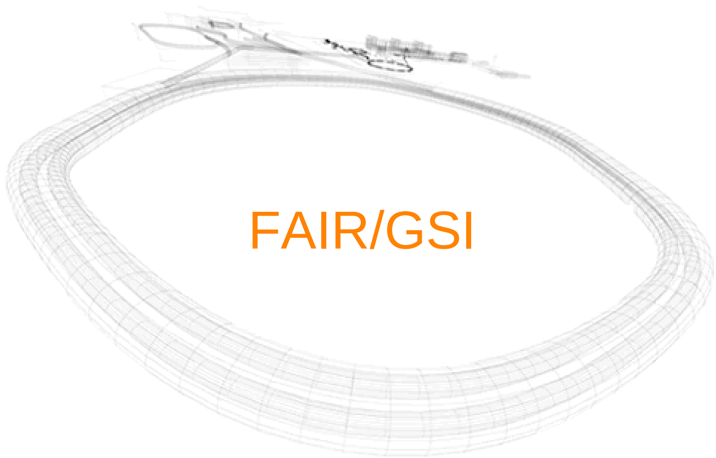
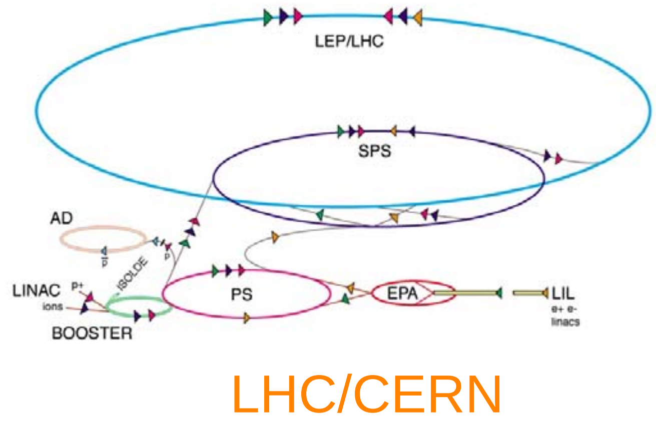
2D Electromagnetic Model of Fast-Ramping SC Magnets

B. Auchmann, R. de Maria, S. Kurz, and S. Russenschuck

Overview

- Fast-ramping SC magnets are a challenge for designers as well as for design-tool makers.
- The FAIR project at GSI requires R&D in the field.
- CERN is investigating fast-ramping alternatives to PS and SPS rings.
- ROXIE as well as other tools are preparing for the new challenges.



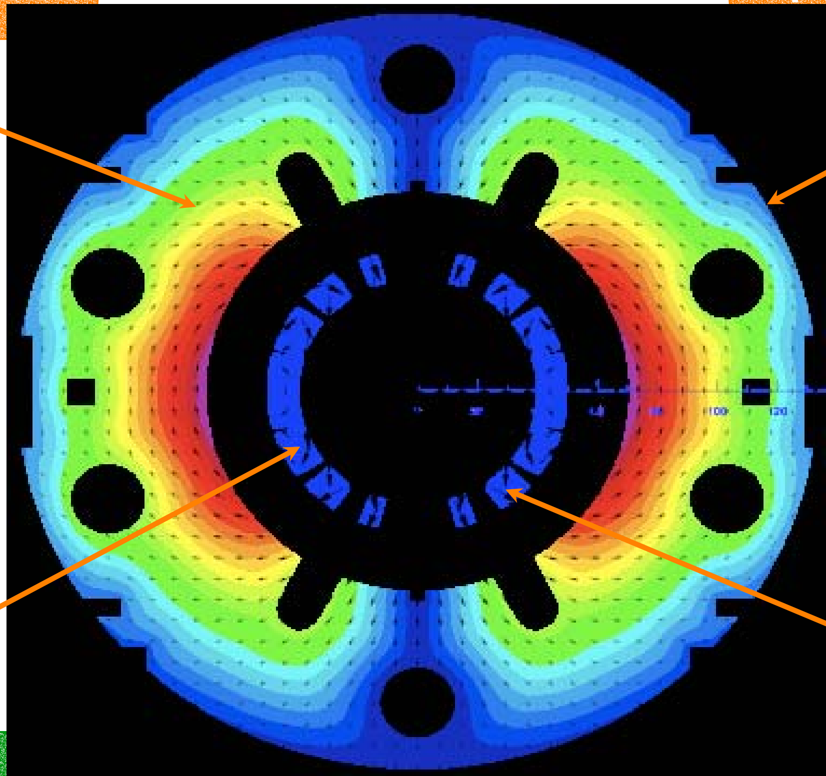


- We present:
  - the basic layout of the ROXIE electromagnetic model of fast-ramping magnets.
  - measurement- and simulation-data for the GSI001 dipole.

