Brookhaven National Laboratory

Jefferson Lab

U.S. DEPARTMENT OF ENERGY

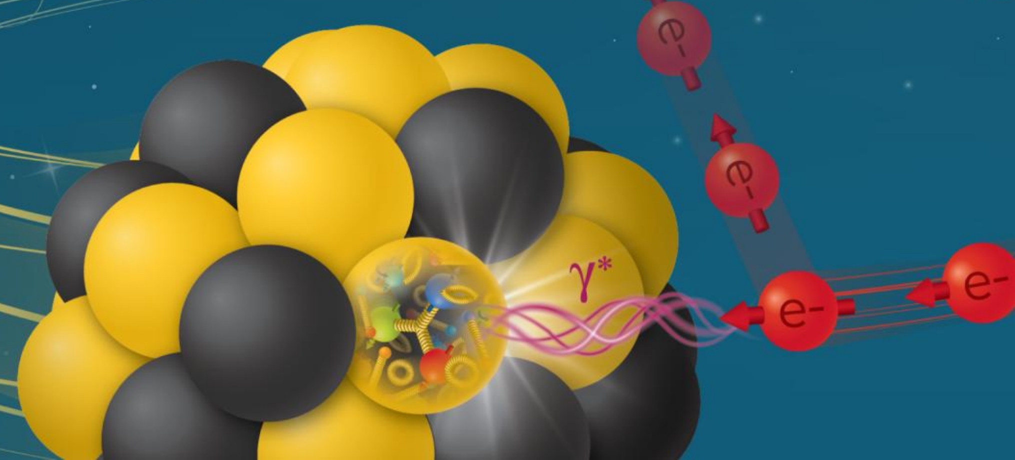
Early work and basic strategies on crosstalk control in EIC IR Magnets

Ramesh Gupta

1st Presentation: 3/13/2026

Last Updated: June 5, 2026

Electron-Ion Collider



Agenda

- **Early work and basic strategies on crosstalk control (Ramesh Gupta)**
  - **Superconducting shielding (SBIR/STTR) and saturation control of non-linear iron (not included in this discussion - onion ring type solution)**
- **Recent work on crosstalk in rear side magnets (Vikas Teotia – next meeting)**
  - **Ferrous alloys, SC shielding, Active corrector, Tuning coils and only yoke**
- **Recent work on Q1BpF – Vittorio Marinozzi, FNAL**
- **Recent work on Q1ApF – Emmanuele Ravaioli, LBNL**

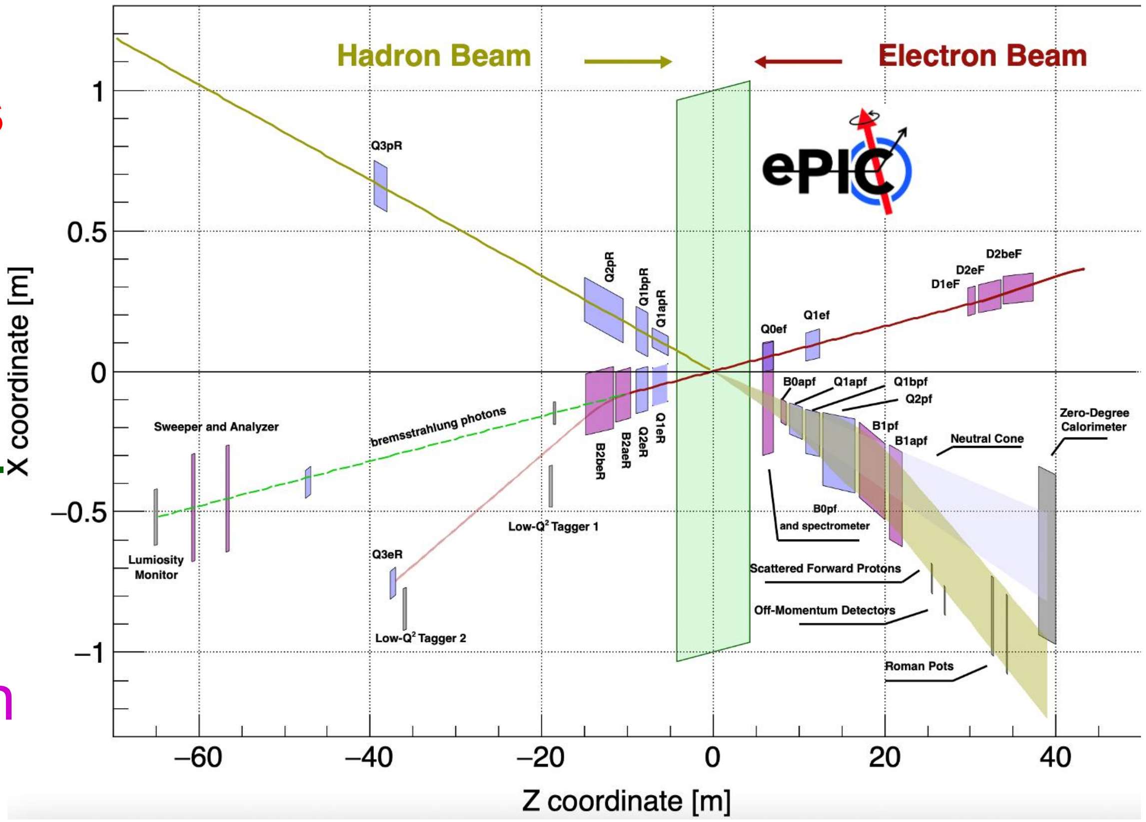
Note: These meetings are meant to have objective and detailed discussion. Please feel free to ask questions. Agenda and the discussion continues to the next meeting.

Crosstalk in EIC IR Magnets

Crosstalk plays a major role in the design & test planning of the EIC IR magnets when the electron beam (sensitive to low fields) traverse very to the high field hadron magnets with a limited space for iron in between to provide the shielding.

Strategies to reduce the crosstalk in EIC IR magnets can be broadly divided In 3 groups

- Making the best use of the available space for iron and adding the rings (onion rings).
- Superconducting (SC) shield to suppress the field. Potential benefits in many EIC magnets. It may reduce the testing cost (more later).
- Controlling the non-linear yoke saturation to force it saturate uniformly to reduce change in harmonics (as in SSC and RHIC magnets).



Two Major Benefits of the Superconducting Shielding

Benefits of superconducting shielding in magnet designs:

- As such the basic performance of all EIC magnets can be reached by NbTi at 4.2 K
- The primary driver for 1.92 K for EIC magnets (or limitation) was the crosstalk. This continues to be a potential limitation/issue in certain magnet designs.
- Superconducting shielding should free-up various choices across the labs.

Benefits of superconducting shielding in reducing testing costs:

- Several expensive tests in fully assembled magnets are planned to know the value of field (field harmonics) for electron beam due to crosstalk from hadron magnets.
- Superconducting shield ensures essentially zero field. No expensive harmonic measurements are required. If desired, Hole probe away from the electron beam path would be sufficient to ensure.

Past Superconducting Shielding Demos for EIC

The inherent value of the superconducting (SC) shielding for EIC has been recognized by multiple programs spanning over several years:

- Two Phase I SBIR/STTR funded (rare) for examining NbTi, Bi2223 and MgB_2 shields
  - NbTi tube demonstrated to shield ~1.4 T field (more than required in any magnet).
  - Bi2212 tube procured and tested at 77K & 4K. MgB_2 tube procured but not tested.

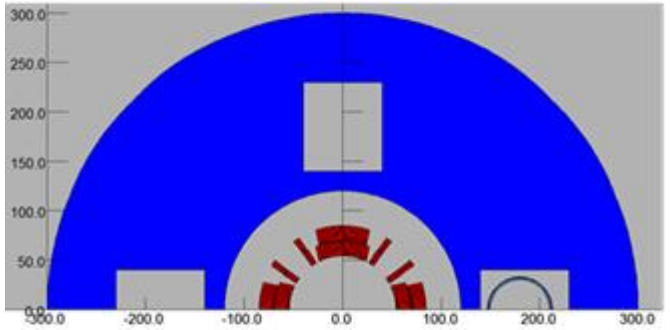
- STTR Phase II demonstrated NbTi SC shielding in R&D B0ApF dipole
  - Another demonstration test is coming up in a couple of months.

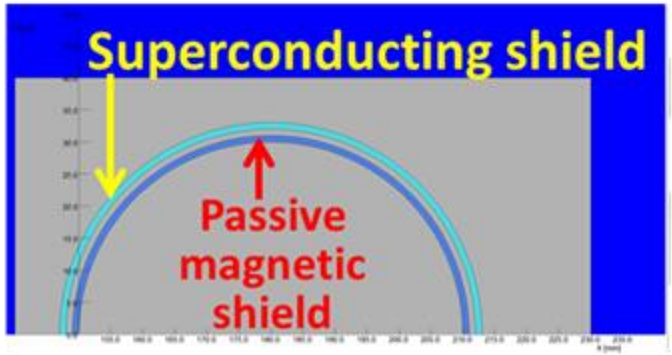
- Internal program tested SC shielding with ReBCO tapes at 77 K.

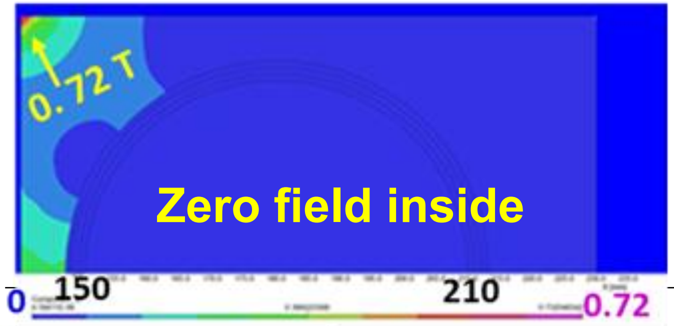
NOTE: Above refers to demonstrations; not just ideas or proposals!

NbTi Shielding for EIC (funded under PBL/BNL Phase I SBIR in 2018)

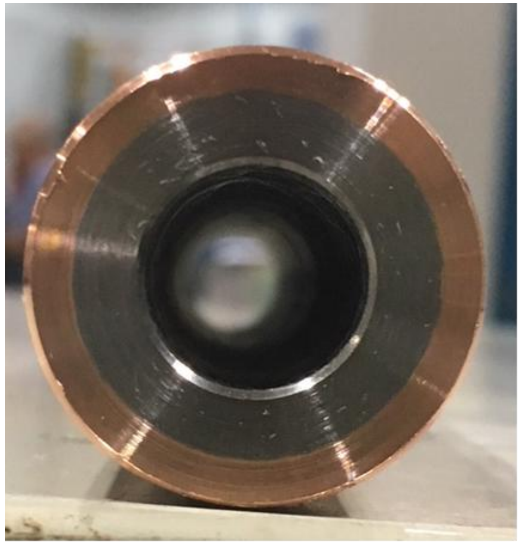
Simulation for a Quad







From Luvata



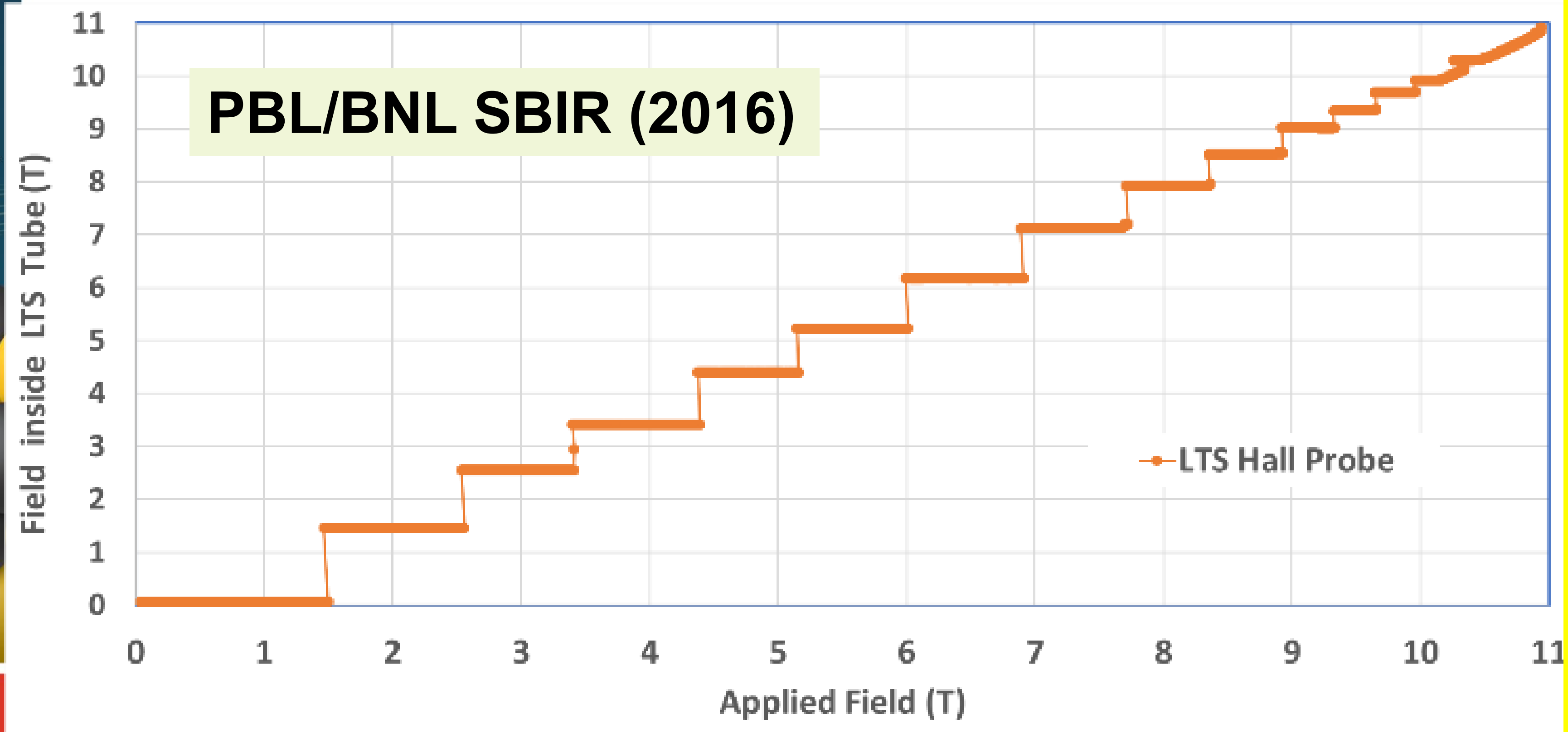
From Bruker

Rods donated by vendors.

Holes drilled by MSD at BNL to make SC shielding tubes.

Demonstration and Understanding of the Superconducting Shield (Applied field/current continuously increased during the test)

Plot below shows the field inside the NbTi tube as a function of the applied field. The shielding is complete up to ~1.4 T. Superconducting tube doesn't allow any change in the field (either from outside to inside or inside to outside).

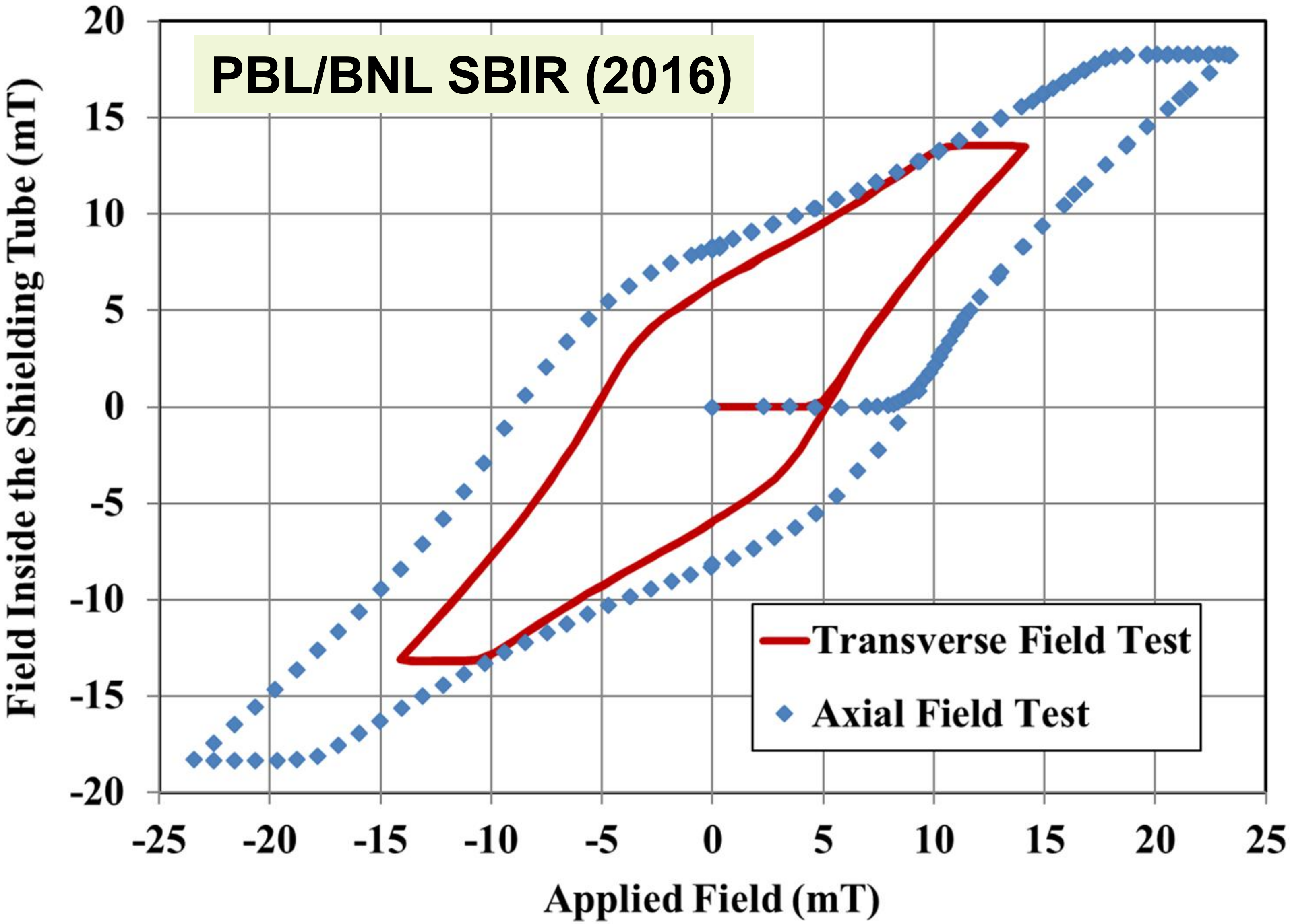


- **Shielding is provided by screening currents in SC tube to prevent a change in field inside the tube.**
- **SC tube quenches when the current required to shield field exceeds I_c.**
- **Then field penetrates.**
- **NbTi Tube cools down & becomes superconducting again; and traps the field going across at that time.**
- **Superconducting shielding is a special case of B = 0.**

Demonstration of HTS (Bi2223, bulk material) Superconducting Shield
(test performed at 4 K and 77 K – field parallel and field perpendicular)

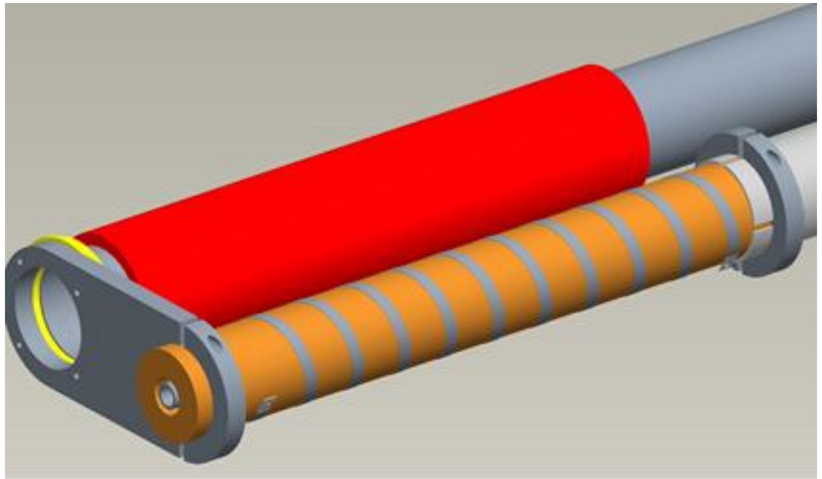
Bi2223 tube provided by CAN superconductor (a Czech company)

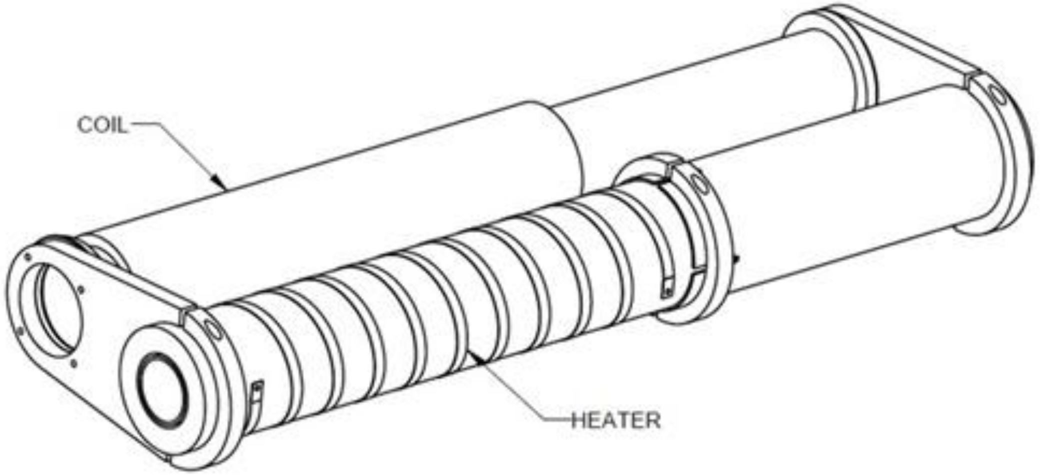
https://www.can-superconductors.com/

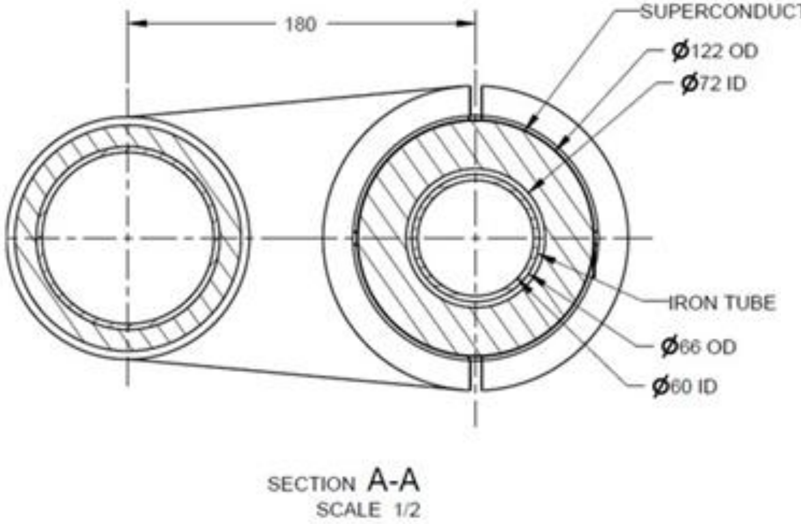


PBL/BNL Phase II Proposal on Superconducting Shielding

- Phase II proposal was made to test superconducting shielding by the side of an existing direct wind manet
- Preliminary engineering work included heaters to warm up the shielding to cleanse any trapped field
- Phase II proposal did not get funded (despite a good progress in Phase I) for non-technical reasons.





