Karlsruhe Institute of Technology

ANKA Synchrotron Radiation Facility

Recent developments on superconducting undulators at ANKA

S. Casalbuoni, A. Cecilia, S. Gerstl, N. Glamann, A. Grau, T. Holubek, C. Meuter, D. Saez de Jauregui, R. Voutta
ANKA, KIT
C. Boffo, Th. Gerhard, M. Turenne, W. Walter
Babcock Noell GmbH

Babcock Noell GmbH

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Outline

- Motivation R&D of SCIDs
- Ongoing collaboration with BNG:
  - SCU15
  - SCU20
- HTS tape stacked undulator for table top FELs
- Tools and instruments for R&D
  - CASPER II
  - COLDDIAG
- Summary

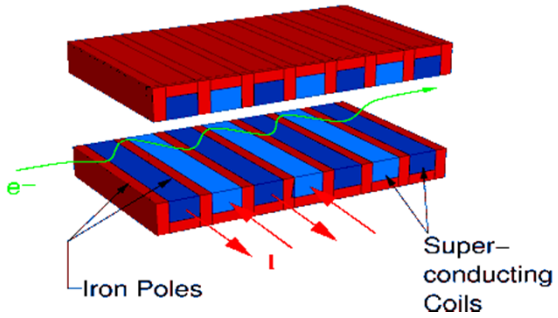
Motivation R&D of scIDs

Develop SCUs for ANKA and low emittance light sources

With respect to permanent magnet undulators SCUs can generate :

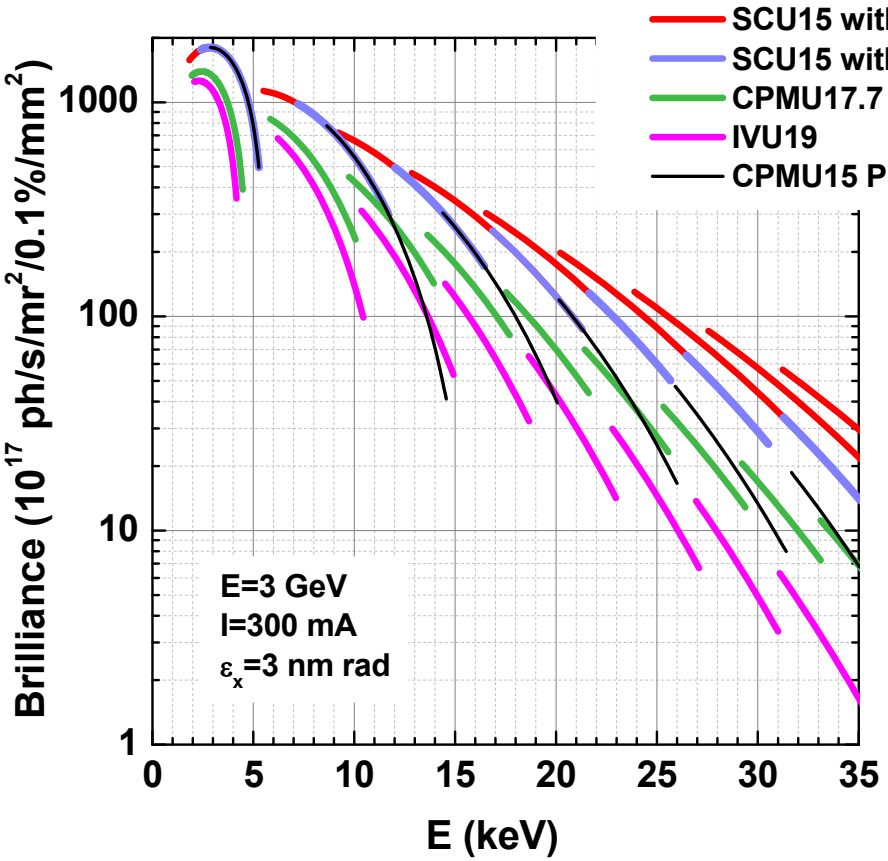
- **Harder X-ray spectrum**
- **Higher brilliance X-ray beams**

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



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

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



	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

Simulations performed with SPECTRA§

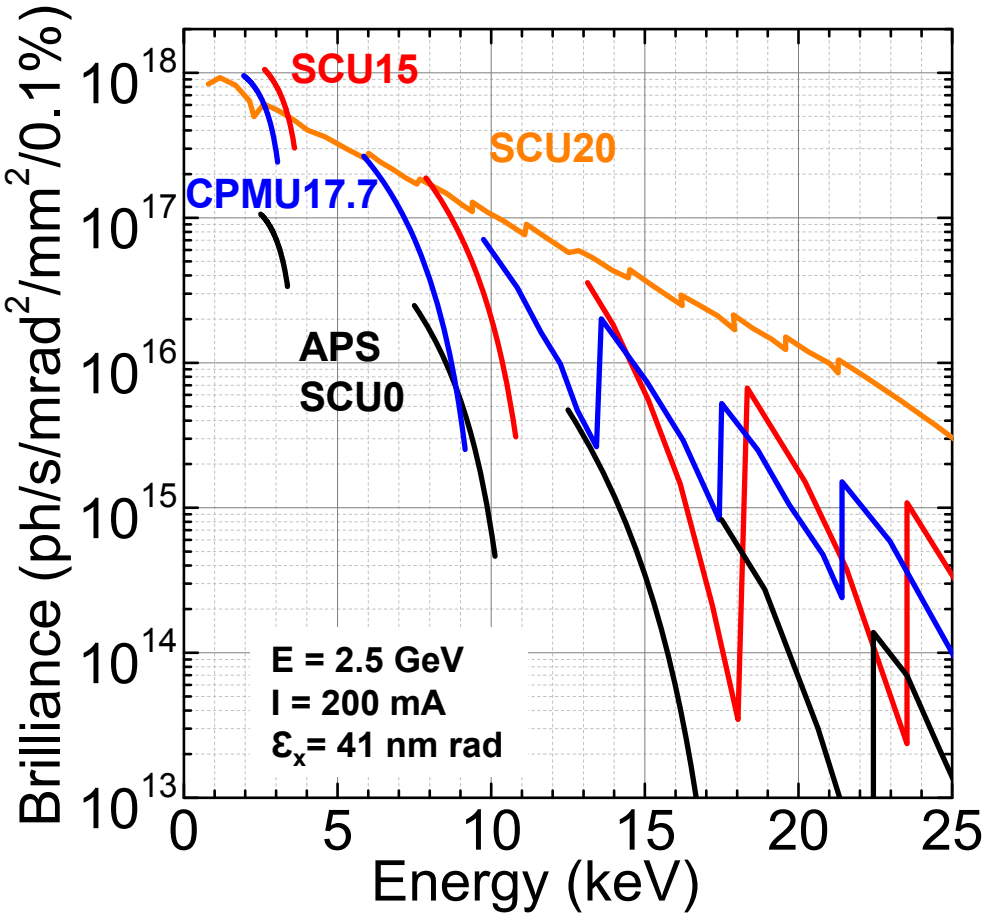
*F. Bødker et al., EPAC06
†C.W. Ostenfeld & M. Pedersen, IPAC10
#M.E. Couprie et al., FLS2012
**D. Saez de Jauregui et al., IPAC11
††T. Holubek et al, IPAC11

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

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

Motivation R&D of scIDs

At ANKA large vacuum gap 7 mm instead of 5 mm
→ longer period lengths



SCU20 has larger brilliance and flux than SCU15

vacuum gap = 7 mm

	CPMU† (DLS)	APS SCU0*	SCU15**	SCU20††
λ_u [mm]	17.7	16	15	20
# of periods	87	20	102	77
B [T]	0.71	0.64	0.70	1.46
K	1.17	0.96	0.98	2.20

