Instrumentation for Local and Integral Magnetic Field Measurements of Superconducting Undulator Coils

Institute for Synchrotron Radiation (ISS)

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for

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Outline

1. **Introduction**
    - Motivation
    - Magnetic field errors
2. **CASPER measurement setups**
    - Cryostat Design
    - Local field measurement setup
    - Accuracy requirements and setup limits
    - Additional components
    - Setup for field integrals
    - Quench diagnostics
3. **Next steps**

Motivation

Task within our R&D program :

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

Magnetic errors can cause:

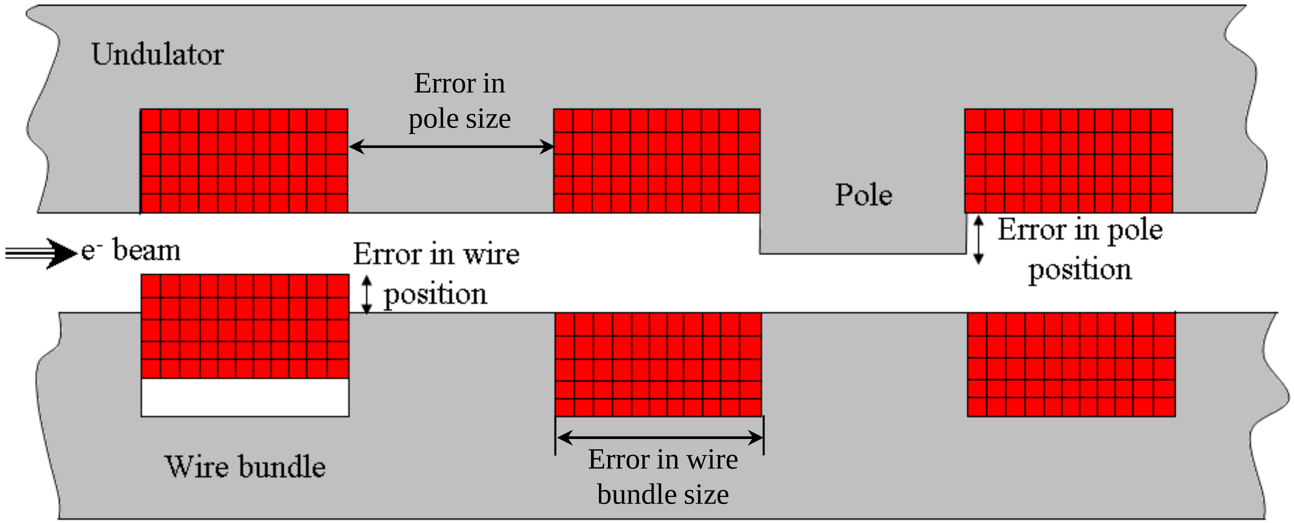
Perturbation of the closed orbit and the dynamics of the electron beam

- Measure field integrals

Reduction of the quality of the emitted radiation

- Local field measurements to obtain phase error

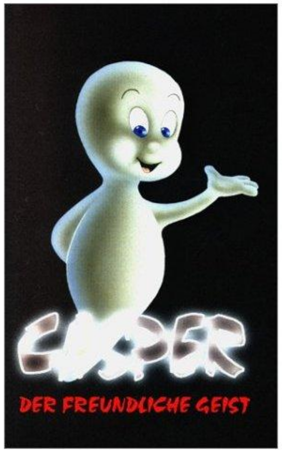
Main errors in superconducting undulators



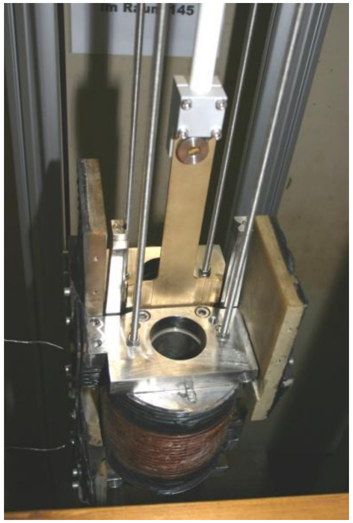
Field errors are mainly caused by:

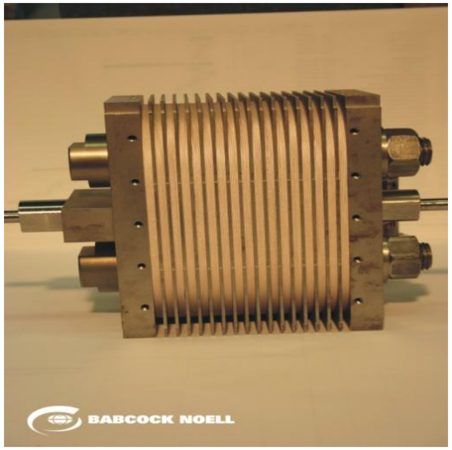
- mechanical deviations of the pole position e.g. the pole height
- bending of the yoke
- the position of the superconducting wire bundles
- pole and wire bundle size