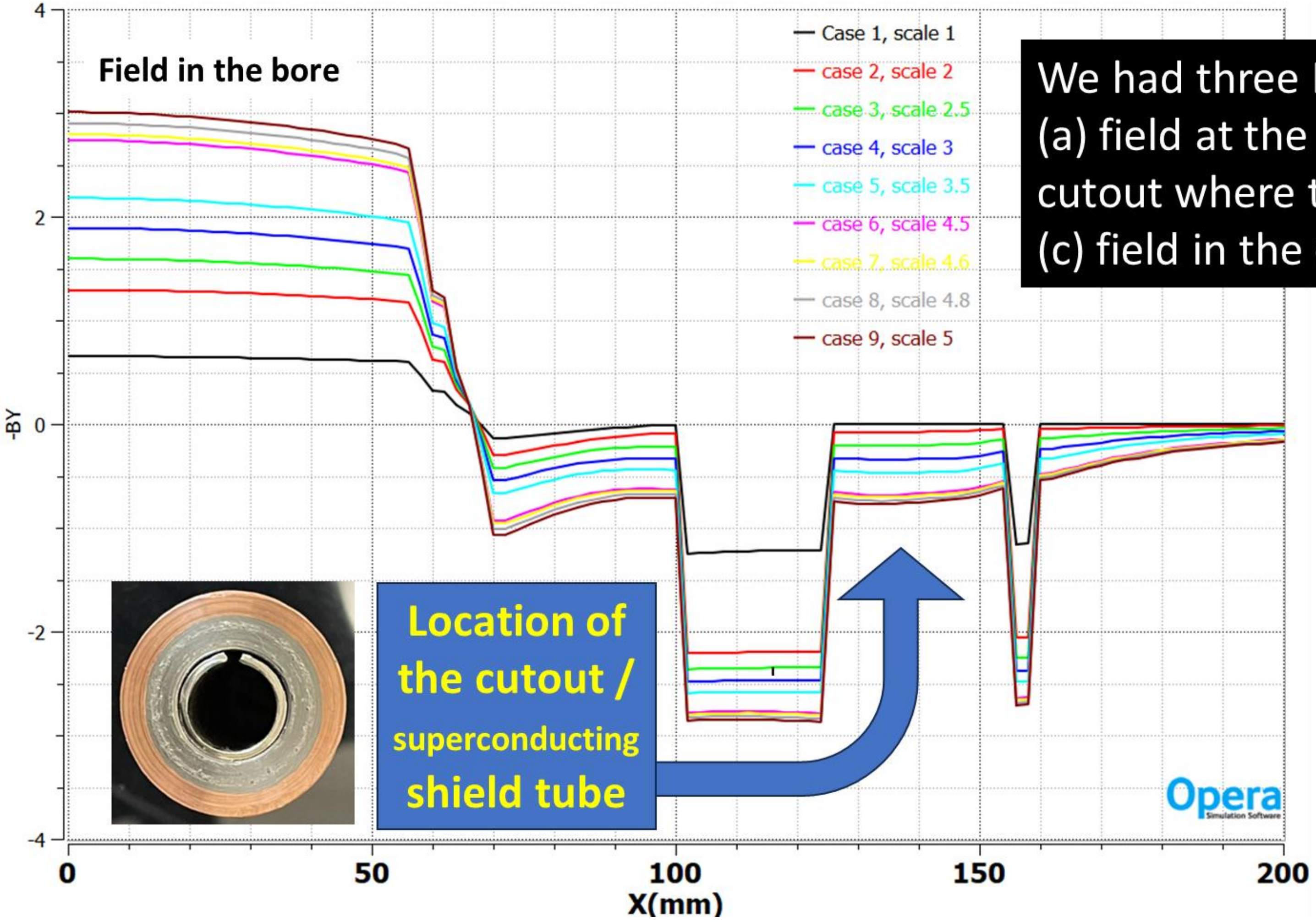


We still found a way to perform superconducting shield experiment by making this a part of another PBL Phase II (more on next two slides)

Superconducting Shielding Test in EIC R&D Magnet

PBL/BNL had a Phase II STTR on B0ApF OID.

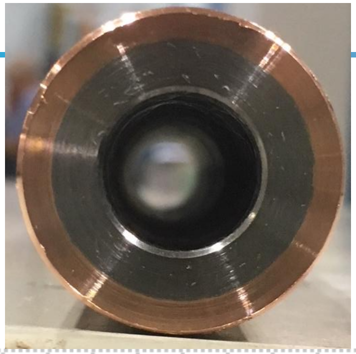
Super-conducting shield and also high mu shield experiments were added to the test

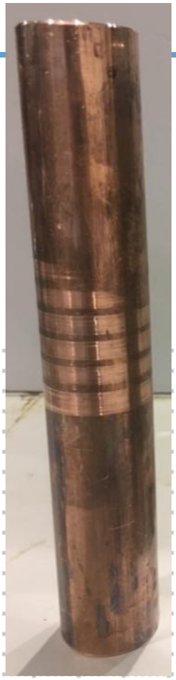


We had three Hall probes to measure (a) field at the center, (b) field in the cutout where the SC shield is (+x) and (c) field in the cutout with no shield (-x).

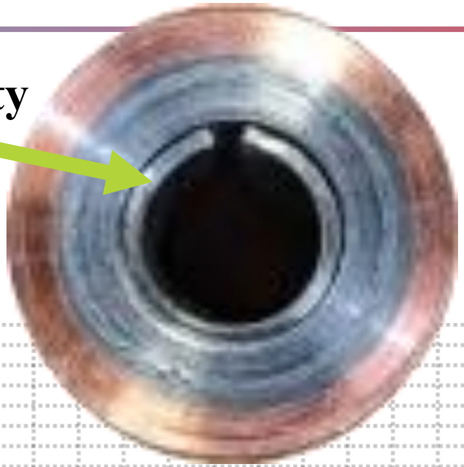
Demonstration of Superconducting Shielding (with Additional A4K)

NbTi tube from Luvata

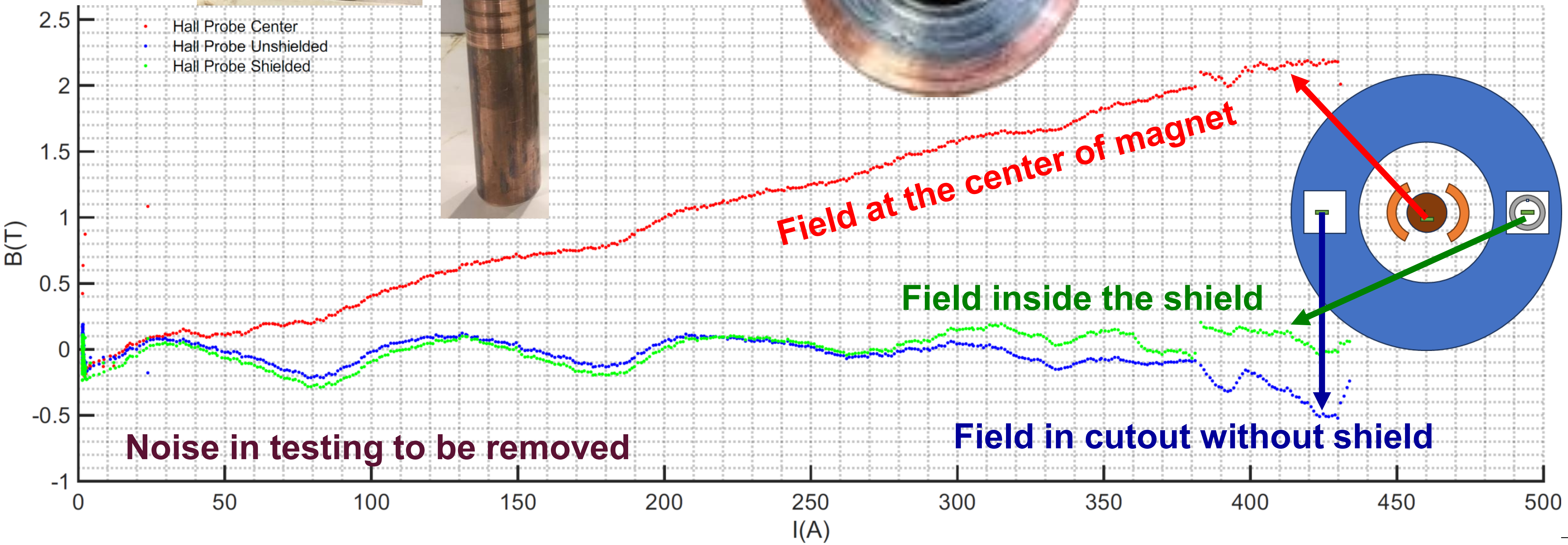




High permeability *A4K to shield persistent field



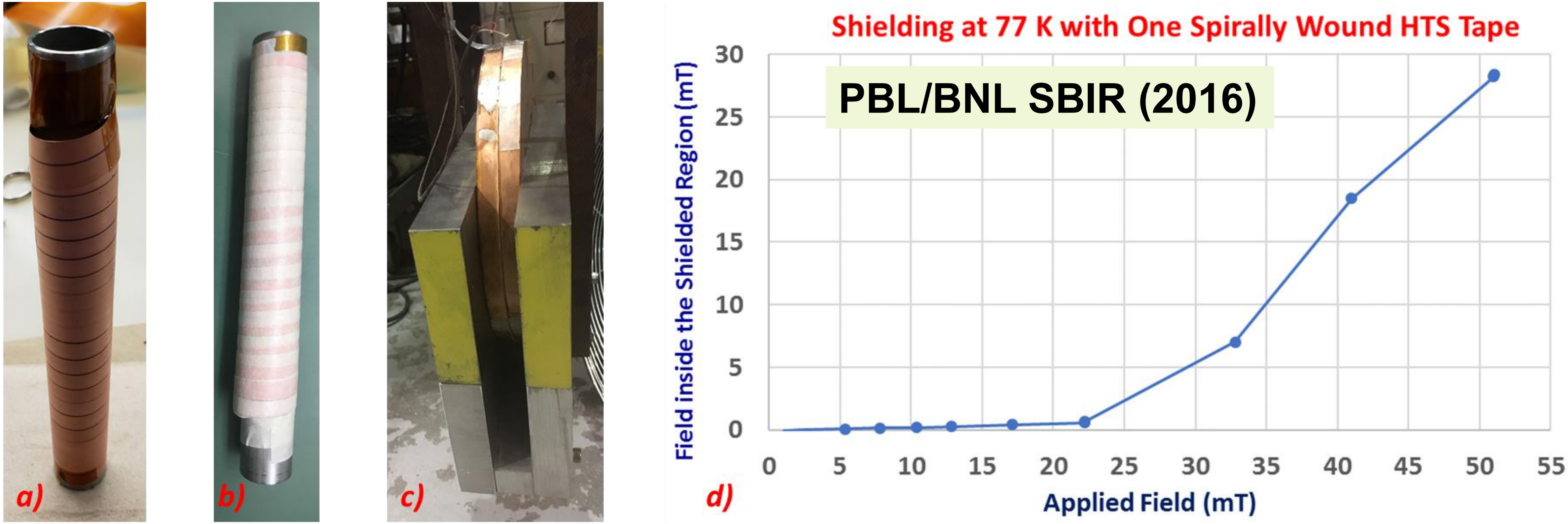
Superconducting shielding works



*A4K: High permeability Amumetal 4K (A4K) from Amuneal Manufacturing Corporation

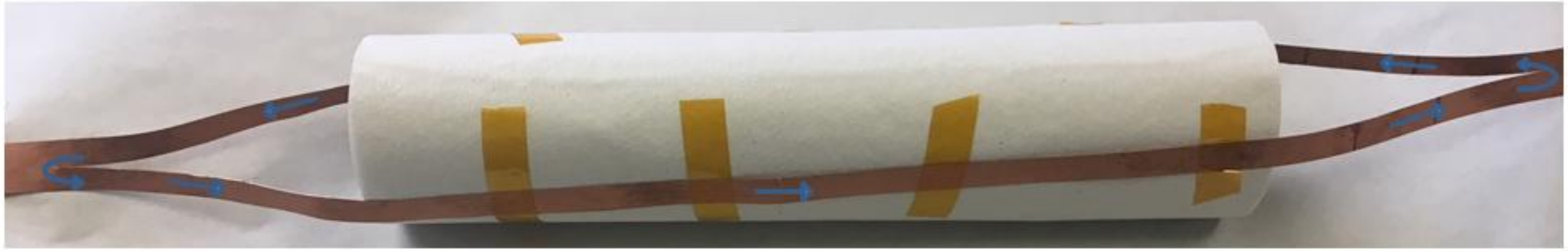
Demonstration of HTS (ReBCO) Superconducting Shield

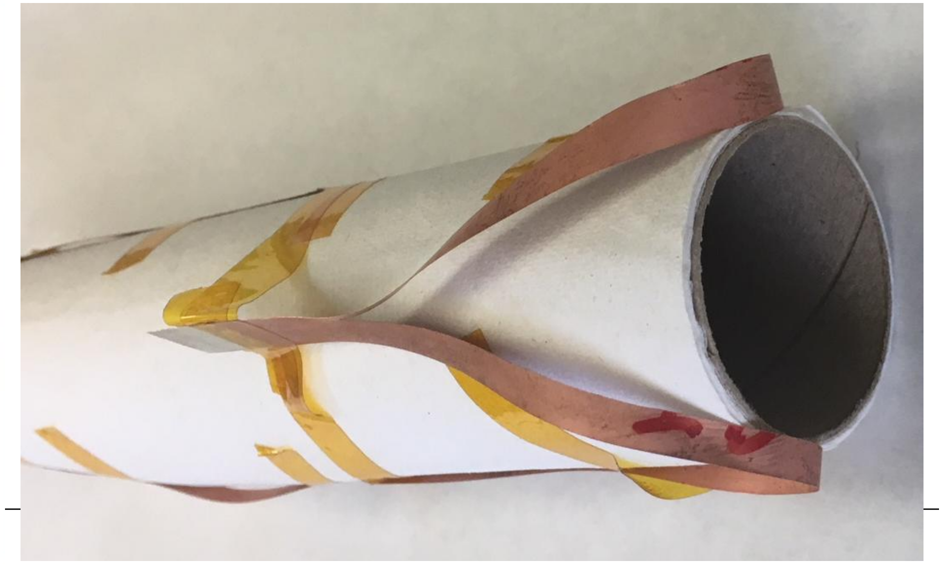
HTS tape was spirally wrapped on the tube. Screening currents must flow parallel to the beam axis and return at the ends to provide the shielding.12 mm width of the tape becomes the length (includes ends). Multiple wraps provided more shielding.



HTS (ReBCO) Superconducting Shield (2)

Recall: For superconducting shielding to work, the screening currents must flow parallel to the beam and in the opposite direction on the two sides of vertical axis (as in a dipole coil) and there should not be any resistive joint in between.





A joint-less loop (with split in the middle) shown here overcomes the limit coming from the width of the tape (12 mm).

- **A variation of this was successfully tested at 77 K.**

Project Consideration for Superconducting Shielding Option

- Difference between a theoretical study and a project consideration: (a) the material must be available in the budget and time frame of the project, and (b) the technique must be demonstrated before accepting in the baseline design.
- Last major application of SC shielding: g-2 experiment; several decades ago; involved several countries; significant budget; private companies making NbTi SC sheets (not available anymore and thus not practical for EIC project).
- Some new and innovative solutions tried:
  - SC shielding tubes made from the NbTi rods (taken out of the routine process of making NbTi filaments from large billets). Available.
  - Tubes from bulk material - HTS & MgB_2 (small sizes, not practical for EIC).
  - A set of split in the middle of ReBCO tape with two ends intact. Available.
- We have discussed shielding suppressing crosstalk for no electron magnet in the hole. In case of a magnet, we may need a pair of shield (more work needed).

Work Remaining on the Superconducting Shielding

- **A significant work on superconducting shielding has been done. However, a clean experimental test in a EIC (or EIC type) magnet is still desirable.**
- **Upcoming test of Optimum Integral Dipole B0ApF also has SC shielding.**
- **While above tests and previous work validate the working of superconducting shielding inside (for electron beam), what is still be missing is the modelling of the screening currents inside the superconducting tube, etc. to determine the impact of shielding currents outside (for hadron beam).**
- **This could be an issue in some cases, particularly when hadron beam is too close with not enough iron in between the electron beam and hadron beam. Going further in the details, these models will need experimental validation.**
- **In many cases, the secondary impact of superconducting shielding on the hadron is small and there we can adapt without waiting for this detailed work.**

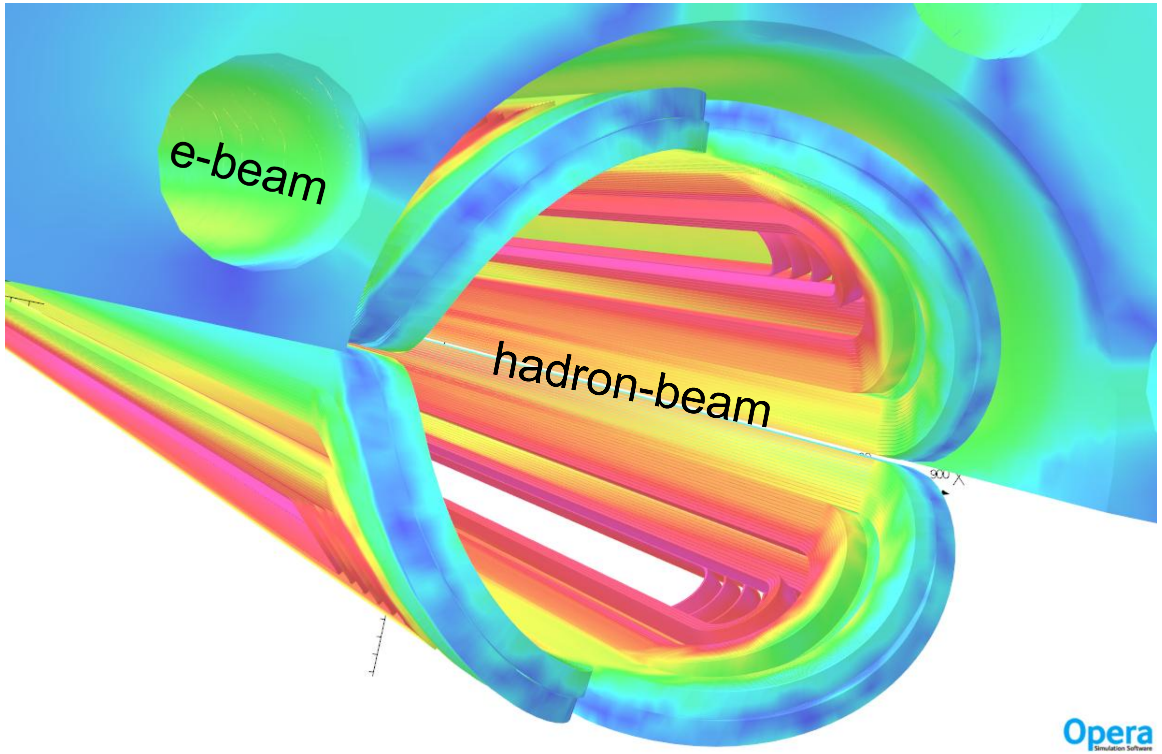
Review of previous work on reduction in crosstalk in EIC IR magnets by controlling the yoke saturation

Classical and alternate approach on cross talk

- Electron beam traverse close to the hadron beam in the EIR IR region.
- The exterior field generated by the high field hadron magnets may have adverse impact on the relatively low momentum electron beam if there is not enough iron (septum) to keep cross talk low.
- Classical or conventional thinking is that not enough iron in between the electron beam and hadron beams is the problem.
- Alternate thinking is that the non-uniform saturation is the issue, as it creates field dependence in higher order harmonics.

Field superimposed over coil and iron

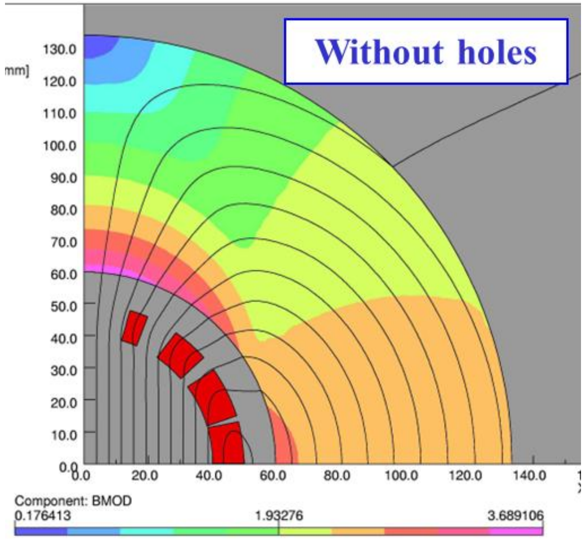
(2-d models at IP end may over-predict as field lines go in 3-d & reduce impact)

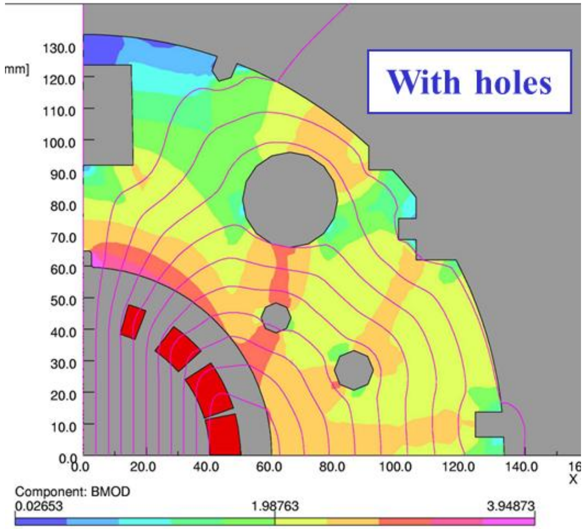


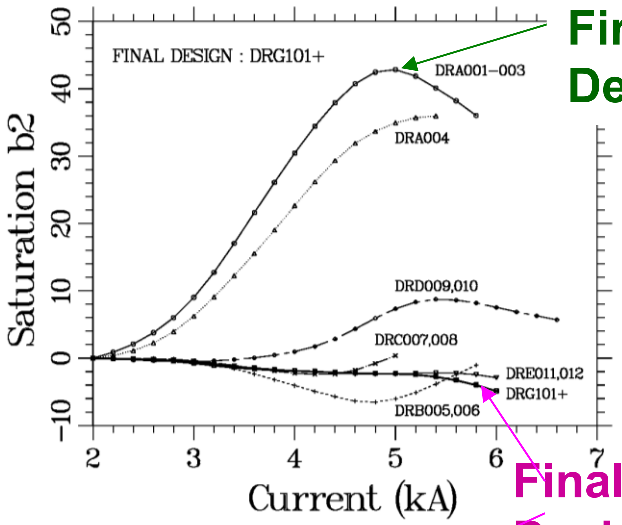
Alternate approach - force uniform saturation by cutting on the iron, etc.