Field Computation Problem

Nonlinear Iron
Eddy Currents

High Saturation and
Fringe Fields



Persistent Currents

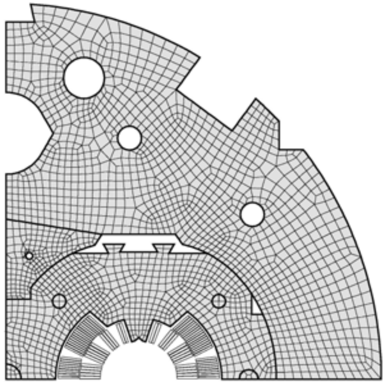
Interstrand
Coupling Currents

Interfilament
Coupling Currents

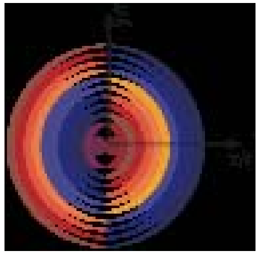
Models

Finite Elements

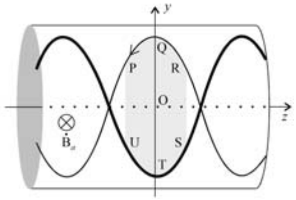
Boundary Elements



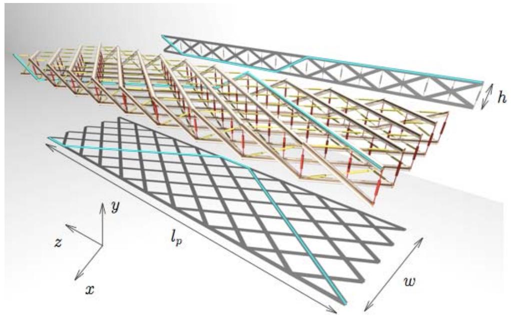
Persistent Current Magnetization Model



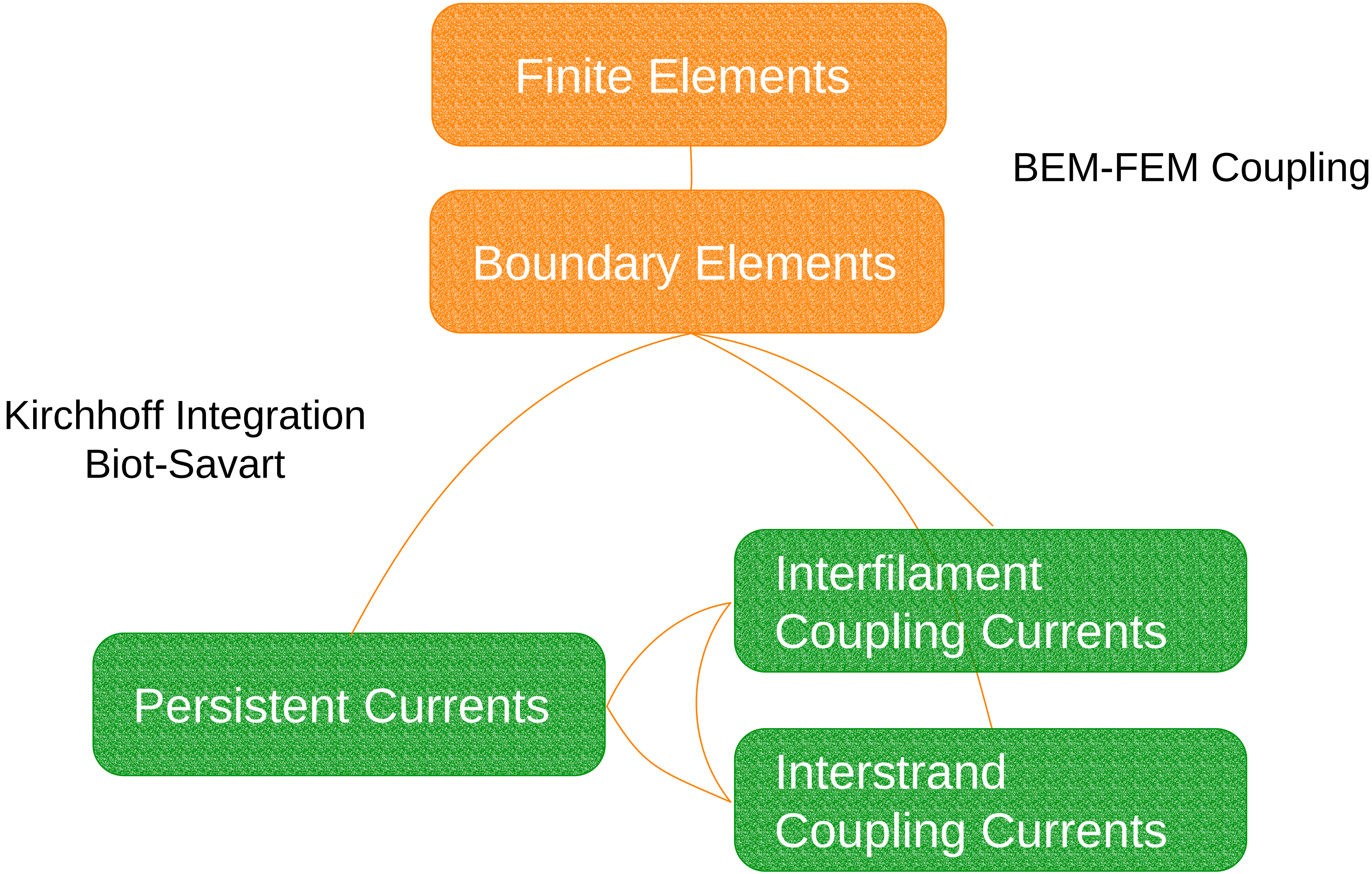
IFCC Magnetization Model



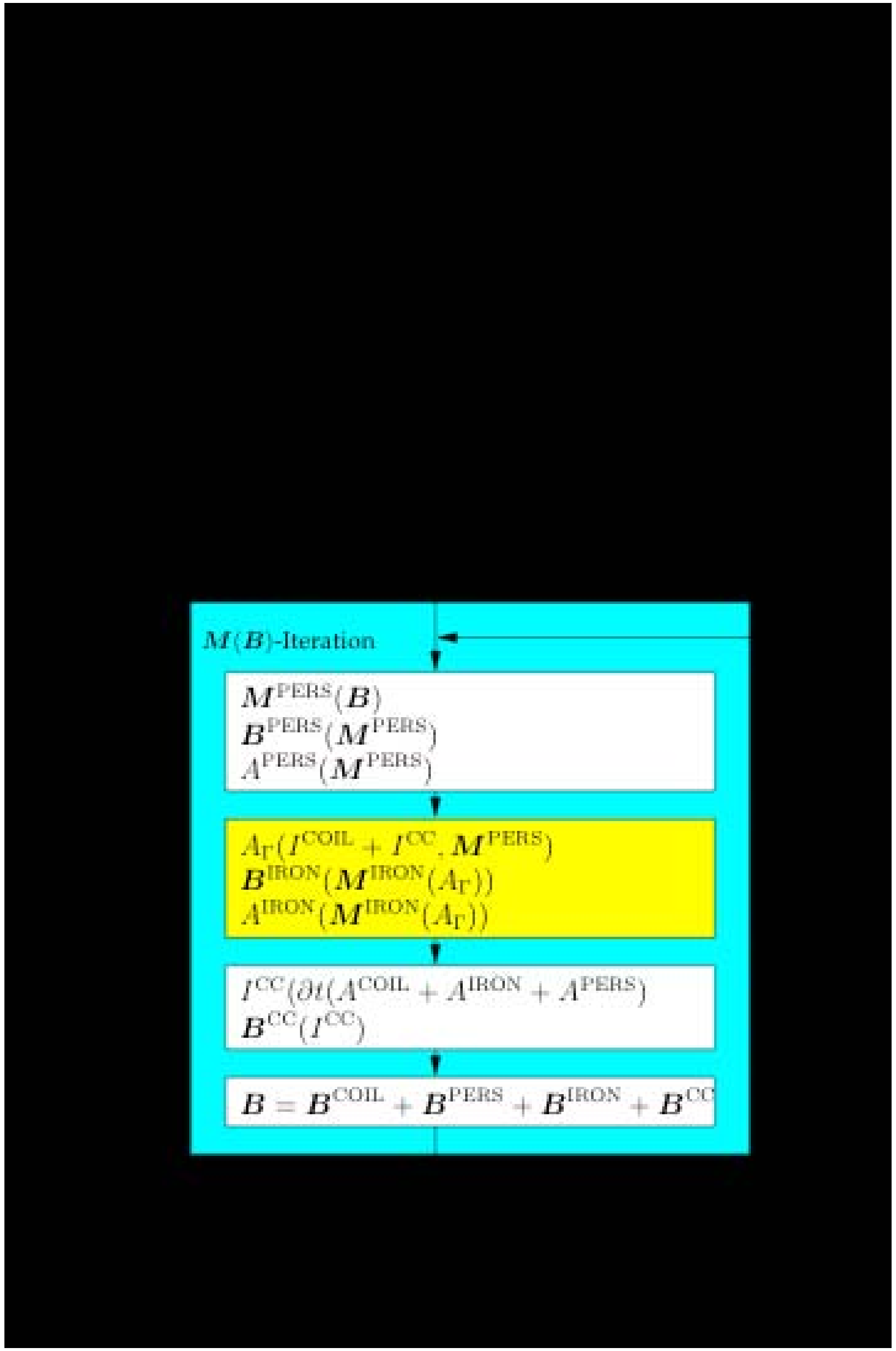
ISCC Network Model



Fixed Point Problem



