Brookhaven National Laboratory

Jefferson Lab

U.S. DEPARTMENT OF ENERGY

Preliminary Magnetic Design of Q1ApF

(in support of the BNL proposal for cable magnet option)

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Magnet Steering Group Meeting

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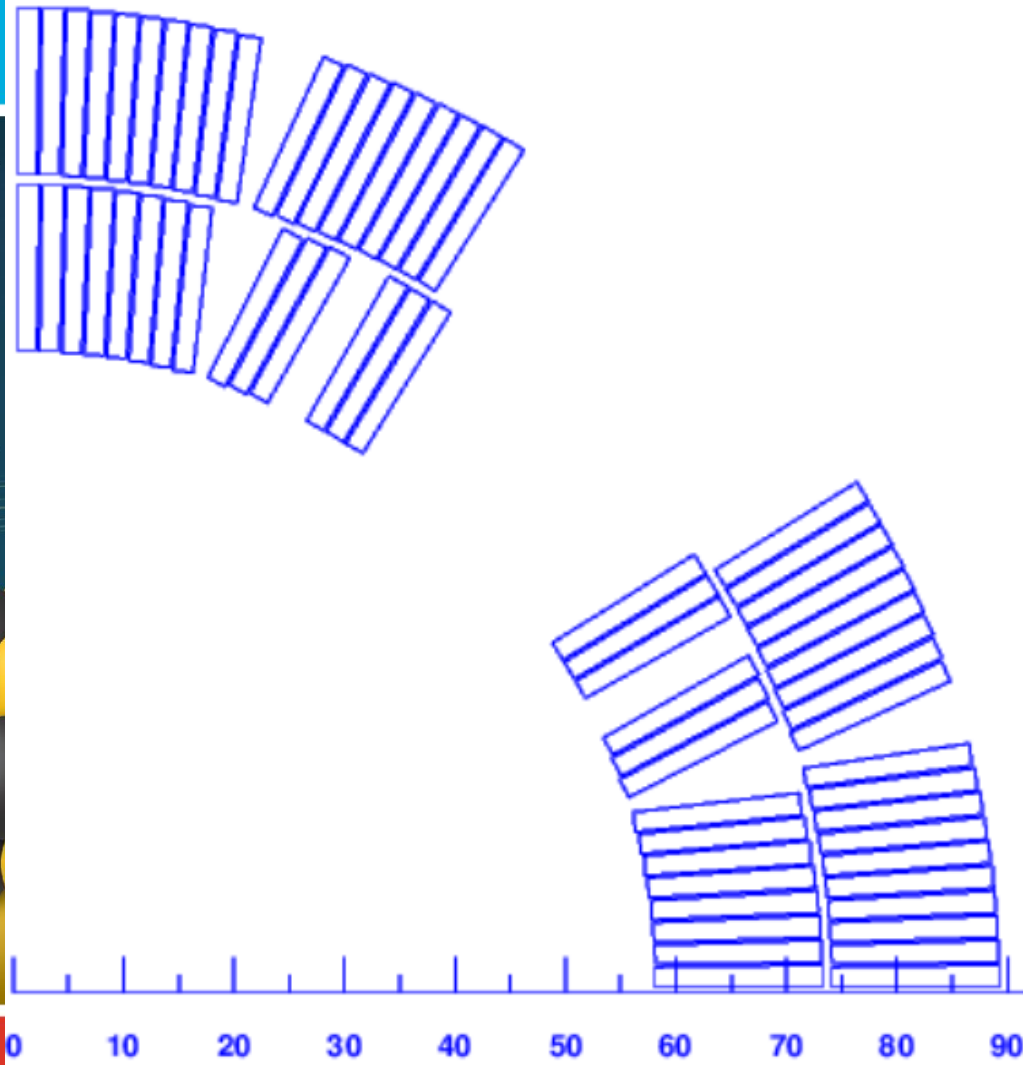
Electron-Ion Collider

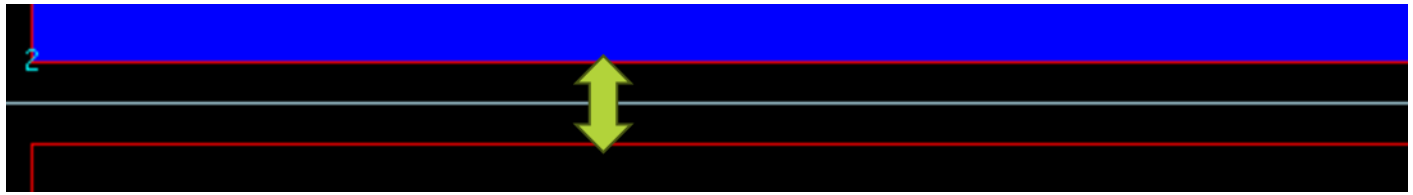
Overview

- This is a preliminary magnetic design of Q1ApF.
- The scope was limited to support the proposed BNL option with a goal to assure that a full magnetic design can be developed to meet the essential magnetic design requirements.
- The presentation includes examinations of various techniques that are relevant to this and many other EIC IR magnets.

Key Features of the Q1ApF Coil Cross-section



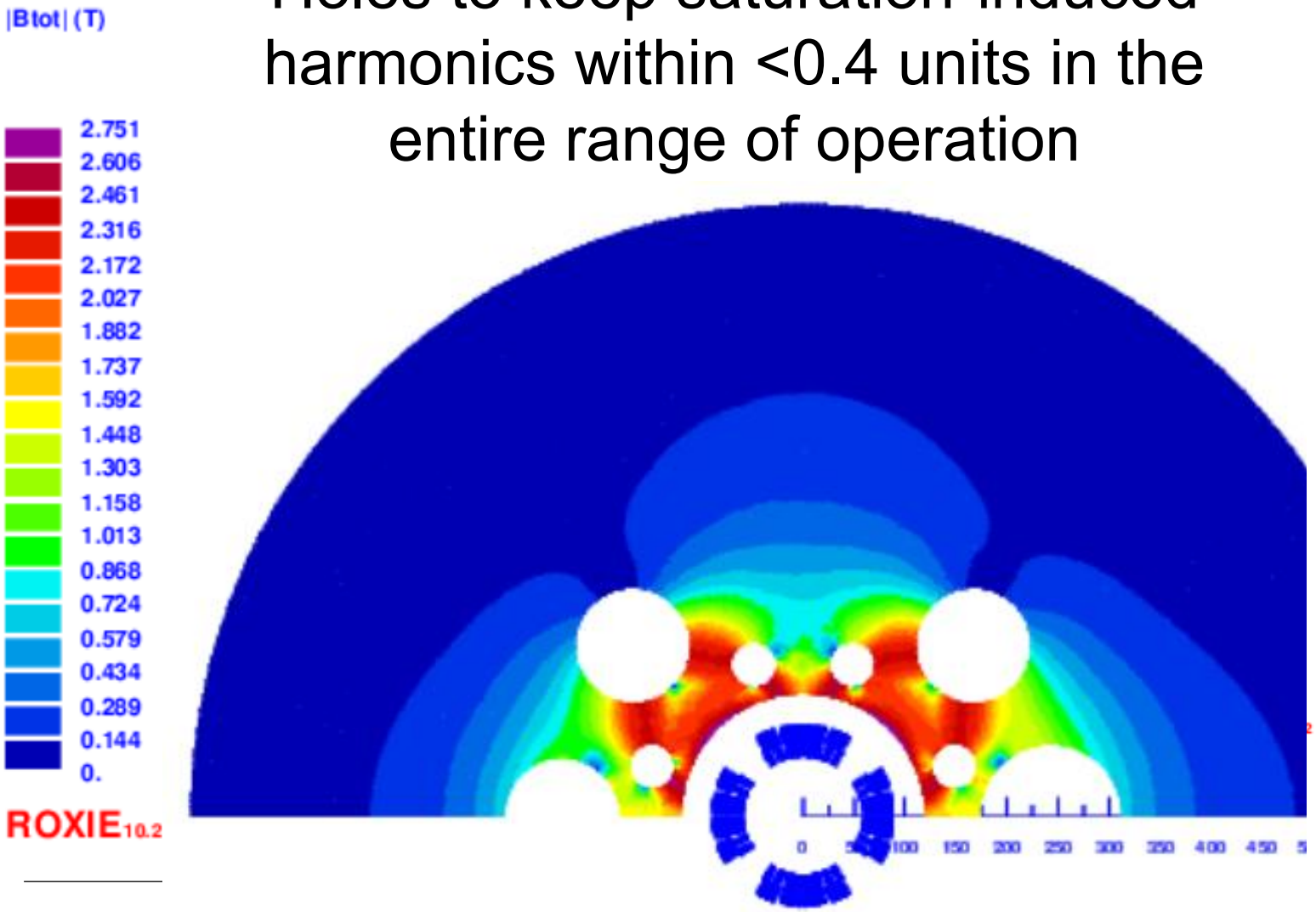
- Symmetric wedges
  (Smaller one made rectangular)
- All harmonics <0.4 units (spec <2 units)
- Larger midplane gap for field quality and pre-stress tuning during production
  (+/- 10 mil instead of +/- 4 mil)



