Some Recent Developments for Undulators at PETRA

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

IMMW20 , 4-9 June, DIAMOND

Outline

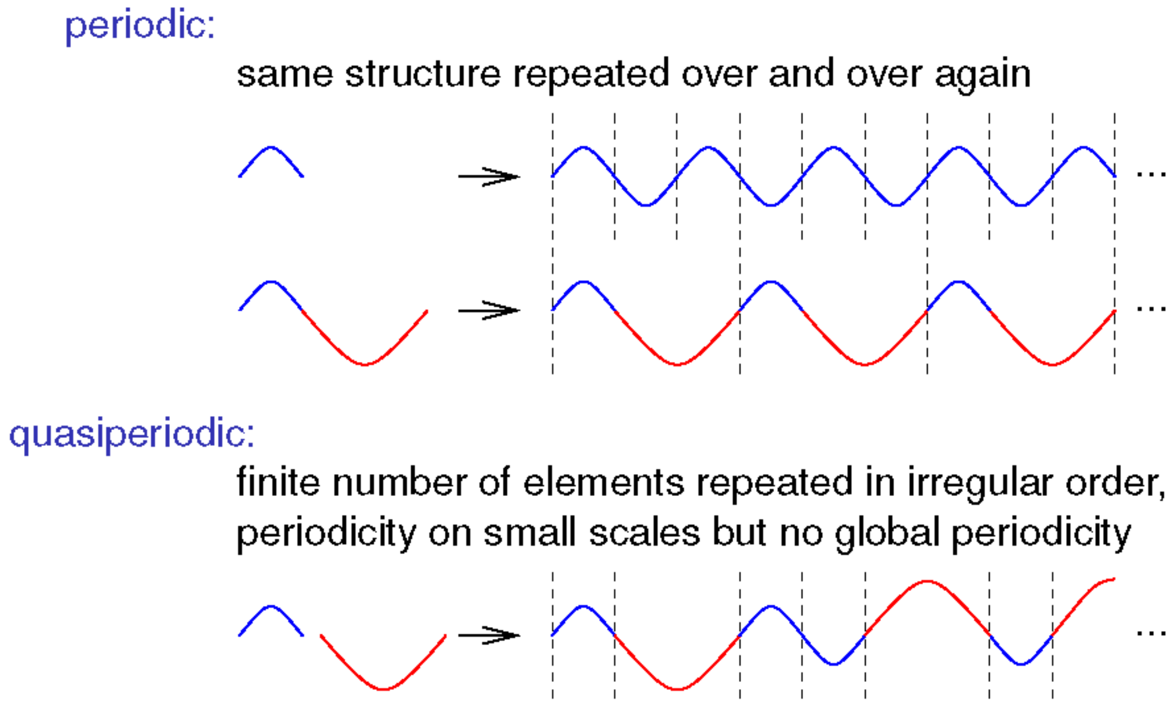
- Phase shifter integrated in an undulator hybrid structure
  - Motivation & Principle
  - Implementation
  - Magnetic response / Measurement results

- Magnetic shimming of *systematic* phase errors (caused by girder deformation)
  - Introduction
  - Shimming strategy
  - Magnetic results

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

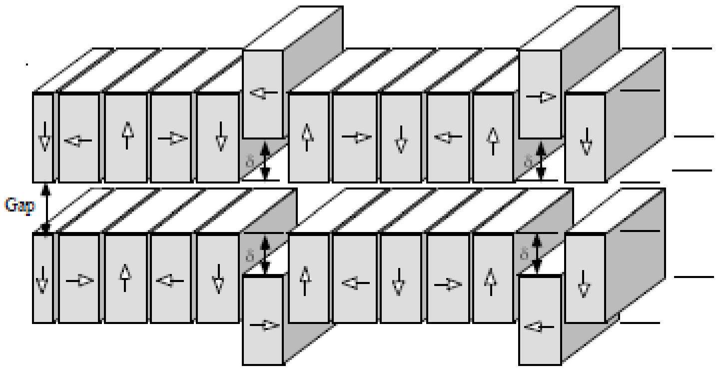


Figure 1: 3D view of the quasi-periodic undulator

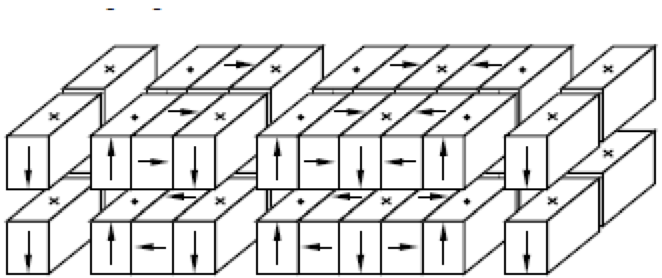


Figure 8: Schematic of the new variable polarization quasi-periodic undulator.

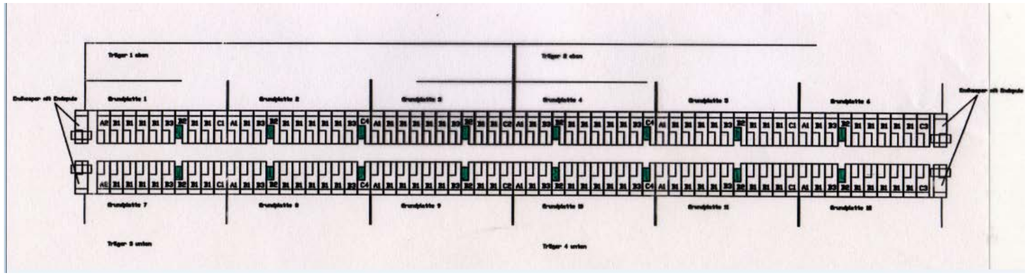


Figure 1: Side view of one UE212 section with the 4.55 m long single piece iron yoke/vertical pole structure and added horizontal poles. The inter coil connections for the two individual vertical power circuits are implemented on left or right side of each beam. The horizontal coils are attached all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

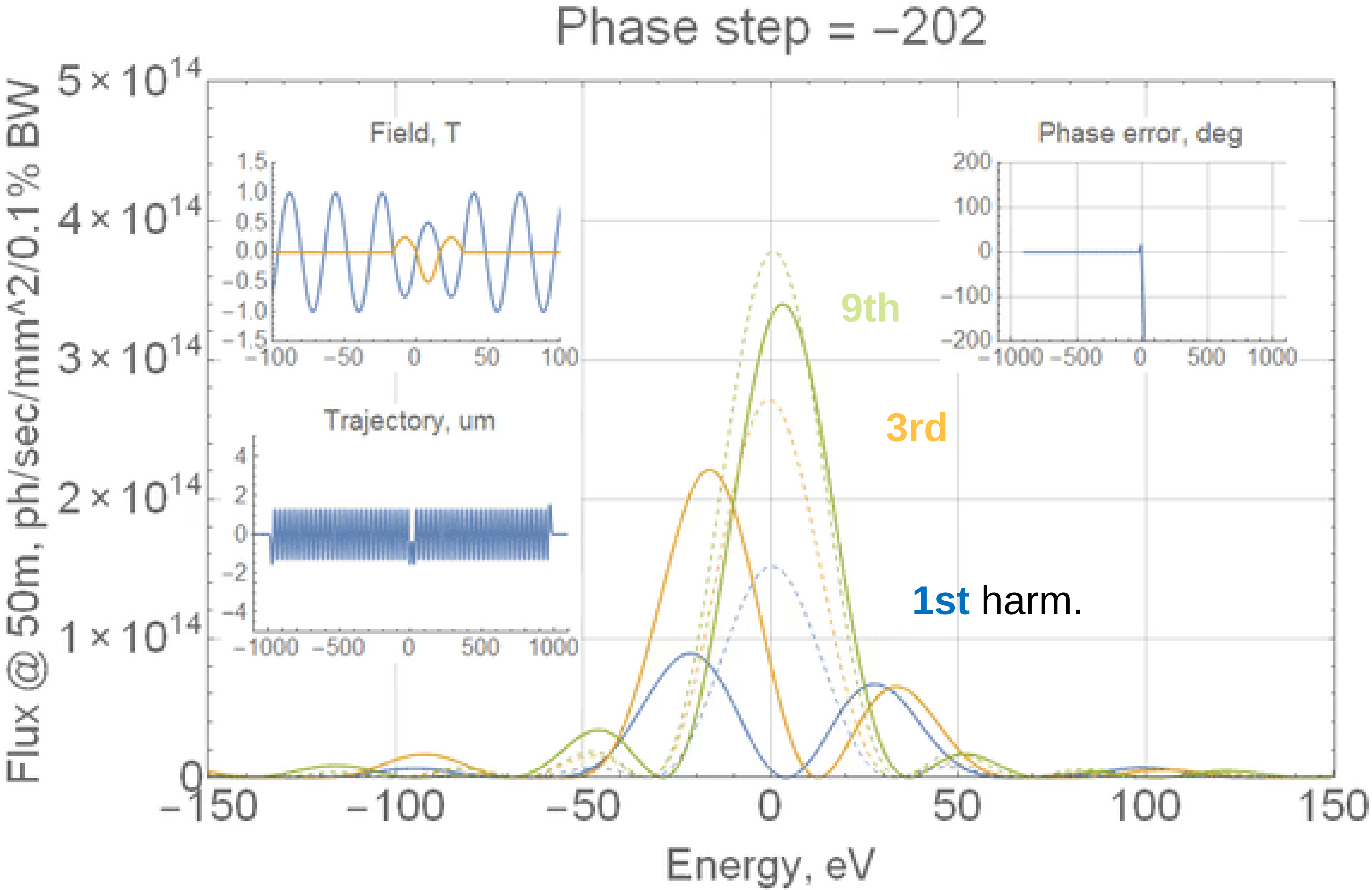
> Properties

- 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

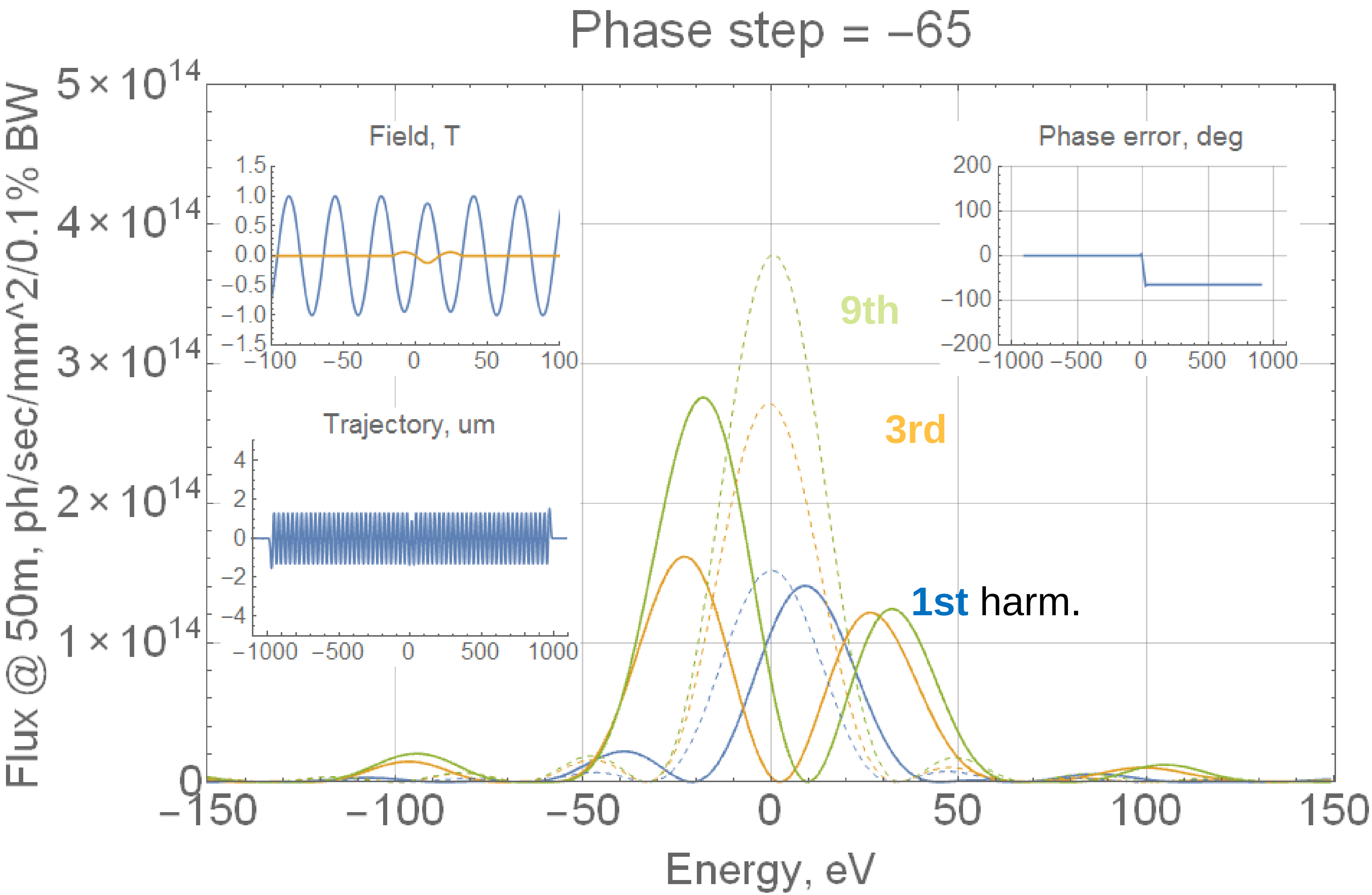
> General idea: generate well-defined phase error by variation of the magnetic field