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

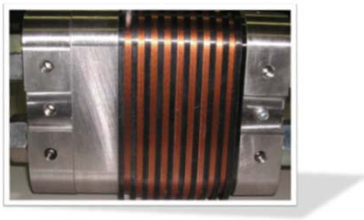
†C.W. Ostenfeld & M. Pedersen, IPAC10
***Y. Ivanyushenkov et al., IEEE Trans. on Appl. Supercon. 4102004, Vol. 24-3 (2014)**
****D. Saez de Jauregui et al., IPAC11**
†† S. C. et al., IEEE Trans. on Appl. Supercon. 4101305, Vol. 24-3 (2014)

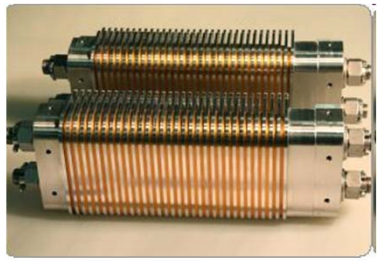
Ongoing collaboration of ANKA and BNG to develop SCUs for ANKA and low emittance light sources

- NbTi wire
- Conduction cooling
- Movable vacuum chamber

Common design ANKA and BNG
Manufacturing: BNG
Testing: ANKA

SCU15



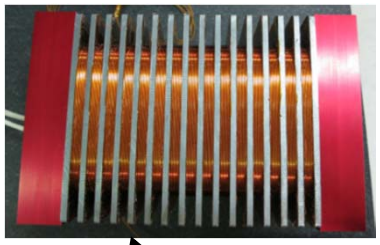


Mockup1 0.15 m

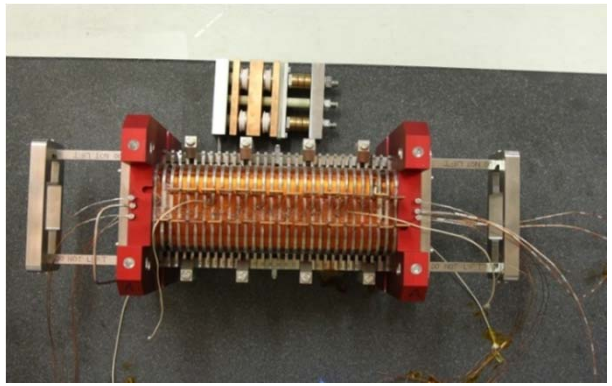
Mockup2 0.30 m

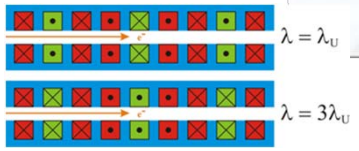
Long coils 1.5 m

time



SCU20





SCUW18-54

Babcock Noell GmbH

SCU15: main characteristics

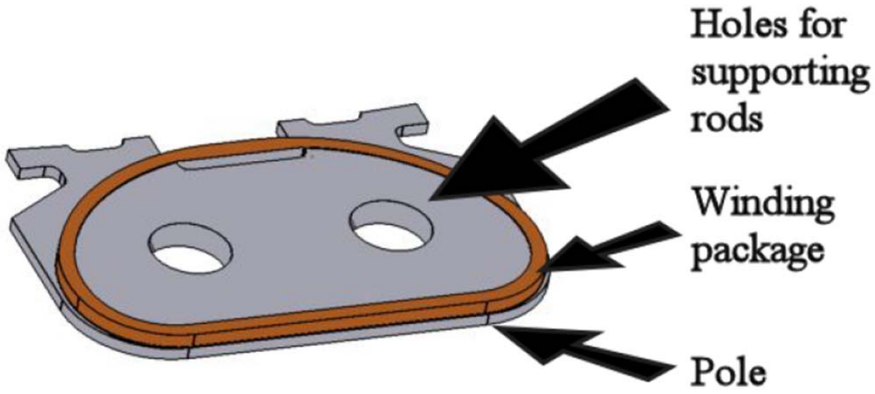
- Period length : 15 ± 0.01 mm
- Number of full periods: 100.5
- Peak field on axis > 0.69 T
- Mechanical accuracies at 300 K < 50 μm
- Beam heat load 4 W
- Beam stay clear

gap closed (open) > 7 (15) mm

- To be better than CPMUs, with NbTi

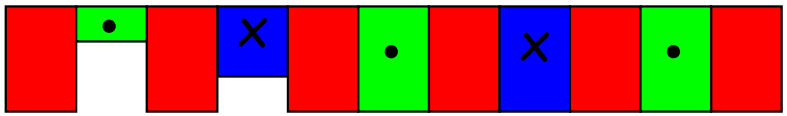
needed nominal difference magnetic and vacuum gap 1 mm

206 plates of high magnetic field saturation cobalt-iron alloy



Cross section NbTi wire:
0.54 mm x 0.34 mm (including insulation)

End fields:
first winding packages 21 turns (3 layers)
second winding packages 63 turns (9 layers)

