Magnetic field measurements of a XFEL 5m undulator segment with two different industrial hall probes

U. Englisch [1], F. Wolff-Fabris [1], P. Li [1,2], T. Wei [1,2], Y. Li [1], J. Pflueger [1]

[1] European XFEL GmbH, Holzkoppel 4, 22869 Schenefeld, Germany
[2] Chinese Academy of Engineering Physics, Mianshan Road 64, Mianyang 621900, China

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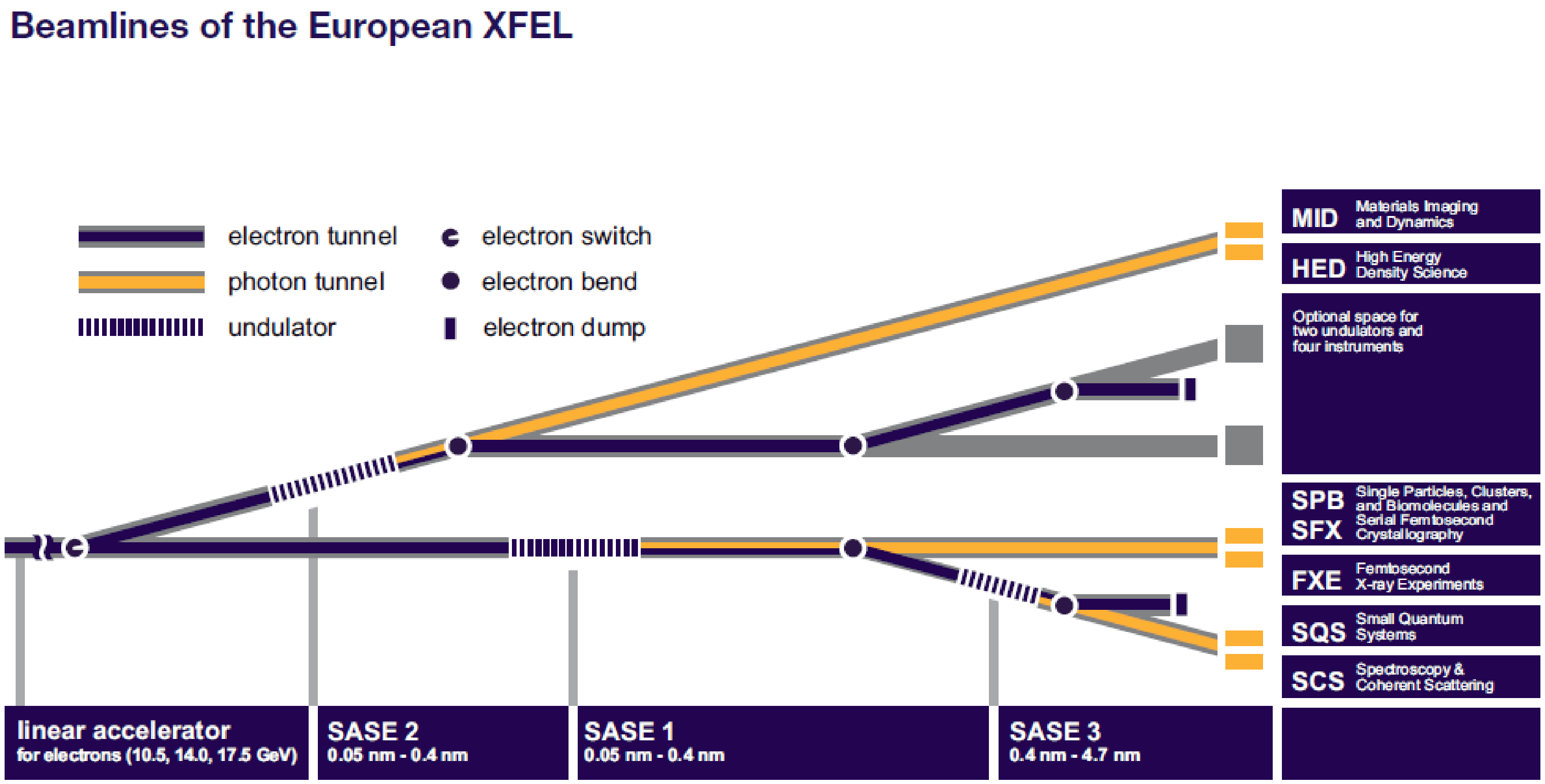
Startup version



- 3 SASE lines
- 91 undulators distributed on 3 SASE-lines
  - SASE 1: planar → 35 undulators
  - SASE 2: planar → 35 undulators
  - SASE 3: at the moment planar 21 undulators
    in future (≥2020) helical with helical afterburner (APPLE-X ID from PSI)
- 1 undulator as spare part

Introduction

- 92 undulators to be tuned in about 2 years
- 3 labs with identical technical equipment in operation
- Because of time reasons undulators of the same SASE line tuned in all 3 labs (MUST!!)

→ Requirements:

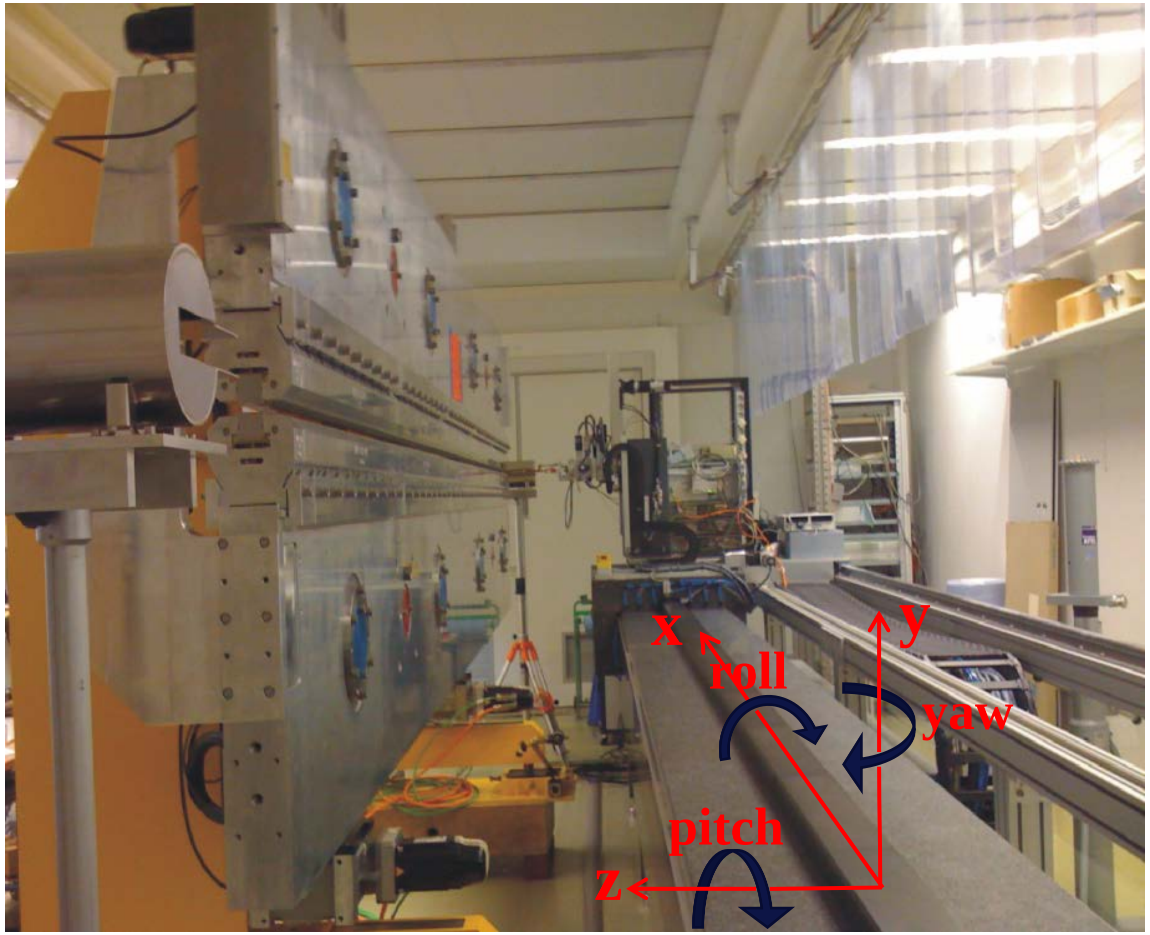
1) Repeatibility accuracy of several measure-ments in single lab: **local accuracy**
2) Tuning undulators of one SASE line in 3 labs: **global accuracy over all labs**

→ **criterium: $\Delta K/K \leq \pm$ 2E-4 (XFELsimulations)**
K is indicator for the magnetic field B and proportional to it

- Not promising observation: significant changes of ratio $\Delta K/K$ by repeating magnetic measurements with probe system used for tuning → local and global accuracy fulfilled?

