MICE CM29

Magnetic Shielding Update

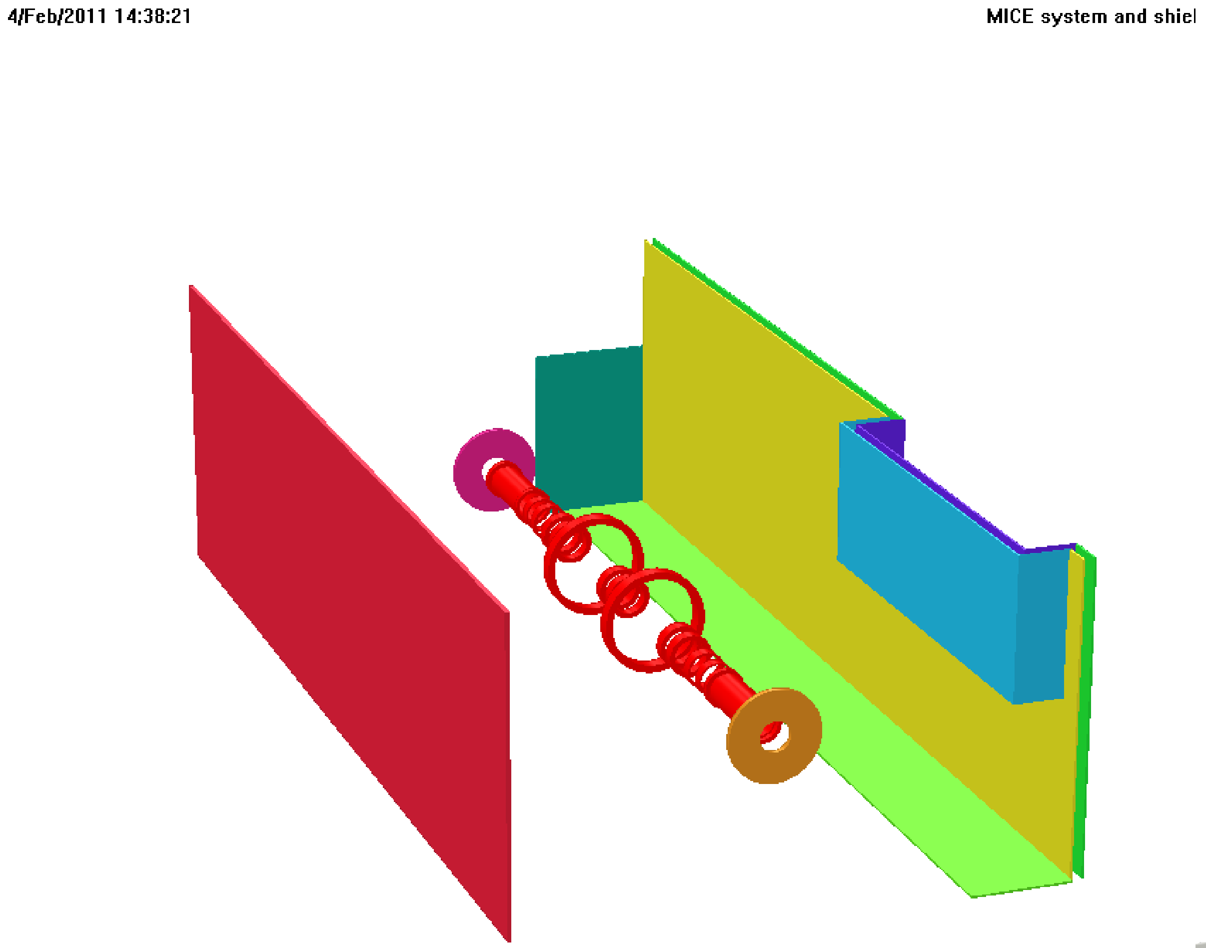
Mike Courthold
16Feb11

Science & Technology Facilities Council

MICE Magnetic Shielding Walls
Reason for their Existence

- The MICE Magnetic Shielding walls were designed to limit the field at the periphery of the MICE Hall (with the exception of the roof) to 5 Gauss (0.5mT)
  - This is a self-imposed limit by RAL & CERN by "Best Practise", due to the possibility that members of the public with Pace-Makers might be present in the ISIS & MICE Control Rooms
  - NB: This is not a limit imposed by legislation
  - ISIS have also imposed a notional limit of 5 Gauss at the wall of the Injector Hall, to avoid fringe field effects on the ISIS LINAC
    - NB: This limit has never been formally justified by ISIS

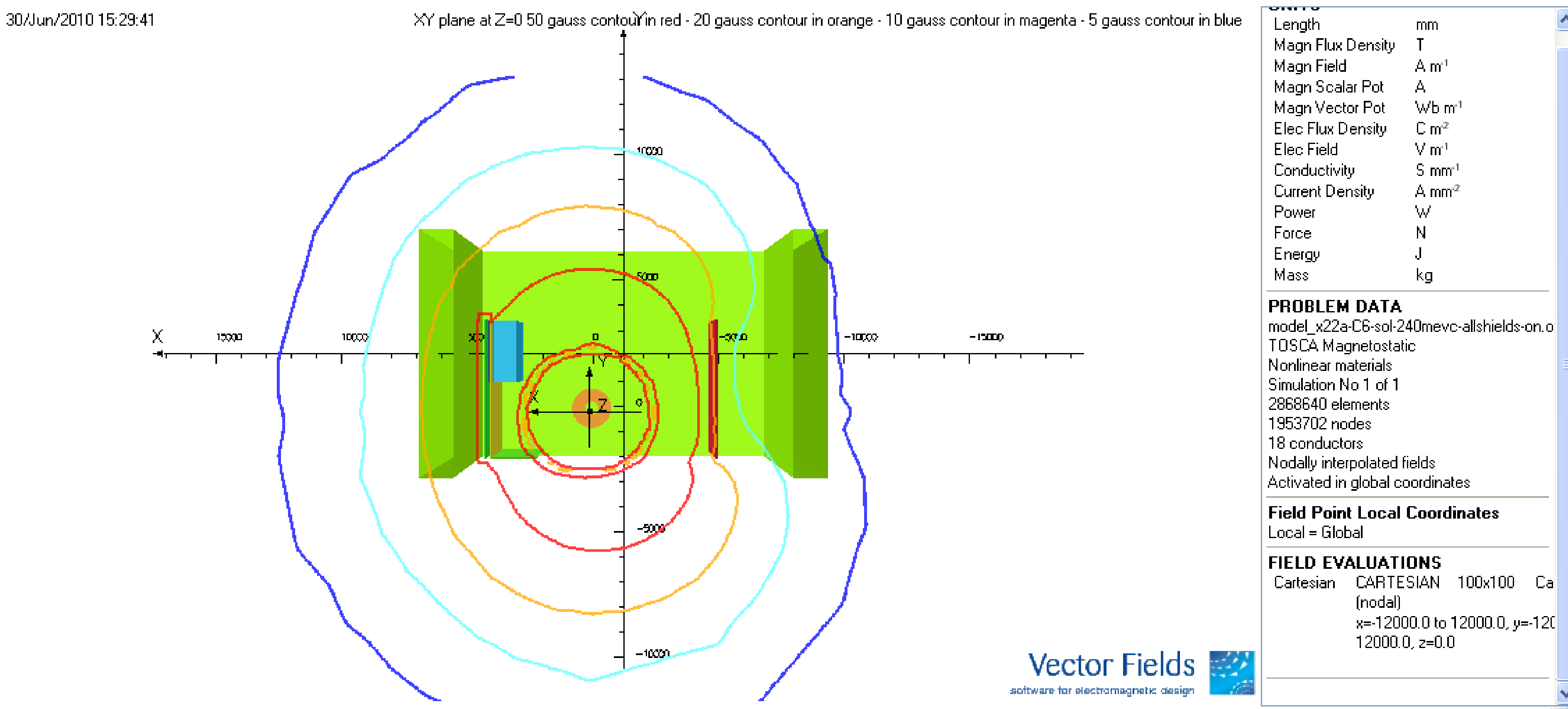
Phase VI, Solenoid mode, 240MeV/c
VF Opera Magnetic Shielding Wall Model