→ single phase step

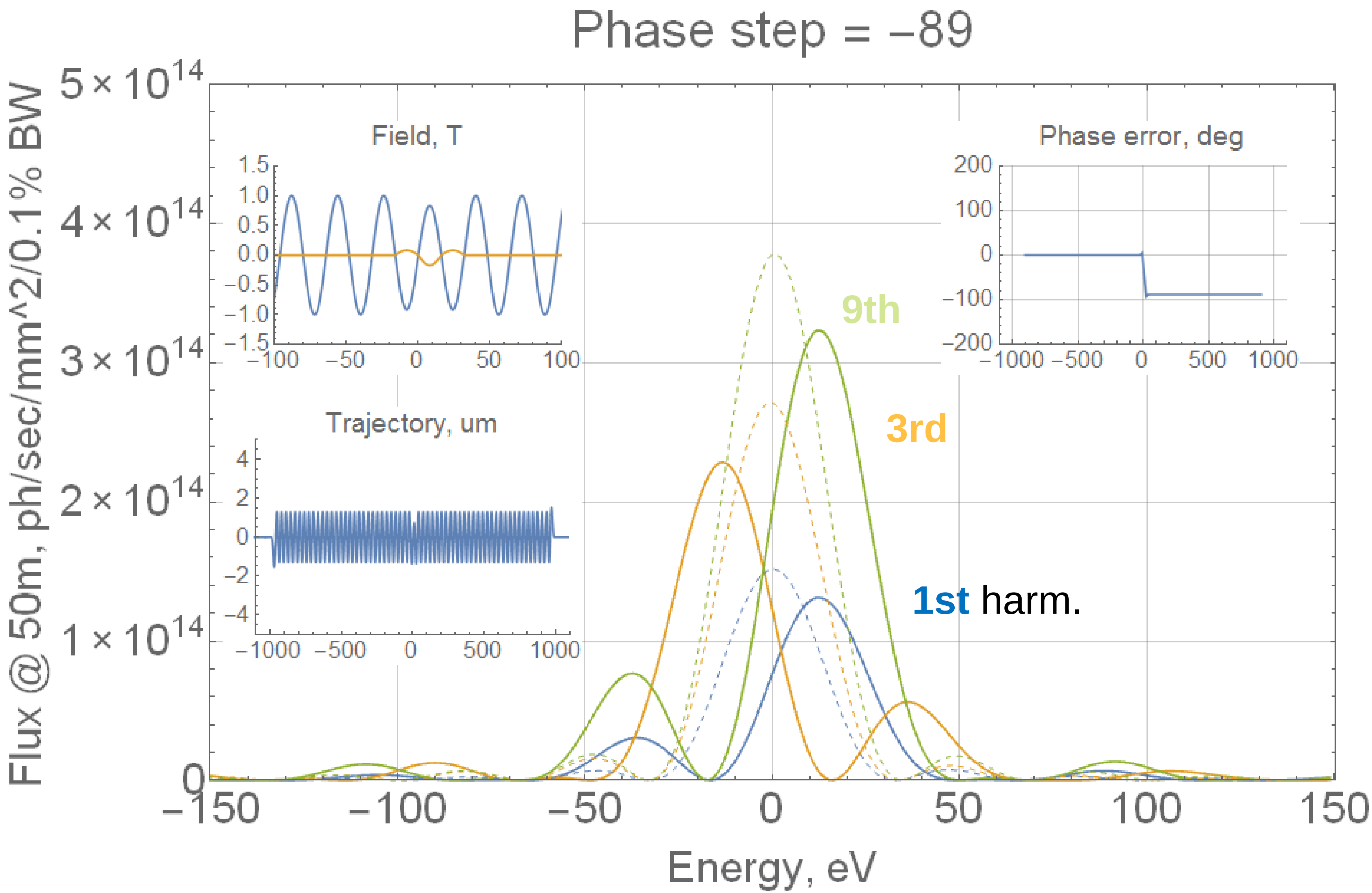
Phase Shift Without Trajectory Offset



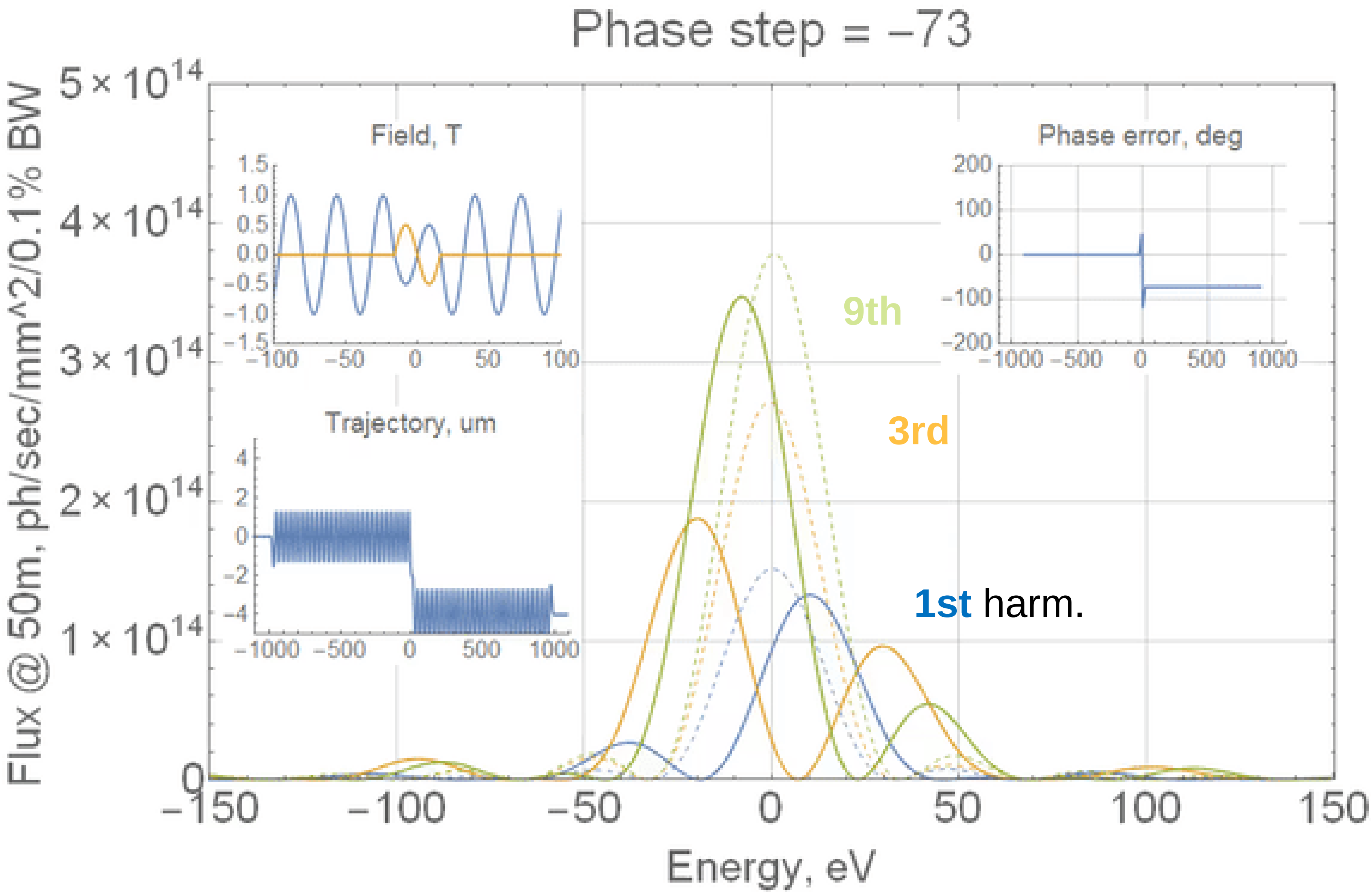
3rd/9th Harmonic Suppression when Operating at 1st



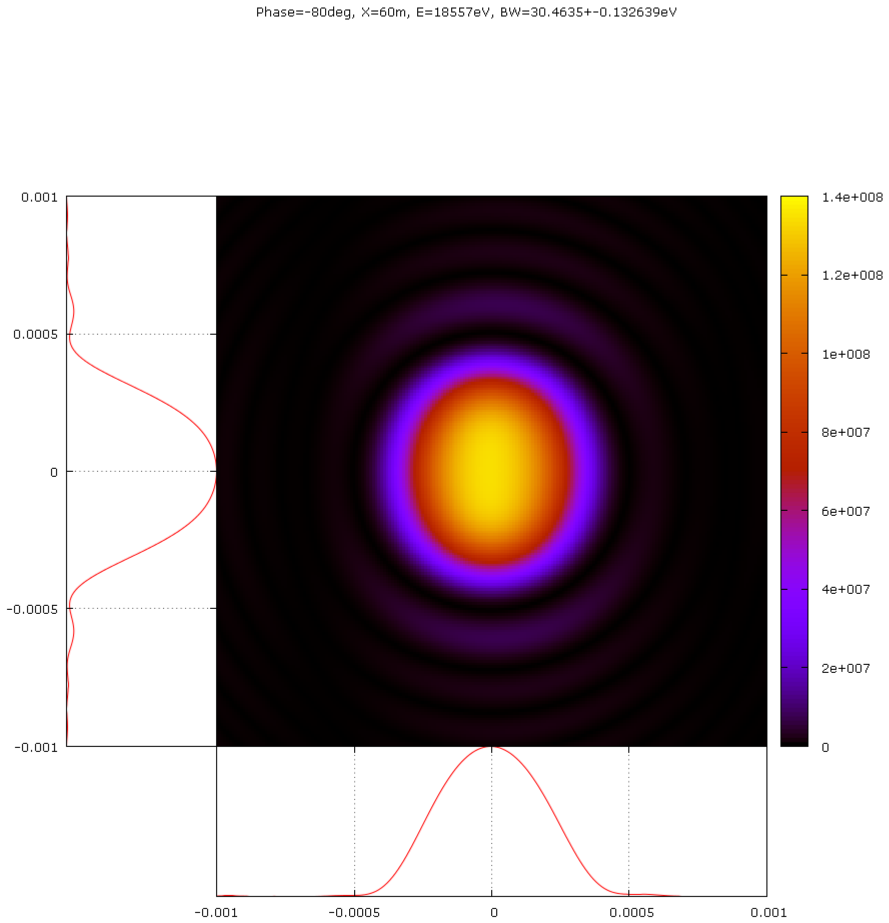
9th Harmonic Suppression when Operating at 3rd

