Persistent Current Effect in 15-16 T Nb_3Sn Accelerator Dipoles and its Correction

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Introduction and outline

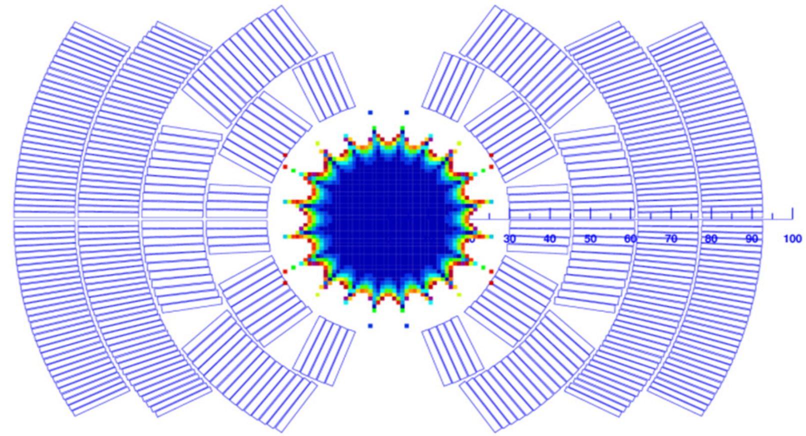
- The persistent current effect in SC accelerator magnets degrades the magnet field quality, which complicates the field correction system.
- In a new generation of accelerator magnets based on Nb_3Sn superconductor, the persistent current effect is considerably larger than in traditional Nb-Ti magnets.

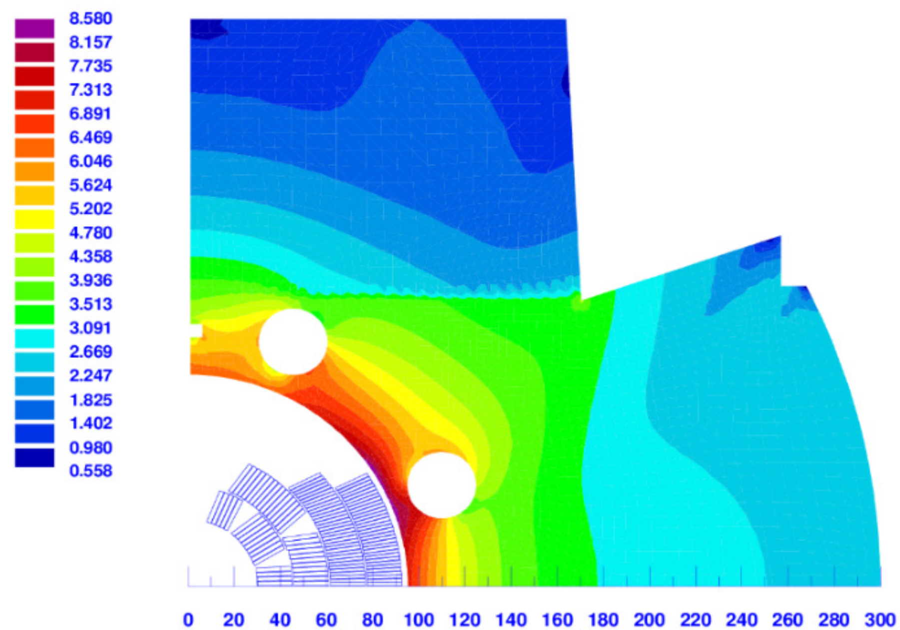
Outline

- FNAL 15 T Nb_3Sn dipole design
- Coil magnetization effect in the FNAL 15 T Nb_3Sn dipole
- Passive correction principle
- Correction options and results