→ Initiation of a remeasurement campaign and a hall probe study including magnetic and calibration curve measurements

The magnetic measurement benches in the XFEL laboratories



Lake shore integrator: Measures coil signal and delivers output voltage

Gaussmeter (Bell probe)/For Senis probes exchanged by transducers: Measures hall probe signal and delivers output voltage

High precison multimeters: Collects output voltages, which will be read out and converted into magnetic field by the measurement program using difference polynoms

- Basis + moving granite on top: for longituidnal movement use of air cushion
- Straightness ≤ 10um for all axes

  Pitch, yaw: X → ±8urad; Y,Z → <±35urad
- Postion accuracy 1um for all axes

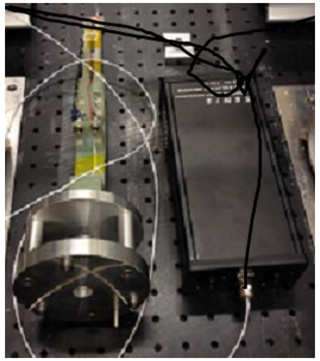
Guaranteed temperature of 21°C ± 0.1°C !
Ambient field application

Investigated hall probe systems

Bell probe with gaussmeter (tuning)

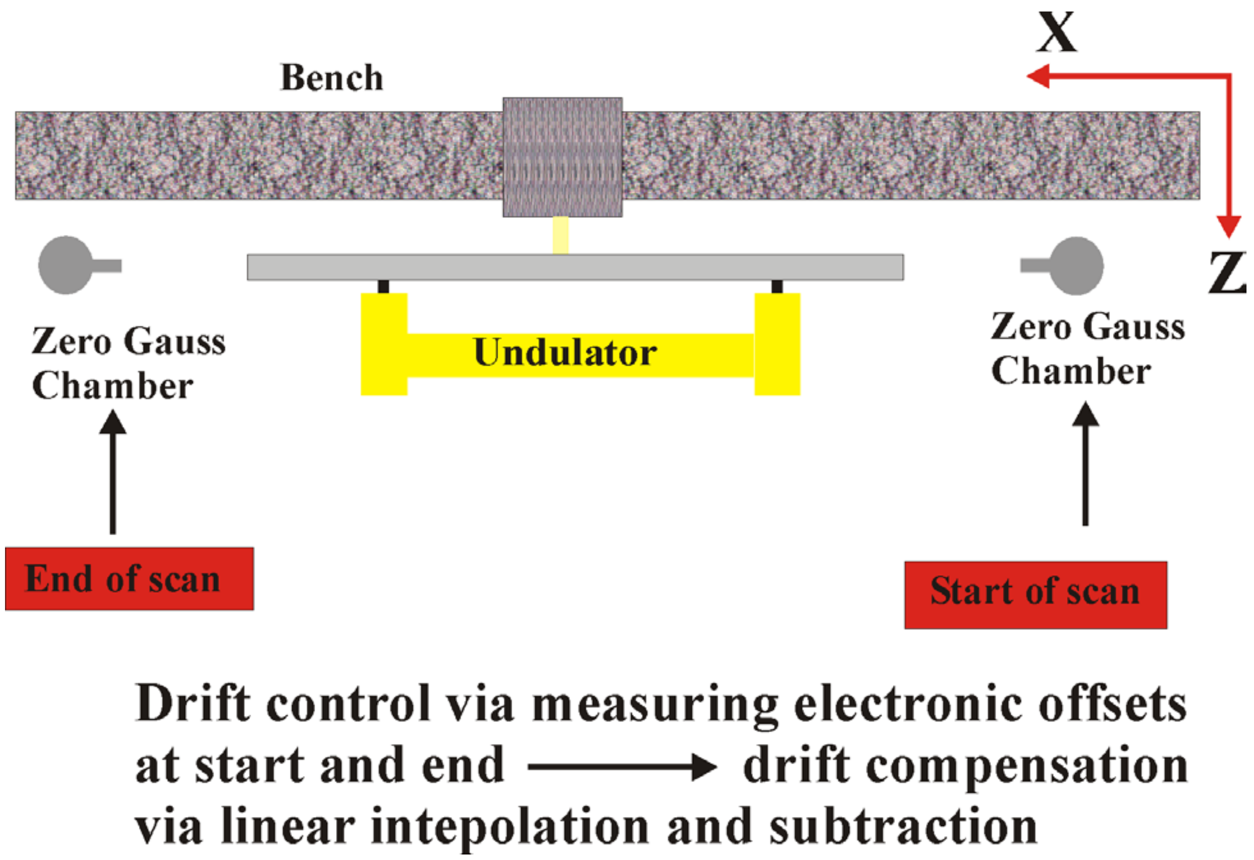
- Gaussmeter used as transducer
- Only use of uncorrected analog output: representative of magnetic flux density measured by Hall probe
- variable probes: automatic algorithm to adapt hall probe and gaussmeter to each other (zeroing)
- Hall probe: sensitive area 0.817mm^2 (circle diameter 1.020mm) probe thickness: 1.524mm (after datasheet)
  $\rightarrow$ large compared to electron beam

Senis probe with transducer (remeasurement)

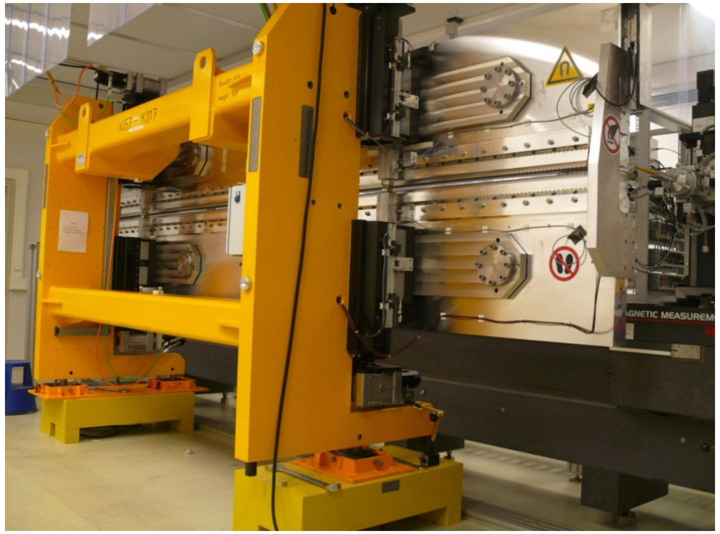


- Uncorrected analog output for voltages
- Converts only hall probe signal to analog output voltage; no automatic temperature effects, non-linearity etc.
- Single probe per transducer
- Compared to Bell probe system noise about factor 10 reduced
- Hall probe: sensitive area 0.0225mm^2 (rectangular with 0.15mm edge length); probe thickness: 1um
  $\rightarrow$ closer to electron beam

Scan regime and reference undulator



Standard undulator of serial production as reference



- 4-fold girder support, 4-axis drive
- Magnetic structure: U40

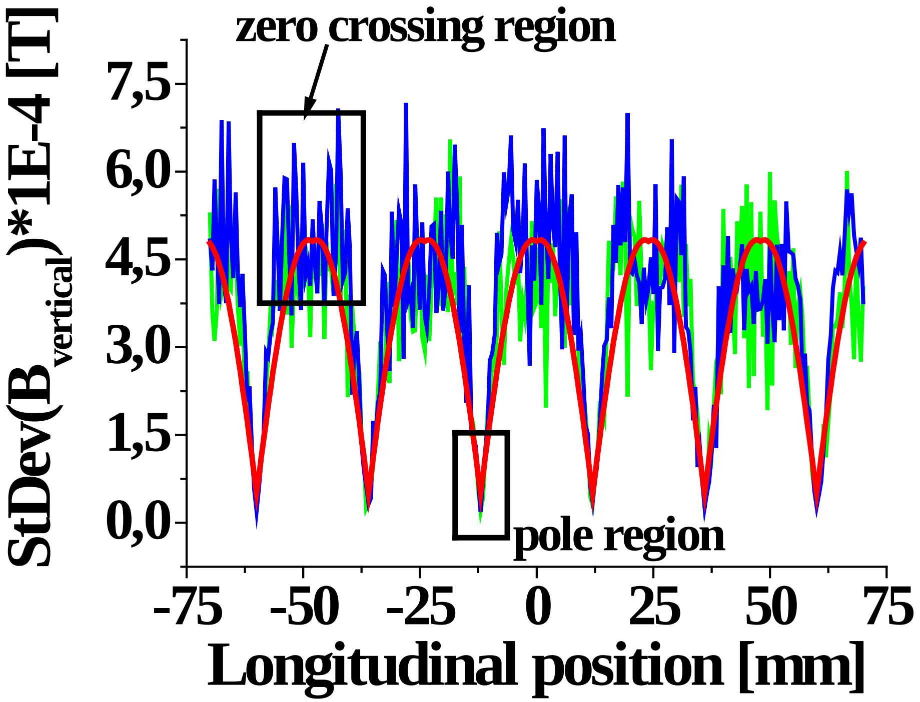
- Scan between zero gauss chambers, in zero gauss chamber offset measurement for hall probe and coil
- 1 measurement consists of 6 longitudinal scans with 0.5mm stepwidth and 50mm/s velocity
- Flip test is done: Measurements at 0deg and 180deg → reducing influence of even coefficients
- Reference undulator: magnetic structure wit 40mm period

