Karlsruhe Institute of Technology

ANKA Synchrotron Radiation Facility

Magnetic Field Measurement Devices for Superconducting Undulator Coils at ANKA

ANKA Synchrotron Radiation Facility

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for

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Karlsruhe Institute of Technology

Outline

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   - Magnetic field errors
2. CASPER I
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R&D of superconducting undulators

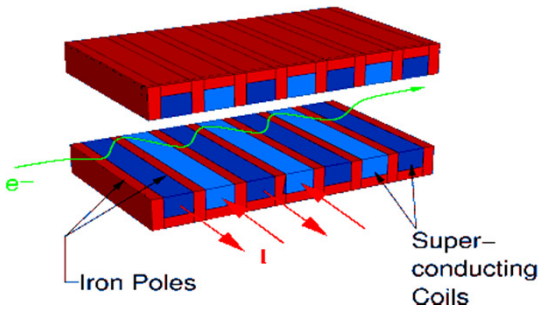
Develop, manufacture, and test superconducting undulators (SCUs) to generate:

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

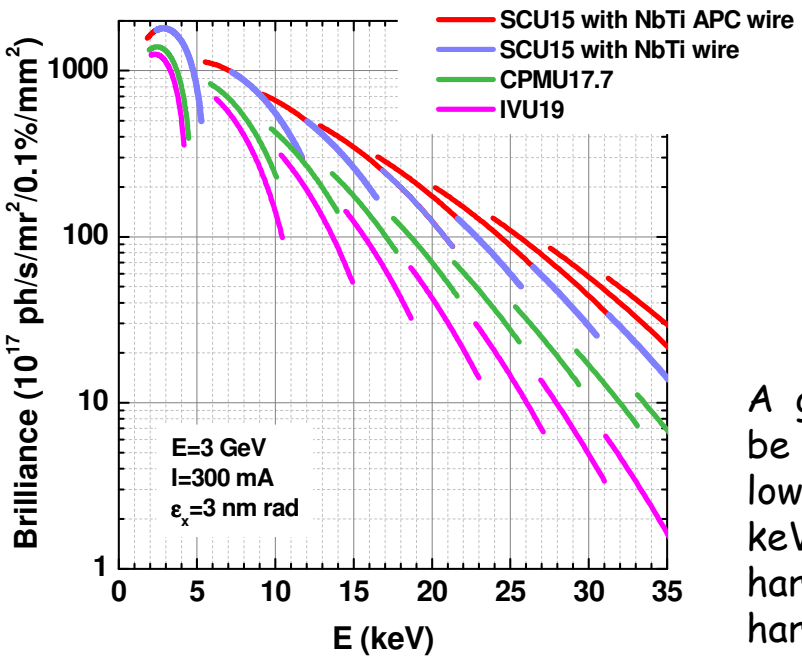
with respect to permanent magnet undulators.

Why?

Larger magnetic field strength for the same gap and period length.



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



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

A given photon energy can be reached by the SCU with lower order harmonic: 20 keV reached with the 7th harm. of SCU, with the 9th harm. of CPMU and of IVU.

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

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

Motivation

Task within our R&D program :

Improvement of **magnetic field properties** and quality assessment.

Magnetic errors can cause:

Perturbation of the closed orbit and the dynamics of the electron beam

- Field integral measurements are needed

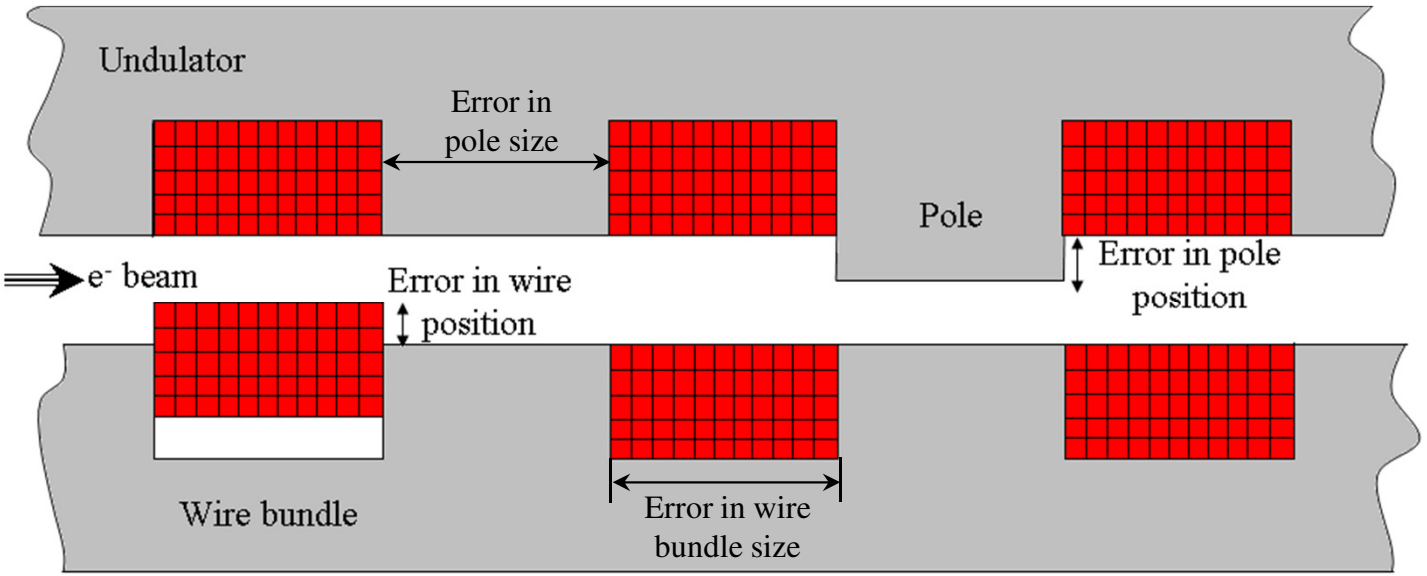
Reduction of the quality of the emitted radiation

- Perform local field measurements to obtain phase error

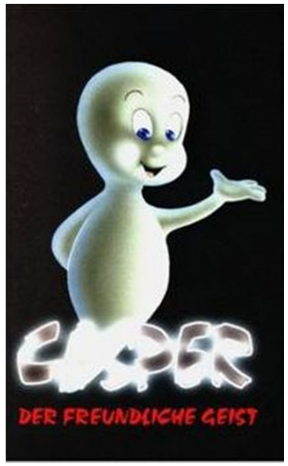
Main errors in superconducting undulators

Field errors are mainly caused by:

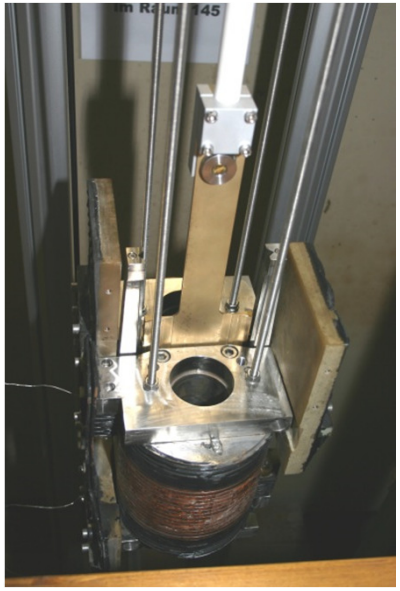
- Mechanical deviations of the pole position e.g. the pole height
- Deviations in the period length
- Bending of the yoke
- The position of the superconducting wire bundles
- Pole and wire bundle size

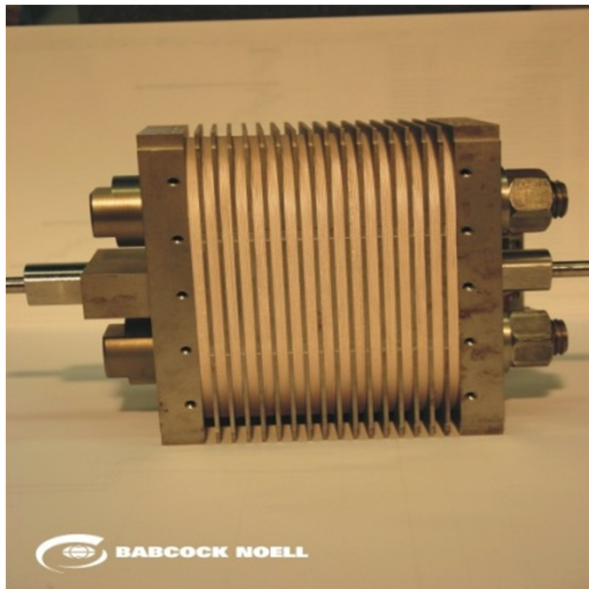


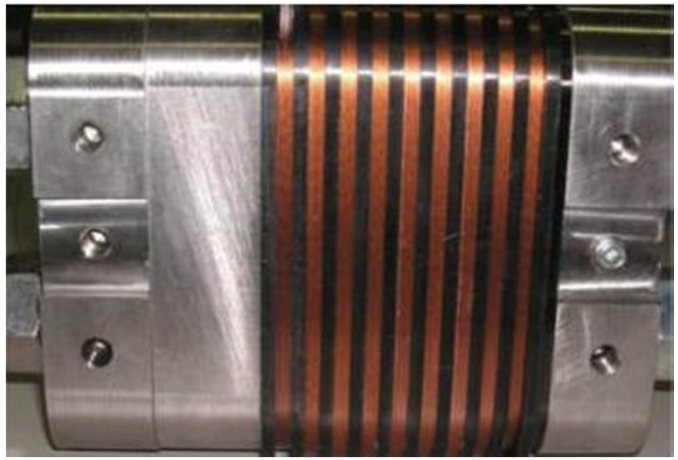
CASPER – Characterization Setup for Field Error Reduction



CASPER I – Measurement setup for short undulator mock-up coils







CASPER II – A measurement system for undulator coils up to 2m length

CASPER I setup

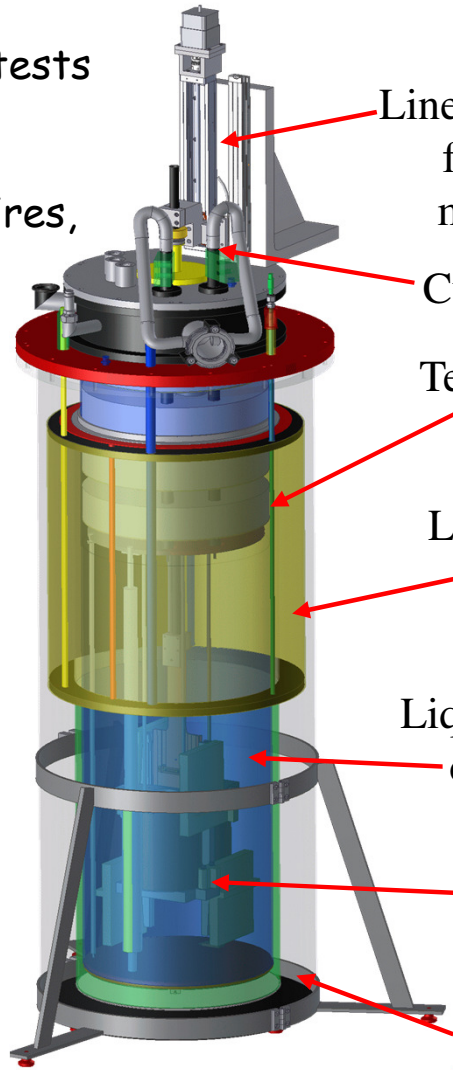
- Perform magnet training and quench tests
- test new winding schemes,
- new superconducting materials and wires,
- and new field correction techniques

