Magnetic Designs for Higher Margin

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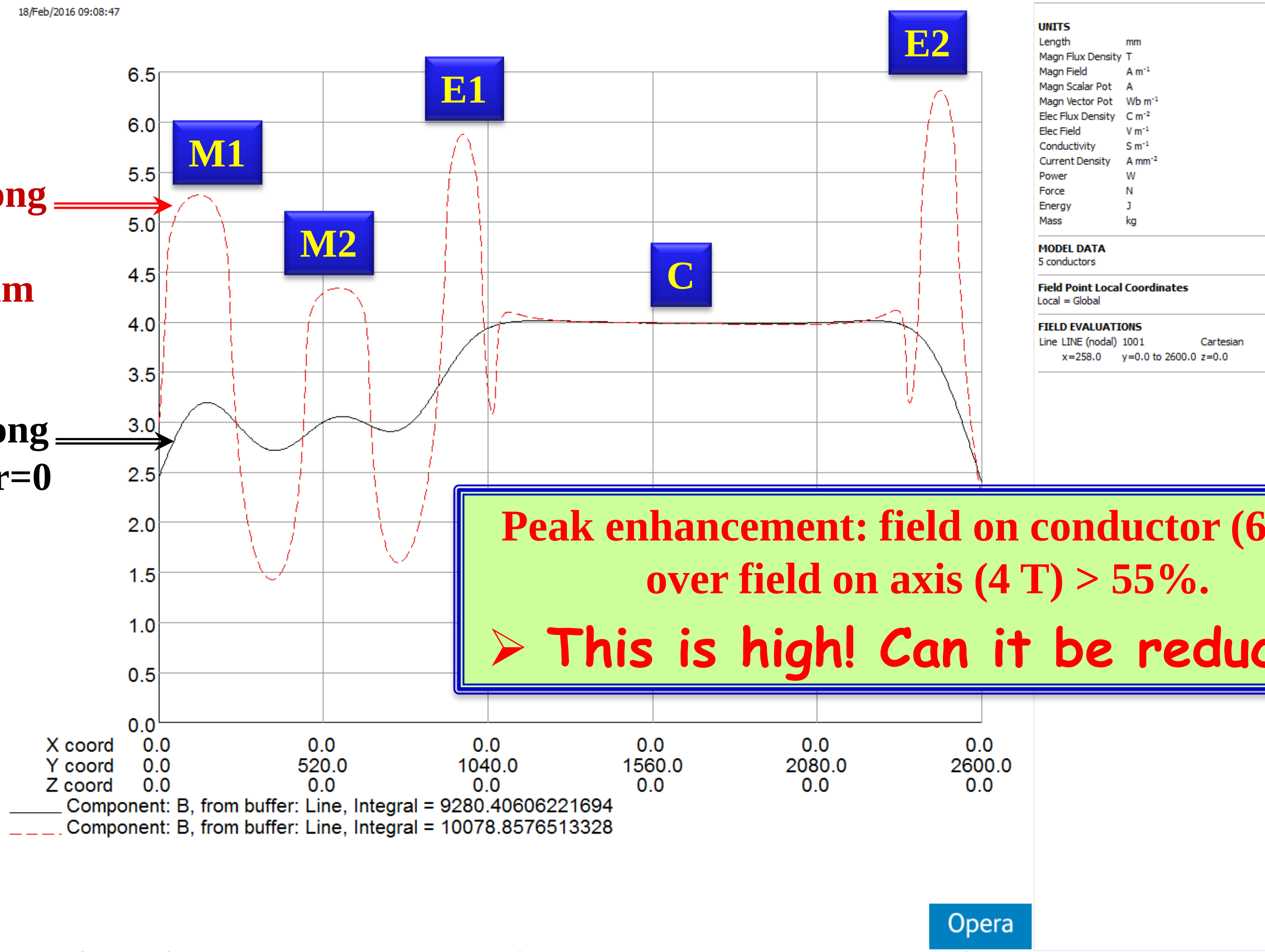
Approach to Improve Performance

- Increase margin. However, by making minimum necessary changes in the overall design concept.
- Only adjust E1, C and E2. No change in M1 and M2.
- Starting suggestion: Increase margin by putting more layers of conductor (less current to produce the same field).
- However, investigations of the existing design gave a possibility of a better alternate way to proceed.

Axial and Peak Fields in Mice Spectrometer Solenoid

Field along the line r=258 mm (coil id)

Field along the line r=0 (axis)

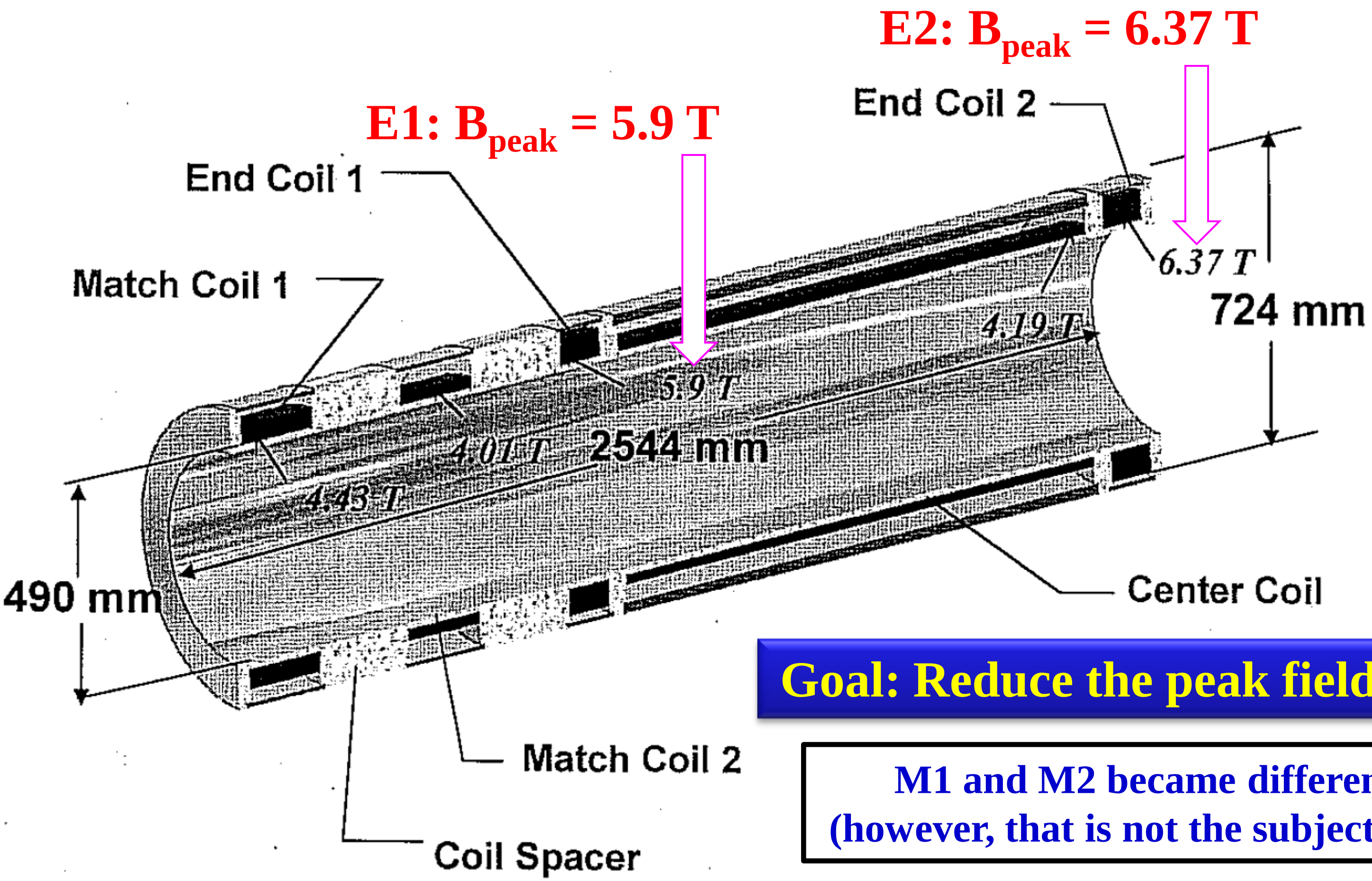


Peak enhancement: field on conductor (6.3 T) over field on axis (4 T) > 55%.

➢ This is high! Can it be reduced?