CASPER - Characterization Setup for Field Error Reduction



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

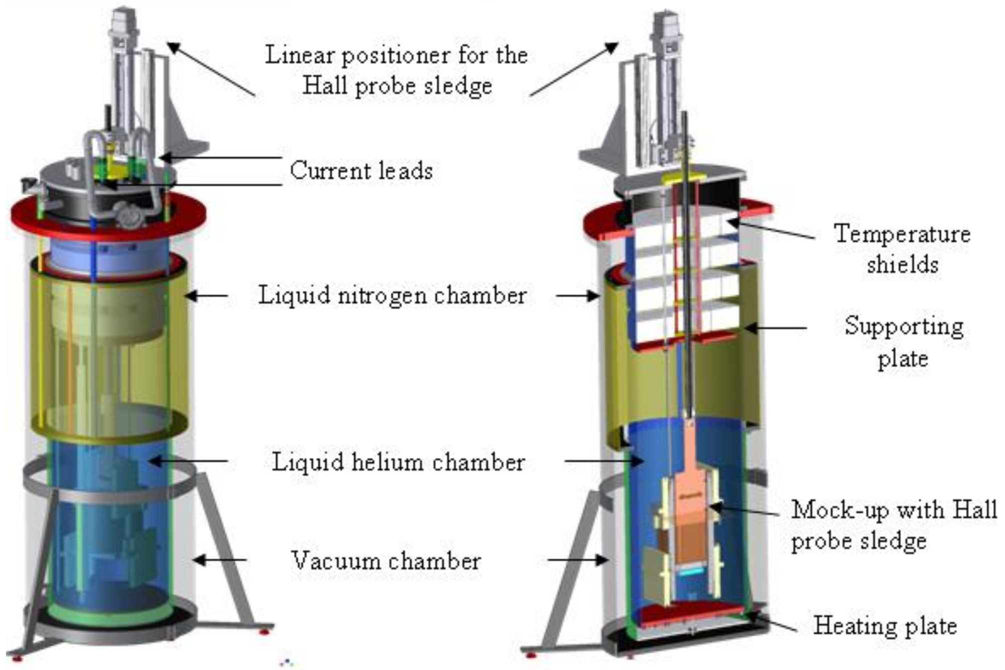




CASPER II – A measurement setup for undulator coils up to 1.8m length

CASPER I

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



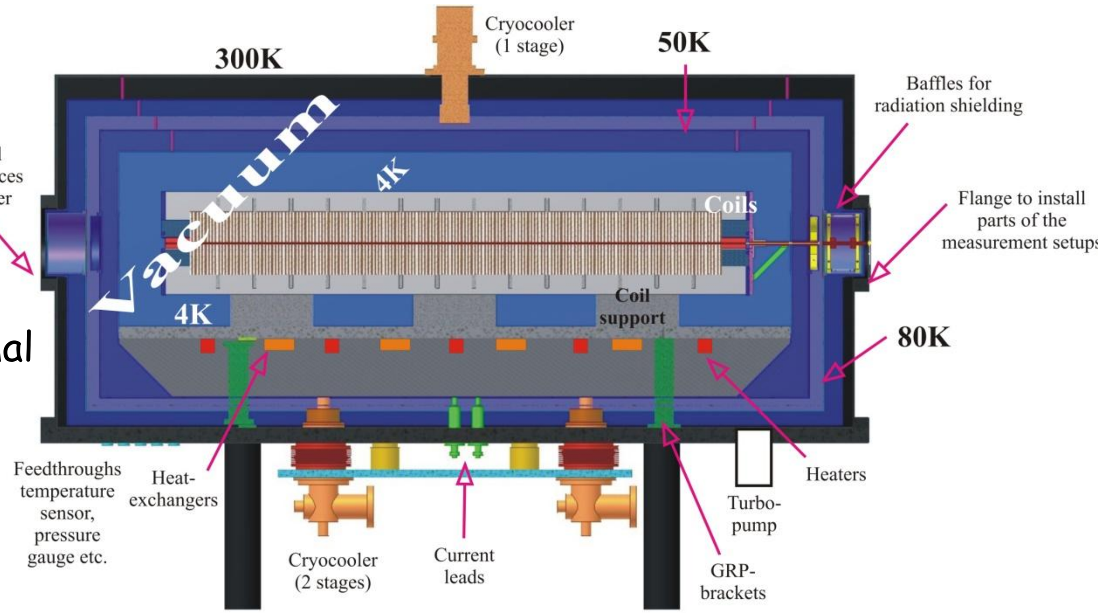
- Operating vertical
- Test of mock-up coils in LHe
- Maximum dimensions 35cm in length and 35 cm in diameter.
- The magnetic field along the beam axis is measured by Hall probes fixed to a sledge moved by a linear stage with the following precision $\Delta B < 1mT$ and $\Delta z < 3\ \mu m$.

E. Mashkina et al., EPAC08

CASPER II - Cryostat

The goal…

Test superconductor performance and measure magnetic field distributions and field integrals of superconducting coils with dimensions like in „real“ IDs (e.g. up to ~1,8 m length, ~50cm diameter)

