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Karlsruhe Institute of Technology

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Performance of SCU15:
The New Conduction-Cooled Superconducting Undulator for ANKA

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Outline

- Introduction to superconducting undulators
- SCU15 main parameters
- Design challenges
- System performance
- Summary
- Outlook

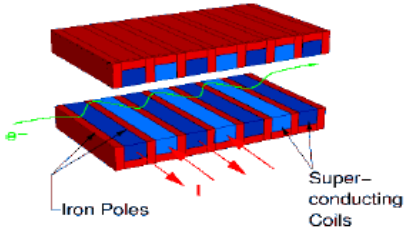
Superconducting undulators

Motivation

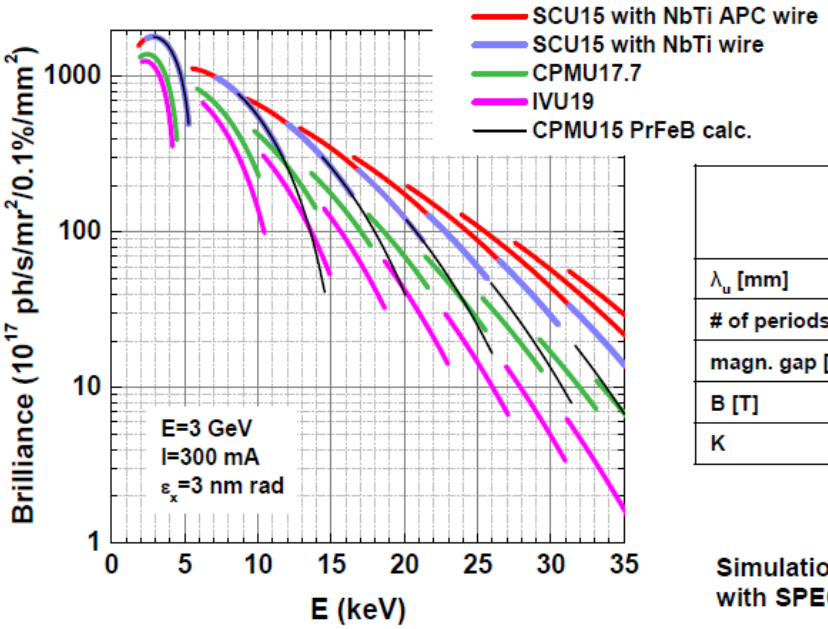
With respect to permanent magnet undulators SCUs can generate :

- Harder X-ray spectrum
- Higher brilliance X-ray beams

Why? Larger magnetic field strength for the same gap and period length



Same magnetic length = 2 m and vacuum gap = 5 mm



S. C. et al., IEEE Trans. on Appl. Supercon. 4101305, Vol. 24-3 (2014)

IVU= in-vacuum undulator
CPMU= cryogenic permanent magnet undulator
SCU=superconducting undulator

	IVU* (SLS)	CPMU† (DLS)	CPMU PrFeB#	SCU NbTi wire**	SCU NbTi APC††
λ_u [mm]	19	17.7	15	15	15
# of periods	105	112	133	133	133
magn. gap [mm]	5	5.2	5.2	6	6
B [T]	0.86	1.04	1.00	1.18	1.46
K	1.53	1.72	1.4	1.65	2.05

*F. Bødker et al., EPAC06
†C.W. Ostenfeld & M. Pedersen, IPAC10
#M.E. Couprie et al., FLS2012
**D. Saez de Jauregui et al., IPAC11
††T. Holubek et al, IPAC11

Simulations performed with SPECTRA§

§T. Tanaka and H. Kitamura, J. Synchrotron Rad. 8, 1221 (2001).

SCU15

Main parameters

- Formers with plate design
- Rectangular NbTi strand 0.35 mm X 0.53 mm
- No insulation between winding package and former
- Movable gap
- Cold corrector coils for minimization of field integrals
- Conduction-cooling design

	Value	Units
Period length	15	mm
Full periods	100.5	
Max field on axis 7 mm gap	0.73	T
Nominal current	150	A
Ramp to nominal current	450	s
Operating gap	7	mm
Injection gap	15	mm
Beam heat load	4	W
Design temperature	4.2	K

