3D calculations of undulators and wigglers new projects at ANKA and a novel shimming method

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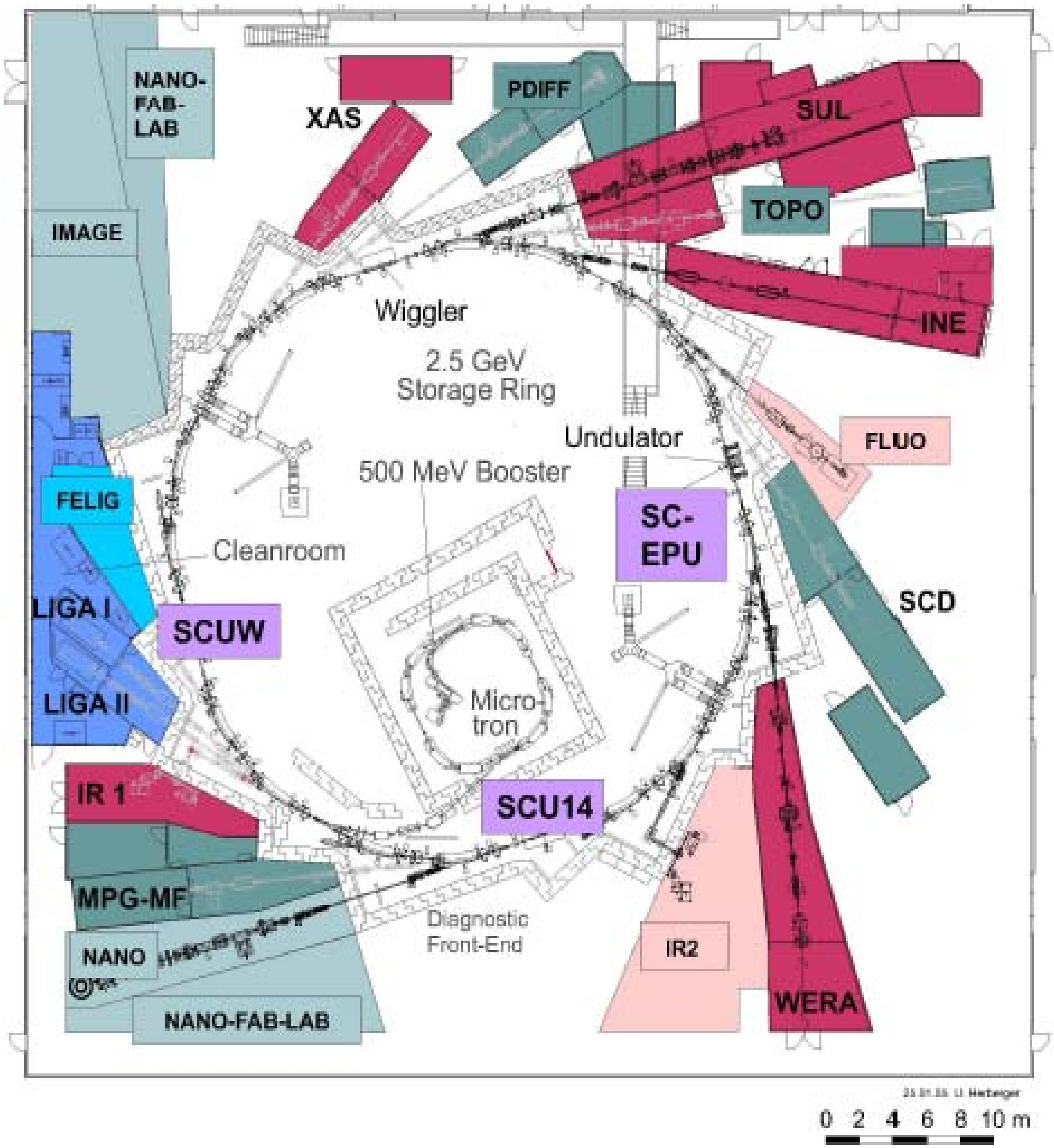
for A. Bernhard, R. Rossmanith, D.Wollmann
and the ANKA collaboration

ANKA



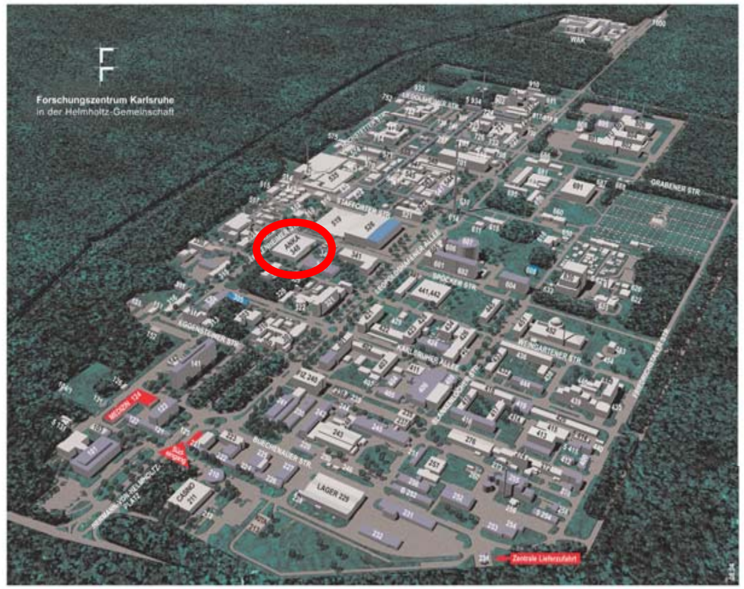
Beam energy 2.5 GeV

Stored current 200 mA,

Life time 20 hrs

Hor. Emittance 40 nm

Circumference 110.4 m



Various projects at ANKA

- SCU14 running since 2005
- Planned SCU-s
  - SCU15 (2009)
  - SCUW (2010)
  - SCU2
- Shimming (field error correction)
  - Classical in-gap
  - Induction shimming

Calculation tasks

- General magnetic design
  - Optimize dimensions etc.
- End period matching
  - Most challenging: SCUW
- Mechanical deviations
- Shimming

Software used

Magnetic calculations and general design:

Vectorfields Opera 3D (finite element calculation)