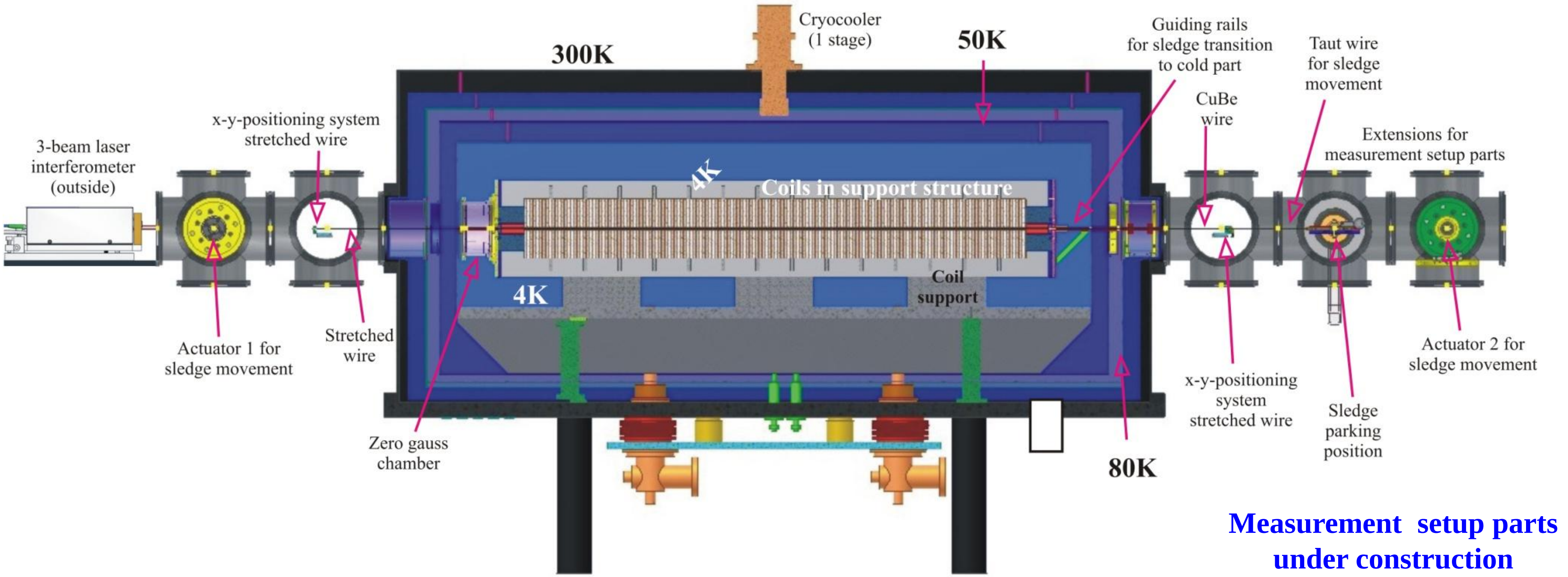


Built by CryoVac
Delivery October 2010

Cryostat overview

- Horizontal 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

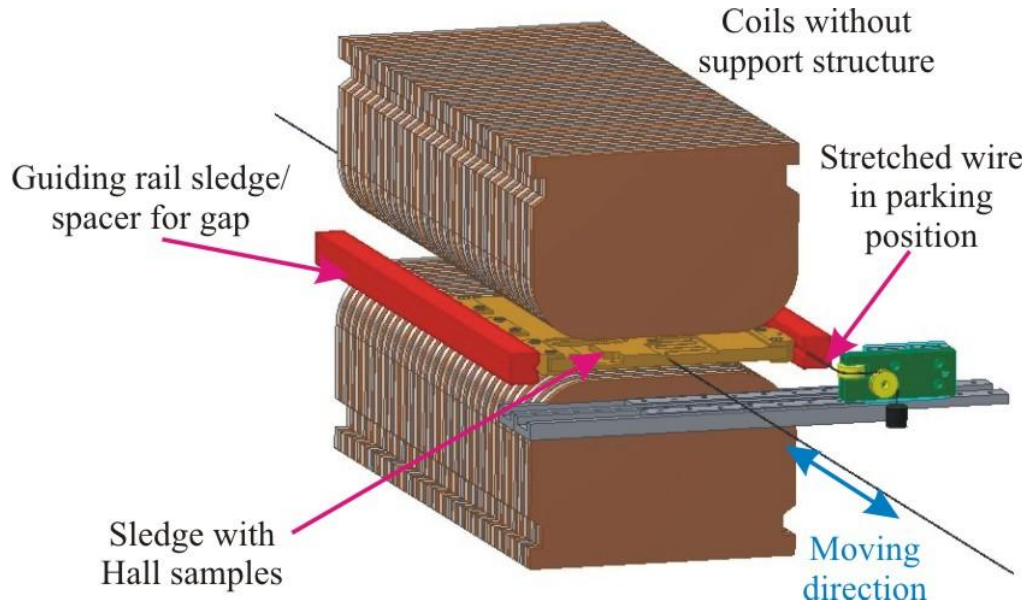
Field measurement setup



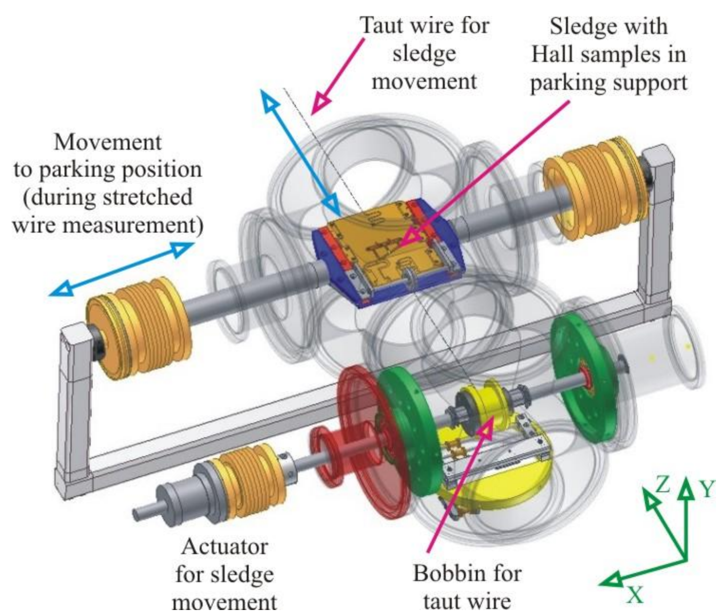
Measurement setup parts under construction

- Local field measurements via Hall samples on a sledge
- Position (z-direction) measurement with laser interferometer
- Zero Gauss chamber for zero check of Hall sample calibration (possible after every thermal cycle)
- possibly in addition 2 Helmholtz coils for linearity check of Hall sample calibration (not shown)
- Integral field measurements with stretched wire technique (CuBe wire Ø125μm)
- Position adjustment for stretched wire in x-y-direction via linear stages with encoders