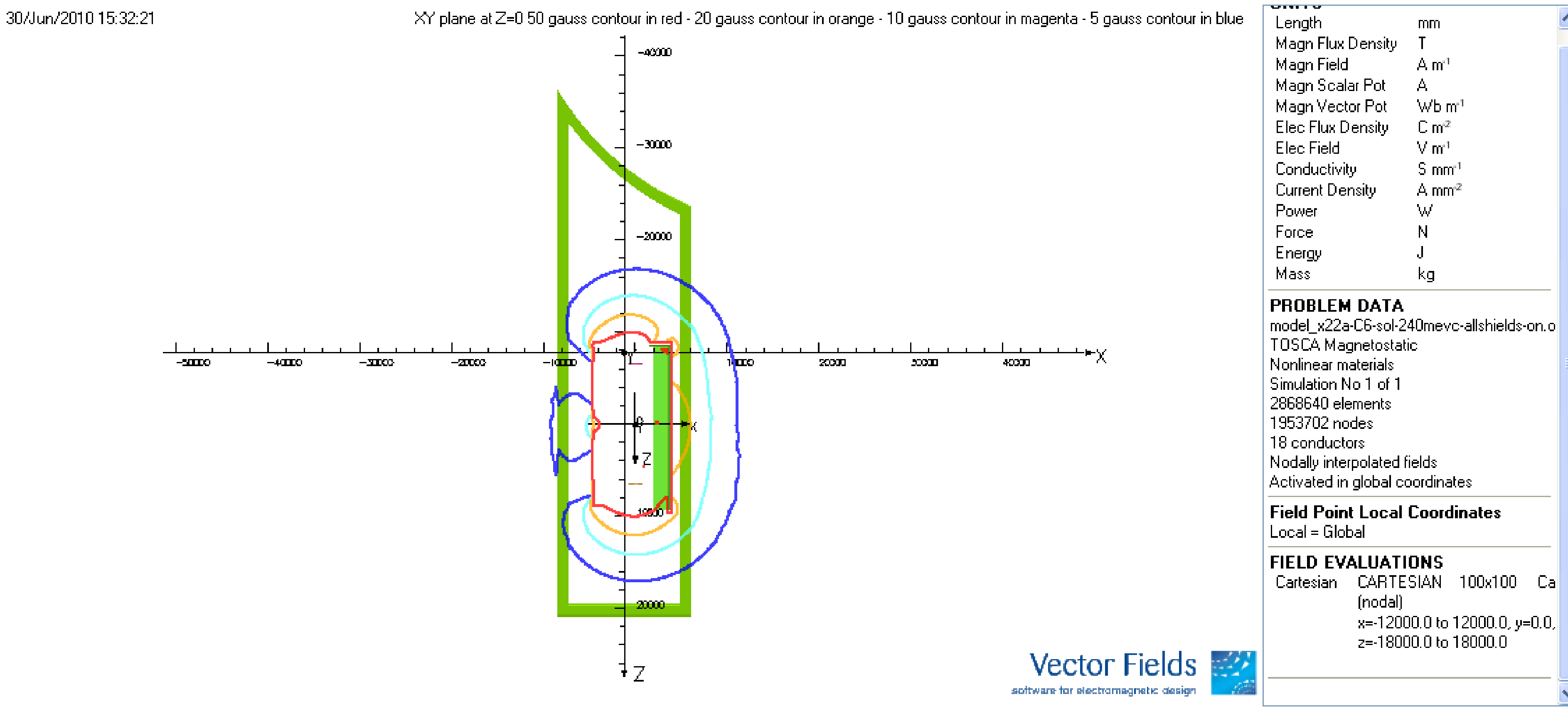
Phase VI, Solenoid mode, 240MeV/c
Problem with conductor definition file

- Additional analysis performed to check the effect of the magnetic shielding wall on beam optics, and subsequently published as a MICE Note, predicted that the peak fields experienced external to the MICE Hall and at the ISIS Control Room wall would be 19.0 & 17.5 Gauss resp.
  - This was significantly higher than the design aim of 5 Gauss maximum for each of these areas, but not noticed at the time.
  - The difference was eventually traced to an error that crept into the conductor definition file for Solenoid mode, which had been altered back in August 2007 to reflect the change from 200 to 240Mev/c, plus conductor geometry changes.
  - All Solenoid mode models since August 2007 were thus in error
  - Representative models were subsequently rerun with corrected data, to compare results, and thus understand the effect of the error on the predicted performance of the magnetic shielding wall
  - Initial conclusions were that the error was only significant for Step VI in Solenoid mode
  - Subsequently, another error was discovered in the data used for Step V, which strongly affects the field produced by the single Coupling Coil in this mode. It is thus important to re-analyse the results for Step V in Solenoid & Flip modes
    - NB: The field of the Coupling Coil in the centre is not cancelled in Step V Flip, unlike other modes

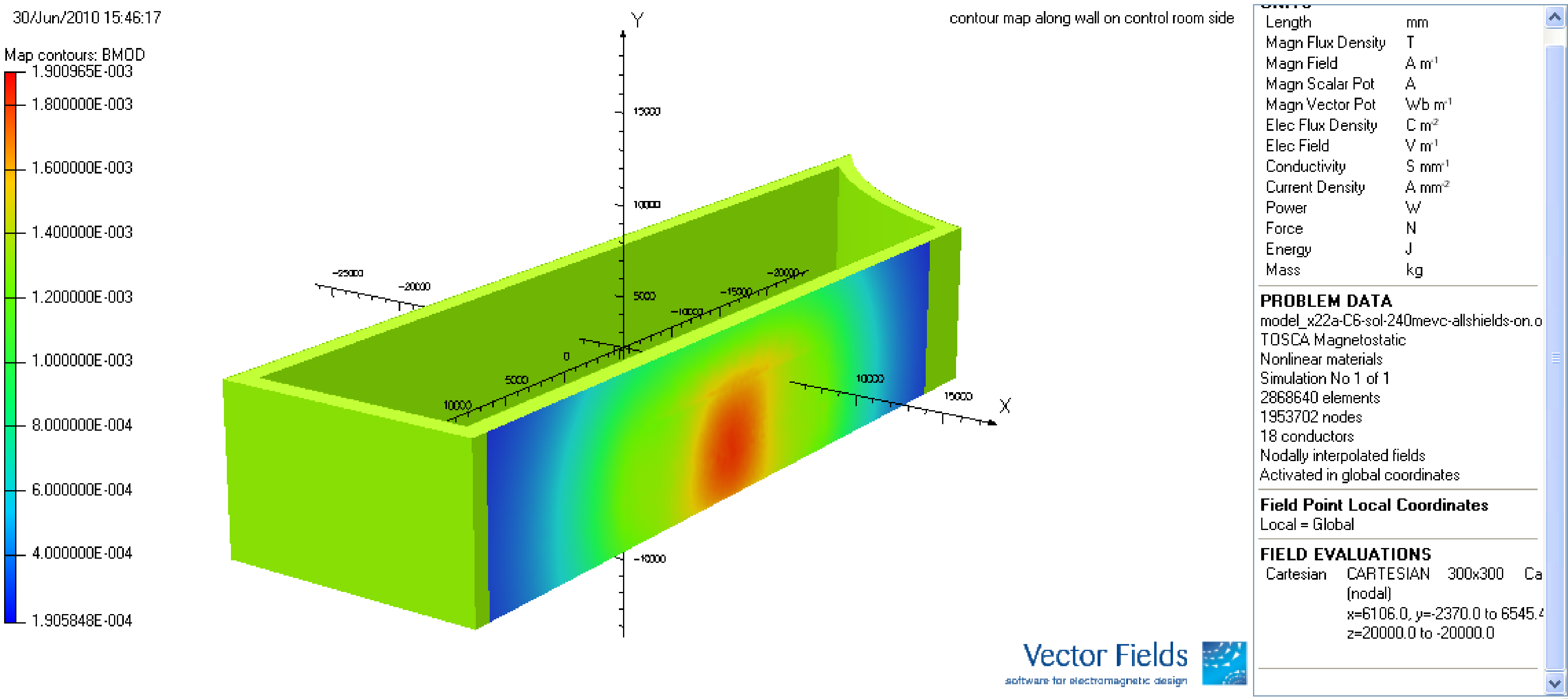
Phase VI, Solenoid mode, 240MeV/c
All shields on



