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Cryogenic Magnetic Shield Update

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02/10/2014

The HiLumi LHC Design Study (a sub-system of HL-LHC) is co-funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

Contents

- Shielding design in Opera
- Mechanical design considerations
- Assembly procedure for internal shield for DQW.
- Mechanical analysis
- Further work

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Magnetic shielding considerations

- We have liased with Magnetic Shields LTD from the UK throughout the design of the shield.

- The magnet group within ASTeC (STFC) have converted the mechanical design CAD files into a simplified geometry acceptable for Opera 3D (Tosca) and then assessed shielding performance based on simulations.

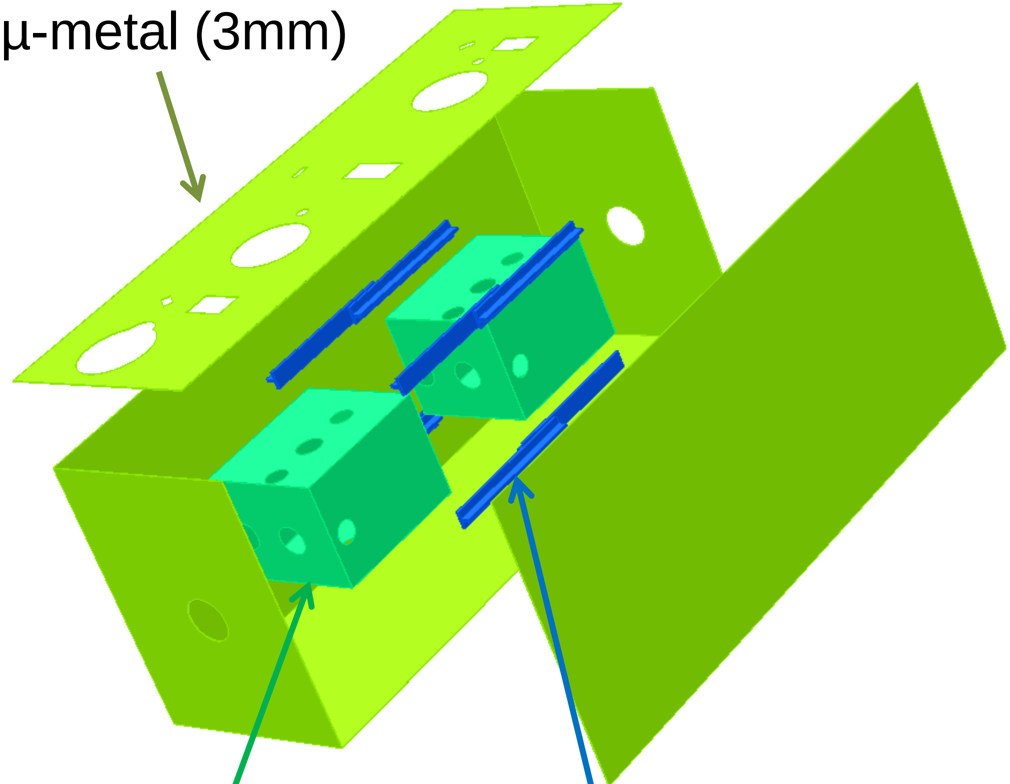
- Two shielding solutions were considered: a single-layer solution (mu-metal only) and a double-layer solution (mu-metal + cryoperm)

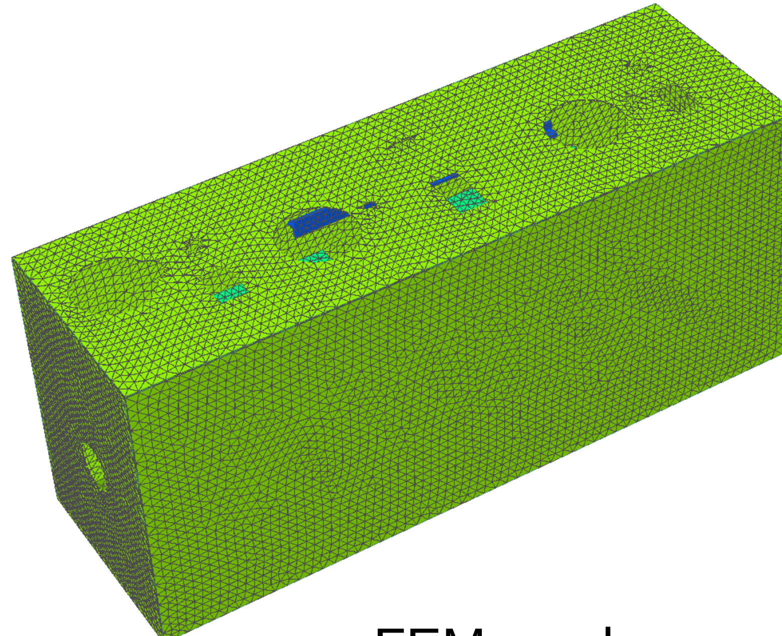
- The conclusion from this work is to go ahead with the double-layer solution. The single layer solution meets the spec by a narrow margin, but there is no room for contingency and the risk is higher.

