Magnet Simulation Activities at Fermilab

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PAC2007, Workshop on June 25-26, 2007

Interesting Simulations and Magnets

- Main Injector Wide Bore Quadrupole optimization and analysis
- Pulsed ORBUMP magnet
- Coupled Helical Solenoid electromagnetic and mechanical analysis
- Booster Multipole Corrector – six magnets in one
- There are a lot simulations of superconducting dipoles and quadrupoles for LHC, HFM and LARP programs (not included in this presentation)

Main Injector Wide Bore Quadrupole

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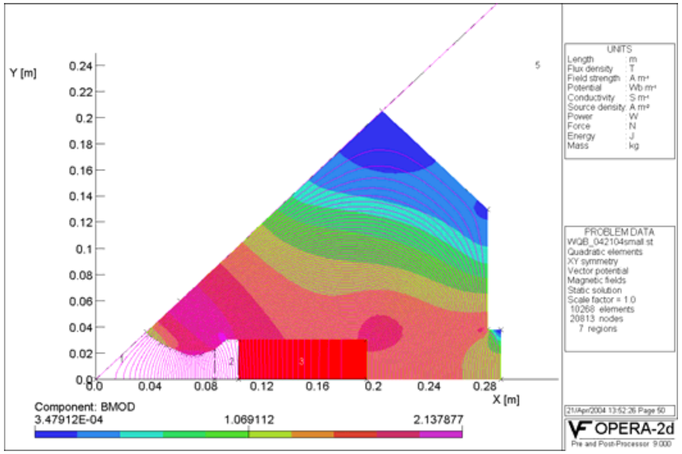
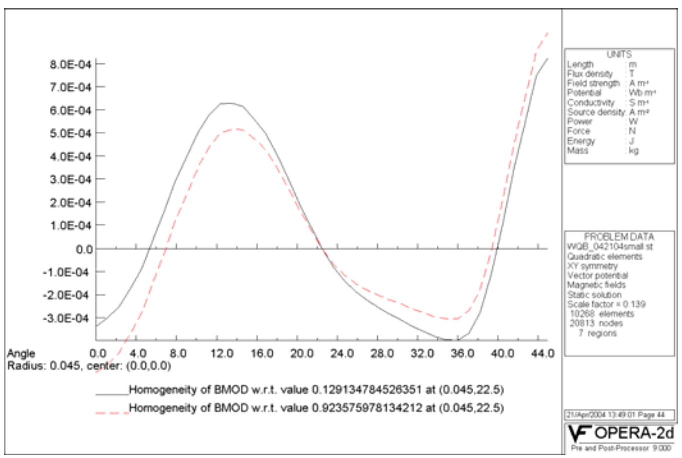
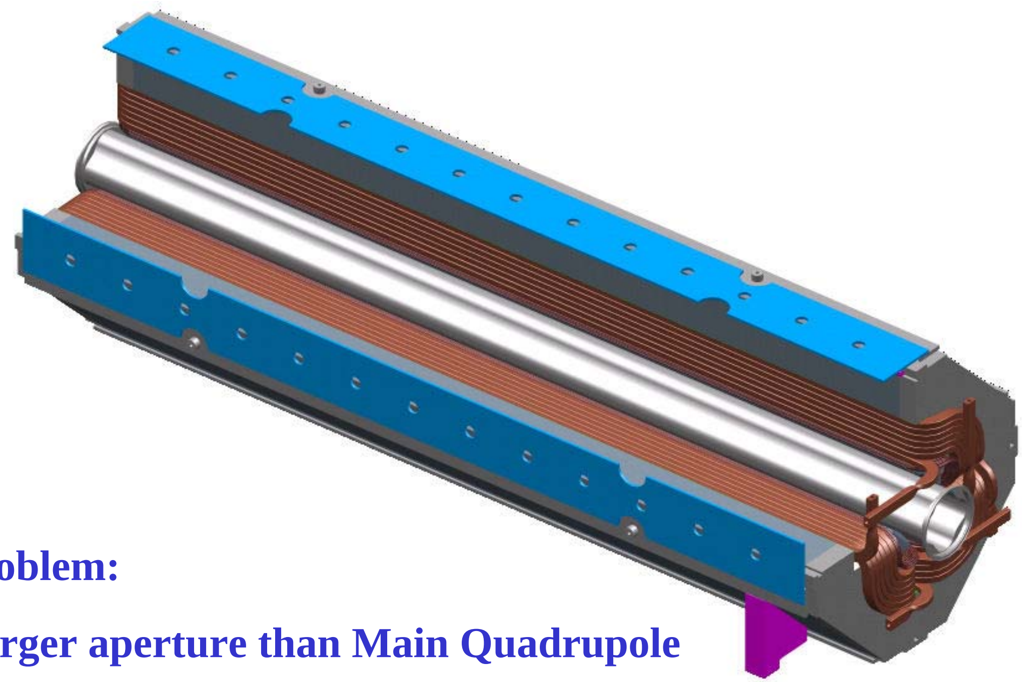




Pole profile optimization: OPERA 2D+Optimizer.