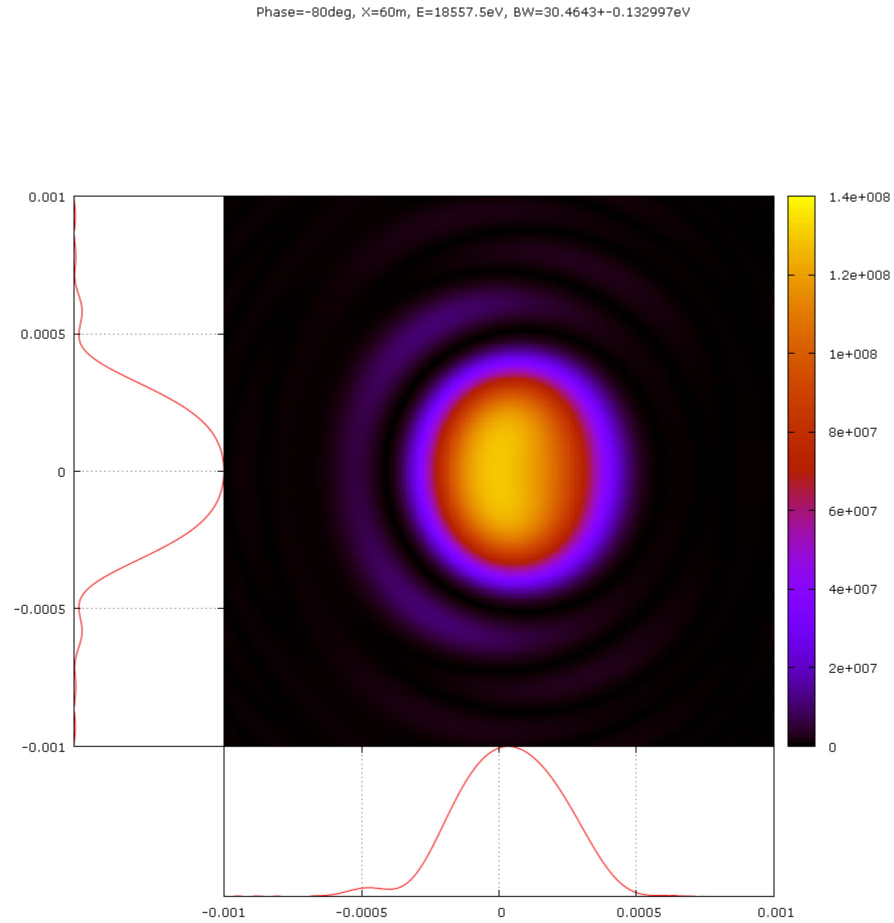


Phase Shift by Trajectory Offset



Spatial Distribution





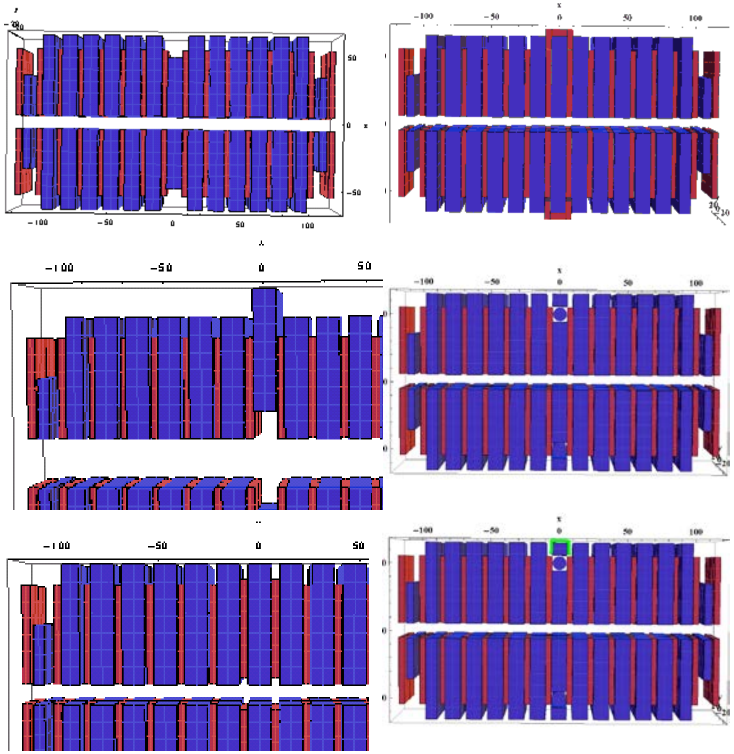
9th harmonic, 80 deg phase shift, with and without trajectory offset

Local Phase Shifter Integrated in a Hybrid Structure

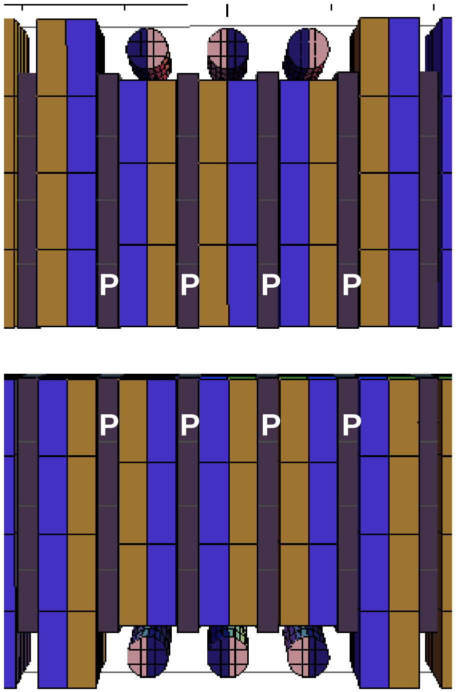
> Goal: Adjust the suppression dynamically and for any gap – or switch it off

- use an ordinary undulator structure
- implement a single phase shifter in the center of the magnet structure

> Various schemes were studied



> **Final concept**



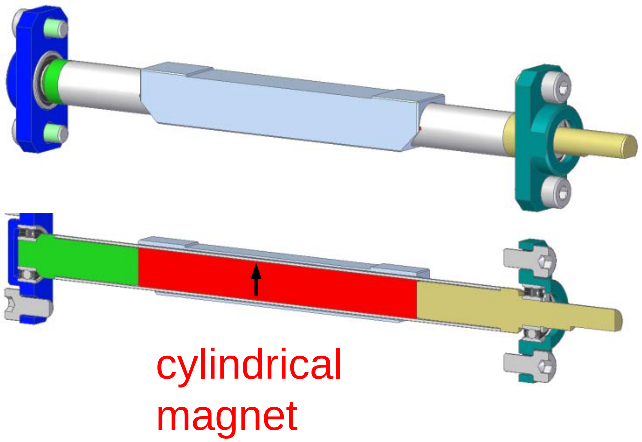
Rotating magnet

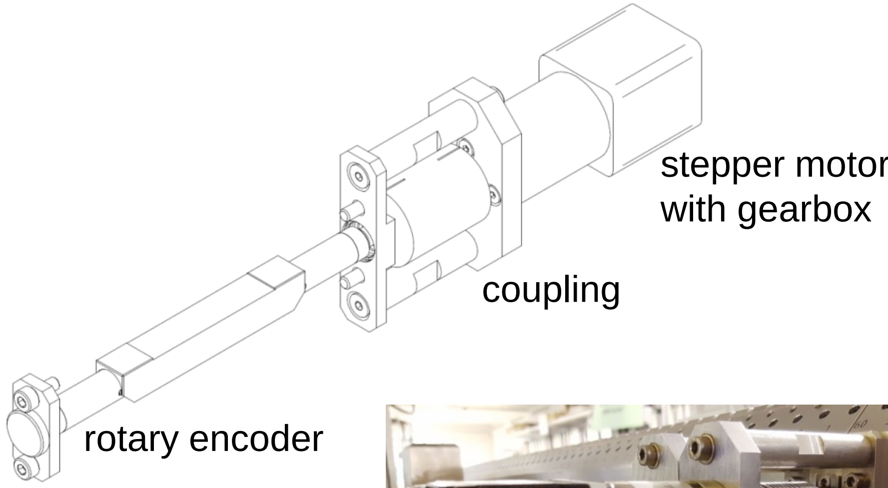
Shortened regular magnets

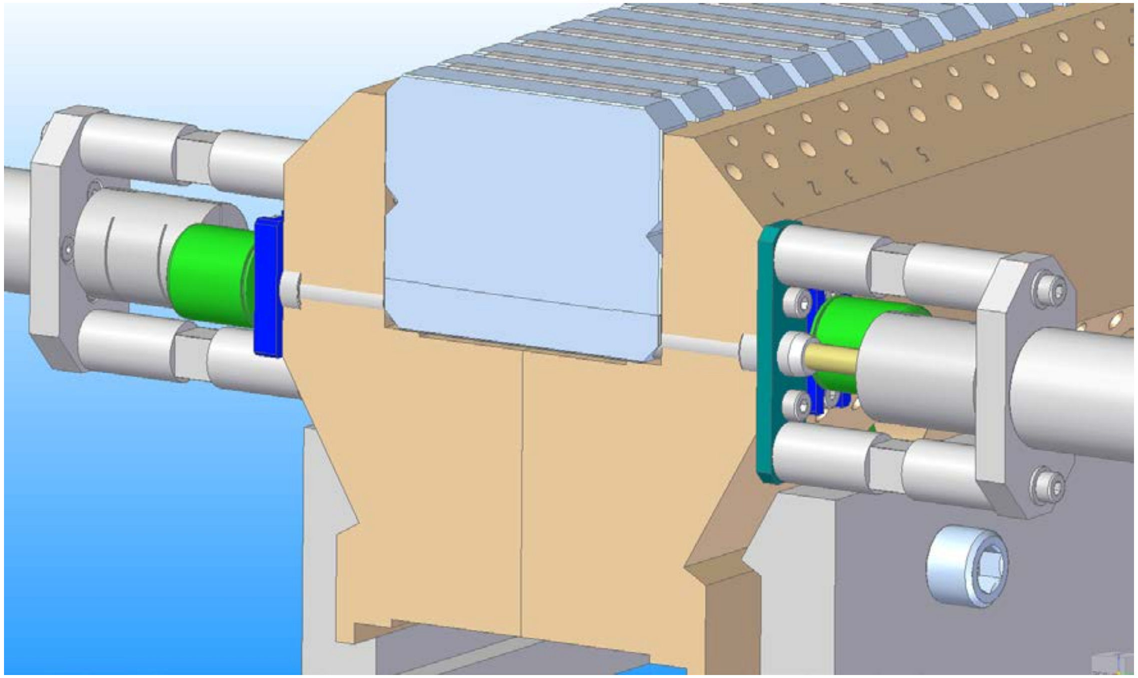
Retracted Poles

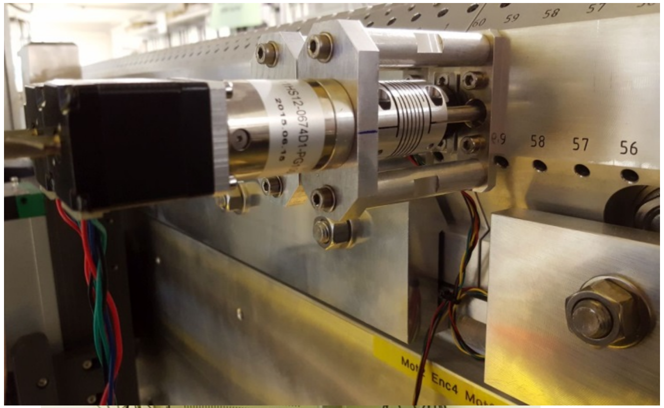
This principle is also applicable for Harmonic Lasing schemes at FELs!