SCU15

Unique challenges

- Mechanical tolerances

  Flatness along 1.5 m < 50 μm

  Period length deviation < 10 μm

  Winding package deviation< 40 μm

- Conduction cooling

  4 GM cryocoolers capable of a total power of 5 W @ 4.2 K

  Two separate cooling circuits for magnets and beam pipe

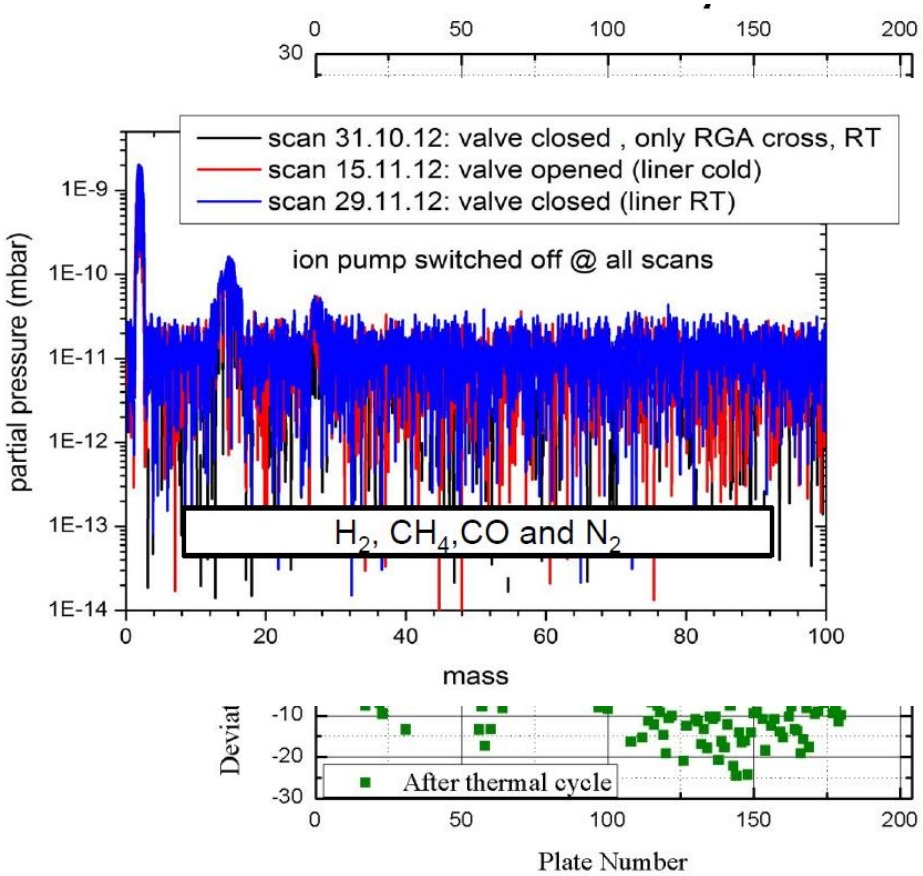
  Thermal separation between coils and beam pipe

- Flexible cold beam pipe

  Open and close from 7 mm to 15 mm at 10 K

  Distance from coils to beam pipe < 0.12 mm along 1.5 m

  Ultra high vacuum < $5 \cdot 10^{-9}$ mbar



SCU15

The device

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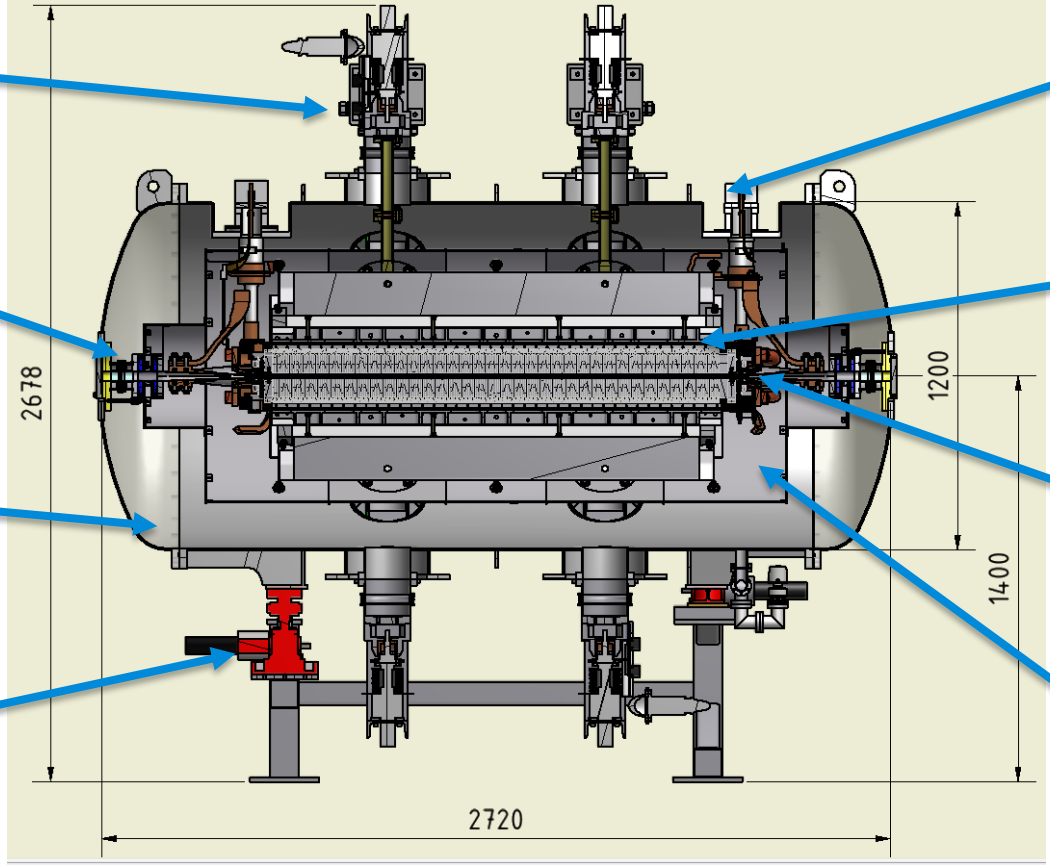


