Commissioning experience with commercial superconducting undulators

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Outline

- Motivation
- KIT-Noell SCUs development
- SCU20 layout
- Magnetic field characterization
- Tests without beam
- Tests with beam
- Conclusions

Motivation

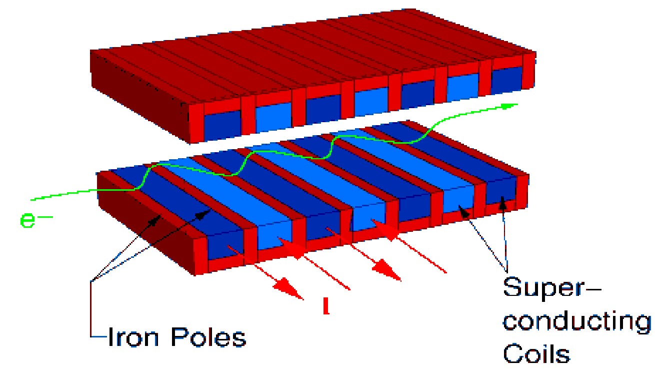
Aim is to develop, manufacture, and test superconducting undulators (SCUs) for low emittance light sources

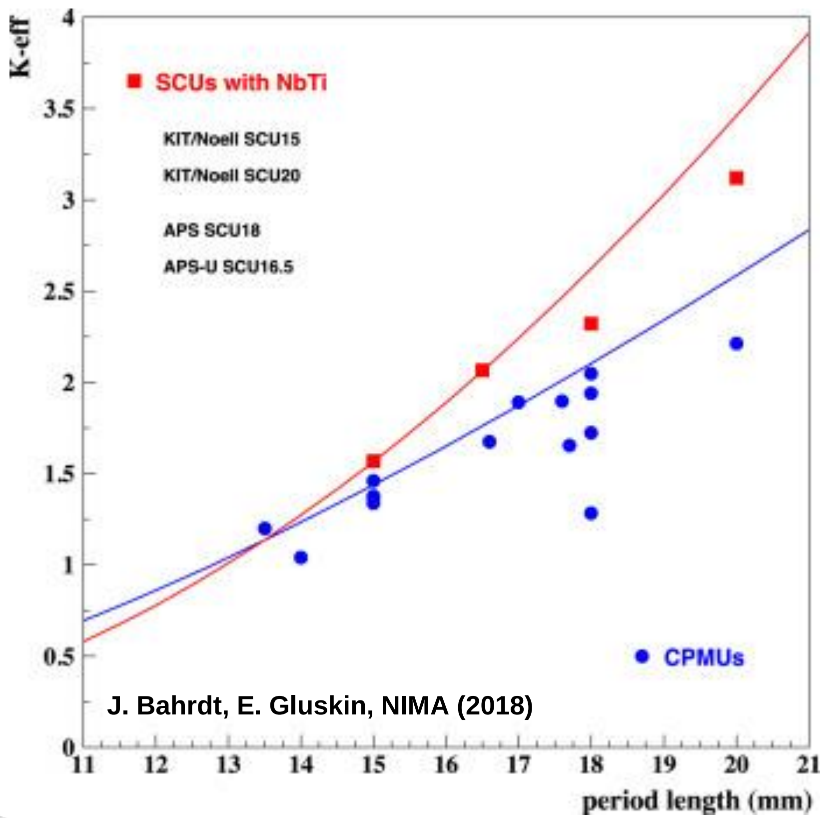
With respect to permanent magnet undulators SCUs can generate :

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

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

- **Radiation hardness**





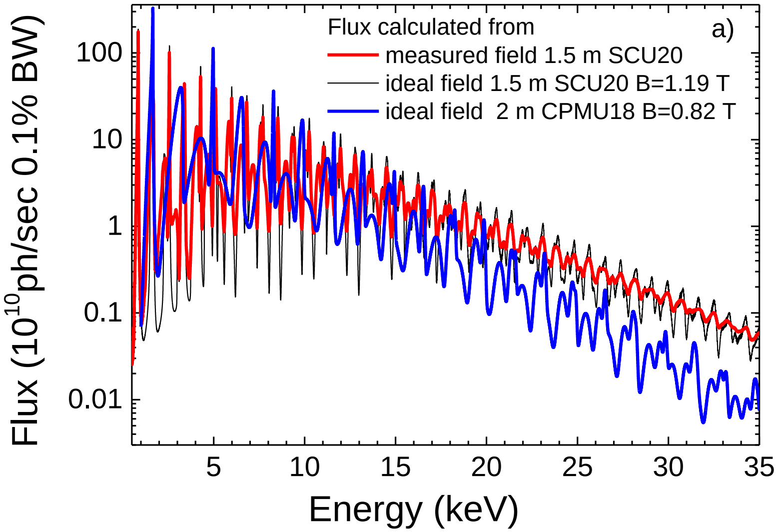
All K-values are scaled to the same vertical aperture of 5.0 mm. The CPMU gap loss is 0.2 mm. The SCU gap losses are 2.5 mm (SCU18), 1.8 mm (SCU16.5) and 1 mm for the KIT/Noell devices