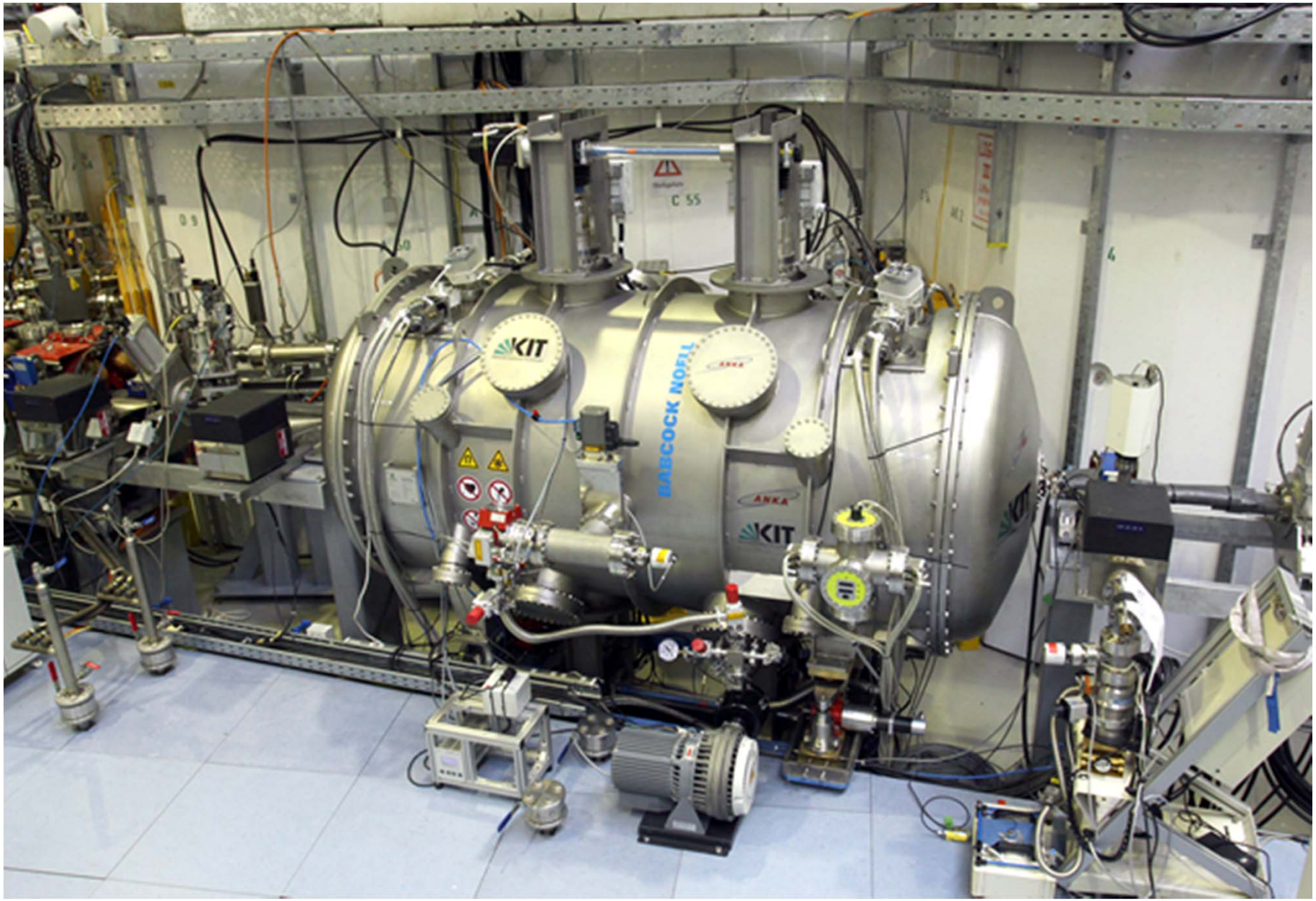


SCU15: tests without beam

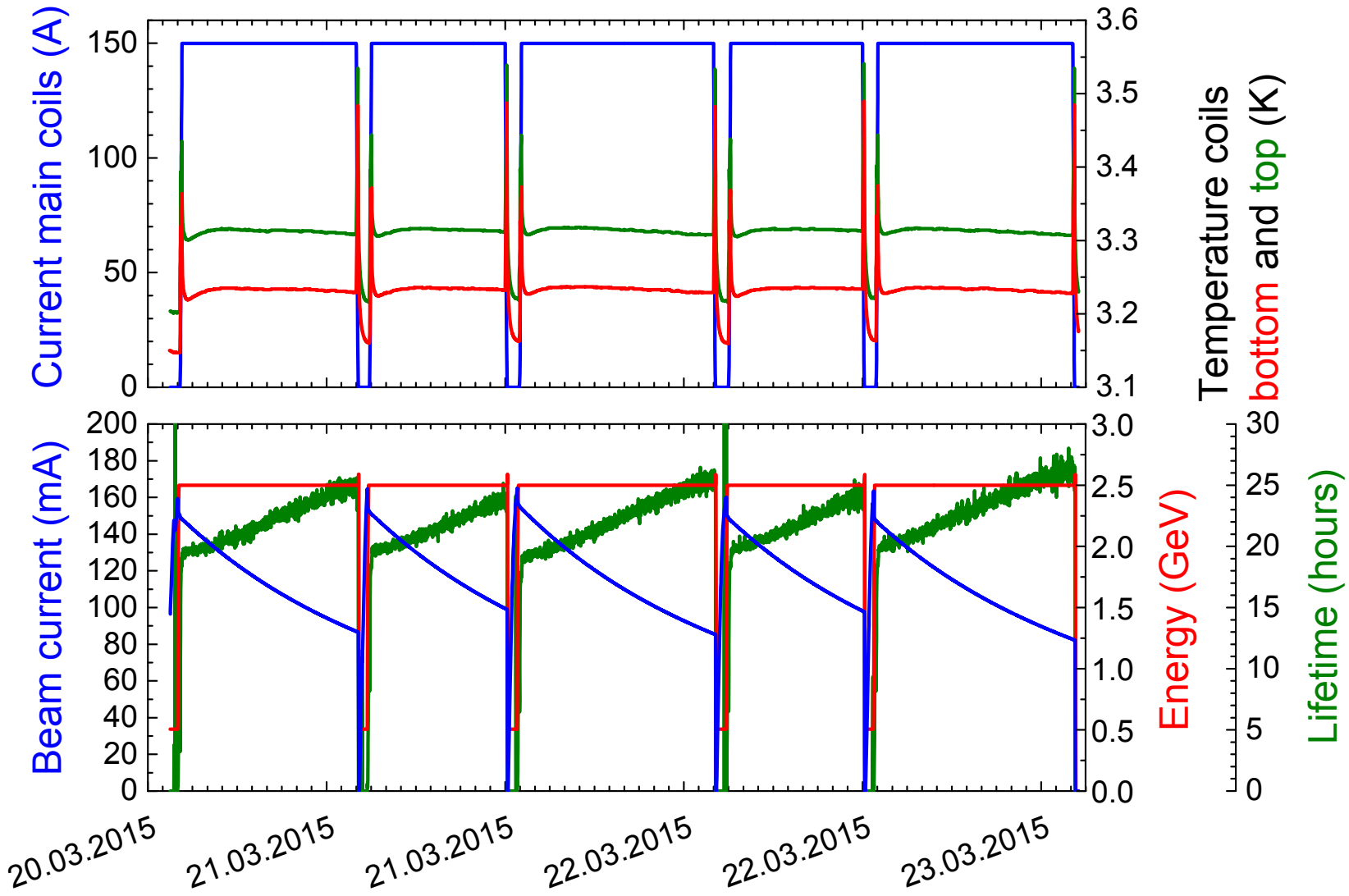
- FAT completed summer 2014
- Installation in ANKA 12.2014-1.2015
- Tests with beam in 2015

- Cooling time 7 days
- Warming up 4 days
- Ramping time < 600 s
- Current stability of main coils at max. current 150 A and correction coils successfully tested for 6 days
- Movable vacuum chamber 7 mm – 15 mm at 10 K: successful vacuum test < 3 x 10^{-10} mbar in cold conditions