Original Design

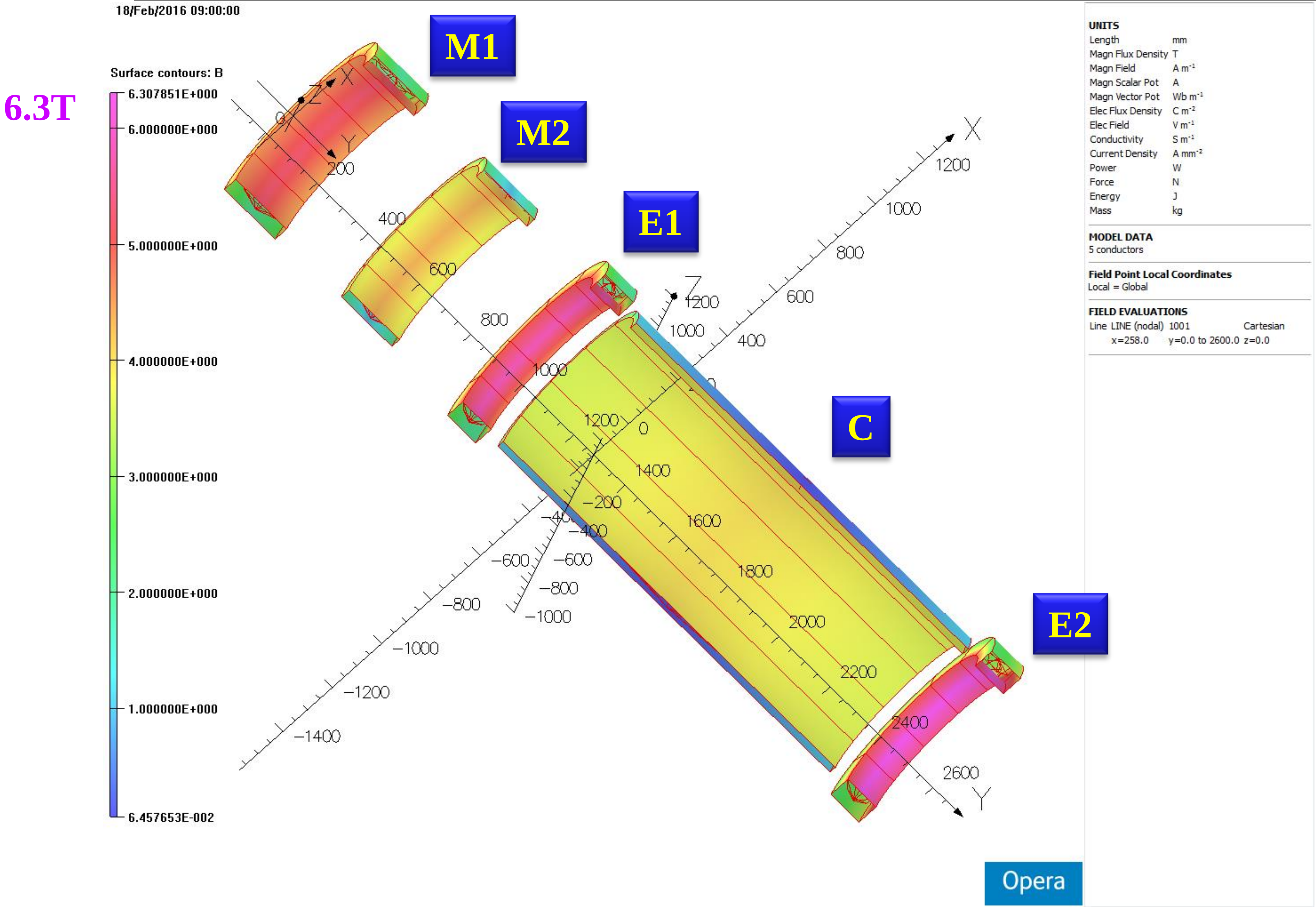
Tracker Solenoid Peak Field



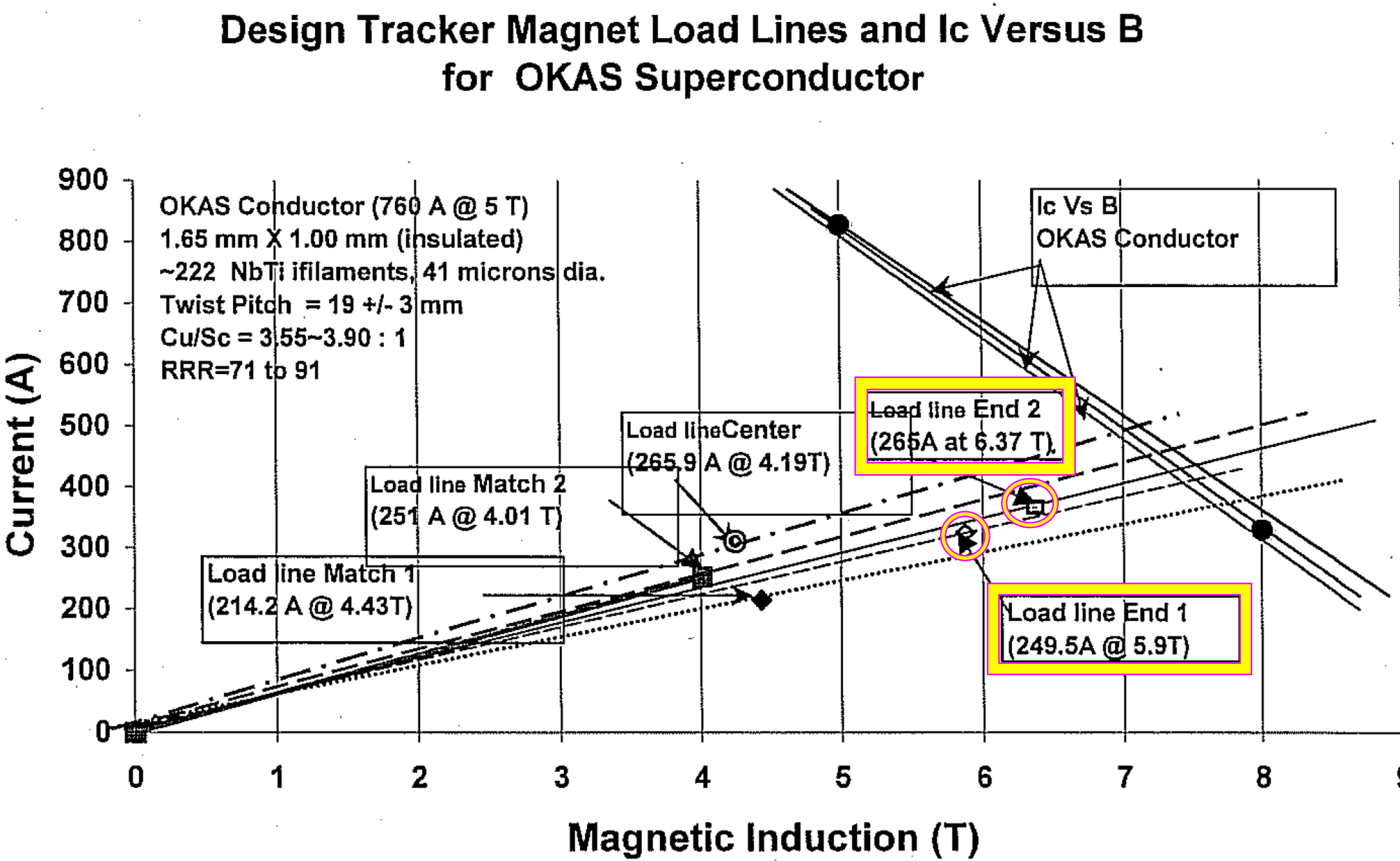
Goal: Reduce the peak fields in E1 and E2

M1 and M2 became different in 2008 design
(however, that is not the subject of the present task)

Cutaway View Showing Field on the surface of all coils (inside view)



Task : Small Changes in the Design to Increase Margin of "E1" and "E2"

