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Effect of an Iron Yoke of the Field Homogeneity in a Superconducting Double-Helix Bent Dipole

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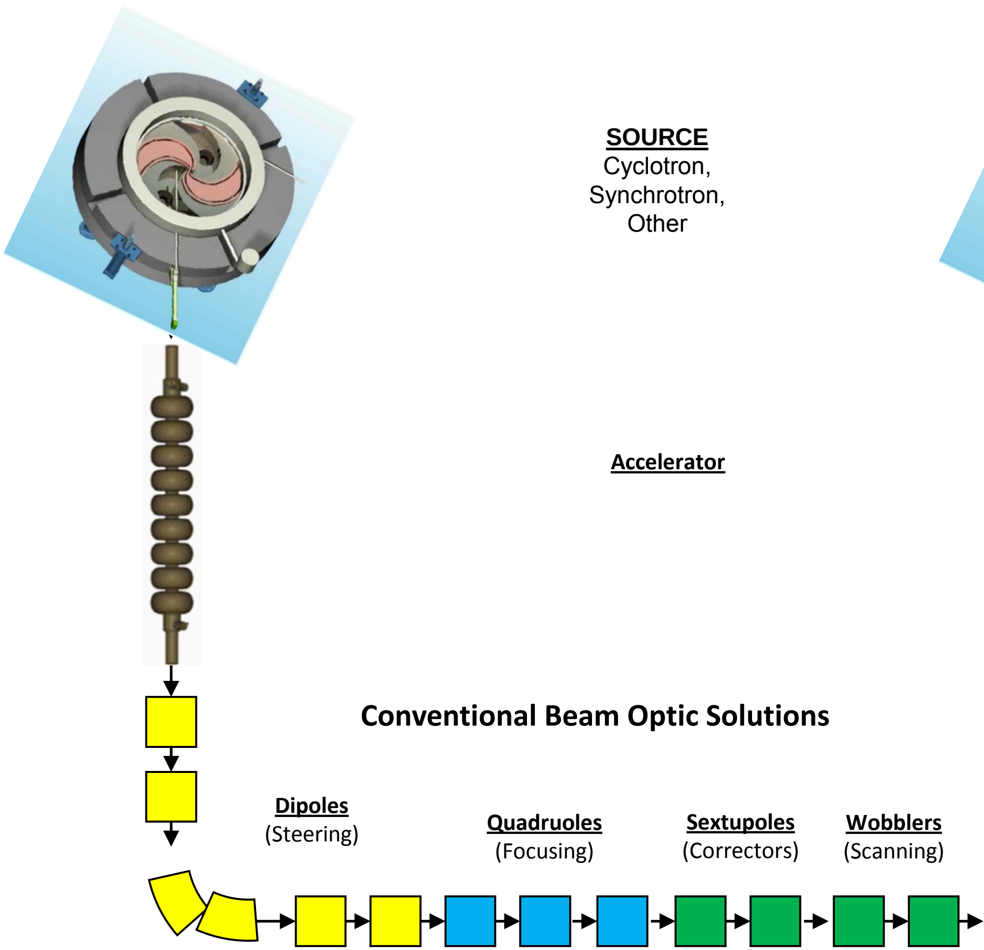
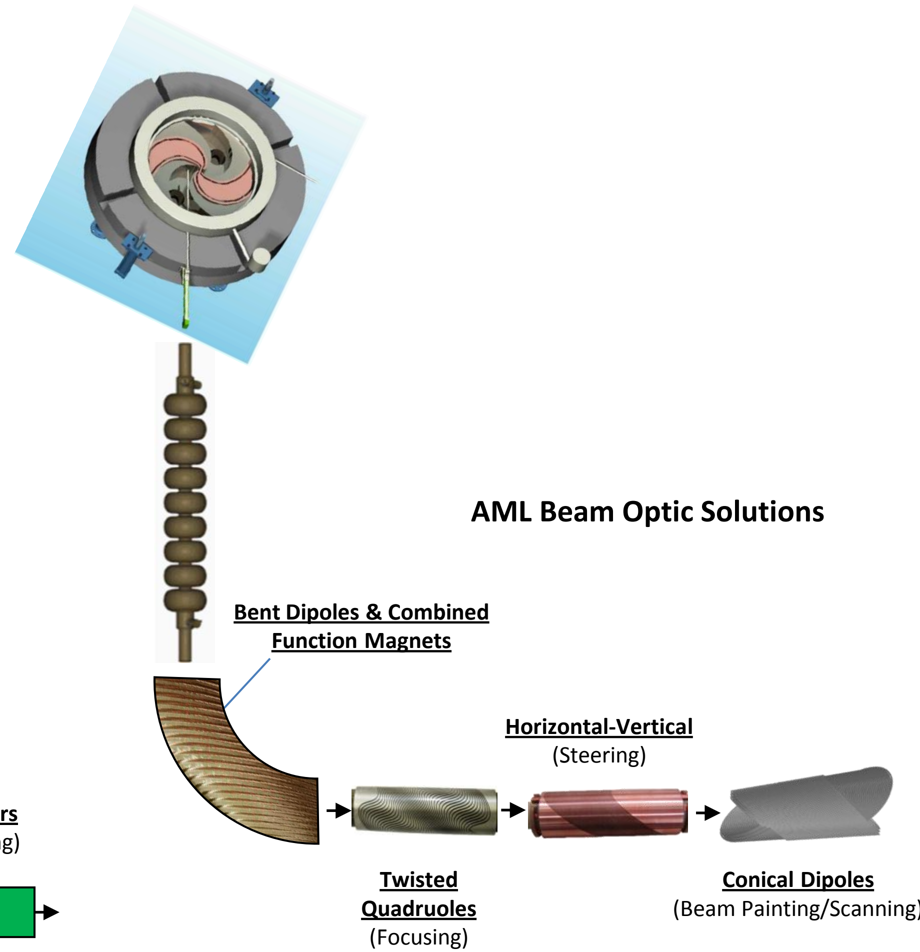
Schematic of a Particle Accelerator

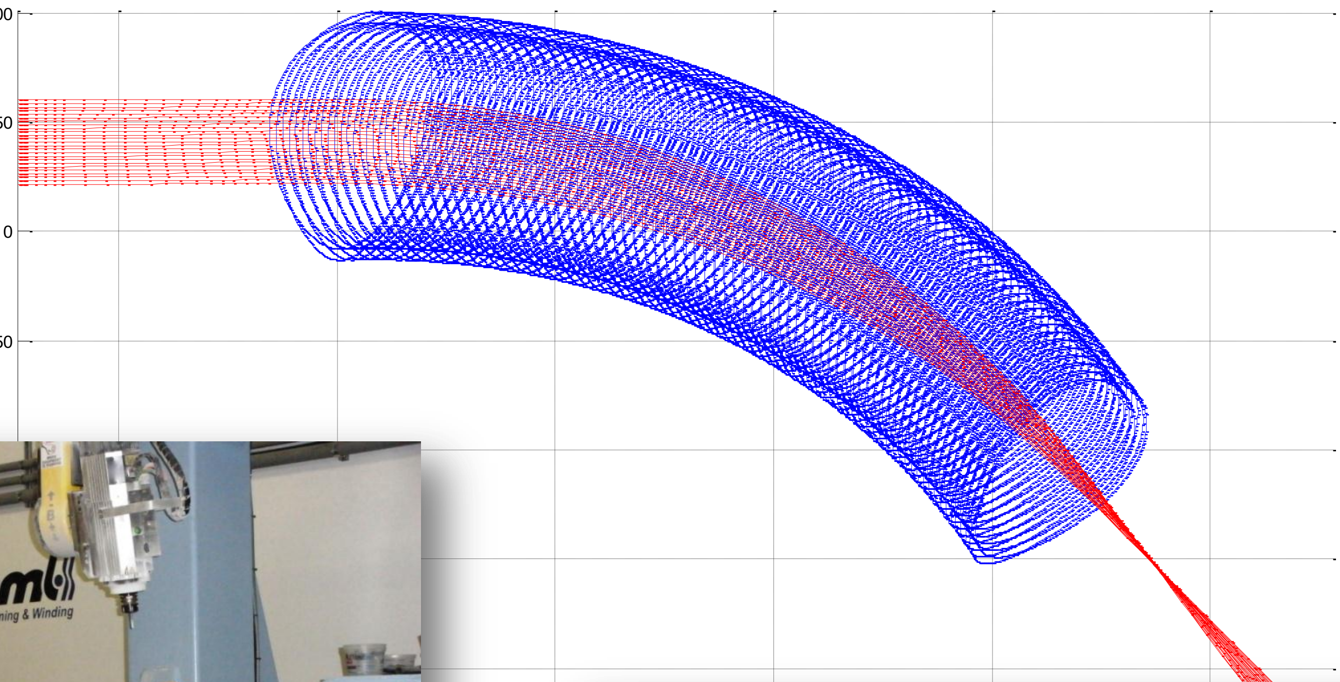
- Particle accelerators come in two basic designs, linear (linac) and circular (synchrotron, shown below).

