Progress on the superconducting undulator for ANKA and on the instrumentation for R&D

Sara Casalbuoni

for

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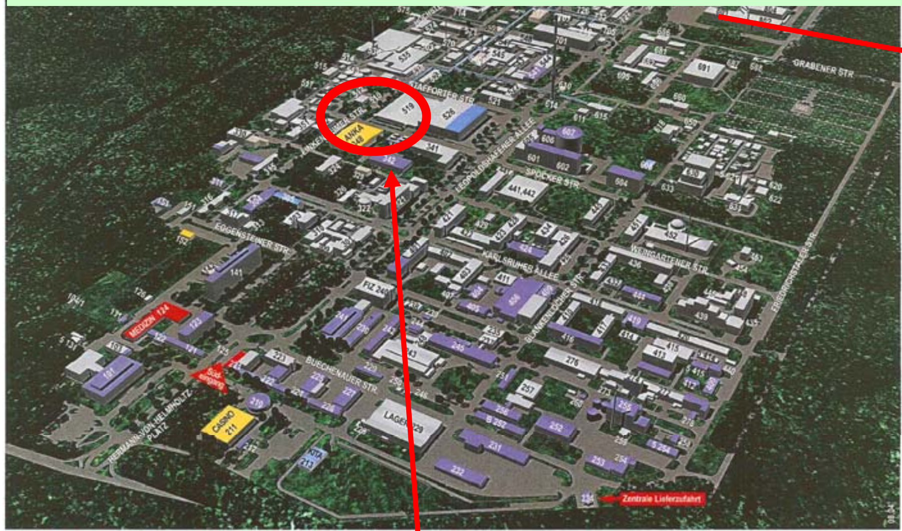
[2]Babcock Noell GmbH, Würzburg, Germany

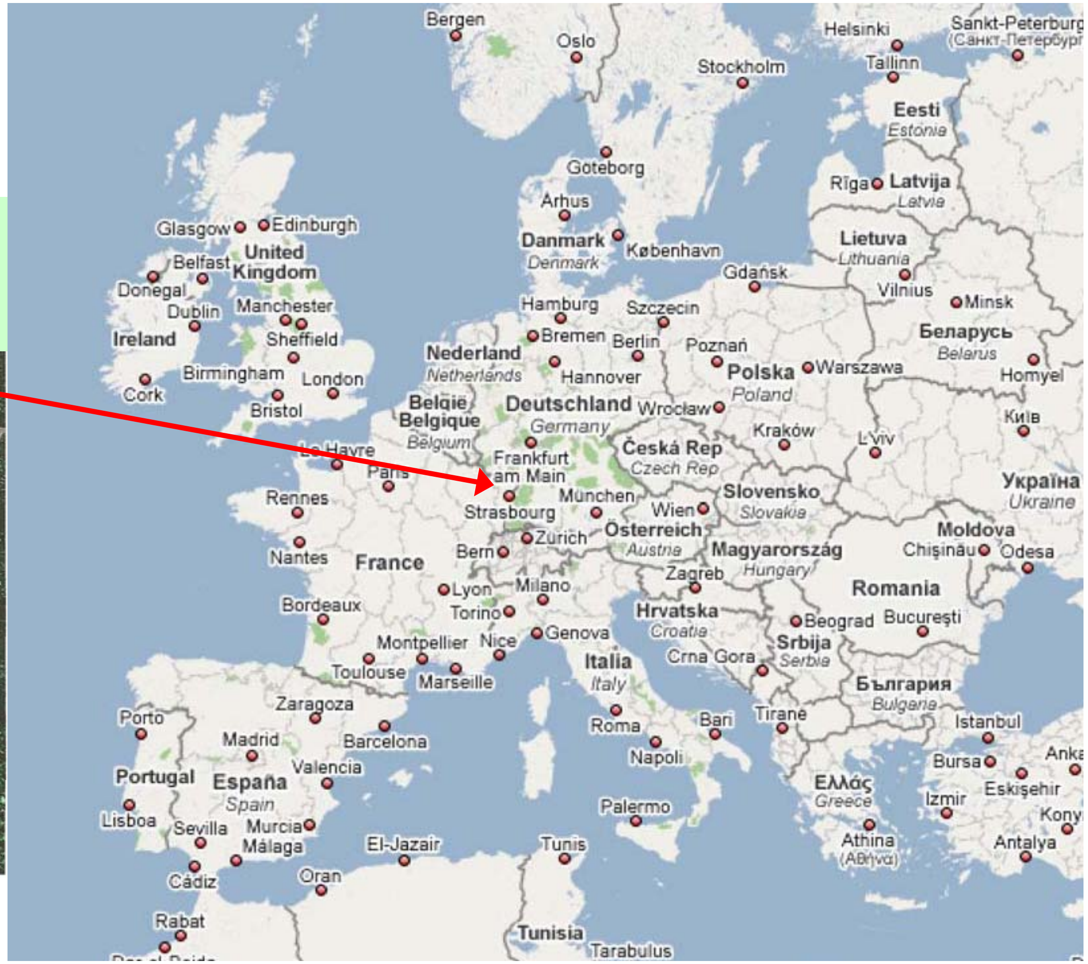
Outline

1. Introduction
   - ANKA
   - Motivation R&D of SCIDs
   - Experience at ANKA
2. Superconducting undulator
   - Design (see talk C. Boffo)
   - Experimental setup
   - Training
   - Magnetic field measurements
3. Experimental demonstration of feasibility of period length switching
4. Tools and instruments for R&D
   - CASPERI
   - CASPERII (see talk A. Grau)
   - COLDDIAG
5. Summary

ANKA

Karlsruhe Institute of Technology Campus North





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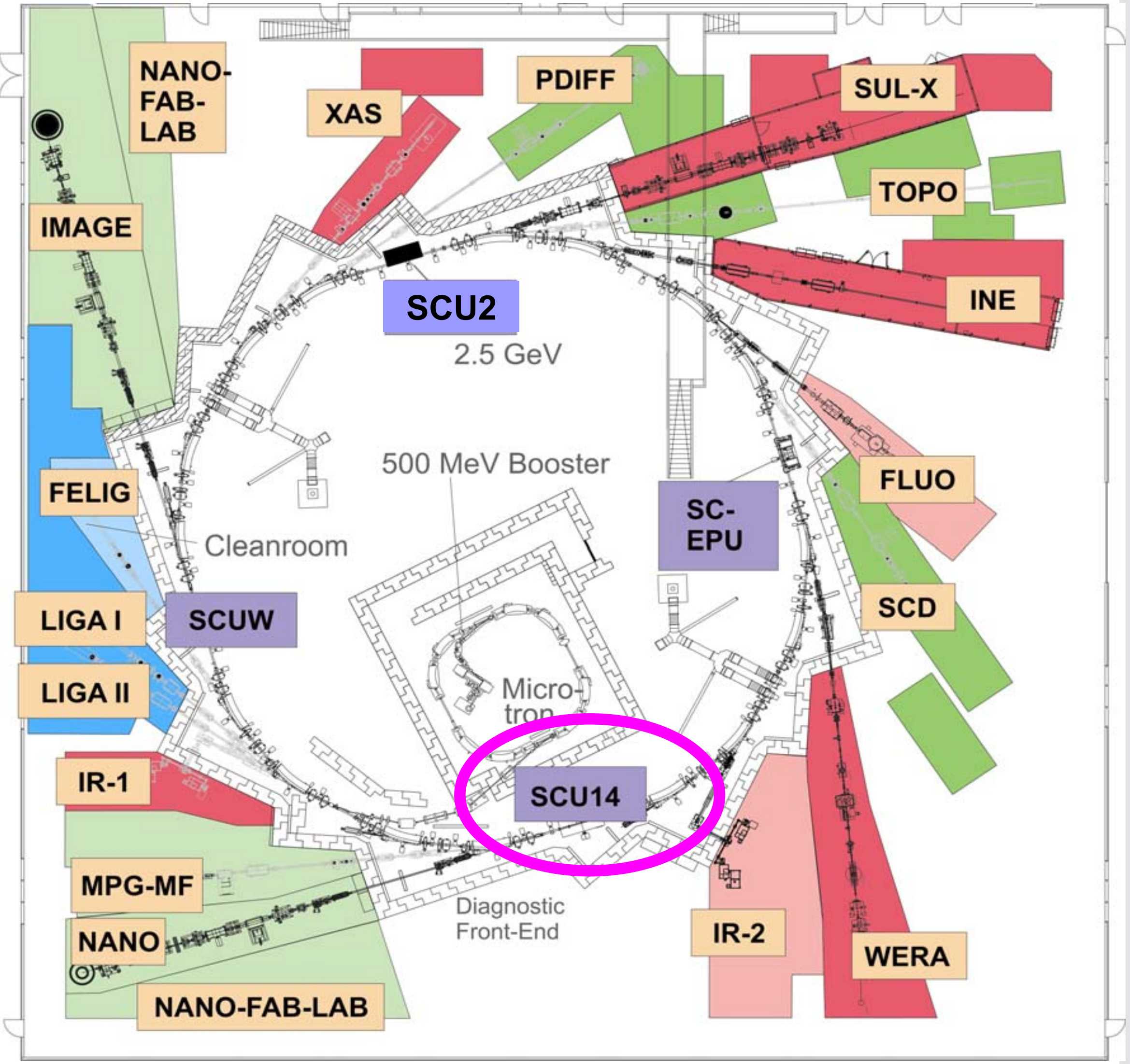
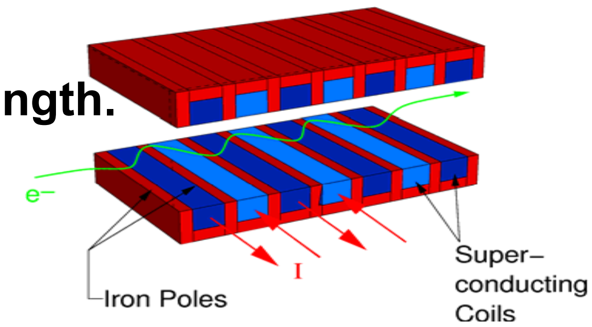


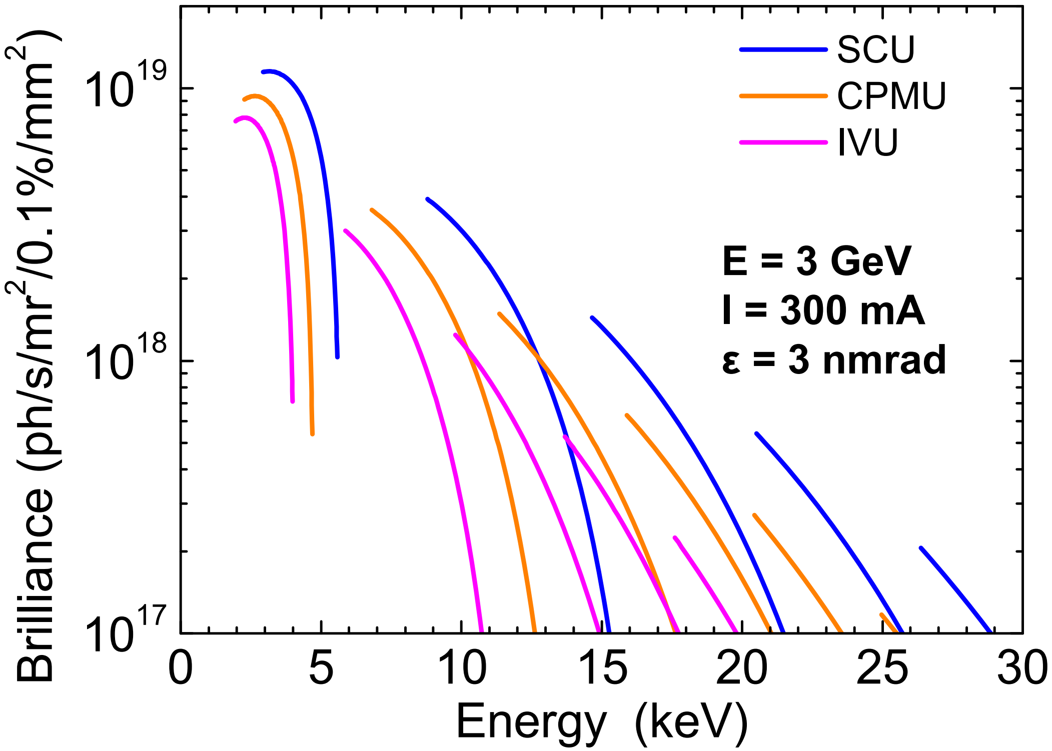
Energy: 2.5 GeV
Current: 200 mA
Circumference: 110.4 m

R&D of scIDs: objective

Develop, manufacture, and test superconducting undulators 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=6mm