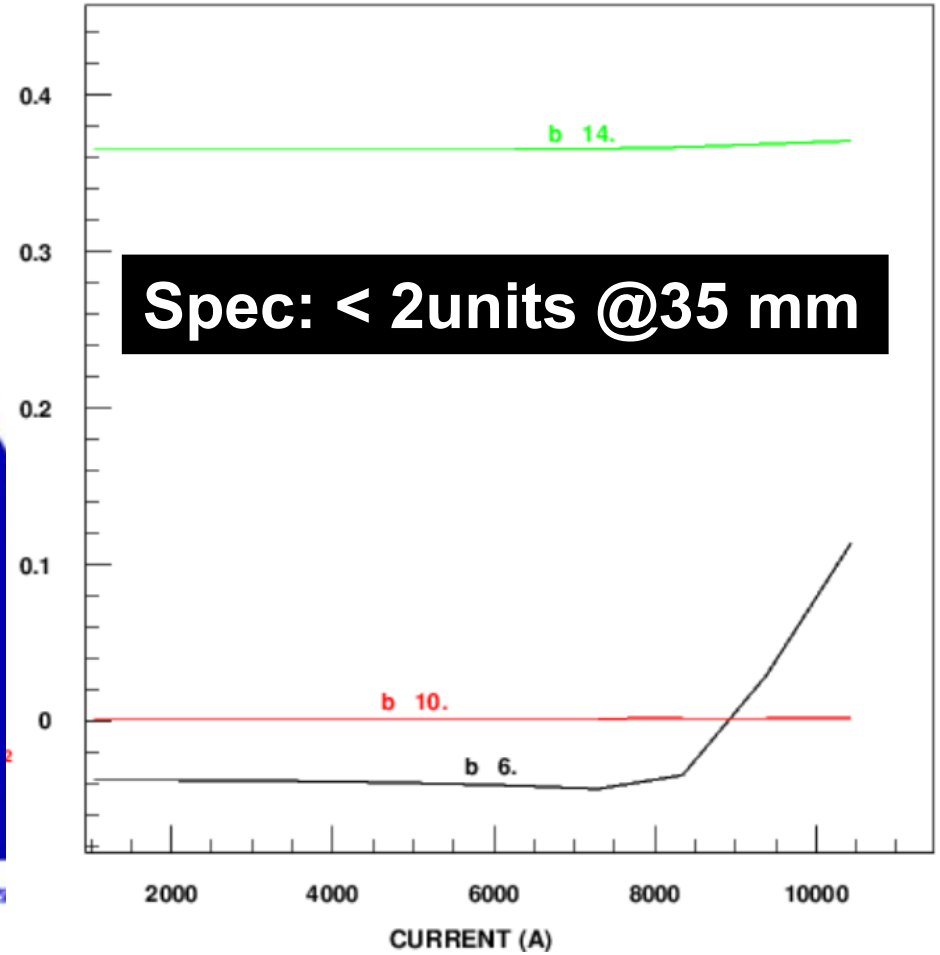
- Inner and outer layers aligned (with space of one turn for splice/double-layer)
- ~65% margin on loadline @10.4 KA
  (the design is not yet fully optimized)

Optimization of Yoke for Hadron Beam

Holes to keep saturation-induced harmonics within <0.4 units in the entire range of operation