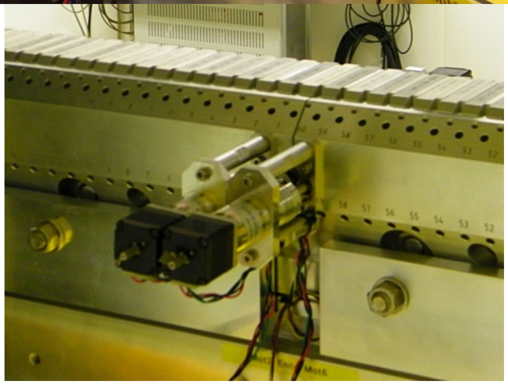
Mechanical Design of Local Phase Shifter





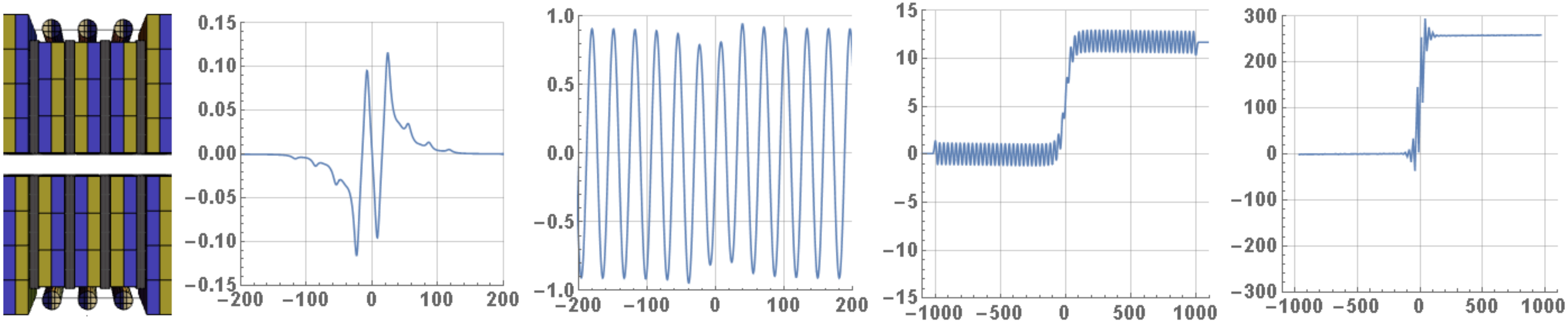




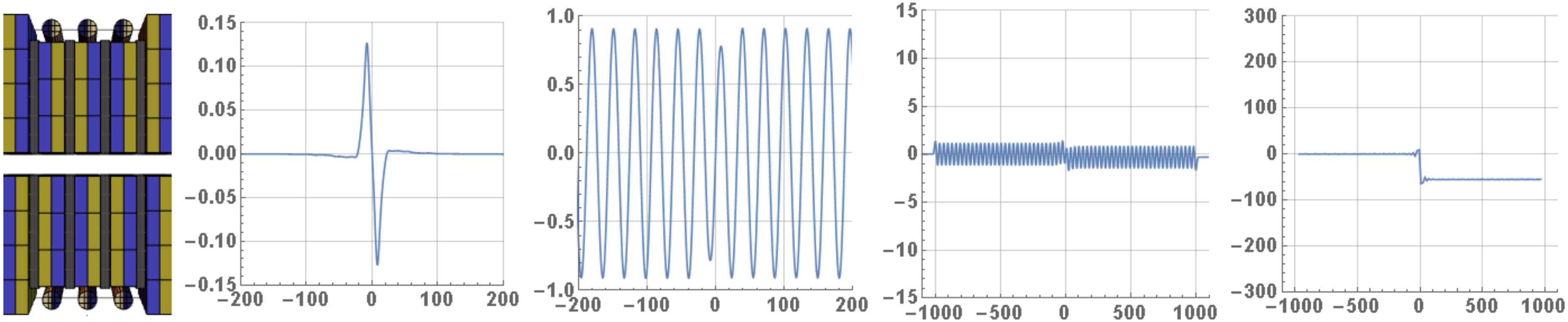


Different Operation Modes

Reversing outer magnets for positive phase shift by trajectory offset



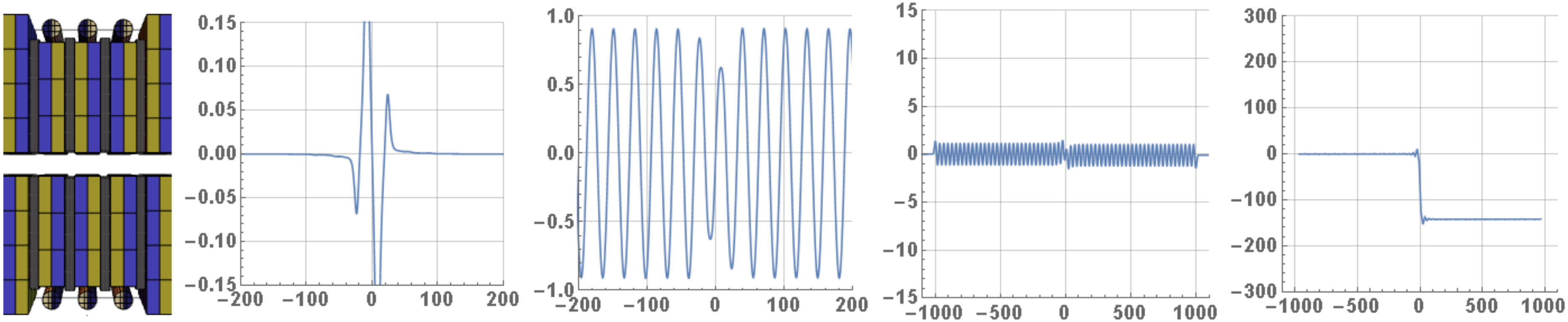
Reversing center magnets for zero trajectory offset and negative phase step



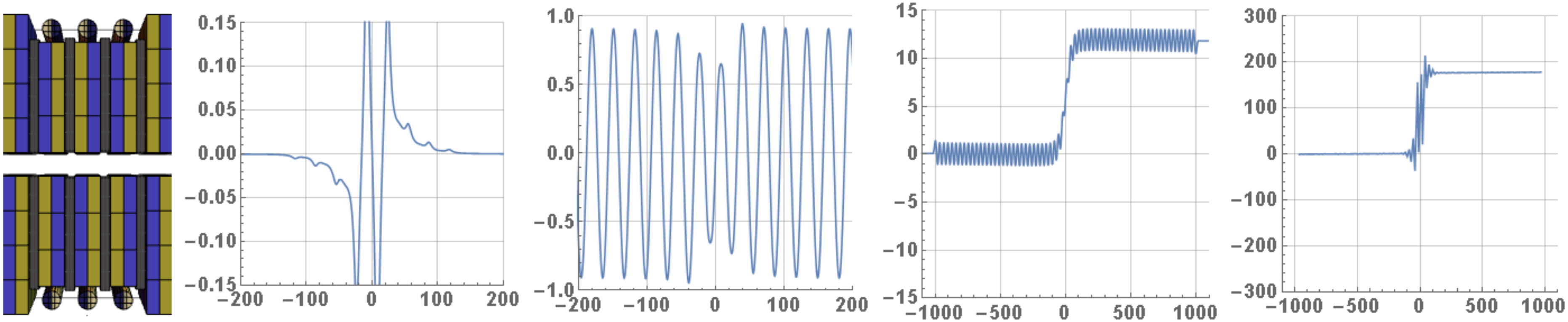
Field signature, T | Field, T | Trajectory, um | Phase, deg

Different Operation Modes

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

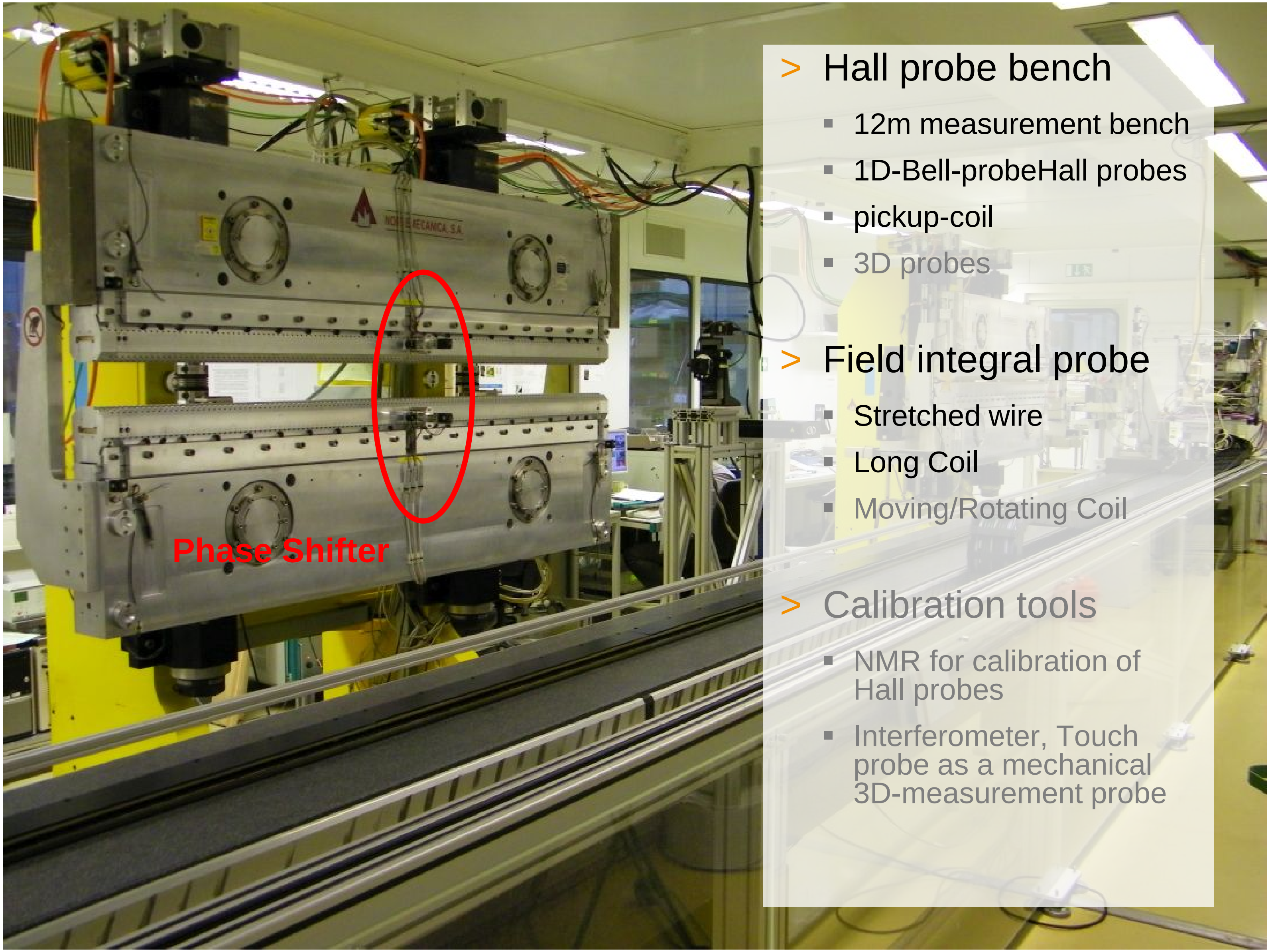


Positive phase step by trajectory offset is stronger even with retracted poles and allow for both positive and negative phase steps +-150deg