Phase VI, Solenoid mode, 240MeV/c
All shields on

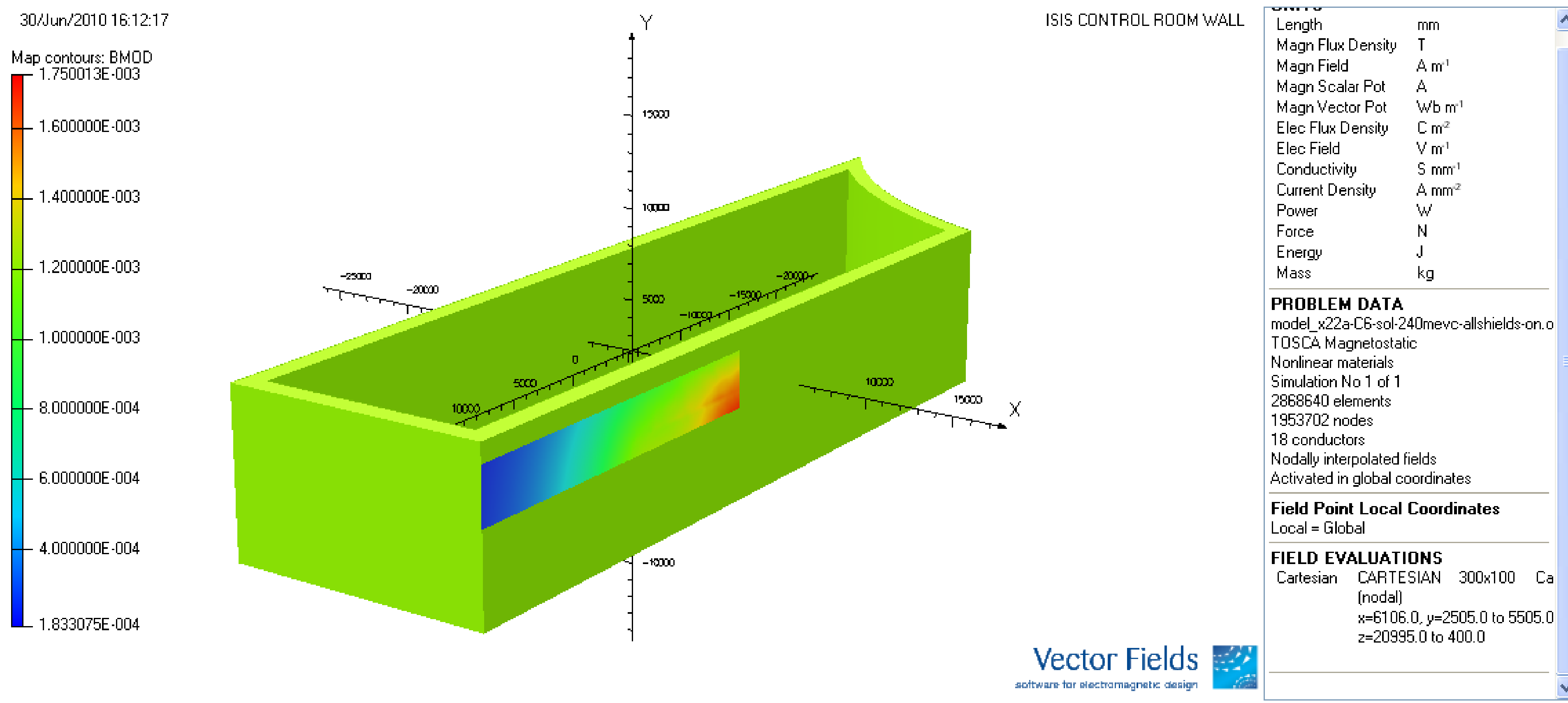


Phase VI, Solenoid mode, 240MeV/c
All shields on



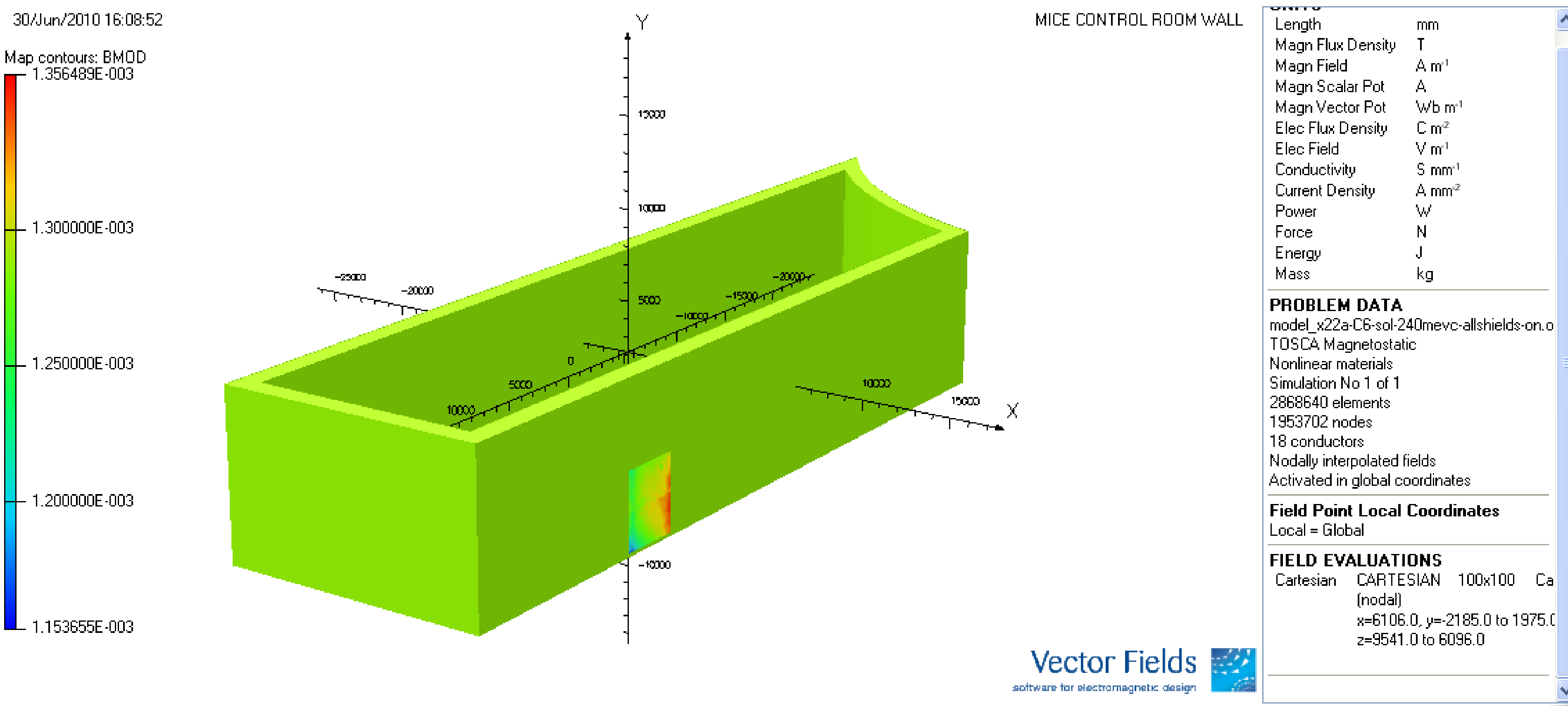
Science & Technology Facilities Council

Phase VI, Solenoid mode, 240MeV/c
All shields on



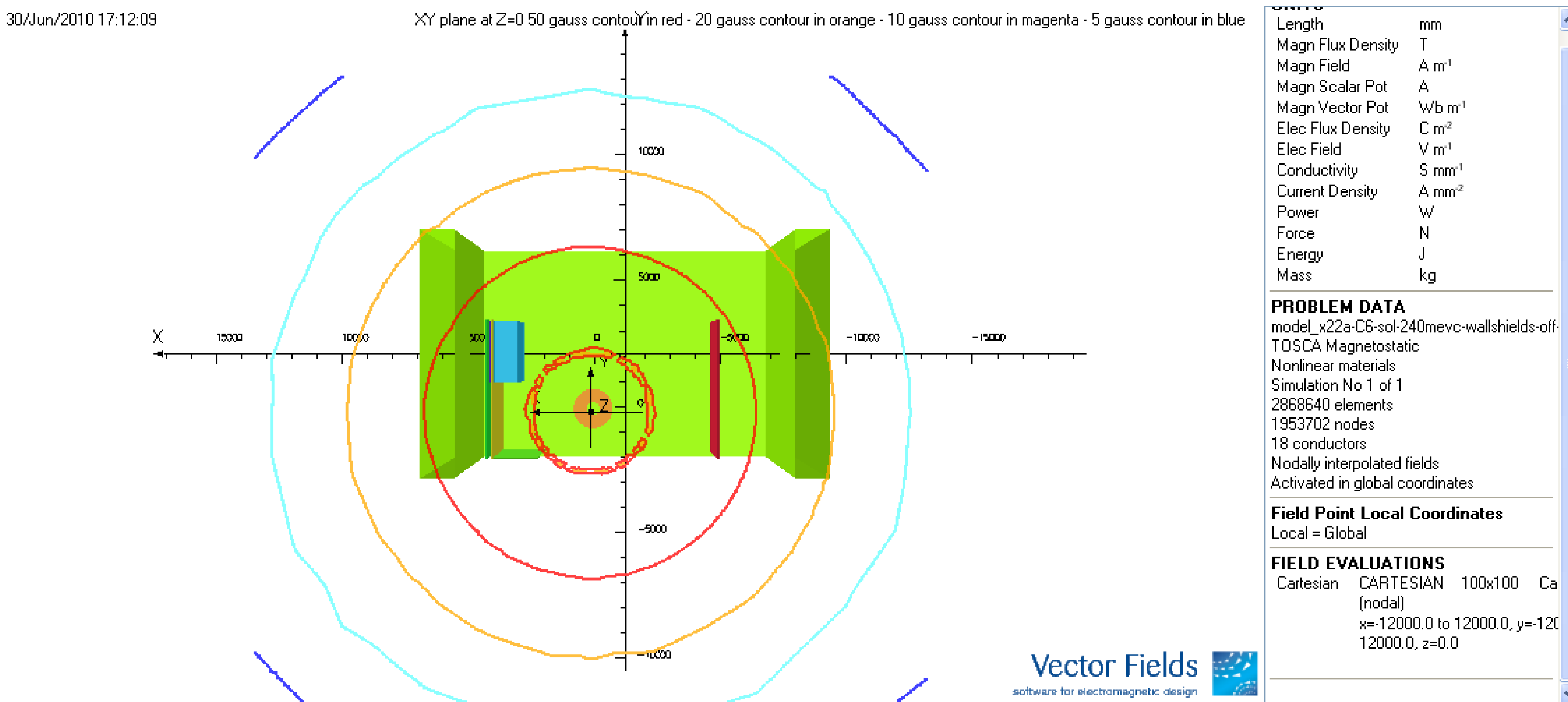
Science & Technology Facilities Council

Phase VI, Solenoid mode, 240MeV/c