Standard deviation of one and several measurements

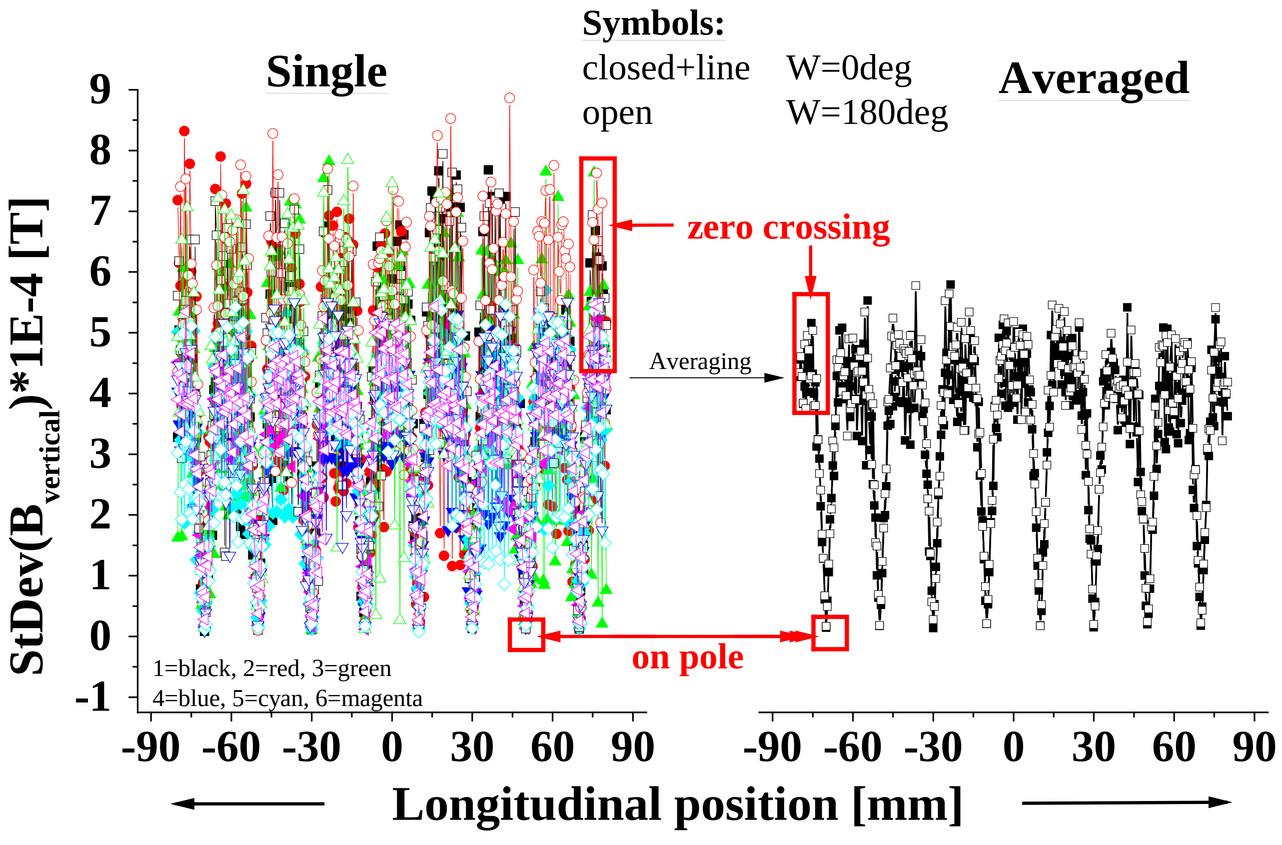
Bell probes: only one measurement

Derivative of magnetic field:

$\Delta B(x) = \Delta B_0 * \sin(2p*x/\lambda) + B_0*(2p/\lambda)*\cos(2p*x/\lambda)*\Delta x$

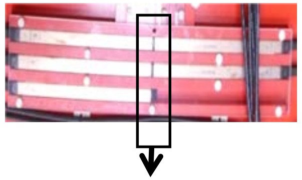


Senis probes: one and several measurements



- Repetition accuracy on poles 50uT for Bell probes and about 20uT for Senis probes, trigger jitter about 2.5um
- with Senis probes magnetic field difference of 1um gap difference can be measured

Reference magnet

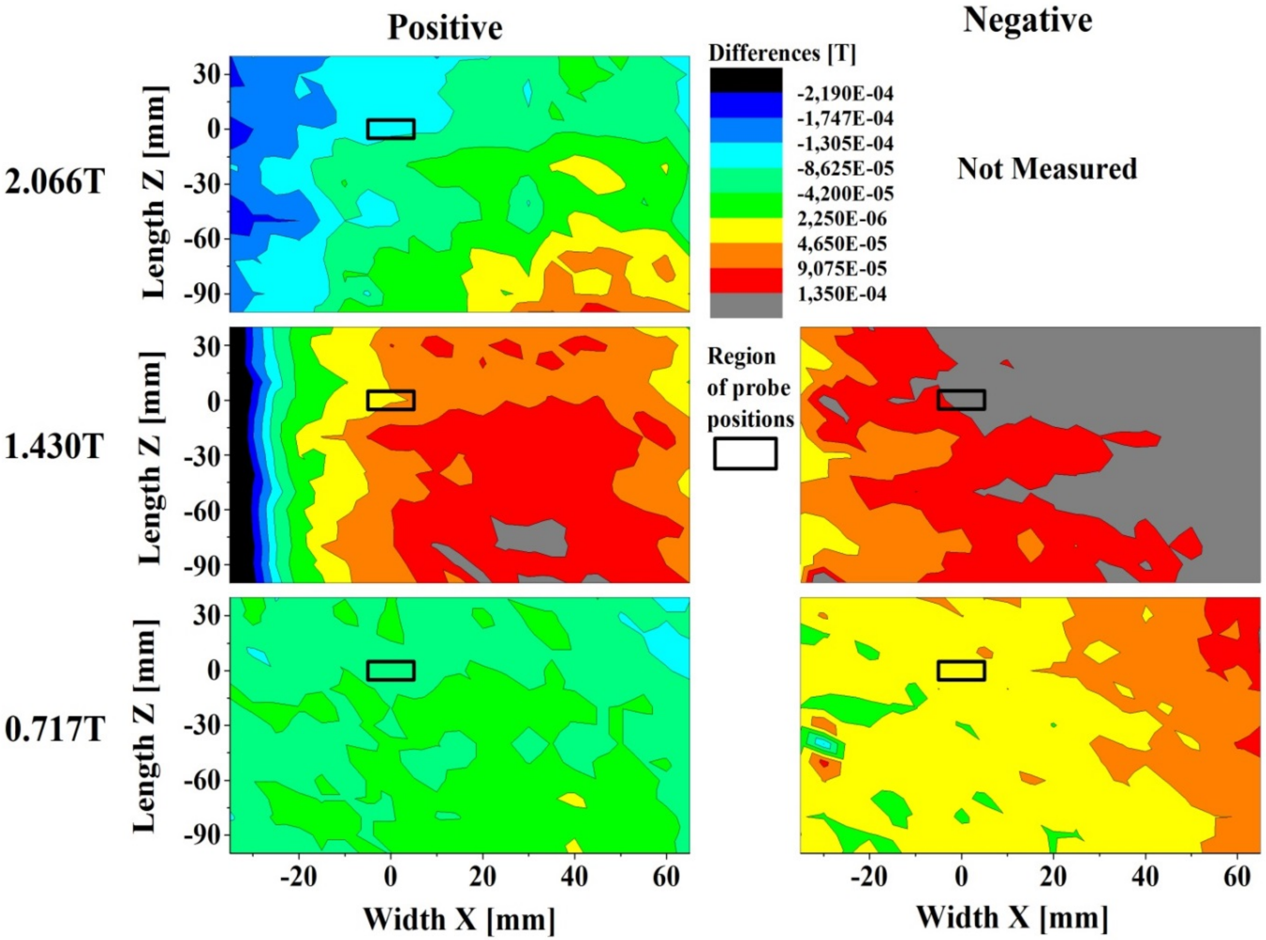


sensitive area of NMR sensors

- Magnet type: Electro magnet
- Maximal magnetic field: ≈ ±2.066T
- Polarity: Switchable