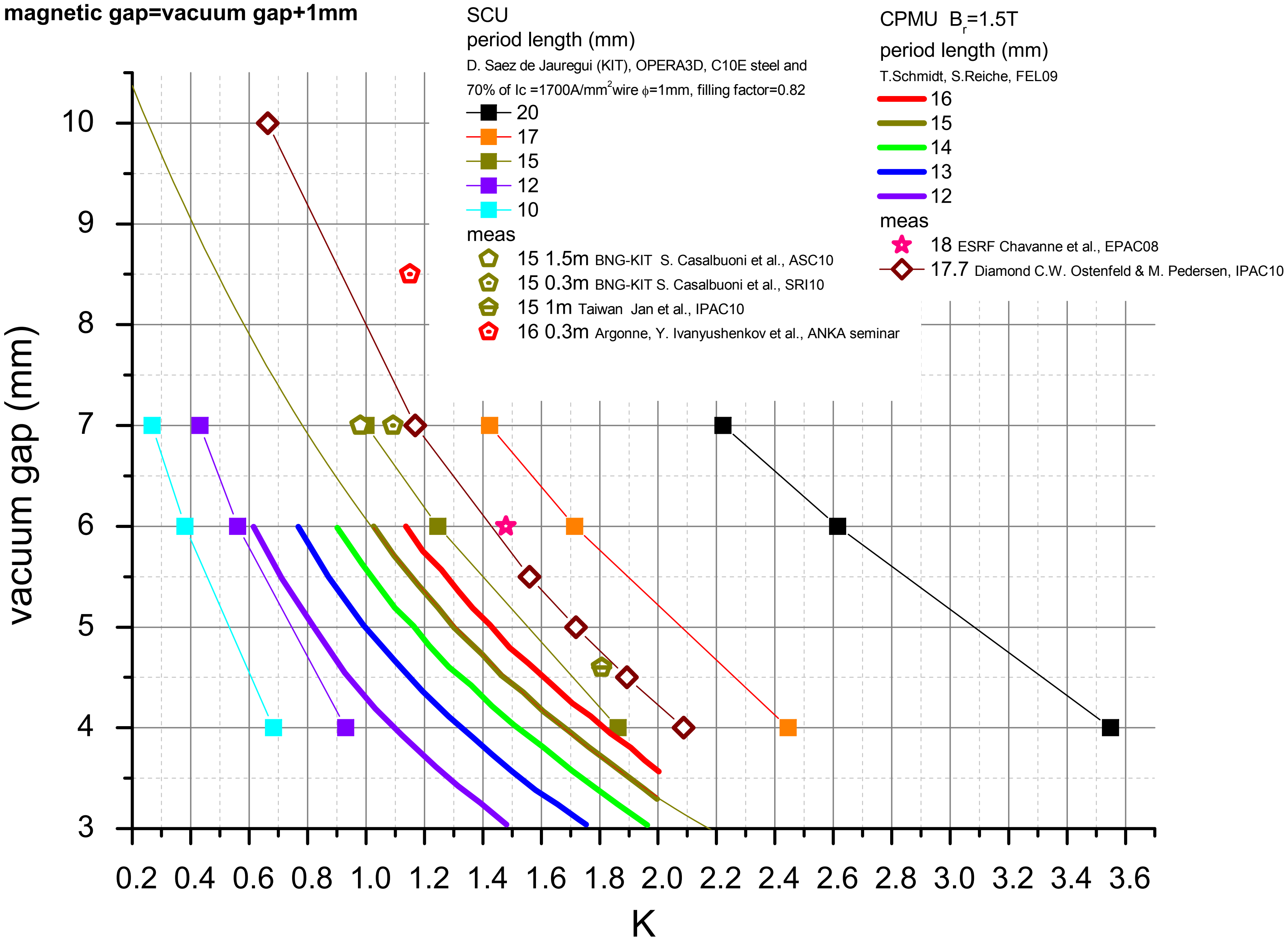
	IVU	CPMU	SCU
λ_u (mm)	21	18	15
N	95	111	133
m. gap (mm)	6	6	7
B (T)	.75	.88	.98
K	1.47	1.48	1.37

A given photon energy can be reached by the SCU with lower order harmonic:
20 keV reached with the 5th harm. of SCU, with 7th harm. of CPMU and with the 9th harm. of IVU

R&D of scIDs

Comparison SCU CPMU

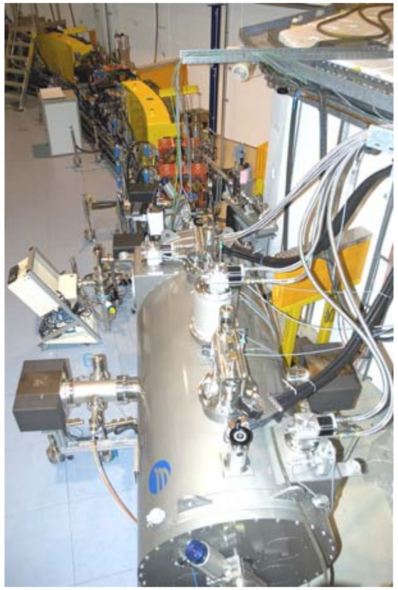
for SCU magnetic gap=vacuum gap+1mm

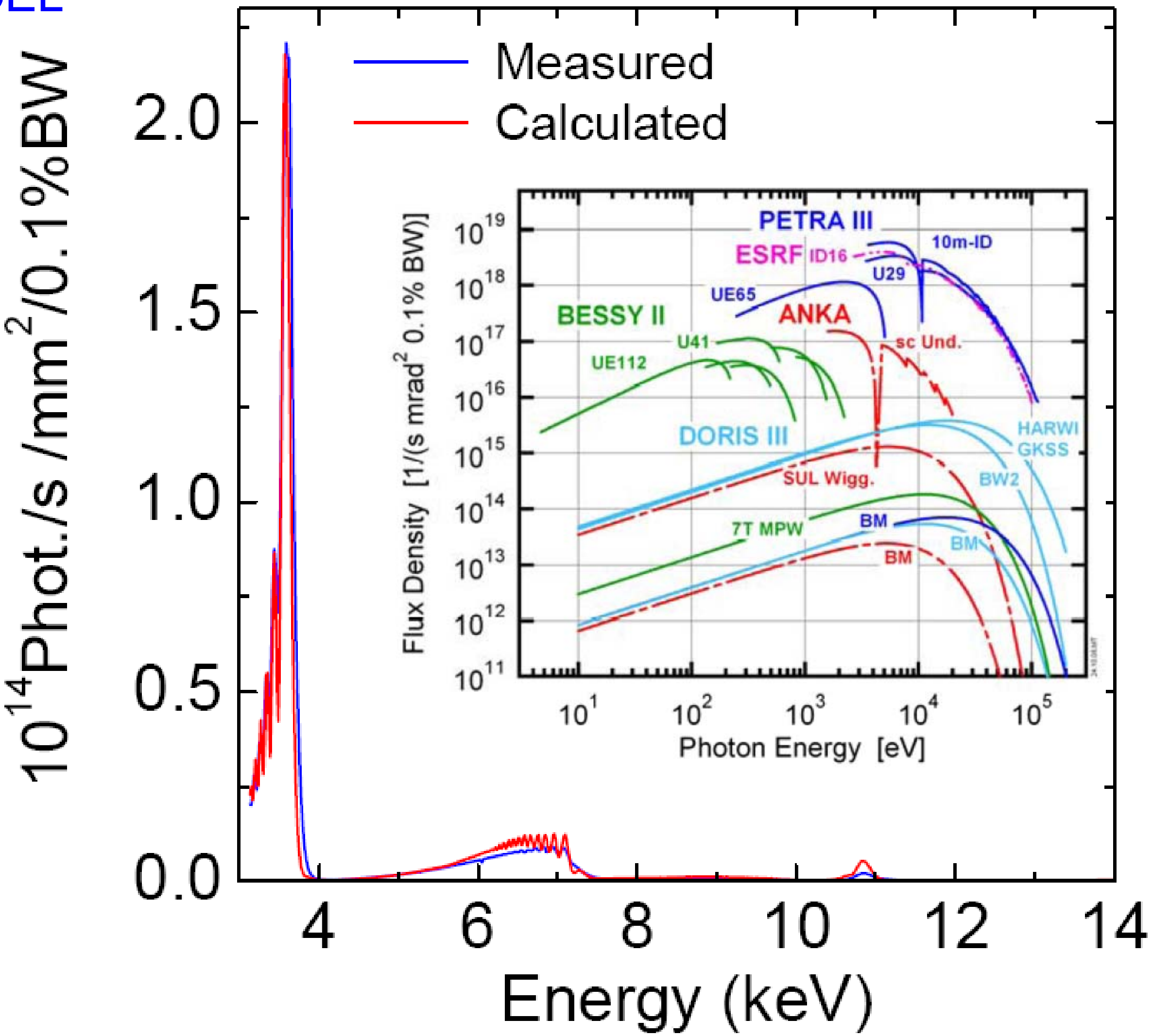


Experience at ANKA: SCU14 demonstrator

Proof of principle of scu technology first time worldwide demonstrated at ANKA (2005) developed in collaboration with ACCEL

- Period length: 14 mm
- Length: 100 periods
- NbTi - coils





Outcome used:

•to measure beam heat load to a cold vacuum chamber at ANKA

•to **improve the design of next generation sc undulators**

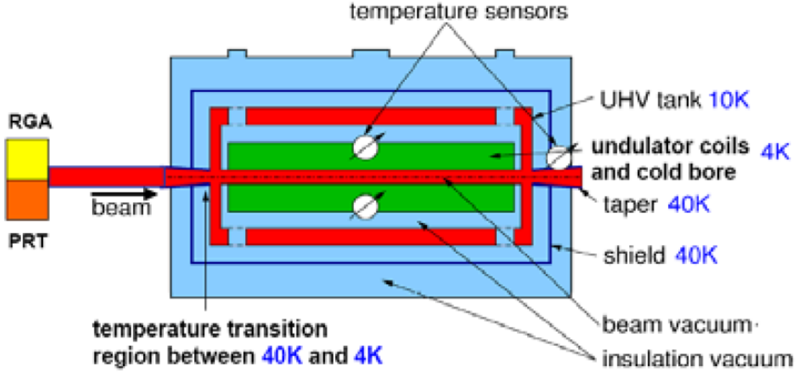
R. Rossmanith et al., SRI06

Experience at ANKA: SCU14 demonstrator

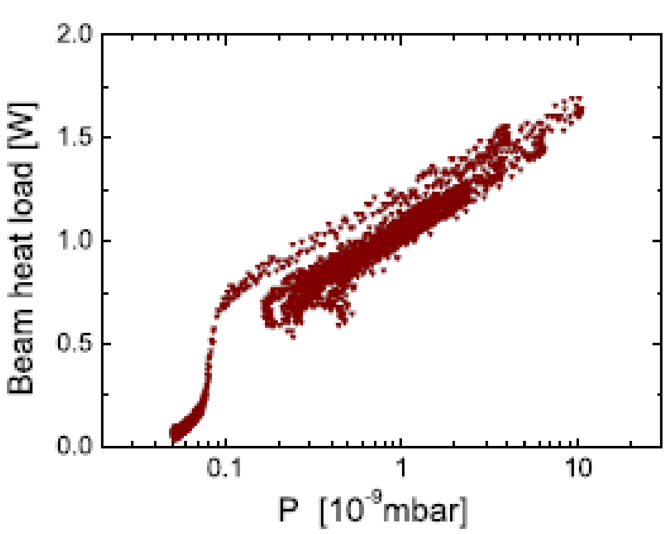
Karlsruhe Institute of Technology

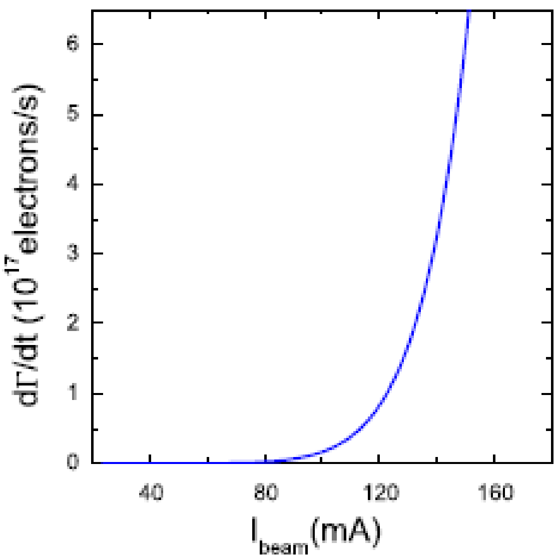
Beam heat load studies

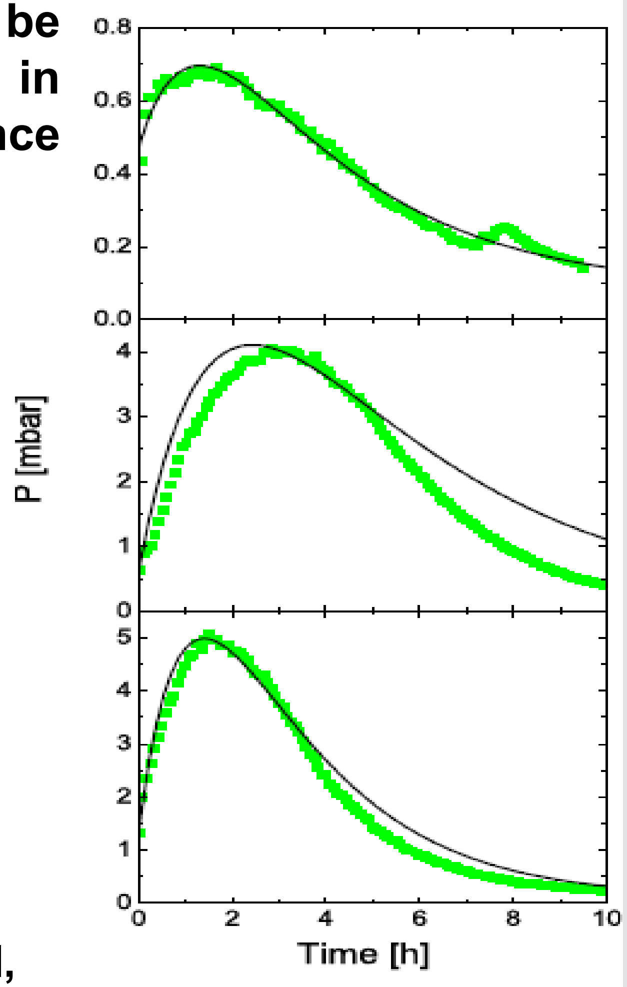
Performance limited by too high beam heat load: beam heat load observed cannot be explained by synchrotron radiation from upstream bending and resistive wall heating. S. C. et al., PRSTAB2007



Pressure rise can be explained by including in eq. of gas dynamic balance electron multipacting.
S. C. et al., PRSTAB2010







