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Magnet Division

Small Bore 3-d Magnetic Design

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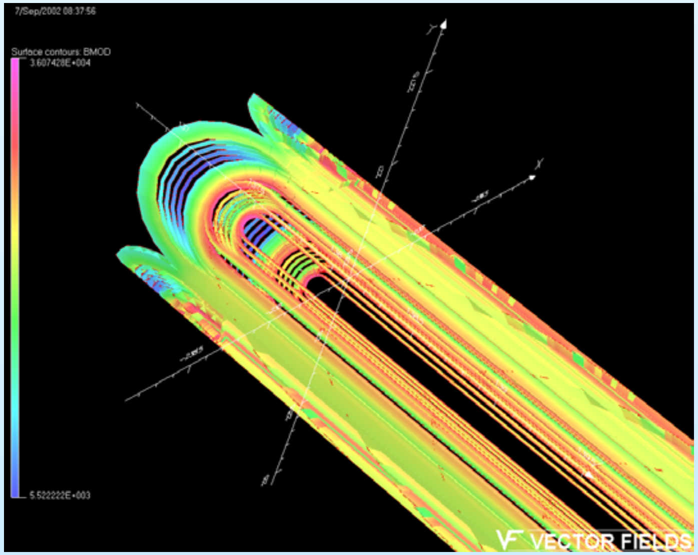
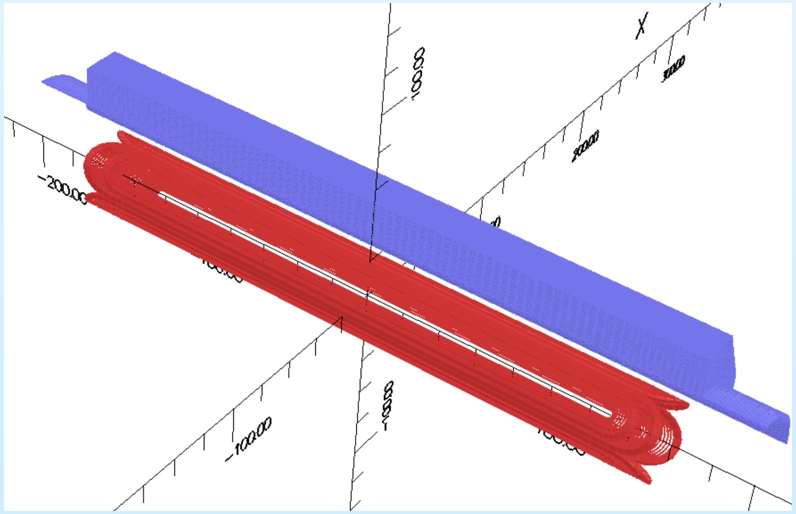




Outline of Presentation

Emphasis will be on the progress since the last review rather than the repetition, except where necessary

- Field harmonics in the ends
  - Including profile along the axis
- Reduction of peak fields in the coil ends
- 3-d calculations with iron yoke and cryostat
  - Yoke saturation and fringe fields

Codes Used in Optimizing and Analyzing Ends

The following are "in house" codes for end optimization:

(CERN advises that the ROXIE can not be used for this application).

CNSTND15: Used for first turn. Starting ellipses. Designs end post.

CNSTND22MB: Designs relative mechanical layout of all turns.

Optimize tilt and deviation from constant perimeter (parameter AKF)

SMINSQ22MB: Minimize harmonics by adding straight sections to turns

ENDHRM22MB: Generates 3-d coordinates of Return end for all turns.

Also generates end spacers and wedge tips.

LENDHRM22MB: Same as ENDHRM22MB but for lead end.

Also extensively used **PARD2DOPT**, a 2-d coil optimization code.

Plus OPERA 3-d, a commercial code for calculations with iron saturation

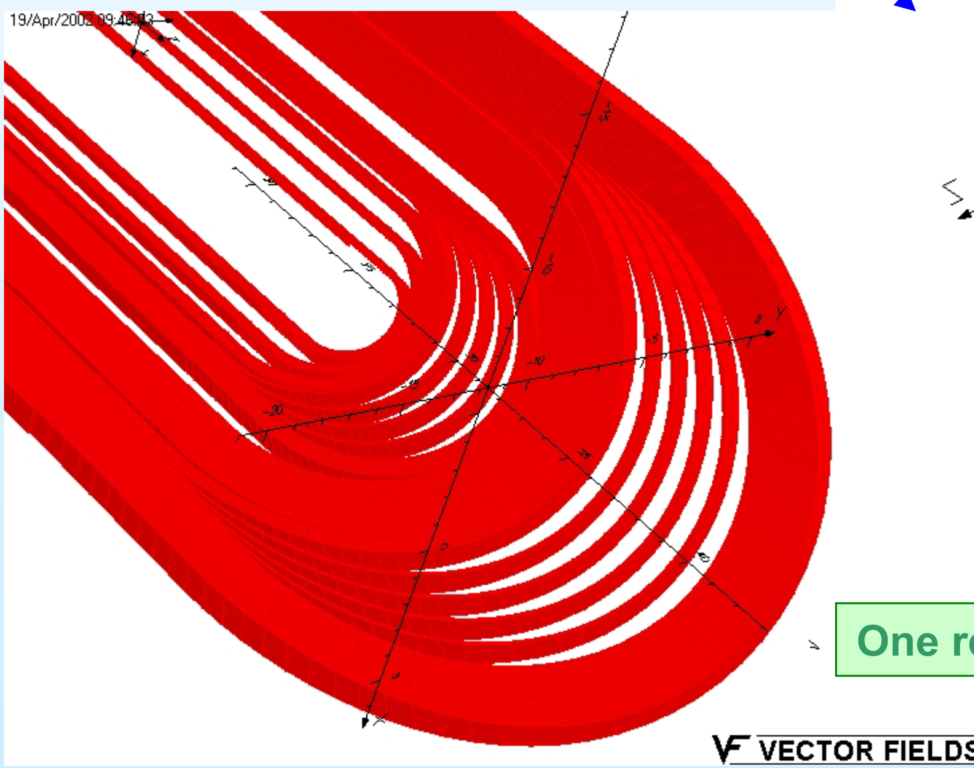
Ends Shown During the Last Review

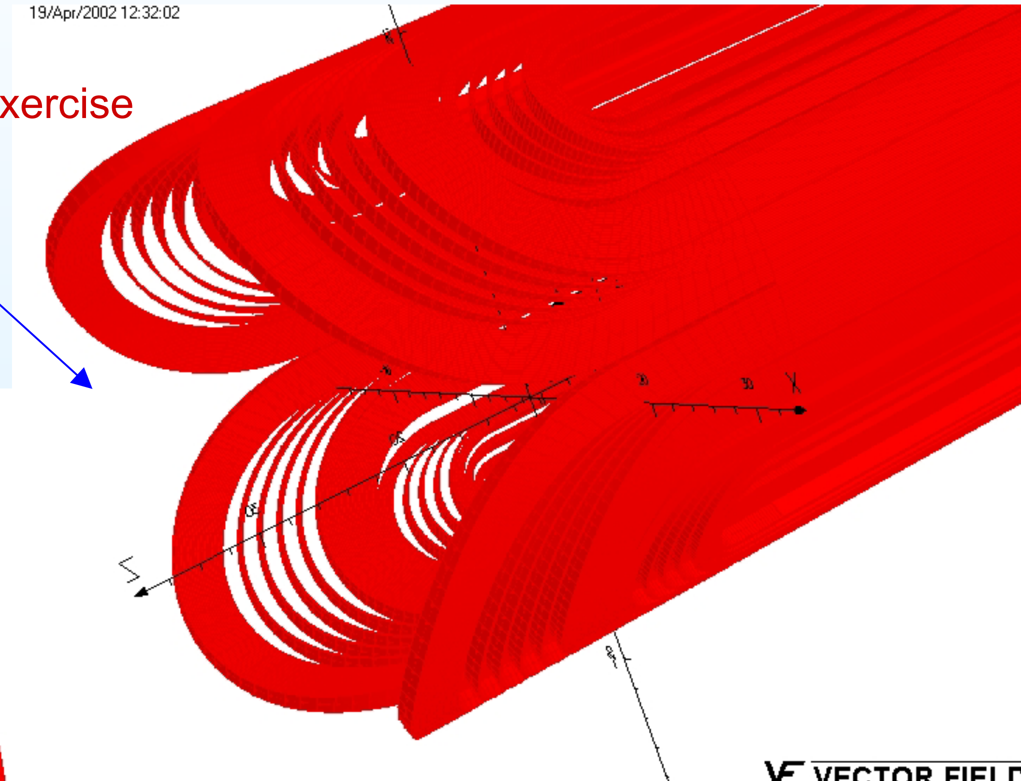
Gerry Morgan was consultant in this project

These ends also served as a tech transfer exercise

Four coils together

One coil





One request was to try different color for the coil

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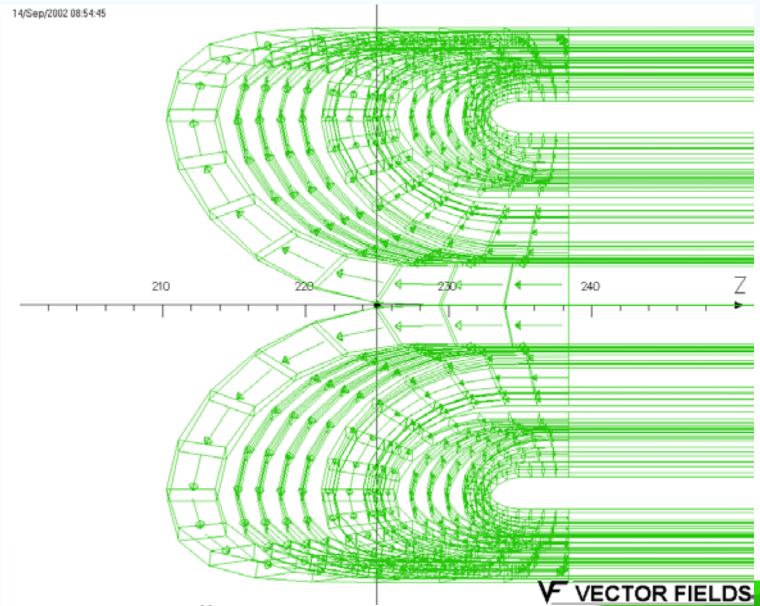
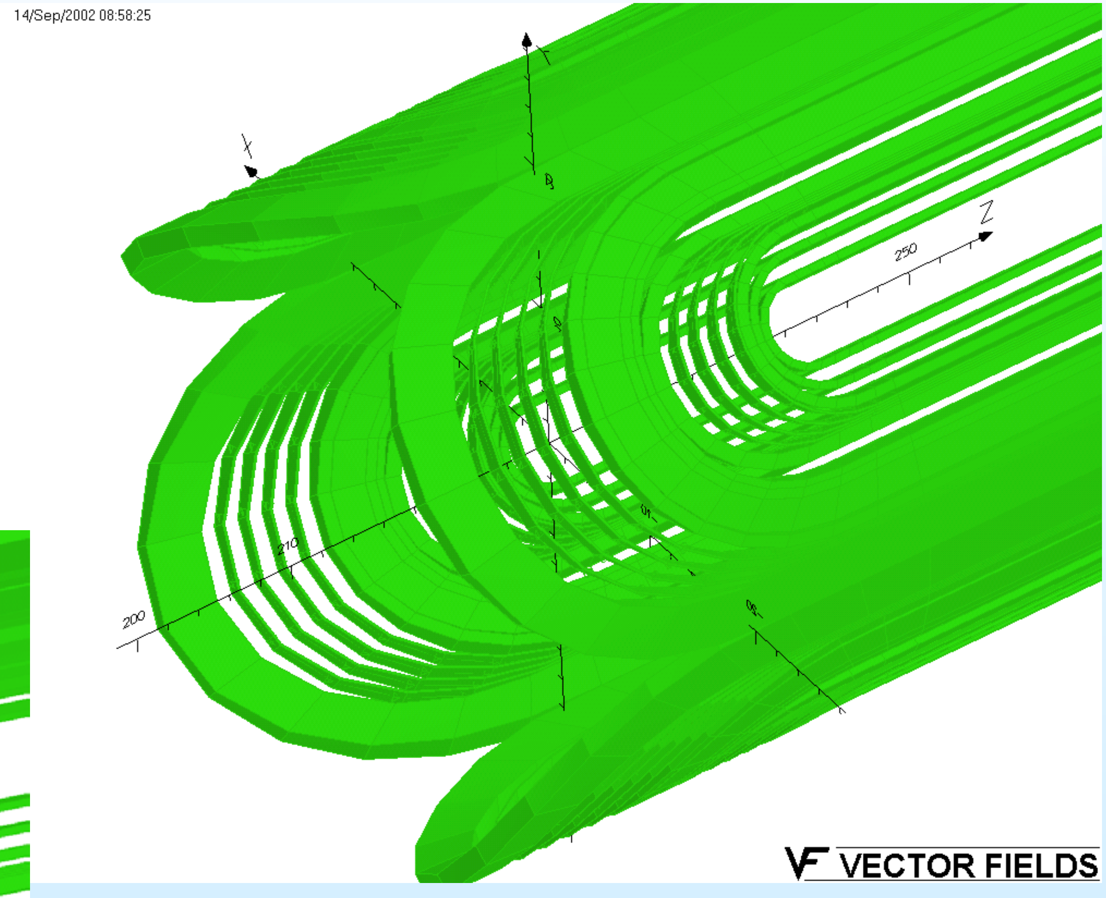
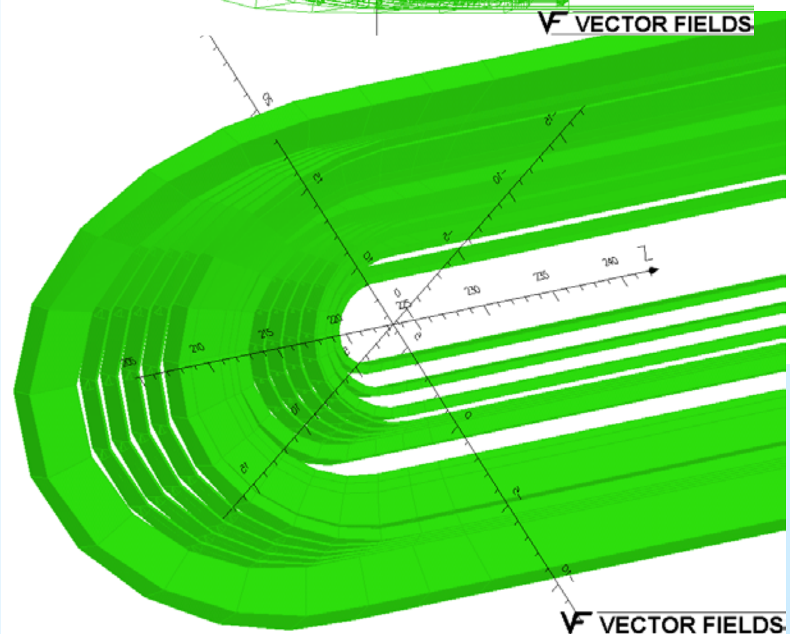
Progress Since the Last Review

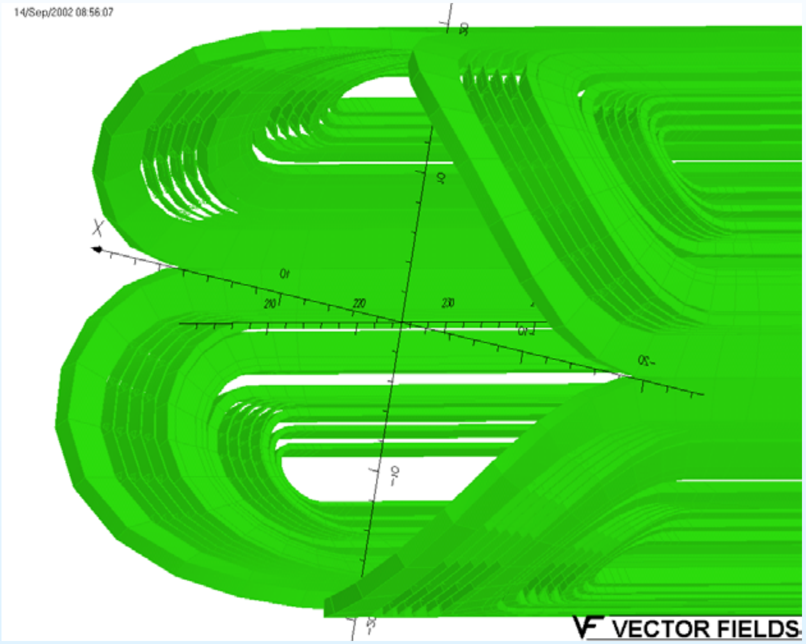


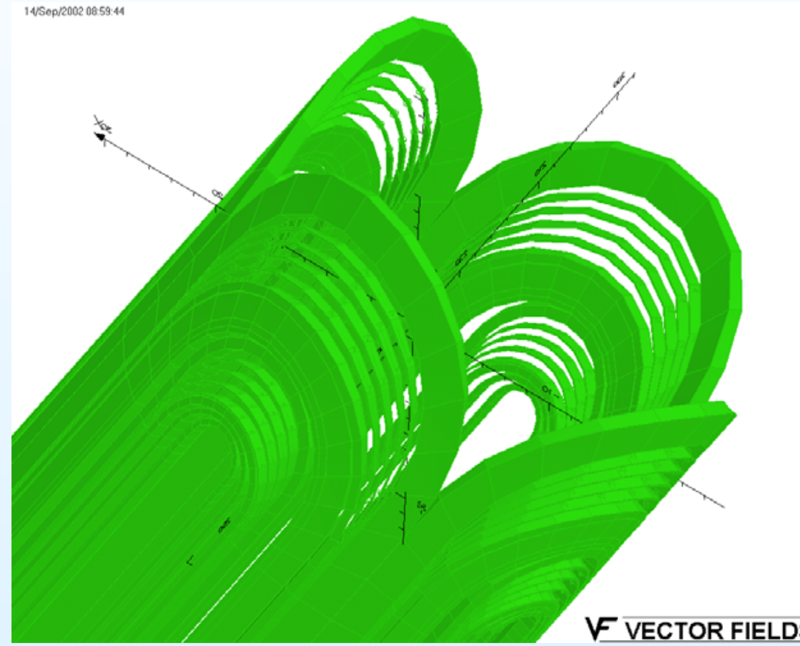


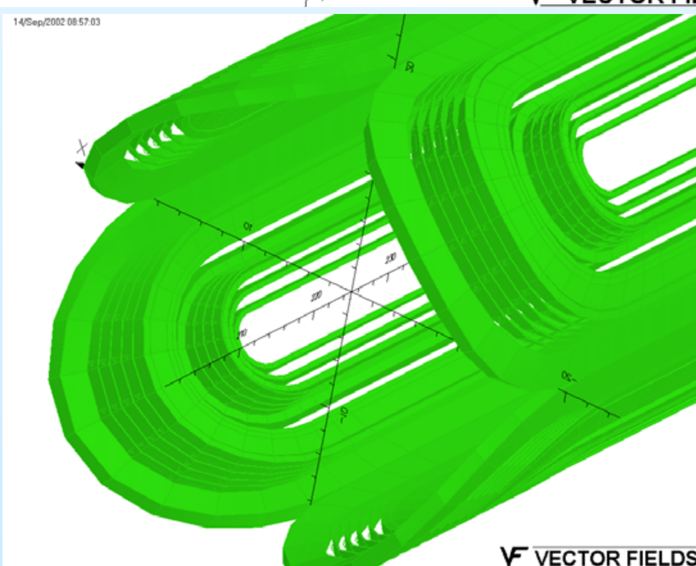


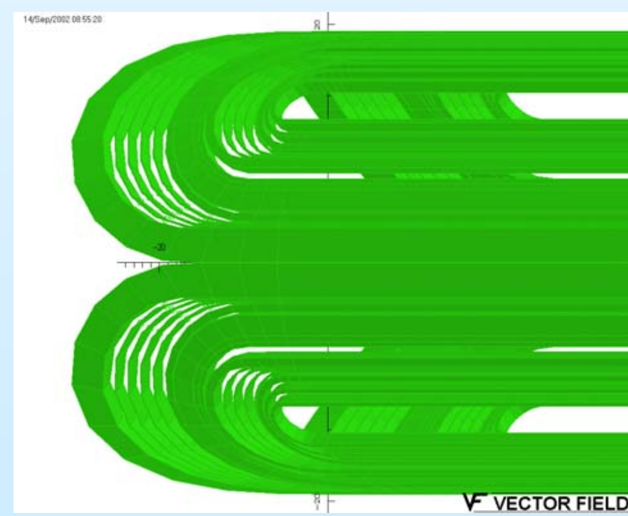
… and we honored the request.

