Test Results and Analysis of RIA HTS Magnetic Mirror Quadrupole

Ramesh Gupta and Bill Sampson
Superconducting Magnet Division
Brookhaven National Laboratory
Upton, NY 11973 USA

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Magnet Test

- Objectives
- Comparison between expectations and measurements
- Lessons learned, unanswered questions (see Bill's presentation)

Bill Sampson will present

- Measurements (including important details)
- New Splice

Objectives

Objectives of this particular magnet test:

- Demonstration of HTS technology in an accelerator R&D magnet
- Demonstration of the ability of this design to tolerate high energy deposition present in RIA (originally this simulation was slated for the next year)
- Demonstration of the conduction cooling (not original part of RIA program)
    - Thus, so far we are way ahead of what we were set out to do by now.

- We are using this opportunity to not only satisfy the RIA requirements but also develop a program that opens up HTS technology for future magnets. We successfully demonstrated the ability of this design to withstand RIA type energy deposition and (b) the conduction cooling (Bill's presentation).
- However, there are a few observations that are yet to be fully understood.

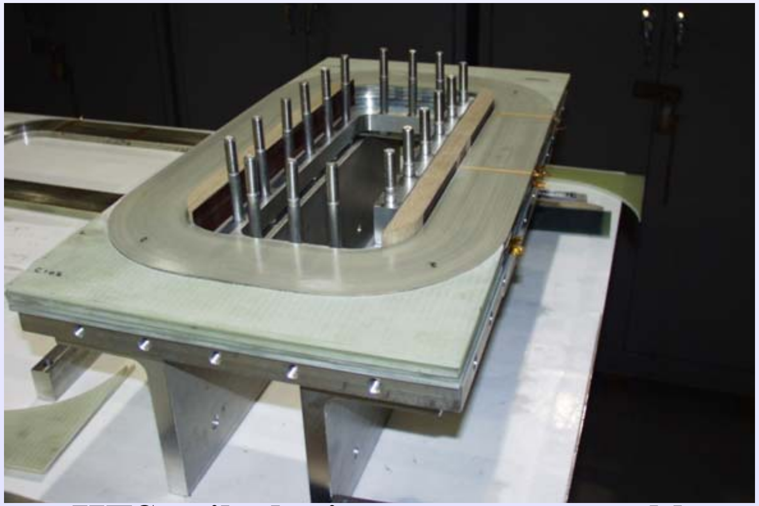
RIA HTS Quadrupole At Various Stages of Construction and Testing

HTS coil winding with SS tape insulator

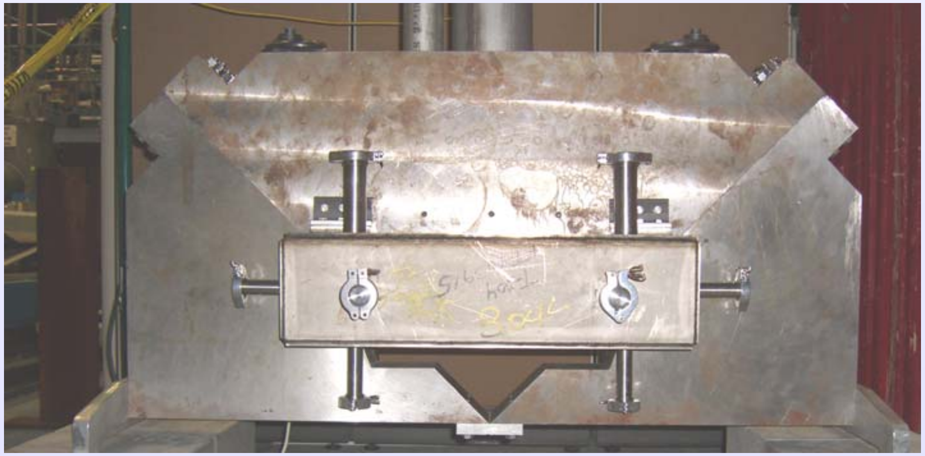
The RIA HTS model magnet has been successfully built and tested at BNL.

Experiments of magnet operating with large energy depositions (tens of watts in 0.3 meter long magnet) have also been carried out.