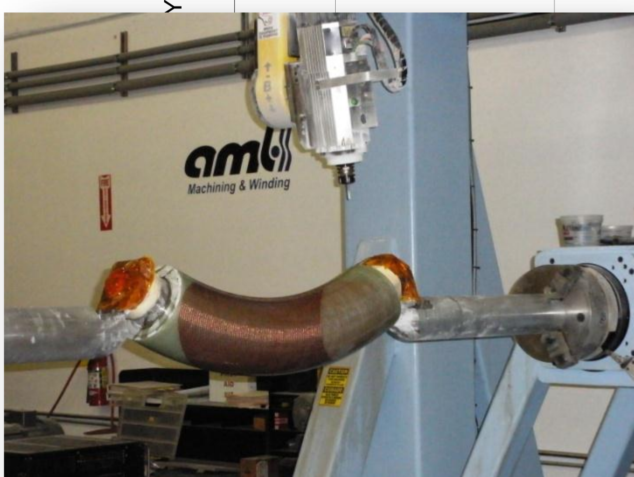




DH Combined Function Magnet

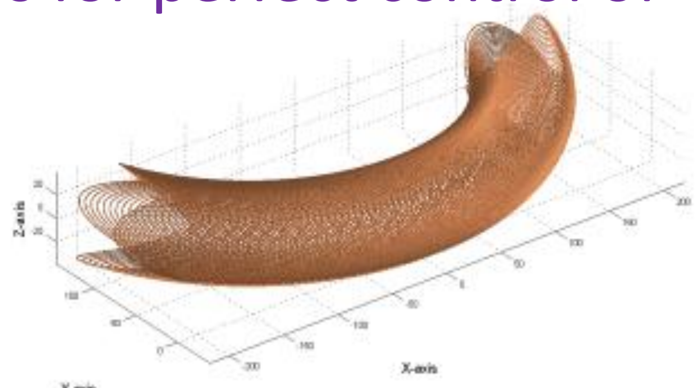
- Double-Helix™ winding enables the development of combined function magnets
- Beam with horizontal spread in bent dipole-quadrupole combined function magnet





Introduction

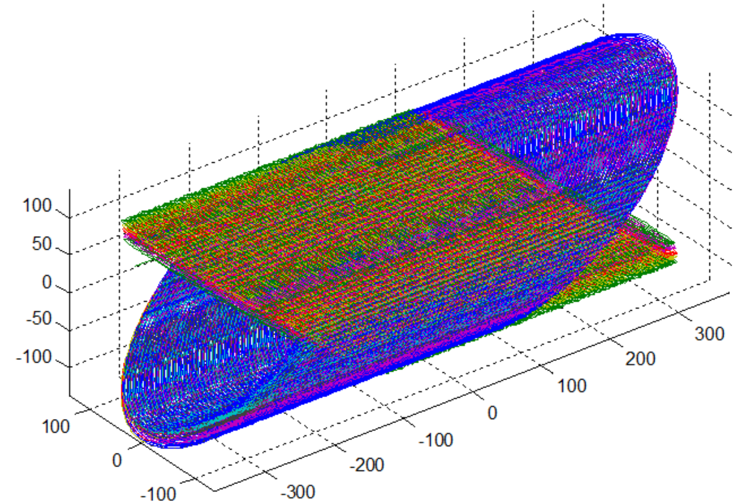
- Particle accelerators require strong dipole fields
- Field homogeneity is of utmost importance
  - Any higher order fields will distort the beam
- Double Helix technology allows for perfect control of the field multipole content
- Iron yokes are used to
  - Enhance the field
  - shield the field

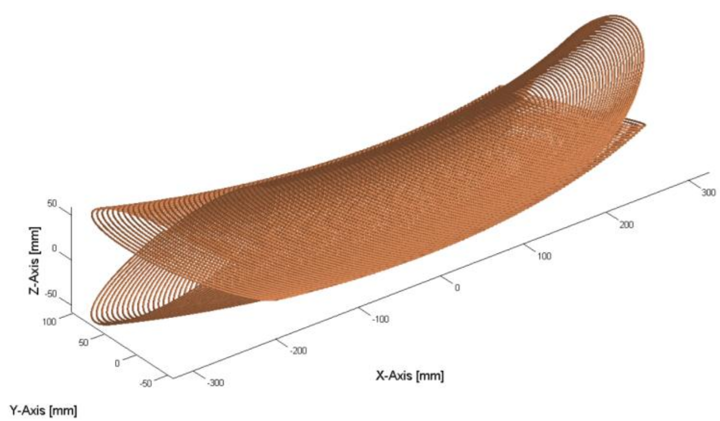


- Iron non-uniform magnetization generate multipole order fields that need to be quantified
- DH magnets are designed to compensate for the field distortion stemming from the iron yoke magnetization

Magnet Specifications

- Aperture 255 mm
- 10 layers
- 1.5 mm OD cable
- Variable Dipole field
  - 2.62 T without iron
  - 3.2 T with iron yoke
- Axis radius 2 m
- Operating current 1000 A





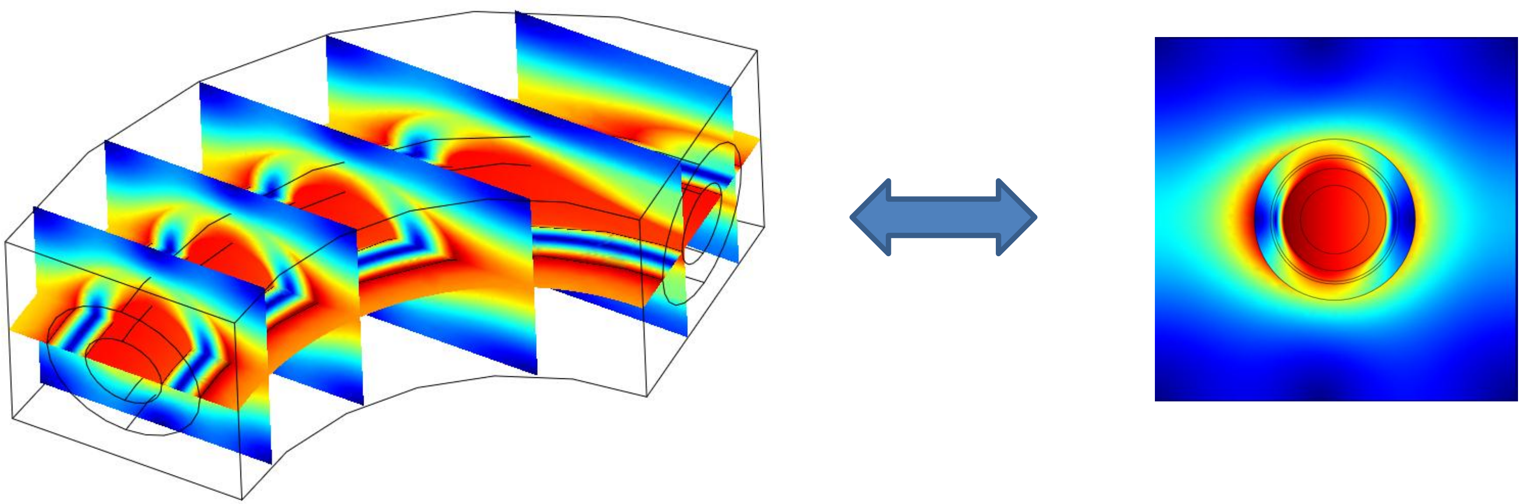
Objectives

Iron magnetization will generate multipole components in the magnet bore. It is important to quantify them and compensate for undesired effects.

- In order to isolate the effect of the iron yoke, the DH winding is models as a perfect source of dipole field
- The minimum dimension of a non-saturated iron yoke is determined
- The effect of the iron is calculated for current from 100 A to the nominal 1000 A
- At the maximum current the effect of iron saturation is investigated through reduction of the iron yoke thickness

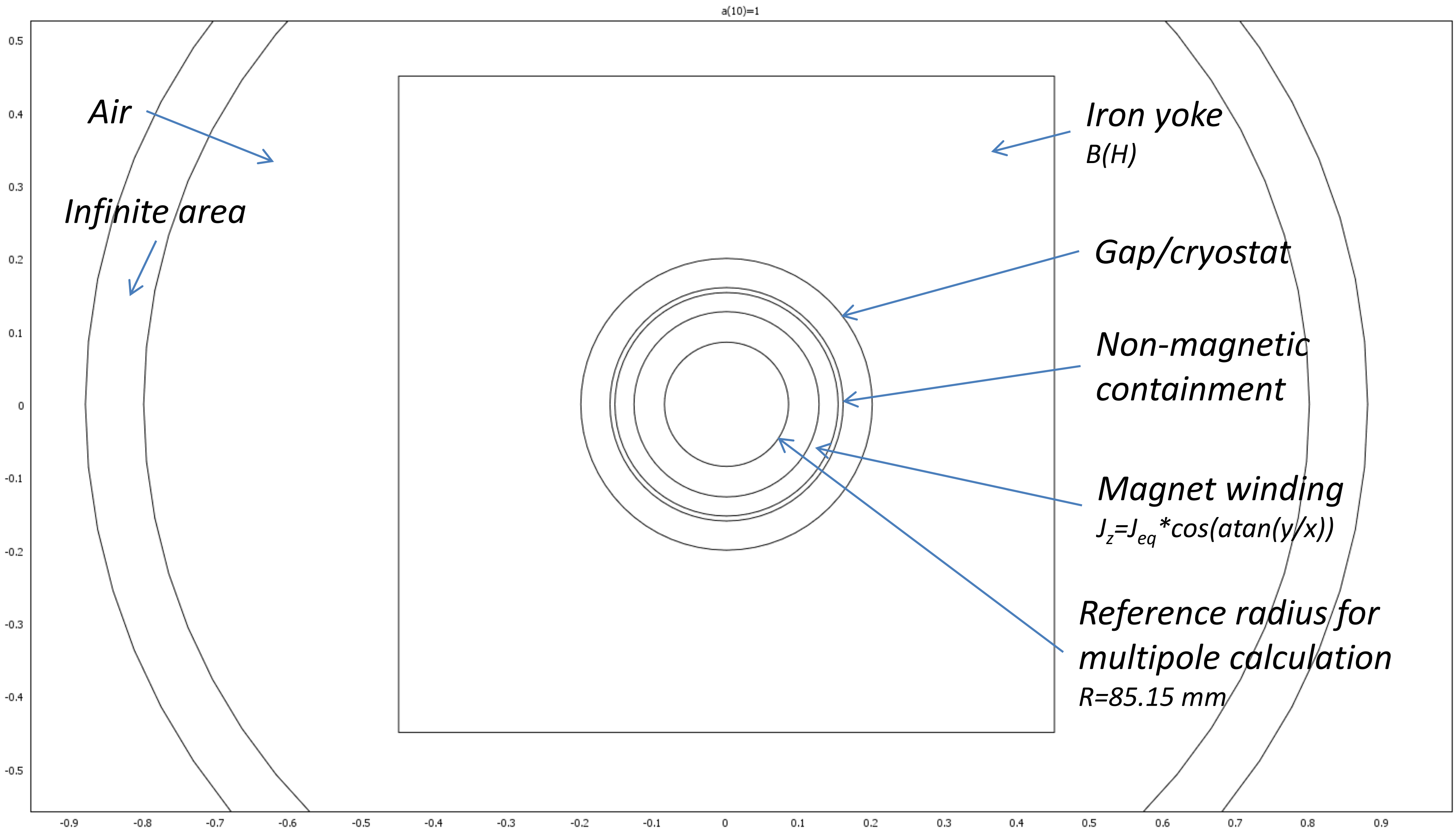
Model Assumptions

- 2D and 2D axial symmetry simulations
  - End effects are neglected
- Fourier analysis performed with Excel solver
  - Values lower than 1e-6 are considered null
  - Only the first 15 harmonics are considered