More Views of the Coil Ends









Block Structure

Straight section (6 blocks, 70 turns):

30 20 10 4 3 3 (counting from midplane)

3 3 4 10 20 30 (counting from pole)

End section (8 blocks, 70 turns):

10 5 8 4 13 4 6 20

(counting from pole)

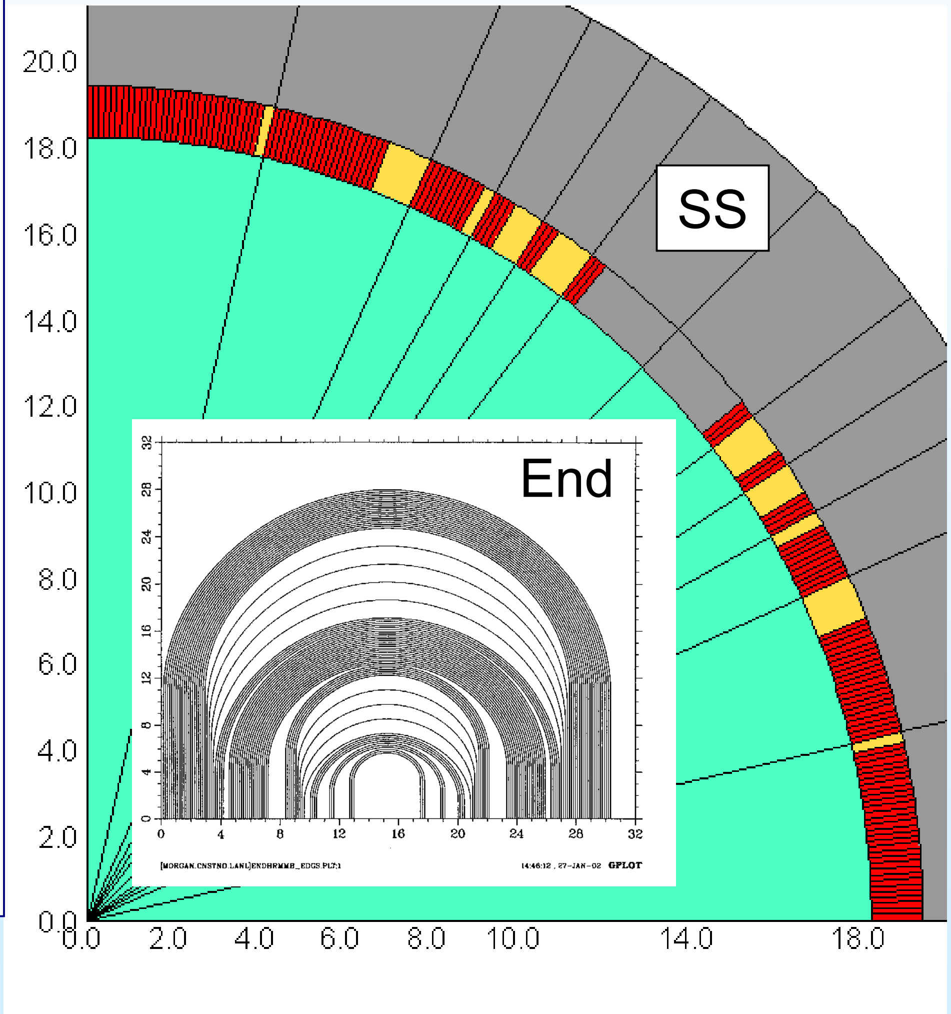
Straight section => pole

3,3,4 => 10

4,10, 20 => 5, 8, 4, 13

30 => 4, 6, 20

Must avoid large Ultum spacers (subdivide, if necessary)



Equal spacing in “Red Color” blocks is used as harmonic optimization parameters

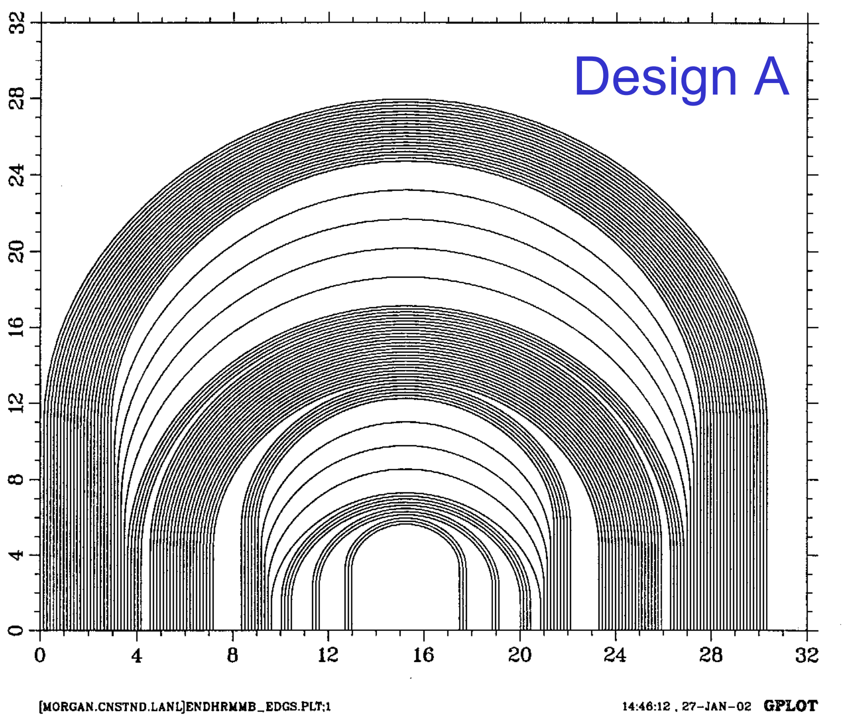
Silent Features of the Current Design

- The design is well optimized for low harmonics in the Ends.
- Mechanical turn layout is developed based on prior experience
- Large radius means lower tilt and lower strain on cable in ends

    In this design the tilt (< 4 degree) and strain (< 4%) on cable is less than what has been in earlier RHIC and SSC Magnets.

Large bore, however, also means one must deal with large end forces.

End Harmonic Optimization: SMINSQ



Block configuration:

(8 blocks, 70 turns):

10, 5, 8, 4, 13, 4, 6, 20

(counting from pole)

Parameters optimized:

End spacers in block #2 (with 5 turns) and end spacer in block #7 (with 6 turns).

All spacers with in a block have the same size.

Changing the size of two group of end spacers was adequate to get all harmonics small.

Computed values:

B_5< 1 unit-meter;