Cold iron magnetic mirror test with six coils



HTS coils during magnet assembly



Warm iron magnetic mirror test with twelve coils

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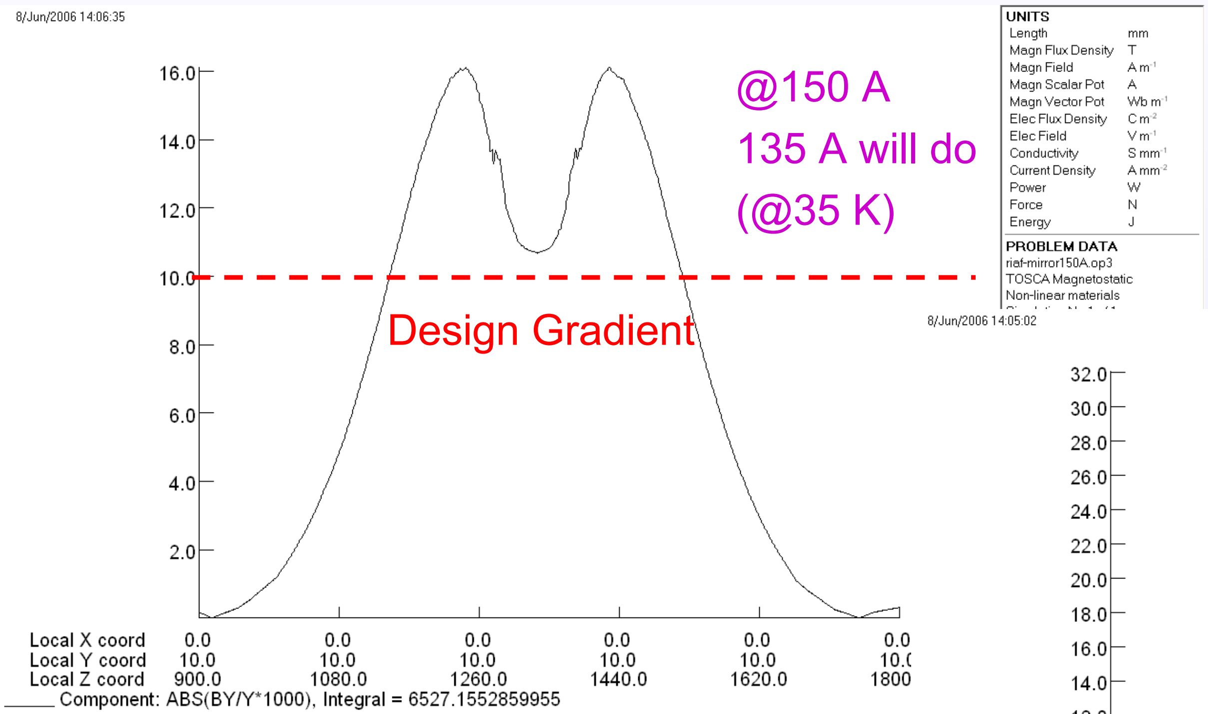
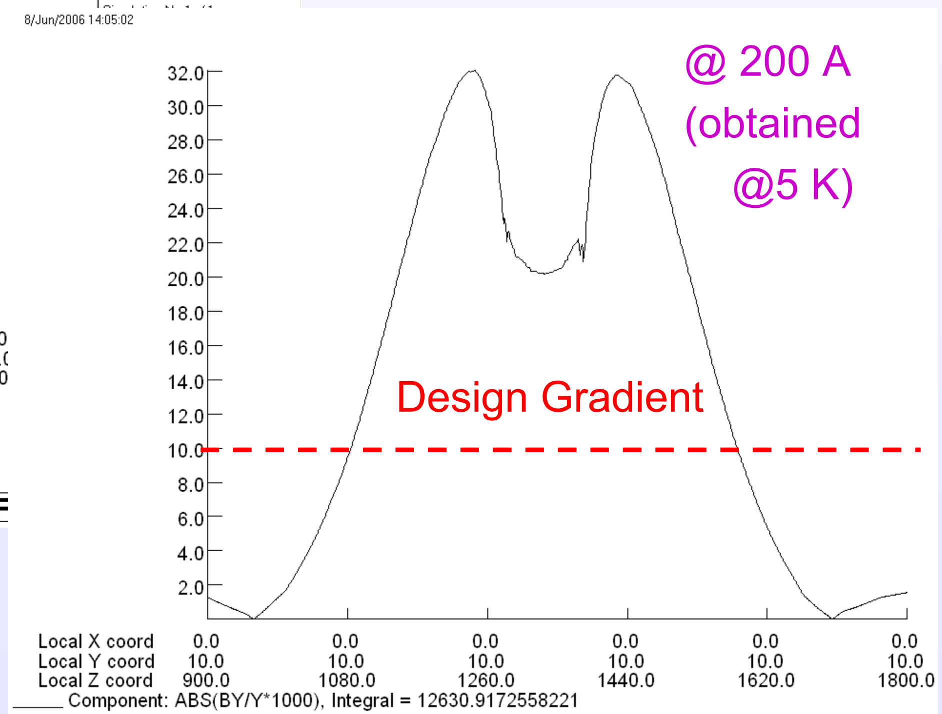
Axial Scan of the Field Gradient



Mirror model with 6 coils (as required for simulation of full magnet with 12 coils).

Higher gradient on two sides because the magnet is too short (end effects).

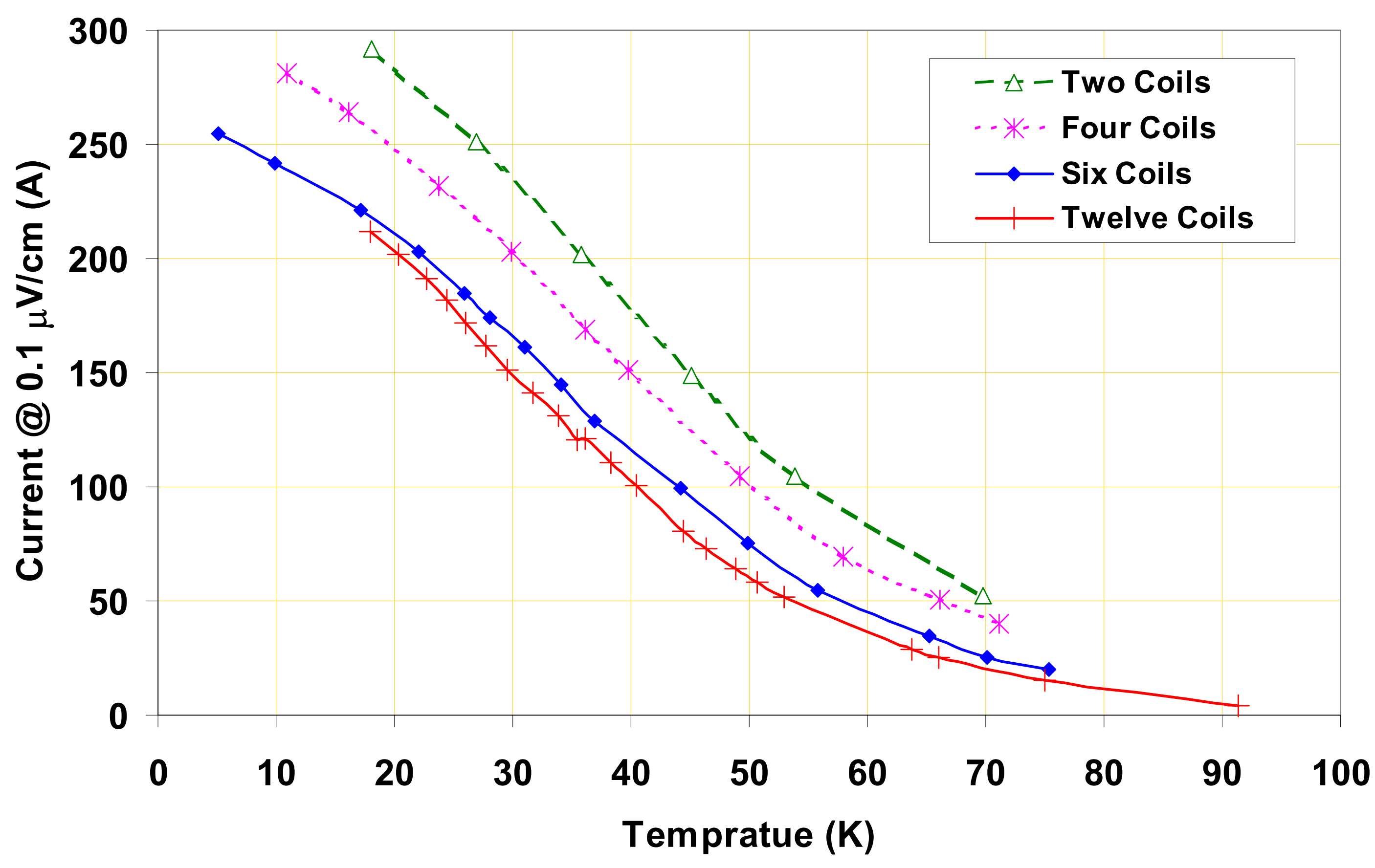
However, higher peak field does not harm (HTS is great).