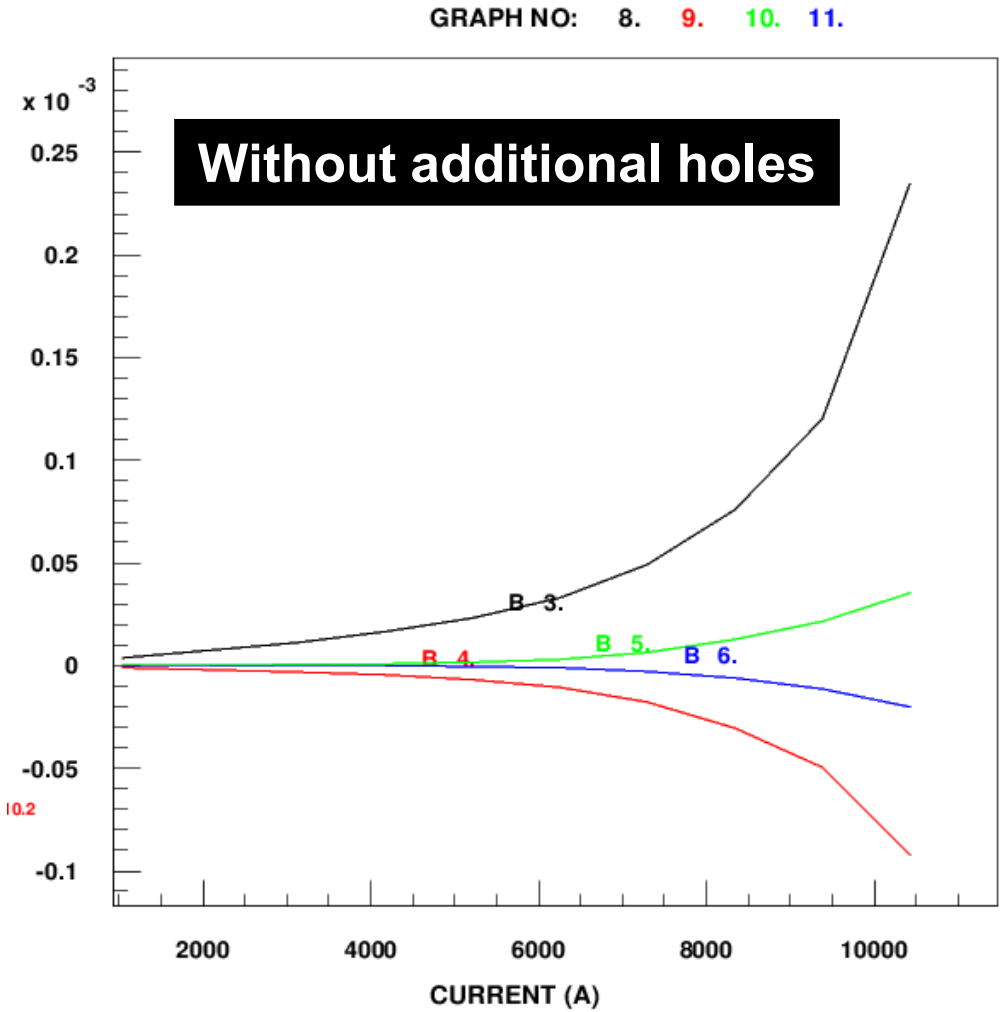
Harmonics as a function of current



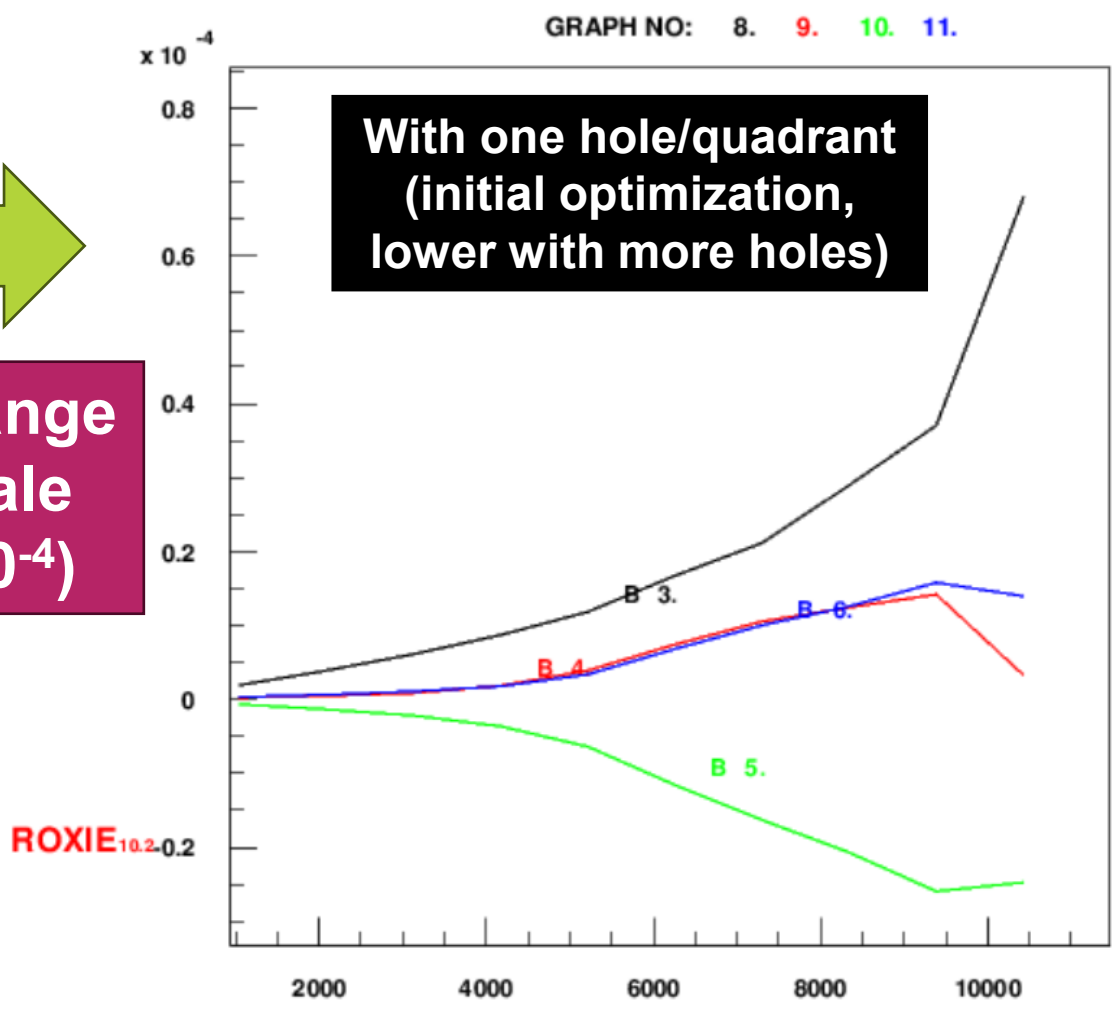
Spec: < 2units @35 mm

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

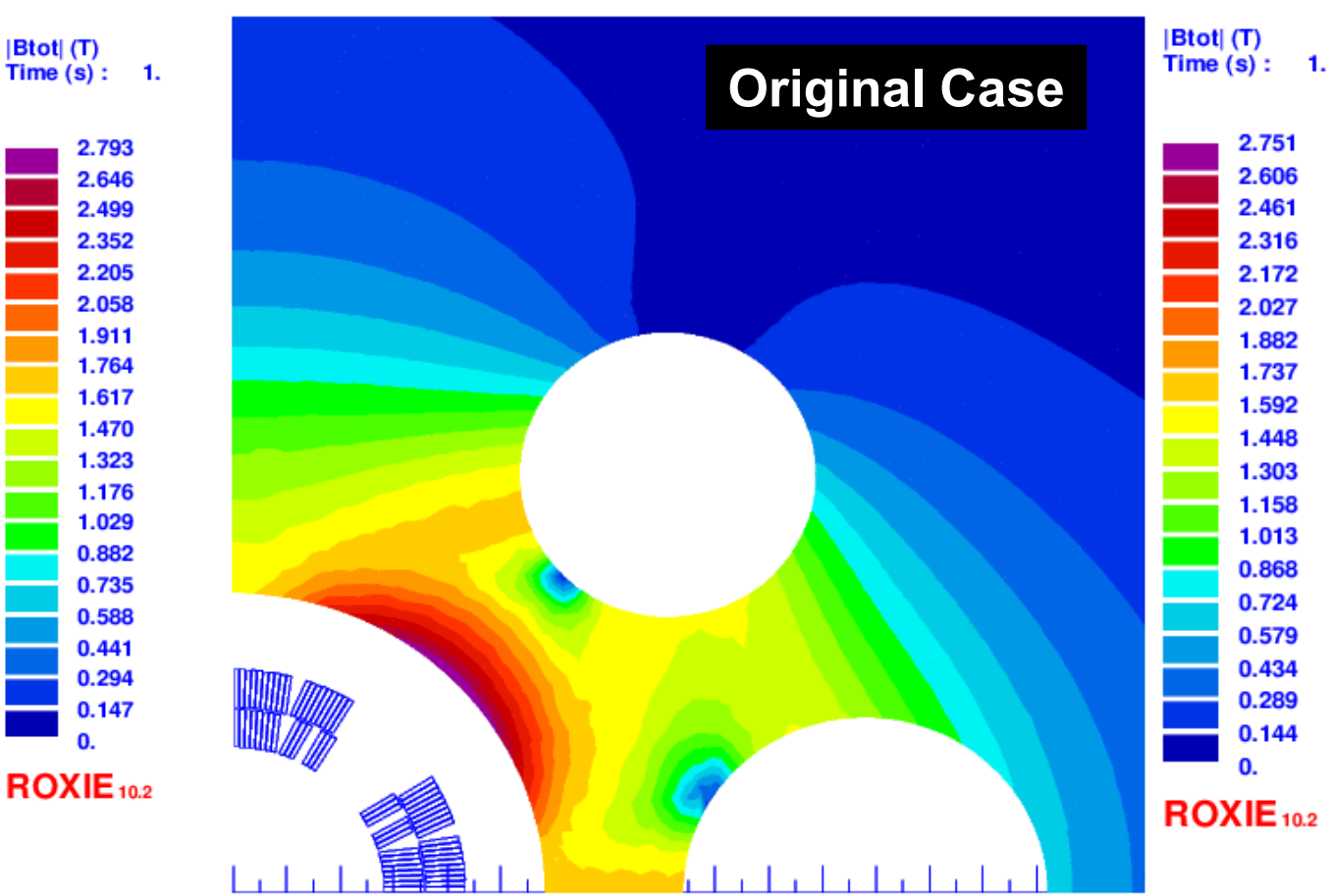
Crosstalk harmonics in Tesla @43 mm for electron beam as a function of current in hadron quad