SCU15 installed in ANKA

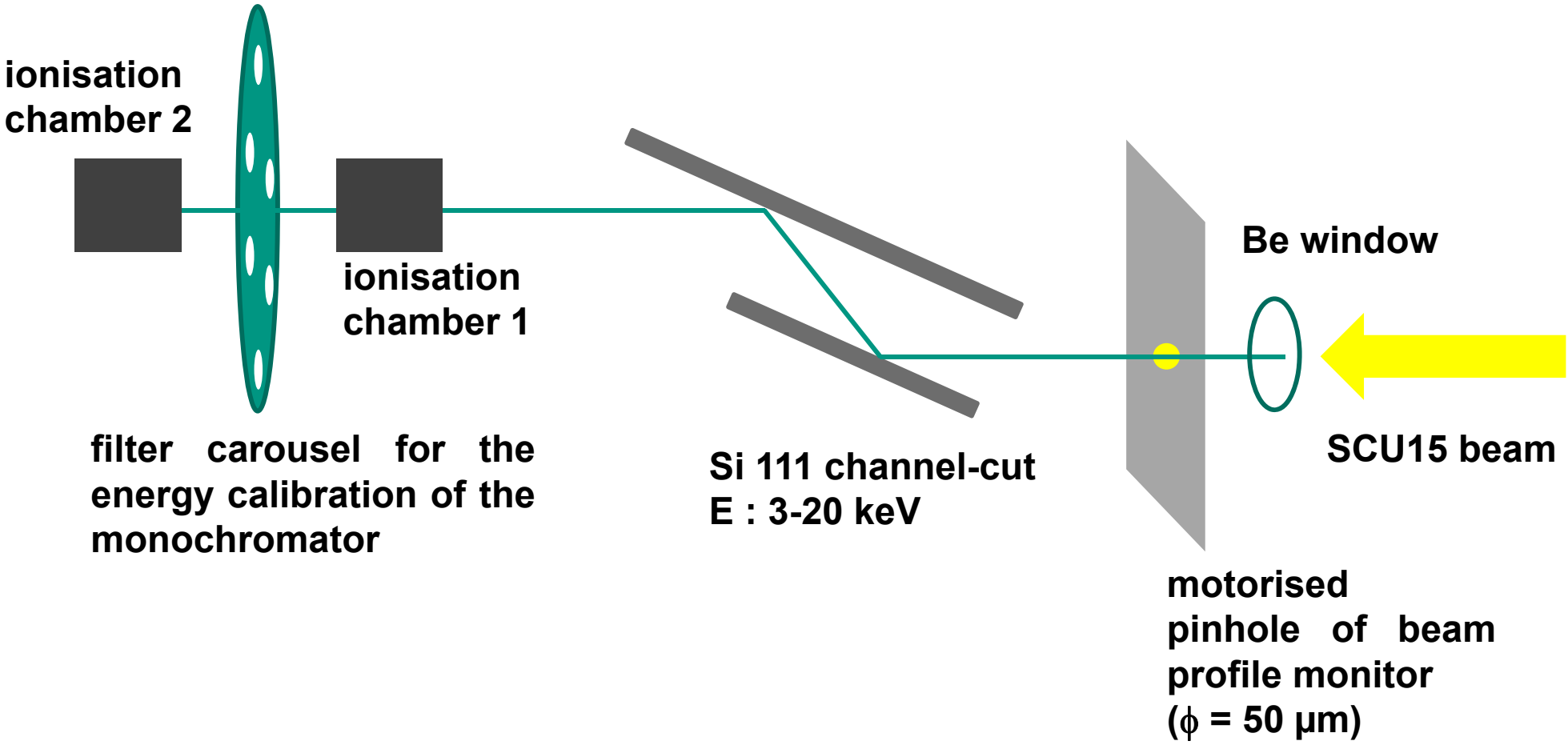


SCU15: tests with beam



Reliable operation

SCU15: Experimental setup for flux measurements

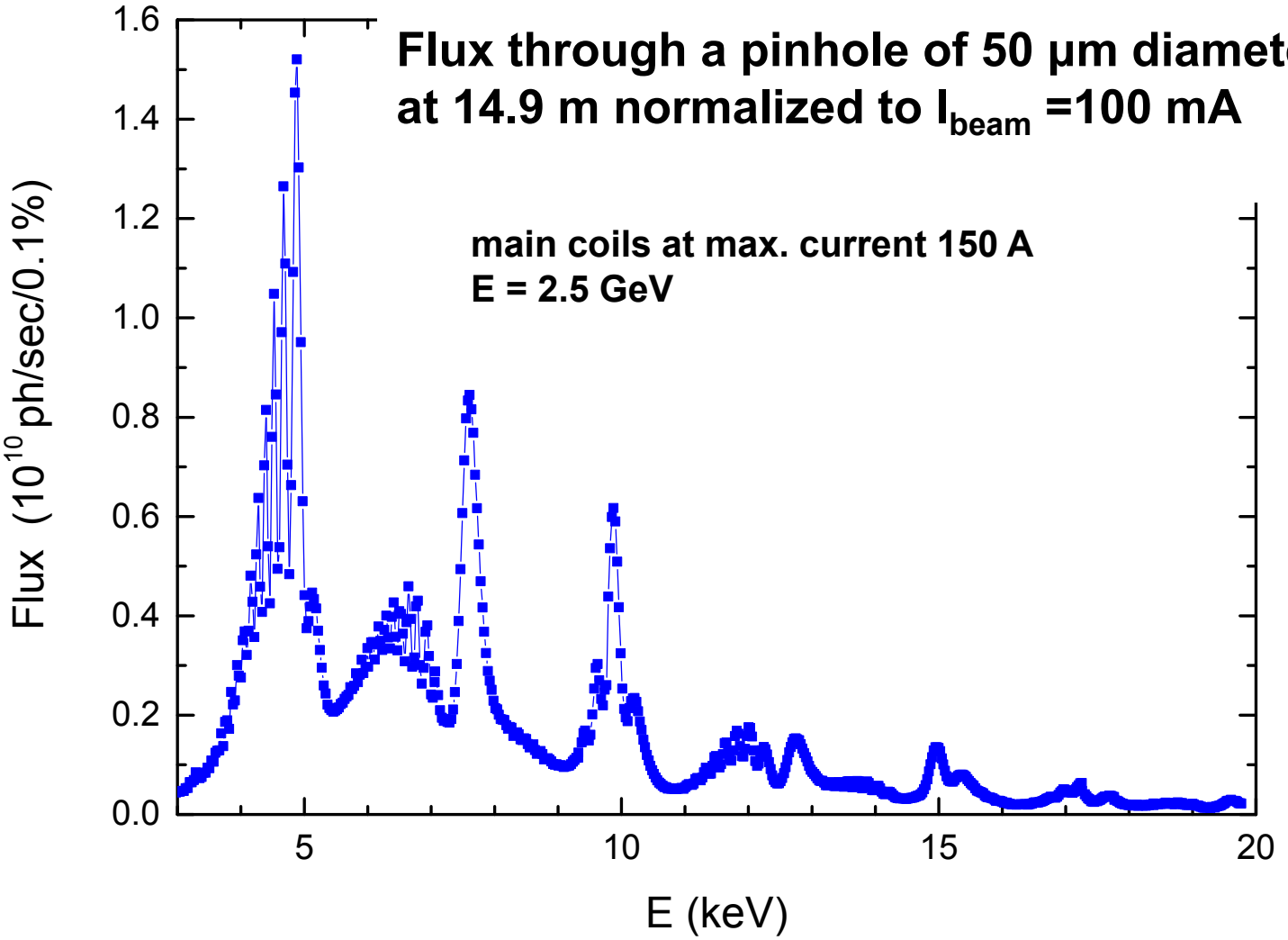


SCU15: tests with beam

Babcock Noell GmbH

Karlsruhe Institute of Technology

Flux through a pinhole of 50 µm diameter at 14.9 m normalized to I_{beam} =100 mA



From 3rd harmonic position B = 0.73 T > B=0.62 T* of CPMU using PrFeB with the same period length of 15 mm and beam stay clear of 7 mm.