Mirror model with twelve coils (2X of required)

I_c Vs Temperature in Magnetic Mirror Model (when 2, 4, 6 or 12 coils are energized)

More coils create more field and hence would have lower I_c at the same temperature

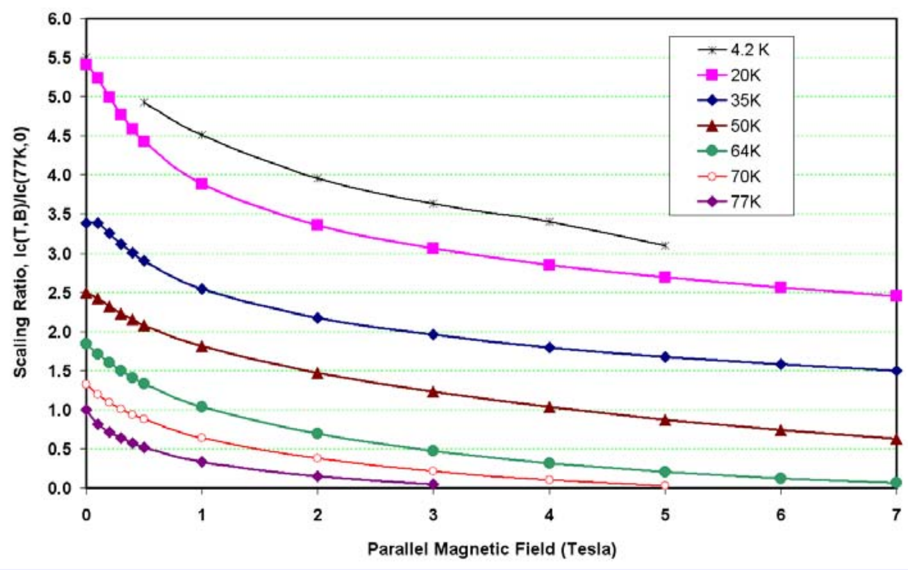


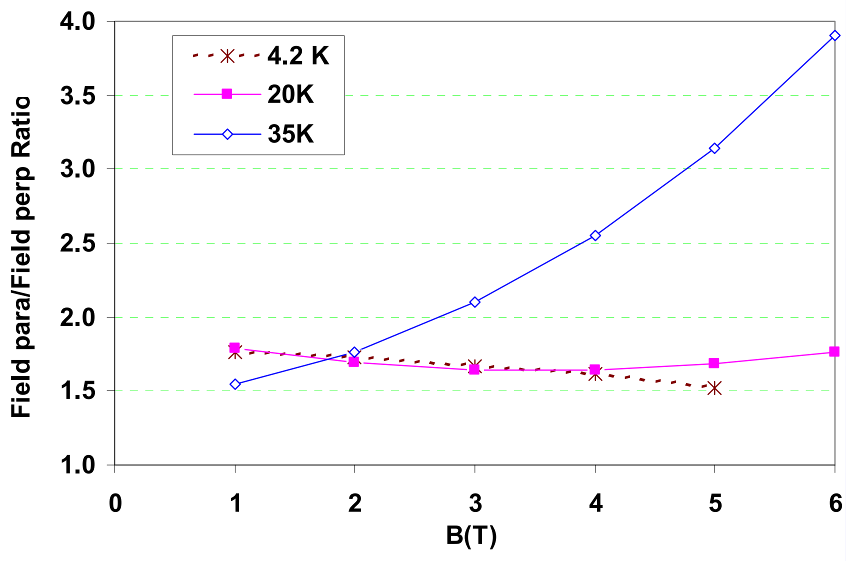
Comparison between measurements and calculations of I_c are much more involved in this HTS magnet than in conventional LTS magnet because

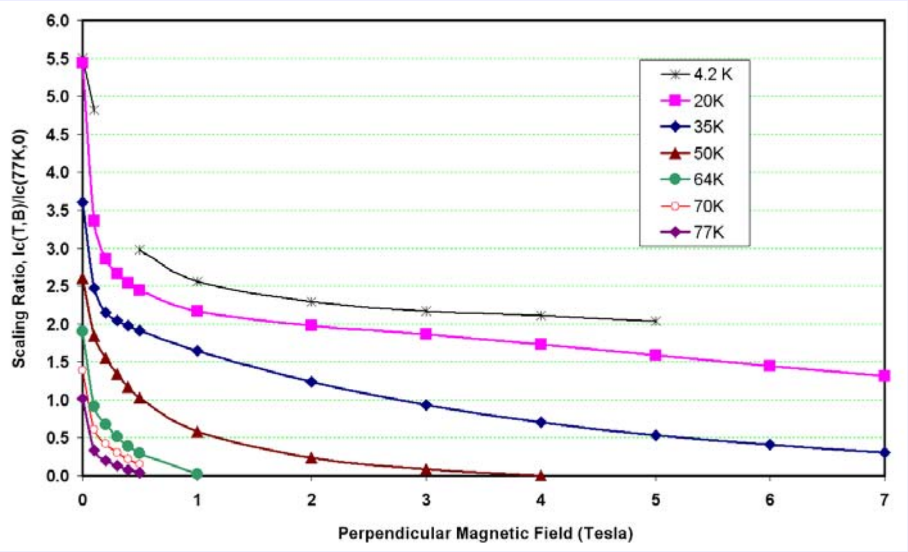
(a) there is a significant difference between field parallel and field perpendicular I_c, with ratio being a strong function of temperature

