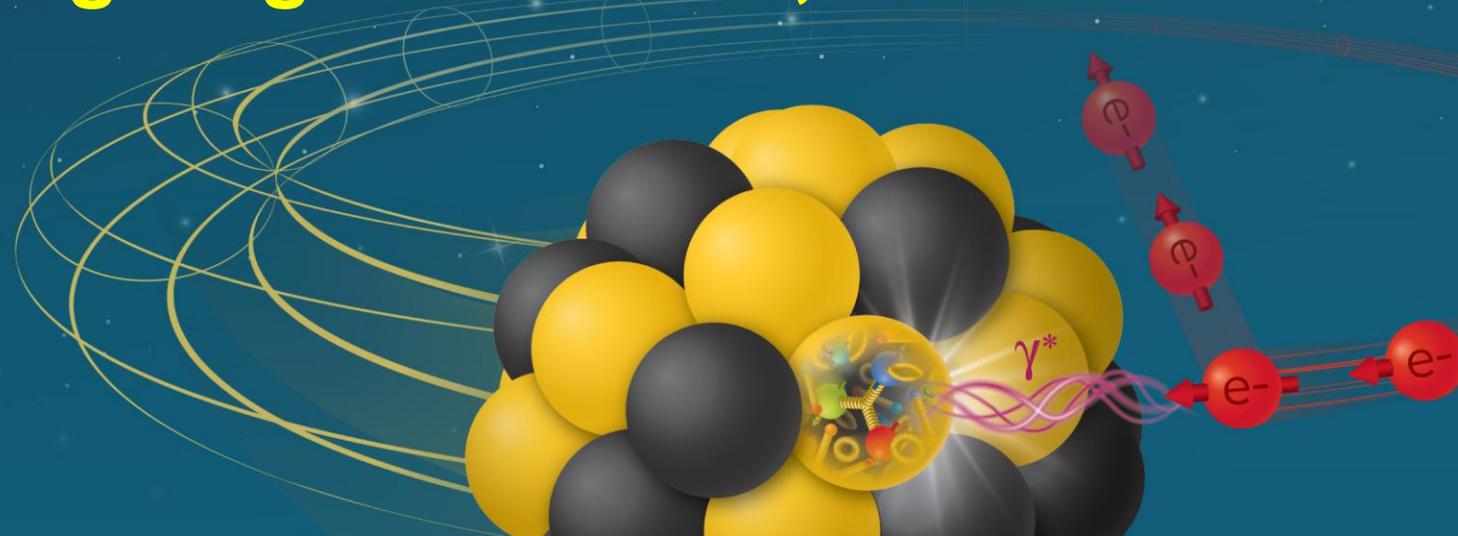# Optimum Integral Design for B0ApF and

em-design of BNL Cable Magnet Option for Q1ApF

Ramesh Gupta

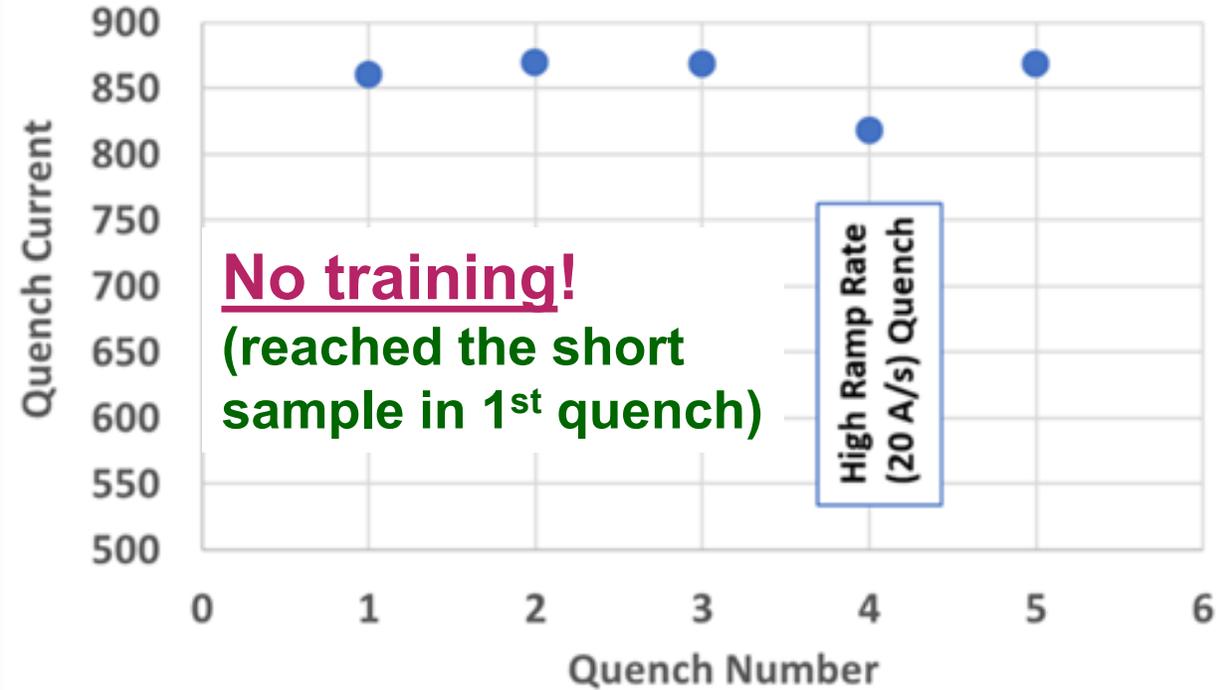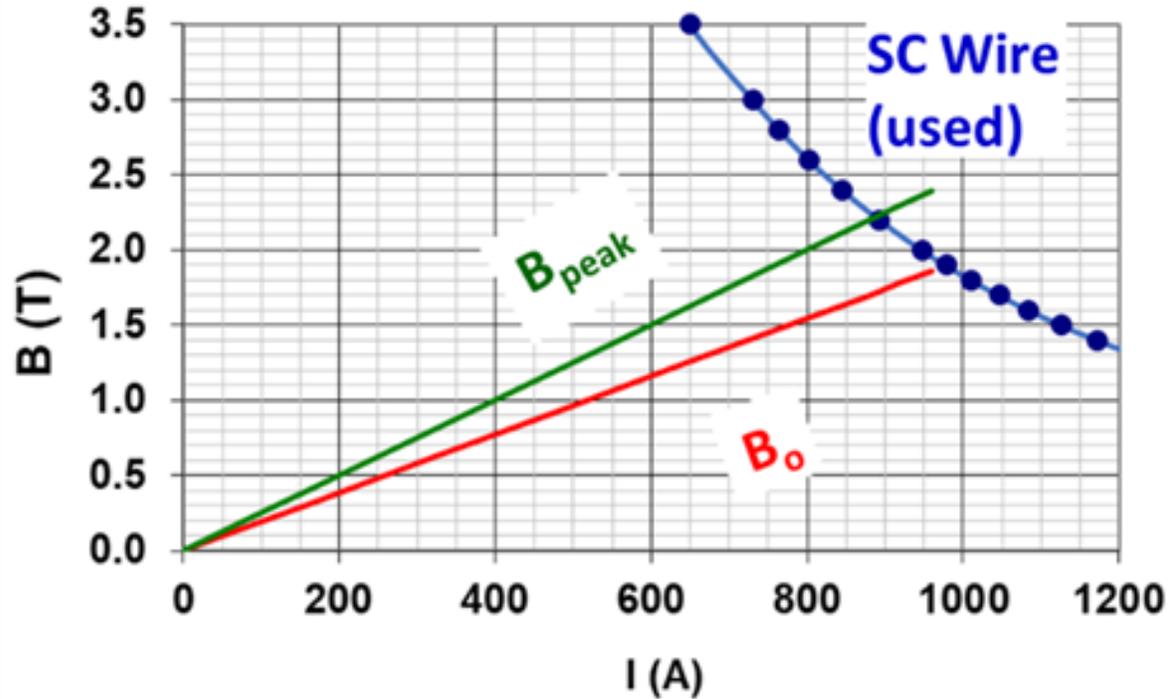**Superconducting Magnet Division, BNL**