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

SCU20

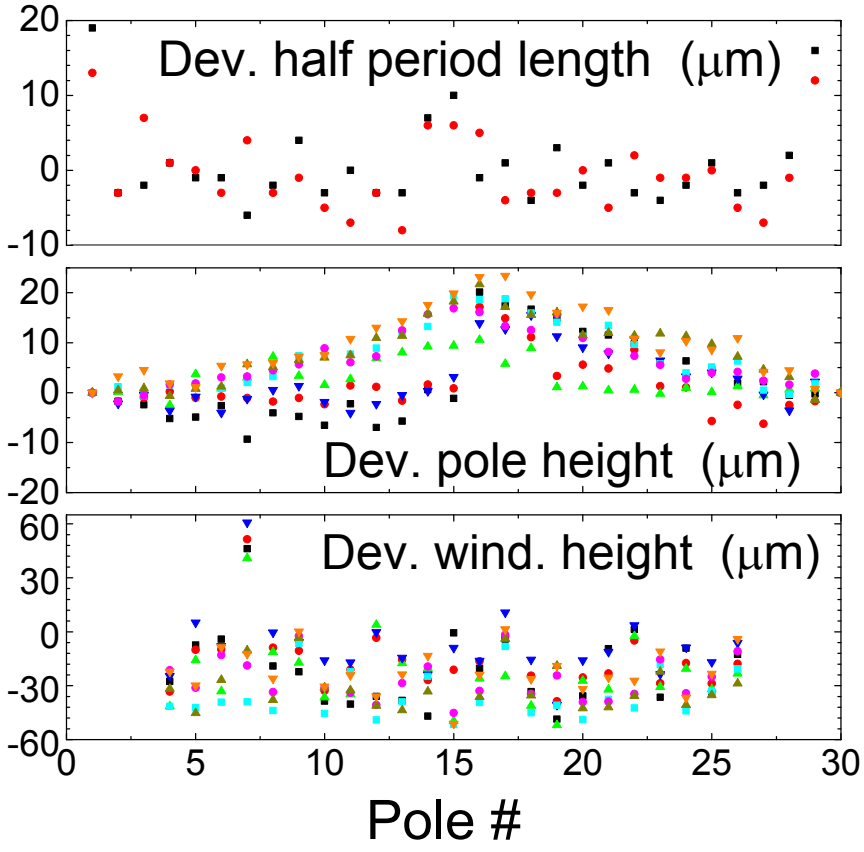
- Lessons learned from previous development of 1.5 m long undulator coils:
  round wire, low carbon stainless steel, blocks ~0.15 m, racetrack,
  new winding scheme: from one groove to the next changing winding direction

- Achievements of Mockup 2 (~ 30 cm long)

  - Mechanical accuracies at 300 K

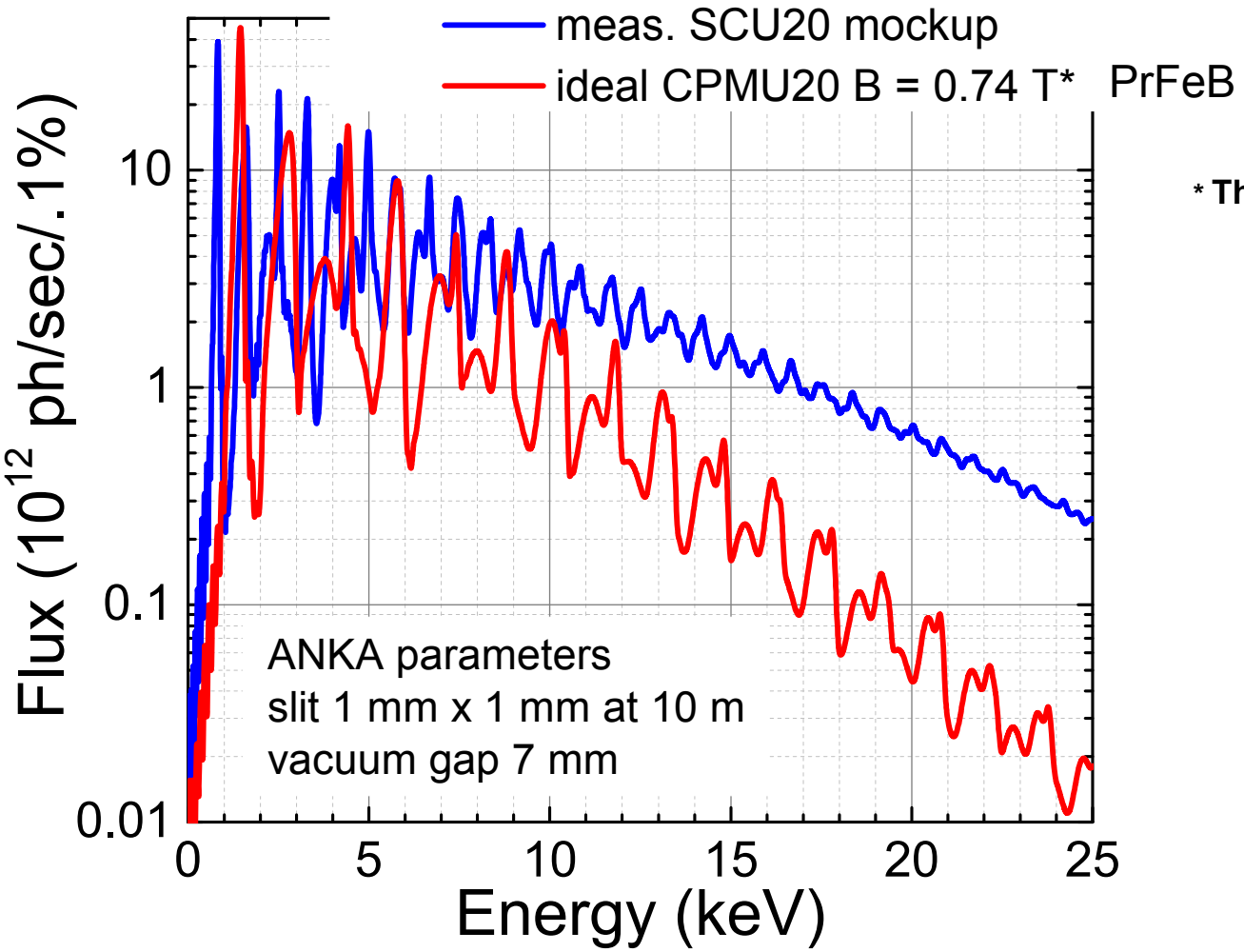
  - Test in LHe and in conduction cooling 400 A reached without quench (nominal current 380 A)

  - In conduction cooling at ~ 4 K
    688 A reached at the end of training



SCU20: Achievements of Mockup 2

Calculated spectral performance with SPECTRA§

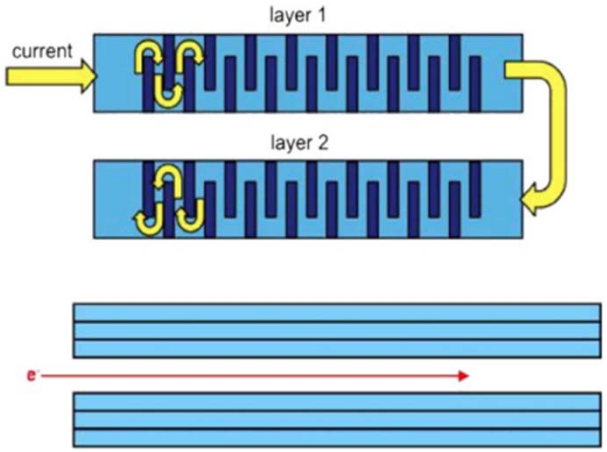


* **Th. Schmidt, private communication.**

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

Considering an operating temperature of the magnet of 4.2 K, design temperature margin of about 2 K.

