Cross-talk Control between Q1BpF & Q1eF

3-d Analysis and Alternate Lower Cost Design

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May 4, 2021

a passion for discovery

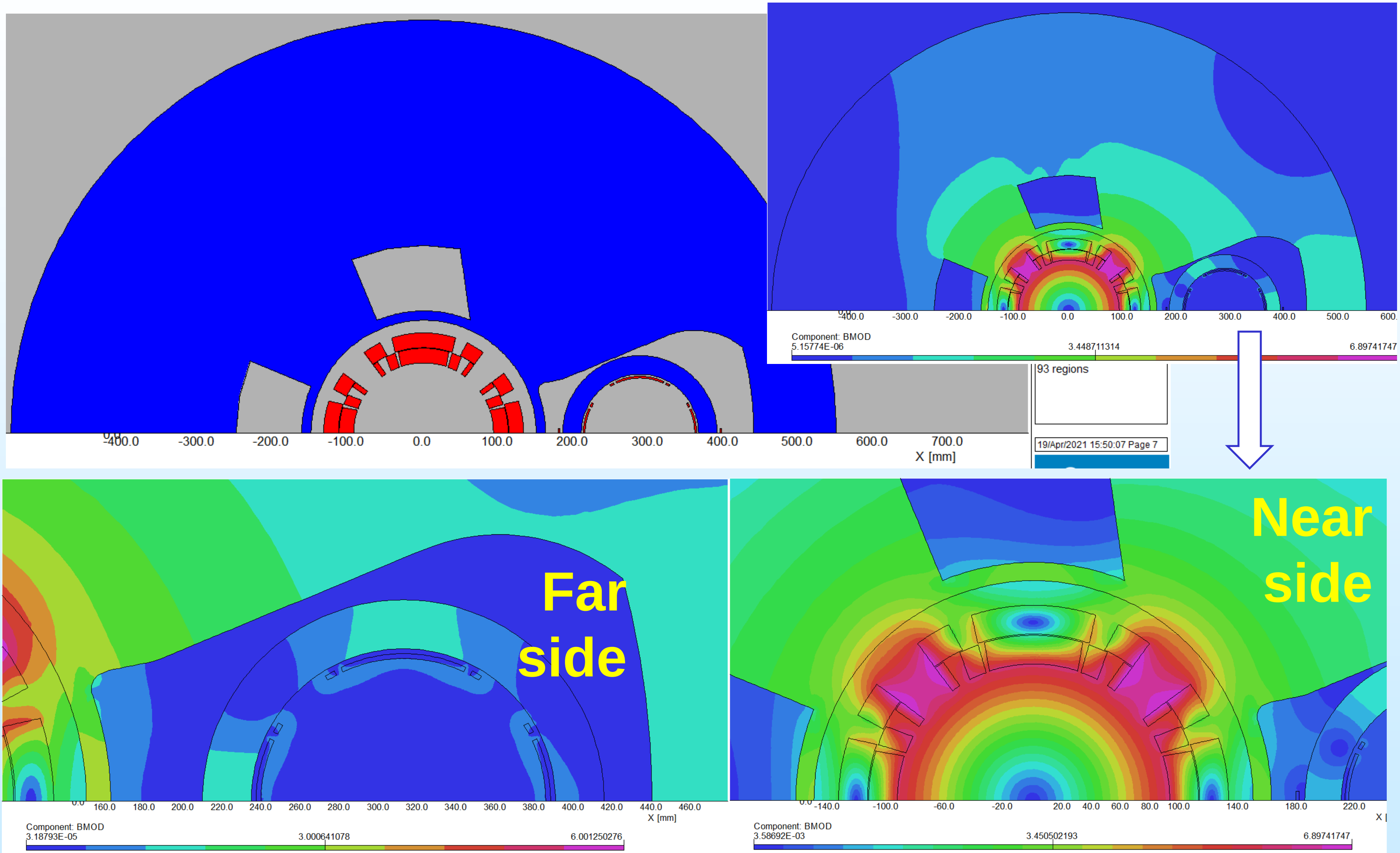
Office of Science
U.S. DEPARTMENT OF ENERGY

Overview

- This presentation completes 3-d analysis:
  - harmonics are examined in 3-d model along the axis as the separation between the electron quad and ion (proton) quad changes
  - different corrector strengths are examined for their impact along the axis (same corrector with the same number of turns is considered for simplicity – changing the number of turn along the axis is simple)
  - Earlier we had done a more detailed optimization of the design with at 2-d slices at different location along the axis
- This presentation also introduces a proposal for Q1A/Q1B to lower cost by reducing the variety of coils, increase margin by reducing the dead space, and help mechanical structure by reducing the Lorentz forces

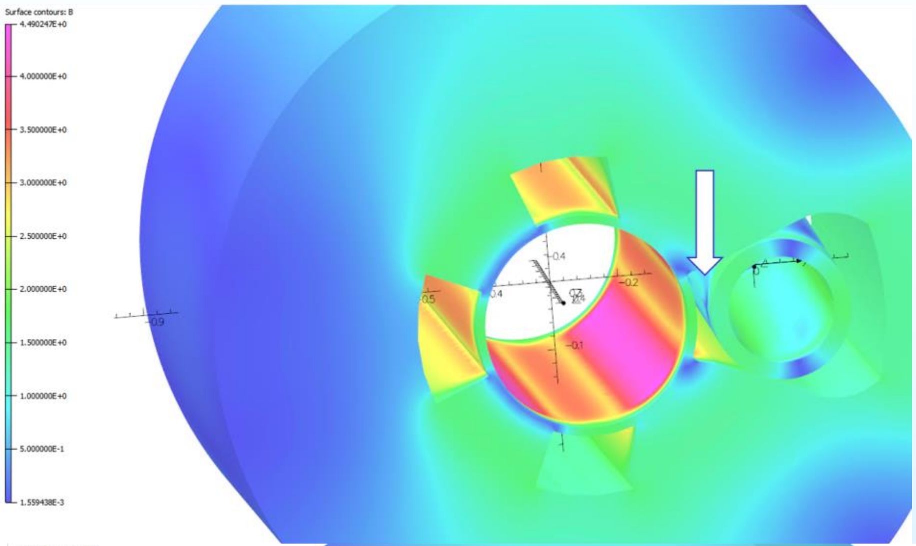
2-d Model (presented a couple of weeks ago)

2-d slices examined at the two ends and in the middle

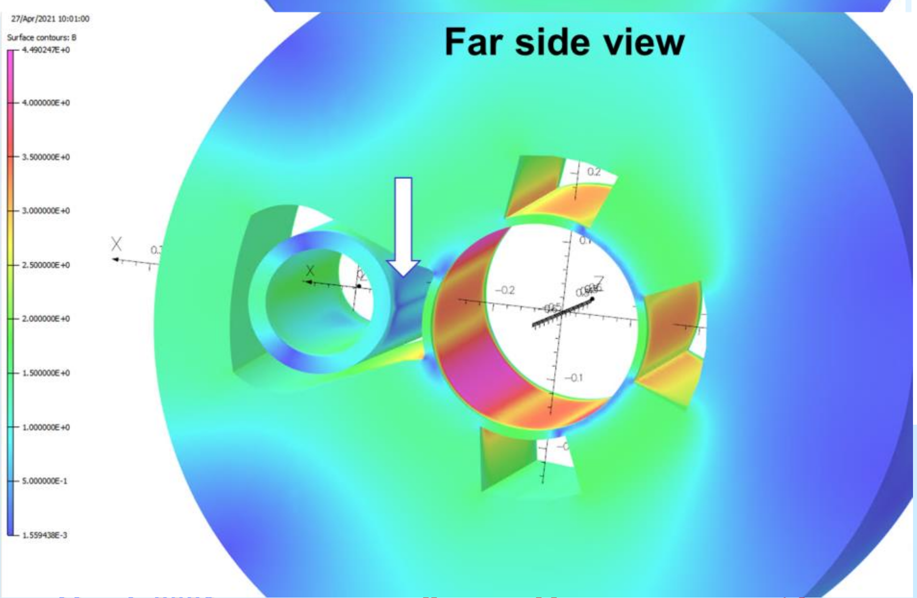


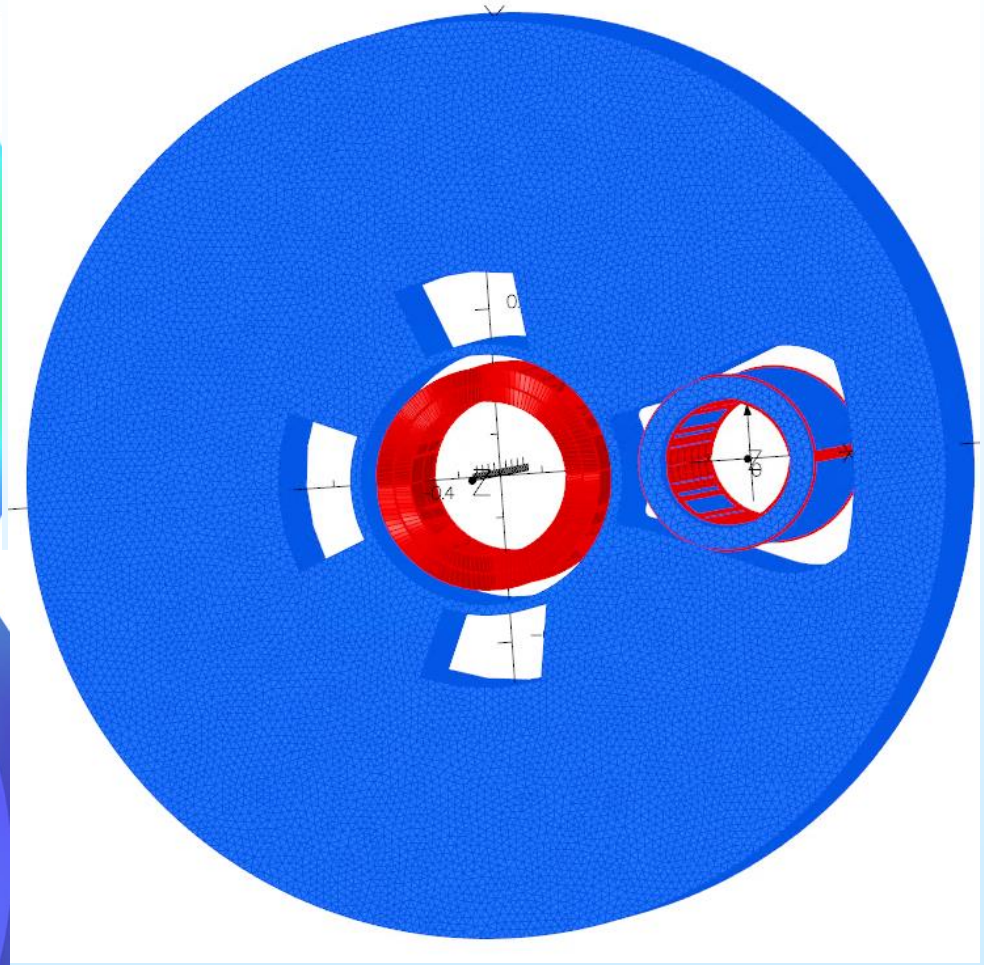
3-d Model Presented Last Week

Near side view



Far side view





Many 3-d Models examined (select cases discussed)