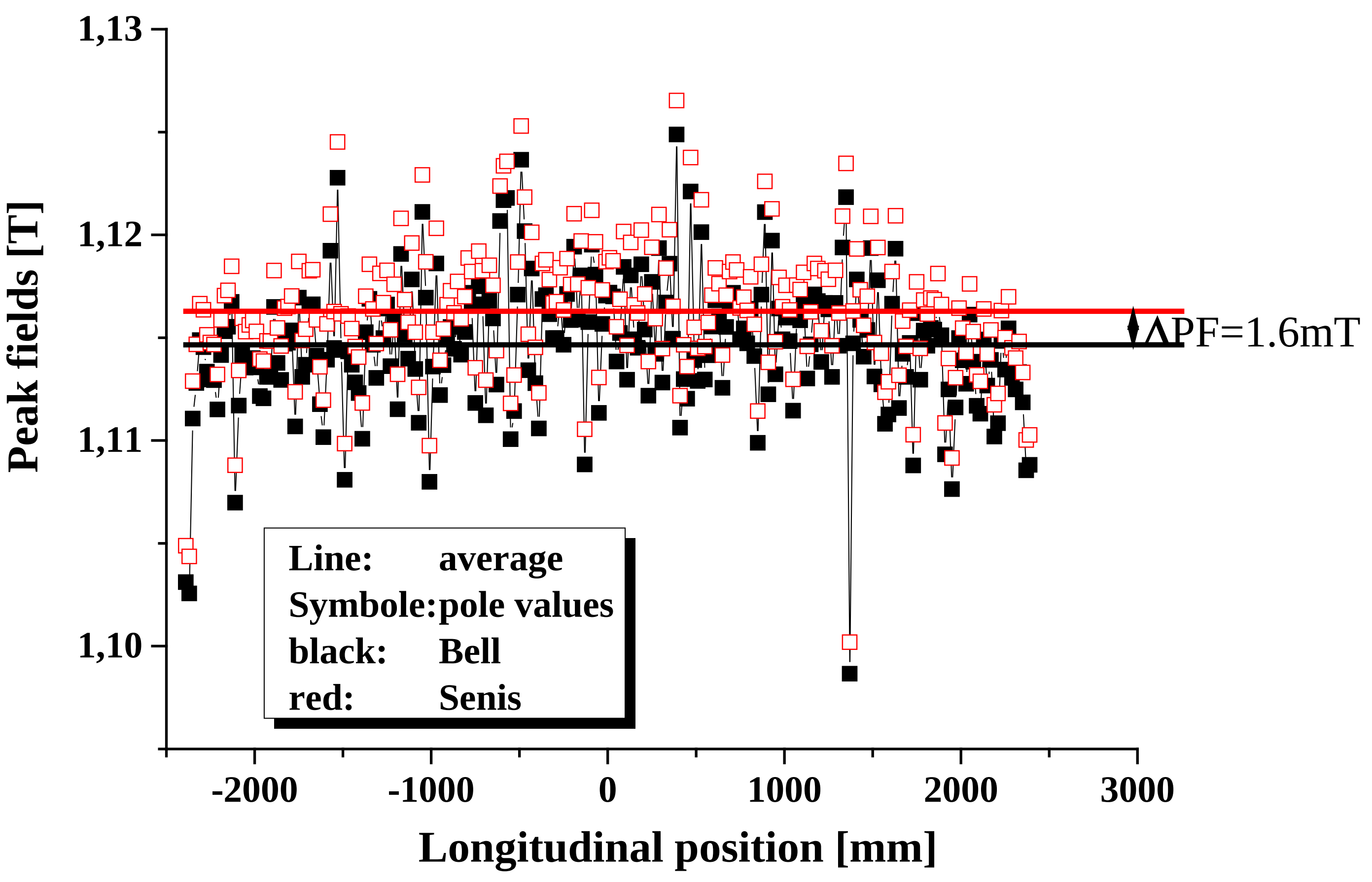
- NMR sensors measure magnetic field with absolute precision of 5ppm

Field homogeneity of reference magnet



- NMR and hall probe on same magnetic field level
- Homogeneity checked with mappings in XZ plane
- Measured homogeneity at location of NMR and hall probe <±2E-4 for positive and negative magnetic field → XFEL condition fulfilled

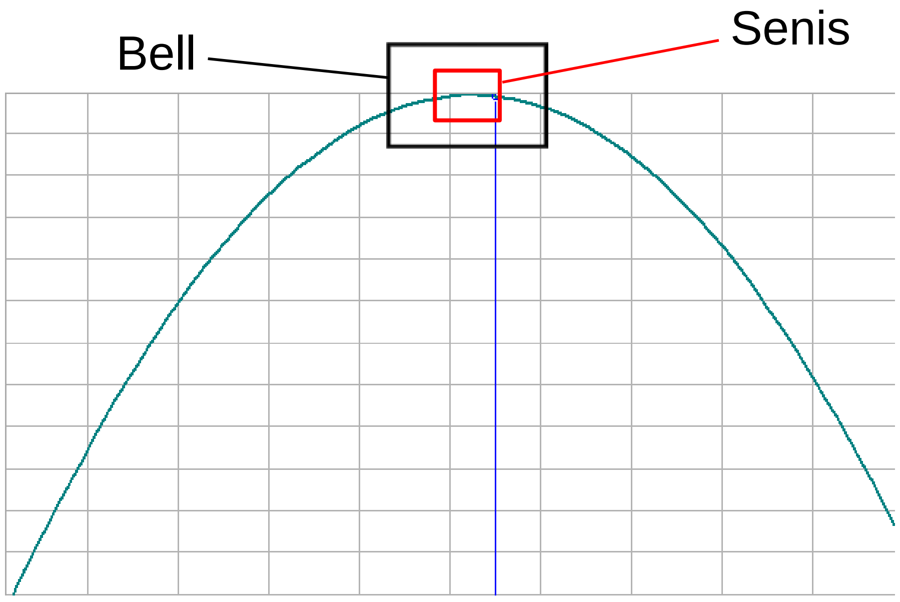
Peak fields for Bell and Senis



sinusoidal profile (for U40 possible) : ΔPF=1.6mT ⟶ ΔK=6.1E-3

- Senis measures more K than Bell

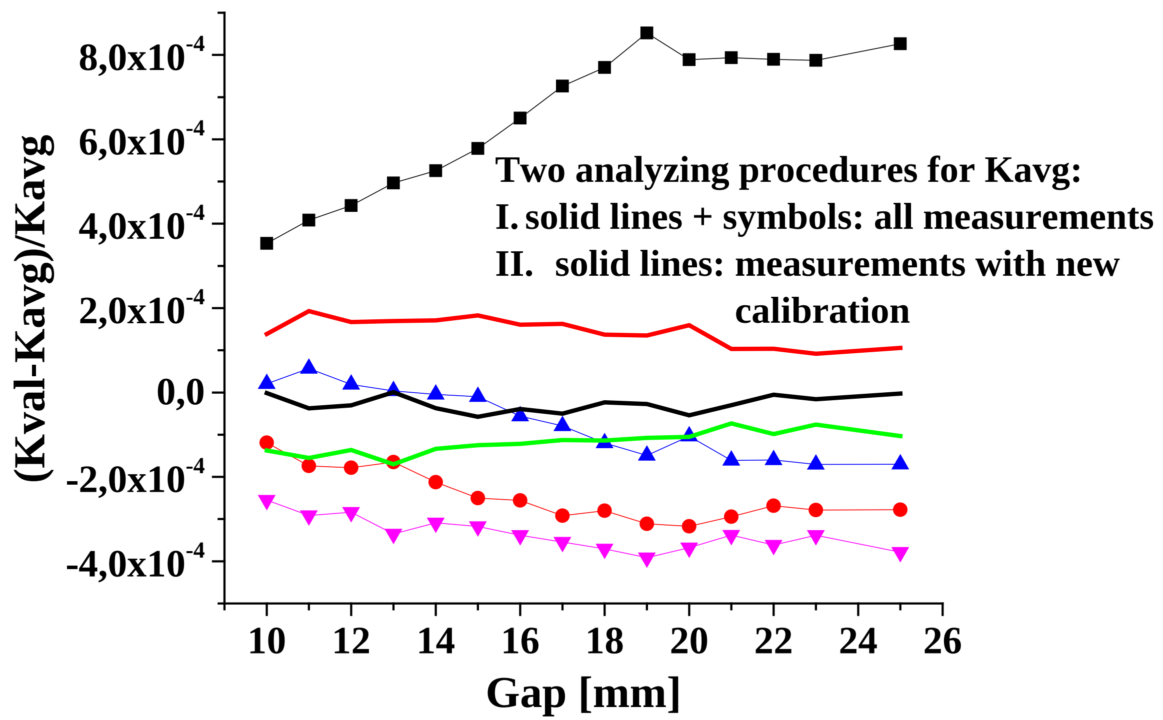
- Larger active area for Bell probes
  → averaging over larger pole area
  → in pole region taken more points on declining edge into account
  → decreased average value