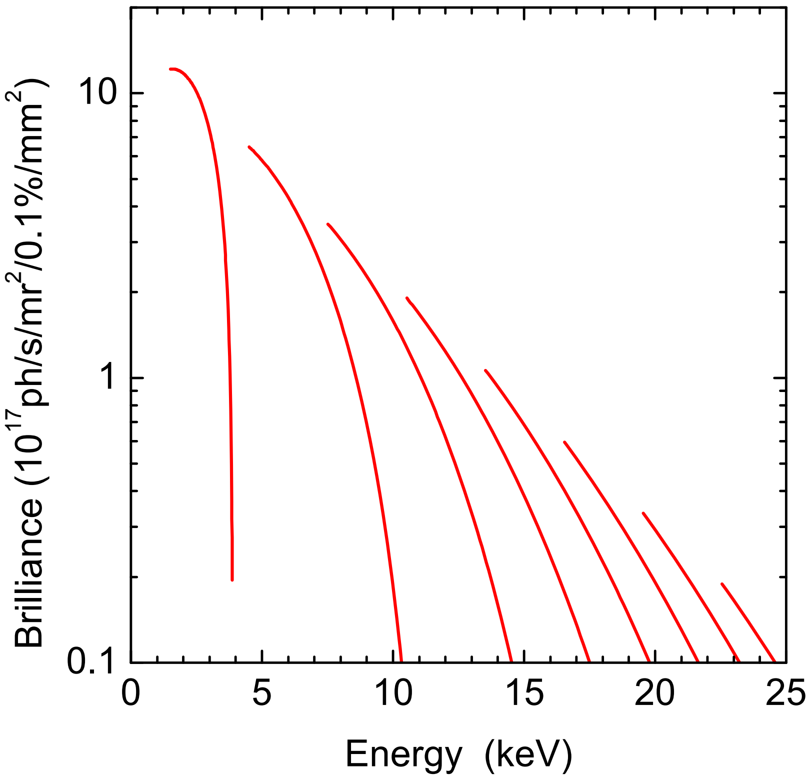
Possible beam heat load source: electron bombardment of the wall, beam dynamics under study

New superconducting undulator for the NANO beamline: SCU15

Under development in collaboration with BNG

Light source for the beamline NANO at ANKA
- High-resolution X-ray diffraction
- Surface and interface X-ray scattering
- In-situ investigations of thin films, multilayers and nano-structured materials

- Cryogen free magnet
- NbTi superconductor
- Local shimming
- Integral field compensation
- Passive quench protection



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	25mm
K value at 5.4 mm magn. gap	2
r.m.s. phase error	**3.5°**
Design beam heat load	**4W**

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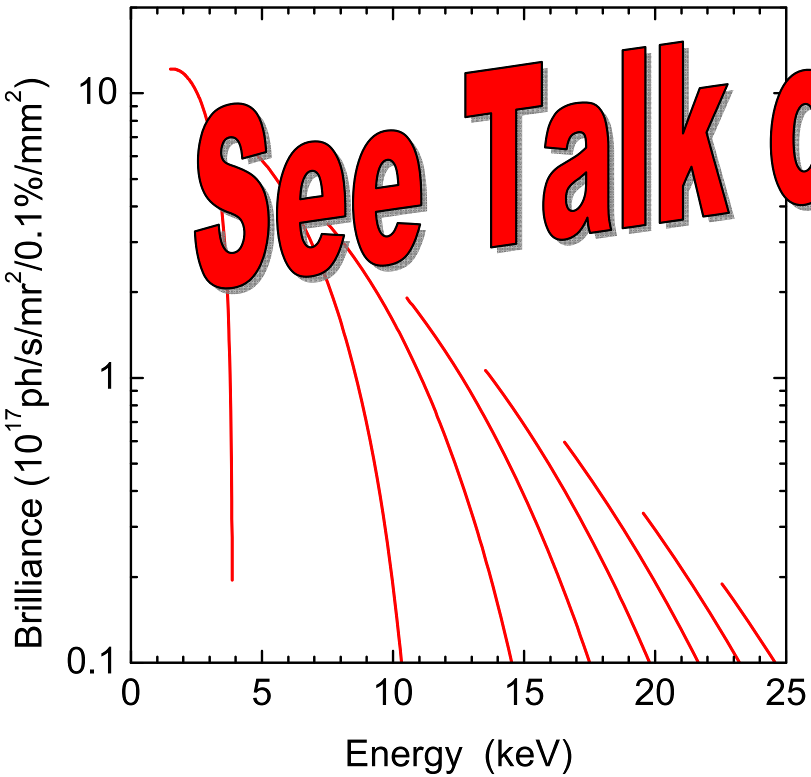
See Talk of Cristian Boffo



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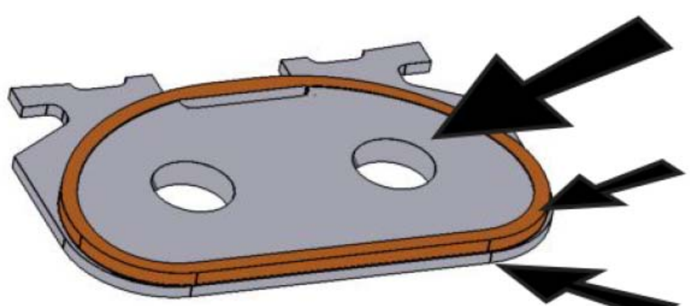
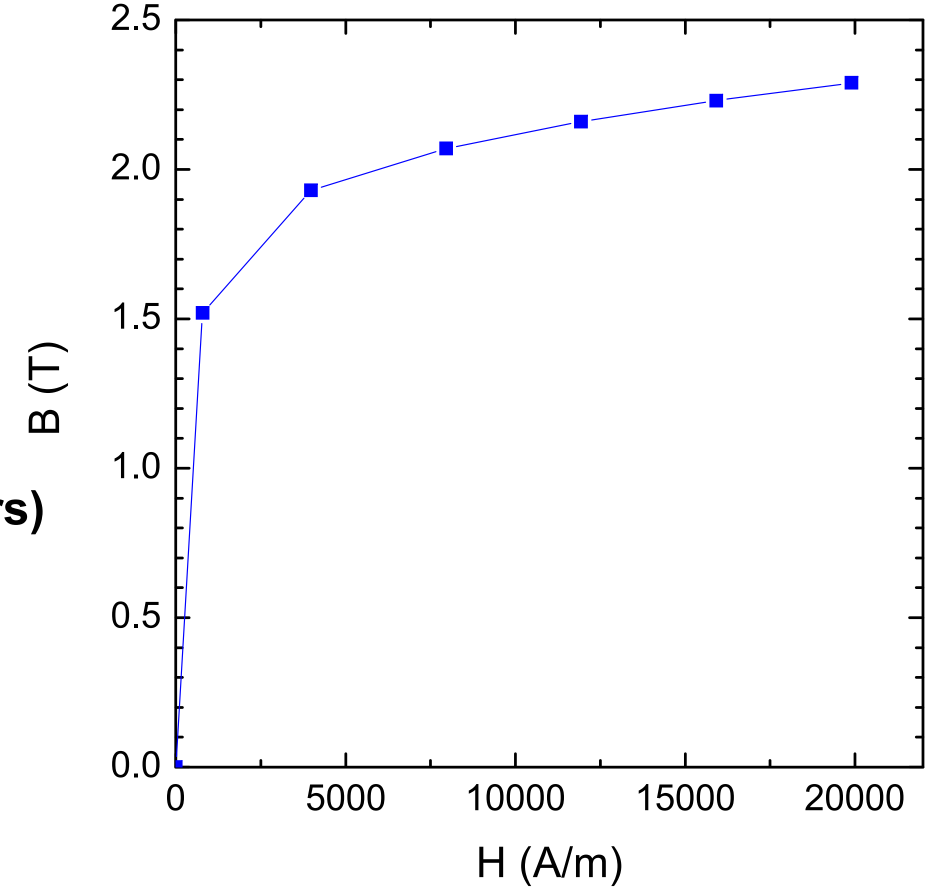
SCU15 demonstrator



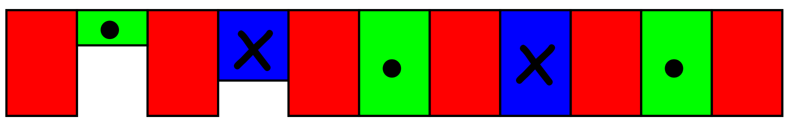
206 plates of high magnetic field saturation cobalt-iron alloy

Magnetization curve of cobalt-iron alloy from constructor @300K

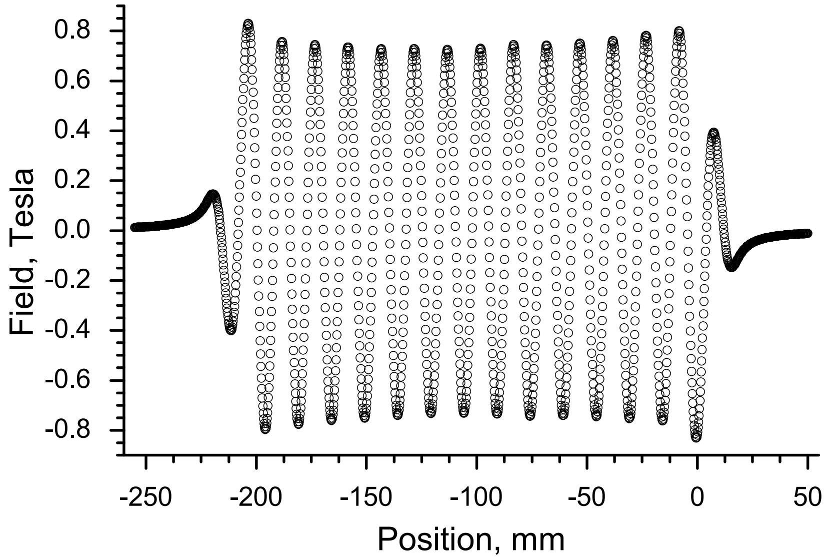


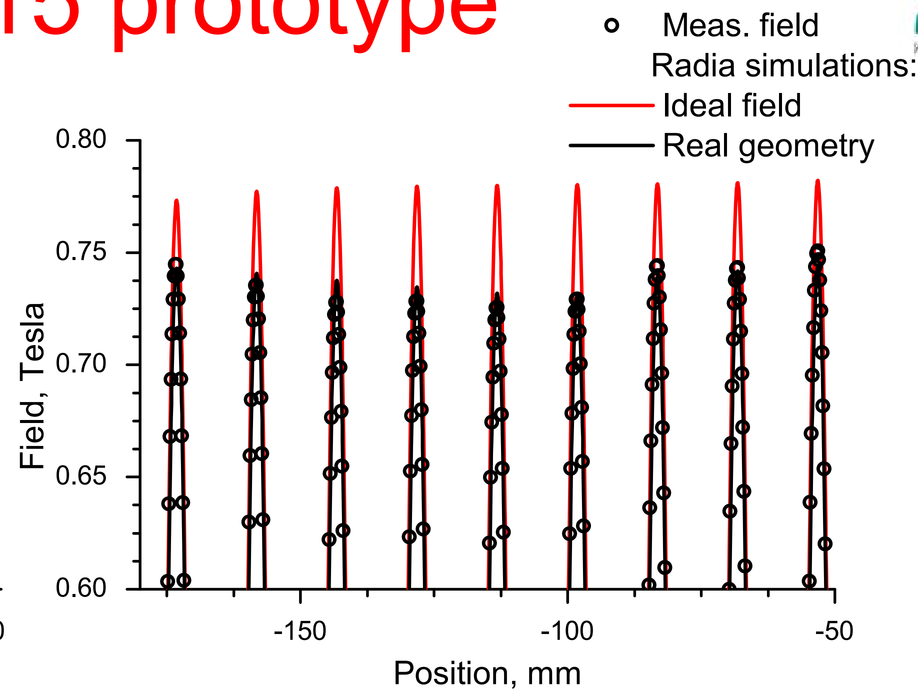
Cross section NbTi wire:
0.54mm x 0.34mm (including insulation)