March 25, 2026

Electron-Ion Collider

PBL/BNL STTR Phase II B0ApF Ready for Testing

- Optimum Integral Design for B0ApF with 114 mm coil id was developed, designed, built and partially tested under a PBL/BNL Phase II STTR.

- The magnet was energized to 331 A (3.3 T) at 4 K. The test was limited by the current leads external to the magnet (no quench till ~70% of SS).

- **Computed integral field at 331 A is 1.47 T.m. Since this is ~40% over the design integral of Layout 2, a PoP magnet is already done!**

- This can be upgraded with an outer SS support tube and another yoke. It is then computed to reach ~2.9 T.m at 1.92 K (~5.5 T bore field, ~6 T peak field) – another PoP as it implies >3.06 T.m for increased length.

- External leads have now been replaced. The magnet is getting ready for test along with the risk reduction B0pF insert coil. Another high field test of direct wind technology is possible if both insert and OID are powered.

- The scope of Phase II included field harmonic measurements to validate a new software based on a different and fast algorithm (already done).

Electron-Ion Collider

PBL/BNL STTR Phase I B0ApF (2-layer OID)

No training!
(reached the short sample in 1st quench)

High Ramp Rate (20 A/s) Quench

B_{int}=~0.91 T.m, B_o= ~1.7 T, B_{pk}= ~2.2 T, Coil i.d.=114 mm (4 K, smaller cable, Cu/Sc ratio = 2.25 and L = 0.6 m)

B_{int} = 1.05 T.m (Layout 2) is expected in a 2-layer OID with a larger cable, lower Cu/Sc ratio, L=0.745 m, @1.92 K with sufficient margin.
➤ **No splice will be needed (same as in Phase I OID).**

Expected B0ApF OID with Corrector Magnets

- **In addition to B0ApF dipole, the complete package requires a vertical corrector dipole and a skew quadrupole corrector.**

- **Optimum integral magnet can be built with a single layer winding. This is the case for the optimum integral dipole in the AGS tunnel.**

- **Given the low integral strength of the two correctors, a single layer of each winding will be sufficient.**

OID in the AGS Tunnel at BNL

Total # of windings expected = 4

➢ **2 for B0ApF**

➢ **1 each for each of 2 correctors**

Why OID requires ½ # of layers as compared to other B0ApF designs?

#1: See slide presented in an earlier MSG

#2: Unlike in double helix & in serpentine, OID doesn't require coil winding in set of two layers. A single layer is acceptable.

Loss in Integral Field Due to Ends and Some Short EIC Magnets

- Relative loss starts becoming important when the length of magnet is so small that the straight becomes comparable to the ends.
- Typical mechanical length of end: ~ 2 coil diameter each in dipole. Total ends in dipole: ~four diameter (~2 coil diameter in quad).
- Compare coil length (L) to coil i.d. (id) ratios. Relative loss will be significant when the ratio is **<8** in dipoles and **<4** in quadrupoles.

Coil length to coil diameter ratios in some EIC magnets:

➢ B0ApF (L = 600 mm, id = 114 mm):   ~5.3

➢ B1ApF (L = 1600 mm, id = 370 mm):   ~4.3

➢ B1pF/B1ApF (L = 2500 mm, id = 363 mm): ~6.9

➢ B0pF/Q0eF (L=1200 mm, id = 656 mm):   ~1.8 (refer to quad)

Reference guide
~8 in dipole
~4 in quads

Brookhaven National Laboratory
Magnet Division   PBL   Optimum Integral Design for EIC -Ramesh Gupta   Magnet Steering Group Meeting   July 25, 2025   8

Electron-Ion Collider
OID for B0ApF and Cable Magnet for Q1ApF   Ramesh Gupta   FC1 Meeting on March 25, 2026

Preliminary Magnetic Design of Q1ApF

Note: This is not a complete magnetic design - limited to support the proposed BNL option to assure that it will meet the basic magnetic design requirements.

This is also an example of (or appeal for) some beneficial design principles to follow.