Iteration Scheme



Boundary Elements

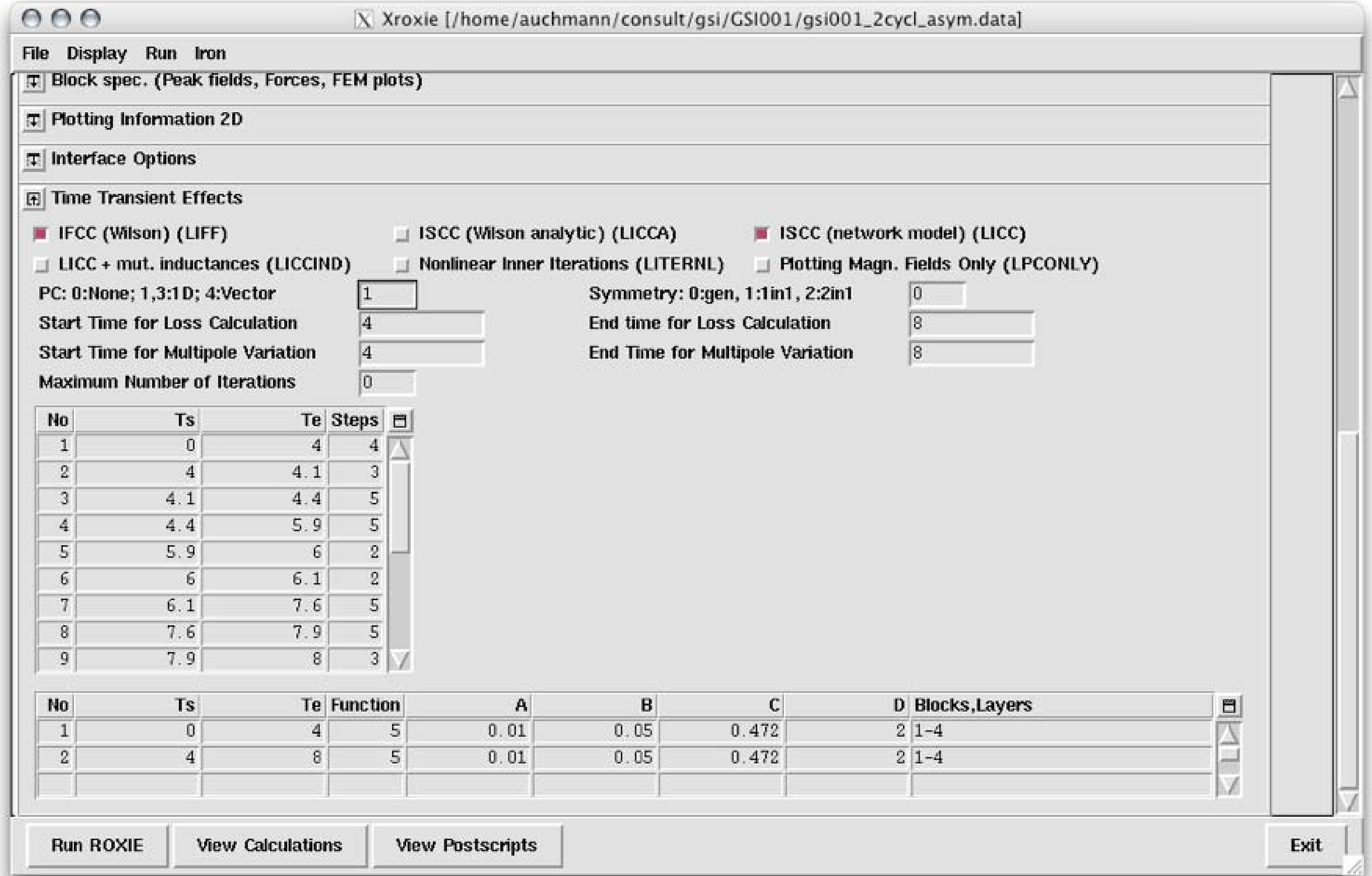
Finite Elements

Interfilament Coupling Currents

Persistent Currents

Interstrand Coupling Currents

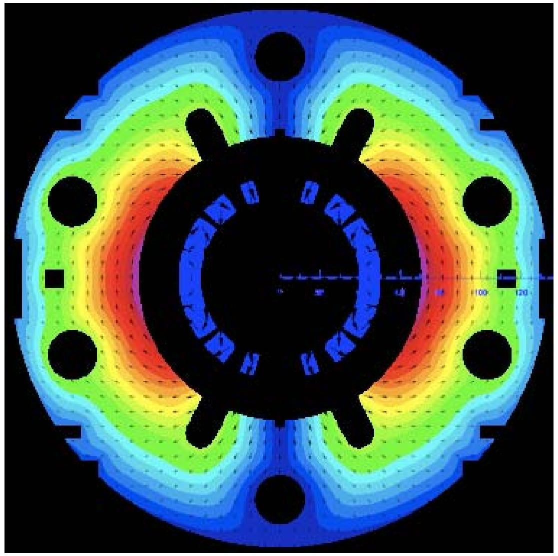
ROXIE Interface

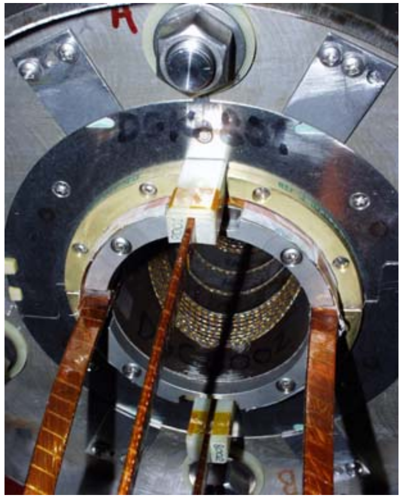


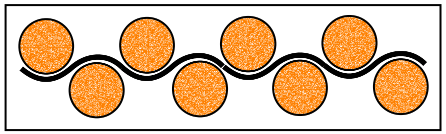
GSI001

- At Brookhaven National Laboratory a test magnet was built for GSI.
- It uses RHIC coil design with cored cable to control ISCC losses.

[A. Jain et al., *Measurements of the Field Quality in SC Dipoles at High Ramp Rates*, PAC 05]