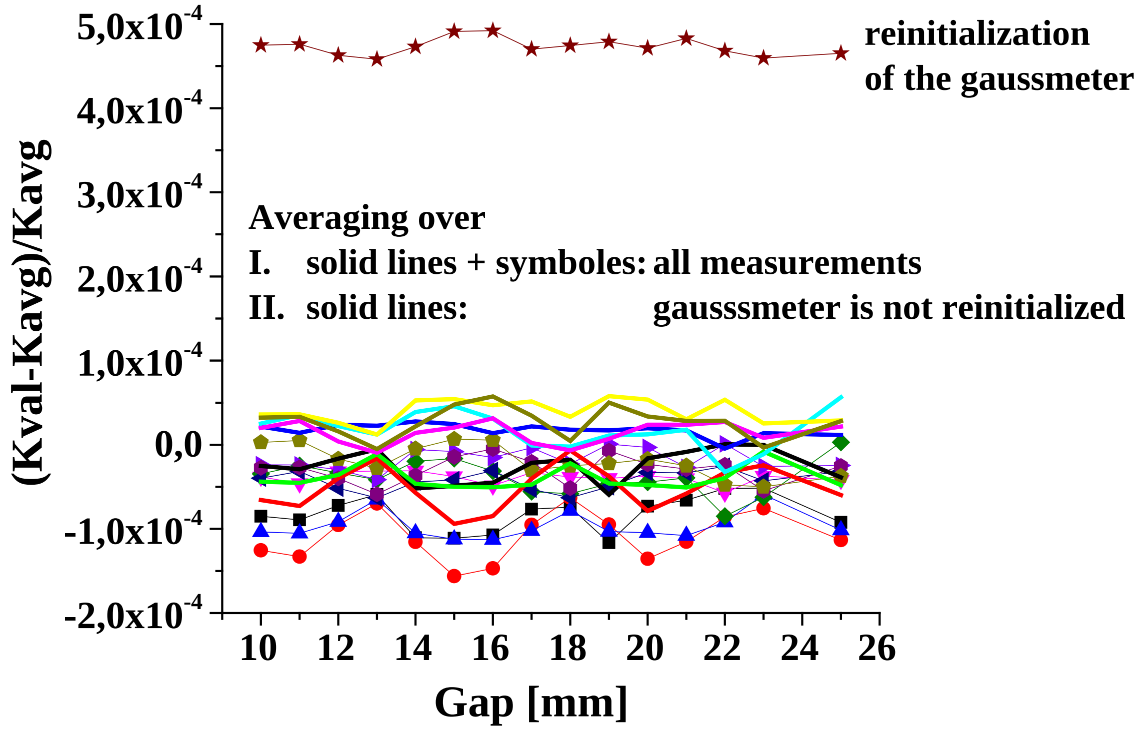
Field in pole region

Local accuracy for Bell probes using U40 structures (continued)

Laboratory XFEL#2: Bell probe 0670024

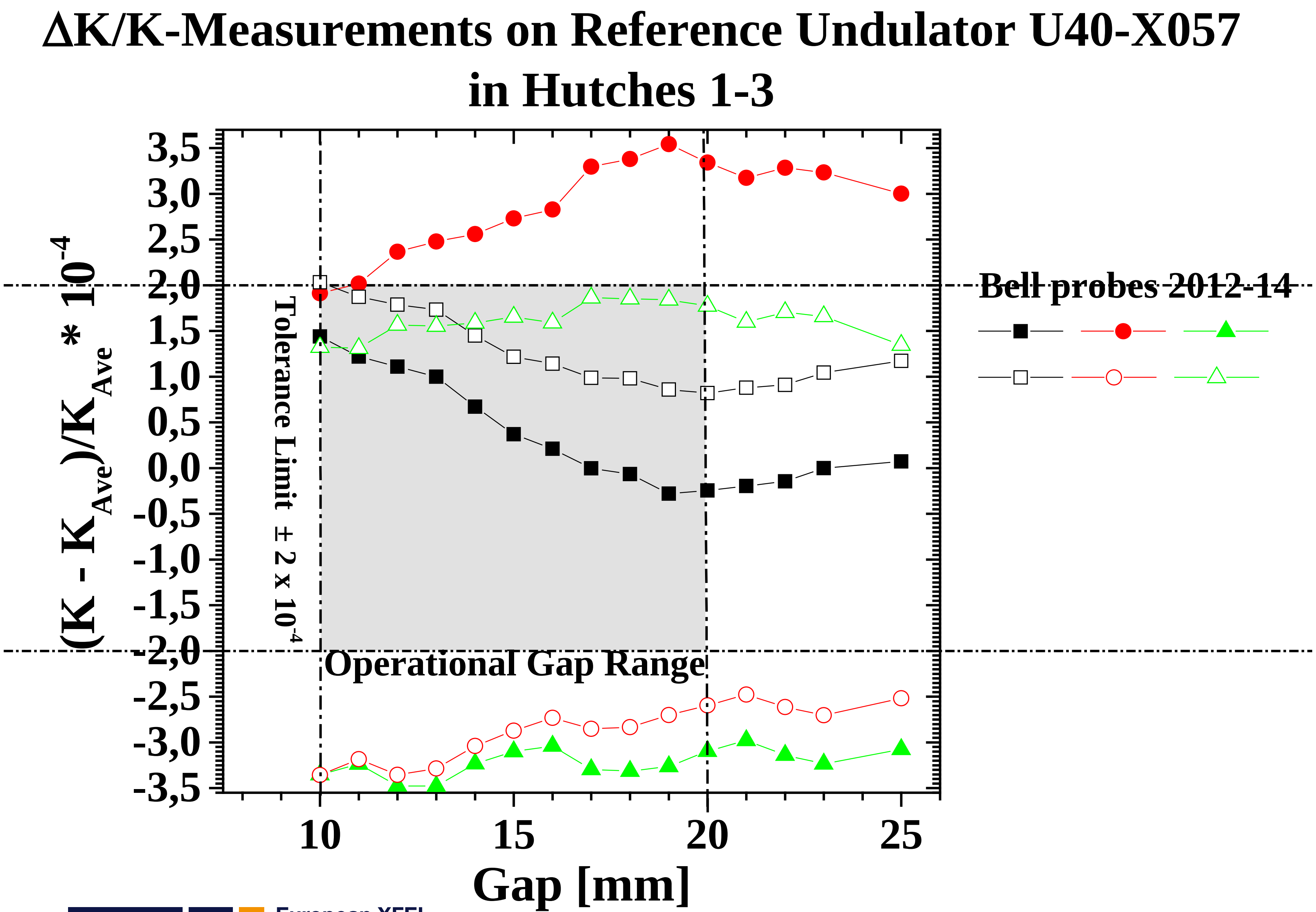


Laboratory XFEL#3: Bell probe 1120479



- K-value was averaged over the measurements taken in the selected laboratory
- **Measurements with ratios ΔK/K ≥ ±2E-4 occur statistically → limited reproducibility/trustability**
- Neglection of these measurements → local accuracy ΔK/K≤±2E-4
- Is the global accuracy given?