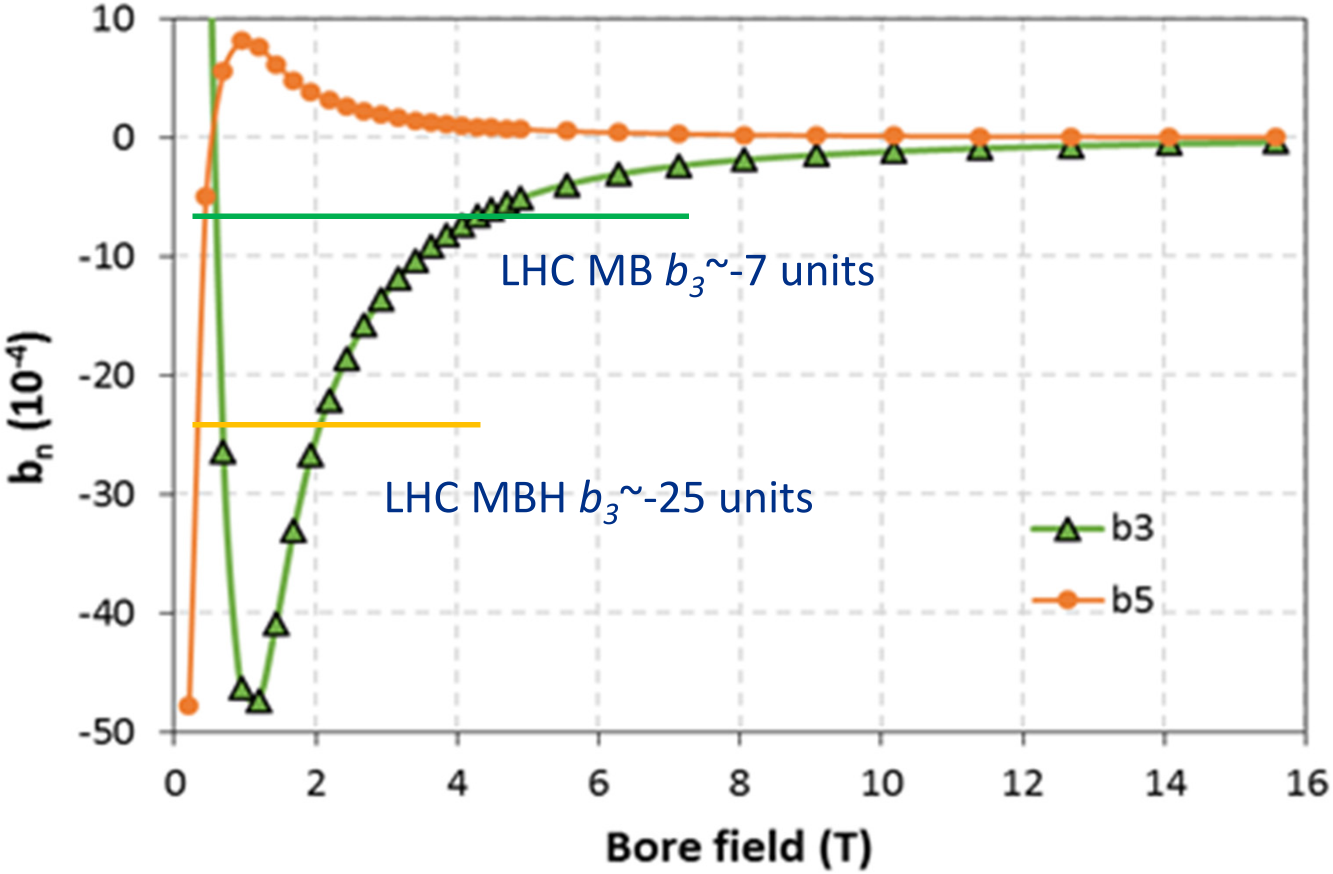
FNAL 15 T dipole design

- The design consists of
  - 4-layer graded coil with 60-mm aperture
  - cold iron yoke with 587 mm outer diameter
  - 2 mm coil-yoke spacer.
- 15 mm wide cables
  - 28-strand inner cable, 1.0 mm Nb_3Sn strand
  - 40-strand outer cable, 0.7 mm Nb_3Sn strand
- B_{max}=15.6/17.0 T @ 4.2/1.9 K.