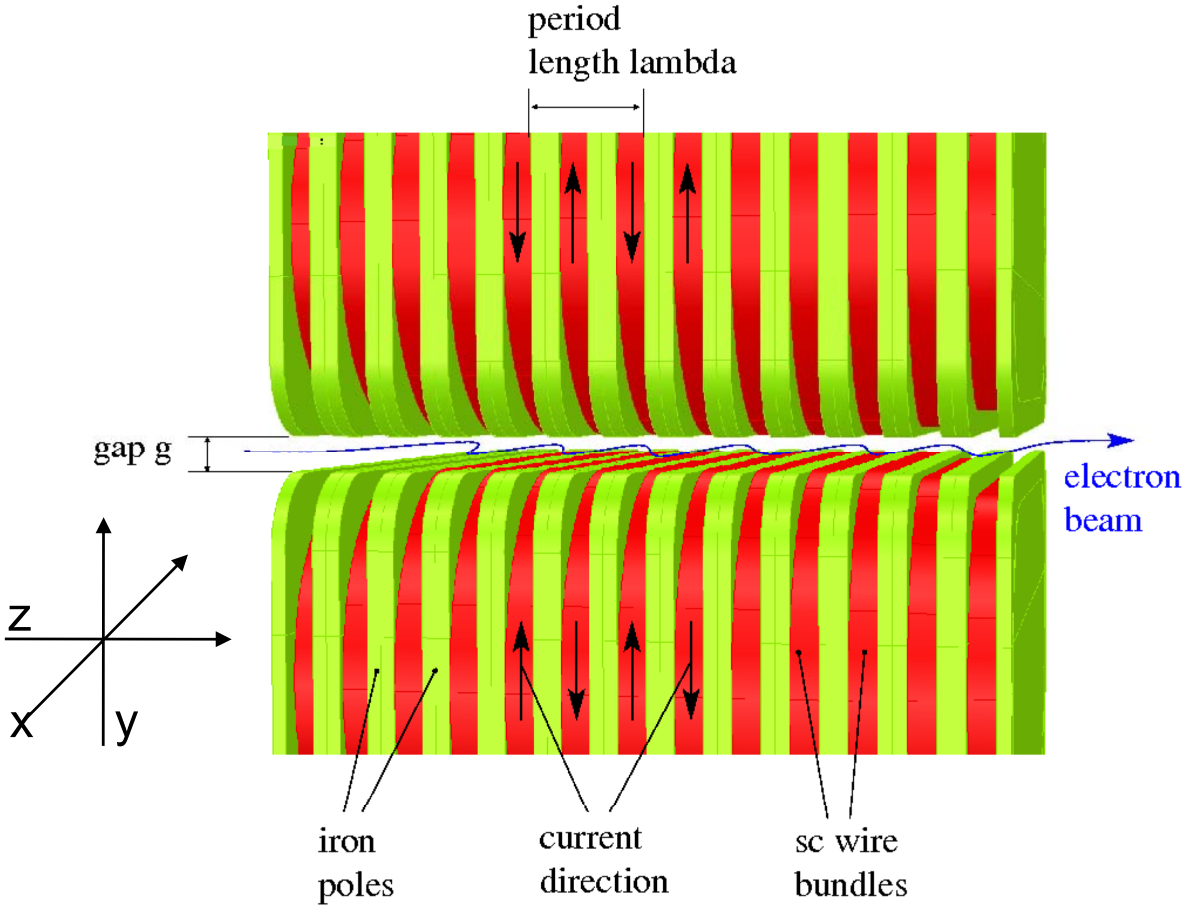
Advantages: very versatile, various specialized solvers for different tasks (here mostly static and dynamic magnetic solvers are used), both GUI and script controlled, relatively fast.

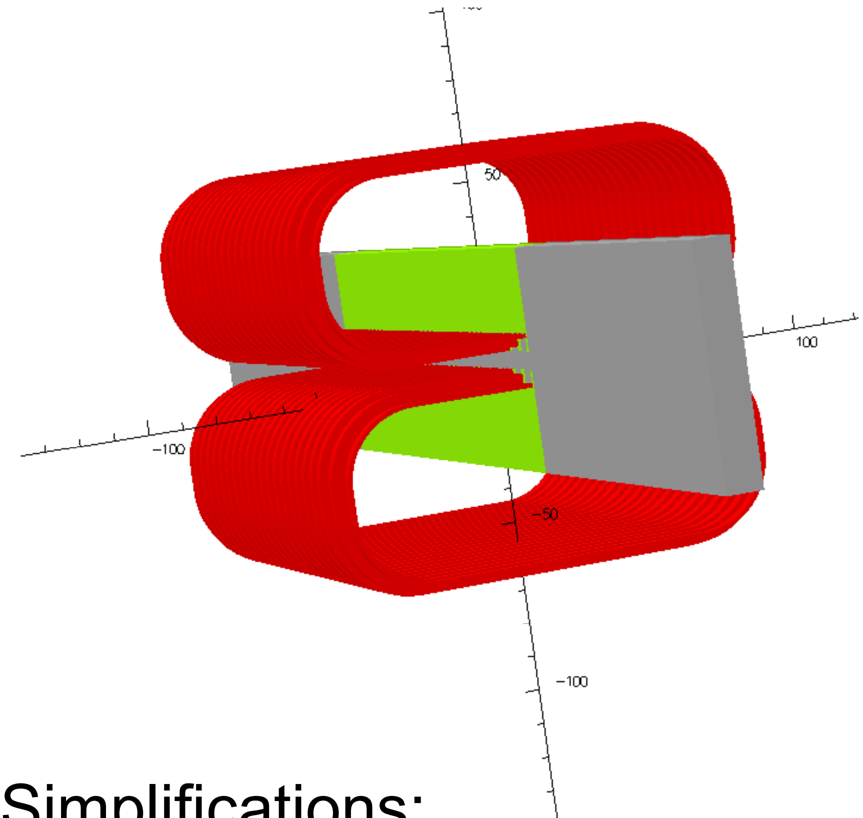
Disadvantages: expensive, many licenses required, resource hungry but not multi-processing capable