Local field measurements



Measurements with 3 Hall probes in a row placed perpendicular to beam axis (20mm distance)



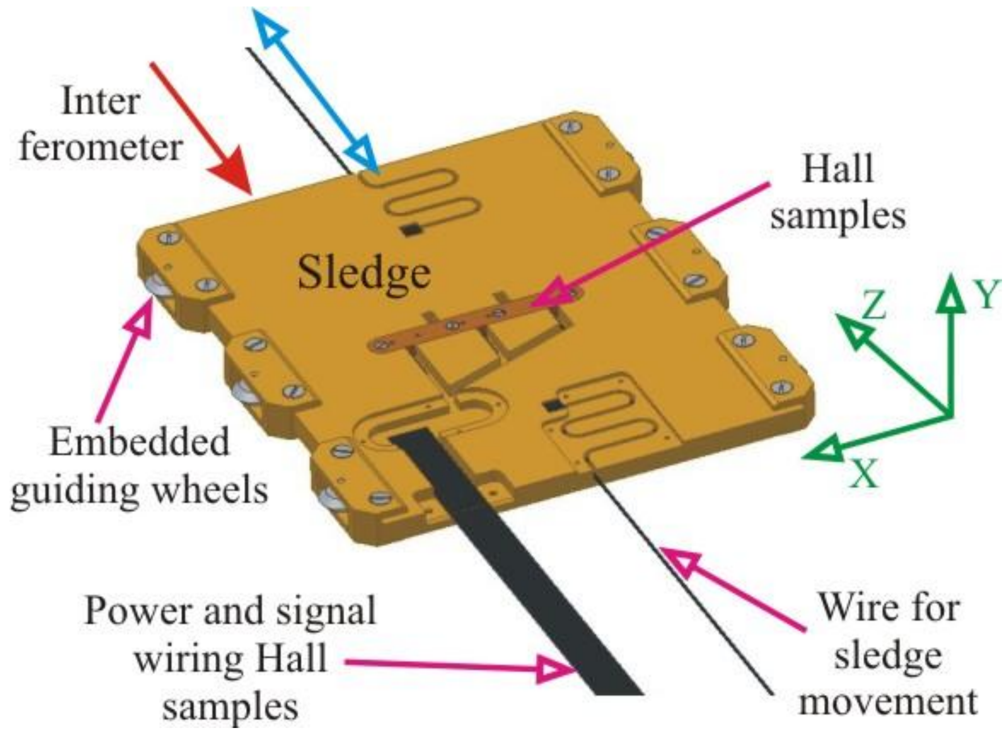
Sledge movement by a taut wire for each direction spooled on a bobbin at each side mounted in the extensions of the cryostat

Field measurement equipment

- Field sensors: 3 calibrated Hall probes
- Hall current provided by a Keithley precision current source
- Hall voltage measured with a Keithley multichannel voltmeter

3 beam laser interferometer for position measurement (SIOS)

- Precise z-position
- Values for angle deviation during moving



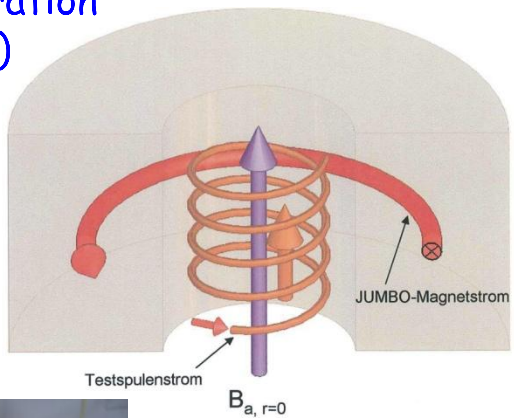
Measurement accuracy

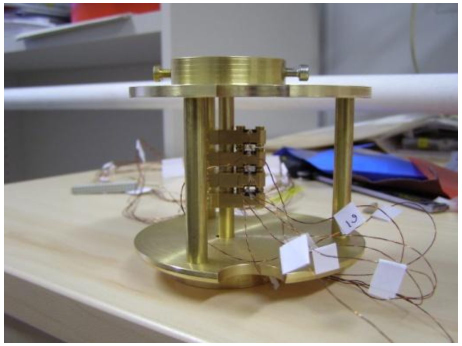
Which main errors effect the local field measurements ?