Q1ApF Coil Cross-section (with some suggestions)
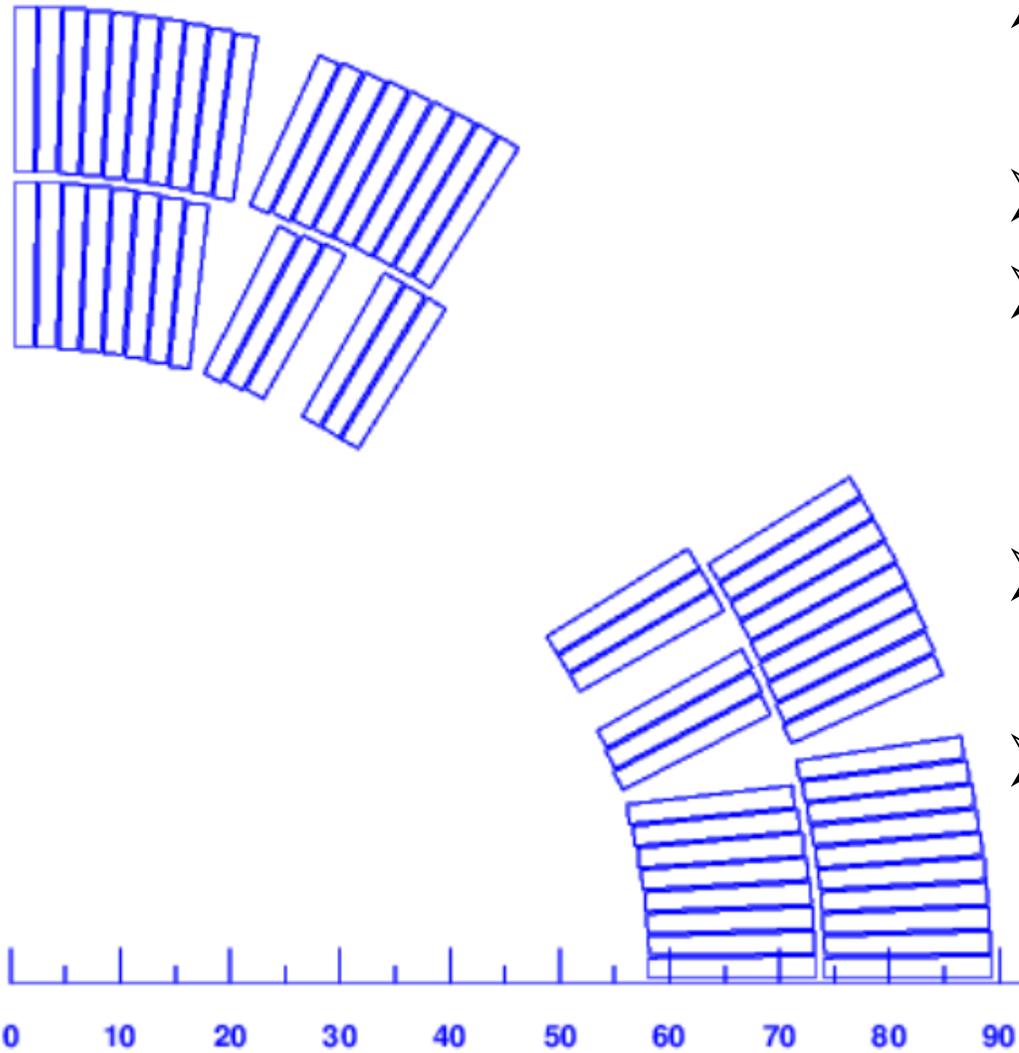
➢ Symmetric wedges
   (Smaller one made rectangular)
➢ All harmonics <0.4 units (spec <2 units)
➢ Larger midplane gap for field quality and pre-stress tuning
   (+/- 10 mil instead of +/- 4 mil)
➢ Inner and outer layers aligned (with space of one turn for splice/double-layer)
➢ ~65% margin on loadline @10.4 KA
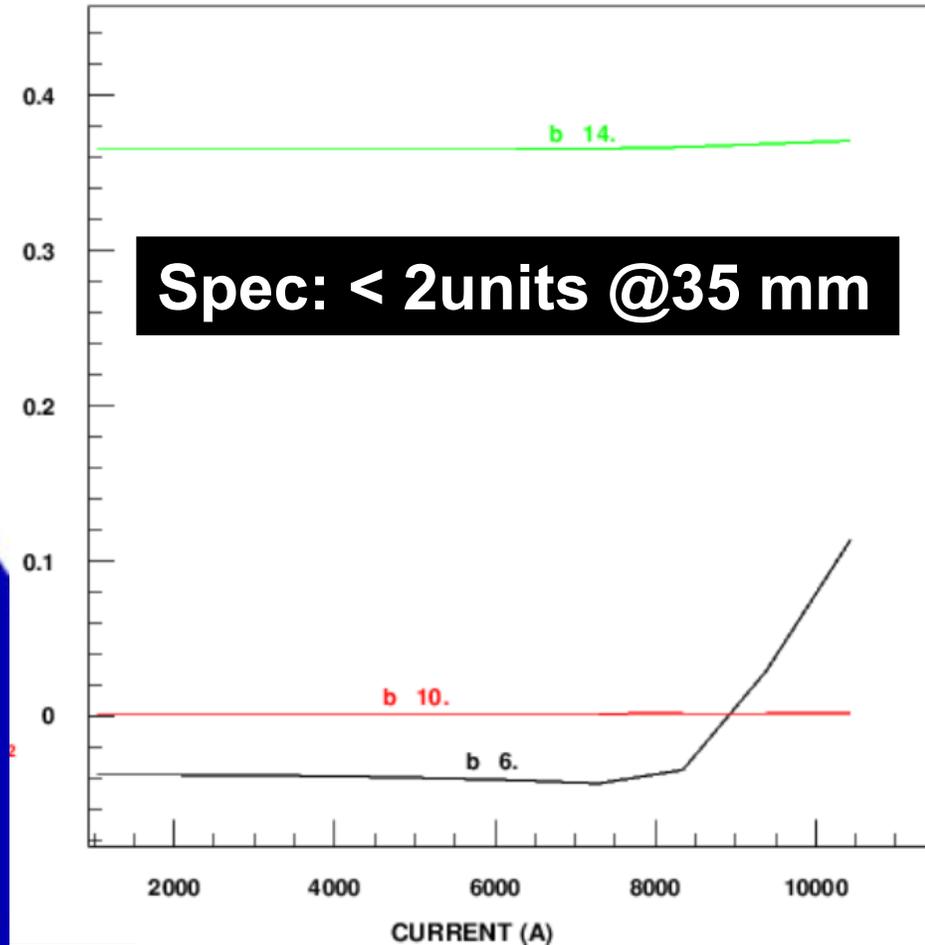   (the design is not yet fully optimized)

