Superconducting Solenoid for e-lens with Fringe Field Coil

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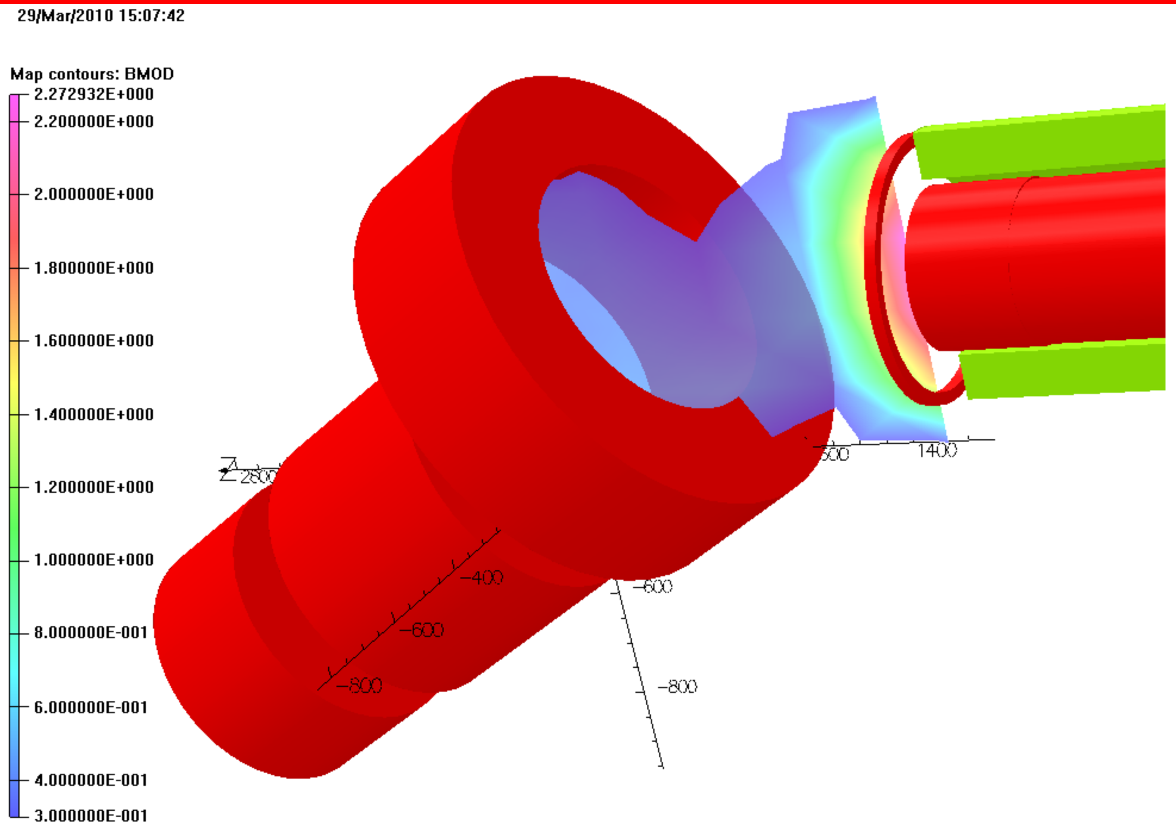
Overview

- Fringe field superconducting solenoidal coils (one on either side) have now become an integral part of the system design.
- They are designed to create a significant field outside the coldmass, in the interface region between the room temperature solenoid and superconducting solenoid (combined field should be greater than 0.3 T).
- Various iterations have made fringe field coils stronger and inner radius smaller.
- This means that now they not only create significant field outside the coldmass but also inside the solenoid. Therefore, the solenoid design to obtain a good field quality (on axis field errors ~5 X 10^{-3} within +/1050 mm) needs to be re-optimized with the fringe field coils included in the calculations.
- This works well if current in main coil and fringe field coils scale linearly.
- However, it is desired that fringe field coils run stronger at lower fields (say 0.3 T or even 0.1 T) as higher contribution is needed in those cases to overcome the lower field in interface region.
- A solution is proposed that seems to do all above plus extend the good field region beyond +/-1050 mm).

Quick Review of the Previous Designs

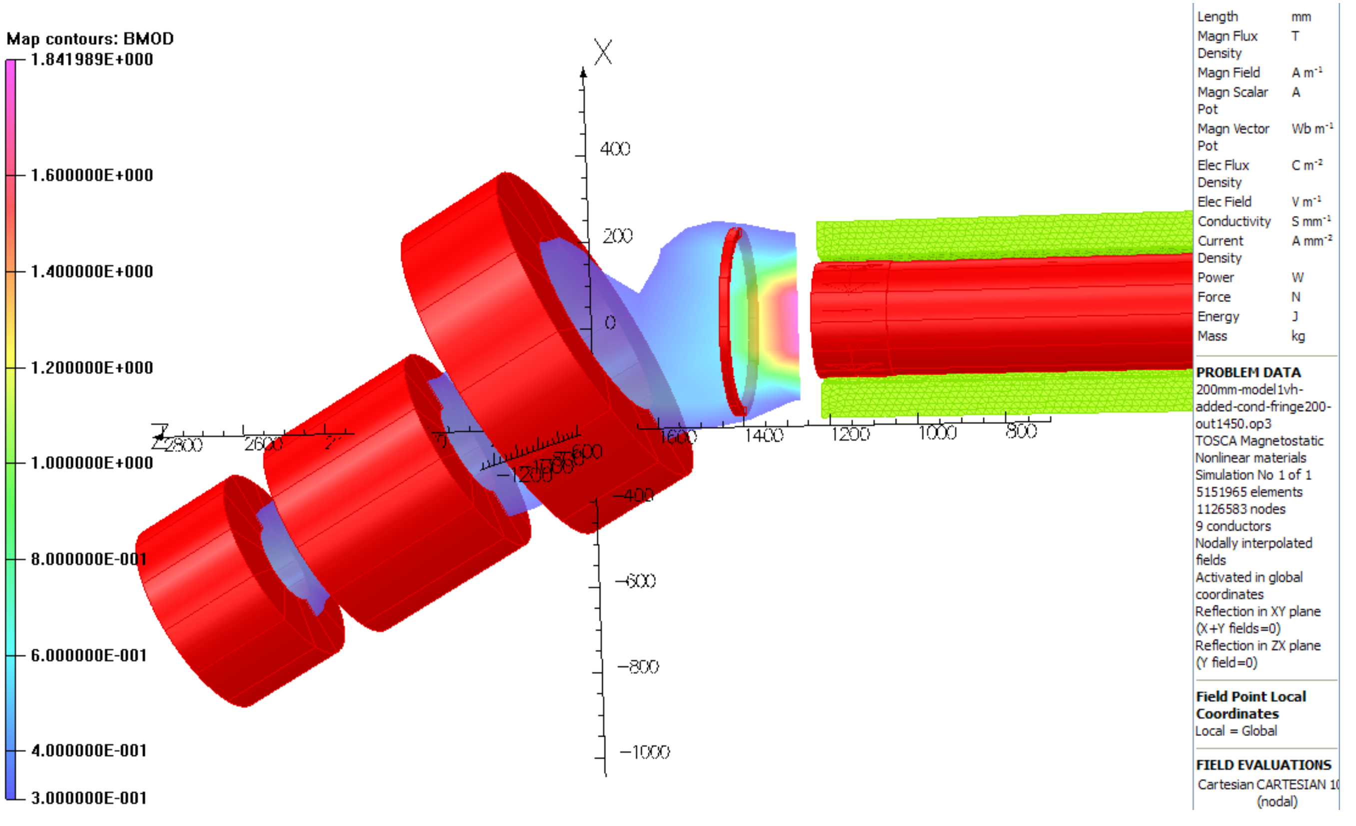
Design #1
(fringe field coil - large radius and close to iron)



- Worked well
- Benefits sold too well and users requested even more.
- But larger radius creates concern in cooling of the top part of the coil.
- Also some concern on field interaction between main and fringe field coil

Design #2
(fringe field coil moved out axially)

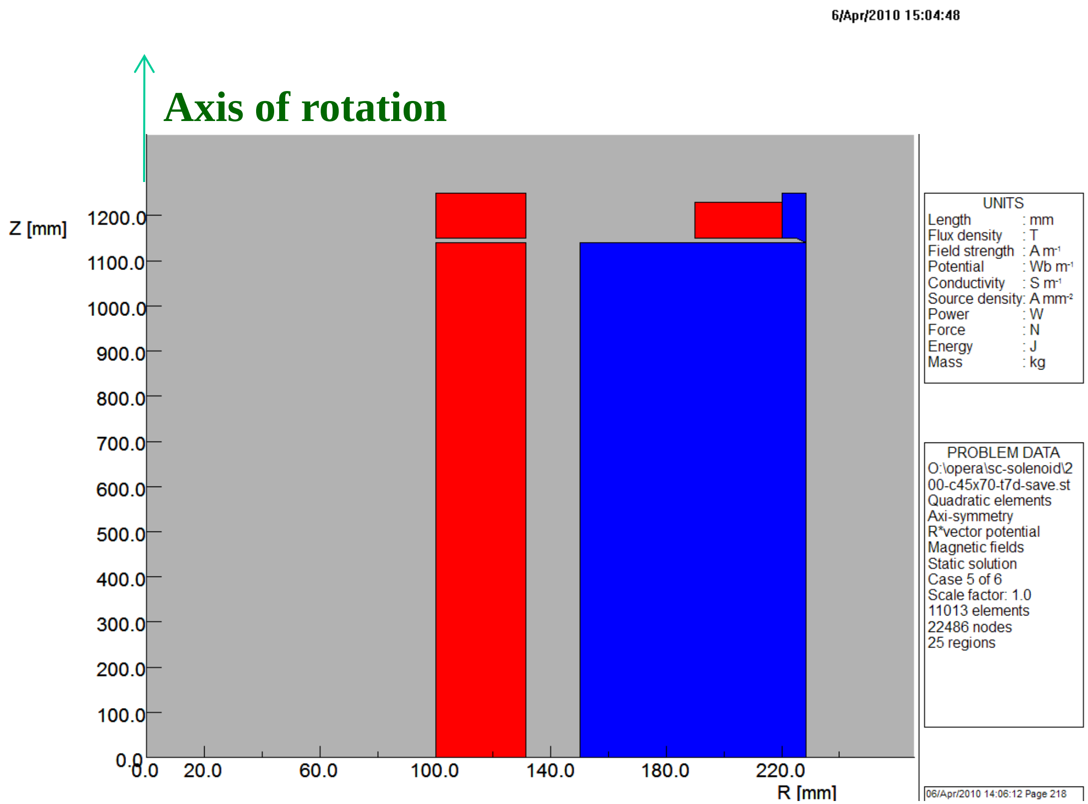
- Request to increase power of fringe field (or exterior field coil).
- Moving it out creates larger fringe field.