General:

- Operating vertical
- Test of mock-up coils in LHe
- Maximum dimensions 35cm in length and 35 cm in diameter

Instrumentation:

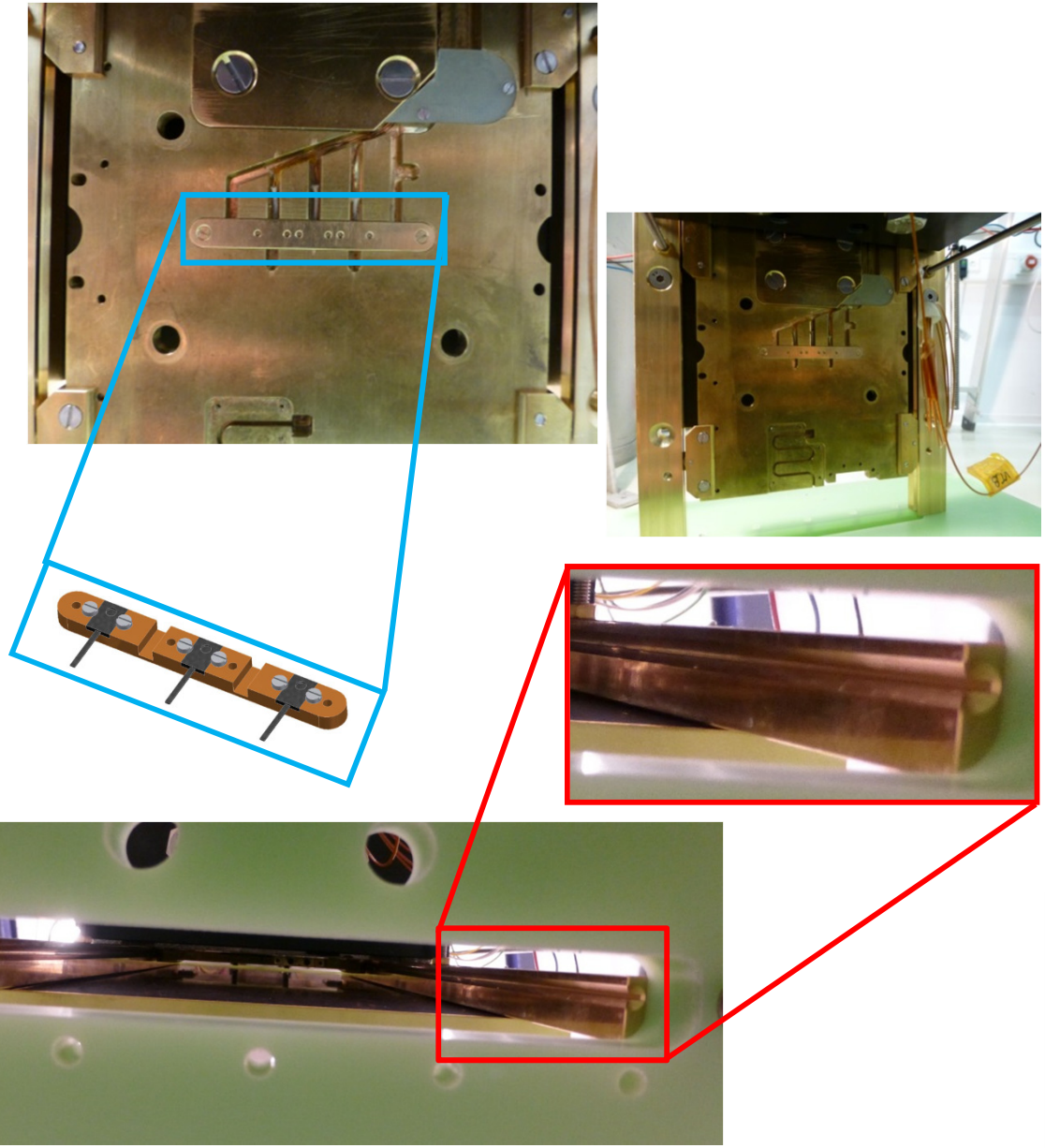
- Keithley constant current source (Hall current)
- Keithley multiplexer voltmeter (Hall voltage)
- 1500A/±5V and 500A/±5V power supplies providing coil operating currents
- Quench detector for coil protection
- Data logging system for quench analysis



E. Mashkina et al., EPAC08

Local field measurements

- Magnetic field distribution measured with Hall samples
- 3 calibrated Hall samples clamped to a holder and mounted to the sledge
- One in the middle and two at ± 10mm perpendicular to the beam axis to measure roll off
- Sledge moved from outside by a lonear stage with stepper motor, gear box and a low expansion coefficient non magnetic tube (system resolution 3 μm)
- Sledge guiding via brass rails



Accuarcy limits

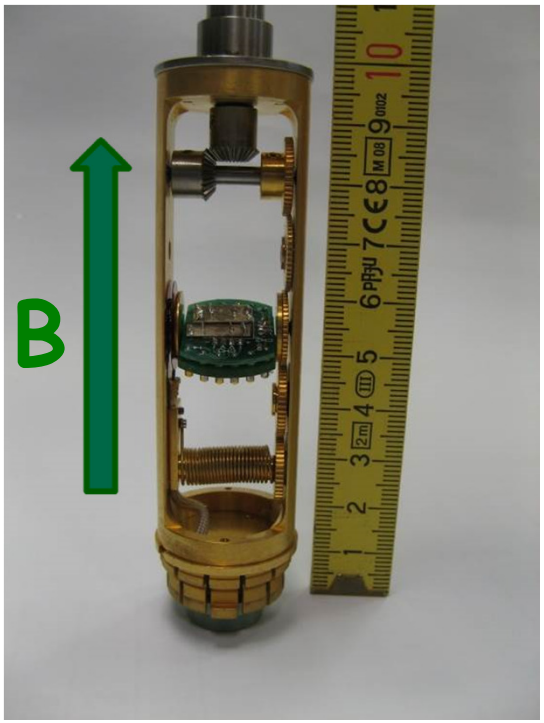
Errors effecting local field measurements

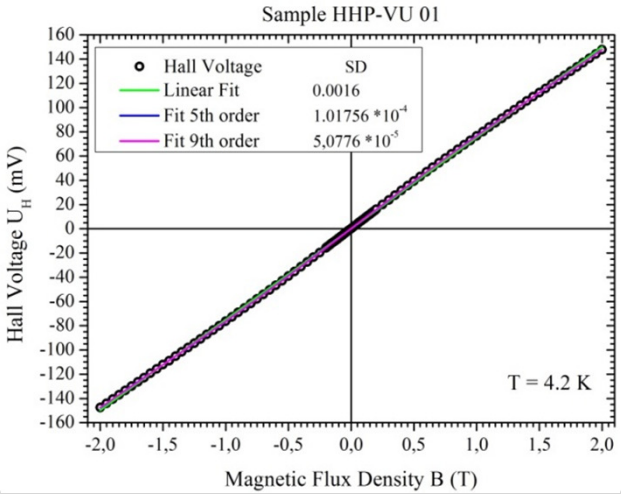
1. Errors caused by Hall sample calibration.
2. Measurement errors due to mechanical misalignment of the guiding rails or the field sensors

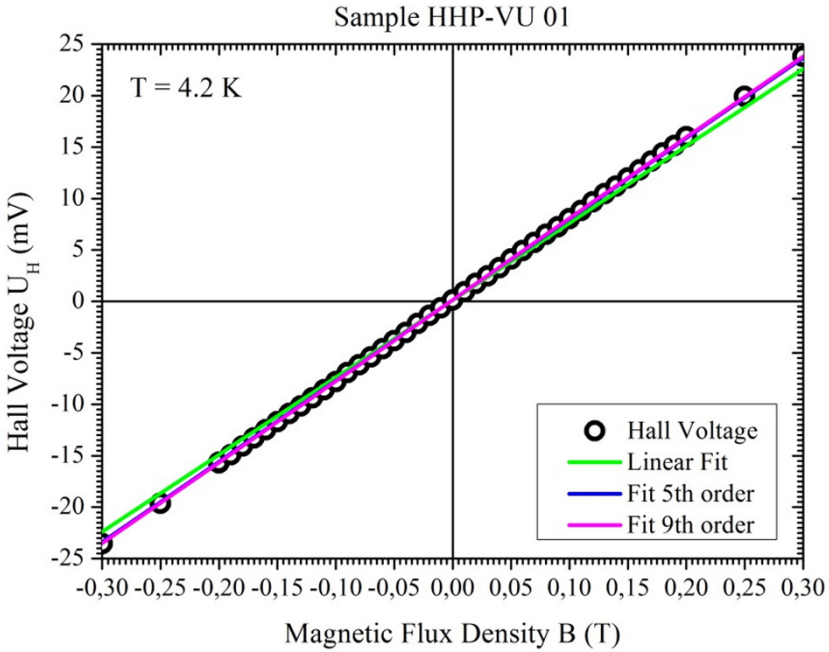
Physical Properties

Measurement System

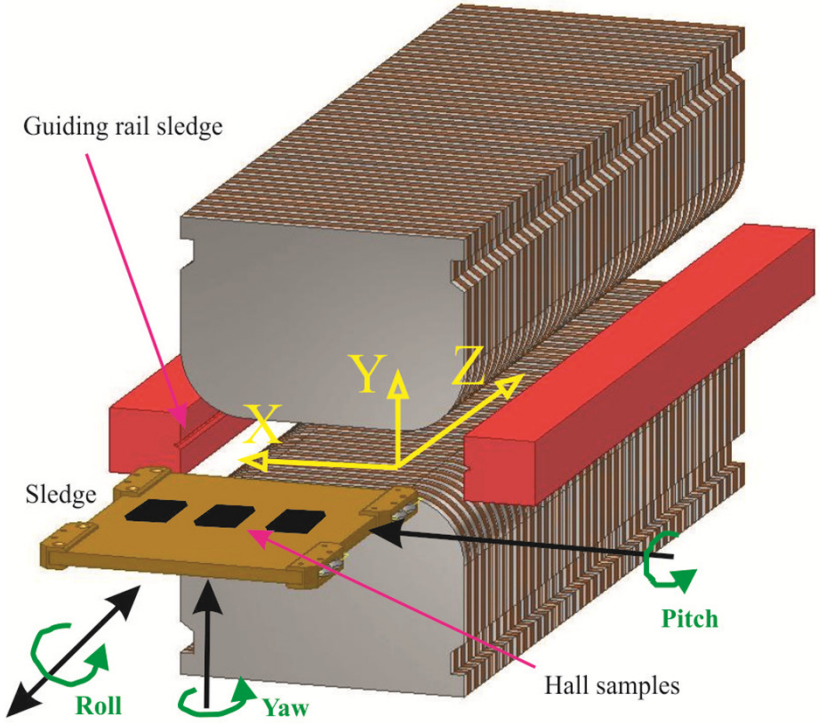
Hall sample calibration
(ITeP at the KIT)







Mechanical accuracy limits



Relative alignment precision of guiding rails 20μm. For the Hall probe in the middle the distance to coils changes by 10μm.