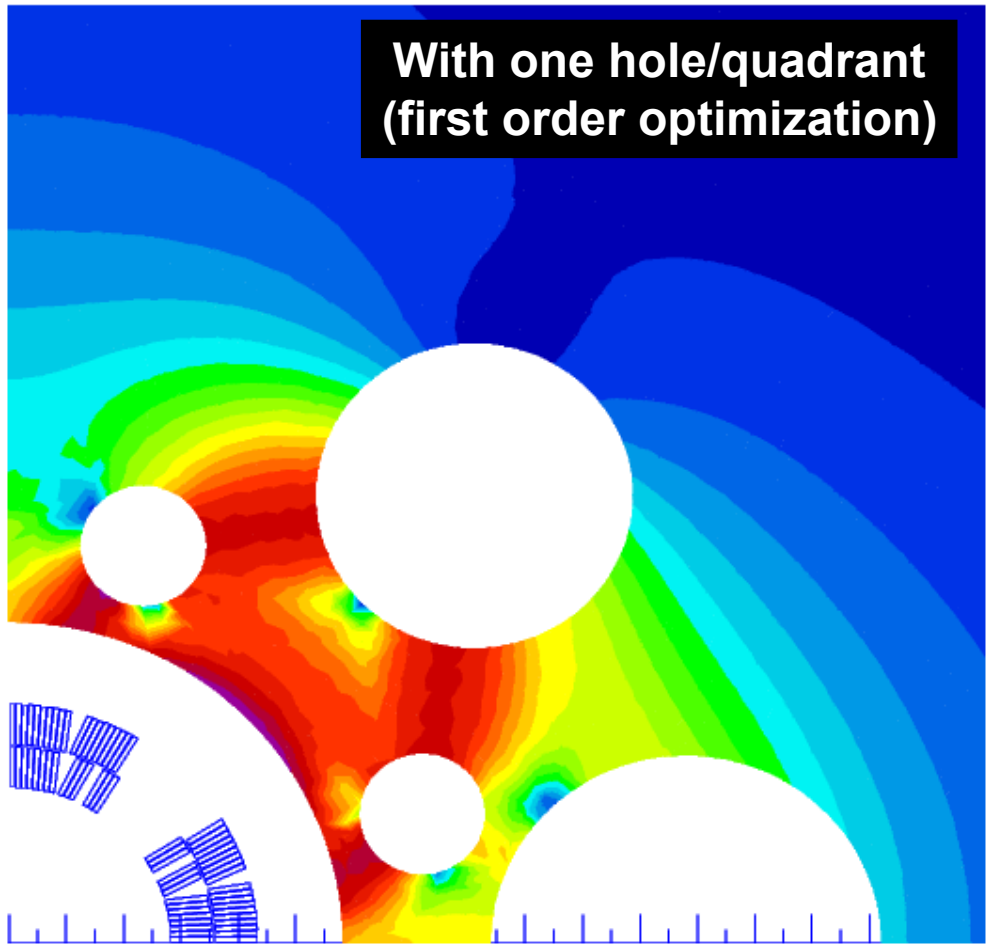


Note a change in the scale (10^{-3} to 10^{-4})



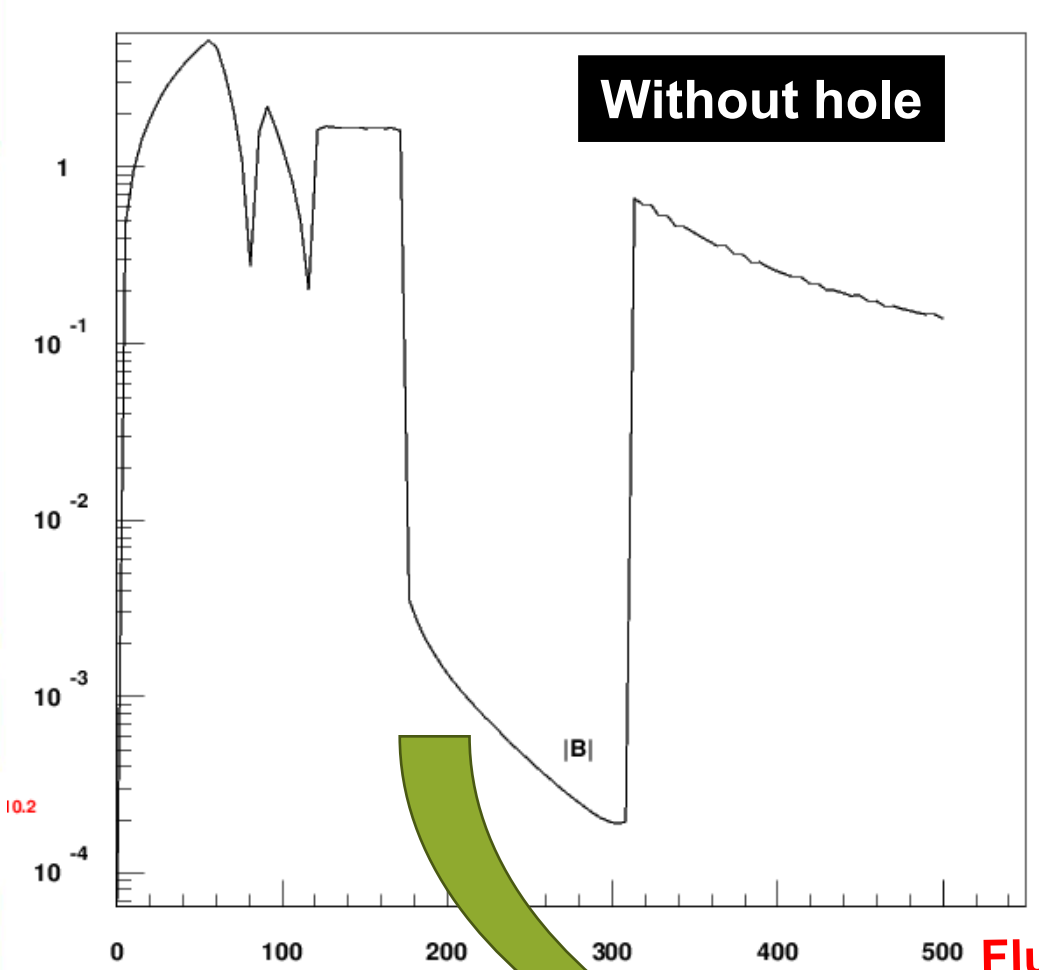
Yoke Optimized for electron Beam : Cross-talk (2)



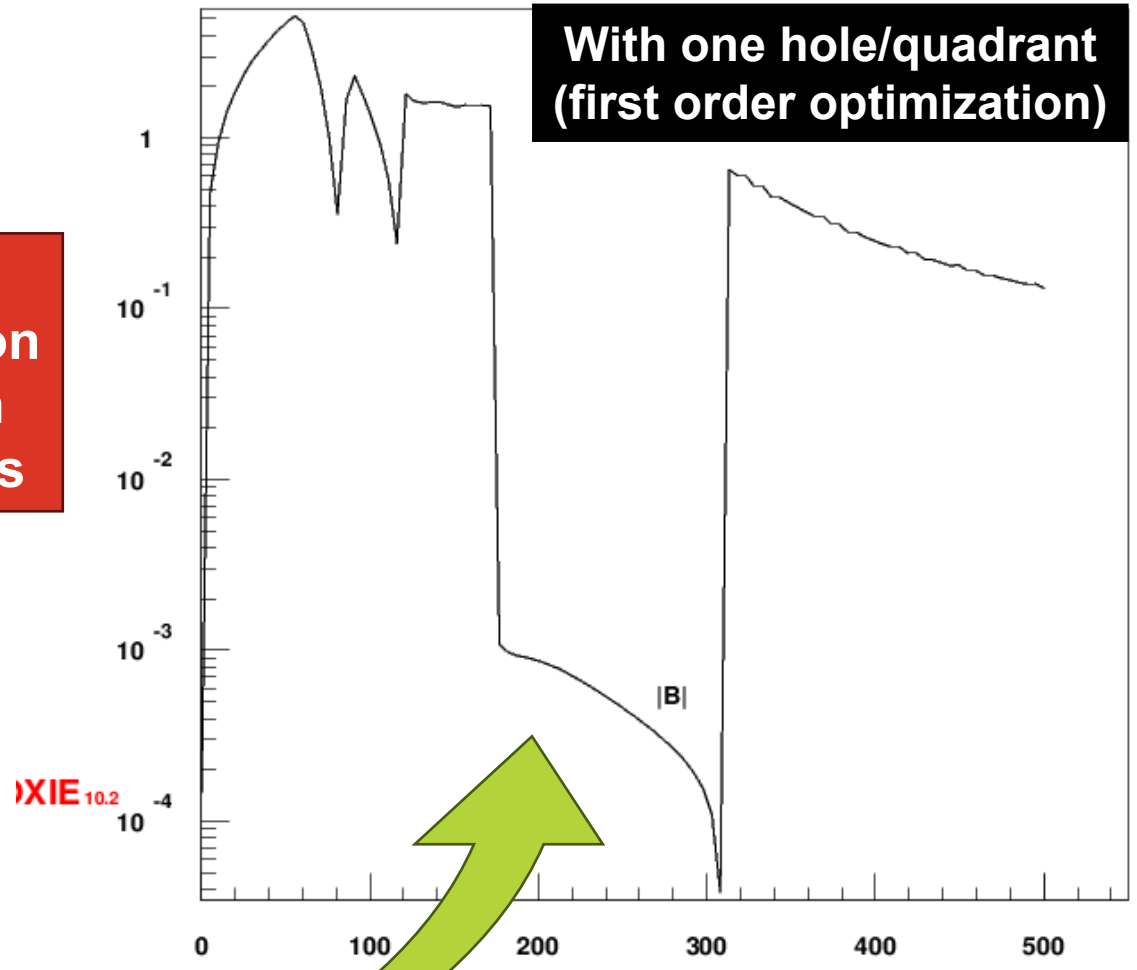


Flux rerouted
(field going to electron hole reduced)