All shields on

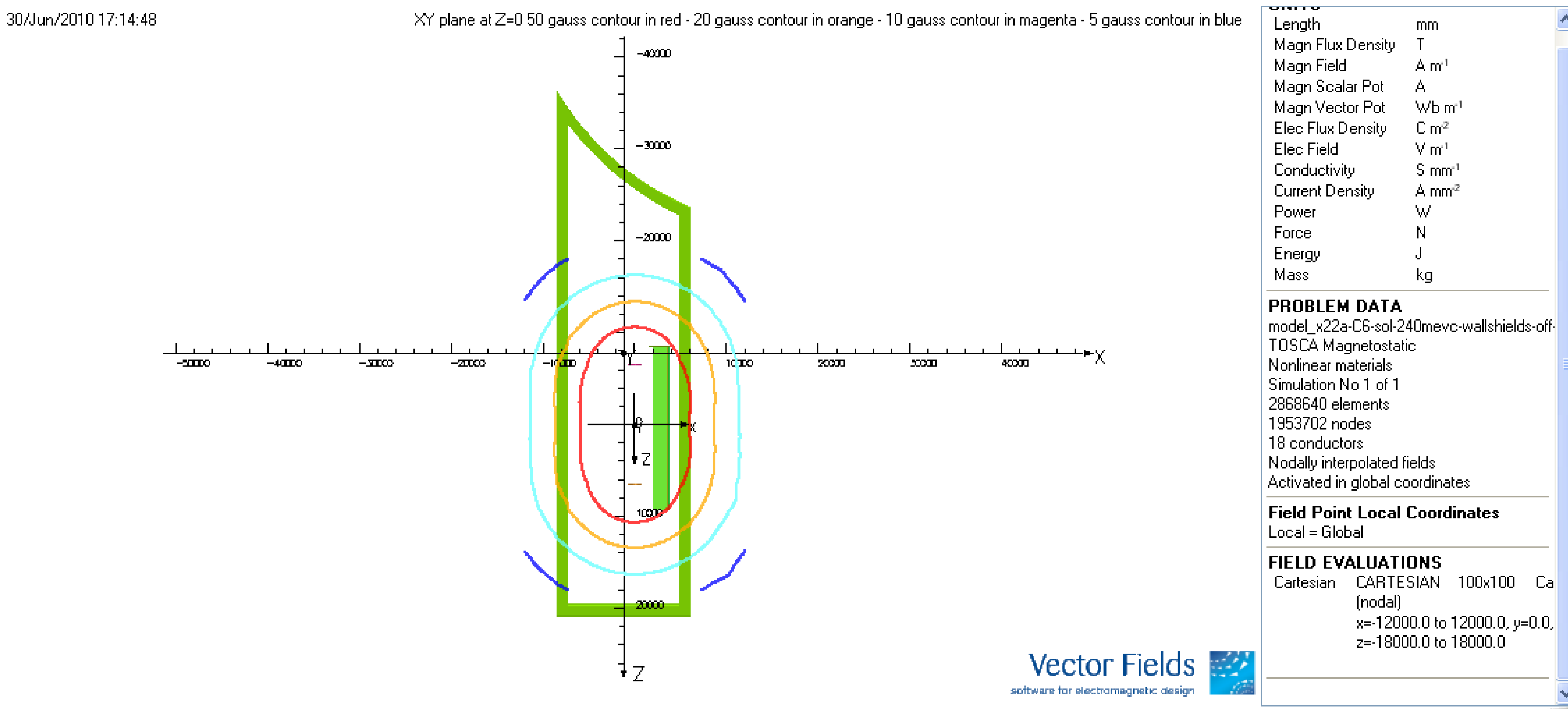


Science & Technology Facilities Council

Phase VI, Solenoid mode, 240MeV/c
Wall shields off

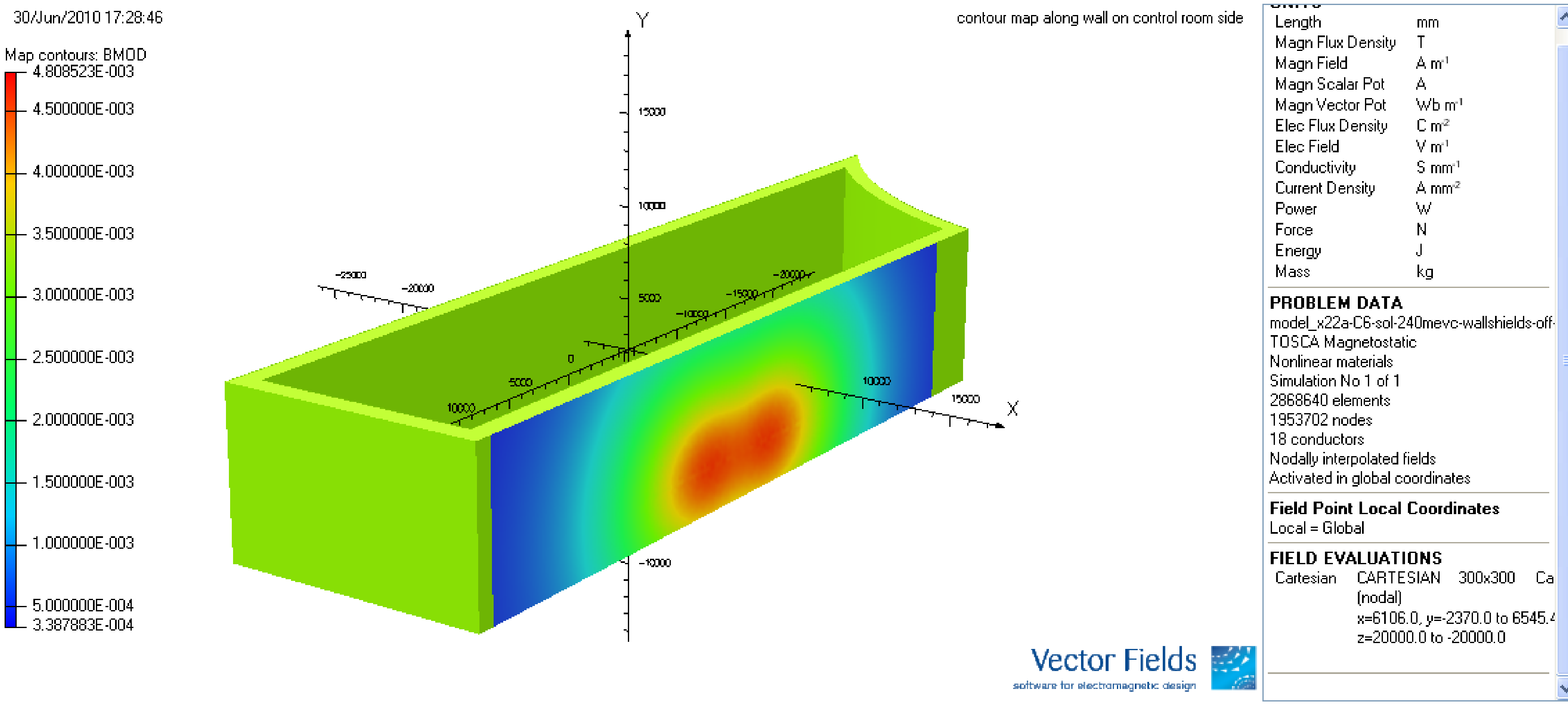


Phase VI, Solenoid mode, 240MeV/c Wall shields off



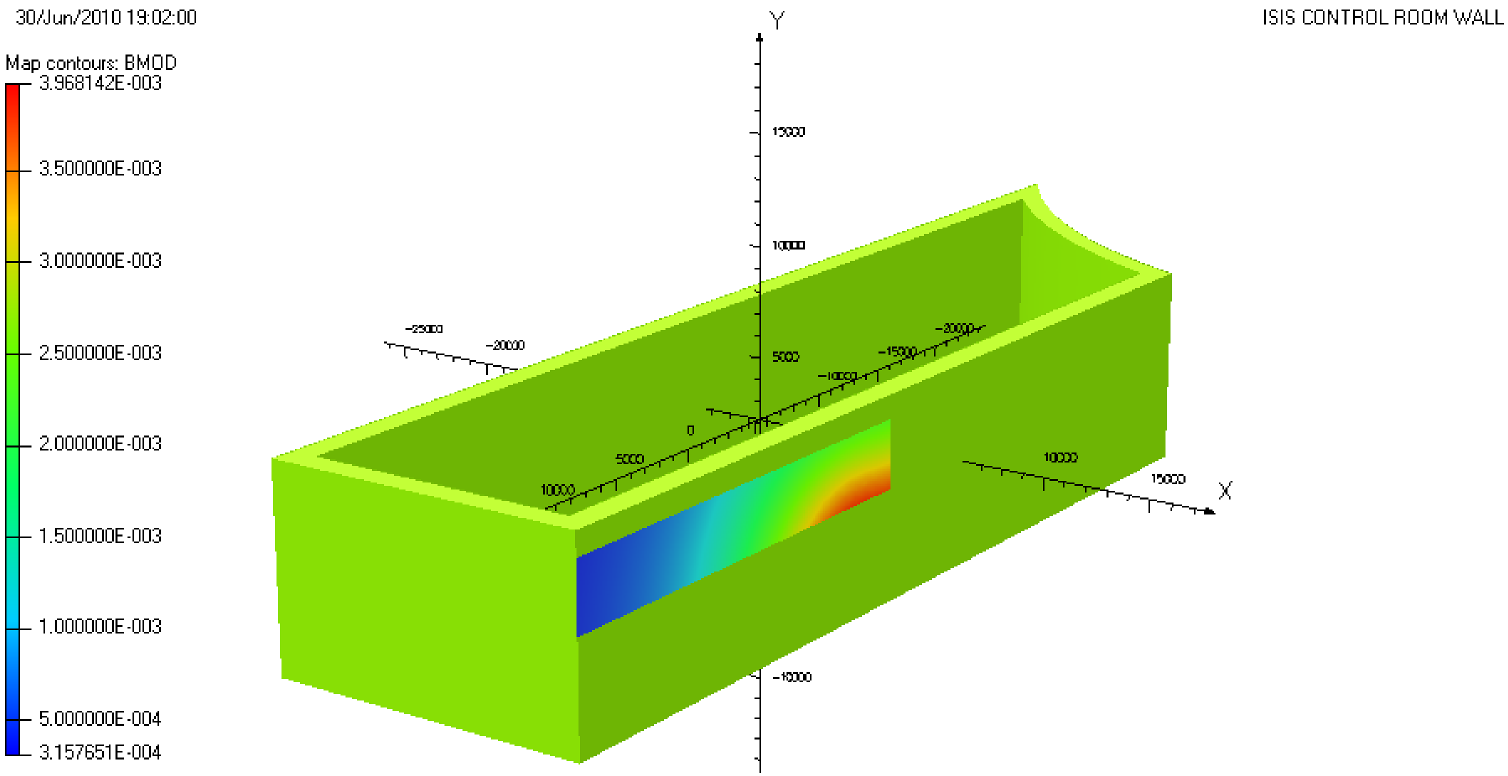
Science & Technology Facilities Council

Phase VI, Solenoid mode, 240MeV/c
Wall shields off



Science & Technology Facilities Council

Phase VI, Solenoid mode, 240MeV/c
Wall shields off



Vector Fields
software for electromagnetic design

Length	mm
Magn Flux Density	T
Magn Field	A m^{-1}
Magn Scalar Pot	A
Magn Vector Pot	Wb m^{-1}
Elec Flux Density	C m^{-2}
Elec Field	V m^{-1}
Conductivity	S mm^{-1}
Current Density	A mm^{-2}
Power	W
Force	N
Energy	J
Mass	kg