Mover system

RF bellow

Cryostat

Adjusting feet

Cryocoolers

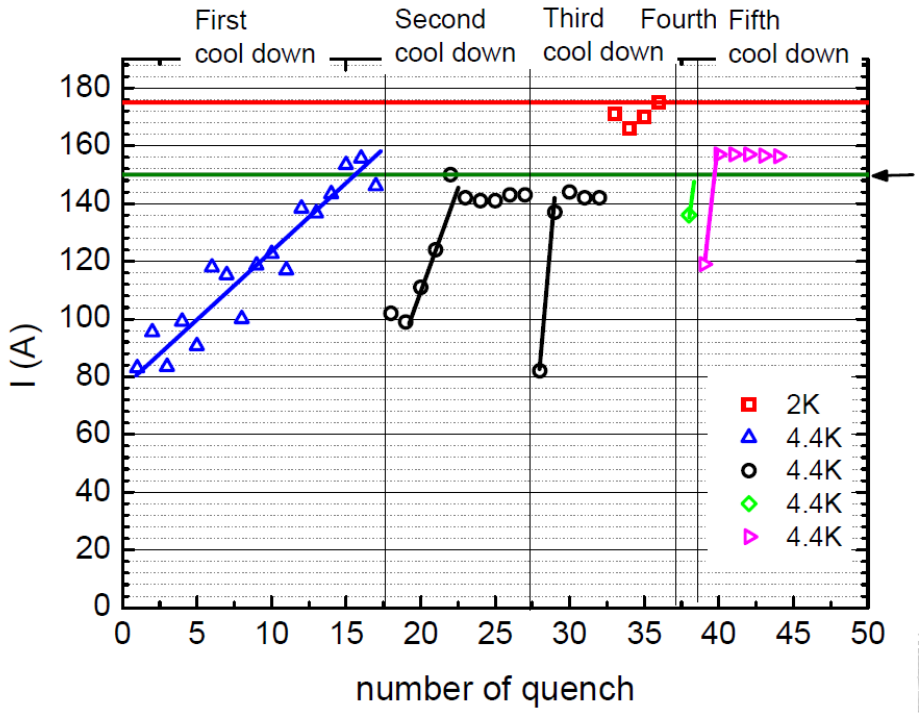
Coils

Beam pipe

Thermal shield

Performance

Vertical tests at CERN



- Five thermal cycles
- Three successful repair processes
- Acceptable training memory after thermal cycling
- Stable operation at 150 A

S.Casalbuoni et al., IEEE Trans. on Appl. Supercond. 1760-1763 Vol. 21-3 (2011)