Other software used: Spectra, Radia and Matlab

How to model undulators and wigglers

Mock up with end period matching



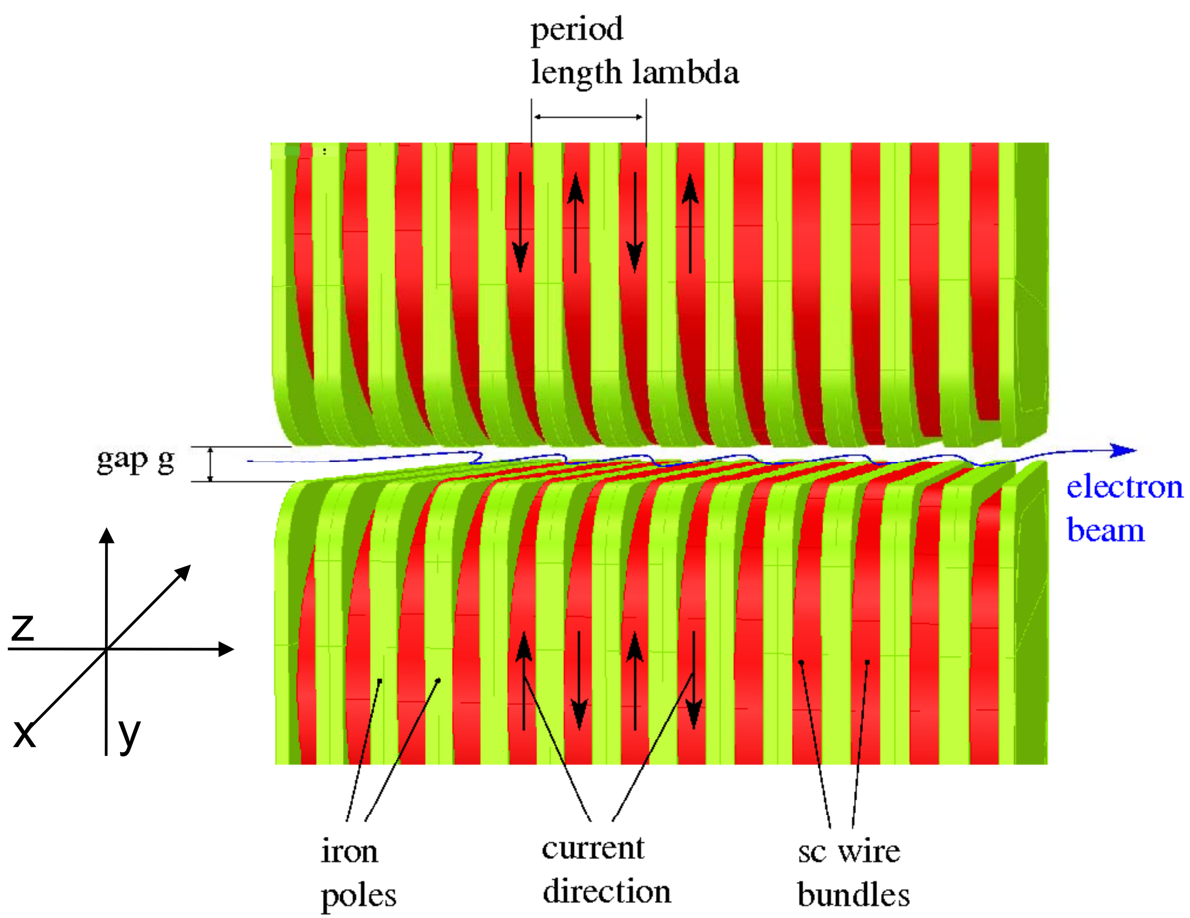


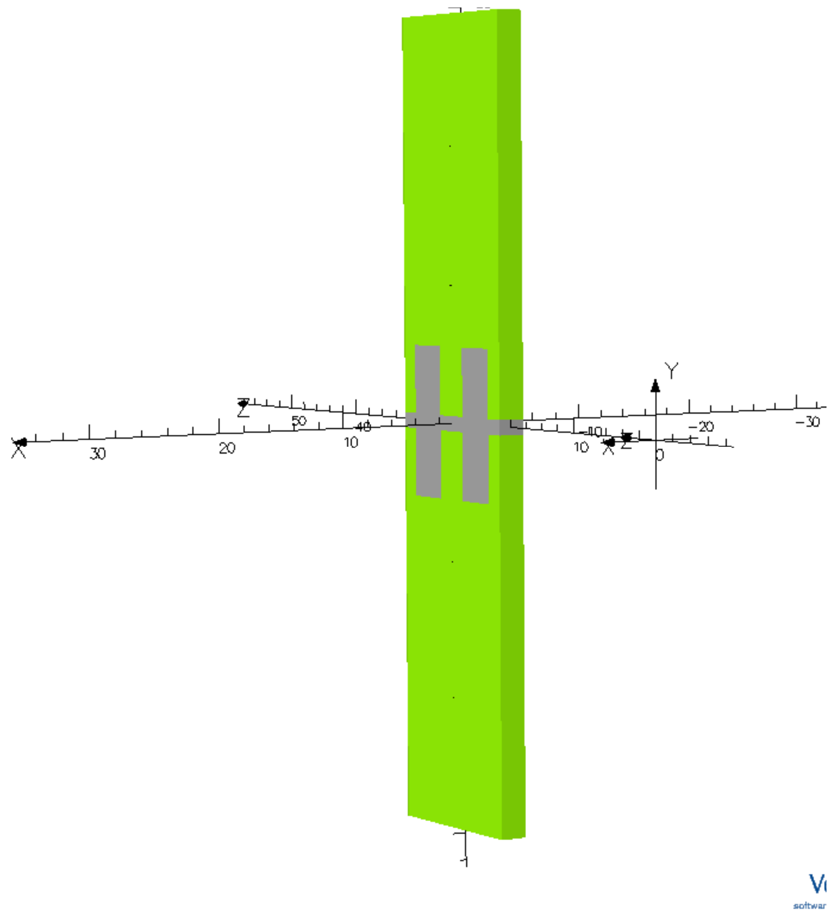
Simplifications:

- coils as 'racetracks'
- create reduced model body with suitable boundary conditions
- e.g. for end period matching: thin (but not too thin) central slice.

How to model undulators and wigglers

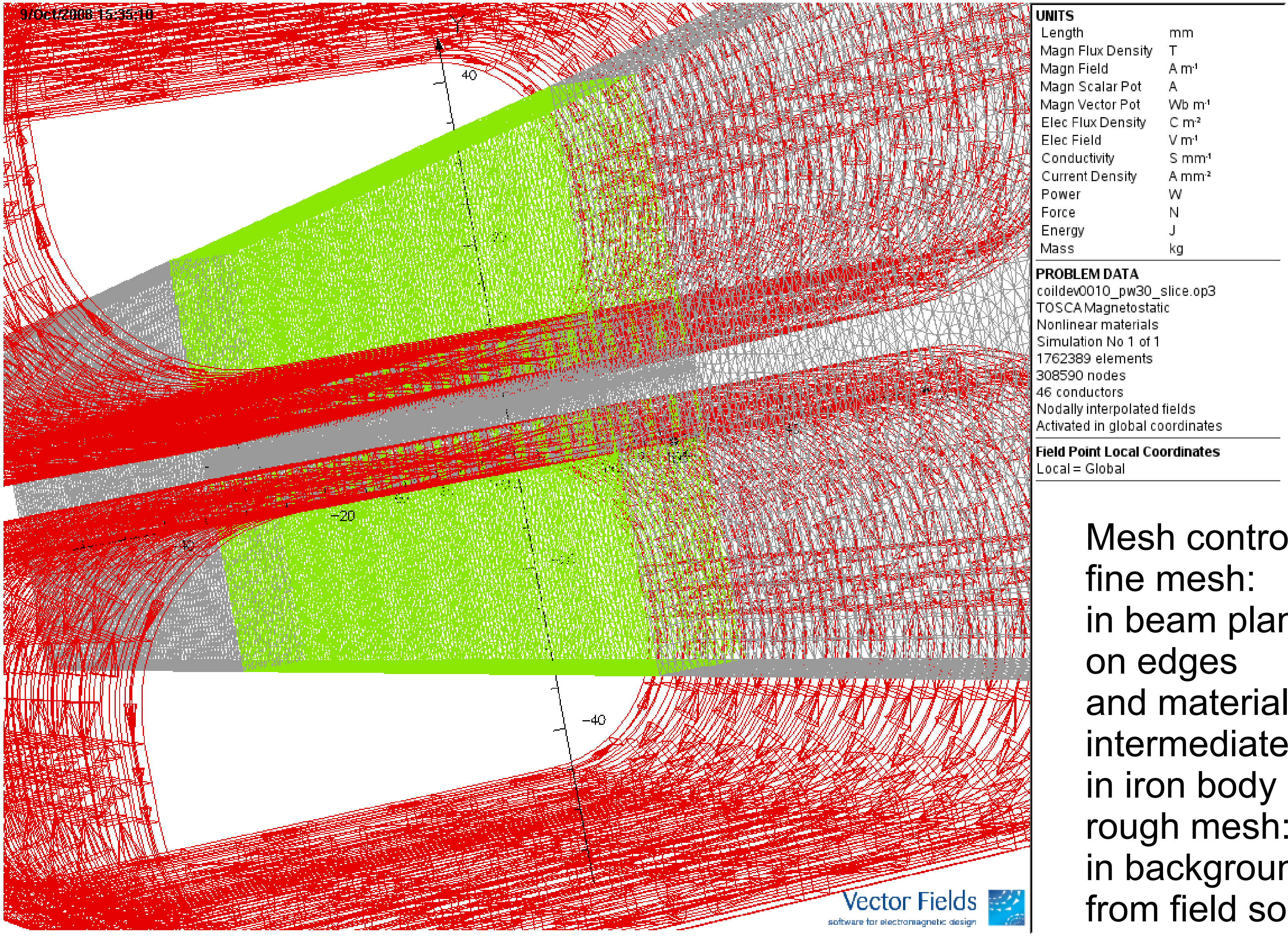
Mock up with end period matching





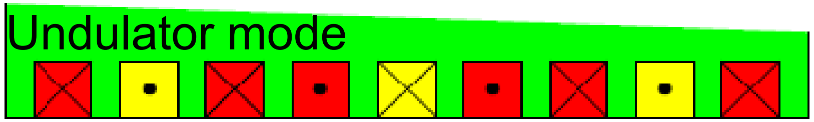
- Or, for parameter optimization: exploit symmetry and create only one full period. (corresponds to infinitely long, ideal undulator)

Meshing

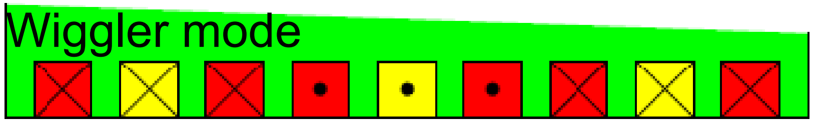


Mesh control:
fine mesh:
in beam plane
on edges
and material borders
intermediate mesh:
in iron body
rough mesh:
in background far
from field sources