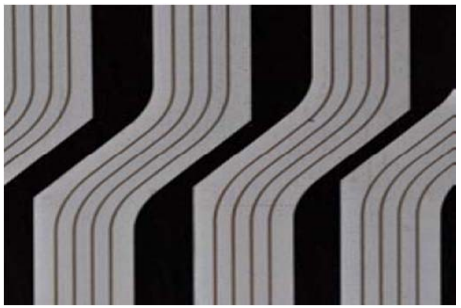
HTS tape stacked undulator for table top FELs

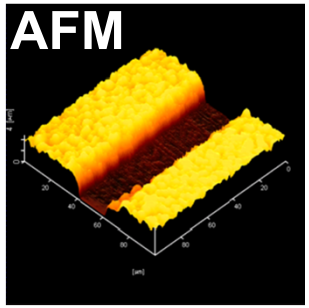


S. Prestemon et al., IEEE Trans. on Appl. Supercond. 1880-1883 Vol. 21-3 (2011)

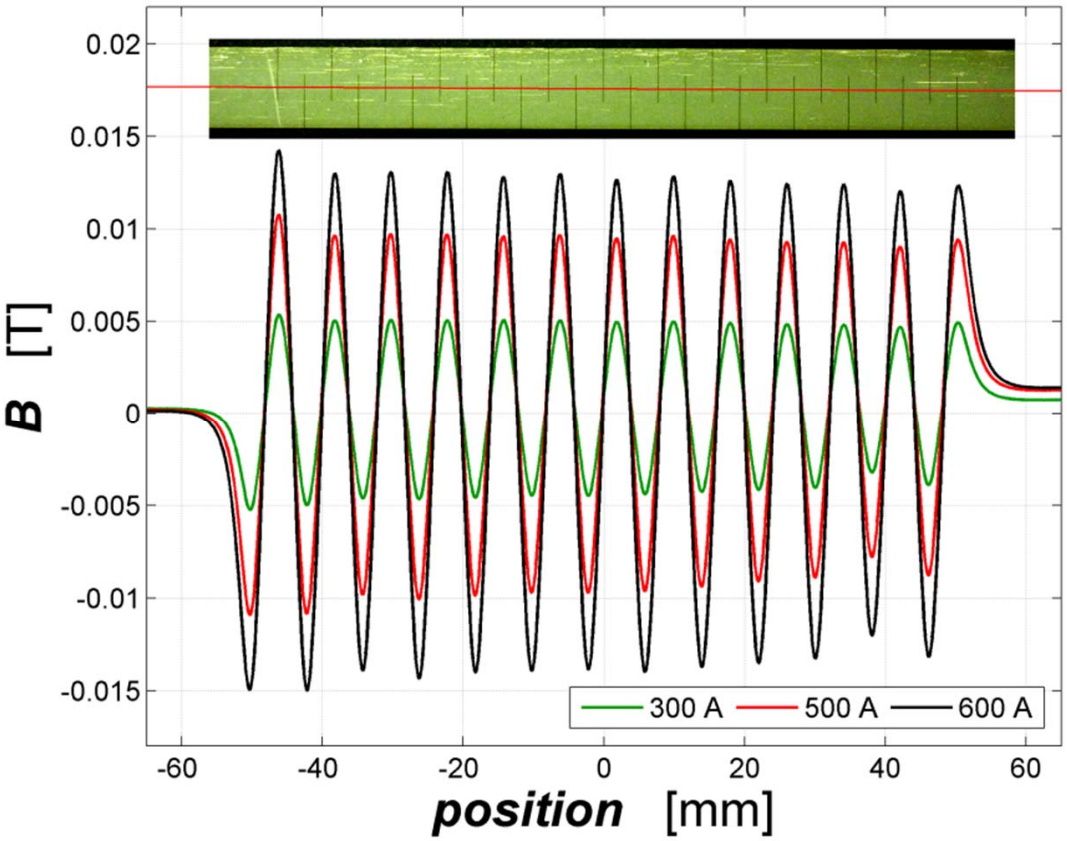
KIT internal collaboration:
ANKA with ITEP

- Etching using Trumpf picosec YAG - IR laser, programmable beam control used for Roebel cables
- Groove formation very reliable applying laser
- No contamination of groove detected (SEM)





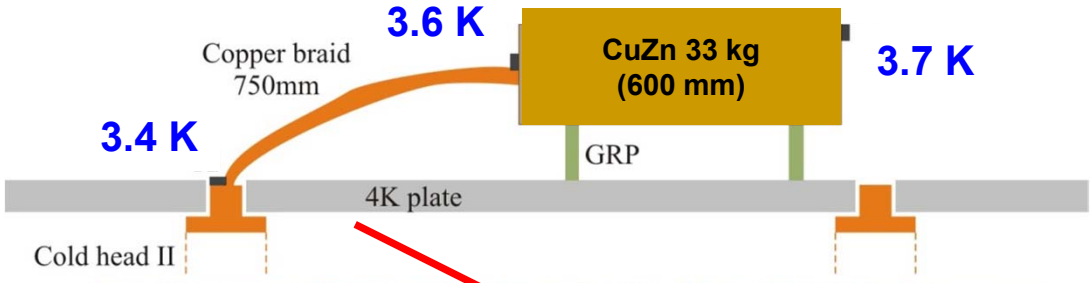
First magnetic field measurements on HTS structured tape