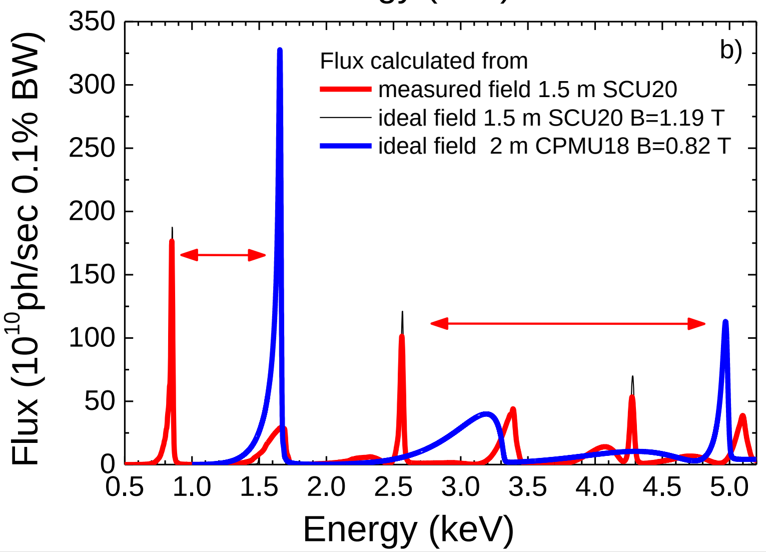
Performance of SCUs and CPMUs

Facility	Start-Finish of Operations	λ_0 (mm)	# of periods	Vacuum aperture (mm)	Gap loss (mm)	B (T)	Cooling
APS 2 SCUs	2015-current 2016-current	18	59.5	7.2	2.3	0.97	4 cryocoolers, LHe closed circuit
APS	2013-2016	16	20.5	7.2	2.3	0.8	4 cryocoolers, LHe closed circuit
KIT/Noell	2014-2015	15	100.5	7, 16 (open)	1	0.73	4 cryocoolers
KIT/Noell	2017-current	20	74.5	7, 15 (open)	1	1.18	4 cryocoolers

Motivation

Flux at 10 m from the source through a slit 50 µm × 50 µm at KARA





1.5 m SCU20 versus an ideal (without mechanical errors and perfect end fields) 2 m PrFeB CPMU18 with the same parameters as the one built at SOLEIL. The vacuum gap is for both 7 mm.**

**** C. Benabderrahmane et al., Phys. Rev. Accel. Beams 20, 033201 (2017)**)

- Larger flux of the SCU20 with respect to the CPMU18 at high energies up to a factor of 5.

- At low photon energies the energy regions allowed with the SCU20, are not reachable with the CPMU18, due to its lower peak field on axis.

S. C. et al, IOP Conf. Series: Journal of Physics: Conf. Series 874 (2017) 012015

KIT and Noell development of SCUs for the KIT synchrotron and low emittance light sources

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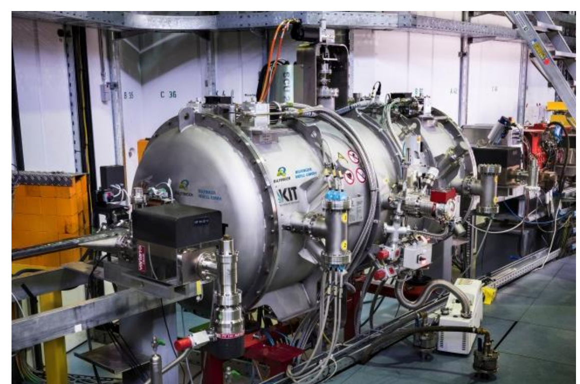
- NbTi wire
- Conduction cooling => no need of cryogenic fluids
- Movable vacuum chamber: highly desirable during commissioning and “nice to have” during operation

SCU15



SCU20

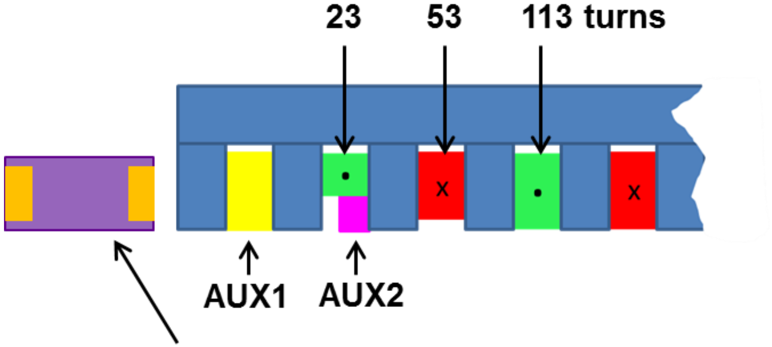
SCU20 layout

- Period length : 20 mm
- Number of full periods: 74.5
- Peak field on axis = 1.18 T
- Mechanical accuracies at 300 K < 80 μm
- Magnetic length: 1.554 m
- Vacuum gap closed (open) > 7 (15) mm
- Design beam heat load : 4 W