SCU15

Assembly at BNG

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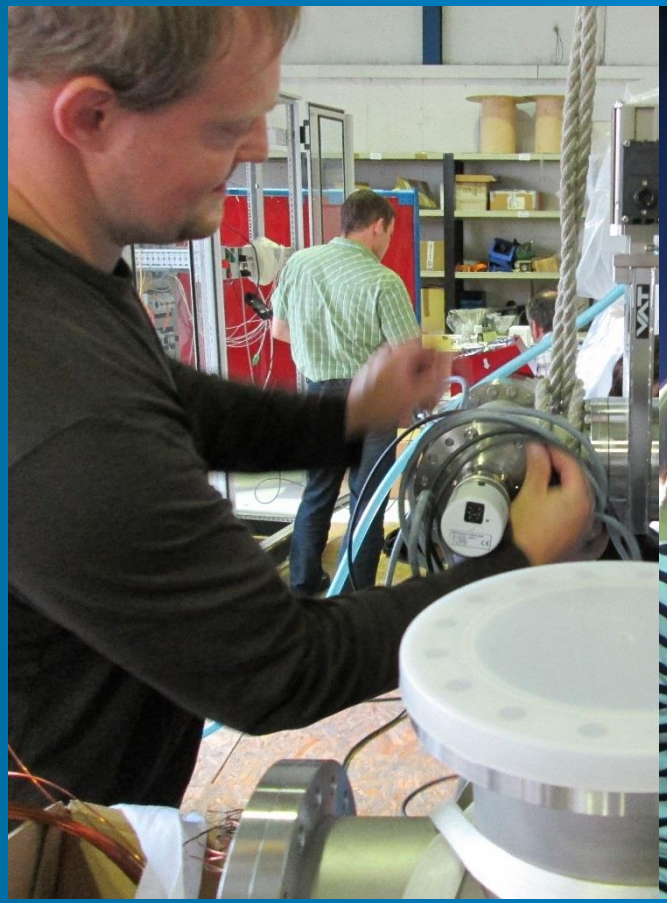
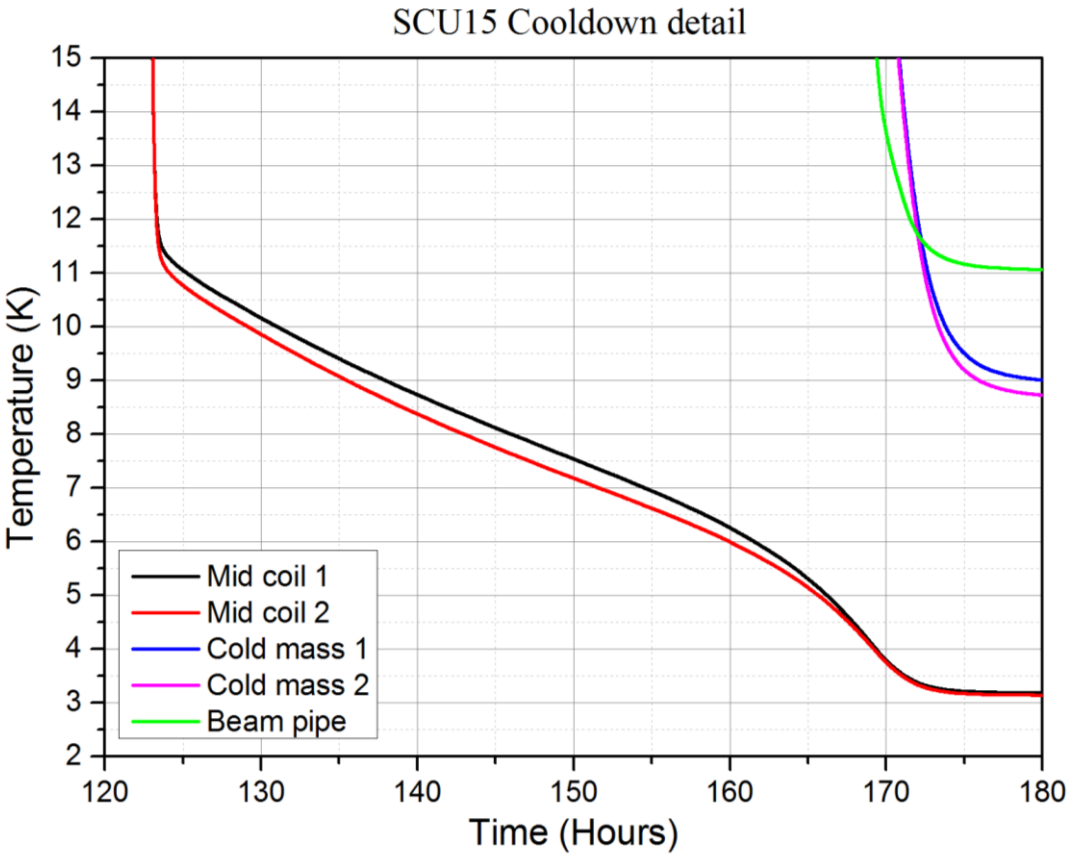