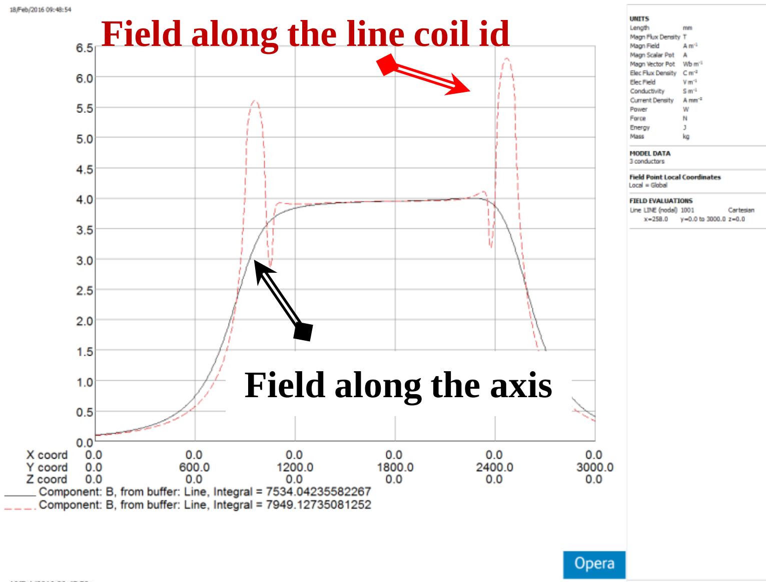


BROOKHAVEN NATIONAL LABORATORY

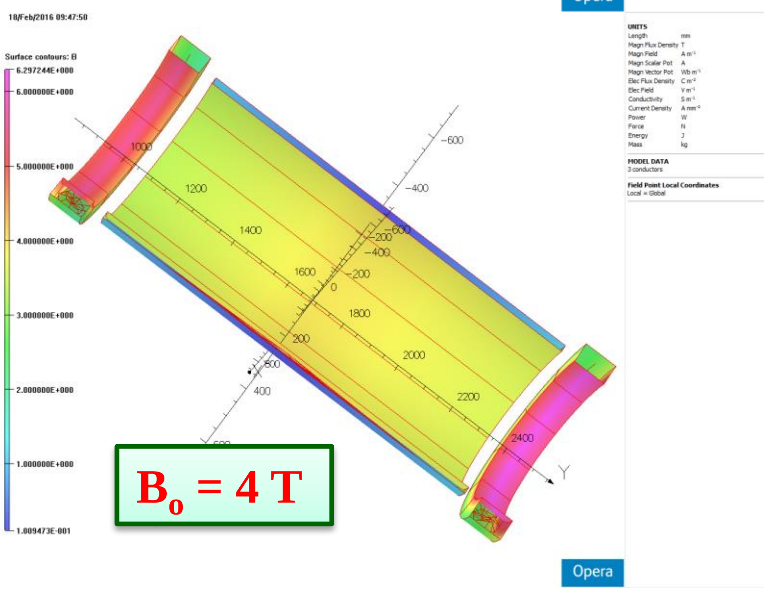
Superconducting Magnet Division

Mice Solenoid Coils E1, C and E2 and RHIC e-lens Solenoid (Main & Trim)

MICE Spectrometer Solenoid

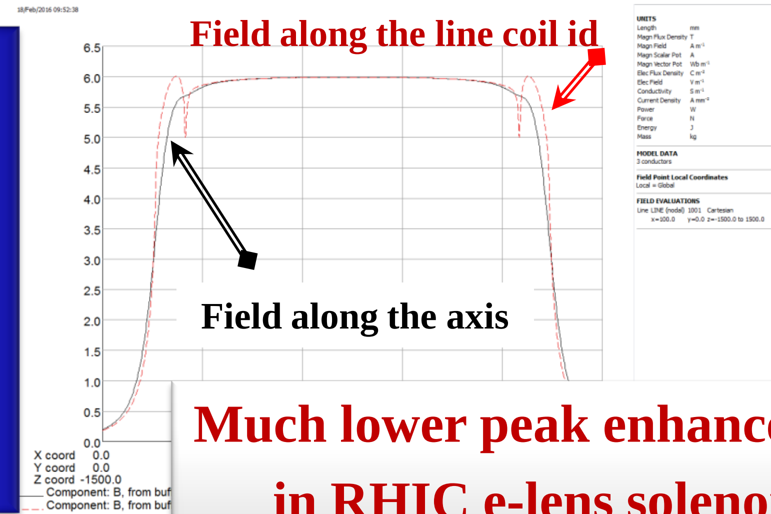


6.3T



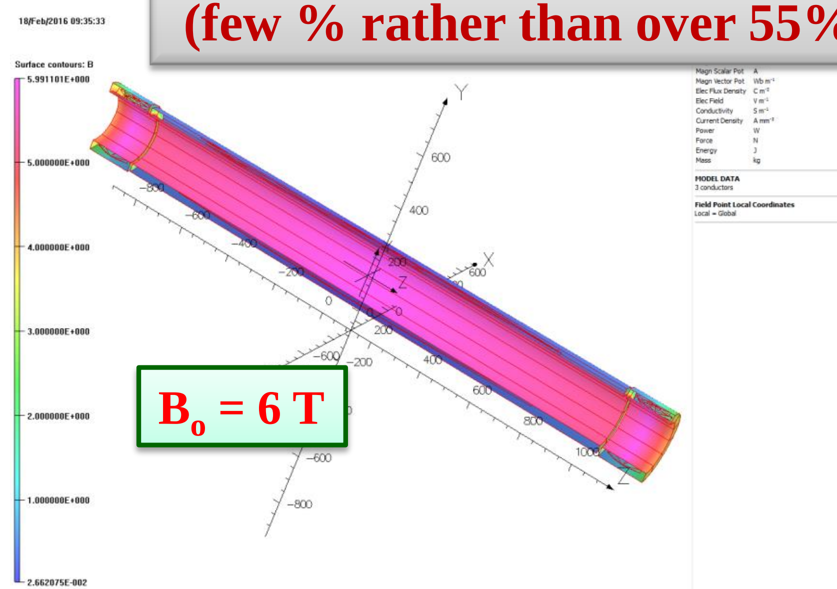
$B_o = 4$ T

RHIC e-lens Solenoid



Much lower peak enhancement in RHIC e-lens solenoid (few % rather than over 55%)

6.0T



$B_o = 6$ T

Comparison between the designs of MICE and RHIC e-lens Solenoids

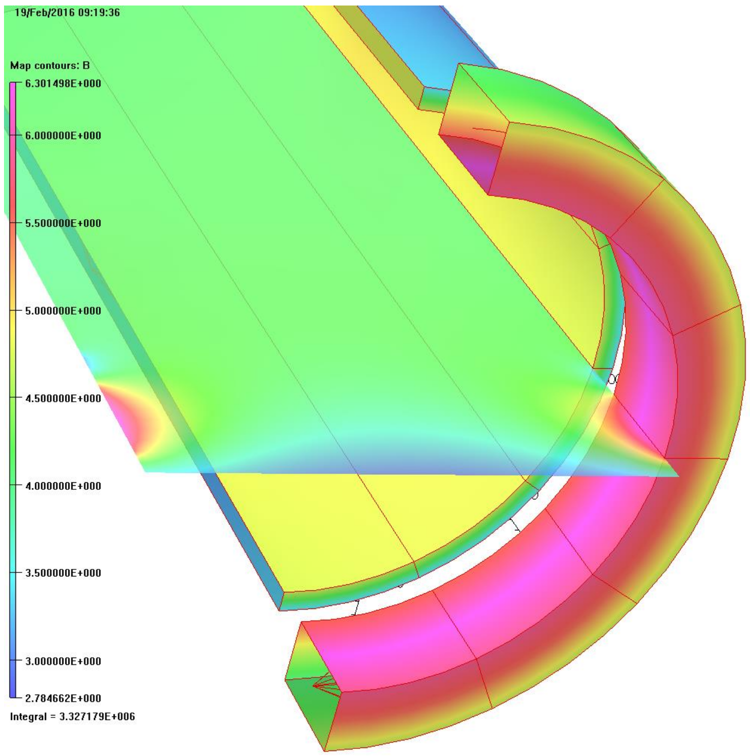
MICE Spectrometer Solenoid

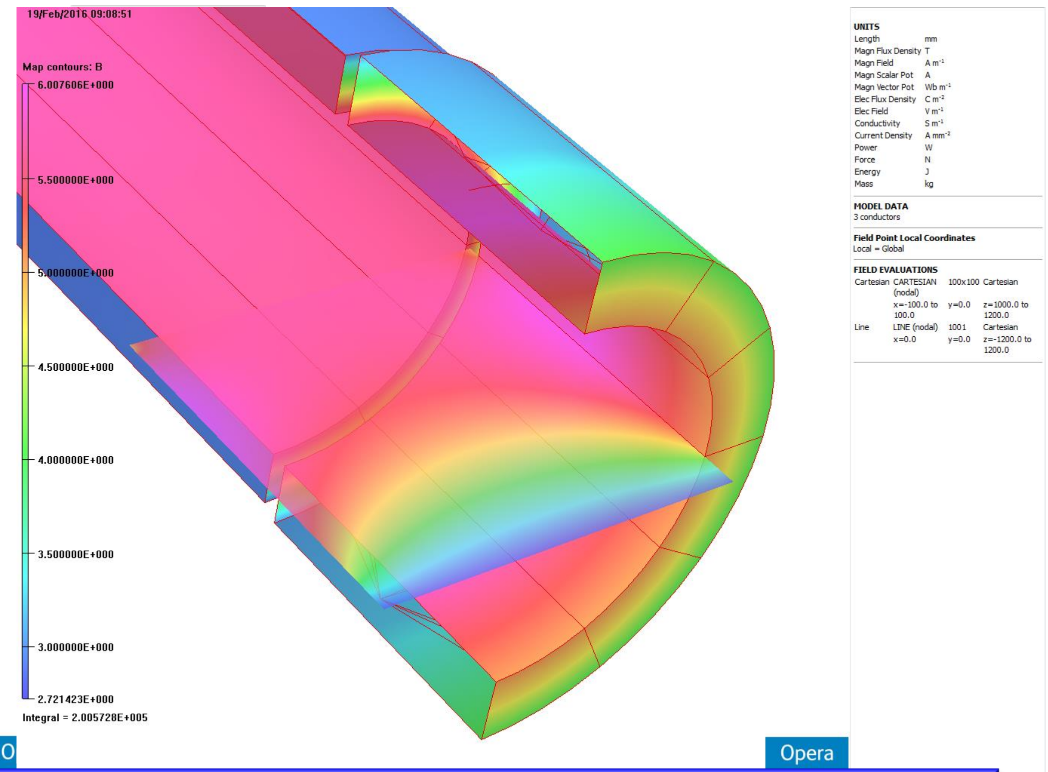
B_o = 4 T B_{pk}=6.3T

Compare the end coil

RHIC e-lens Solenoid

B_o = 6 T B_{pk} = 6.0T





Note: A major difference in the aspect ratio (length vs width)