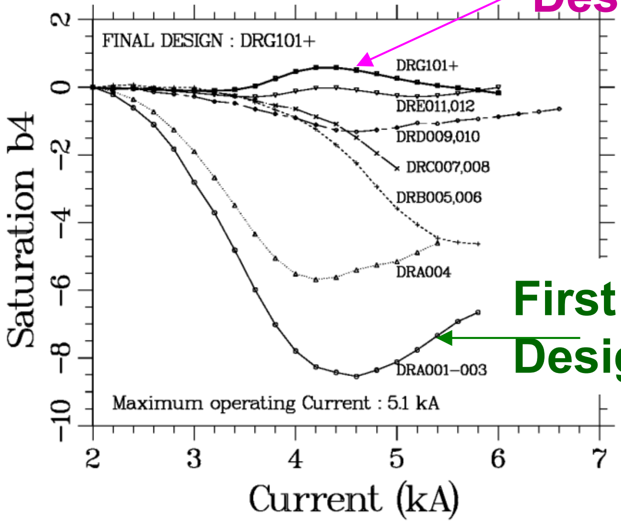
Value of Alternate Approach of Forcing Uniform Saturation
(large reduction in the change in field harmonics)

RHIC 80 mm Dipole

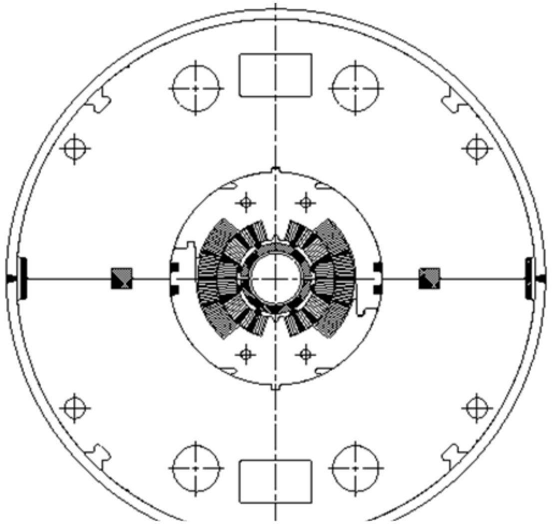


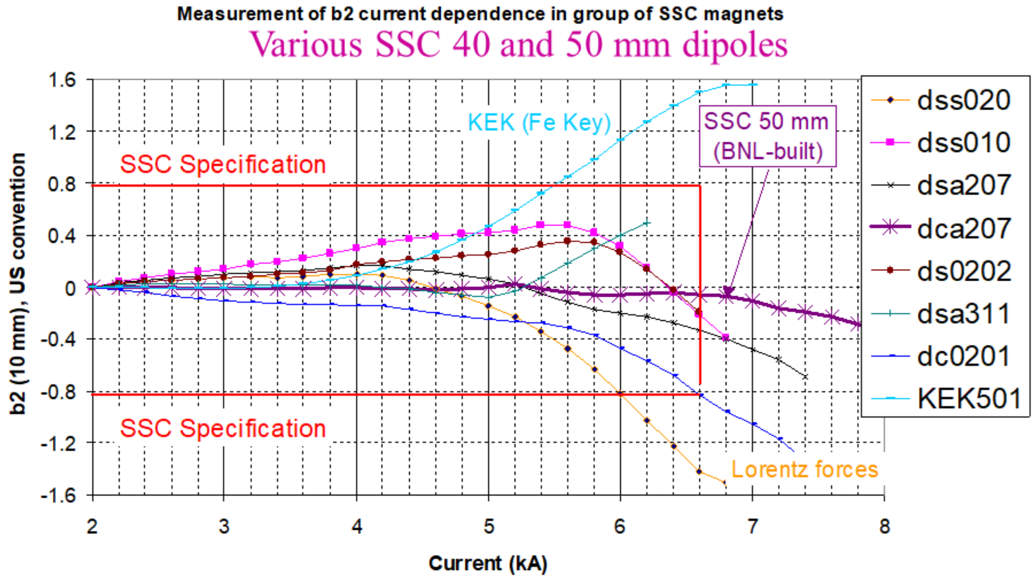






SSC 50 mm Dipole





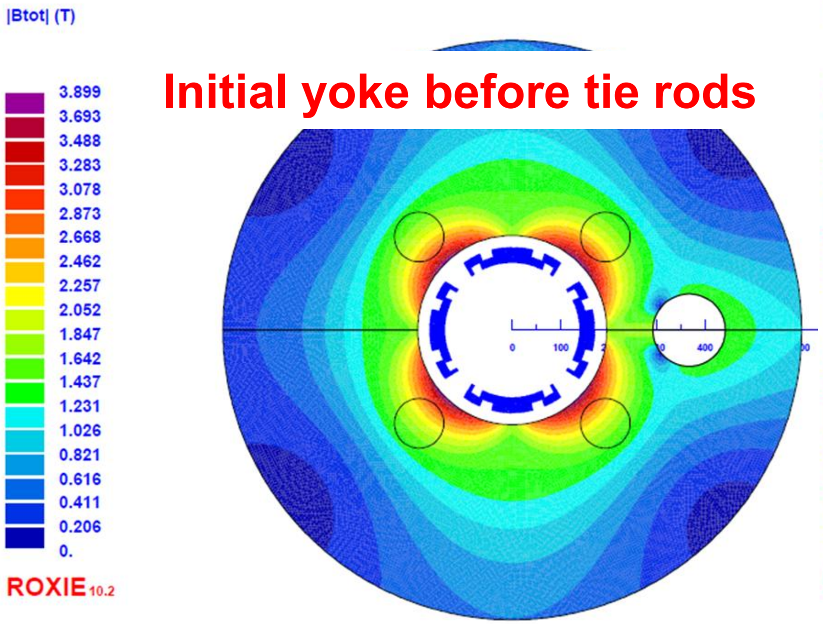
(these results overcame the major objections from the experts)

Q2pF

(earlier design, larger aperture)

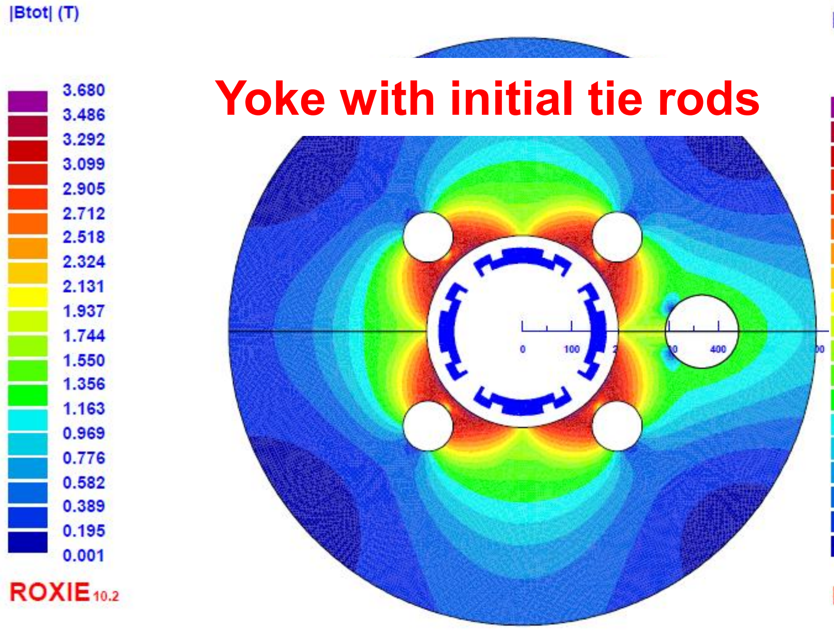
Use of Holes in Yoke to Control Saturation & Crosstalk in EIC IR Magnets

- The example is for Q2pF. The concept, however, is applicable for all magnets.
- Since it may not be obvious or appreciated, let's examine with the first principles.
- Change in the cross-talk induced harmonics in the electron aperture is due to non-linear yoke saturation, just as the harmonics in the hadron aperture.
- Therefore, properly placed and sized holes/cutout may significantly control both.



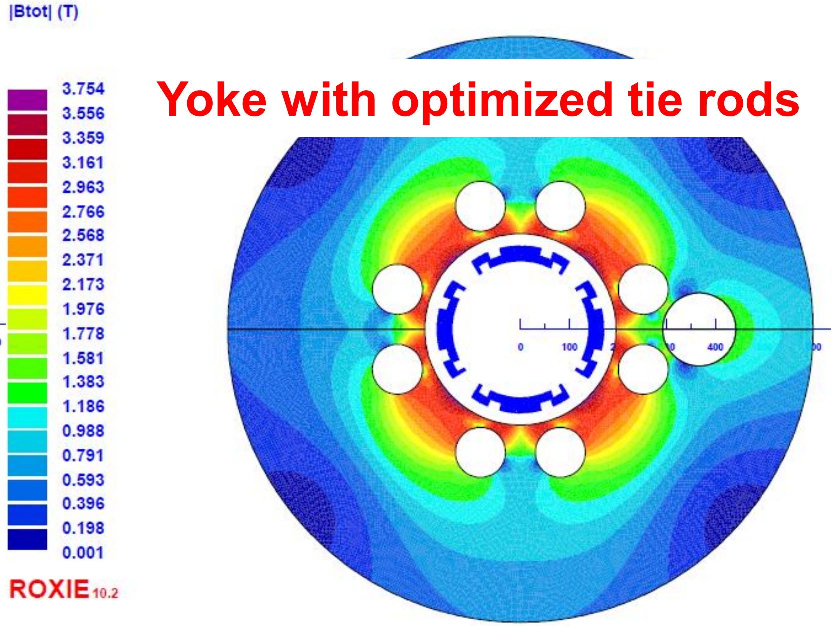
Initial yoke before tie rods

Good for hadron, bad for electron



Yoke with initial tie rods

Bad for hadron, remains the same (still bad) for electron



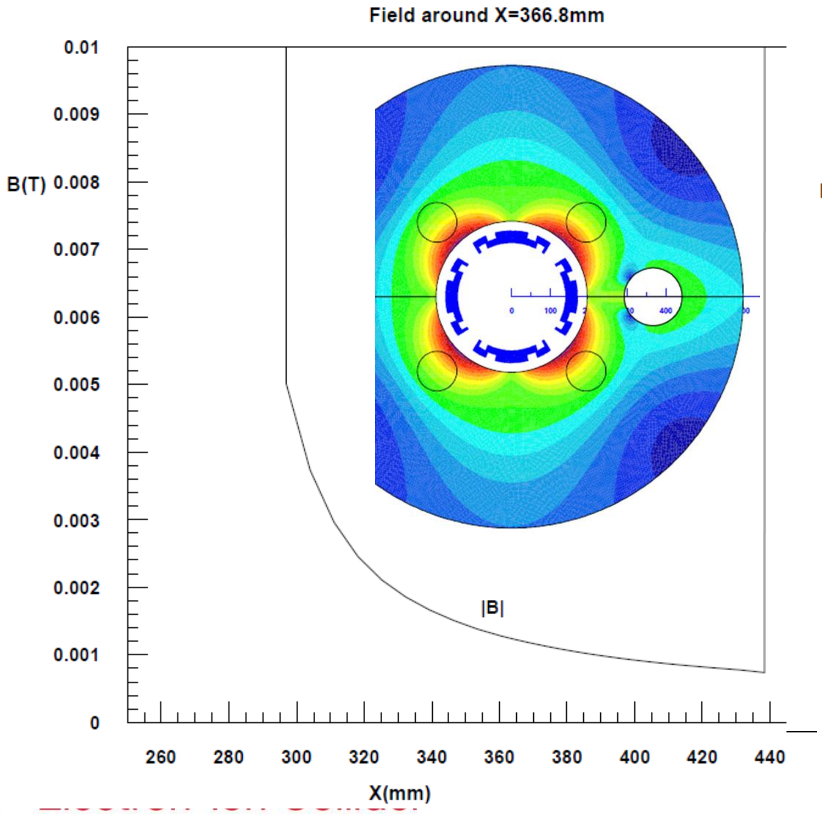
Yoke with optimized tie rods

Good both for hadron & electron

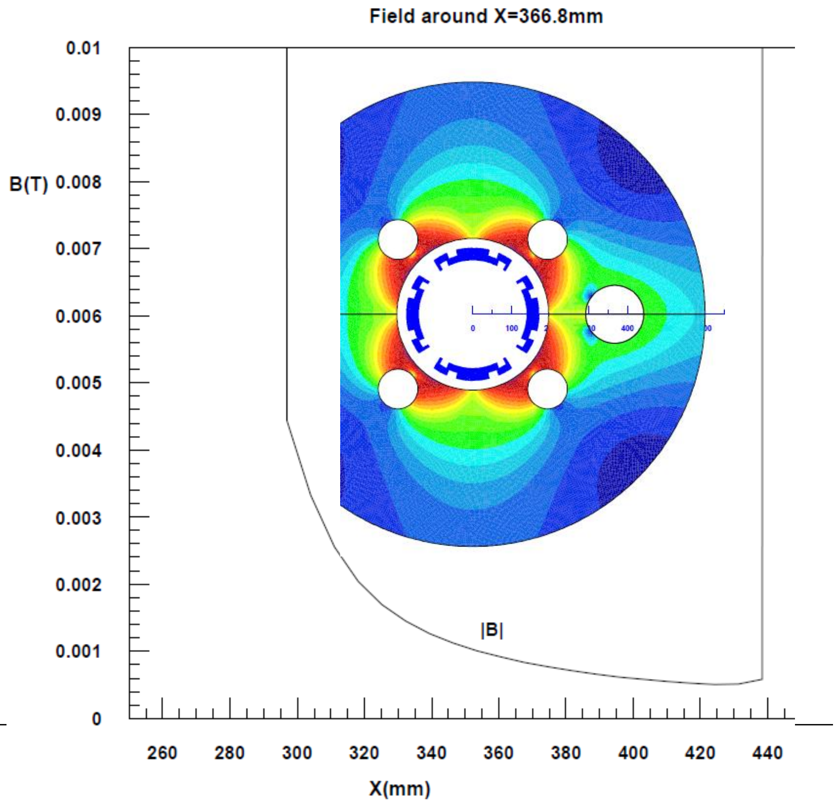
Field on the horizontal axis of the electron Hole

- The field profile in the electron aperture can be made flat by controlling the yoke saturation with the help of holes or cutout (see below).
- A flat-profile should drastically reduce the crosstalk harmonics, even if it doesn't have a similarly large impact on the maximum value of the field.

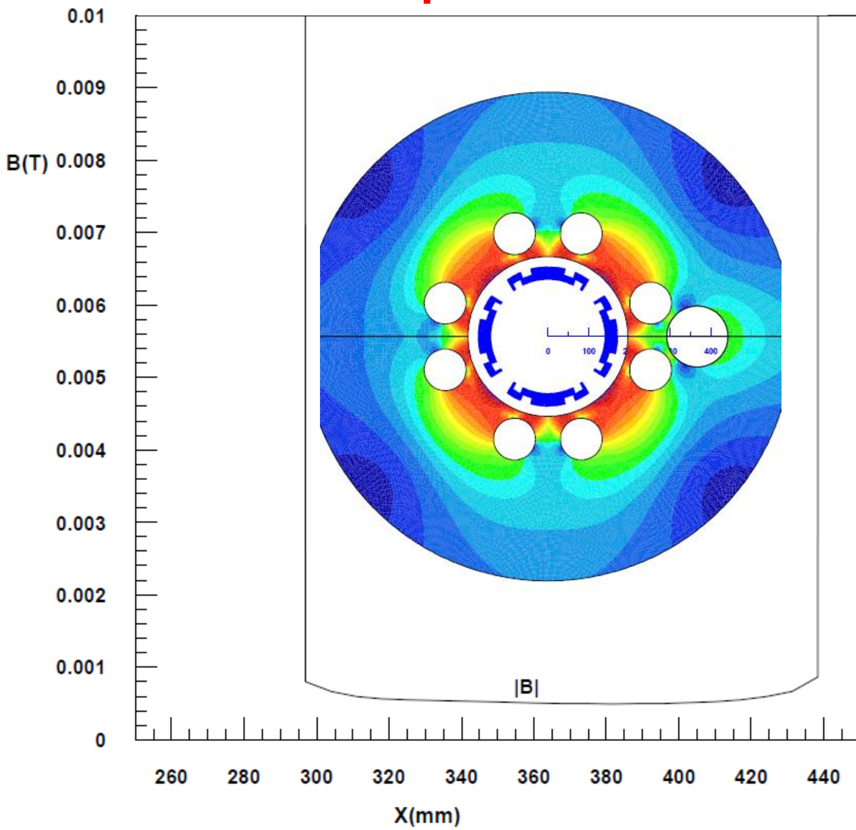
Initial yoke before tie rods



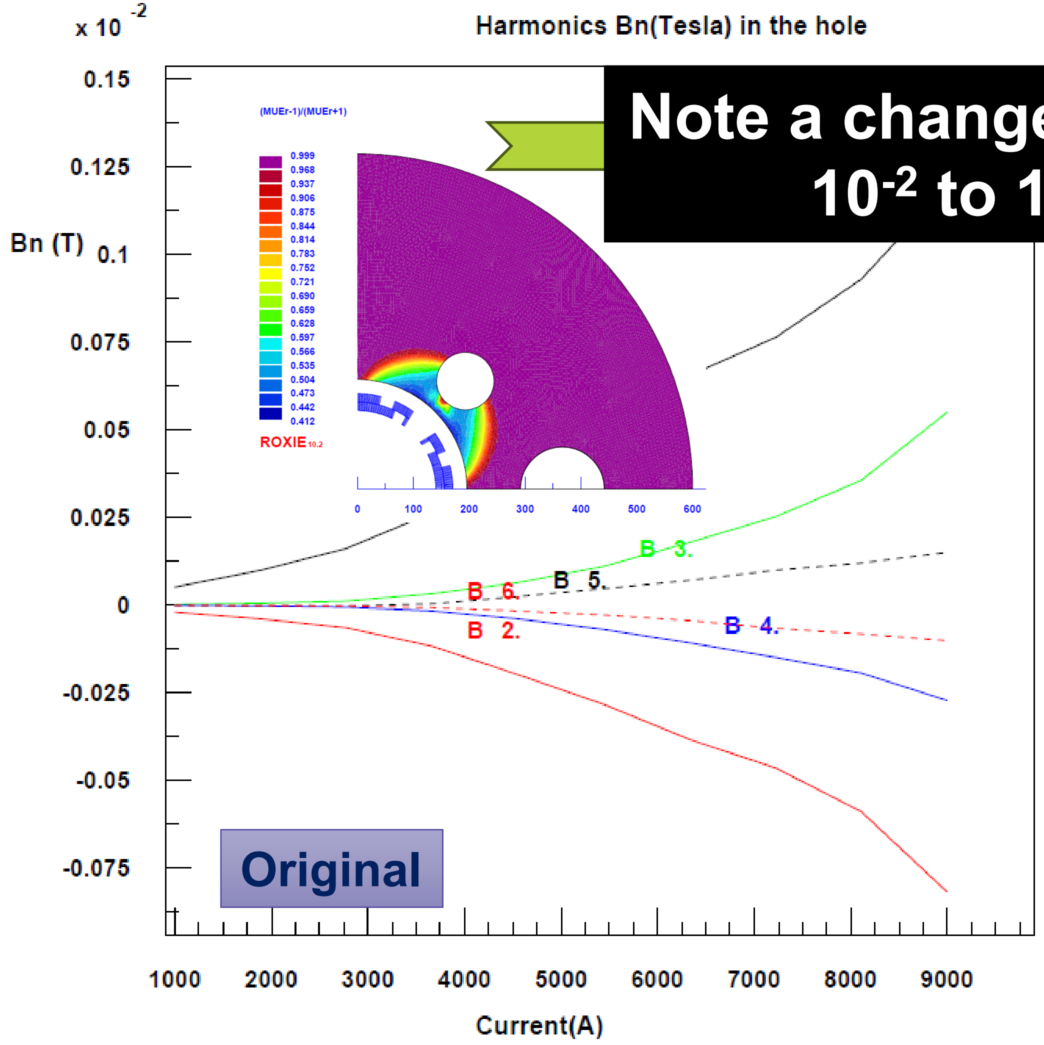
Yoke with initial tie rods



Yoke with optimized tie rods



Reduction in Field Harmonics in Hole for electron beam

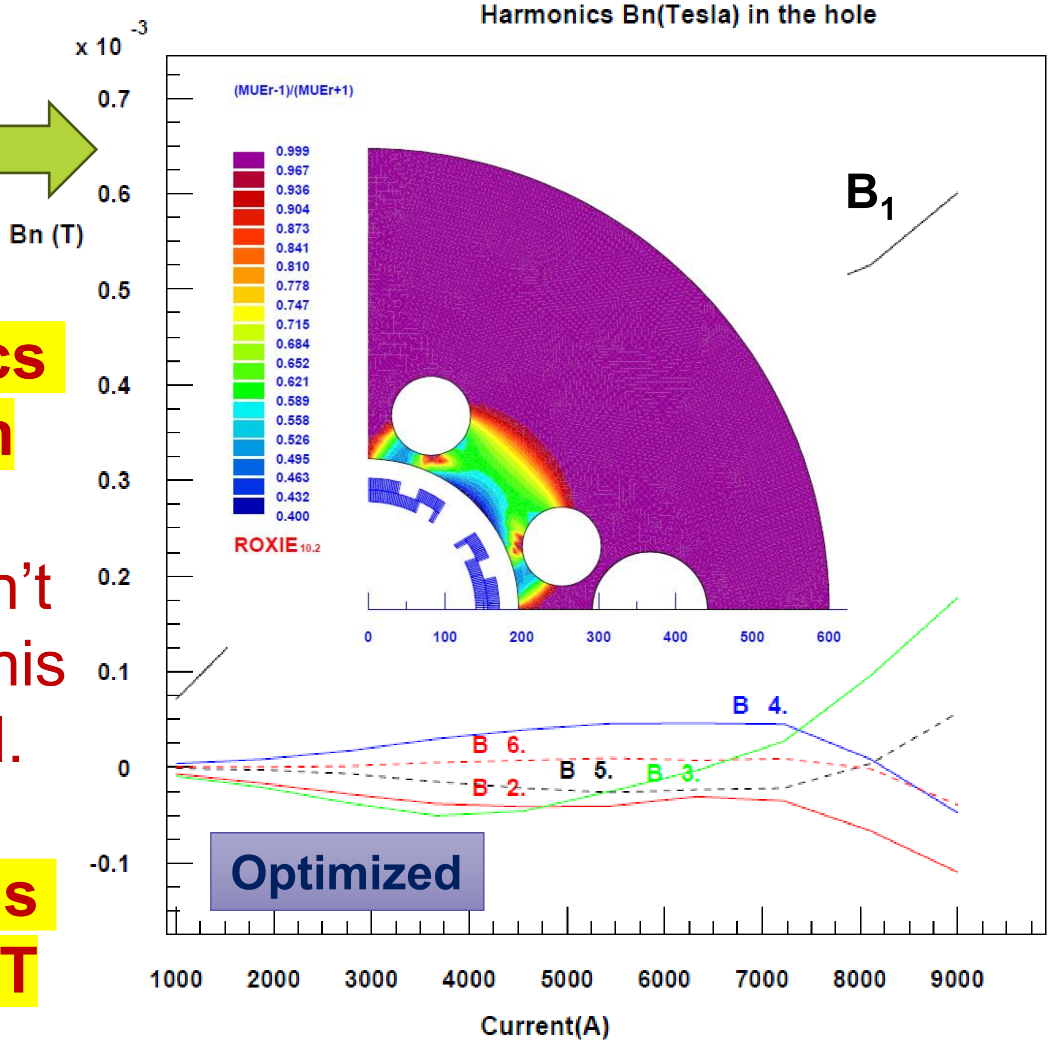


Note a change in scale 10^{-2} to 10^{-3}

Harmonics @50 mm

B_1 shouldn't matter at this field level.

Other B_n's are $<10^{-4}$ T



Optimization of hole in yoke: Major reduction in harmonics in the e-beam aperture

What should be the acceptable value of B_n in T.m?

- **Use the harmonic field error specifications in (T.m) in electron magnets to determine the allowed integral field errors in field free region due to crosstalk.**
- **Harmonic specification in electron magnet is 10^{-4} at the reference radius.**

- **Compute integrated harmonics for the entire length of all electron magnet in T.m at the design operating gradient. Most are about the same.**
- **The most relevant may be Q1eF, the forward side quadrupole. Therefore, the equivalent integral specification for crosstalk should be: <0.5 T.m (in 10^{-4} units) or <0.5 10^{-4} T (for 2-d average) at 43 mm.**

Electron Quadrupols in EIC IR	*Good field Reference Radius (mm)*	Integral field (T)	*Lattice Length (m)*	Integral Field (times) Reference Rad (T.m)
Quad Q1EF	43.0	9.8	1.61	0.42
Q0EF tuning quad	20.0	15.8	1.2	0.32
Quad Q1ER	27.6	25.3	1.8	0.70
Quad Q2ER	32.0	19.8	1.54	0.63

Early Work and Strategies on Crosstalk Control in EIC Magnets

June 5, 2026

(continuing from the discussion started on 3/13/26)

Upcoming Superconducting Shielding Experiment

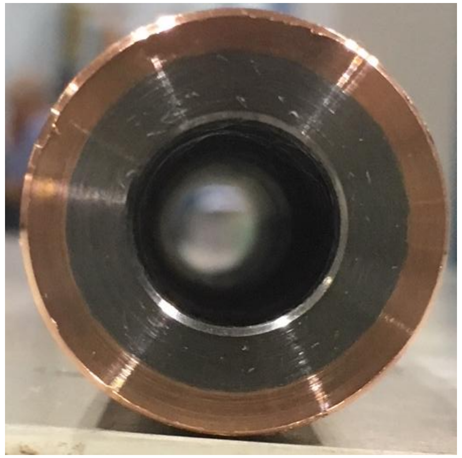
(next week – week of June 8, 2026)

If we can ensure zero field in the path of electron beam despite cross talk, then
(a) problem solved, and
(b) the need for cross-talk harmonic measurements may be relaxed

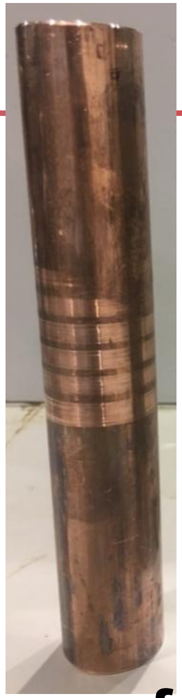
(simple Hall probe somewhere will suffice to ensure => cost implications).