In x-direction the field is fairly uniform
➡ error is negligible

In y-direction the 10μm yields according to [1] with λ_u=0.015 to:

$$\cosh\left(\frac{2\pi\Delta y}{\lambda_u}\right) = 1 + \frac{\Delta B}{B}$$

$\Delta B/B = 9 * 10^{-6}$

In longitudinal direction $\Delta z < 5\ \mu m$

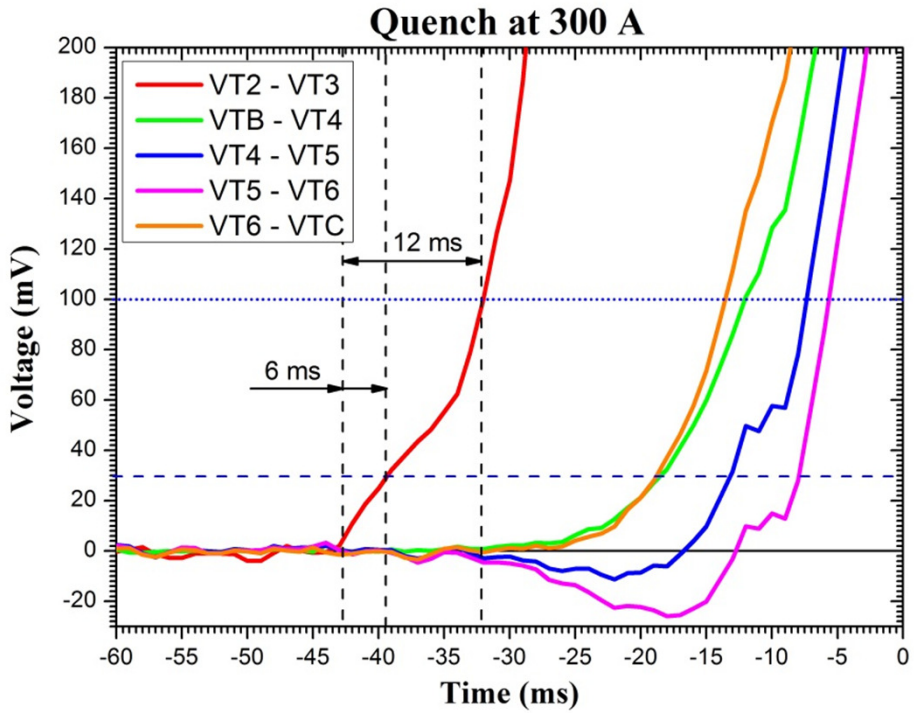
The angle errors cause a $\Delta B/B < 5 * 10^{-8}$

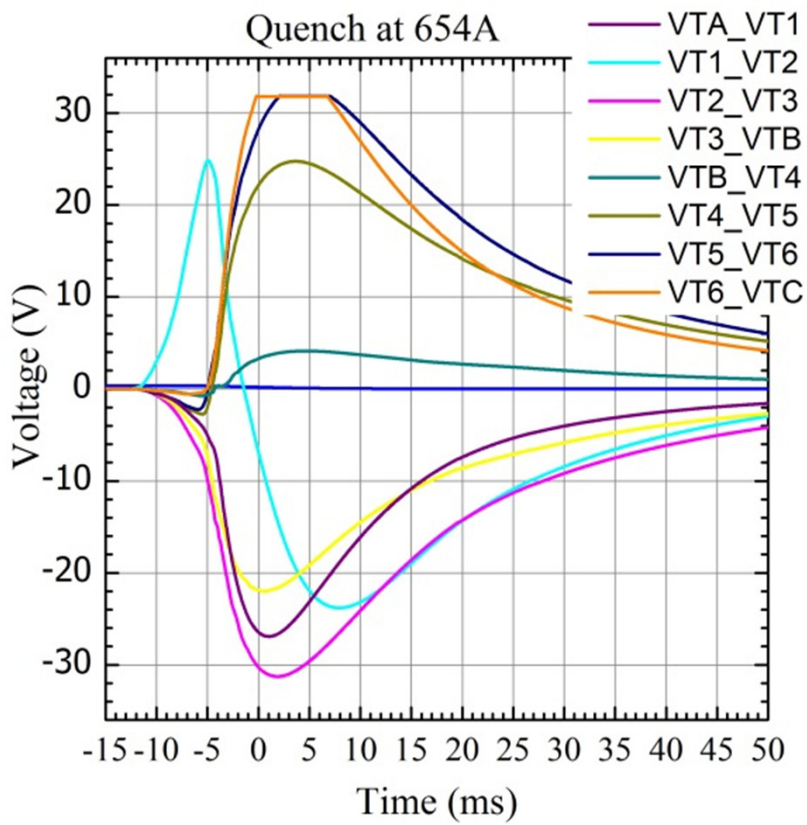
[1] Zachary Wolf, "Requirements for the LCLS Undulator magnetic measurement bench", Technical report # LCLS-TN-0, 4-8 http:/www-ssrl.slac.stanford.edu/lcls/technotes

Measurement activities

Quench tests and analysis

- Test coils electrically divided in sections (Voltage taps)
- Data logging system with 16 Channels (100 kS/s max., Company IMC)
- System trigger from quench detector



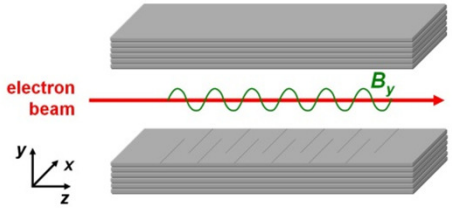


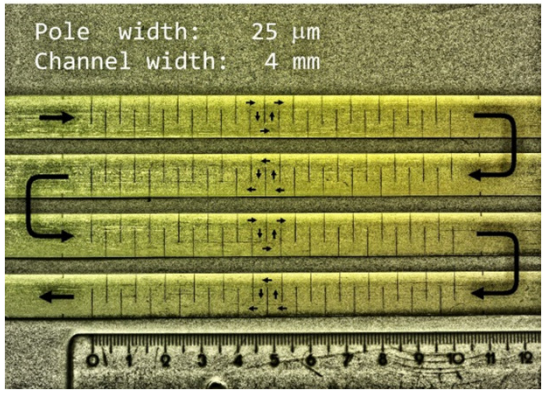
Measurement activities

Tests and measurements on structured HTS tapes

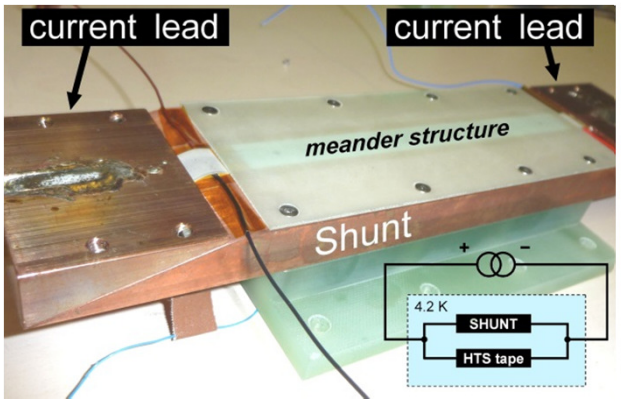
Idea: To build an undulator out of stacked structured HTS tapes

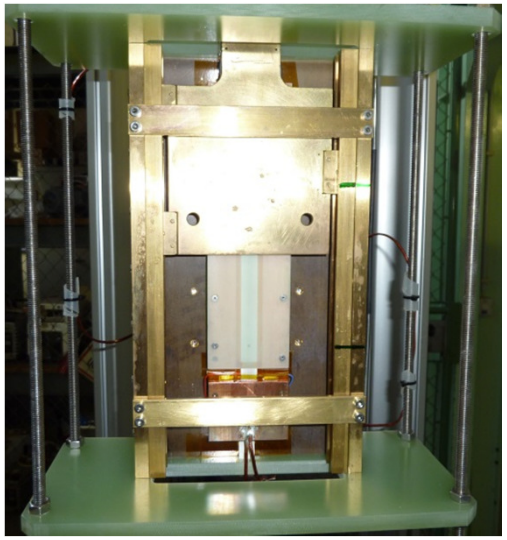
S. Prestemon et al., IEEE Trans. on Appl. Supercond., Vol 21, No. 3, 1880-1883 21-3 (2011)