Each coil is made by 11 blocks

Diameter NbTi wire:
0.76 mm (including insulation)

End fields upstream and downstream:



Helmholtz coils upstream and downstream
NbTi wire with diameter 0.254 mm (including insulation)

AUX1 and the HH DS have been used to keep $|I_{1v}| < 3\ 10^{-5}$ T m, and $|I_{2v}| < 4\ 10^{-4}$ T m^2

Magnetic field characterization

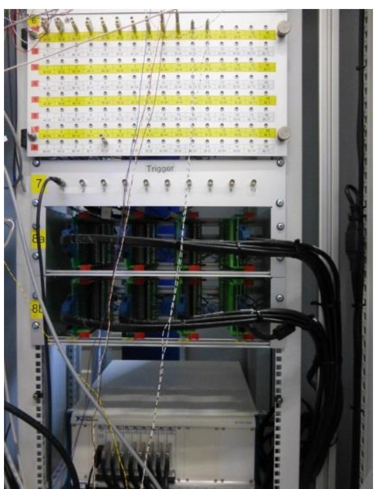
Unique horizontal cryogen free test stand to characterize conduction cooled undulator coils up to ~ 2 m long

CASPER II

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

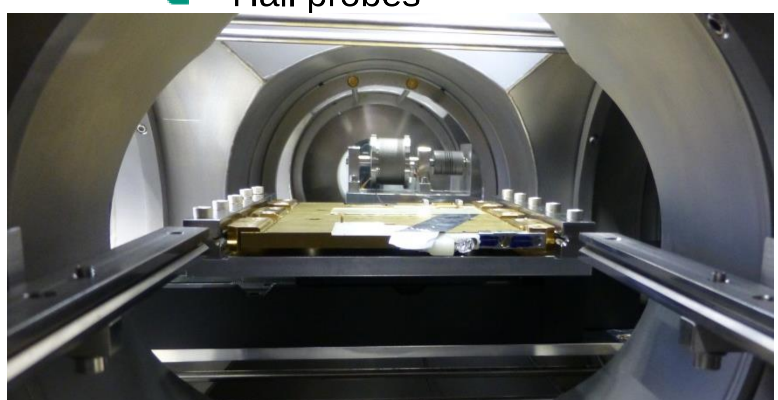
Training:

- Quench detection
- Quench analysis



Local field measurement:

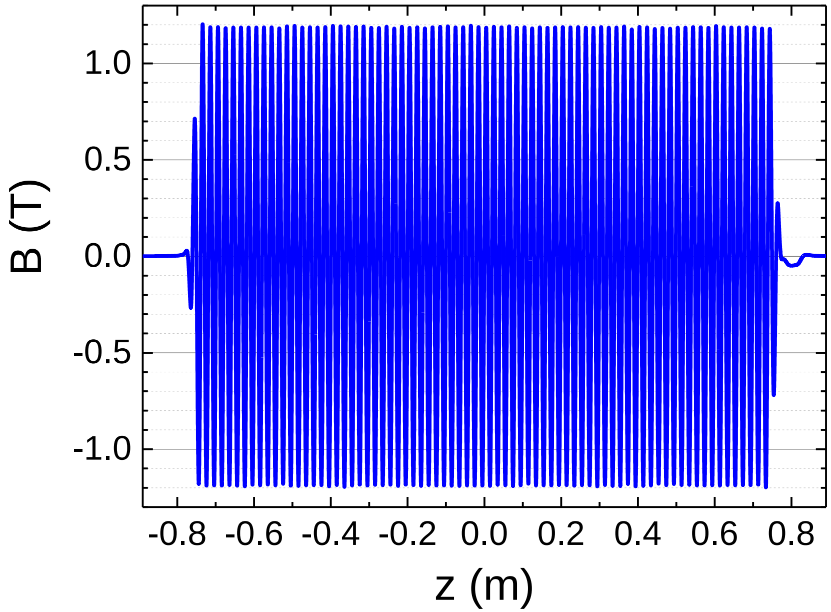
- Hall probes



Integral field measurement:

- Stretched wire

Magnetic field characterization



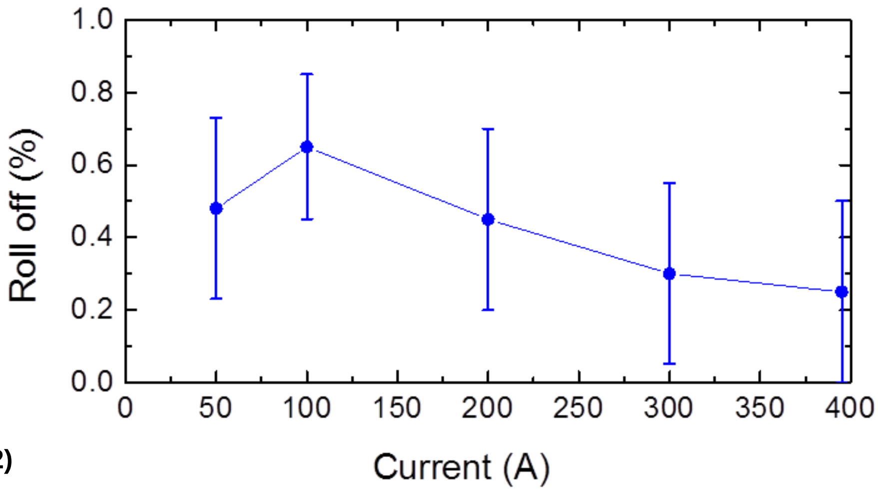
I = 395 A

S. C. et al, IOP Conf. Series: Journal of Physics: Conf. Series 874 (2017) 012015

The roll off measured induces a negligible dynamic kick*

***J. Safranek et al., PRAB, 010701 5 (2002)**

$$\text{Roll off} = \frac{|B(x = \pm 10\ \text{mm}) - B(x = 0\ \text{mm})|}{|B\ (x = 0\ \text{mm})|}$$



S.C. et al., IEEE Trans. on Appl. Supercond. 9001504 22-3 (2012)