Minimization of field distortions at reference radius.



Problem:

Larger aperture than Main Quadrupole

The same current and transfer function

Good field quality at all currents

WQB Quadrupole

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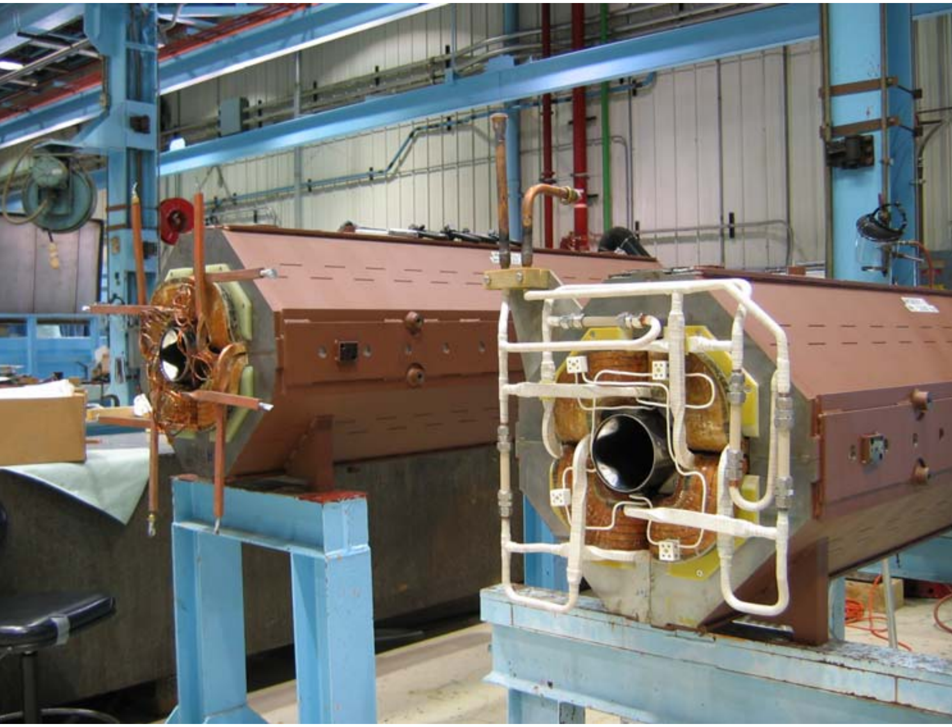