B_9 and B_{13} <0.1 unit-m

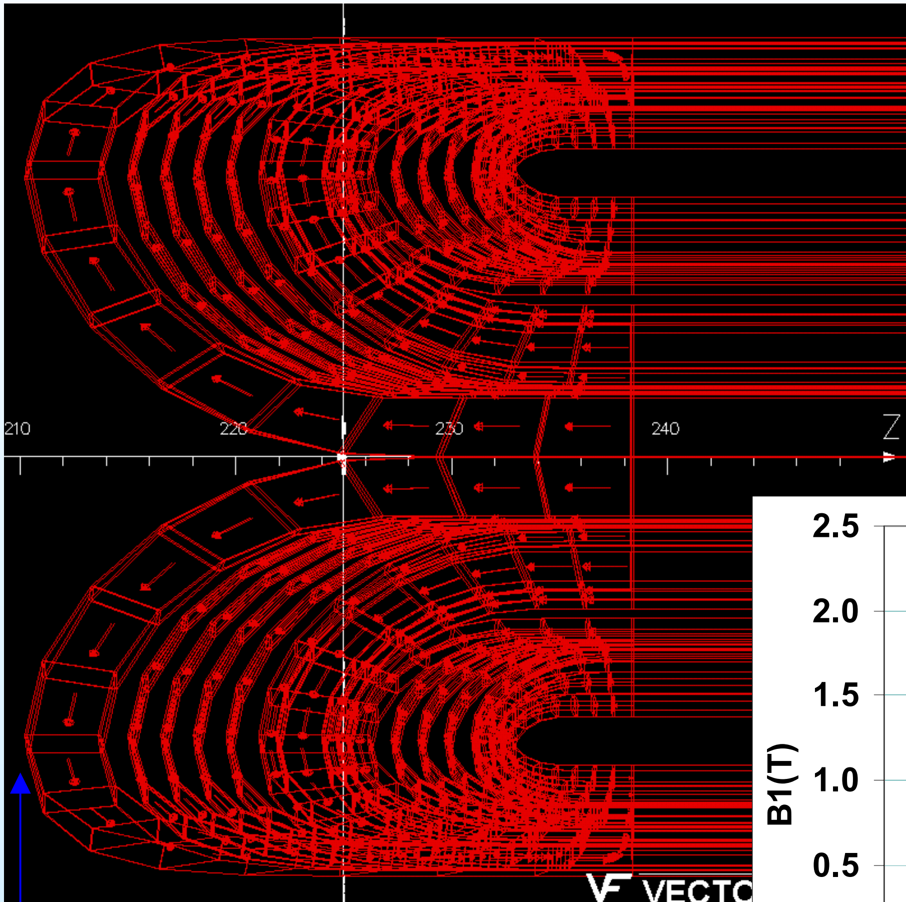
Effective Magnetic Length ~15.6 cm

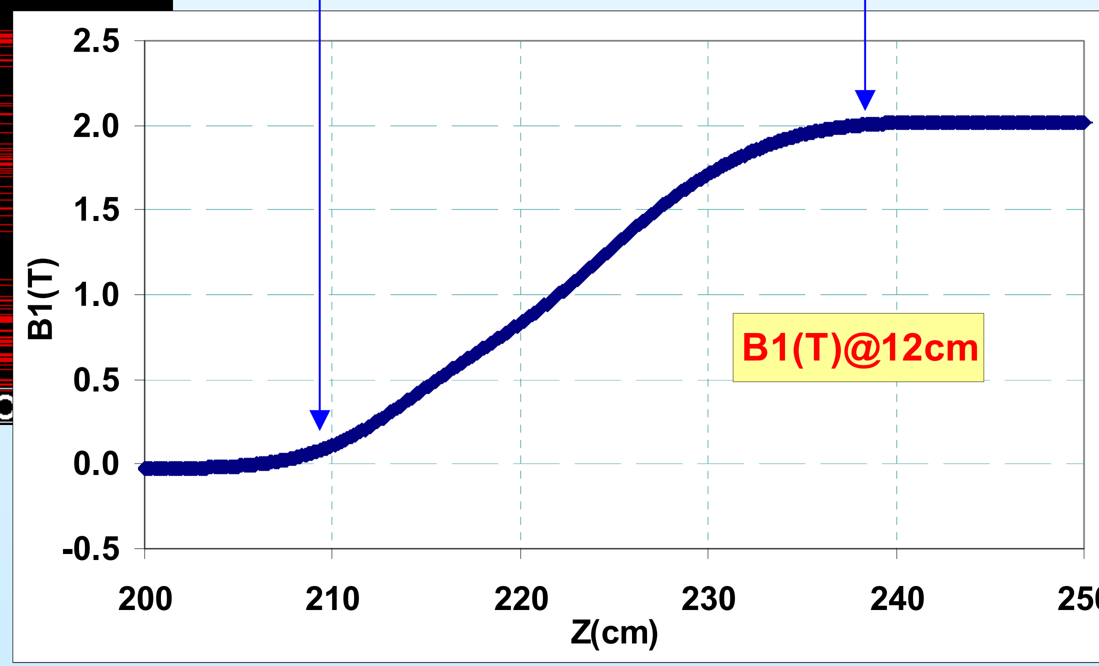
Mechanical Length ~28 cm + End Saddle

Field through the Coil Ends

Mechanical length of this end (including end saddle) ~34 cm : ~ 2 coil diameters

Contribution to magnetic length ~16 cm





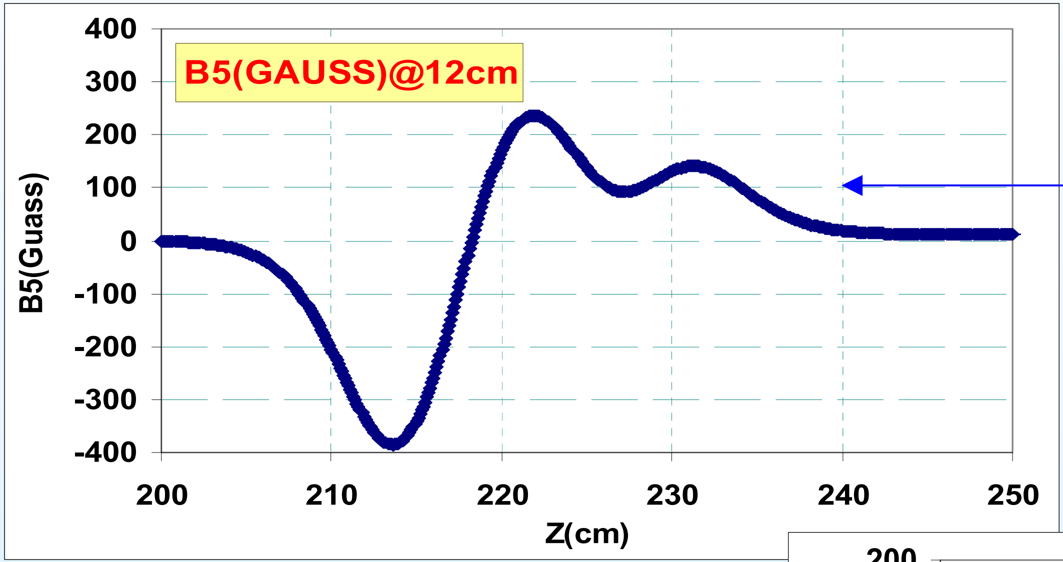
Last turn

END=>SS

Last turn

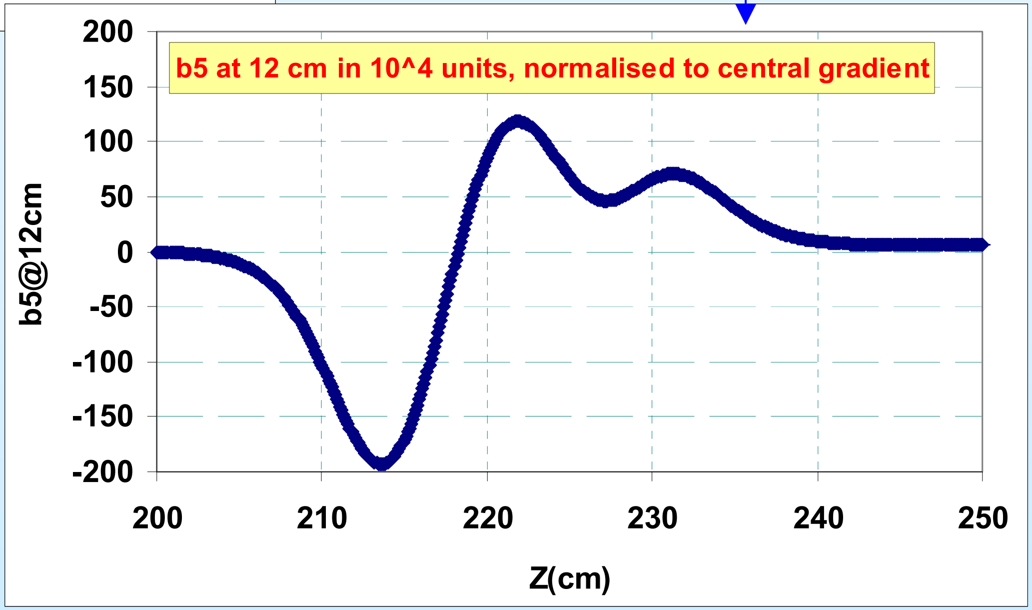
END=>SS

Field Harmonics through the End
b_5: dodecapole



Harmonic in Gauss

Harmonic in Units



End spacers are optimized to produce low integral harmonics

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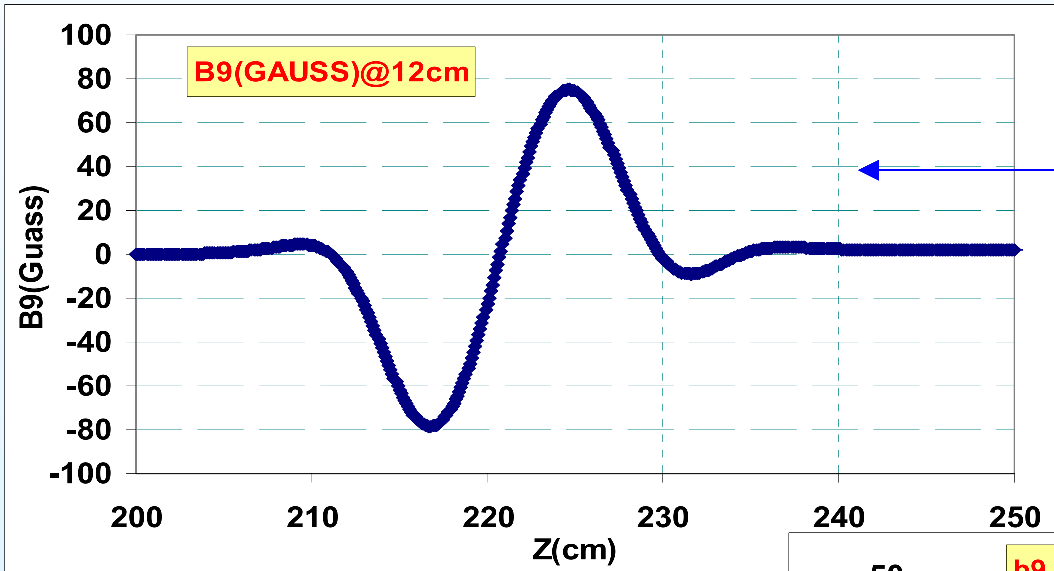
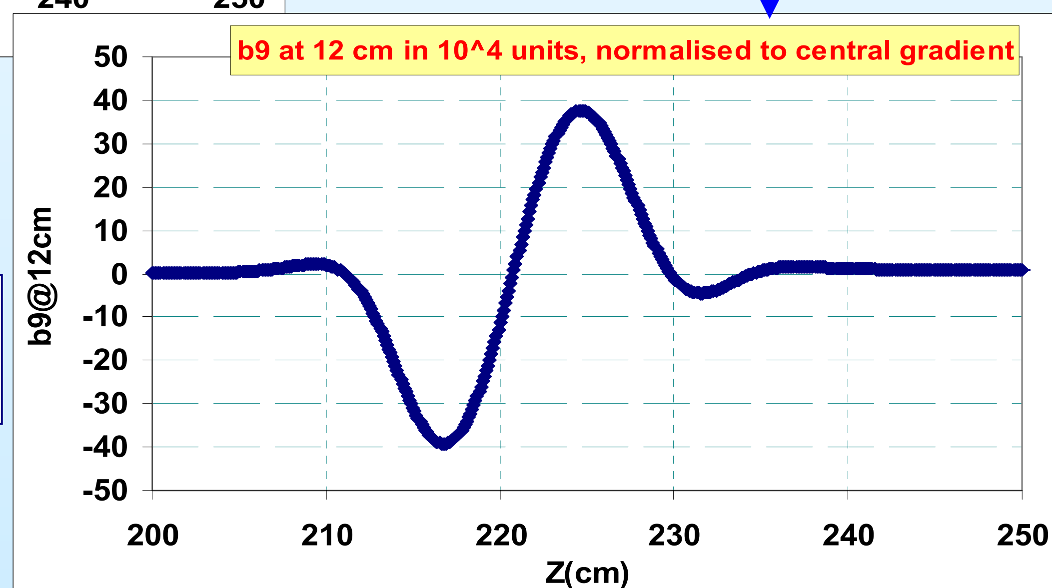
Field Harmonics through the End : b_9



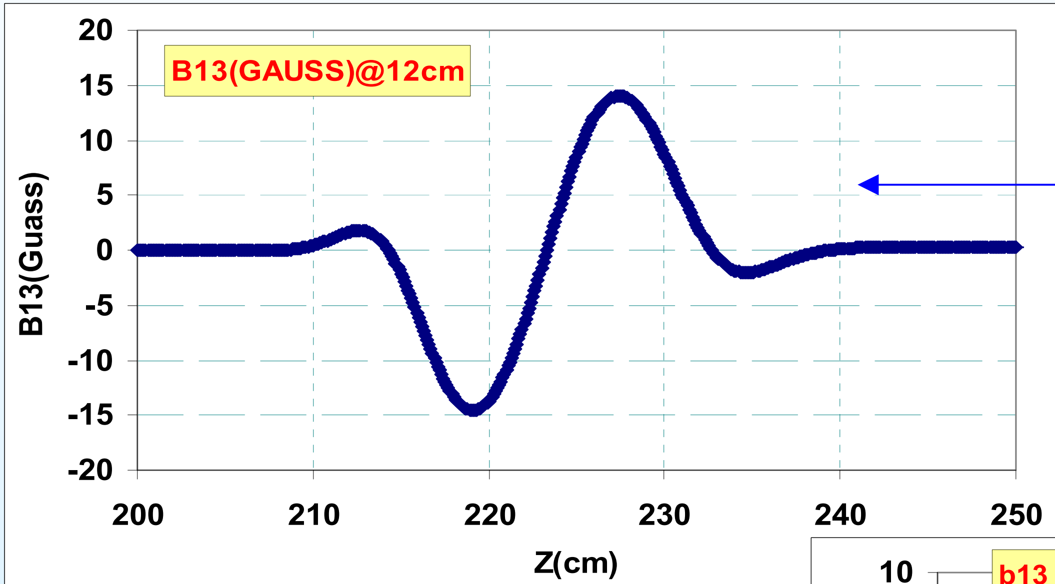
Harmonic in Gauss

Harmonic in Units



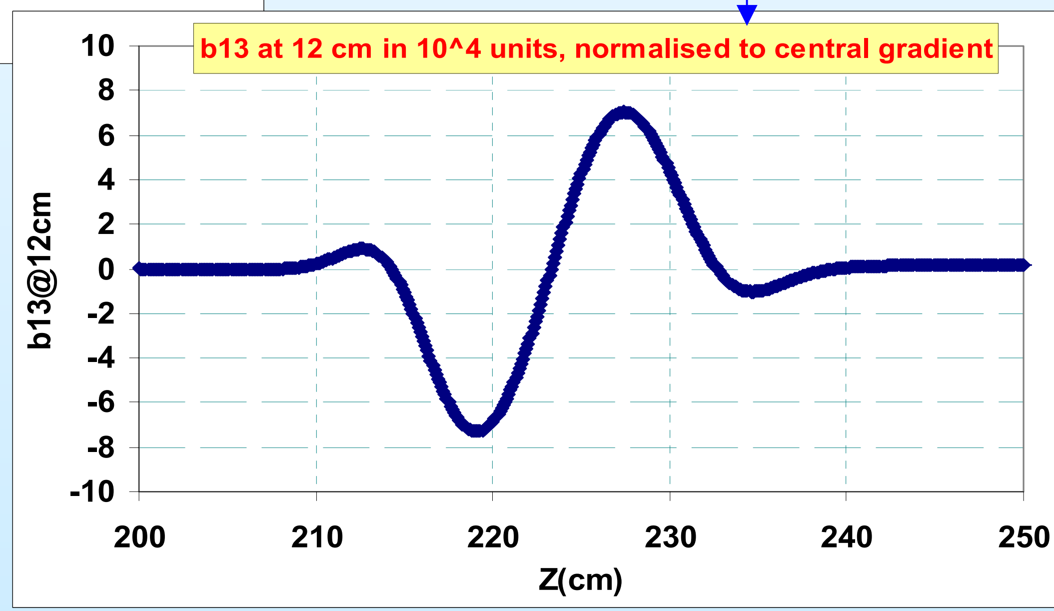
End spacers are optimized to produce low integral harmonics

Field Harmonics through the End : b_{13}



Harmonic in Gauss

Harmonic in Units



End spacers are optimized to produce low integral harmonics

Do We Expect to Meet the Spec?

The current specifications for ends are equivalent of 5 unit of straight section for b_5 and 1 unit for other harmonics.

1 unit for 3 meter magnet => 3 unit-meter in ends

Do we Expect to meet the spec for End Harmonics?

YES for B_5, B_9 and B_{13} and also most other harmonics.

This is not only from the theoretical calculations but also based on our experience with SSC and RHIC Ends.

For A_2 and B_2 we need to study the influence of leads and of coil length mis-match but we think it should not be a problem.

Peak Field in the Ends

As mentioned in the last review, the peak field in the current ends is higher than that in the body.

Here, we present the work in progress to re-design the ends.

Note: The cable tilt and strain will not change much, only the layout will.

In cosine theta magnets, the conductors in the ends are more strained and the mechanical design is generally less robust.

Therefore, we like peak field in the ends to be less than that in the body of the magnet so that there can be a larger conductor margin there.

In this application, the ends are subjected to lesser heat load(?)

Does this mean that even if ends have some what less computed short sample, they may still have larger operating margin?

At this stage we would try the ends to have a similar margin as that in the straight section of the magnet.

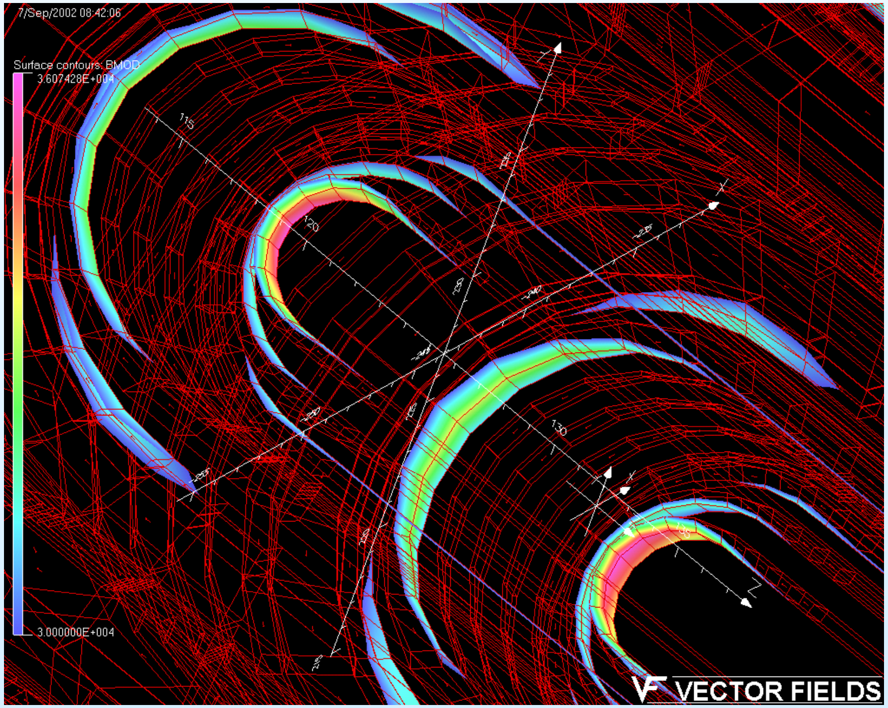
The issue is mechanical length Vs. magnetic length of the magnet.

Reductions of the Peak Fields in the Ends (Summary Slide)

OPERA3d Calculations for coil only

Design presented in the last review

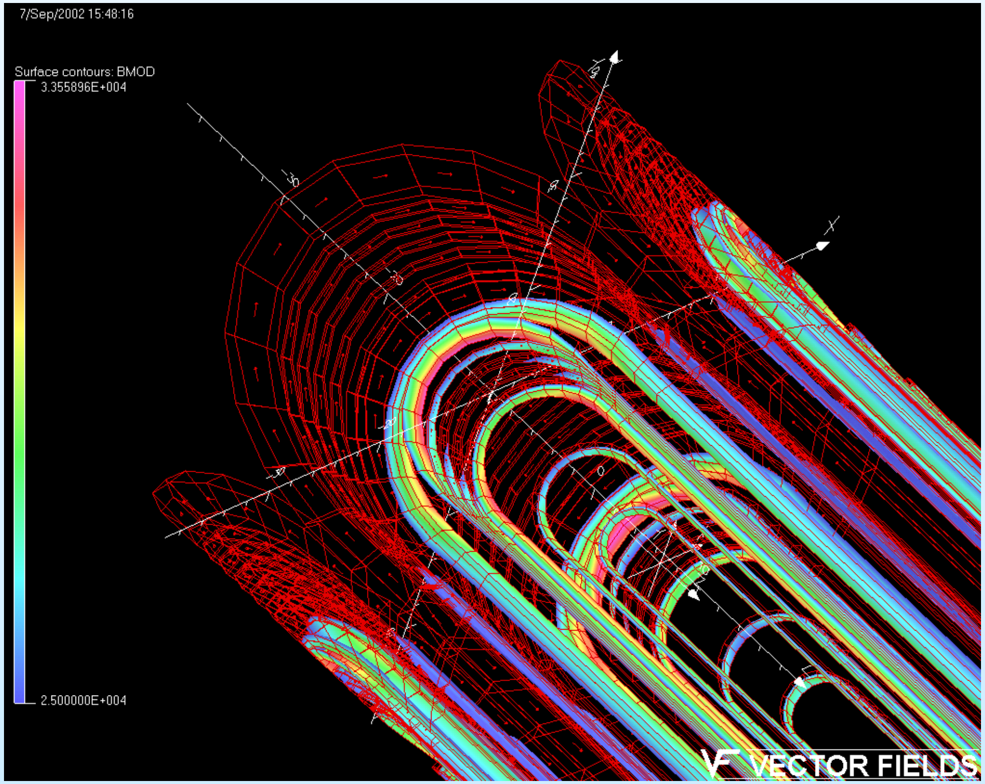
Peak Field =3.61 T



Peak Field in S.S. ~3 T
(more accurate calculations give lower)
Grad = 13.4 T/m, radius = 18cm
Field @ coil inner radius ~2.45 T

Two pole spacers reduce peak field
=> 3.61 T to 3.36 T

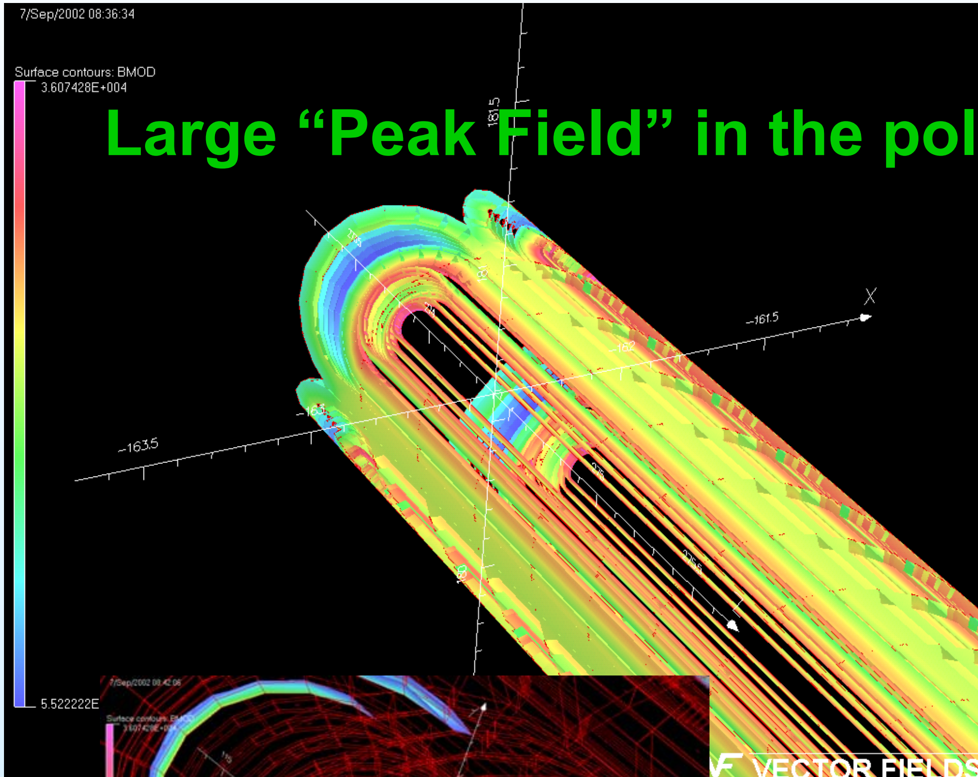
Three readjusted spacers
=> 3.61 T to ~3 T

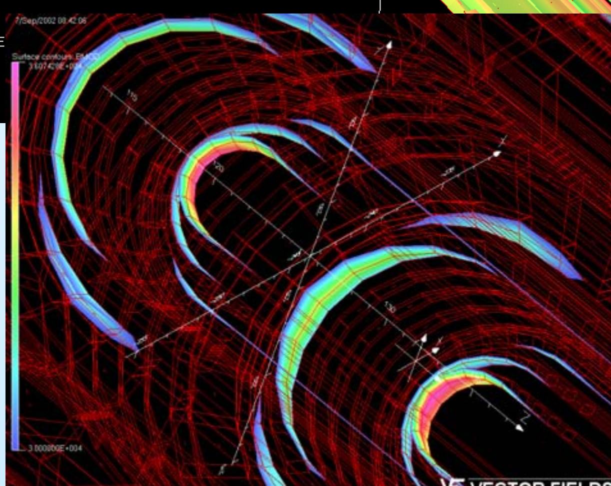


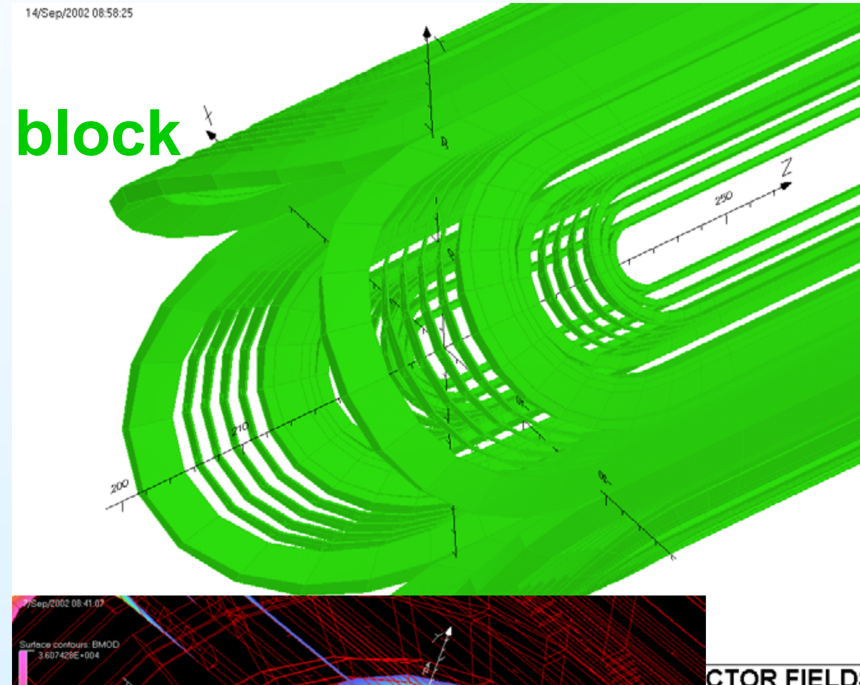
More Views of Peak Field in the Ends

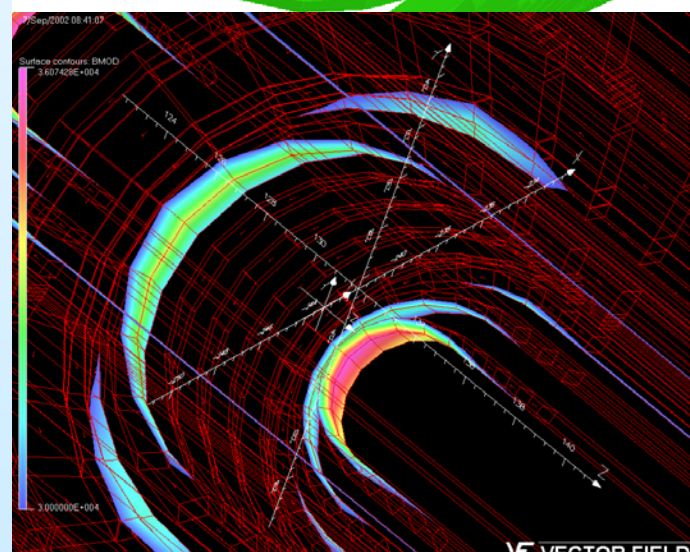
(Improved model of the design presented last time)