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

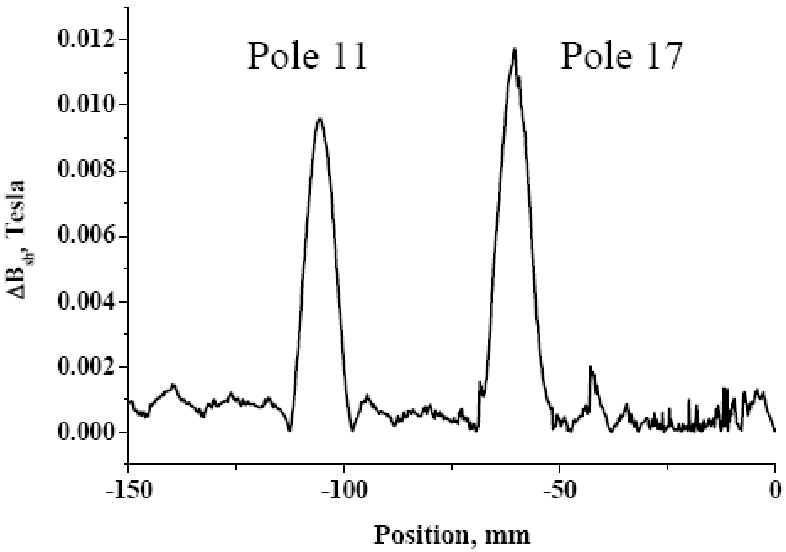


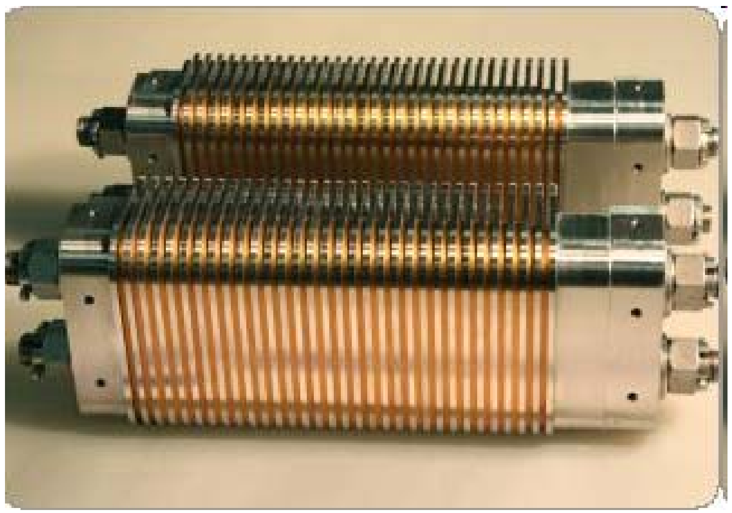
SCU15 prototype





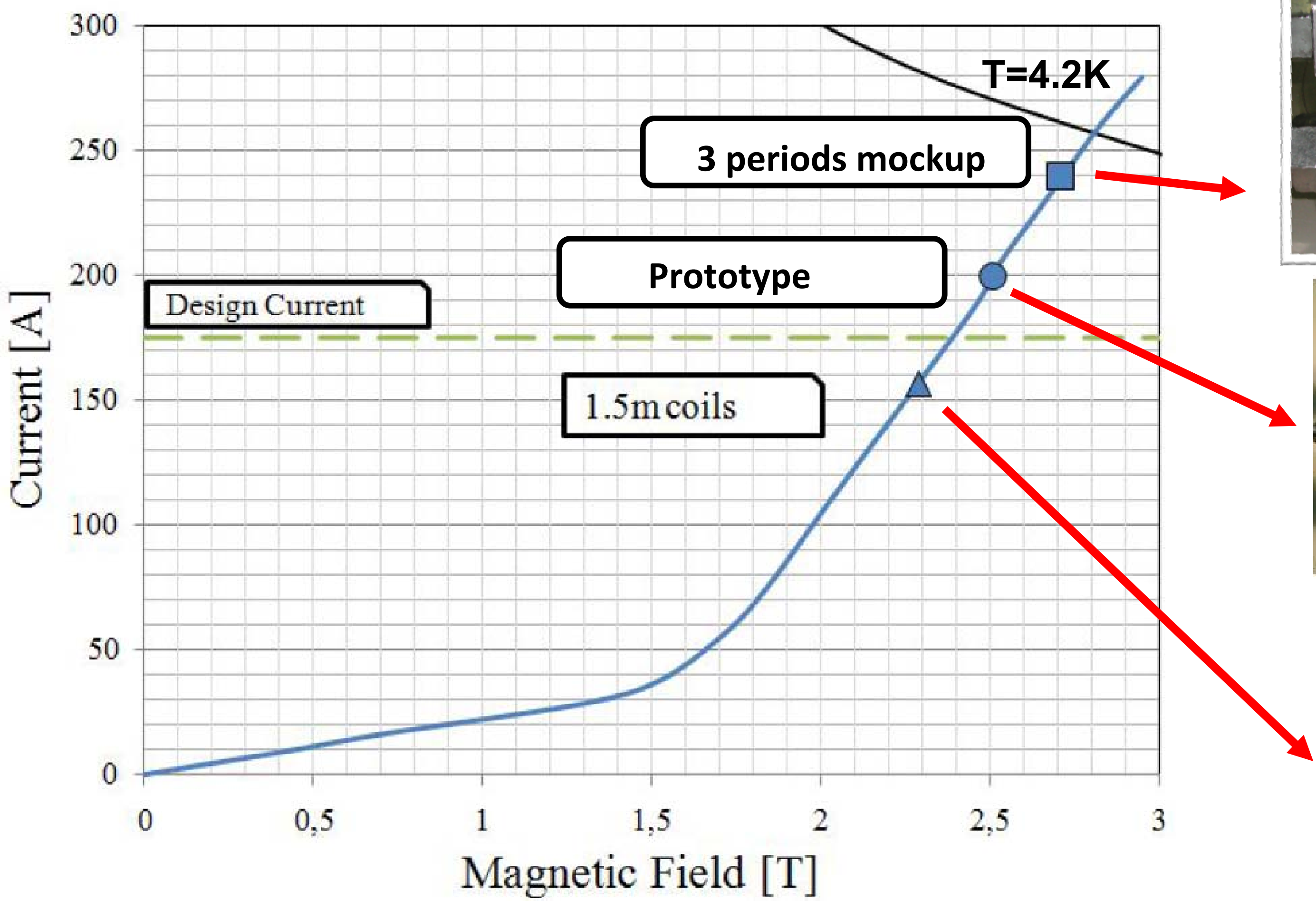
Active shimming using racetrackcoils



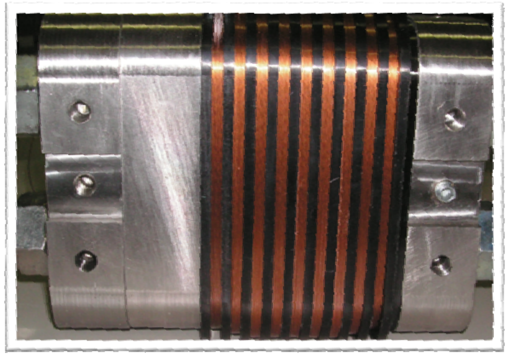


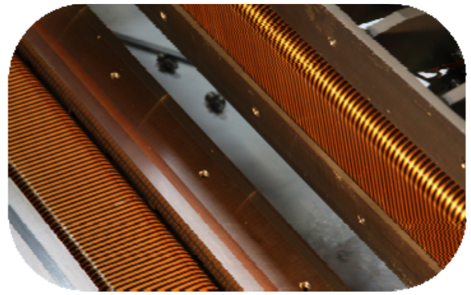
S. C. et al., SRI09

SCU15 demonstrator: magnet loadline



Measured @KIT



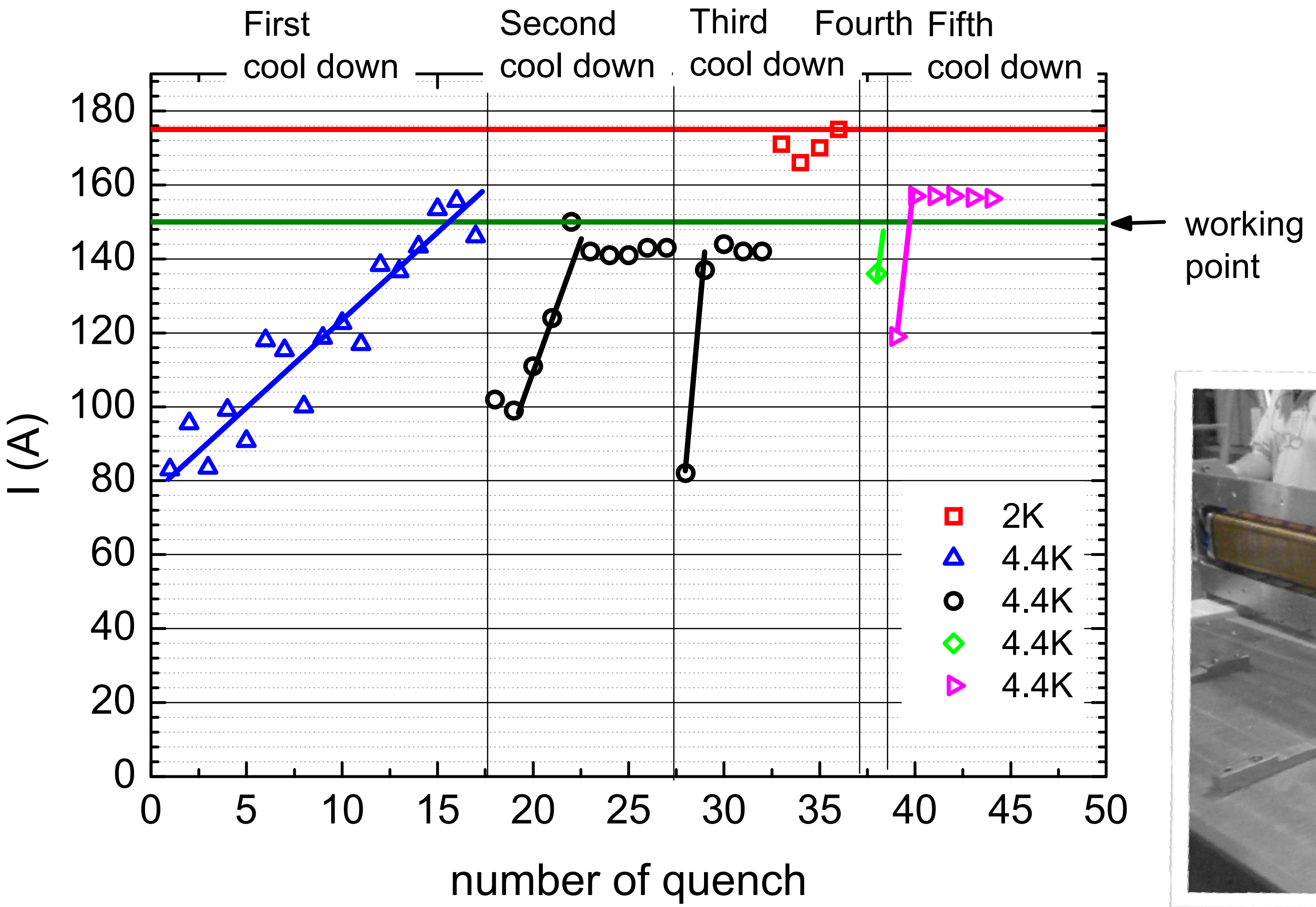


Measured @CERN

C. Boffo et al., ASC10

SCU15 demonstrator: training

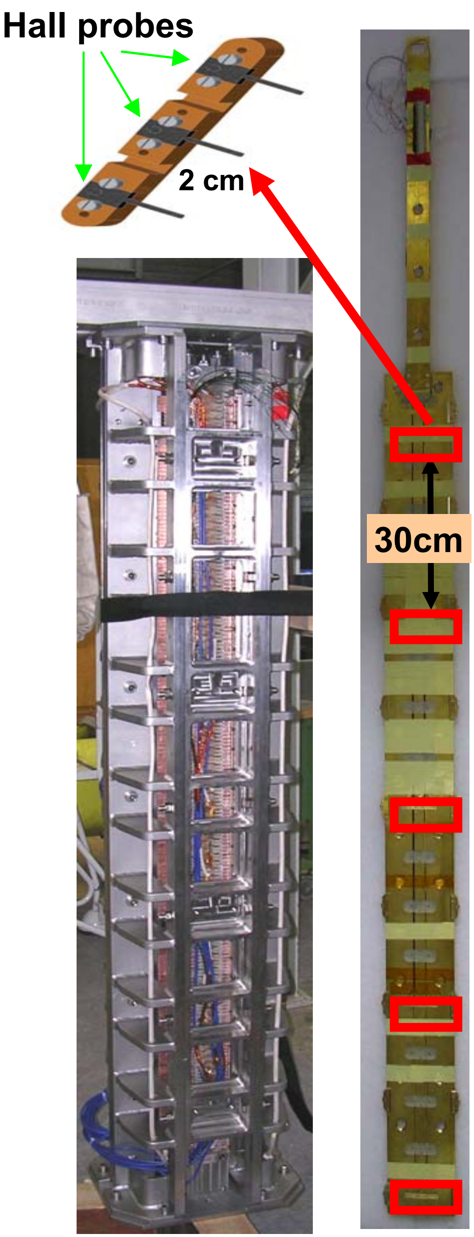
Measured @CERN

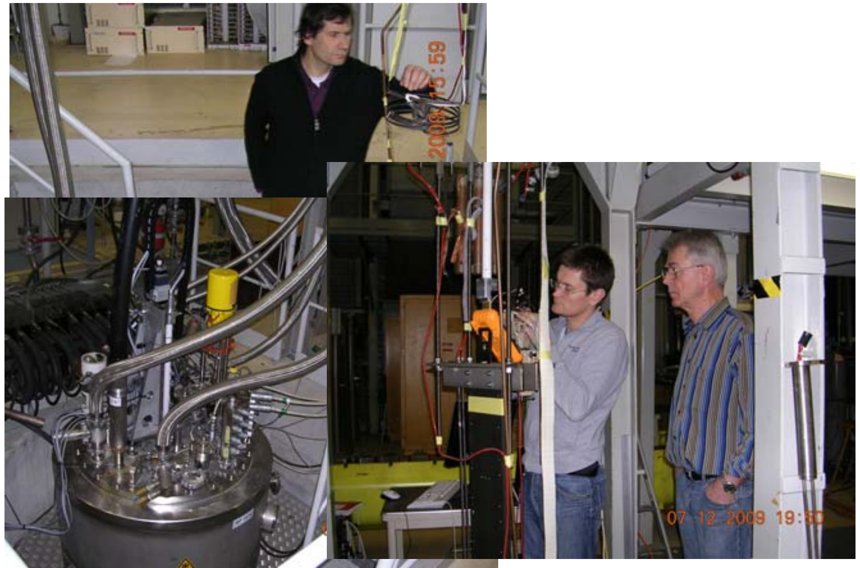


Next devices thicker wire and for the yoke C10E steel.