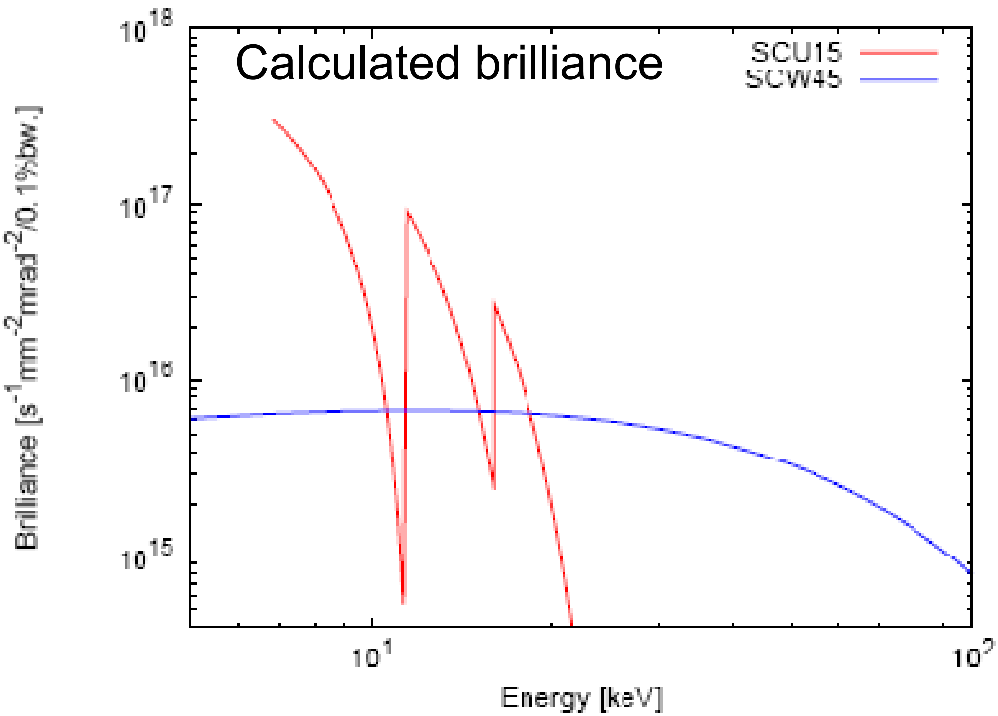
SCUW



$\lambda = 15\,\mathrm{mm}$



$\lambda = 45\,\mathrm{mm}$



Super-Conductive Undulator / Wiggler

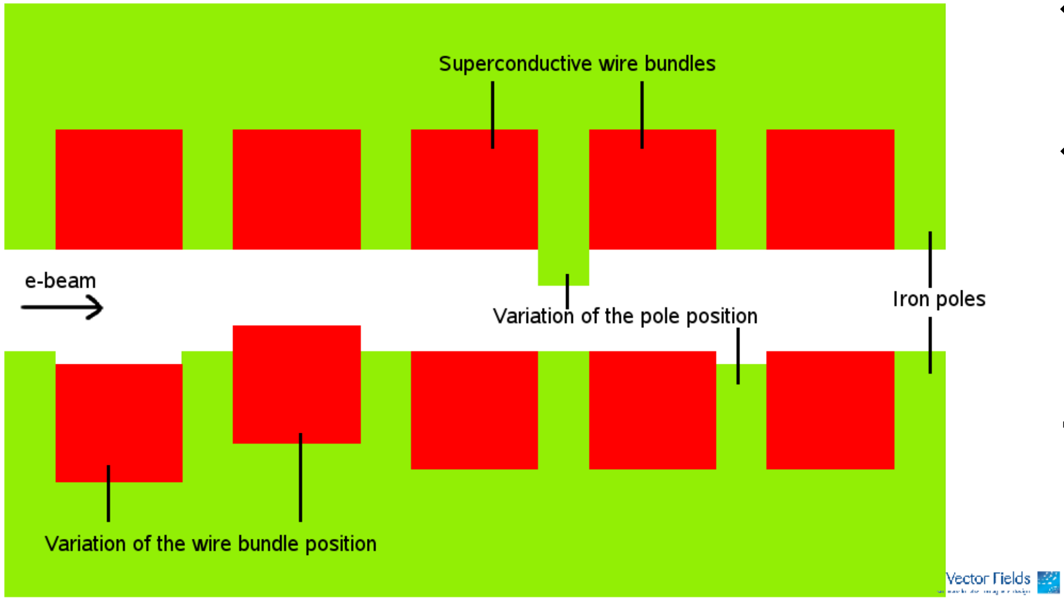
- Two independent circuits
- 'red' circuit:
  - fixed current direction
- 'yellow' circuit:
  - current direction switchable

→ three grooves with identical current direction
→ period tripling

Other Project:
Planar/Helical Undulator
= undulator with switchable polarization of emitted light

Mechanical deviations and trajectory errors

Mechanical errors



Not shown: period length errors

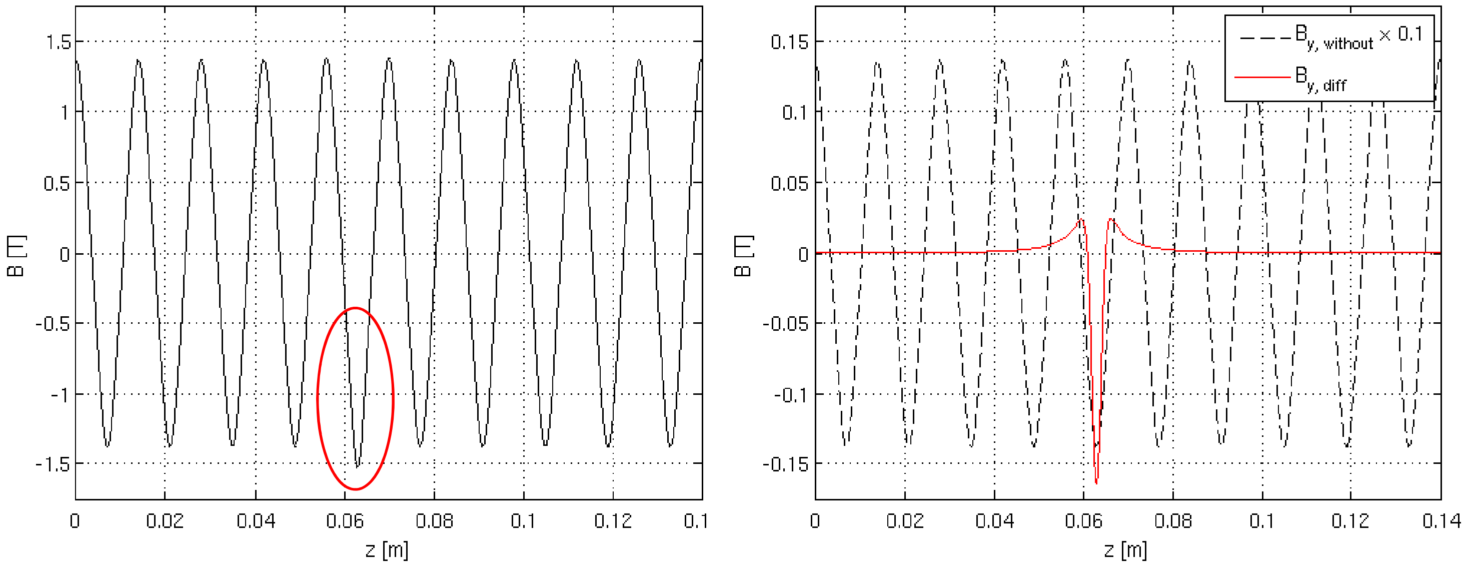
- Field errors influence particle trajectory.
- For a fully transparent wiggler the first and second field integral have to vanish.