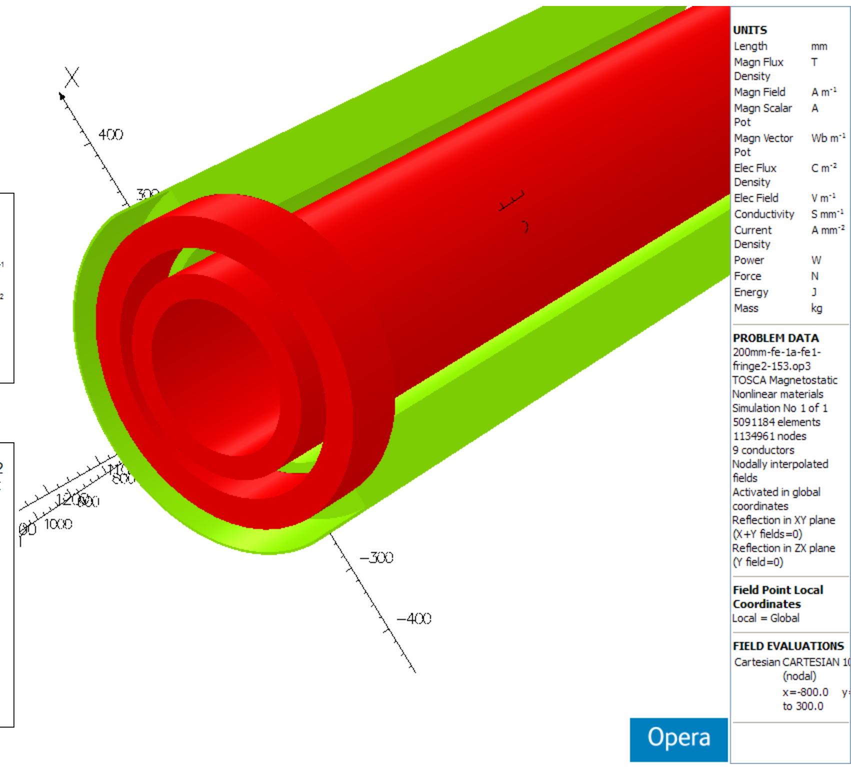


However, detailed design found that there is not enough space to move this far out.

Design #3
(fringe field coil inside the iron)

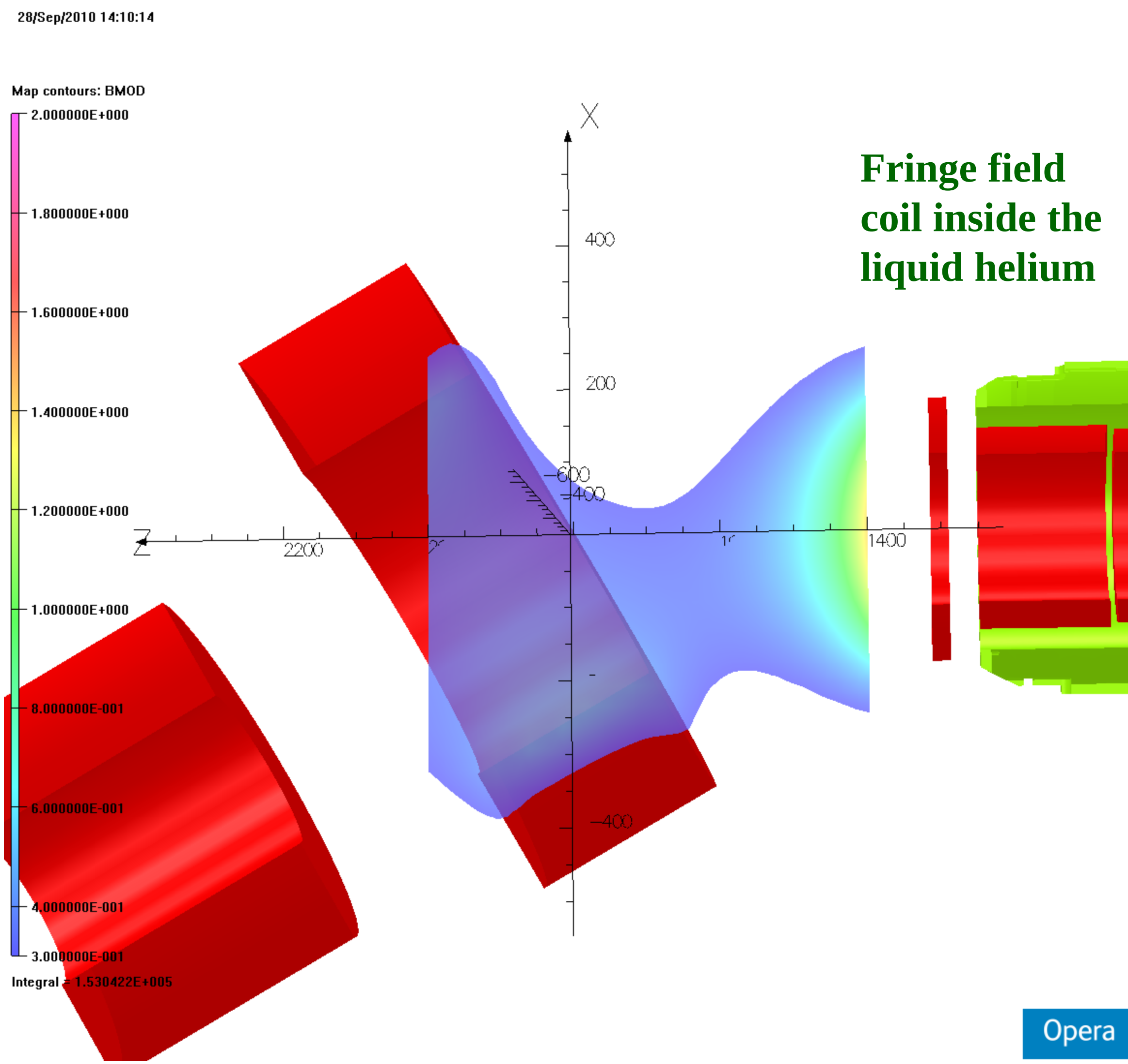
• Magnetic interaction between the main coil and fringe field coil is minimized for on-axis field quality inside the main solenoid.
• This is the design that is widely used by CAD in their review presentations.
• However, the concern remain on the cooling of the top part of the coil as that part is not submerged in liquid helium.

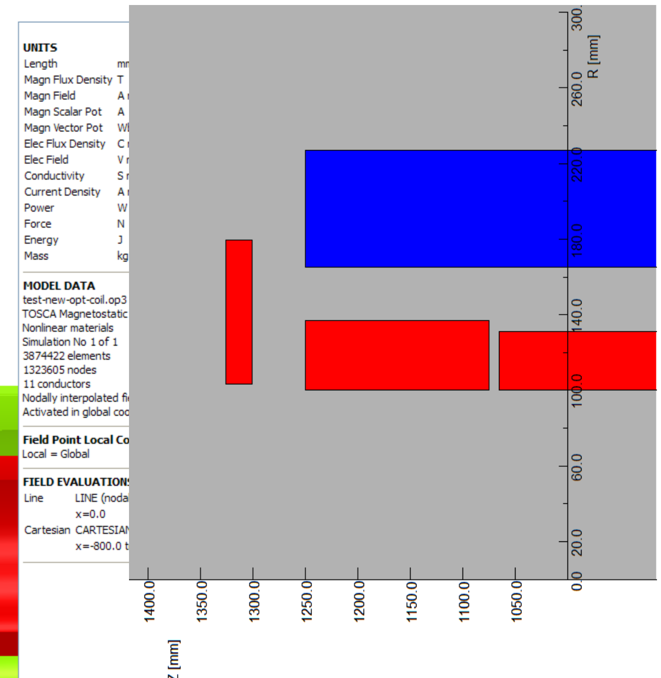




Current Design with Engineering (Design #4)

(one before the now being proposed)