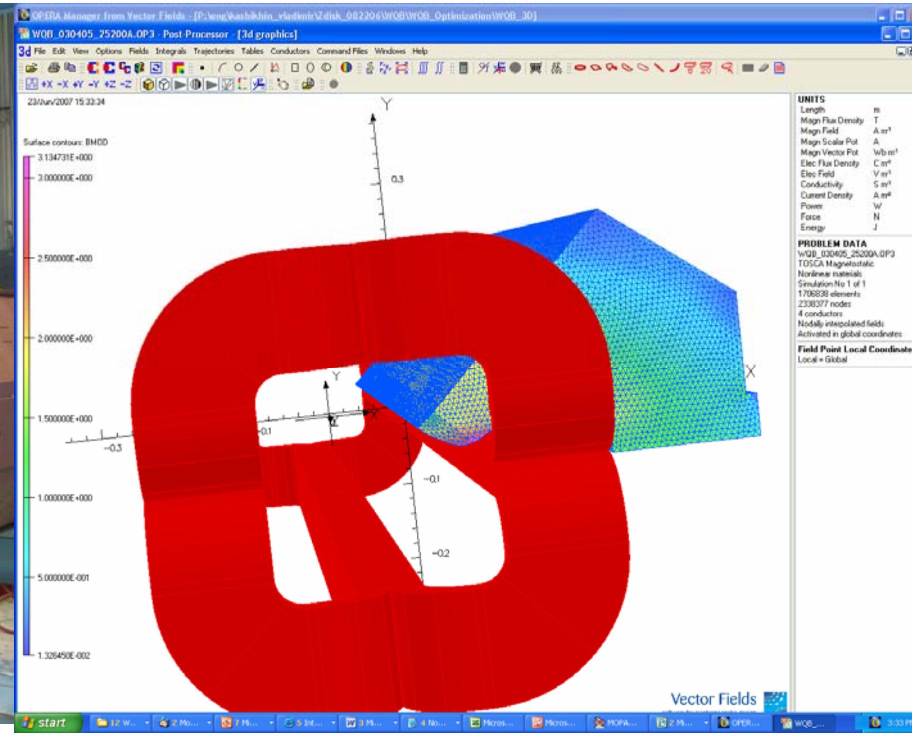

2D Pole profile optimization

3D Pole end optimization for integrated field and final analysis

2.2 million nodes, Magnets installed and work in Fermilab Main Injector

Pulsed ORBUMP Booster Magnet

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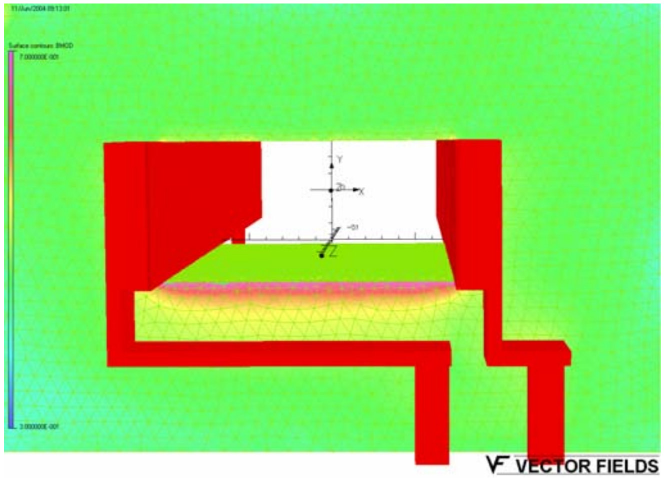
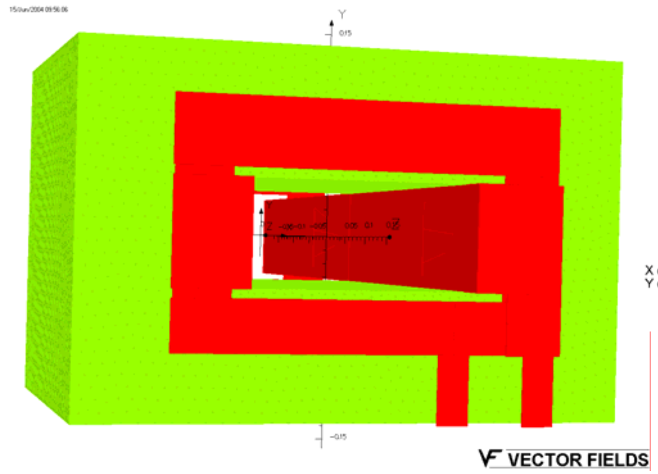
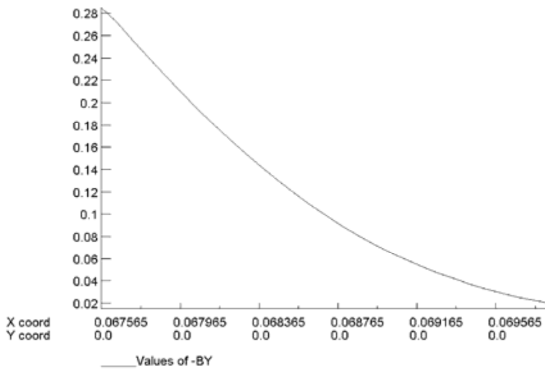
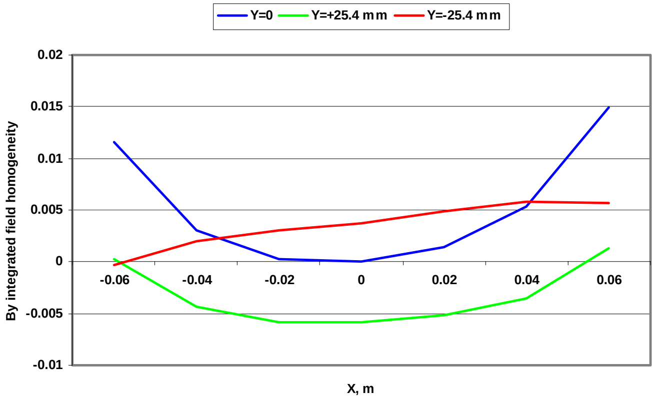
OPERA 2D, TOSCA, ELEKTRA used for simulations