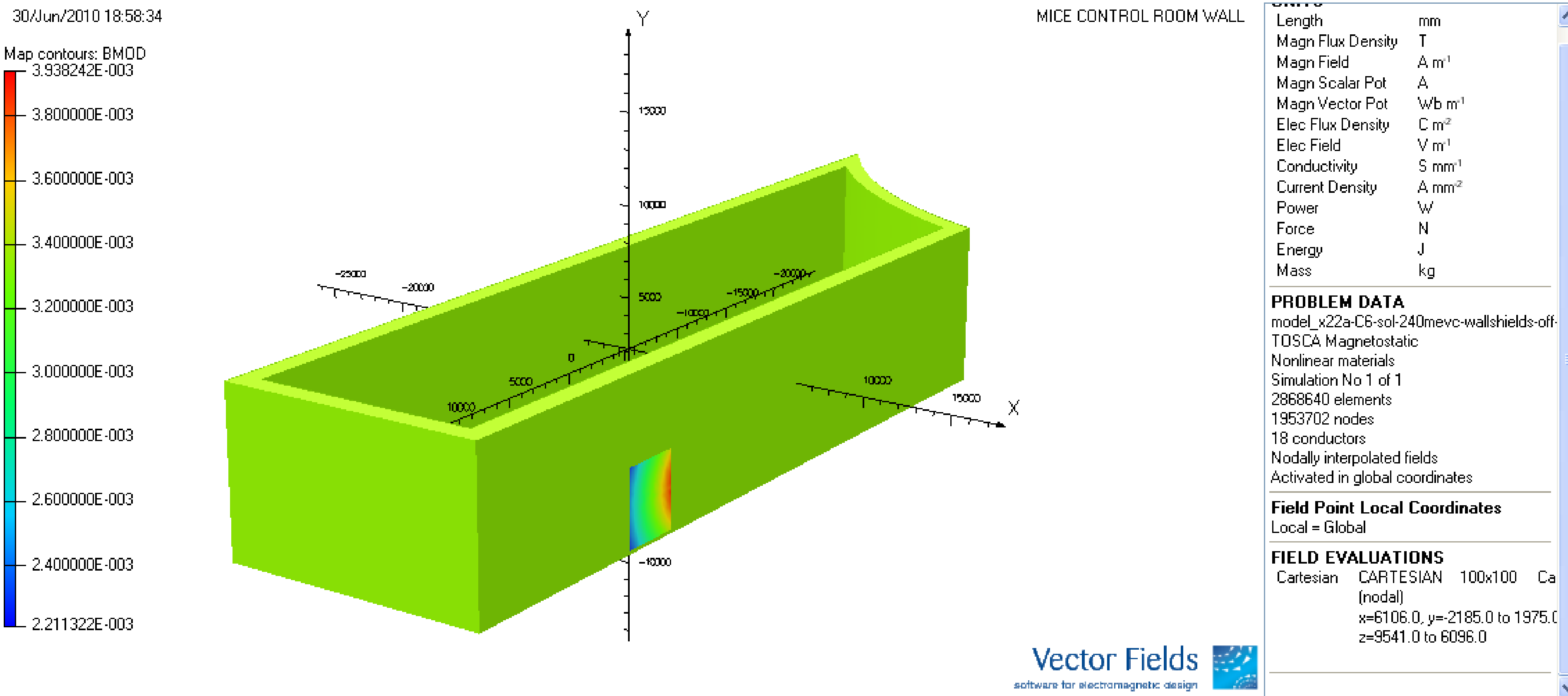
PROBLEM DATA
model_x22a-C6-sol-240mevc-wallshields-off-
TOSCA Magnetostatic
Nonlinear materials
Simulation No 1 of 1
2868640 elements
1953702 nodes
18 conductors
Nodally interpolated fields
Activated in global coordinates

Field Point Local Coordinates
Local = Global

FIELD EVALUATIONS
Cartesian CARTESIAN 300x100 Ca
(nodal)
x=6106.0, y=2505.0 to 5505.0
z=20995.0 to 400.0