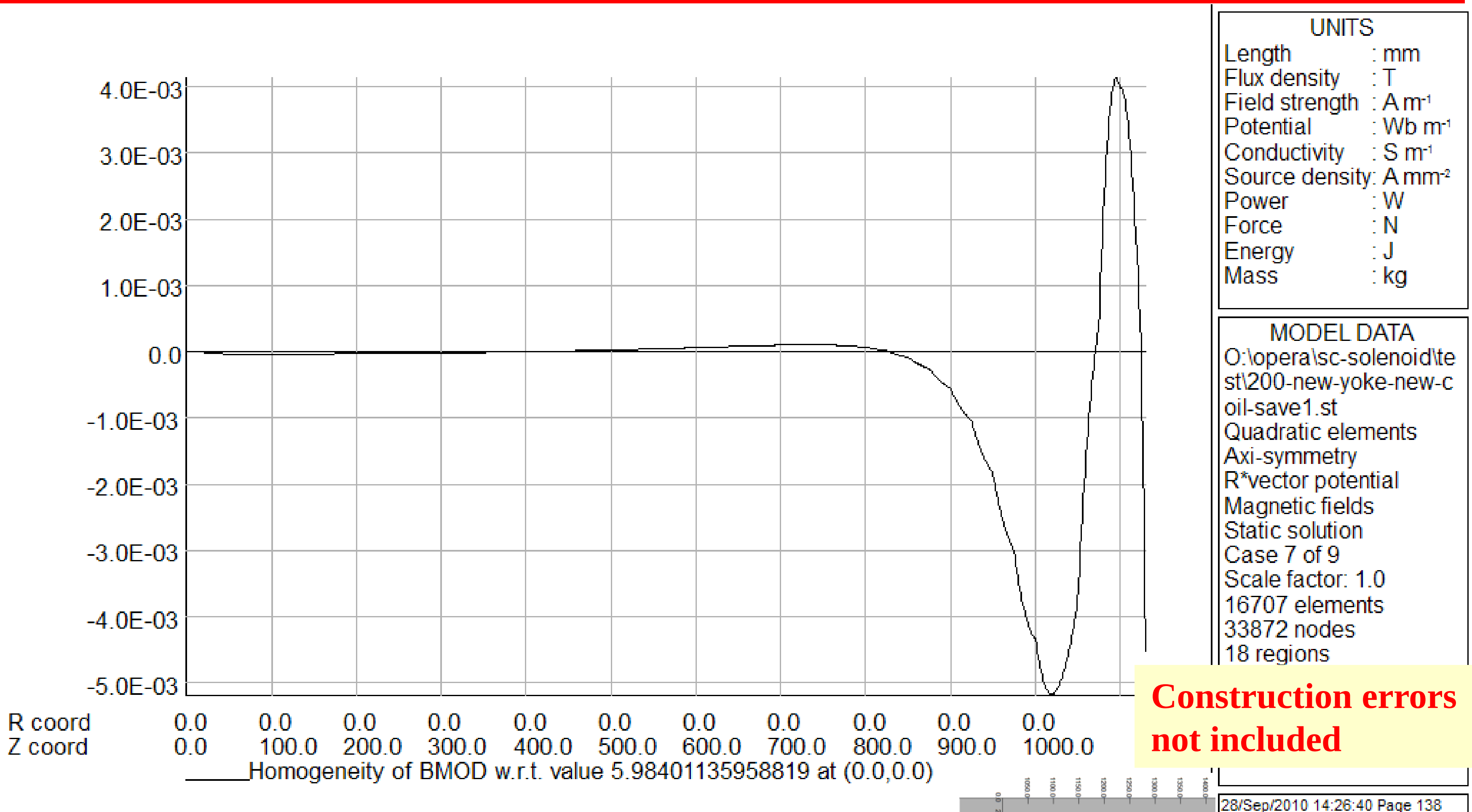




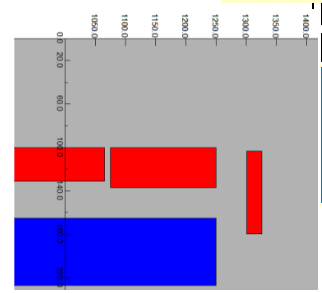
- However, it is @6T main field.
- If one wants >0.3 T independent of the main field, then the fringe field coils have to be independently powered.

- What happens to on-axis field quality inside the solenoid?

On-axis field quality inside the Solenoid



Construction errors not included

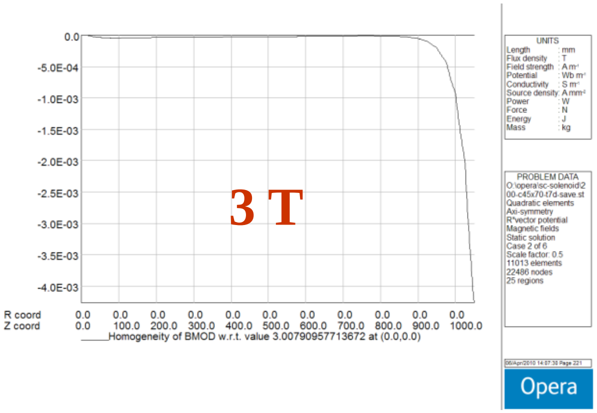


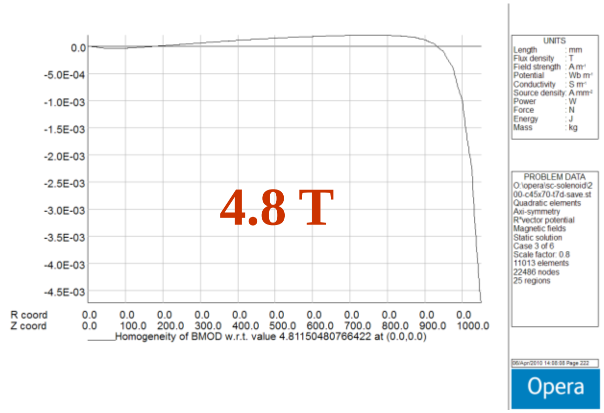
Opera

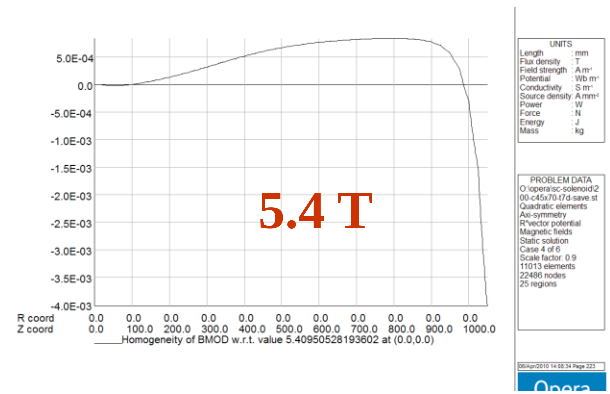
- The request was to make field errors ~10^{-3} within +/-1050 mm
- SMD and fringe field coils are your friends
  - ➢ field quality is made good to +/-1130 mm

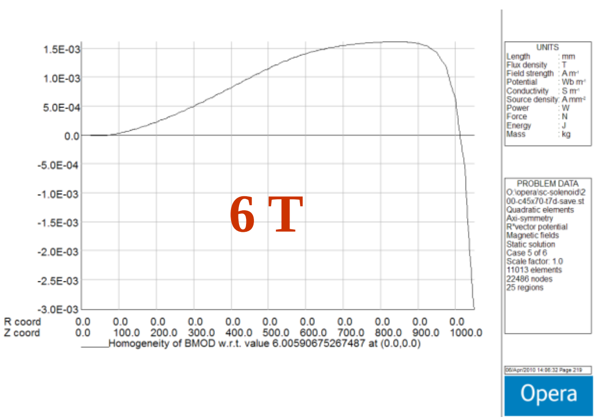
Field Errors at Different Fields
(earlier design)

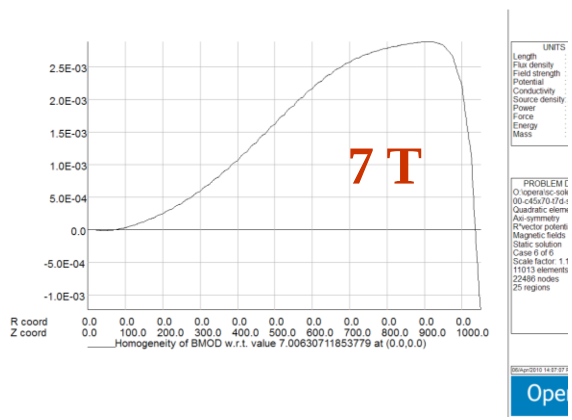
- Proof of principle design to show relative errors ~5 X 10^{-3}
- Relative field errors are plotted from center to 1050 mm axially