S. C. et al., ASC10

Experimental setup

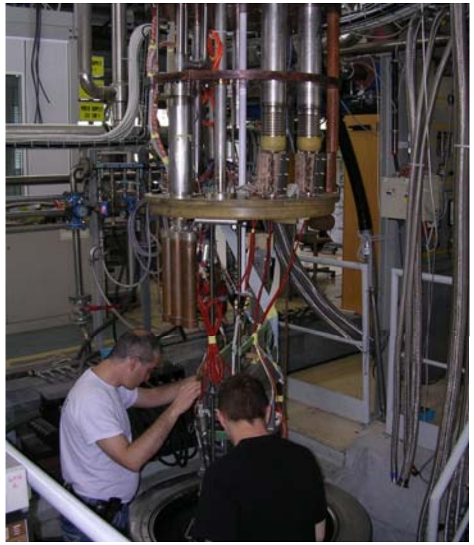



Test sledge 8.12.10

Installation 31.03.10

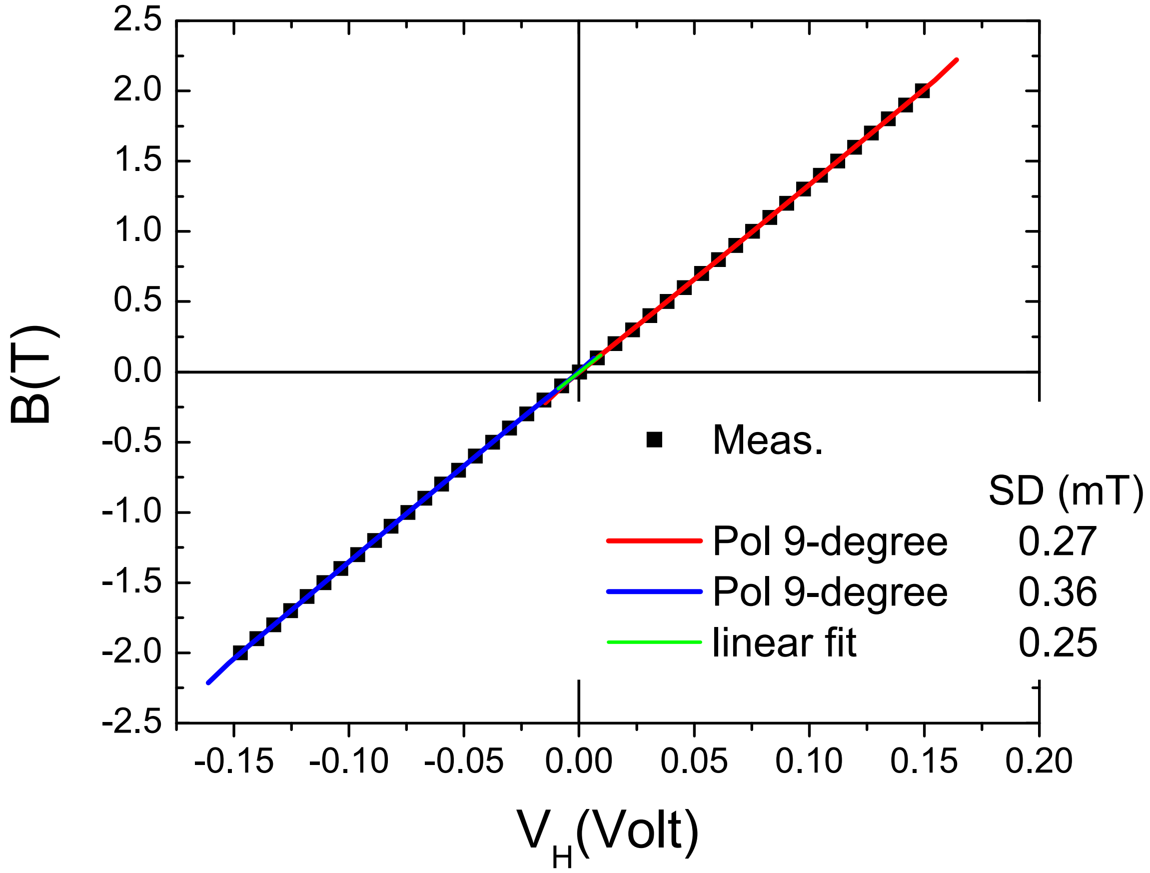

First magnet arrival 12.01.10

Deinstallation 03.05.10



Hall probes calibration

Hall probes calibrated at the Institute of Technical Physics (KIT) in a liquid helium bath in a field -3T<B<3T with homogeneity better then 10^{-4}.



Local phase error induced by calibration of the Hall probes ΔB<1mT:

$$\Delta\Phi = \frac{K^2}{1+K^2}\frac{\Delta B}{B}360^\circ < 0.35^\circ$$

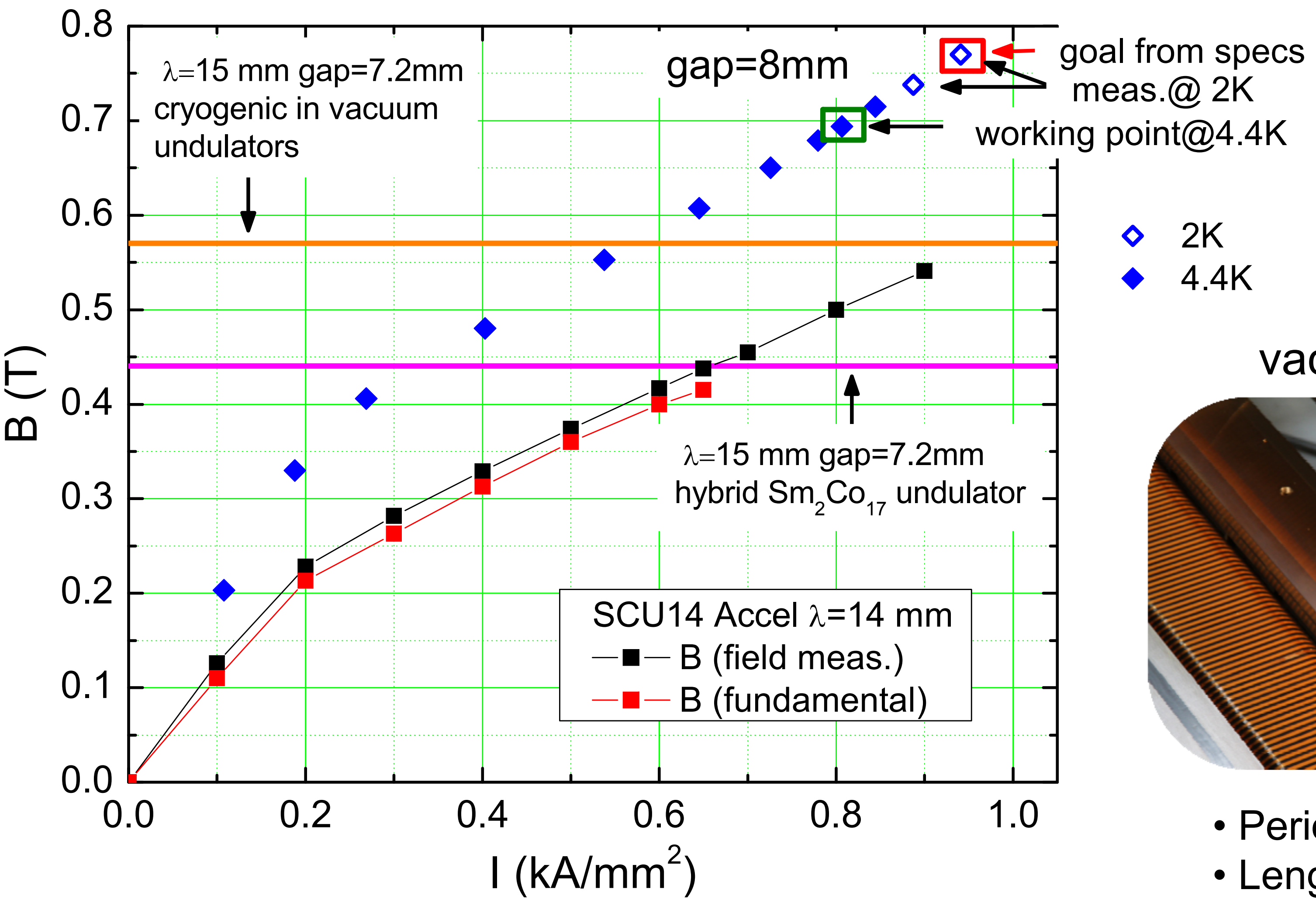
$$K = 93.37\lambda_u B = 1.08$$

$$\lambda_u = 0.015\text{m} \quad B = 0.77\text{T}$$

S. C. et al., ASC10

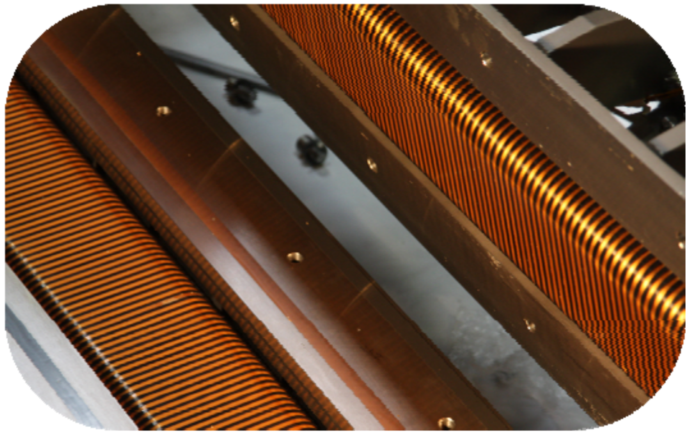
SCU15 demostrator

Comparison with competing technologies and with SCU14 demonstrator



S. C. et al., ASC10

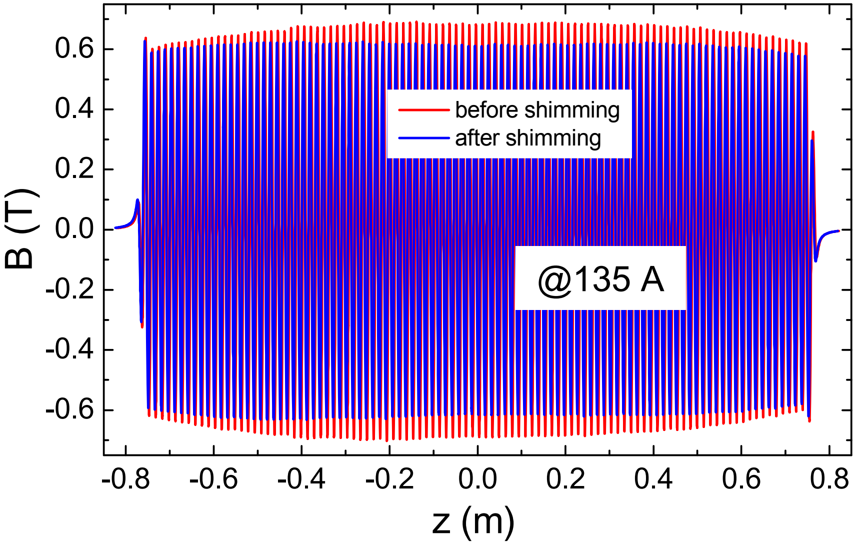
vacuum gap=7 mm



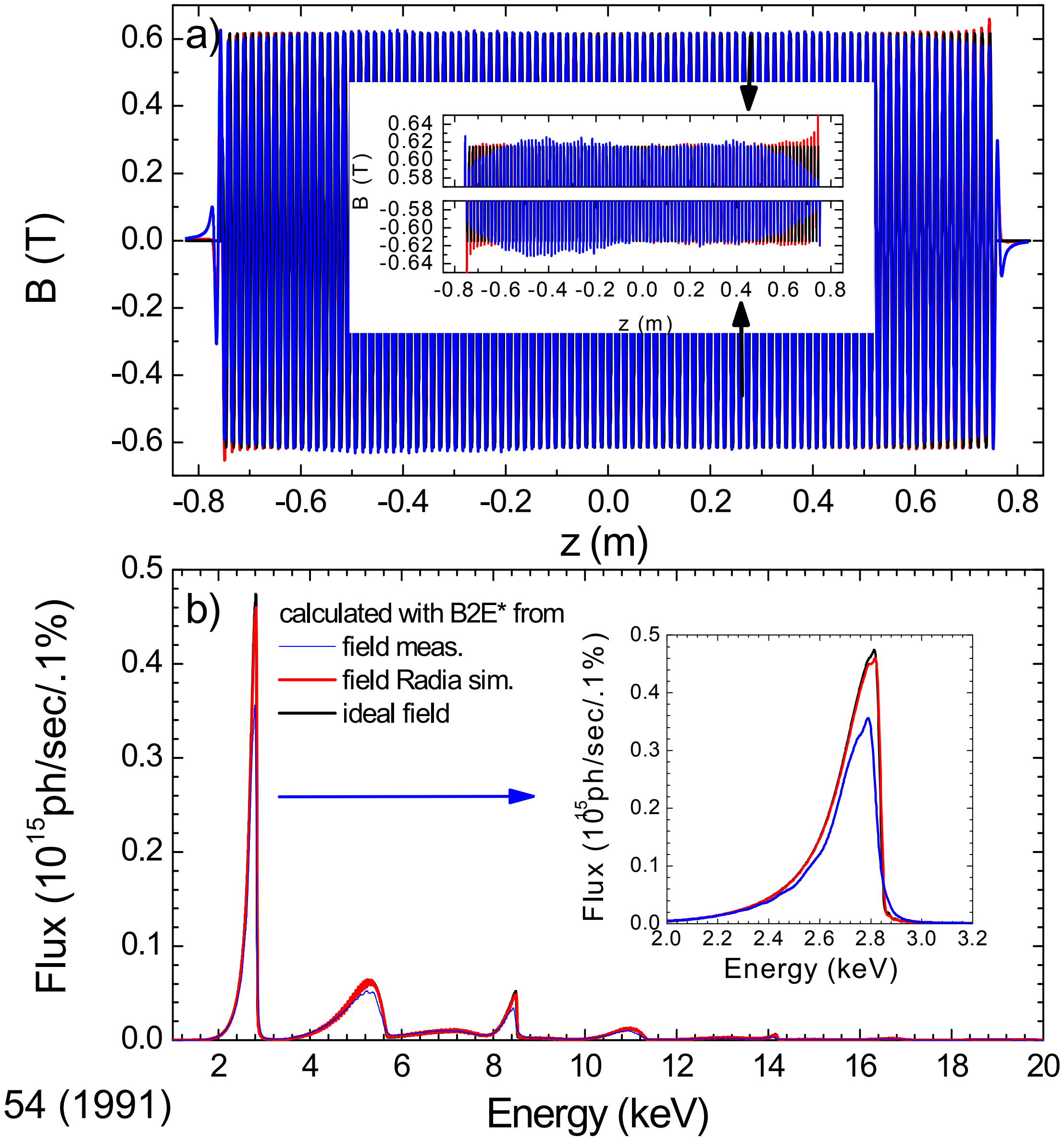
- Period length: 15 mm
- Length: 100 periods
- NbTi - coils

SCU15 demonstrator: field quality

Stainless steel support structure, which fixes the magnetic gap at room temperature to 8 ± 0.01 mm.