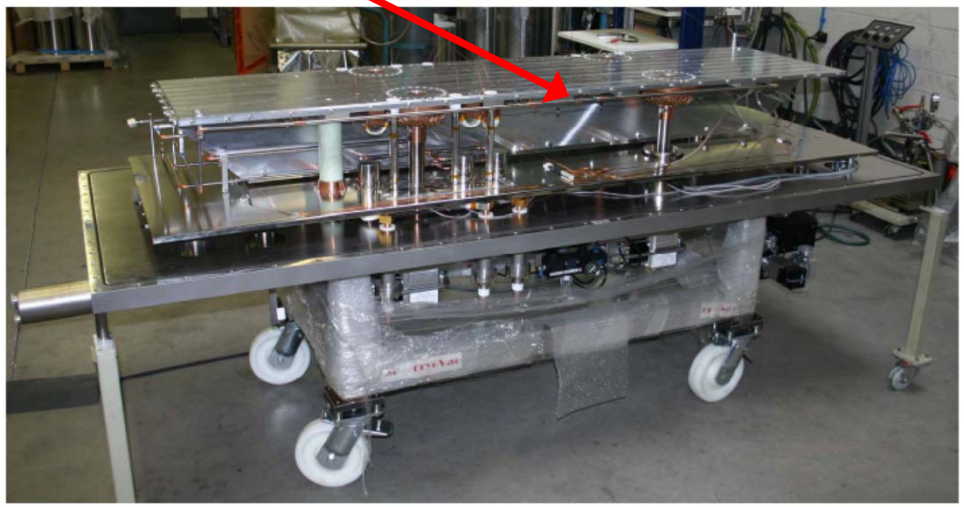


T. Holubek et al., IEEE Trans. on Appl. Supercond. 4602204 Vol. 23-3 (2013)

Tools and instruments for R&D: CASPERII

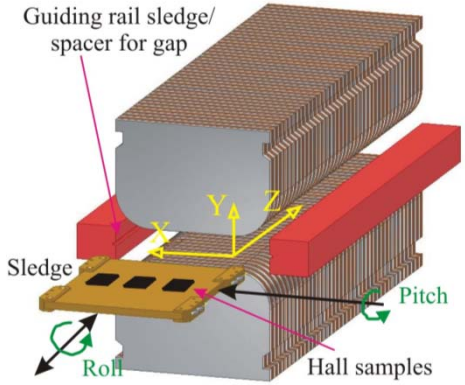
Successful factory acceptance test



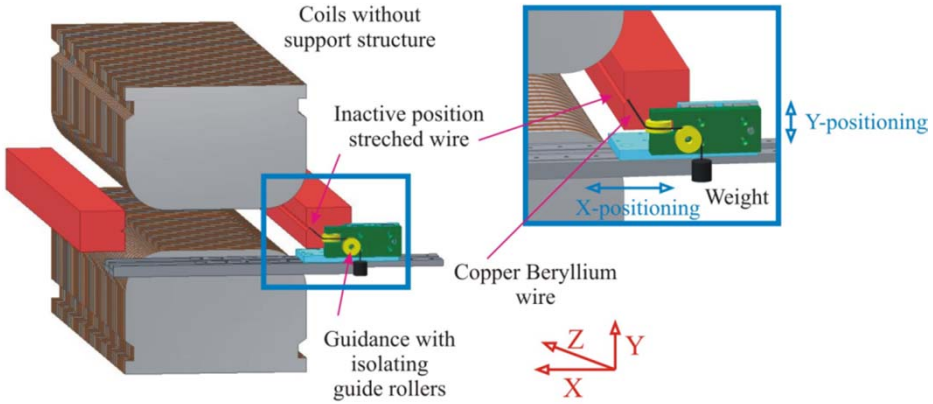


A. Grau et al., IEEE Trans. on Appl. Supercond. 9001504 Vol. 22-3 (2012)

- **Local field measurements with Hall probes**



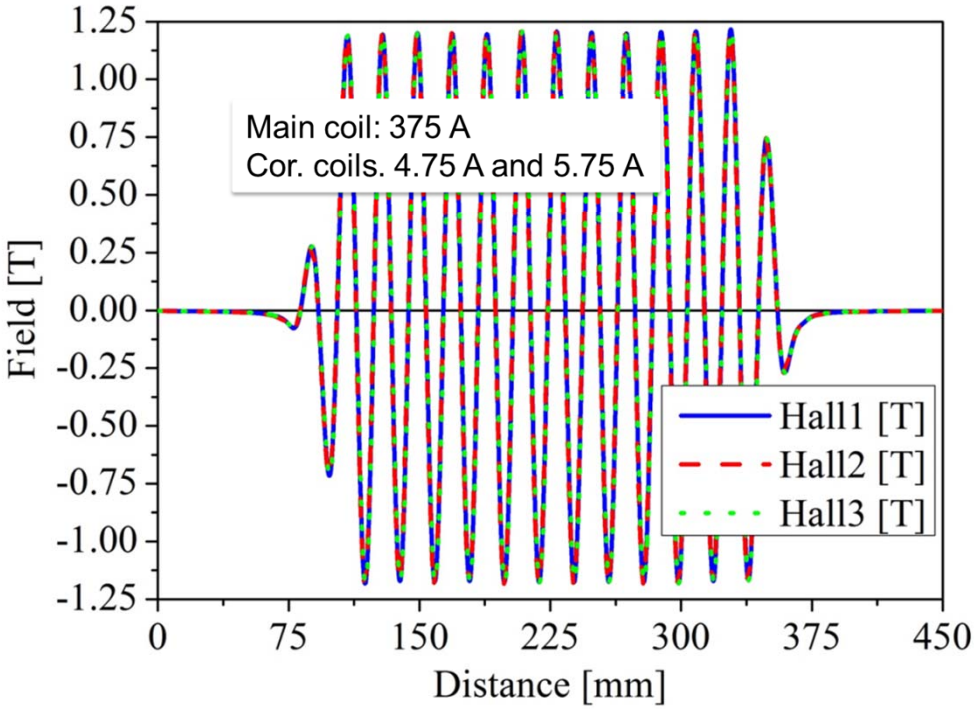
- **Field integral measurements with stretched wire**

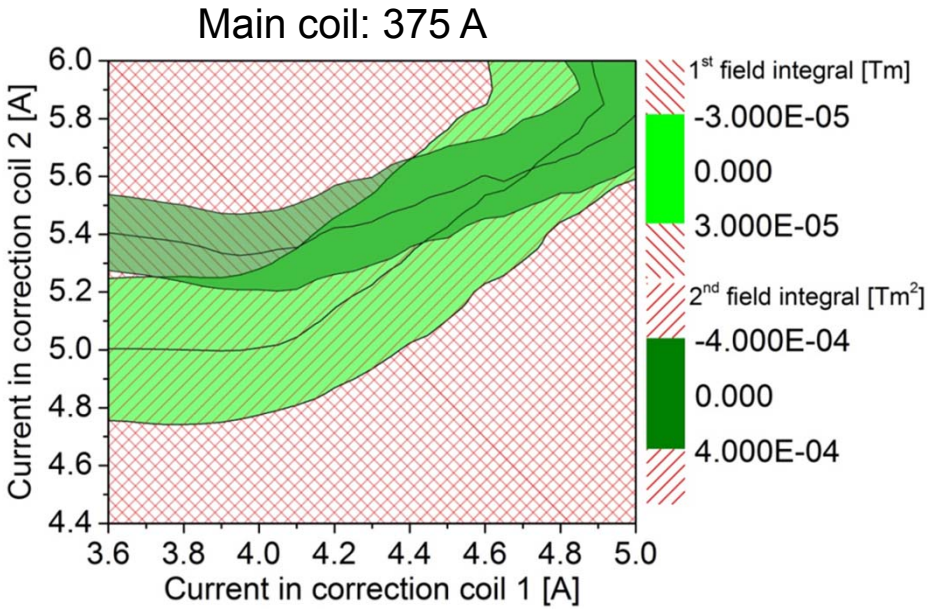


A. Grau et al., IEEE Trans. on Appl. Supercond. 2312-2315 Vol. 21-3 (2011)

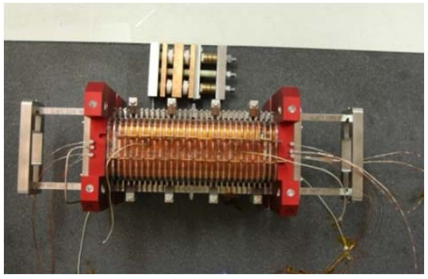
Tools and instruments for R&D: CASPERII

Commissioning of local and integral field measurement systems accomplished





Poster S. Gerstl, WEPMA027



SCU20 Mockup 2

Tools and instruments for R&D: COLDDIAG

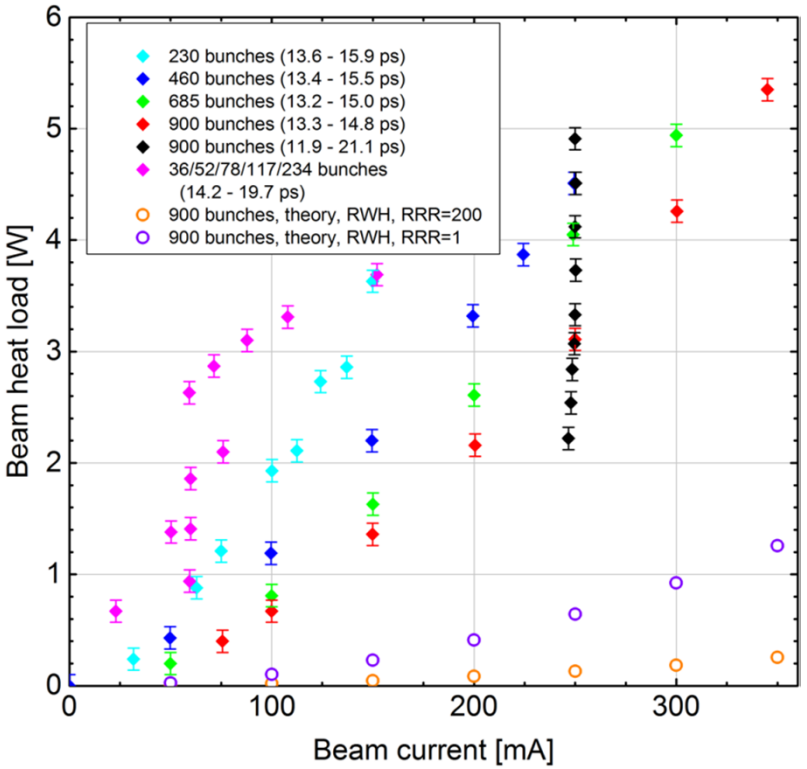
Cold vacuum chamber for diagnostics to **measure the beam heat load** to a cold bore in different synchrotron light sources