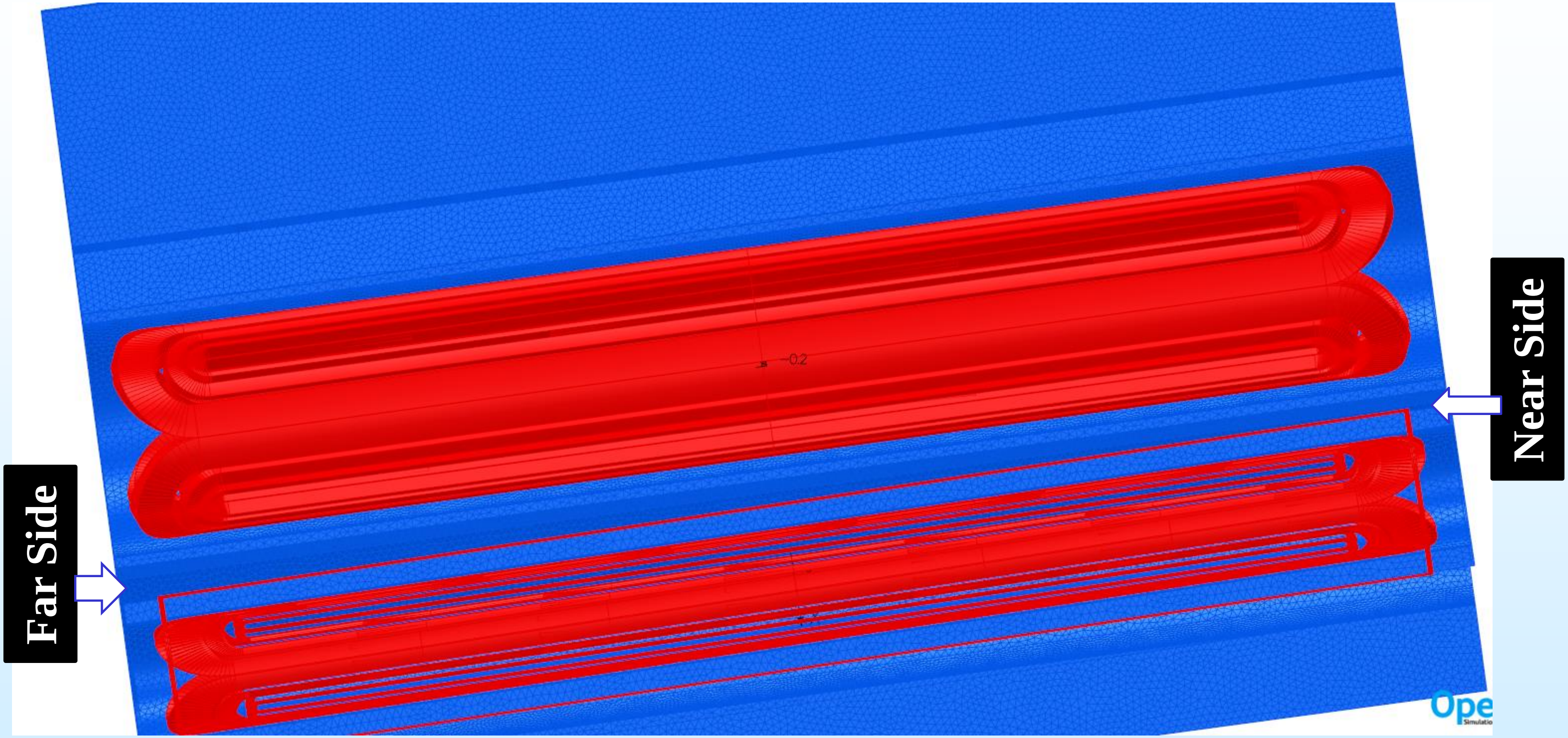
Several 3-d model of the optimized 2-d models examined:

Select cases presented for field and harmonics along the axis

1. **Low field (iron not saturated, no cross-talk expected)**
2. **Design field with cutout only (no corrector)**
3. **Design field with corrector strength 50% of 2-d**
   - **expected value since we didn't need any corrector on far side**
4. **Design field with corrector strength 100% of 2-d**
5. **Design field with corrector "–"ve polarity (to explain)**

Computed but not to be presented: different excitation, etc.

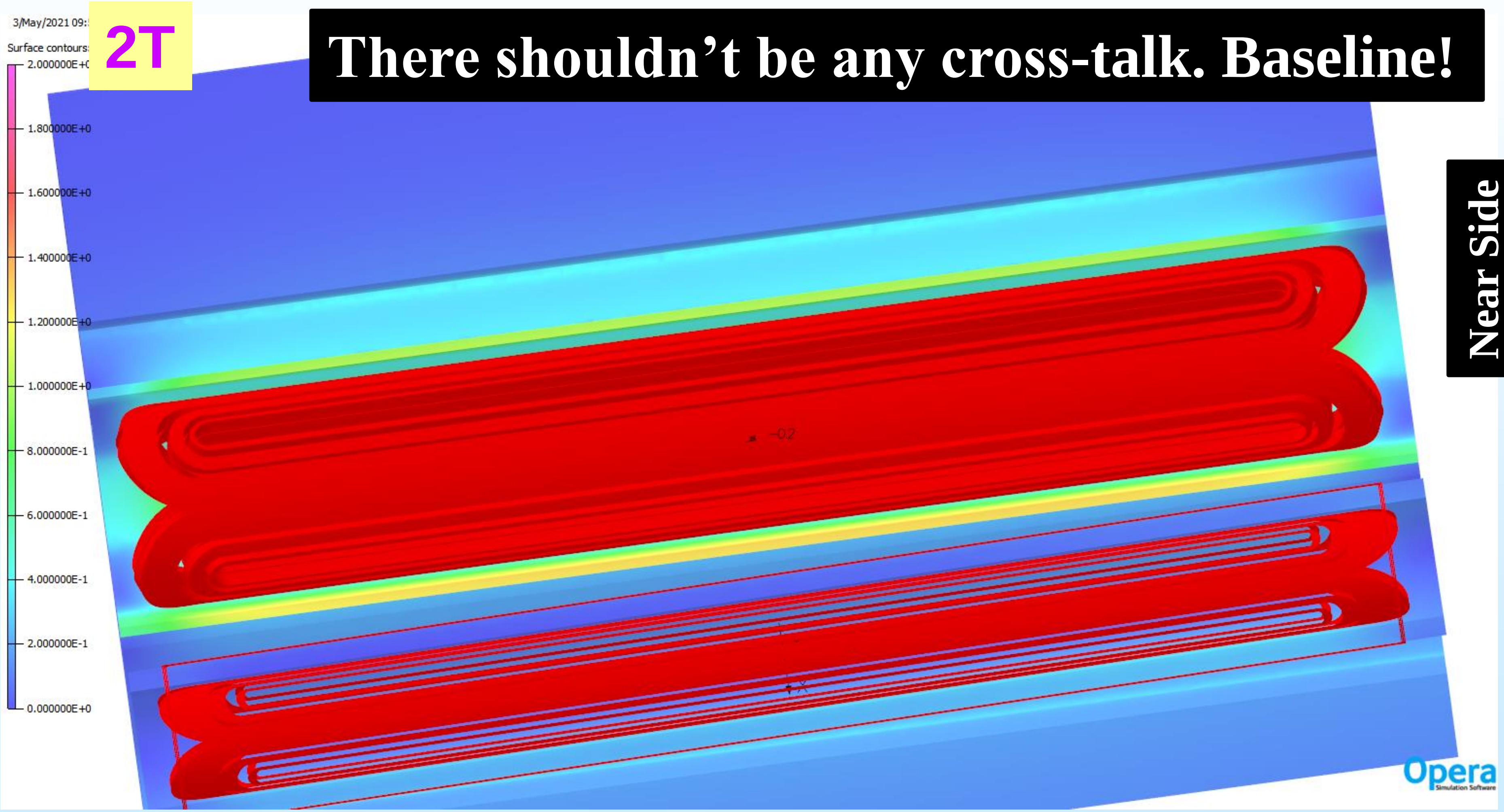
Basic Model



- Yoke is purposefully made longer to suppress art-effect of the end
- If yoke extends over the coil ends, there shouldn't be any cross-talk since the field is lower in the ends.