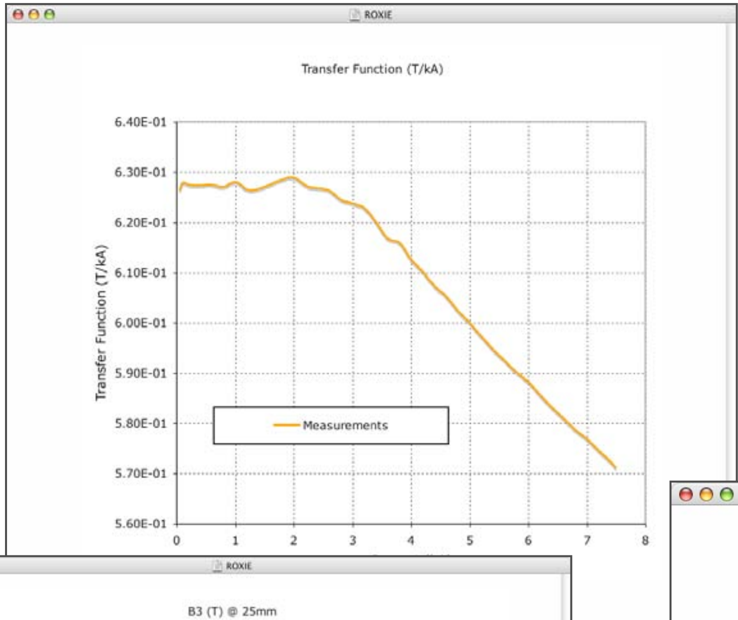


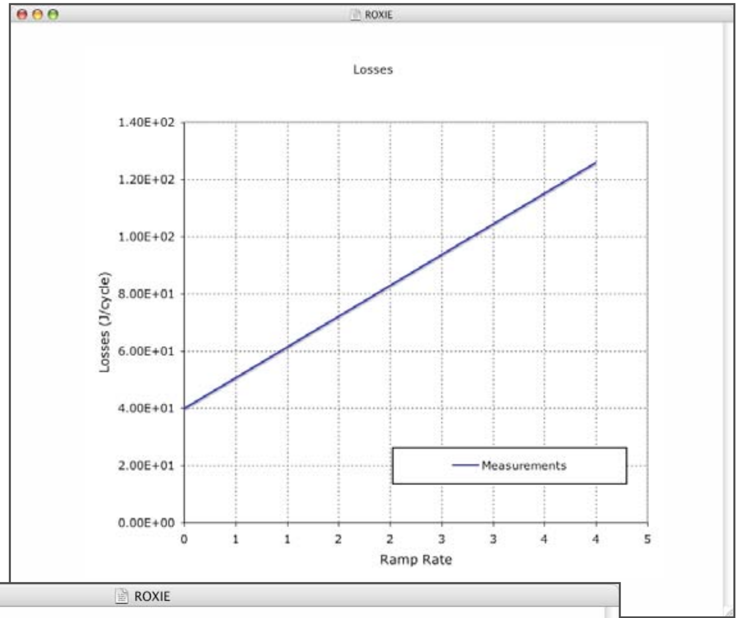


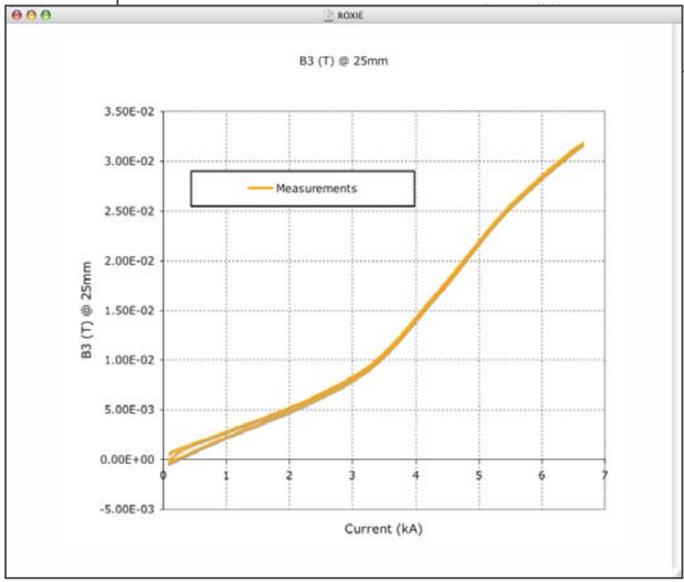


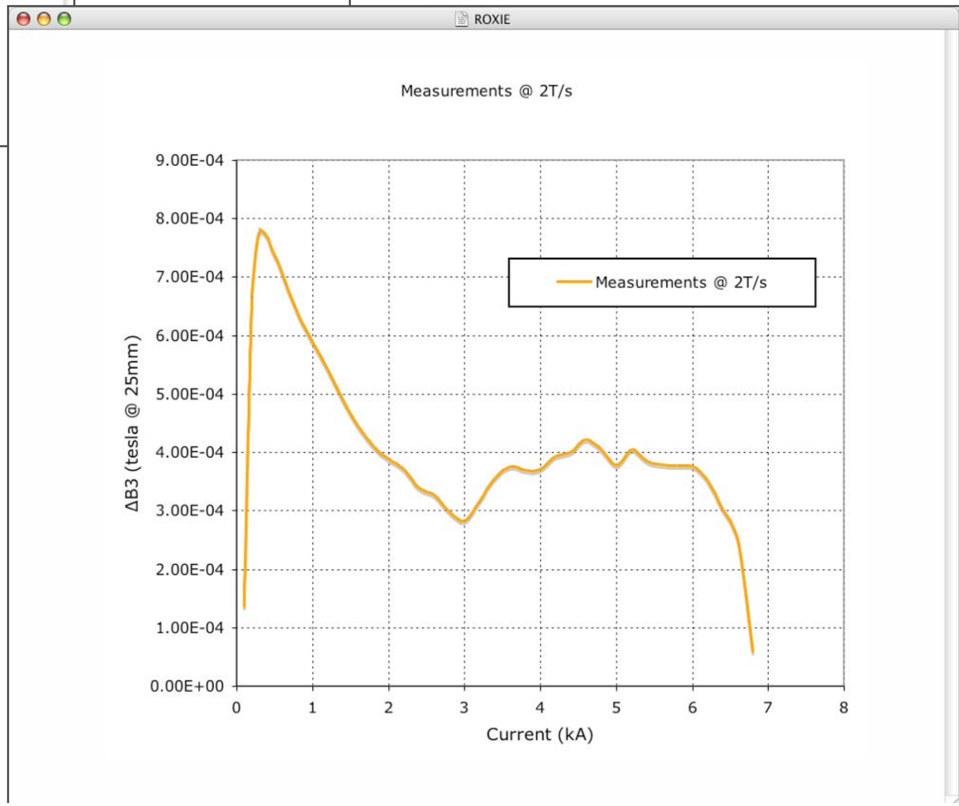
- Ramp rate up to 4T/s.
- Peak field 4T.
- Validate a new measurement system for fast multipole analysis.
- Measure losses per cycle.
- Measure field distortions.