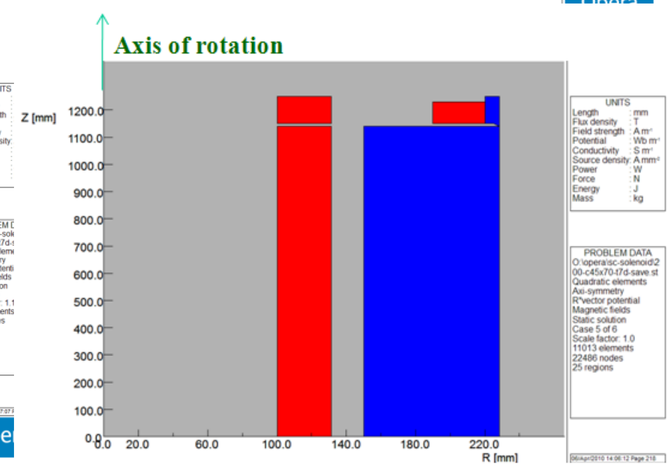








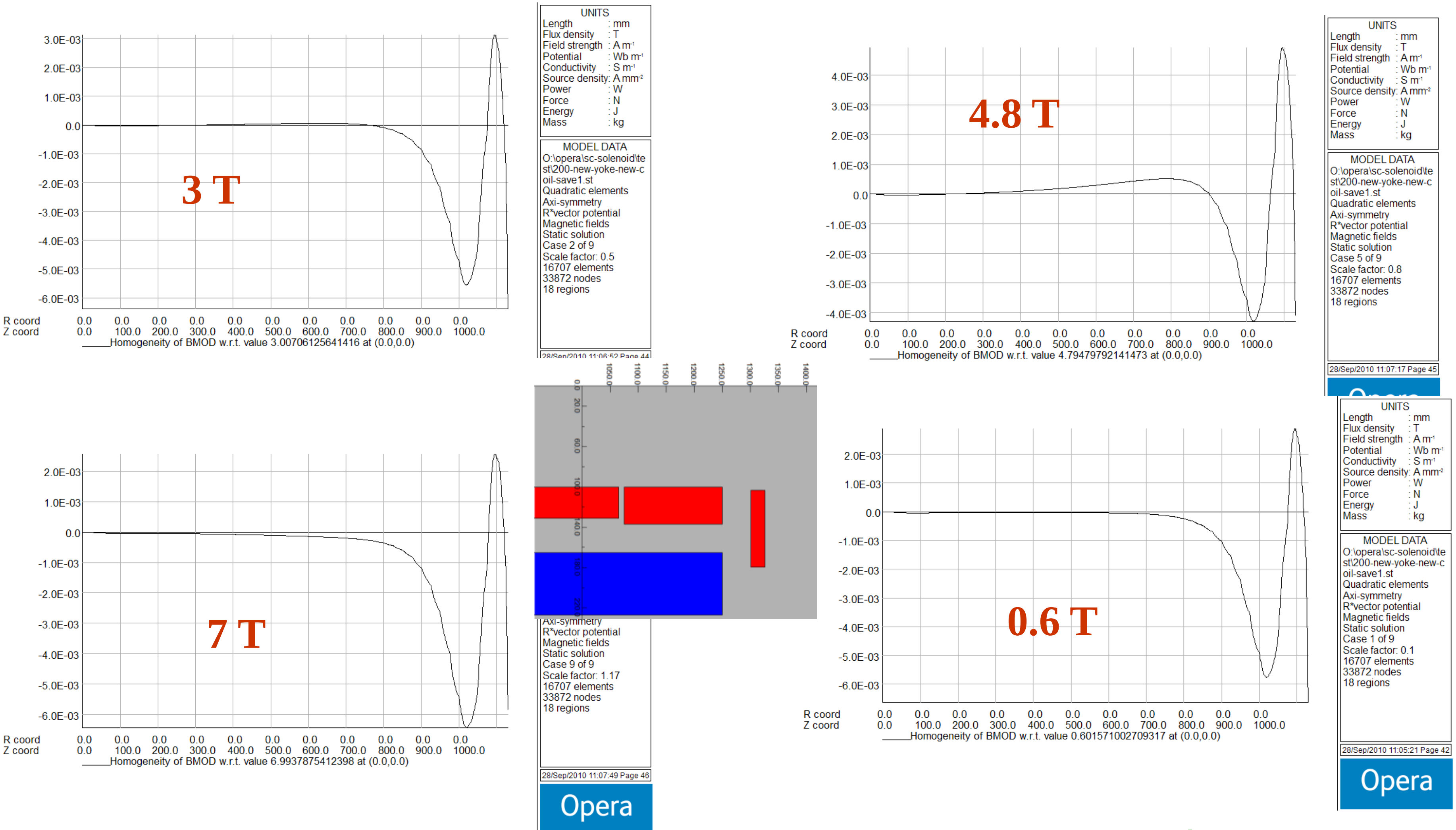




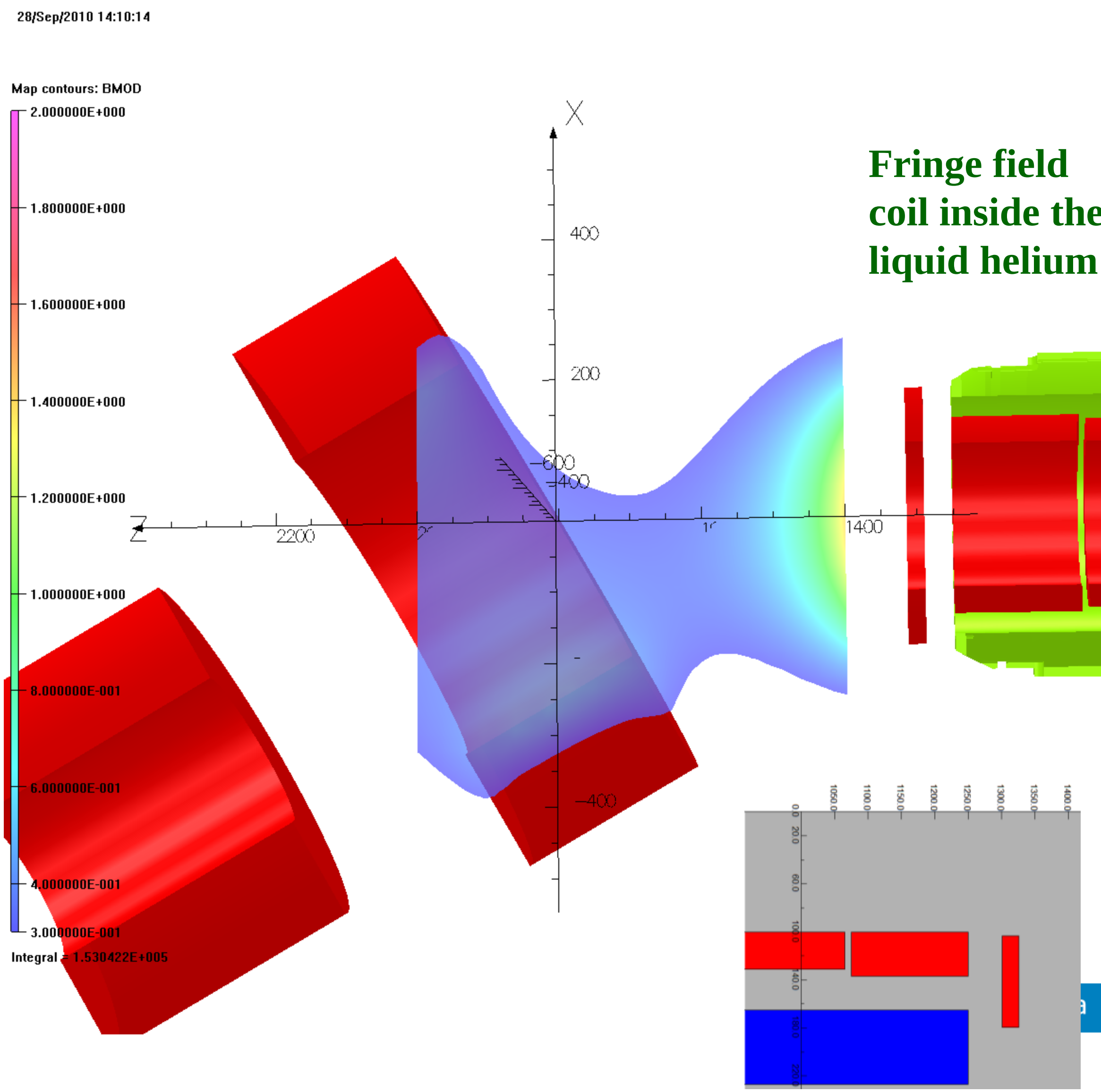
Field Errors at Different Fields

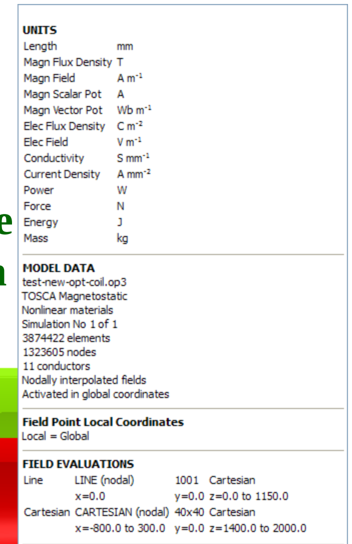
(Current design)

- All coils (main coil and fringe field coils) are powered in series
- Relative field errors remain ~5 X 10^{-3} to +/-1130 mm from 0.6 T to 7 T ---- wow!



Current Design
(magnitude of the field)





- @6T main field is barely above 0.3 T.

- Situation would be worse at lower field.

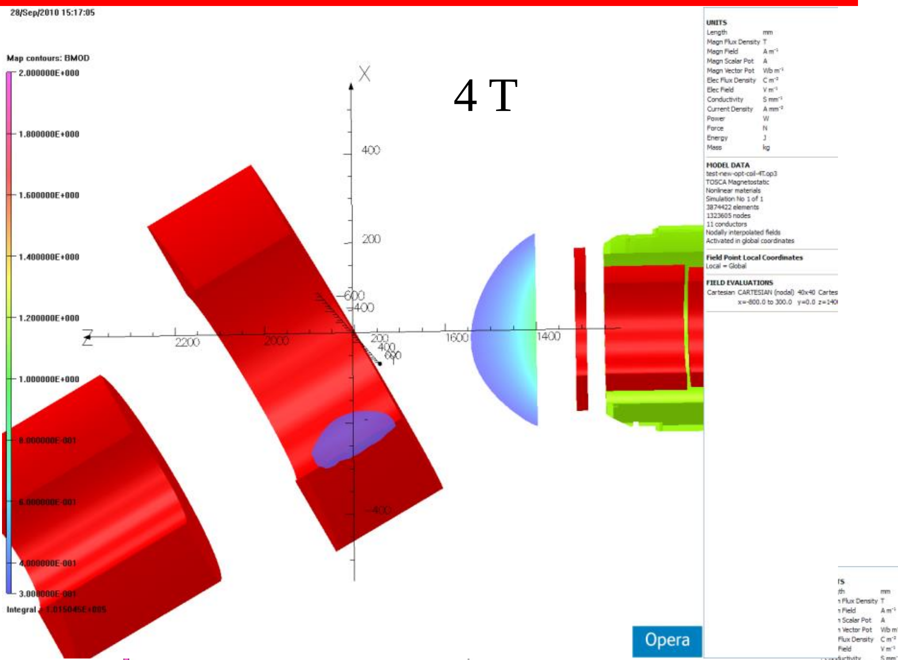
- Fringe field coil parameters: inner radius 103.19mm, outer radius 179.19 mm, thickness 25 mm

