Recent Developments for Undulators at PETRA

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– on behalf of the DESY Insertion Device Group FS-US –

PHANGS, 4-5 December 2017, Trieste

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

DESY

Outline

> Magnet sorting for hybrid structures

- Magnet sorting for PPM and hybrid structures
- Sorting by M and single point NS data only
- Magnet error model
- Measurement of magnet errors by a Hall probe array
- Results

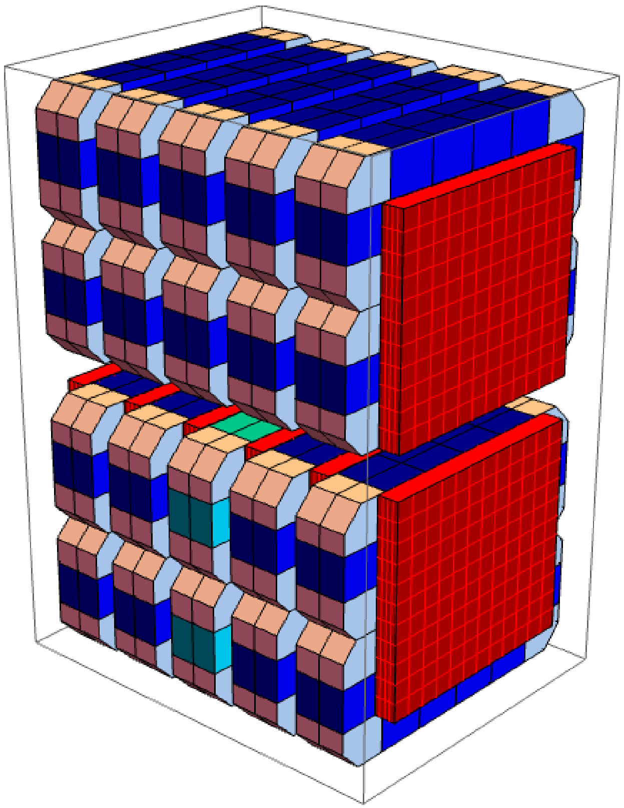
> Phase shifter integrated in an undulator hybrid structure

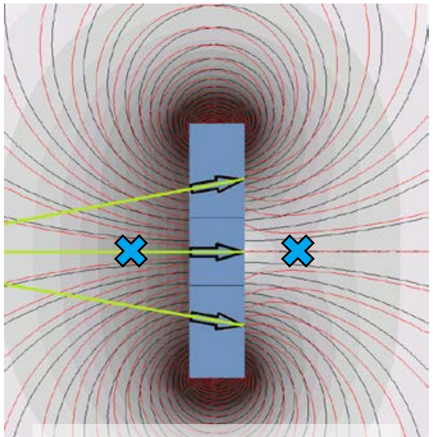
- Motivation & Principle
- Implementation
- Magnetic response / Measurement results

Coworkers: Pavel Vagin, Andreas Schöps, Paul Neumann, Thorsten Vielitz, Daniel Hemmenga

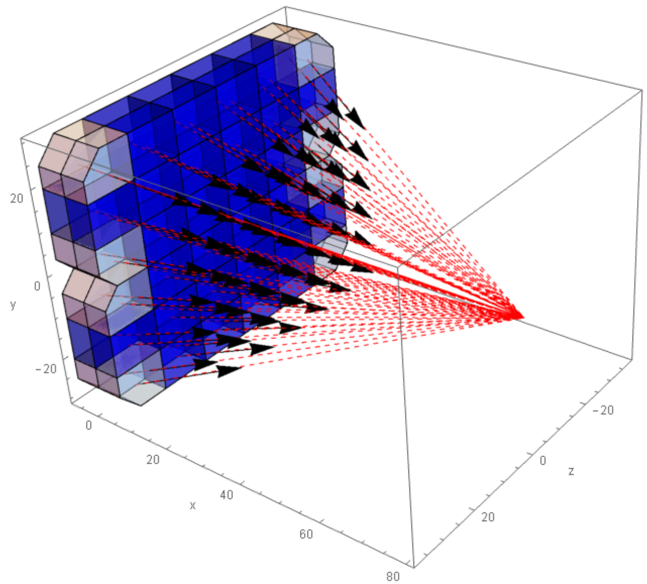
Helmholtz coils + single point North-South

- Sorting by M and single point NS values only is not efficient for a hybrid structure
- Magnet model with individual magnetization of each subblock according to Helmholtz and NS measurements, as single „focal“ point
- Radia model of short undulator with non-ideal magnet in different orientations (pos/neg, top/bot) to get signatures for sorting





North-South measurement

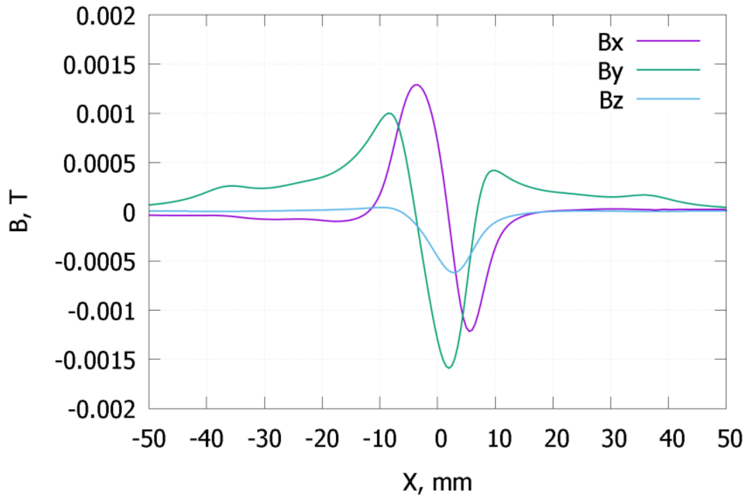


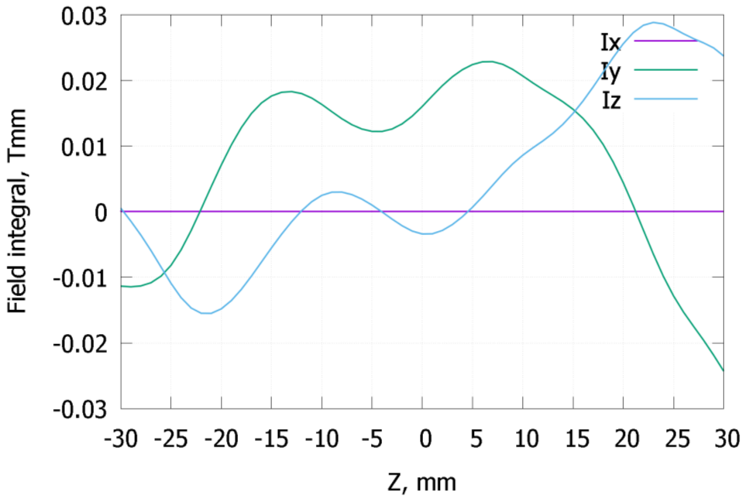
On-axis field and field integral signatures of magnet errors

On-axis field longitudinal dependence

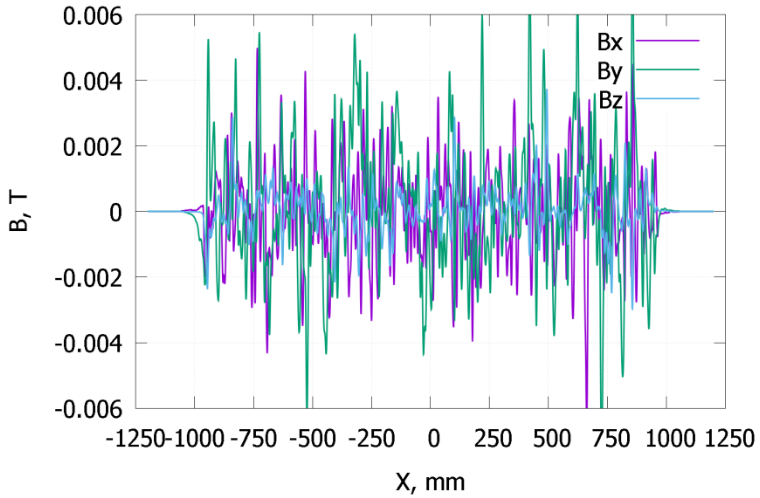
Field integral transverse dependence

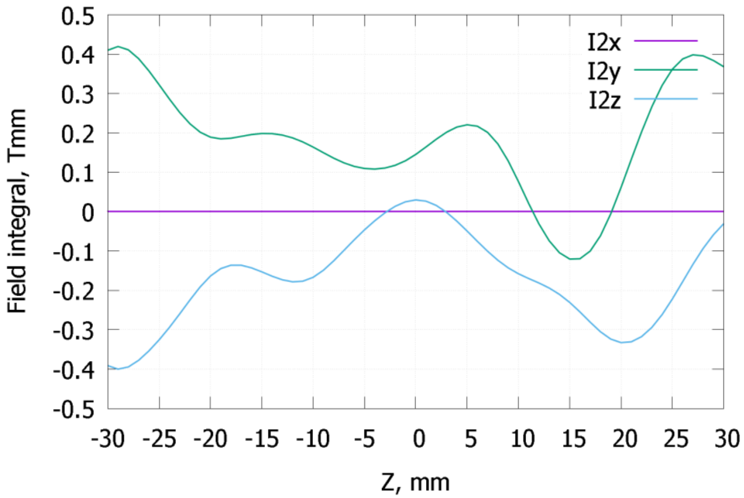
Single magnet





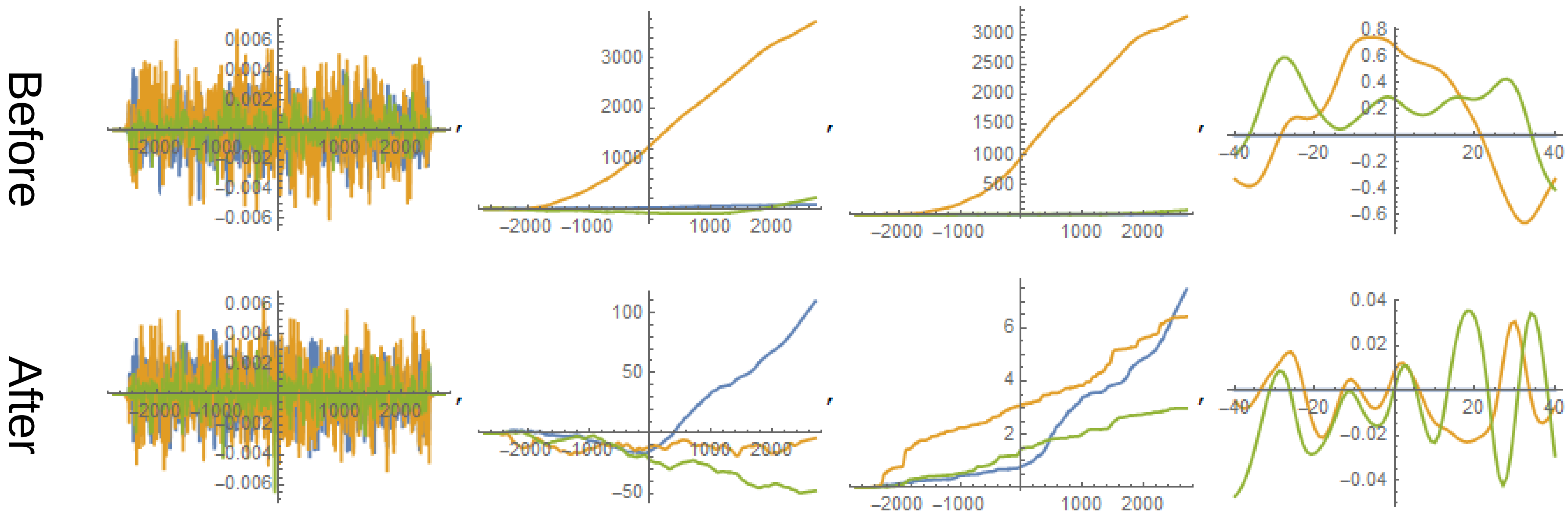
2m undulator, 250 magnets





Optimization of sorting by random swap of magnets

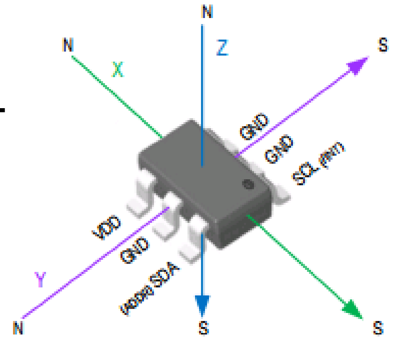
- Take two random magnet positions
- Swap them and calculate error
- If new error is larger, then put magnets back
- Repeat