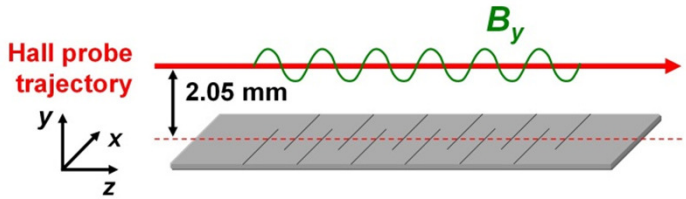


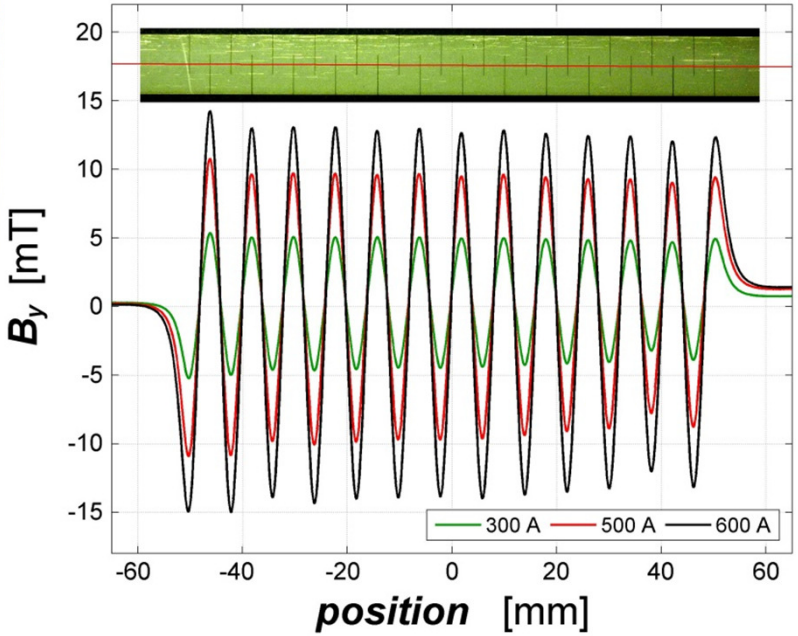


Perform field measurements

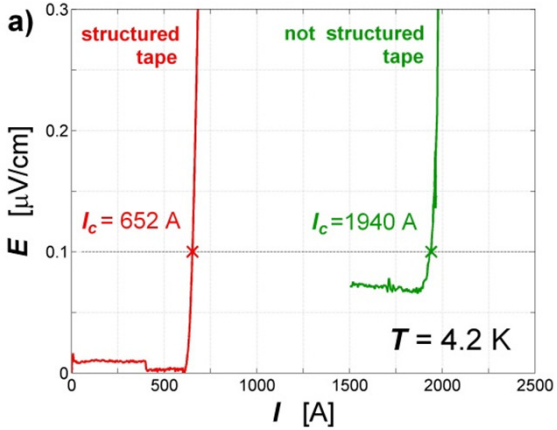








Test maximum current

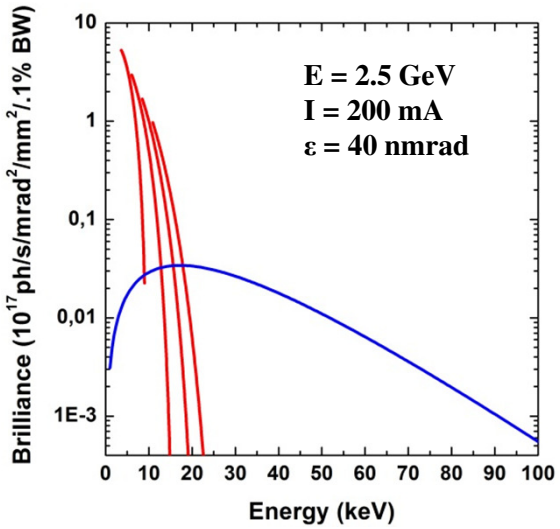


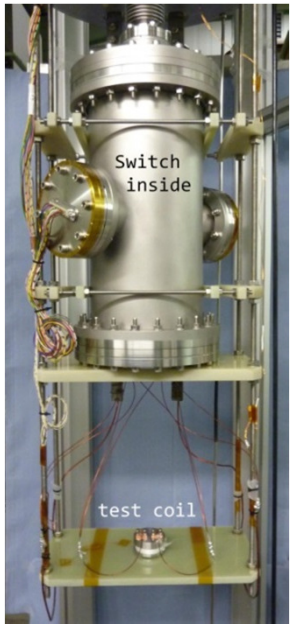
T. Holubek et al., IEEE Trans. on Appl. Supercond. Vol. 23, No. 3, 4602204 (2013)

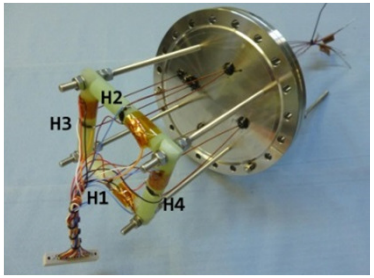
Measurement activities

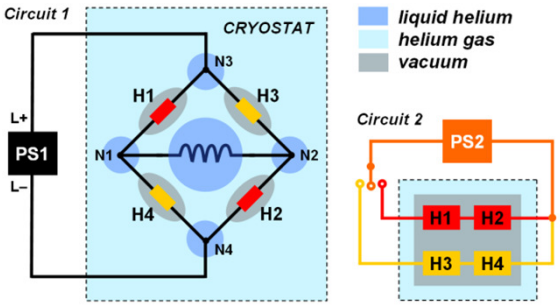
Superconducting switch (SCS)

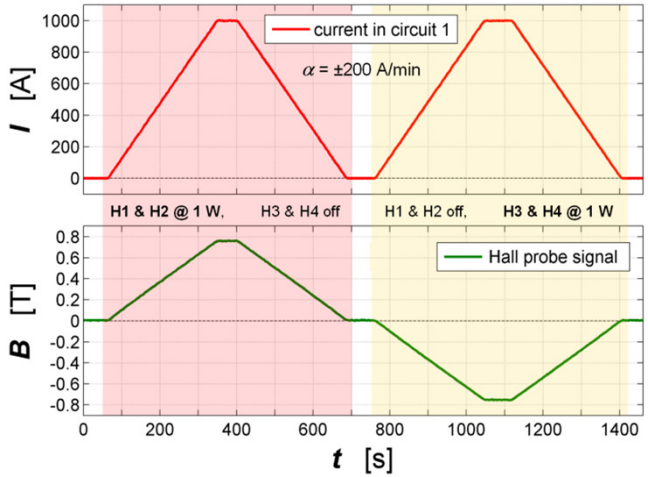
- Switching the period length allows to increase the tunability of an insertion device
- Superconducting undulator/wiggler (SCUW 18/54) planned for the IMAGE beamline at ANKA
  - High brilliance of the undulator 6keV to 15keV for imaging, wiggler mode for higher photon energies (phase contrast tomography)
- Current has to be reversed in a separately powered subset of the windings
- Use SCS instead of two power supplies (conduction cooled)











Finally the heating power was reduced to 200mW per heater pair.

T. Holubek et al., IEEE Transactions on Appl. Superconductivity, Vol. 23, No. 3, 3800104 (2013)

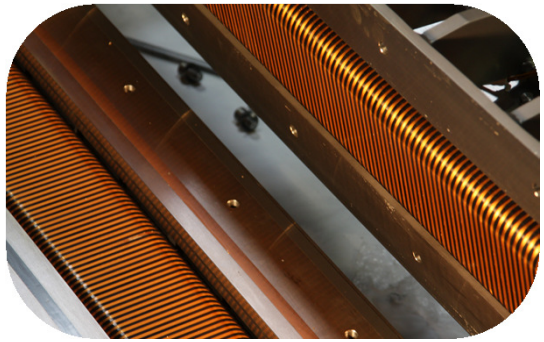
[1] R. Schlueter, S. Prestemon, Synchrotron Radiation News, 2004

Final Device

Light source under development in collaboration with BNG for the beamline NANO at ANKA

Period length	15 mm
Number of full periods	100.5
Max field on axis with 5.4 mm magnetic gap	1.43 T
Max field on axis with 8 mm magnetic gap	0.77T
Max field in the coils	2.4 T
Minimum magnetic gap	5.4 mm
Operating magnetic gap	8 mm
Operating beam gap	7 mm
Gap at beam injection	16mm
K value at 5.4 mm magnetic gap	2
Design beam heat load	4W

Delivery end of 2013

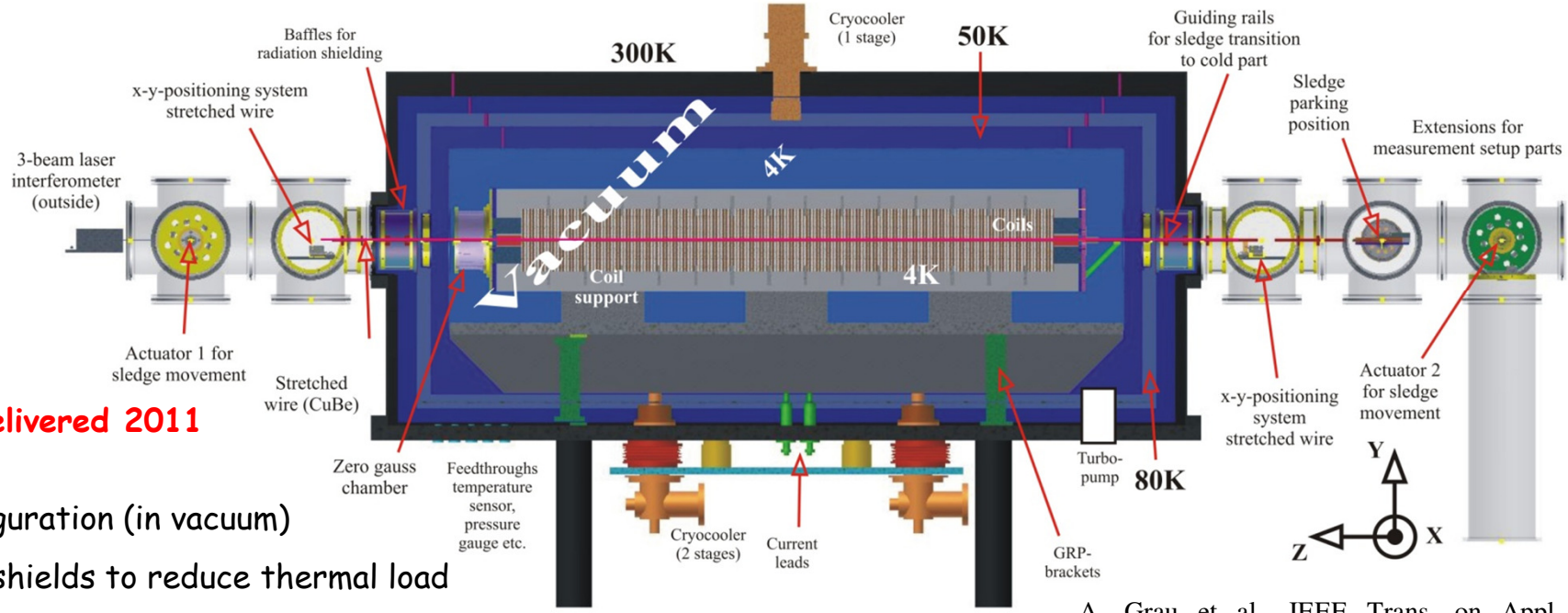


C. Boffo et al., IEEE Trans. on Appl. Supercond Vol. 21, No. 3, 1756-1759 (2011)

Cryostat CASPER II

The goal…

Measure magnetic field distributions of superconducting coils with dimensions like in „real" IDs (e.g. up to ~2 m length, ~50cm diameter)



Cryostat delivered 2011

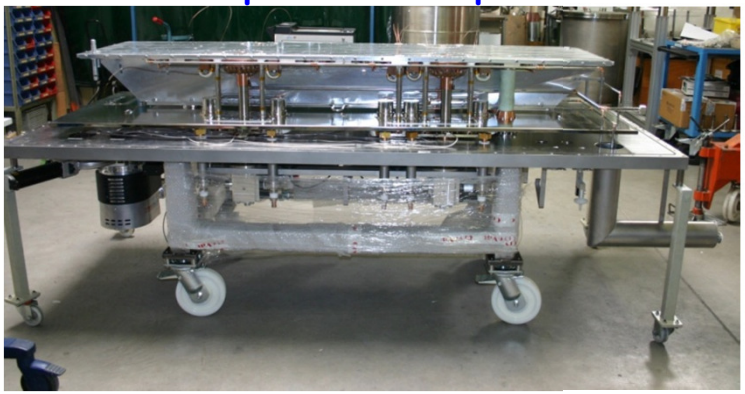
A. Grau et al., IEEE Trans. on Appl. Supercond., Vol. 22, No. 3, 9001504 (2012)

- Vertical configuration (in vacuum)
- Temperature shields to reduce thermal load
- Partially cryogen free :
  - To 4K via cryocooler
  - precooling 4K plate and thermal shields (80K) with liquid N_2
- Dimensions 4K region 2m x 0.5m x 0.5m
- Current leads 8 x 500A, can be variable connected
- Local and integral field measurements possible, access through the flanges

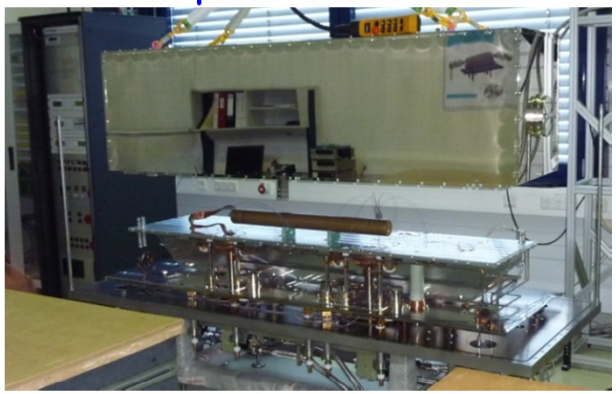
For **quality certification** of new sc-insertion devices developed together with the industrial partner Babcock Noell GmbH.