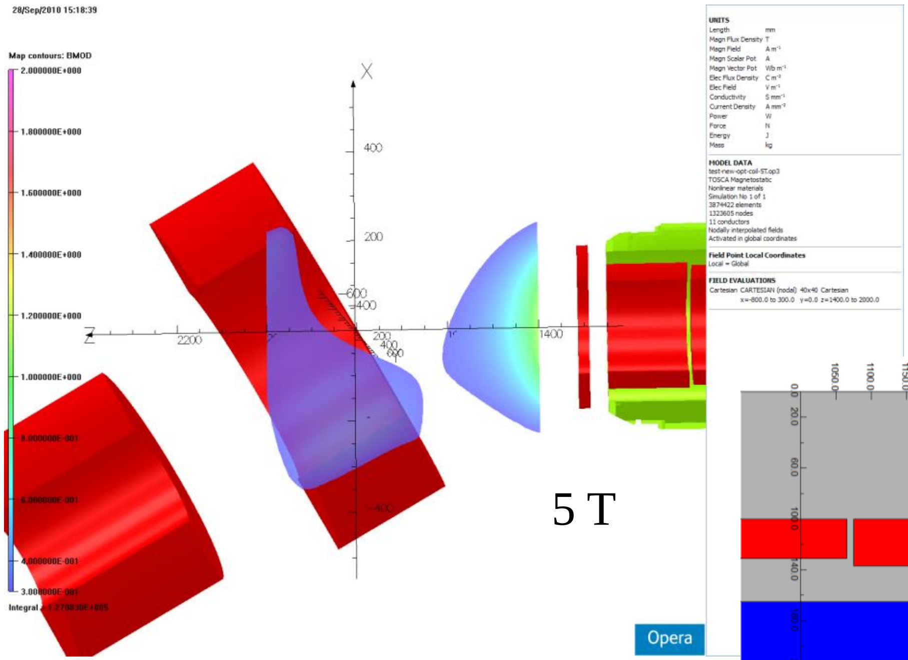
(coil o.d. can be slightly increased)

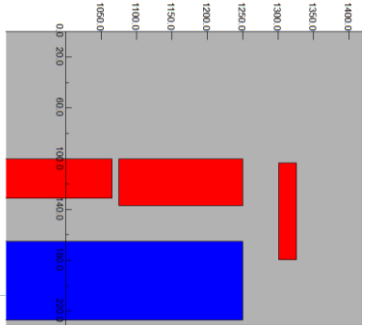
Current Design

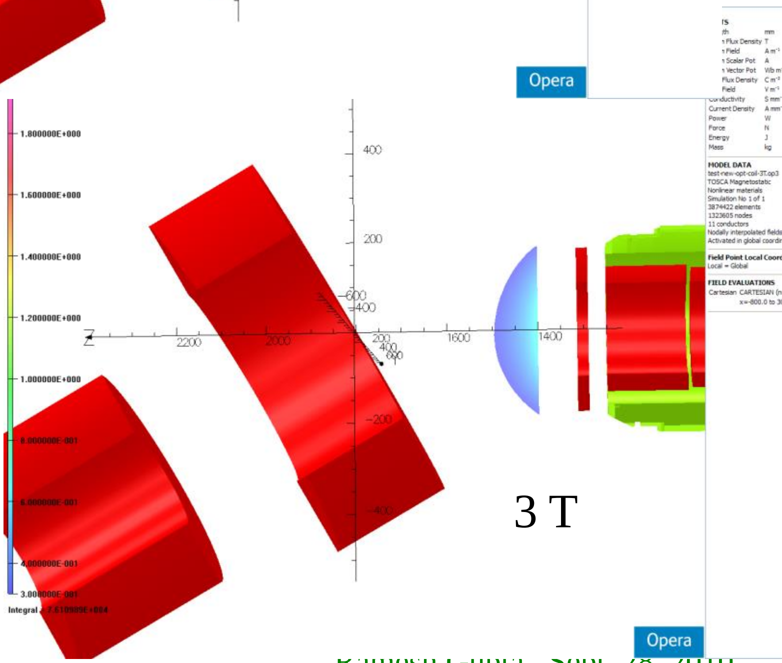
(magnitude of the field at lower main field)

- Obviously there is not enough power in the fringe field coil to generate >0.3 T at lower fields.
- Solution: increase the size
- Also see if we can power the fringe field coil independently while maintaining good field quality