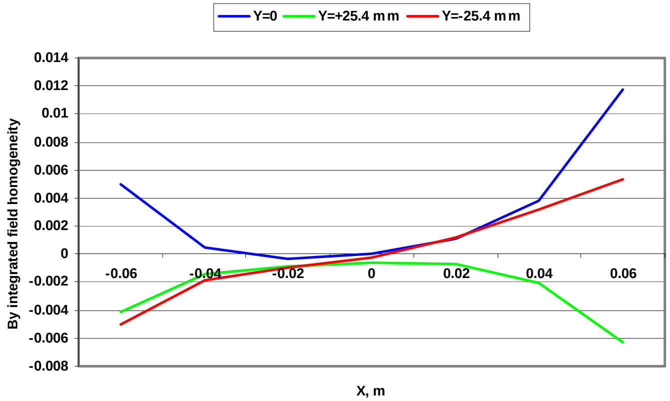


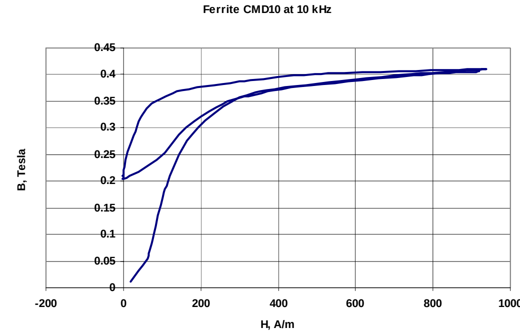




Field diffusion into conductor







Non-symmetrical coil current leads

Symmetrical coil current leads

High saturation ferrite

Pulsed ORBUMP Magnet

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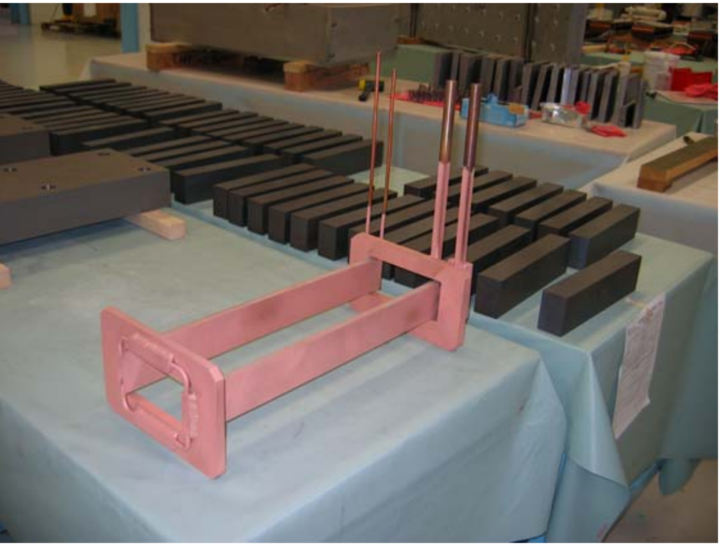
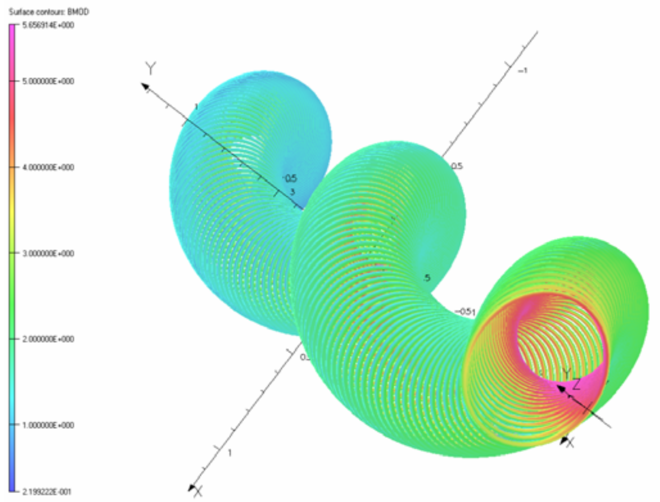
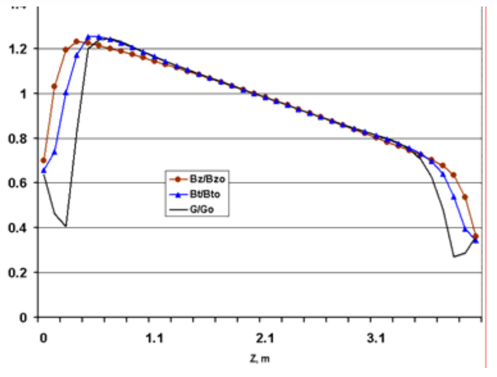


- 4 magnets built and successfully work in Booster
- Used new high flux density ferrite with Bs=0.4 T
- TOSCA code gave qood prediction of magnet ends asymmetry
- ELECTRA code was difficult to implement for this task. It seems, problem in solving coupled systems of equations: induced eddy currents balancing with transport current and total voltage.
- Magnets installed and work in Booster