Performance

FAT: cooldown and vacuum performance

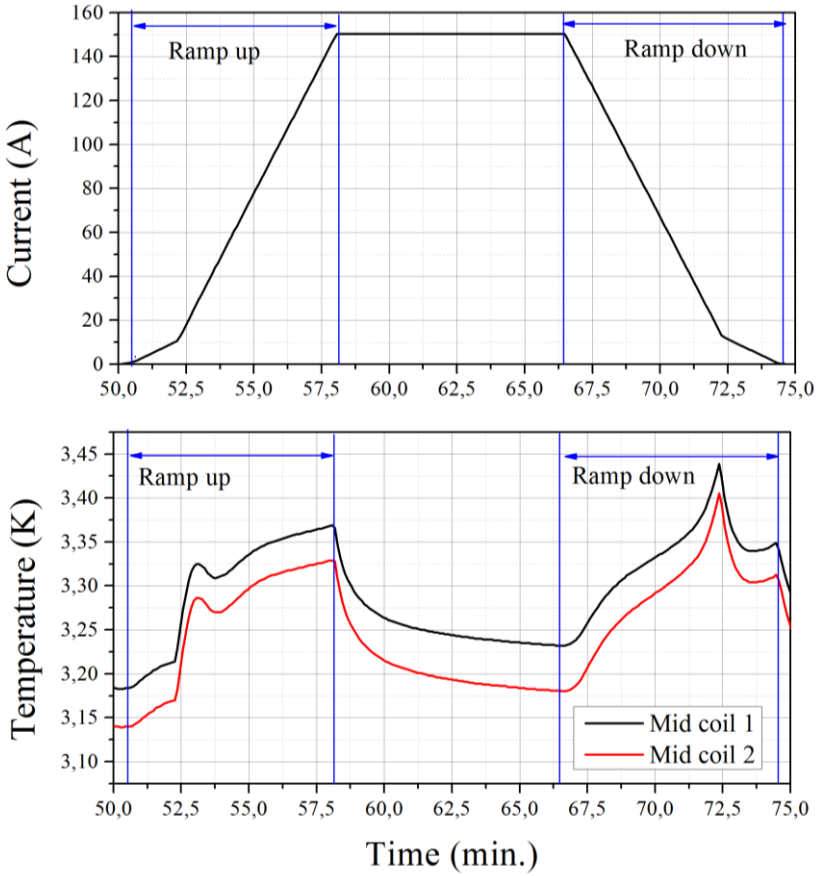
- Pump down to 10^{-4} mbar within 24 hours
- System cooldown in 1 week
- Cooldown dominated by thermal capacity of aluminum components of the cold mass
- Base temperature of the coils with no current < 3.2 K
- Base temperature of the beam pipe ~10 K