Magnetic field characterization

First and second vertical field integrals minimized below

$|I_{1v}| < 3\ 10^{-5}$ T m, and $|I_{2v}| < 4\ 10^{-4}$ T m^2

by powering the AUX1 and HH DS coils to values up to 5.6 A and 0.82 A

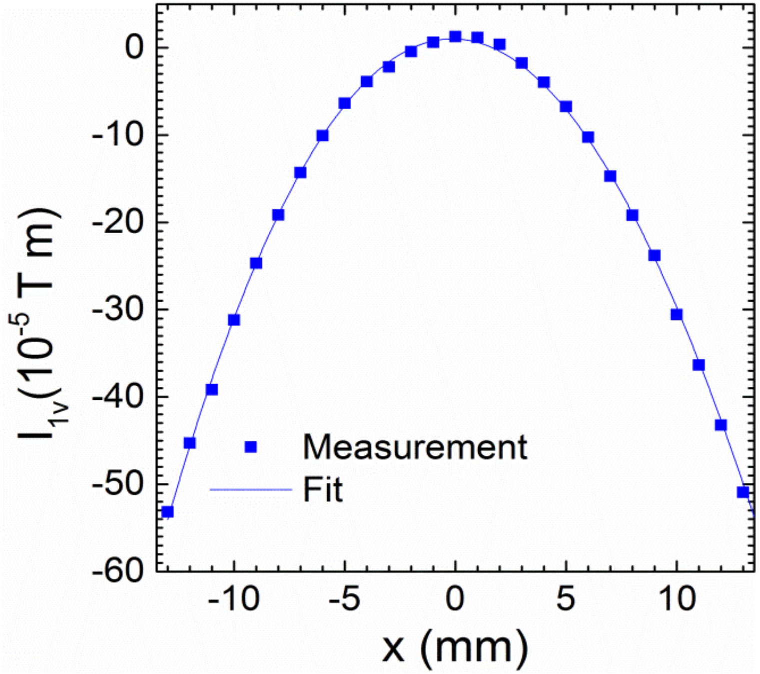
To reach

$|I_{1h}| < 3\ 10^{-6}$ T m, and $|I_{2h}| < 10^{-5}$ T m^2

correctors are added outside the cryostat

Multipoles

$|Q|<0.005$ T, $|S|<5$ T/m and $|O|<15$ T/m^2

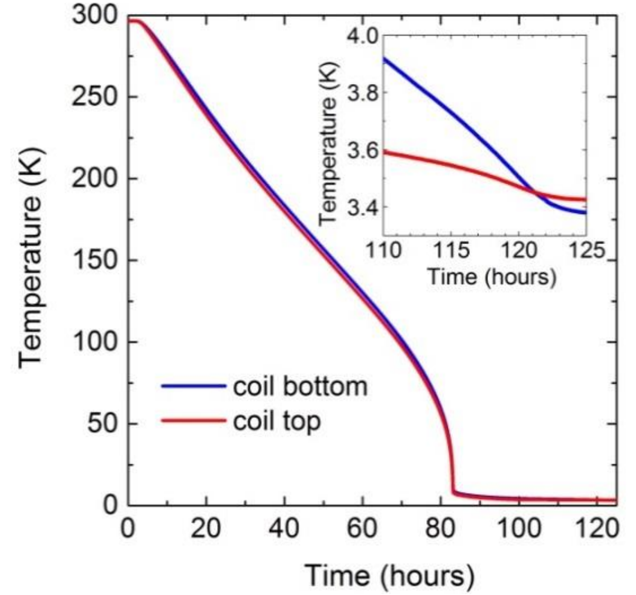


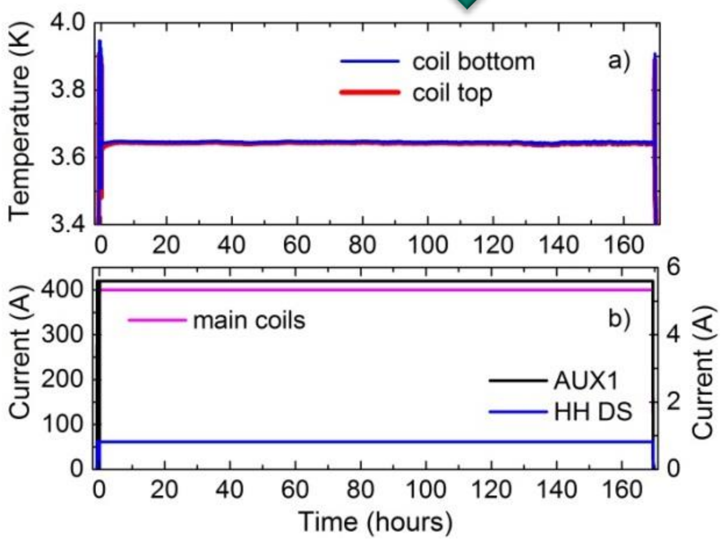
For all currents the values of the integrated multipoles are small enough not to change the dynamic aperture of the beam for the 2.5 GeV operation of KARA

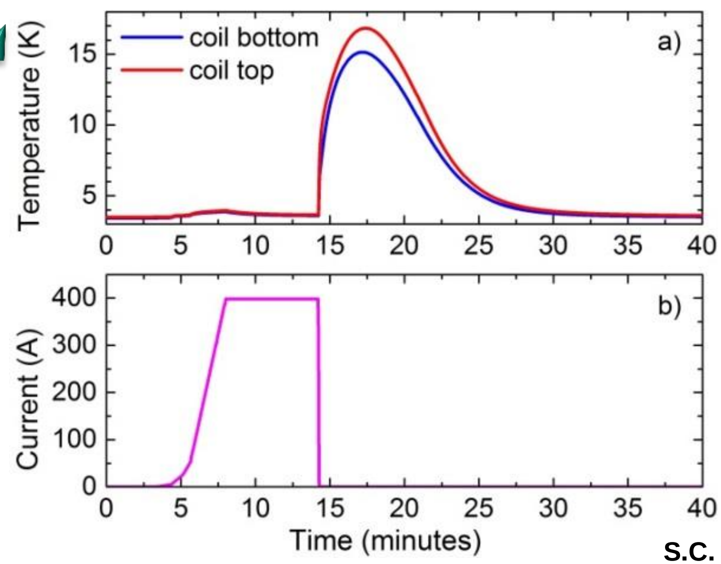
S.C. et al., IEEE Trans. on Appl. Supercond. 9001504 22-3 (2012)

Tests without beam

- **Cooldown time : approx. 5 days**
- **Warmup time: approx. 4 days**
- **Quench recovery: approx. 15 min.**
- **Stability tested for 7 days**
- **P_{UHV} =2.5 x 10^{-10} mbar**