Muon Cooling Helical Solenoid

OPERA 3D, G4Beamline, COMSOL



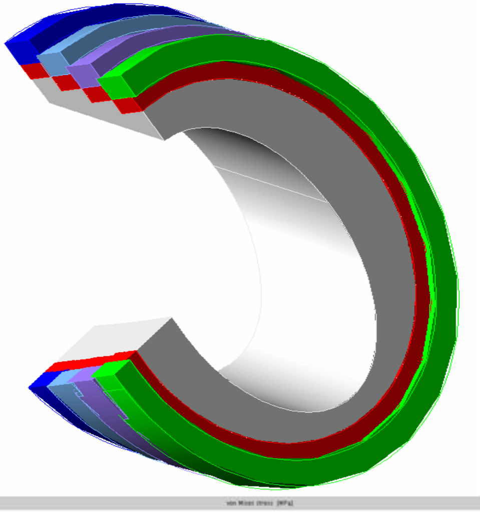


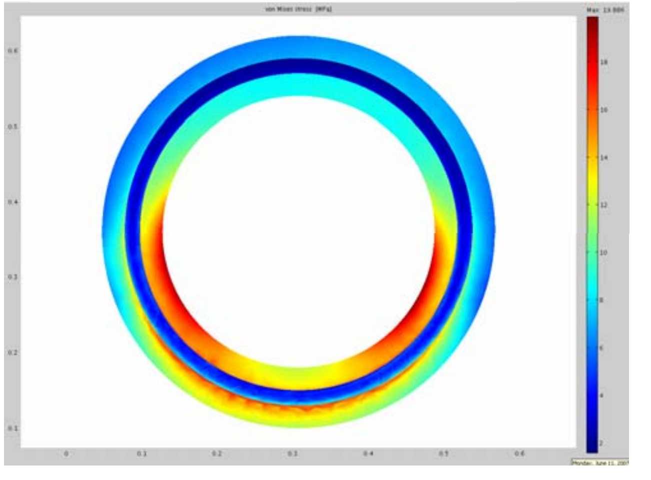
Used only OPERA3D Postprocessor for field calculations.

OPERA3D field map was used as G4Beamline input

For Muon tracking and cooling analysis.

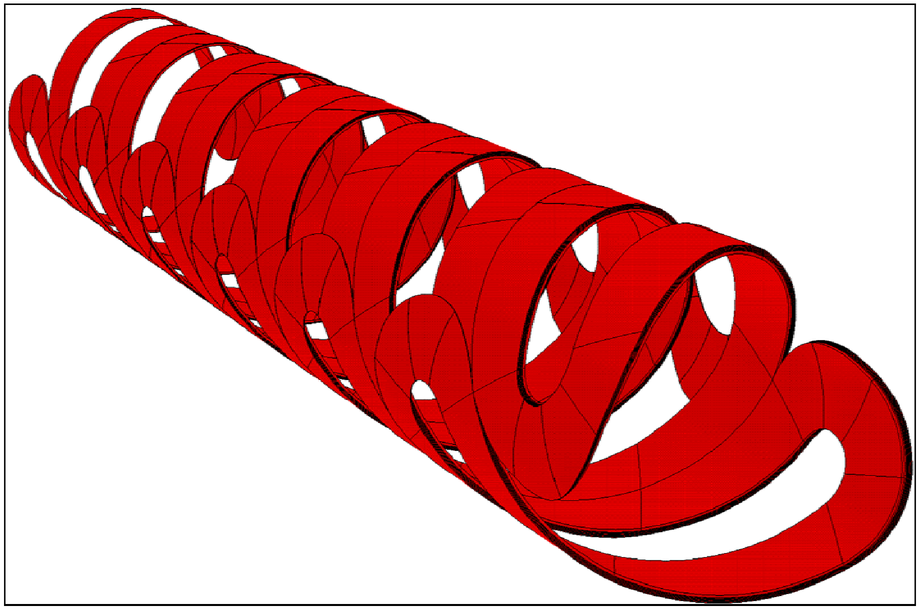
Relative gradients d/dz are the same 0.17 1/m !