→ Errors have to be corrected (even more crucial for undulators – phase requirement)

→ Shimming

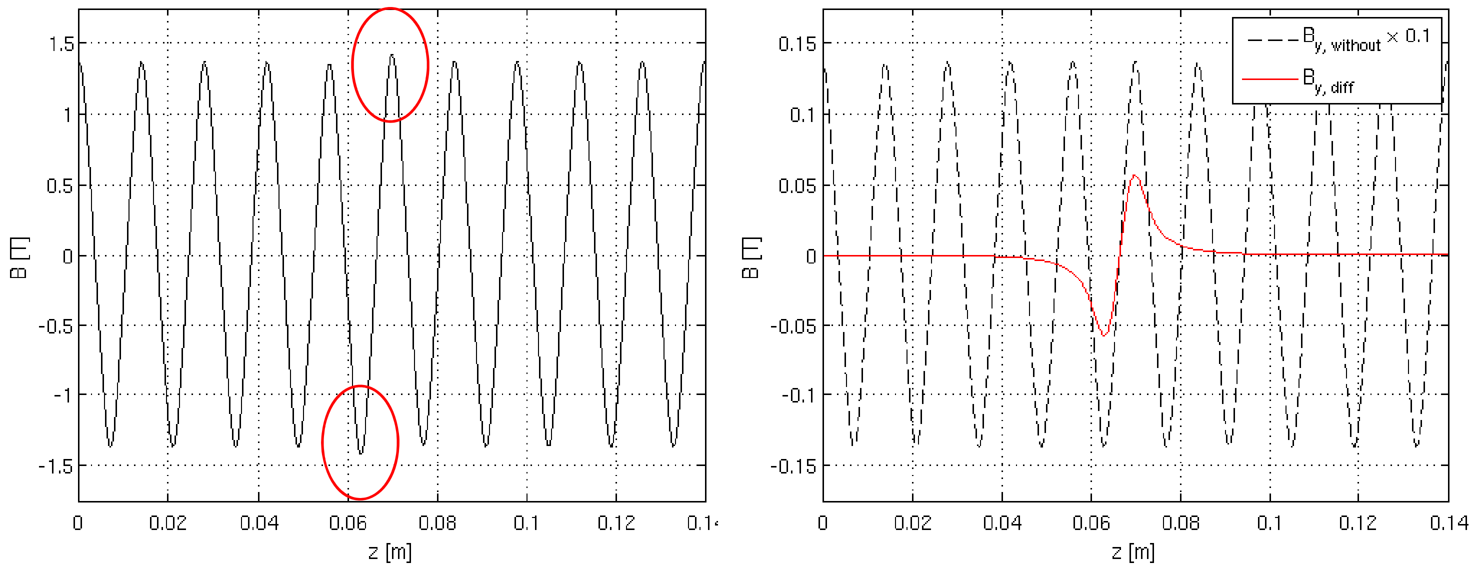
Error contributions from iron and coils scale differently with current.
→ at least two independent (active) shimming systems needed.

Error type examples

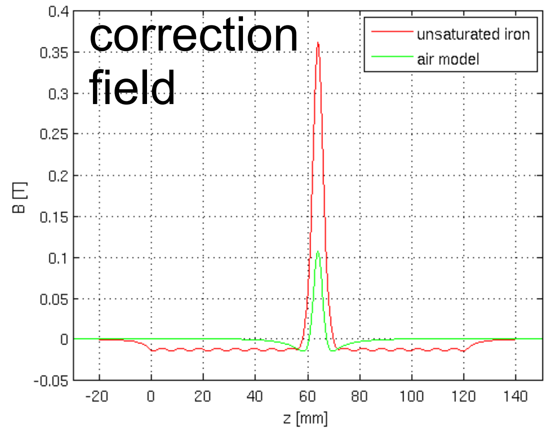


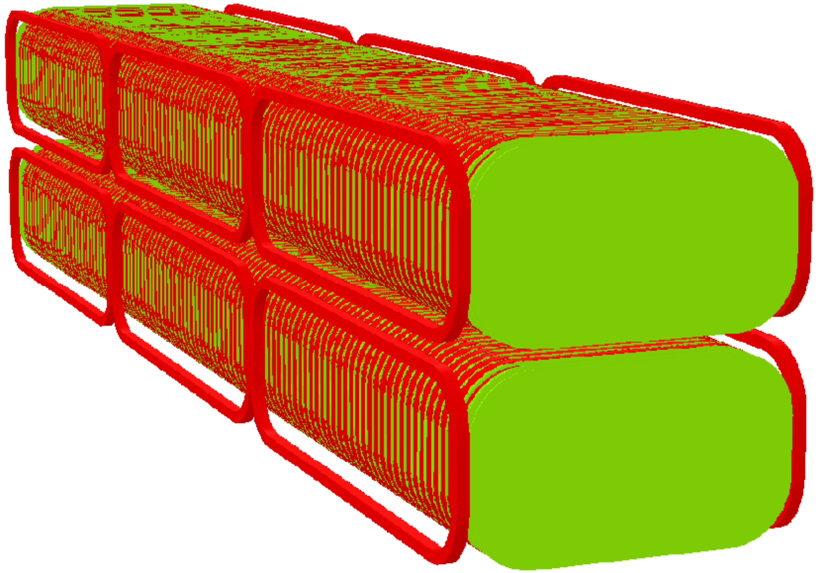
Uncorrected field and difference to an ideal field for a pole height error

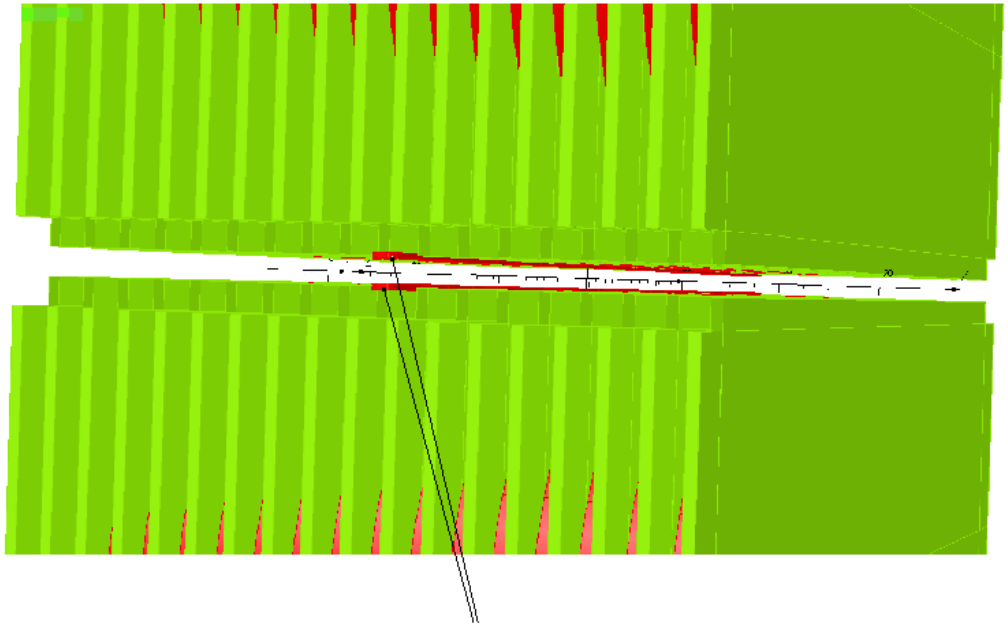
Uncorrected field and difference to an ideal field for a coil position error



Classical Shimming







in gap shim coils

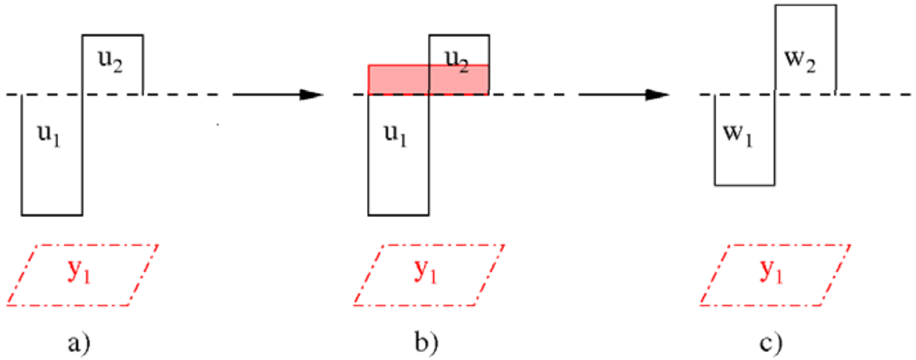
Integral correctors:
- overall correction of electron trajectory
- transparency of the undulator/wiggler
- but no local control of field quality