The cryostat

4K plate & base plate



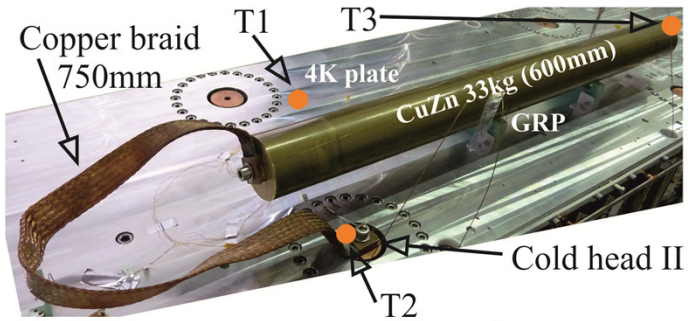
4K plate & 50K shield



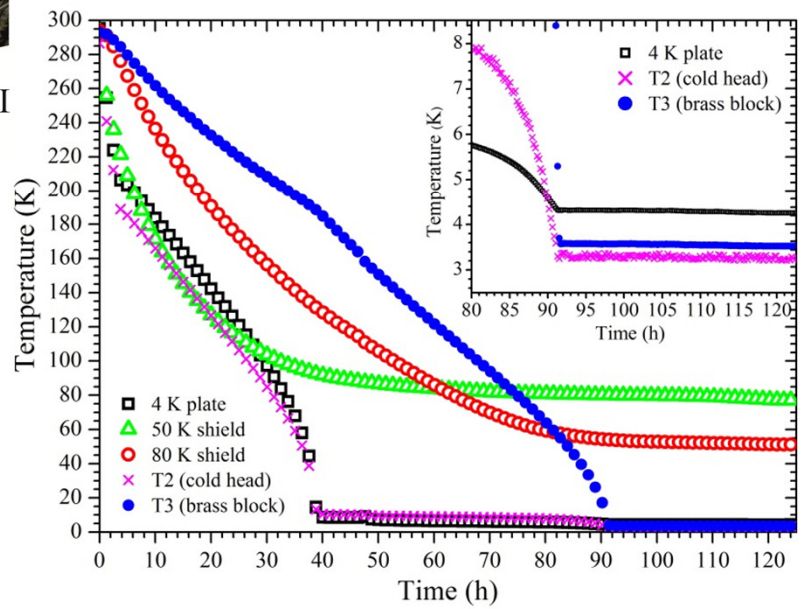
Complete

Final acceptance test

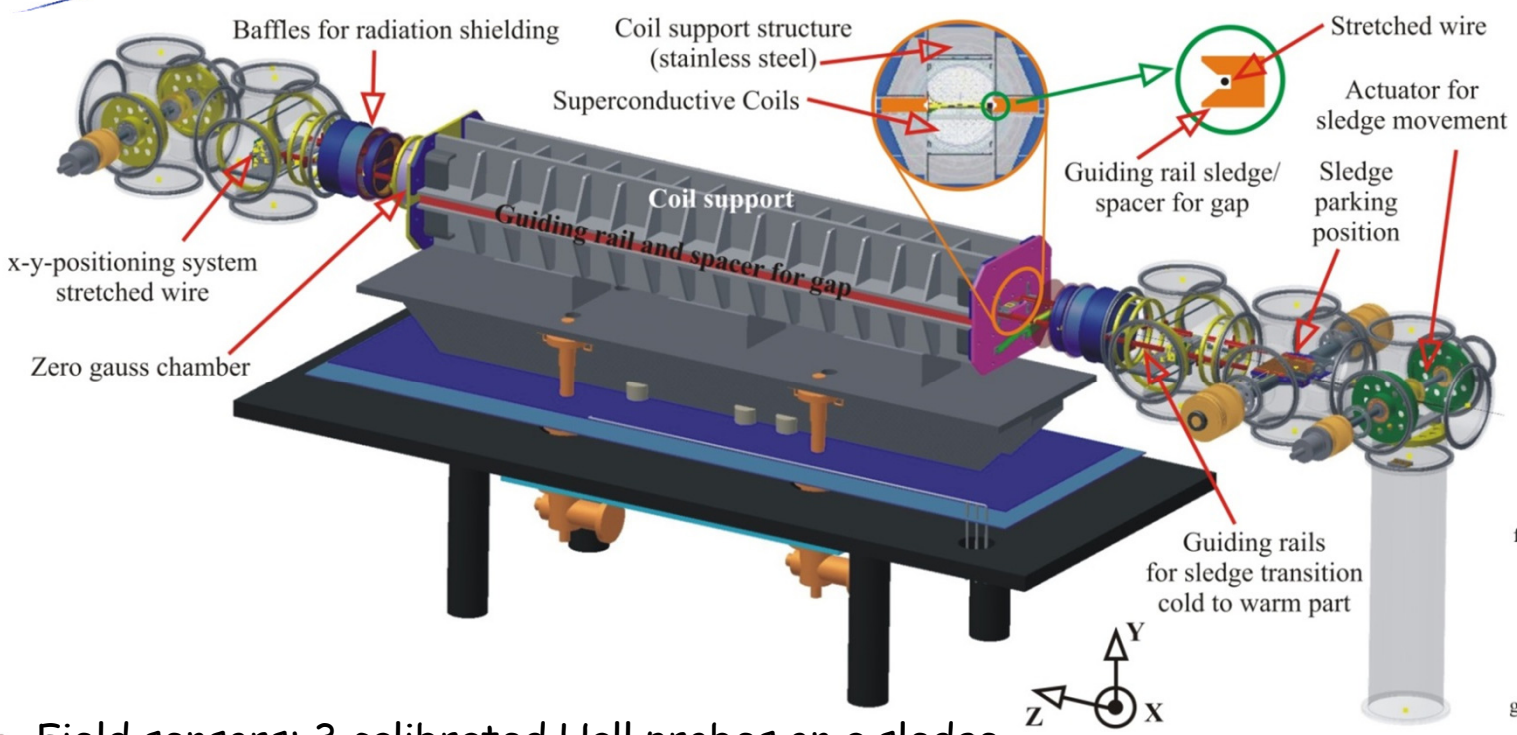
Testsetup to simulate temperatures in 4K region.

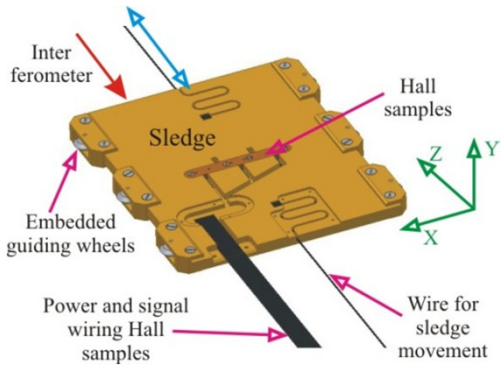


Component	Specified value	Reached value
Temperature 80K-plate	T < 85 K	∅ 83 K
Temperature 80K-shield	T < 100 K	∅ 81 K
Temperature 50K-shield	T < 60 K	∅ 46 K
Temperature 4K-shield	T < 10 K	∅ 5.2 K
Temperature 4K-plate (T1)	T < 4.5 K	∅ 4.8 K
T2	targeted < 4 K	3.3 K
T3	"	3.5 K



Setup





- Field sensors: 3 calibrated Hall probes on a sledge
- Hall current provided by a Keithley precision current source
- Hall voltage measured with a Keithley multichannel voltmeter
- Field integral measurements with stretched wire technique (CuBe wire Ø125µm)
- Position adjustment for stretched wire in x-y-direction via linear piezo stages with encoders (precision ~1µm)

- Position measurements with a 3 beam laser interferometer (SIOS)
  - Precise z-position $\Delta z \sim 10^{-6}$
  - Values for angle deviation of the sledge during movement

Position measurement

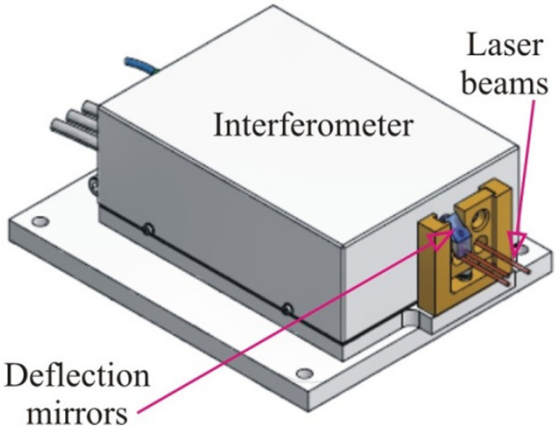
Laser interferometer (3 beams)

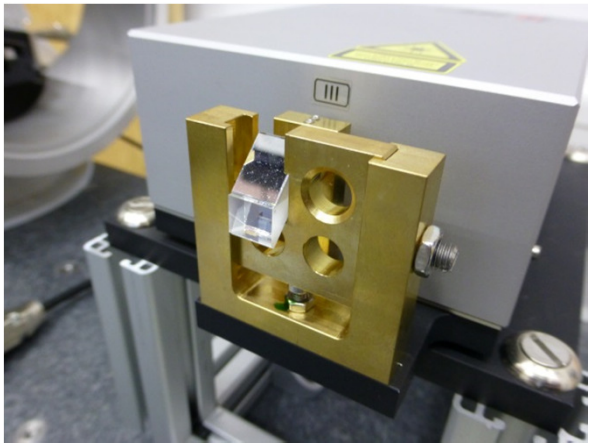
- Measure z-position of the sledge (1 beam)
- Angle deviation during moving (3 beams)

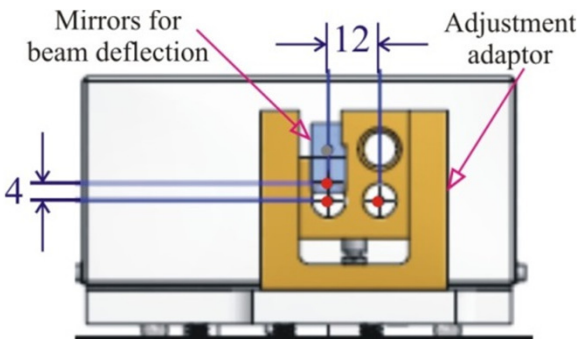
Usable gap in the undulator max. 7mm.

➡ Beam distance has to be reduced from 12mm, beacuse usable gap in the undulator max. 7mm

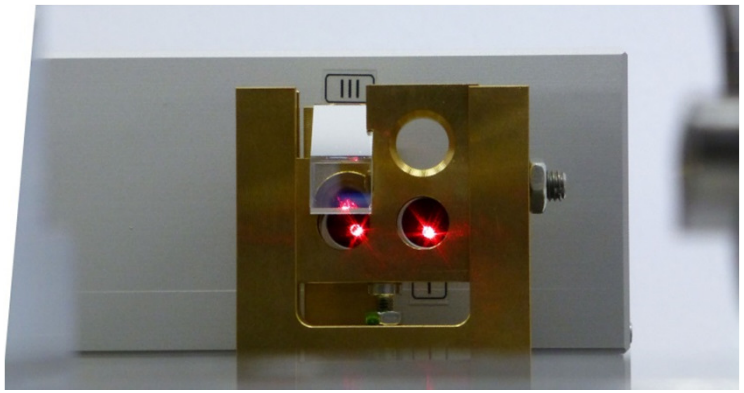
Commercial interferometer with two prisms attached for beam distance rescaling.