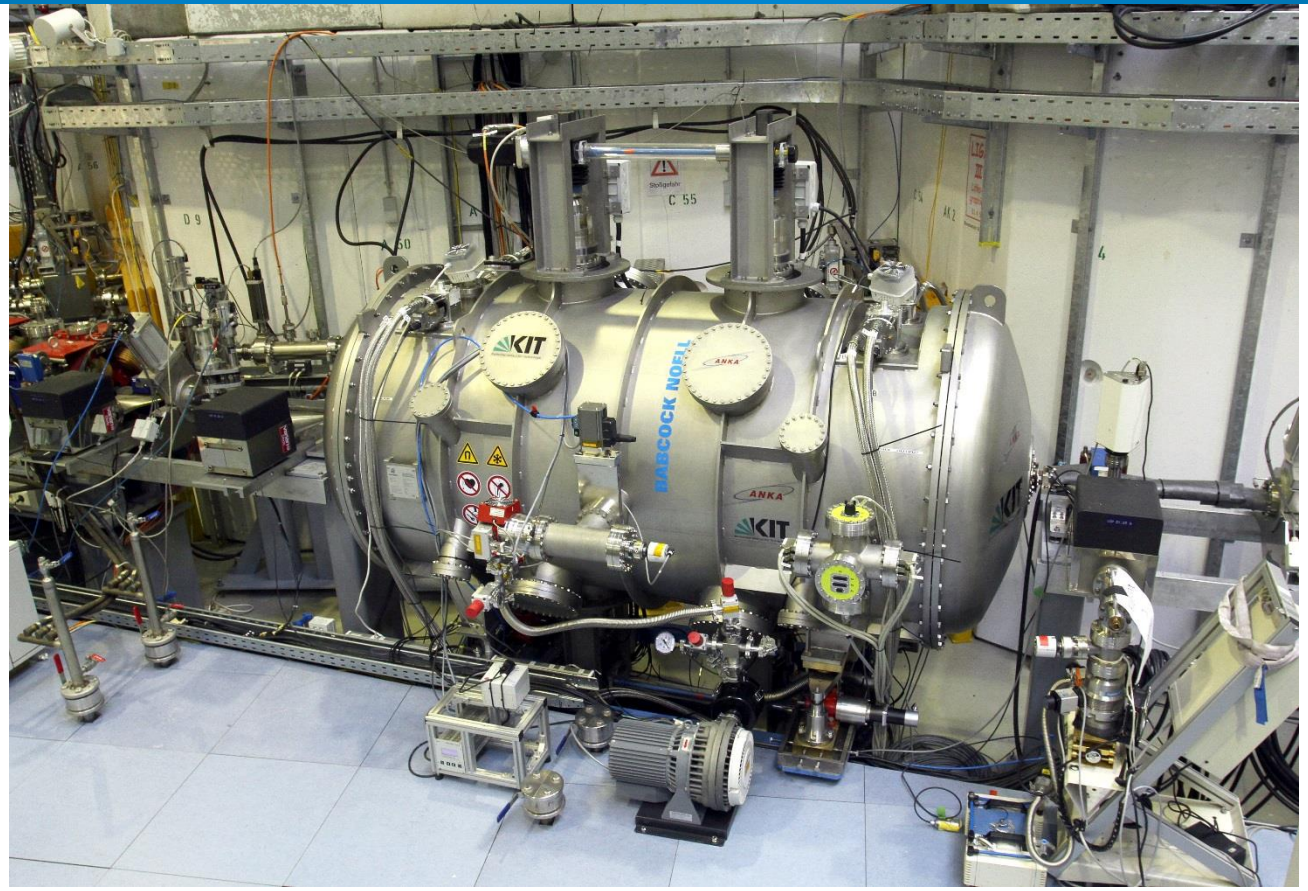
Performance

FAT: operation with current

- Nominal current of 150 A reached without additional training
- Ramp to 150 A in 450 s with slow start to minimize dynamic losses
- Temperature increase during ramp < 0.25 K
- 12 hours system stability demonstrated with current in 10 ppm range



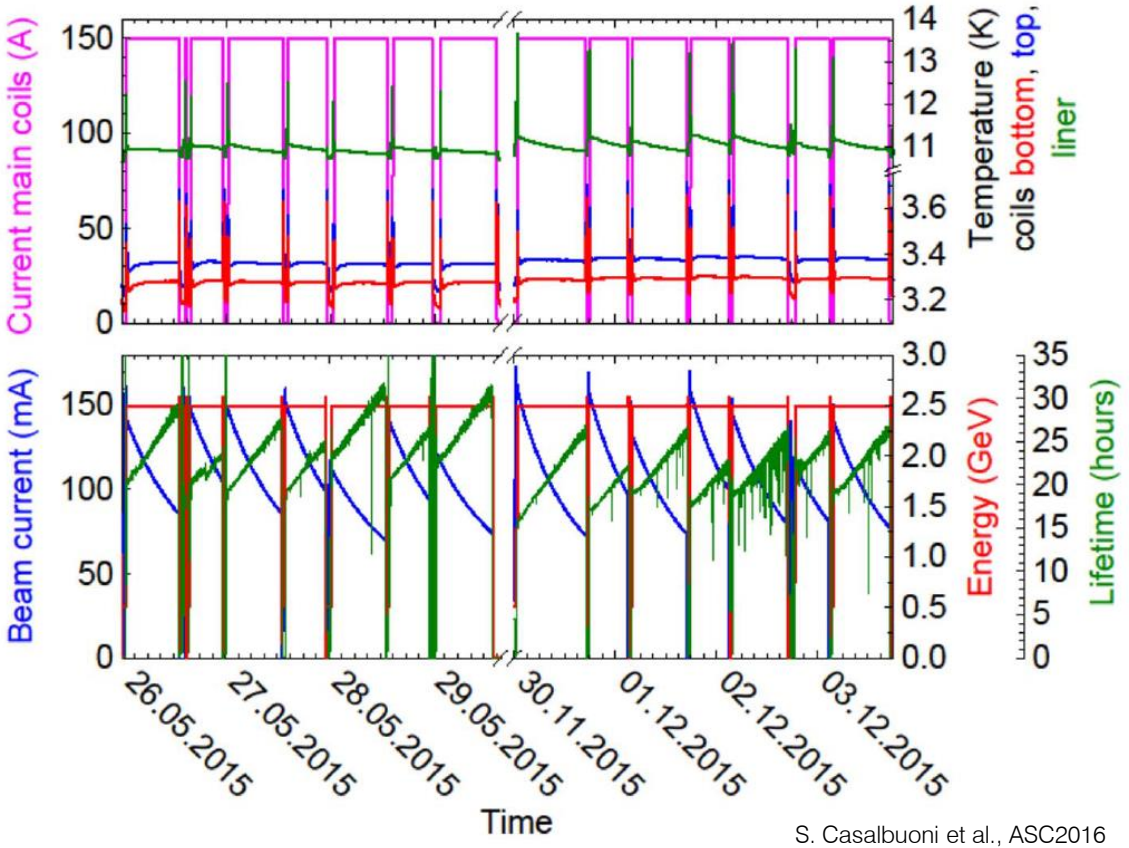
SCU15 in the ANKA ring



Operation in the ANKA ring

Reliable operation

- Reliable operations
- Good thermal decoupling between coils and liner (separated by < 200 um along 1.5 m)