Science & Technology Facilities Council

Phase VI, Solenoid mode, 240MeV/c Wall shields off

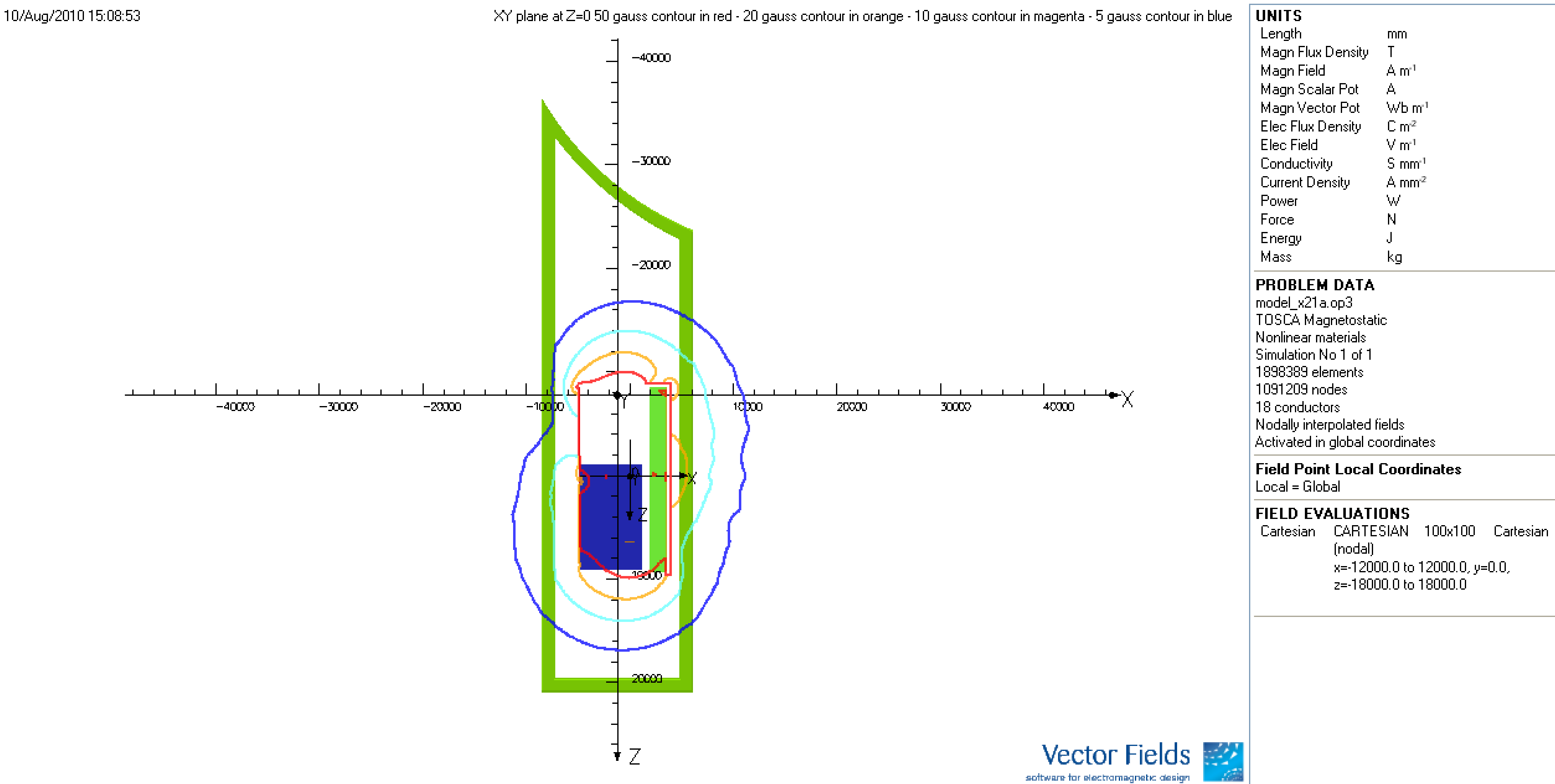


Options to fix the problem

- **Increase the shielding thickness?**
  - 2x35mm -> 19.8/18.2 G
  - 2x40mm -> 17.2/15.8 G
  - 2x45mm -> 14.6/13.5 G
  - 2x50mm -> 12.2/11.3 G
  - Thus increasing the thickness of the existing sheets in not enough !
- **Add extra iron sheets to ISIS Control Room wall?**
  - 5mm -> 21.3/18.4 G
  - 10mm -> 21.6/18.4 G
  - 15mm -> 21.6/18.4 G
  - 20mm -> 21.7/18.4 G
  - Thus adding iron sheets to the ISIS Control Room wall does not help at all !
- **Increase the length of the shielding walls?**
  - This had no significant improvement, and is quite impractical anyway
- **The presence of additional iron sheet on the floor does help**
  - 40mm thick iron sheet as the false floor gives 16.88/15.13 G
  - This is clearly an improvement, and more runs should be performed with various sizes and positions of iron sheet on the floor
    - However, floor plates must be applied uniformly, to avoid the creation of asymmetric fields which would upset the beam optics.

Science & Technology Facilities Council

Phase VI, Solenoid mode, 240MeV/c
Effect of adding extra iron floor plate



Science & Technology Facilities Council

Consult with Vector Fields
as a matter of urgency
for expert advice on increasing the affectivity of the shielding walls

Interim Report from Vector Fields

- **Accuracy of the Existing Model**
  - The Opera software uses methods that allow the fields from coils and iron to be separately calculated (reduced potentials)
  - The coil fields are calculated to very high accuracy by integration
  - The iron fields are calculated using a finite element method
    - However in regions where the coil and iron fields cancel, this approach tends to amplify the errors in the total field.
      - This can be avoided by specifying whether a total field FE solution is required in particular regions of space.
    - The magnetic shielding in the models reduced the field in the ISIS & MICE Control Rooms from 16 mT to 1.8mT, implying 90% cancellation of the coils' fields
      - It is thus appropriate to use total field solutions in shielded areas.
      - Opera reported an expected error of 1% in its FE solution; the cancellation would increase the error in the total field to approximately 10%.
      - The models were thus modified to use the total field solutions in all regions exterior to the cylinder containing the superconducting coils.
        - »The calculated fields in the control room changed by approximately 8%, in good agreement with the program's expected error.

Interim Report from Vector Fields

- The accuracy of Opera's finite element solution is related to the element size and the solution exhibits quadratic convergence as the finite element's linear dimensions are reduced.
    - The element size was therefore reduced in the MICE model, to establish confidence in the programs expected error calculation.
        - The results obtained using Opera agreed with the programs error predictions and behaved consistently when the models were refined.
        - The program predicts maximum fields of 1.7mT in the ISIS and 1.5mT in the MICE control rooms with the existing shielding configuration, when the shields are manufactured from annealed US1010 steel.

Science & Technology Facilities Council

Interim Report from Vector Fields

- **Steel characteristics**
  - Annealed US1010 steel has been frequently used to manufacture magnetic shielding for high field NMR magnets.
  - The magnetic characteristics of the steel have been measured for many samples and the performance of the shields has been reliable.
  - The magnetic performance of US1010 that has not been annealed is very variable.
    - The initial model for the MICE shielding has been recalculated using average properties for un-annealed US1010 steel and the fields in the ISIS and MICE control rooms increased to 2.5mT.
  - Annealed US1010 properties are used for all results in the interim report, except where other steels are used to look at sensitivity.

Interim Report from Vector Fields

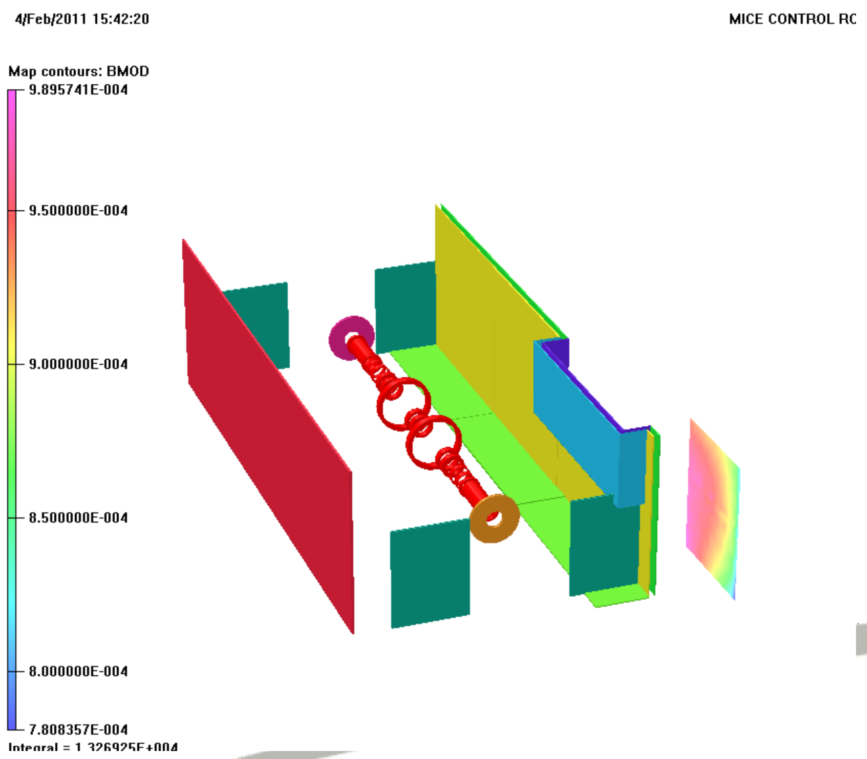
- **Options for Improving MICE magnetic Shielding**
  - The initial configuration of shields shows some saturation of the steel in the Control room shielding walls and floor plate.
    - A calculation using a fixed high permeability for the steel provides an easy way to check the maximum efficiency of a shielding configuration.
    - This calculation showed that if the shielding walls were increased in thickness so that the flux density in the steel was below 1T, the maximum field in the ISIS control room would be 0.47mT and in the MICE control room 0.46T.
    - The constant permeability result also gives an immediate indication of the positions where increased shield thickness is required.
  - NB: Increasing the shielding plate thickness is an option, but the safety margin is small.