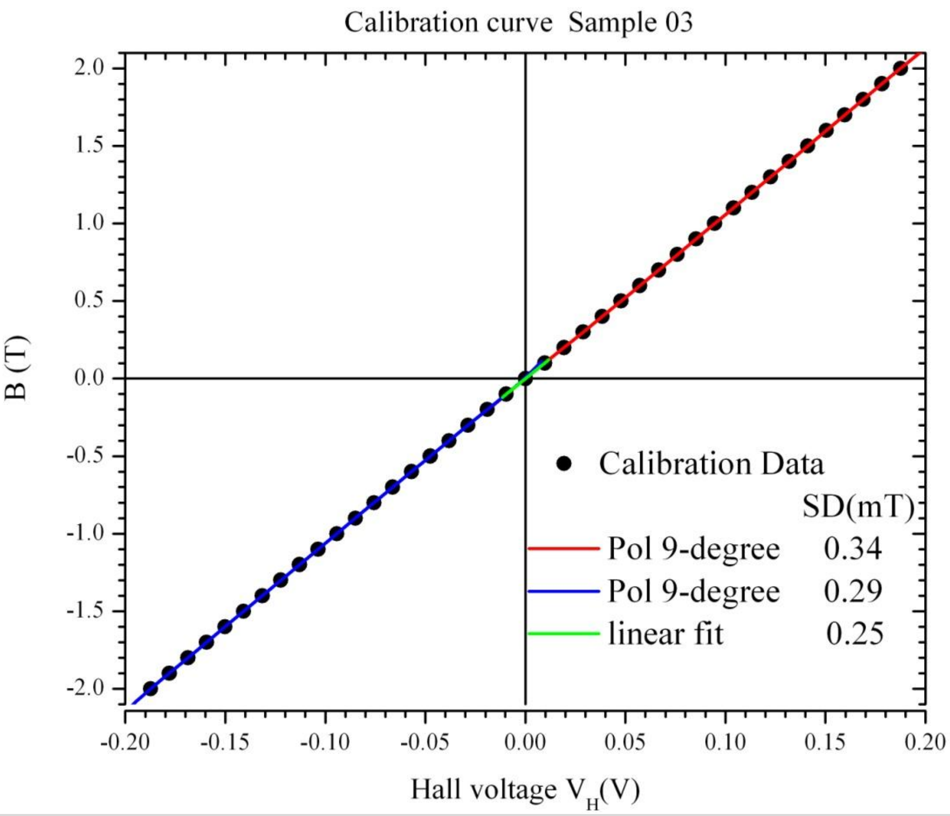
1. Errors caused by Hall sample calibration

2. Field errors mainly due to mechanical misalignment of the guiding rails or the field sensors

Hall sample calibration
(ITeP at the KIT)





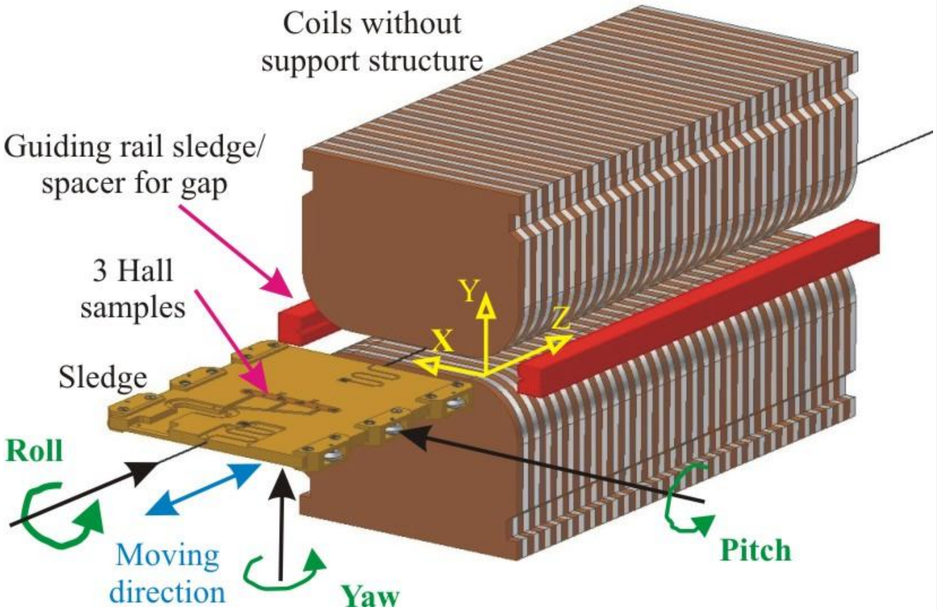


Accuracy requirements

Mechanical requirements to reach measurement accuracy for phase error

$\Delta\phi$ = 1° (λ_U=15mm, K=1.1, ANKA SCU 15):

Parameter	Calculated value [1]	Set limit
Horizontal deviation (Δx)	500 µm	300 µm
Vertical deviation (Δy)	200 µm	50 µm
Horizontal deviation (Δz)	13 µm	3 µm
Roll angle error (α)	2.5 mrad	1 mrad
Pitch angle error (β)	83 mrad	30 mrad
Yaw angle error (χ)	500 µrad	300 µrad



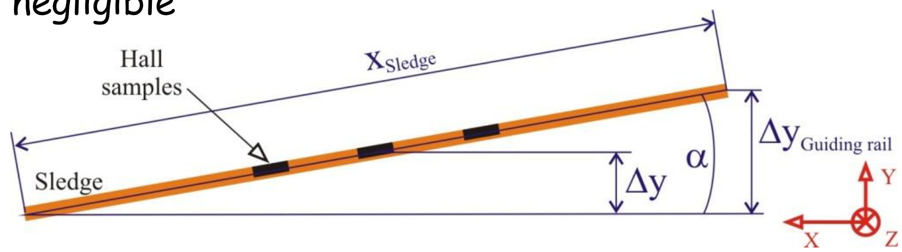
[1] Zachary Wolf, "Requirements for the LCLS Undulator magnetic measurement bench", Technical report # LCLS-TN-0, 4-8 http:/www-ssrl.slac.stanford.edu/lcls/technotes

(A.Grau et al., ASC 2010, Washington)

Setup limits

Relative alignment precision of guiding rails $\Delta y_{Guiding\ rail}$=40µm. For the Hall probe in the middle the distance to coils changes by Δy=20µm.