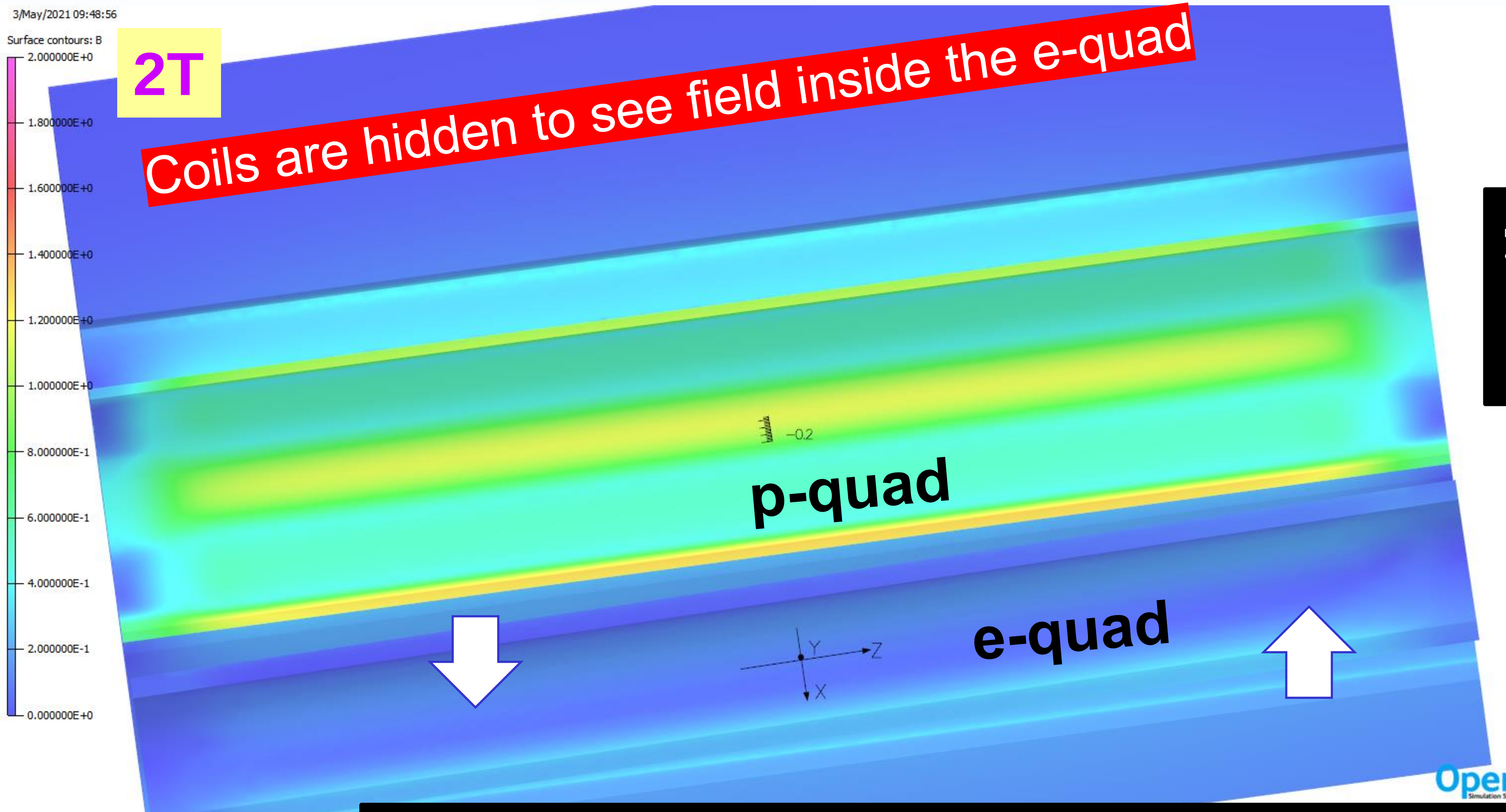
Field Superimposed over Iron (1) [Low Field, 10% of the design]

- Field in yoke very low, particularly around the e-quad



Field Superimposed over Iron (2) [Low Field, 10% of the design]

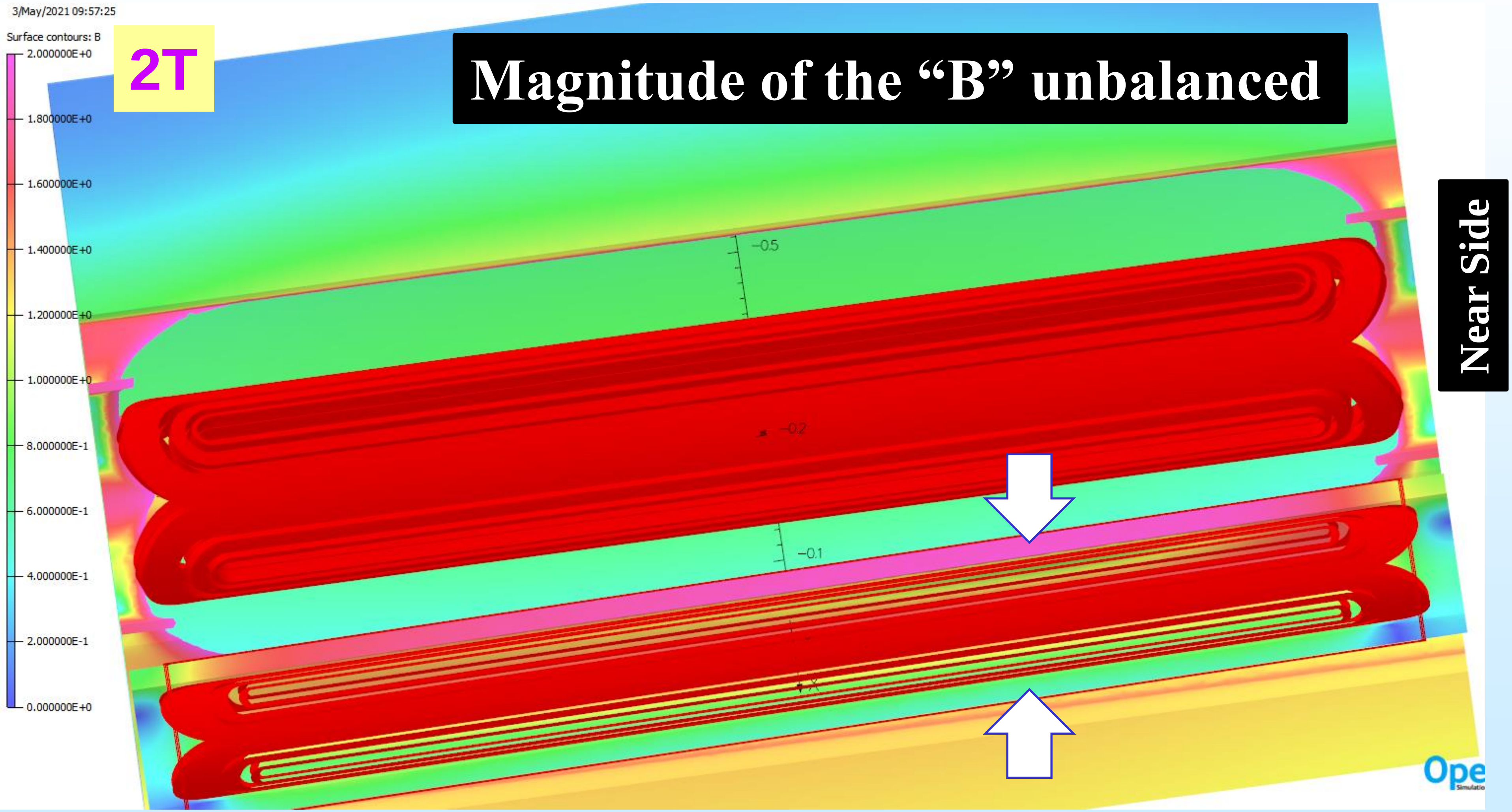
- Field in yoke very low, particularly around the e-quad



There shouldn't be any cross-talk. Baseline!

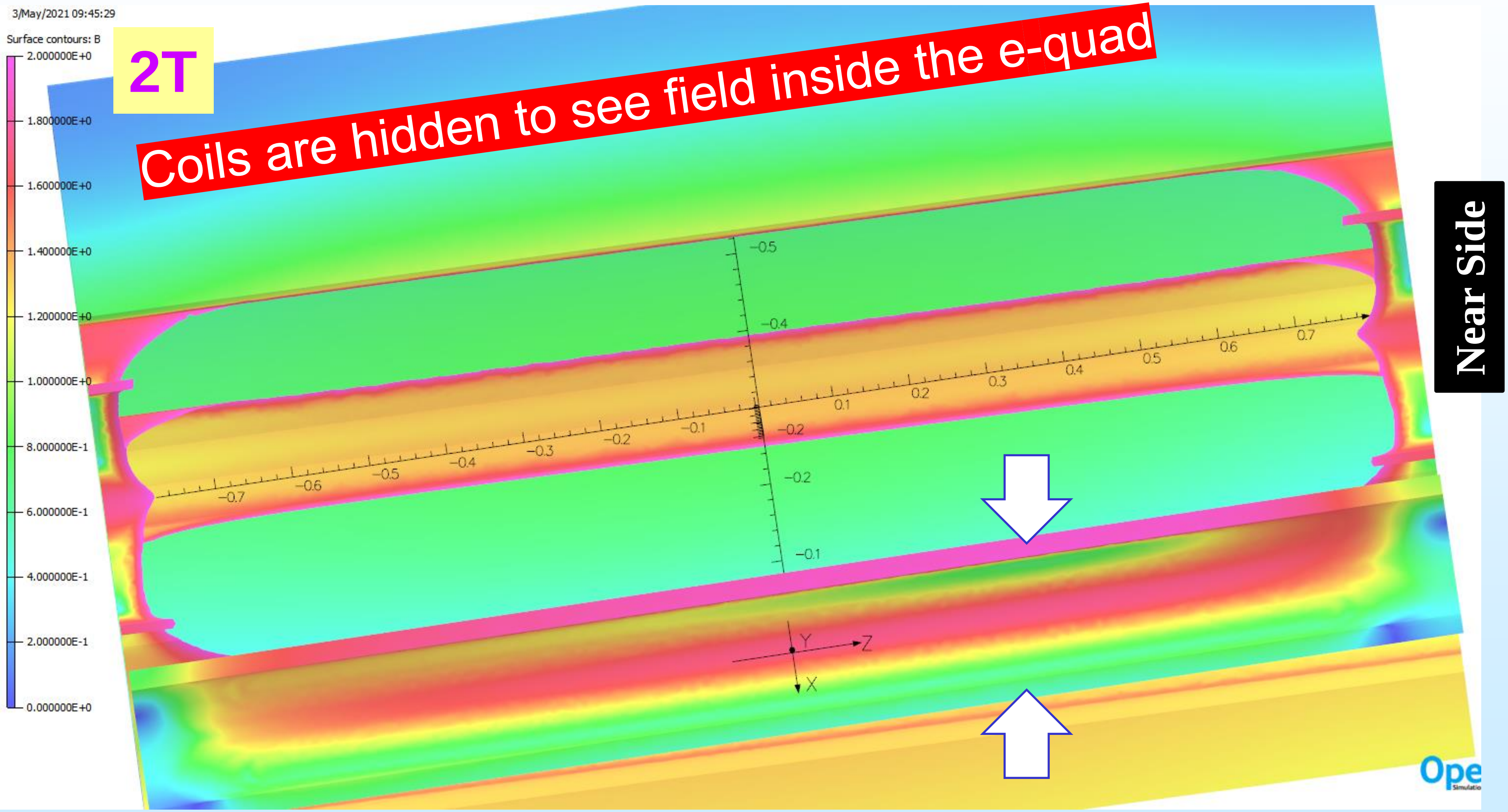
Field Superimposed over Iron (1) [@design gradient, no corrector]