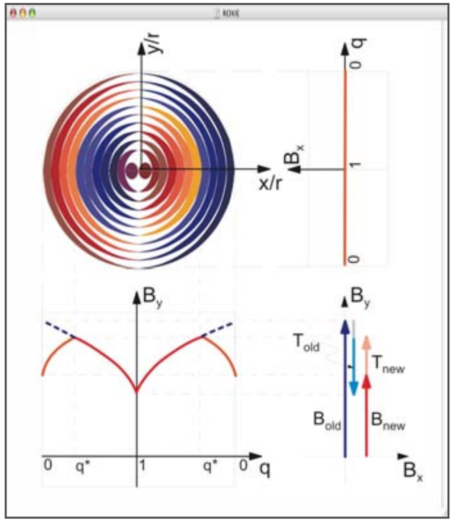
Observed Quantities



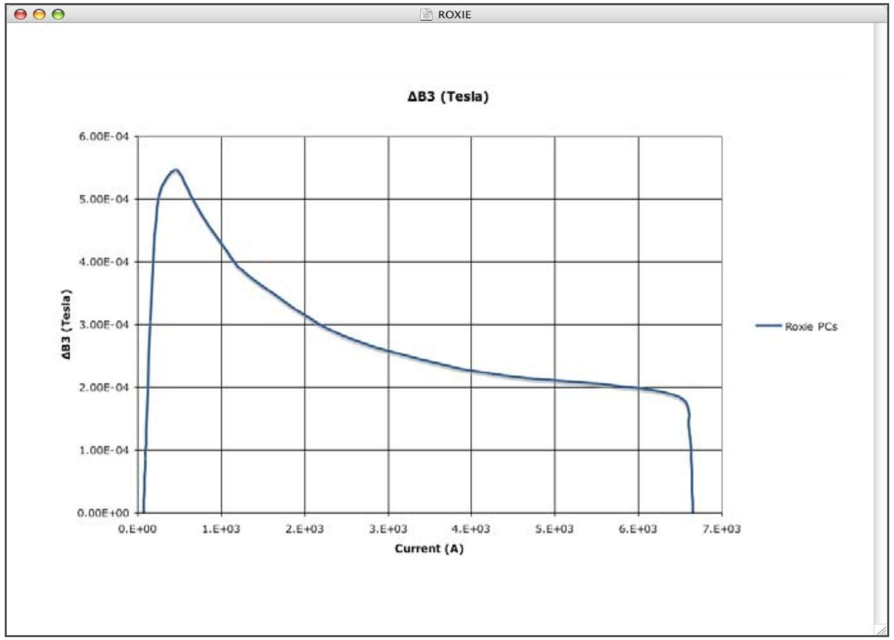


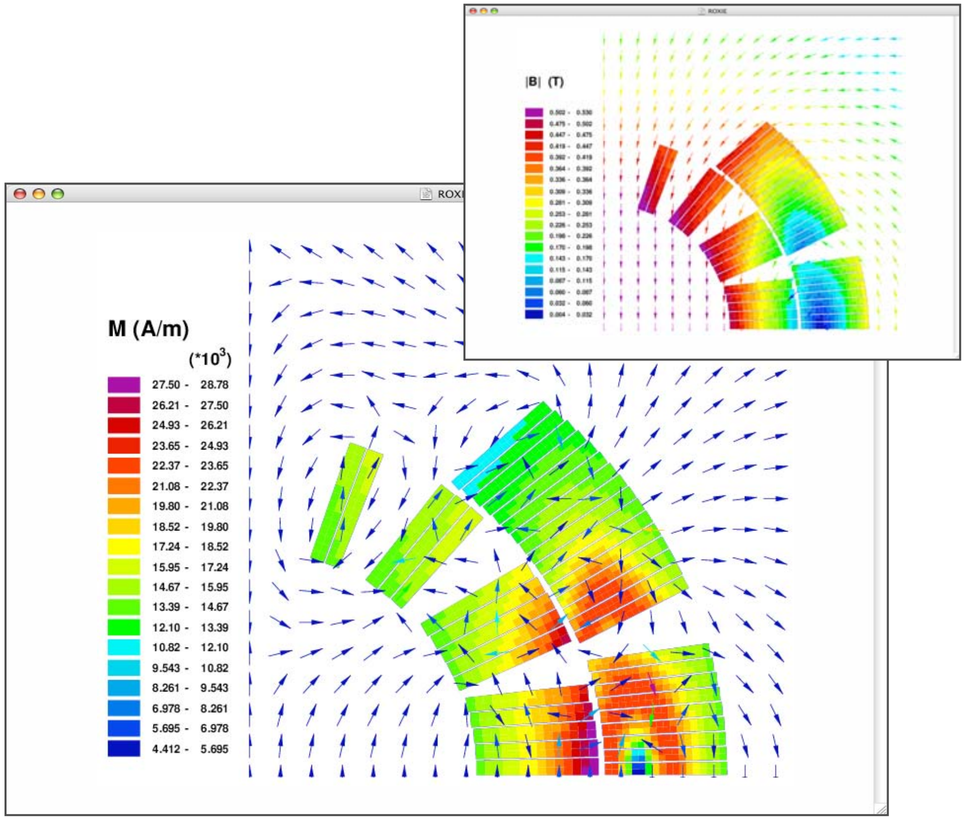




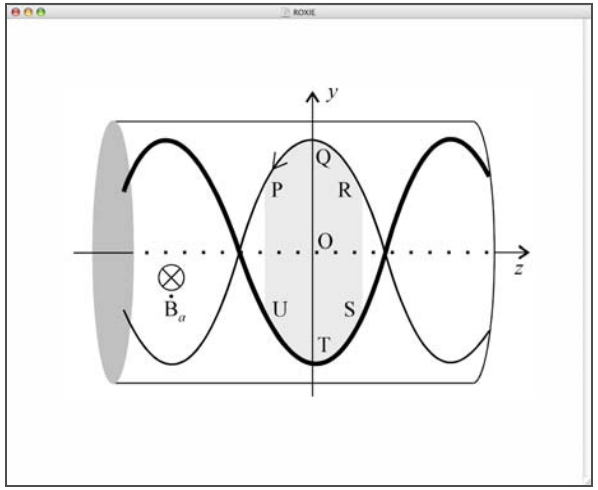


$$M_i = \frac{4r\xi}{\pi} \int_{q_i}^{q_{i+1}} j_c(B(q))(1-q)^2 \,\mathrm{d}q = \frac{4r\xi\,\mathcal{F}}{\pi} \int_{q_i}^{q_{i+1}} \frac{(1-q)^2}{\sqrt{B(q)}} \,\mathrm{d}q$$