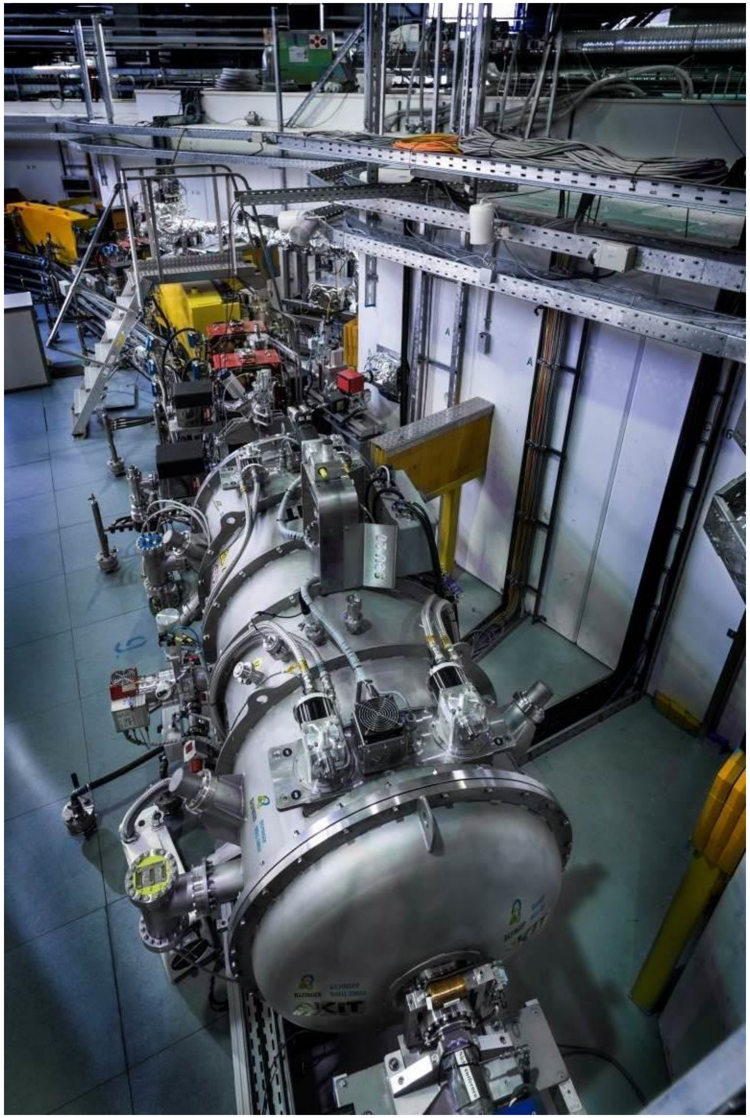






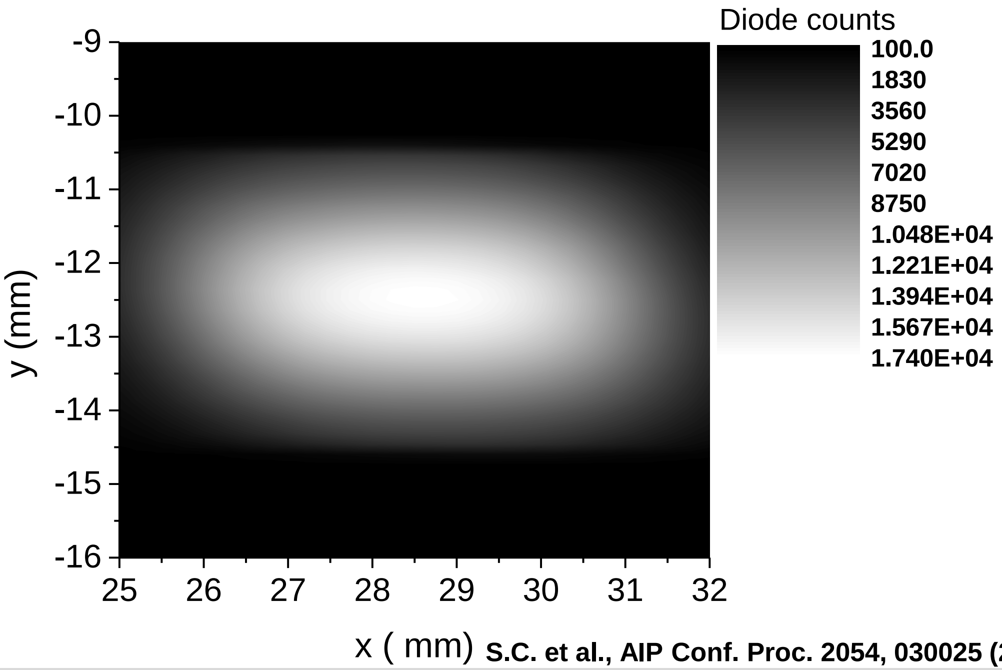
S.C. et al., IPAC2018

Tests with beam



- **Installation in December 2017**
- **Successfully operating in the KIT synchrotron since January 2018 without quenches**
- **First X-rays 10.1.2018**

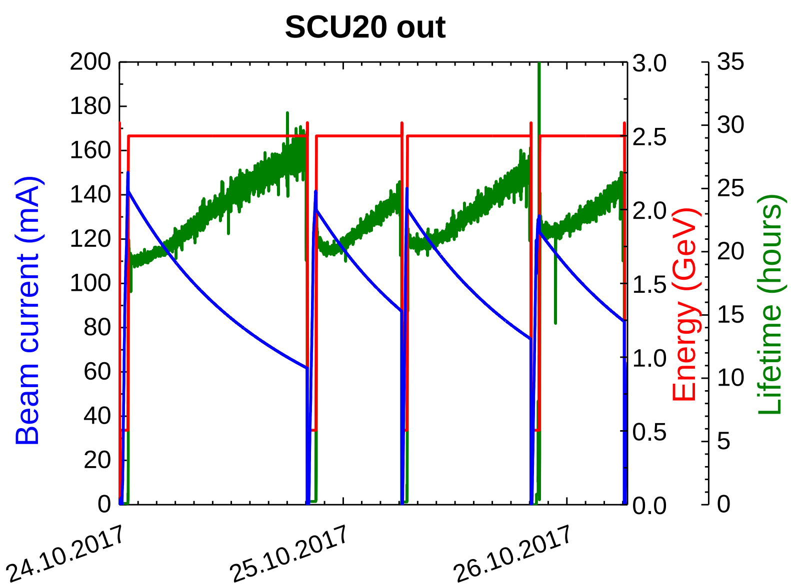
Image of white beam scanning diode after 15 µm pinhole @ 17.1 m from the source and CVD diamond window 3mmx 2mm @ 8.3 m