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



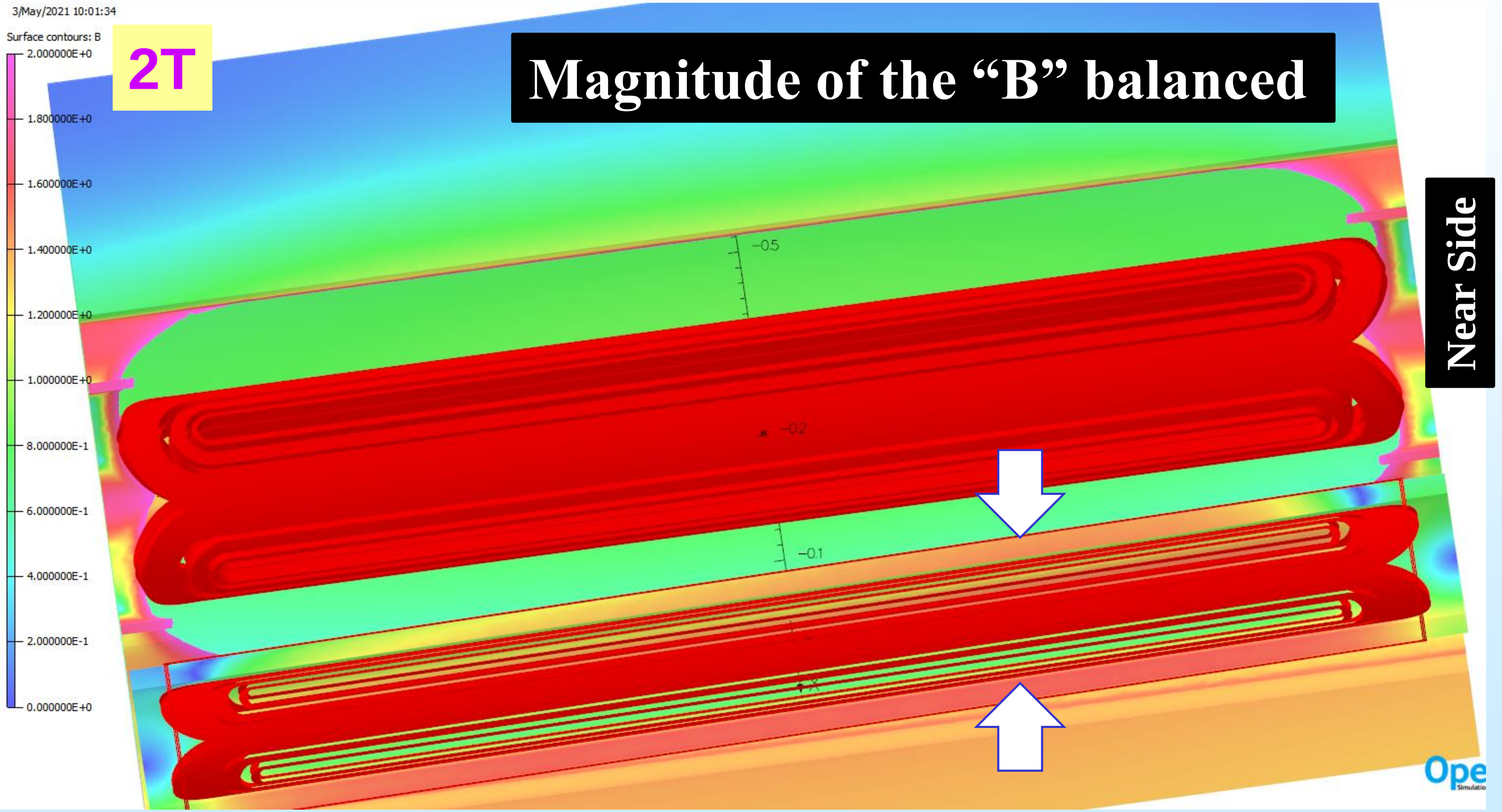
Field Superimposed over Iron (2) [@design gradient, no corrector]

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



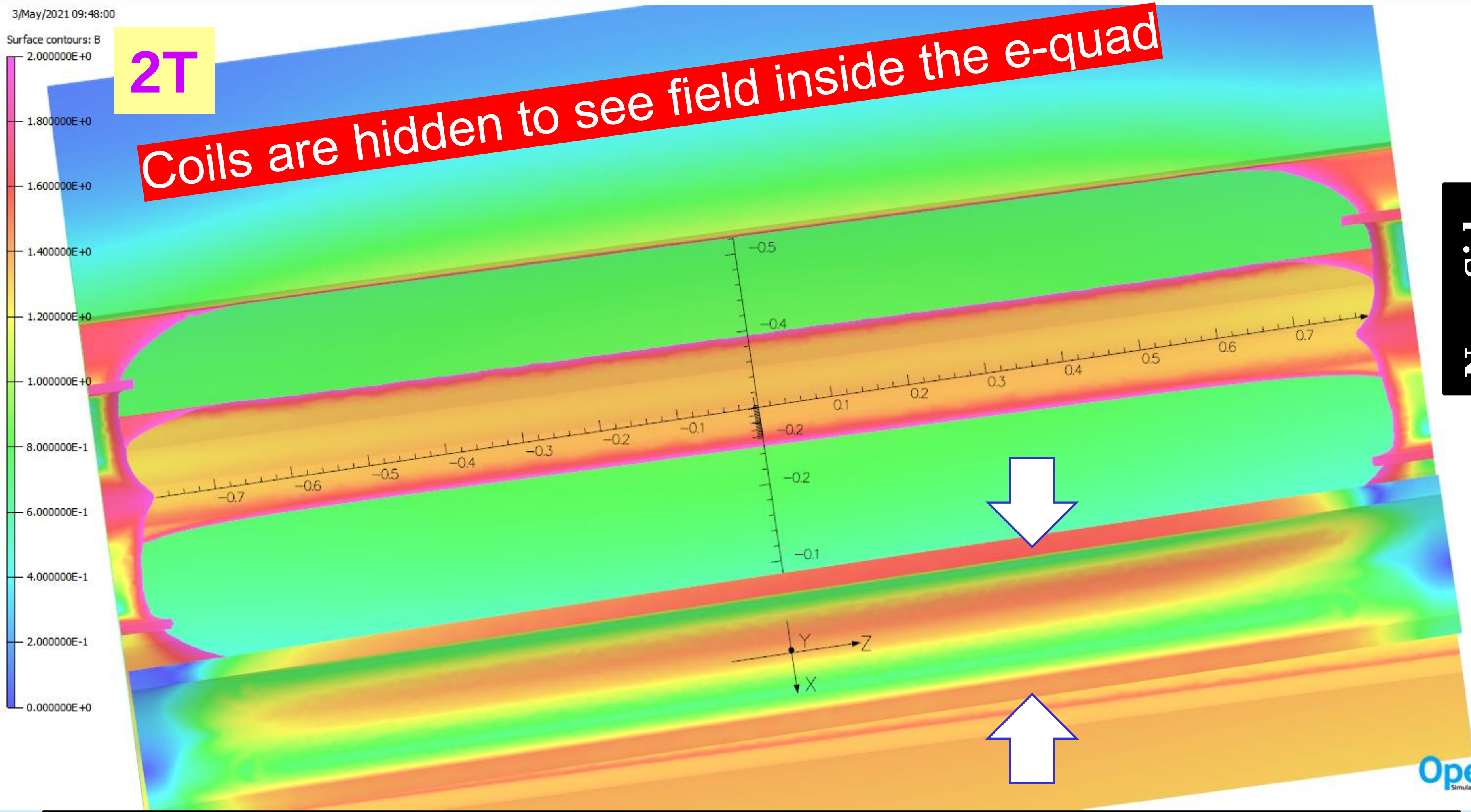
Field Superimposed over Iron (1)
[@design gradient, 50% of 2-d corrector]