Superconducting Tube for Shielding Experiment (together with high permeability A4K)

NbTi tube from Luvata

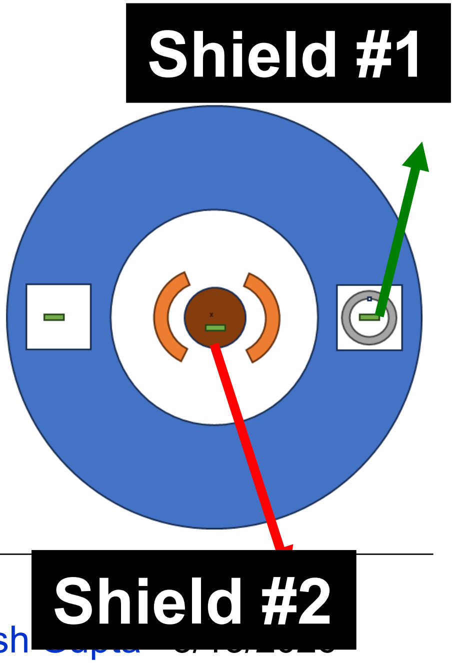


High permeability *A4K to shield small field (may be from persistent currents)



*A4K: High permeability Amumetal 4K (A4K) from Amuneal Manufacturing Corporation

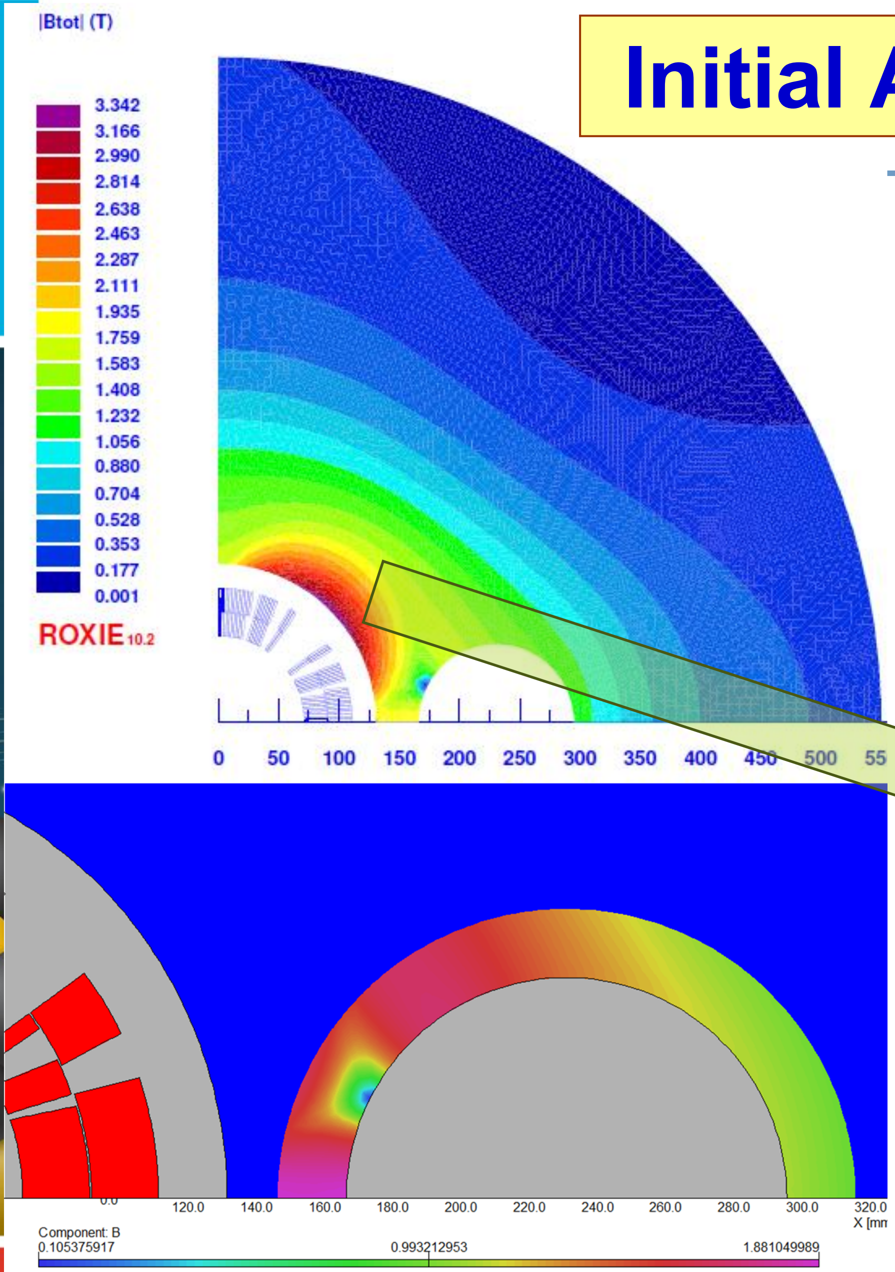
- **Yoke was purposefully chosen and oriented to test efficiency of shielding (high field in cutout, order of magnitude higher)**
- **Tube will shield ~1.2 T (a factor of 2 more than at shield #1)**
- **Shield #2 will face more field and will have 3 Hall probes for input to models (one inside for zero or trapped field, another axially offset for actual field and third outside horizontally where field will be higher than actual due to shielding currents)**

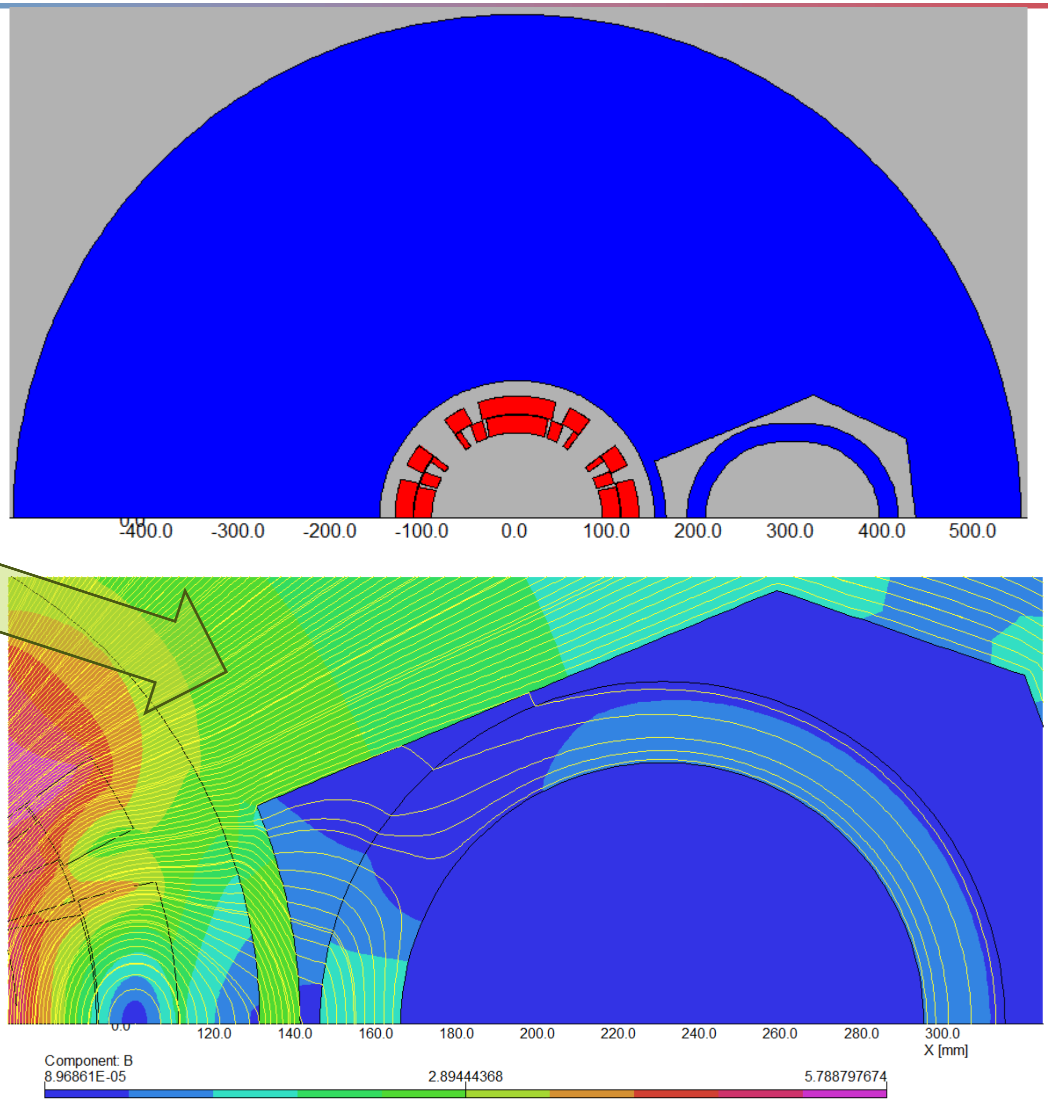


Design principles and strategies used earlier for reducing crosstalk in Q1ApF and in Q1BpF (with Q1eF)

-Ramesh Gupta 3/13/2026
Updated for 6/5/2026

Initial Attempts to Reduce Cross-talk in Q1ApF

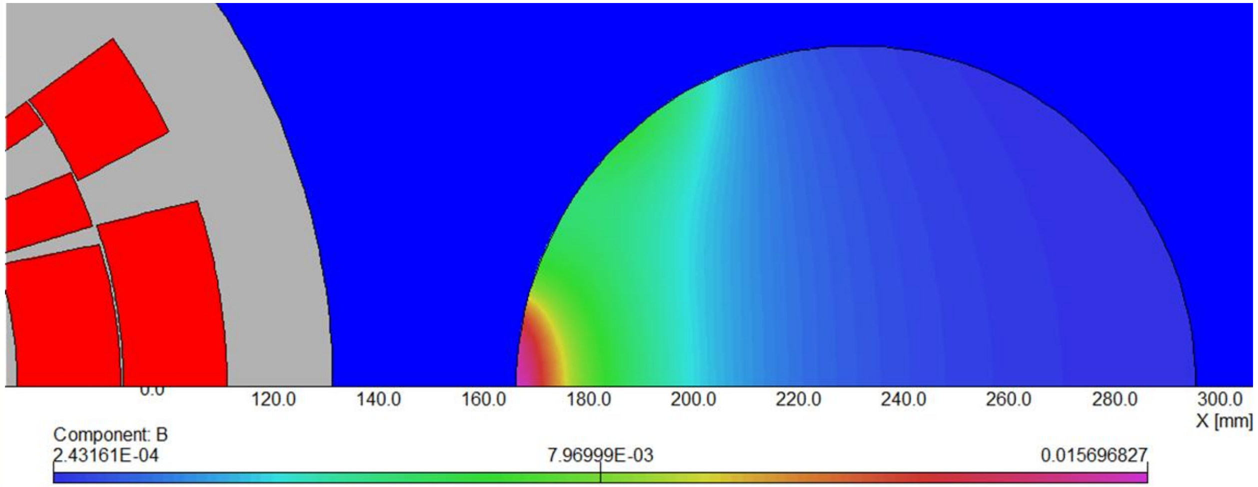


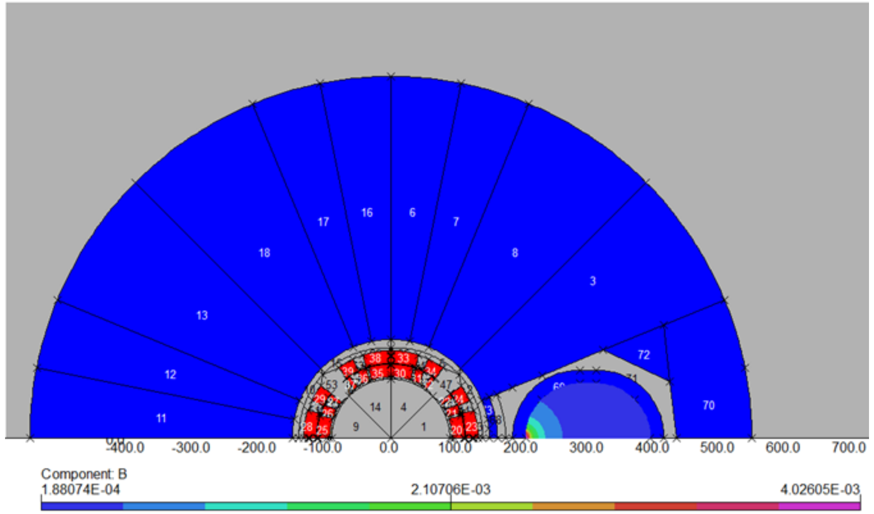


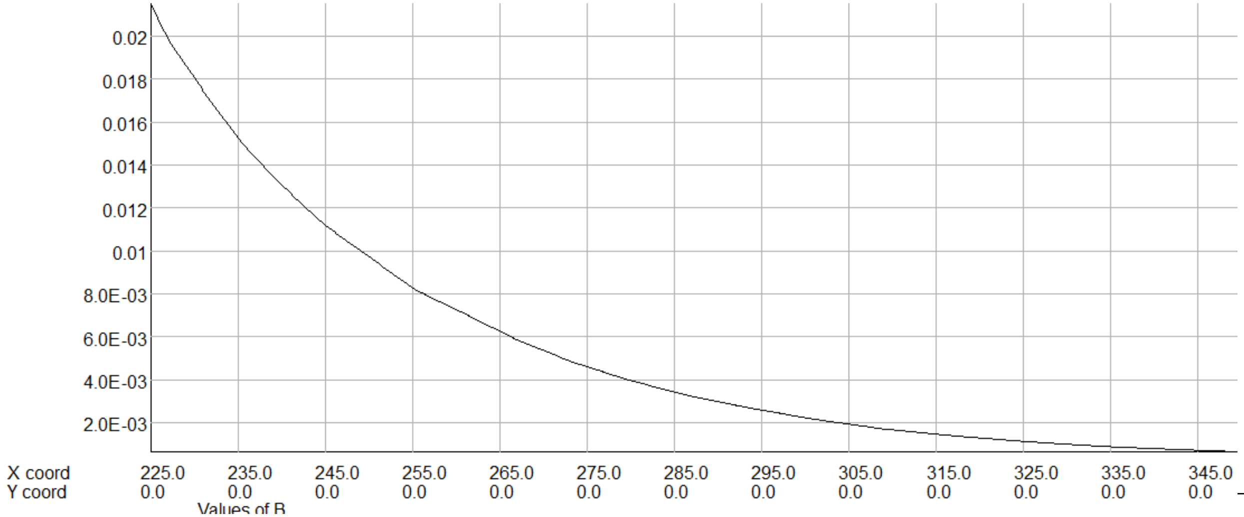
Cutout in the yoke around electron beam (a) to control saturation for the hadron beam yoke, and (b) guide flux lines and to control yoke saturation around electron beam path

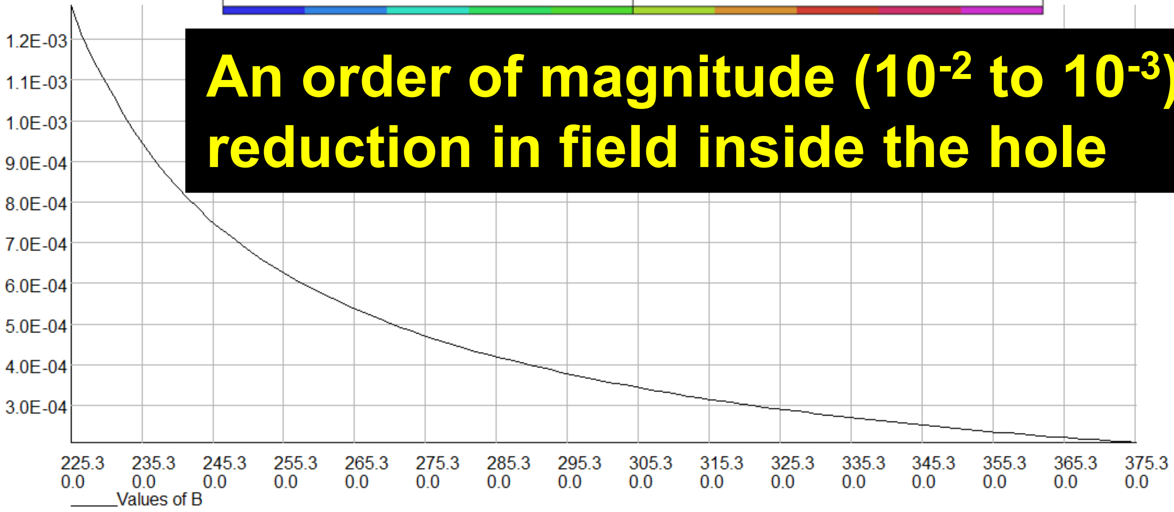
There could be tabs at the midplane joining the two so that the yoke can be a single unit/lamination

Cutout in the yoke to reduce cross-talk in Q1ApF (by an order of magnitude - we are not done yet)



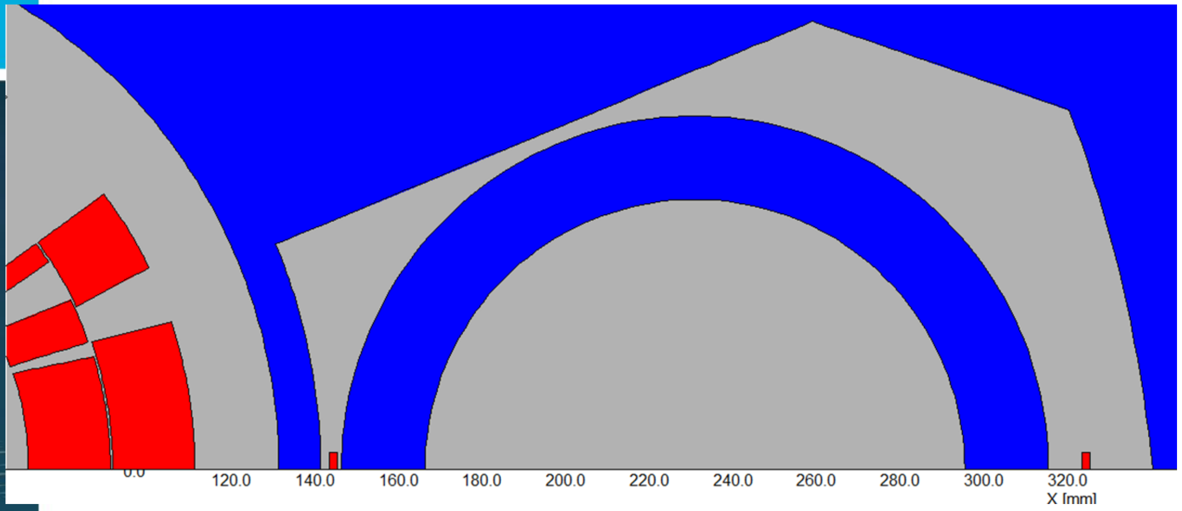






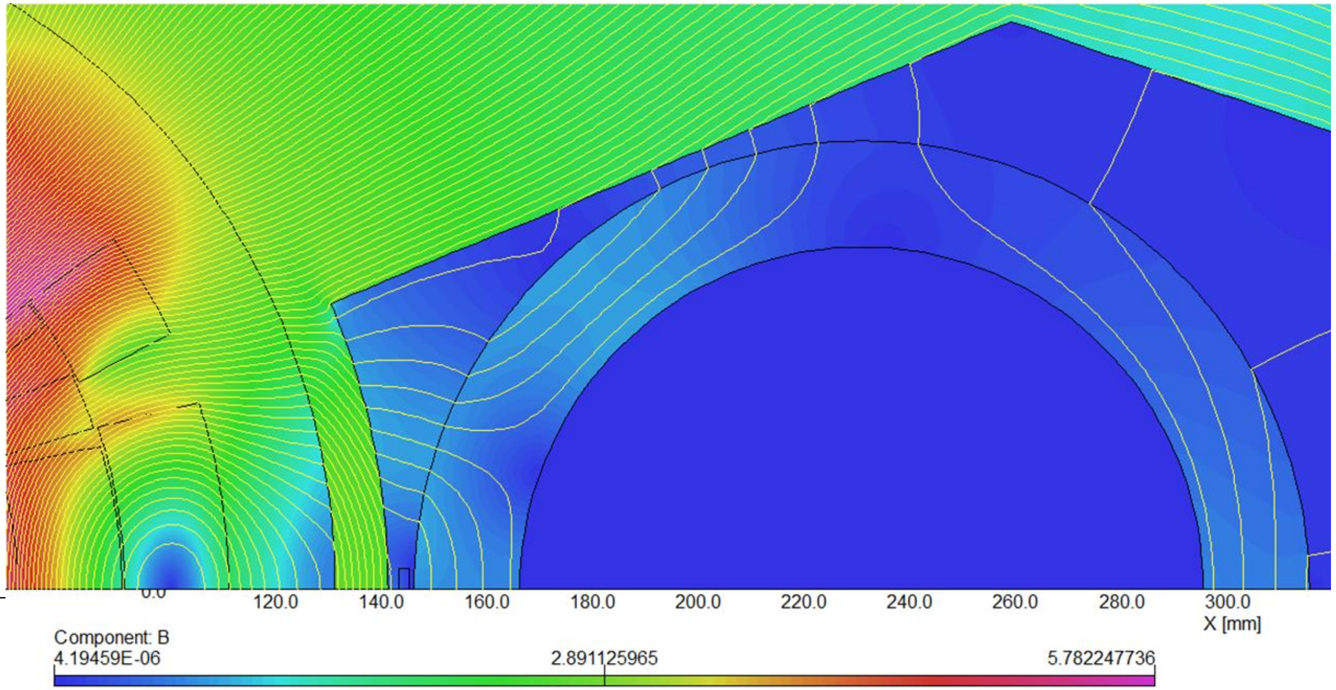
An order of magnitude (10^{-2} to 10^{-3}) reduction in field inside the hole

Further reduction in the cross-talk in Q1ApF
(by two orders of magnitude by cutout and a tiny current)



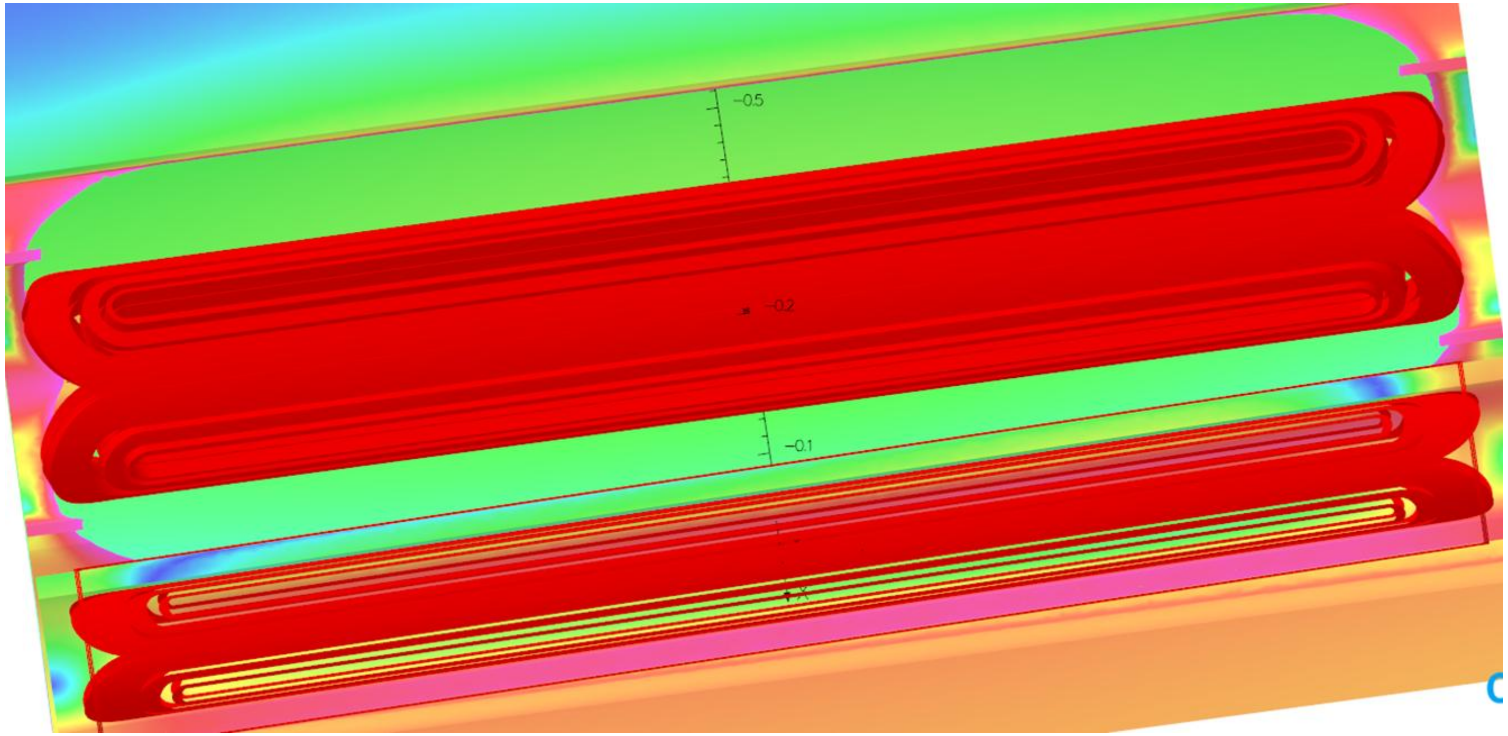
Path of flux lines is navigated with cutout in yoke, plus small coils on the two side of yoke over the e-beam region. This further navigated the flux lines. reduced saturation and the field in the electron-beam region