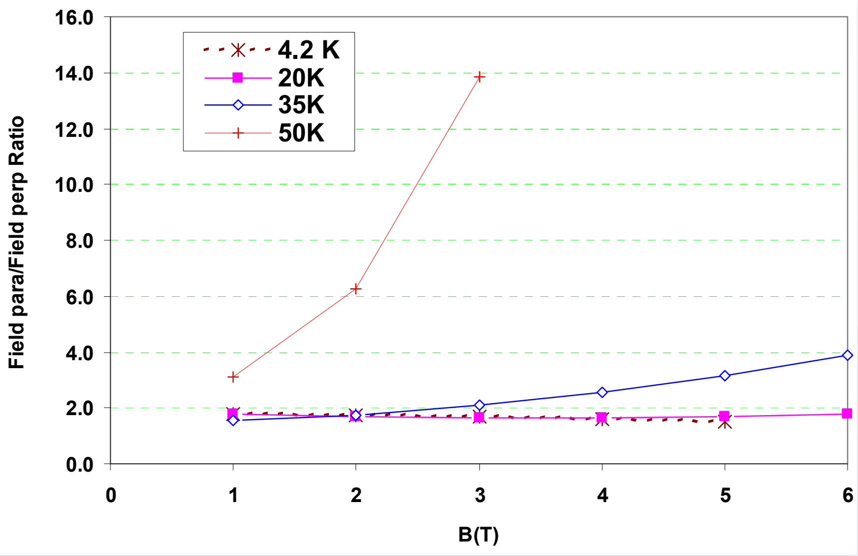
(b) requires 3-d analysis because the magnet is very short

Impact of Parallel and Perpendicular Field in the I_c of HTS (2223 Tape)









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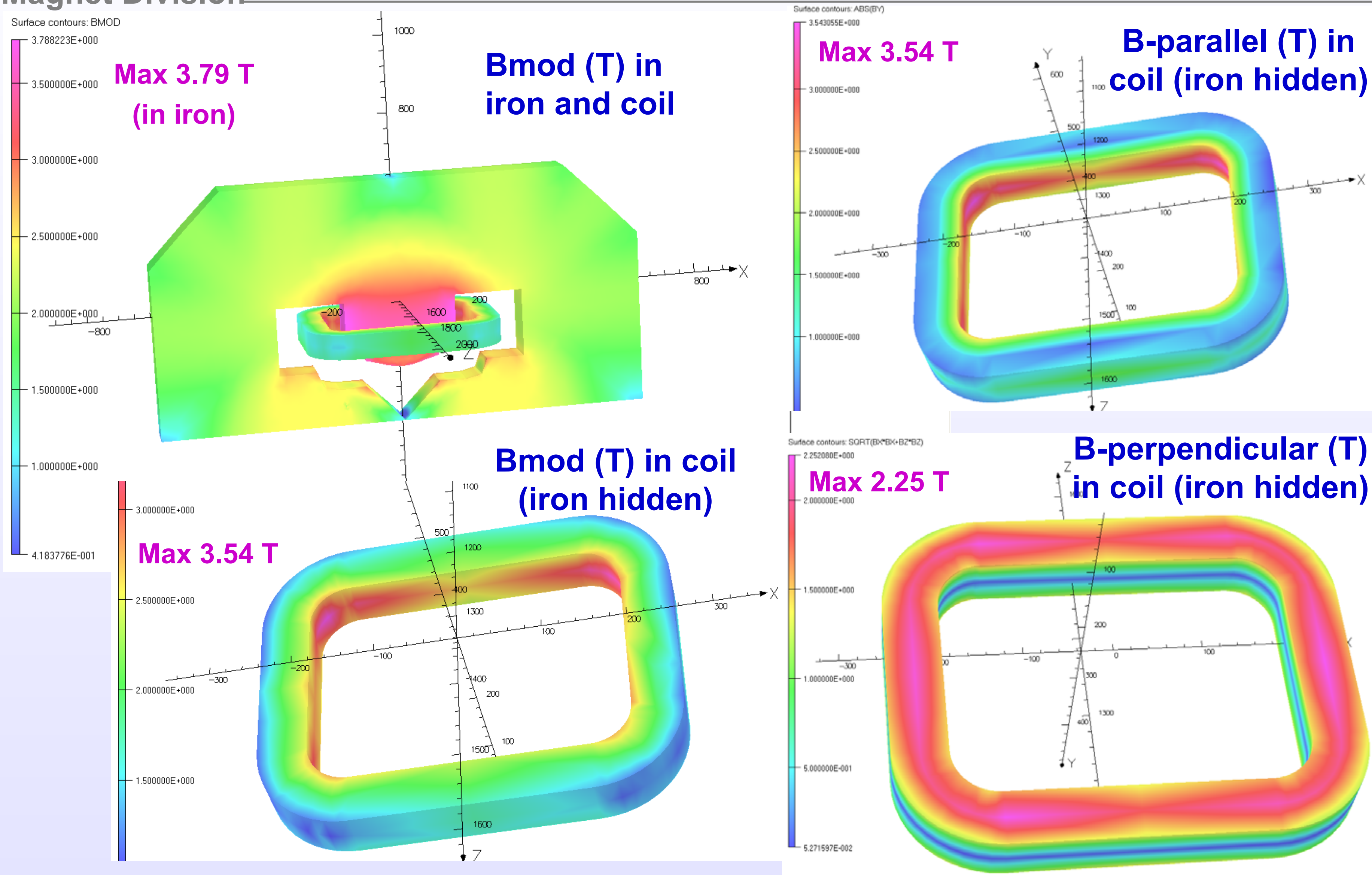
Field in RIA Warm Iron Design with 12 coils (175 turns each) at 200 A