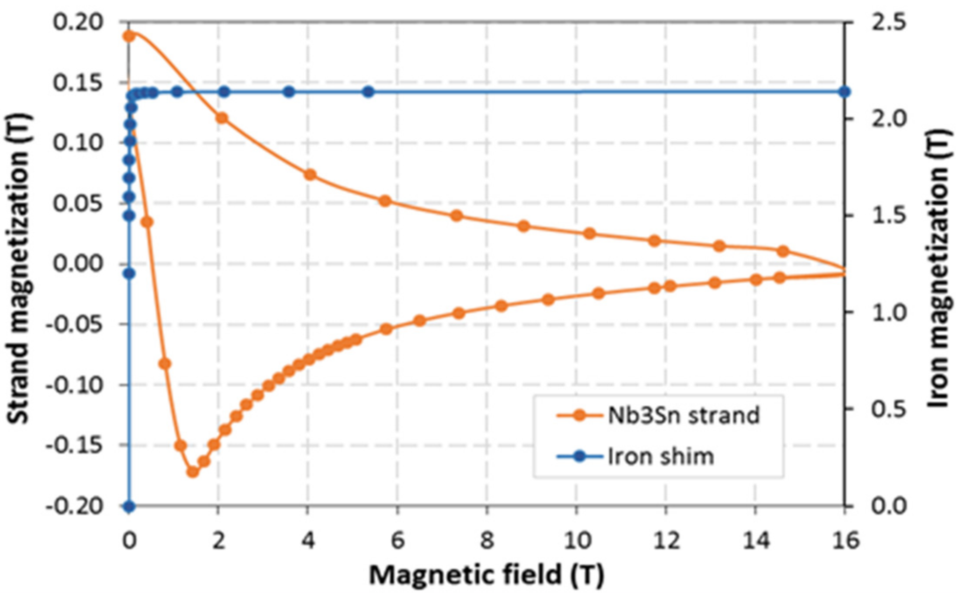
b_3 and b_5 in FNAL 15 T Nb_3Sn dipole

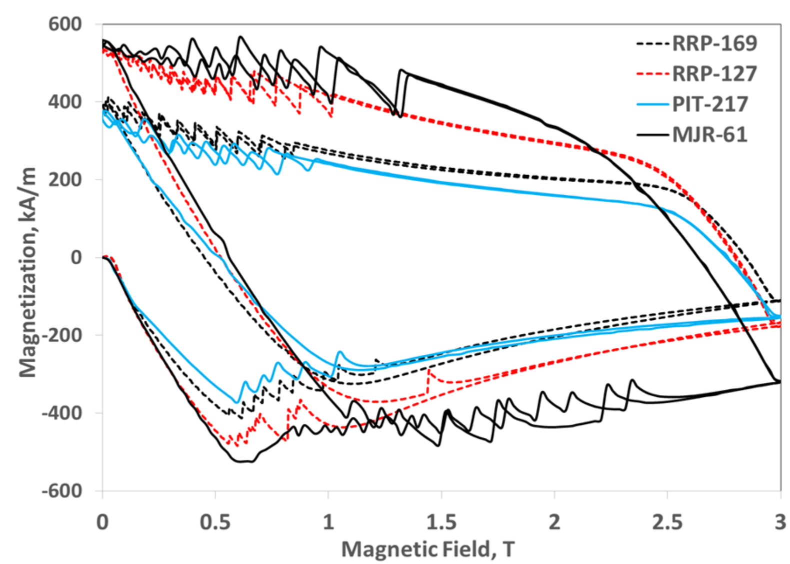


- For the selected conductor parameters and coil geometry the peak values of b_3=-48 and b_5=+8 units @ B~1.4 T.