Two orders of magnitude (10^{-2} to 10^{-4}) reduction in field inside the hole



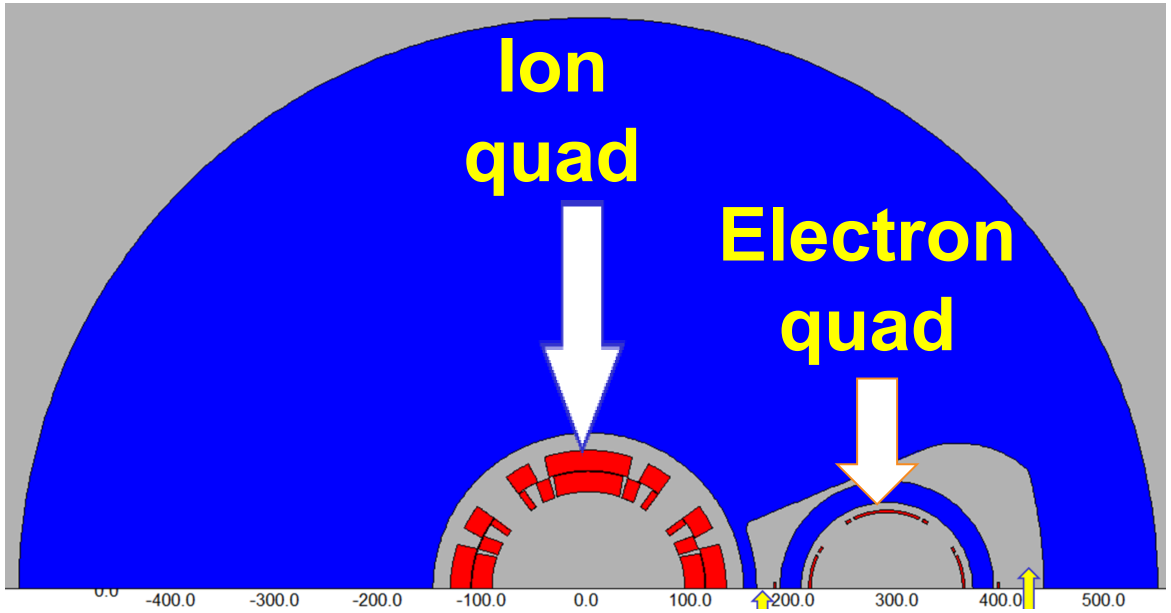
Q1BpF with Q1eF

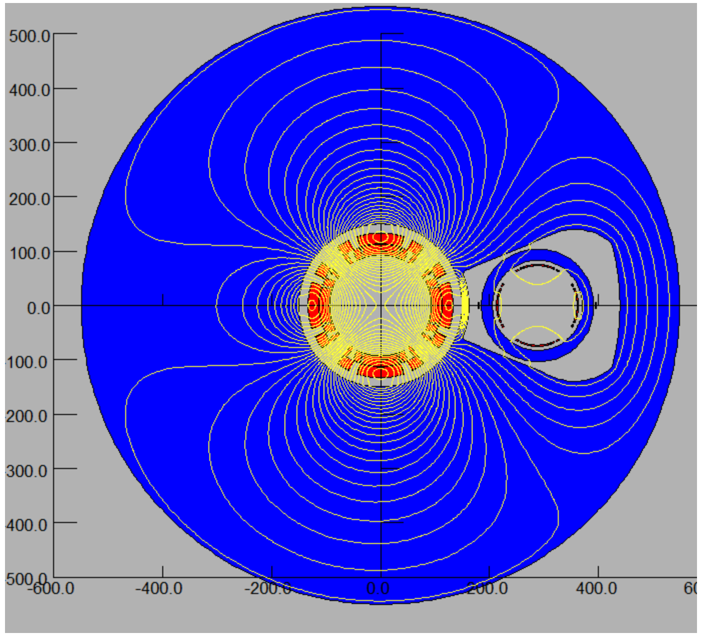
(this was/is the most challenging case for the crosstalk as both magnets influence the impact of each another, which changes with separation)

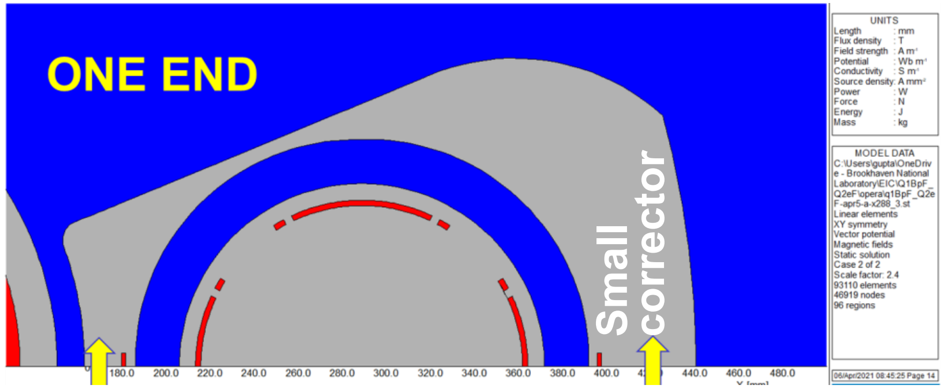


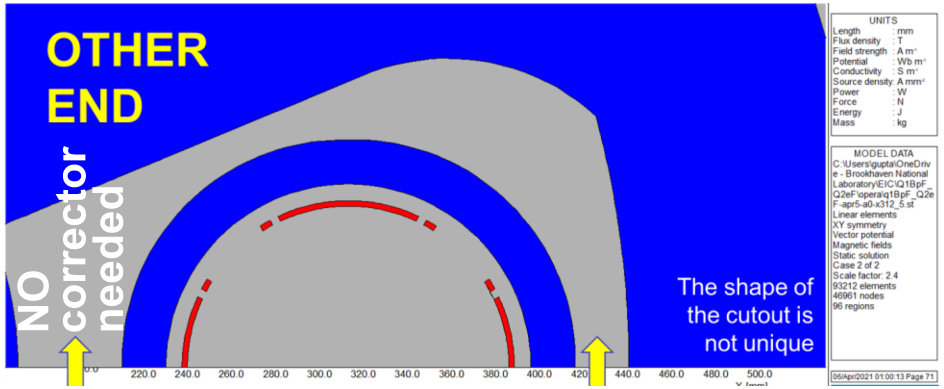
Now the aperture is reduced, and the operation is at 1.9 K. That should make it less challenging.

2-d Models for Crosstalk in Q1BpF-Q1eF



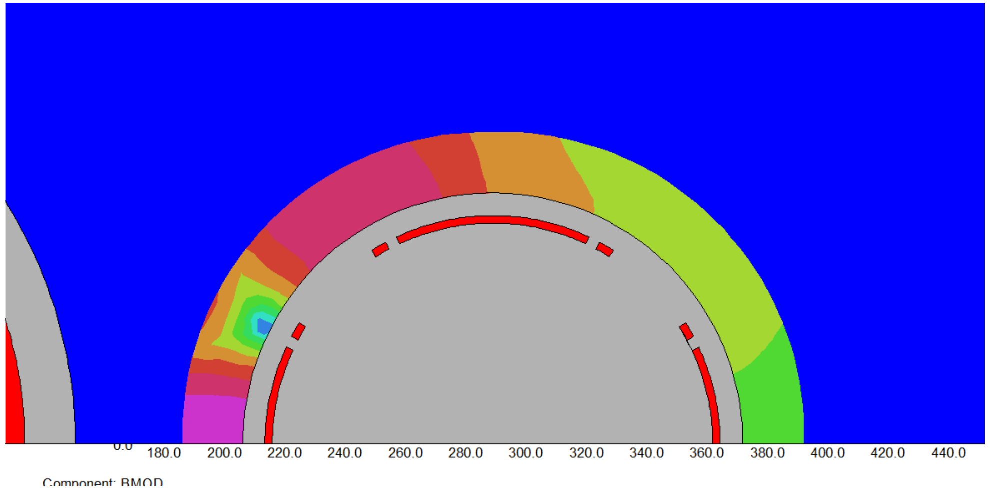






Strategy to Reduce Crosstalk Harmonics in Q1eF Due to Q1BpF

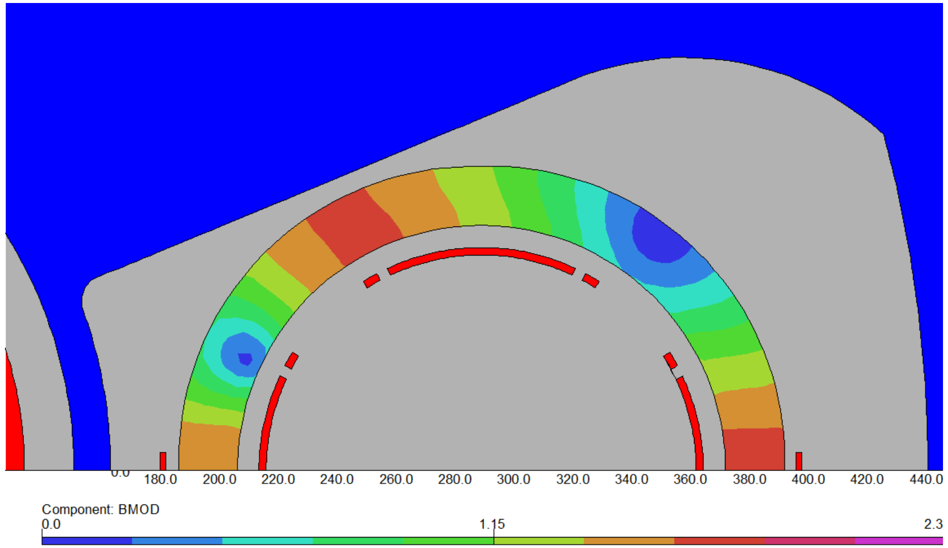
(reduce variation in field in the yoke around Q1eF, good results will follow)



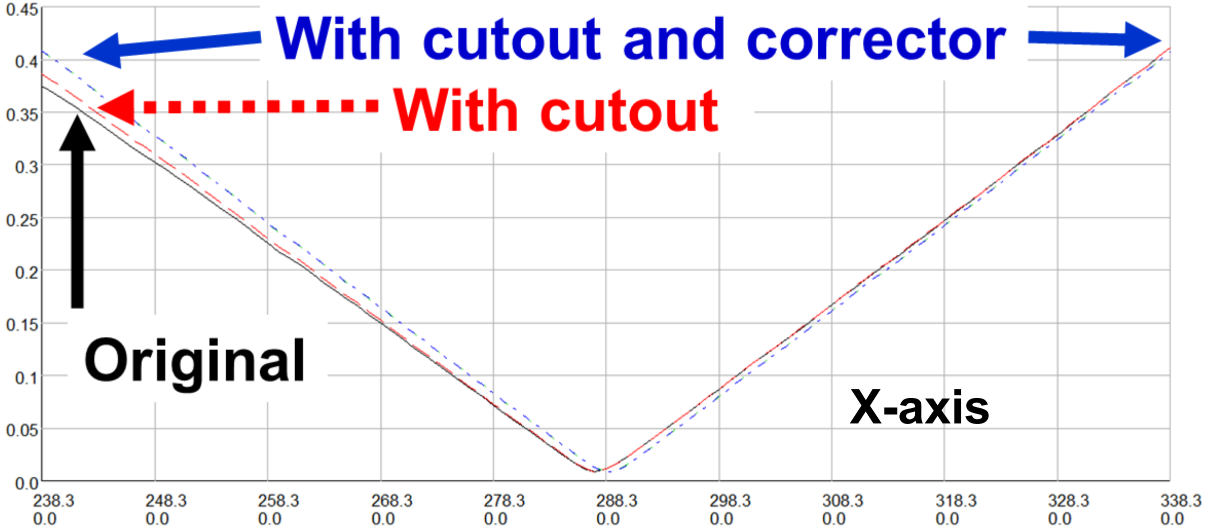
Step 0: Done Nothing

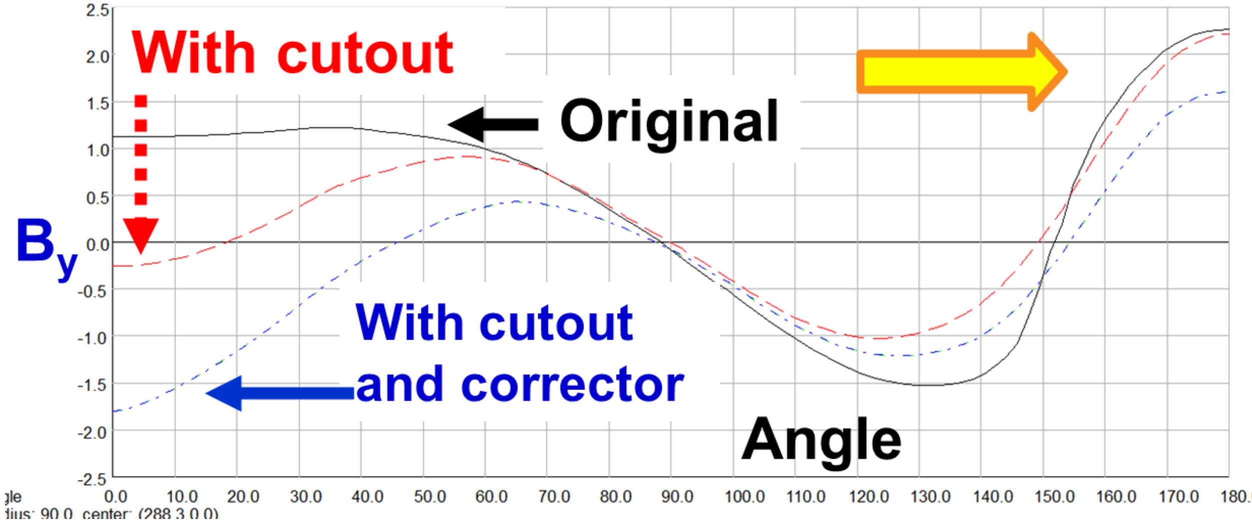
Step 1: Cutout

Step 2: small coils



Field @yoke id

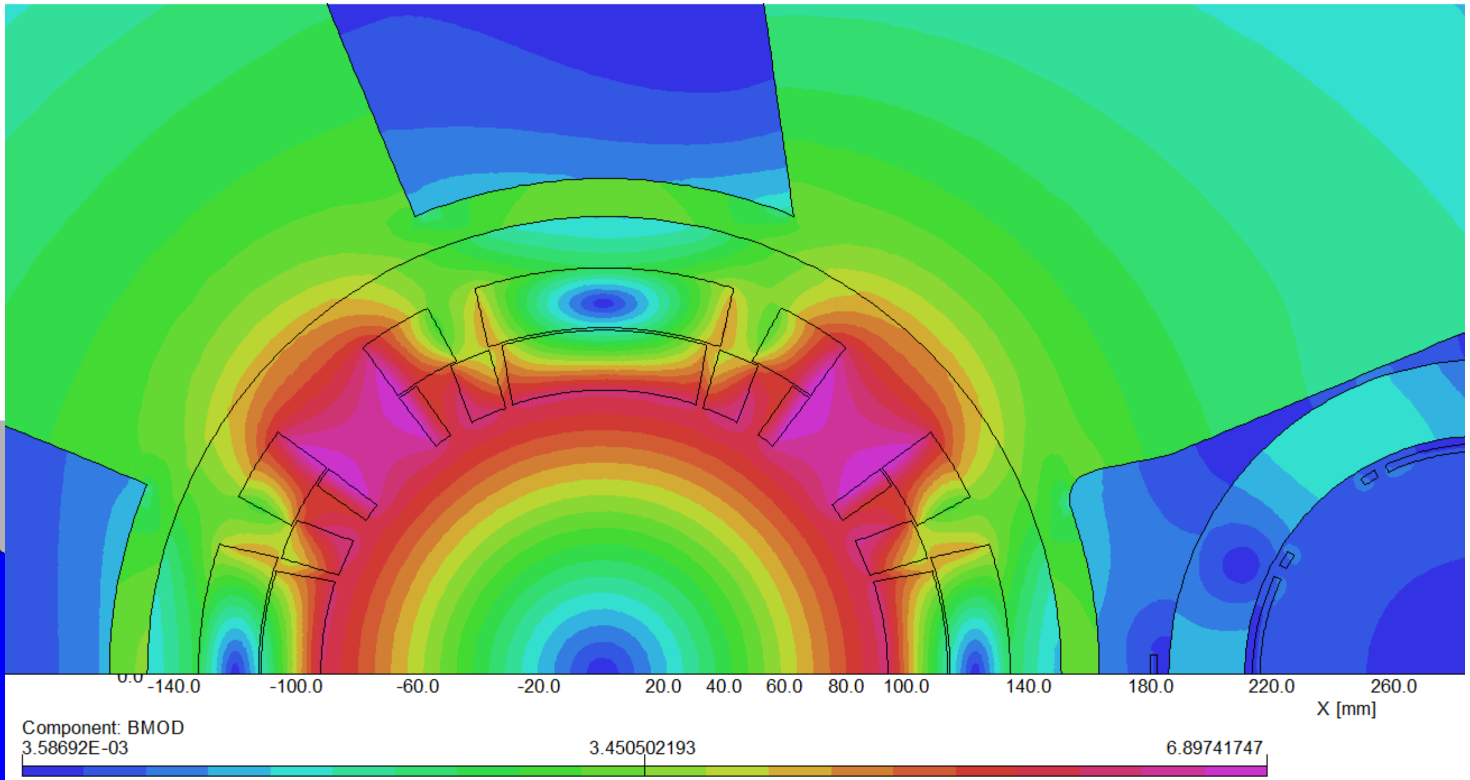


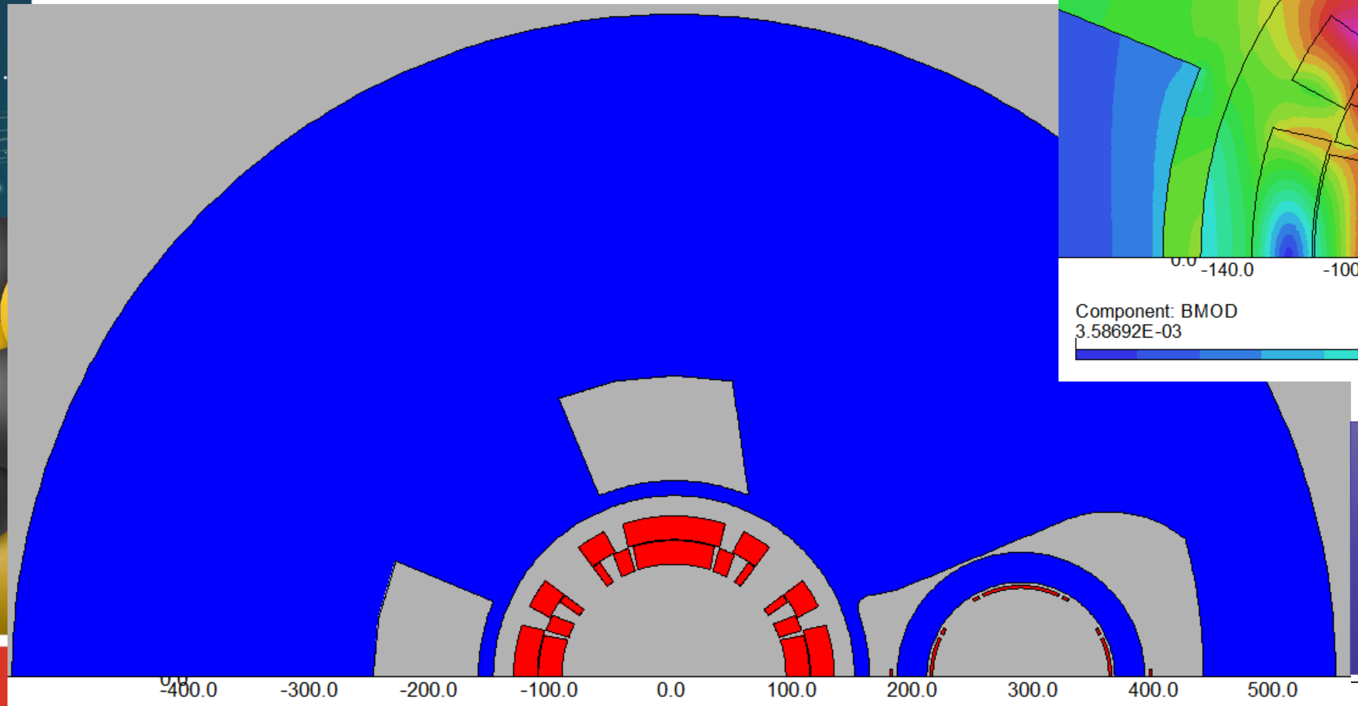


Harmonics in Hadron Quad Q1BpF due to Electron Quad
(Modified Yoke to Force a Uniform Saturation in Hadron Quad)

>>There will be non-allowed saturation induced harmonics if yoke is not effectively symmetric

>>There could also be crosstalk from electron quad to hadron quad





Critical region for reducing saturation induced harmonics in hadron quad will be the yoke closer to hadron coil

Harmonics as a function of excitation in the electron quad (Q1eF) and the hardon quad (Q1BpF) in the optimized yoke

Electron quad Q1eF

Note: Change in harmonics small in hadron quad and electron quad (both made small)

Hadron quad (Q1BpF) (design value 66.2 T/m)

q1BpF_Q2eF-apr14-a-x288_3-save-ep.BNS | q1BpF_Q2eF-apr14-a-x288_3-save-pe.BNS

eCASE	CUR(A)	pGrad(T/m)	eGrad(T/m	b3	b4	b5	b6	b7	b8	b9
1	0.007	2.976	-0.378	0.329	-0.242	0.013	7.606	0.003	-0.014	-0.006
2	0.028	11.903	-1.511	0.329	-0.242	0.013	7.606	0.003	-0.014	-0.006
3	0.055	23.790	-3.022	0.276	-0.261	0.007	7.604	0.002	-0.014	-0.006
4	0.069	29.642	-3.777	0.265	-0.298	0.005	7.604	0.002	-0.014	-0.006
5	0.083	35.218	-4.532	0.249	-0.360	0.000	7.602	0.001	-0.014	-0.006
6	0.096	40.533	-5.286	0.217	-0.465	-0.018	7.599	-0.002	-0.015	-0.006
7	0.110	45.673	-6.039	0.183	-0.623	-0.056	7.595	-0.008	-0.016	-0.006
8	0.124	50.681	-6.790	0.194	-0.872	-0.137	7.594	-0.018	-0.019	-0.006
9	0.138	55.597	-7.536	0.232	-1.302	-0.320	7.595	-0.038	-0.028	-0.006
10	0.151	60.455	-8.271	0.356	-1.981	-0.684	7.607	-0.065	-0.045	-0.006
11	0.165	65.272	-8.998	0.573	-2.748	-1.199	7.613	-0.084	-0.071	-0.006
12	0.179	70.055	-9.727	4.695	-4.096	-1.611	7.574	-0.040	-0.119	0.000