Yoke Optimized for Hadron Beam

Saturation-induced harmonics remain <0.4 units in the entire range of operation
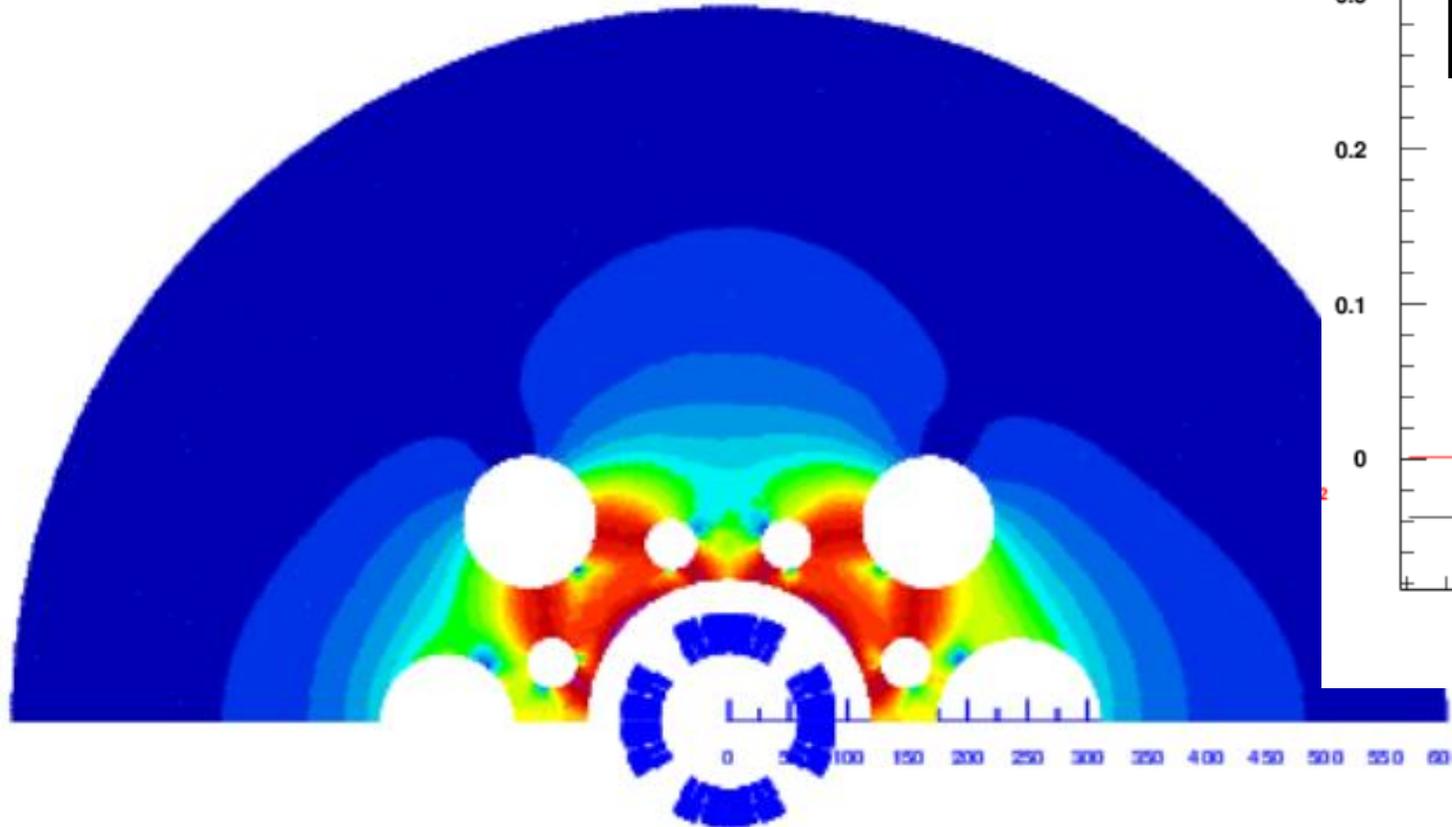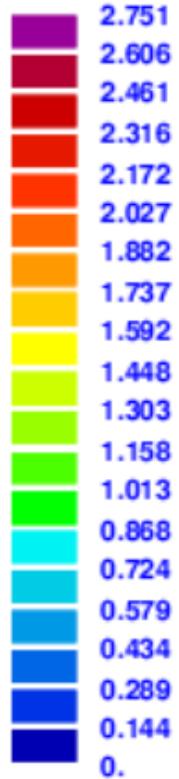
Spec: < 2units @35 mm

Yoke Optimized for electron Beam : Cross-talk (1)

Harmonics in Tesla @43 mm at the center of electron hole as a function of current in the hadron quad