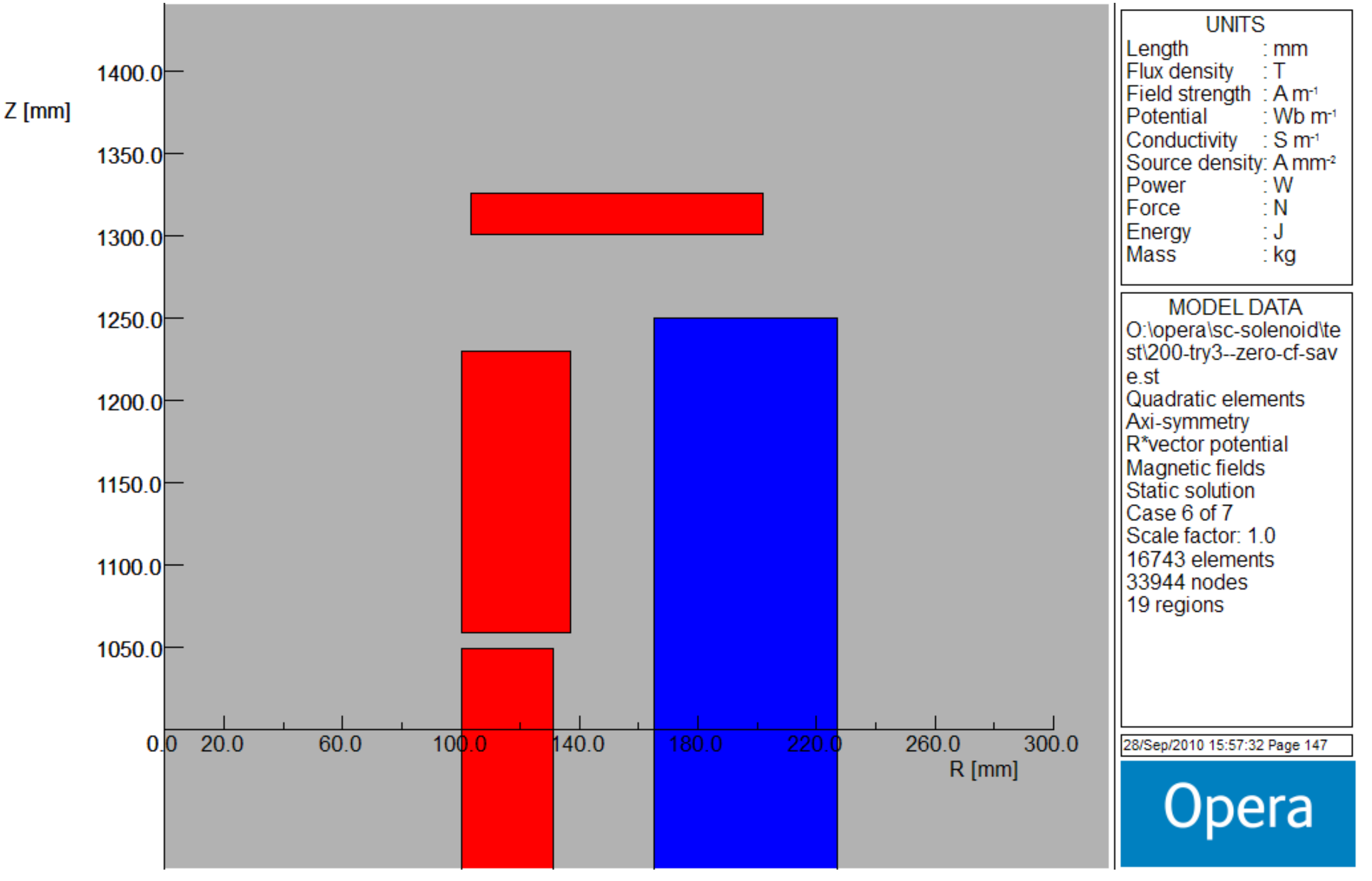




Proposed Design

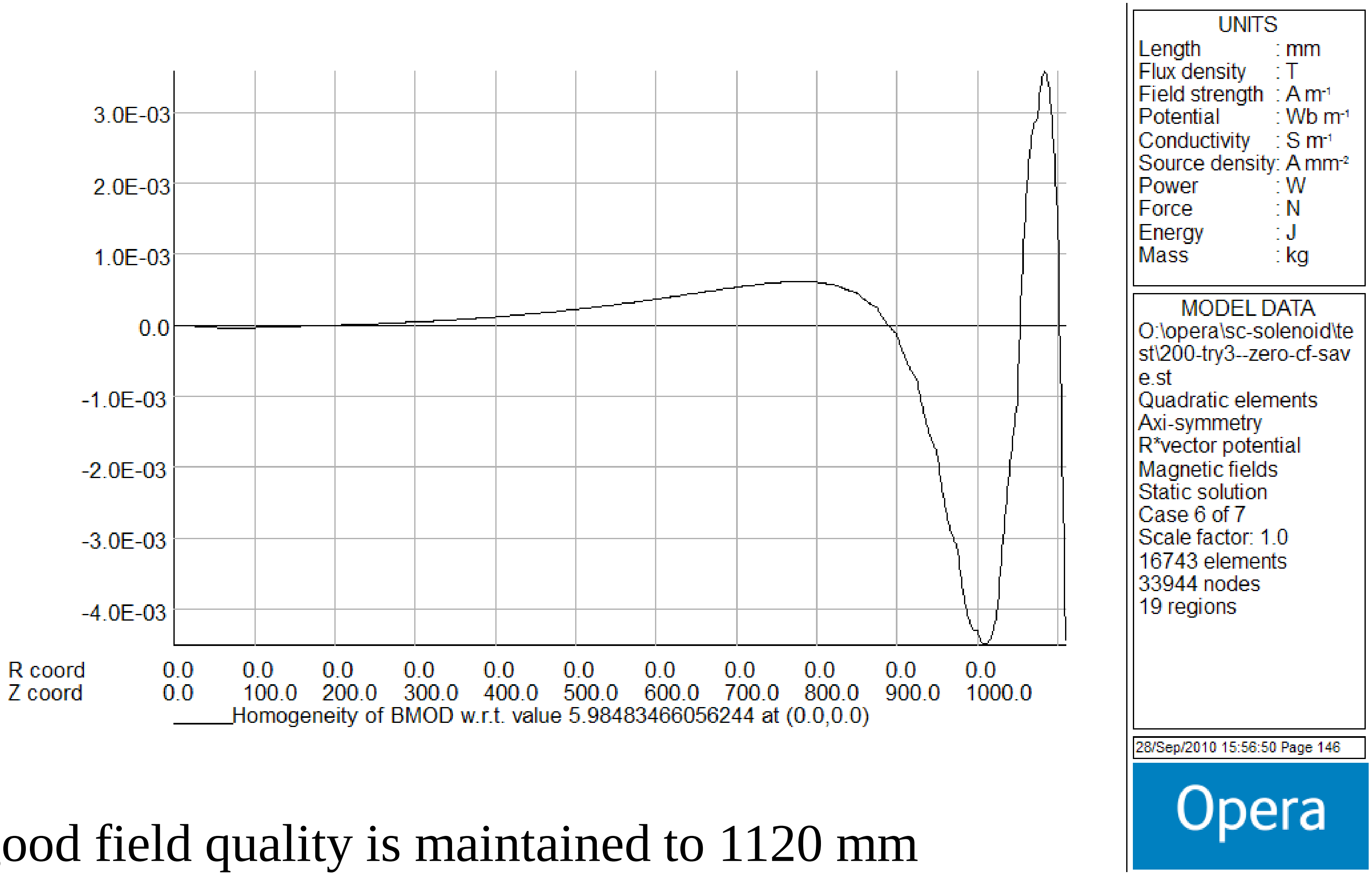
- Power fringe field coil separately from main coil
- Don’t scale fringe field coil with the main coil and power the fringe field coil near the design current when main coils are running at lower field
- To obtain good field quality inside the solenoid, insert a correction coil within the tube of the main solenoid.
- Let’s see if it works?

Field errors at 6 T with correction coil
(correction coil not powered at 6T)



Additional correction coil not powered and not shown above

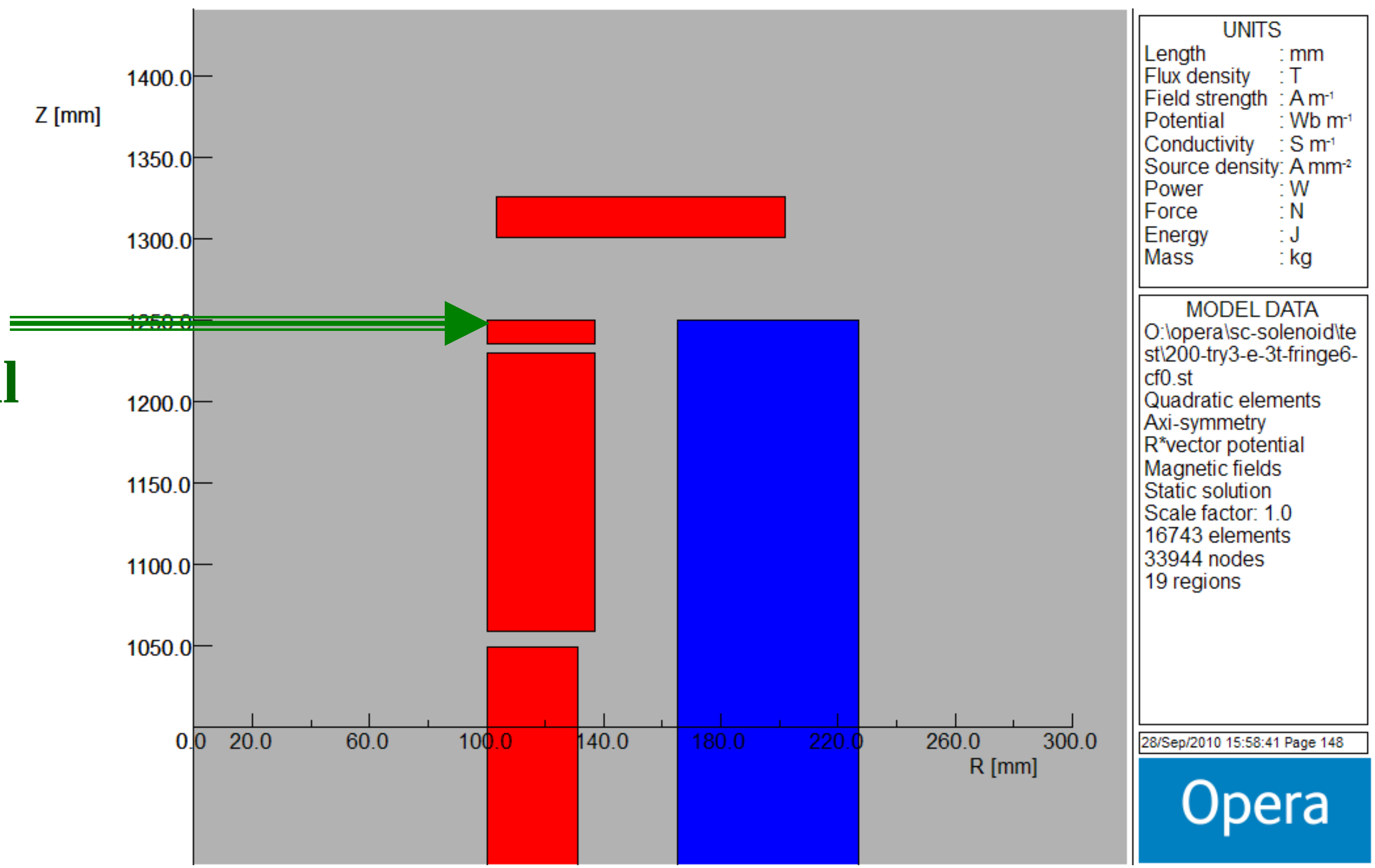
Field errors at 6 T with correction coil
(correction coil not powered at 6T)



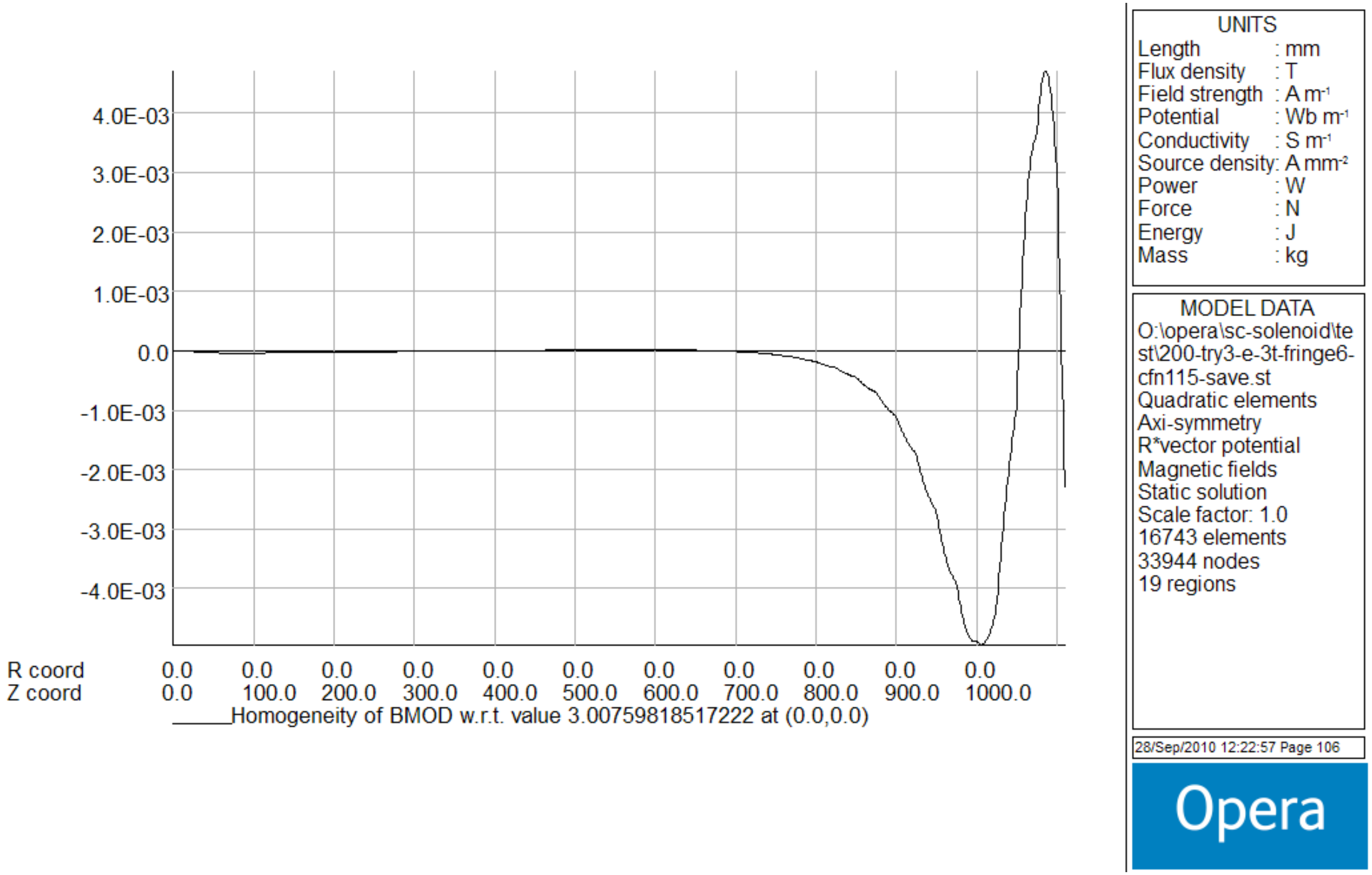
A good field quality is maintained to 1120 mm