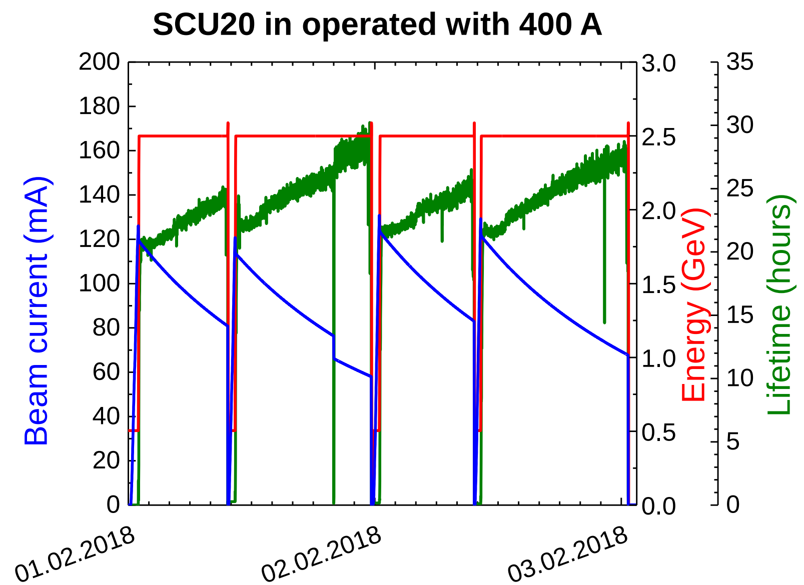


S.C. et al., AIP Conf. Proc. 2054, 030025 (2019)

Tests with beam

- **Beam lifetime (23 h at 100 mA) was recovered in about 3 weeks of beam operation of the storage ring at 2.5 GeV**





- **Transparent to electron beam with values of correctors very close to the ones measured in CASPER II**
- **Adjustment of the currents in the vertical and horizontal correctors in few hours**
- **Tuning of SCU20 is compatible with the operation of all the beamlines of the KIT synchrotron while performing their most sensitive experiments**

S.C. et al., AIP Conf. Proc. 2054, 030025 (2019)

Tests with beam

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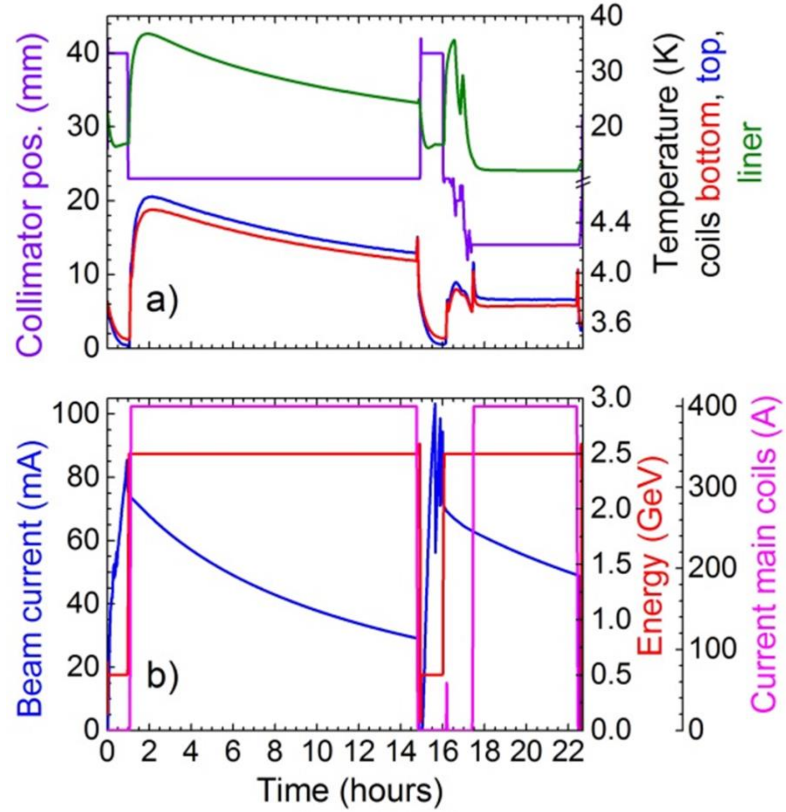
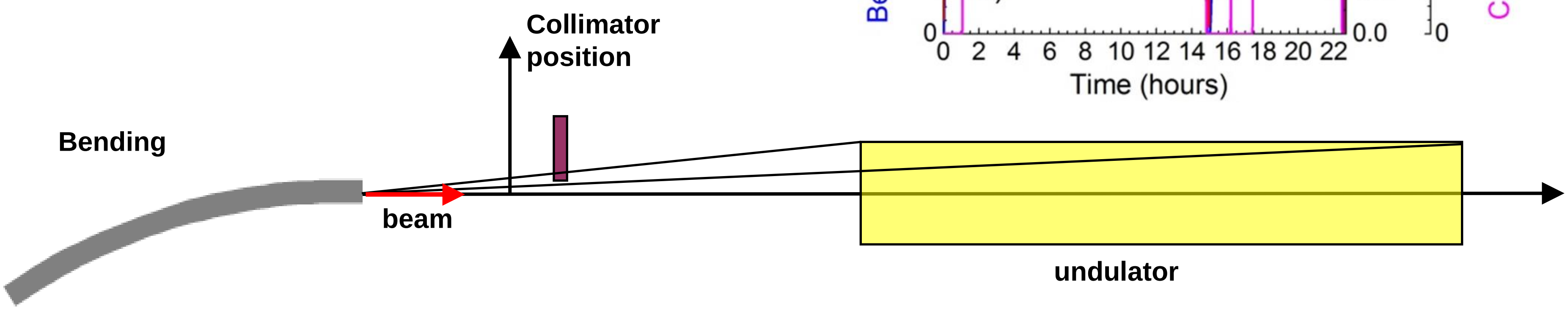
- **Beam heat load 8 W**
- **Operation temperature margin of at least 0.8 K (normal operation at 3.8 K, but working also at 4.6 K)**
- **Excellent thermal decoupling between liner (35 K) and coils (4.6 K)**