Unfavorable aspect ratio increases peak field and stresses

Optimization of New Design (Design 2)

Guiding Principles:

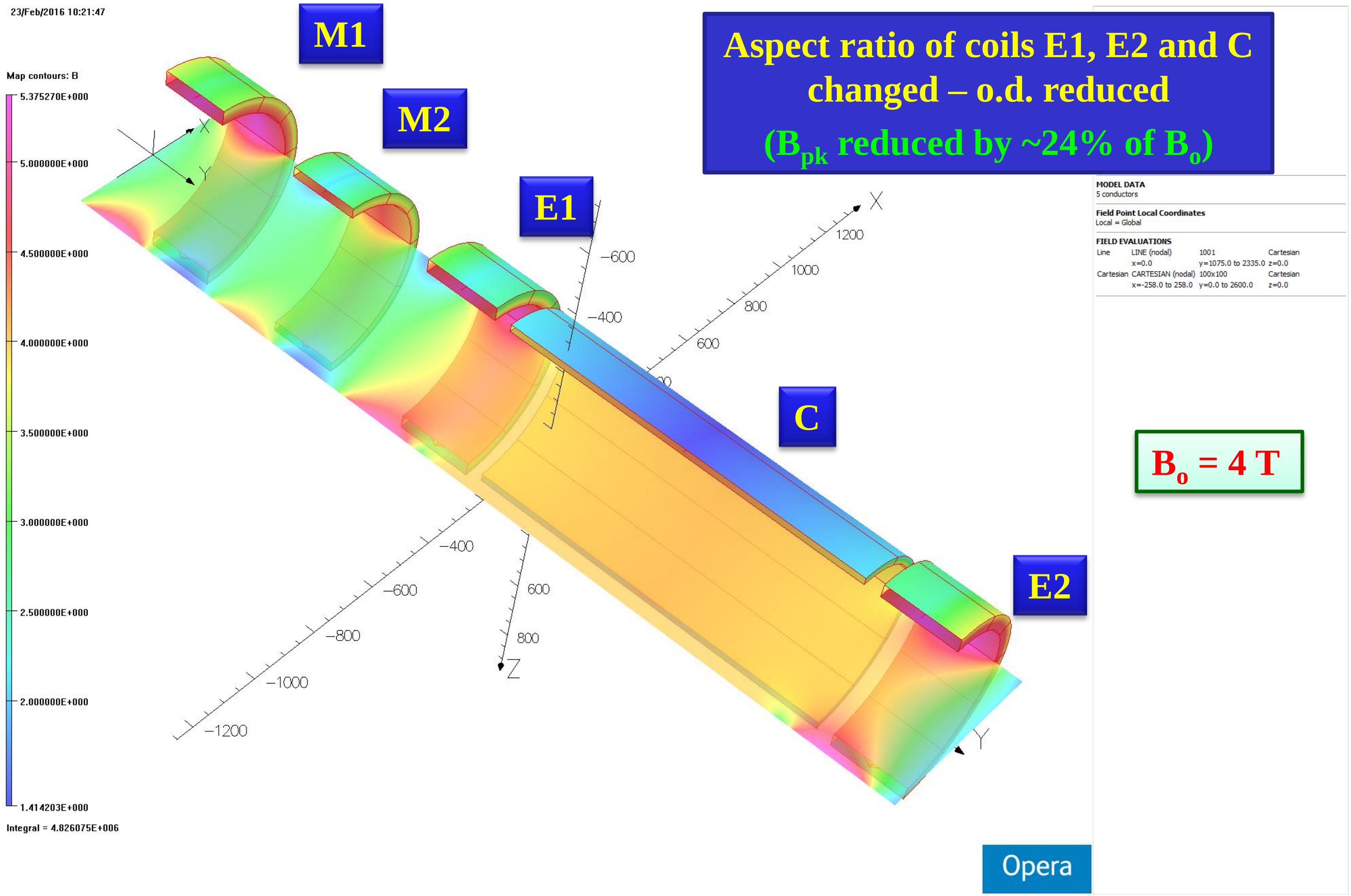
- No change in the overall length of "E1" + "C" + "E2"
- No change the starting or end position of E1 and E2
- Change the aspect ratio of "E1" and "E2" by increasing their length (length of "C" reduces to satisfy the above restrictions).

- Several cases were examined. The chosen design has length of E1 and E2 increased by a factor of two. Width (number of layers) is adjusted to maintain the required field quality. Currents in C, E1 and E2 are also slightly tweaked. These can be adjusted more to further improve the field quality – both in the design and also to accommodate construction errors.

Reduced Peak Field Design of MICE Solenoid (Design 2)

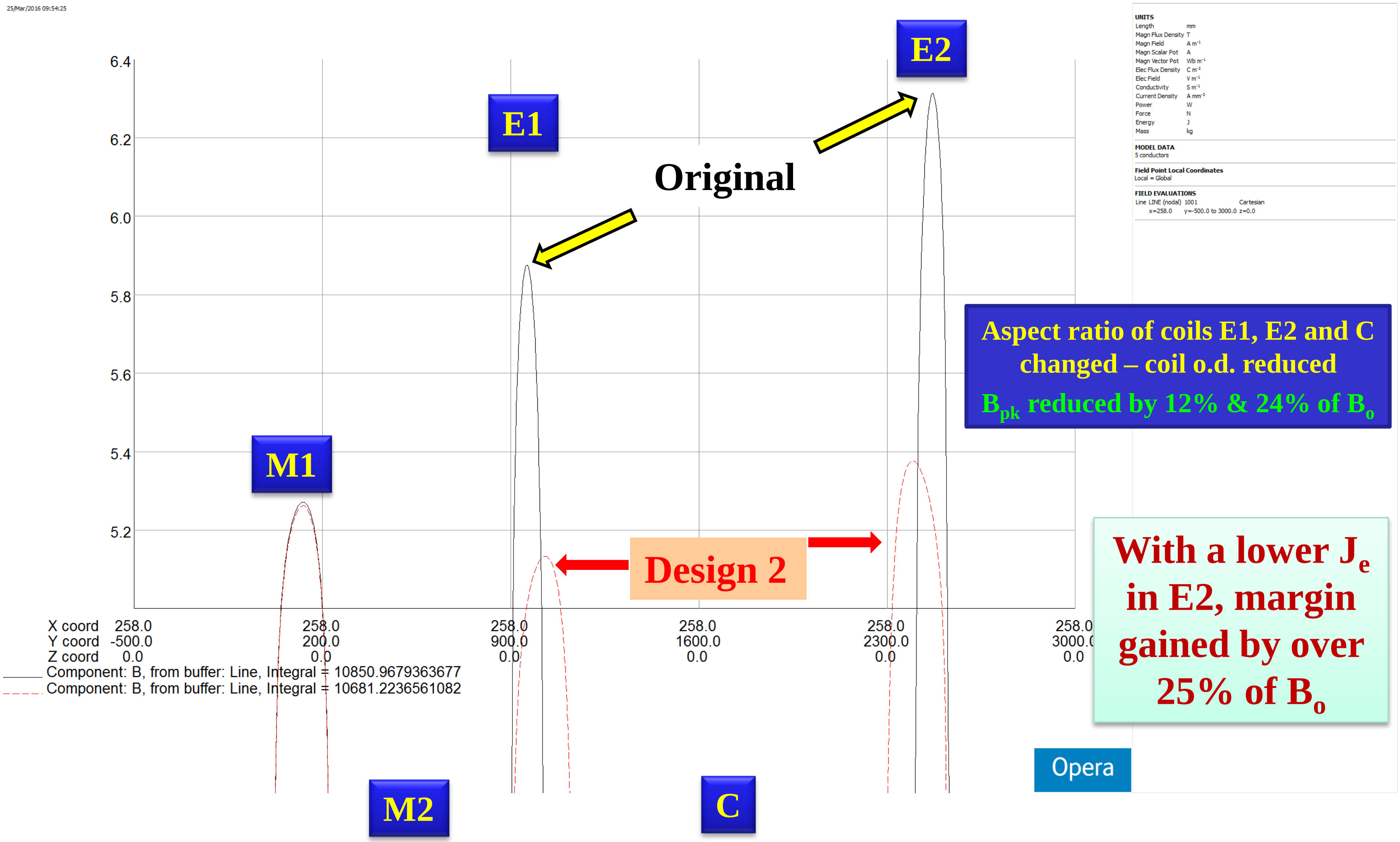
Aspect ratio of coils E1, E2 and C changed – o.d. reduced
(B_{pk} reduced by ~24% of B_o)

5.37 T



$B_o = 4$ T

Reduction in Peak Fields (Original and Revised Designs)