- 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**

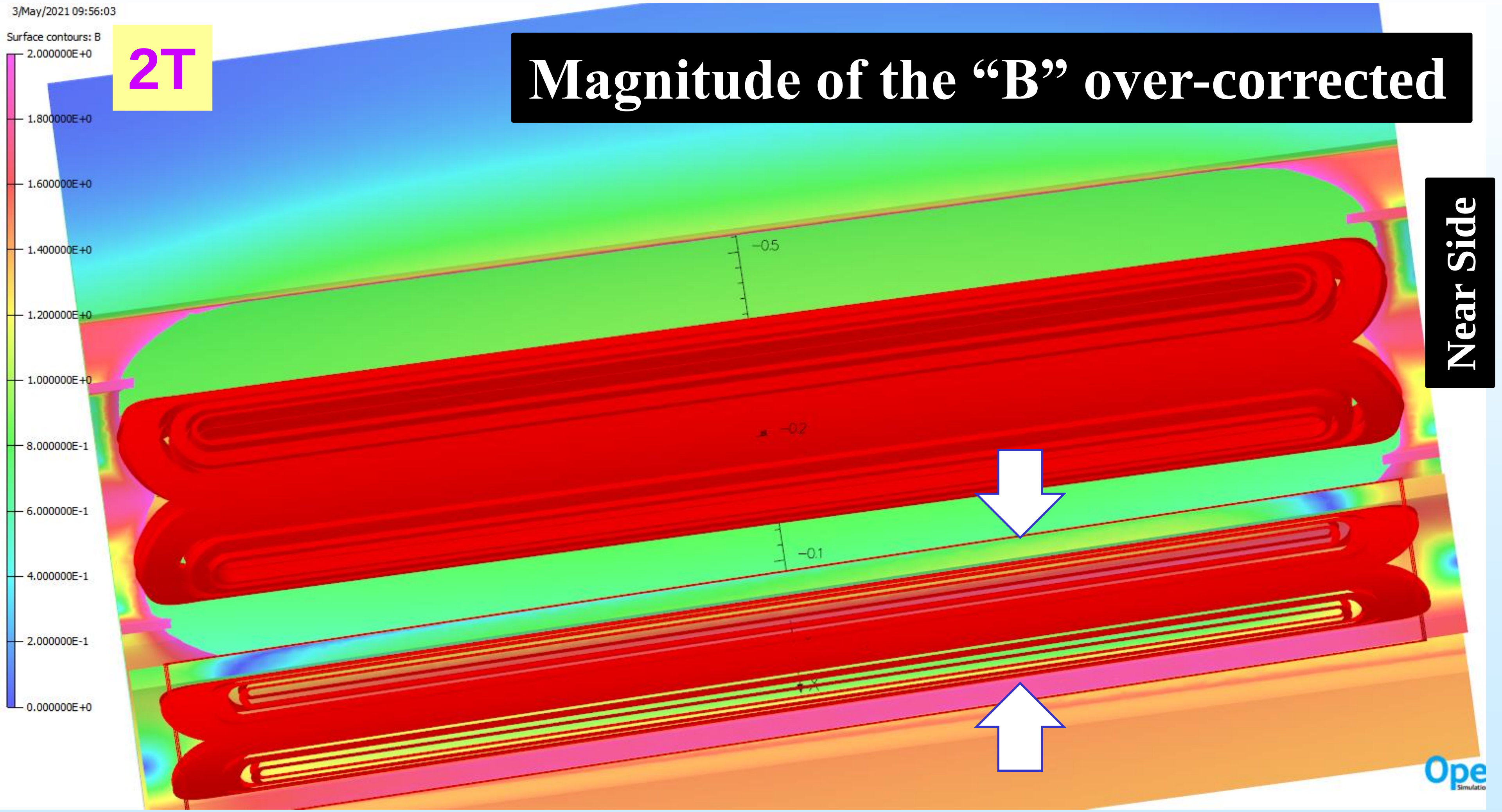


Near Side

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**



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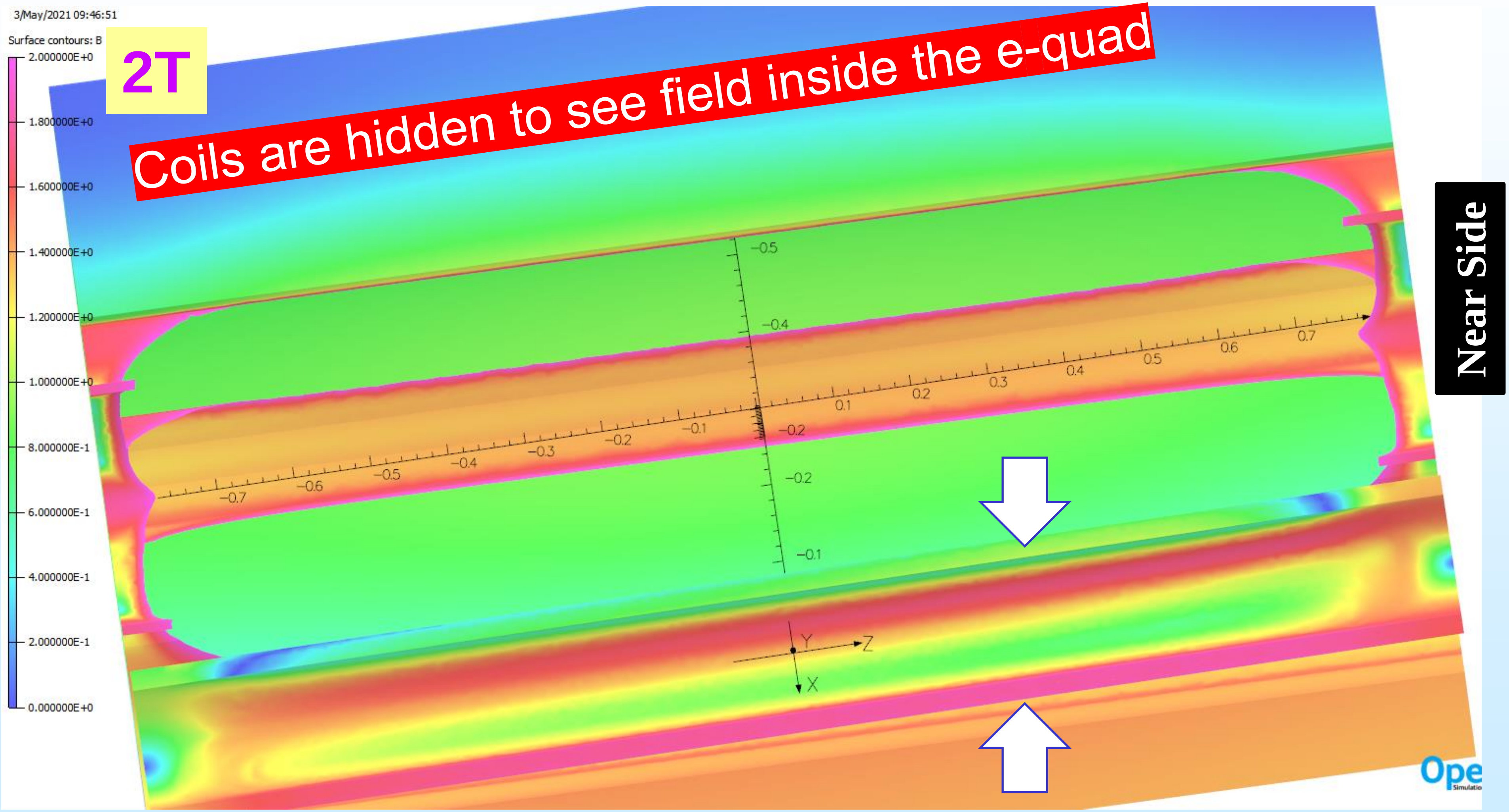
Field Superimposed over Iron (2) [@design gradient, 100% of 2-d corrector]

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



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

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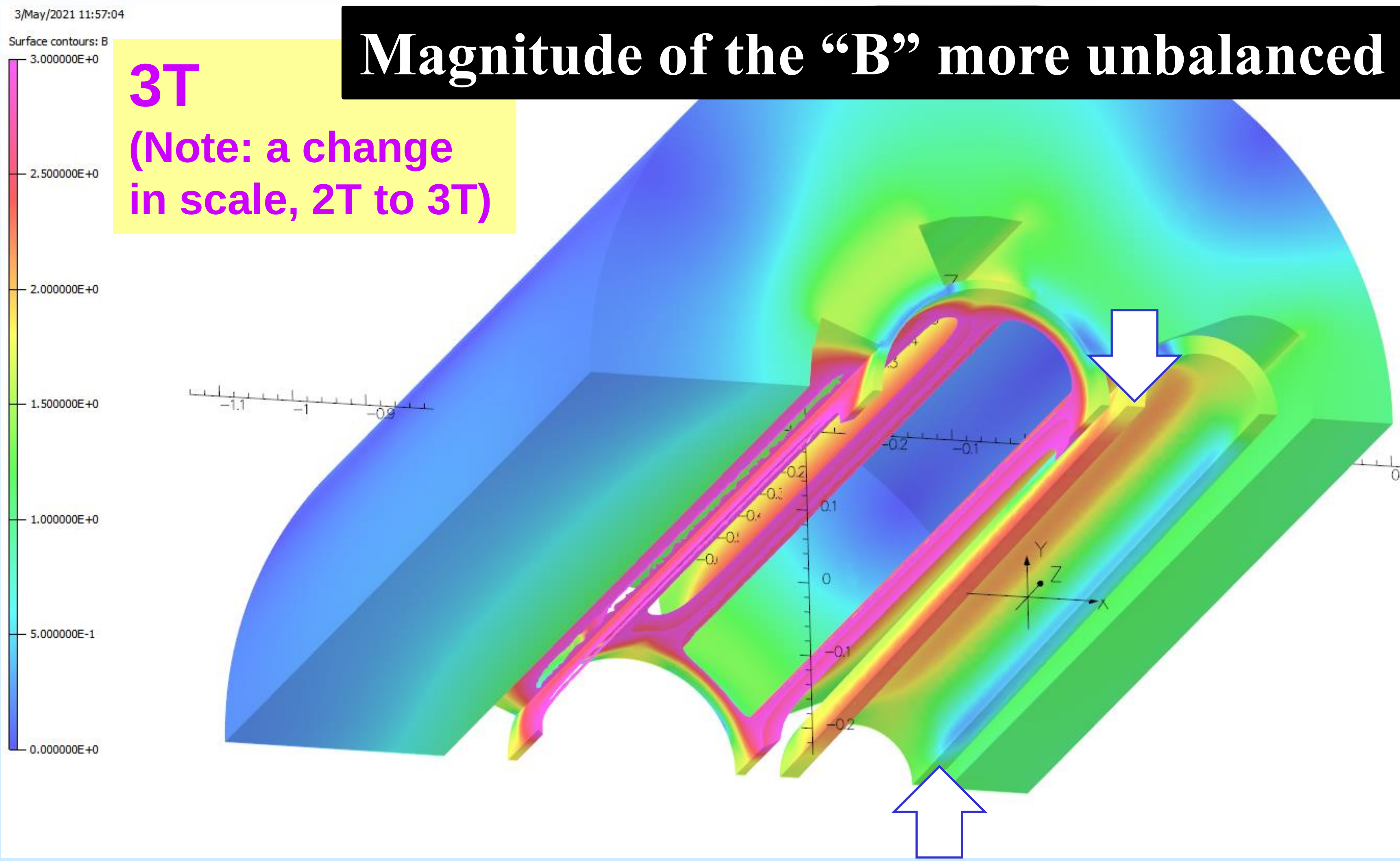
Field Superimposed over Iron (1)
[@design gradient, wrong sign of corrector]

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

Magnitude of the "B" more unbalanced

3T

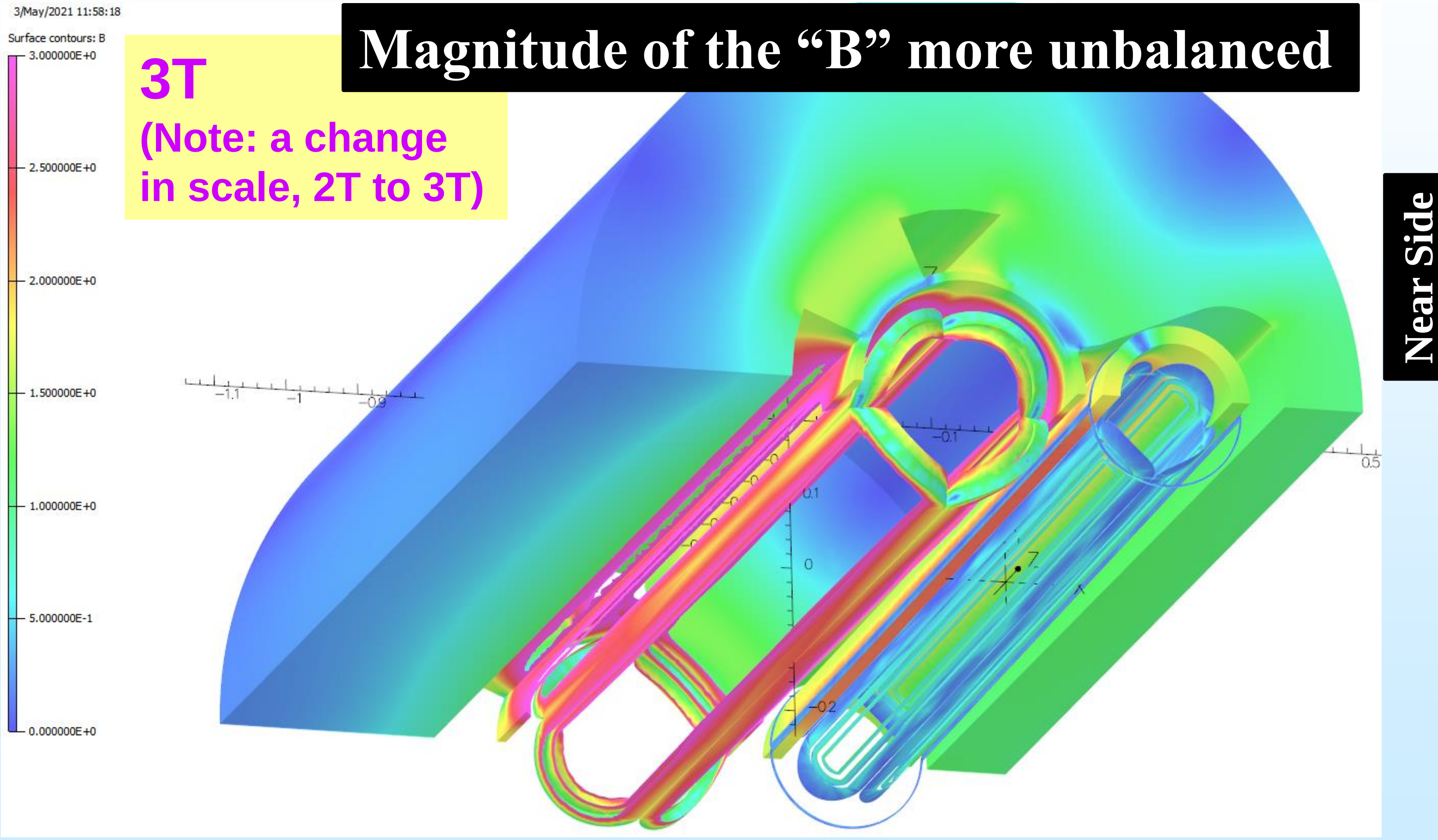
(Note: a change in scale, 2T to 3T)