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



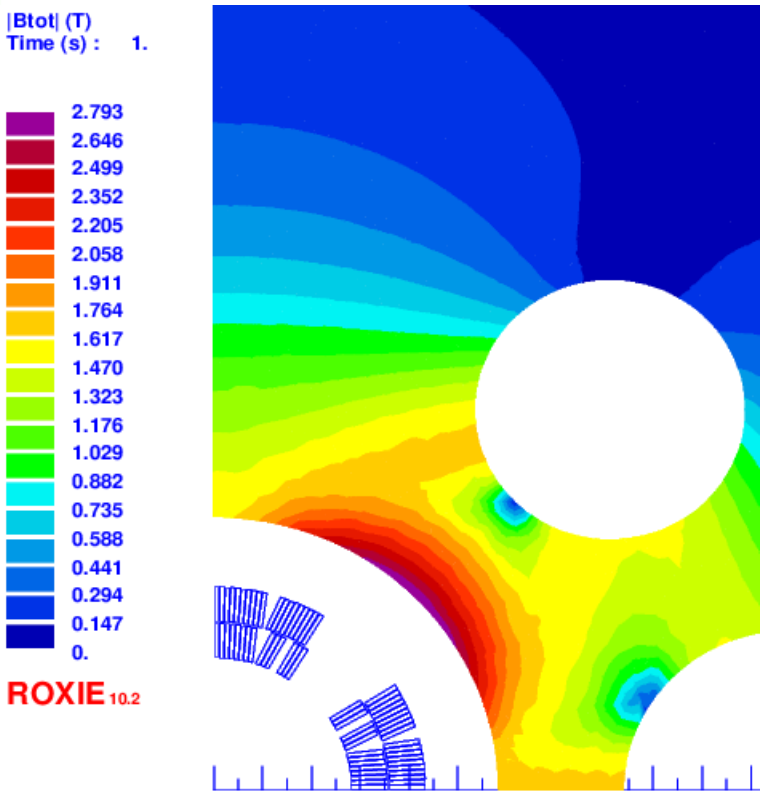
Better optimization seen with more holes



Flux rerouted
(field going to electron hole reduced)

Other Ways to Further Reduce the Crosstalk (#1)

(these are simple techniques and may have a major impact)



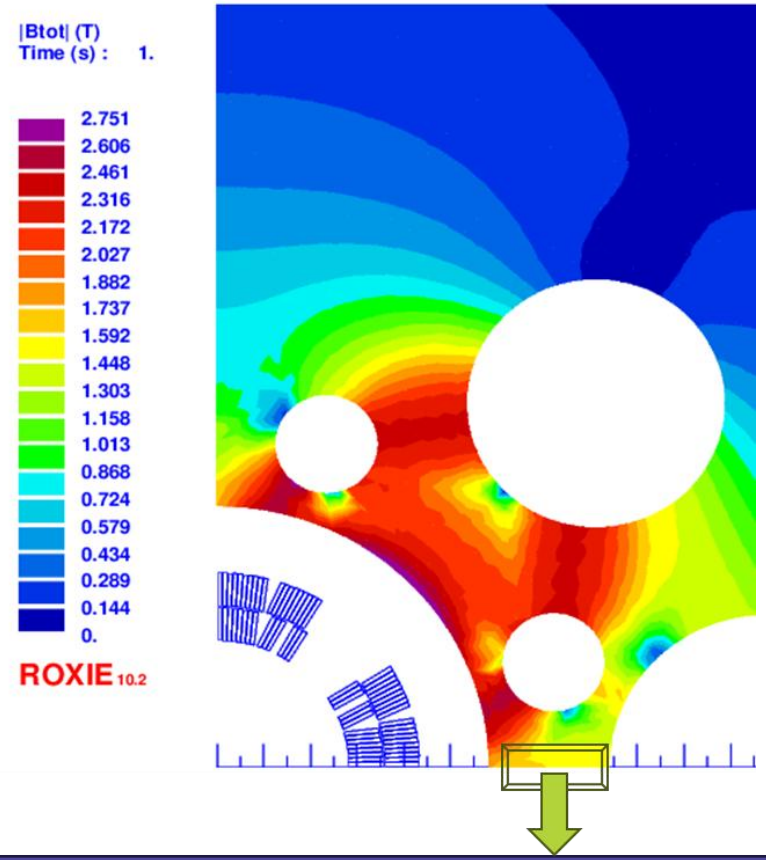
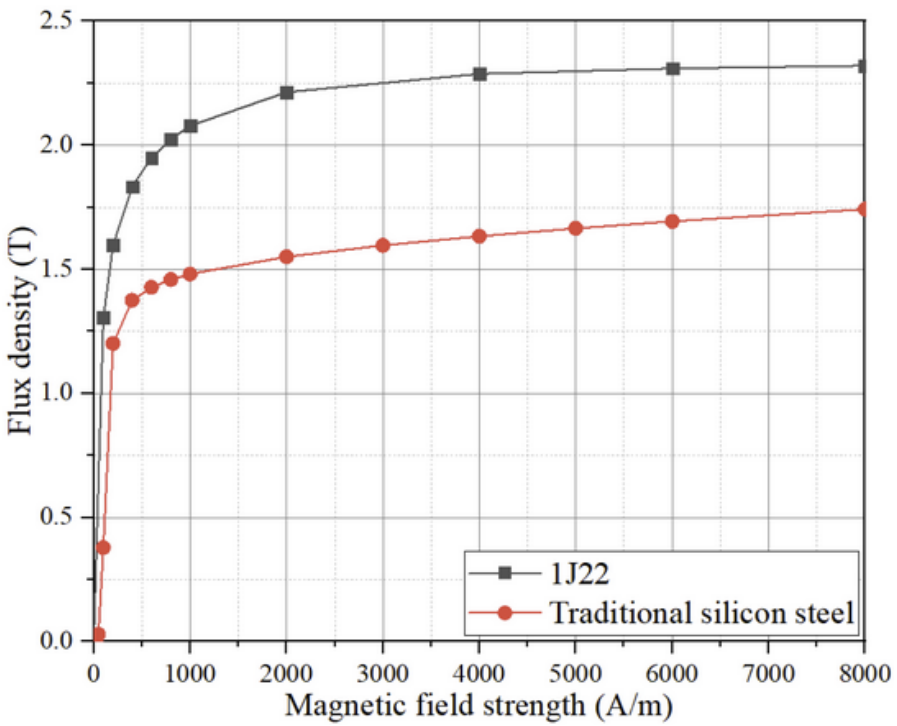


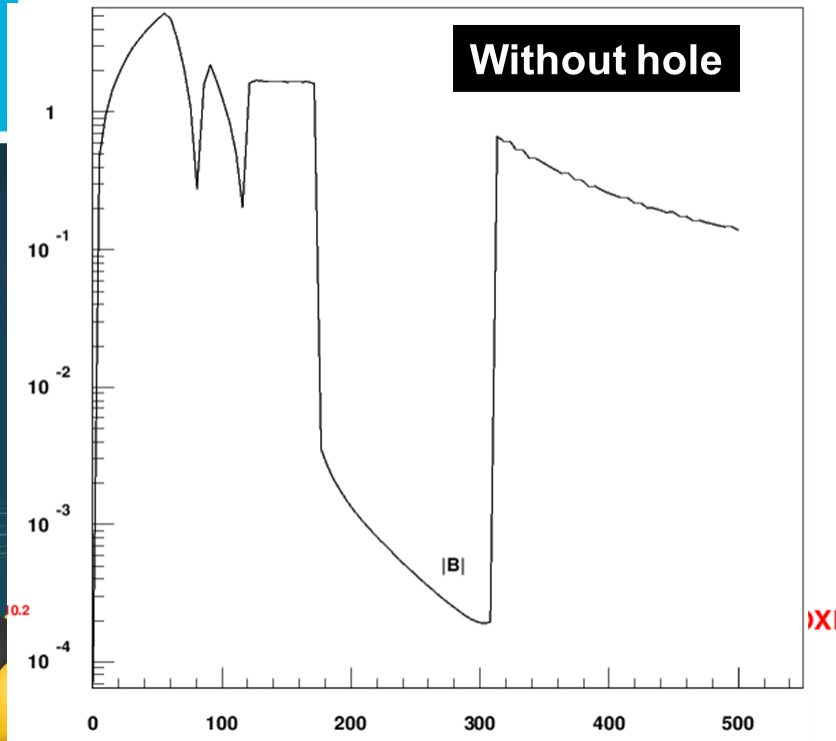
Figure 3. B–H curve of 1J22 and traditional silicon steel.