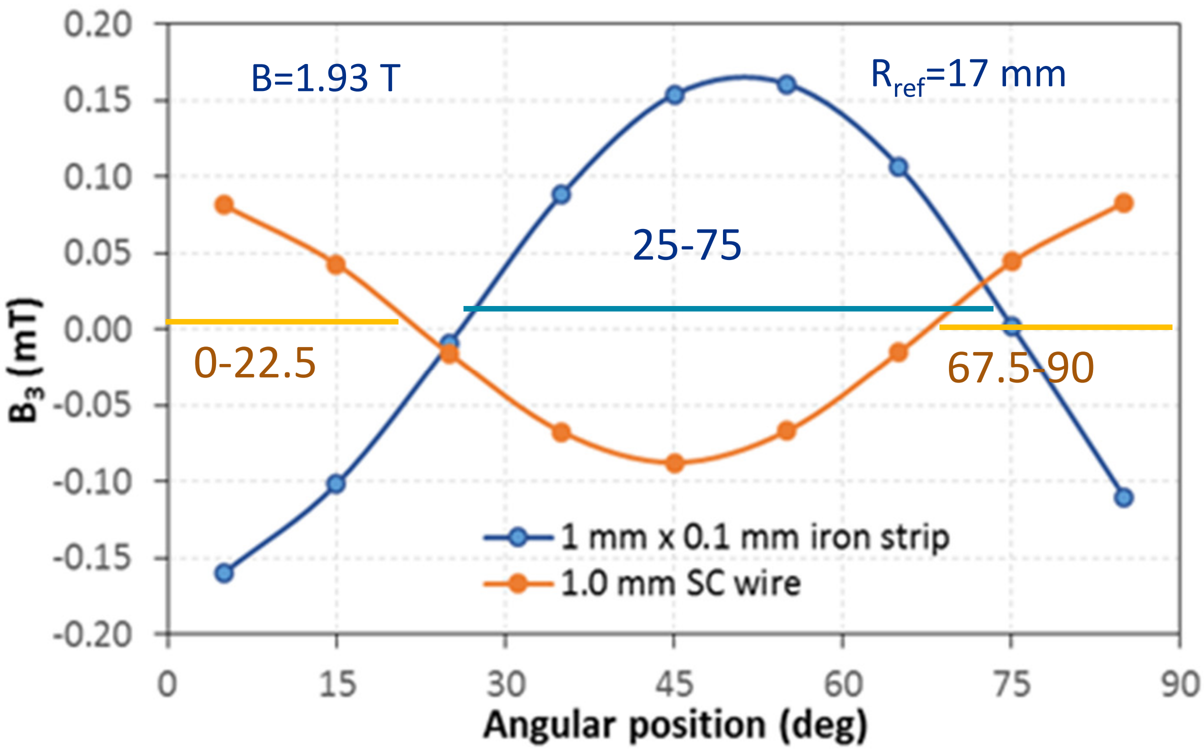
Coil magnetization correction

- Several passive correction schemes were proposed
  - passive SC wires in magnet aperture
  - iron strips in aperture
  - iron strips inside the coil, SC wires with magnetic matrix, etc.
- SC wire parameters: OD=1 mm, J_c=2.7 kA/mm^2 at 12T/4.2K, d_{eff}=57 µm, $Cu:nonCu$=1.13.
  - J_c and d_{eff} were selected to avoid flux jumps at low fields.