Near Side

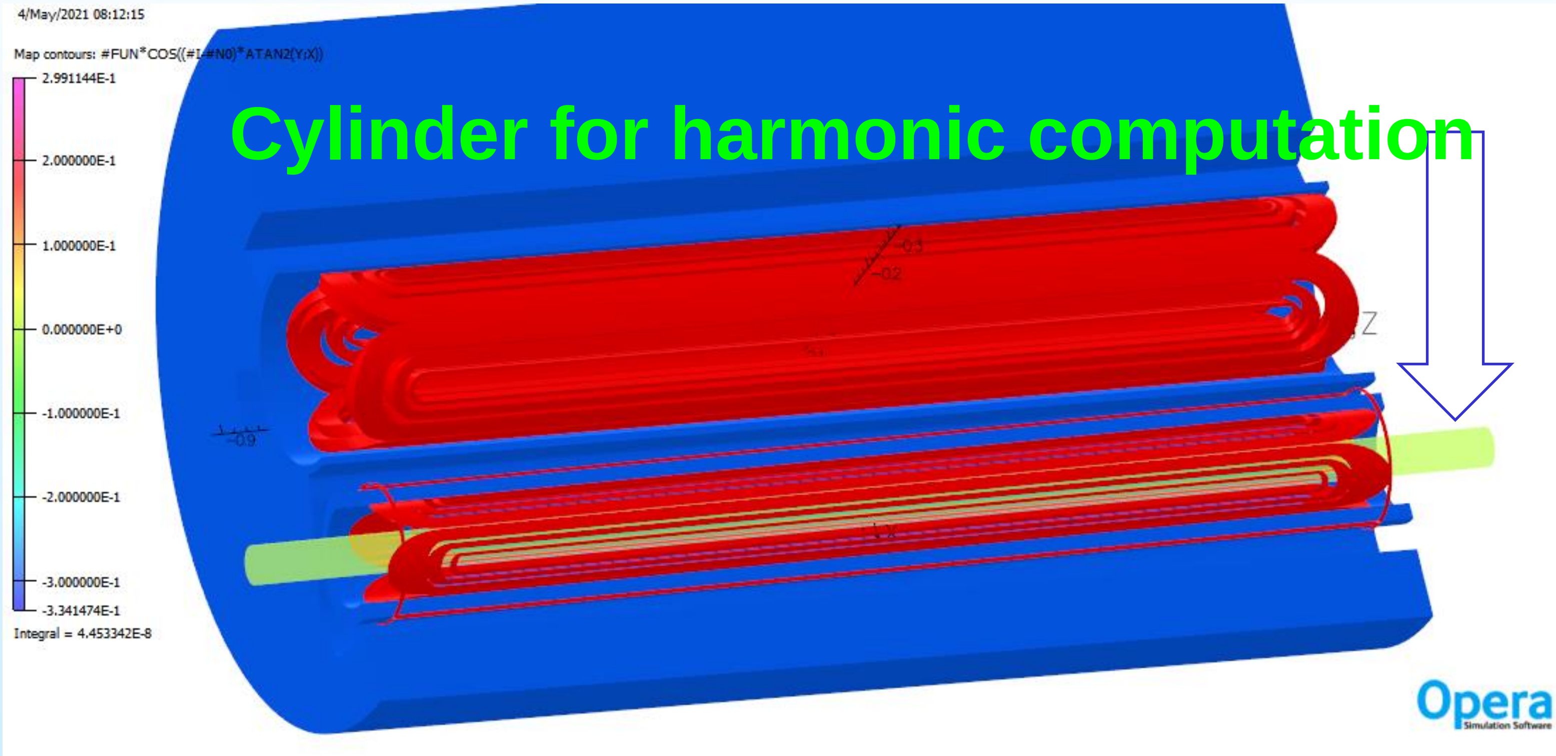
Field Superimposed over Iron (2) [@design gradient, wrong sign of corrector]

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



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

Mesh is reasonable to get results in ~24 hours in a single core machine. A denser mesh can be used for the final case.

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Integral Field Harmonics

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

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

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

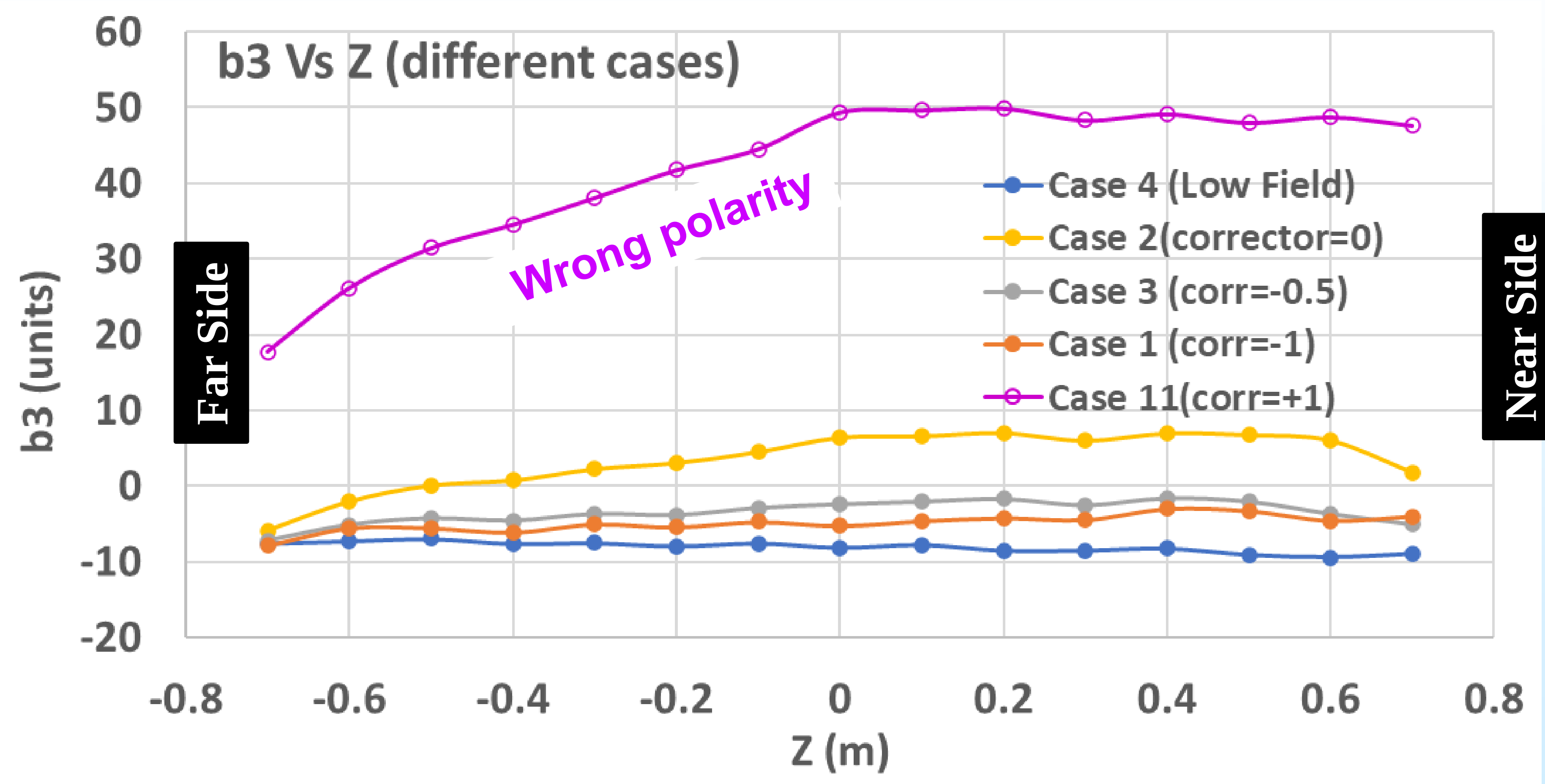
Order	A(n) Sine	B(n) Cosine
1	0.0	8.483569E-03
2	-2.60215E-12	-1.0
3	5.063747E-12	5.599381E-04
4	2.168573E-12	1.906077E-04
5	-3.32527E-12	2.562996E-04
6	-3.48989E-14	-9.92698E-05
7	4.127435E-12	1.308909E-05
8	-3.61216E-12	1.548179E-05
9	-1.71285E-12	1.914785E-06
10	5.814557E-12	1.311253E-05
11	-3.37494E-12	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 -100% corrector

Order	A(n) Sine	B(n) Cosine
1	0.0	-0.052837672
2	2.689525E-12	-1.0
3	-5.23362E-12	-4.12085E-03
4	-2.24117E-12	6.341864E-04
5	3.436843E-12	-1.46669E-03
6	3.621122E-14	3.958518E-04
7	-4.26574E-12	-8.50682E-05
8	3.733657E-12	3.952683E-05
9	1.770379E-12	-1.69653E-05
10	-6.00914E-12	1.8279E-05
11	3.488353E-12	-2.0836E-06
12	3.561087E-12	1.510108E-07
13	-7.24883E-12	-2.33234E-07
14	2.850273E-12	9.935928E-07