Phase error of 7.4 degrees over a length of 0.795 m, obtained by a simple mechanical shim, which is easily applicable to fixed gap devices.

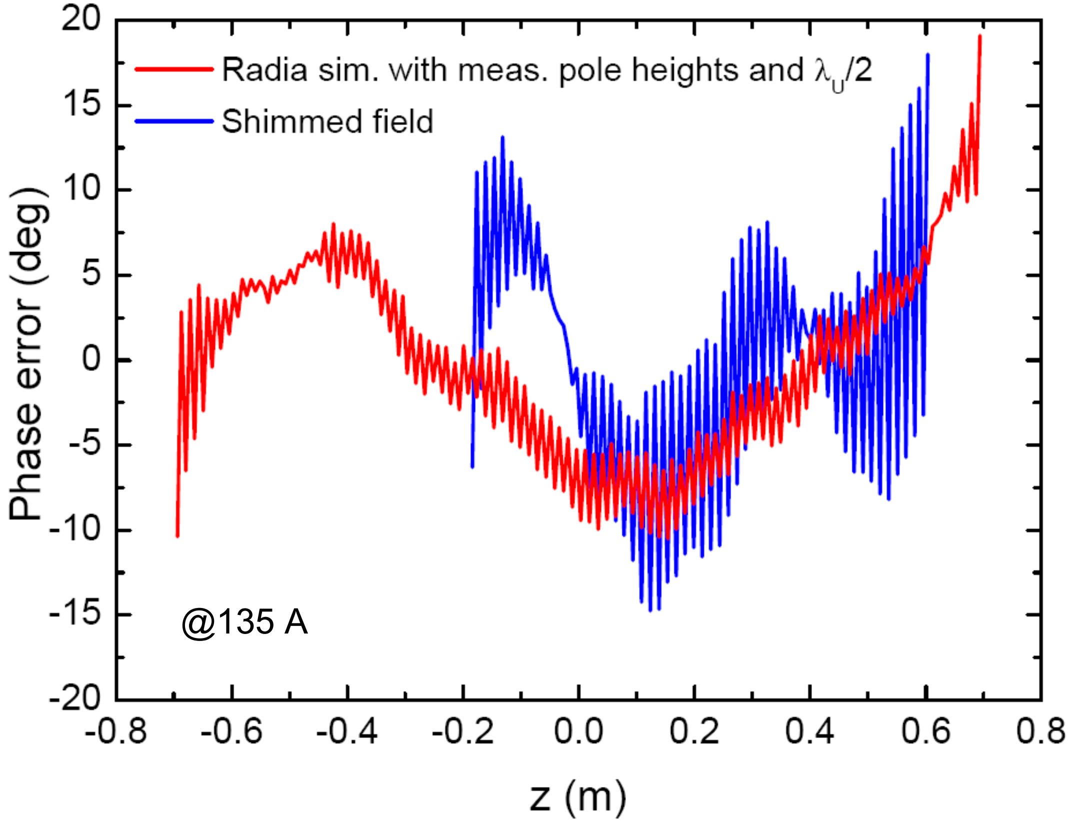


*P. Elleaume, X. Marechal, Report ESRF-R/ID-9154 (1991)

S. C. et al., ASC10

slit of 1mm x 1mm @10 m distance

SCU15 demostrator: phase error



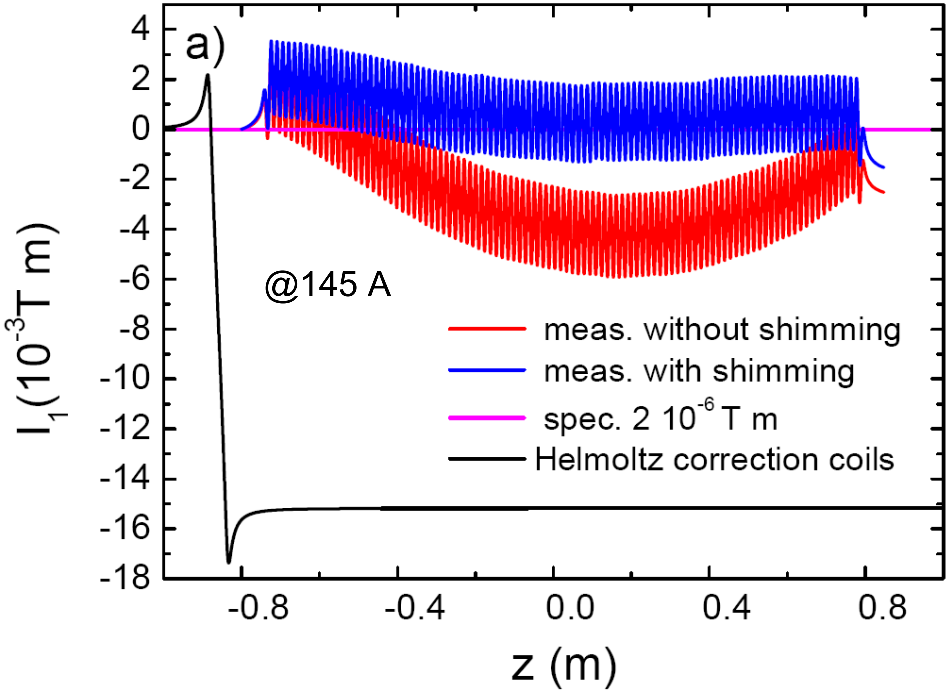
S. C. et al., ASC10

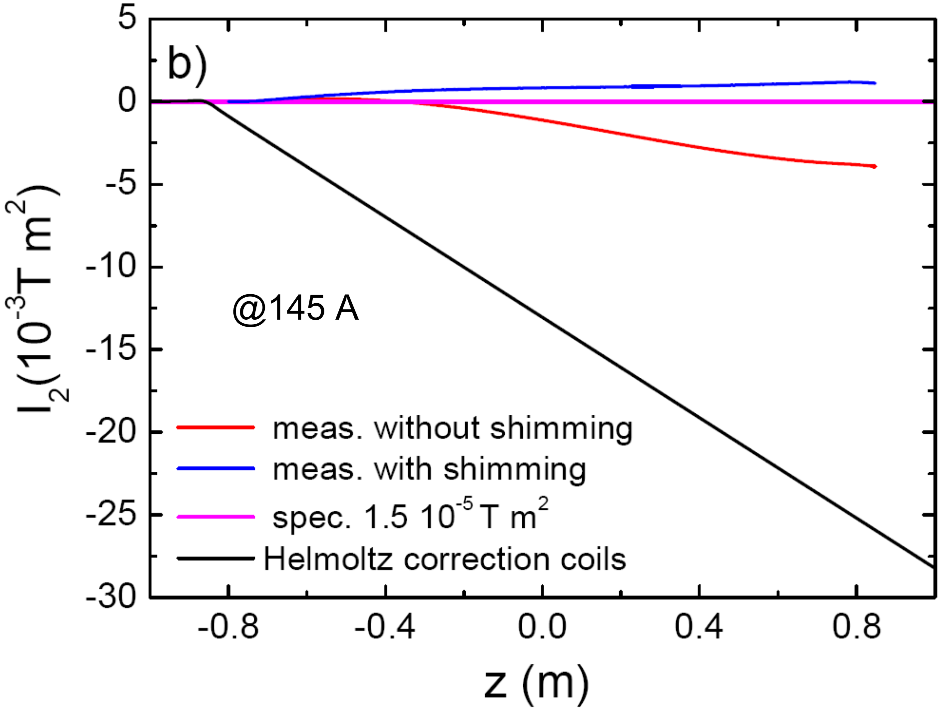
Shimmed field:
Phase error of 7.4 degrees over a length of ~0.8 m
Radia* simulations with meas. pole heights and half period lenghts at 300K (~50μm):
Phase error of 5.6 degrees over a length of ~1.4 m

The use of mechanical shims to reduce the bimetallic effect, applicable to fixed gap undulators, together with a planarity further reduced to 40 μm would make it possible to reach 3.5 degrees phase error without additional correction coils.

*P. Elleaume, O. Chubar, J. Chavanne, PAC97

SCU15 demostrator: field integrals





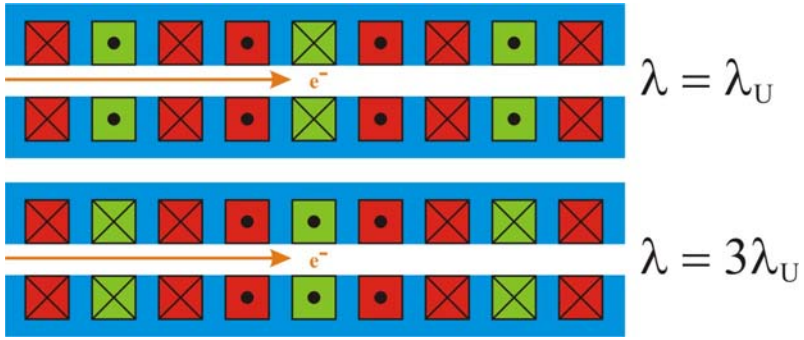
For all currents it is possible to correct the first and second field integrals by means of two pair of Helmoltz coils.

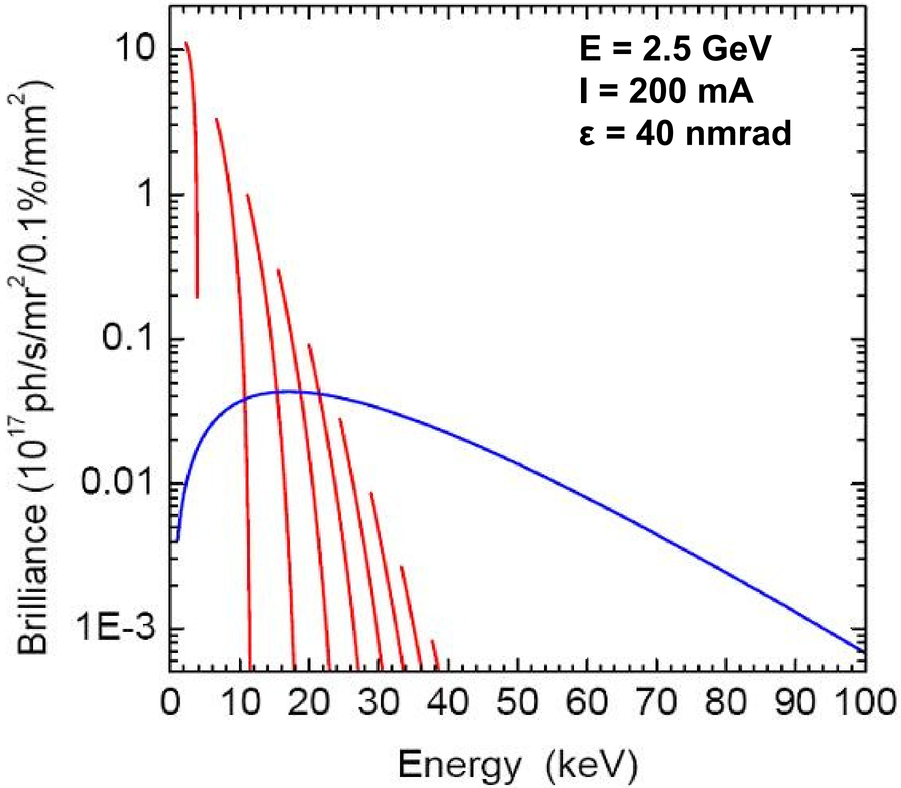
S. C. et al., ASC10

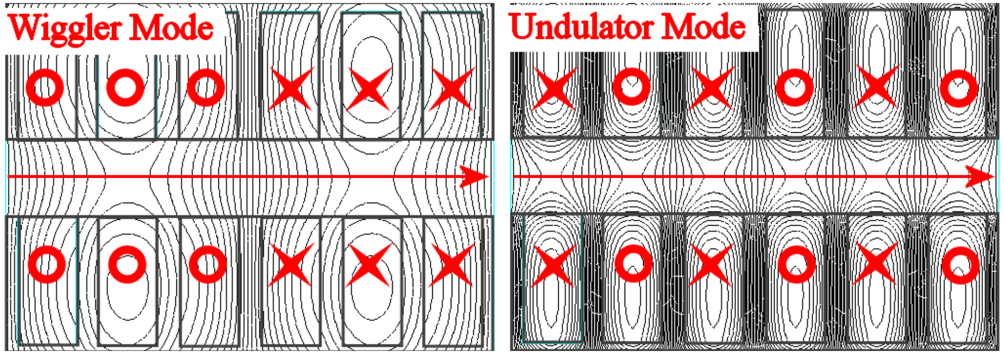
Sc Undulator Wiggler

A device which allows switching between a 15 mm period length undulator and a 45 mm wiggler.