Interim Report from Vector Fields

- **Increased shielding plate thickness**
  - (Model ref M1). The thickness of the floor plate on the control room side was increased by 35mm from Z=-3M to +3M (measured from the centre of MICE along the beam line direction) and the thickness of the outer control room wall plates was increased by 25mm from Z=-3M to +2.366M.
    - The maximum field in the ISIS control room = 0.94mT
    - The maximum field in the MICE control room = 0.91mT
  - The thickness of the outer control room wall plates was increased by a further 25mm from Z=-3M to +2.366M (ie. total increase is 50mm)
    - The maximum field in the ISIS control room = 0.8mT
    - The maximum field in the MICE control room = 0.76mT
  - These results indicate the scale of the increases in thickness needed to improve the shielding performance.

Interim Report from Vector Fields

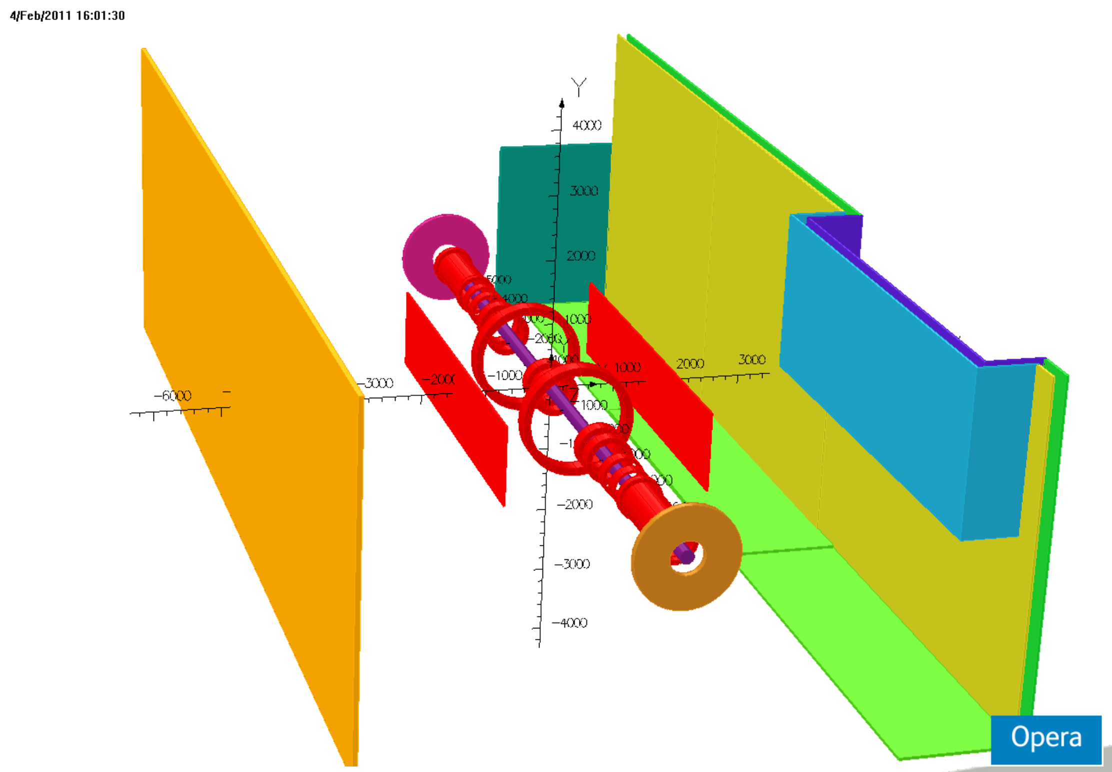
- **Modified Geometry**
- (Model ref M2). The geometry of the shields can be changed so that less field escapes from the MICE hall. Three copies of the existing fridge shield upstream plate were added to model reference M1 to give the system shown
  - Unfortunately this change increased the field in the MICE control room by 0.1mT. The plates collect more field from the coils, but this increases the flux density in the control room wall plates.



Science & Technology Facilities Council

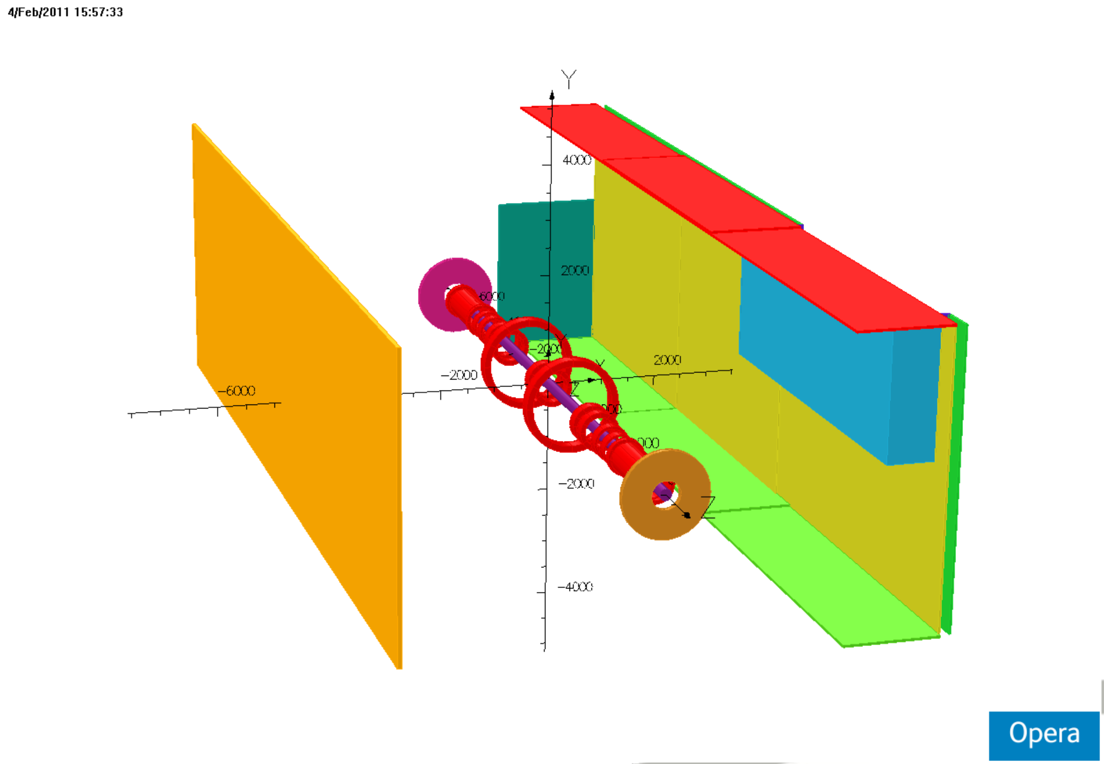
Interim Report from Vector Fields

- Other options to be considered
  - Smaller shielding wall plates could be placed symmetrically, closer to the MICE magnets



Interim Report from Vector Fields

- Other options to be considered
  - A ‘ceiling’ plate could be added on the control room side (for example a plate of the same dimensions and position as the existing floor plate, but at a height 5M above the floor plate
    - This option is not practical, due to interference with the gantry crane, and components on the mezzanine.



What Next?

- Obtain final report from Vector Fields
  - This is proving to be far too time-consuming than was originally implied by VF
- Check the affectivity of the magnetic shielding for Step V for both Solenoid and Flip modes
- Make hard decisions regarding a solution to the shielding issue
- Analyse effect of final magnetic shielding walls on beam optics
- Produce field maps to assist with the placement and potential shielding of Cooling Channel ancillary plant (eg pumps, cryo-cooler compressors, equipment racks, control valves and relays, etc.)