- In x-direction the field is fairly uniform ⇒ error is negligible
- Δy=20µm in y-direction fulfills the requirements
- In longitdinal direction precision for Δz = 1µm



Roll

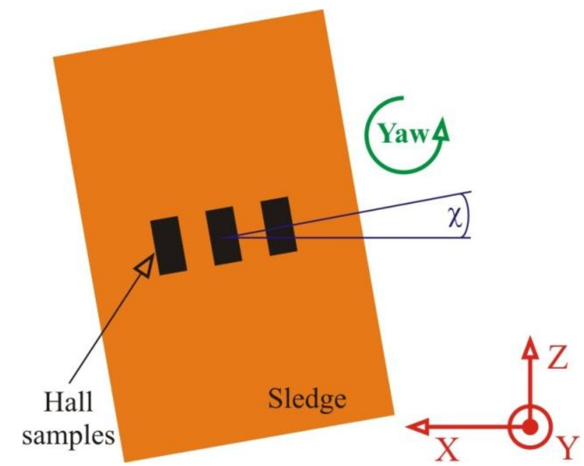
According to the drawing with x_{sledge}=0.15m the maximum roll angle α=266µrad

➡ below the limit

Yaw

The yaw angle χ=270µrad results from taking into account a maximum misalignment of the guiding rails with respect to the coils of 0.2mm along the whole support structure length of 1.8m (z-axis)

➡ set limit fulfilled



Pitch

Due to guiding rail precision the limit for pitch angle β=30mrad (rotation around x-axis) is not a critical point

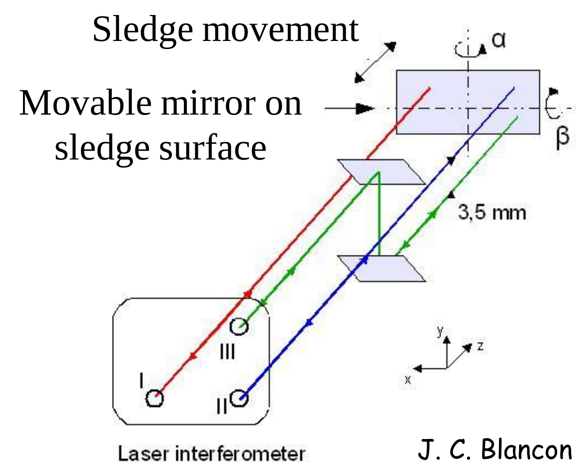
⇒ Limiting factor on measurement precision is the Hall probe accuracy

A.Grau et al., ASC 2010, Washington

Position measurement

Laser interferometer (3 beams)

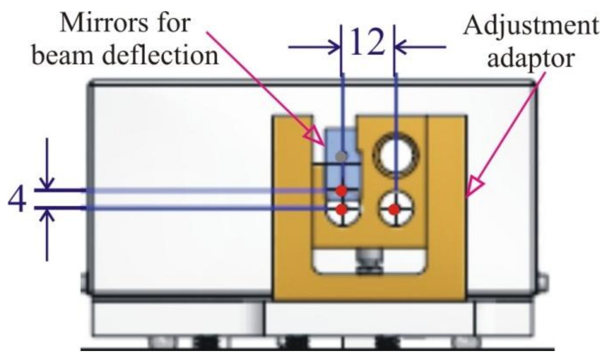
- Z-positioning (1 beam)
- Angle deviation during moving (3 beams)



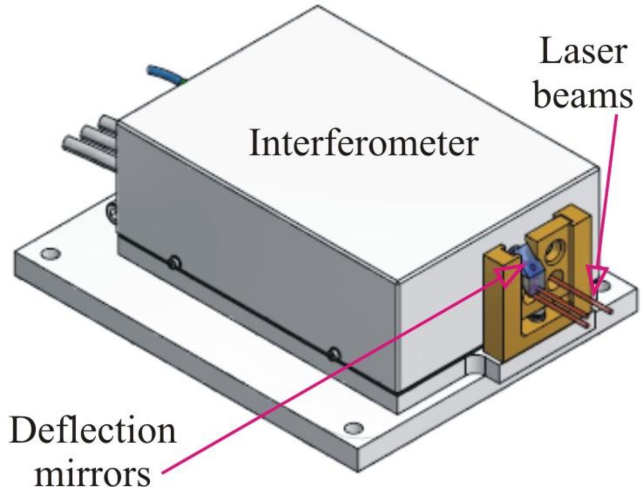
Problem : Beam distance 12mm, usable gap in the Undulator max. 7mm

➧ preliminary test and setup to reduce vertical beam distance

Final Device :
Commercial interferometer with attachment of two mirrors for beam distance rescaling