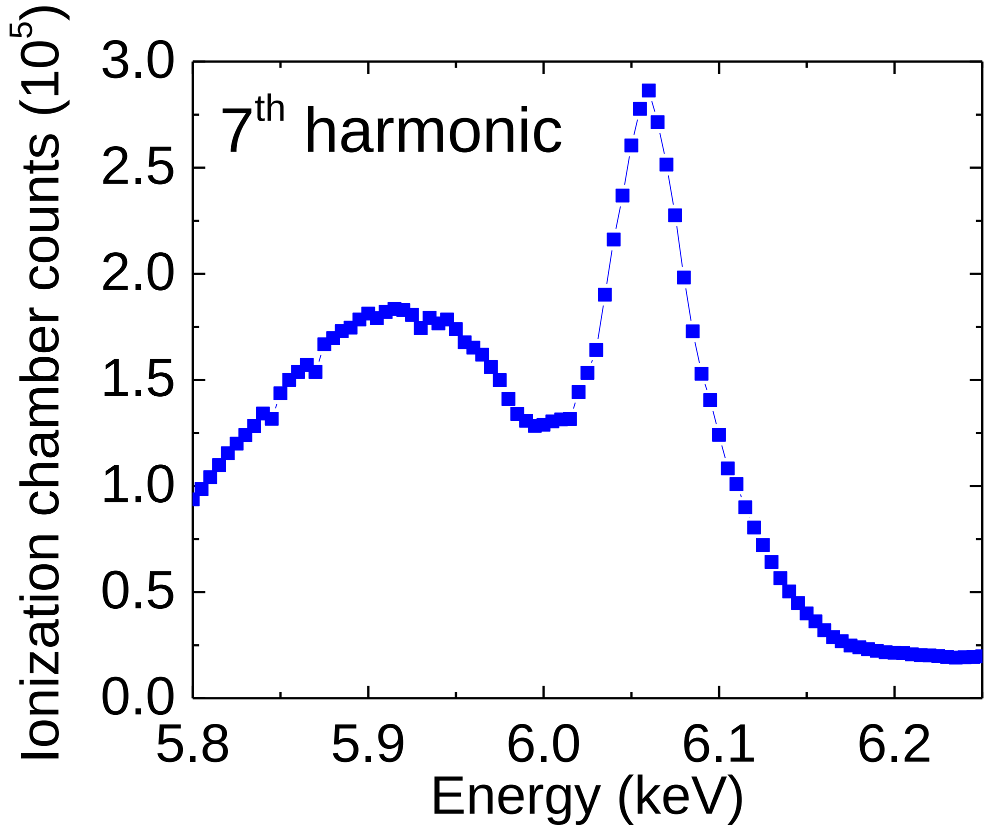




S.C. et al., IPAC2018

Tests with beam

- **Seventh harmonic of SCU20 measured at the NANO beamline through 70 µm x 30 µm at 17 m from the source with an ionization chamber at 2.5 GeV electron beam energy**



S.C. et al., AIP Conf. Proc. 2054, 030025 (2019)

Conclusions

- **SCU20 is the first commercially available undulator worldwide:**
  - **a robust device**
  - **with reasonable delivery time (approx. 2 years)**
  - **easy handling during installation and operation**
  - **providing superior performance compared to other available technologies**

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Superconducting Undulators: From Development towards a Commercial Product

Synchrotron Radiation News, 31:3, 24-28 (2018)
DOI:10.1080/08940886.2018.1460171

Thank you for your attention