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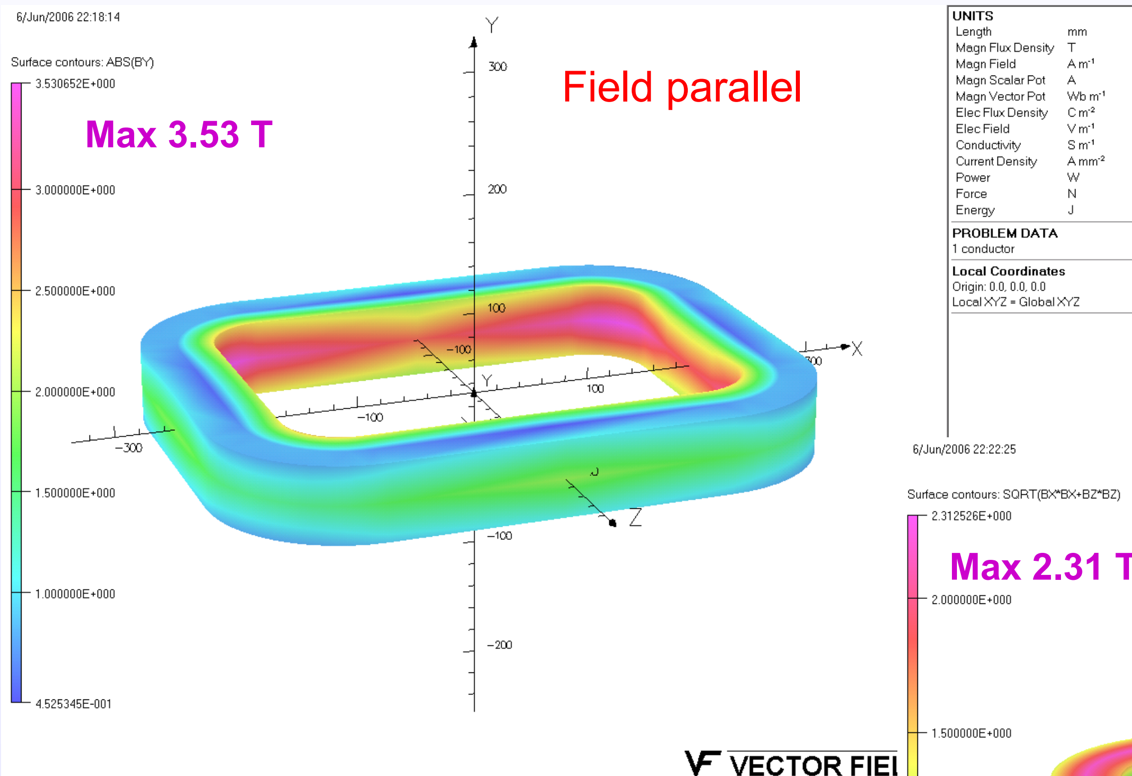
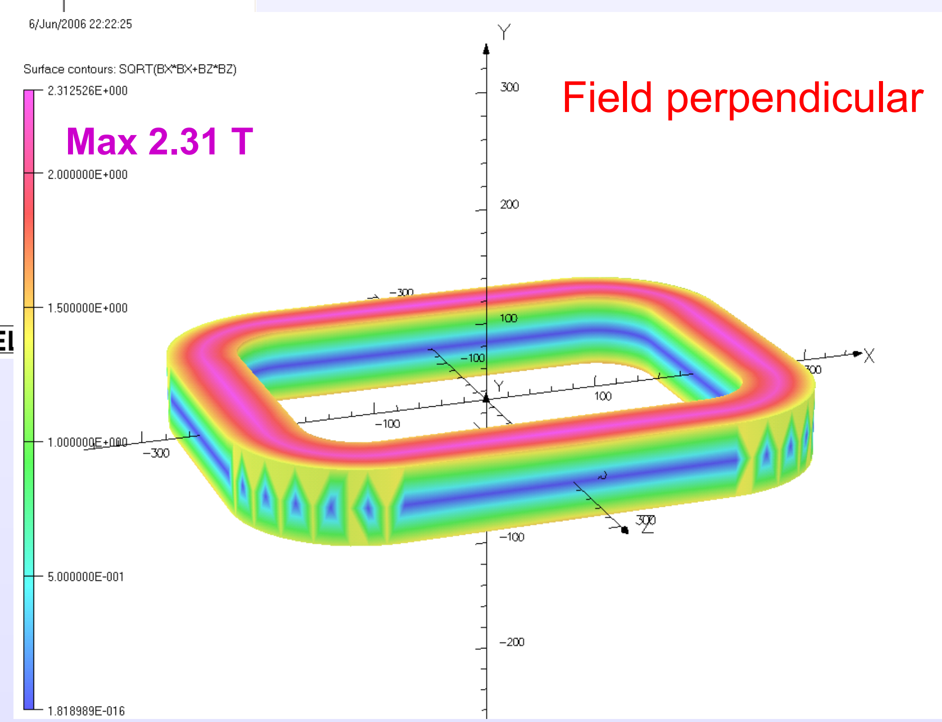
Coil Only Calculations (12 coils at 200A, 175 turns each)



- It turns out that the coil only calculations gives field within a few % level of actual field (in particular at high fields).
- Coil only analysis is much faster and relative accuracy is much better.



We need to scan parallel and perpendicular field components to study various scenarios