Next few slides on the change in harmonics along the axis

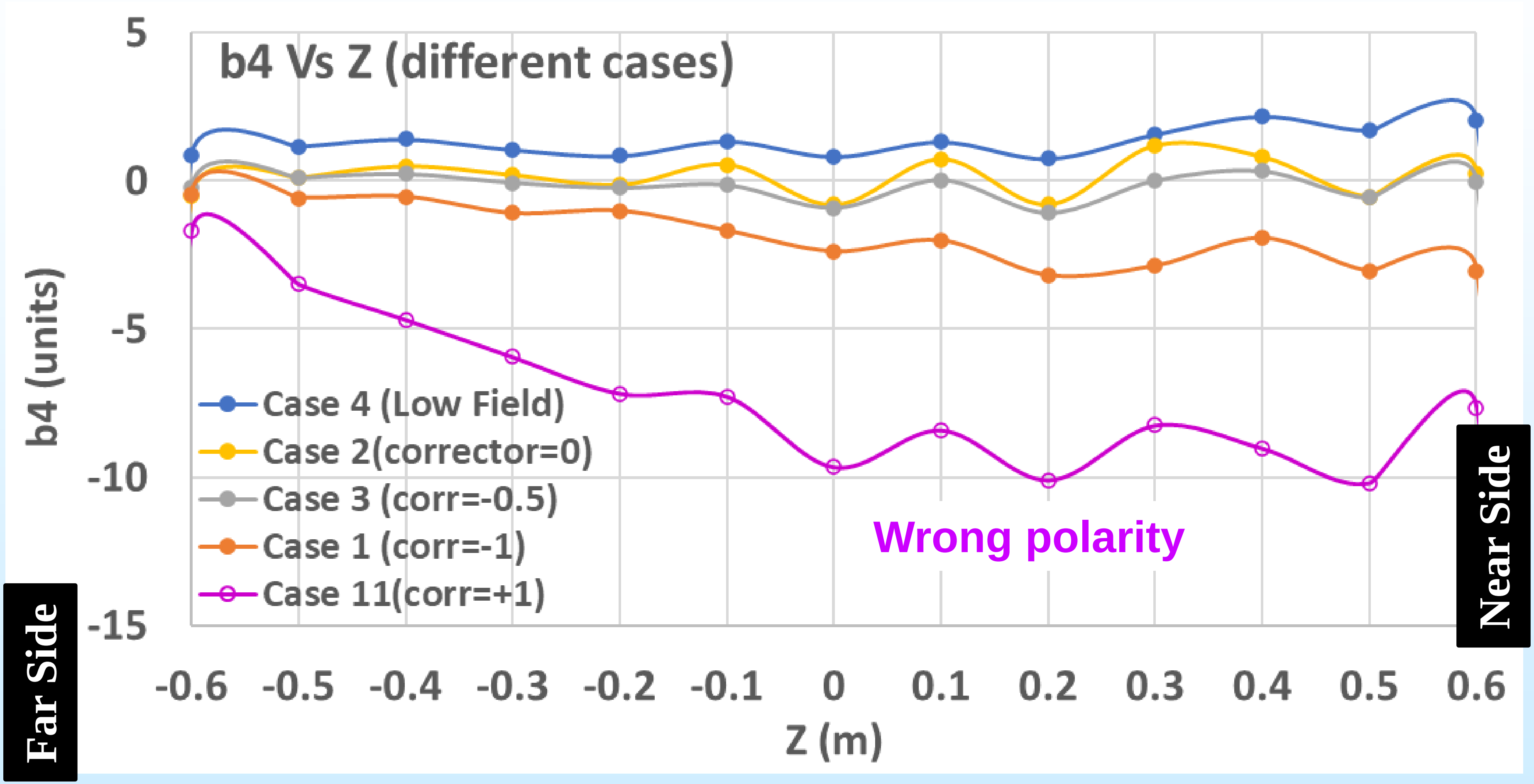
b_3 Along the Length in Various cases



Compare various cases to the low field case (#4).

- **½ strength corrector case (#3) may be ok !**

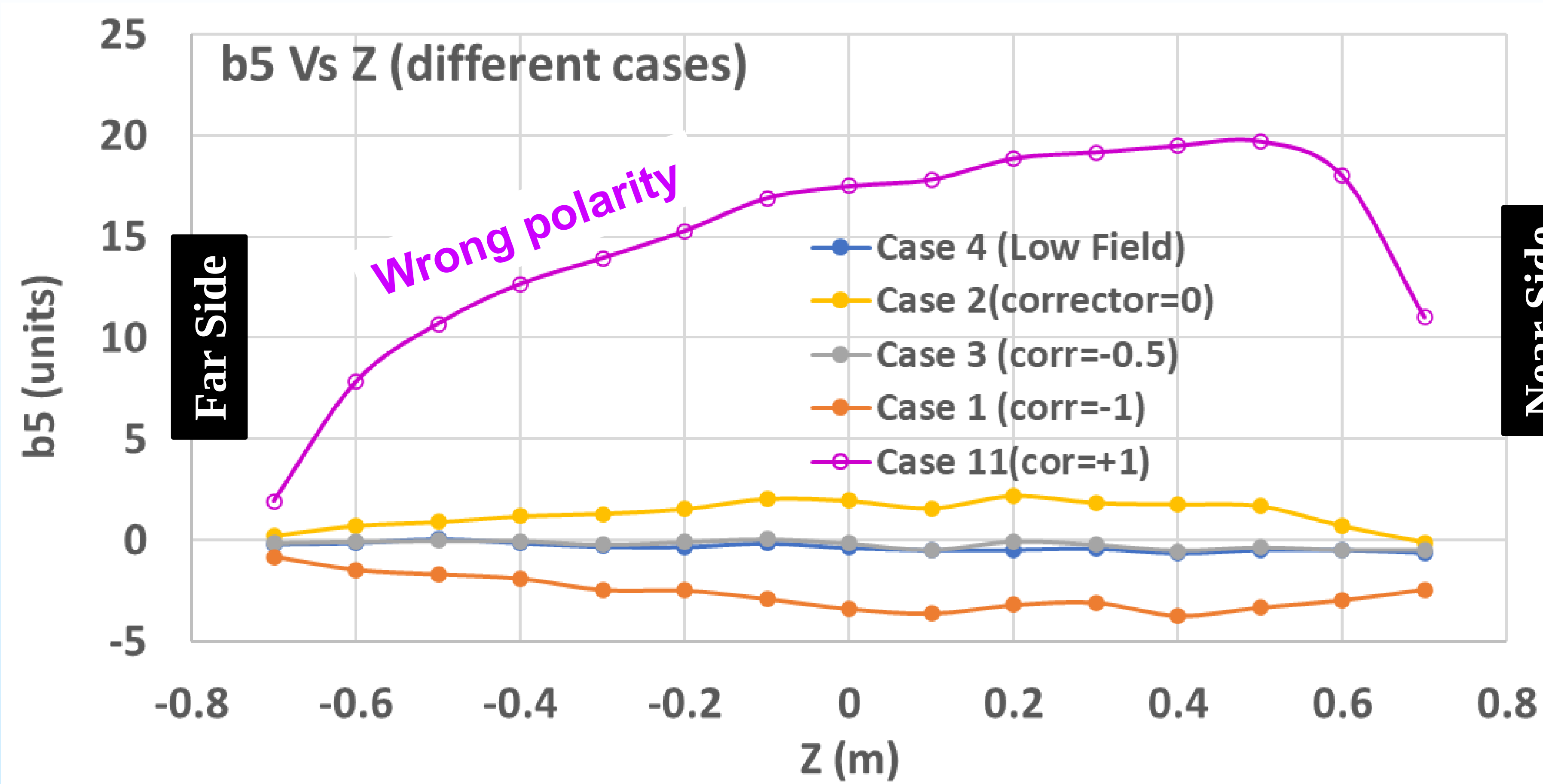
b_4 Along the Length in Various cases



Compare various cases to the low field case (#4).

- **½ strength corrector case (#3) may be ok !**

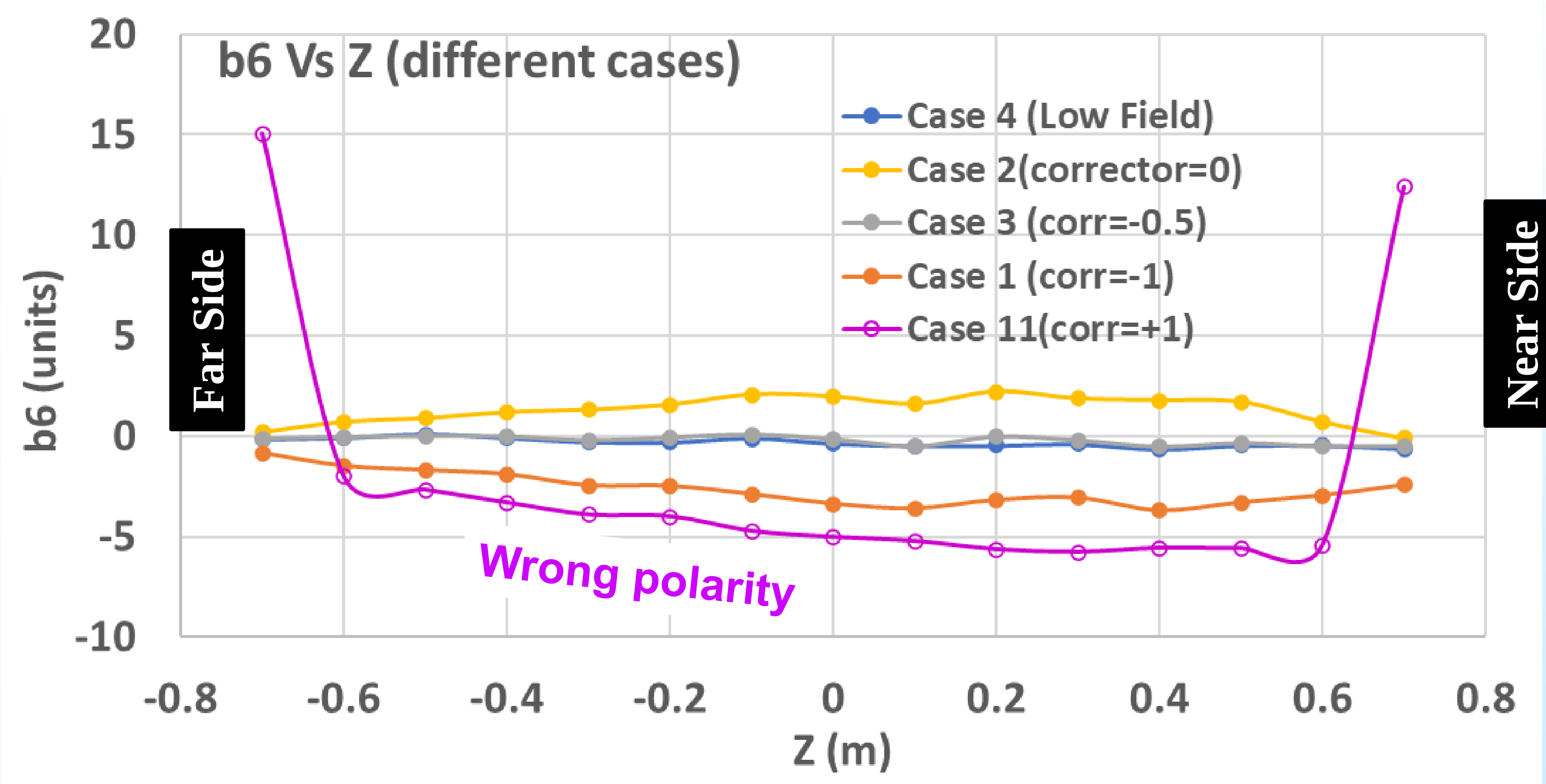
b_5 Along the Length in Various cases



Compare various cases to the low field case (#4).