Large "Peak Field" in the pole block









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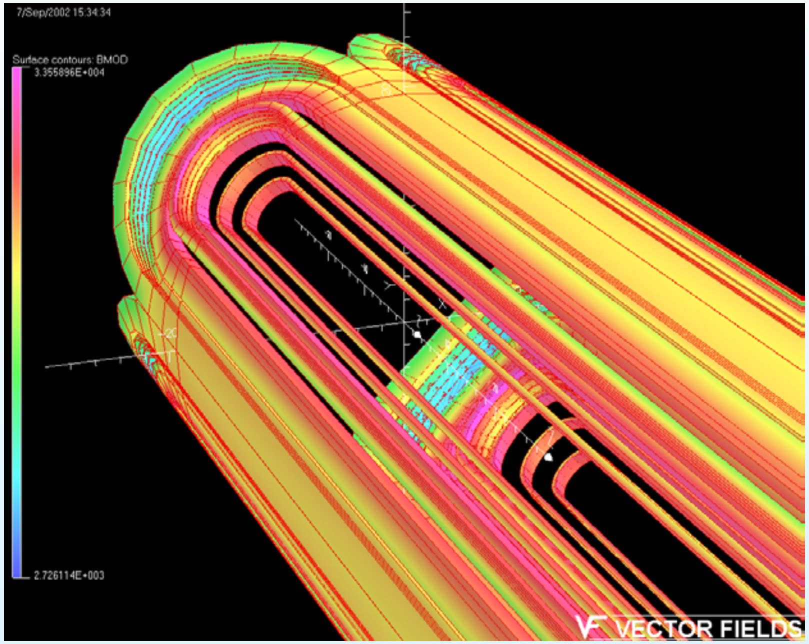
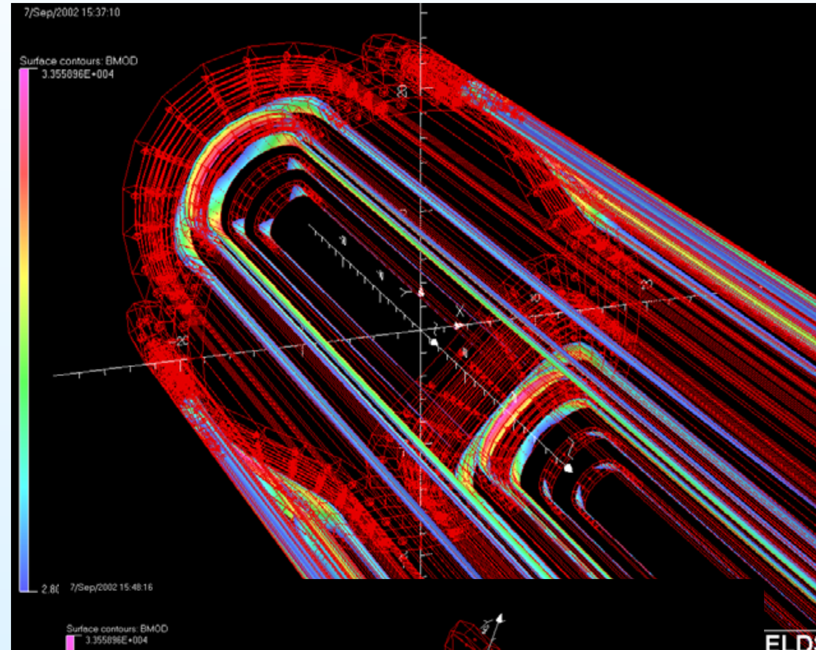
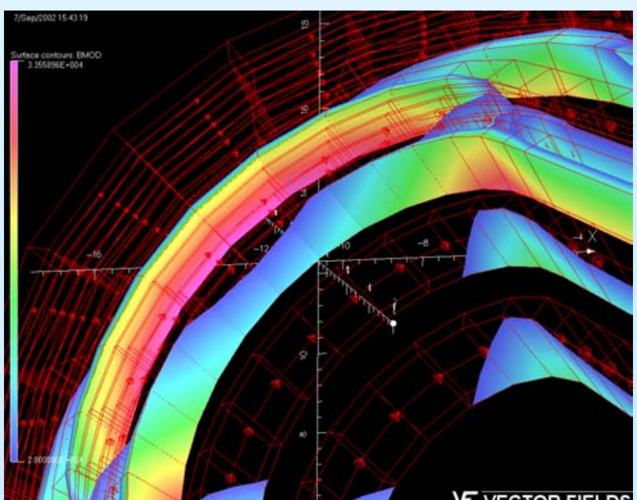
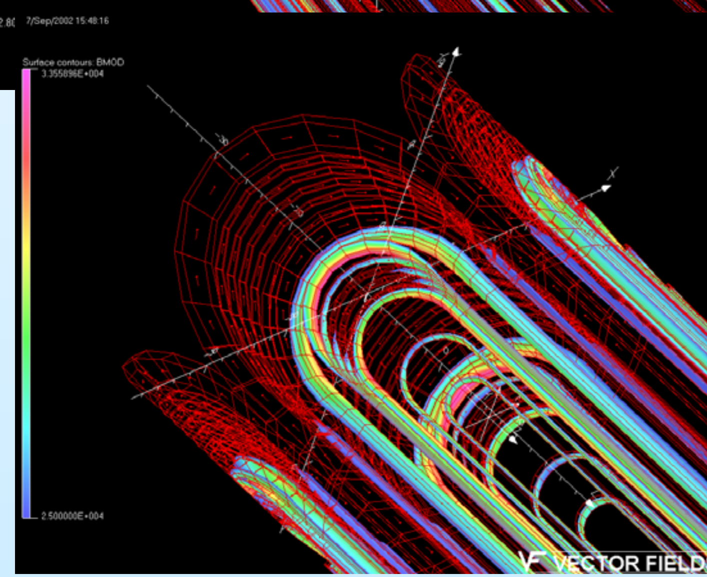
More Views of the Current Model

Spacers to Reduce the Peak Field in the Pole Blocks

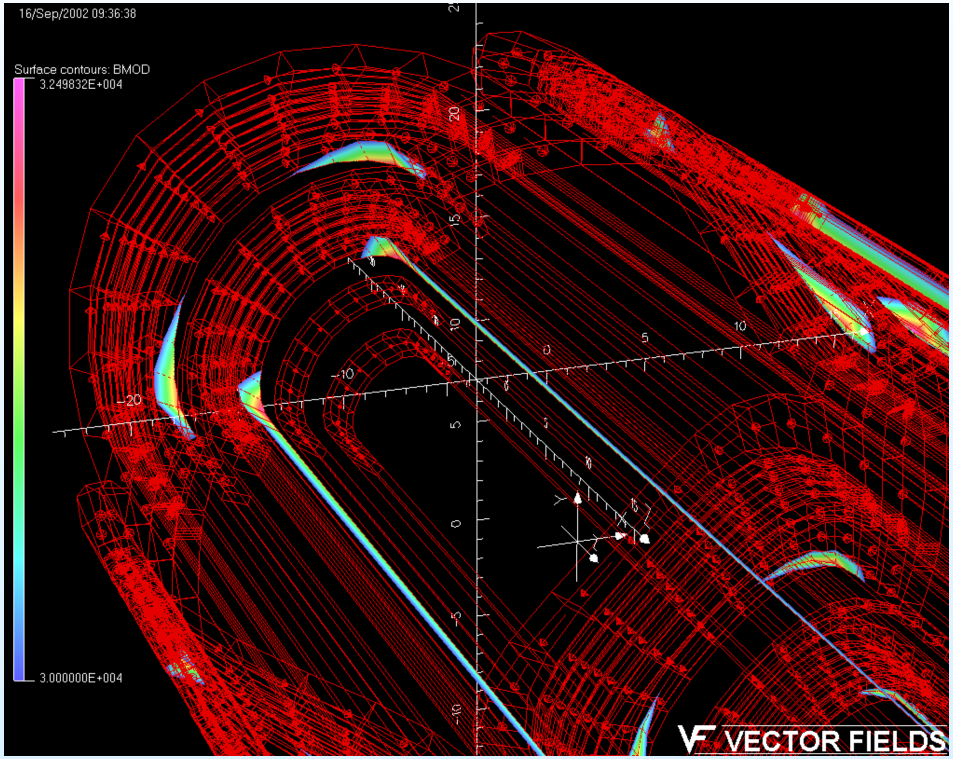






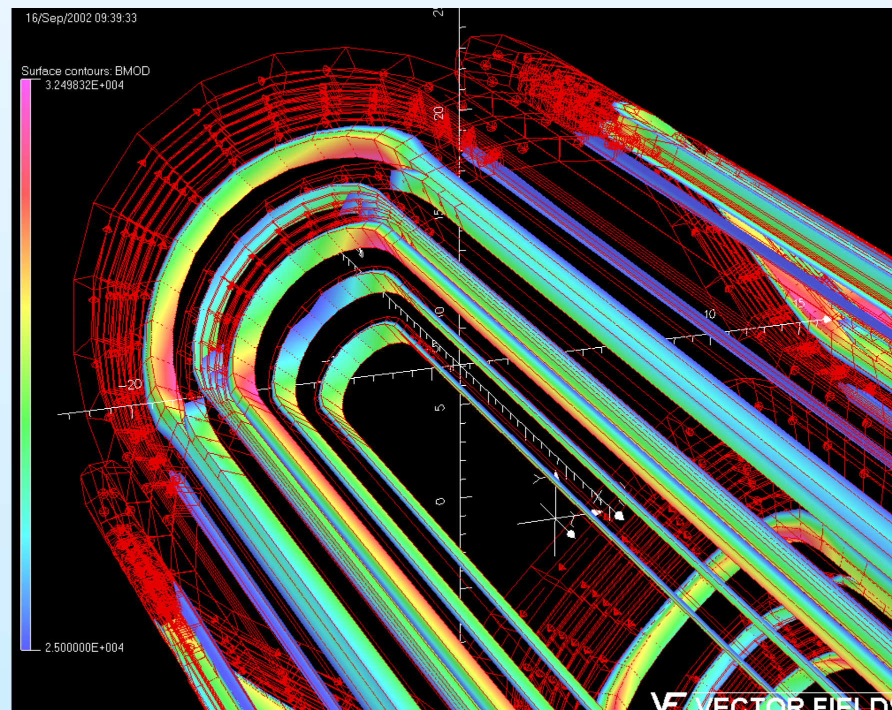


Ends with 3 Re-adjusted Spacers



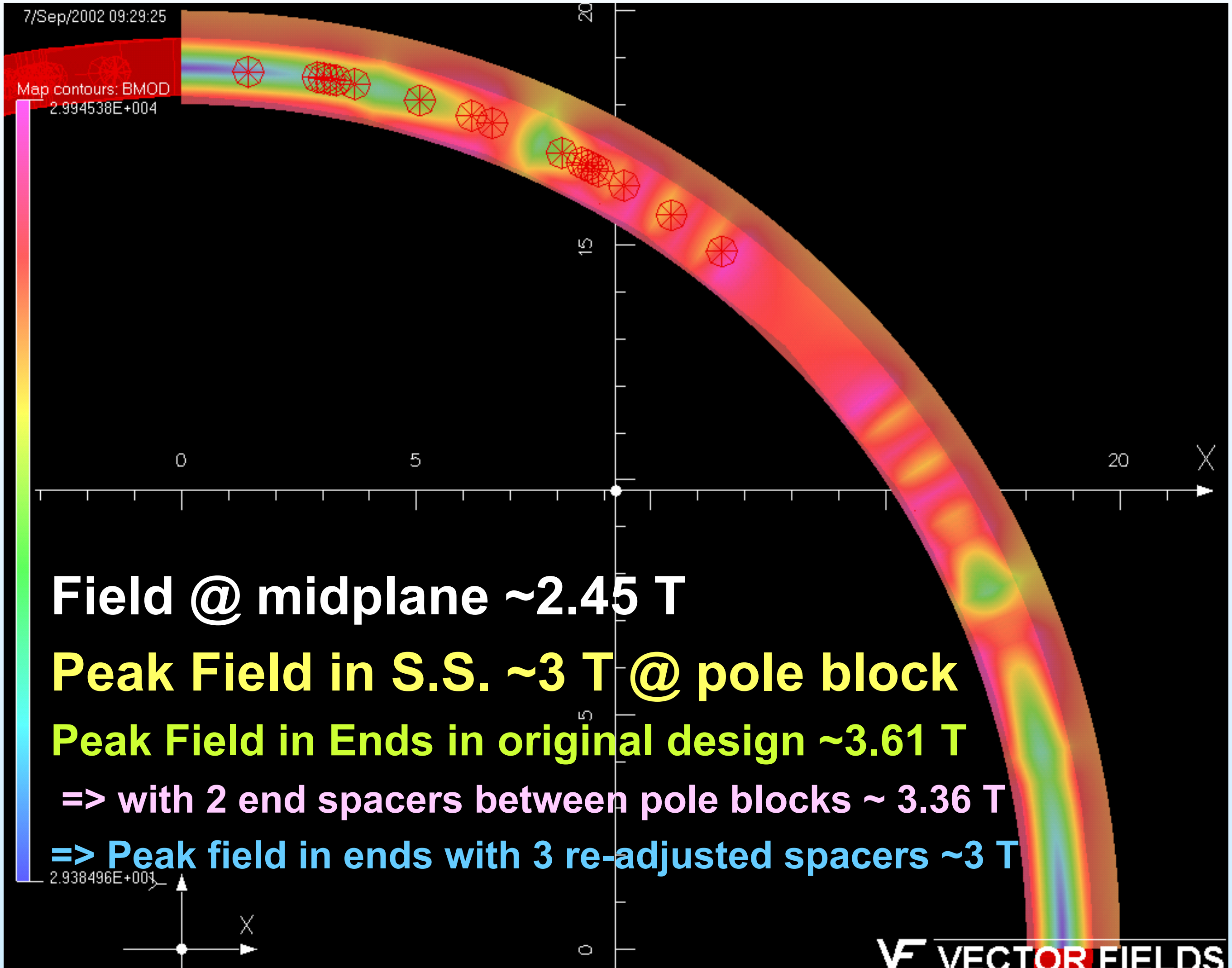
3 re-adjusted spacer should bring field down to S.S. level.

Work in progress.



This information will be used in optimizing new ends. The mechanical layout of the turns (tilt angle, strain on the conductor) do not change; only the value of end spacers changes.