Original Case
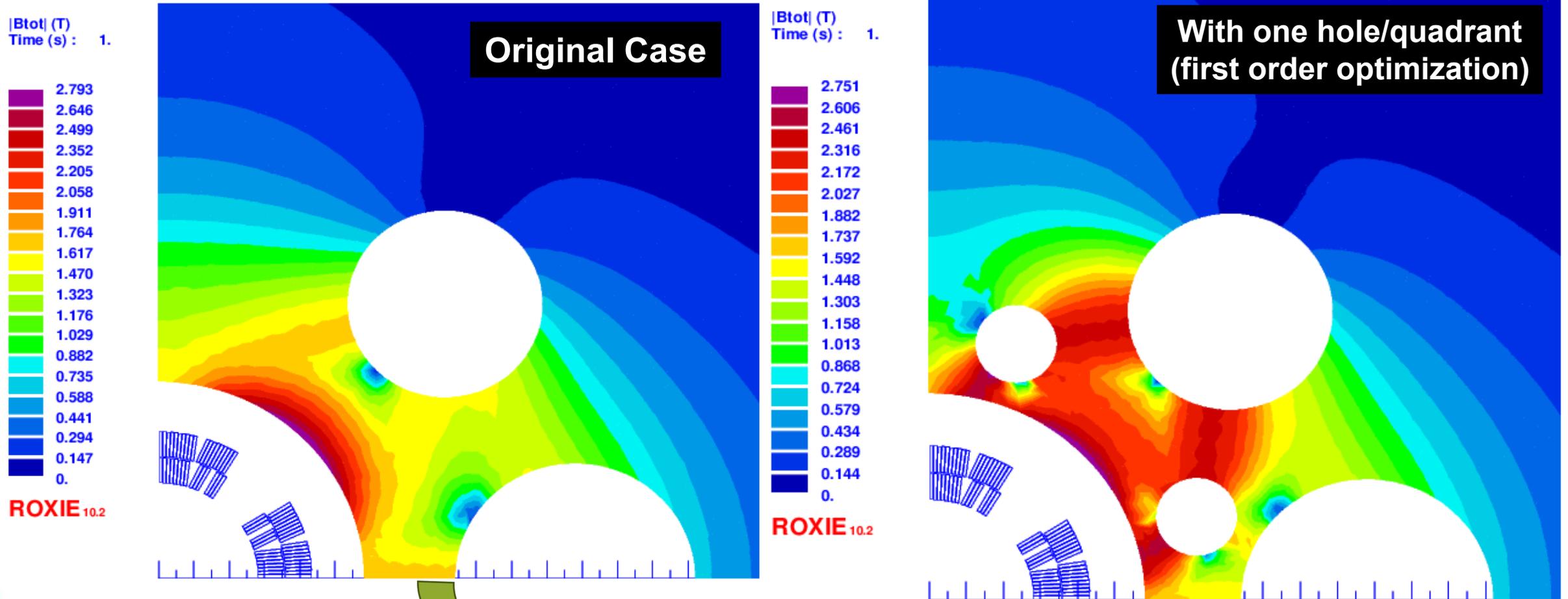
With one hole/quadrant (first order optimization)
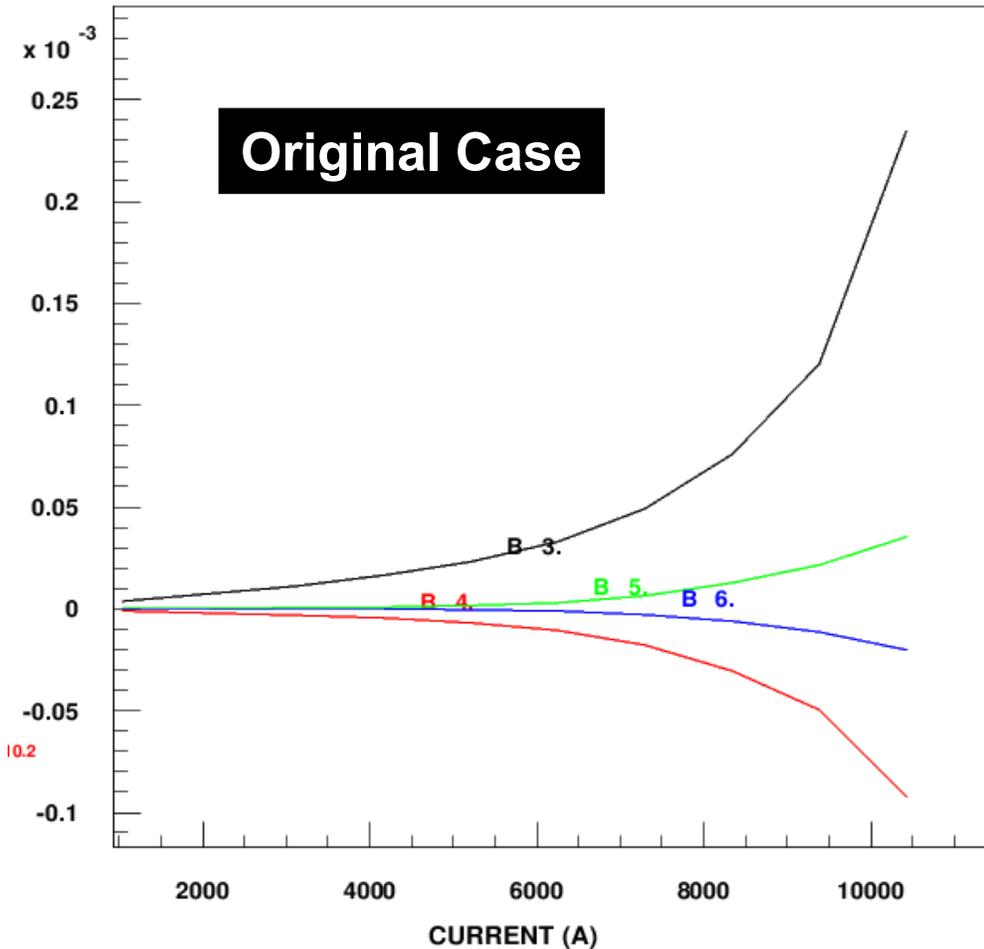
Note a change in the scale (10^{-3} to 10^{-4})
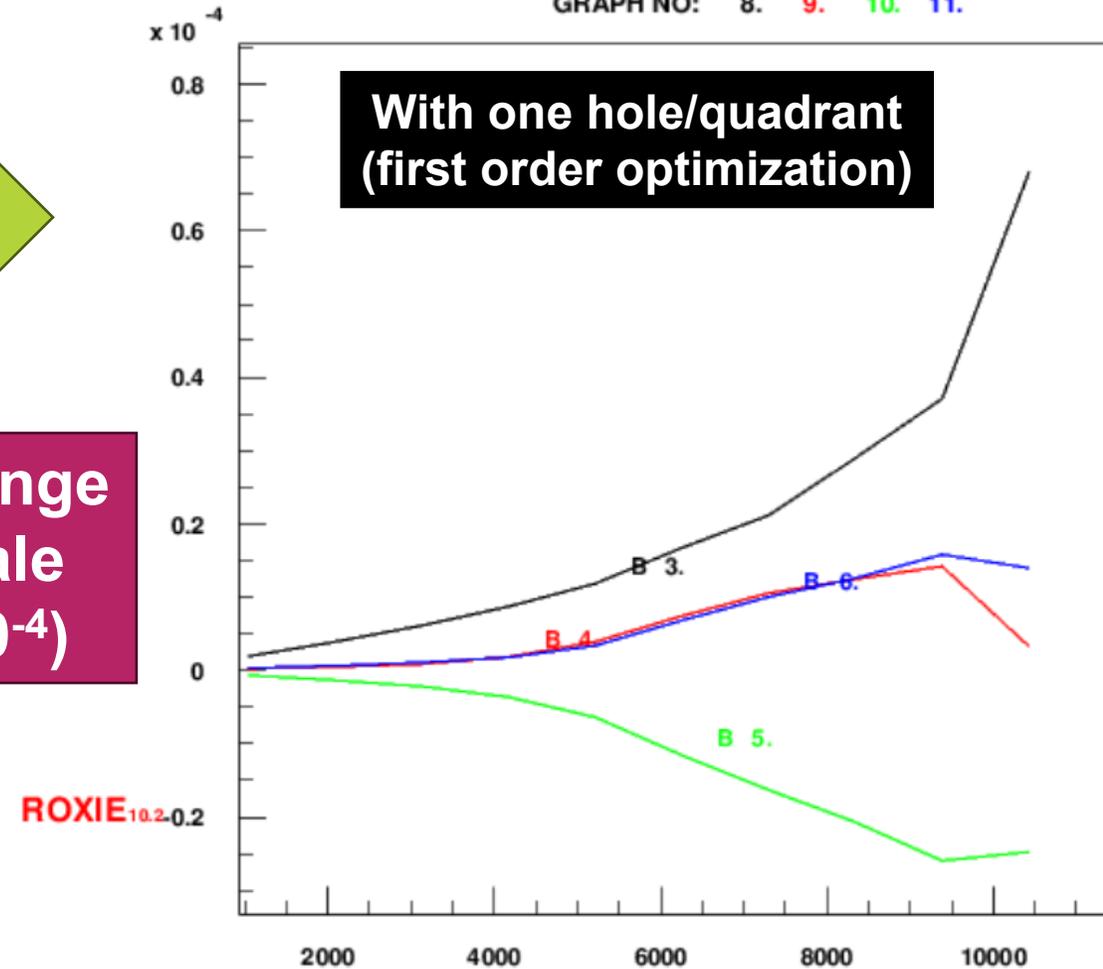
Yoke Optimized for electron Beam : Cross-talk (2)