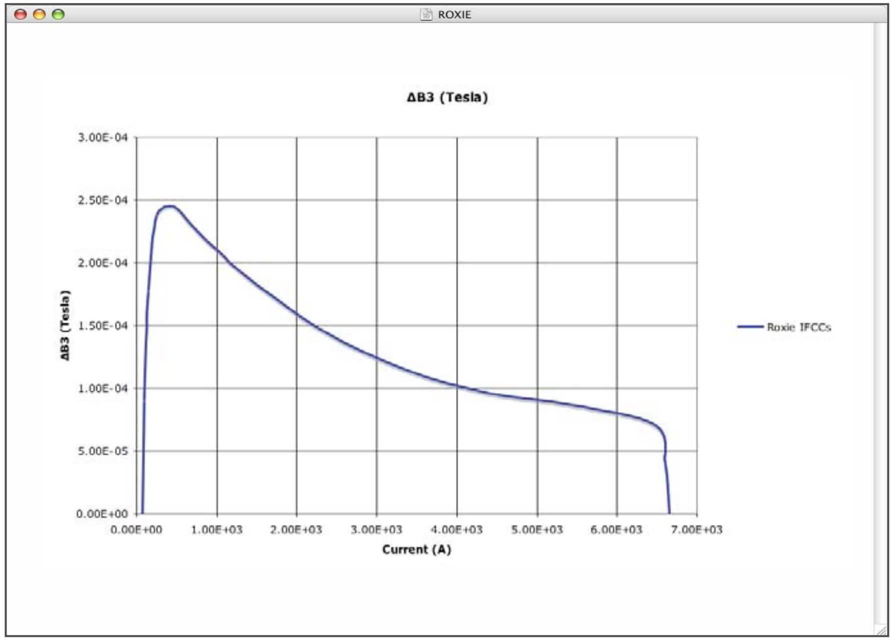


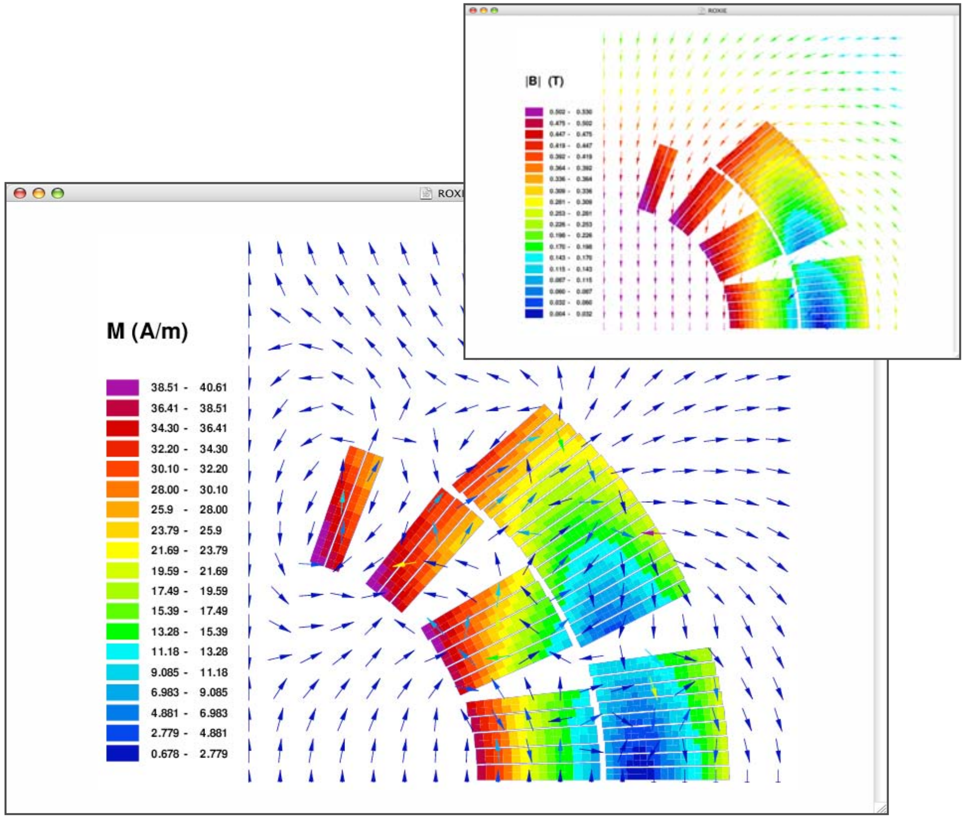


Interfilament Coupling Currents

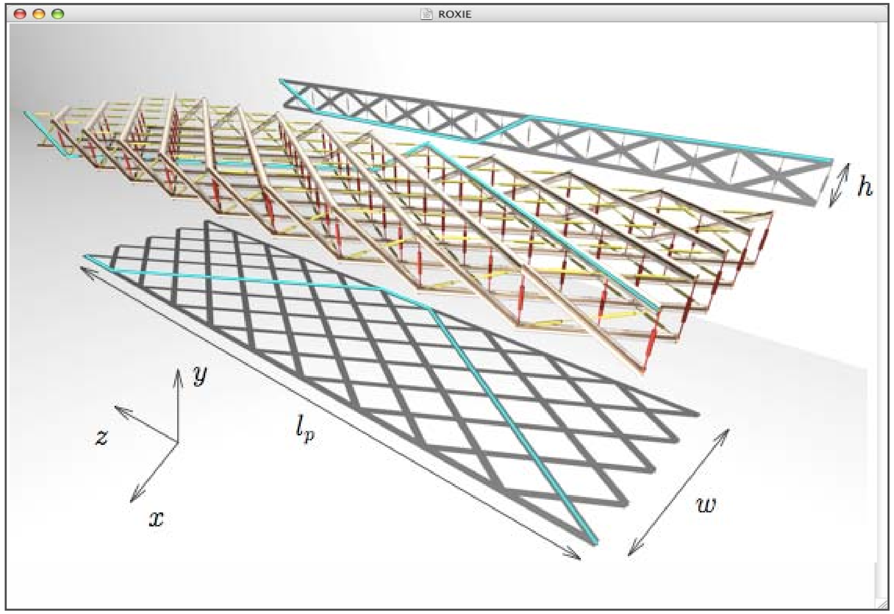


$$M_\mathrm{f} = \lambda_\mathrm{w}\, \partial_t B\, \frac{l_\mathrm{w}}{2\pi}\, \underbrace{\frac{1}{\rho_0 + \rho_1 B}}_{\rho_\mathrm{eff}.}$$