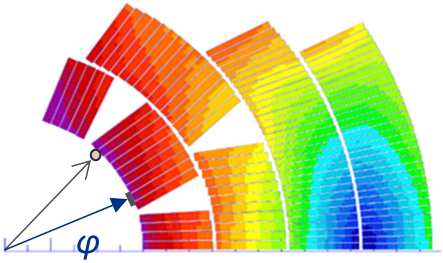




SC wire and iron strip effects on B_3



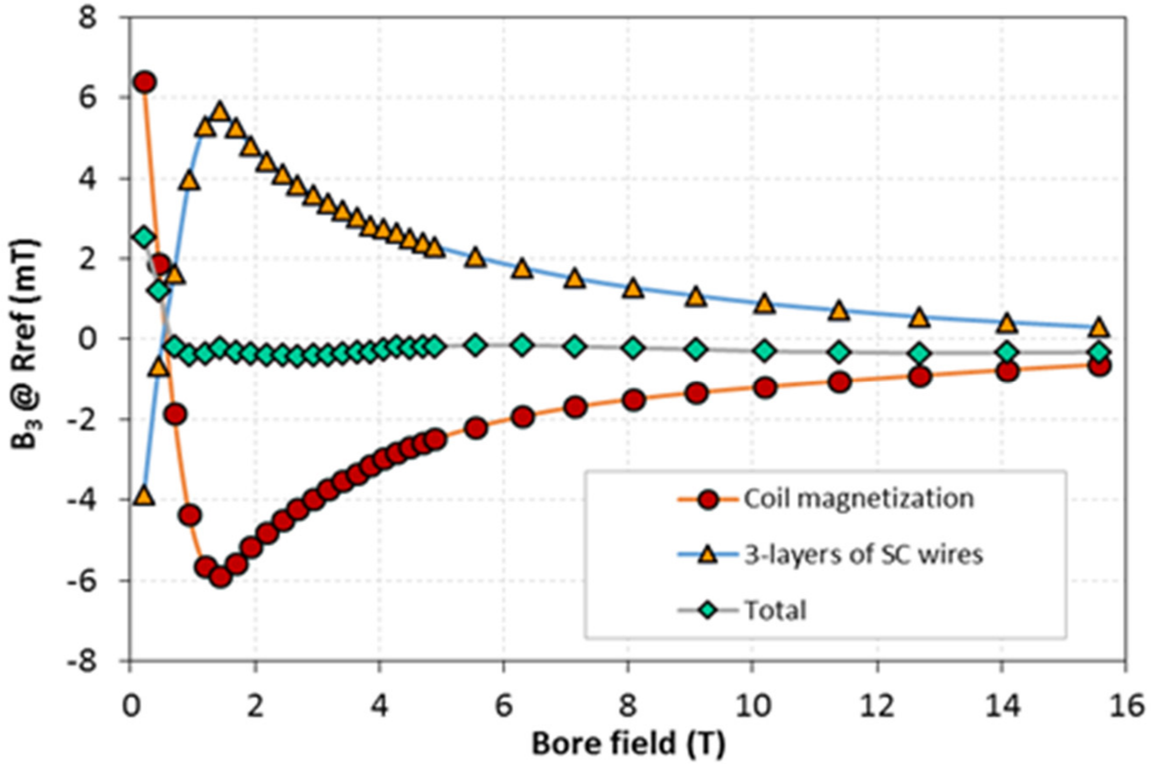
1 mm Nb_3Sn wire, 1 mm wide x 0.1 mm thick iron strip placed on the coil inner surface.



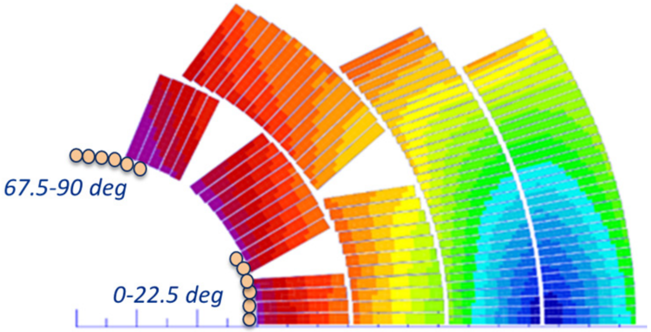
- 22 1 mm SC wires/quadrant at 0-22.5 and 67.5-90 degrees produce B_3=1.57 mT (~30% of coil B_3=-5.17 mT).
- 0.1 mm iron strips at 25-75 degrees in each quadrant produce B_3=2.56 mT (~50% of the coil B_3).