Original Case

With one hole/quadrant (first order optimization)

Flux rerouted
(field going to electron hole reduced)

Yoke Optimized for electron Beam : Cross-talk (3)

Original Case

With one hole/quadrant (first order optimization)

Flux rerouted (field going to electron hole reduced)

Even better optimization were seen with more holes
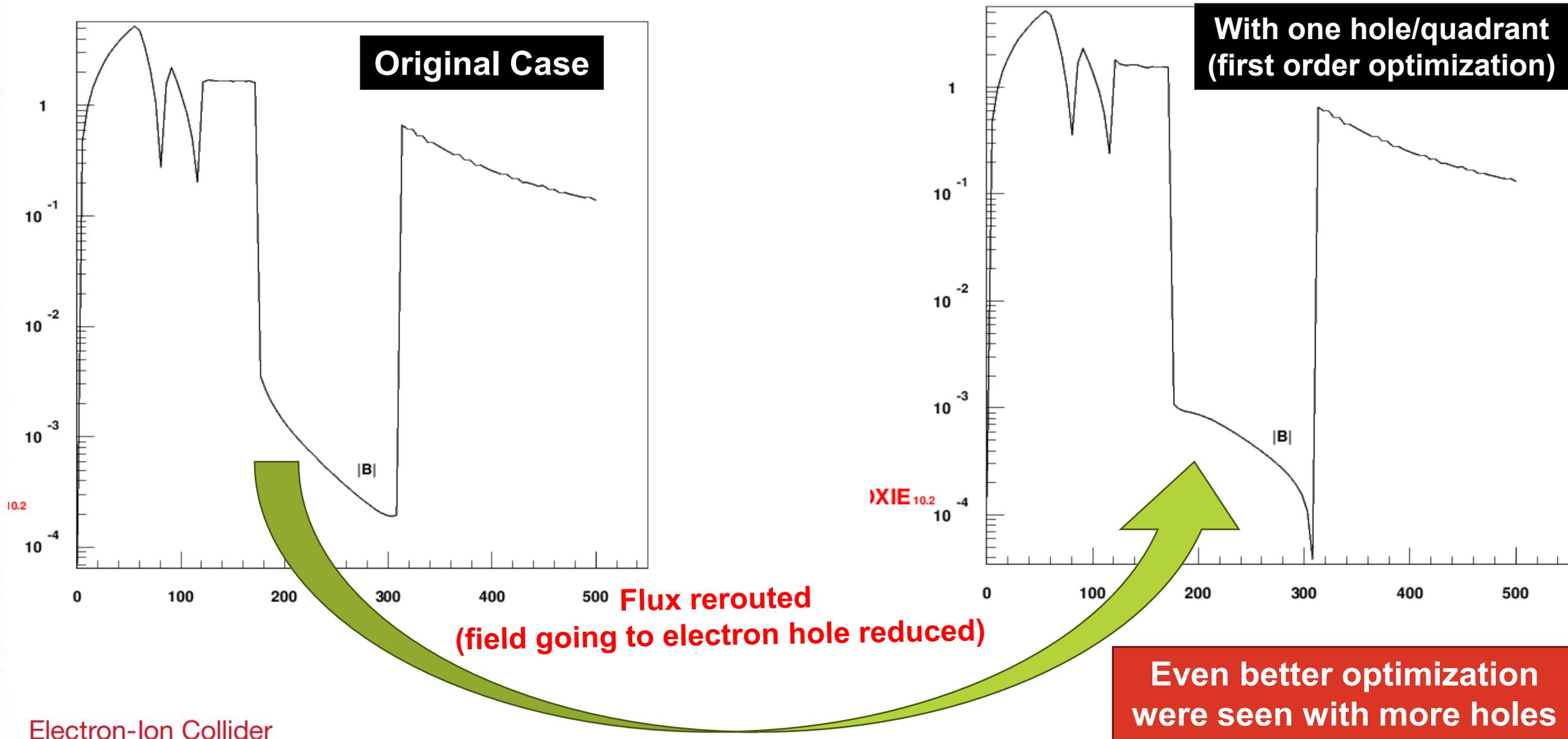
Impact of Mesh Size (Reduced by 60% in this case)

GRAPH NO: 8. 9. 10. 11.

Mesh used in various analysis

Mesh size reduced by 60%

(no significant impact)