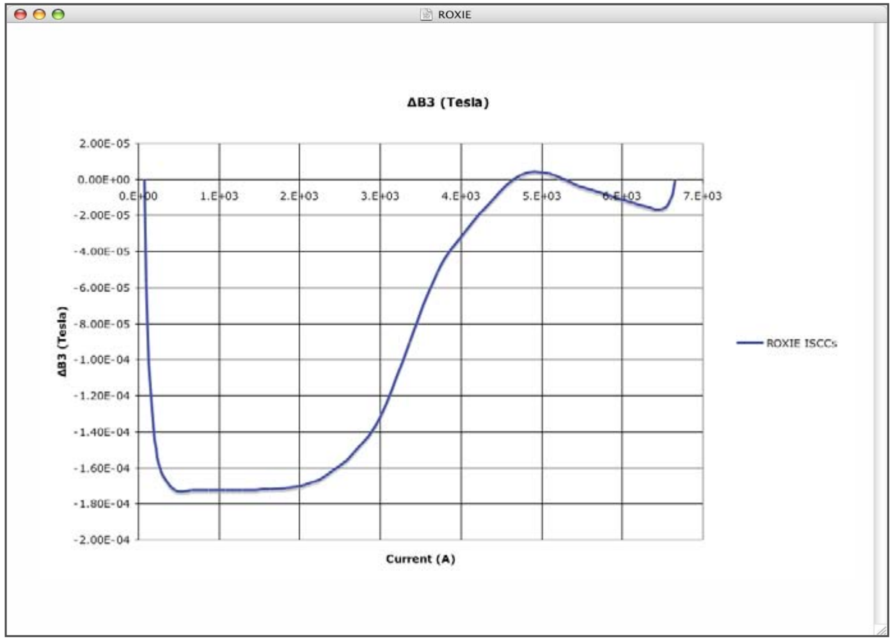


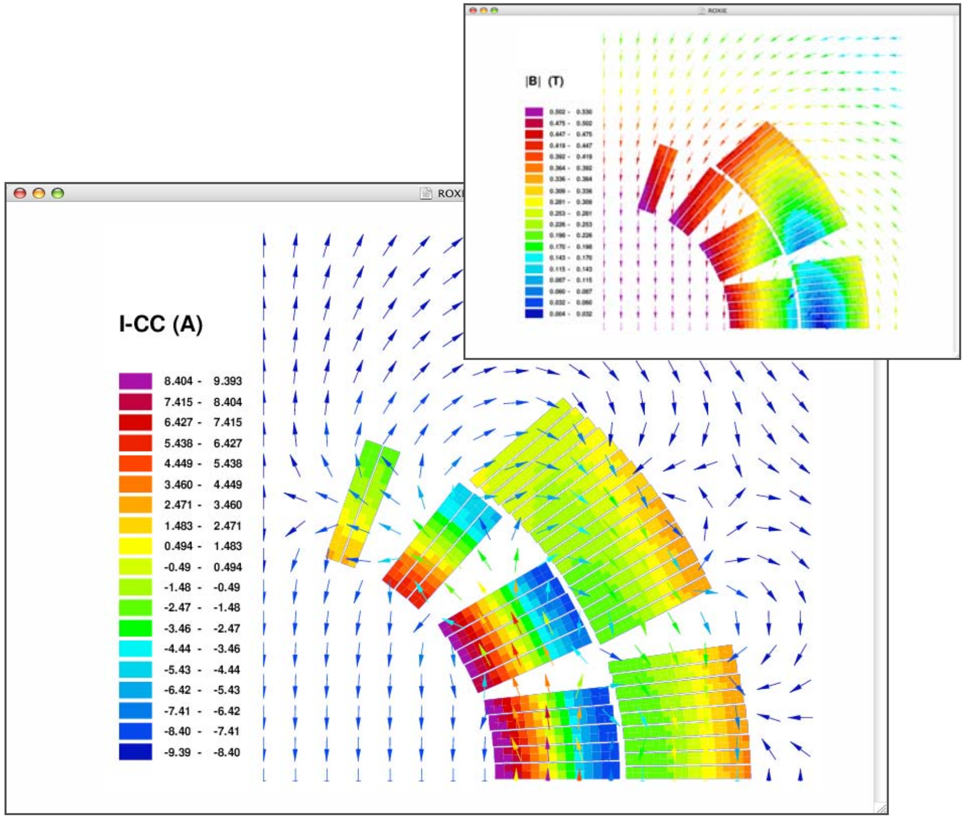


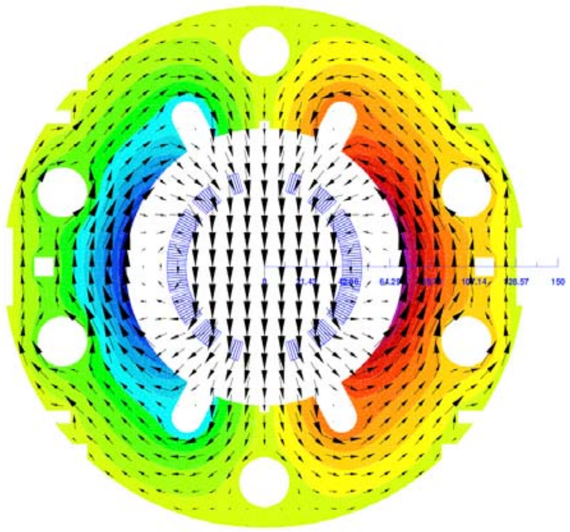
Interstrand Coupling Currents

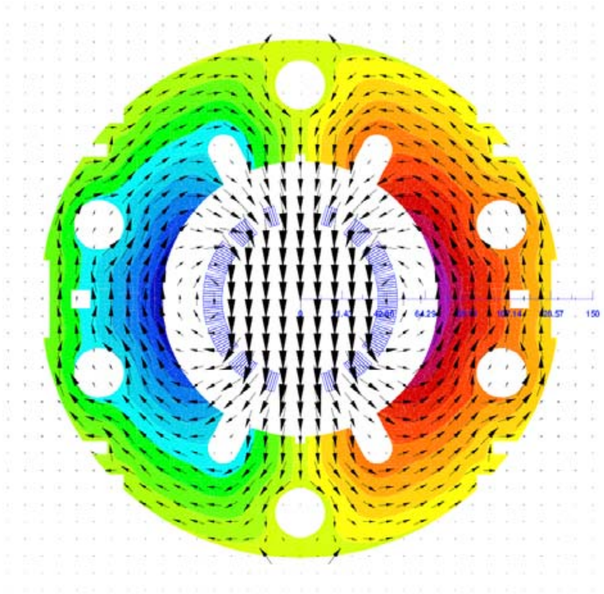


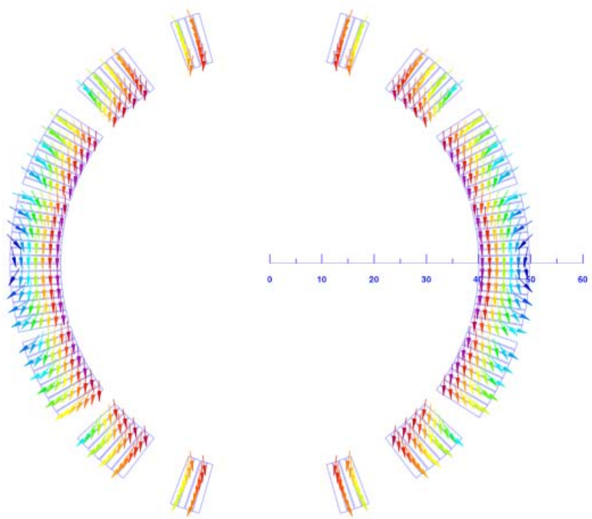
$$\{I\} = -[\mathrm{M}]([\mathrm{M}][\mathrm{R}][\mathrm{M}]^{\mathrm{T}})^{-1}[\mathrm{M}]\{\partial_t A\}$$