Peak Field
Straight Section vs. Ends



Field @ midplane ~2.45 T

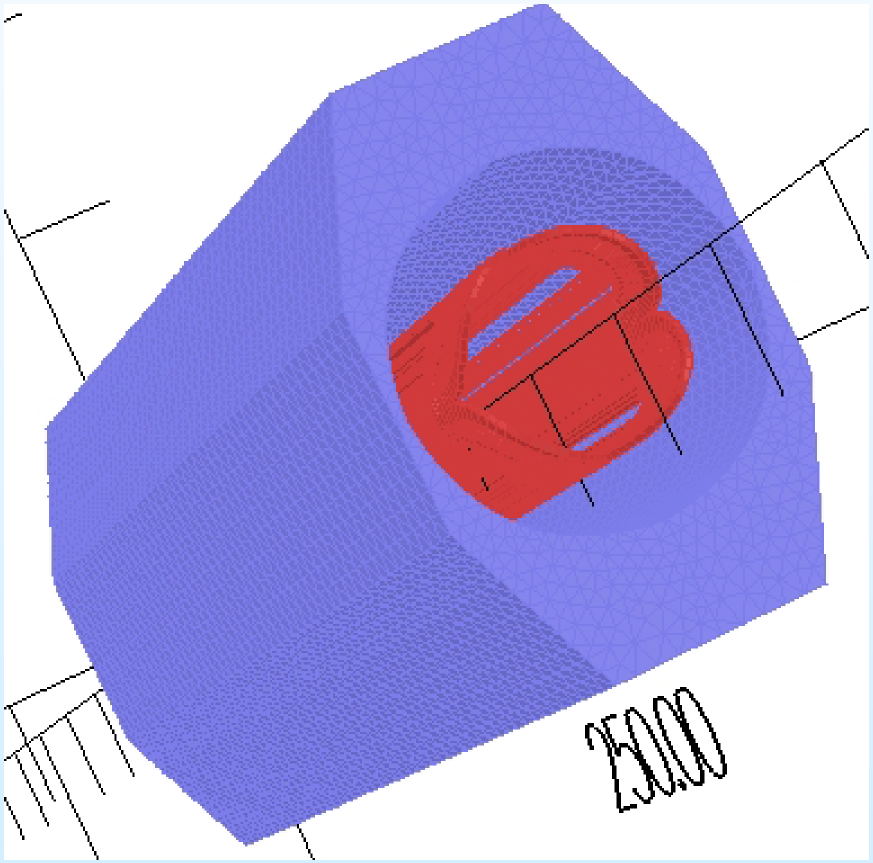
Peak Field in S.S. ~3 T @ pole block

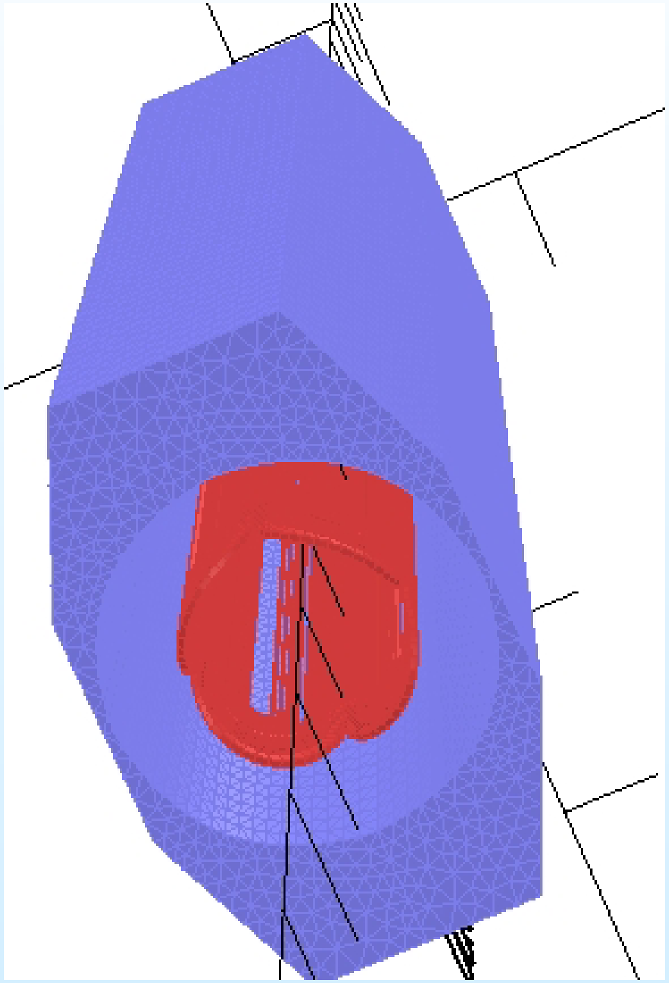
Peak Field in Ends in original design ~3.61 T

=> with 2 end spacers between pole blocks ~ 3.36 T

=> Peak field in ends with 3 re-adjusted spacers ~3 T

3-d Calculations with Iron Yoke (model shown during the last review)



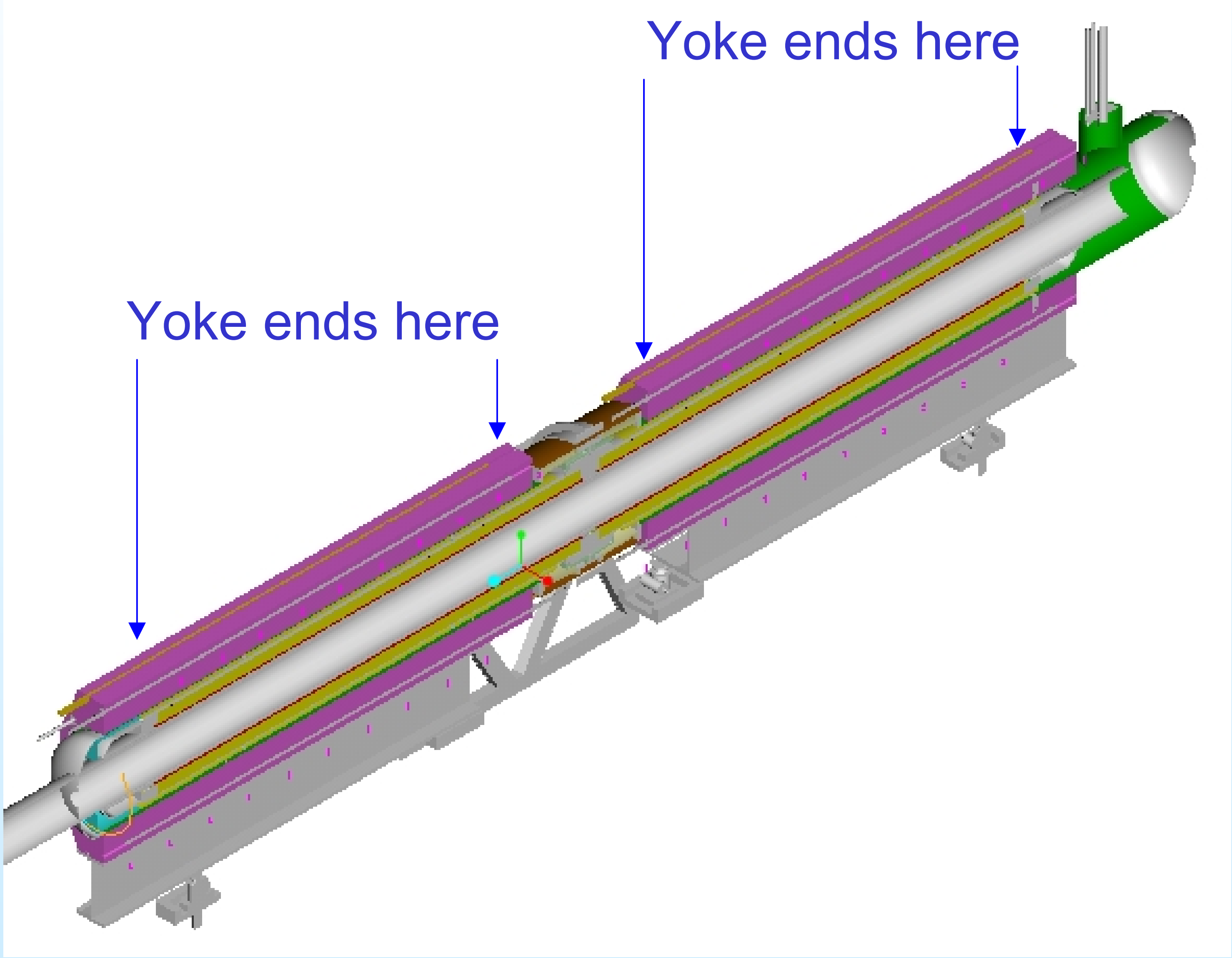


If cross talk is present, it would be maximum when the separation between the two quads is minimum. It should drop rapidly as the separation increases.

Important z-locations

	Trig	sin(7.5)	tan(7.5)
	3000	391.57	395
17inch+	3431.8	447.93	452
15inch+	3812.8	497.66	502
103/2 inch+	5120.9	668.39	674
103/2 inch+	6429	839.13	846
15inch+	6810	888.86	897
4.85inch+	6933.2	904.94	913
133inch+	10311.4	1345.87	1357

Overall Isometric View (cut)



Magnetic Shielding in Interconnect Region

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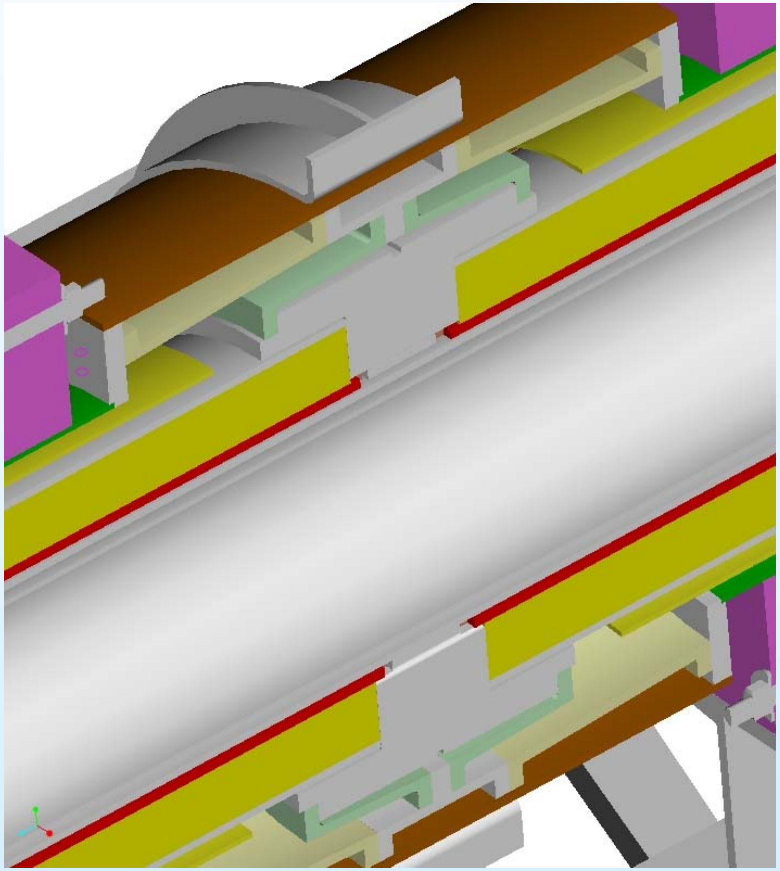
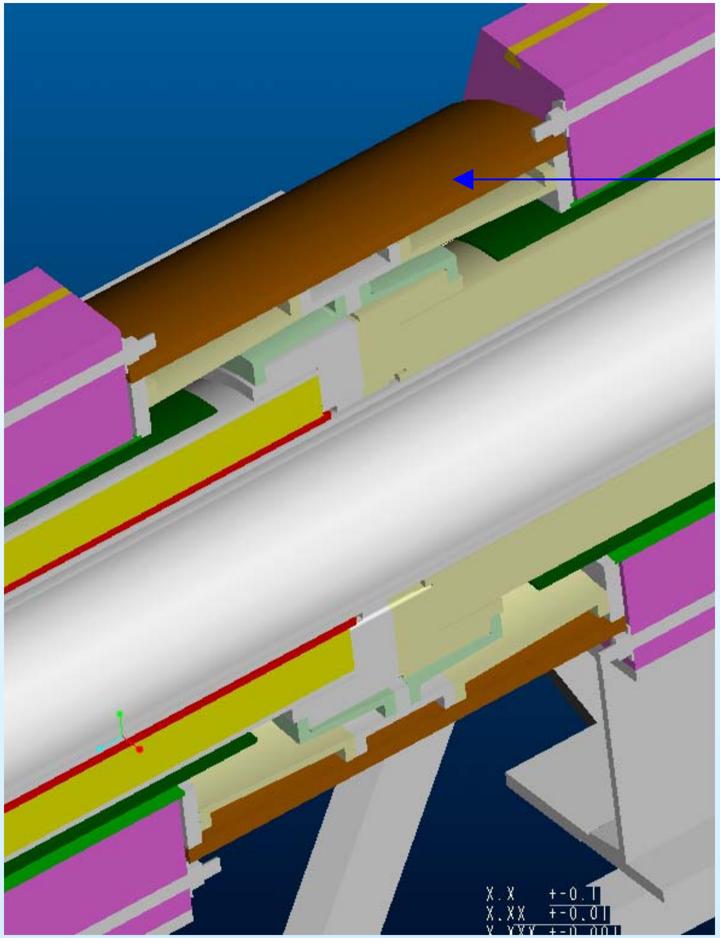


cryostat (green)
heat shield yellow)
shells (silver)
collars (yellow)
coils (red)

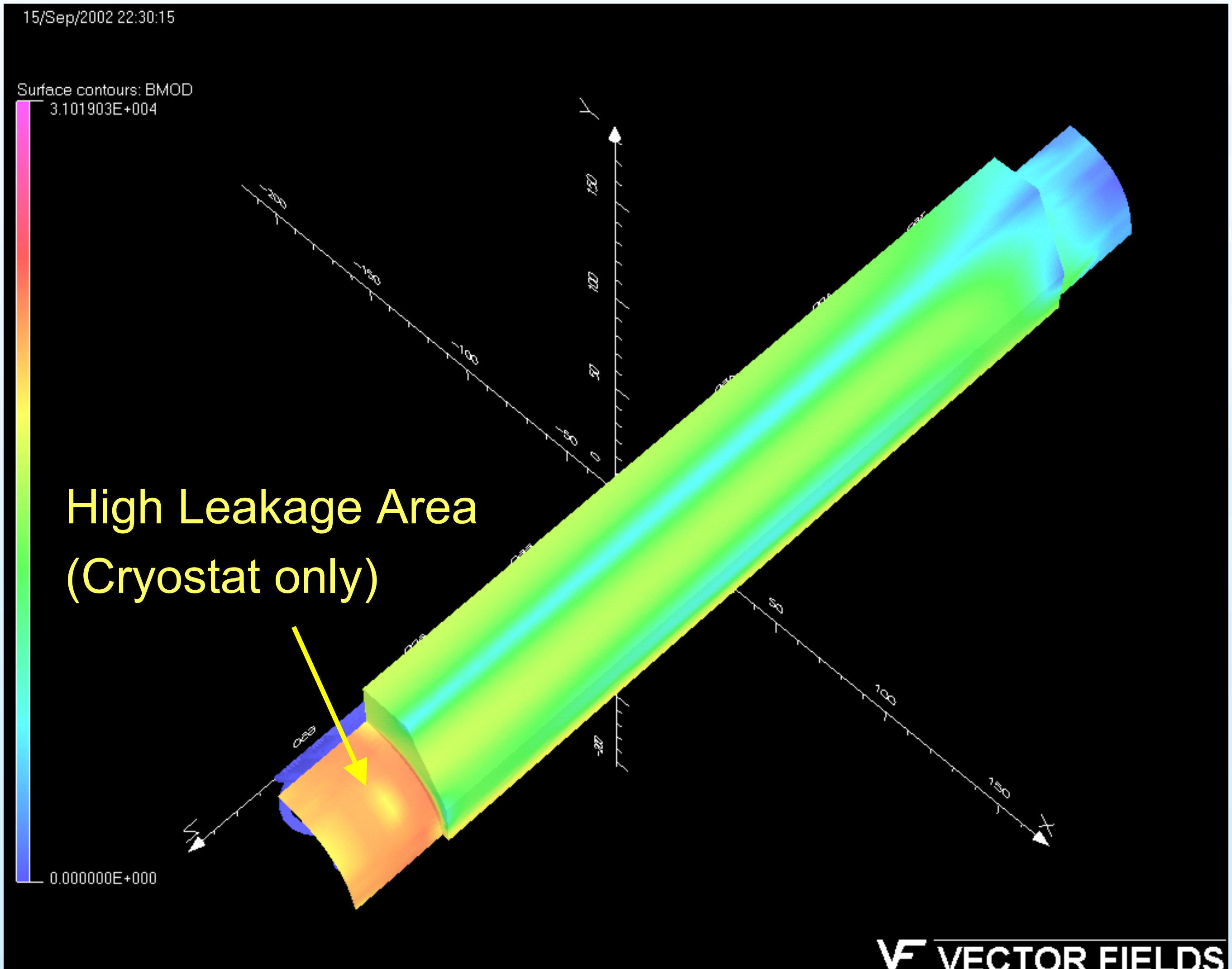
Previous Design



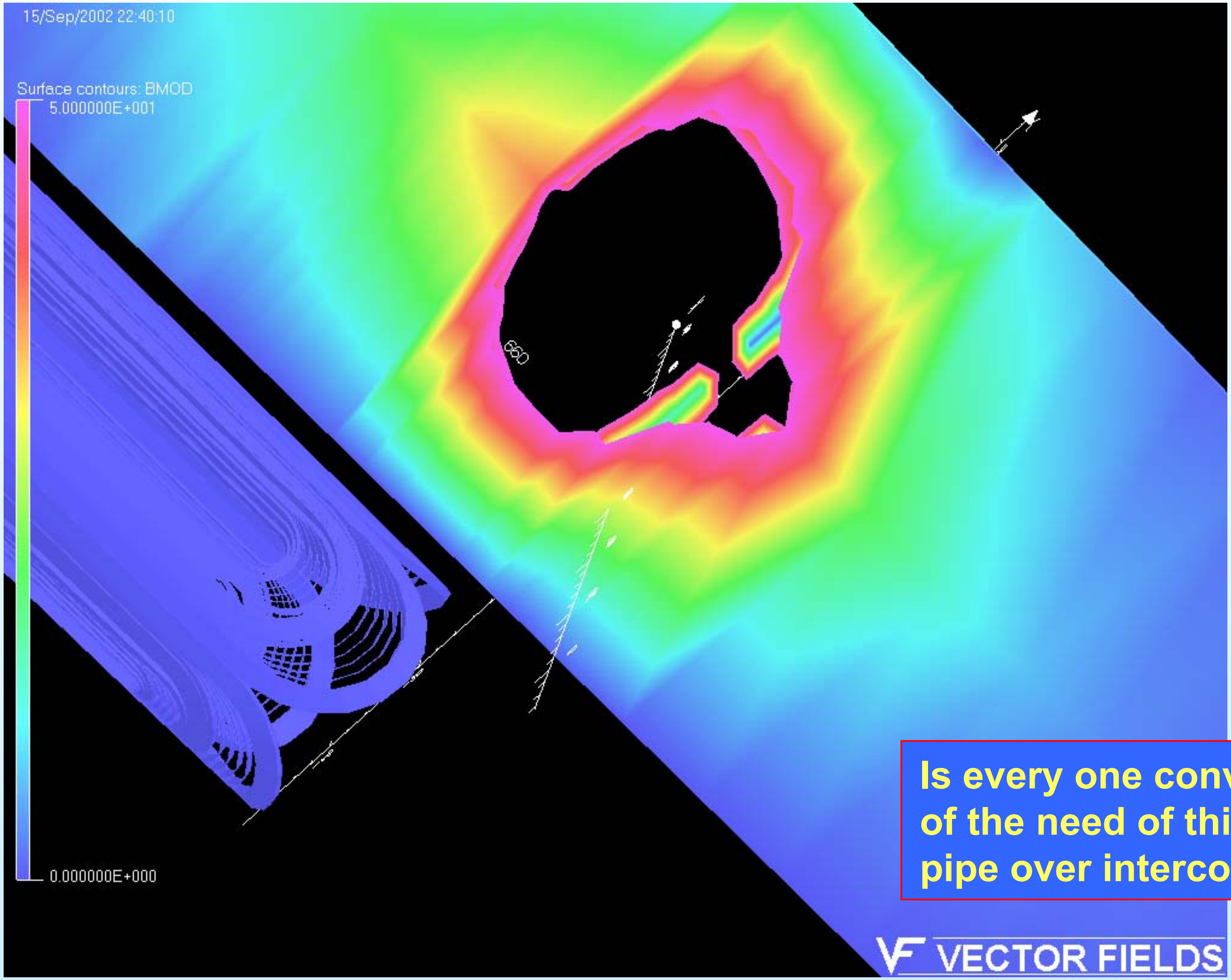
Magnetic pipe thick enough to shield the flux