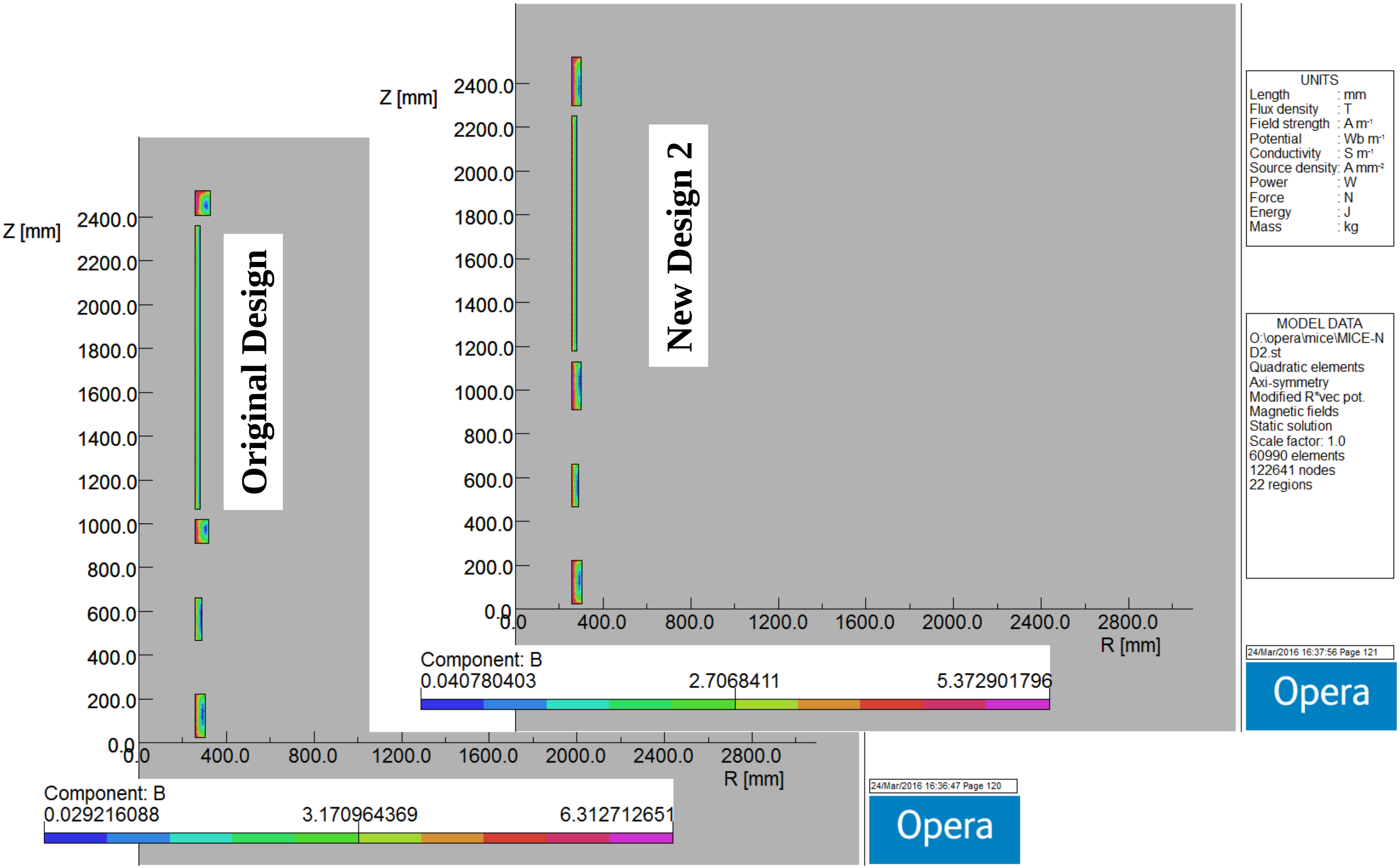


Aspect ratio of coils E1, E2 and C changed – coil o.d. reduced

B_{pk} reduced by 12% & 24% of B_o

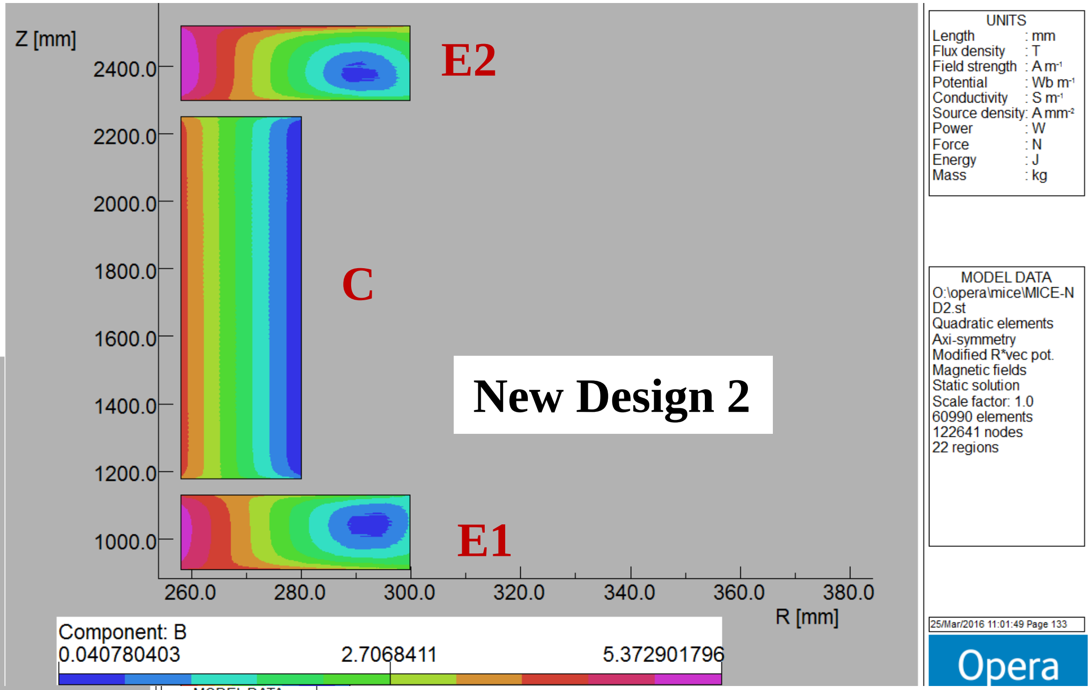
With a lower J_e in E2, margin gained by over 25% of B_o

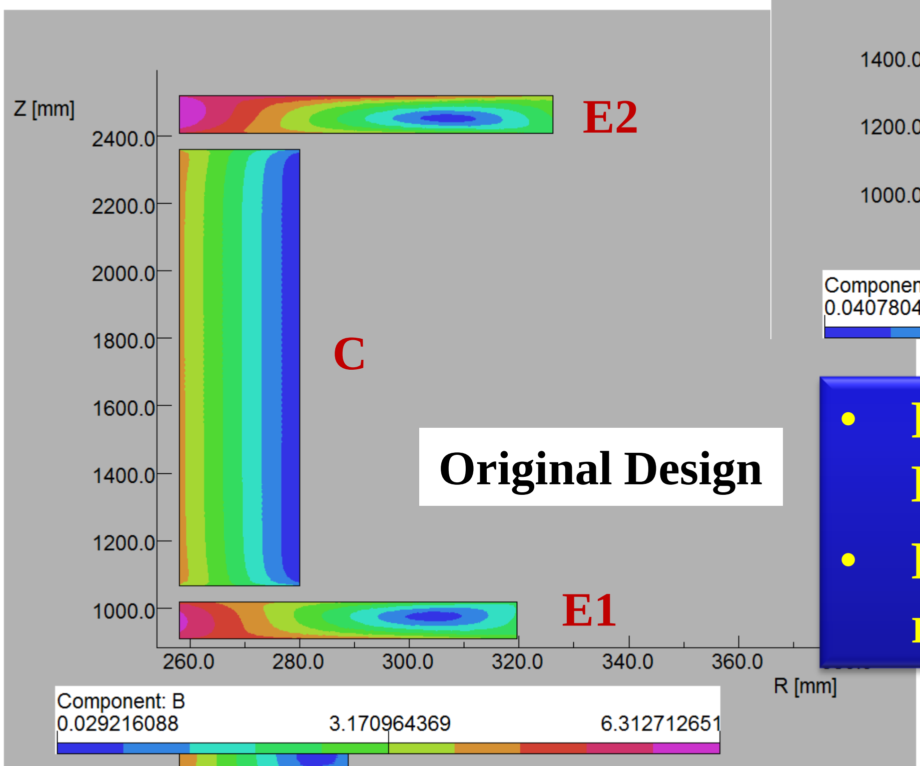
Reduction in Peak Field on the Conductor to Increase Margin (1)



Reduction in Peak Field on the Conductor to Increase Margin (2)