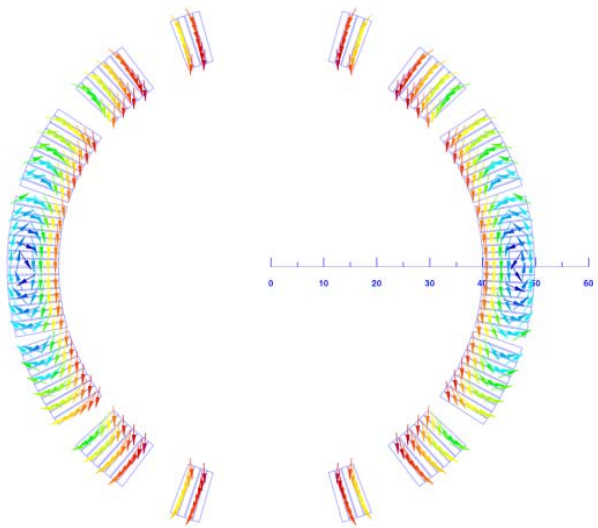




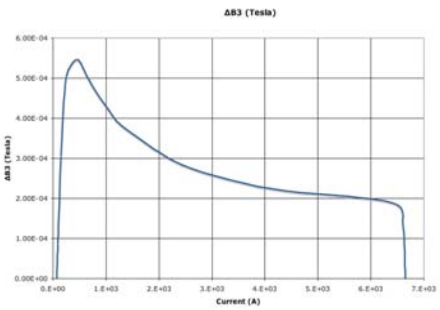





0
10
20
30
40
50
60

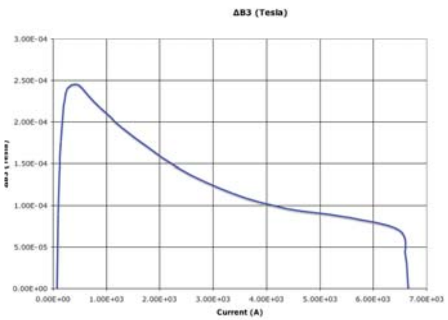

0
10
20
30
40
50
60

Bringing the Models Together



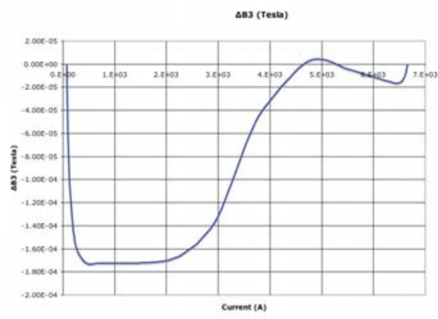
PCs

+



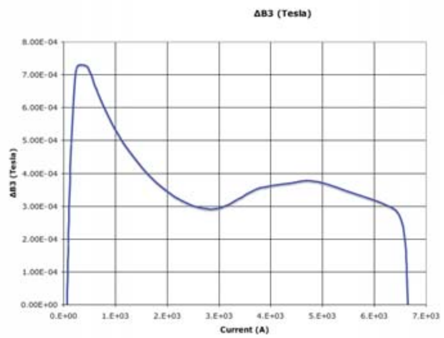
IFCCs

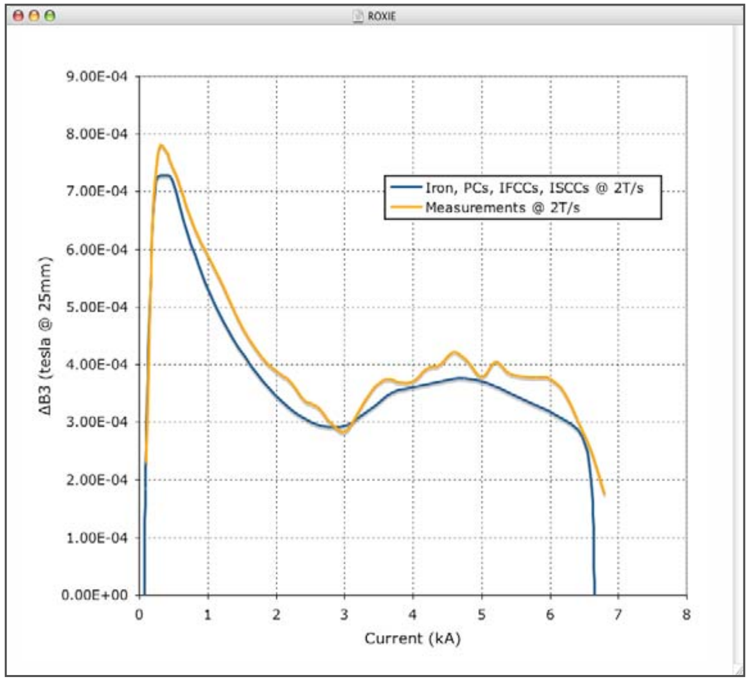
+

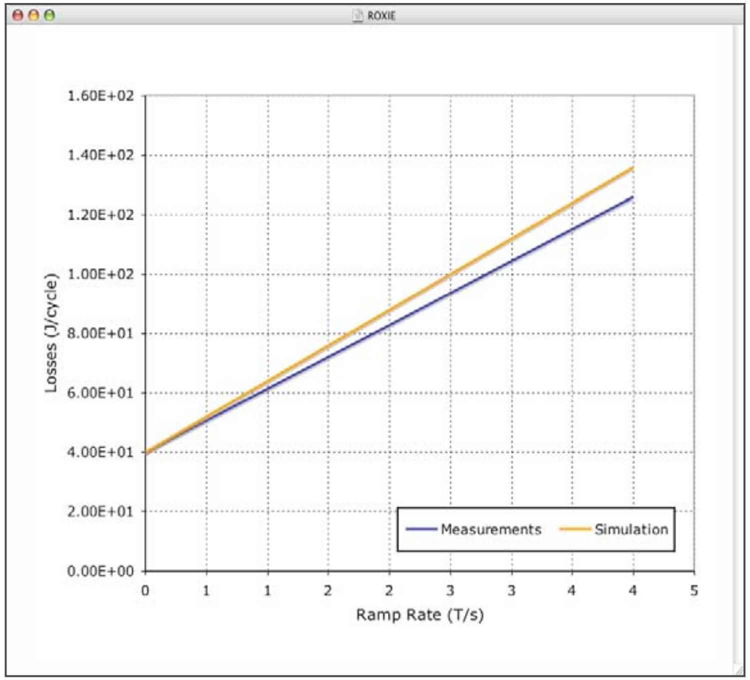


ISCCs

=



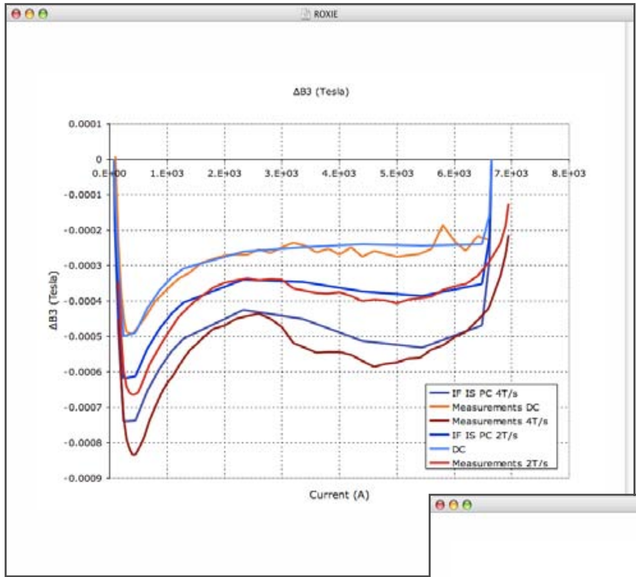


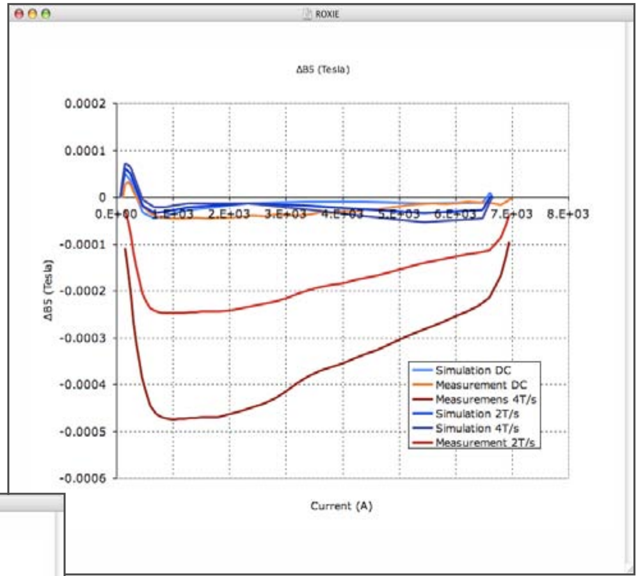


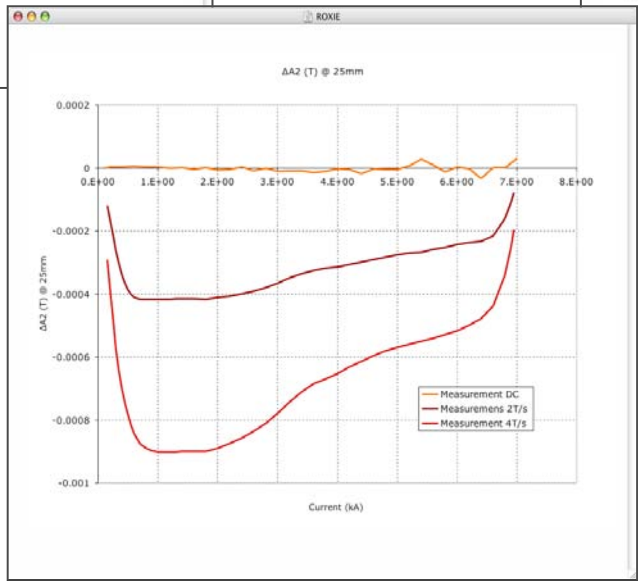
Are we done?

→ We have ignored iron-hysteresis losses and parasitic eddy-current losses.

→ We do not predict B5 and A2 correctly.



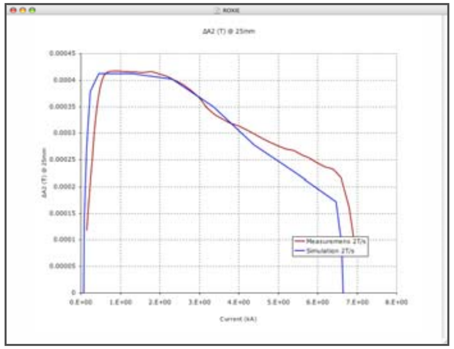


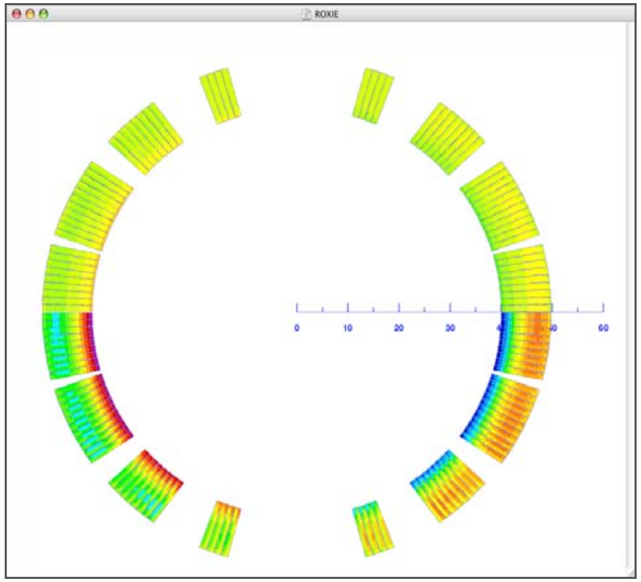


+ we are overpredicting losses already!

More Questions and Answers

- ➔ Does an up-down asymmetry in adjacent resistance account for A2?
- ➔ Is a factor 5 between upper and lower coil realistic?





- ➔ And where does B5 come from?

- ➔ The presented work points to an unidentified conductive body in vicinity to the magnet aperture.
- ➔ Investigate eddy currents in the yoke structure.
- ➔ Look out for more conductive parts in the magnet.