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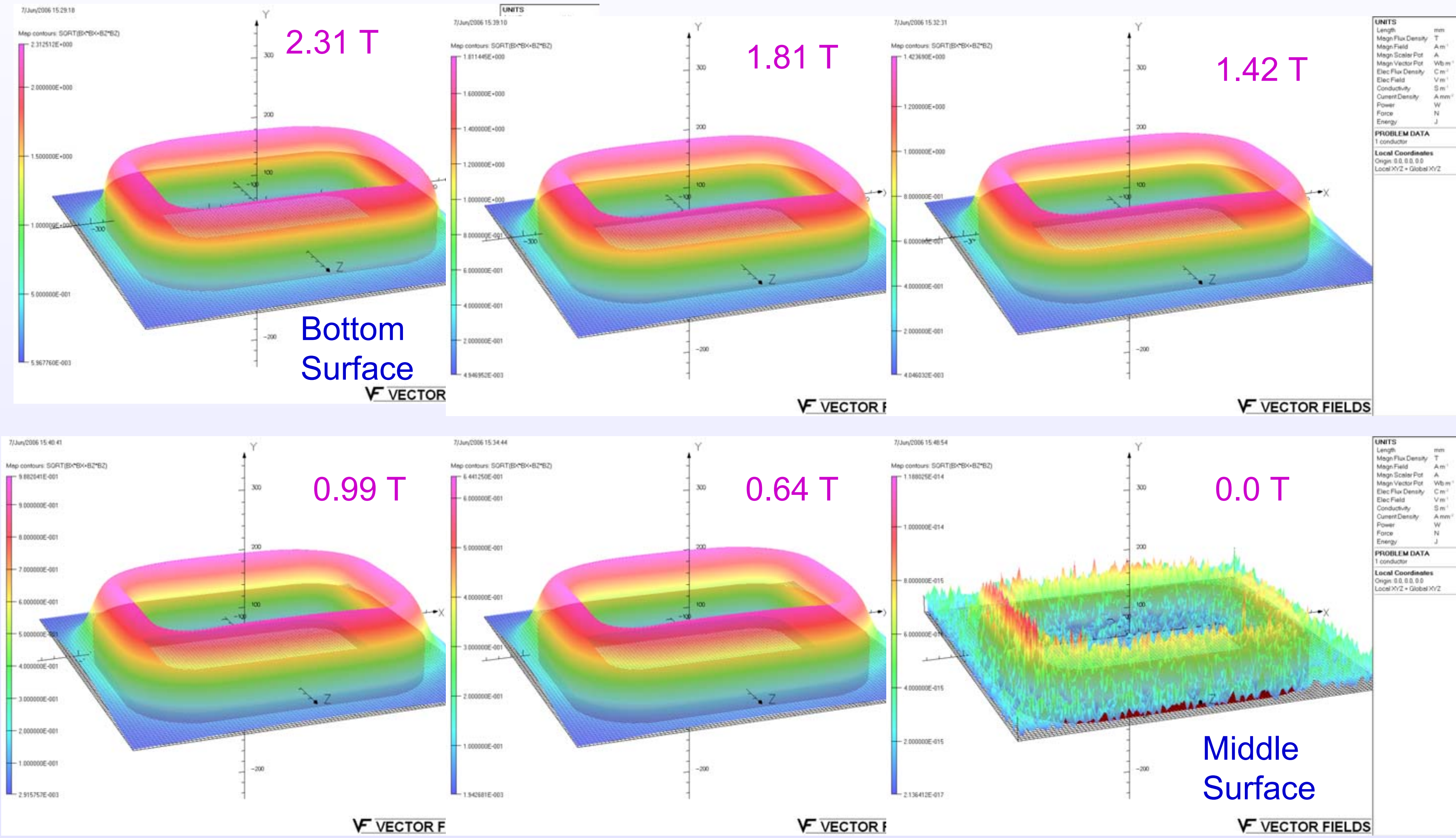
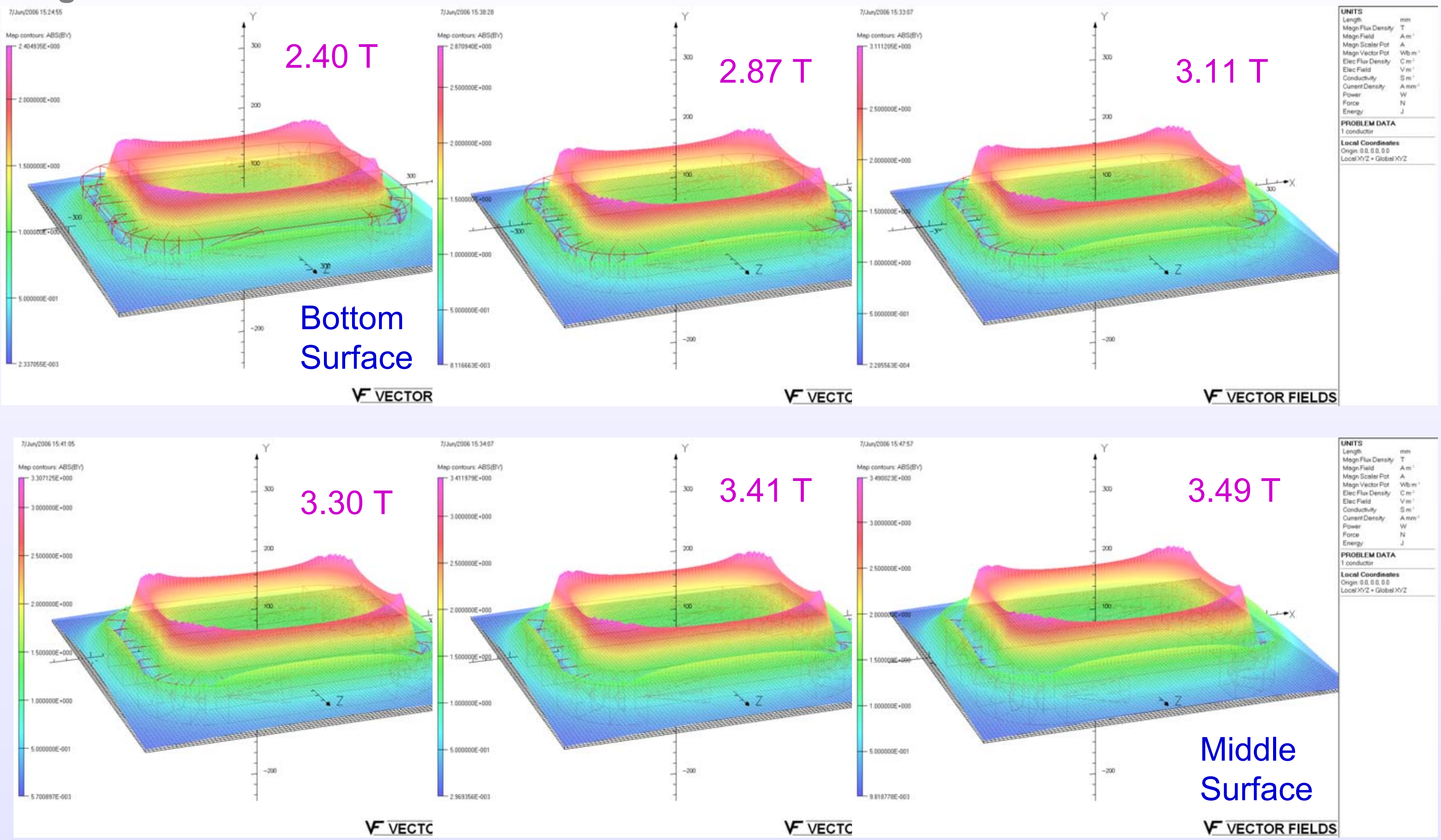
Perpendicular Component of the Field While Slicing through the Coil