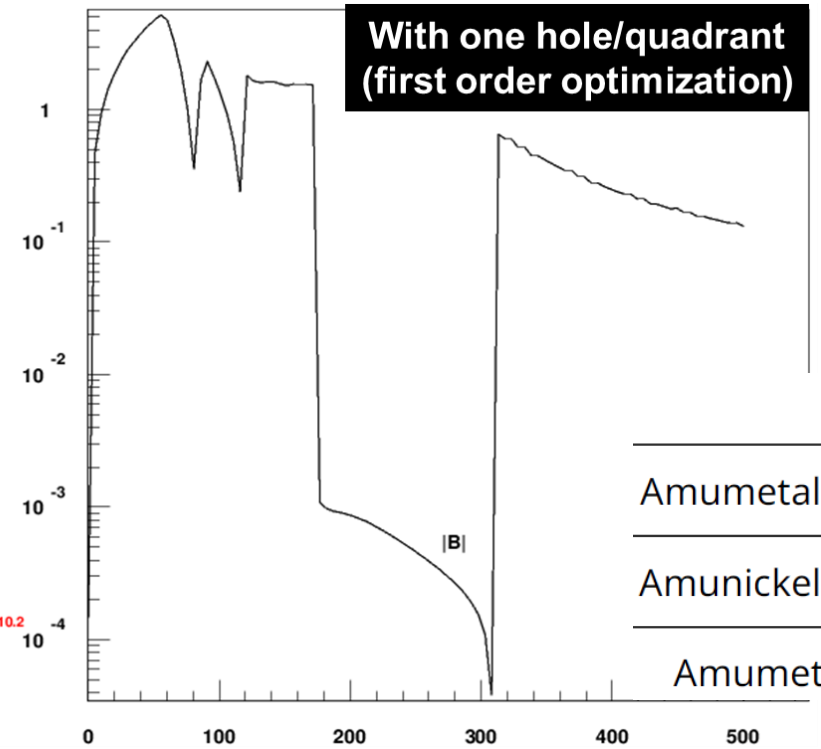


- **Make a cutout in the iron yoke and insert a relatively small piece of special steel with high saturation.**
- **A pre-reduction in field with holes in septum region helps significantly.**

Other Ways to Further Reduce the Crosstalk (#2)

(these are simple techniques and may have a major impact)





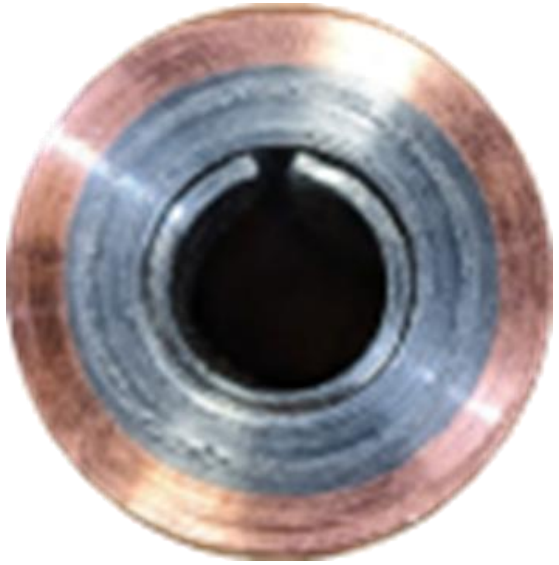
Material	Saturation (Gauss)	Permeability μ Max
Amumetal (80% Nickel)	8,000	400,000
Amunickel (48% Nickel)	15,000	150,000
Amumetal 4K (A4K)	8,000	250,000

- Put a sheet wrap of high permeability material over the electron beam tube (where no electron magnet is present)
- A pre-reduction in the maximum field with holes in the electron beam region helps as it requires fewer shielding at lower field.

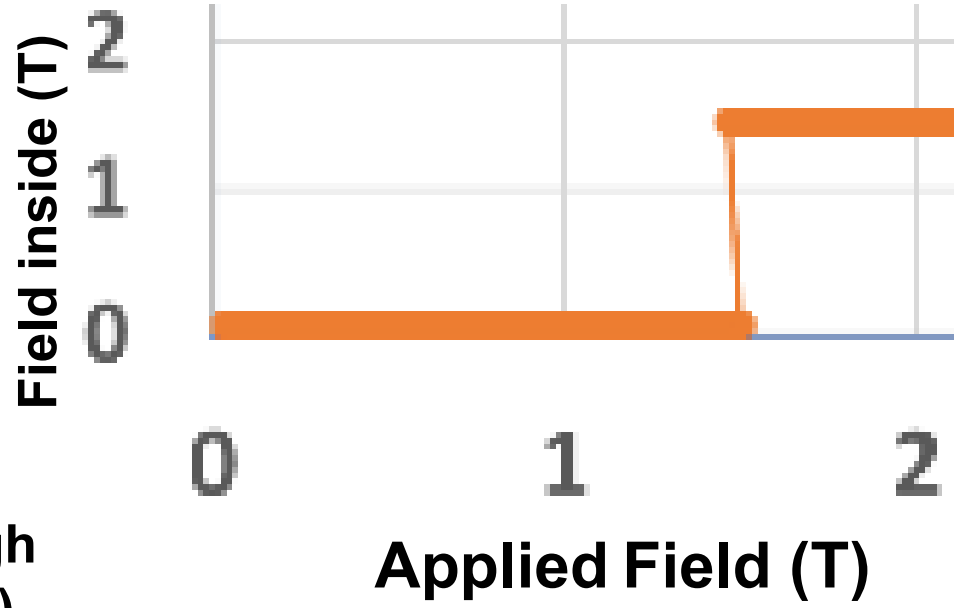
Other Ways to Reduce Crosstalk (#3) – SC shielding

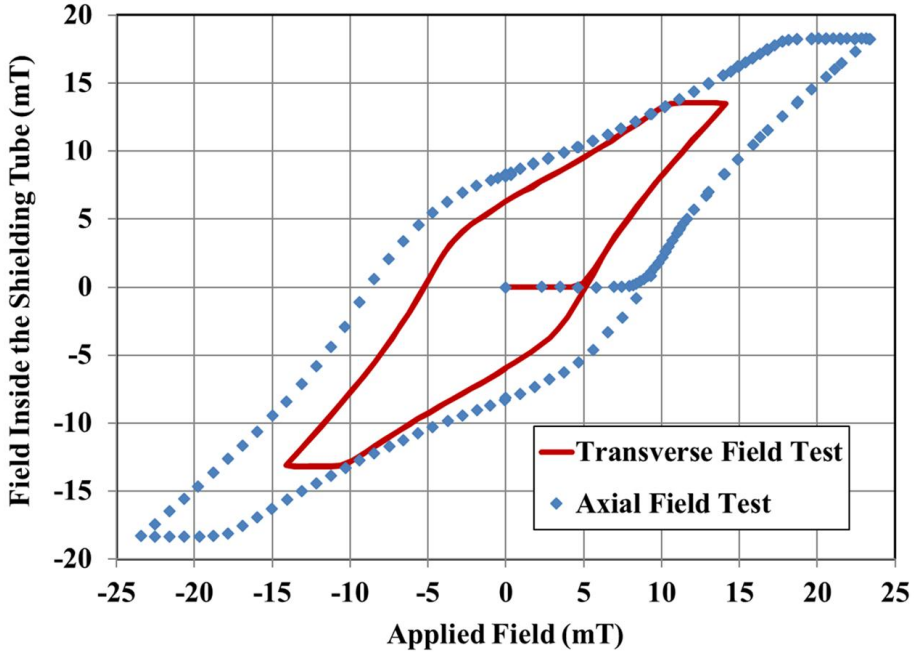
(more involved but essentially eliminates the issue in most cases)

- Superconducting shield completely excludes field in the e-beam region.
- Specifically explored for EIC with two Phase I SBIR and one Phase II.