The beam heat load is needed to specify the cooling power for the cryodesign of superconducting insertion devices

The **diagnostics** includes measurements of the:

- **heat load**
- **pressure**
- **gas composition**
- **electron flux of the electrons bombarding the wall**

Poster R. Voutta, TUPWA025

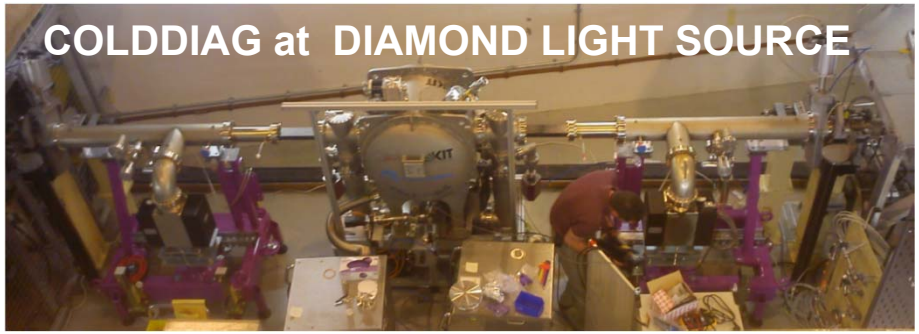


Significant discrepancy compared to theoretical expectations …

S. C. et al., JINST 7 P11008 (2012)

In collaboration with
CERN: V. Baglin
LNF: R. Cimino, B. Spataro
University of Rome ‚La sapienza': M. Migliorati
DLS: R. Bartolini, M. Cox, E. Longhi,
G. Rehm, J. Schouten, R. Walker
MAXLAB : Erik Wallèn
STFC/DL/ASTeC: J. Clarke
STFC/RAL: T. Bradshaw

S. Gerstl et al., PRSTAB, 17, 103201 (2014)

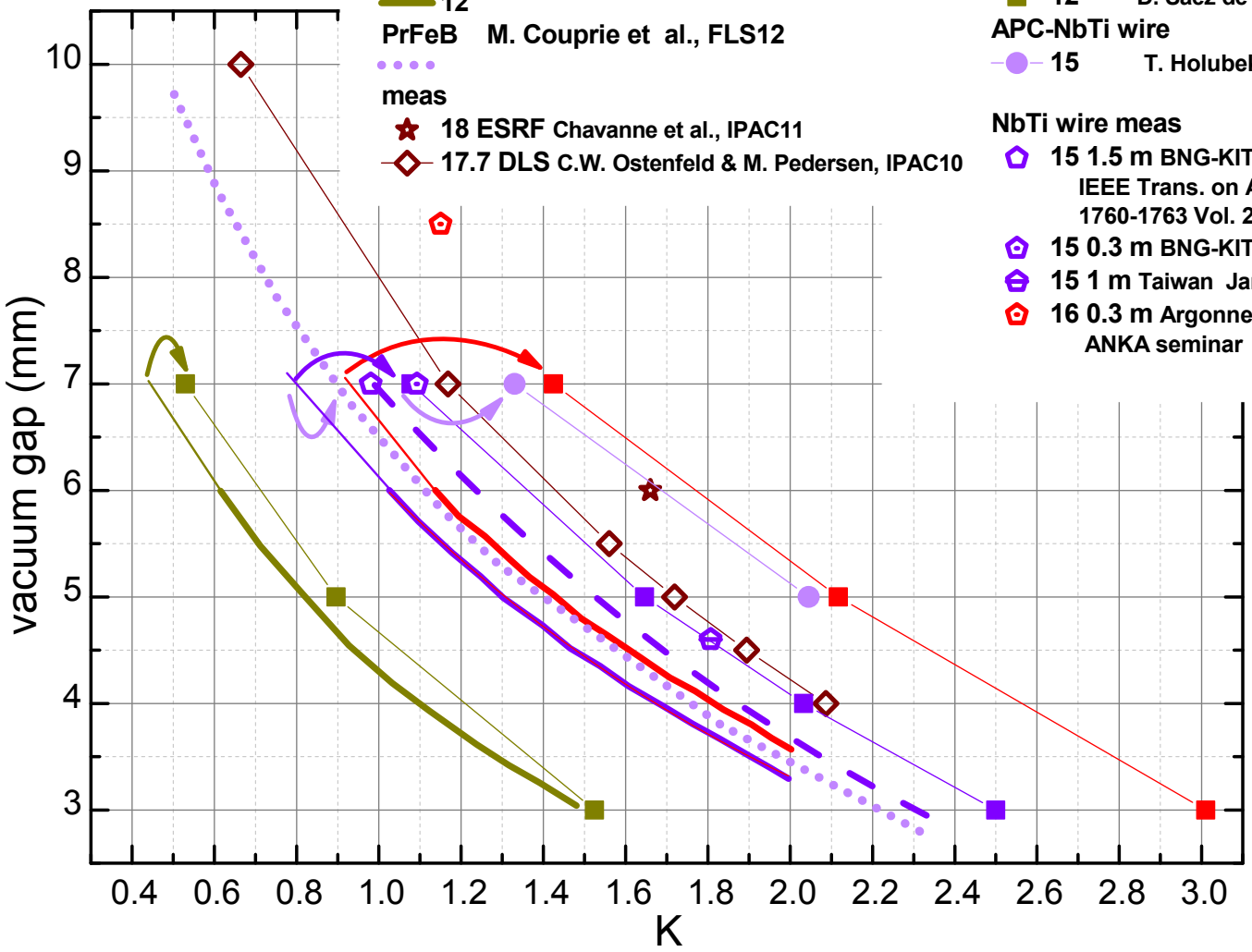


Summary

- **SCU15**
  - Reliable operation of a full scale device with 15 mm period length in the ANKA storage ring
  - For the first time for SCUs with beam, higher fields than CPMUs with the same geometry
- **SCU20** **0.3 m mockup**
  - Mechanical tolerances at RT < 60 μm
  - Test in cond. cooling 688 A reached at ~ 4 K (nominal current 380 A)
  - Spectral performance advantages on CPMU
- **HTS stacked undulator**
  - The first magnetic field measurements on a HTS structured tape have been successfully performed in the test facility CASPER I (liquid helium bath)
- **Development tools for R&D on SCIDs**
  - CASPER II: commissioning of local and integral field measurement systems accomplished
  - COLDDIAG: measured beam heat load to a cold bore installed in the DLS

Backup slides

Motivation R&D of scIDs



SCU
period length (mm)
NbTi wire
- 16 D. Saez de Jauregui et al., IPAC11
- 15 T. Holubek et al, IPAC11
- 12 D. Saez de Jauregui et al., IPAC11

APC-NbTi wire
- 15 T. Holubek et al, IPAC11

NbTi wire meas
- 15 1.5 m BNG-KIT S. Casalbuoni et al., IEEE Trans. on Appl. Supercond. 1760-1763 Vol. 21-3 (2011)
- 15 0.3 m BNG-KIT S. Casalbuoni et al., SRI10
- 15 1 m Taiwan Jan et al., IPAC10
- 16 0.3 m Argonne, Y. Ivanyushenkov et al., ANKA seminar

Comparison SCU - CPMU
for SCU magnetic gap = vacuum gap + 1 mm

- **SCU higher K CPMU, most pronounced for longer period lengths**
- **Novel materials give further improvements, especially for SCUs**

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