Current Design

Field on the Surface of Iron without Shield Ring



Fun Picture: Flux Punching through an Imaginary Wall at 60 cm



Is every one convinced now of the need of thicker iron pipe over interconnect region

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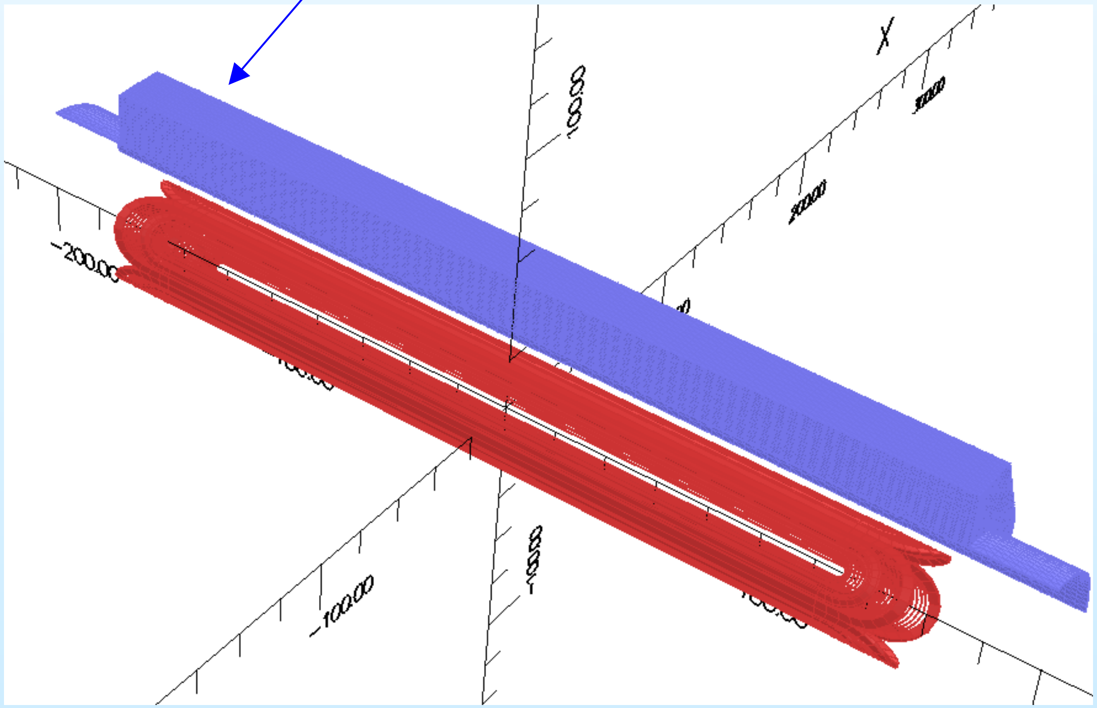
3-d Calculations with Iron Yoke

Iron over end side (case).

This is on the side of no inter connect magnet.

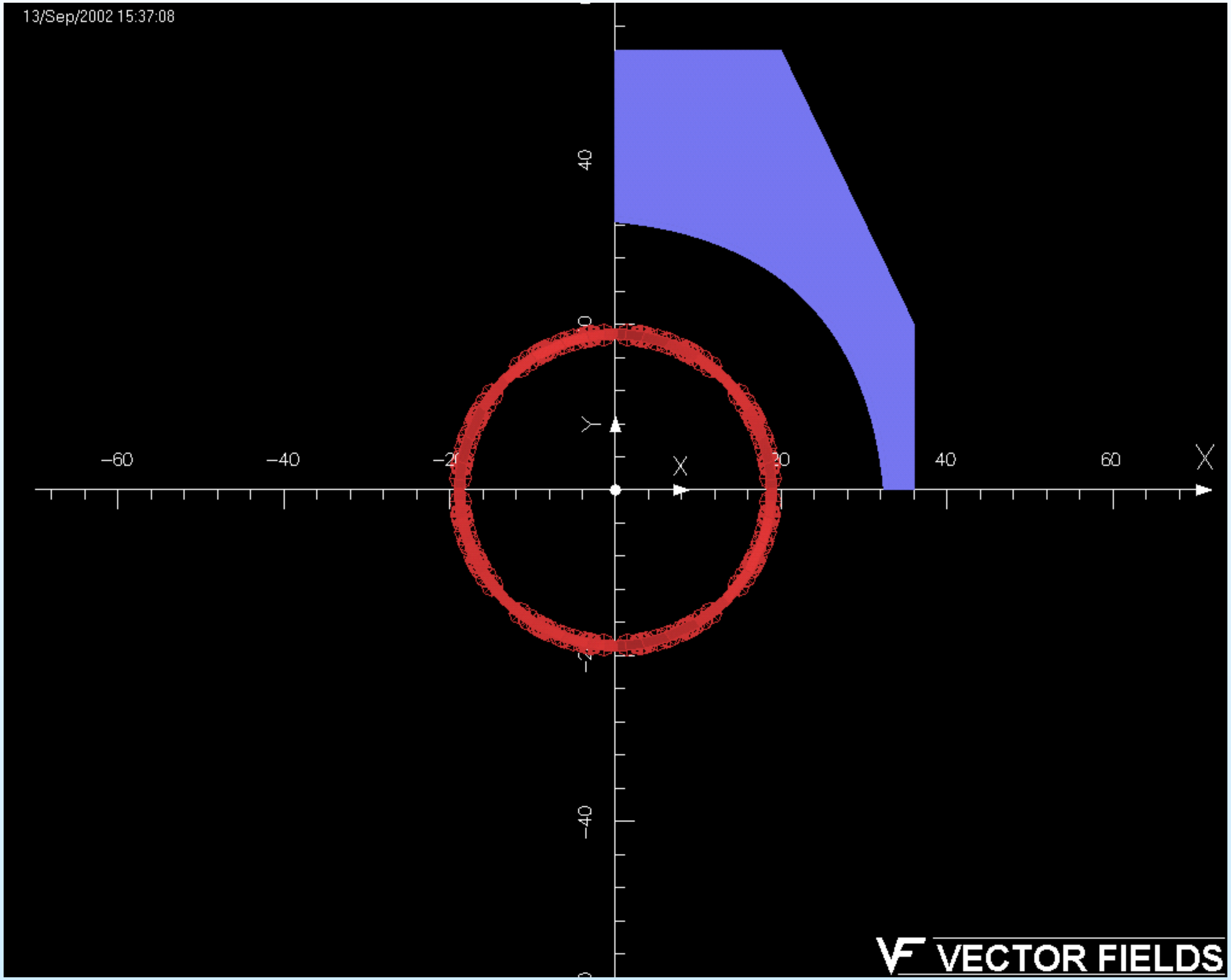


Except for the magnets closet to target, the adjacent magnets are well separated to ignore the field of the other magnet.

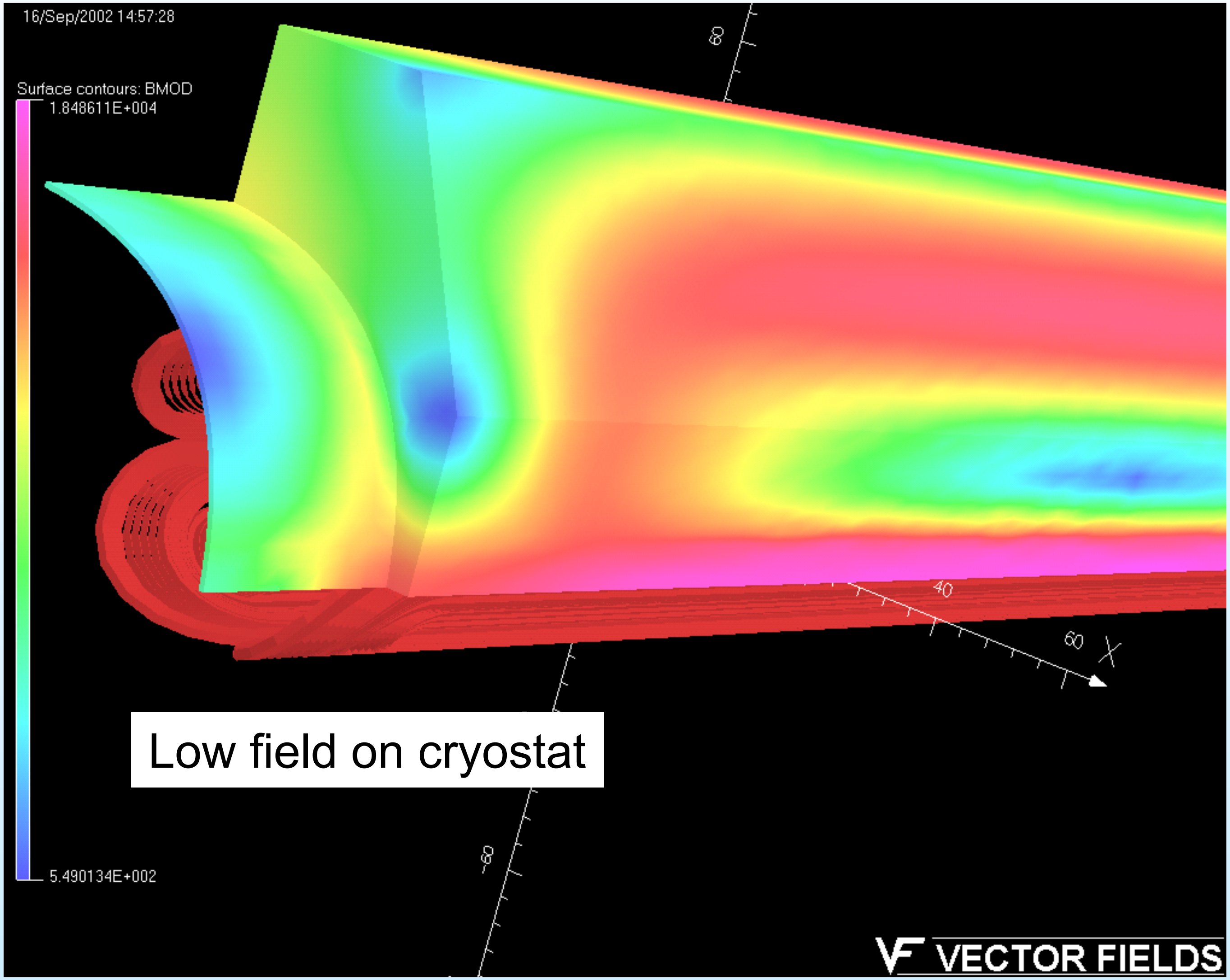
Models such as this (with boundary condition far away) represent all those cases.

Model in XY Plane (Cut)

Boundary far away, iron over end



Field on the Surface of Yoke



1. 85 T

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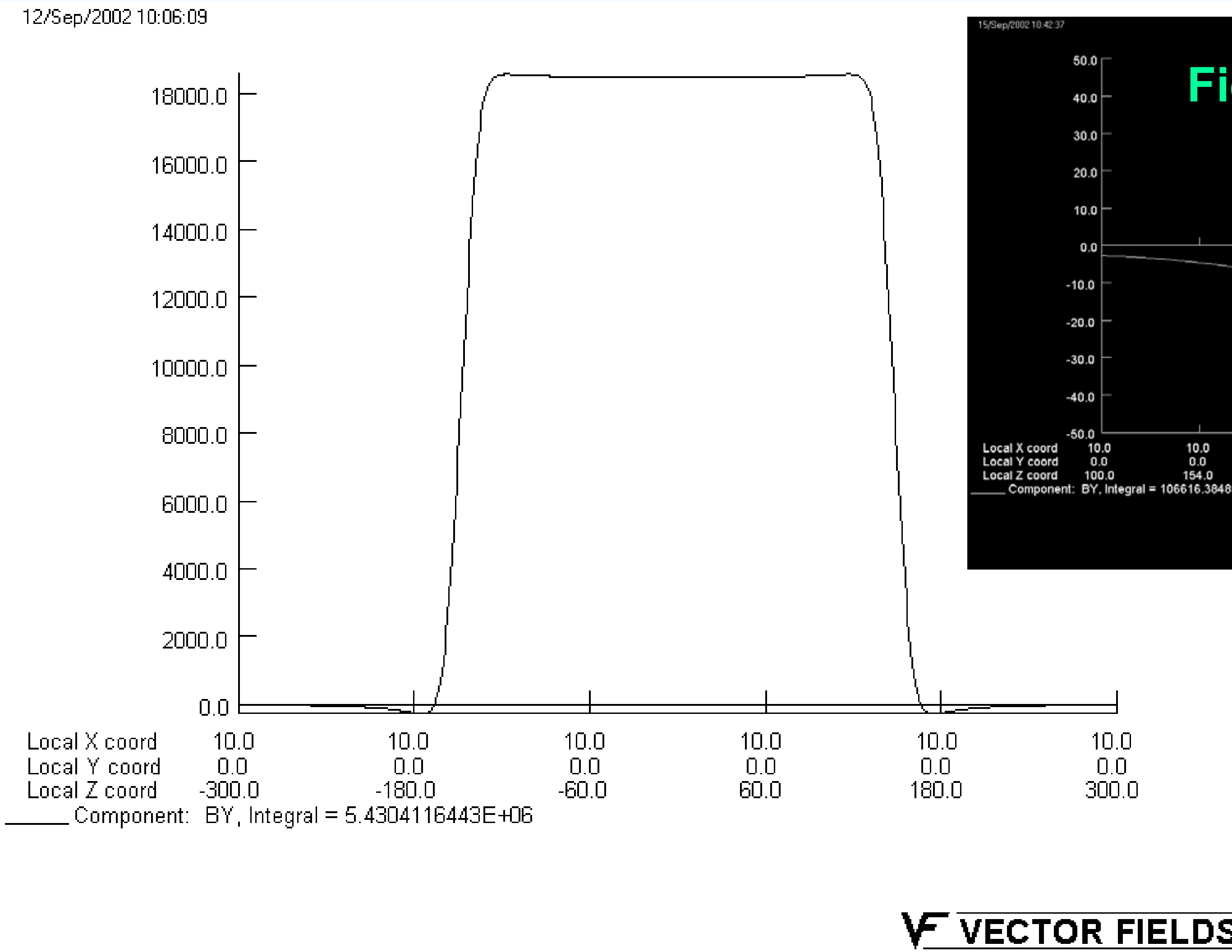
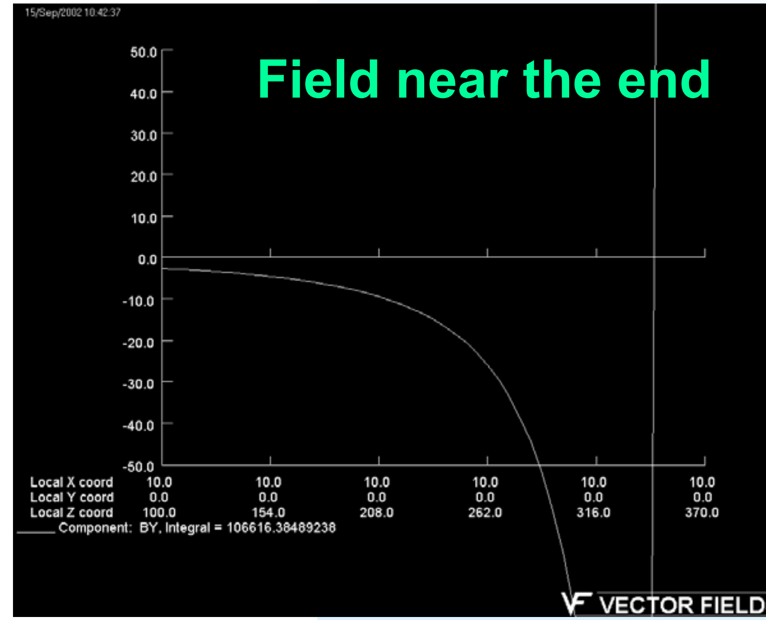
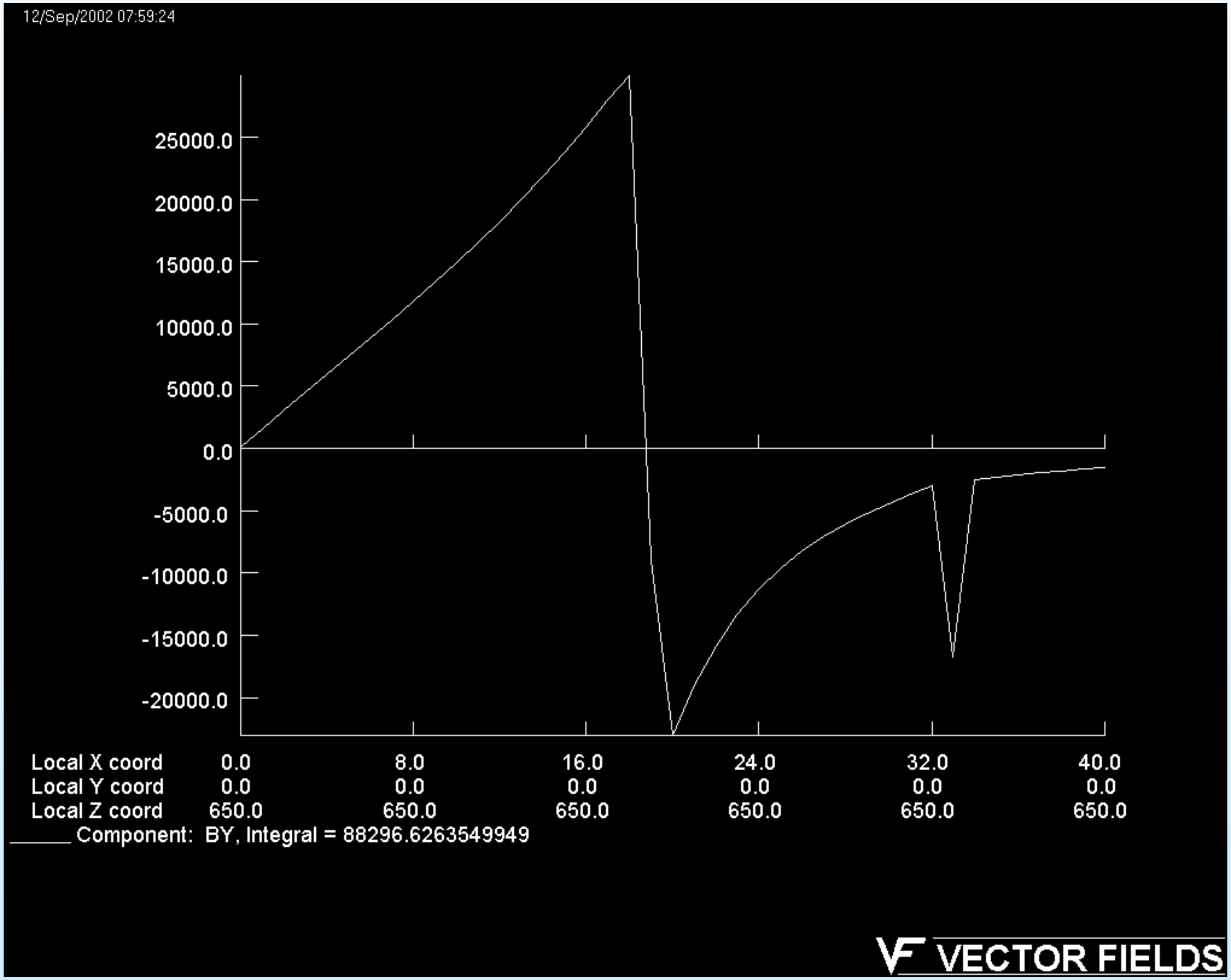
By at x=10 cm along z-axis