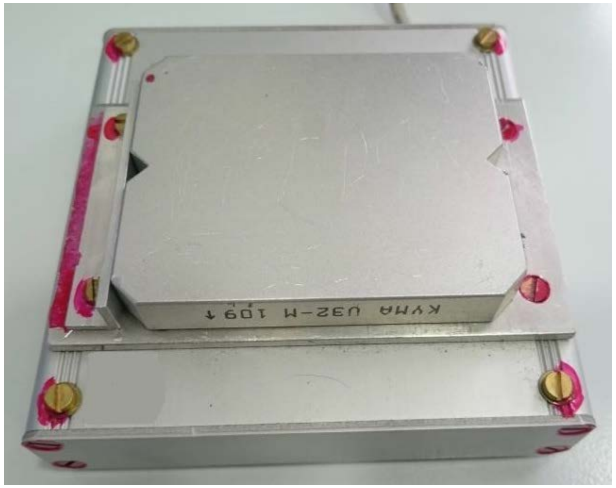


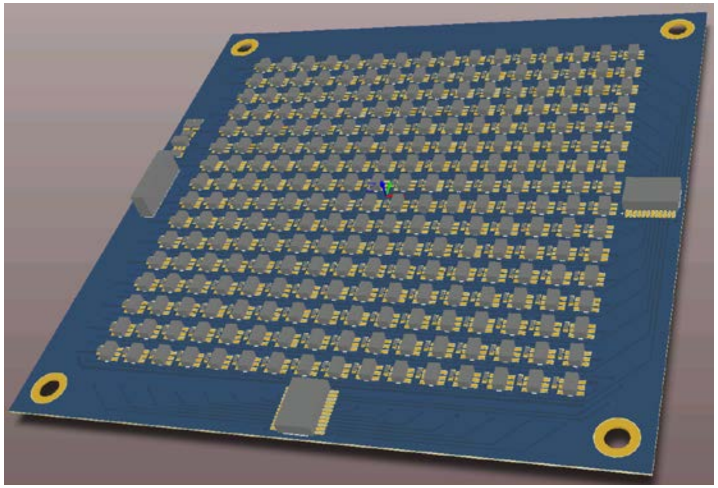
Field, T   Trajectory, Tmm^2 "Phase advance", a.u.   Multipoles, Tmm

TLV493D Hall sensor array

- Infineon TLV394D integrated 3D hall probe
- Built-in 12-bit ADC(100uT/LSB), temperature sensor, I2C interface
- 3x3mm TSOP-6 footprint, 5mm sensor pitch on PCB
- Linear (<1LSB) field measurement range up to +-130mT
- Angular positioning error and gain calibrated with NMR
- Measurement of the whole fieldmap within few seconds

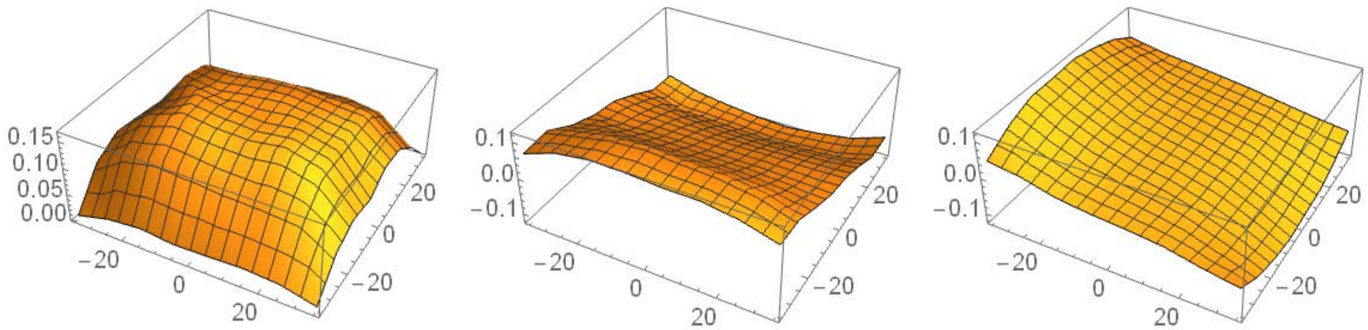


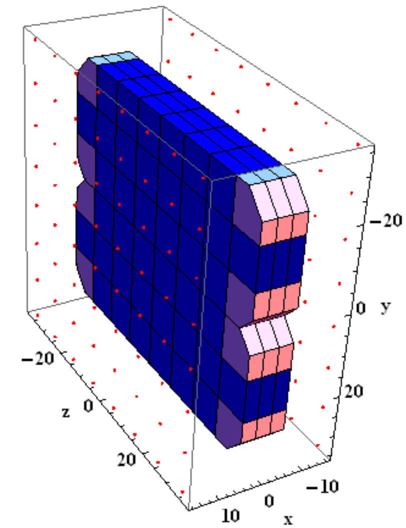




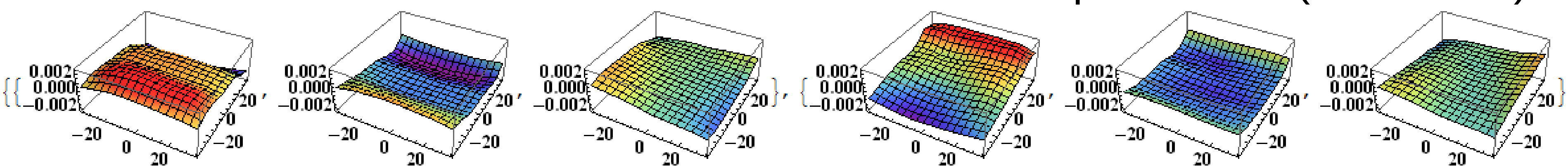
Random optimization of magnet errors to match the measured field

Measured fieldmaps

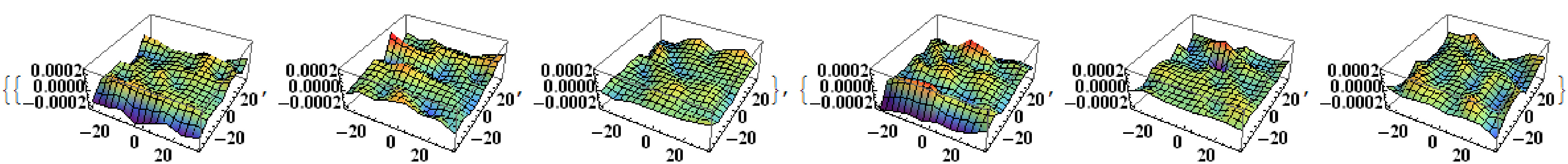




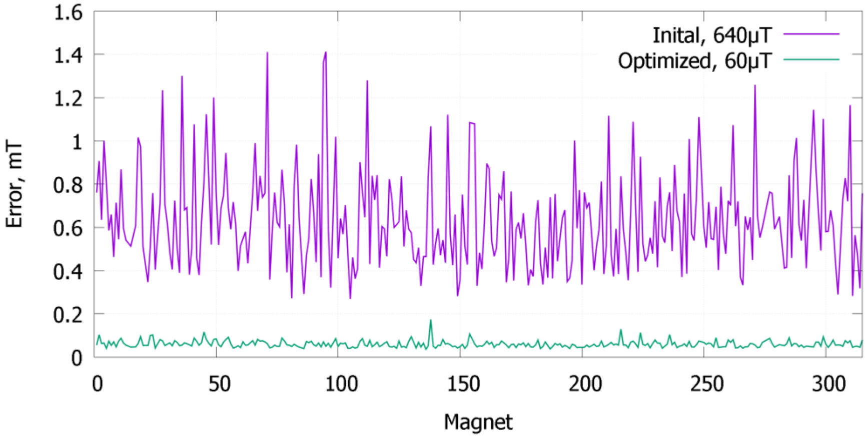
Field difference of model and measurement before optimization (2mT scale)

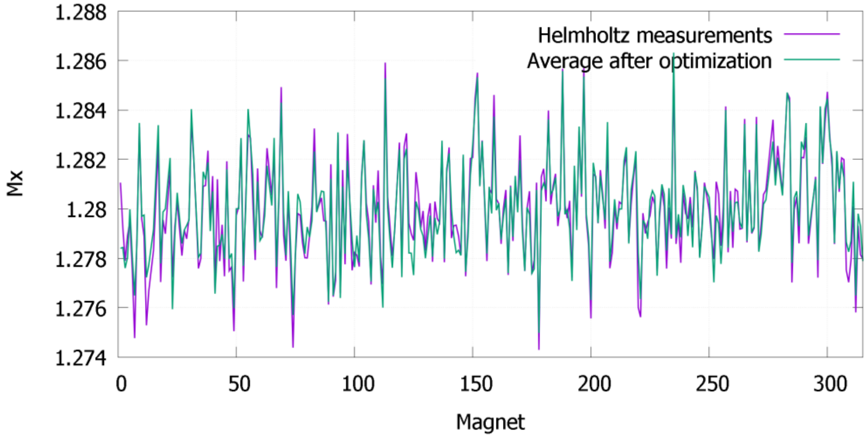


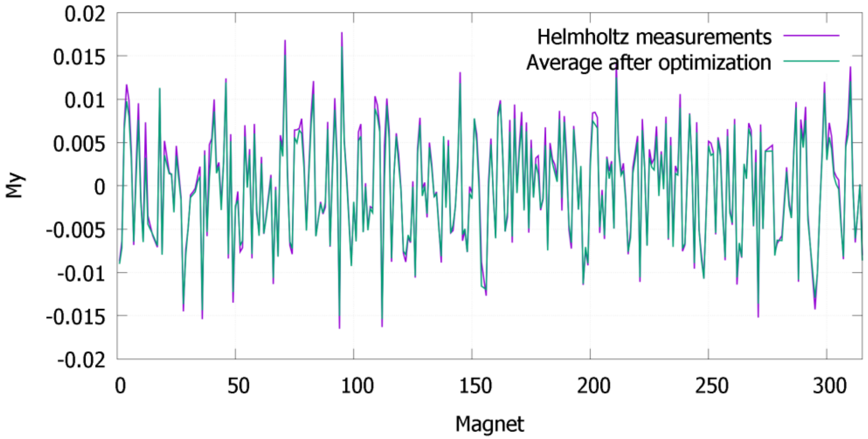
Field difference of model and measurement after optimization (0.2mT scale)