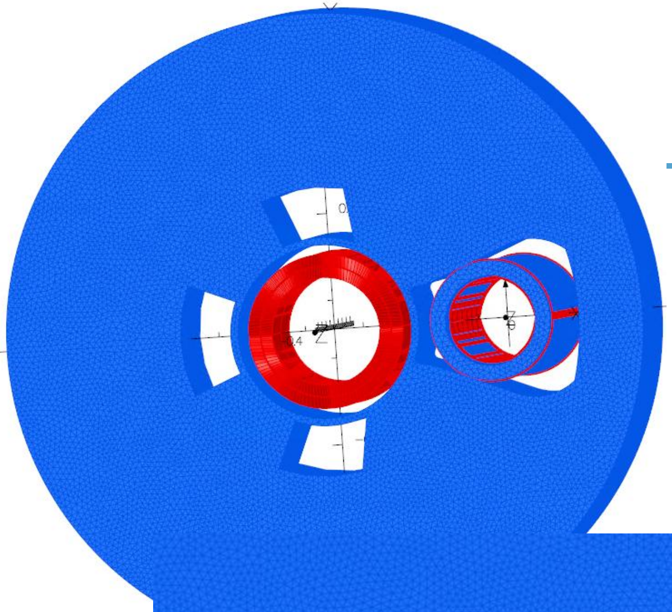
q1BpF_Q2eF-apr14-a-x288_3-save-ep.BNS | q1BpF_Q2eF-apr14-a-x288_3-save-pe.BNS

pCASE	CUR(A)	pGrad(T/m)	eGrad(T/m	b3	b4	b5	b6	b7	b8	b9
1	0.007	2.976	-0.378	0.207	-0.200	-0.141	-8.188	-0.002	-0.008	0.008
2	0.028	11.903	-1.511	0.141	-0.209	-0.154	-8.210	-0.004	-0.008	0.008
3	0.055	23.790	-3.022	0.265	-0.159	-0.114	-8.399	0.003	-0.006	0.009
4	0.069	29.642	-3.777	0.553	-0.295	0.004	-9.077	0.032	-0.005	0.010
5	0.083	35.218	-4.532	0.259	-1.293	0.071	-9.807	0.099	-0.015	0.010
6	0.096	40.533	-5.286	0.422	-2.397	0.182	-10.403	0.169	-0.025	0.005
7	0.110	45.673	-6.039	1.181	-3.067	0.309	-10.792	0.216	-0.028	0.000
8	0.124	50.681	-6.790	1.899	-3.388	0.408	-11.097	0.246	-0.026	-0.002
9	0.138	55.597	-7.536	2.516	-3.470	0.487	-11.319	0.262	-0.021	-0.003
10	0.151	60.455	-8.271	3.169	-3.377	0.547	-11.461	0.275	-0.016	-0.003
11	0.165	65.272	-8.998	3.793	-3.177	0.597	-11.541	0.284	-0.009	-0.002
12	0.179	70.055	-9.727	4.349	-2.920	0.640	-11.578	0.290	-0.002	-0.002

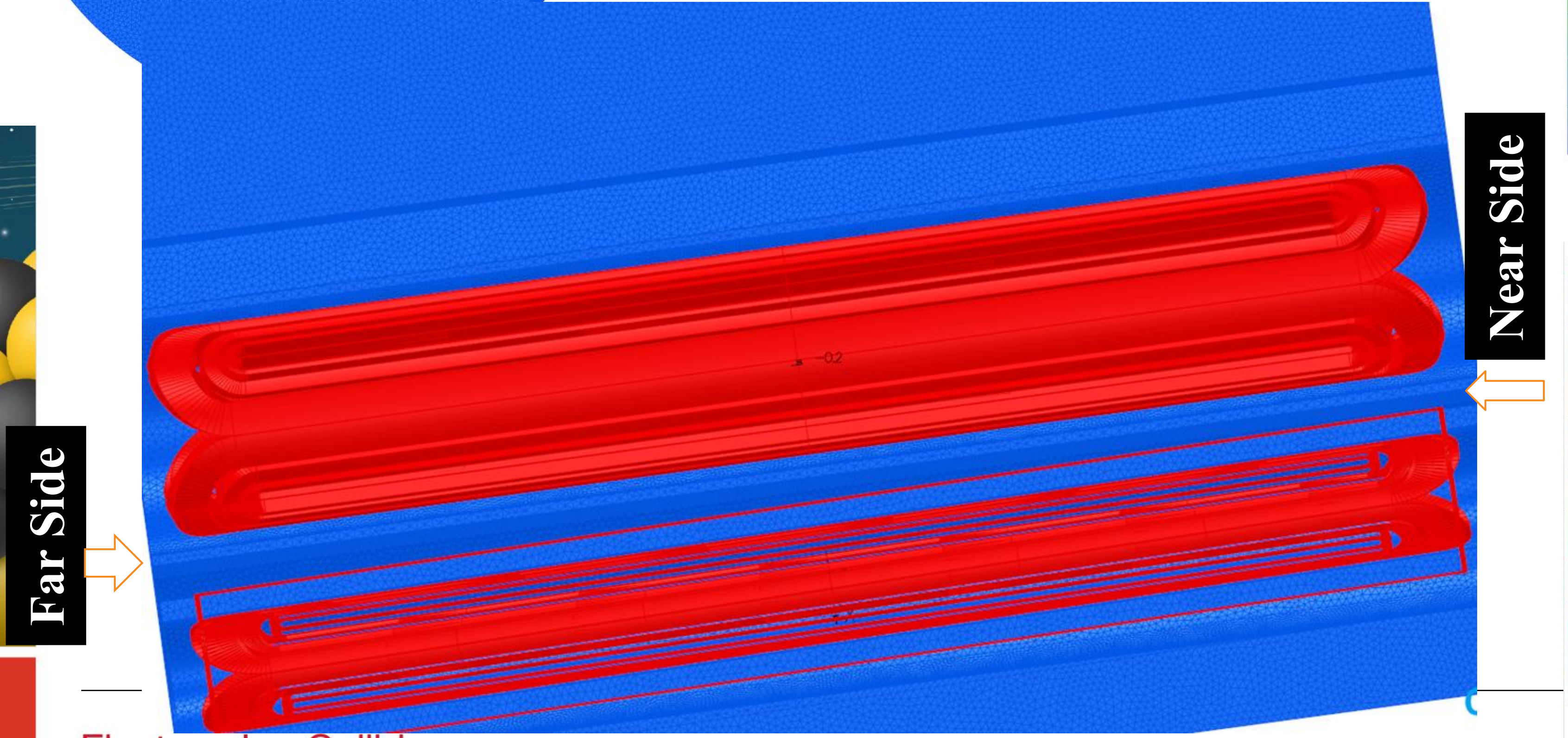
3d Modelling of the Crosstalk (between Q1BpF and Q1eF)

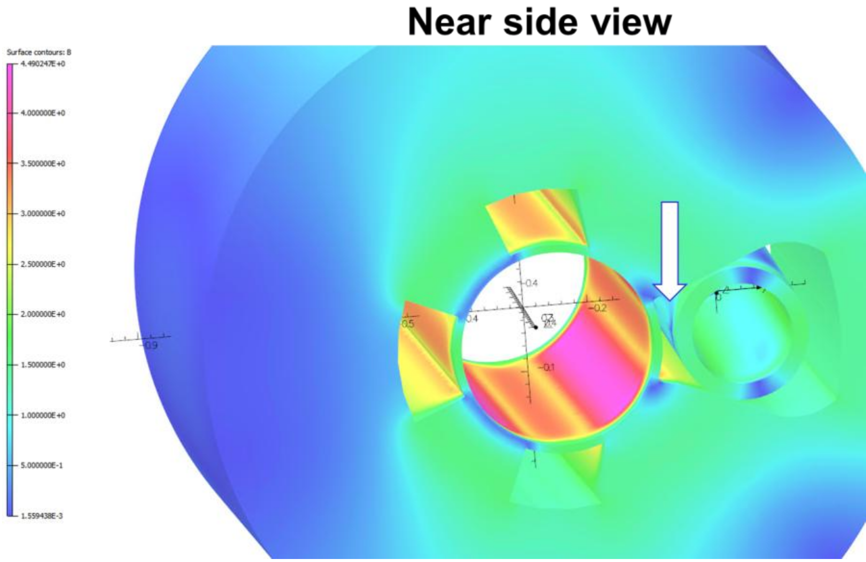
-Ramesh Gupta 3/13/2026
Updated for 6/5/2026

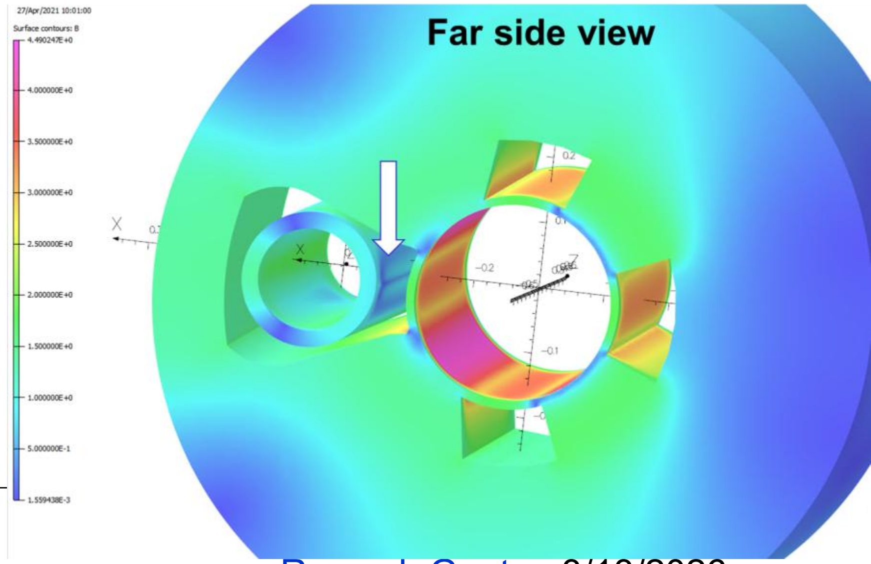
Basic 3-d Model of Q1BpF with Q1eF



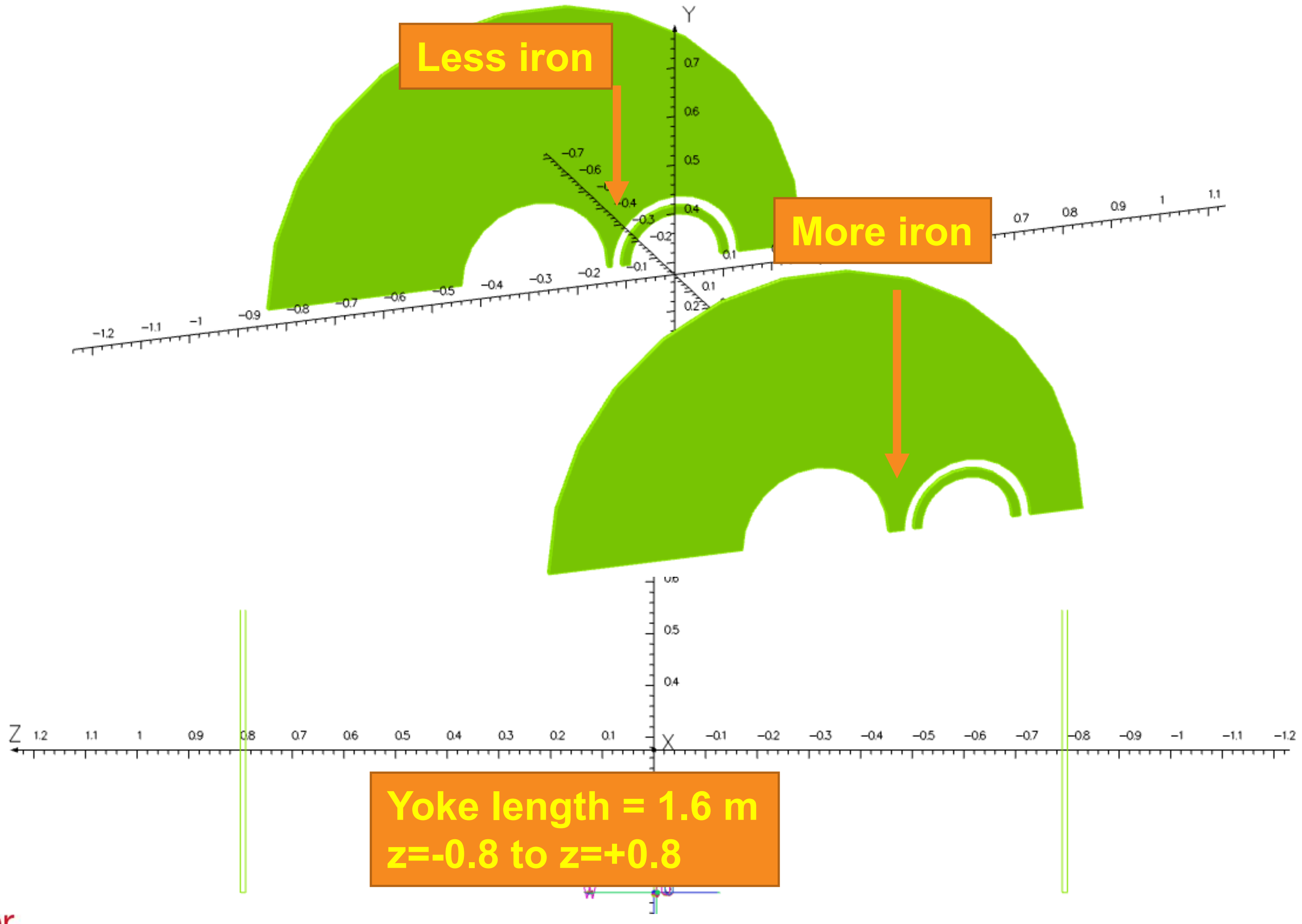
With separation between the Q1BpF and Q1eF changing, some adjustment in geometry and/or correction coil may be needed.





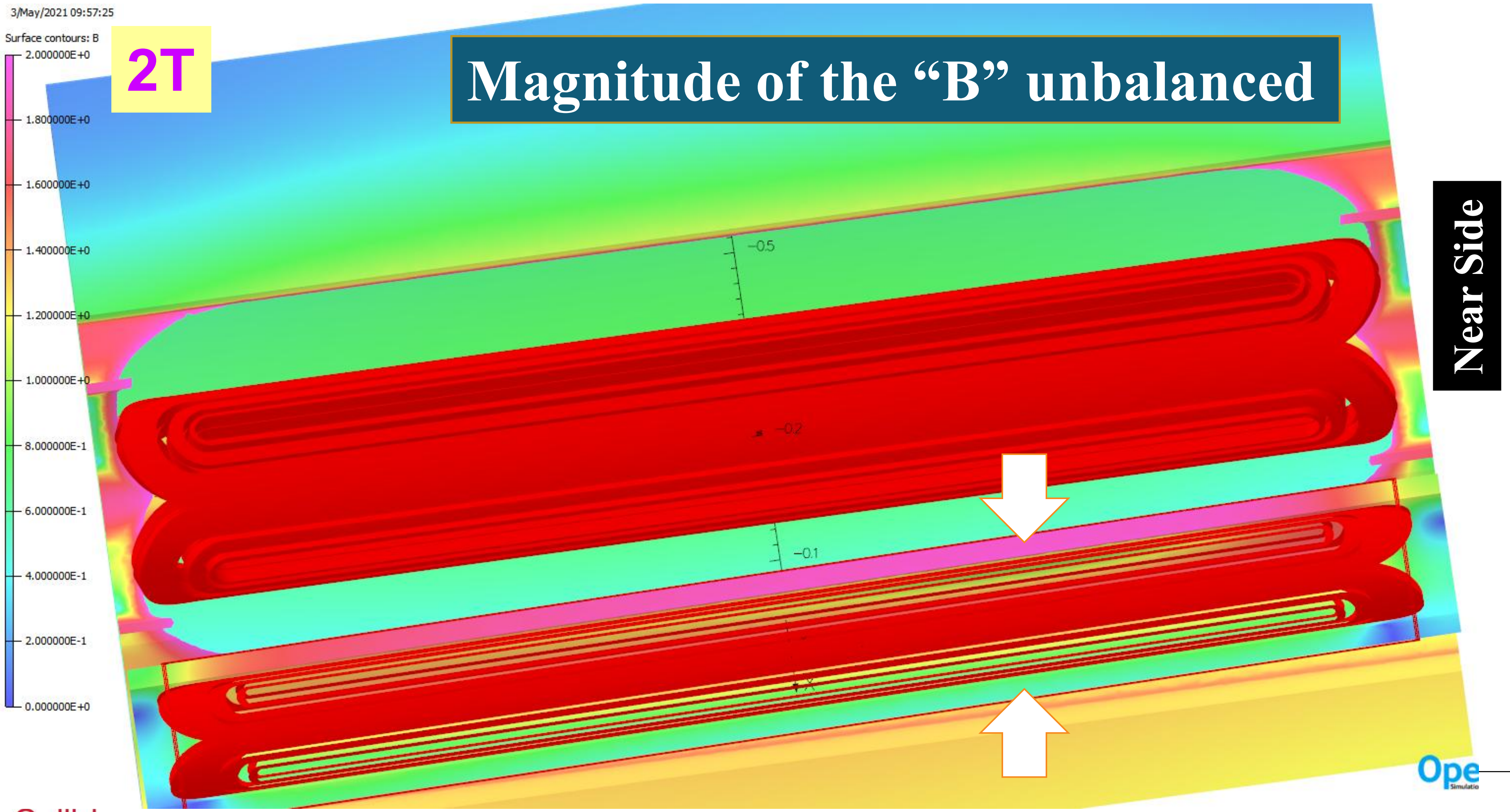


View of the Yoke at two Ends



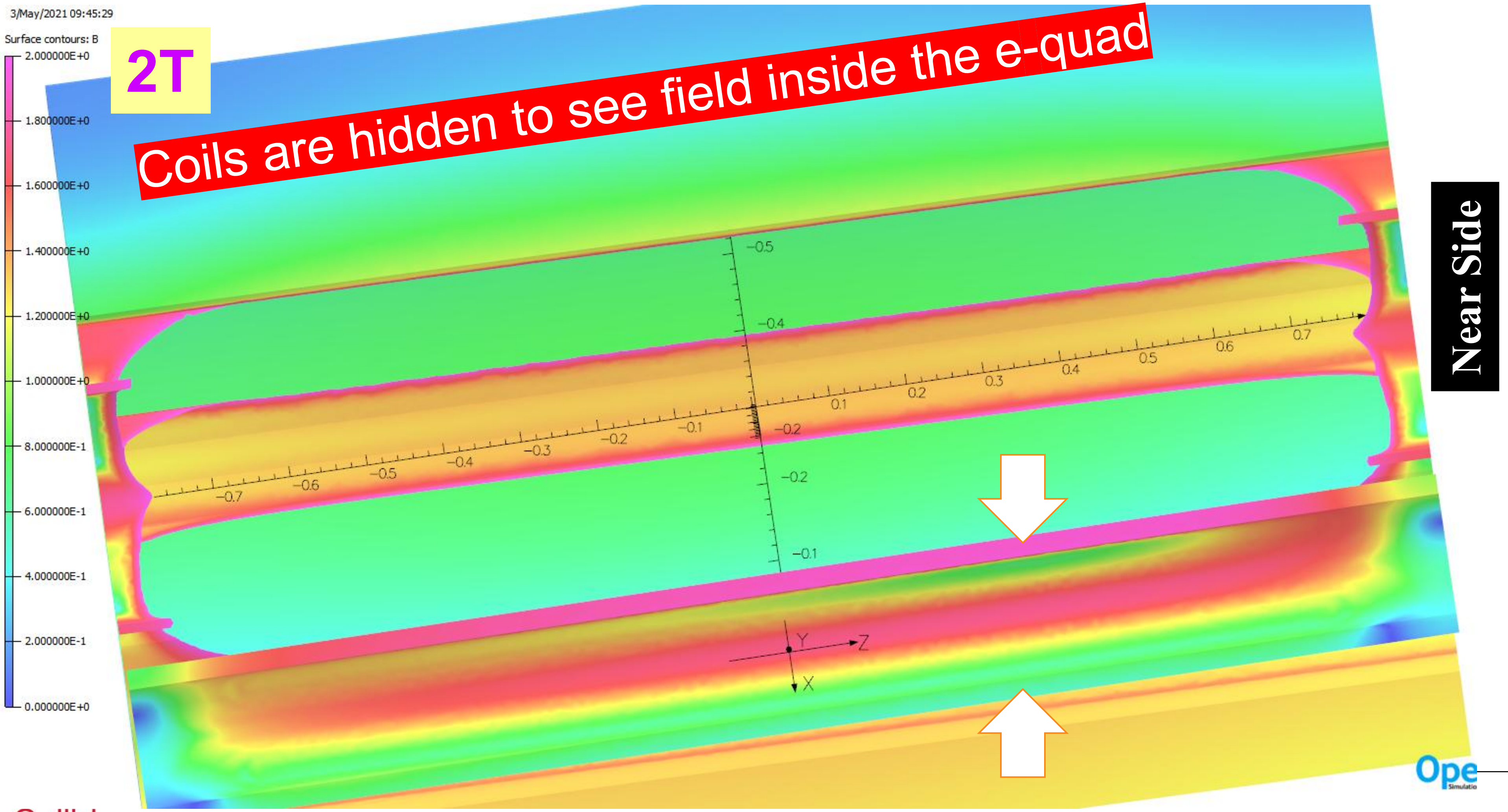
Field Superimposed over Iron (1)
[@design gradient, no corrector]

- Compare field on two sides of the yoke around e-quad



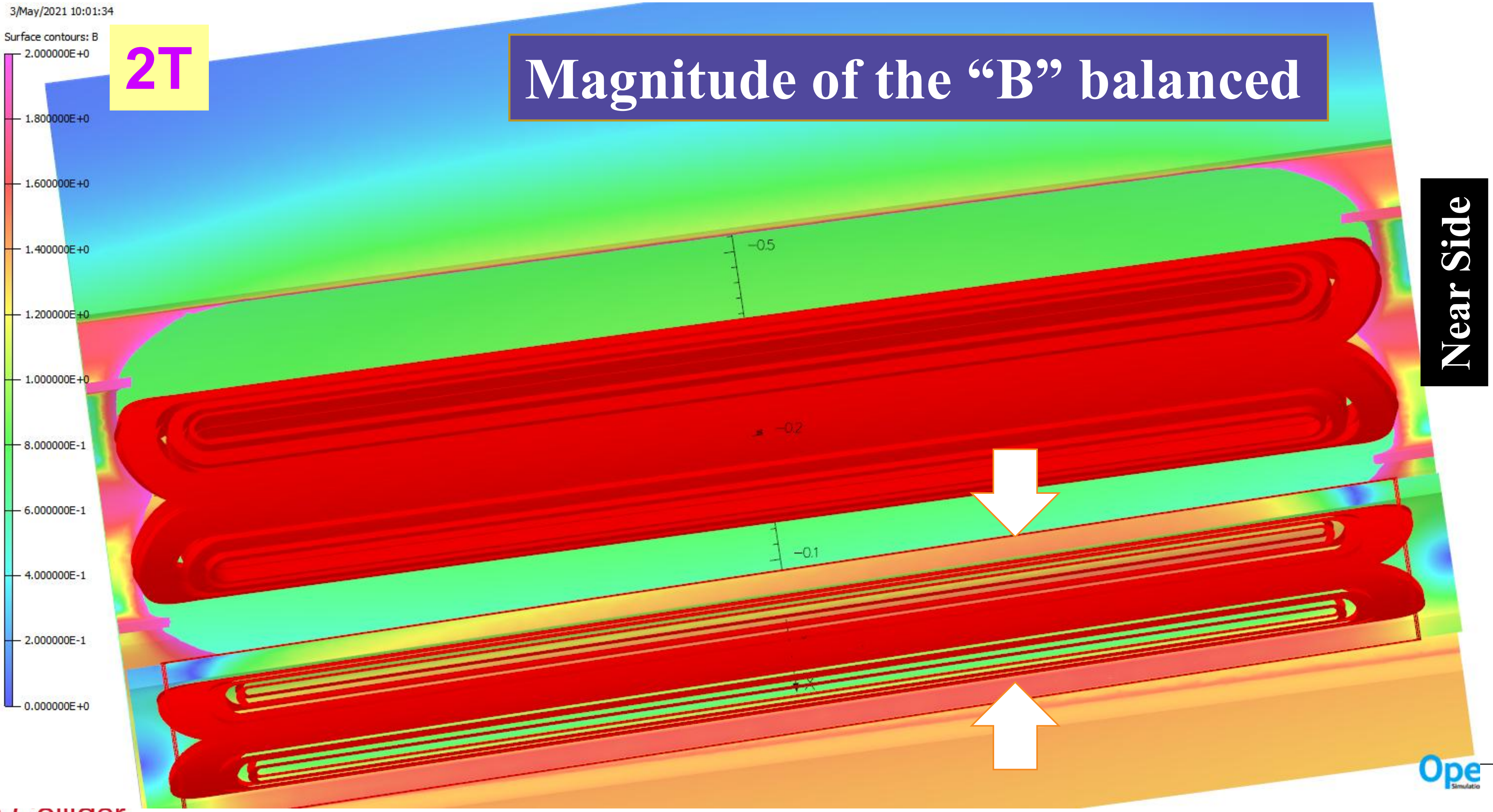
Field Superimposed over Iron (2)
[@design gradient, no corrector]