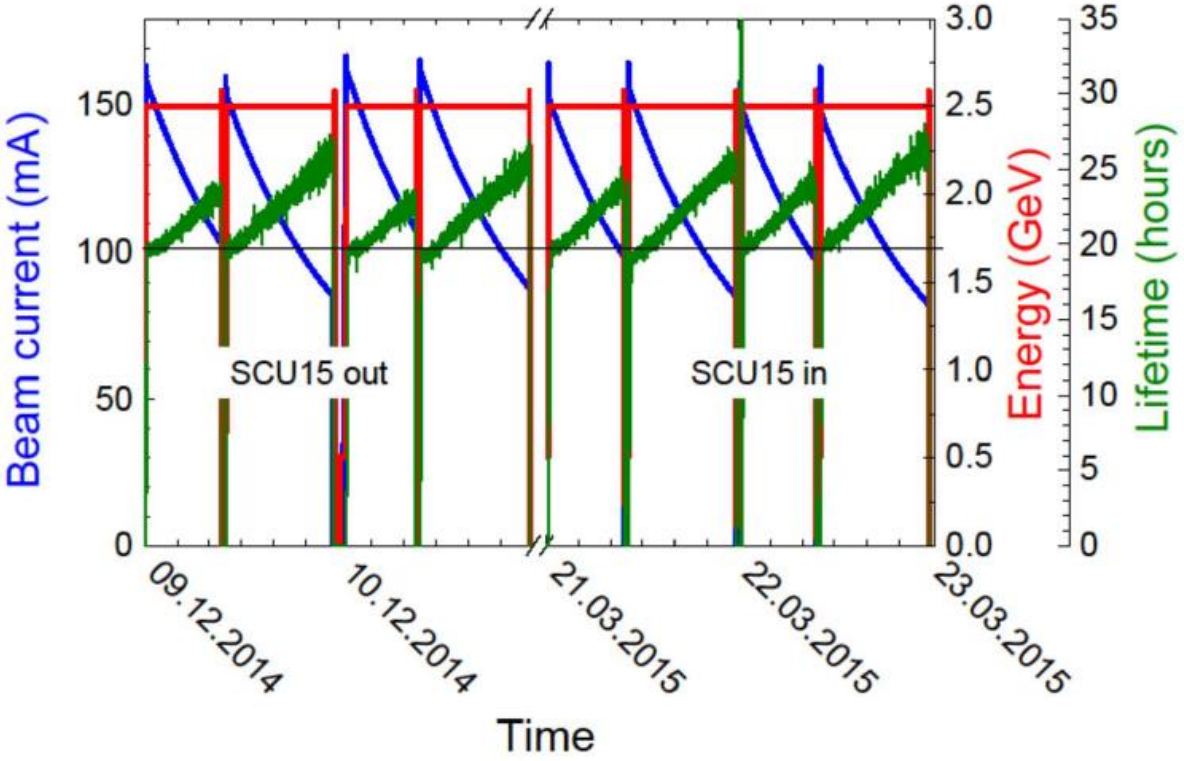


S. Casalbuoni et al., ASC2016

Operation in the ANKA ring

Beam lifetime

- Beam lifetime not affected with SCU15 in the rin
  and in operation.



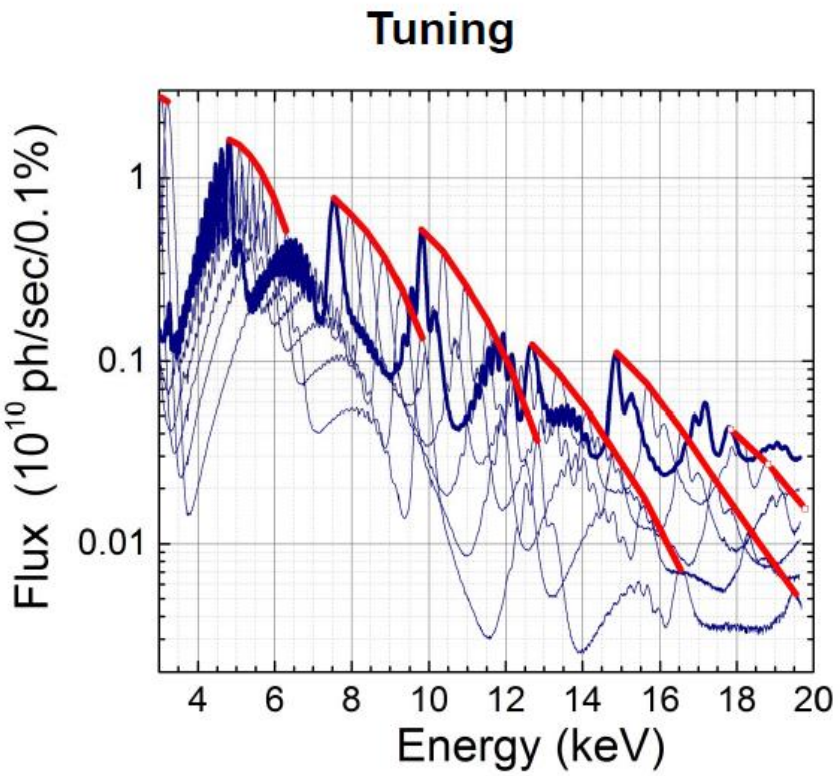
S. Casalbuoni et al., ASC2016

Operation in the ANKA ring

Flux measurement

- Flux through a pinhole of 50 um diameter at 14.9 m normalized to I_{beam} = 100 mA
- Main current in coils 50, 70, 90, 110, 130 and 150 A
- From 3rd harmonic position at max coil current 150 A, B = 0.73 T > B = 0.62 T* of CPMU using PrFeB with the same period length and beam stay clear