- **½ strength corrector case (#3) may be ok !**

b_6 Along the Length in Various cases



Compare various cases to the low field case (#4).

- **½ strength corrector case (#3) may be ok !**

An Opportunity for Q1A/Q1B Integration

- Lower cost by reducing the variety of coils
- Increase margin by reducing the dead space
- Help mechanical structure due to lower Lorentz forces

A Comparison of Q1A and Q1B Coils

- Both Q1A and Q1B use the same Rutherford cable
- Gap between Q1A and Q1B is 0.4 m

Q1A

Inner coil id: 71 mm
Outer coil id: 91.2 mm
Coil length (cable): ~1.6 m
Magnetic length:
Design current: ~9.3 kA

Q1B

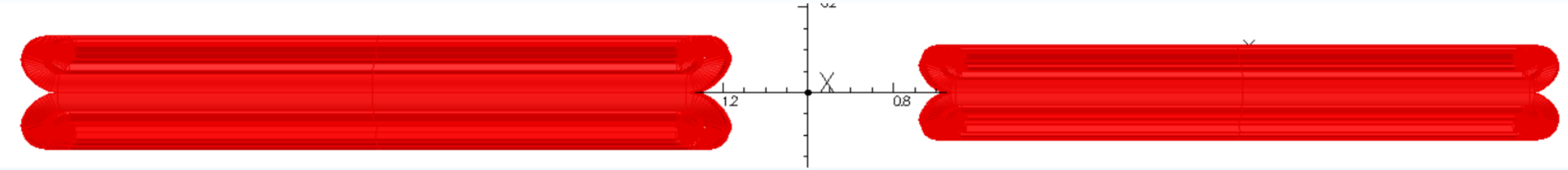
Inner coil id: 93 mm
Outer coil id: 103.2 mm
Coil length (cable): ~1.61 m
Magnetic length:
Design current: ~9.8 kA

Integrated design of Q1A and Q1B (more in next slides):

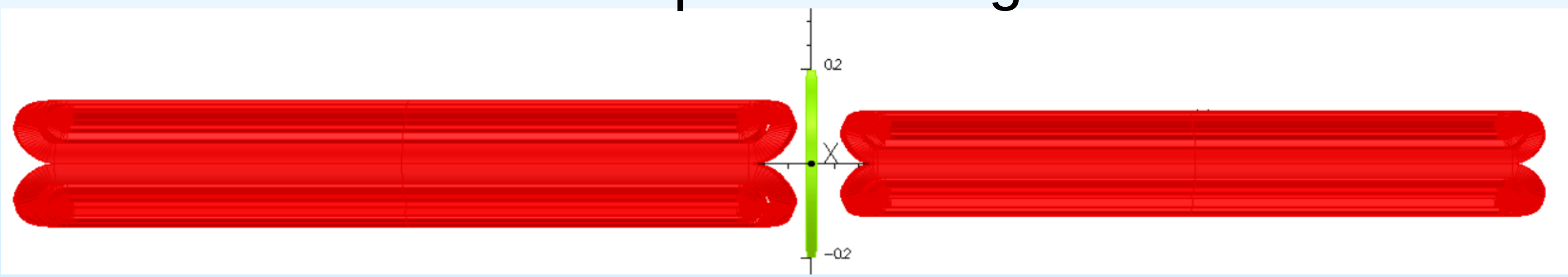
- Make Q1A outer coil the same as Q1B inner. Exact id need adjustment.
- Make a common Q1A+Q1B coldmass. Separation between the two coil packs: two end-saddles (~15mm) and a SS plate (~20 mm?). This means we should gain ~0.35 m in magnetic length to increase margin margin.
- The Lorentz forces between the two quads should be small. Tie rods would go across the combined coldmass.

Field in Iron Only (4)

Present Design



Proposed Design

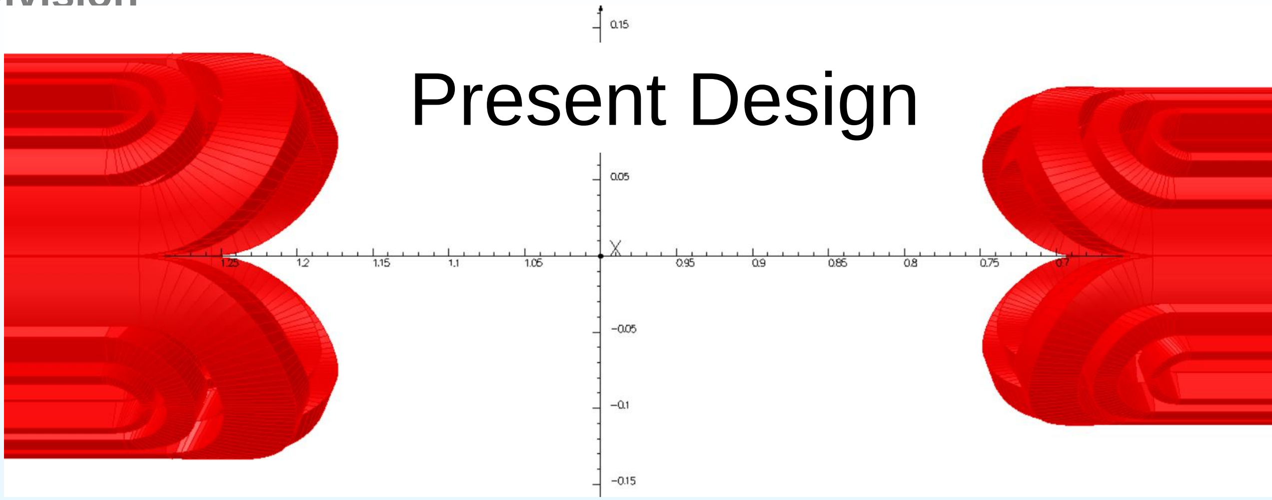


Longer length, means lower operating current, means gain in margin. Allow most of the gain in margin to go to Q1B

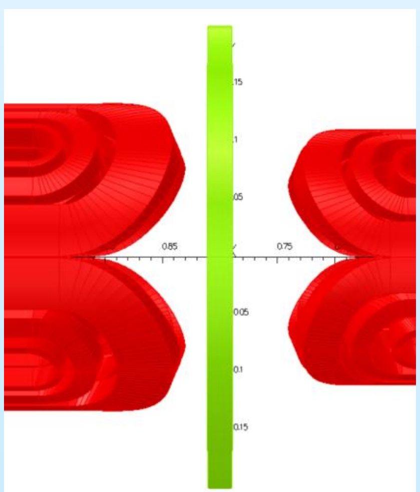
Expect ~20% gain in Q1B margin and ~40% reduction in Lorentz forces

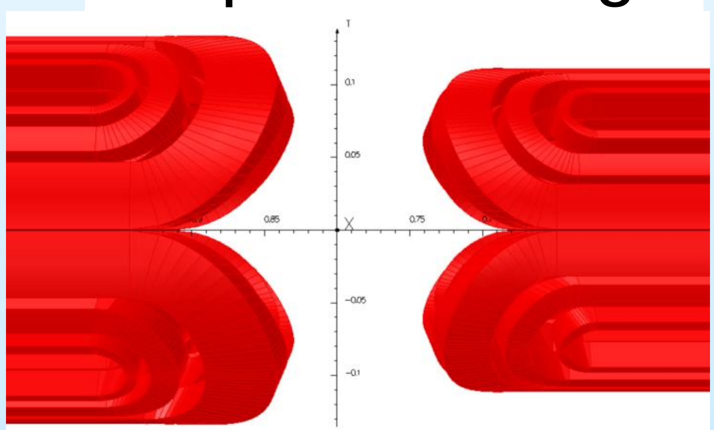
Proposed Design

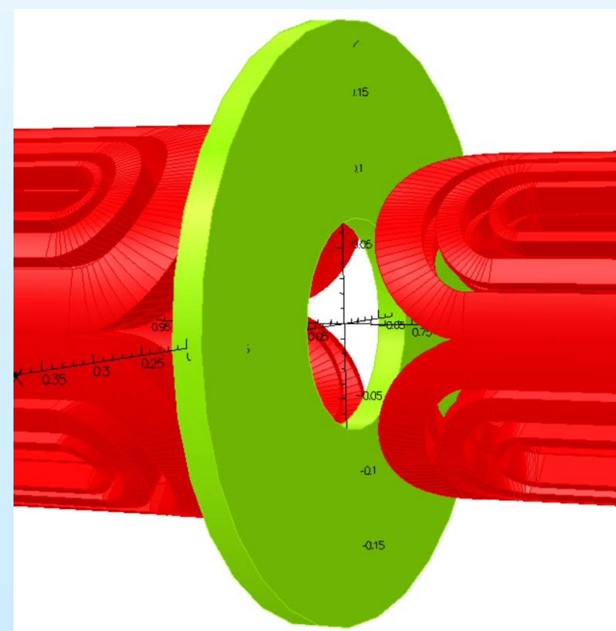
Present Design



Proposed Design







Summary

- 3-d harmonics analyzed. Cross-talk harmonics can be controlled in a 4 K design
- Q1A outer coil is almost the same as Q1B inner coil. Making the two identical saves a significant amount on tooling, etc. Q1A inner id may need to increase slightly.
- Integrating Q1A and Q1B coldmass gives a significant and crucial gain in margin. Mechanical structure needs to be examined but it looks promising in many ways.
- Update designs for increased angle or anything else to match with the latest parameters at the same time.