Design to Reduce Field errors at 3 T
with additional correction coil

Additional correction coil

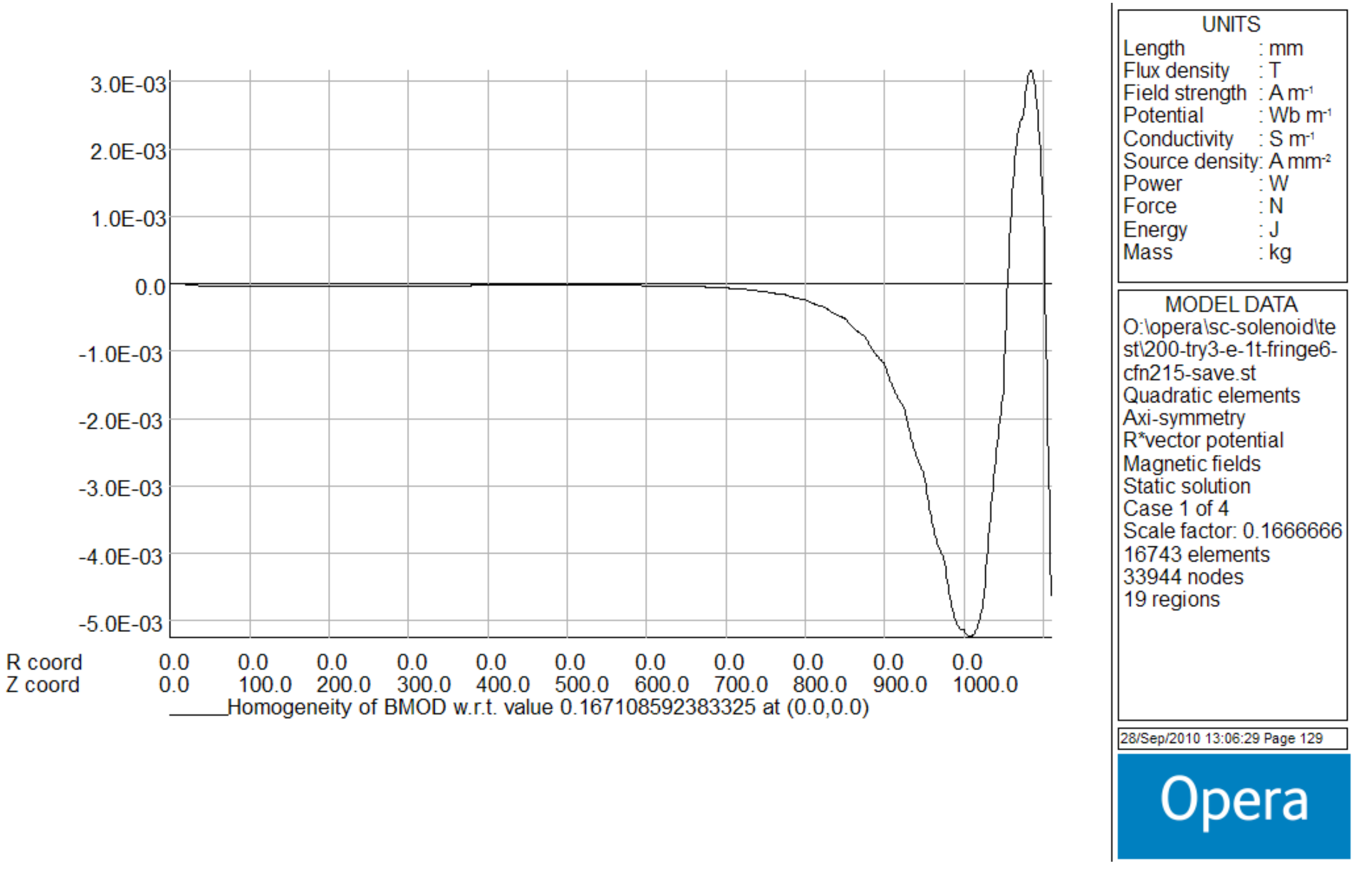


Field errors at 3 T with correction coil



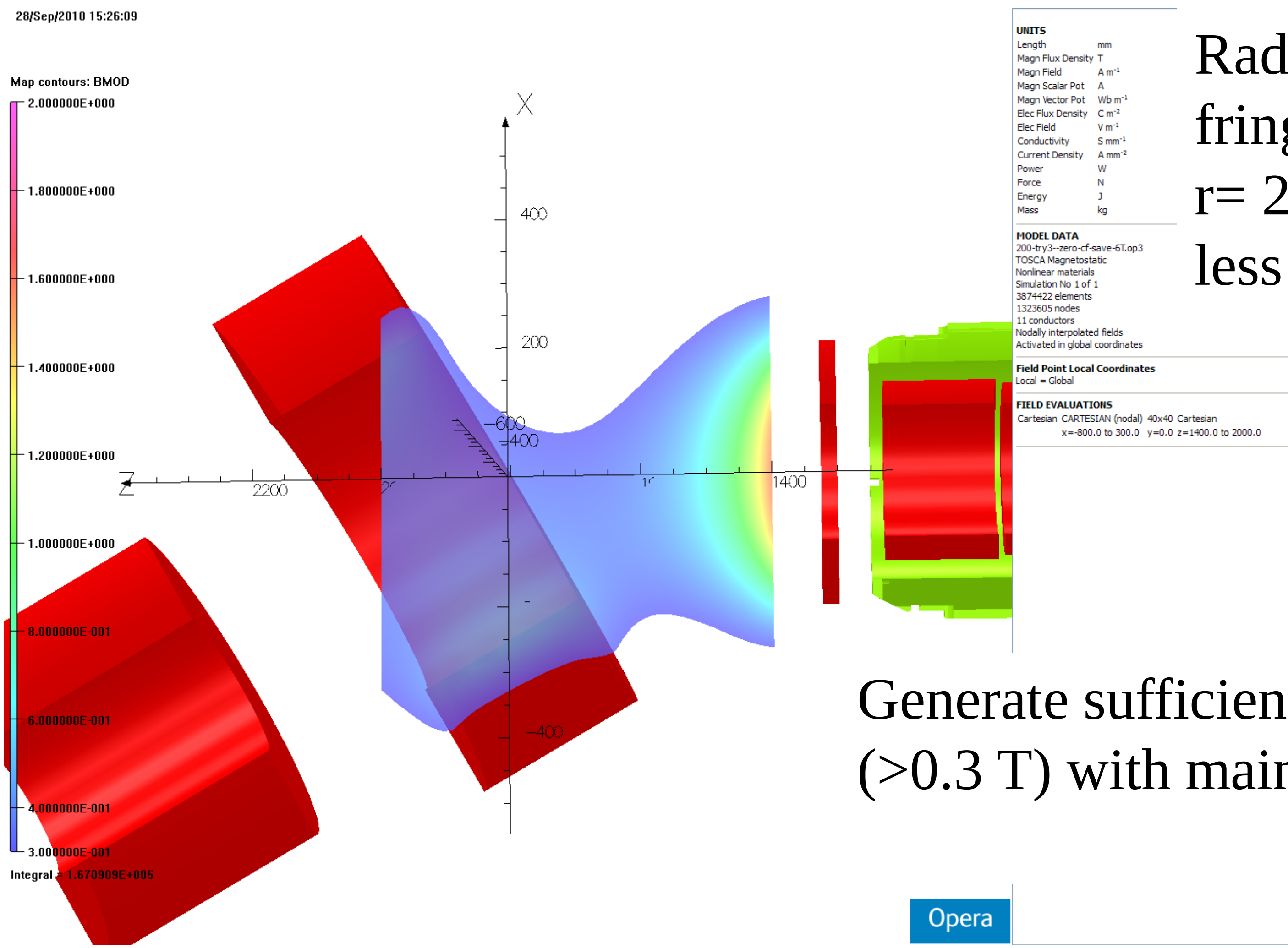
A good field quality is maintained to 1120 mm down to 3 T

Field errors below 1 T with correction coil



A good field quality is maintained to 1110 mm even at very low fields (as low as 0.17 T in case above)

