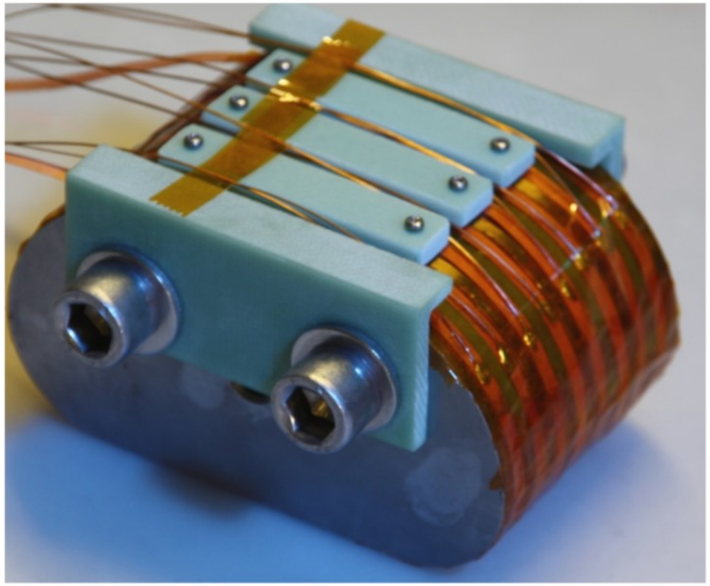
- Flatness 4 μm
- Pole positioning 1 μm
- Overall winding groove flatness 5 μm

Winding process:

- Co-winding 50 μm Kapton tape
- GRP layer as non magnetic material
- Side ground insulation 50 μm Kapton

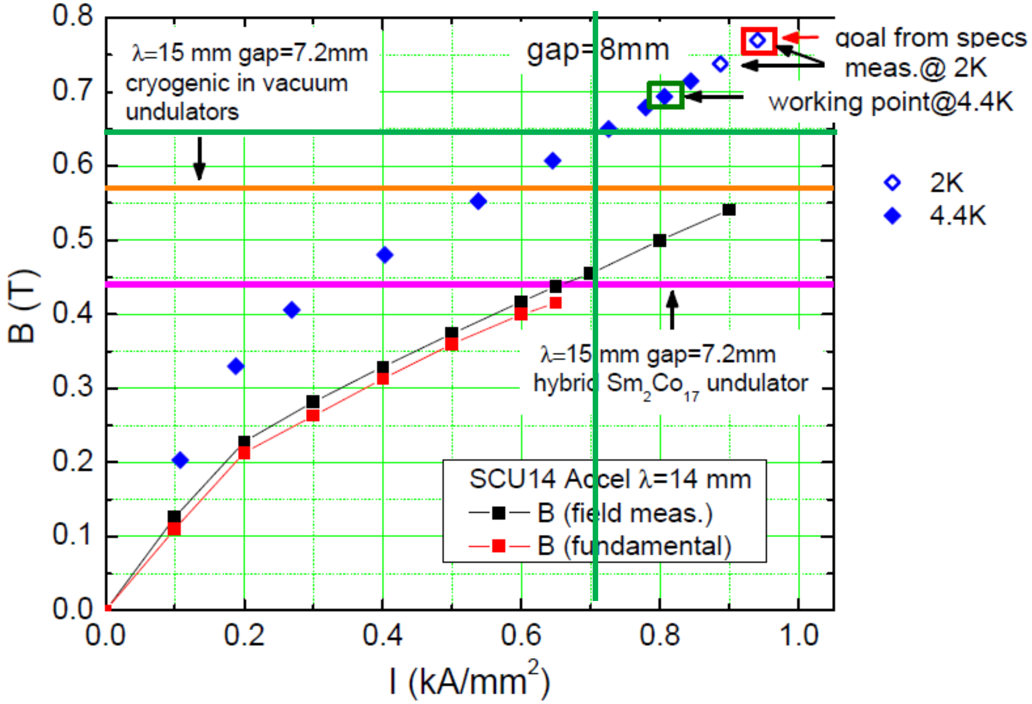






Results

- Resistance of the joints is 50 nOhm (40 mm long)
- Thickness of each layer including interlayer insulation 0.16 mm
- Thickness of the joints 0.25 mm (2 HTS plus soldering)
- **Maximum current 420 A equivalent to an J_{eng} of 700A/mm²**
- Still the quenching behavior has to be analyzed.
- Possible improvement by reducing the interlayer insulation thickness.



Test at KIT and plot courtesy of S. Casalbuoni
C. Boffo et al., ASC2010

Conclusions and Outlook

- *BNG is collaborating with ANKA on development of SC undulators*
- *The 1.5 m long magnet will be placed in the ANKA ring next year*
- *A short undulator/wiggler prototype has been built and tested demonstrating the switching concept.*
- *A short HTS prototype has been built and tested to demonstrate the application of these new materials to the SCU technology.*