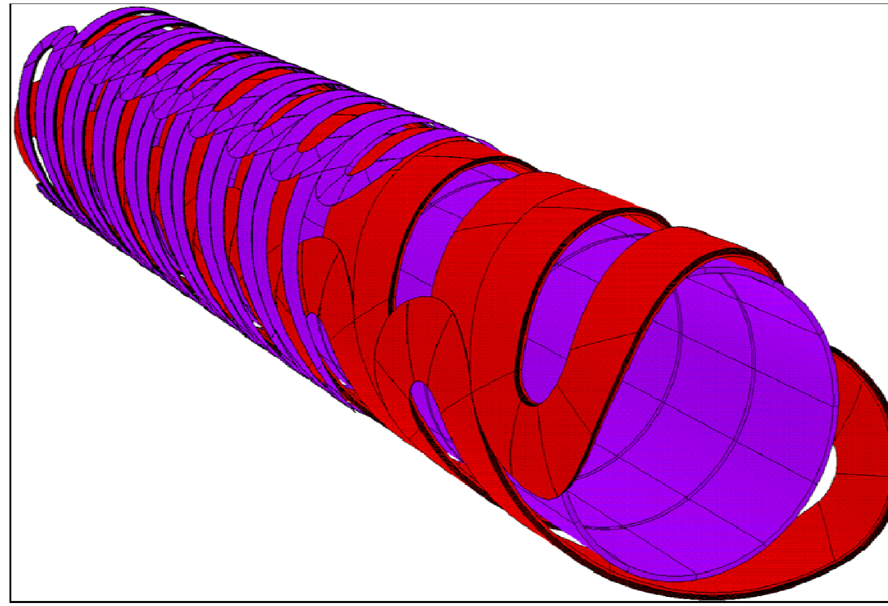




COMSOL 3D Magnetic+Mechanical analysis

Large Bore Muon Cooling Channel



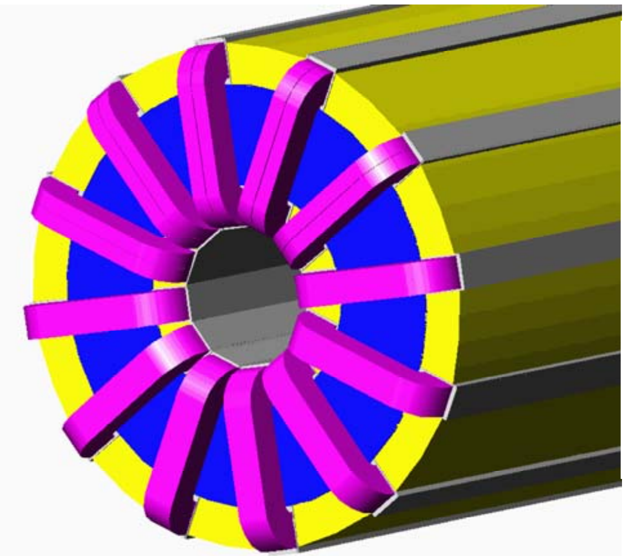


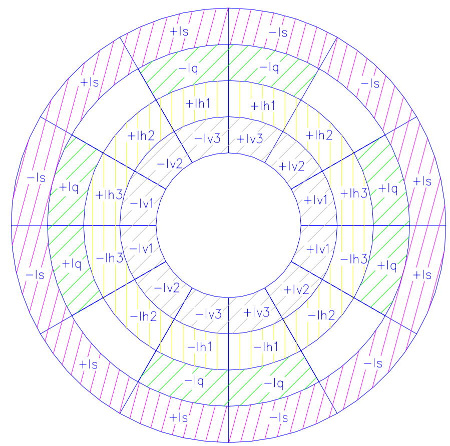
Helical Dipole modeled using current subelements in OPERA3D. MODIFY operations for current elements will help a lot in such cases.

Vadim Kashikhin simulated this complicated superconducting system. Helical Dipole+Helical Quadrupole+Solenoid with Field Decay along Z

Superconducting Multipole Corrector

Combined multipole field generated by 12 coils powered separately





Dipole+Quadrupole+Sextupole Coil Currents:

$I_1 = I_{12} = I_{d1} + I_q + I_s$ $\quad$ $I_{12} = - I_1$

$I_2 = I_{11} = I_{d2} - I_s$ $\quad$ $I_{11} = - I_2$

$I_3 = I_{10} = I_{d3} - I_q - I_s$ $\quad$ $I_{10} = - I_3$

$I_4 = I_9 = -I_{d3} - I_q + I_s$ $\quad$ $I_9 = - I_4$

$I_6 = I_7 = -I_{d1} + I_q - I_s$ $\quad$ $I_7 = - I_6$

$I_5 = - I_2$

$I_8 = - I_5$

A proper programming of power supplies can eliminate also all field deviations caused by manufacturing deviations, iron saturation effects, etc. The current of each N coil is the sum of the dipole, quadrupole and sextupole components:

IN = IND + INQ + INS

Design was proposed for BTeV. Project closed.