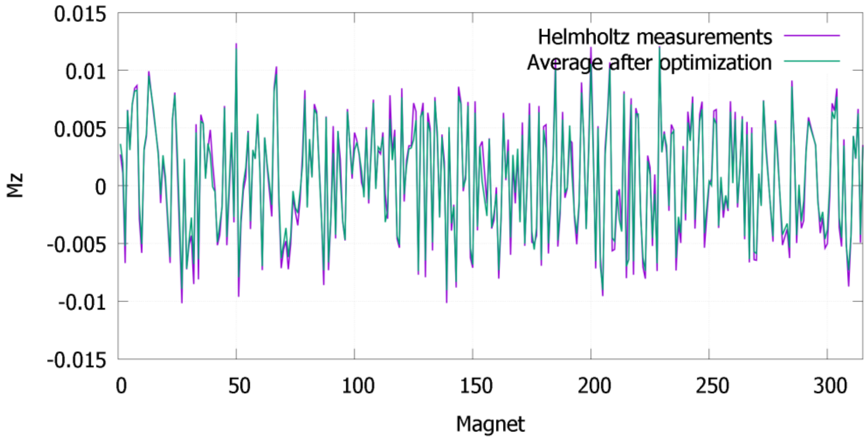


Magnet model optimization results compared to Helmholtz measurements



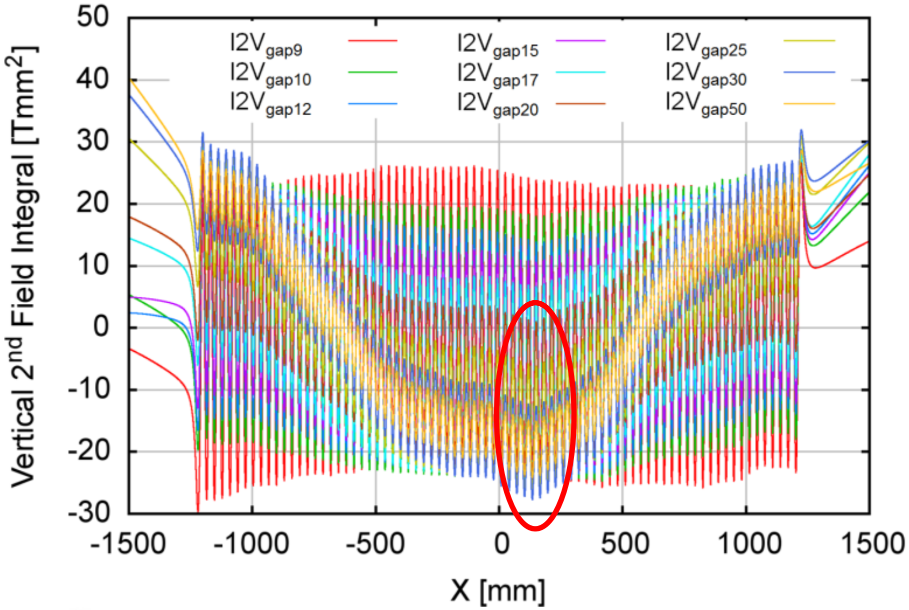


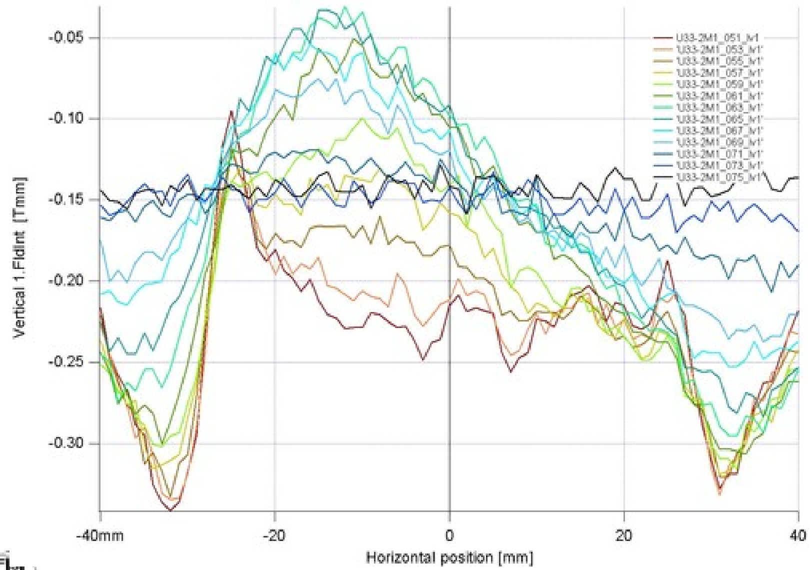


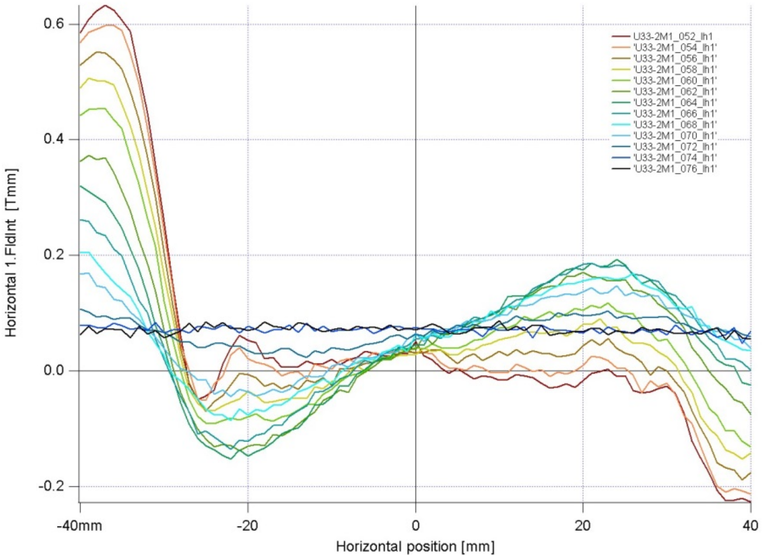


Previous experience, without proper sorting

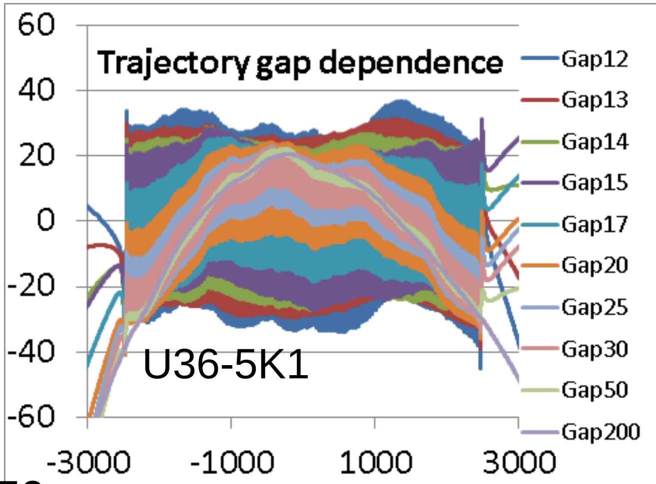
- Gap dependent kicks
- Multipoles gap dependence
- Require additional gap dependent shimming

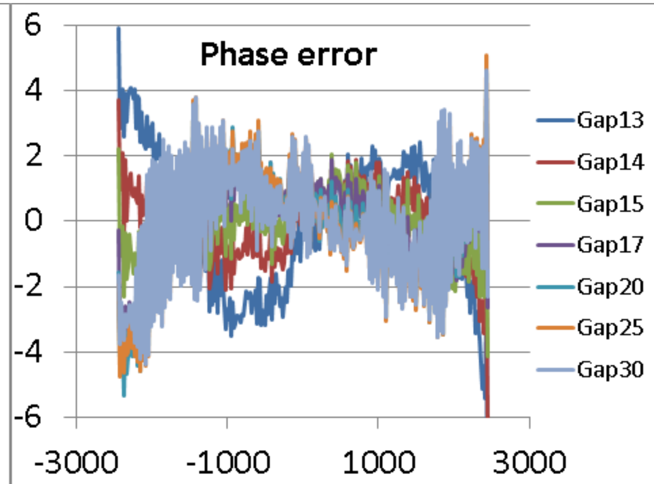


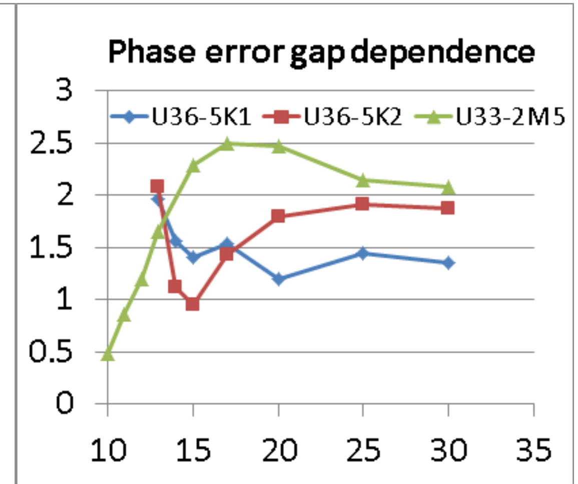


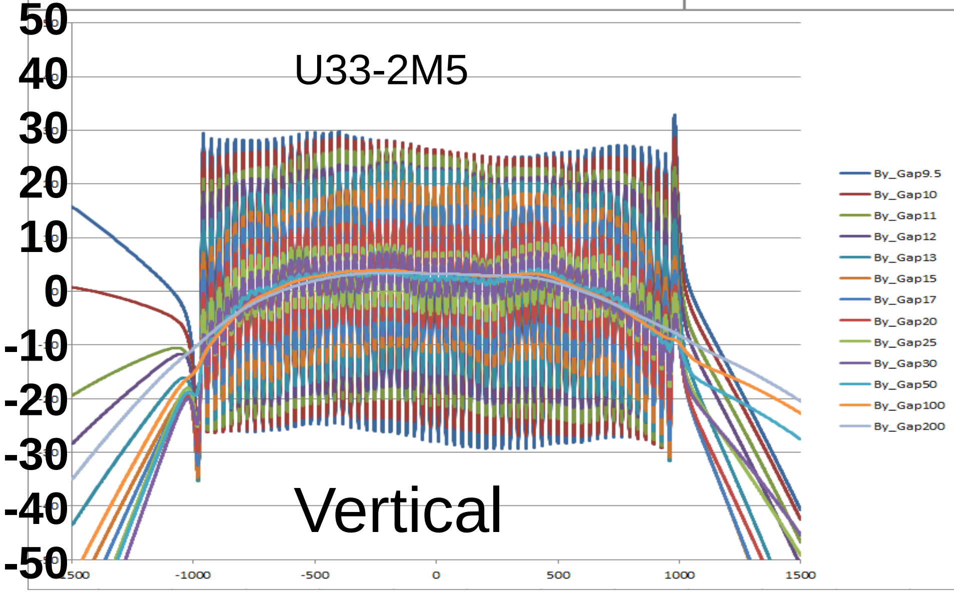


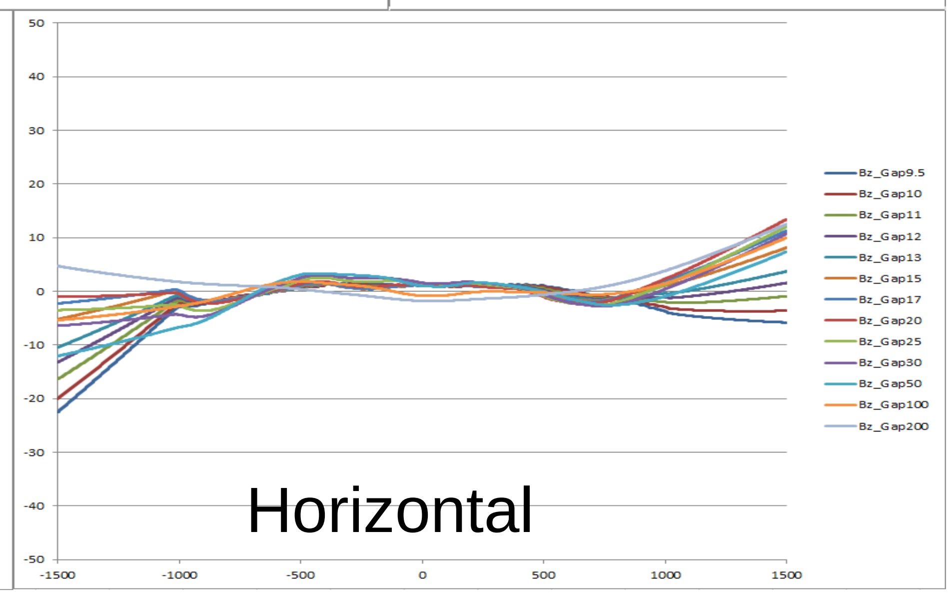
Last devices with new sorting, gap dependence