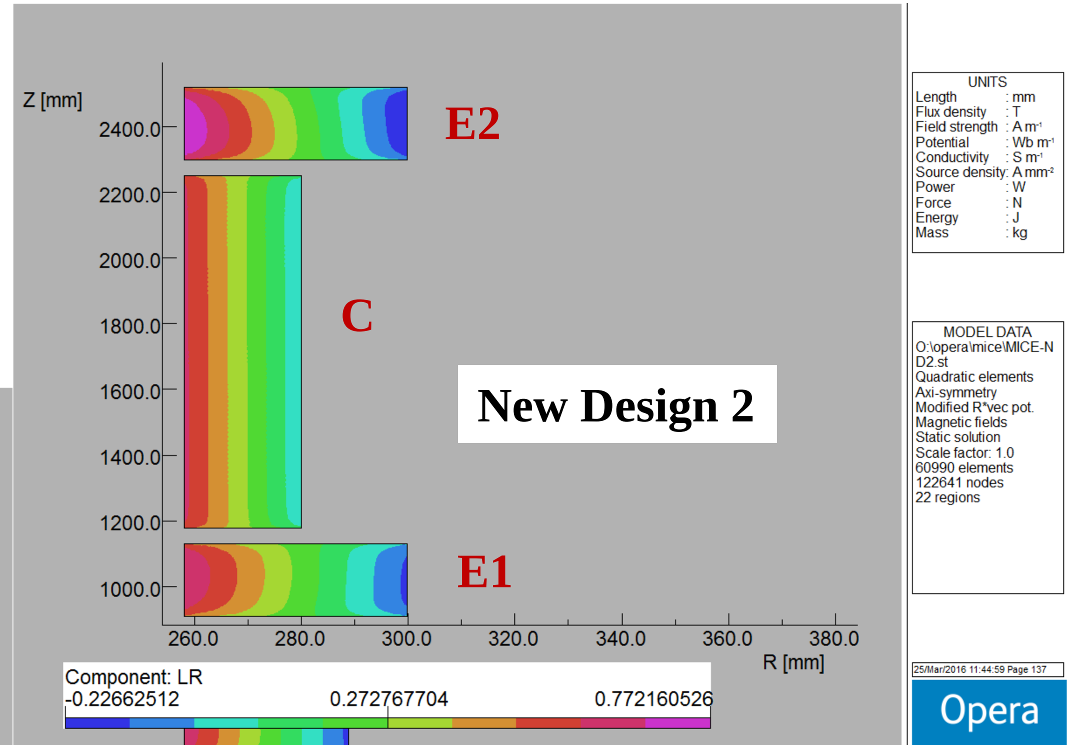
Scale changed to better view the difference (no longer 1:1 aspect ratio)

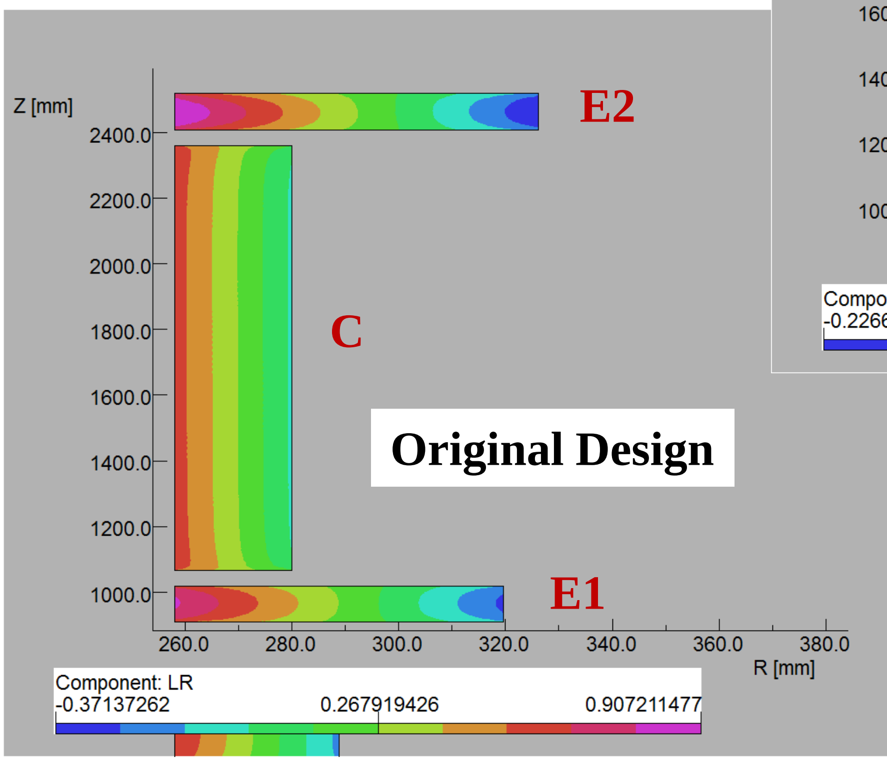




- Reduction in field would also reduce Lorentz forces, both axial and radial
- Reduction in radial width should further reduce radial stress accumulation

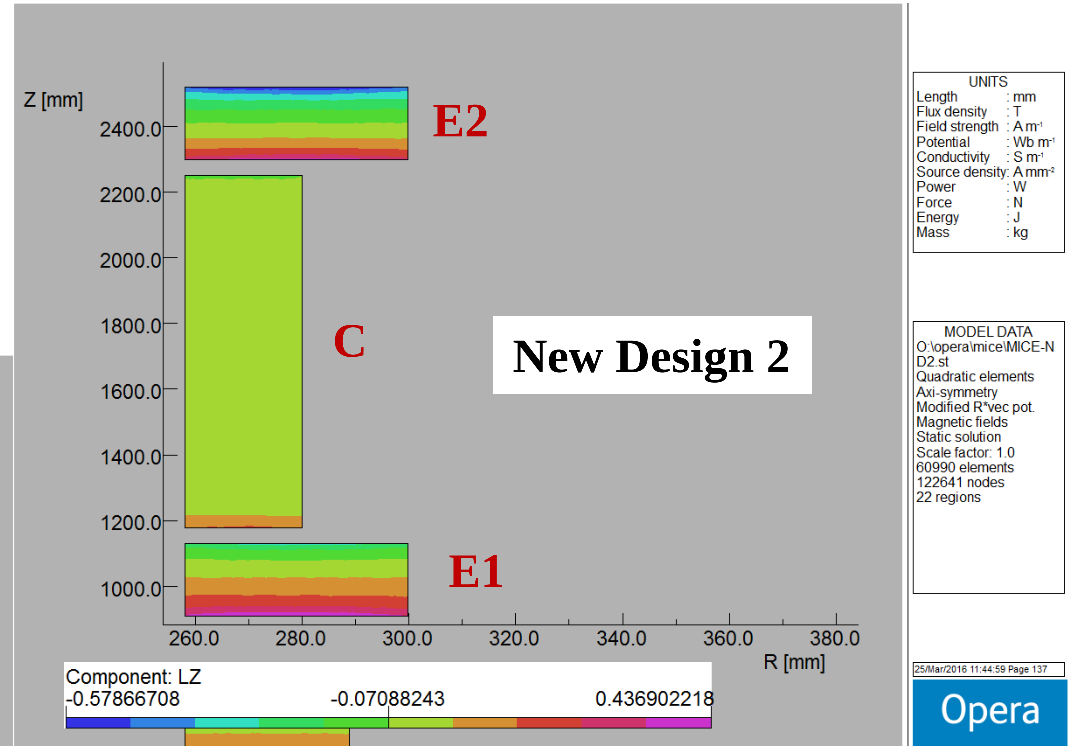
Radial Lorentz Force Density on the Conductor at Full Field (4 T)

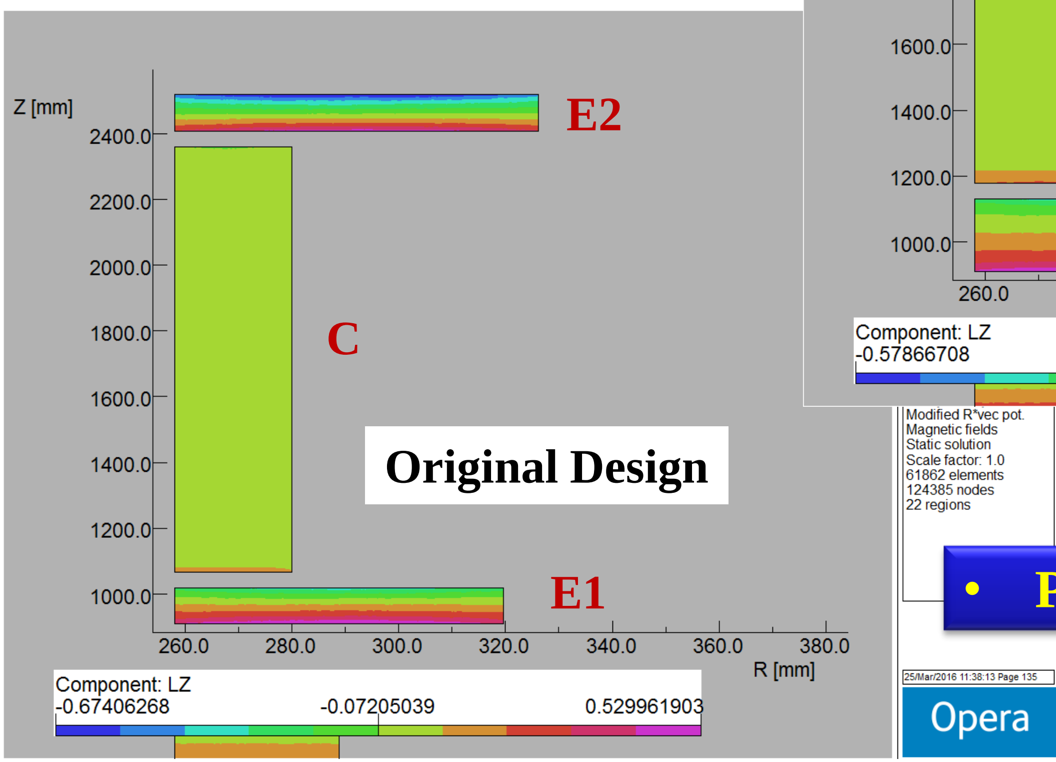




- Peak Lorentz force density reduced
- Reduction in radial width makes accumulated radial stress ~2/3