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

Magnetic Measurement Methods

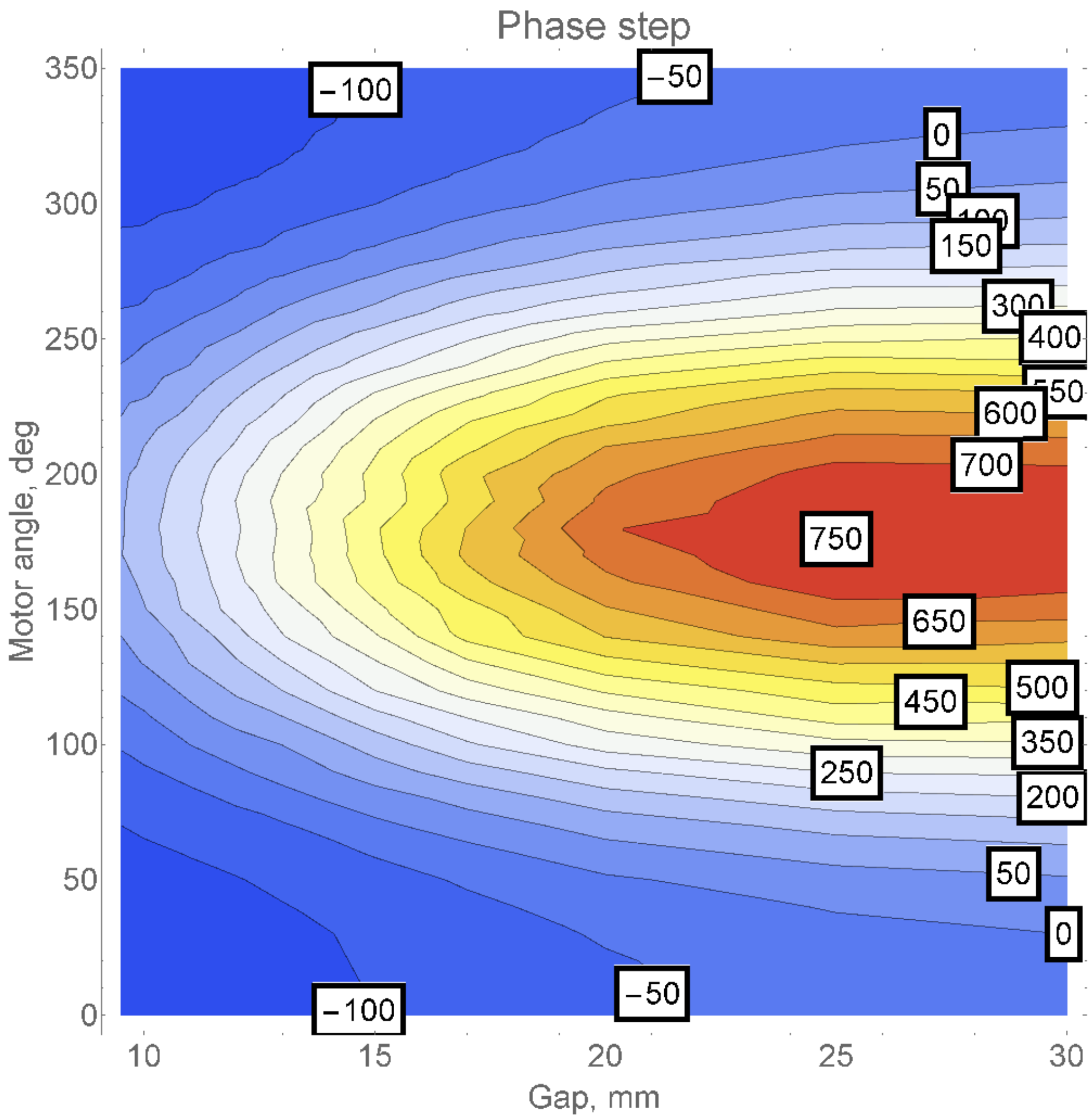


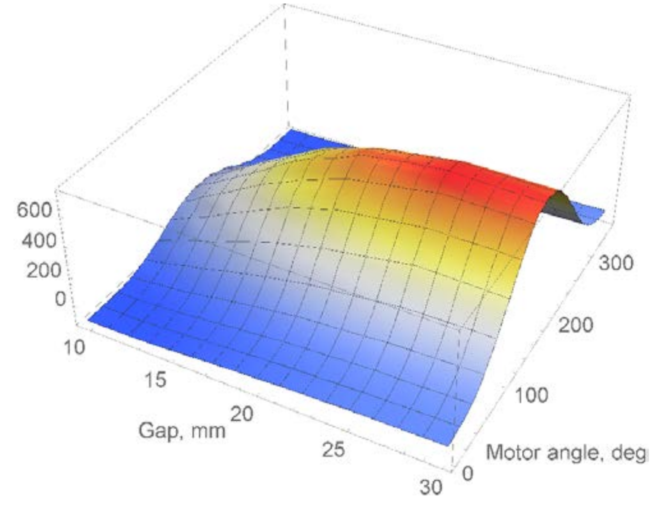
> Hall probe bench
- 12m measurement bench
- 1D-Bell-probeHall probes
- pickup-coil
- 3D probes

> 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

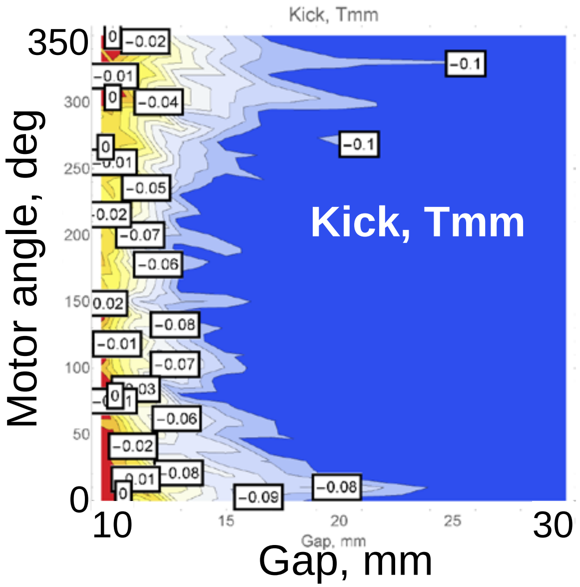
Phase Adjustment by Outer 4 Motors

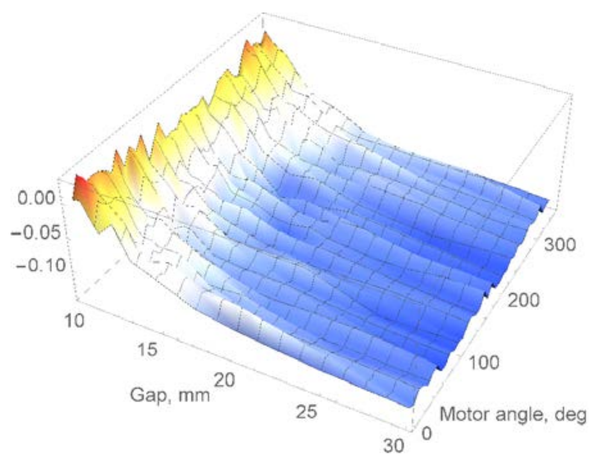


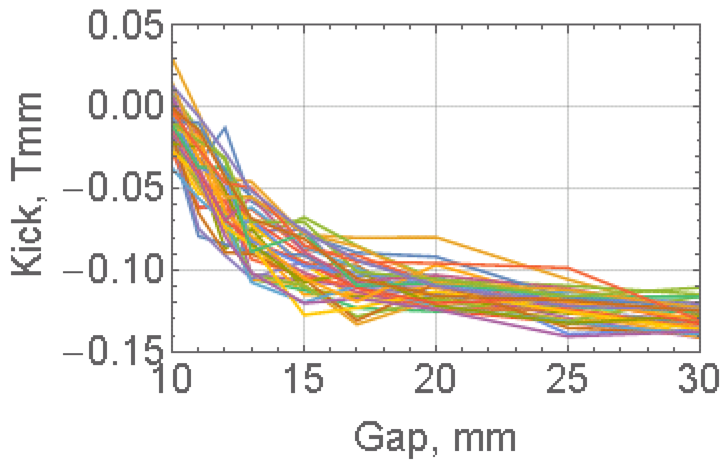


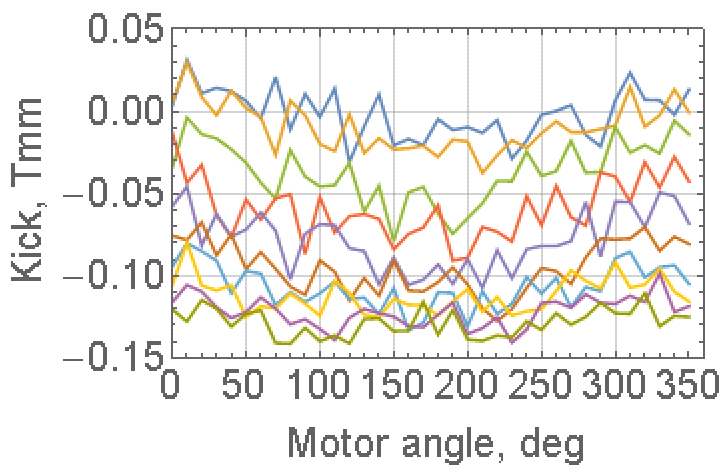
- Phase step is derived from Hall probe data for all rotation angles and gaps
- Rotation angles need to be adapted in order to preserve a constant phase when gap is changing

Phase Adjustment by Outer 4 Motors – Remaining Kick









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

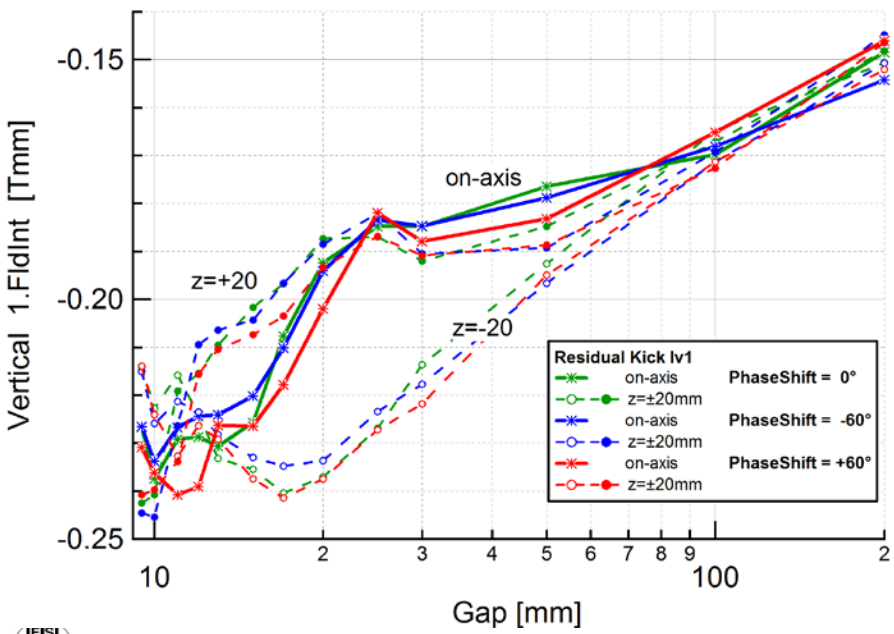
Integral Kick Errors

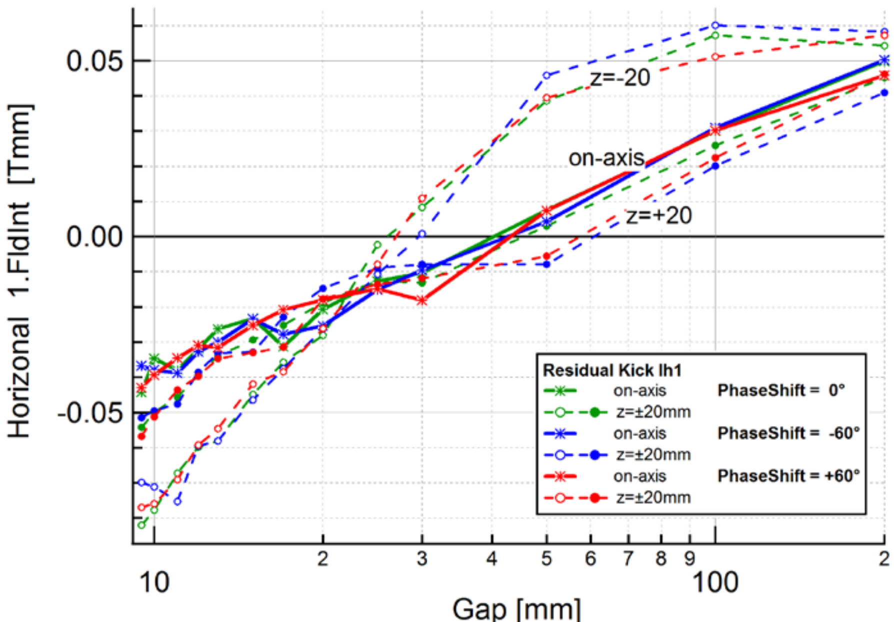
> Stretched wire measurements for different operation modes