- NO gap dependent kicks inside the structure, phase error <2 deg
- Negative curvature at open gaps - Earth field

Last devices with new sorting, multipoles gap dependence

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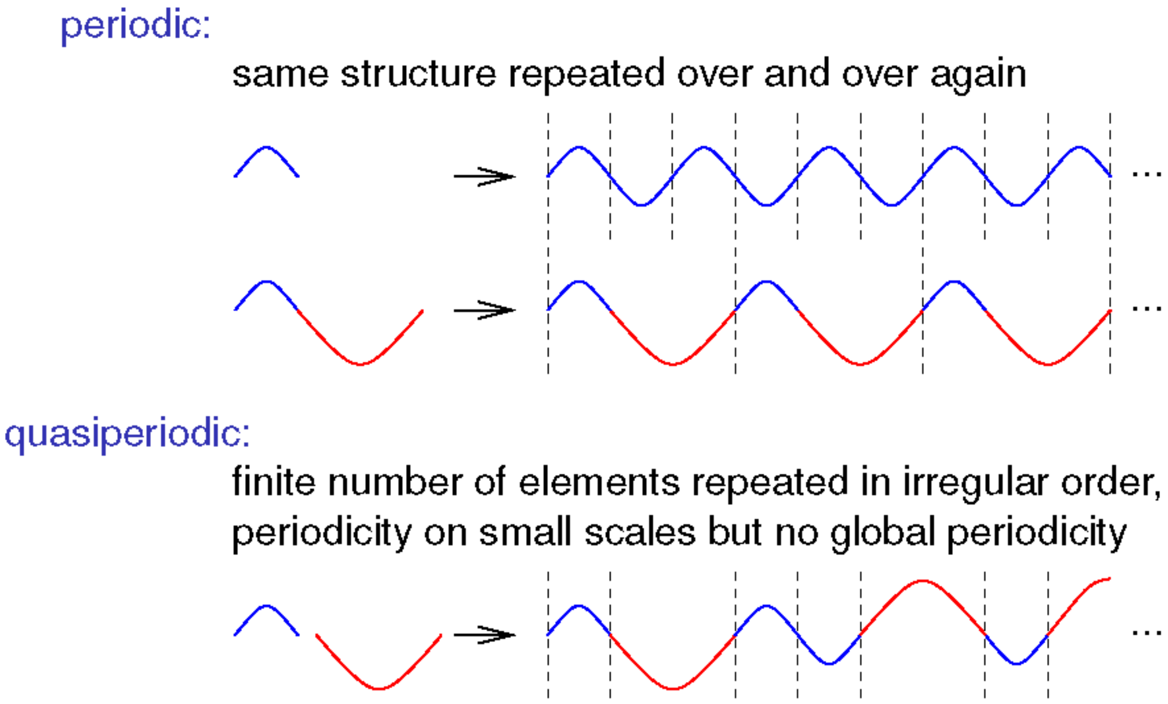
Suppression of Higher Undulator Harmonics

> Problem: usual X-ray monochromators also transmit the higher undulator harmonics very efficiently → degradation of signal/background

> Solutions: modify the undulator emission characteristics such that higher harm. are shifted to non-integer multiples

- "Quasi-periodic" undulator (S.Sasaki, 1995 ff.)



- Other means: mirrors (suppression >1e-6), monochromator detuning (suppr. 1e0…1e-2) energy dispersive detectors (suppr. 1e-1…1e-2)

Existing QPUs in the World

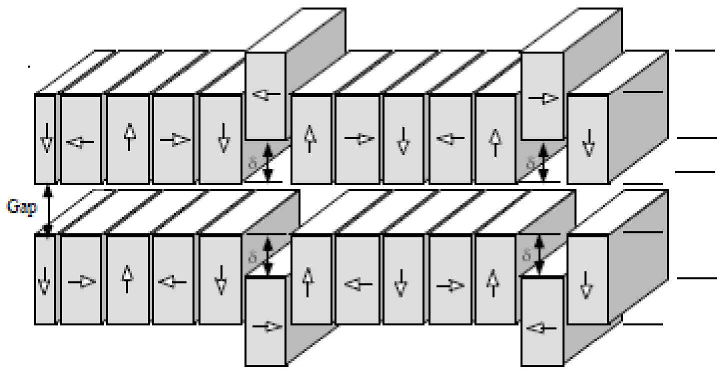


Figure 1: 3D view of the quasi-periodic undulator

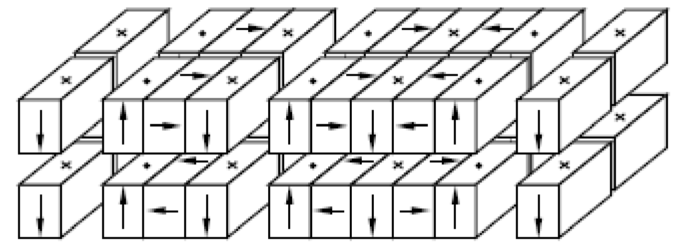


Figure 8: Schematic of the new variable polarization quasi-periodic undulator.

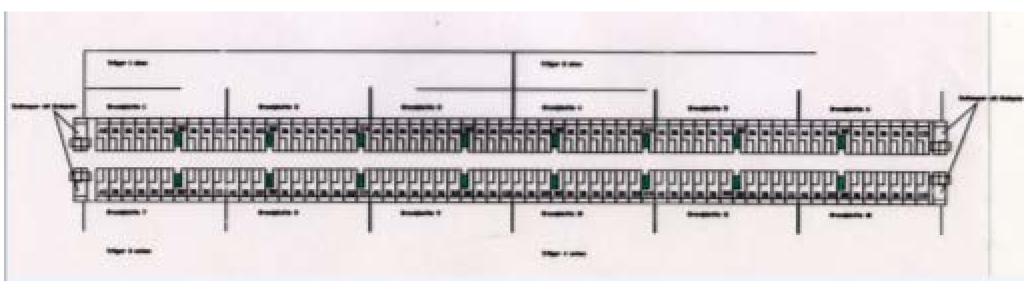


Figure 1: Side view of one UE212 section with the 4.55 m long single piece iron yoke/vertical pole structure and added horizontal poles. The inter coil connections for the two individual vertical power circuits are implemented on left or right side of each beam. The horizontal coils are attached all in series.

Courtesy of S.Sasaki

Quasi-Periodic Undulators

> Various QPU schemes have been implemented at several SR-facilities

- realized in permanent magnet or electromagnetic technology
- applied to planar and helical undulators

> Usual concept

- use the same mechanical design of the magnet structure as for the regular device
- apply a (reversible) quasi-periodic modification of the magnet structure
- alternative approach: also a periodical modification will cause a shift of the harmonics (J.Skupin, unpub.)

> Properties

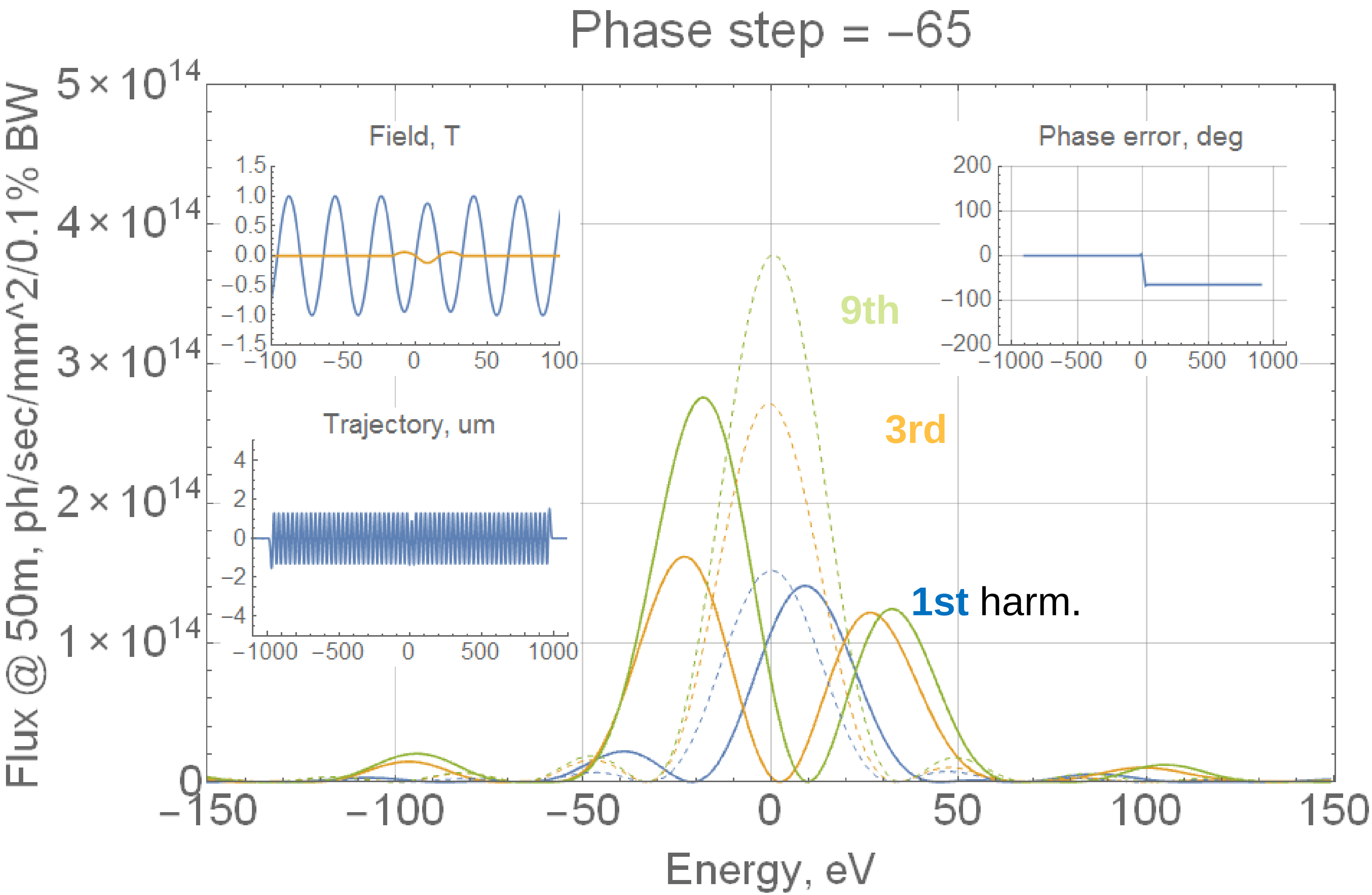
- higher harmonic suppression in the order of ~0.1…0.02
- flux reduction of the desired harmonics by up to ~30%
- suppression can usually only be optimized for one energy and pair of harmonics