Booster Multipole Corrector

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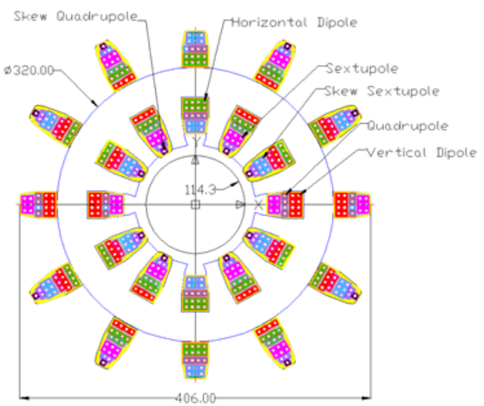
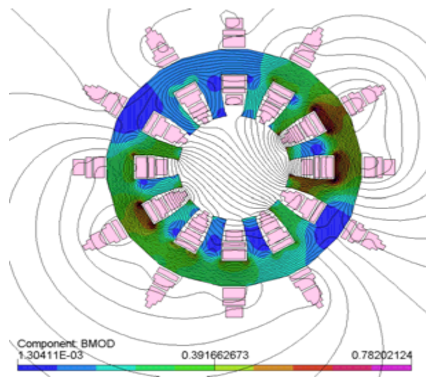
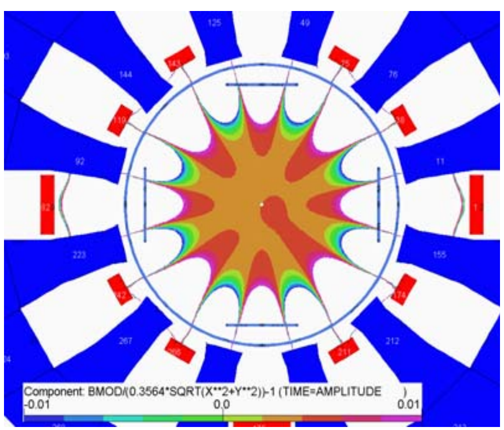
6 Magnets in one + BPM