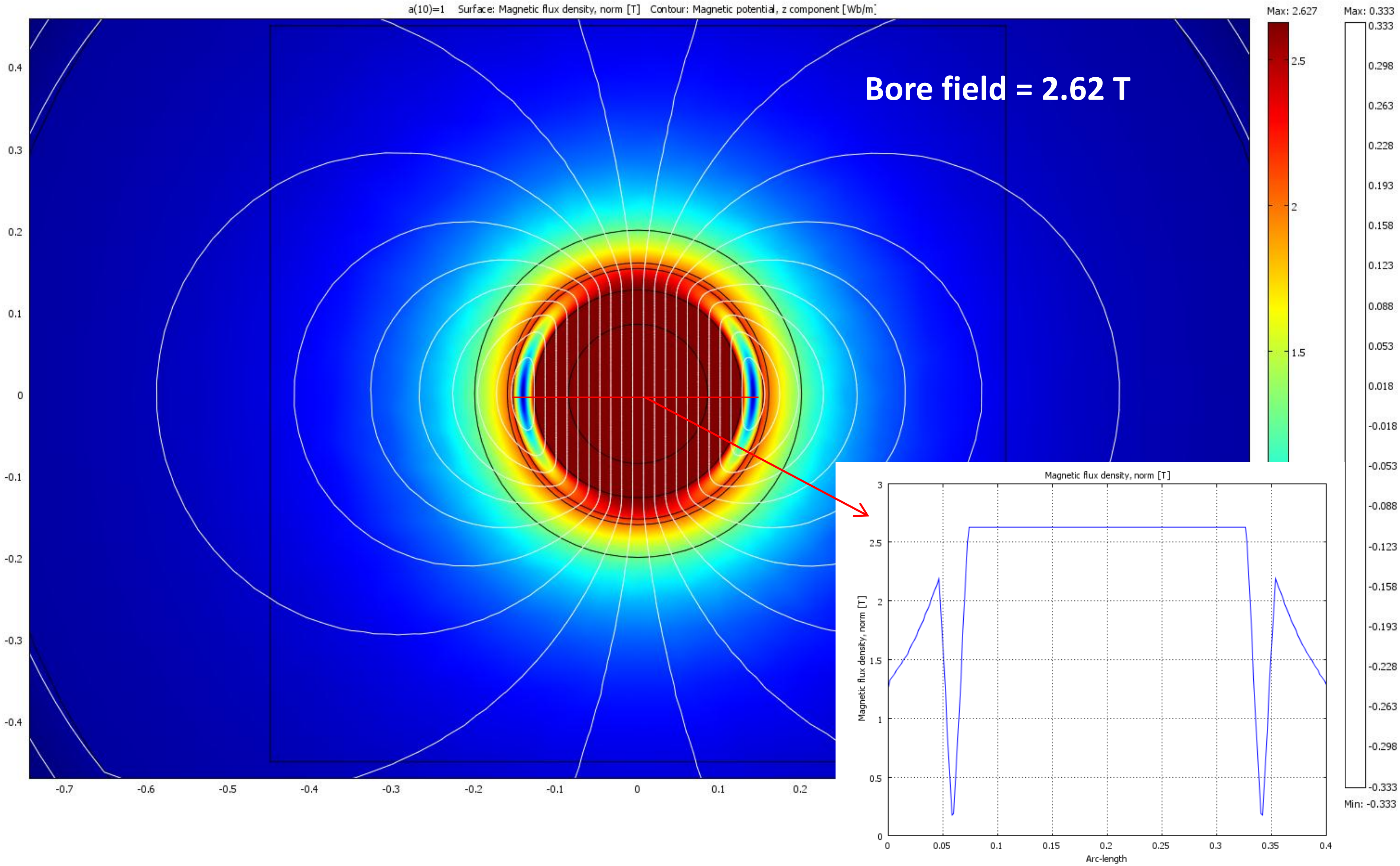


STRAIGHT MAGNET

Geometry, Sources and Boundary Conditions

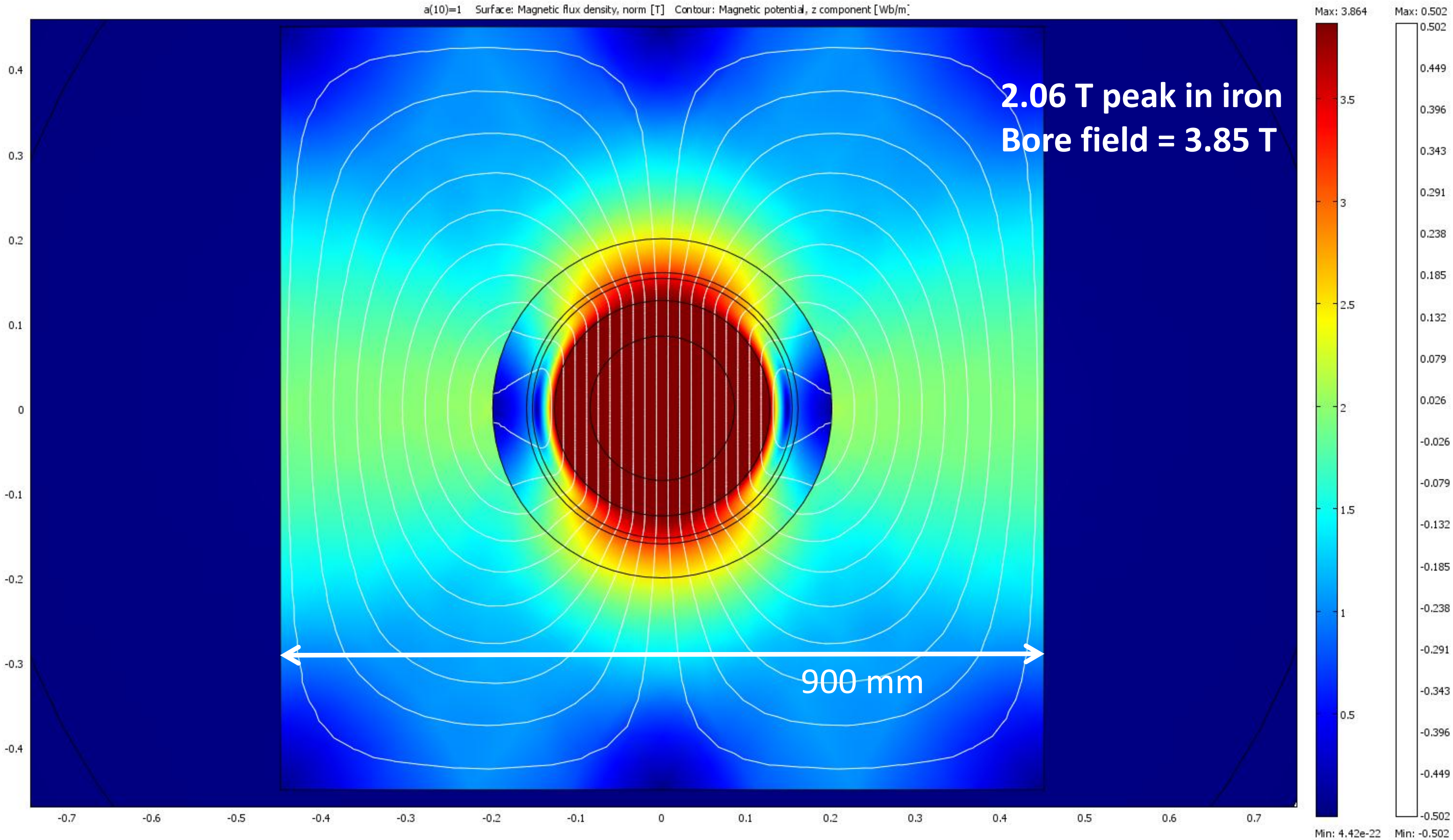


Magnetic Flux Distribution Without Iron



Iron Yoke Dimensions

- Flux density in iron yoke should be lower than 2 T @ 1000 A



Bore Field vs. Operating Current

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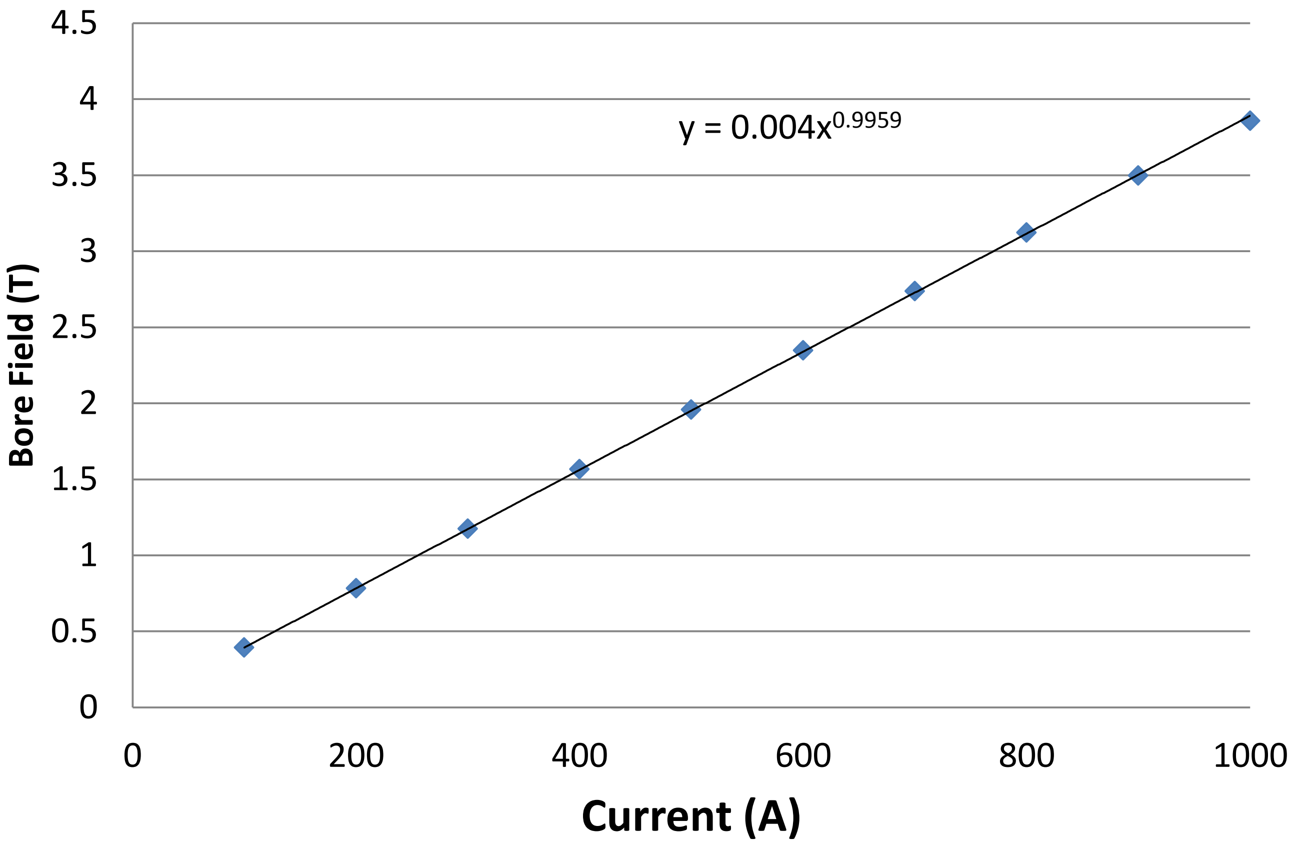