> General idea: generate well-defined phase error by variation of the magnetic field

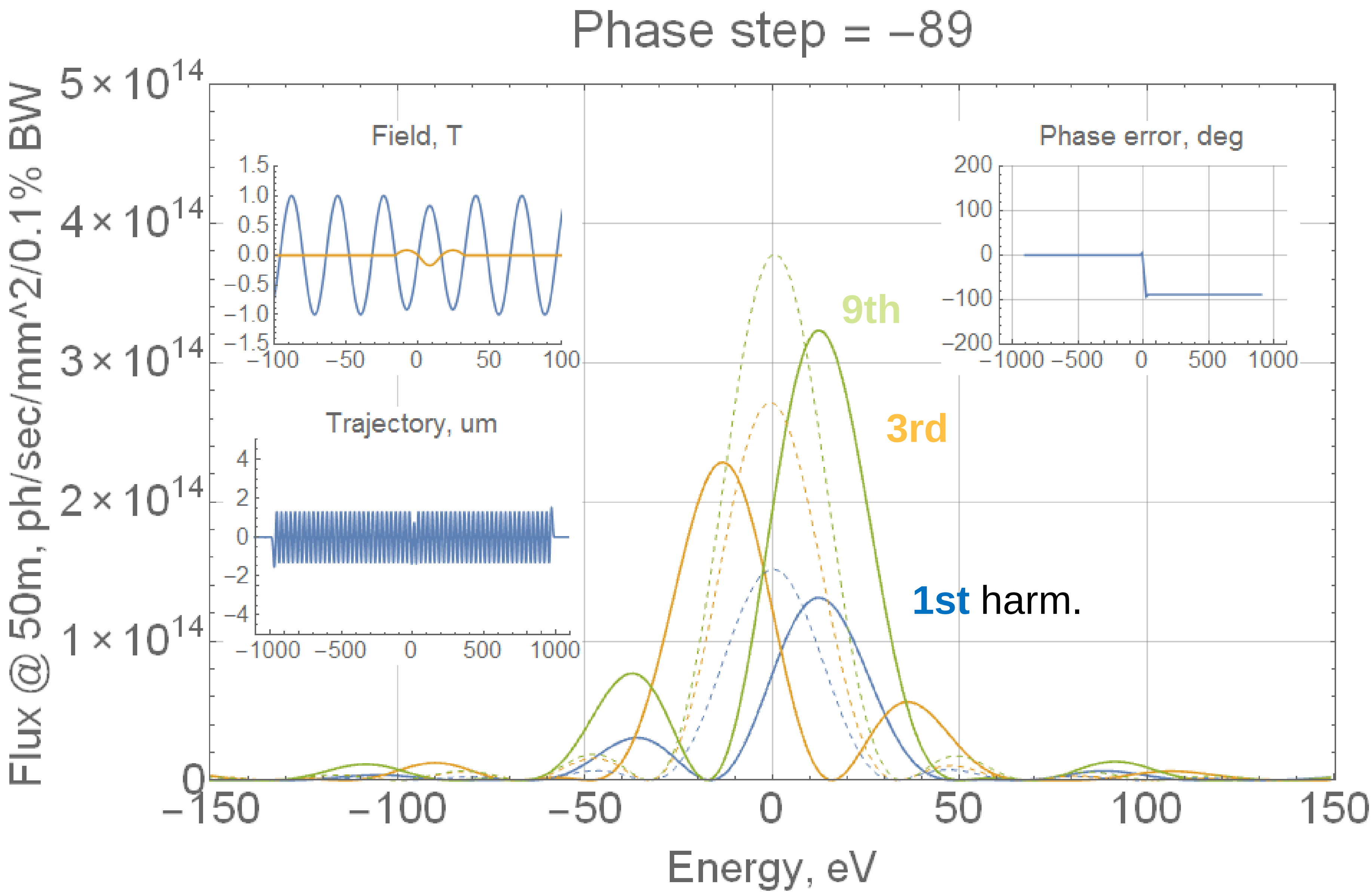
→ single phase step

Phase Shift Without Trajectory Offset

3rd/9th Harmonic Suppression when Operating at 1st

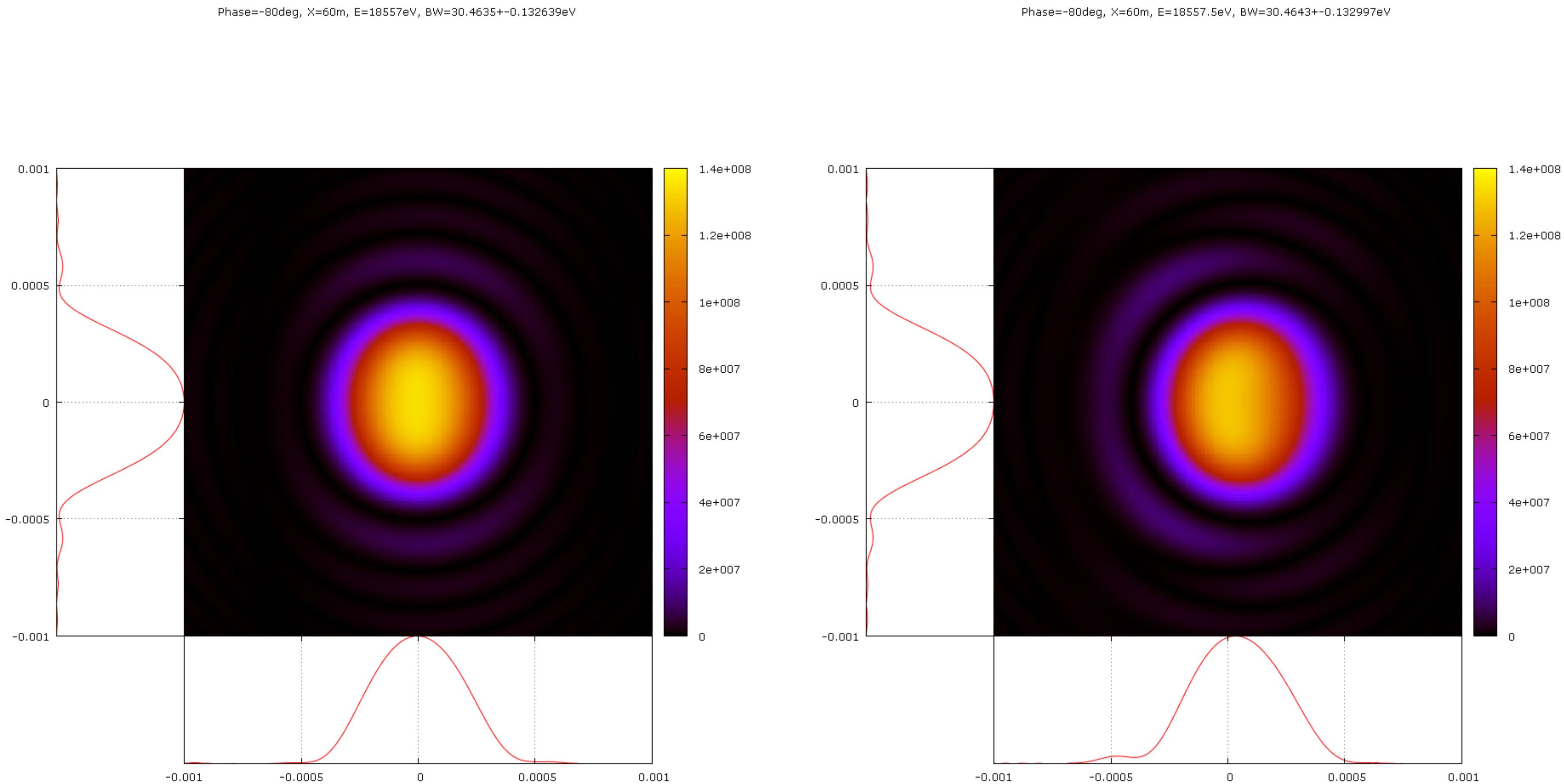


9th Harmonic Suppression when Operating at 3rd



Phase Shift by Trajectory Offset

Spatial Distribution

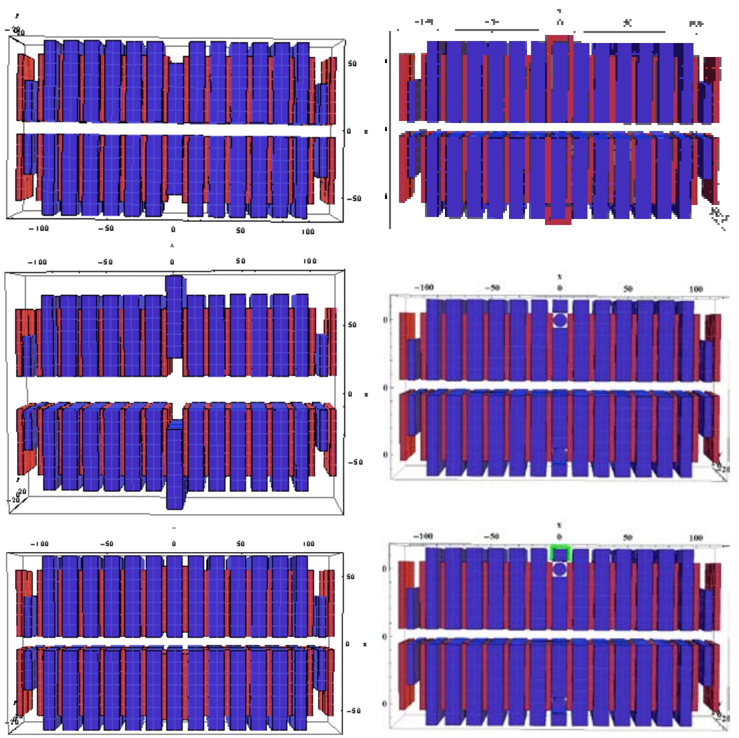


9th harmonic, 80 deg phase shift, with and without trajectory offset

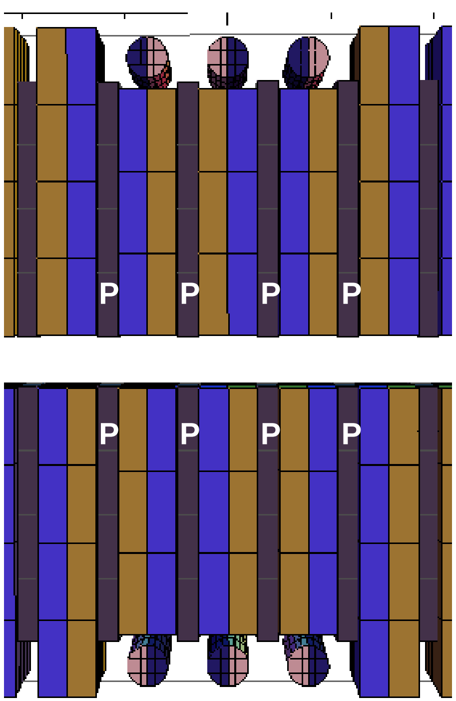
Local Phase Shifter Integrated in a Hybrid Structure

> Goal: Adjust the suppression dynamically and for any gap – or switch it off
- use an ordinary undulator structure
- implement a single phase shifter in the center of the magnet structure