Fermilab

Passive SC wires in aperture

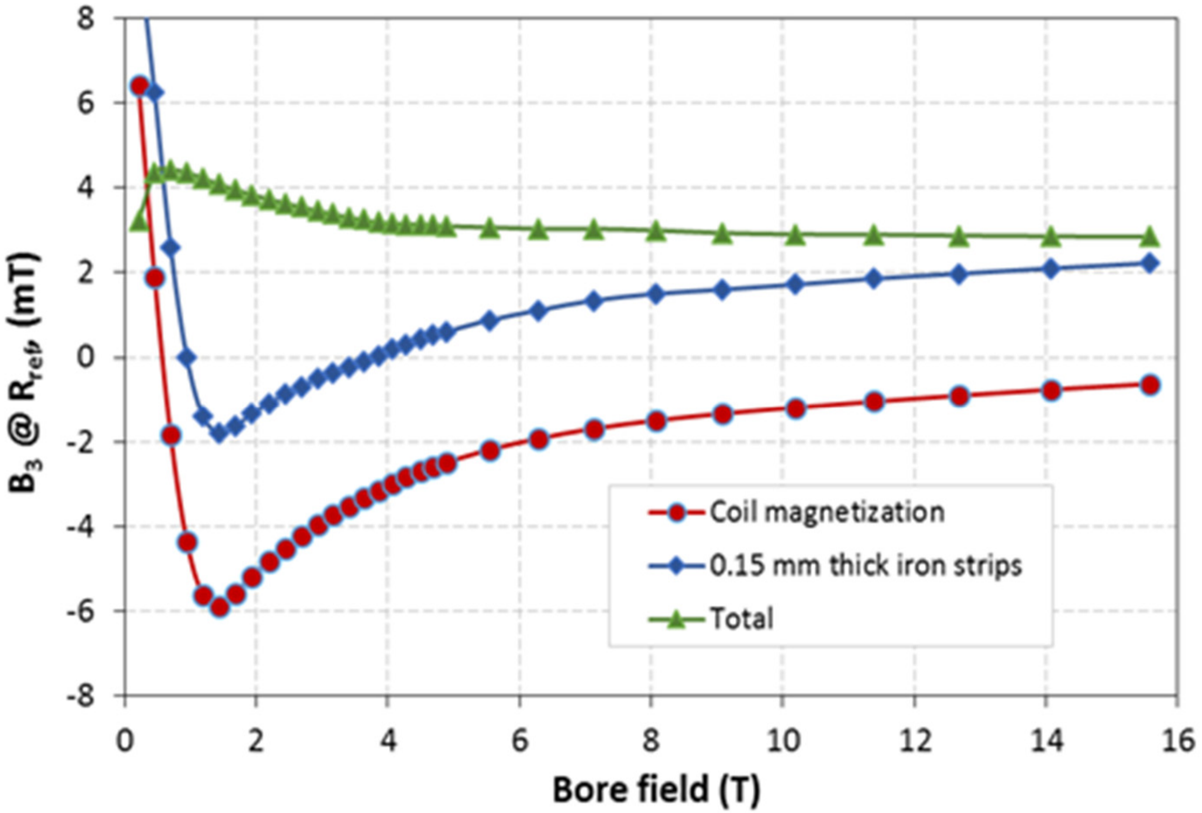


3 layers of 1 mm SC wires in aperture at 0-22.5, 67.5-90 degrees in each quadrant.

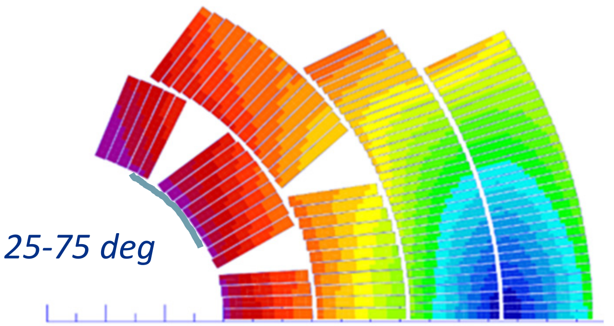


- -0.4 mT< B_3 < 0 mT at B>0.7 T, B_3 reduction by a factor of 13.
- Relatively large radial size of 3 mm can be reduced by using SC wires with smaller *Cu:nonCu* ratio and better wire compaction in the corrector.