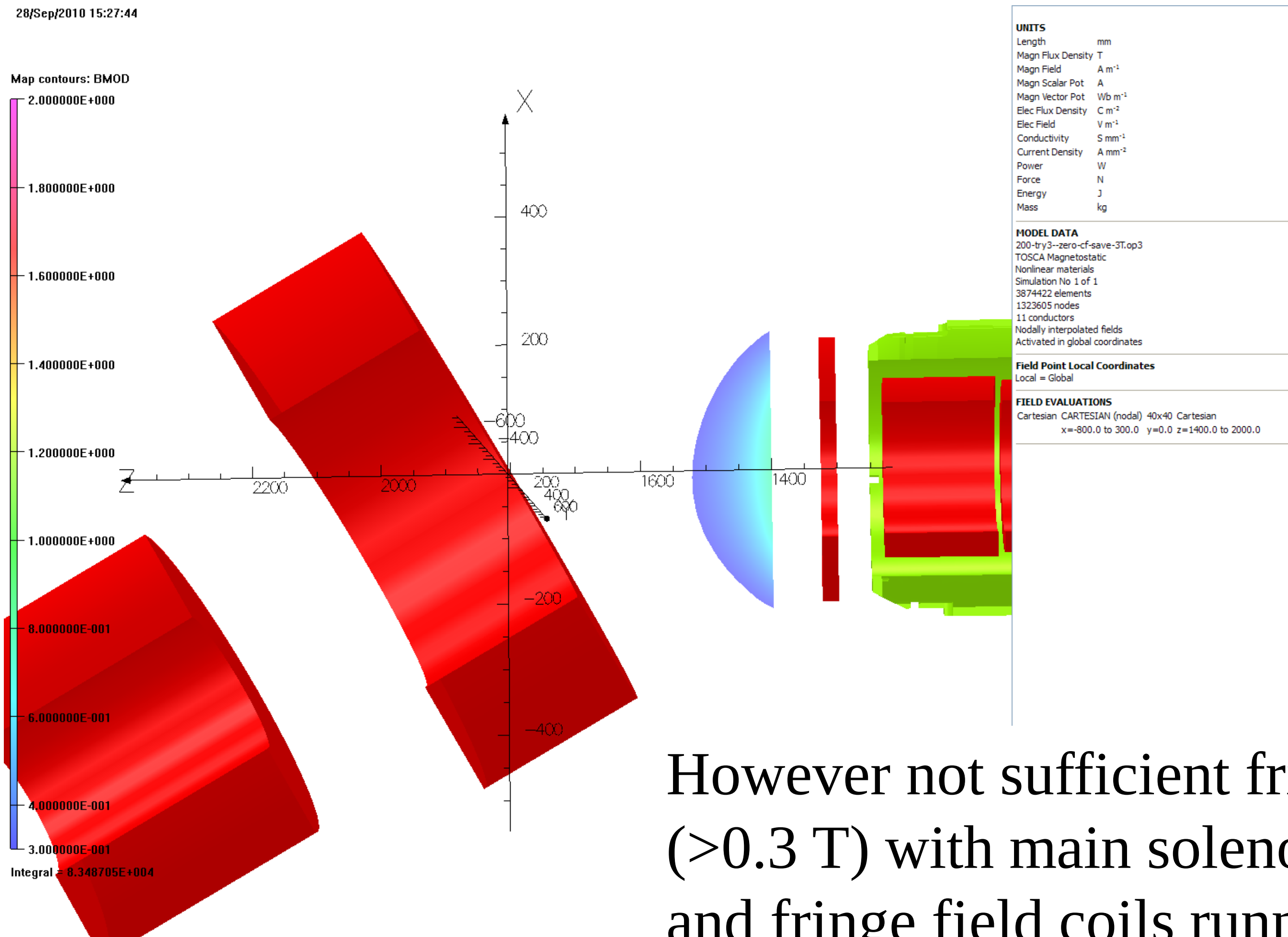
New Design at 6 T



Radial increase in fringe field coil (to r= 202 mm, 25 mm less than the yoke)

Generate sufficient fringe field (>0.3 T) with main solenoid at 6 T

New Design at 3 T

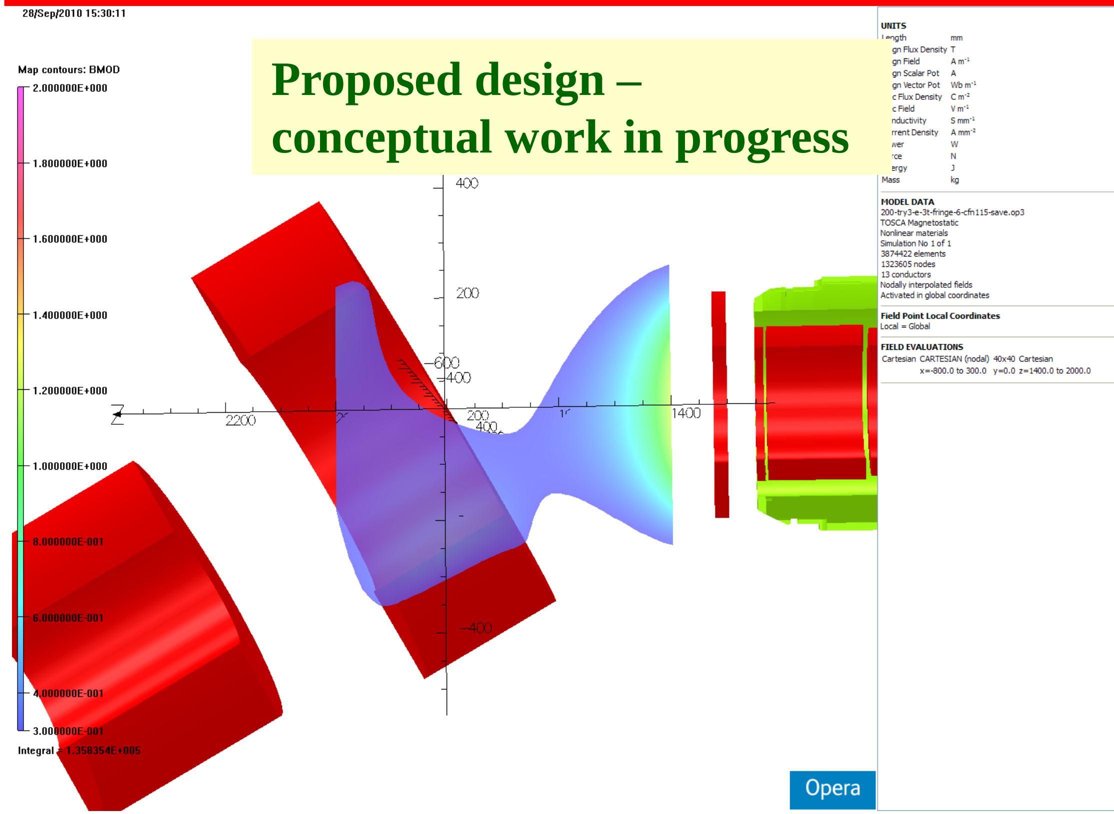


However not sufficient fringe field (>0.3 T) with main solenoid at 3 T and fringe field coils running in series (amp-turns scaled down linearly)

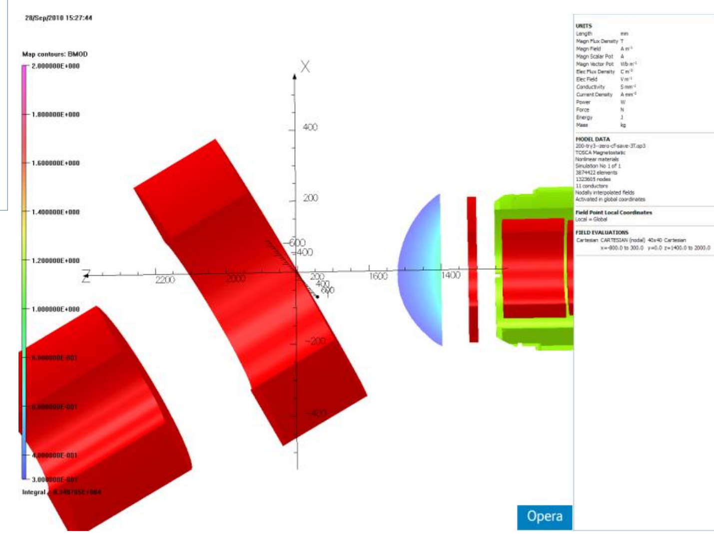
•Next: Get extra field from fringe field coil by powering it to full current

New Design at 3 T
(with fringe field and trim field coils)

Proposed design – conceptual work in progress



- Fringe field coils are powered at the limit of current leads (50 A)
- Trim coils near the main coil powered to maintain good field quality.
- Situation is significantly improved but not enough



<u>Solution under consideration:</u>

- Increase the width of fringe field coil
- Obtain extra space by cutting size of the main solenoid as smaller length can still produce good field quality to +/-1050 mm

Summary

- It is possible to maintain good field quality inside the solenoid
  - o Relative field errors can be kept at ~5 X 10^{-3} to > +/-1050 mm (even longer length with fringe field coils playing a helping role) at all fields in main solenoid (1T to 6T).
  - o This has been already demonstrated in the cases examined.
- With fringe field coil running independently, it should be is possible to obtain >0.3T in the region between superconducting solenoid and room temperature solenoids provided enough amp-turns are allowed in the fringe field solenoid
  - o In this case, additional correction coils running on a separate power supply will be required to maintain good field quality inside the main solenoid.
  - o It may be necessary to reduce the length of the main solenoid (estimated by 25 mm on each side) to allow enough space for enough-amp turns in the fringe field coil.
  - o Higher amp-turns in fringe field coils are needed when the main solenoid is running at lower field (say 3 T, or even 1T) as the leakage field becomes smaller when the main solenoid and room temperature solenoids are running at lower fields.
- We need to demonstrate that we can maintain both good field quality and required fringe field for 3 T (1T?) to 6T in main solenoid. It appears possible in principle but we need a consistent design meeting all magnetic, mechanical, electrical and cryogenic requirements. We need it soon.