An insignificant change in B4/B6

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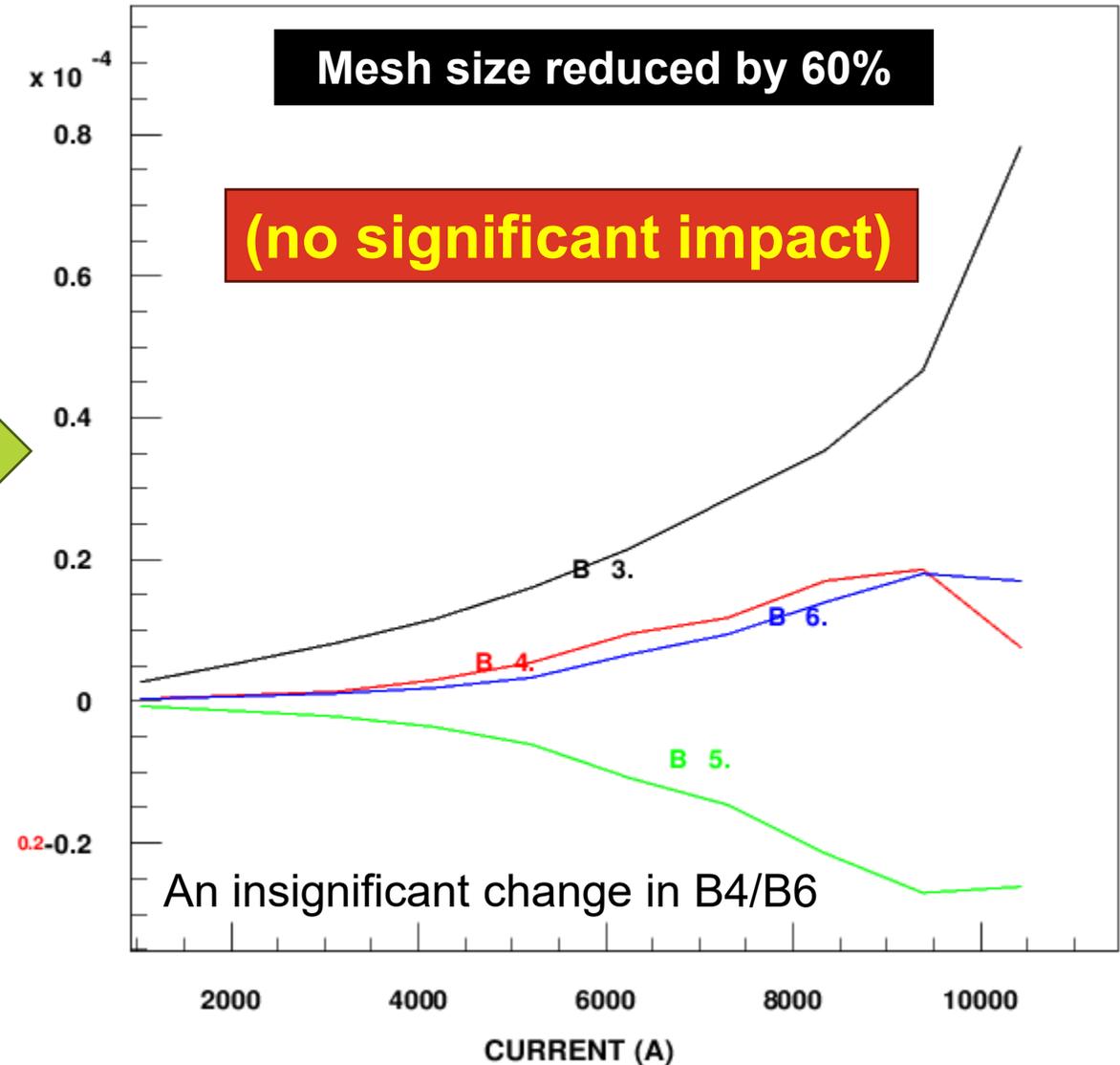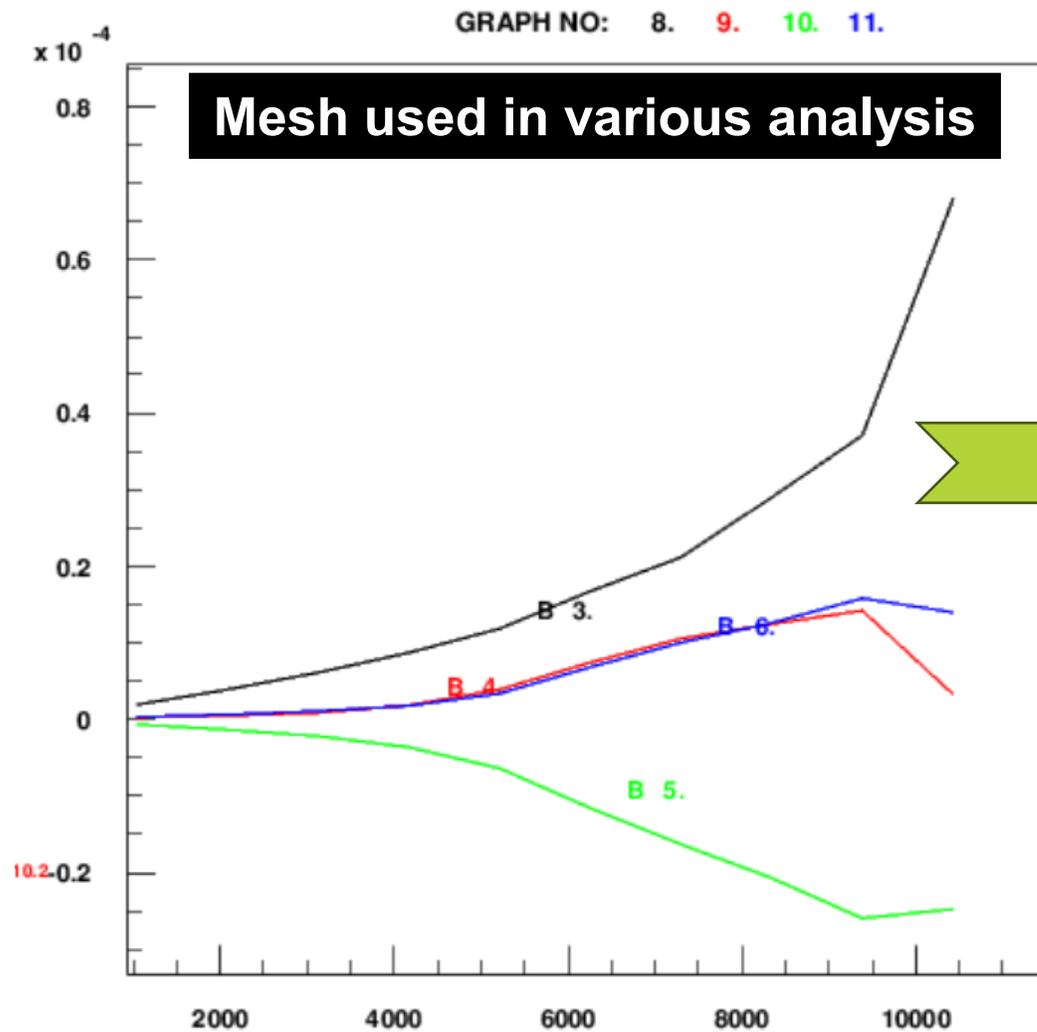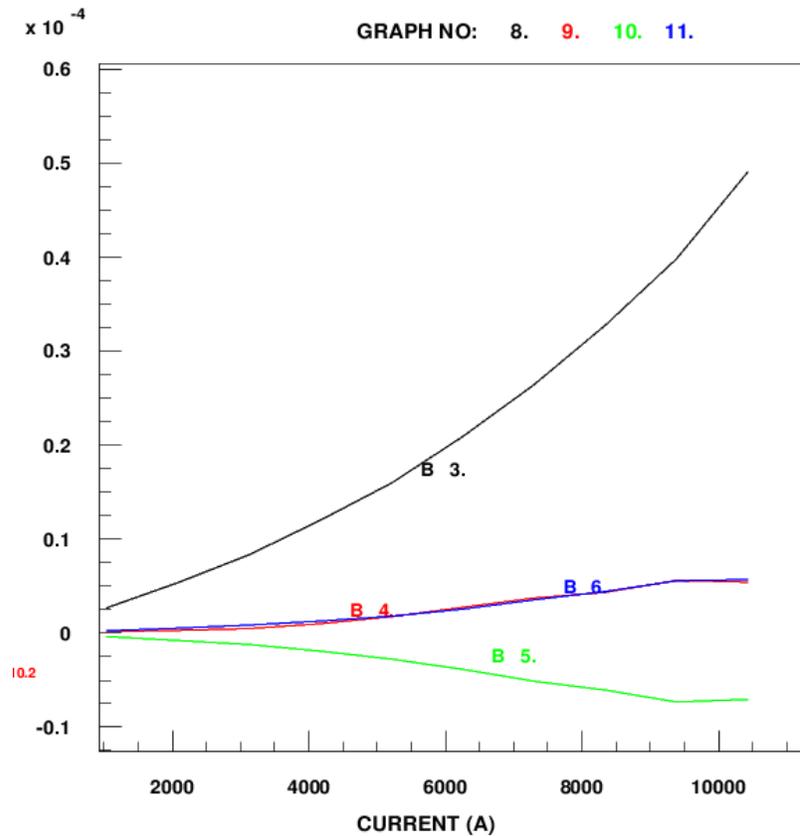
Cross-talk Harmonics at various axial location