* M. E. Couprie et al., FLS 12, Newport News, VA (2012)



S. Casalbuoni et al., ASC2016

Summary

- SCU15 is a full scale device reliably operating in the ANKA ring at KIT.
- For the first time a SCU when operating in ring with beam reaches a higher magnetic field than a CPMU with the same geometry
- Very encouraging results for the implementation of SCUs in low emittance light sources

SCU15 -> SCU20

Lessons learned

Lesson learned from the SCU15 project:

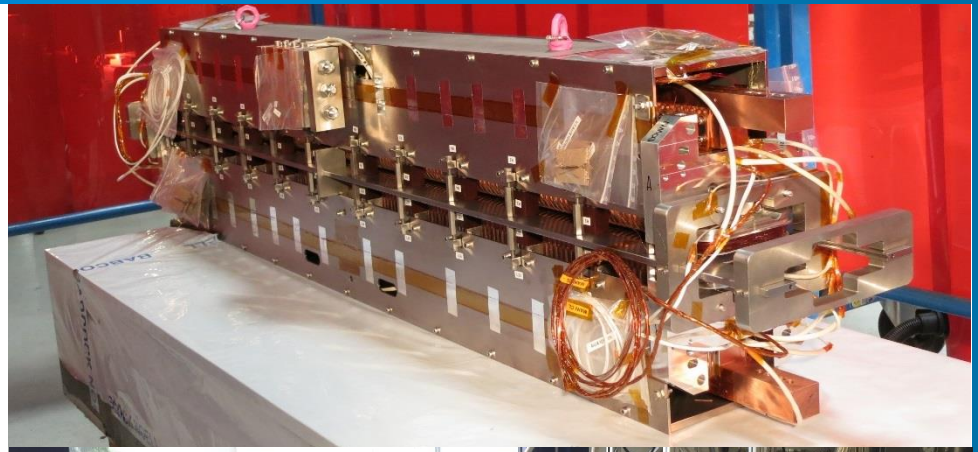
○ Use standard low-carbon steel for the yoke	→	○ reduce procurement risks and machining issues
○ Use a block design for the former	→	○ improve accuracy during assembly
○ Use round superconductor and insulate the former	→	○ avoid electrical shorts between former and wire
○ Minimize the cold mass weight	→	○ reduce the cooldown time
○ Use the flexible pipe as magnet spacer	→	○ improve the uniformity of the gap along the coils

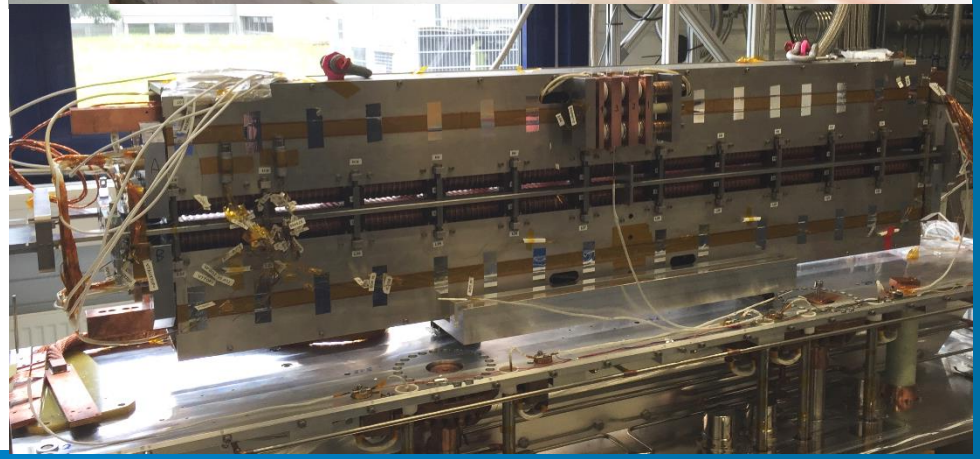
These lessons learned have been implemented in the design of SCU20,
a 20 mm period length, 1.5 m long device.

SCU20

Performance

- The coils (in horizontal configuration) reached nominal current after a short training in the CASPER II facility at KIT
- According to the test results in CASPER II the specified field quality is reached
- An improved liner is being qualified





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