- Compare field on two sides of the yoke around e-quad



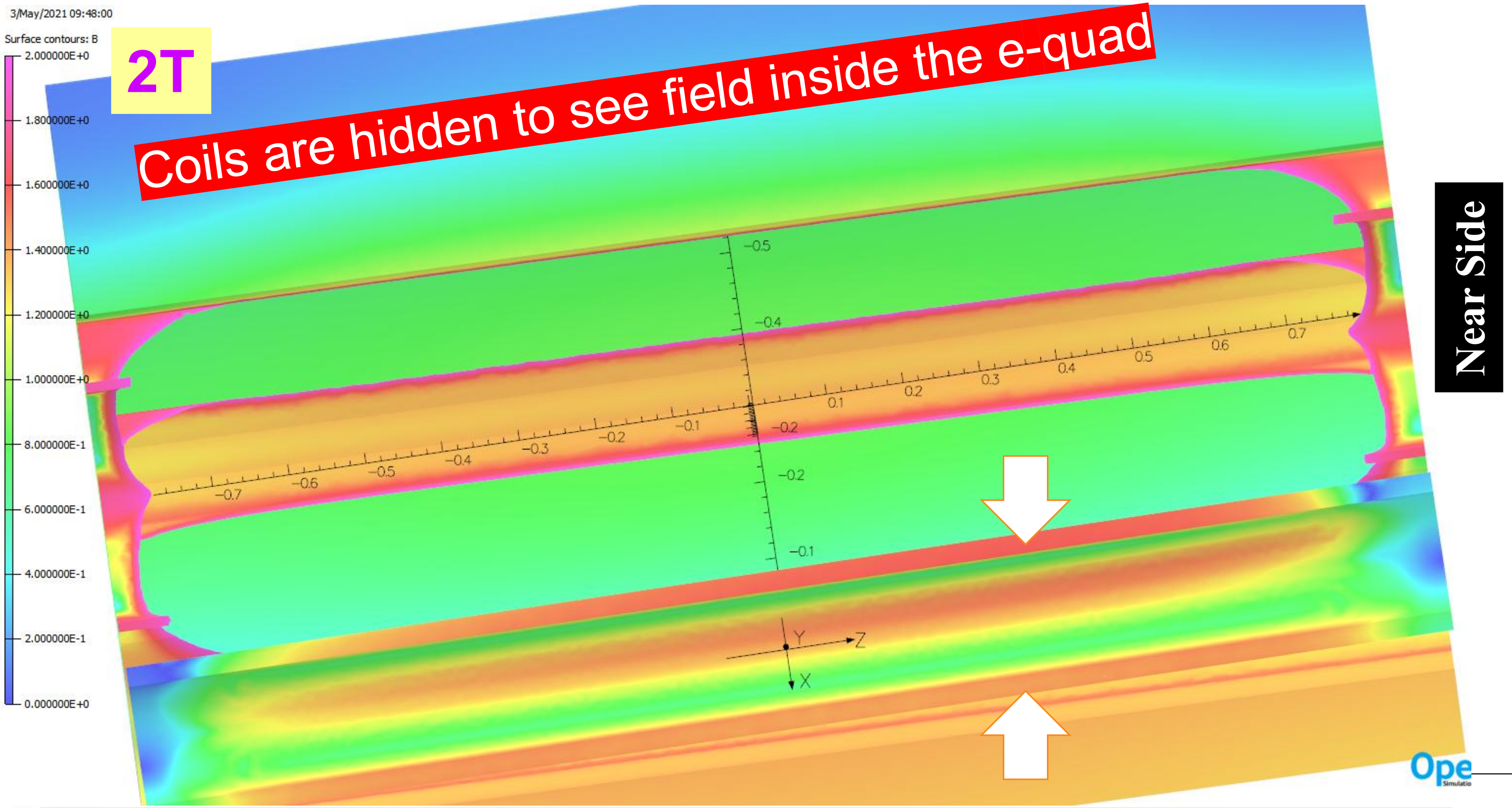
Field Superimposed over Iron (1)
[@design gradient, 50% of 2-d corrector]

- Compare field on two sides of the yoke around e-quad



Field Superimposed over Iron (2)
[@design gradient, 50% of 2-d corrector]

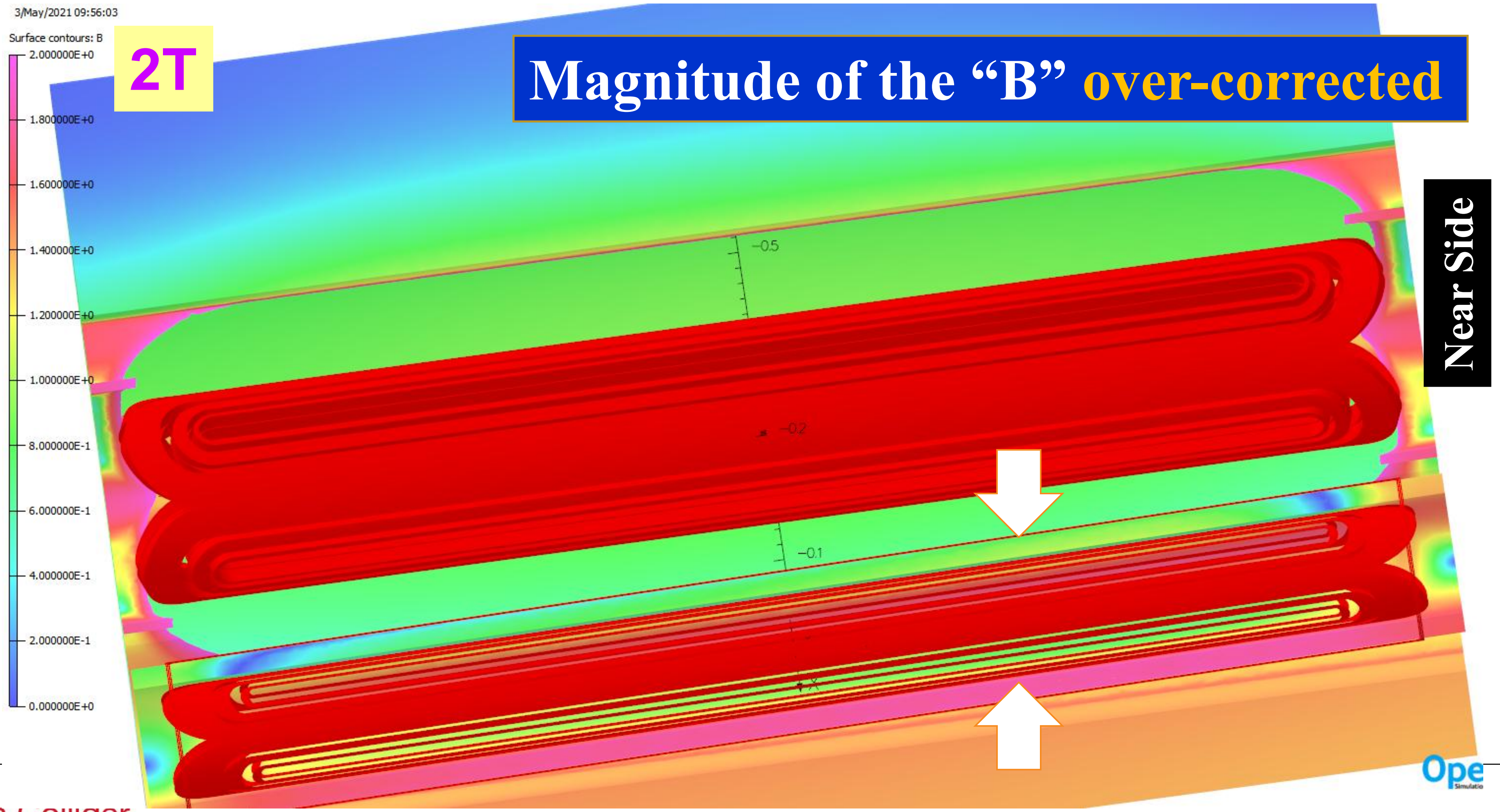
➤ **Compare field on two sides of the yoke around e-quad**



Magnitude of the "B" balanced. Expect lower change in harmonics from the baseline

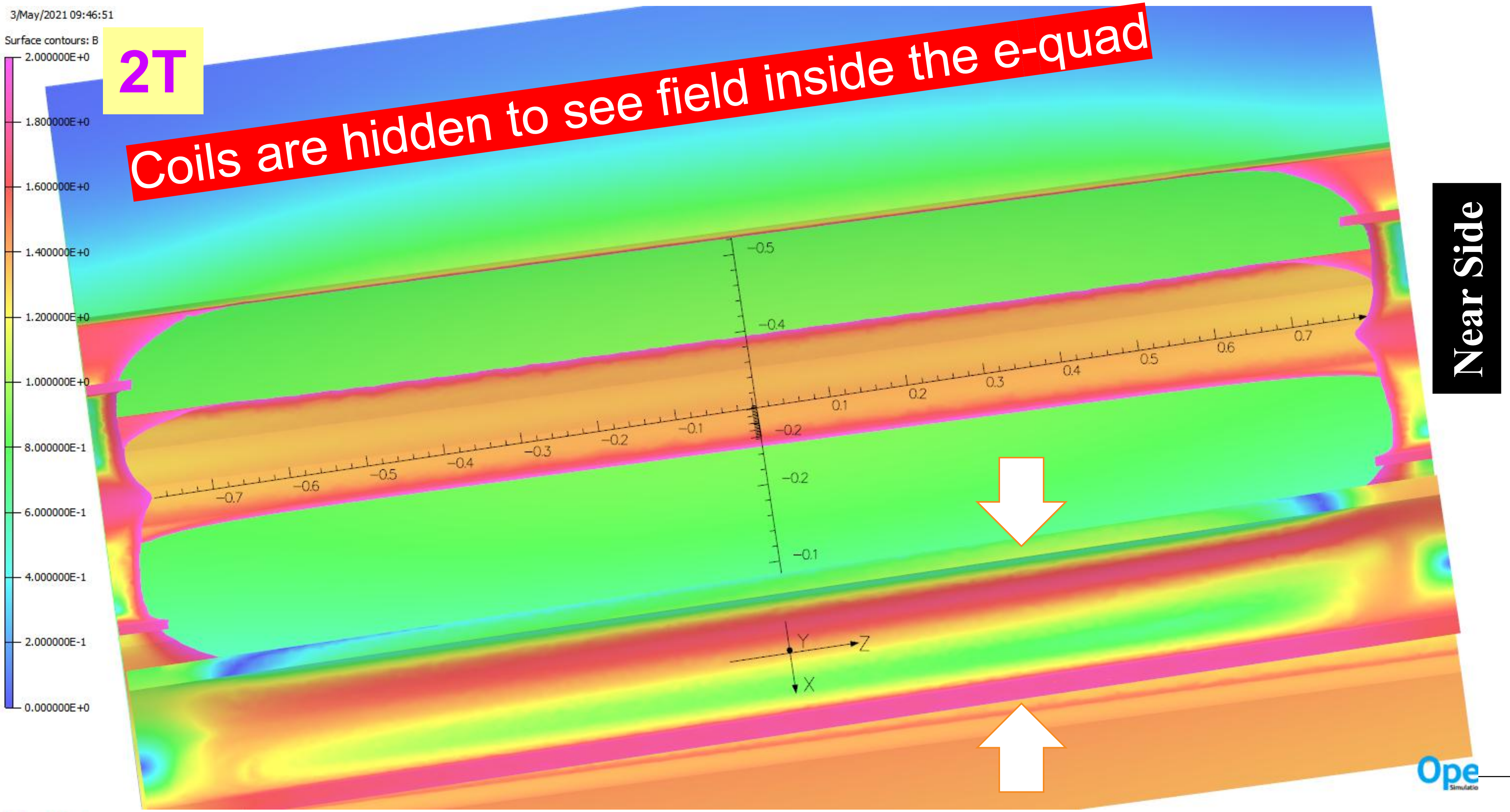
Field Superimposed over Iron (1)
[@design gradient, 100% of 2-d corrector]

- Compare field on two sides of the yoke around e-quad



Field Superimposed over Iron (2)
[@design gradient, 100% of 2-d corrector]

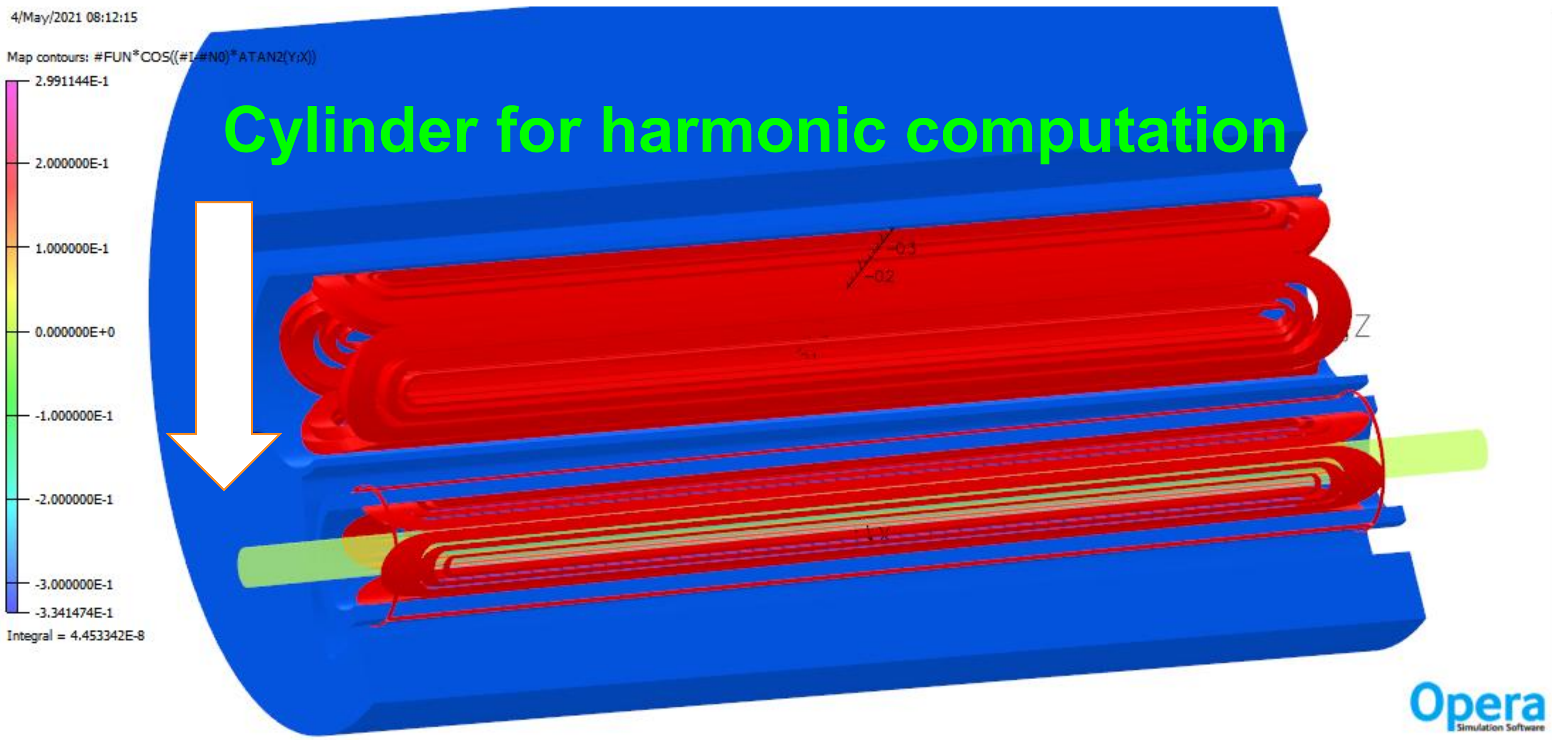
- ➢ **Compare field on two sides of the yoke around e-quad**



Magnitude of the "B" over-corrected. Examine change in harmonics from the baseline

Field Harmonic Computations

- First "*Integral Harmonics*" are computed for various cases
- Then Harmonics along the length are examined



	(integral) r=0.03	θ=0.0 to 360.0	z=-1.1102E-16
Circle11	CIRCLE (integral) r=0.03	43 θ=0.0 to 360.0	Cylindrical z=0.1
Circle12	CIRCLE (integral) r=0.03	43 θ=0.0 to 360.0	Cylindrical z=0.2
Circle13	CIRCLE (integral) r=0.03	43 θ=0.0 to 360.0	Cylindrical z=0.3
Circle14	CIRCLE (integral) r=0.03	43 θ=0.0 to 360.0	Cylindrical z=0.4
Circle15	CIRCLE (integral) r=0.03	43 θ=0.0 to 360.0	Cylindrical z=0.5
Circle16	CIRCLE (integral) r=0.03	43 θ=0.0 to 360.0	Cylindrical z=0.6
Circle17	CIRCLE (integral) r=0.03	43 θ=0.0 to 360.0	Cylindrical z=0.7
Circle18	CIRCLE (integral) r=0.03	43 θ=0.0 to 360.0	Cylindrical z=0.8
Circle19	CIRCLE (integral) r=0.03	43 θ=0.0 to 360.0	Cylindrical z=0.9
Polar	POLAR (integral) r=0.03	42x201 θ=0.0 to 360.0	Cylindrical z=-1.0 to 1.0

Integral Field Harmonics

Goal is that in change in harmonics is 10^{-4}, not 10^{-3}. Optimize more in the final design.

Low Field Harmonics

Order	A(n) Sine	B(n) Cosine
1	0.0	2.762311E-03
2	-2.59624E-12	-1.0
3	5.052216E-12	8.692267E-04
4	2.16361E-12	-1.50301E-04
5	-3.31769E-12	3.185755E-05
6	-3.48256E-14	-1.23097E-04
7	4.118028E-12	2.985923E-07
8	-3.60392E-12	5.82841E-07
9	-1.70893E-12	2.995355E-07
10	5.801297E-12	1.232019E-05
11	-3.36725E-12	-2.29664E-07
12	-3.43765E-12	-2.87763E-07
13	6.997675E-12	-7.84056E-08
14	-2.75102E-12	9.214695E-07

With NO corrector

Order	A(n) Sine	B(n) Cosine
1	0.0	-5.99299E-04
2	-2.61789E-16	-1.0
3	5.917225E-16	-2.58894E-04
4	2.638959E-16	-1.94354E-05
5	-3.31179E-16	-1.35463E-04
6	1.074947E-16	7.120178E-06
7	4.285154E-16	-3.02109E-05
8	-1.86818E-16	4.434663E-06
9	-1.1213E-16	-3.74202E-06
10	7.62408E-16	1.427452E-05
11	-2.32051E-16	-6.77881E-07
12	-3.62523E-16	-1.75198E-07
13	7.388668E-16	-1.25079E-07
14	-5.88128E-17	9.30508E-07

With 100% corrector

Order	A(n) Sine	B(n) Cosine
1	0.0	8.483569E-03
2	-2.60215E-12	-1.0
3	5.063747E-12	5.599381E-04
4	2.168573E-12	1.906077E-04
5	-3.32527E-12	2.562996E-04
6	-3.48989E-14	-9.92698E-05
7	4.127435E-12	1.308909E-05
8	-3.61216E-12	1.548179E-05
9	-1.71285E-12	1.914785E-06
10	5.814557E-12	1.311253E-05
11	-3.37494E-12	2.993815E-07
12	-3.44554E-12	-1.77487E-07
13	7.01365E-12	-5.09554E-08
14	-2.7573E-12	9.401927E-07

With 50% corrector

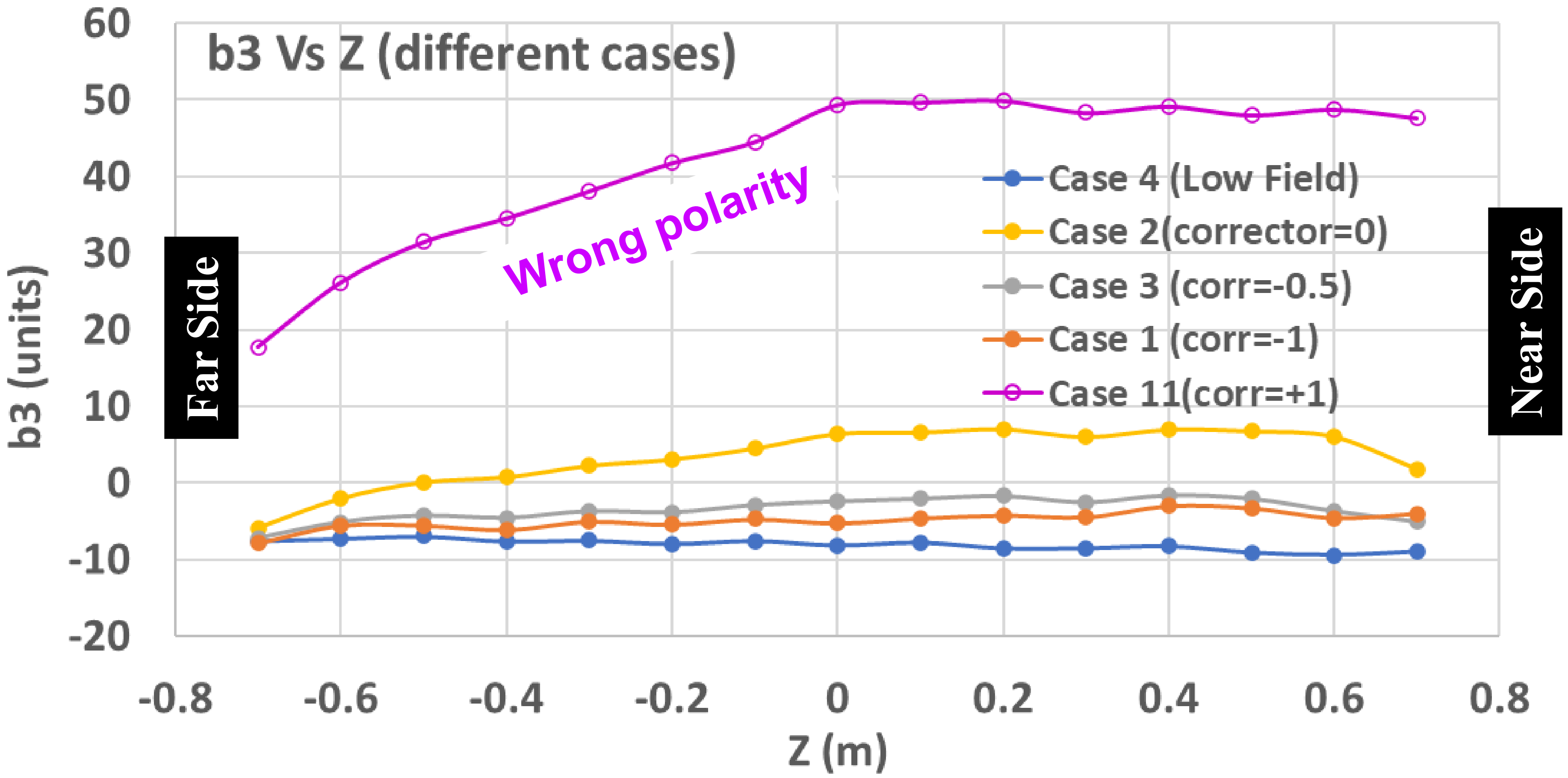
Integral Harmonic Analysis of By
With B_ref normalisation