SC shield tube with high μ material inside (A4K)





- Such techniques (and other topics of common interest) are discussed in more technical details in regular EM analysis meetings within EIC collaboration.

Notes on Reviewing/Relaxing Cross-talk Requirements

We are also reviewing crosstalk requirements.

They are already a bit lower than previously targeted.

Can they be further relaxed? That may have a significant impact.

Harmonic specification for e-quad is 1 part in 10^-4.

Following calculation assumes the same error for crosstalk.

Note: Higher errors allowed for B_1 (dipole) and B_2 (quad).

Shoudn't the spec for B_3 be also a little higher?

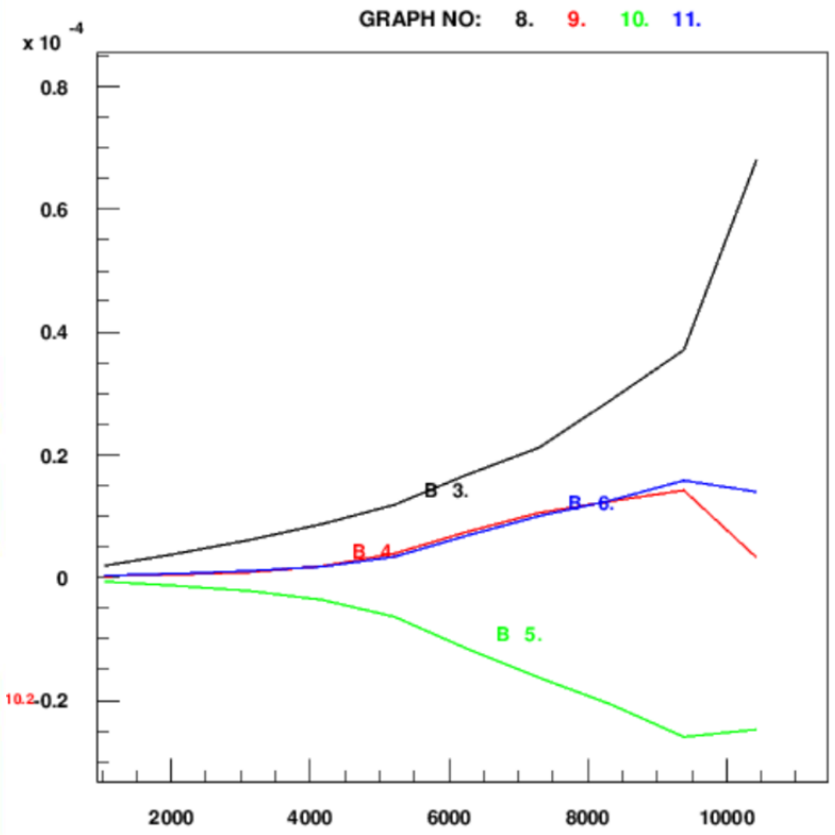
Electron Quadrupols in EIC IR	*Good field Reference Radius (mm)*	Integral field (T)	*Lattice Length (m)*	Integral Field (times) Reference Rad (T.m)	Harmonic Integral Error for 10^{-4} (microT.m)	2-d Harmonics X 10^{-4} Integral Field/Length (T)
Quad Q1EF	43.0	9.8	1.6	0.42	42	0.26
Q0EF tuning quad	20.0	16	1.2	0.32	32	0.26
Quad Q1ER	27.6	25	1.8	0.70	70	0.39
Quad Q2ER	32.0	20	1.5	0.63	63	0.41

Needs to be a factor of two tighter for lower energy electron beam.

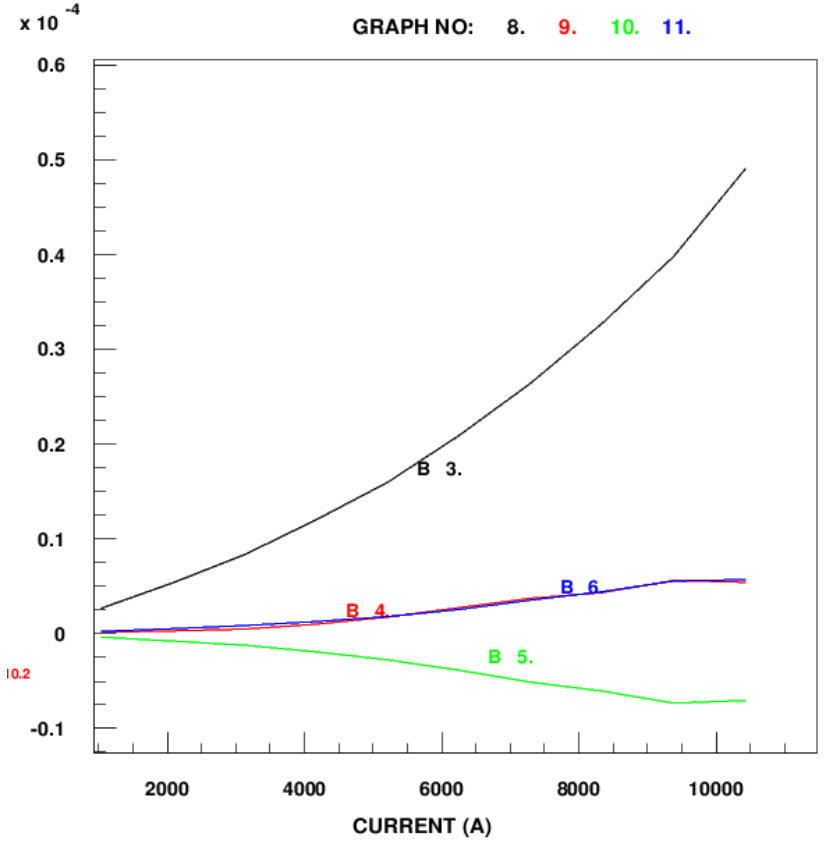
Cross-talk Harmonics at various axial location