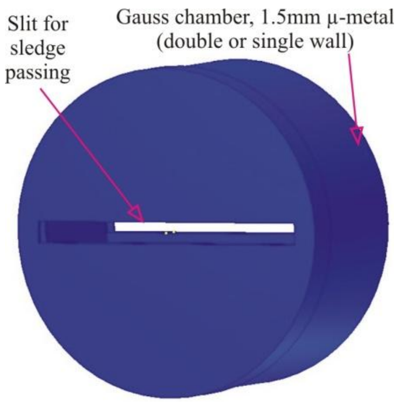


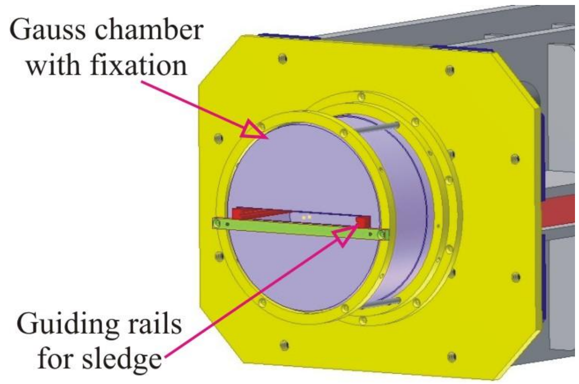
Company SIOS

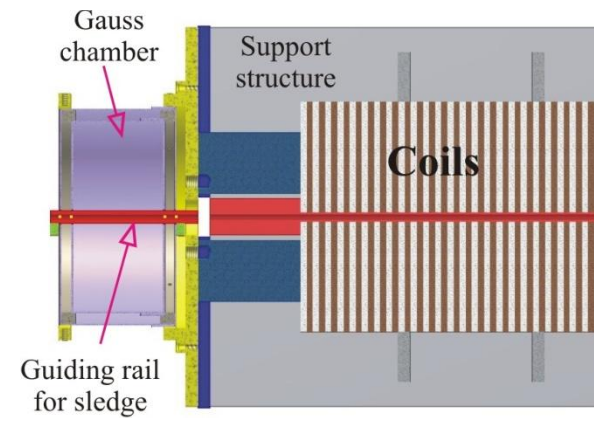


Supplementary

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





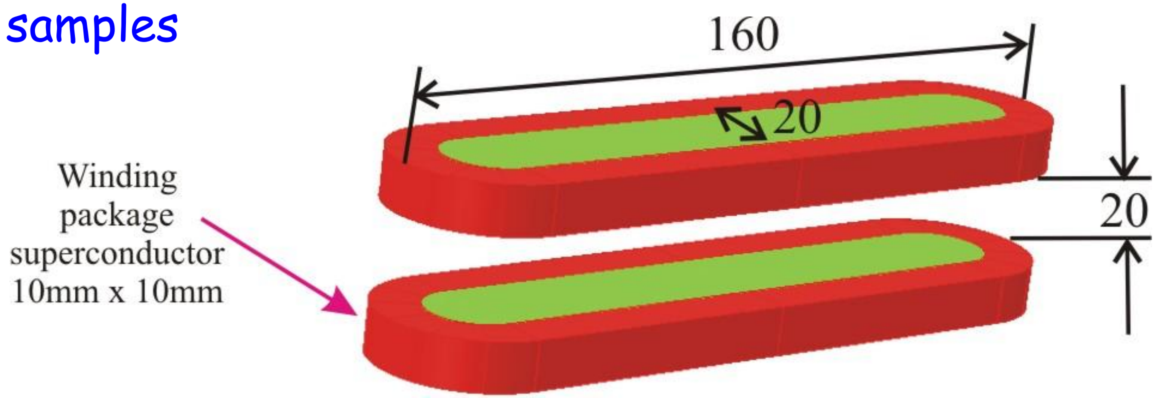


Company Sekels

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

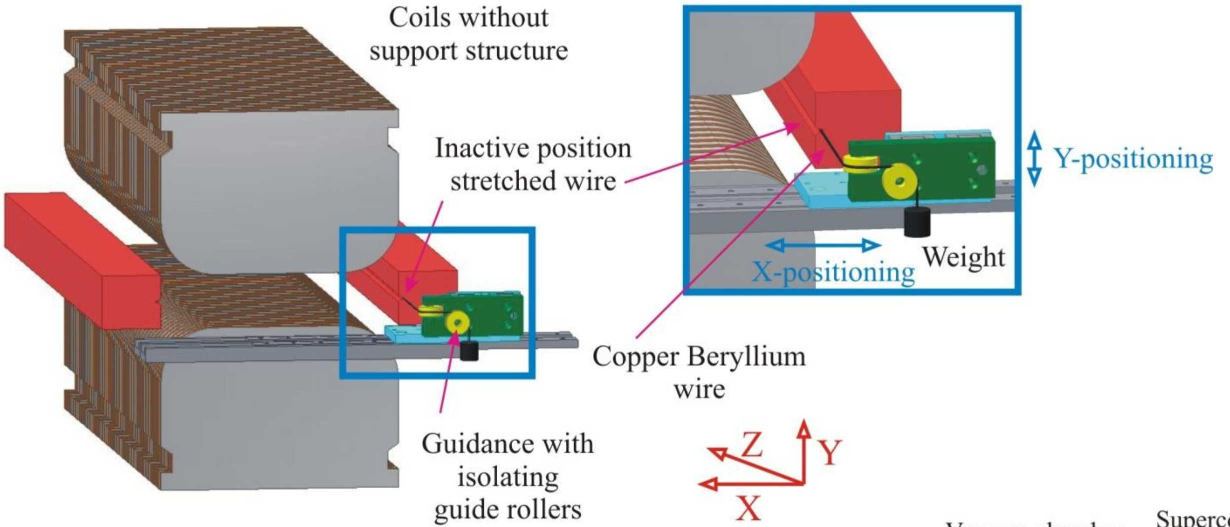
Field homogeneity over 40mm in the center ~0.2mT

⇒ Can be improved (in design stage)