R. Schlueter et al., Synch. Rad. News, 2004
B. Kostka et al., PAC05, 2005
A. Bernhard et al., EPAC06, 2006
A. Bernhard et al., EPAC08, 2008







Foreseen for the planned IMAGE beamline at ANKA.

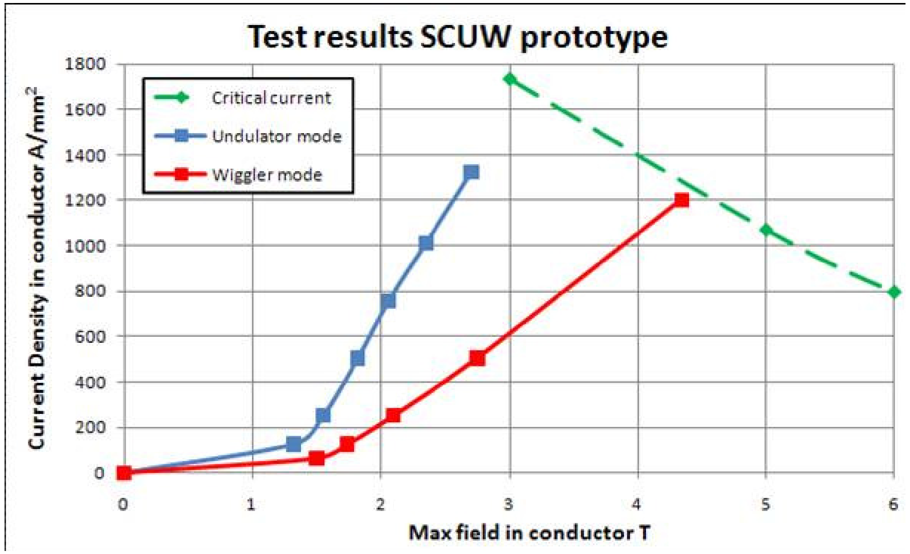
Applications:

- High brilliance of the **undulator** from 6 to 15 keV for imaging,
- **wiggler** mode for higher photon energies to perform phase contrast tomography.

Sc Undulator Wiggler

First experimental demonstration of period length switching for scIDs

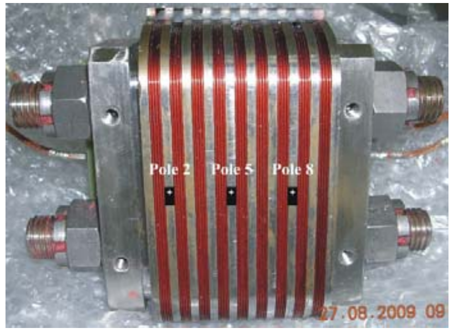
Training



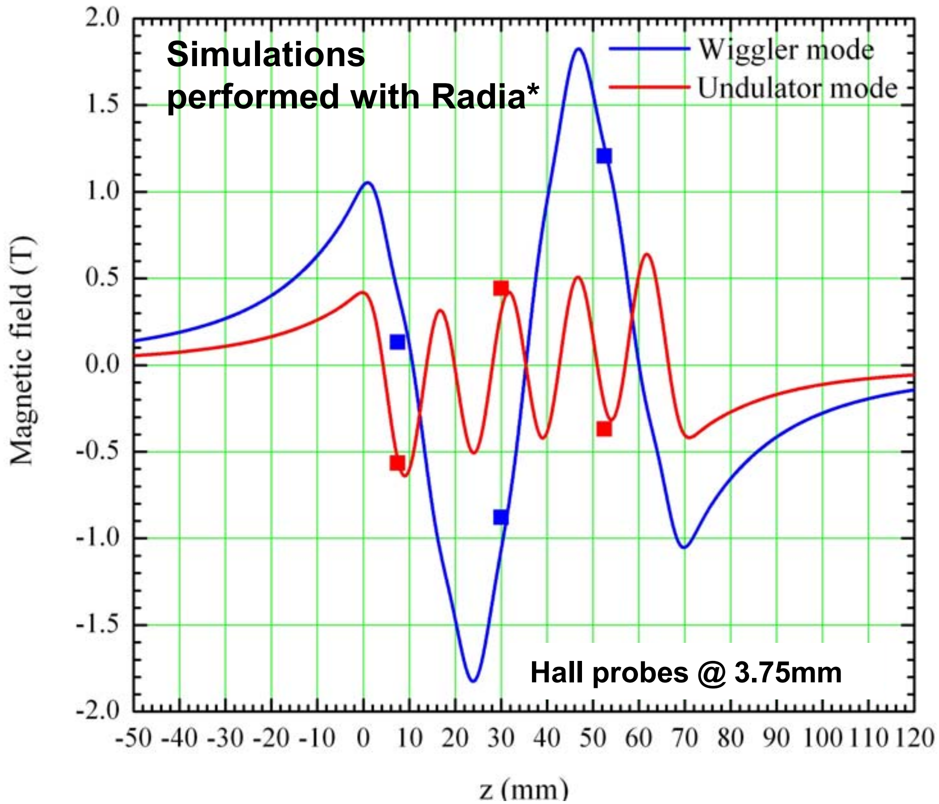
	undulator		wiggler	
Mag. Gap	B (T)	K	B(T)	K
8 mm	0.77	1.08	3.00	12.6
5 mm	1.46	2.05	4.34	18.2

A. Grau et al., IPAC10

*P. Elleaume, O. Chubar, J. Chavanne, PAC97



Built by BNG



R&D strategy

Tasks

- Design and test winding schemes
- Develop and test field correction techniques
- Apply and test different superconducting materials and wires

CASPERI

- Quality assessment of magnetic field properties

CASPERII

COLDDIAG

- Understand beam heat load mechanisms

- Test performance of the device with beam

How to realize this program?

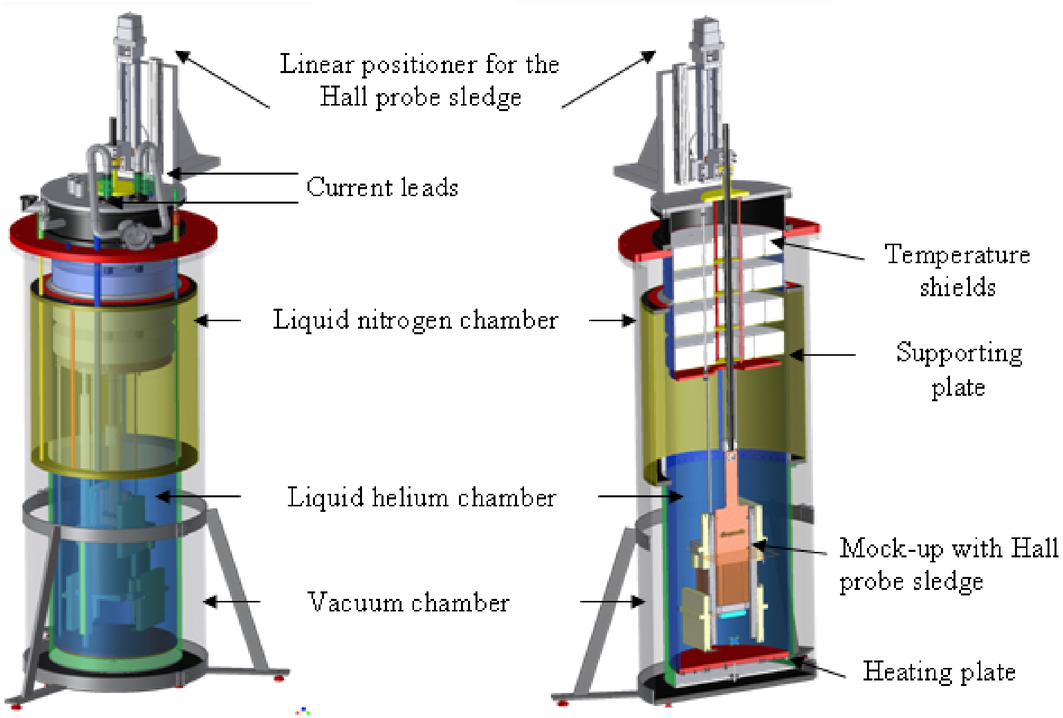
i) Close collaboration with our industrial partner Babcock Noell GmbH (BNG)

ii) Tools and instruments to improve the magnetic field properties and understand the beam heat load mechanisms

iii) Need of a dedicated straight section and front end for tests

CASPERI

To test:
- **New winding schemes**
- **New superconducting materials and wires**
- **New field correction techniques**



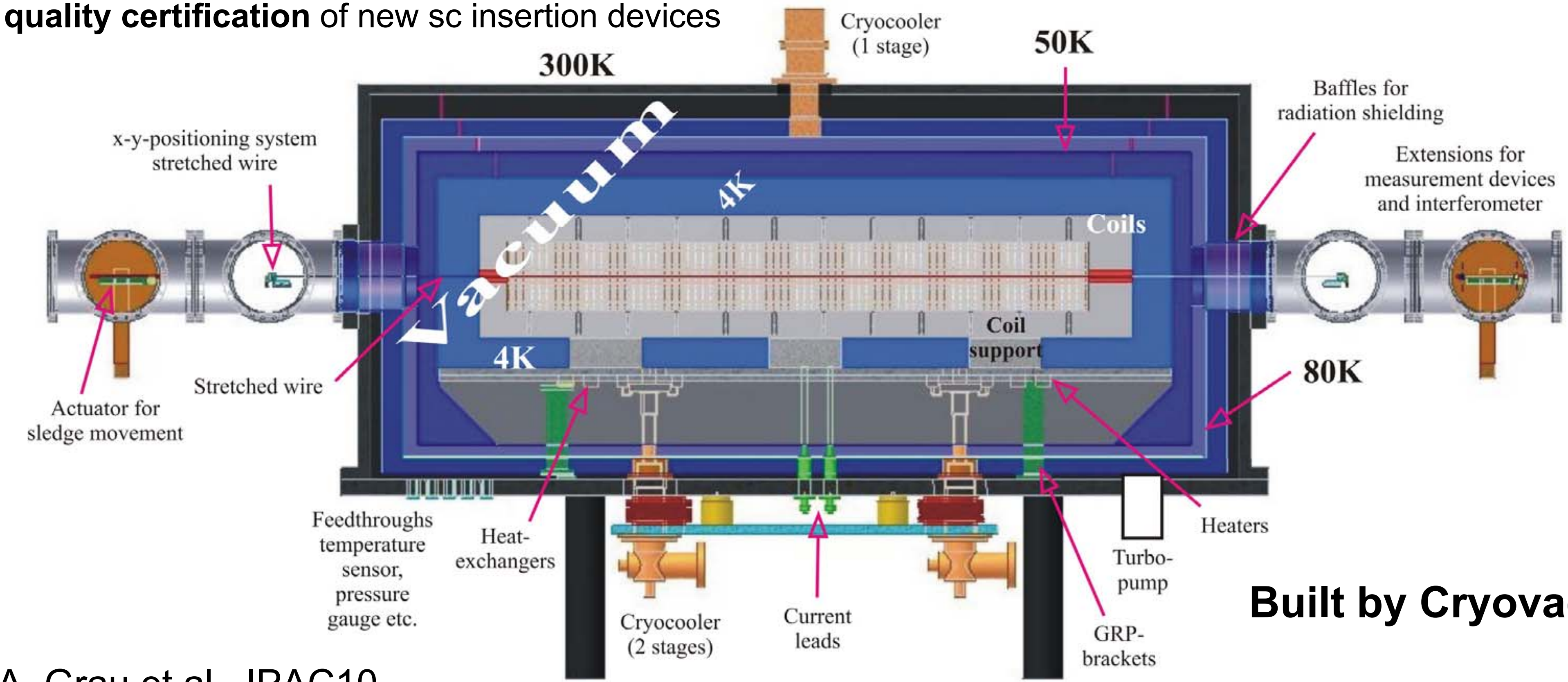
•**Operating vertical test in LHe of mock-up coils** with maximum dimensions 35 cm in length and 30 cm in diameter.

•The magnetic field along the beam axis is measured by Hall probes fixed to a sledge moved by a linear stage with the following precision ΔB< 1mT and Δz< 3 μm.

E. Mashkina et al., EPAC08

CASPERII

For **quality certification** of new sc insertion devices



Built by Cryovac

A. Grau et al., IPAC10

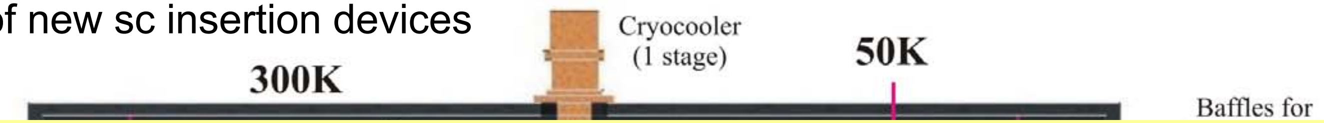
•**Under construction horizontal cryogen free test of long coils** with maximum dimensions 1.5 m in length and 50 cm in diameter.

•Local field measurements with Hall probes. Field integral measurements with stretched wire.

The magnetic field along the beam axis is measured by Hall probes fixed to a sledge moved by a linear stage with the following precision ΔB < 1mT and Δz = 1 μm.

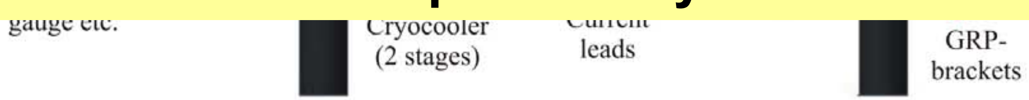
CASPERII

For **quality certification** of new sc insertion devices



Timeplan

- **Factory acceptance test October 2010**
- **Hall probe sledge and streched wire December 2010**
- **Fast aquisition system for quench detection**
  - **1) first tests with 5 channels at CASPERI November 2010**
  - **2) multichannel data acquisition system at CASPERII February 2011**



•**Under construction horizontal cryogen free test of long coils** with maximum dimensions 1.5 m in length and 50 cm in diameter.