Global accuracy for Bell hall probe systems

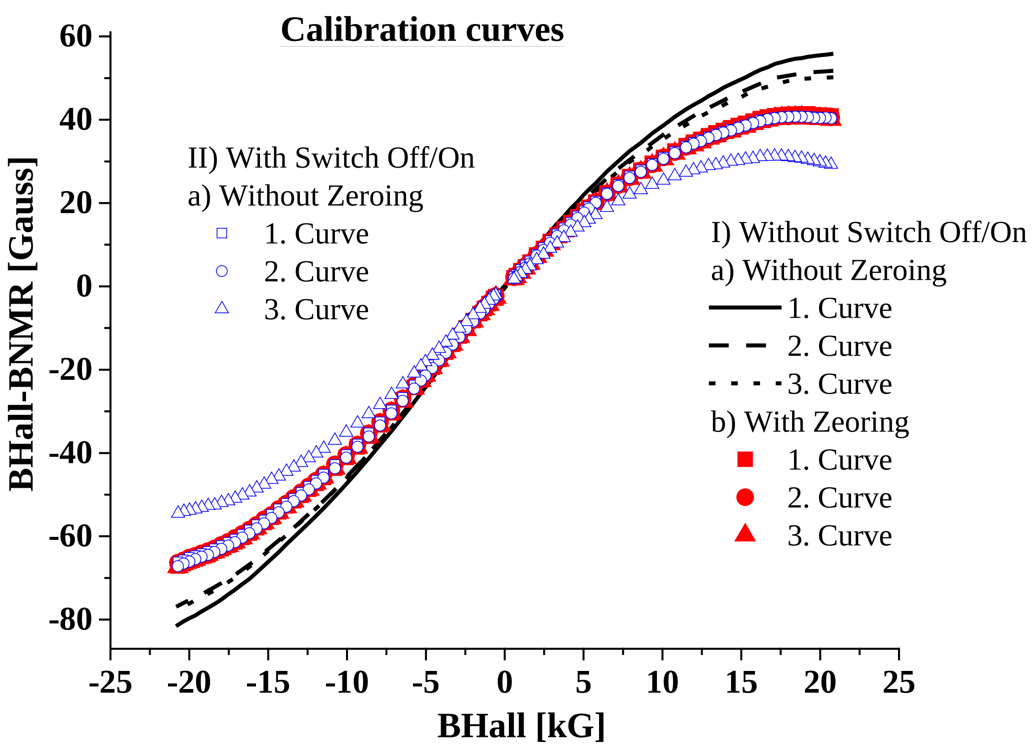


- K-averaging over the measurements taken with Bell probes in all(!!) laboratories
- Several measurements with Bell probes hit the critierium ΔK/K≤2E-4
- Calibration problem?

Bell hall probe systems

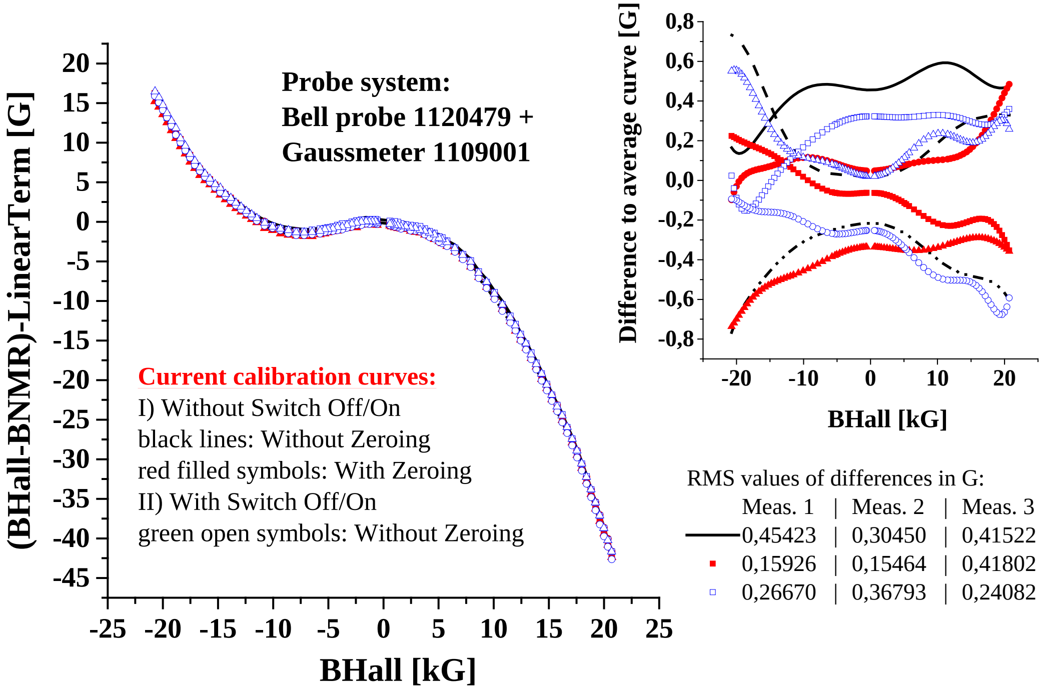
- Two probe systems were investigated because of global accuracy
- Different procedures for the gaussmeter initialization: Investigation of hall probe behaviour after shutdown

a) System: Probe 1120479 + Gaussmeter 1109001



- Less reproducibility
- Strong gain
- Strong gain change in absolute values
- Neglection of the slope: Calibration curves close together

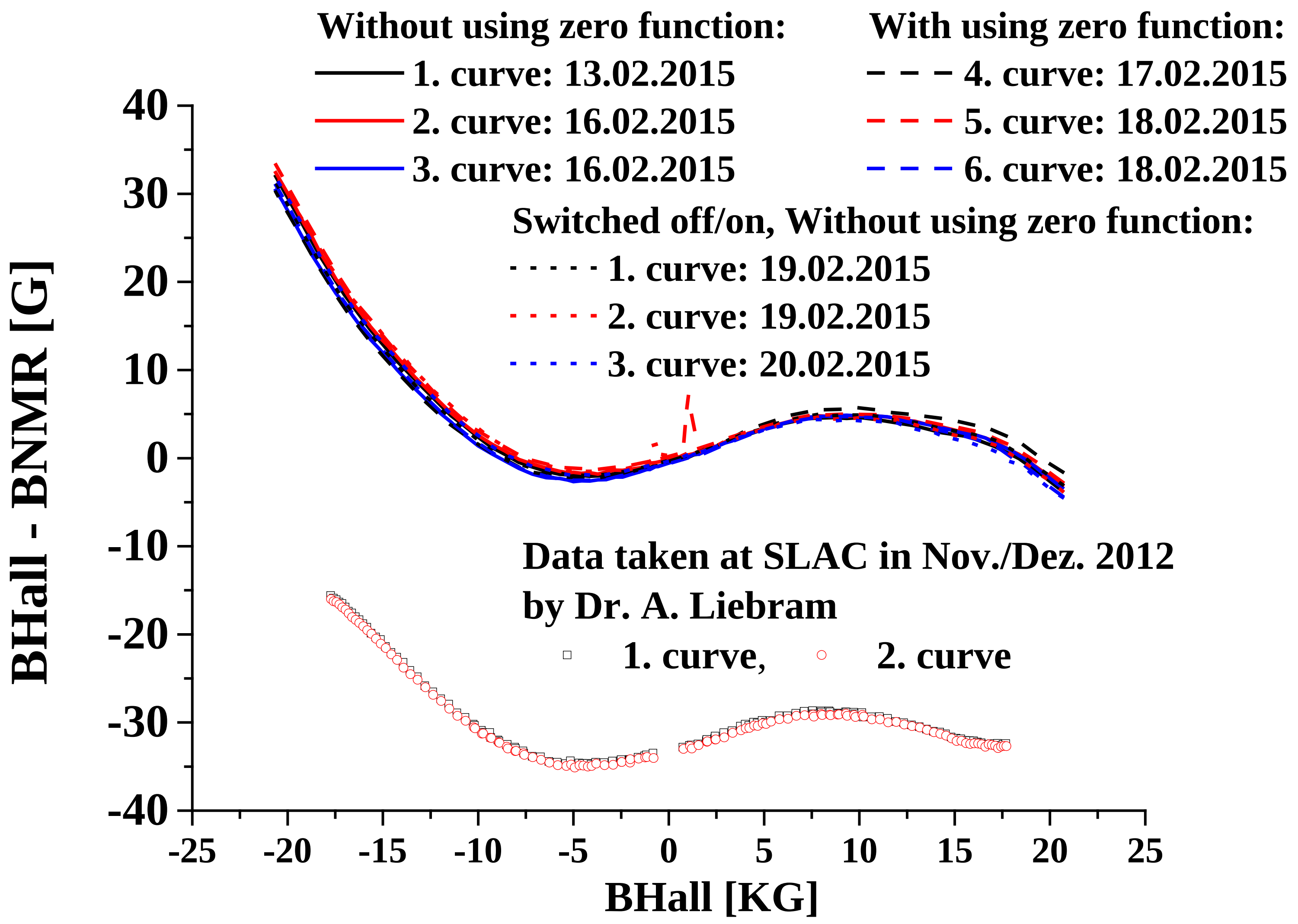
Calibration curves neglecting the linear term