Iron strips in aperture

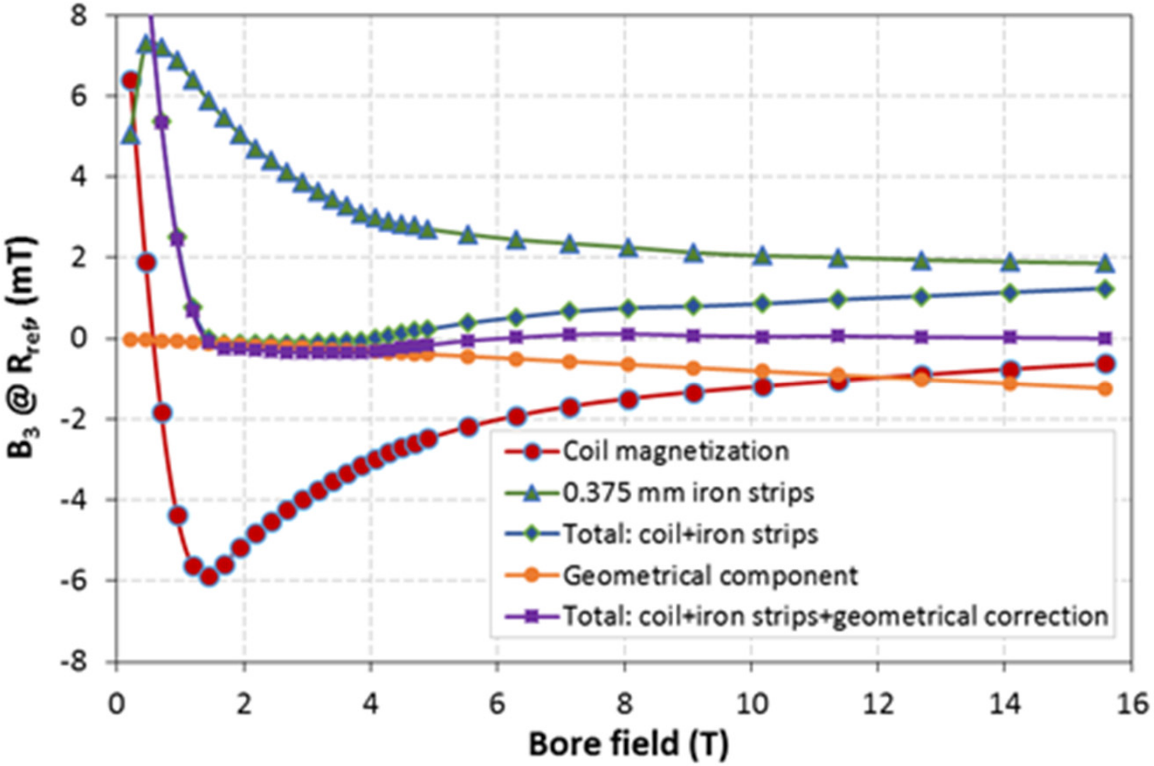


0.375 mm iron strips in aperture at 25-75 degrees in each quadrant.

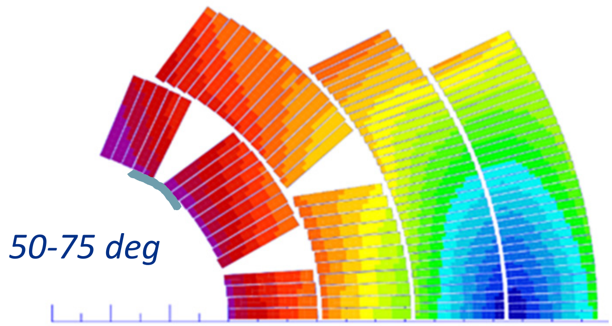


- Variations of B_3=±2 mT in bore field range of 0.7-15 T.