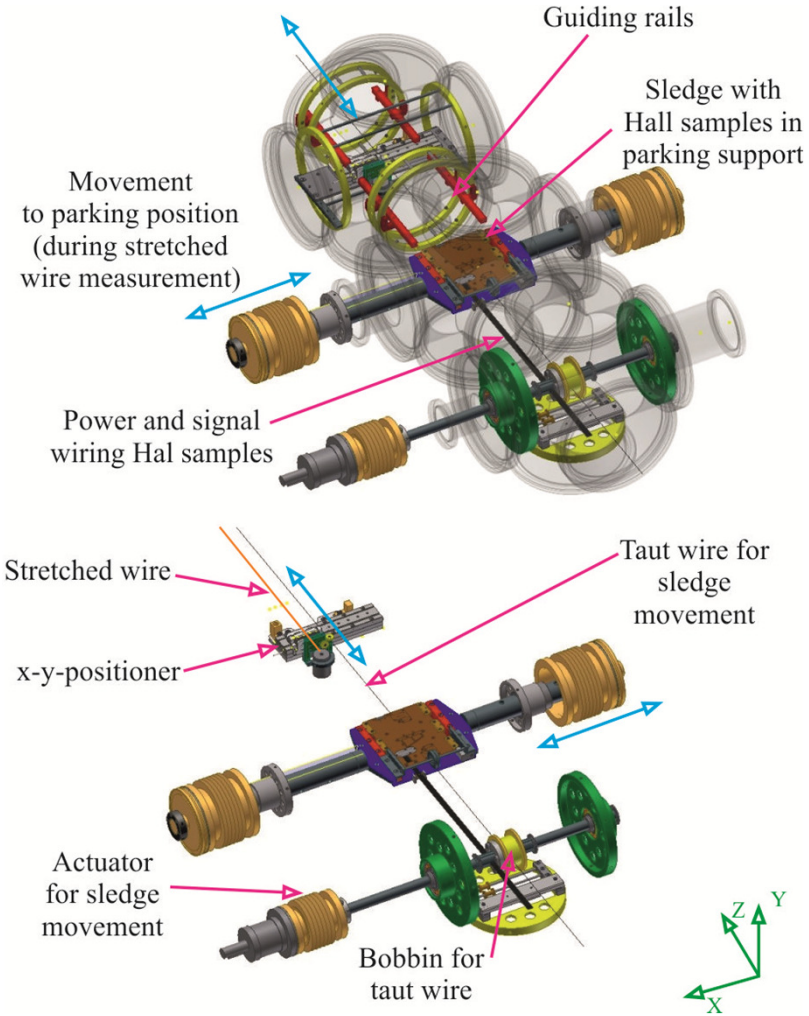


Company SIOS

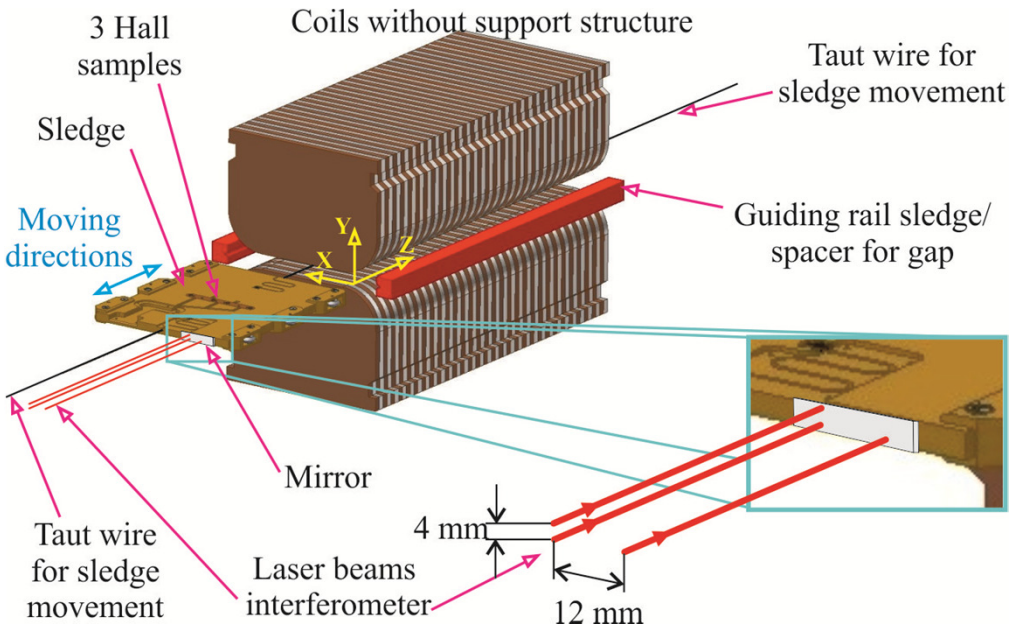


Local field measurements

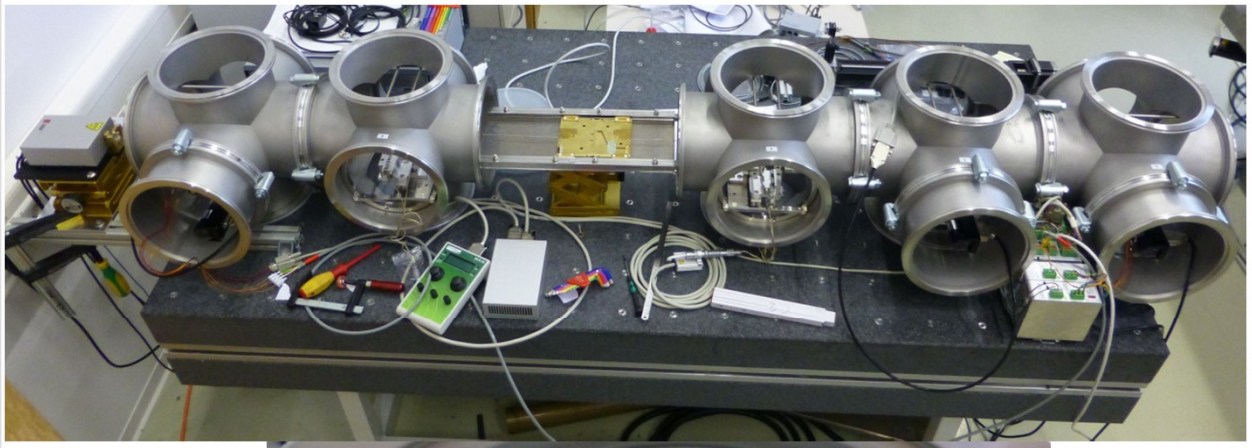
3 Hall probes in a row placed perpendicular to beam axis (10mm distance)

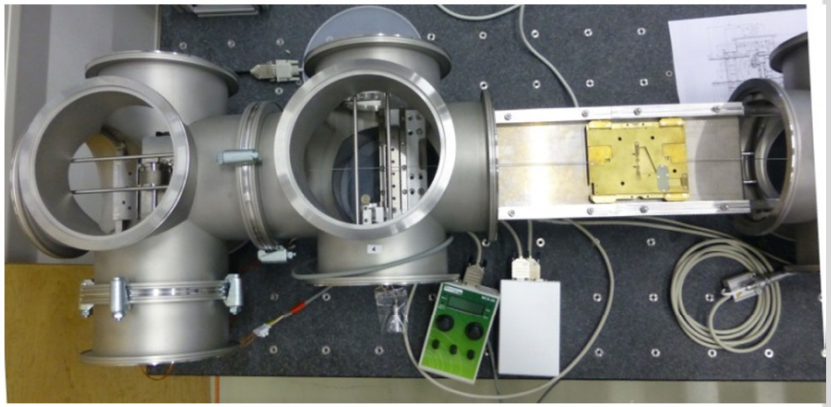


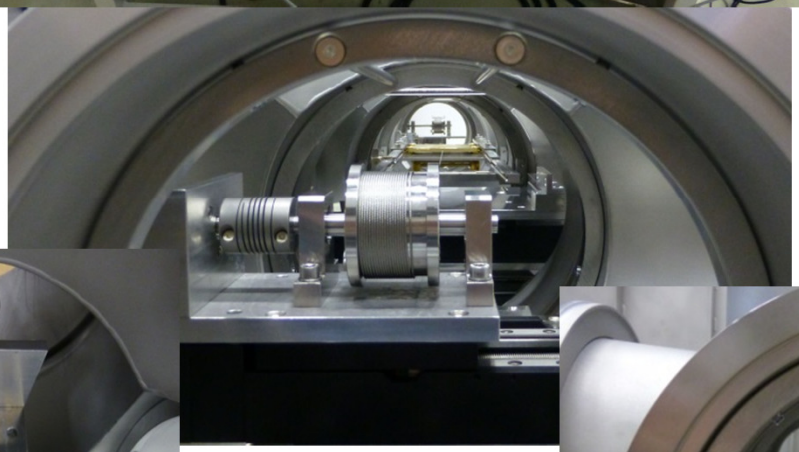
Sledge movement by a taut wire for each direction spooled on a bobbin at each side mounted in the extensions of the cryostat.