Axial Lorentz Force Density on the Conductor at Full Field (4 T)

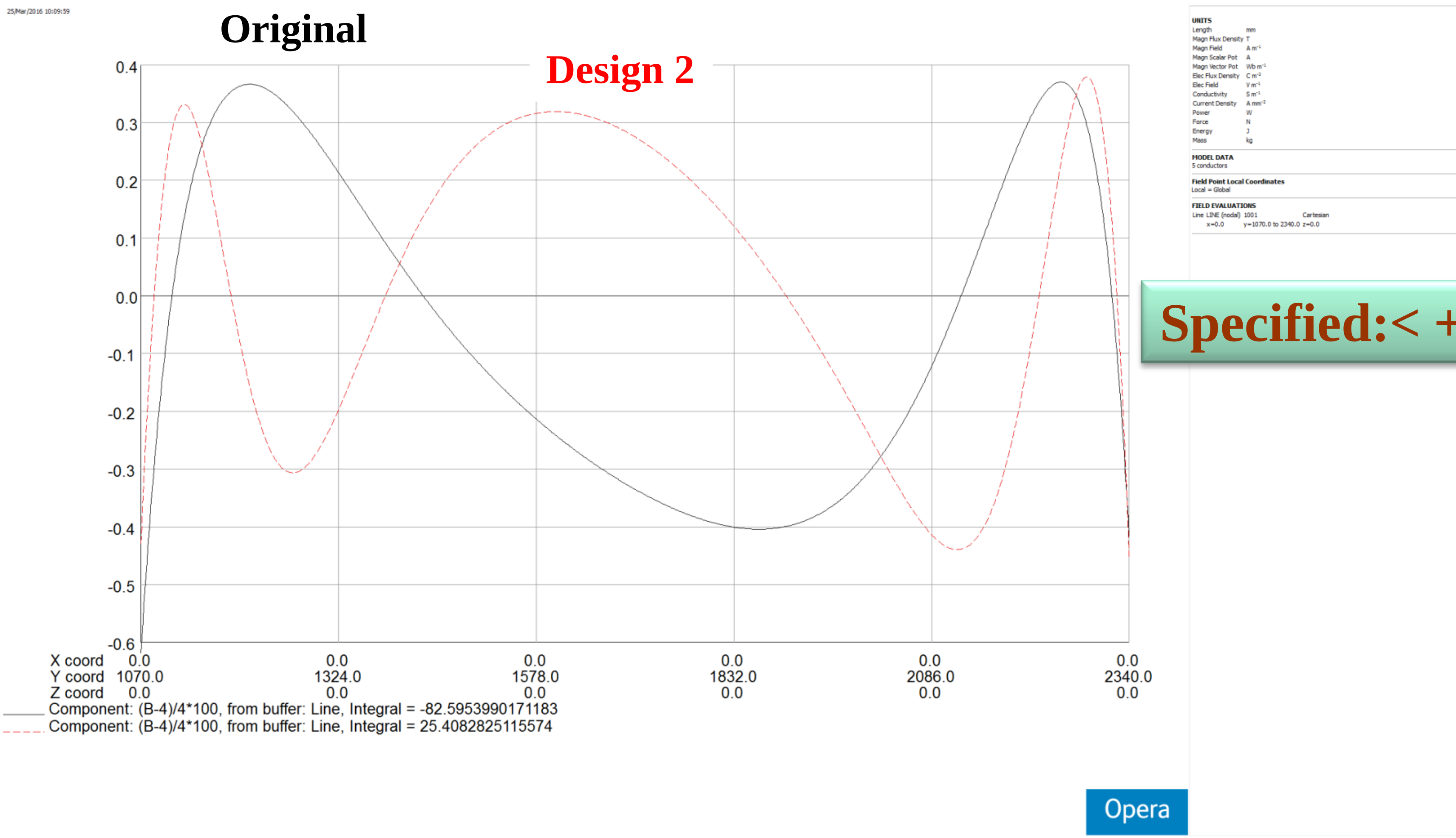




- Peak Lorentz force density reduced

Relative Field Errors in Percentage (Original and Design 2)

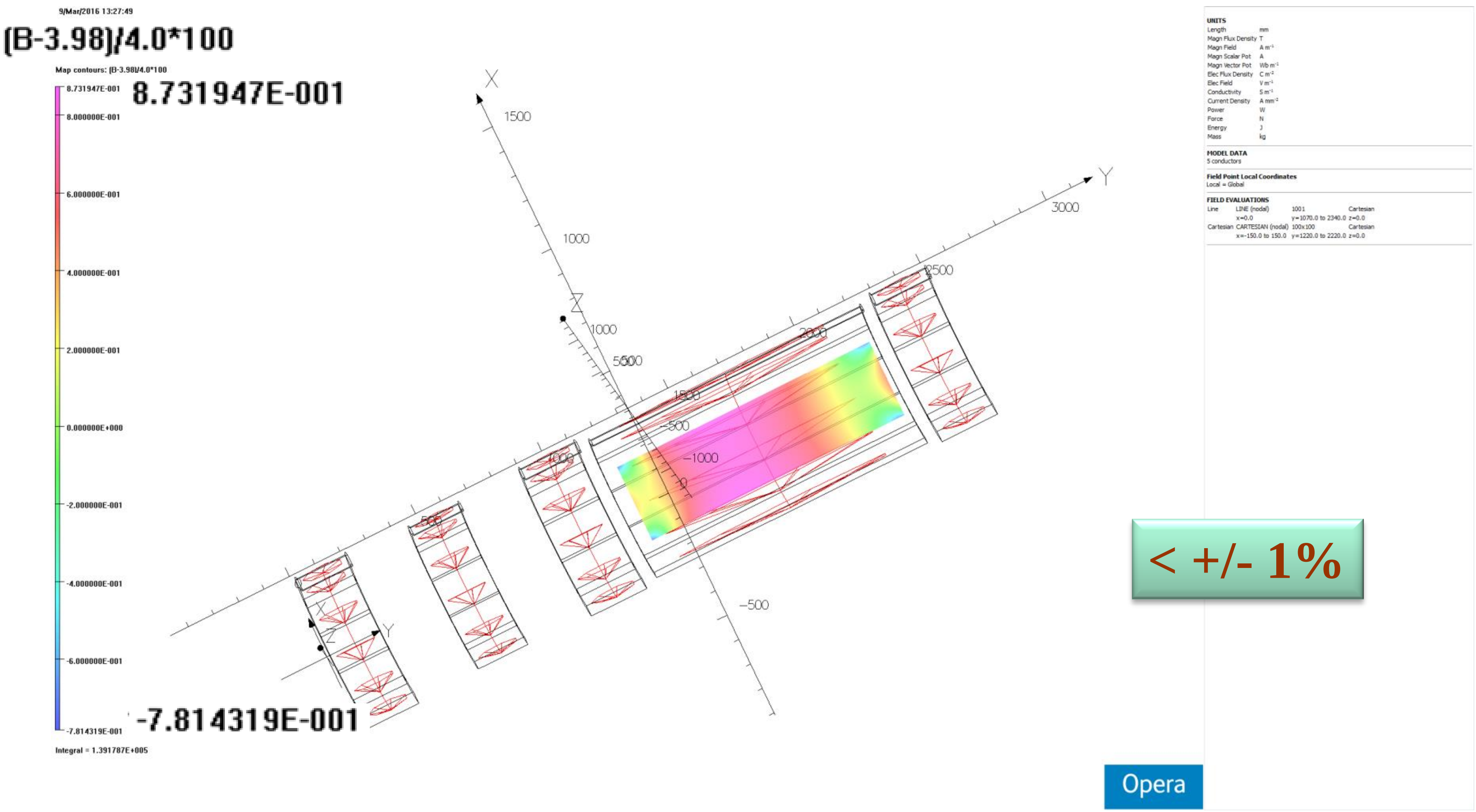
Relative field error on axis (in %)



Specified:< +/- 1%

Relative Field Errors in Percentage (Design 2)