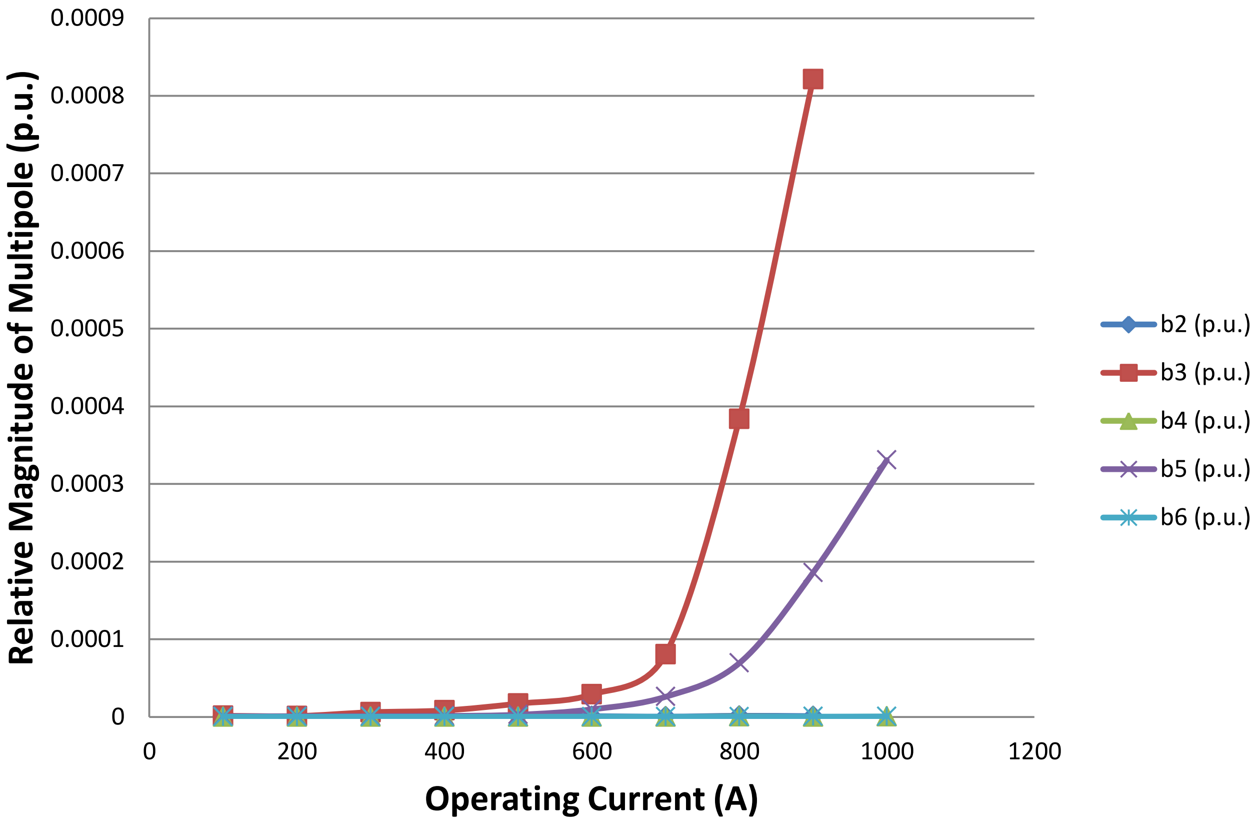
- Bore field shows no saturation up to nominal current

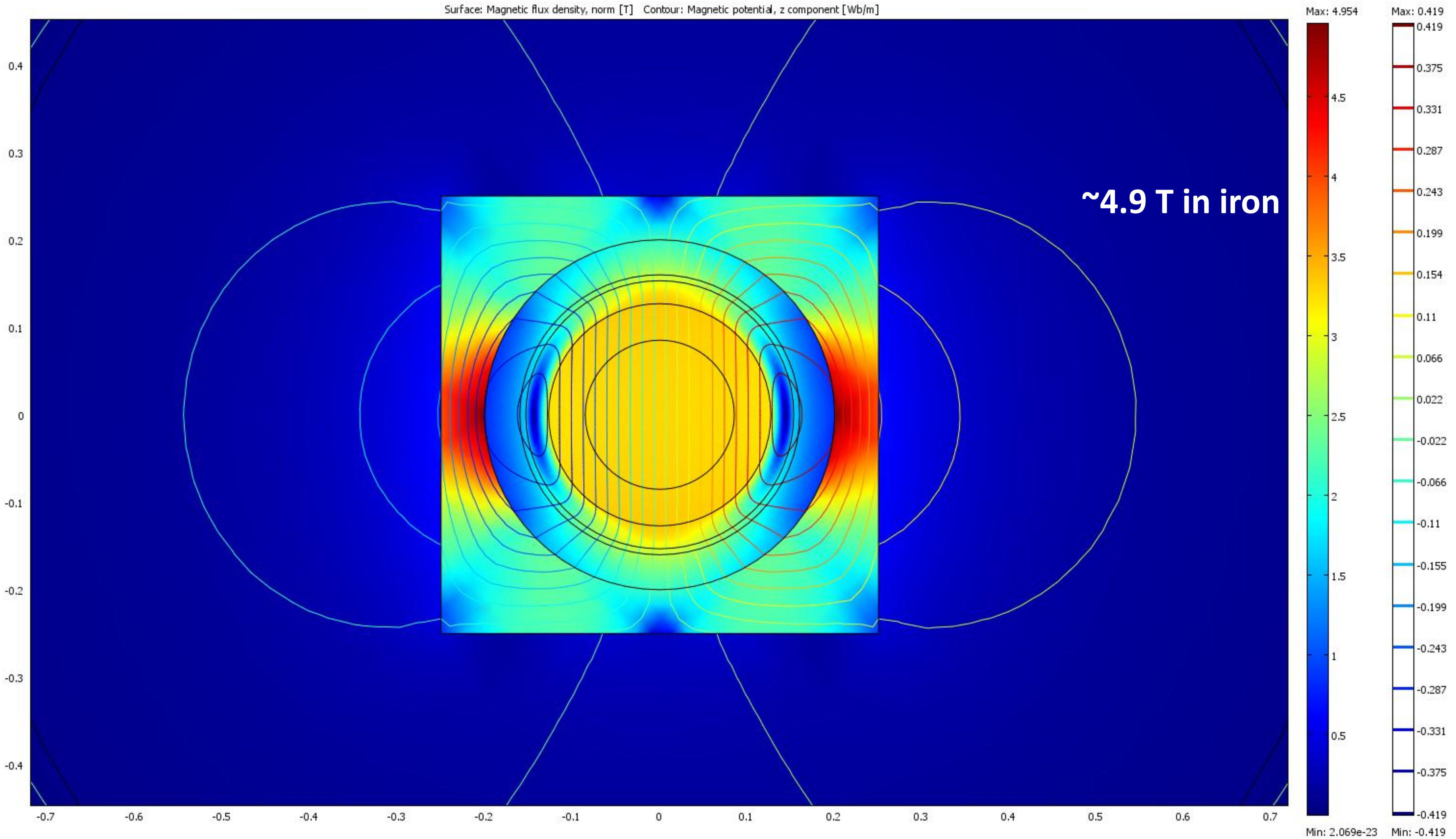


Multipole Content vs. Operating Current

- The iron yoke creates both a **sextupole** field up to **0.08%** and a **decapole** field up to **0.035%** of the dipole field at nominal current.