Radius	Z1	Z2
0.03	-1.0	1.0

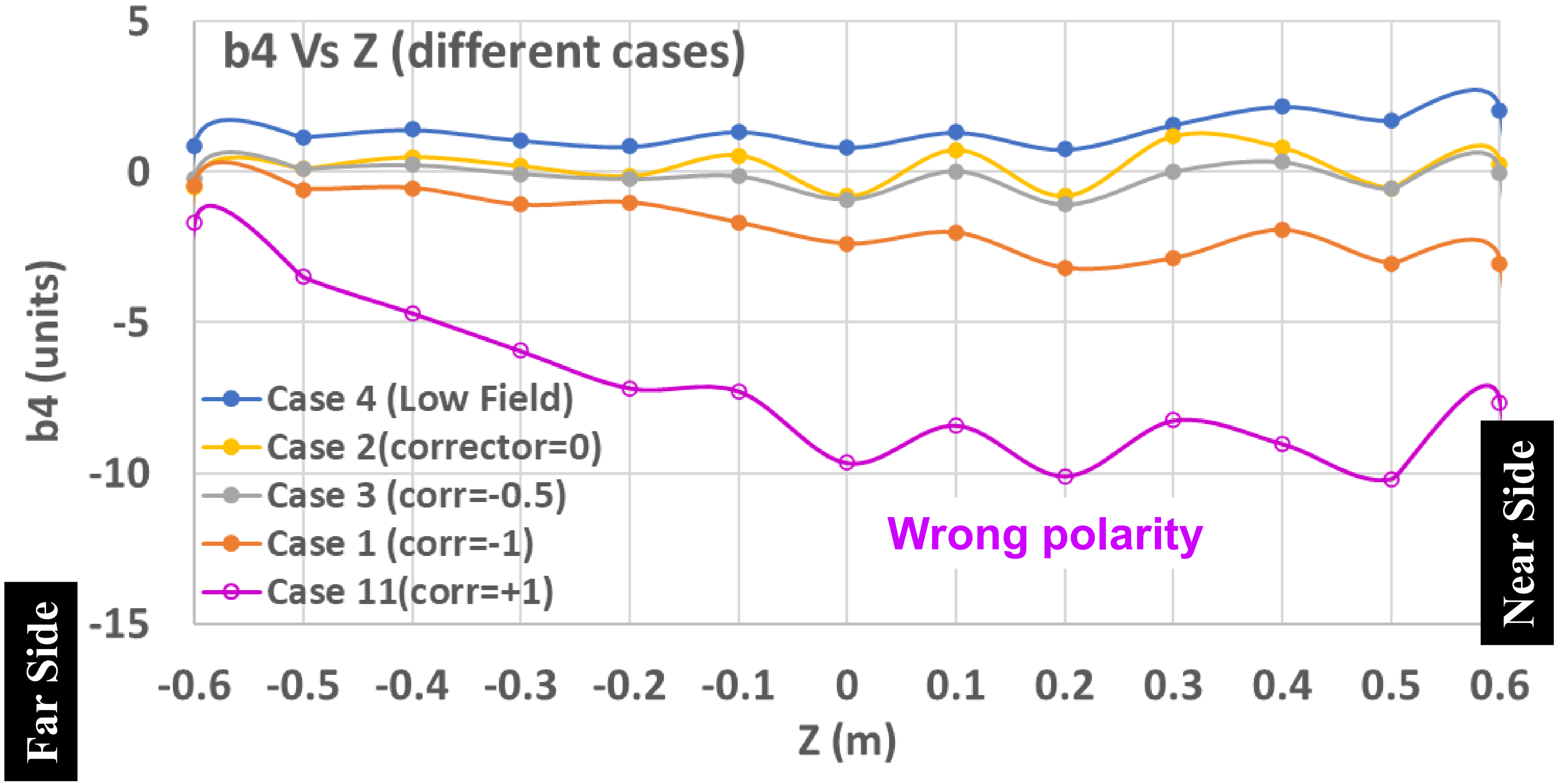
Order	A(n) Sine	B(n) Cosine
1	0.0	3.702225E-03
2	-1.29856E-12	-1.0
3	2.526978E-12	4.188606E-04
4	1.08221E-12	-1.95199E-06
5	-1.65934E-12	1.821075E-05
6	-1.73939E-14	-8.59783E-05
7	2.05972E-12	-1.03914E-05
8	-1.80244E-12	6.087515E-06
9	-8.54696E-13	-2.3381E-07
10	2.901686E-12	1.294904E-05
11	-1.68414E-12	-3.56281E-07
12	-1.71941E-12	-1.88173E-07
13	3.499991E-12	-8.94631E-08
14	-1.37585E-12	9.292278E-07

Next few slides on the change in harmonics along the axis

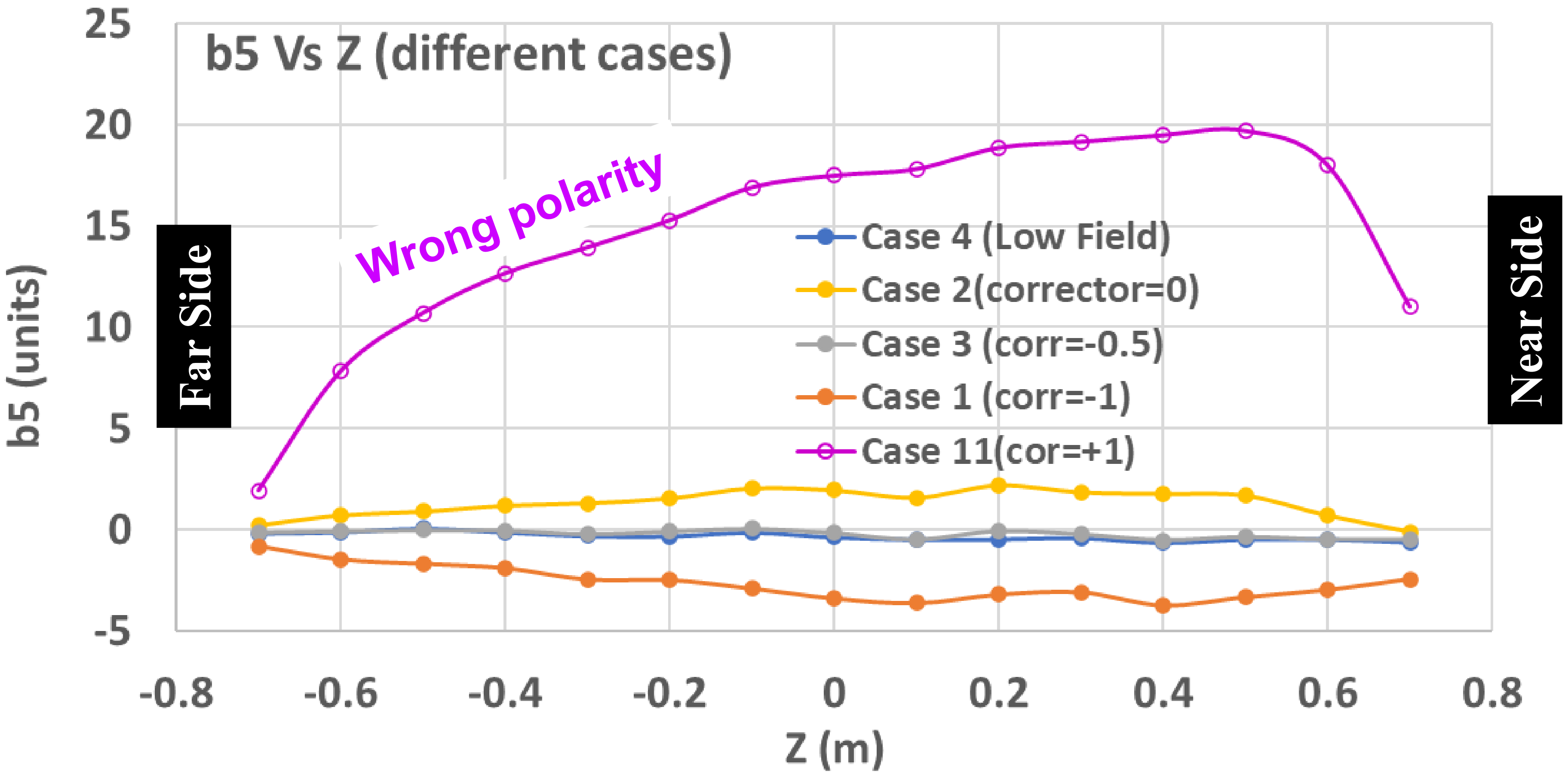
b_3 Along the Length in Various cases



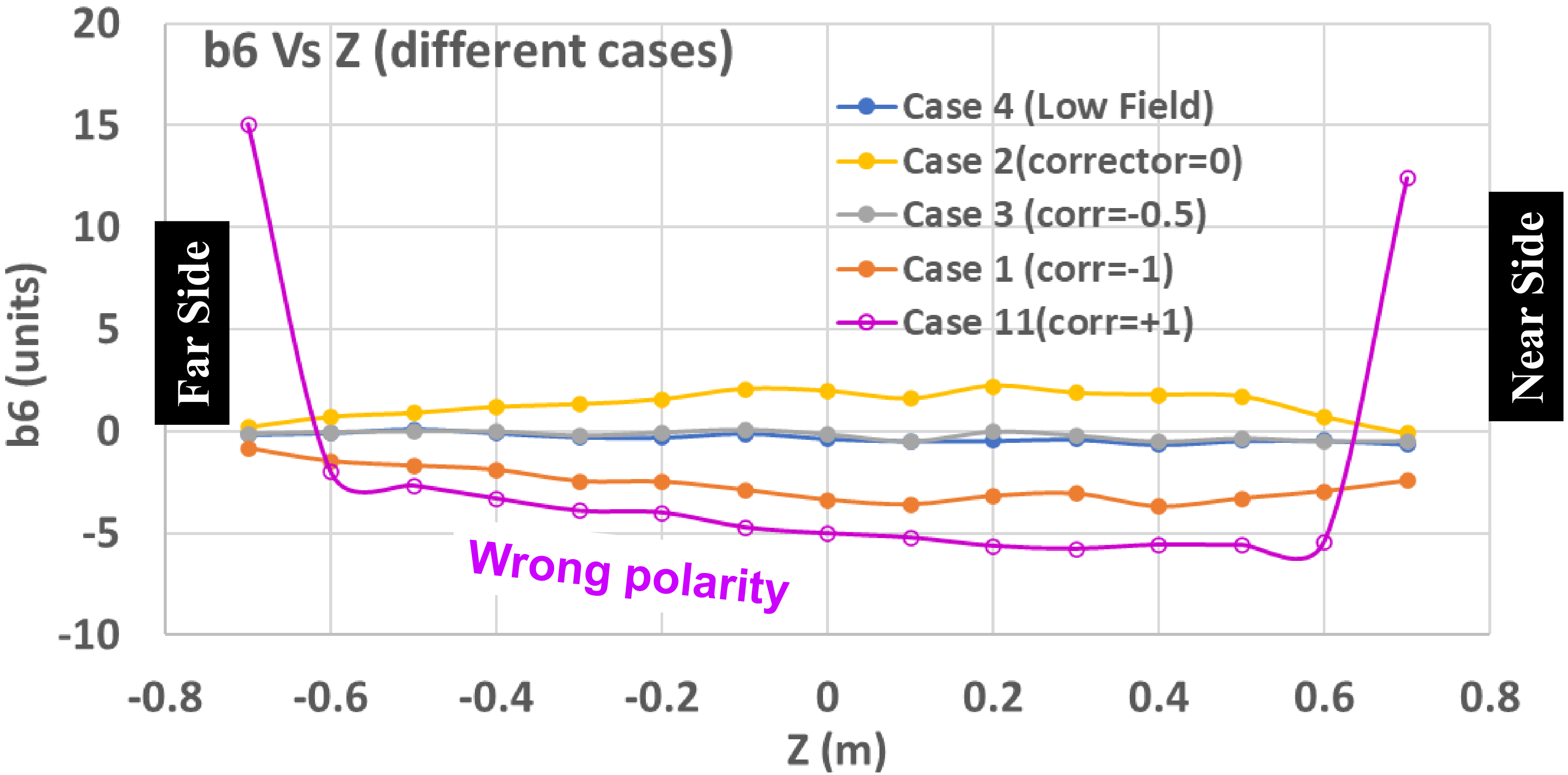
b_4 Along the Length in Various cases



b_5 Along the Length in Various cases



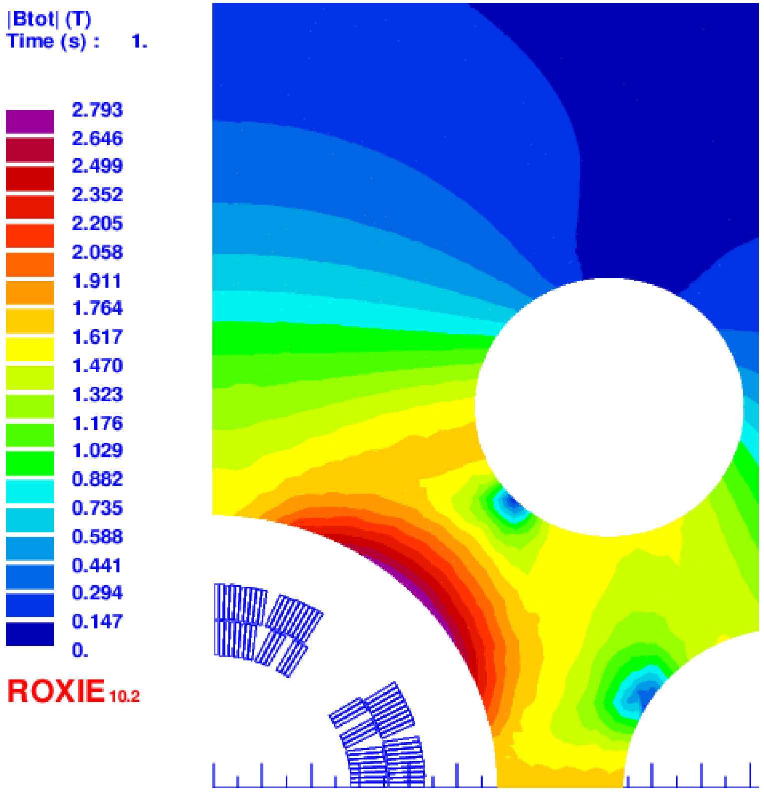
b_6 Along the Length in Various cases



Two slides on the two additional techniques should be examined, as they could be game changer

(mentioned earlier but not implemented in models yet)

Technique #1 to Reduce the Crosstalk
(use high saturation steel only in a small area)



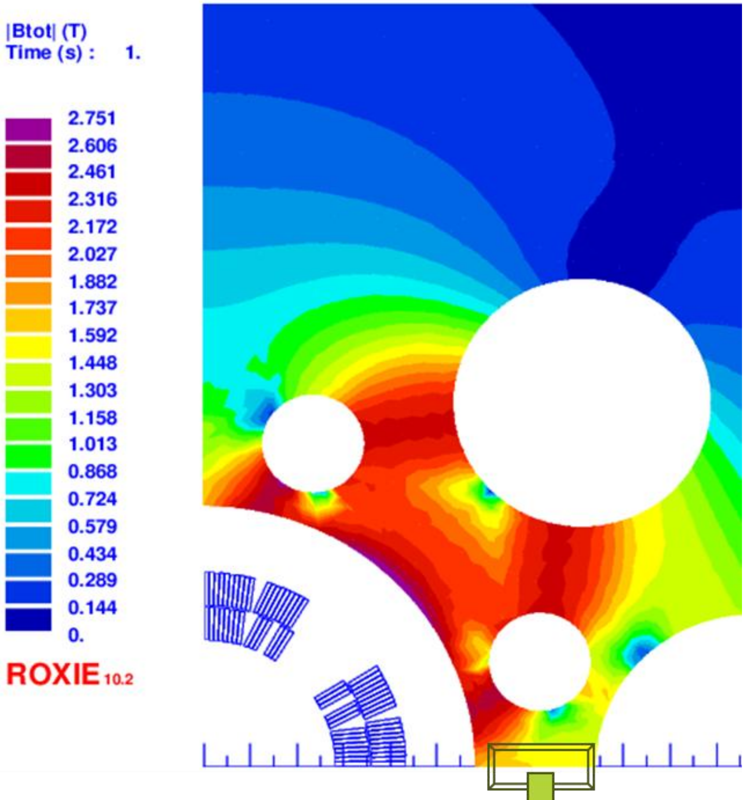
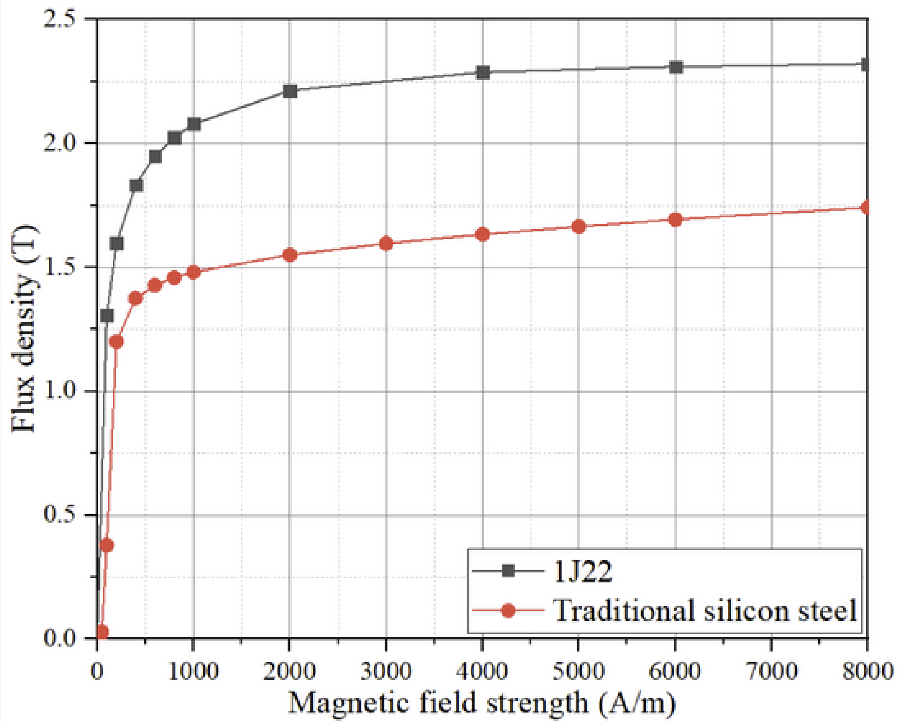


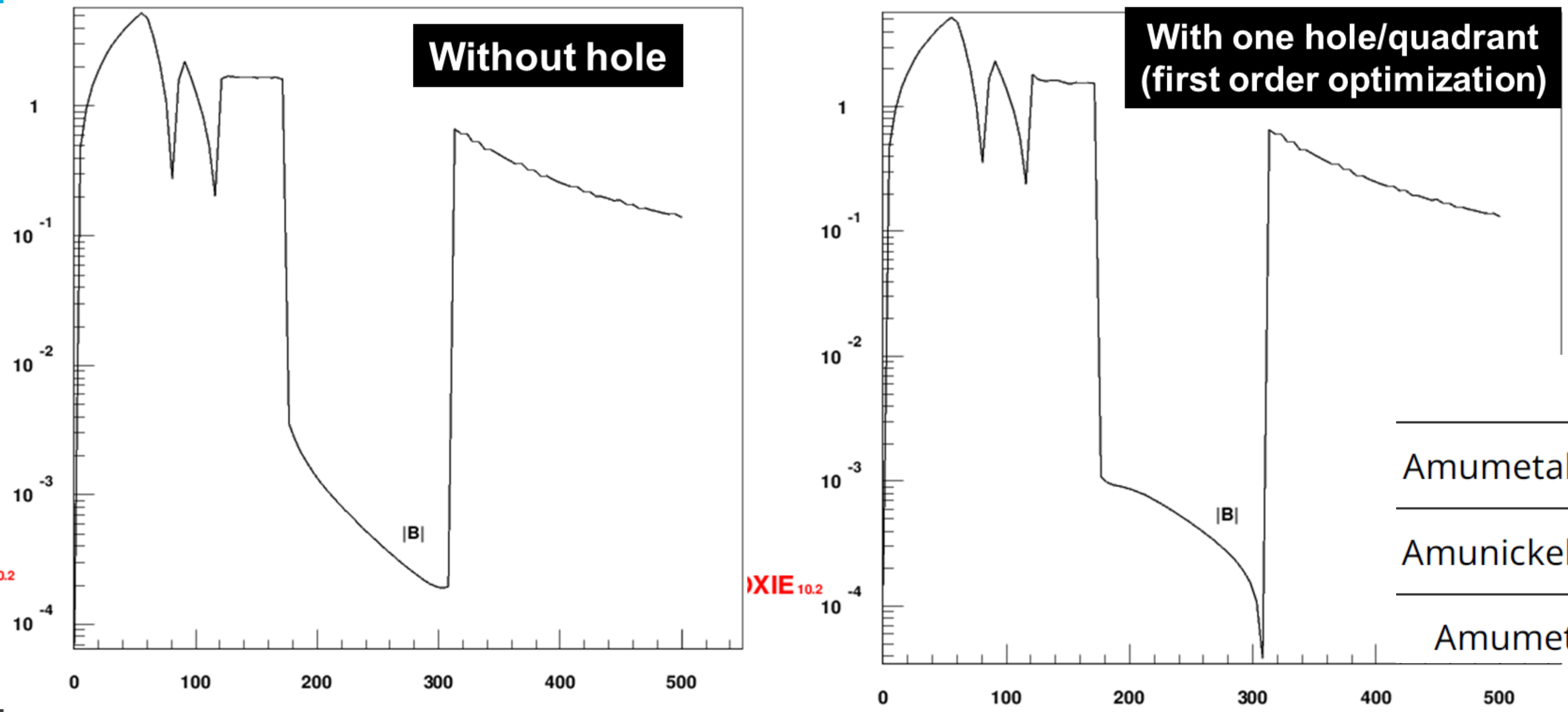
Figure 3. B–H curve of 1J22 and traditional silicon steel.



- Make a cutout in the iron yoke and insert a relatively small piece of special steel with high saturation.

Technique #2 to Reduce the Crosstalk

(use high permeability material in critical area where field is low)



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 (when no electron magnet is present)**

Iron Property (BH curve) discussion for EM Analysis of EIC Magnets

Suggested approach

- An elaborate R&D and test program of iron properties and a task force was constituted for the RHIC magnet program. That is not realistic now.
- BH curve on the right (input file to OPERA) is what was finally agreed upon and used for RHIC magnets.
- Find out the BH curve of the appropriate iron available in market. We should insist for the vendor from each we are purchasing the iron.
- Find how sensitive a design each for different B-H curve. Don't make it unnecessarily too demanding.
- An easy way to evaluate of a design is change the packing fraction.
- In the meantime, EIC should provide a few standard curves, including the one on the right.

30	0	0
0.0000000	0.0000000	
2800.000	0.5500000	
5200.000	1.110000	
7400.000	1.600000	
10080.00	2.320000	
12100.00	3.420000	
13100.00	4.730000	
13700.00	6.190000	
14110.00	7.170000	
14600.00	9.630000	
15900.00	20.30000	
16300.00	28.20000	
16820.00	41.60000	
17220.00	57.40001	
17740.00	85.60000	
18120.00	112.0000	
18420.00	133.0000	
19880.00	263.0000	
21510.00	596.0000	
22350.00	1173.000	
22720.00	1516.000	
23800.00	2253.000	
24810.00	3557.000	
28520.00	7259.000	
32920.00	11660.00	
37920.00	16660.00	
43620.00	22360.00	
50220.00	28960.00	
57820.00	36560.00	
66620.00	45360.00	

Other Topics

- Discussion on the reliability of modelling with various code
- Discussion on validating codes with measurements and of the measurement techniques for the demanding requirements of EIC.
    - ➢ This, in principle, can be done with room temperature magnets.

Summary

Solutions presented to eliminate/reduce crosstalk in EIC IR magnets:

- ❑ **Superconducting shield**
  - ➢ **It essentially eliminates the issue of cross-talk**
  - ➢ **It may significantly save on the testing costs (horizontal tests) as the measurements pf the crosstalk induced harmonic may not be required**
  - ➢ **Even though some experimental work has been done (and more coming with the upcoming optimum integral dipole test), EIC specific validation program needs to be in performed before inducting in the project**
- ❑ **Yoke optimization**
  - ➢ **Next best thing to have enough yoke is to avoid it entering in the non-linear region to reduce the variation in field in the critical area of yoke so that it saturate more uniformly. It reduces the change in harmonics with current.**
- ❑ **Partially or not included in this presentation**
  - ➢ **Special iron-(a) high saturation, (b) high permeability), and onion rings, etc**