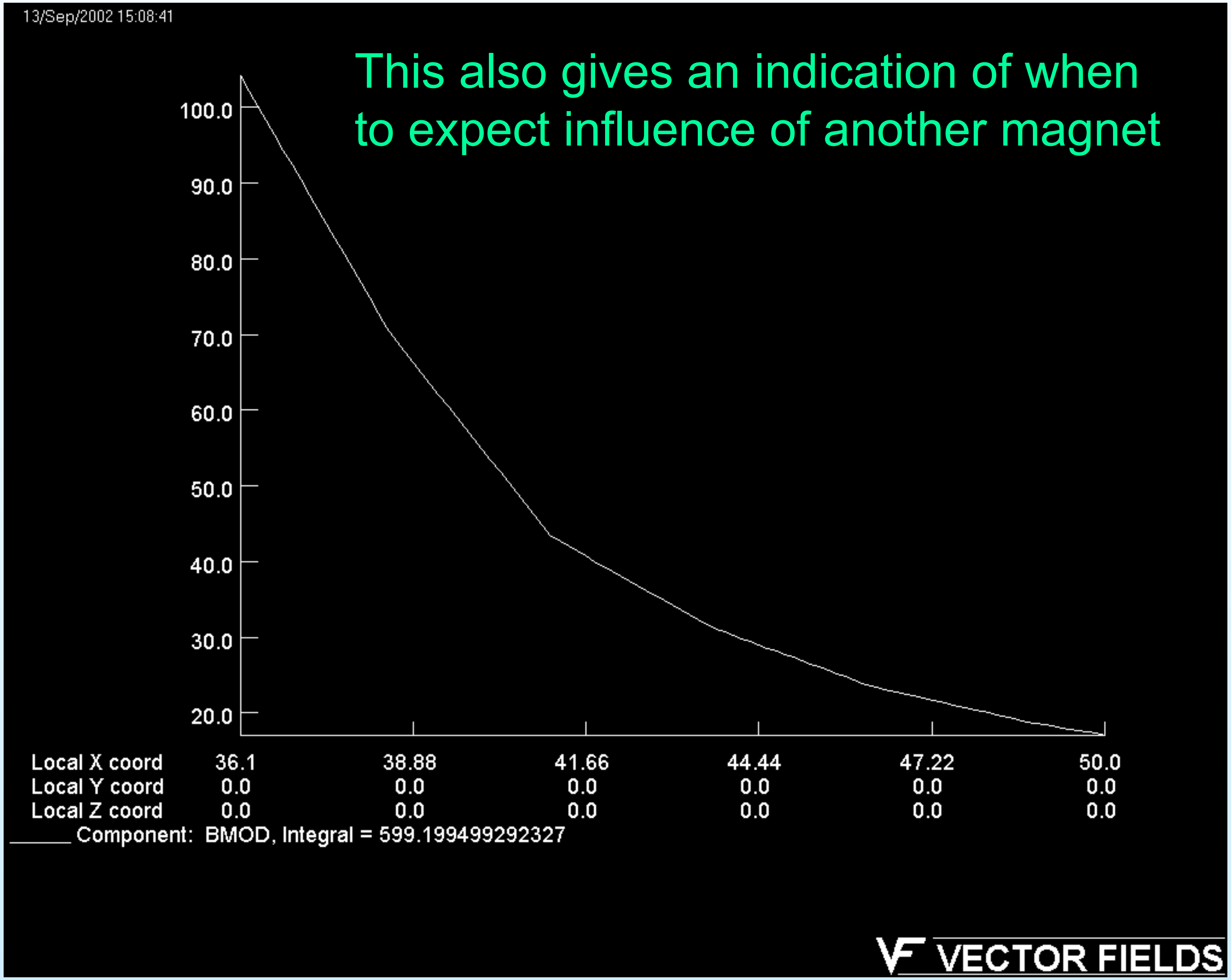




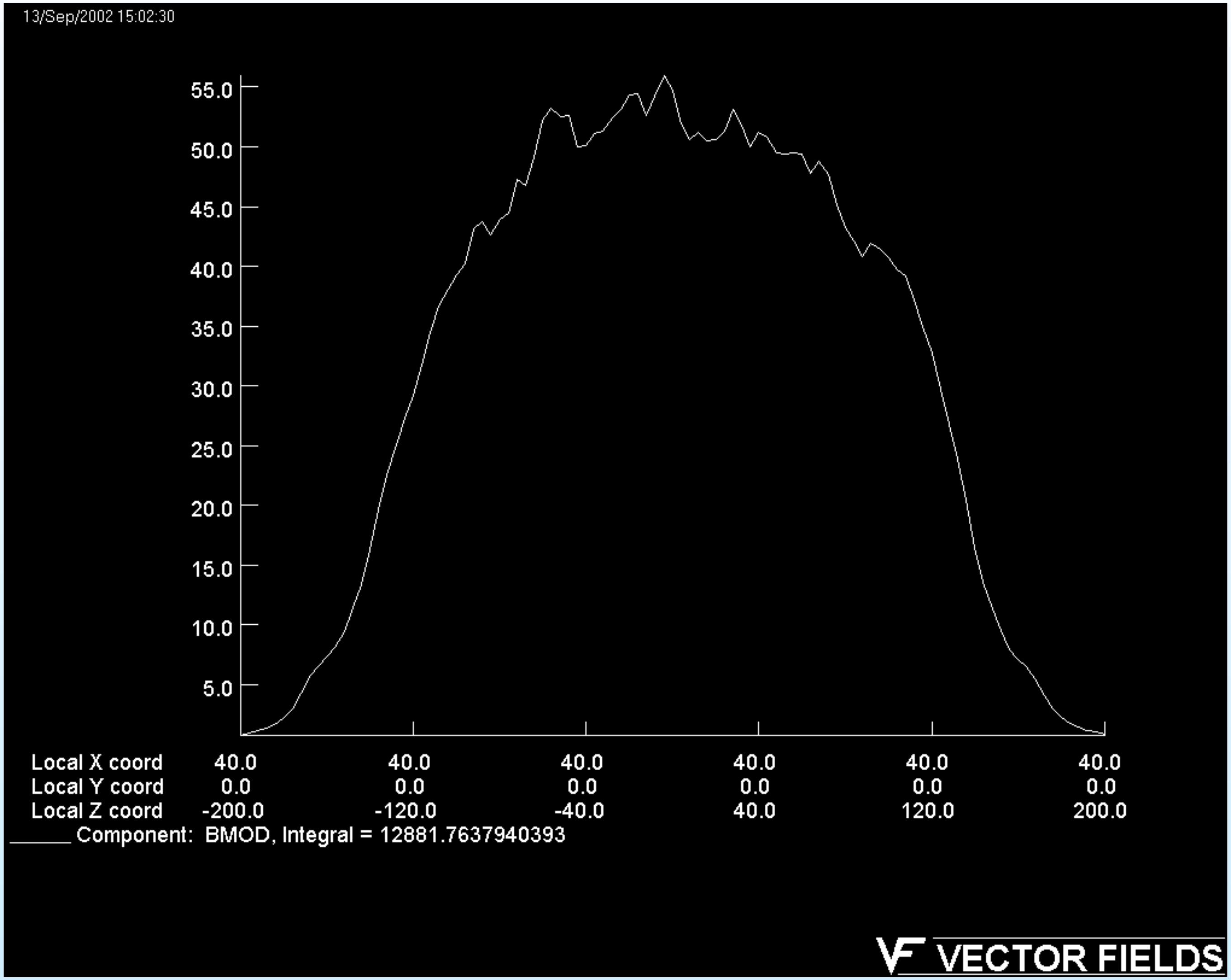
Field along x-axis in the Middle of Magnet



Field along x-axis Outside the Yoke in the Middle of Magnet

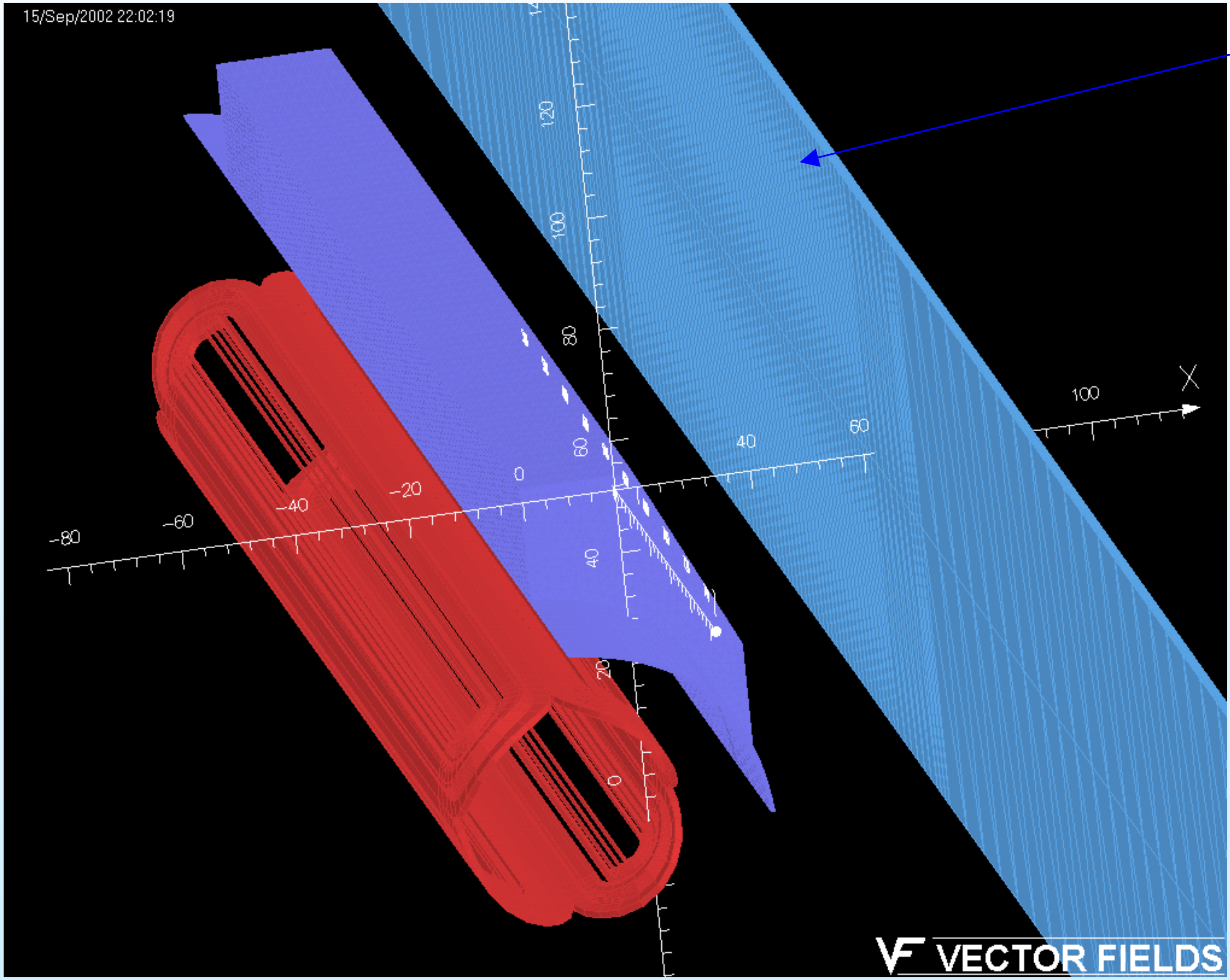


Field ~4 cm away from yoke (X=40 cm)



Accuracy limited by mesh resolution (average should be more accurate)

Case when Two Magnets are close by (apply appropriate boundary condition)



Boundary

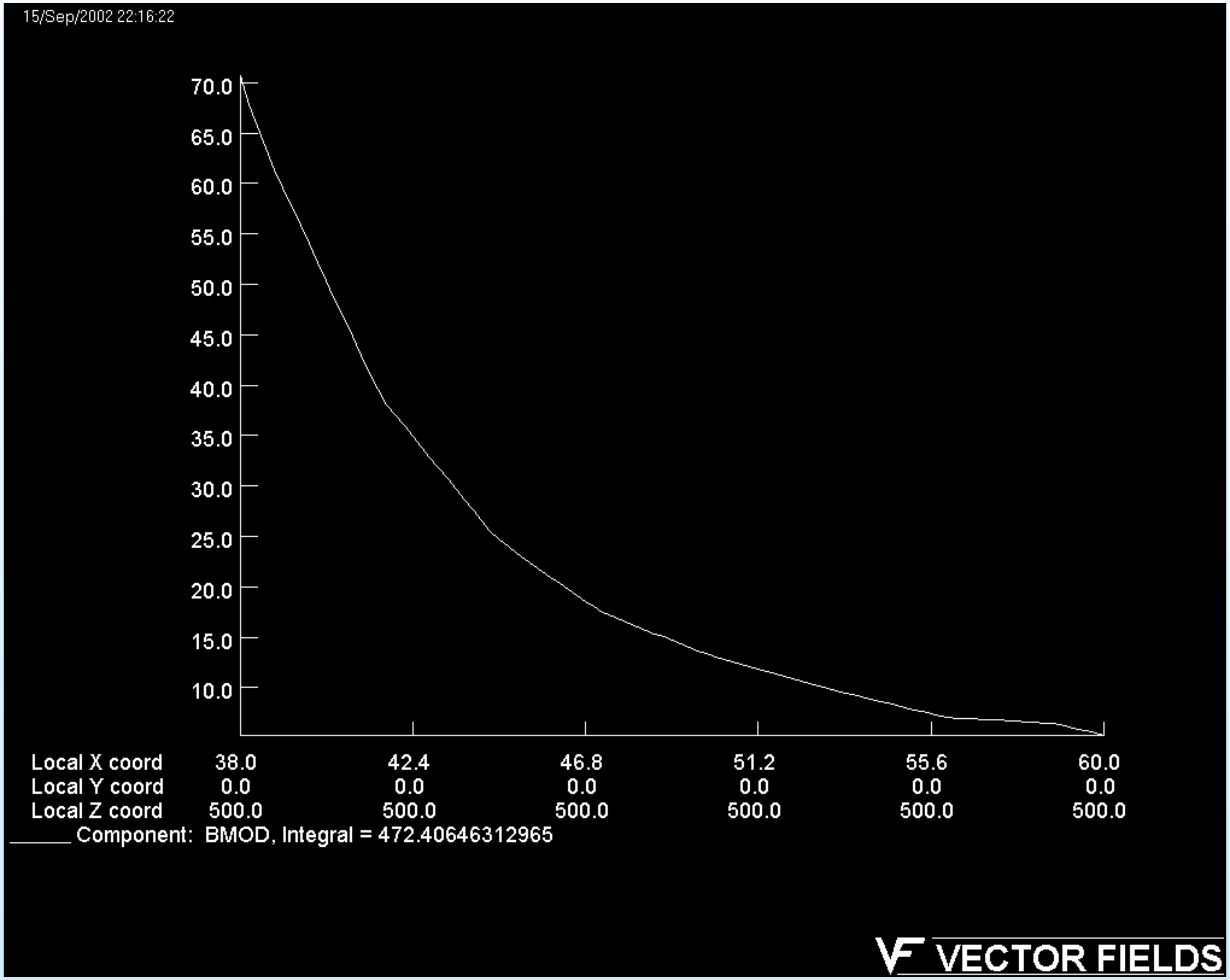
Field normal when two quads have the same sign of gradient, tangential when opposite)

In this model boundary is placed at the magnet midpoint.