	Meas. 1	Meas. 2	Meas. 3
(black line)	0,45423	0,30450	0,41522
(red filled symbol)	0,15926	0,15464	0,41802
(open symbol)	0,26670	0,36793	0,24082

- Coefficients of higher order than slope/gain equal inside error bar, error bars large

2. System: Probe 0067024 + Gaussmeter 1045120



- Probe system show opposite behaviour compared to the first probe
- Little gain, moderate absolute gain variation
- Coefficients of higher order equal inside error bar, for higher order coefficients error bars large
- SLAC and DESY calibration curve comparable neglecting the offset: curve profile reproducible, “limited” long term stability

Bell probes:

→ Bell hall probe systems show different behaviour: one with strong and one with little gain

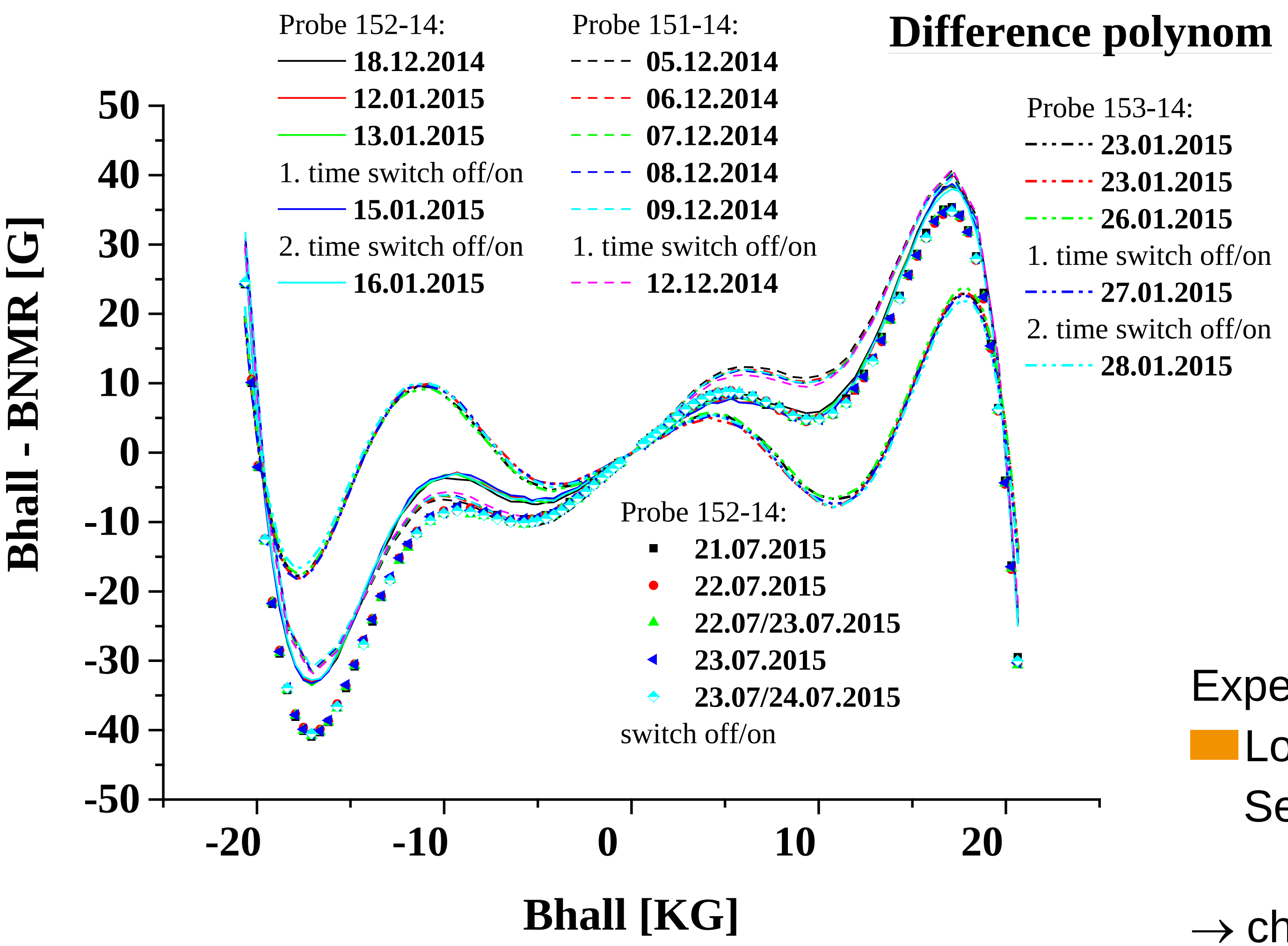
→ Probe with strong gain show less reproducibility in calibration, **gain changes statistical**

→ Probe with low gain show **gain change in magnetic measurement**

→ Gain changes can influence the ratio $\Delta K/K$ on the level ±2E-4

→ Trustability for this probe system is suffers apart from large sensitive probe area

Senis hall probe systems



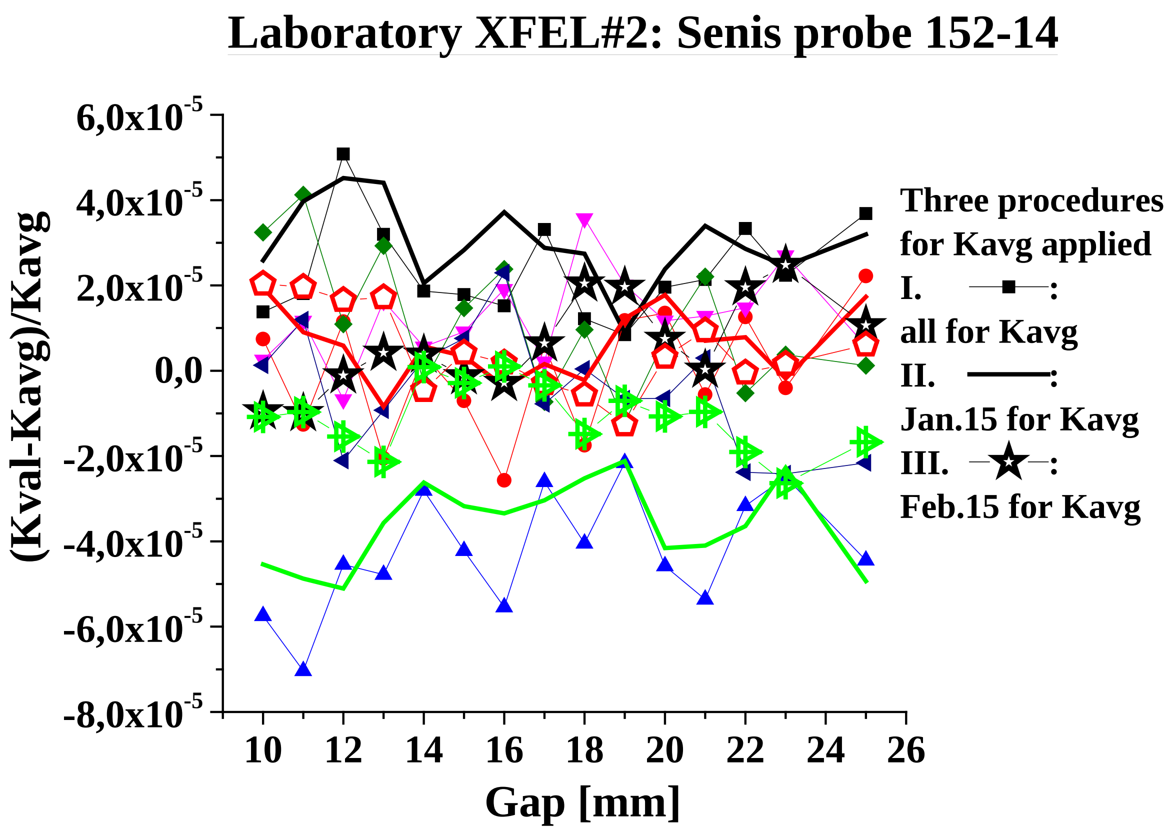
- All senis probes show little gain
- Gain fluctuations inside one calibration cycle negligible, high reproducibility
- For one probe calibration polynoms of several repetititions are inside the error bars indentical
- Calibration polynoms of the 3 Senis probe systems are comparable to each other
- Calibration curve is not much changed after several month