Parallel Component of the Field While Slicing through the Coil



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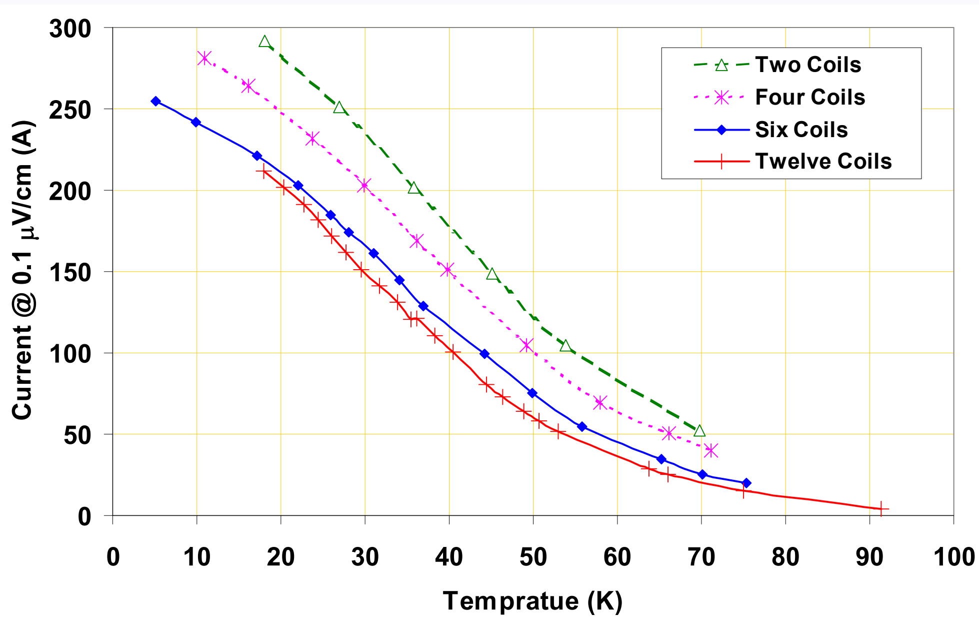
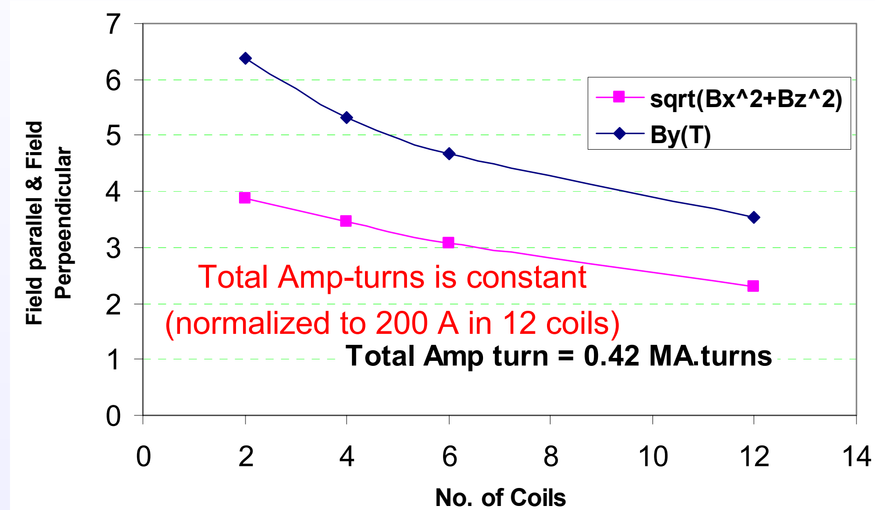
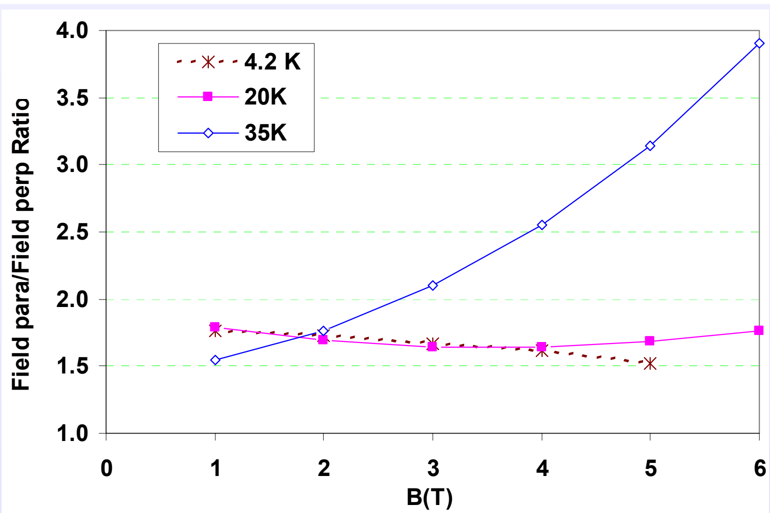
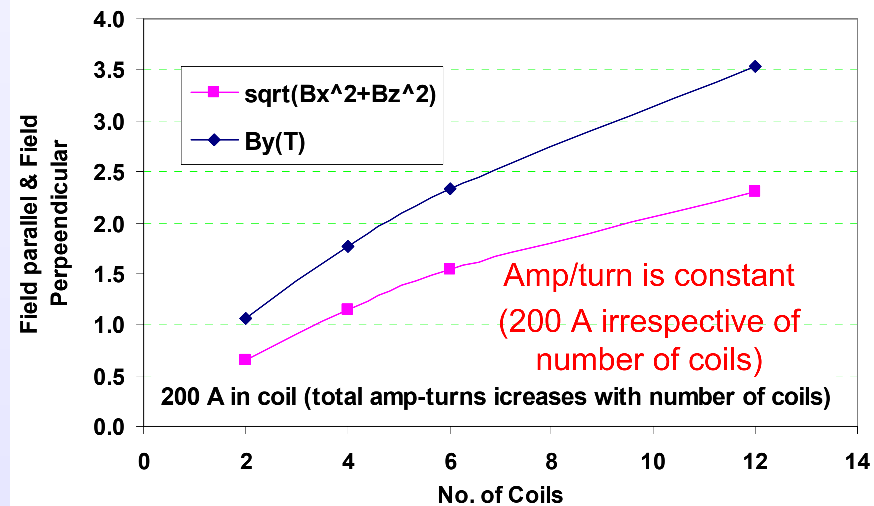
Variation of Field with Current for Different Number of Coils







The ratio is ~1.6 for 4 to 20 K. And that's about what we have !!!