Normal and skew: dipoles, quadrupoles, sextupoles

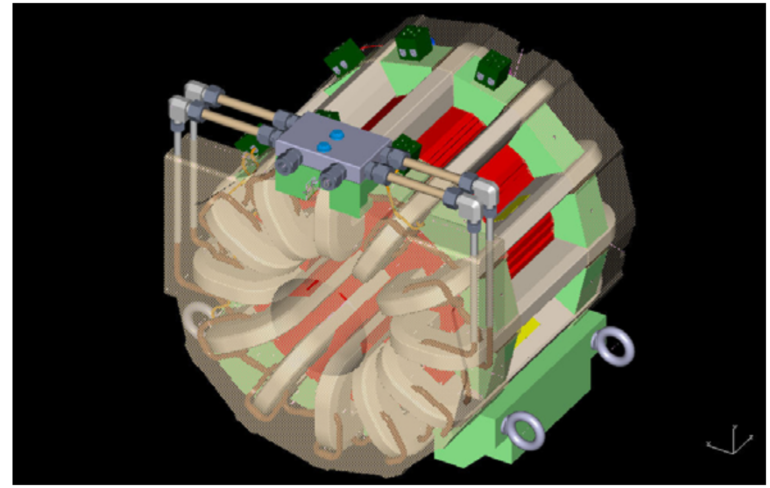


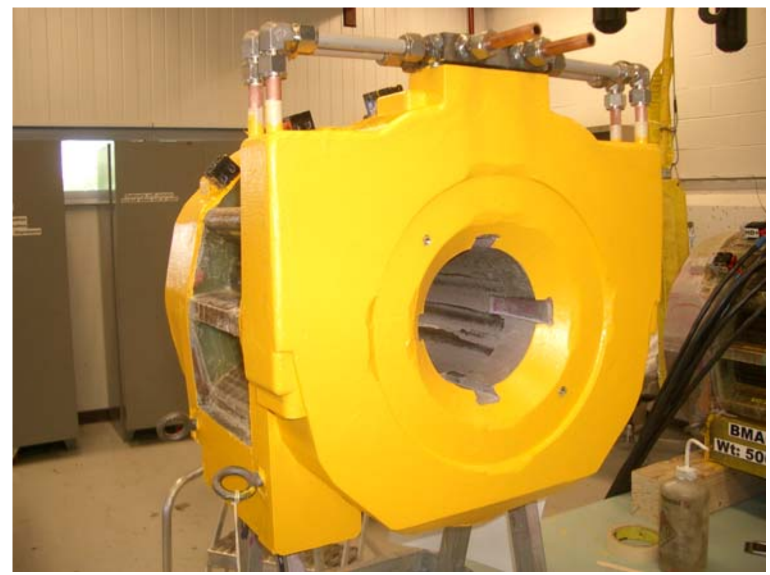




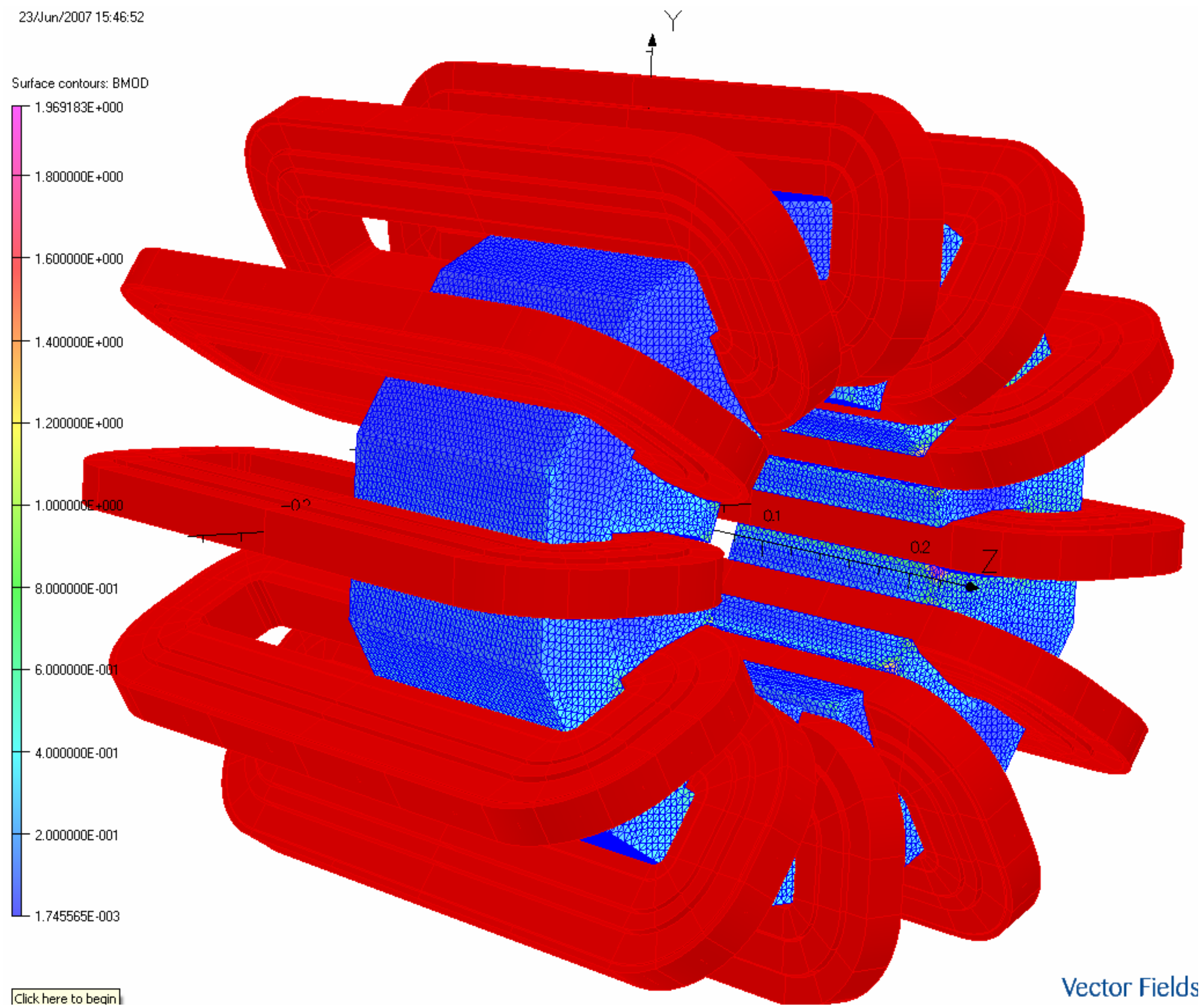
Field distortions because of eddy currents in BPM at 1 ms ramp, OPERA 2D TR.

24 Magnets will be installed in Booster on August 2007.





3D Magnetic Simulation of Corrector



TOSCA code

4.2 million elements

Shown variant when all coils powered by maximum current

To check iron maximum field

Summary

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• Magnet simulations at FERMILAB based on OPERA 2D, OPERA 3D (TOSCA, ELEKTRA), ANSYS, ROXIE, COMSOL, G4Beamline, MathCad

• Magnet simulations provide opportunity for optimization: pole profiles, holes in pole, pole ends, winding turns position and currents.

• All used software provide correct solutions at promised accuracy.

• Next generation software should include optimization software which suitable for magnet design.

• The cooperation between different platforms at low level. Problems to transfer data from CAD to Magnet software, use field maps for beam optics analysis, solve coupled problems by different codes.

• Not exists a magnetic and superconductor material data base.

• Nevertheless, progress in software and computers helped design novel and good quality magnets.