See Talk of Andreas Grau

•Local field measurements with Hall probes. Field integral measurements with stretched wire.

The magnetic field along the beam axis is measured by Hall probes fixed to a sledge moved by a linear stage with the following precision ΔB < 1mT and Δz = 1 μm.

COLDDIAG

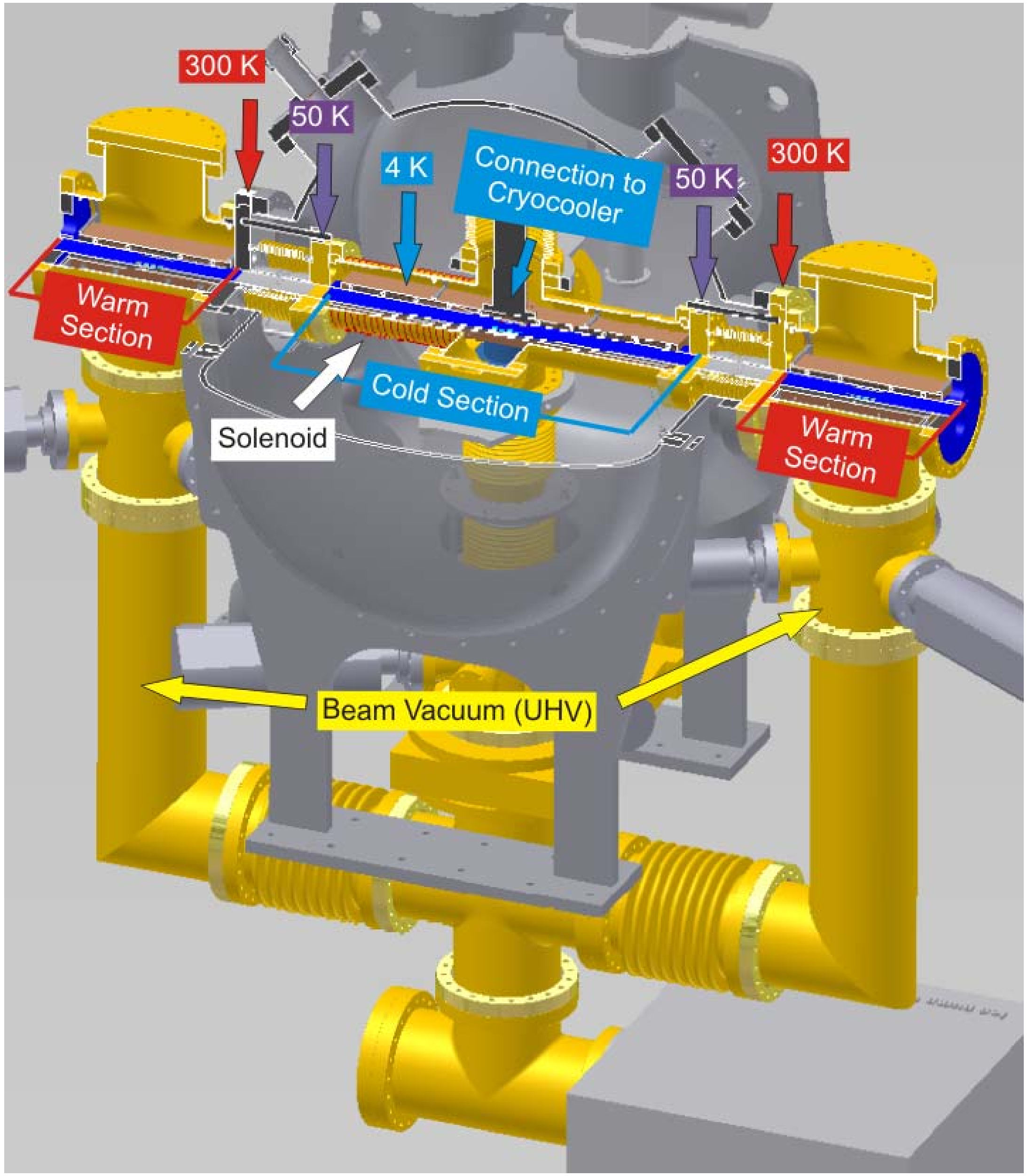
Under construction cold vacuum chamber for diagnostics to **measure the beam heat load** to a cold bore in a storage ring. The beam heat load is needed to specify the cooling power for the cryodesign of superconducting insertion devices.

In collaboration with
CERN: V. Baglin
LNF: R. Cimino, M. Commisso, B. Spataro
University of Rome ‚La sapienza‘: A. Mostacci
DIAMOND: M. Cox, J. Schouten
MAXLAB :Erik Wallèn
Max-Planck Institute for Metal Research: R. Weigel,
STFC/DL/ASTeC:J. Clarke, D. Scott
STFC/RAL: T. Bradshaw
University of Manchester: I. Shinton, R. Jones

A first installation at the synchrotron light source DIAMOND is foreseen in June 2011.

S. Gerstl et al., IPAC10

COLDDIAG: the vacuum chamber



- Cryogen free: cooling with Sumitomo RDK-415D cryocooler (1.5W@4.2K)
- Cold vacuum chamber located between two warm sections to compare beam heat load with and without cryosorbed gas layer
- 3 identically equipped diagnostic ports with room temperature connection to the beam vacuum
- Exchangeable liner to test different materials and geometries
- Copper bar copper plated (50µm)

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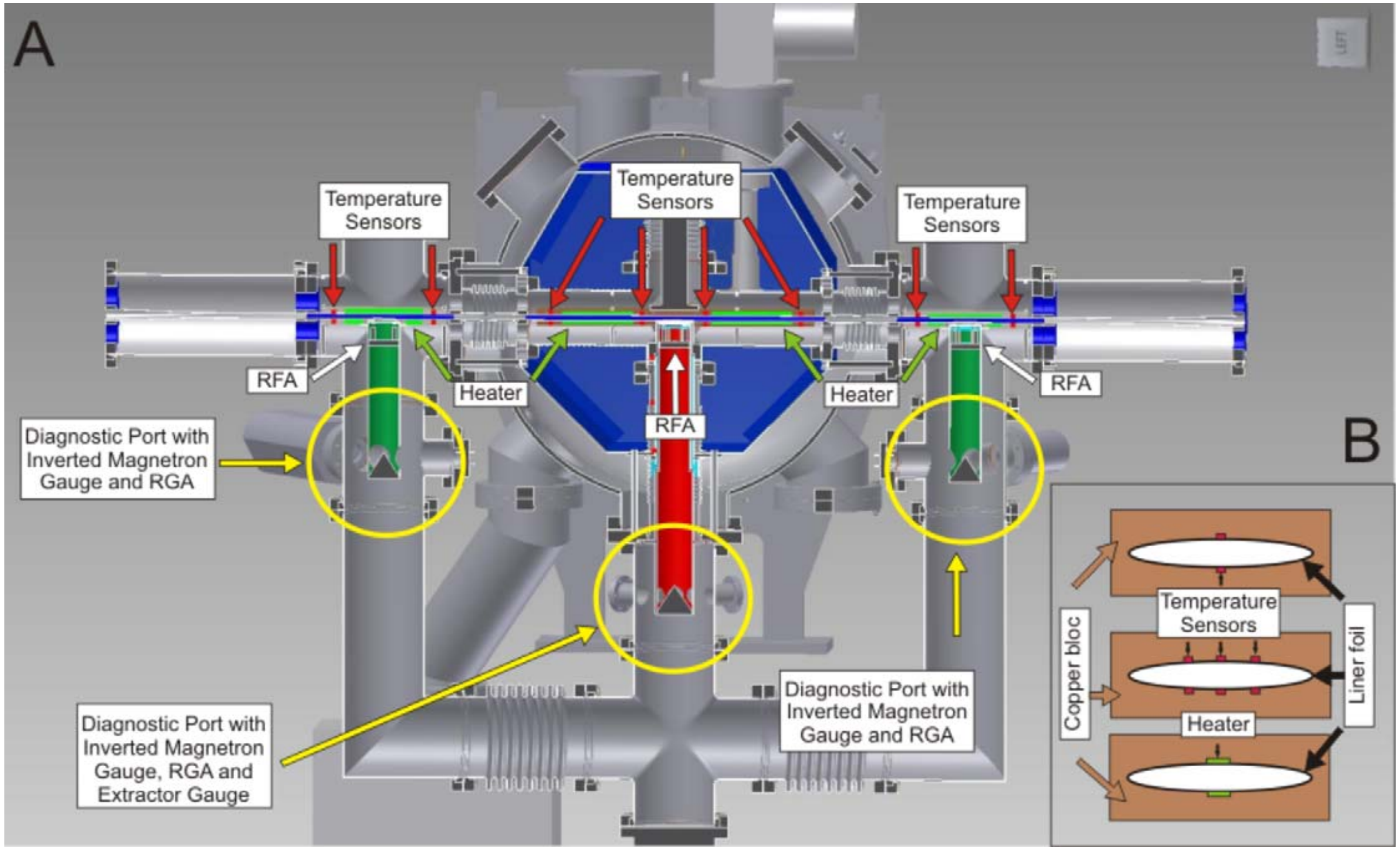
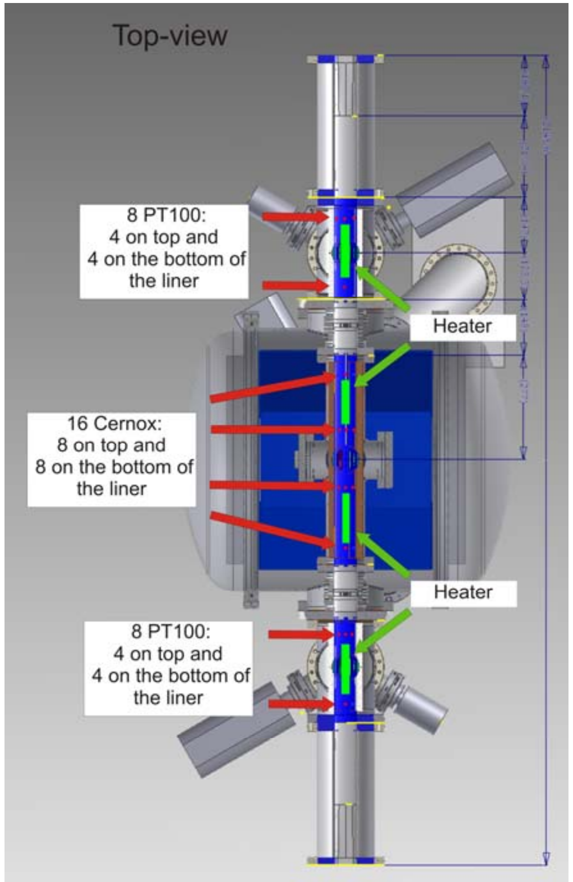
COLDDIAG: diagnostics

Possible Beam Heat Load Sources: 1)Synchrotron radiation from upstream bending magnet, 2) Resistive wall heating, 3) RF effects, 4) Electron and/ or ion bombardment





The diagnostics will include measurements of the **heat load**, the **pressure**, the **gas composition**, and the **electron flux of the electrons bombarding the wall**.

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KIT – die Kooperation von Forschungszentrum Karlsruhe GmbH und Universität Karlsruhe (TH)
Forschungszentrum Karlsruhe in der Helmholtz-Gemeinschaft

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Under construction cold vacuum chamber for diagnostics to **measure the beam heat load** to a

Timeplan

- **Factory acceptance test November 2010**
- **Tests at ANKA out of the storage ring December2010-February2011**
- **Delivery to DIAMOND March 2011**
- **Installation in DIAMOND June 2011**

Max-Planck Institute for Metal Research: R. Weigel,
STFC/DL/ASTeC:J. Clarke, D. Scott
STFC/RAL: T. Bradshaw
University of Manchester: I. Shinton, R. Jones

A first installation at the synchrotron light source DIAMOND is foreseen in June 2011.

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Planned Measurements

Monitoring the temperature, the electron flux, pressure and gas composition with different:

- **average beam current** to compare the beam heat load data with synchrotron radiation and resistive wall heating predictions
- **bunch length** to compare with resistive wall heating predictions
- **filling pattern** in particular the bunch spacing to test the relevance of the electron cloud as heating mechanism
- **beam position** to test the relevance of synchrotron radiation and the gap dependence of the beam heat load
- **injected gases** naturally present in the beam vacuum (H_2, CO, CO_2, CH_4) to understand the influence of the cryosorbed gas layer on the beam heat load

Summary

1. **Training and magnetic field measurements of 1.5 m undulator coils**

   •Reached peak field 0.7 T for an undulator with 15 mm period length and a magnetic gap of 8 mm. This value overperforms the competing technologies for the same geometry.

   •We have proved that coils wound with single length wire can be repaired without rewinding the whole coil.

   •Furthermore, we have demonstrated for the first time that it is possible to build superconducting undulator coils with a phase error of 7.4 degrees over a length of 0.795 m, obtained by a simple mechanical shim, which is easily applicable to fixed gap devices.

   •The thin rectangular wire used will be replaced in the next devices by a thicker wire and for the yoke C10E steel will be used.

2. **First experimental demonstration of period length switching for scIDs**

3. **Tools and instruments to improve the magnetic field properties (CASPERI, CASPERII) and understand the beam heat load mechanisms (COLDDIAG)**

Thanks

To:

- Jerome Feuvrier, Julienne Hurte, Michael Ky, Patrick Viret… from Block 4
- Marta Bajko, Luca Bottura, Christian Giloux

For the tests at CERN

And to you all for your attention!

COLDDIAG
Gas injection