> Various schemes were studied



> **Final concept**



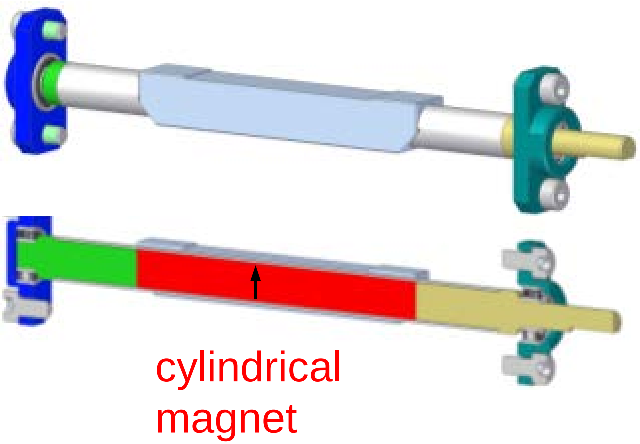
Rotating magnet

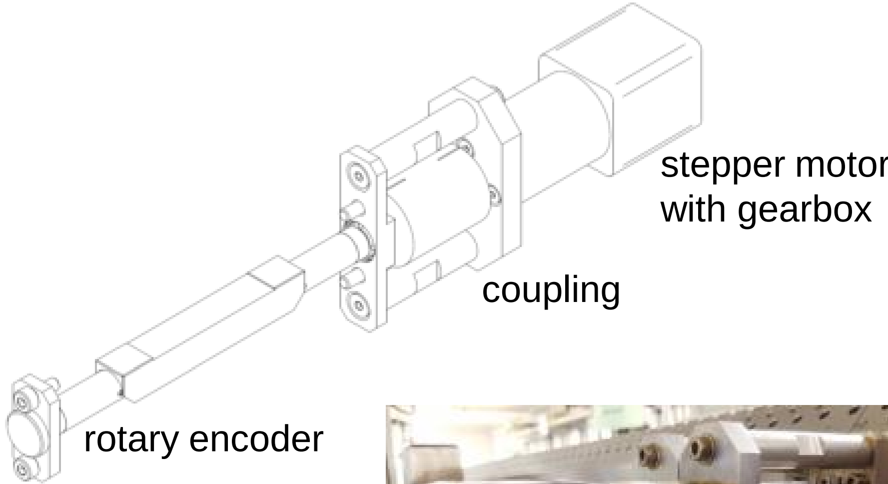
Shortened regular magnets

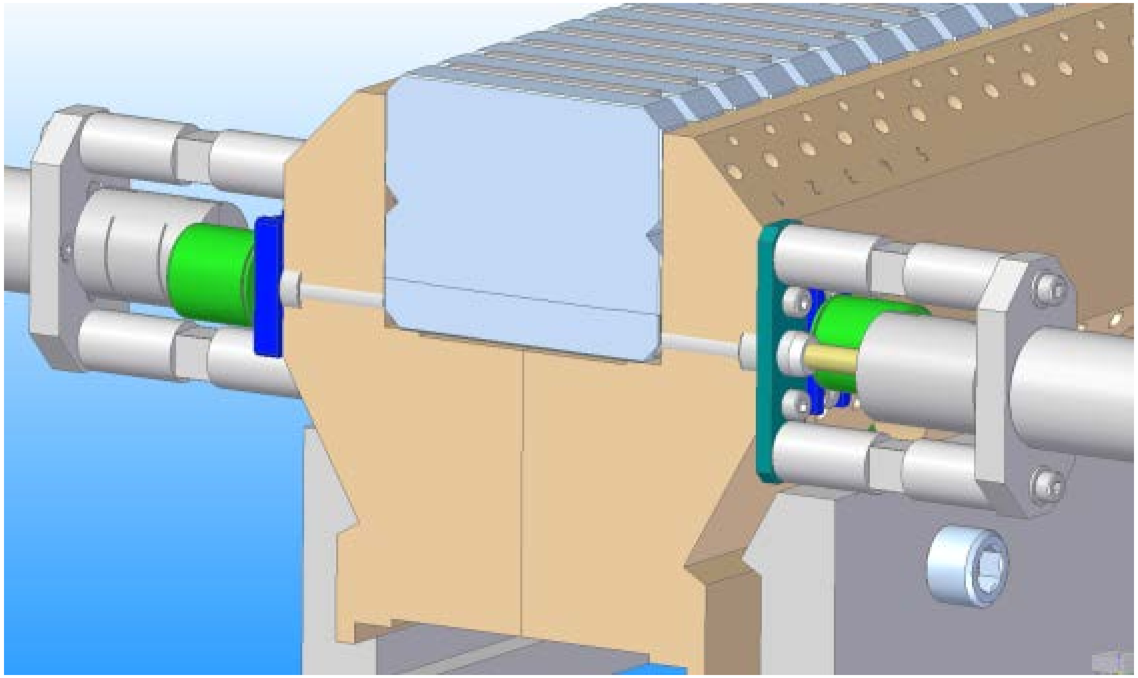
Retracted Poles

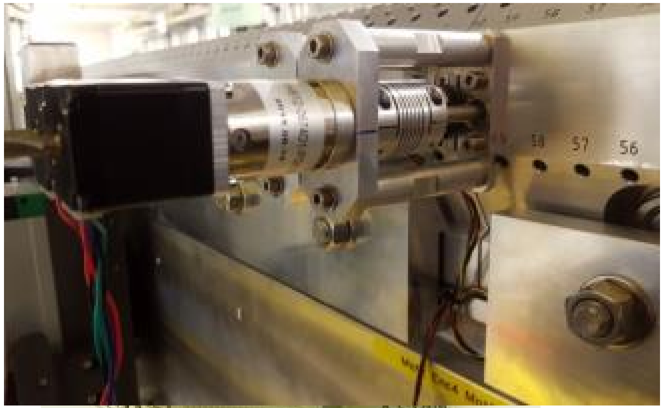
This principle is also applicable for Harmonic Lasing schemes at FELs!

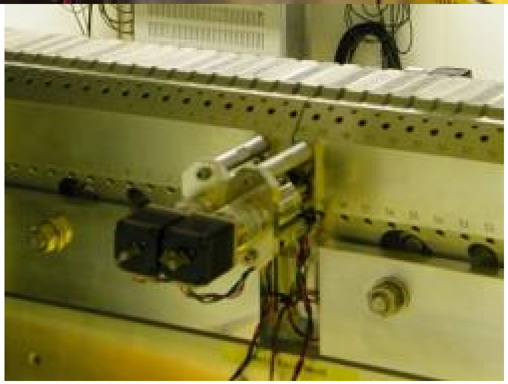
Mechanical Design of Local Phase Shifter





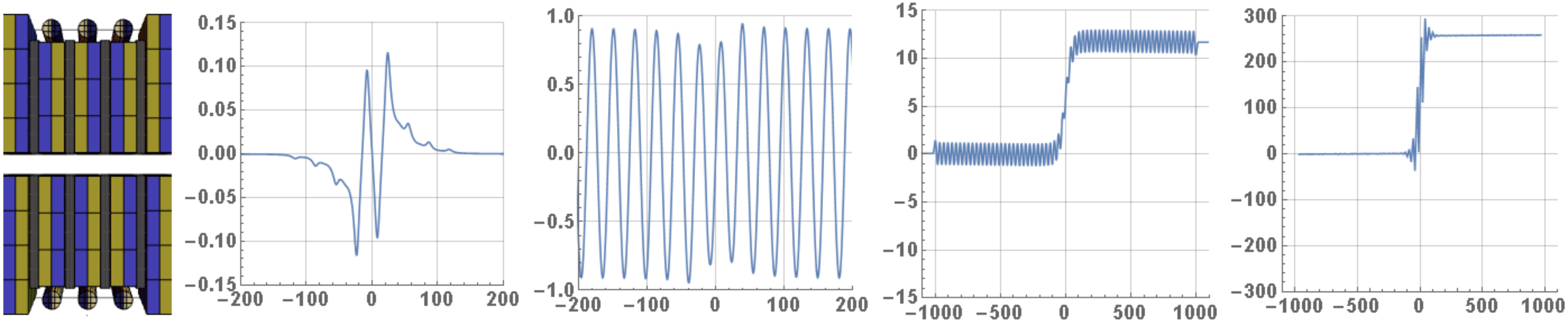




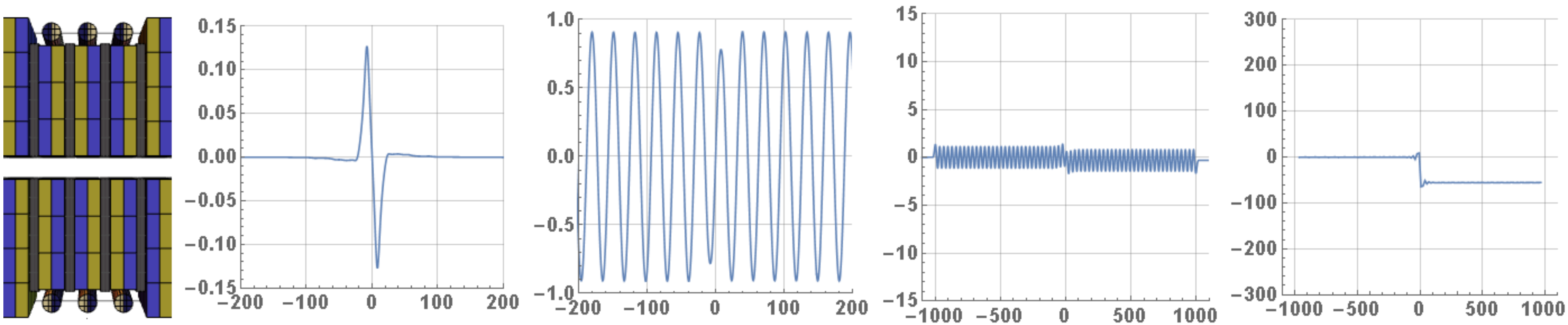


Different Operation Modes

Reversing outer magnets for positive phase shift by trajectory offset



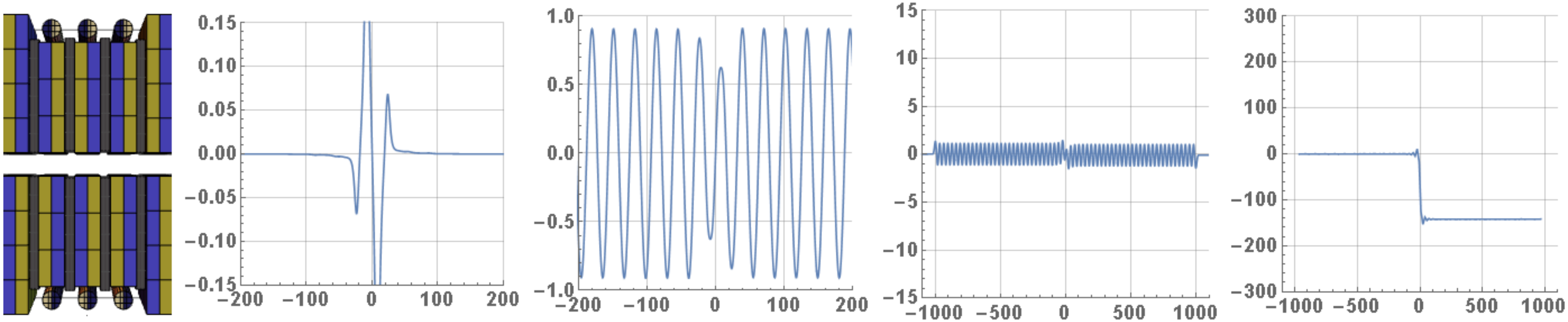
Reversing center magnets for zero trajectory offset and negative phase step