Magnetic analysis by Kiril Marinov (ASTeC)

Opera 3D model

Magnetic analysis by Kiril Marinov



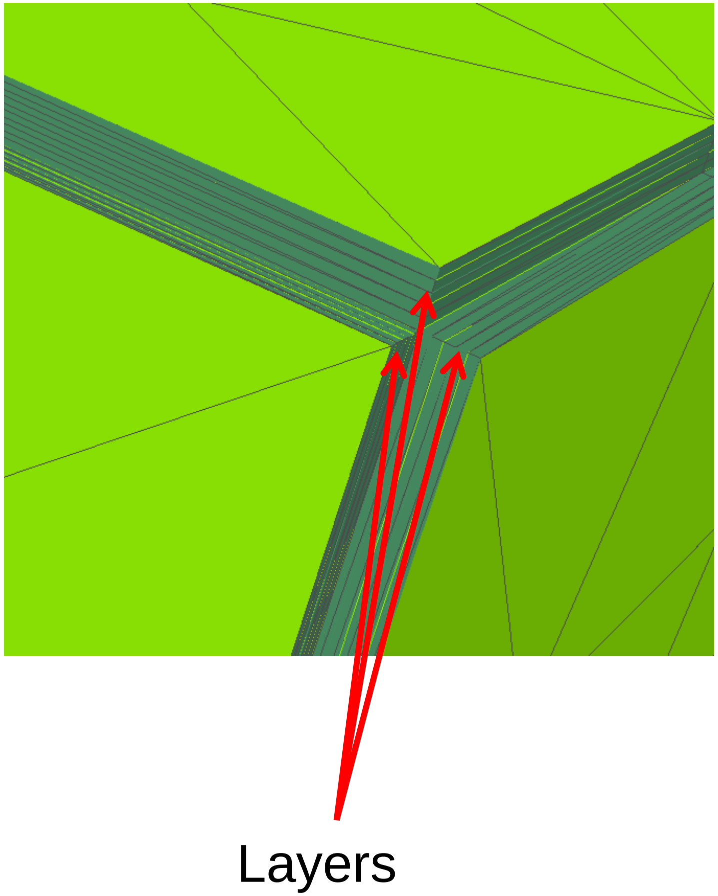


FEM mesh

Non magnetic components not relevant to the shielding performance (thermal, structural) have been omitted

Mechanical CAD model → Magnetic model

Details of the mesh



- Tosca and Elektra are static and quasi-static solvers. There is no such thing as surface impedance (RF) here. Adequate mesh is essential for field penetration calculations.

- Large aspect require layered mesh, which is not easy to generate.

- We asked an expert from Vector Fields (who make Opera) to examine an early version of the model. His recommendations were taken on board in developing the mesh.