Parallel/Perpendicular ratio is 1.64 for 2 coils and ~1.53 for rest

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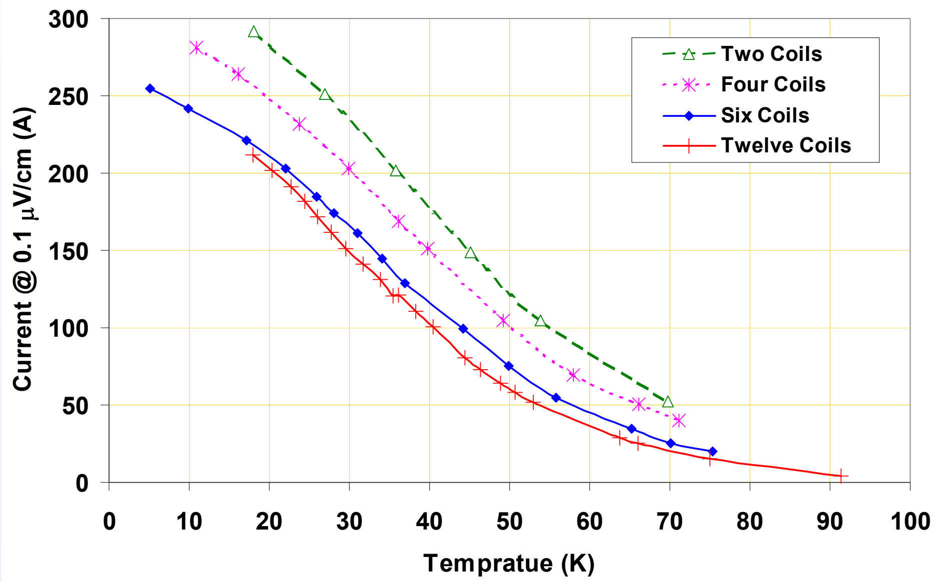
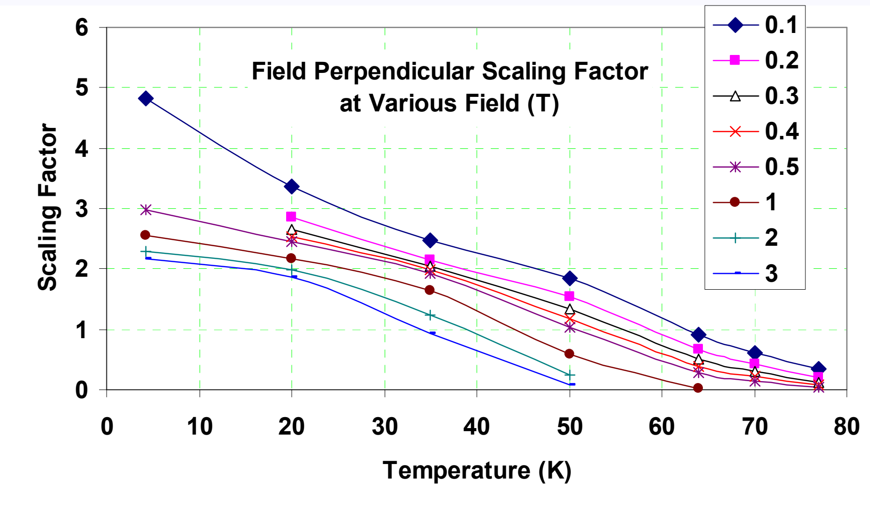
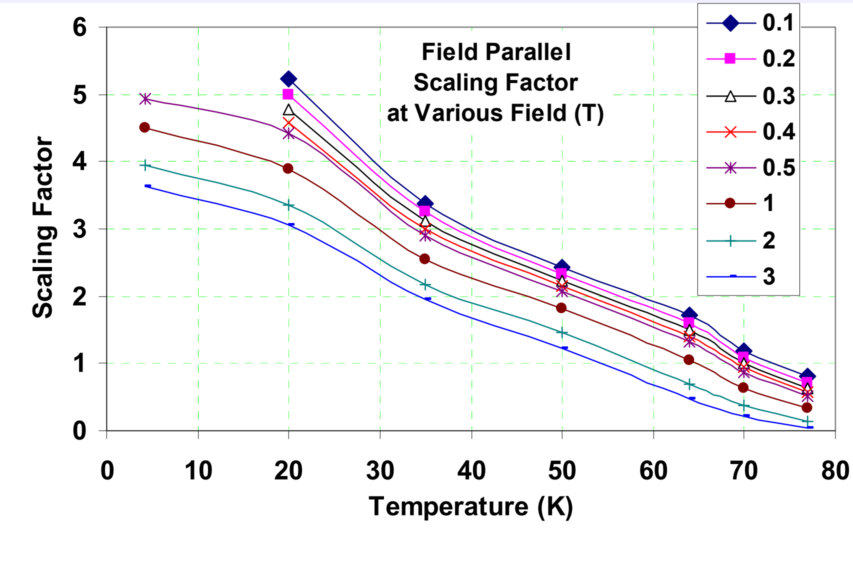
Comparison Between Calculations and Measurements







- We specify critical current at 0.1 μV/cm whereas HTS industry specifies at 1 μV/cm.
- The detailed calculations performed in select cases show that we are measuring 5-20% more current than expected.
- At high temperature the current and field is low and one needs to do non-linear iron calculations.
- Higher I_c may be due to re-distribution of currents.
- There is a significant uncertainty in scaling also.
- Bottom line: It meets the RIA requirements.

Summary of RIA HTS Magnet R&D Program

We designed RIA R&D program not only to build a magnet

- Most people would have started with a set objective of building magnet and would still be building components with no results to show yet.

However, we designed a flexible RIA R&D program to develop and prove HTS technology along the way with a number of test demonstrations

- We have done reasonably well in proving the technology despite the fact that we have not yet built the magnet. We and other people are already discussing what we have demonstrated and are making future programs based on that. In fact, building magnet now appears to be a routine task that must be done for the sake of completeness.
- This is due to a step by step program that we instituted. This included 77 K coil testing, magnetic mirror model with cold iron design, magnetic mirror model with warm iron design and now to the real magnet…
- We used a prudent combination of both conservatism (e.g., choosing conductor with stainless steel backing) and looked and grabbed new opportunities (for example, conduction cooling, energy deposition test).