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

> Results:

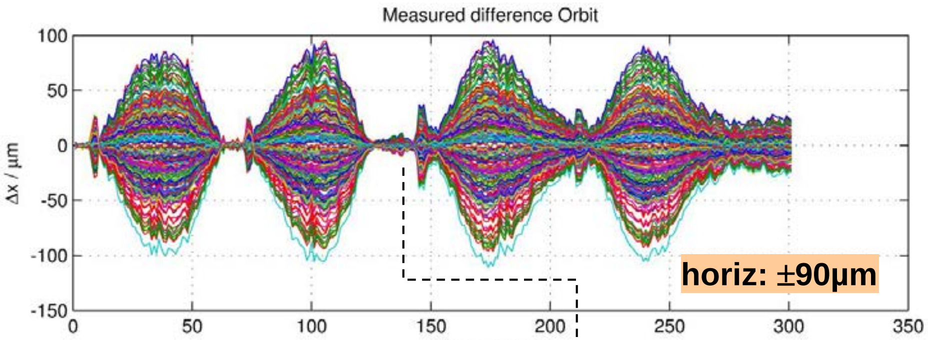
- Remaining kick variations of ~100Gcm due to gap-dependent end-kick errors
- Agreement between different phase settings ~10Gcm → **no phase shift dependent kick errors**
- Negligible crosstalk into the vertical plane
- Same results for off-axis field integrals



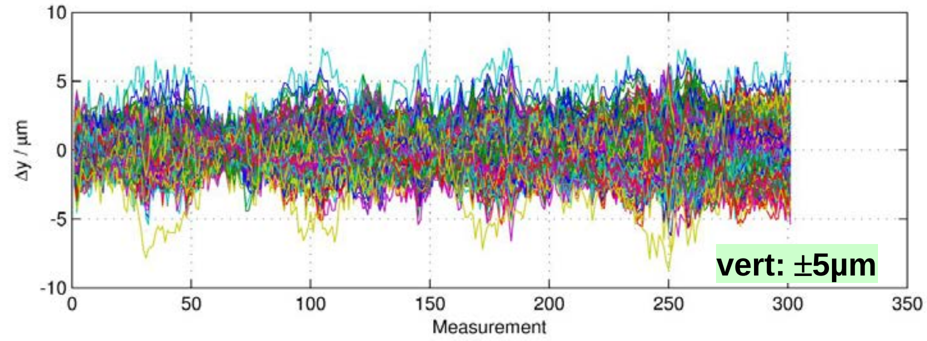


First Commissioning Results

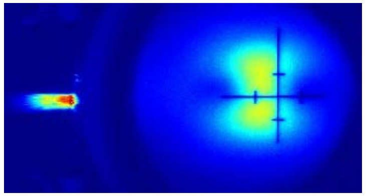
- Completion and installation of undulator in January ’17, but frontend operable only since very recent
- Initial test with beam 2 weeks ago
- Feedforward setting of phase shift motors as function of gap implemented in ID control system for various phase shift values
- ORM measurements for various settings of phase shift and gap in order to study Closed Orbit Distortions and to extract residual kick errors
- Data analysis still ongoing…
  - **CODs are promising small!**
  - → refinement of feedforward kick correction
  - no cross-talk to the vertical plane confirmed



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



- Investigation of spectral and spatial properties will start in fall 2017 after completion of the photon beamline



Outline

> Phase shifter integrated in an undulator hybrid structure

- Motivation & Principle
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> Magnetic shimming of *systematic* phase errors (caused by girder deformation)

- Introduction
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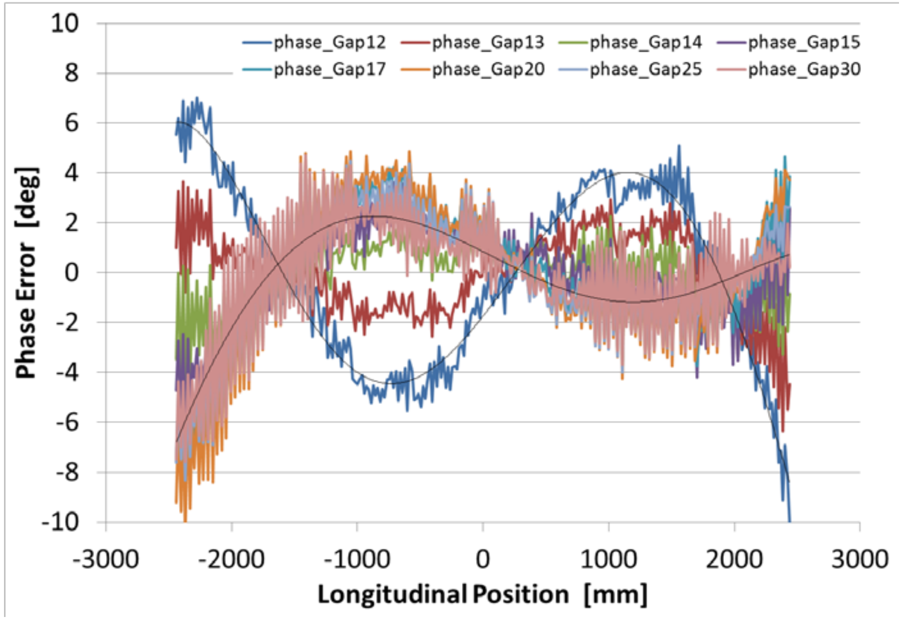
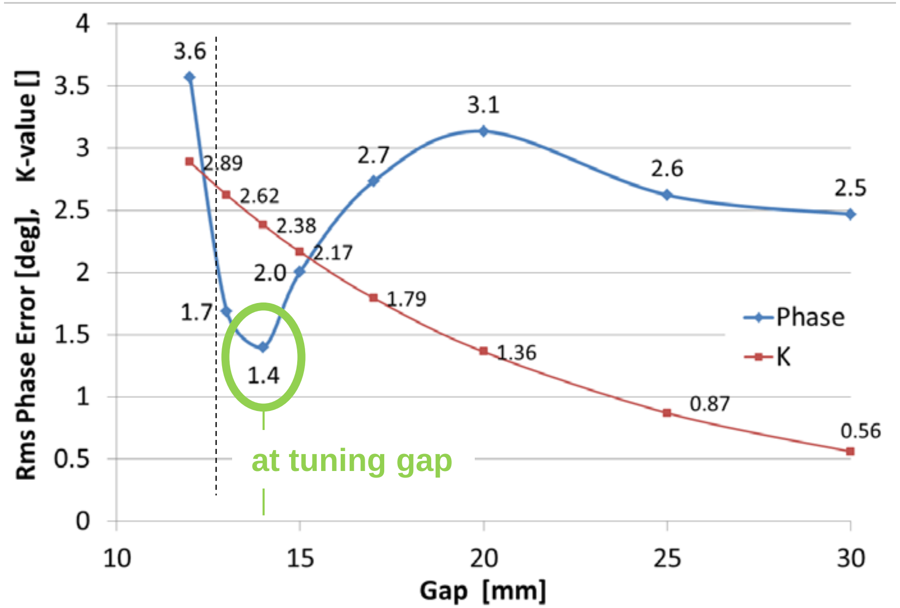
Magnetic Shimming of (systematic) Phase Errors

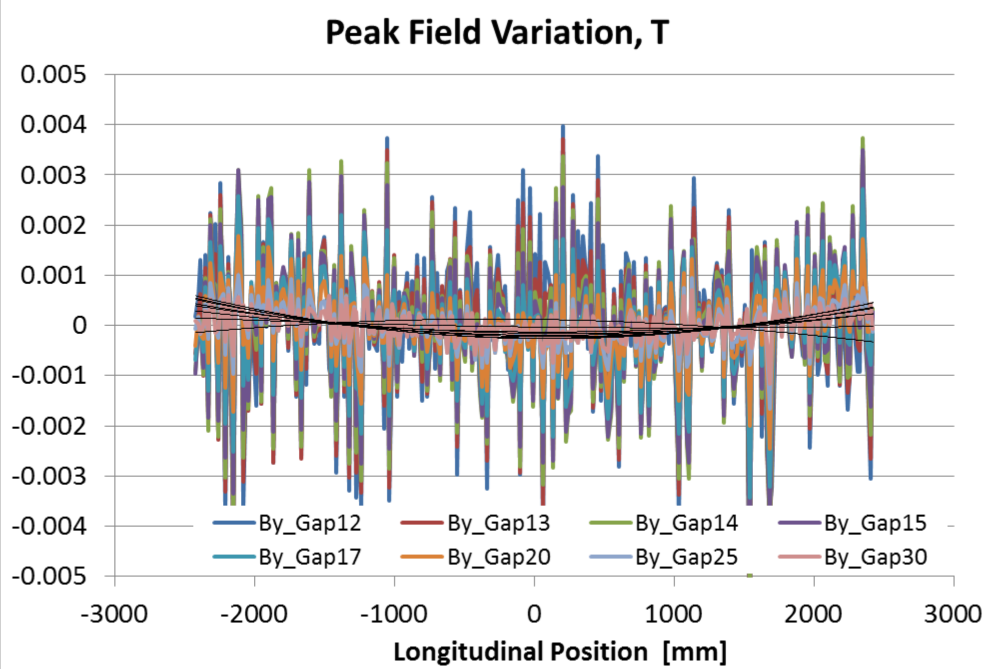
> Observation during recent tuning of 5m long undulators
  - excellent phase error at tuning gap = 14mm
  - but systematic phase error changes with gap
  - minimum operating gap is 13mm



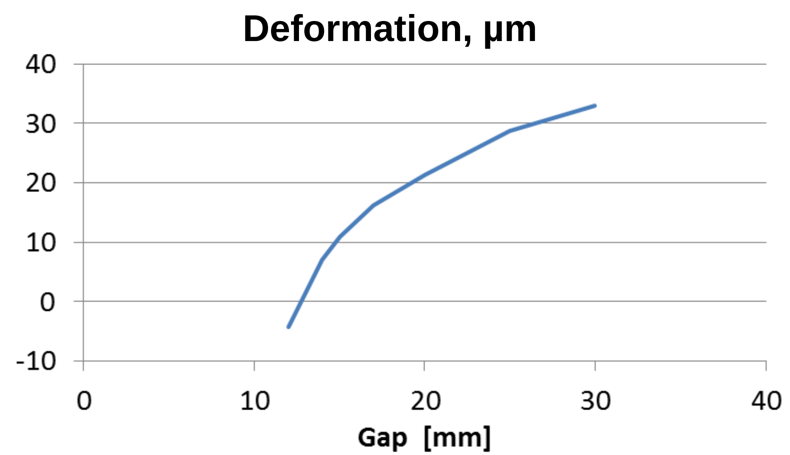


Magnetic Shimming of (systematic) Phase Errors

- Reason for systematic phase errors was found in a dynamic girder bending
- Deformation depends on magnetic load, i.e. on the gap
- Proven independently by magnetic and mechanical measurements