Local harmonics in Tesla @43 mm at the center of electron hole as a function of current in the hadron quad
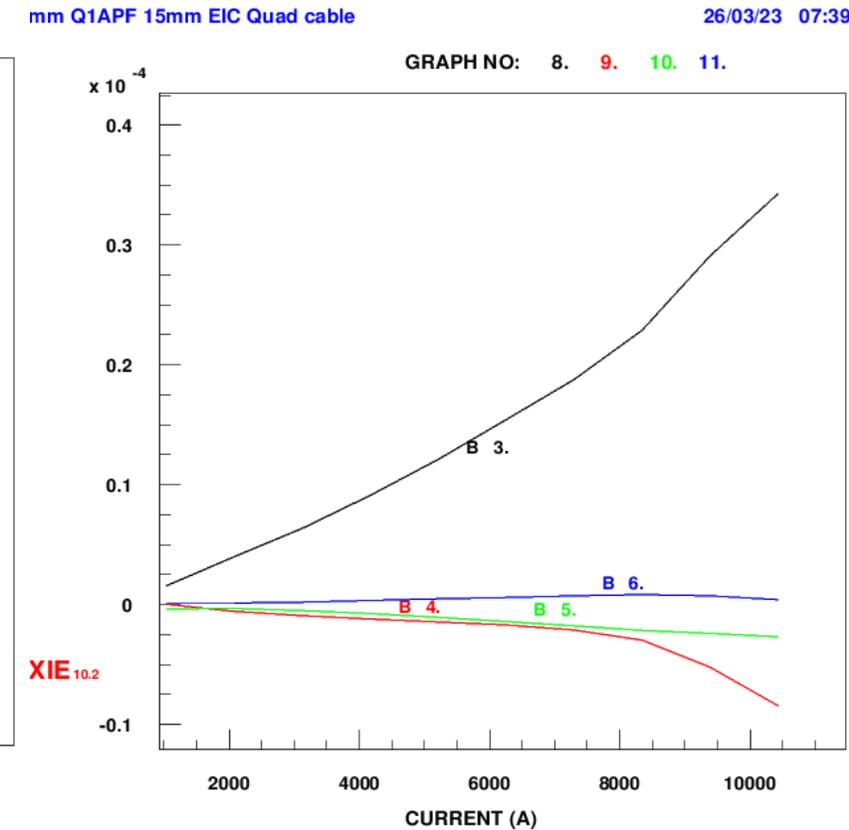

IP-end
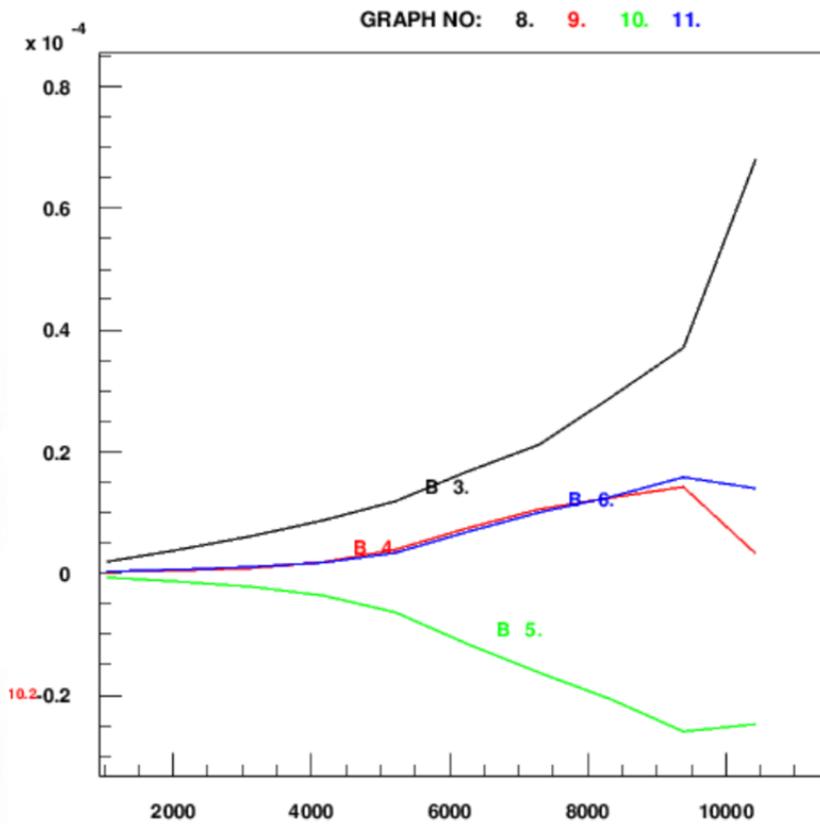
Middle of the magnet

Non-IP-end

Even better optimization were seen with more holes

Thanks. Any Question?