- local correction of field errors
- space needed in gap
- increased gap or decreased beam stay clear

Induction shimming

Details published in PhD thesis by D. Wollman

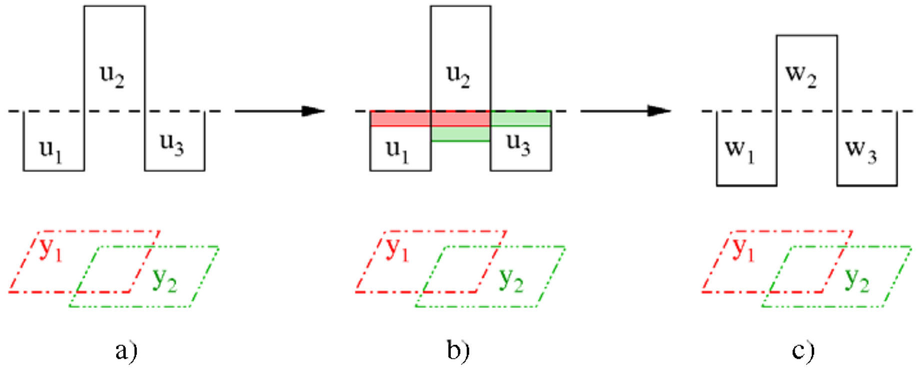
Starting idea: in an ideal undulator the integral over one full period vanishes.



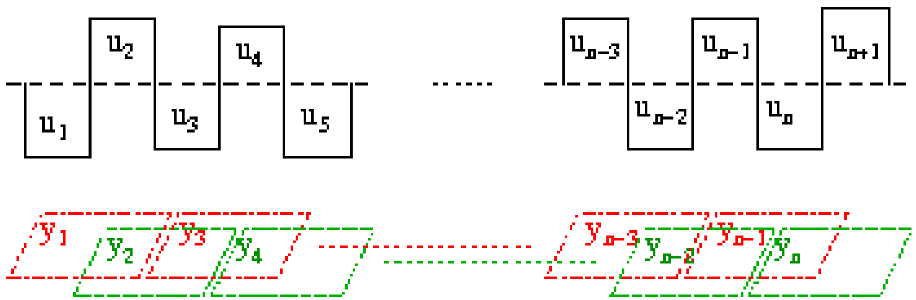
- Superconductive loop over one period
- Enclosed flux = 0 in the ideal case
- In presence of field errors, flux ≠ 0
- Faraday's law: *current is induced in a closed loop such that the change of flux enclosed by the loop is compensated.*

→ **induced current generates field that exactly counteracts the field error**

3/2 periods: 2 overlapping coils.

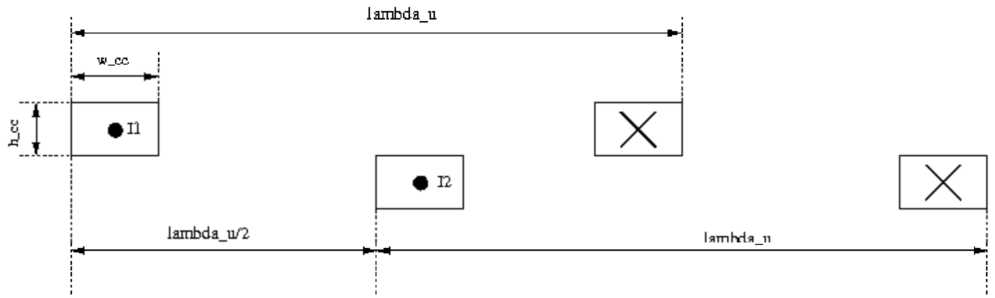


Generalization (n+1)/2 periods: n coils.

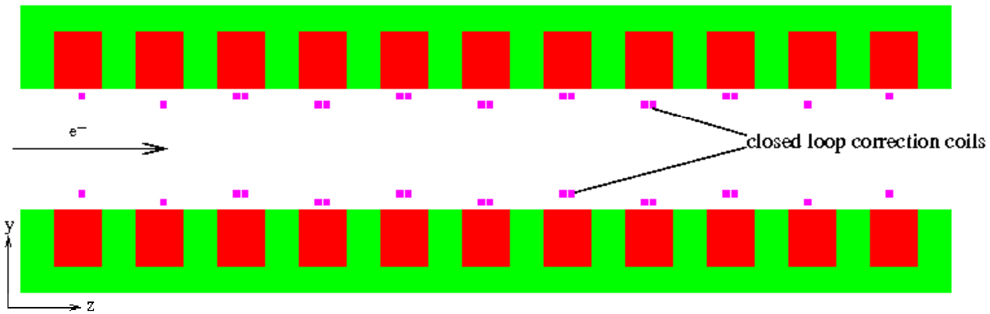


Induction shimming calculation

Modelling:

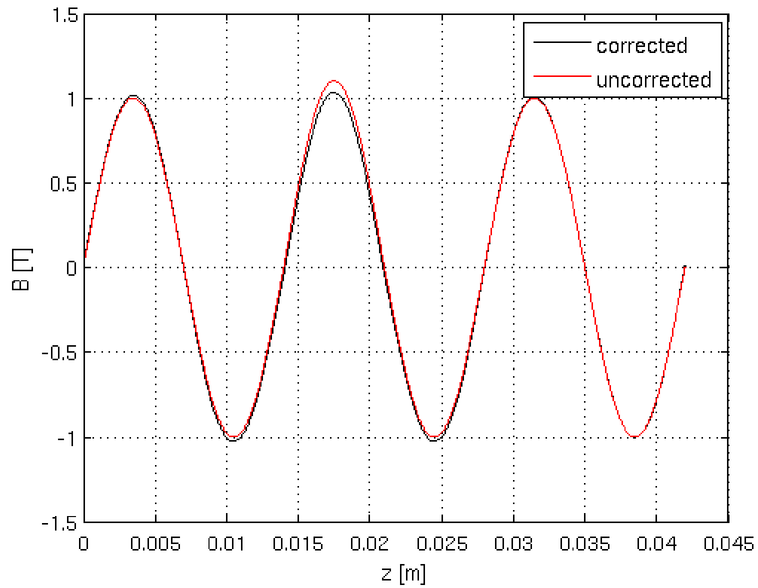


Overlapping pair-wise connected ideal conductors

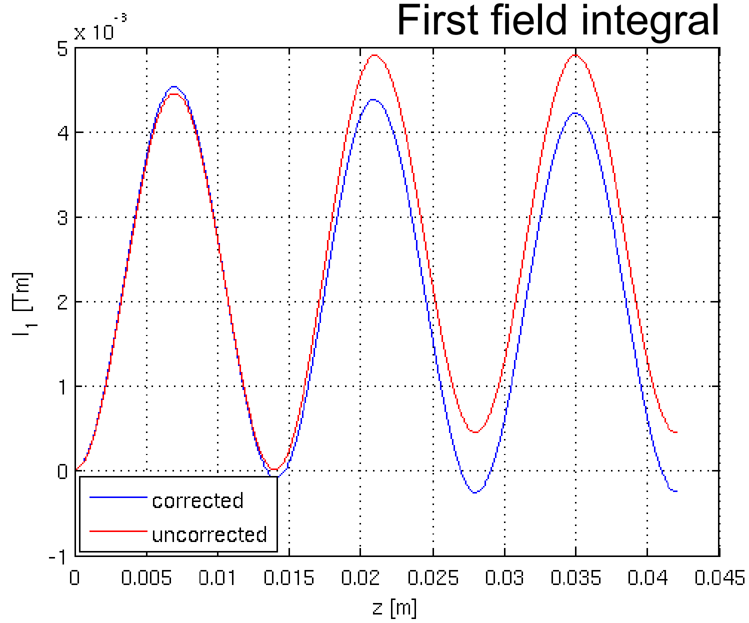


...over the full undulator length

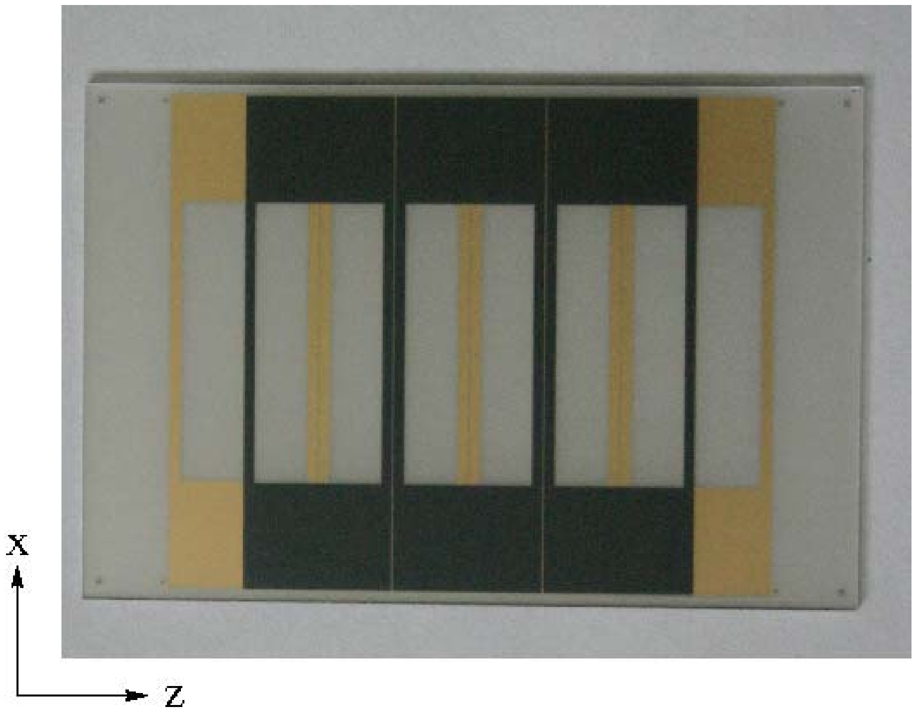
Field comparison



First field integral



Induction shimming Experiment



2x 330 nm thick YBCO structures on sapphire substrates (0.5 mm) separated by thin capton foil.

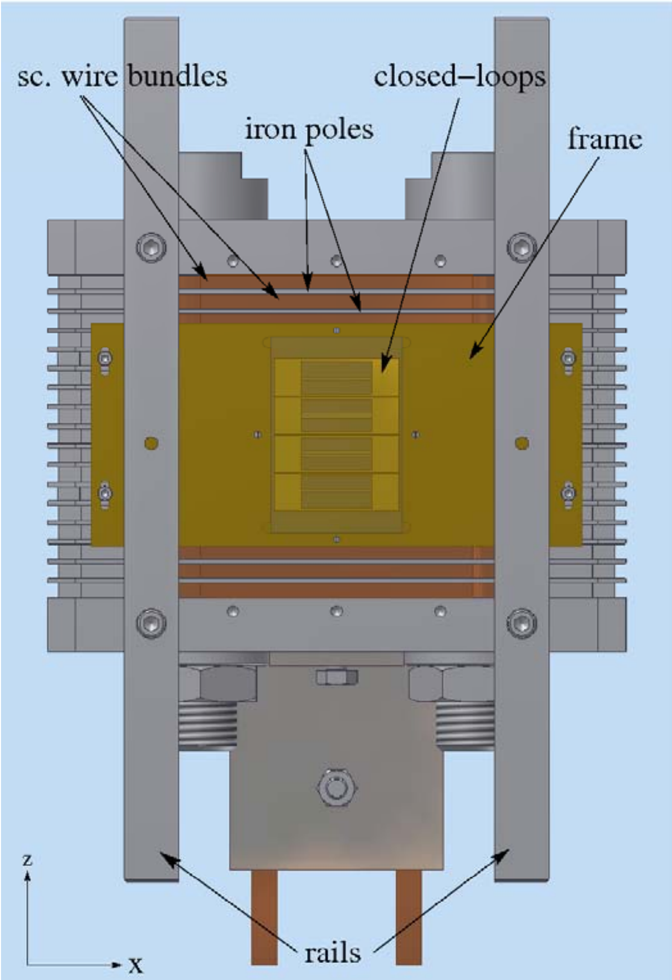
YBCO protected by gold layer

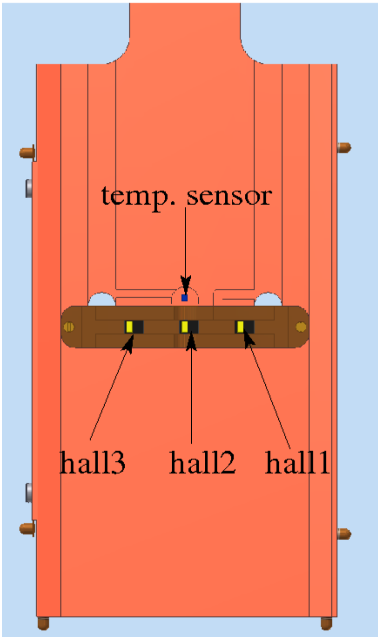
7 closed loops total (3 + 4)

Each loop: 14x44 mm, conductors 1 mm and 10 mm wide.

Mounted on a mock up coil and tested in a LHe cryostat for magnetic measurements (CASPER at FZK)

Induction shimming
Test setup



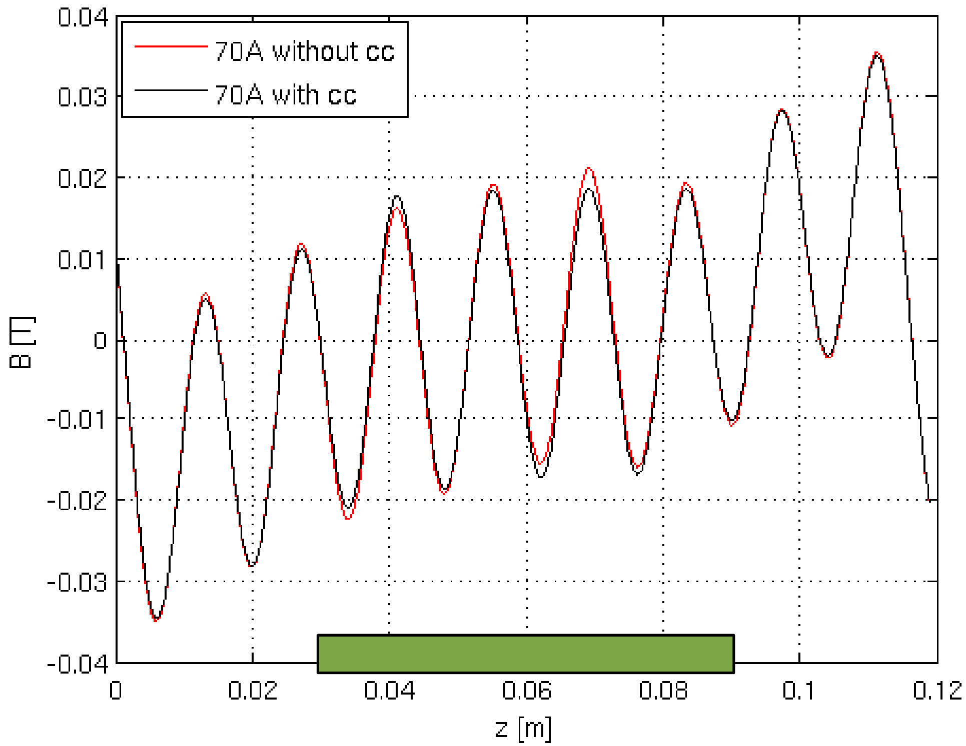


Induction shimming system mounted on mock up.
Center plane of system 1 mm away from pole faces