- Peak fields
  - for all gaps, normalized by average field
  - systematic trend found for a parabolic fit
  - recalculated to a to mechan. deformation of about 10-20µm at the end of *each* girder

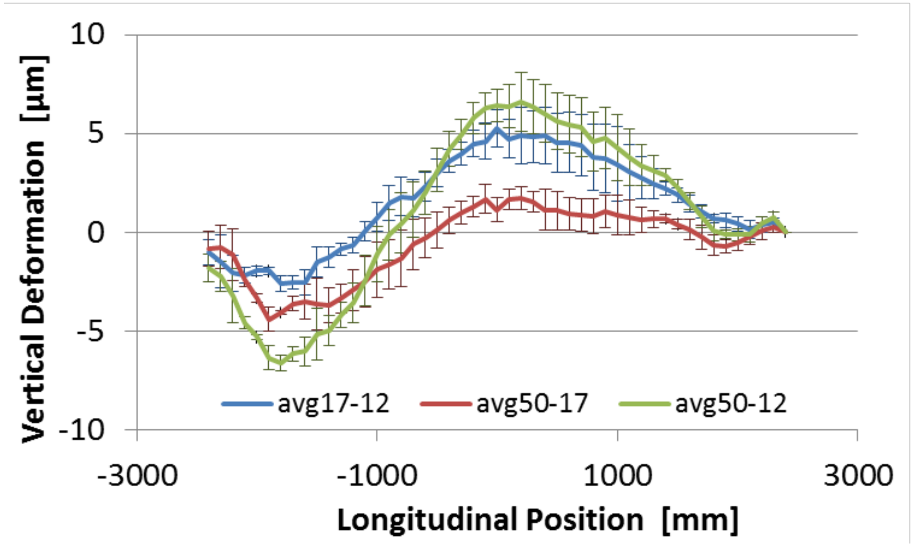


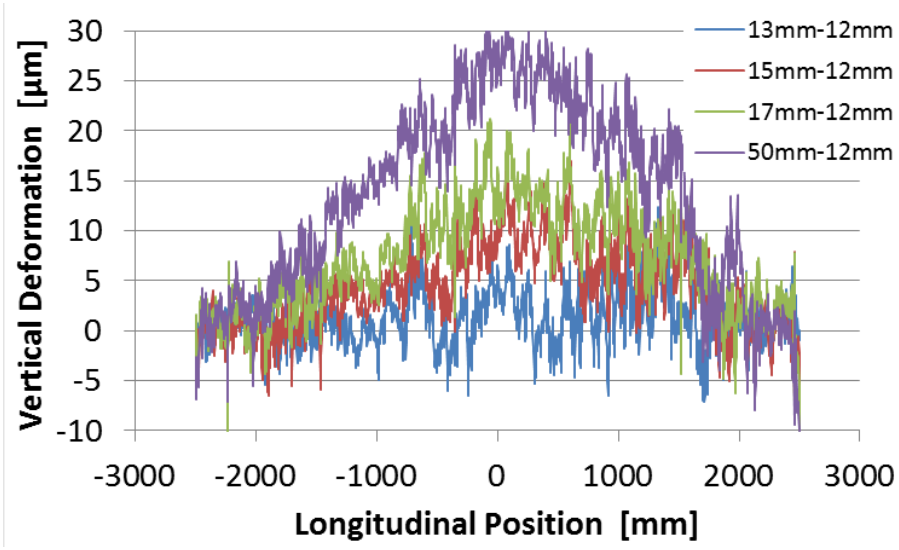
Magnetic Shimming of (systematic) Phase Errors

> Direct mechanical measurements

- **water level measurements** at a *single* girder
- dynamic girder deformation up to ~15µm for a single girder
- deformation is not the same for all girders

- **capacitive sensor** (µε) on Hall probe bench
- qualitative agreement with magnetic results
- dynamic gap deformation of ~30µm or 15µm per girder





Trajectory Gap Dependence Shimming

> Some magnet errors create gap dependent kicks

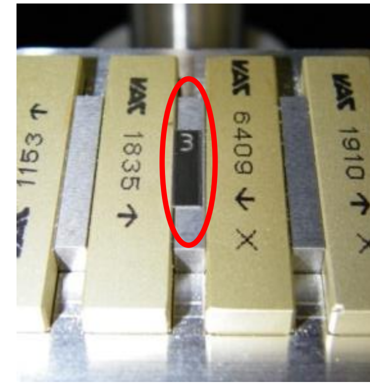
> Located inside the structure and could not be corrected by electromagnetic correction coils at the ends

> Could be corrected by pole tuning only for one particular gap, but with trajectory errors for other gap settings

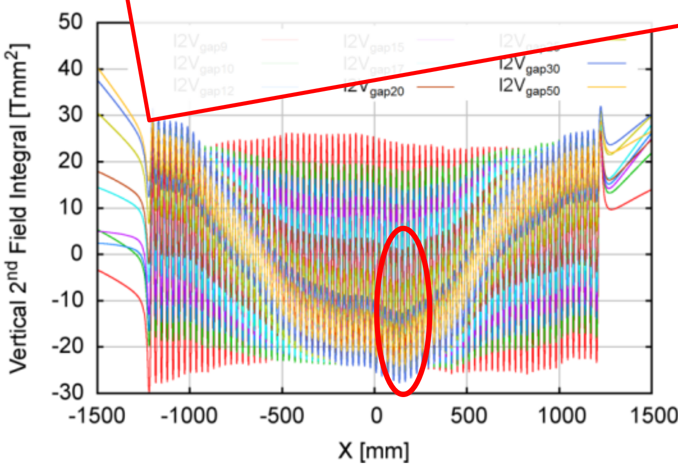
> Pole with the small iron shim have different gap dependent kick signature and when placed with the proper polarity could correct for the gap dependent errors

> Different shim configurations with different signatures could be used to correct various errors

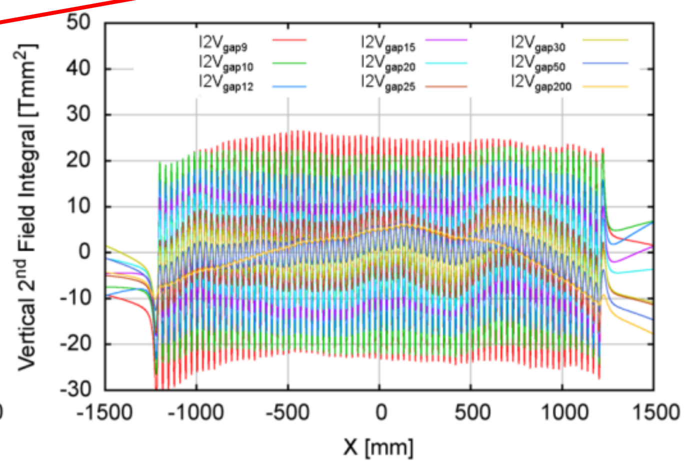
Previously good experience with „sextupole“ shims for correction of gap dependent trajectory kicks



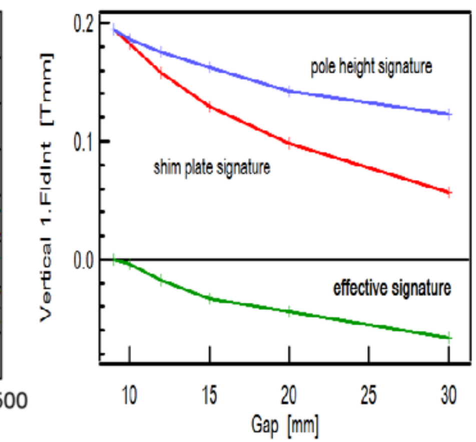
Iron shim



Initial trajectory gap dependence with gap dependent kick at X=150mm



Trajectory gap dependence with shim



Proc. IPAC2014 p.1235

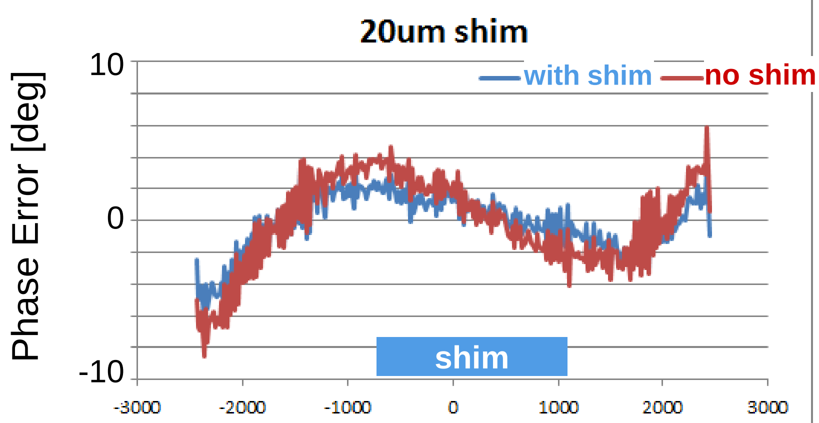
Magnetic Shimming of (systematic) Phase Errors

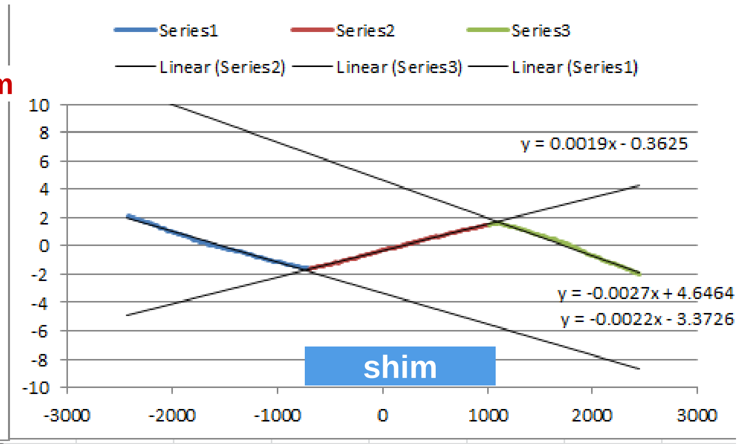
> 2 Examples of a phase shim

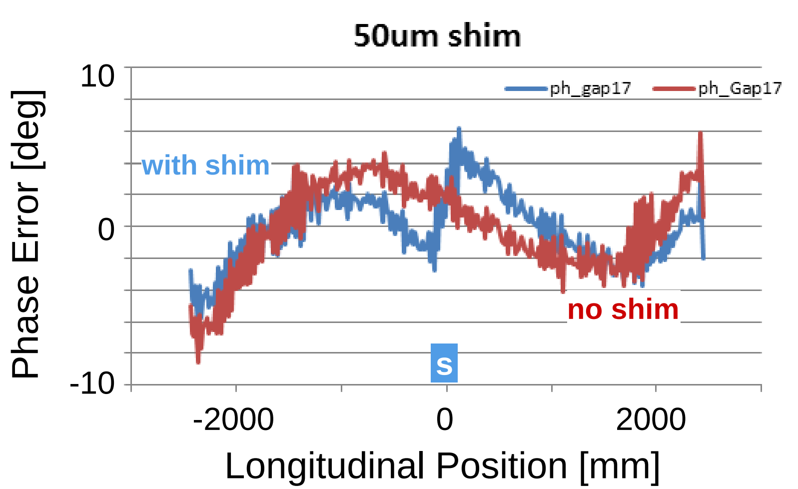
- feeler gauge tape put onto magnet structure