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

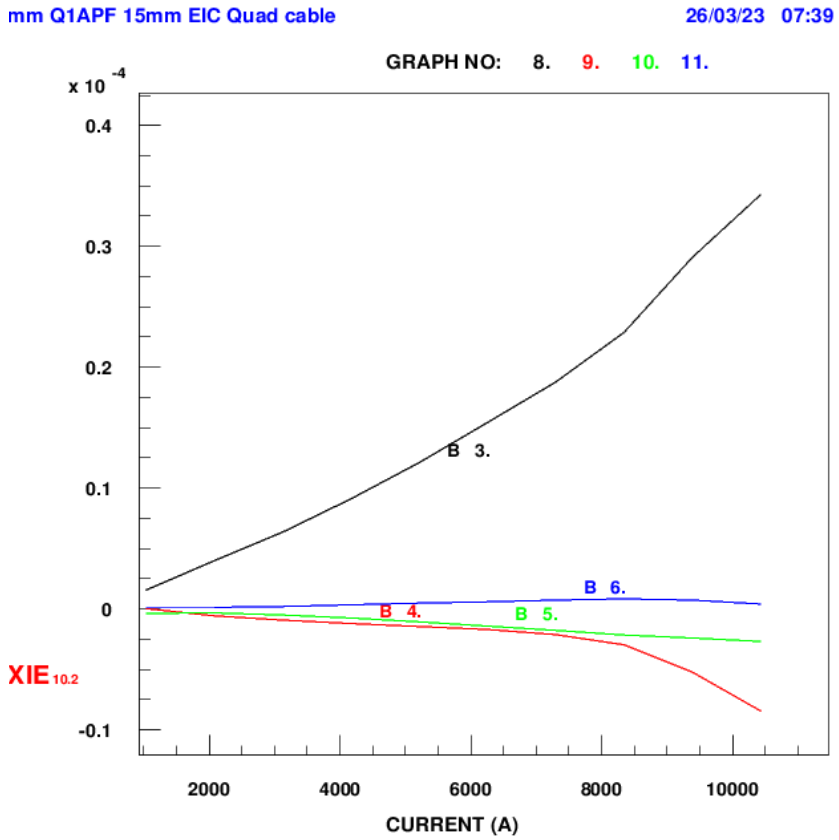
IP-end



Middle of the magnet

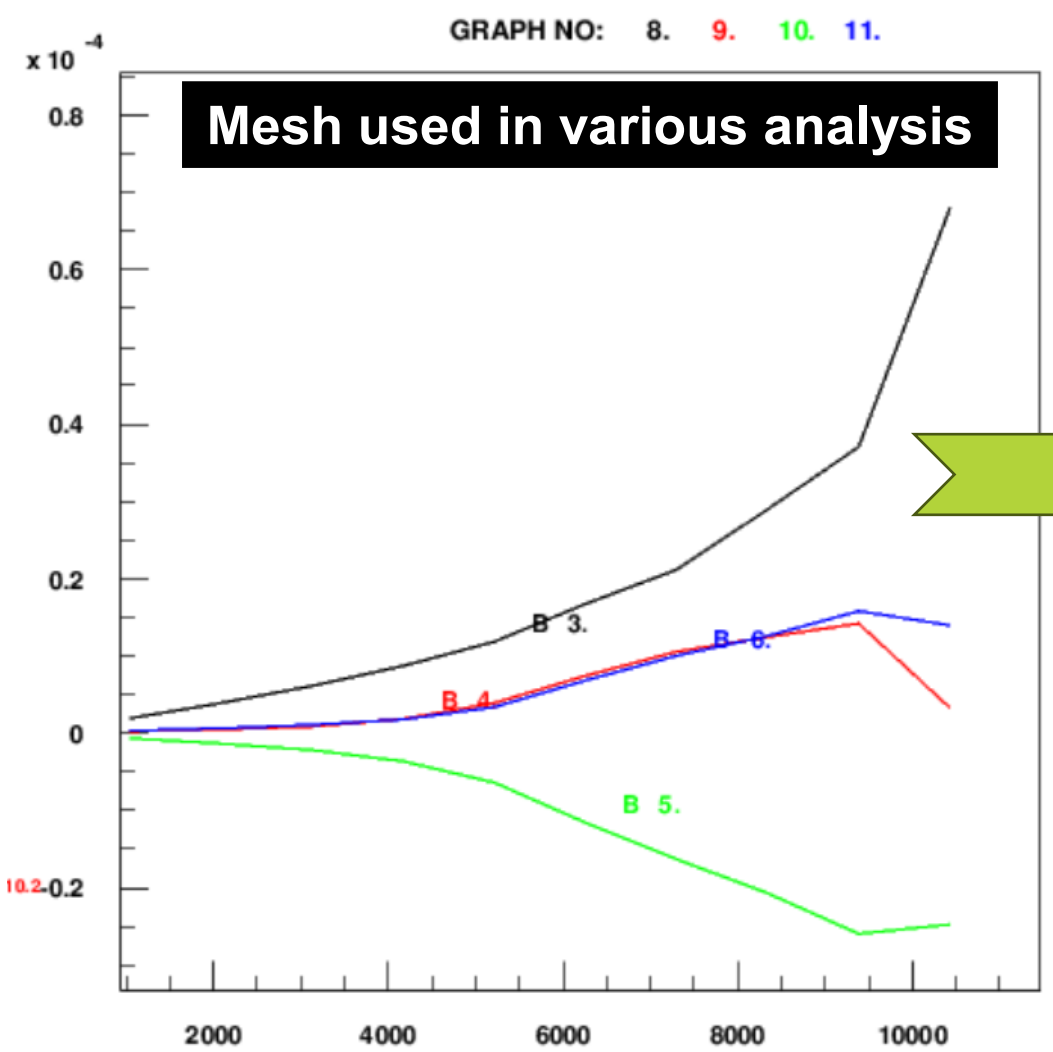


Non-IP-end

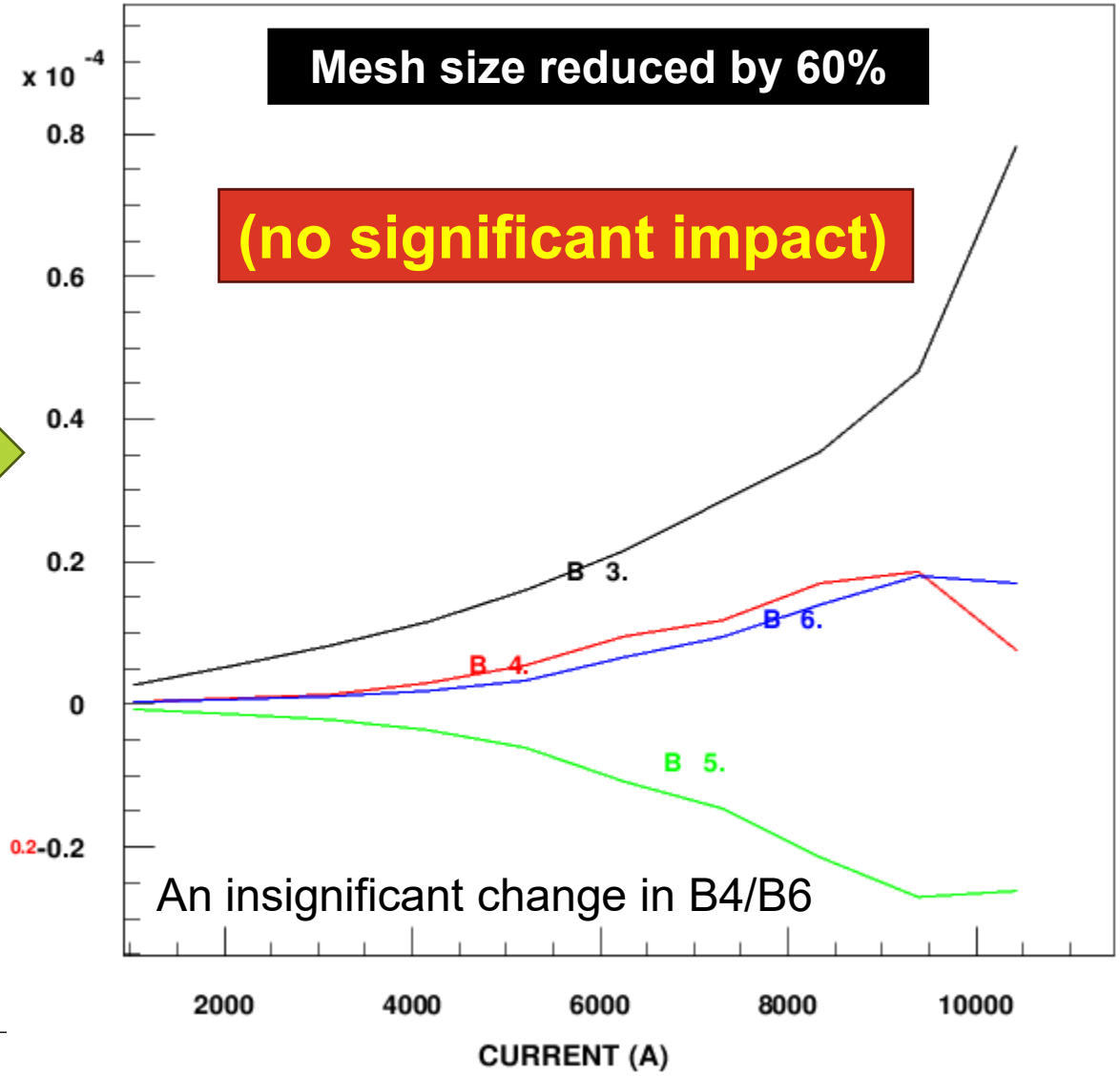


Even better optimization were seen with more holes

Impact of Mesh Size (Reduced by 60% in this case)



Mesh used in various analysis



Mesh size reduced by 60%

(no significant impact)

An insignificant change in B4/B6

Summary

- This was a quick investigation (not meant to be a complete or fully optimized design) to show that the magnetic design shown will meet the basic requirements.
- Cross-talk harmonics are close and can be brough within the current specifications with more iteration or using the techniques applied in various EIC magnets.
- A flexible coil cross-section approach will help meet the field quality and pre-stress requirements in the first magnet itself without prototypes. It was applied in various RHIC magnets and should be considered in the design of all EIC magnets.
- Magnetic flux in the yoke can be routed to significantly reduce the crosstalk.
- Relaxation of crosstalk specifications, without compromising the performance, will help. These evaluation can be evaluated harmonic by harmonic.
- Other techniques, e.g., adding a small piece of high saturation steel within yoke, or a high permeability wrap of sheet or tube over electron beam pipe. These and other key magnetic design issues are being examined in EM analysis meetings.