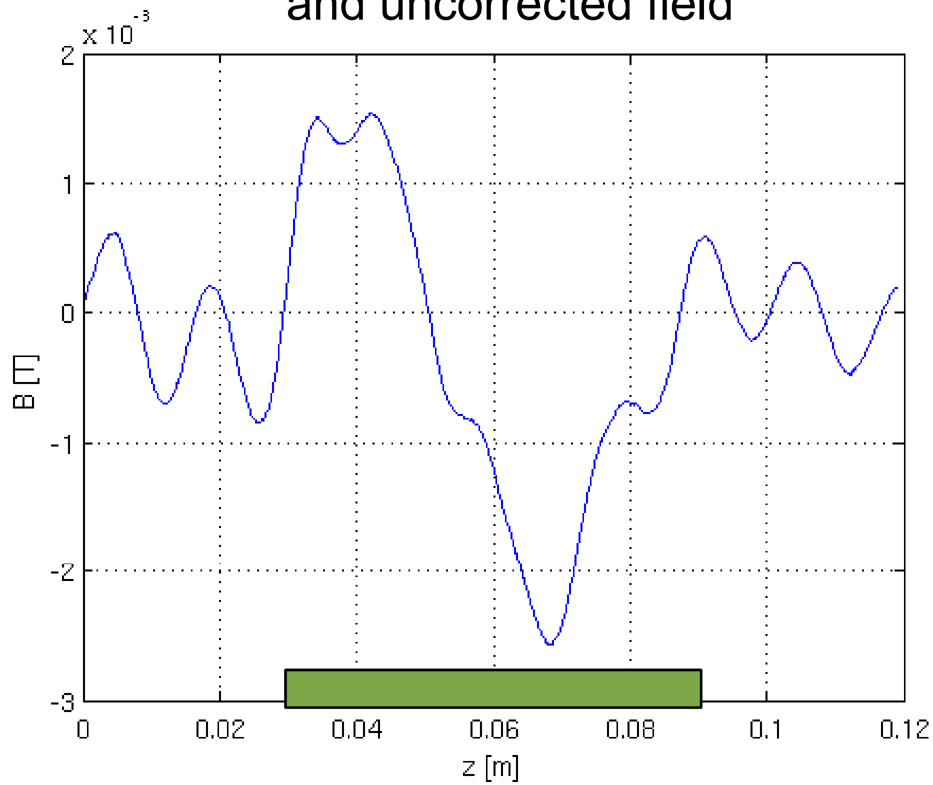
3 Hall probes mounted on test sled moving on rails, 8 mm away from pole faces.

Induction shimming
Experimental results

Uncorrected field and field with correction coils



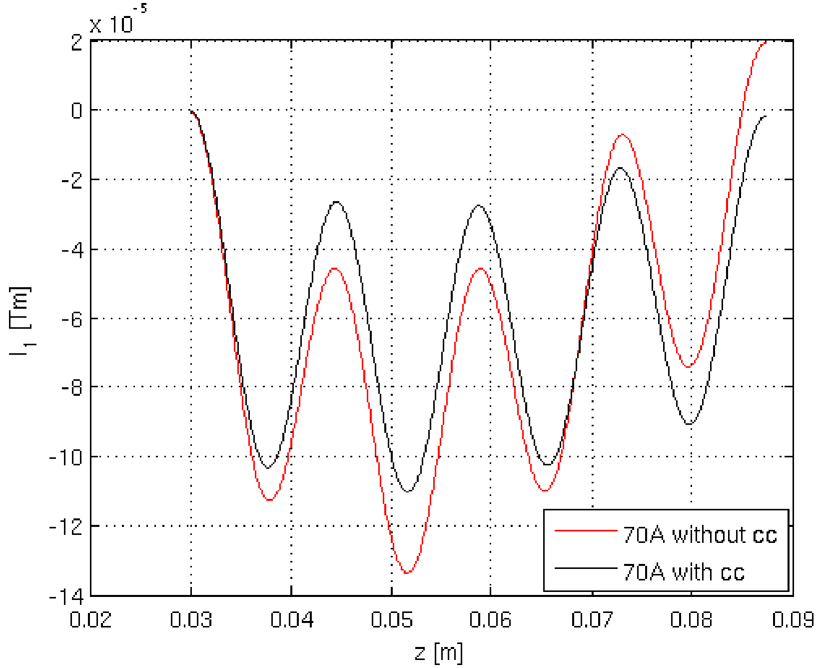
Difference between corrected and uncorrected field



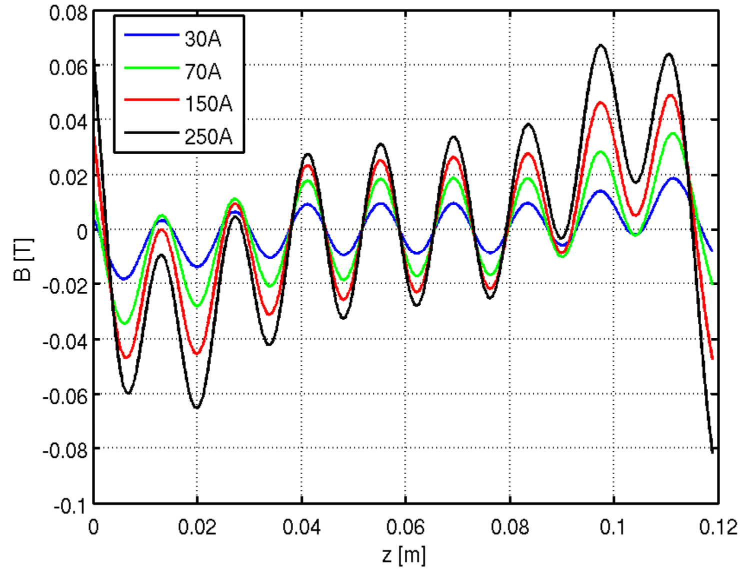
green: position of cc system

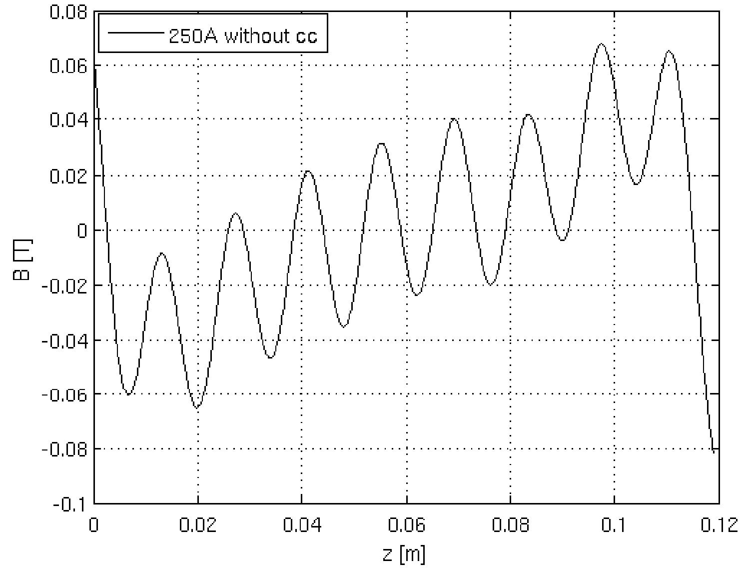
Experimental results continued

First field integral (70 A)



Correction at different currents





- Up to 160 A (485 kA/mm²) induced in correction coils.
- Caveat: if cc saturates, hysteresis effects occur
- But errors in a real device will be >1 order smaller so in spite of higher total fields the induction shimming system will be sufficient even in the current layout.

Conclusions

- 3D calculations:
  - Opera3D is a very powerful tool with a multitude of possible tasks.

(static and dynamic magnetic properties, forces, heat distribution, quenches, particle tracks etc.)

- Note to other Opera users: use latest version (12.027) !

- ANKA schedule:
  - SCU15 will be installed some time 2009
  - SCUW will follow one year later
  - Stay tuned! Exciting projects are upcoming.

- Induction shimming:
  - Works!
  - Easier to use than regular shimming
  - Needs no additional feed-through
    - Reduced heat load
  - However: reduced beam-stay-clear
  - Work on substrate thickness ongoing