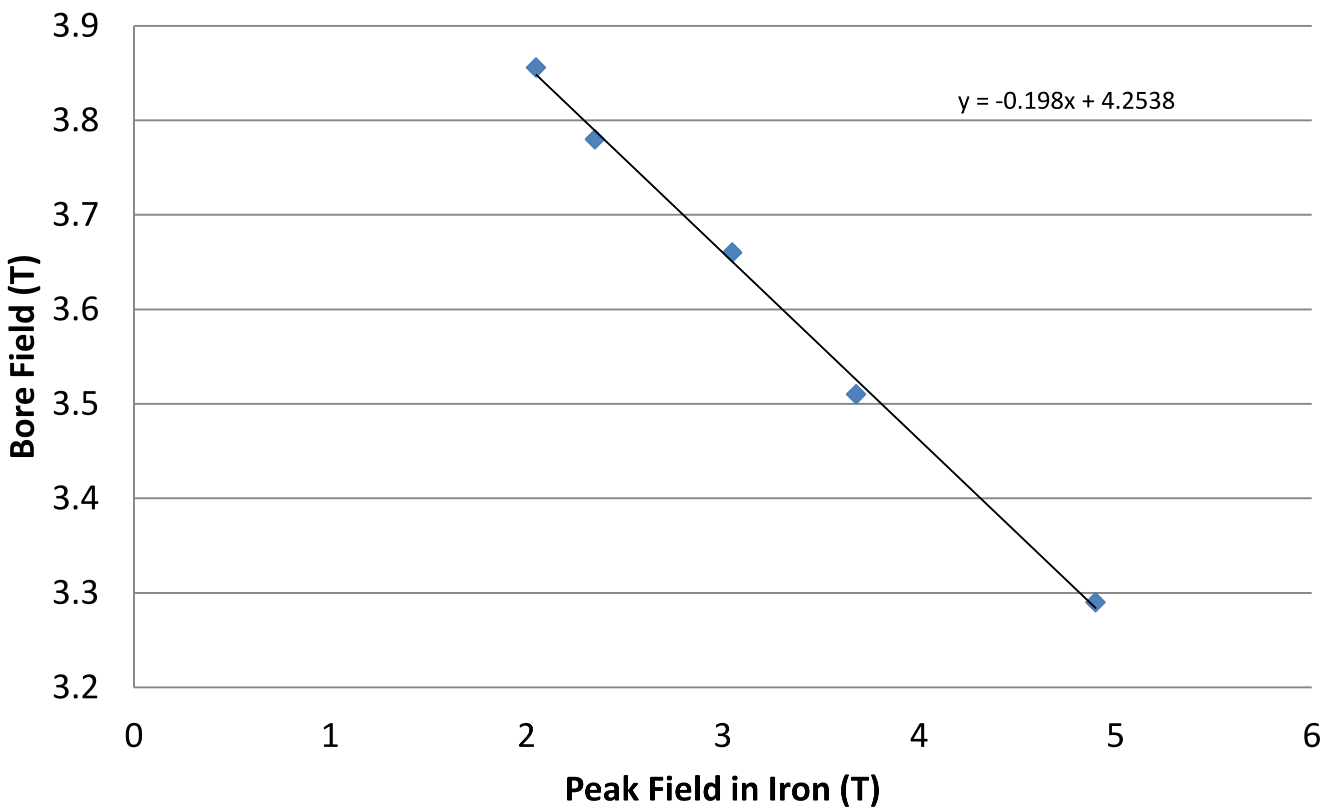


Effect of Iron Saturation – Flux Density Distribution



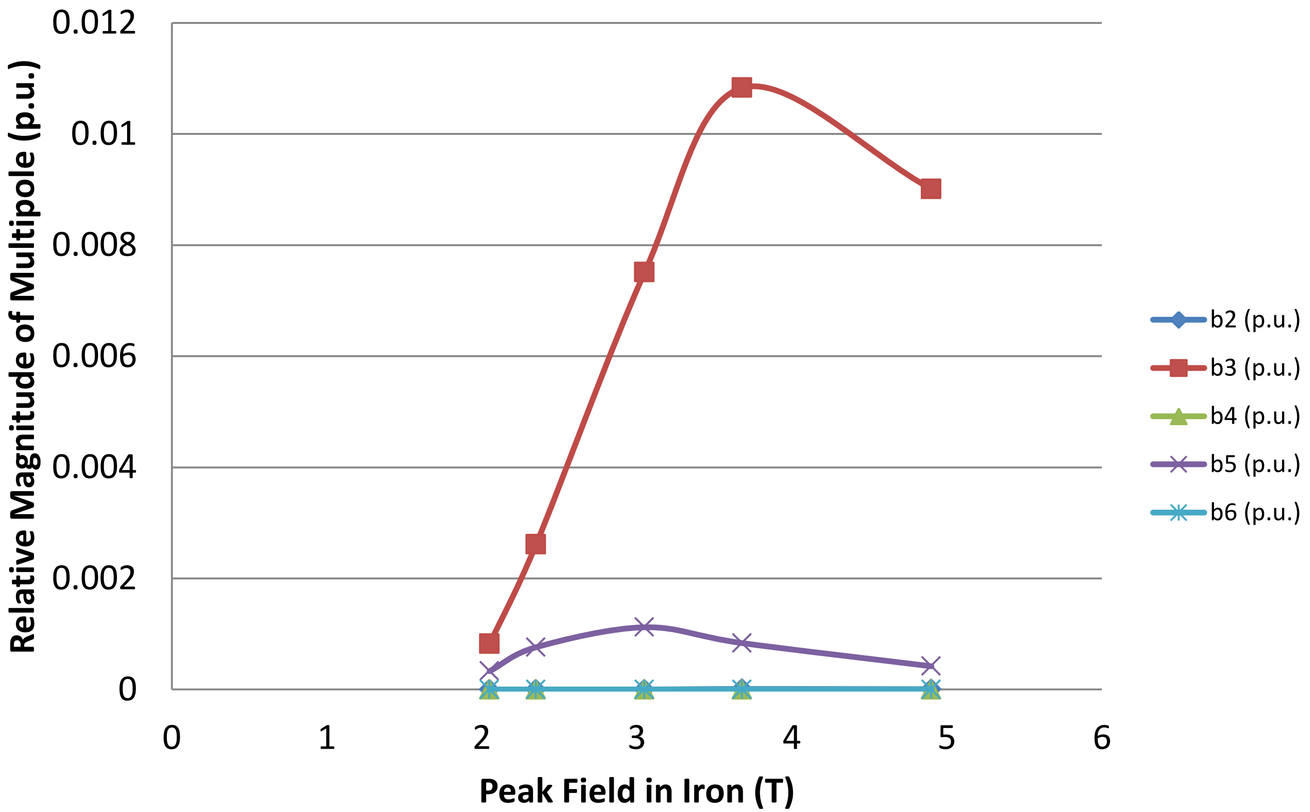
Effect of Iron Saturation – Bore Field

- Bore field decreases as iron becomes more saturated



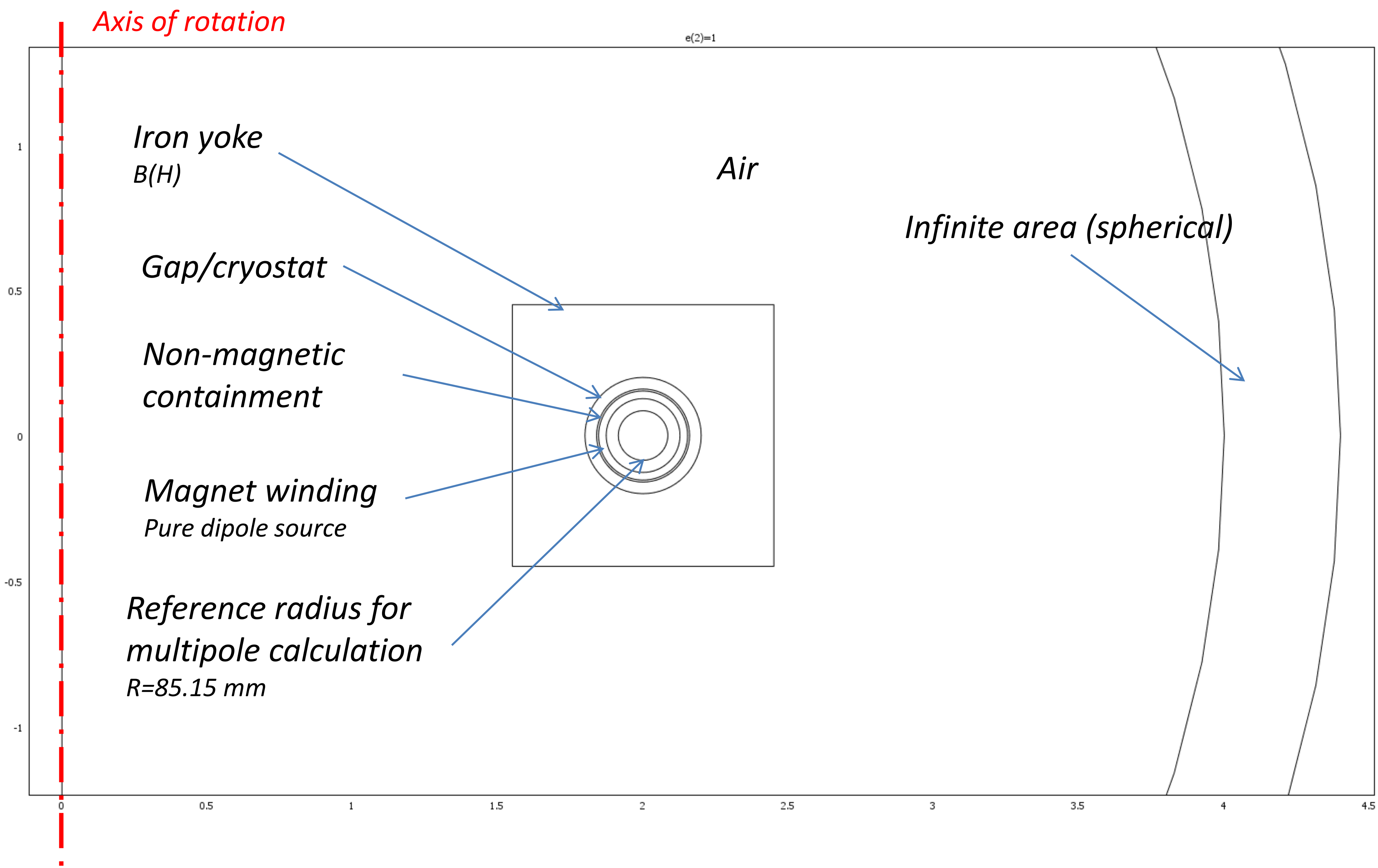
Multipole Content for Saturated Yoke

- Iron saturation leads to a sextupole of up to 1.1% and a decapole field of up to 0.15 %
- As the field increases in the iron, it becomes more “uniformly” magnetized lowering the multipole fields.