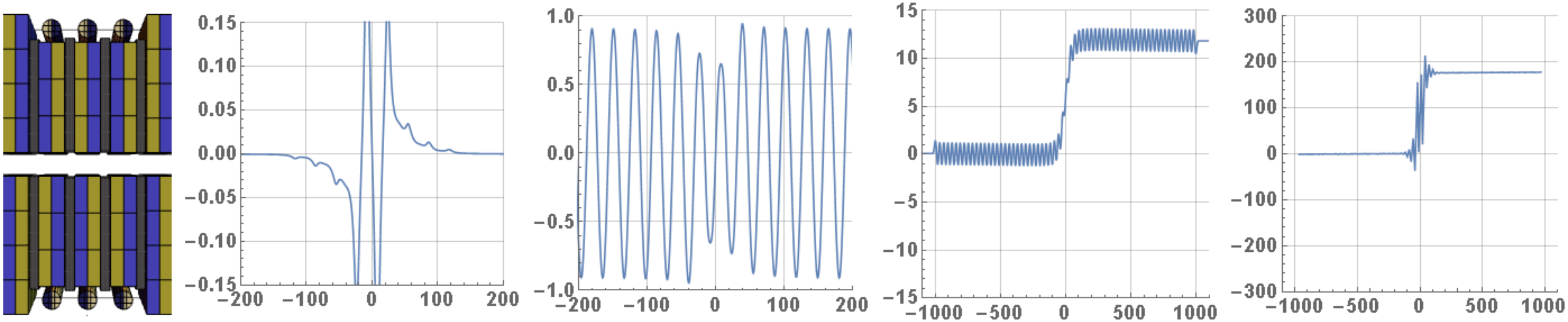
Field signature, T | Field, T | Trajectory, um | Phase, deg

Different Operation Modes

Retract poles for maximum negative phase step (decreased with gap opening)

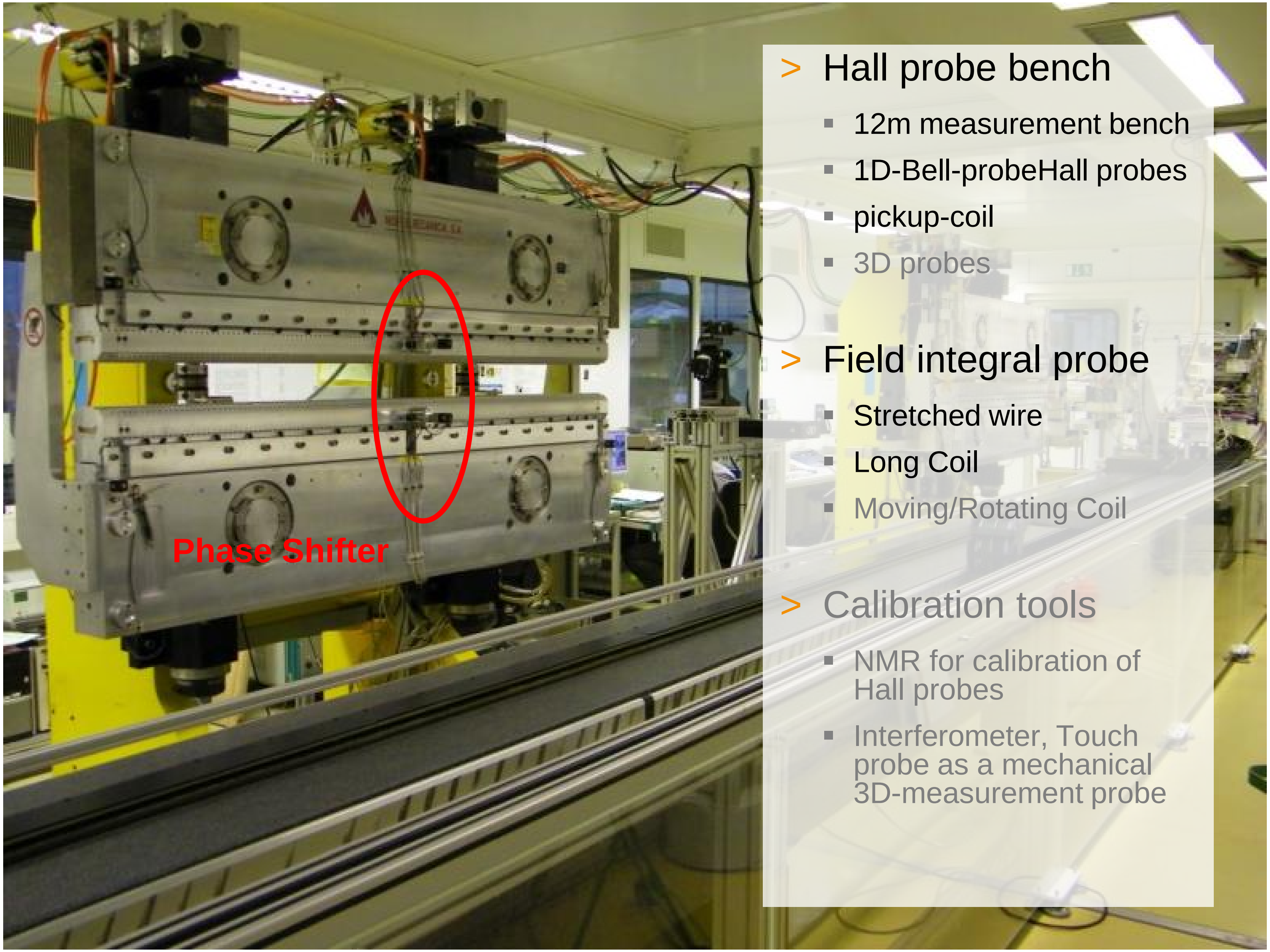


Positive phase step by trajectory offset is stronger even with retracted poles and allow for both positive and negative phase steps +-150deg



Field signature, T | Field, T | Trajectory, um | Phase, deg

Magnetic Measurement Methods

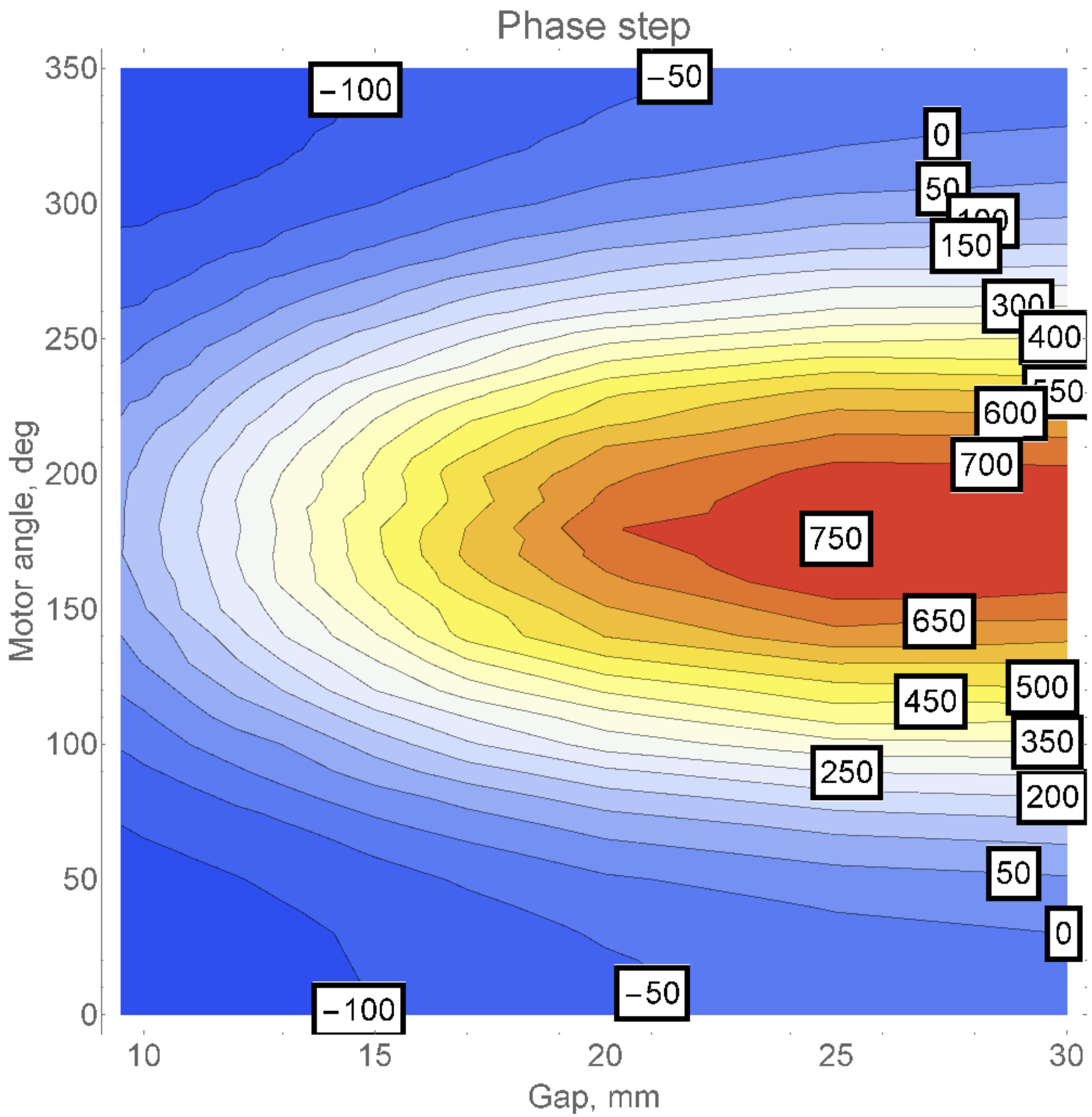


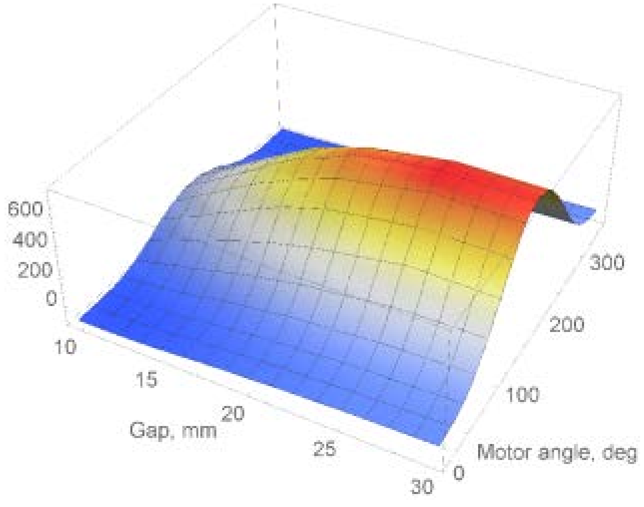
> Hall probe bench
- 12m measurement bench
- 1D-Bell-probeHall probes
- pickup-coil
- 3D probes

> Field integral probe
- Stretched wire
- Long Coil
- Moving/Rotating Coil

> Calibration tools
- NMR for calibration of Hall probes
- Interferometer, Touch probe as a mechanical 3D-measurement probe