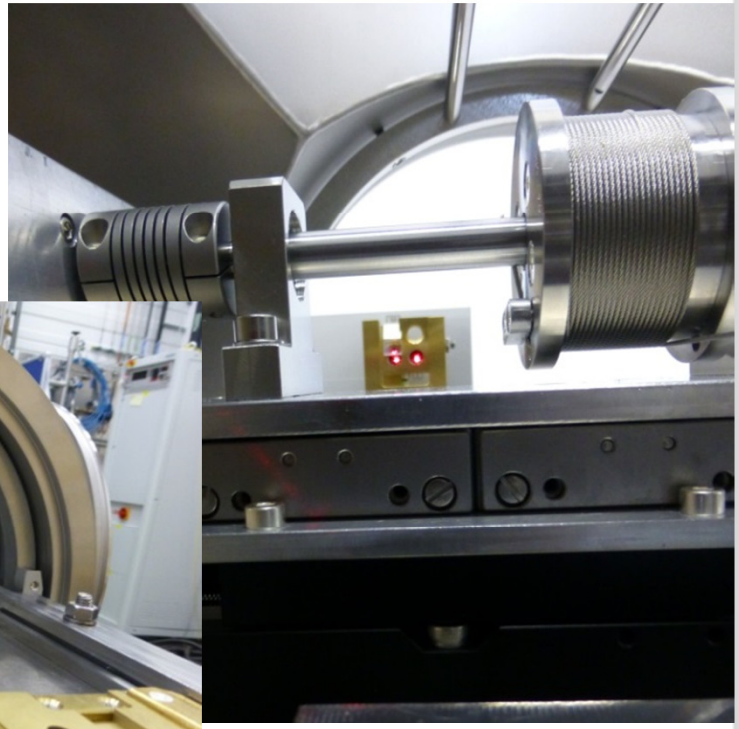


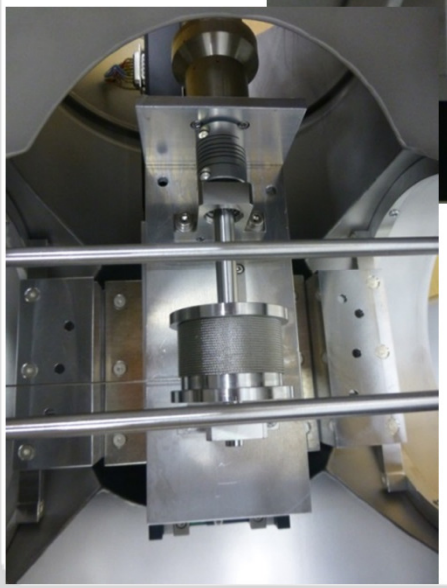
Test setup

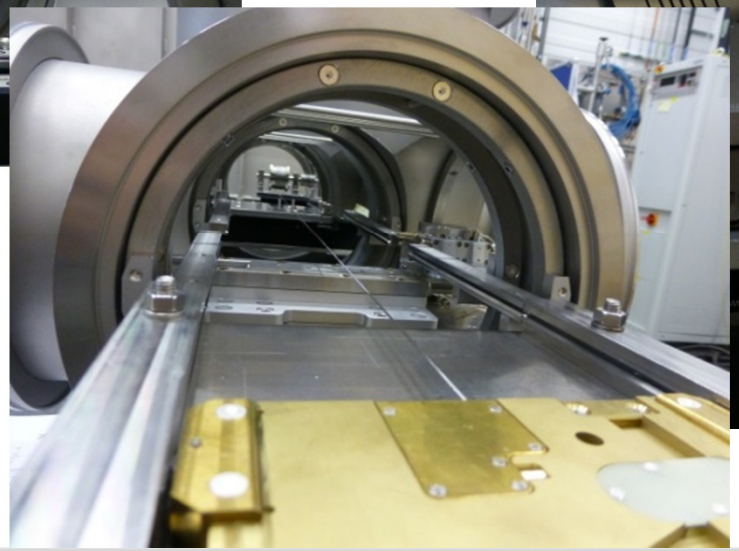






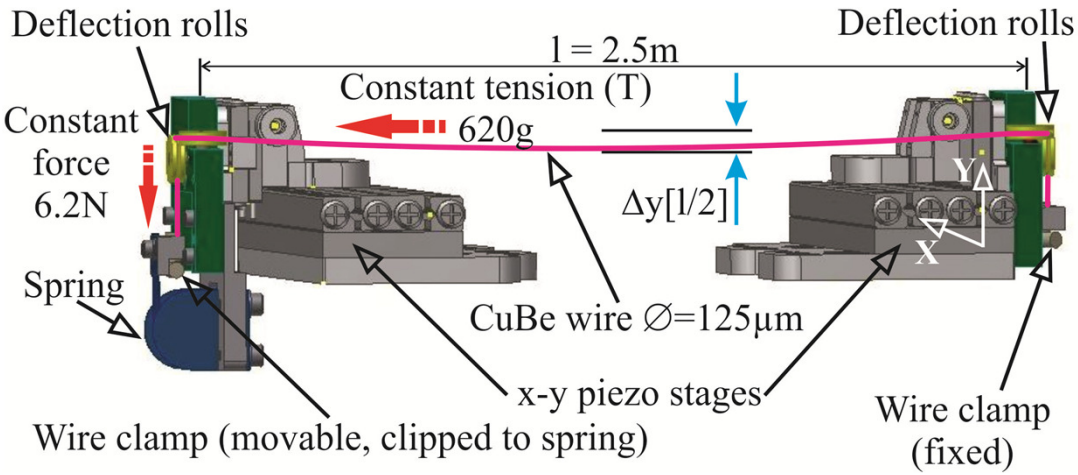






Stretched wire setup

- Copper Beryllium wire
- Diameter 125μm
- Length through the whole cryostat ~2.5m
- Movable along 2 axes (150mm x-axis, 20mm y-axis) synchroneous or opposite directions



Error consideration

Accuracy limit is set by the sag Δy in the middle (l/2) of the wire and depends on the tension and the self-weigth [1]

$$\Delta y\left(\frac{l}{2}\right) \cong -\frac{\omega_{CuBe}\, l^2}{8T} = -82\,\mu m$$

With $\varnothing_{CuBe}$ = 125 µm, ω_{CuBe} = 0.064g/m, and λ_U = 0.015m

Resulting Error in the field integral from [2]

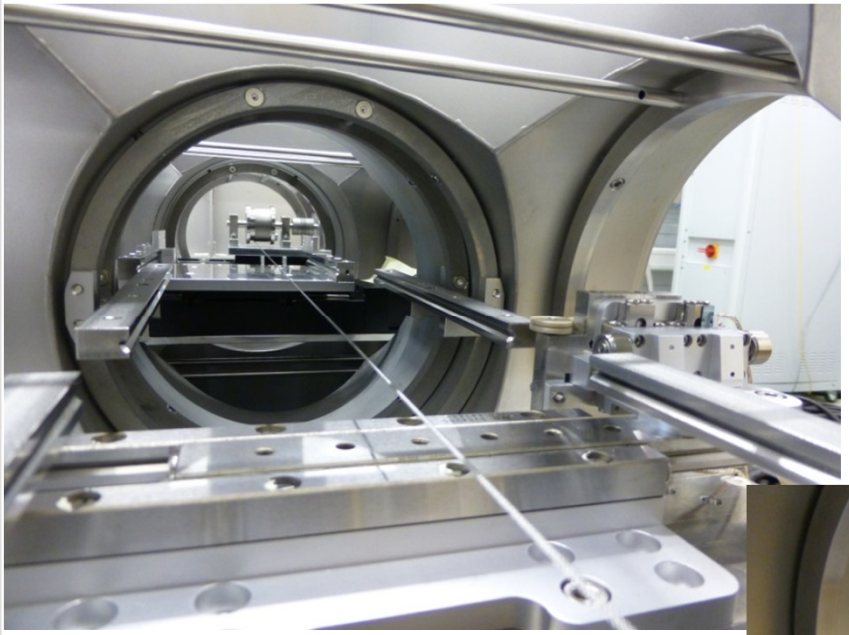
$$\frac{\Delta I_y}{I_y} \approx \frac{1}{2}\left(\frac{2\pi}{\lambda_U}\right)^2 \cosh\left(\frac{2\pi}{\lambda_U}\Delta y\right)(\Delta y)^2 \approx 5.9\times 10^{-4}.$$

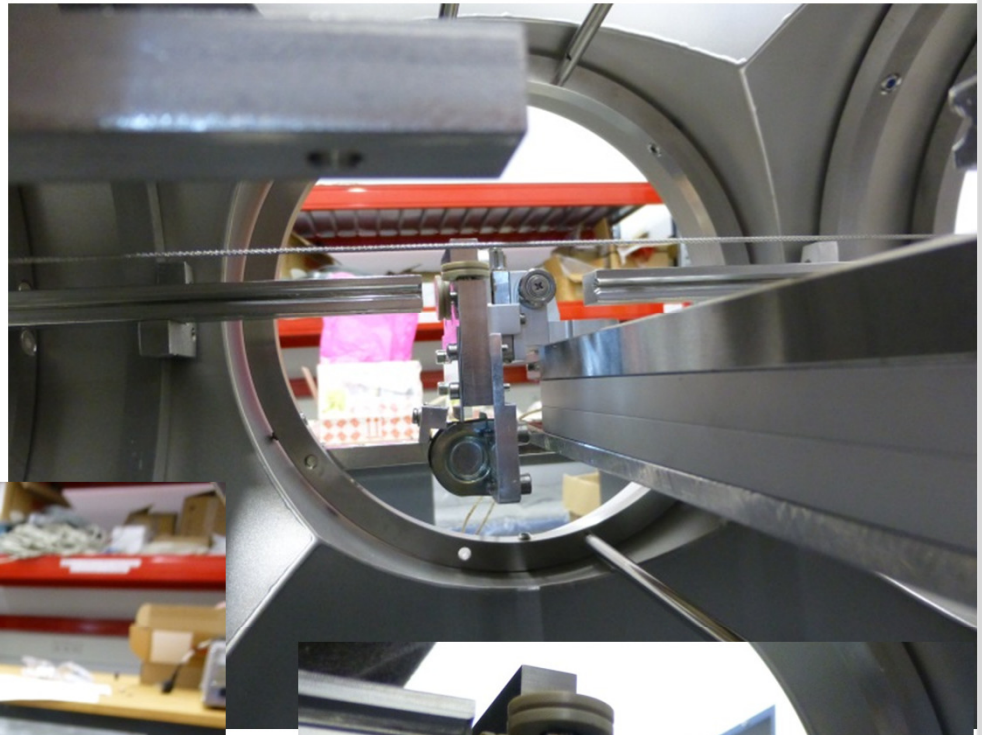
- Result for sag checked with a testsetup with l=2m and T= 620g.
- Vertical distance between the CuBe wire and table surface at both ends and in the middle of the wire measured with gauge blocks.
  - yielded to a sag of Δy = 50μm.
  - good agreement with Δy = 53μm from calculations [1]

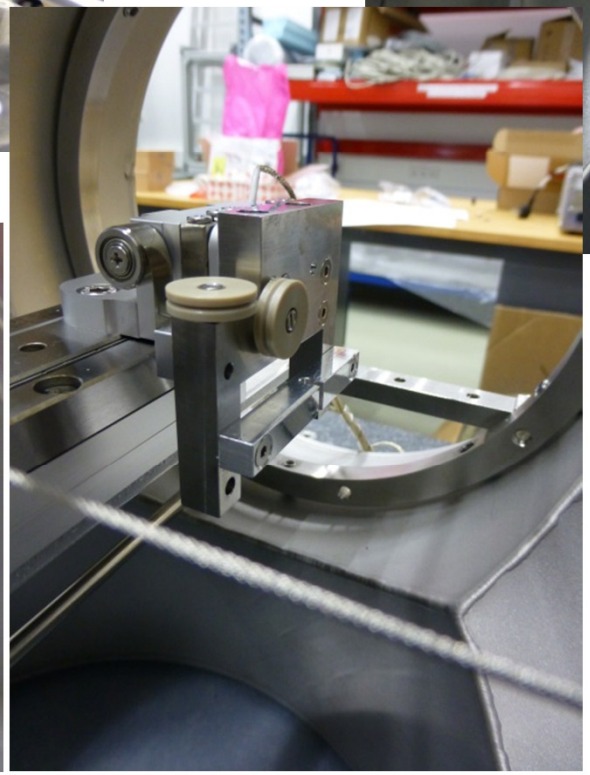
[1] G. Bowden "stretched wire mechanics," Technical report, #SLAC-Pub-11465, Stanford Linear Accelerator Center, 2004