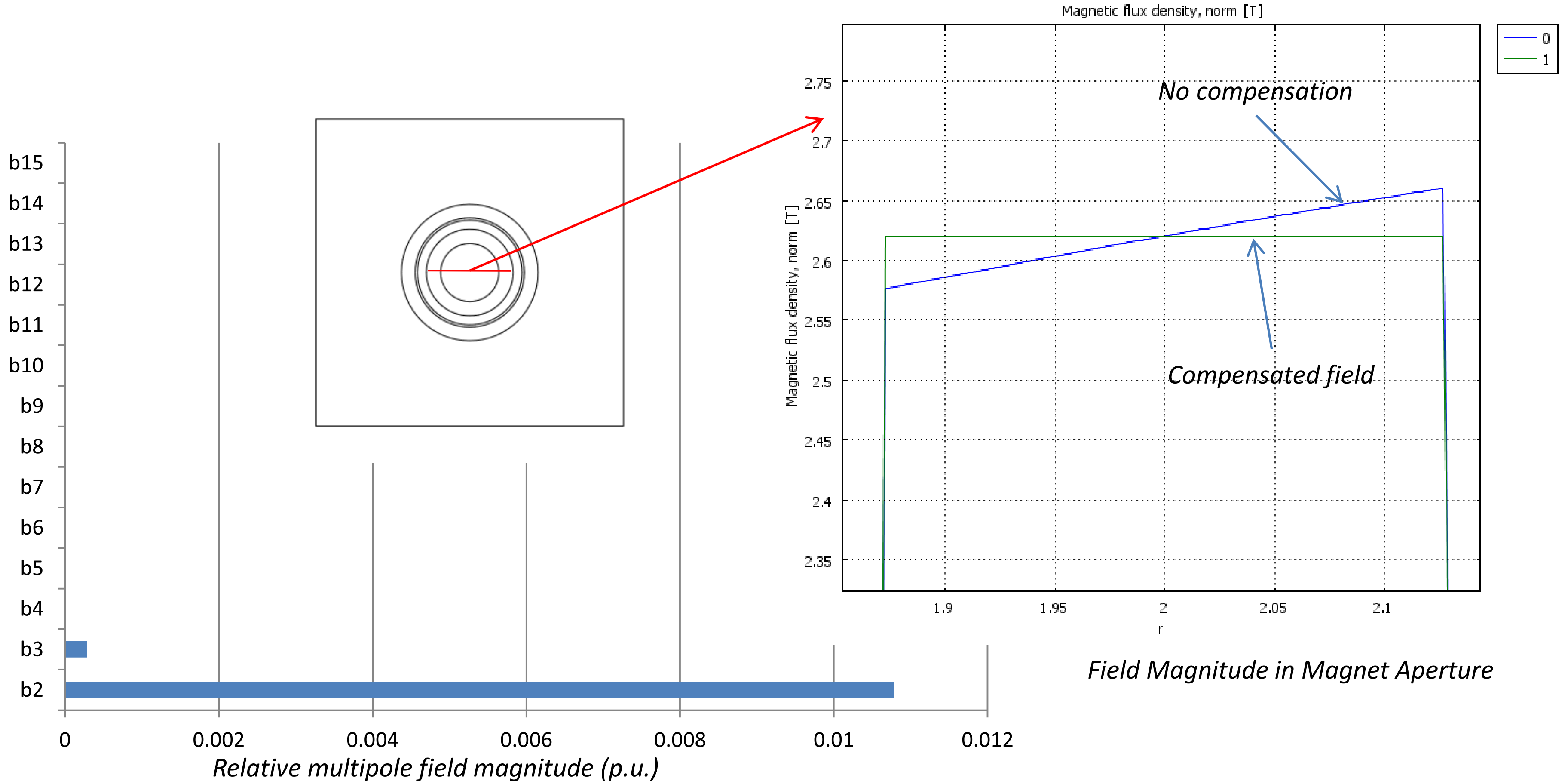
BENT MAGNETS

Geometry, Sources and Boundary Conditions



Effect of Bending on Multipole Content

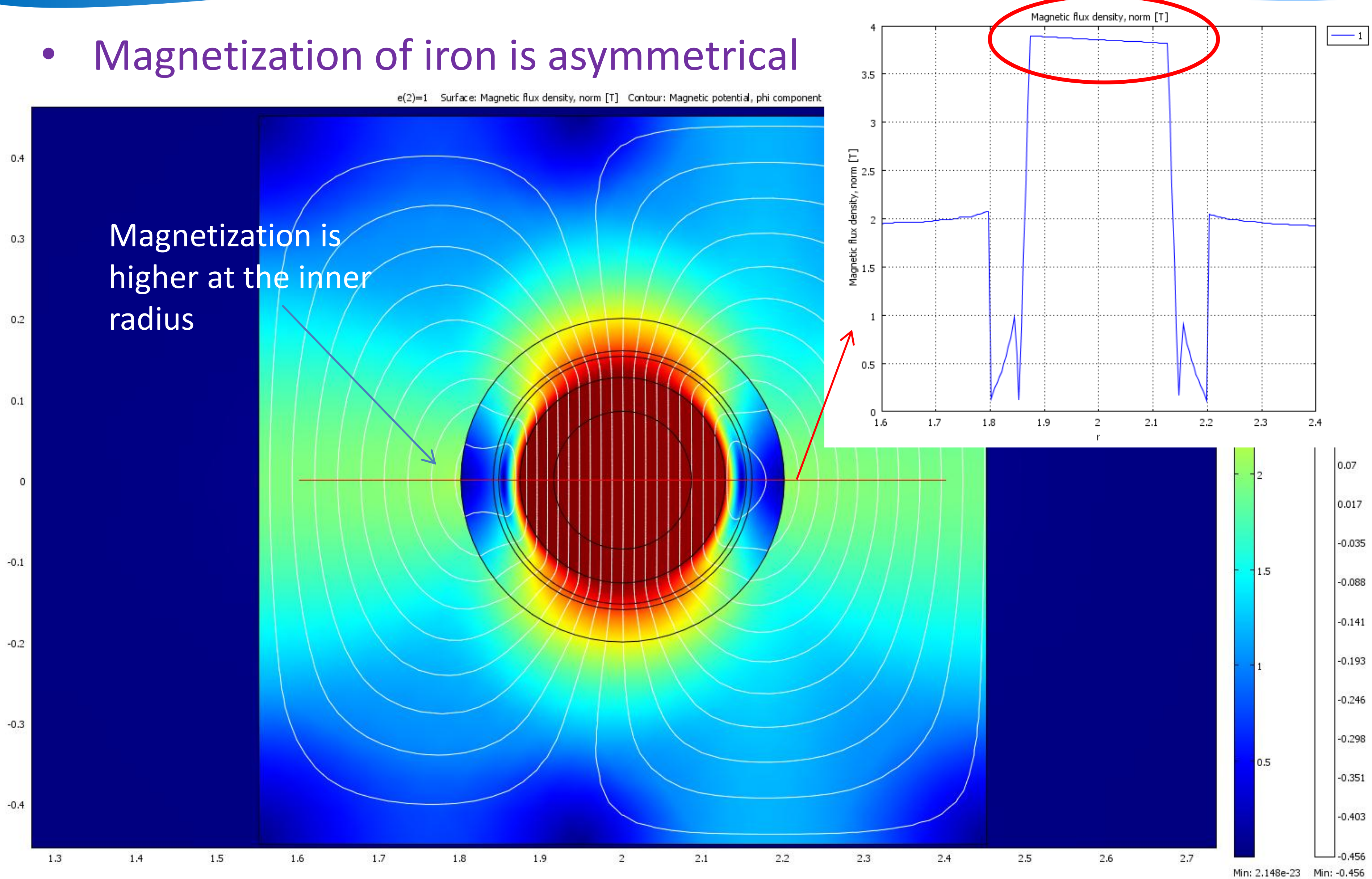
- Bending the magnet creates a strong quadrupole field (~1%) and a sextupole component (~0.03%)
- Current is adjusted in the model to compensate for the multipole content (<1e-6) allowing for the effects of the iron to be isolated