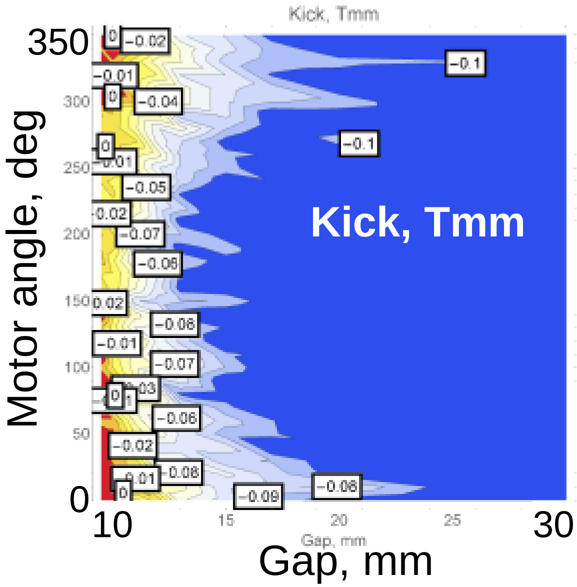
Phase Adjustment by Outer 4 Motors

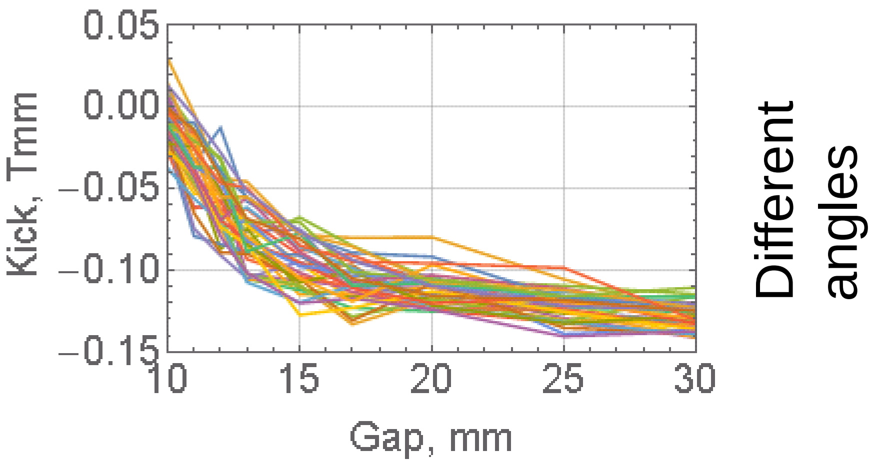


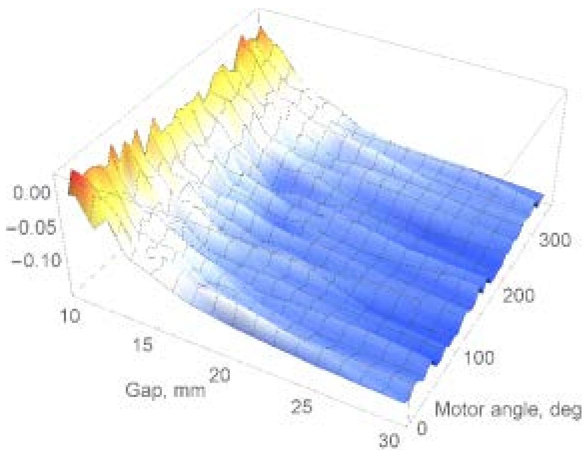


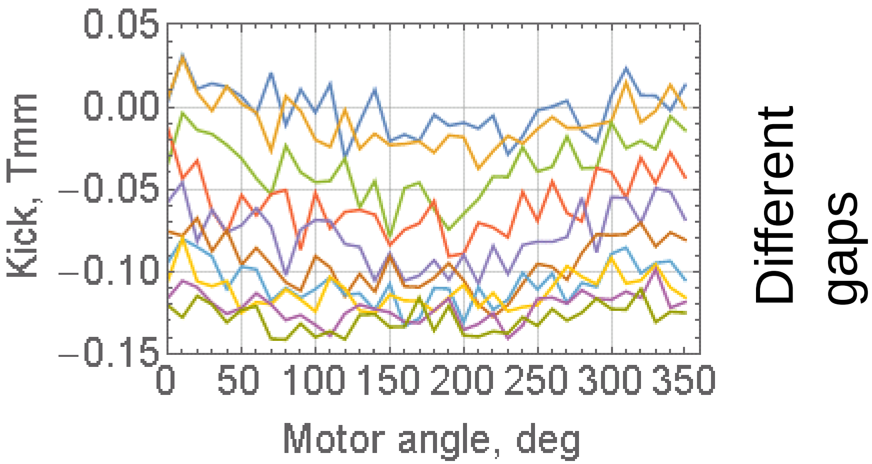
- Phase step is derived from Hall probe data for all rotation angles and gaps
- Rotation angles need to be adapted in order to preserve a constant phase when gap is changing

Phase Adjustment by Outer 4 Motors – Remaining Kick









> Kick is dependent only on gap, minor dependence on phase (<30Gs*cm)

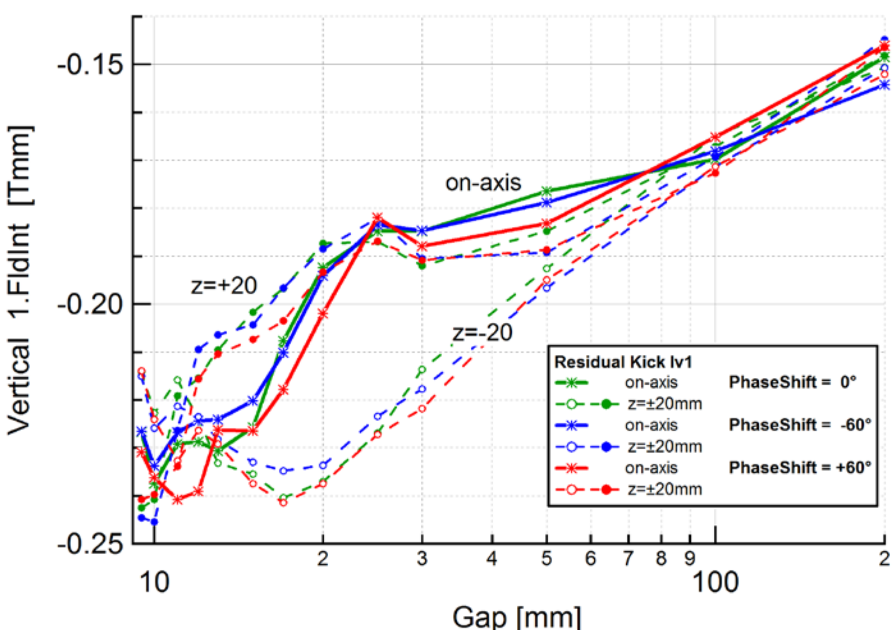
Integral Kick Errors

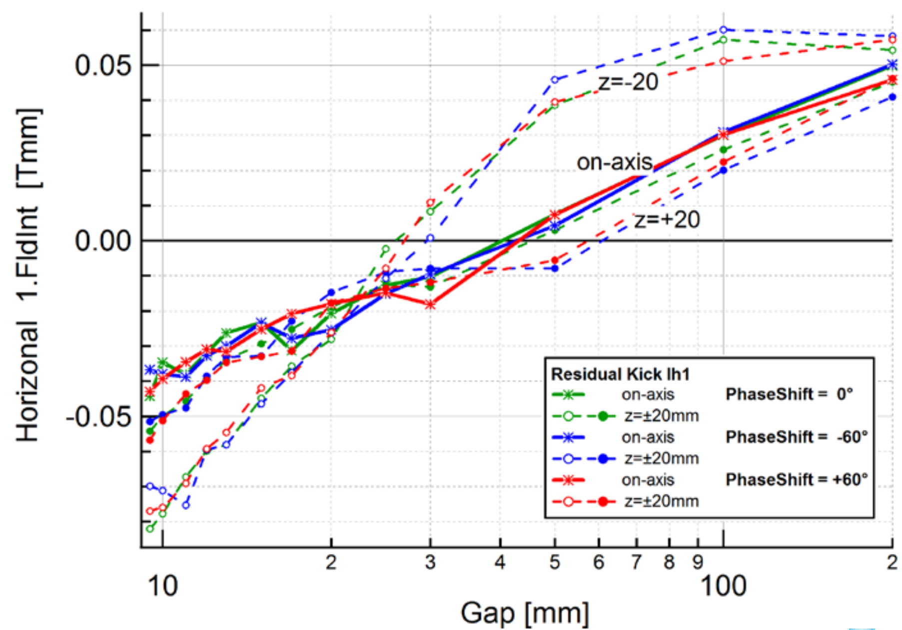
> Stretched wire measurements for different operation modes

- Feedforward on the magnet rotation angles
  adjusts the optical phase shift to a constant value (0°, or ±60°) for all undulator gaps

> Results:

- Remaining kick variations of ~100Gcm due to gap-dependent end-kick errors
- Agreement between different phase settings ~10Gcm → **no phase shift dependent kick errors**
- Negligible crosstalk into the vertical plane
- Same results for off-axis field integrals

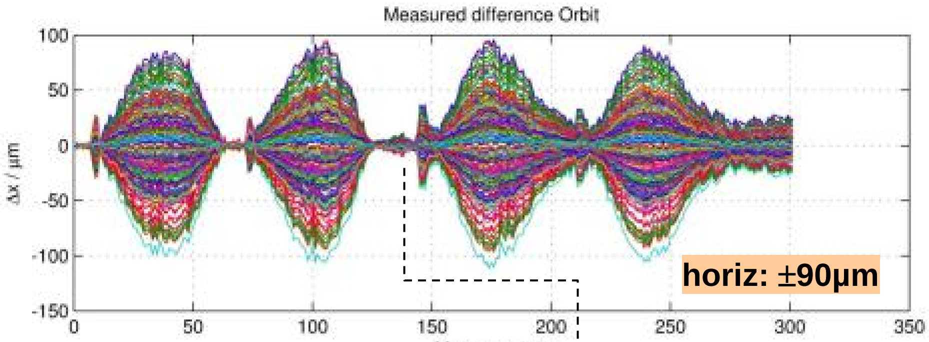




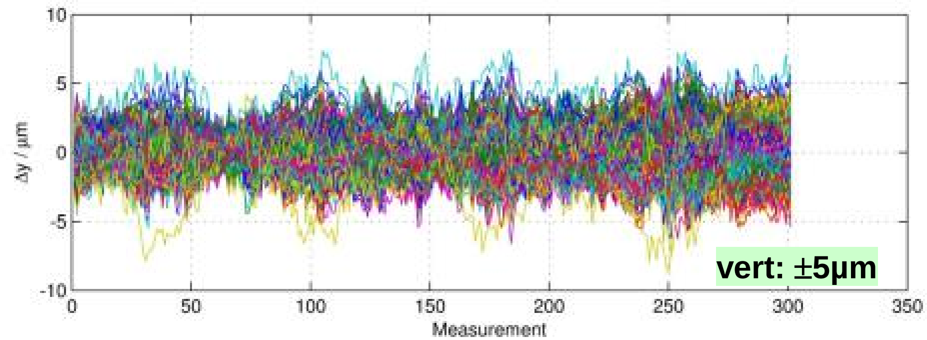
First Commissioning Results

- Completion and installation of undulator PU23 in January ’17,
- Initial test with e-beam in mid-May’17

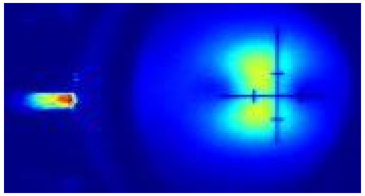
- Feedforward setting of phase shift motors as function of gap implemented in ID control system for various phase shift values
- ORM measurements for various settings of phase shift and gap in order to study Closed Orbit Distortions and to extract residual kick errors
- Results
  - **CODs are promising small!**
  - → refinement of feedforward kick correction ok!
  - no cross-talk to the vertical plane confirmed



PhaseShift rotation: 0 → 2Pi → 4Pi → 2Pi → 0



- Investigation of spectral and spatial properties will start in the “next days”… (photon beamline went online last week)



> Thanks!