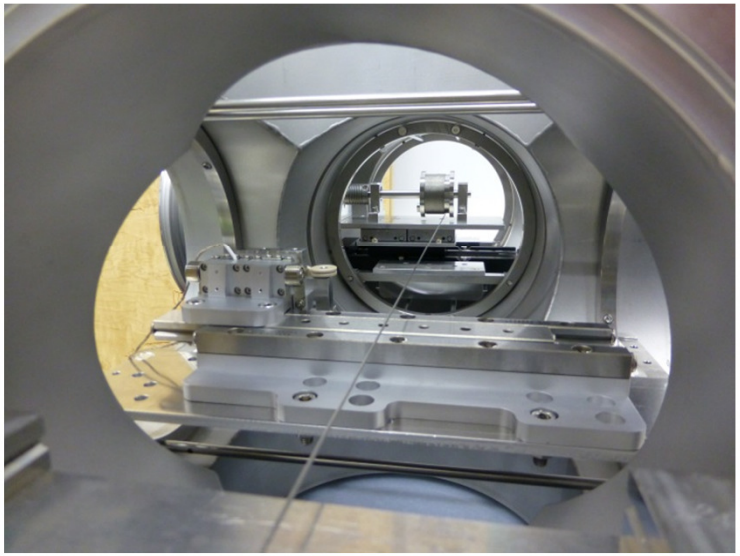
[2] F. Ciocci et. Al. „some considerations on the SPARC undulator magnetic measurements," Technical report #SPARC-FEL-06/001, ENEA Frascati, 2006

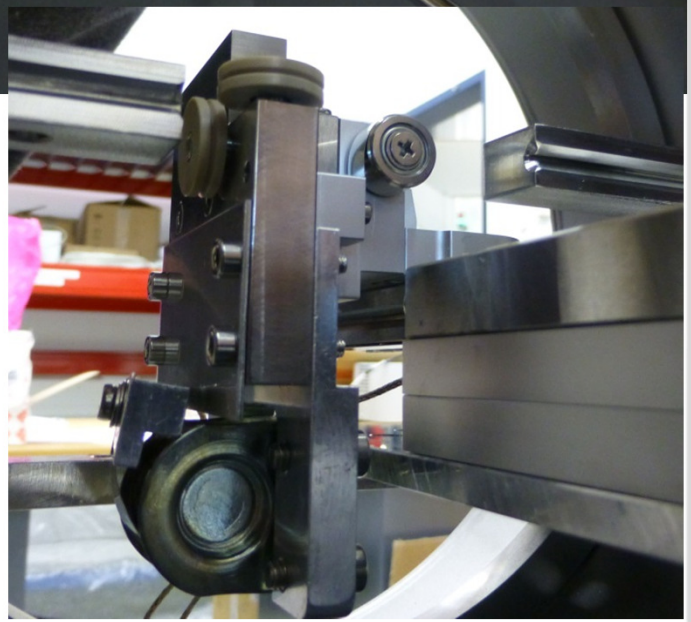
Stretched wire parts





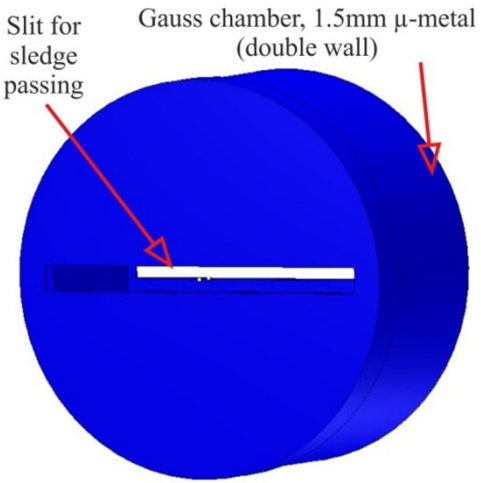


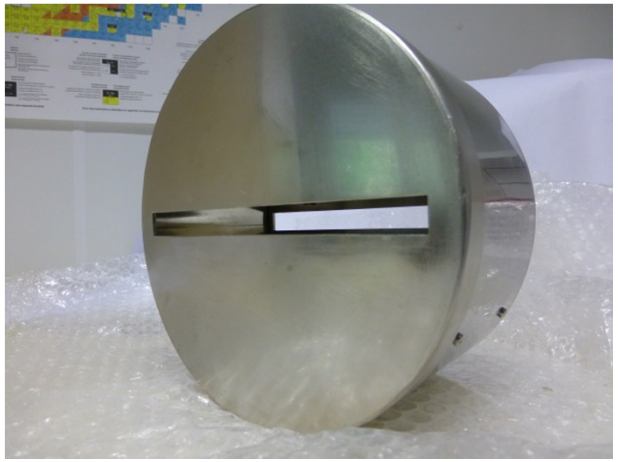


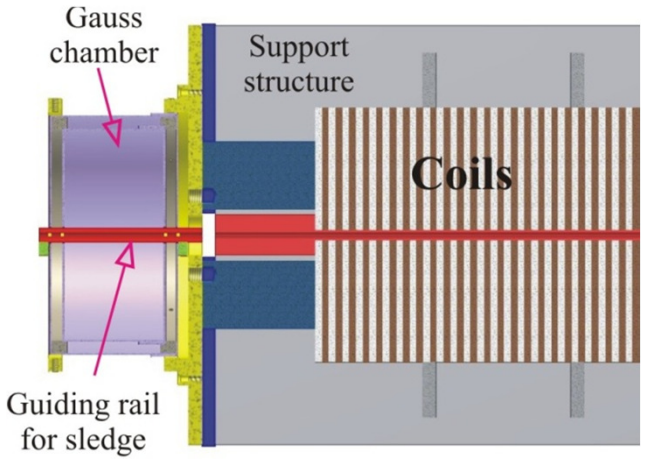


Additional components

Field shielding chamber to adjust the zero-point of Hall samples when cold

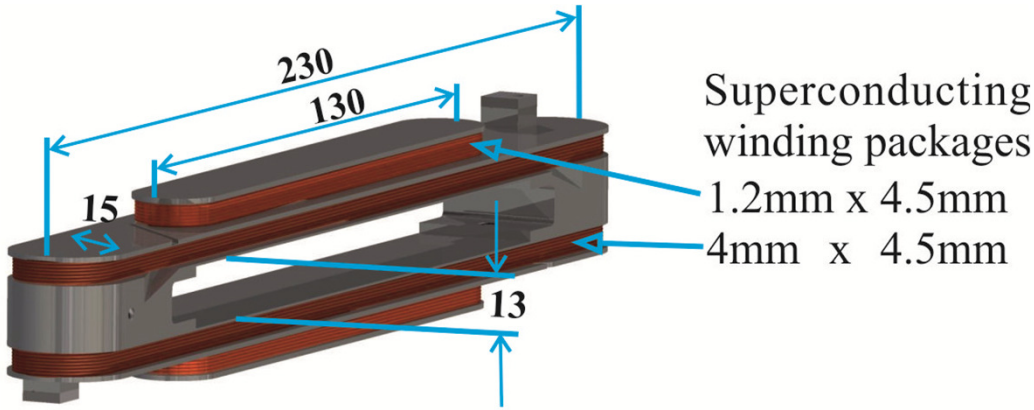






Stacked racetrack coils mounted in Helmholtz configuration to check calibration curve of the Hall samples

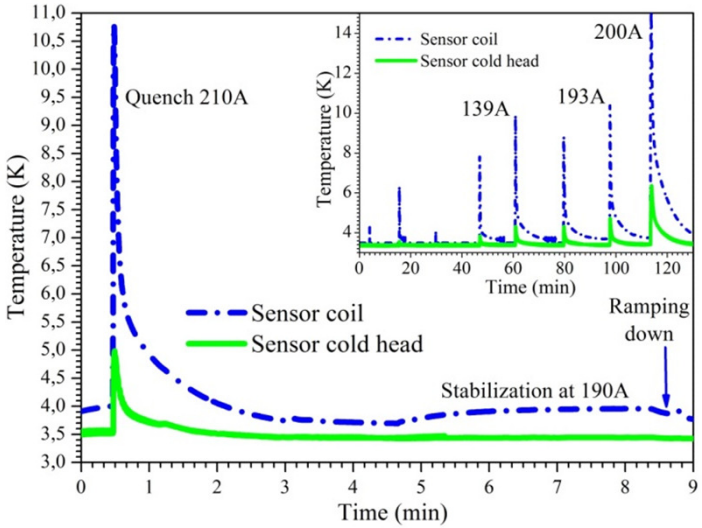
- Field at I=400A in the SC wire 650mT
- Field homogeneity over 20mm in the center 0.15mT
- In the design phase, improvement possible
- Design and winding at KIT



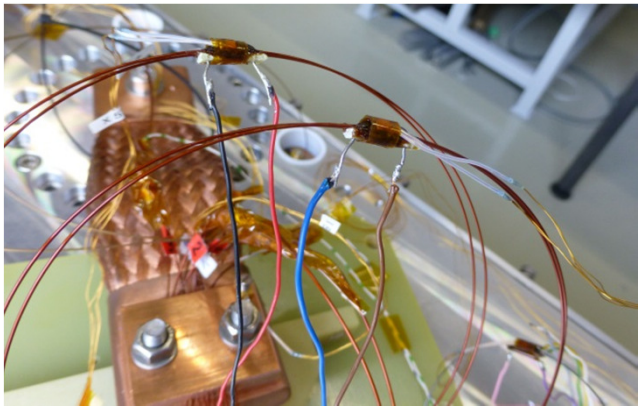
Activities

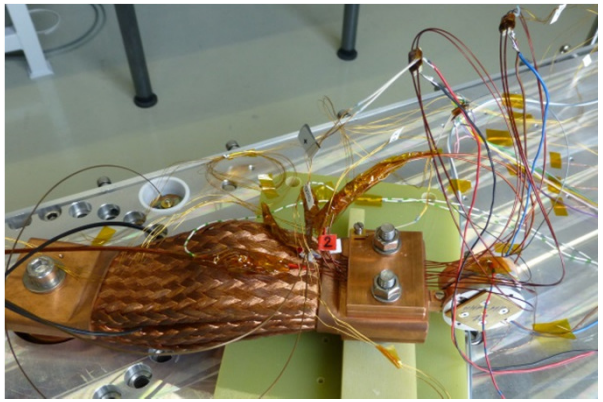
First quench tests with a conduction cooled test coil

- Conduction cooling is performed like for the final device connected via a copper braid (560mm²) to a coldhead
- Temperature reached at the superconducor 3.6K with a gradient of 0.2K to the coldhead
  - Improved connection compared to the FAT
- Reached 200A after a few quenches
- Time to recover from quench ~5min.
- At higher currents (210A) a quench occurs due to superconducter warming (joints)
- Stable cooling possible up to 190A
  - Well above the operation current 155A



Test SCS in vacuum and conduction cooled





Next steps

Mechanically

- Final alignment of the guiding rails in the cryostat extensions
- Alignment of the extension parts to each other and fixation
- Final preparation of the sledge for measurements (Hall samples, wiring etc.)
- Alignment of moving stages in the cryostat extensions
- Adjustment of Stretched wire parts
- Define fiducial points at the measurement system for alignment at the cryostat
- Completion of the support structures for the measurement parts
- Assembling of measurement system and cryostat

Sofware programming (LabView)

- Two rotating stepper motors for sledge movement
- Three Linear stages
- Laser Interferometer
- Two x-y axis piezo stages for stretched wire measurements
- Data recording from Hall samples and stretched wire
- Power supplies for main current
- Data acquisition system up to 64 channels, sampling rate 250 kS/s
- Data processing for quench analysis

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. . . and to you for your attention !