Ideally, the boundary should be inclined

Field Outside the Yoke at Mid-point

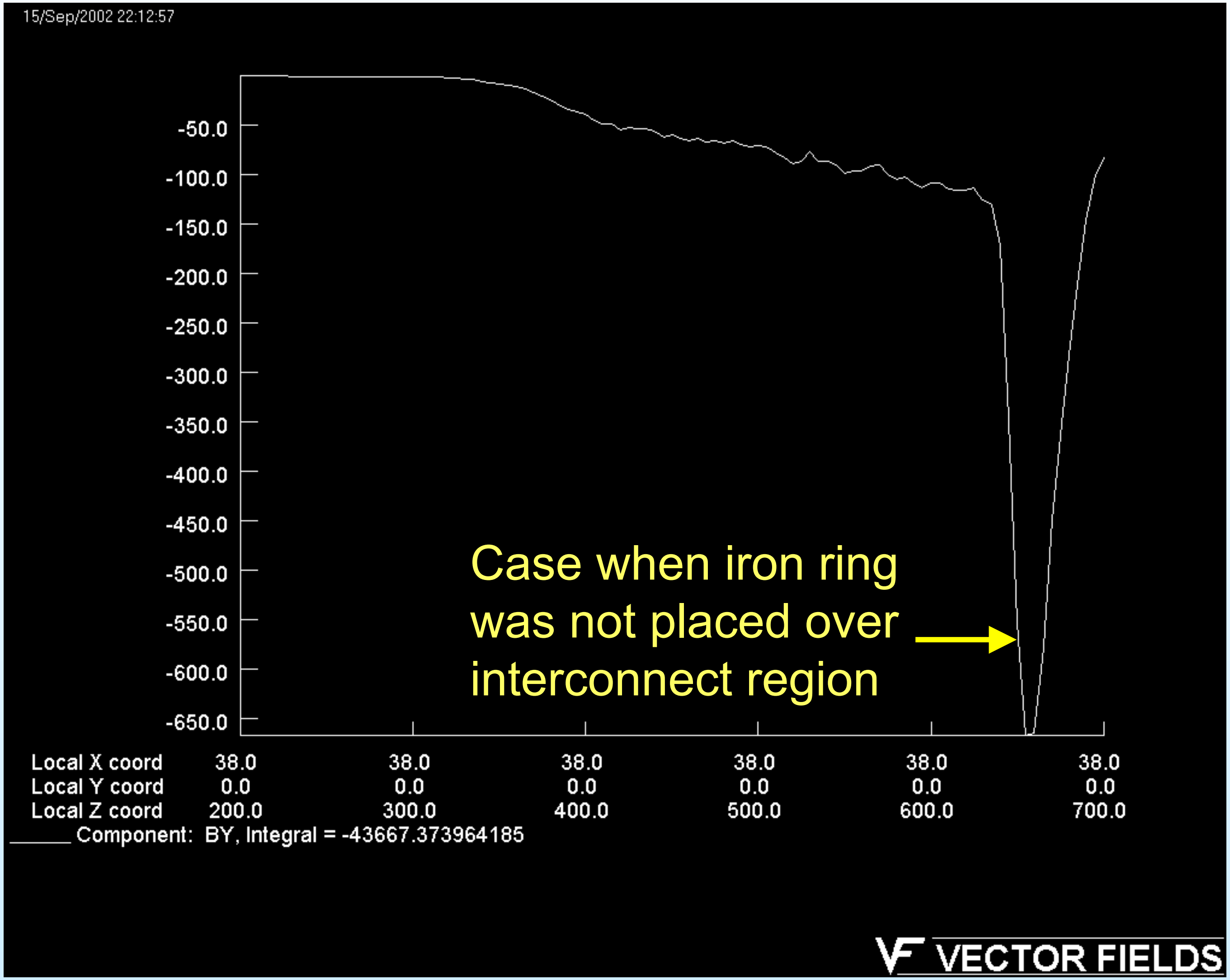
Field normal boundary with boundary condition at magnet midpoint location (X~66 cm)



Two quads powered for producing gradient having the same sign

Field along z-axis just outside the yoke

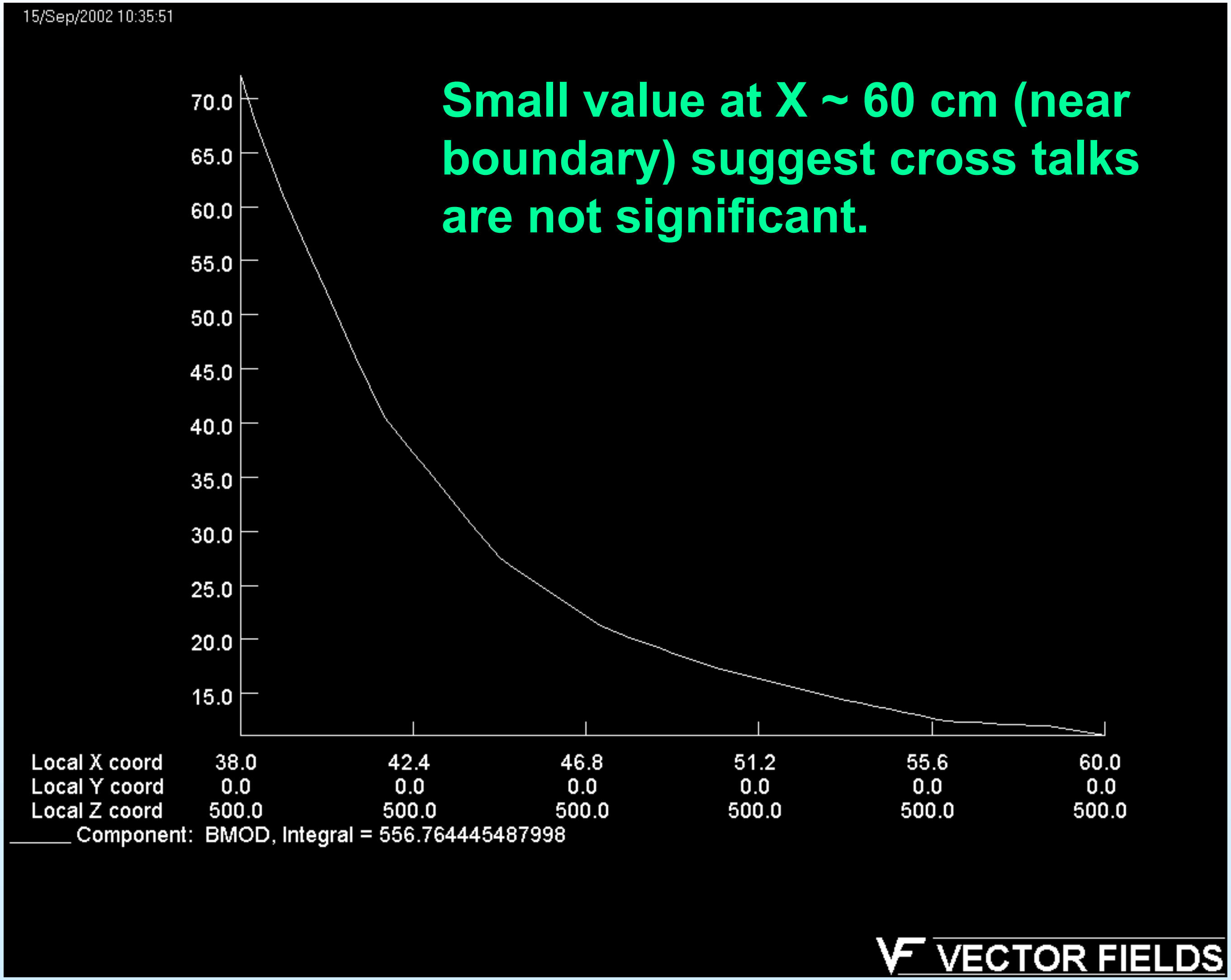
Field normal boundary with boundary condition at magnet midpoint separation



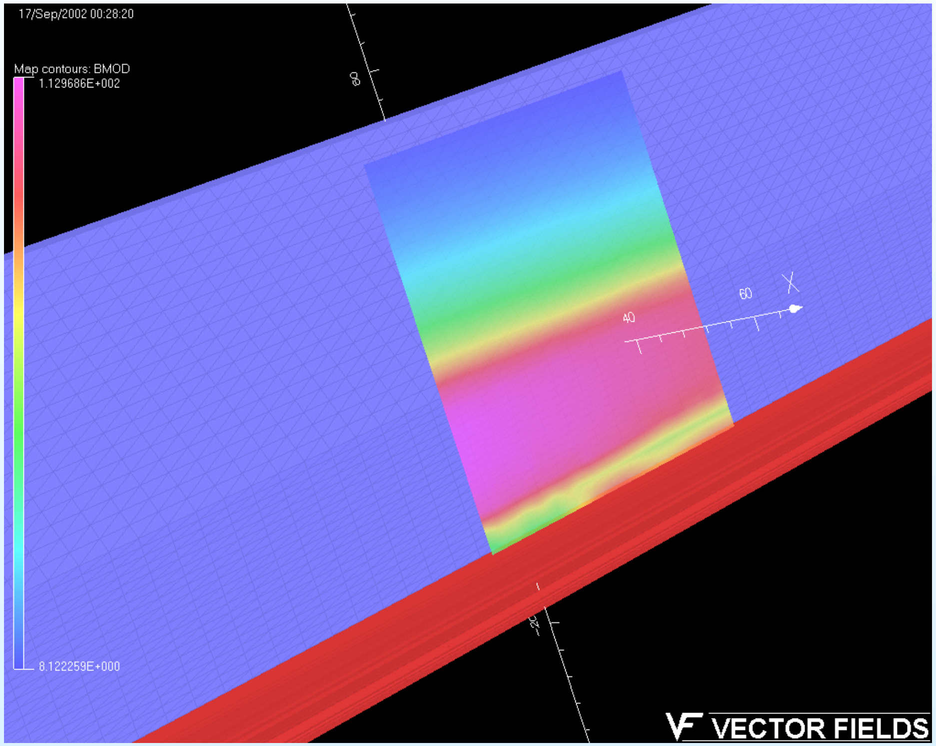
Tangential Boundary Condition

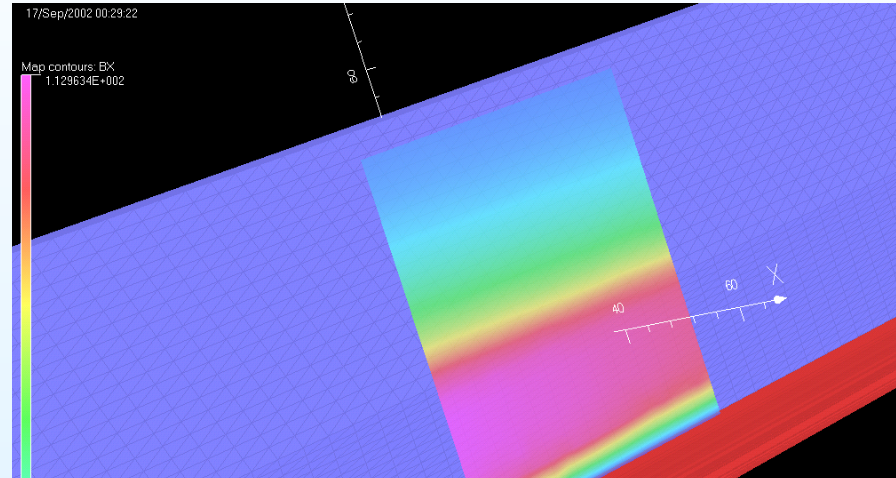
Field tangential boundary with boundary condition at magnet midpoint location (X~66 cm)

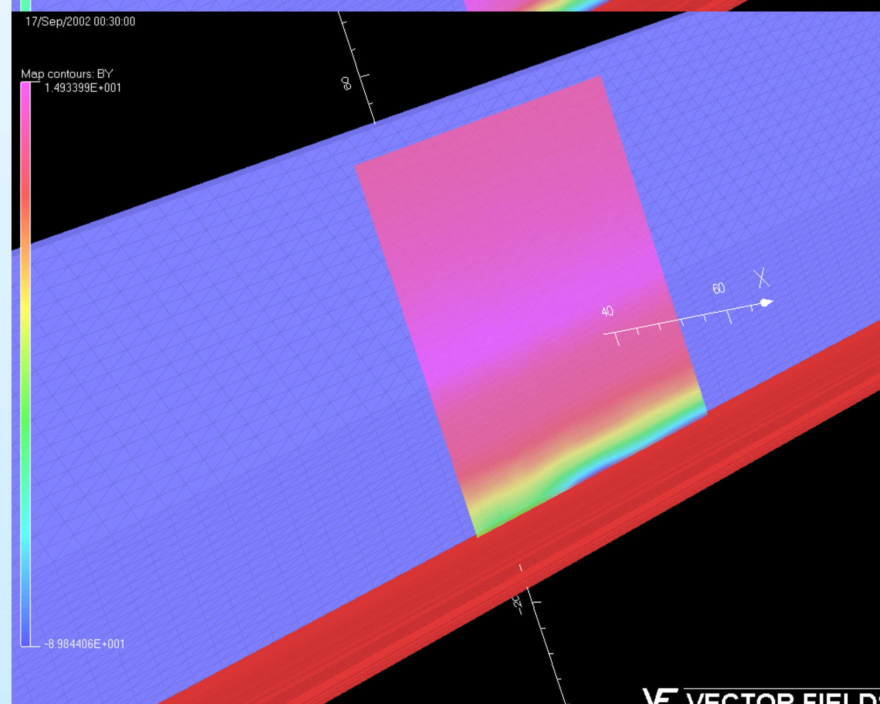
Two magnets powered with the opposite polarity



Normal Boundary Condition (applied at the entrance location)



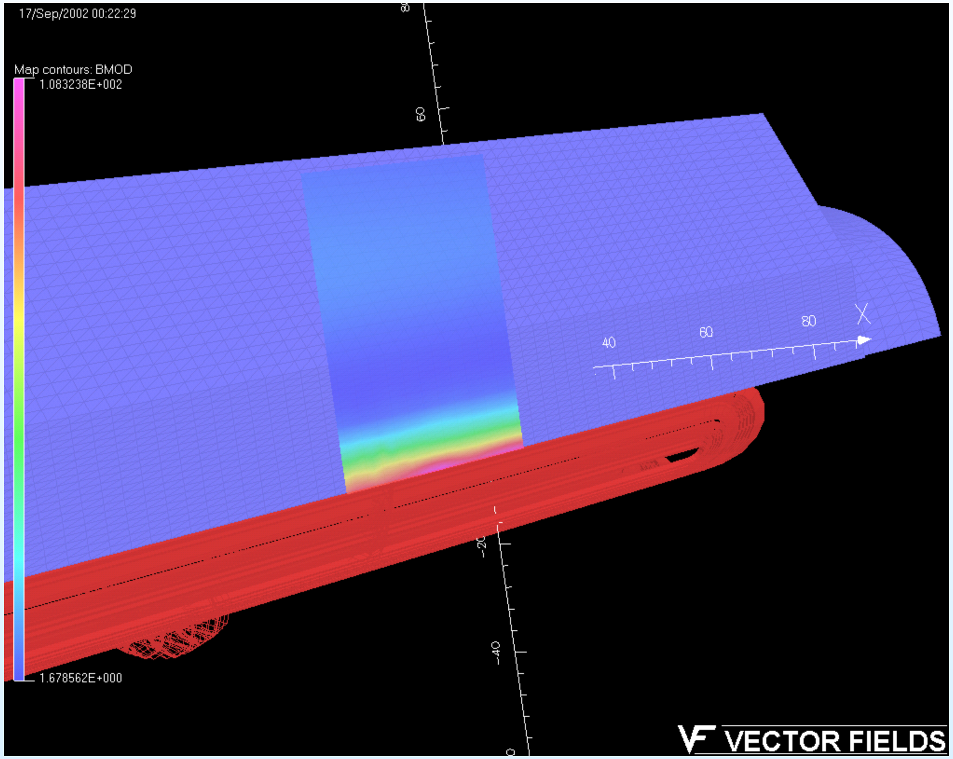


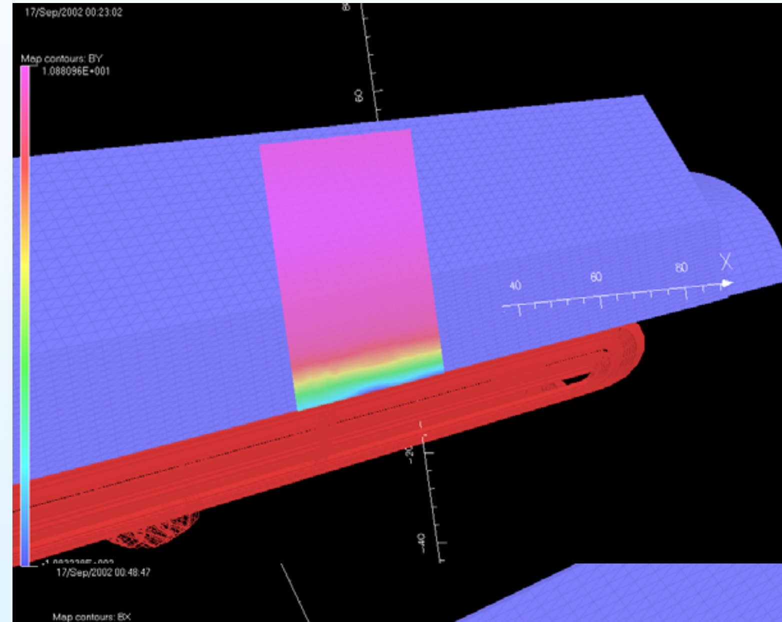


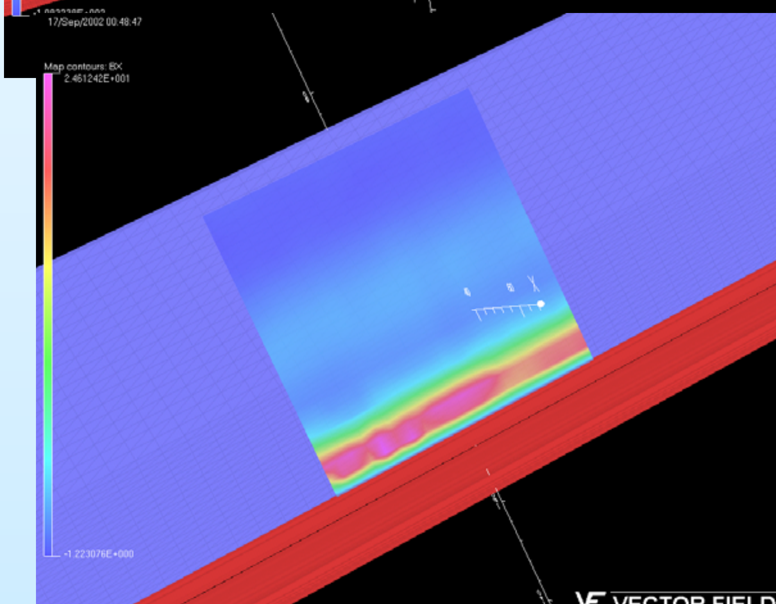
Field normal boundary with boundary condition at the entrance of coil (end saddle and iron yoke) X ~40-45 cm

Two adjacent magnets are powered with the same polarity

Tangential Boundary Condition (applied at the entrance location)







Field normal boundary with boundary condition at the entrance of coil (end saddle and iron yoke) X ~40-45 cm

Two adjacent magnets are powered with the opposite polarity

SUMMARY

•This is still work in Progress!

• We have a good mechanical layout of end turns (end block).

Low tilt and low strain; to be maintained in iterated ends because of the way it is being iterated.

• Theoretical calculations show that low end harmonics can be obtained. PARNDOPT design is verified by OPERA3d.

• Strategy for low peak field presented.

➢Need to carry out this optimization process further for both low peak field and low end harmonics. Should work.

➢Expected to meet the required field quality tolerances.

• Influence of yoke is computed.