Iron strips in aperture + coil geometry

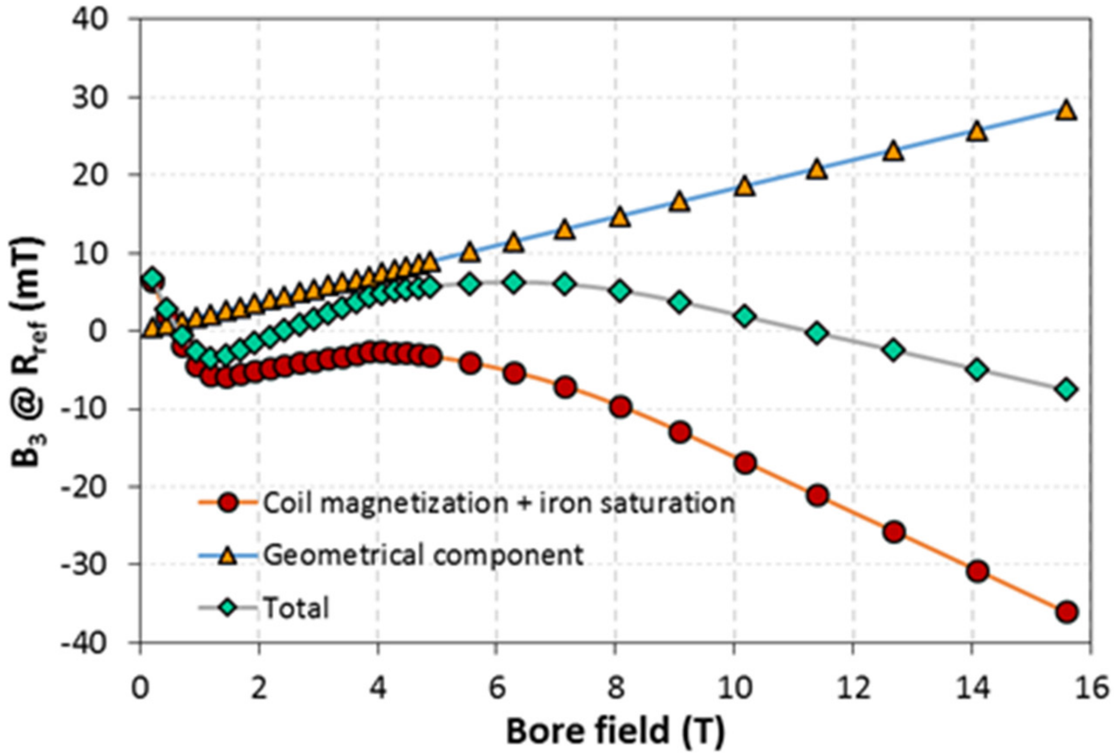


0.375 mm iron strips in aperture at 50-75 degrees in each quadrant and geometrical component b_3=-0.8 units.



- For 0.375 mm iron strips -0.13 mT<B_3<1.25 mT for B>1.2, reduction of B_3 variation range by a factor of 3.8.
- For geometrical component b_3=-0.8 and 0.375 mm thick iron strips B_3 varies between -0.37 and 0.11 mT, range reduction by a factor of 11.

Iron Saturation Correction



- Large iron saturation effect, B_3=-35 mT at B~15 T.
- Correction holes in the iron yoke are not effective.
- Geometrical sextupole b_3=+18 units reduces B_3 variations range by a factor of 2.5 to approximately ±7 mT.

Conclusions

- The analysis of the coil magnetization effect on the field quality of the FNAL 15 T Nb_3Sn dipole shows that for the present magnet design and superconductor parameters B_3 is relatively large at low fields.
- It was shown that 3 layers of 1 mm diameter Nb_3Sn wires or 0.375 mm thick iron strips (combined with small geometrical component) in the magnet bore provide an effective reduction of B_3 related to the coil magnetization effect by a factor of 13 and 11 respectively.
- The FNAL 15 T Nb_3Sn dipole has also a large iron saturation effect. It was shown that the geometrical correction of b_3=+18 units allows reduces B_3 variations to approximately ±7 mT.