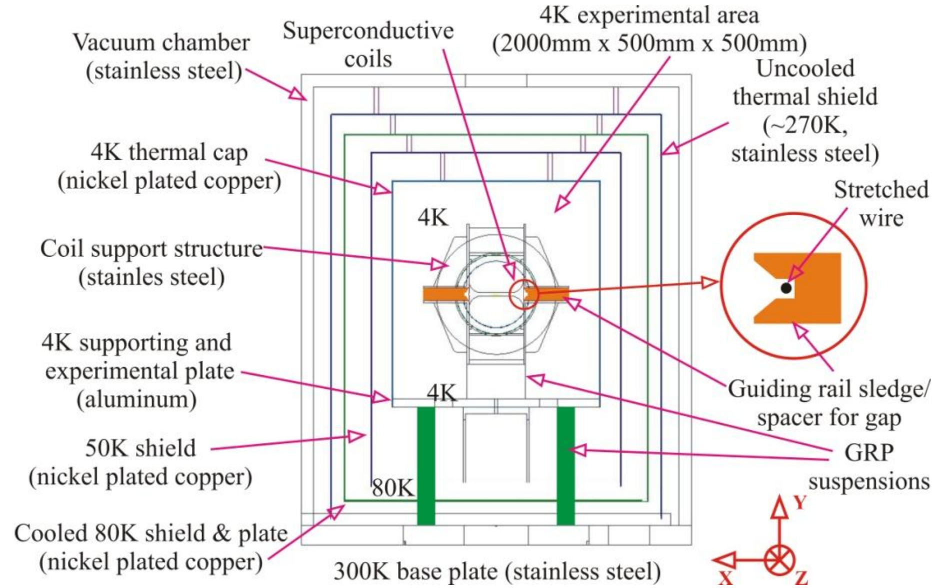
Winding at ITeP at KIT

Stretched wire



Integral field measurements with stretched wire

- Copper Beryllium wire
- Diameter 125µm
- Length through the whole cryostat ~2.5m
- Position adjustment via linear stages with encoders
- movable along 2 axes (150mm x-axis, 20mm y-axis) synchroneous or opposite directions

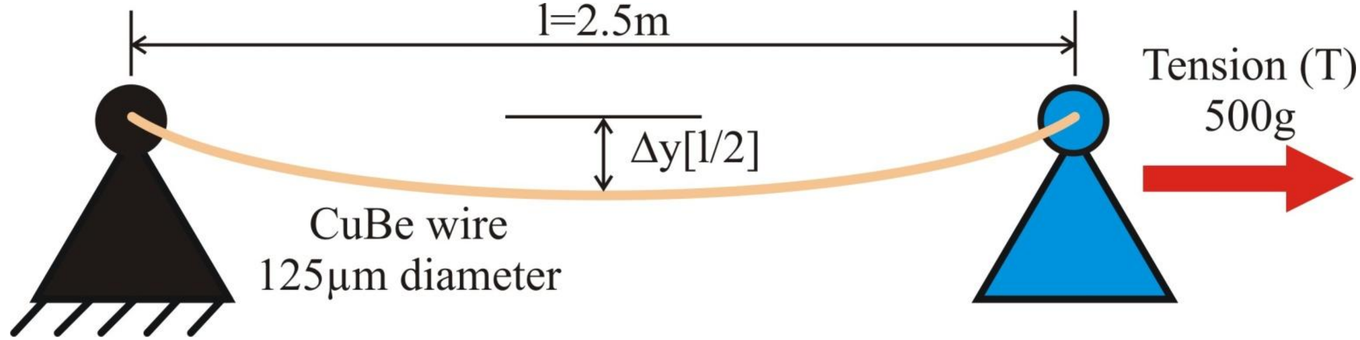


Error consideration

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]

With

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



$$\Delta y\left(\frac{l}{2}\right) \cong -\frac{\omega_{CuBe}\, l^2}{8T} = -100\,\mu m$$

A.Grau et al., ASC 2010, Washington

Resulting Error in the field integral [2]

$$\frac{\Delta I_y}{I_y} \approx \frac{1}{2}\left(\frac{2\pi}{\lambda_U}\right)^2 \cosh\left(\frac{2\pi}{\lambda_U}\Delta y\right)(\Delta y)^2 \approx 8.8\times10^{-4}.$$

[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

Quench diagnostics

Quench detection

- 6 quench detectors to protect superconducting wire during training an quench tests
- sampling rate 100 kS/s
- adjustable parameters : pre- and post-trigger time, quench limit voltage, quench time, voltage offset between compared coil parts, etc.
- software controlled
- suitable for individual connection to all coil parts
- manufactured by IPE at KIT

Quench diagnostics

- Data acquisition system up to 64 channels
- 8 x 8 channel simultaneous sampling multifunction cards
- Sampling rate 250 kS/s
- pre- and post-trigger time variable up to 5s
- data processing for quench analysis via Labview (IPE)

CASPER II status

Done :

- Final drawings and calculations
- Recipient is built, Temperature shields are fabricated and assembled
- Cooling components like cryocoolers, heat exchanger are present at the company, pumping units are bought and delivered
- Temperature sensors and controllers are delivered
- Other „hardware“ components are machined and ready for assembling (flanges, cryostat base structure, LN2 connections etc.)
- Vacuum parts for measurement setup are ordered

To do :

- Complete assembling, wiring, factory acceptance test and final acceptance at ISS
- ~50% construction of measurement setup parts (N. Glamann) and complete assembling
- Purchasing of parts for stretched wire measurement setup (linear stages and encoders)
- Special adapted interferometer will be procured soon
- Procurement of Keithley current sources, voltmeters and additional power supply
- Quench detection and diagnostic system is in the ordering stage (from IPE at KIT and NI)

Acceptance Test

Check specific values like :

- Functionality of all mechanical and electrical parts, pumps, pressure gauges and temperature sensors

- Pumping time to start Turbo pump (p = 0.5mbar, time = 1h)
- Time to reach base pressure of 10^{-4}mbar for cooling start (time = 2h)
- Pumping to working pressure < 10^{-5}mbar (time = 12h)
- Check for leaks

- Nitrogen preecooling of the „4k" plate (T~80K)
- Nitrogen cooling of the „80k" plate (T~85K)
- Temperature „80K" shield (~120K, cooled by a one stage cryocooler)
- Temperature „50K" shield (T~45K, cooled by the first stage of the cryocoolers)
- Cooling of „4K" region (T=4K, at sensor in the middle of the 4K plate)

- Over all cooling time 60h
- Warm up time 30h

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ITeP
IPE

Karlsruhe Institute of Technology

Fa. Cryo Vac
SIOS
National Instruments

. . . and to you for your attention !

For sure we get nice results