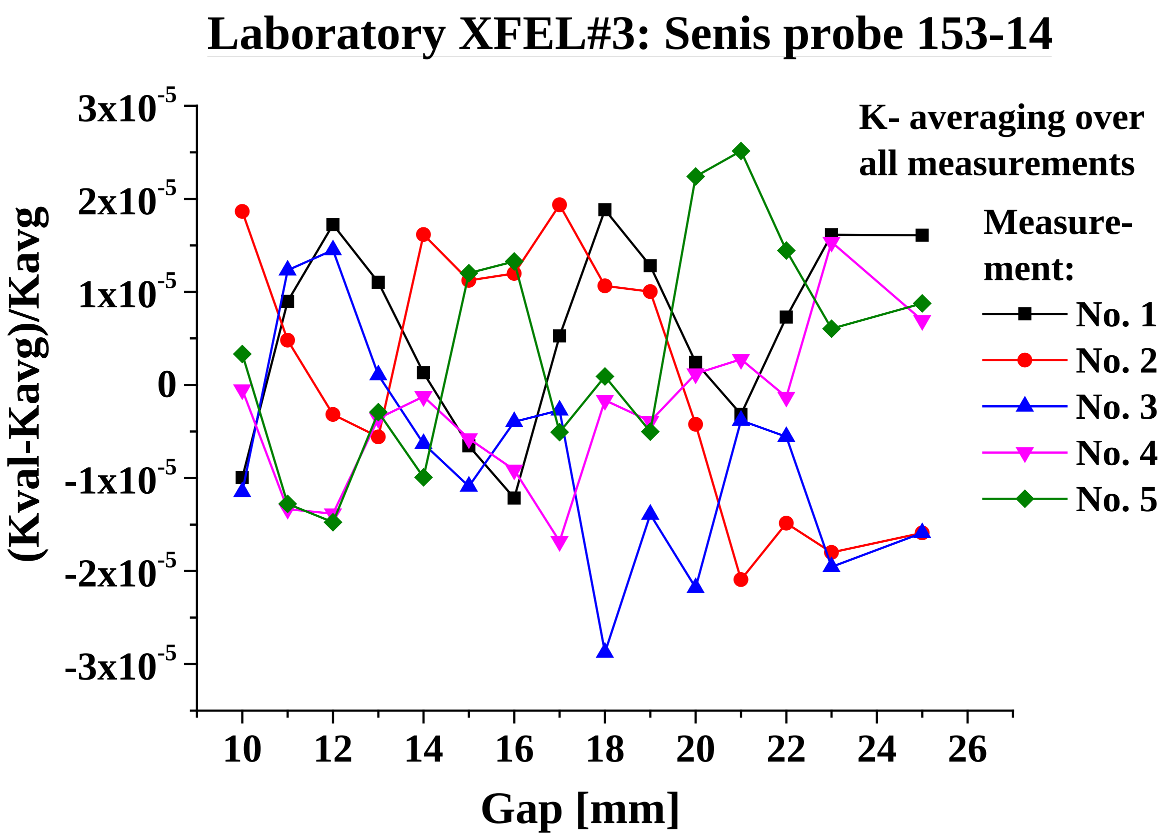
Expectations:

- Local and global accuracy better fulfilled for Senis than for Bell hall probe systems

→ check will be done with magnetic measurements at the XFEL benches

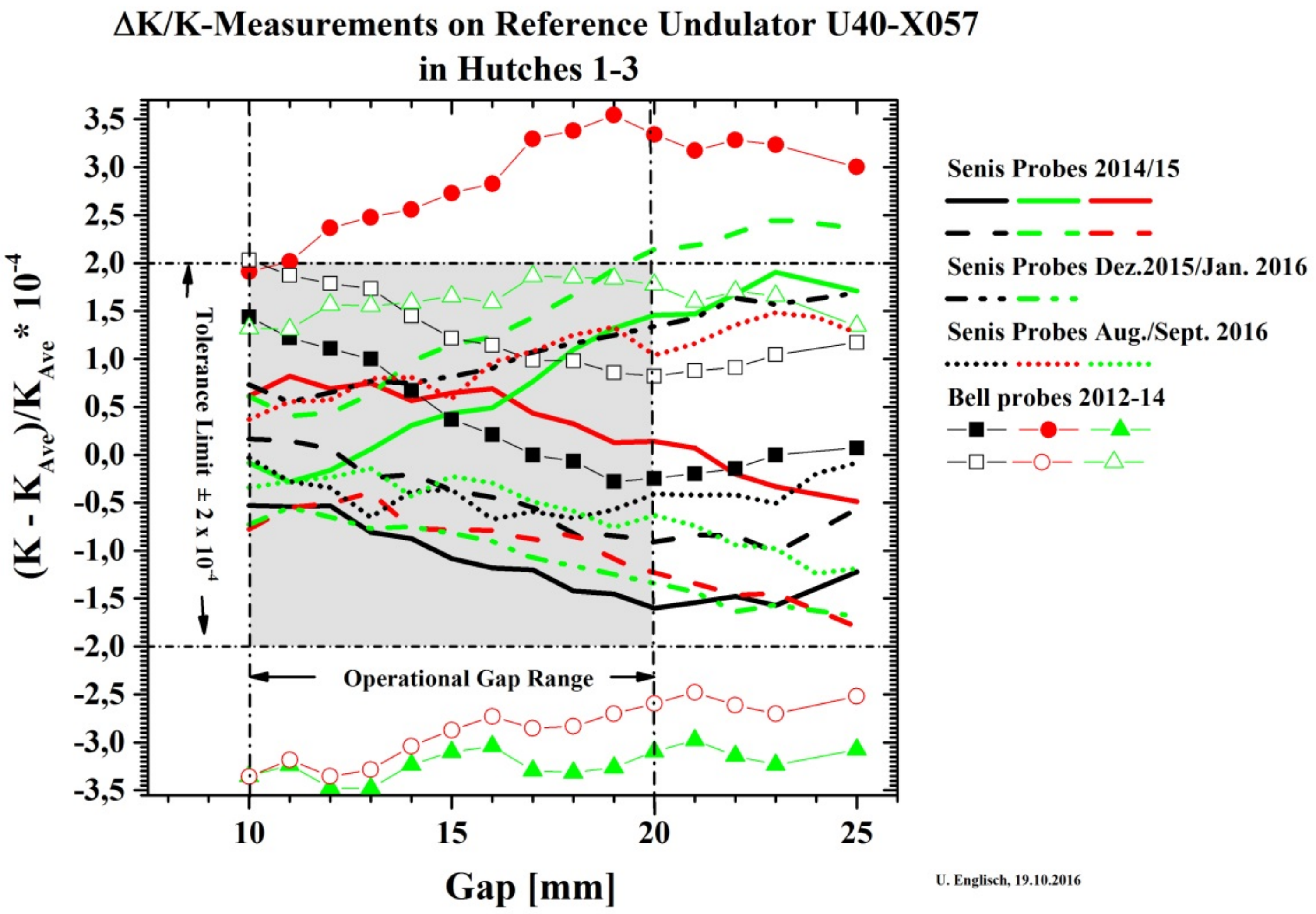
Local accuracy for Senis hall probe systems





- Like for Bell probes: K-value averaged over the measurements taken in selected lab
- Repetition accuracy for ΔK/K in both labs in 1E-5 range
- Local ΔK/K accuracy almost a factor 2 better than the Bell Probes
- Both hall probe systems: global accuracy?

Global accuracy for Bell and Senis hall probe systems



- K-averaging over the measurements taken in all(!!) hutches/laboratories
- All(!!) magnetic measurements with Senis hall probe systems are inside the specified range of ±2E-4
- Several magnetic measurments with Bell hall probe systems hit the specified limits or are above
- Instabilities of gaussmeters limits the usage of the Bell hall probe systems for our intentions

Summary

- XFEL undulators for one SASE line tuned in different labs: local and global accuracy is studied
- Used industrial hall probe systems show complete different behaviour:
  Bell probes: not comparable, statistical gain fluctutations in calibration and measurement
  → local and global accuracy only limited fulfilled
  Senis probes: comparable and reproducible → local and global accuracy completely fulfilled
  local accuracy: $\Delta K/K \leq 1E\text{-}5$ range, global accuracy: $\Delta K/K \leq \pm 2E\text{-}4$
- Senis probes see higher K-value then Bell probes because of sensitive area
- Experimental stations:
  Bench accuracy: Peak field reproducibility ≤50uT, trigger jitter 2.5um, for Senis probes 1um gap difference is magnetically seen
  Reference magnet: homongeneity in NMR-hall probe region $\Delta B \leq 2E\text{-}4$

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First lasing observed at 2nd May 2017

Thank you for your attention!