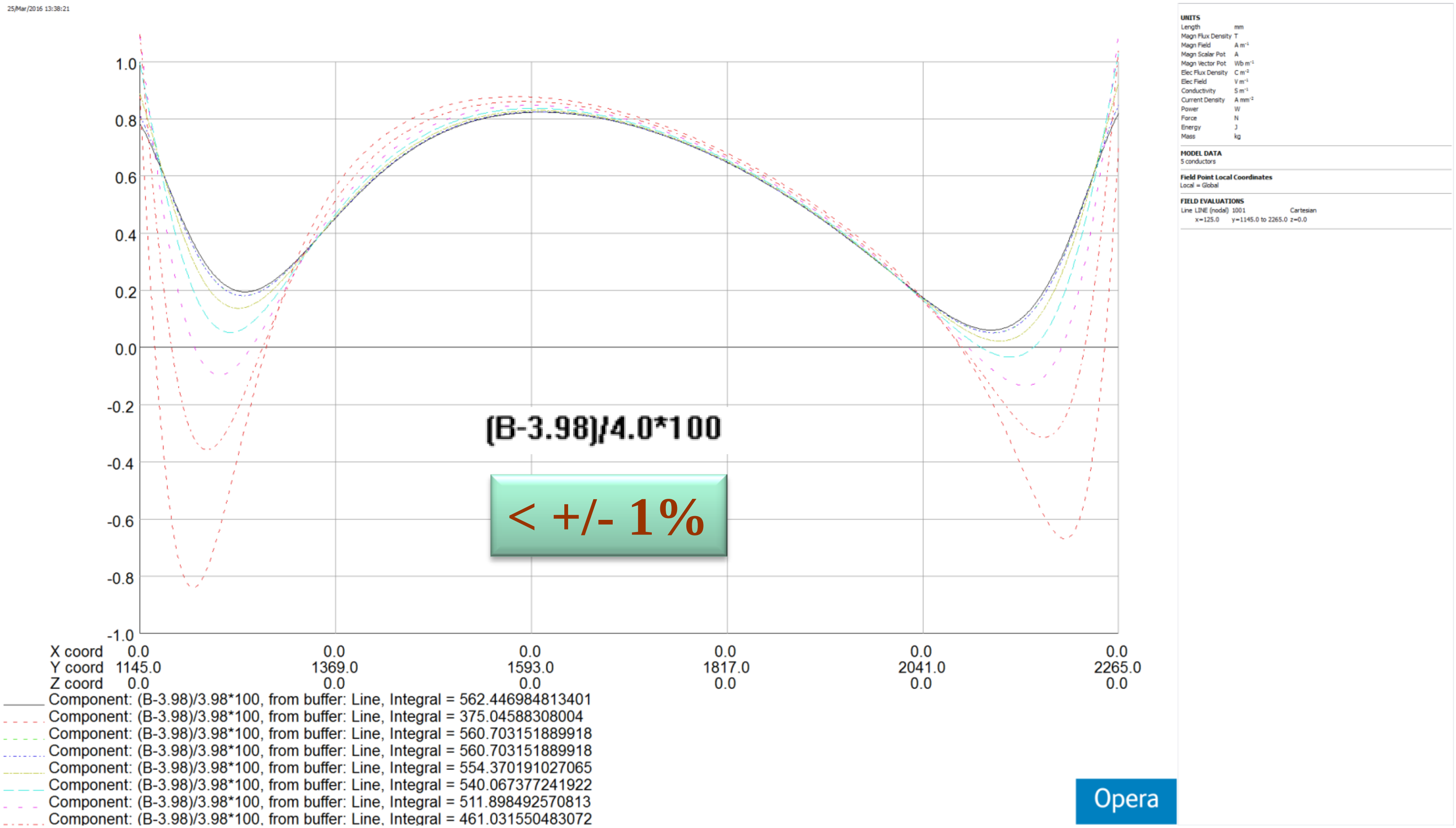
Relative field error in 300 mm diameter 1000 mm patch (in %)



< +/- 1%

Relative Field Errors in Percentage (Design 2)

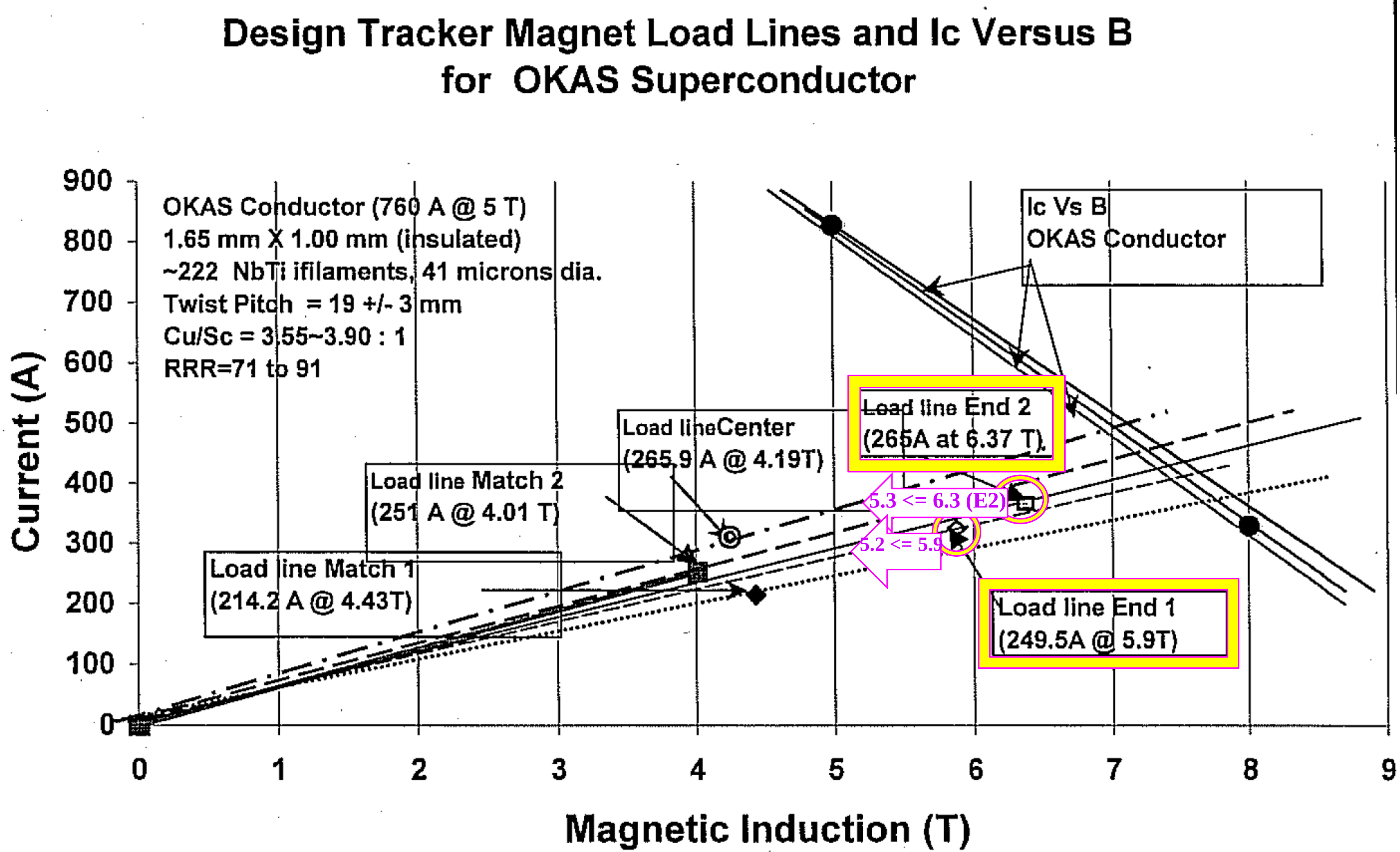
Relative field error in 0 to 300 mm diameter in L > 1000 mm



Major Parameters of Original Design and New Design

Coil E1	Original	New Design 2	Coil E2	Original	New Design 2
Coil Thickness (mm)	61.6	41.8	Coil Thickness (mm)	68.2	41.8
Coil Length (mm)	110	220	Coil Length (mm)	110	220
Number of Layers	56	38	Number of Layers	62	38
No. of turns per layer	66	132	No. of turns per layer	66	132
Total number of turns	3696	5016	Total number of turns	4092	5016
Coil C	Original	New Design 2			
Coil Thickness (mm)	22	22			
Coil Length (mm)	1294	1074			
Number of Layers	20	20			
No. of turns per layer	784	652		Original	New Design 2
Total number of turns	15680	13040	Total # of turns in E1+C+E2	23468	23072

New Design has Significantly reduced Peak Fields and Increased Margin



Other Possible Approaches

- Remove/reduce space between E1, C and E2 or combine these coils in different ways

- Those techniques may further reduce peak fields

SUMMARY

- **Significant reduction in peak field and hence significant increase in margin can be obtained by changing the aspect ratio of E1 and E2 (and also C).**

- **Overall length and field quality is maintained.**

- **This is not the final design (for example field quality can still be improved by slightly adjusting currents in E1, C and E2) but it provides a reasonable reference design to increase margin.**

- **Reduction in peak field also reduces Lorentz stresses on the coil.**