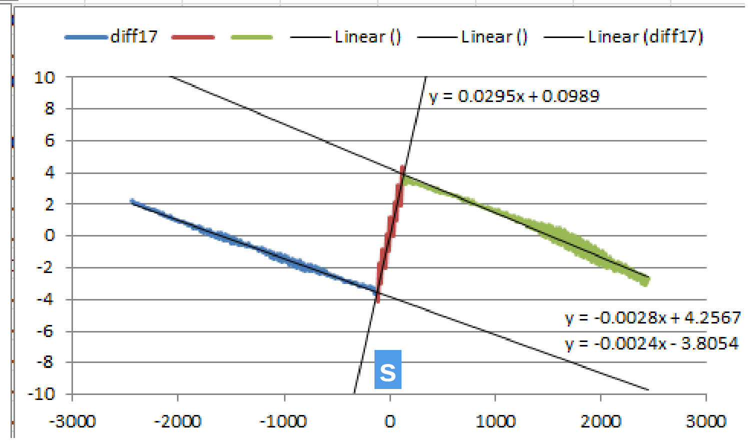
> **Phase Shim Signature**

= slope change in longitudinal phase dependence





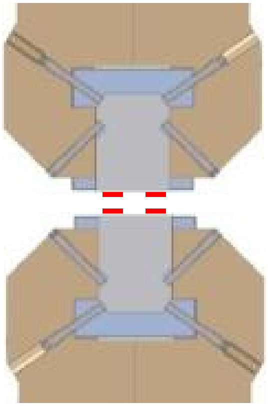


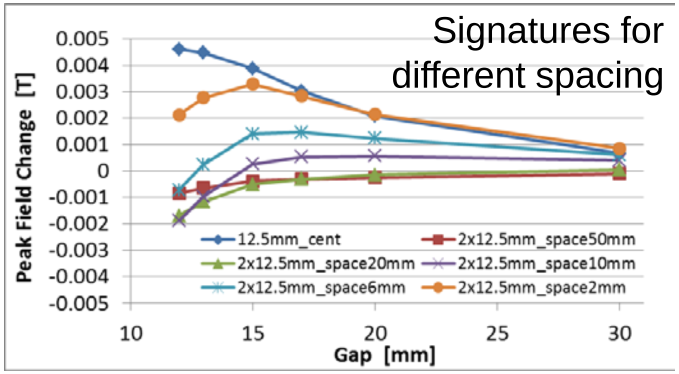


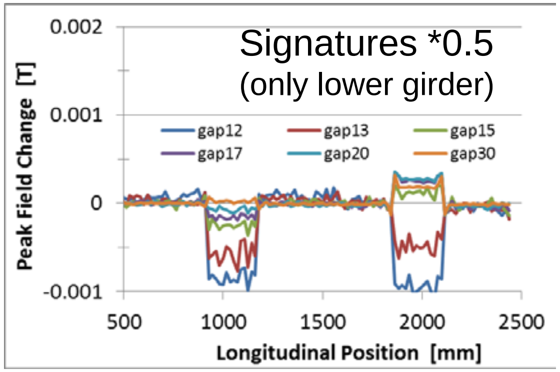
Magnetic Shimming of (systematic) Phase Errors

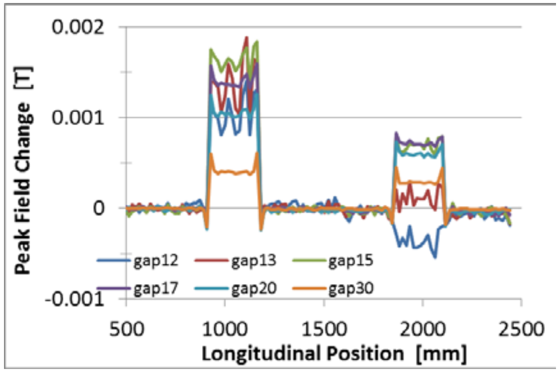
> Signature of phase shim is driven by various effects

- the shim shunts some part of the magnetic flux and *decreases the on-axis field*
- the shim decreases the gap at the poles locally and *enhances the on-axis field*
- different gap dependencies cause a gap-dependent dipole term of such a shim
- the spacing and the width of the 2 foils can be used to define a gap value where the shim inactive, i.e. does not change the phase.
- shim length = n * full period
  → no kick nor multipoles





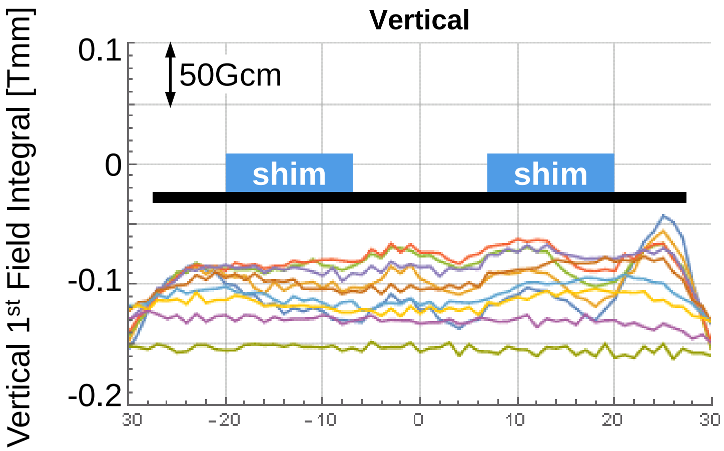


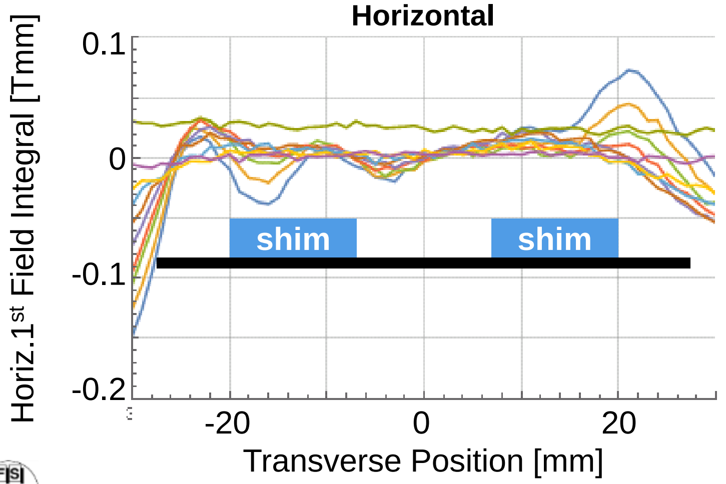


Magnetic Shimming of (systematic) Phase Errors

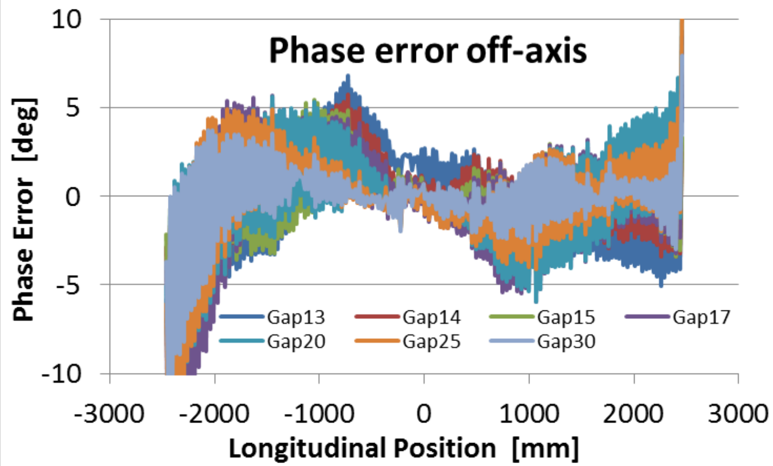
Final Shimming Results

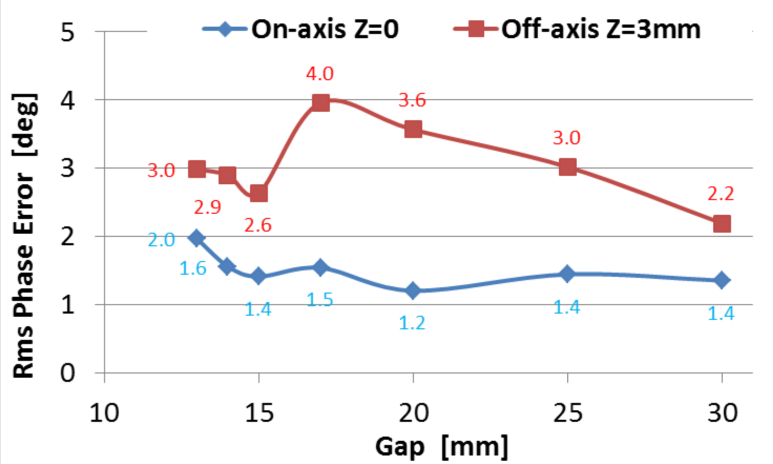
> Multipoles





> Off-axis Phase Errors



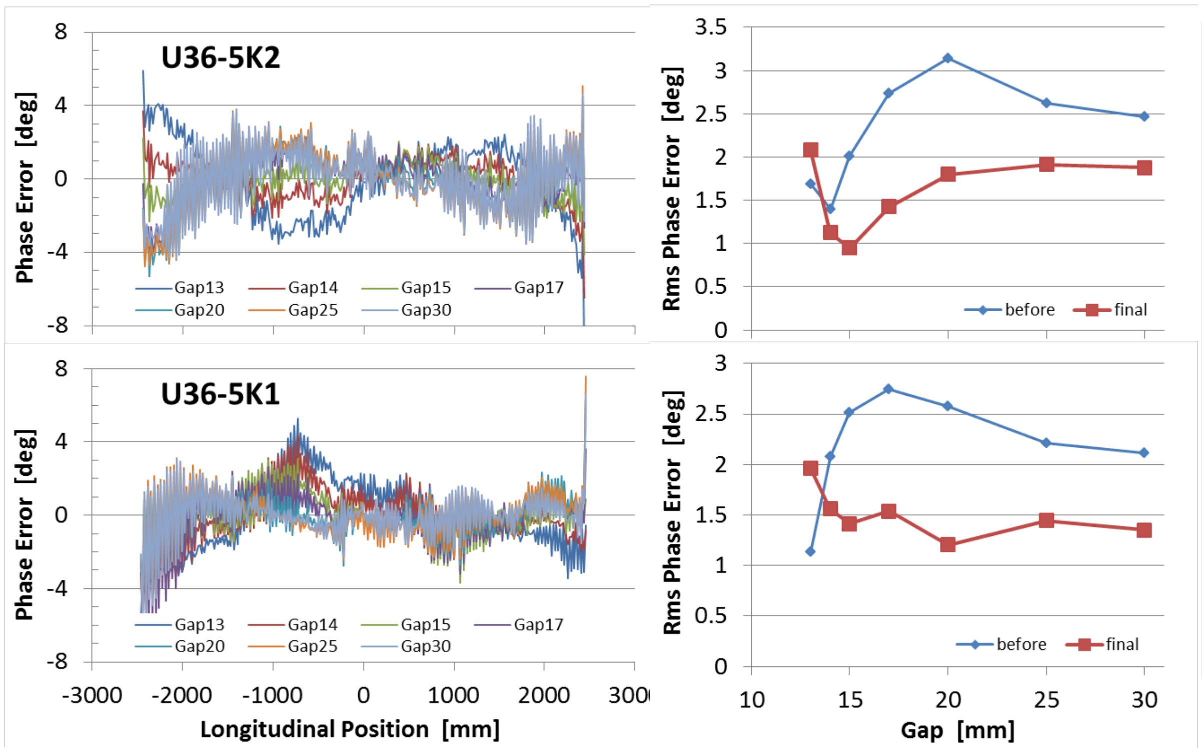


Magnetic Shimming of (systematic) Phase Errors

Final Shimming Results

> Gap Dependence of rms Phase Error of 5m long U36 Undulators

- Improvement to <1.5° and <2° max. rms error over all working gaps
- Shimming could be refined much further if time allows and specs require
- Individual pole tuning is not affected at all



> Pros

- simple, efficient
- fast
- no effect on integrated multipoles

> Cons

- sacrifies the minimum gap, but only by 2*30…50µm
- Magn. properties of feeler gauge foils are highly non-constant (vendor and batch variations)

> Thanks!