Field Magnitude in Magnet Aperture

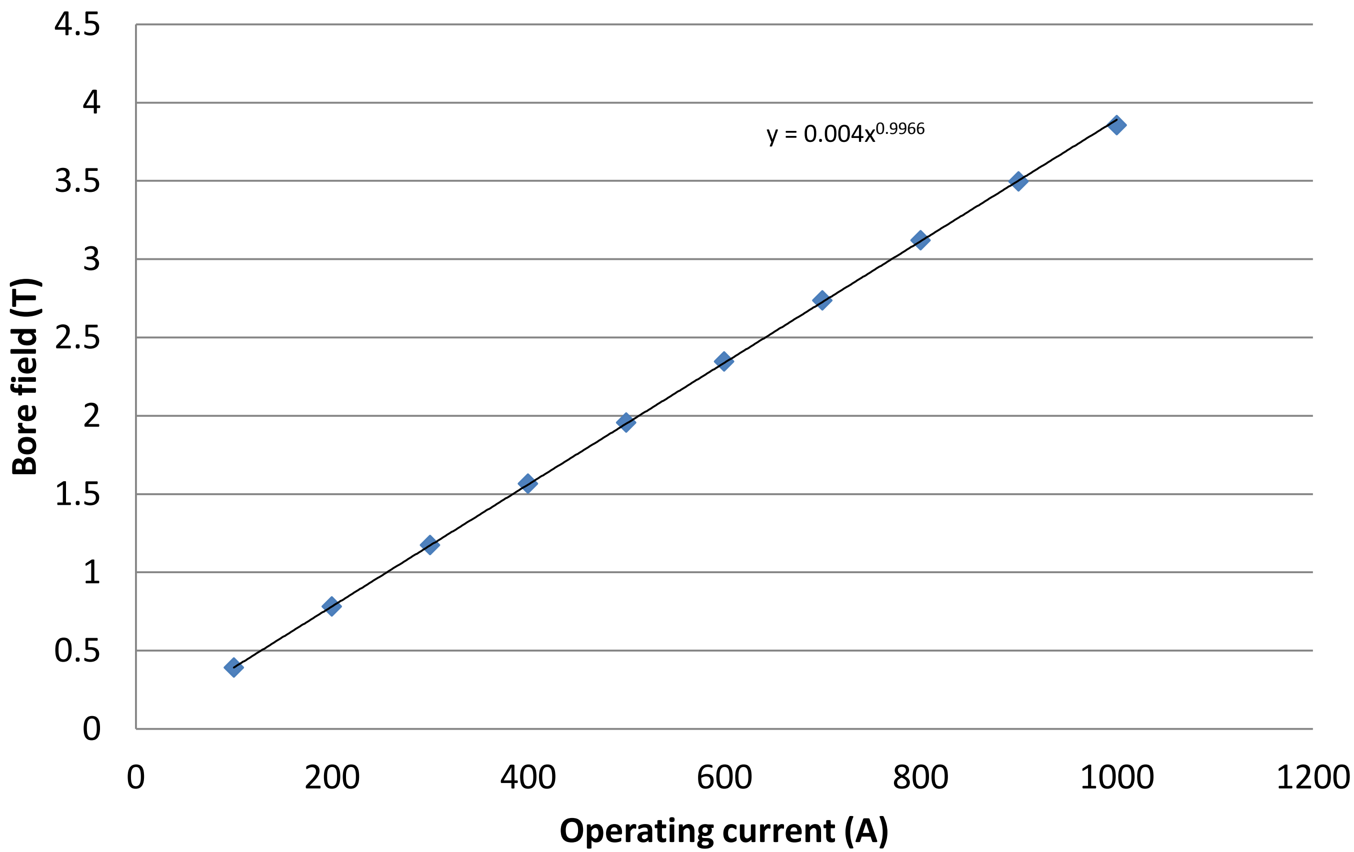
Flux Density Distribution

- Magnetization of iron is asymmetrical



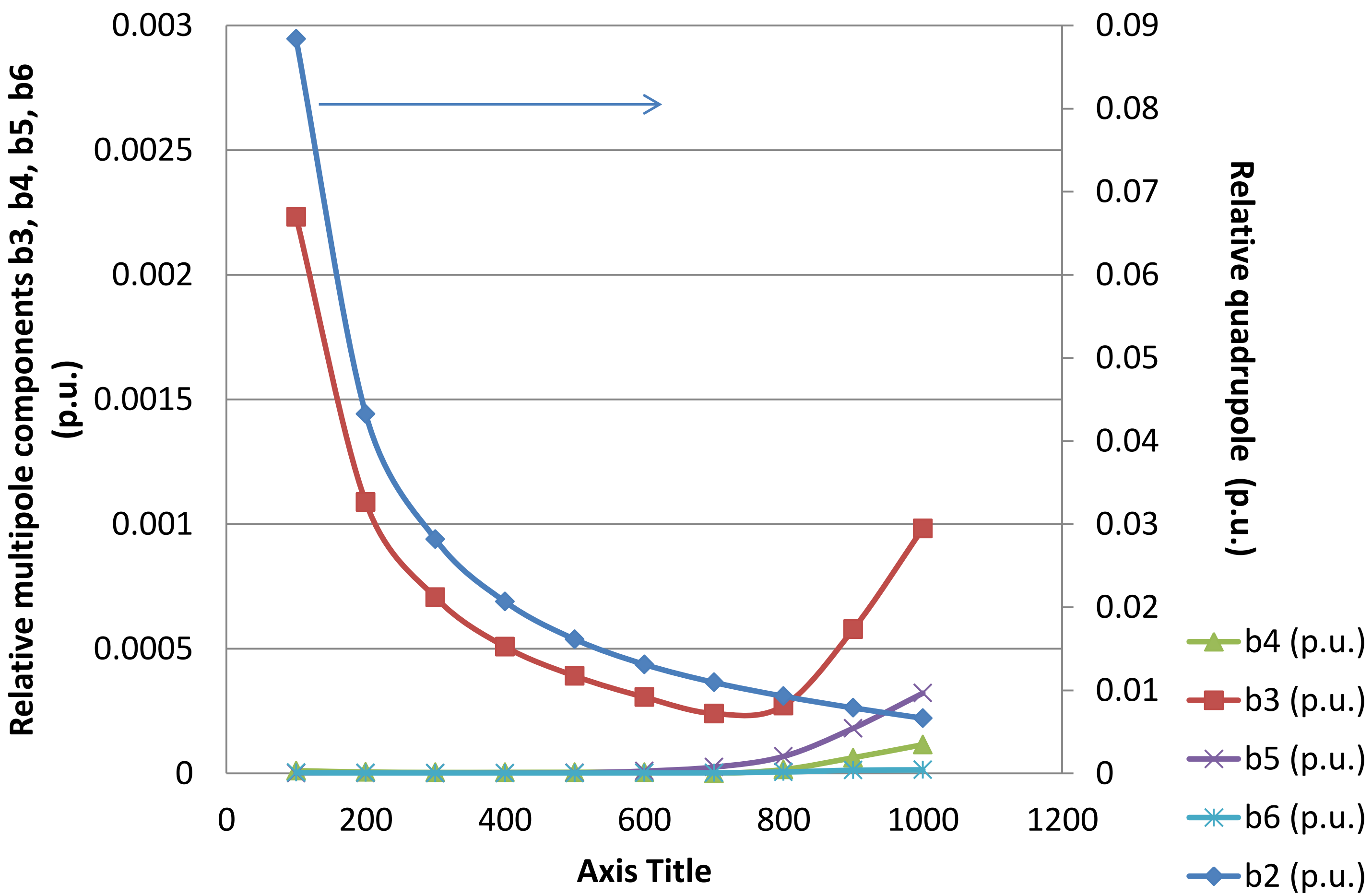
Bore Field vs. Operating Current

- Bore field shows no saturation up to nominal current

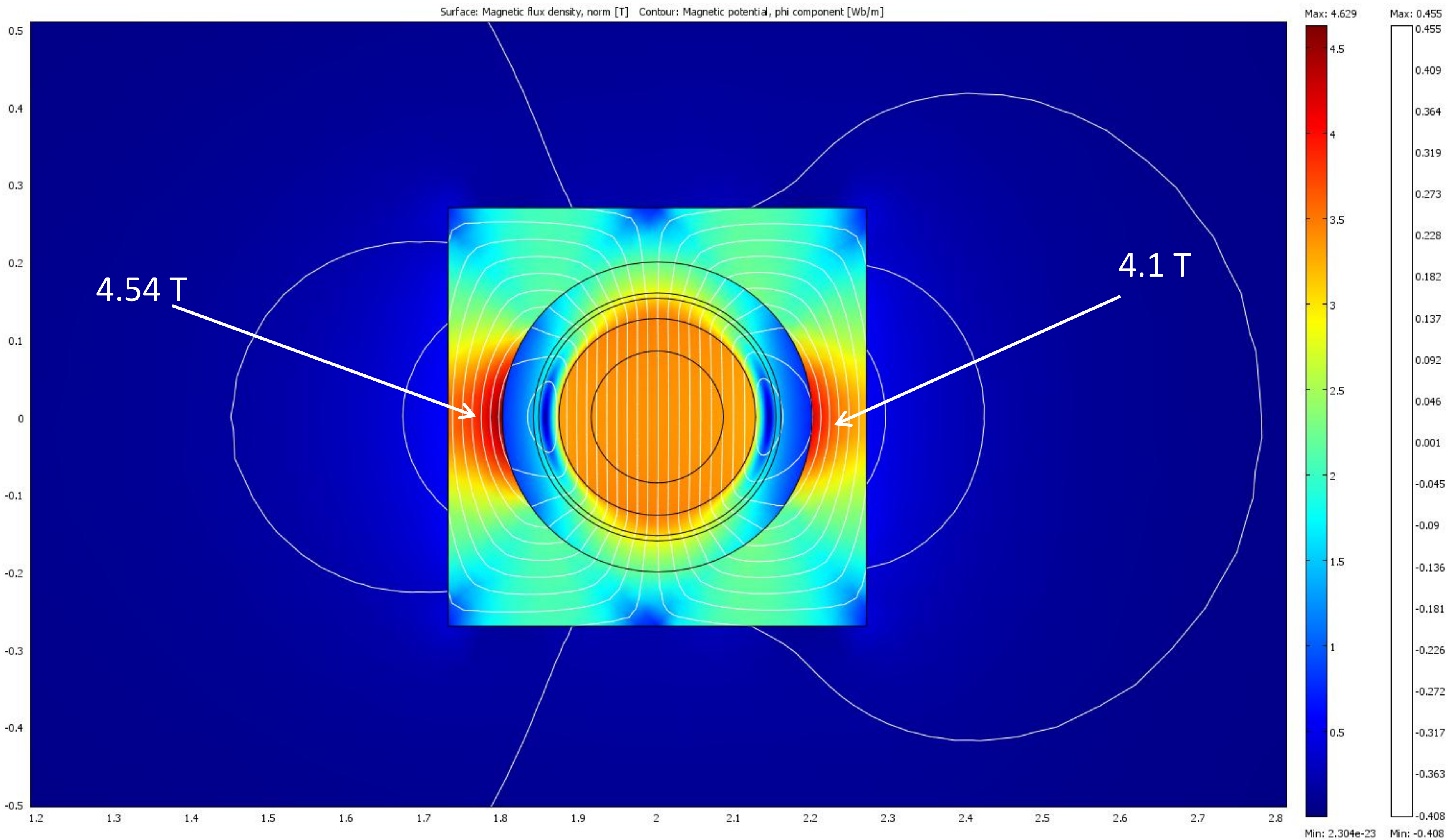


Multipole Content vs. Operating Current

- The bent iron yoke creates a strong **quadrupole** field up to **9%** at low field, a strong **sextupole** field up to **0.22%** of the dipole field. A quadrupole and decapole field become significant after 800 A (0.02%)



Effect of Iron Saturation – Field Plots



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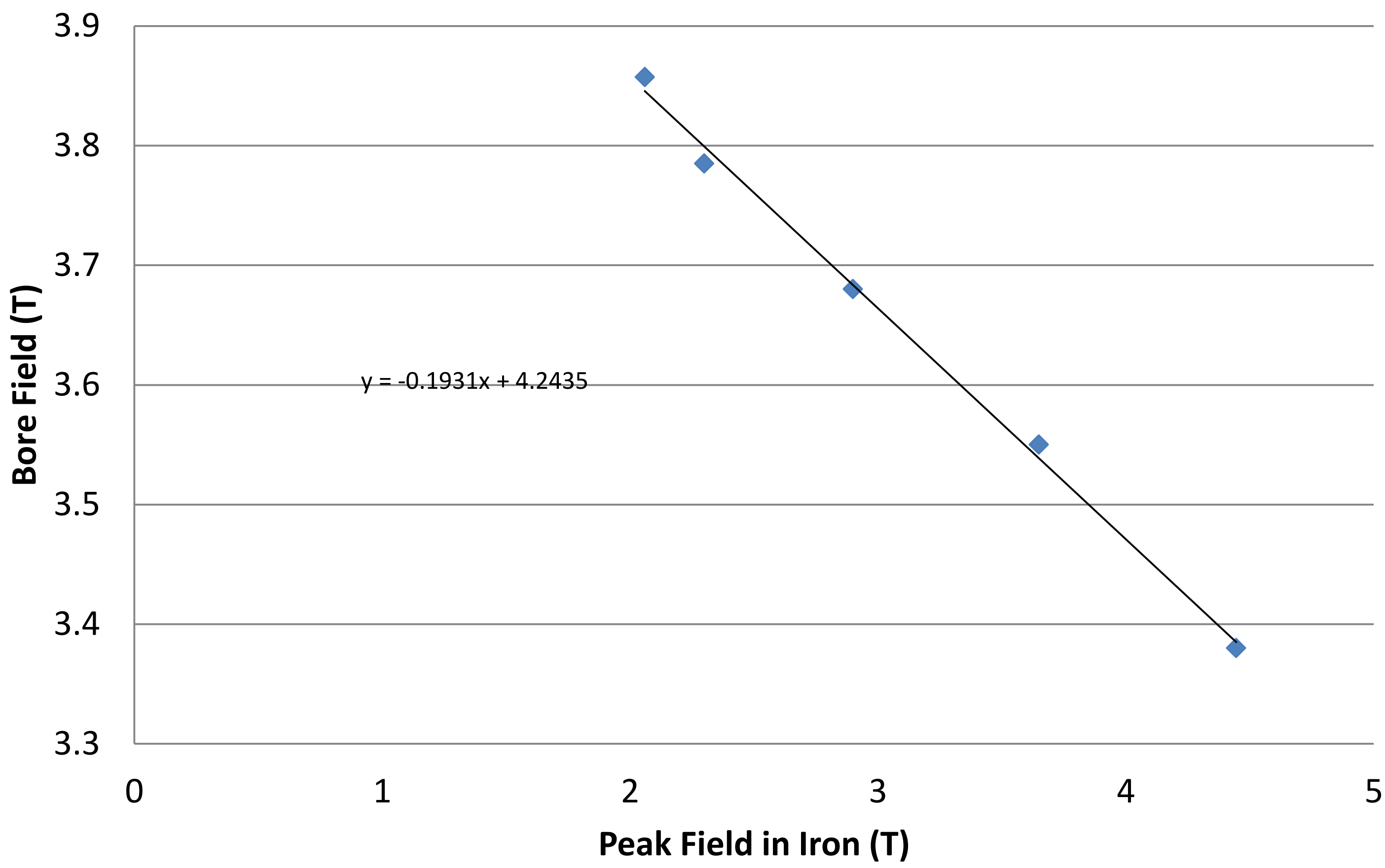
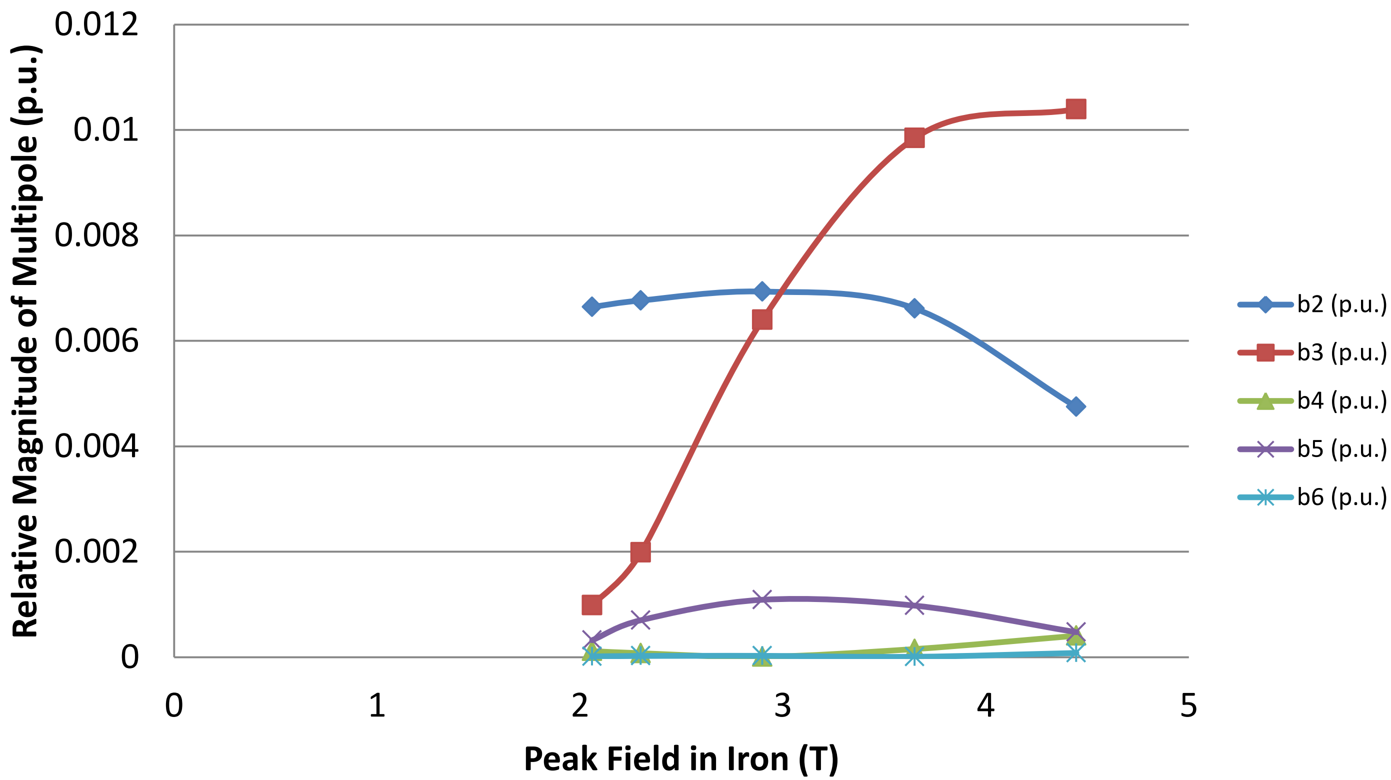


Multipole Content for Saturated Yoke

- Iron saturation leads to a quadrupole of up to 1.1%, a quadrupole field of up to 0.7 %, a decapole field up to 0.1% and a small octopole appears at high saturation.
- As the field increases in the iron, it becomes more “uniformly” magnetized lowering the multipole fields.



Straight Magnet Conclusions

- Because of its shape, the iron yoke of a bent dipole has a much stronger effect on field uniformity than a straight one.
- The multipole fields created would have a significant effect on the beam and need to be compensated.
- The magnitude of the multipole fields depends strongly on the operating current which makes active compensation necessary

- The Double-Helix™ magnet technology enables the development of bent combined function magnets