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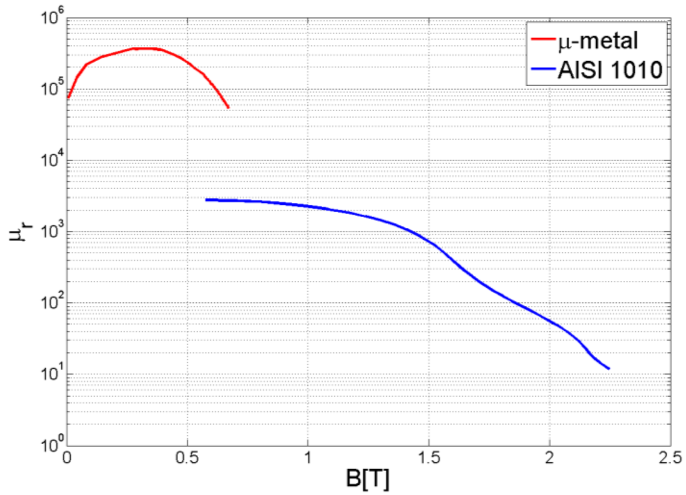
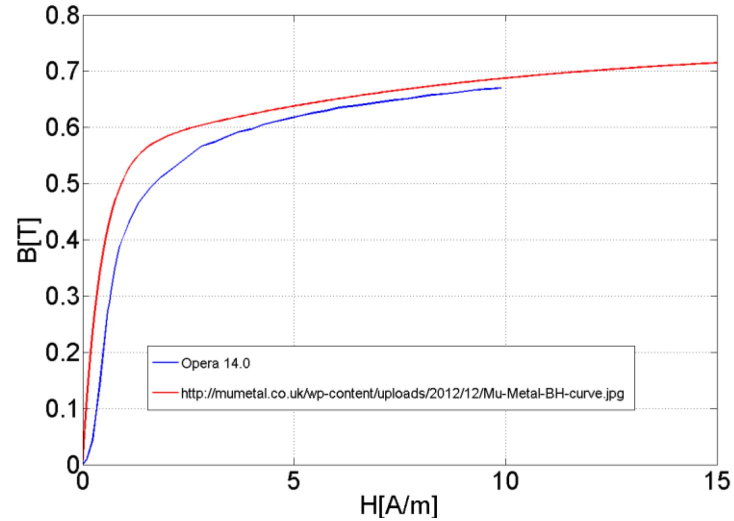
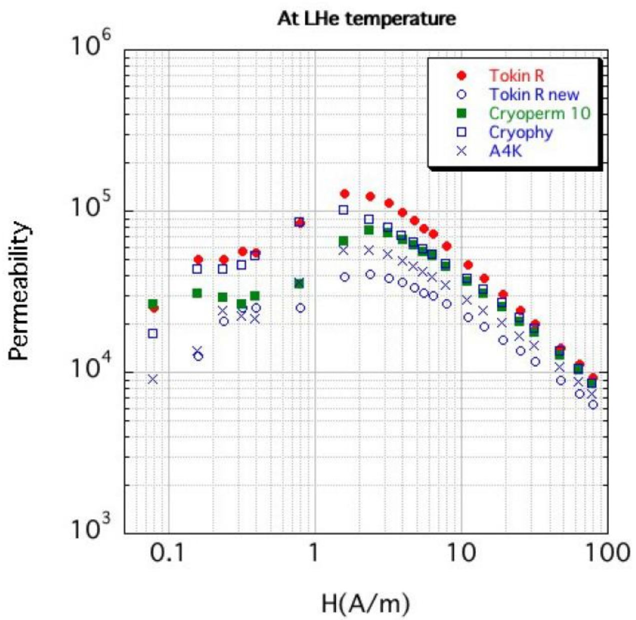
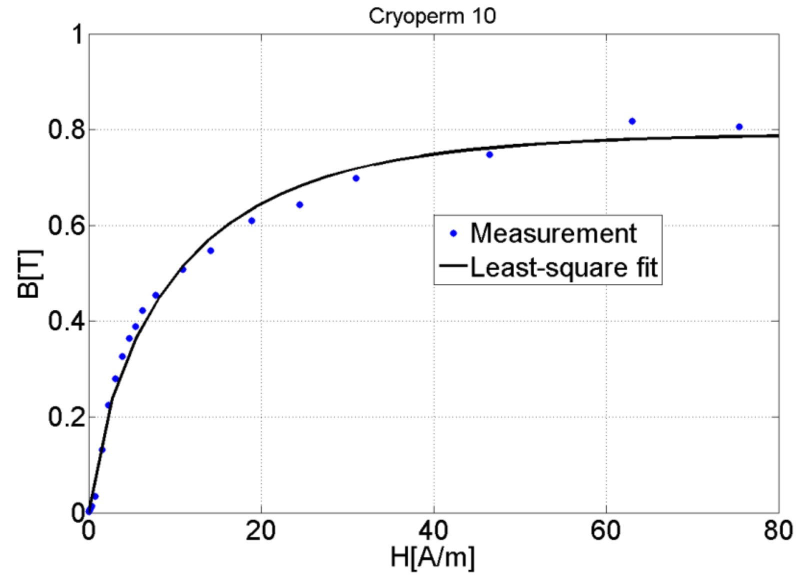
Magnetic properties of shielding materials









MAGNETIC SHIELDING: OUR EXPERIENCE WITH VARIOUS SHIELDING MATERIALS

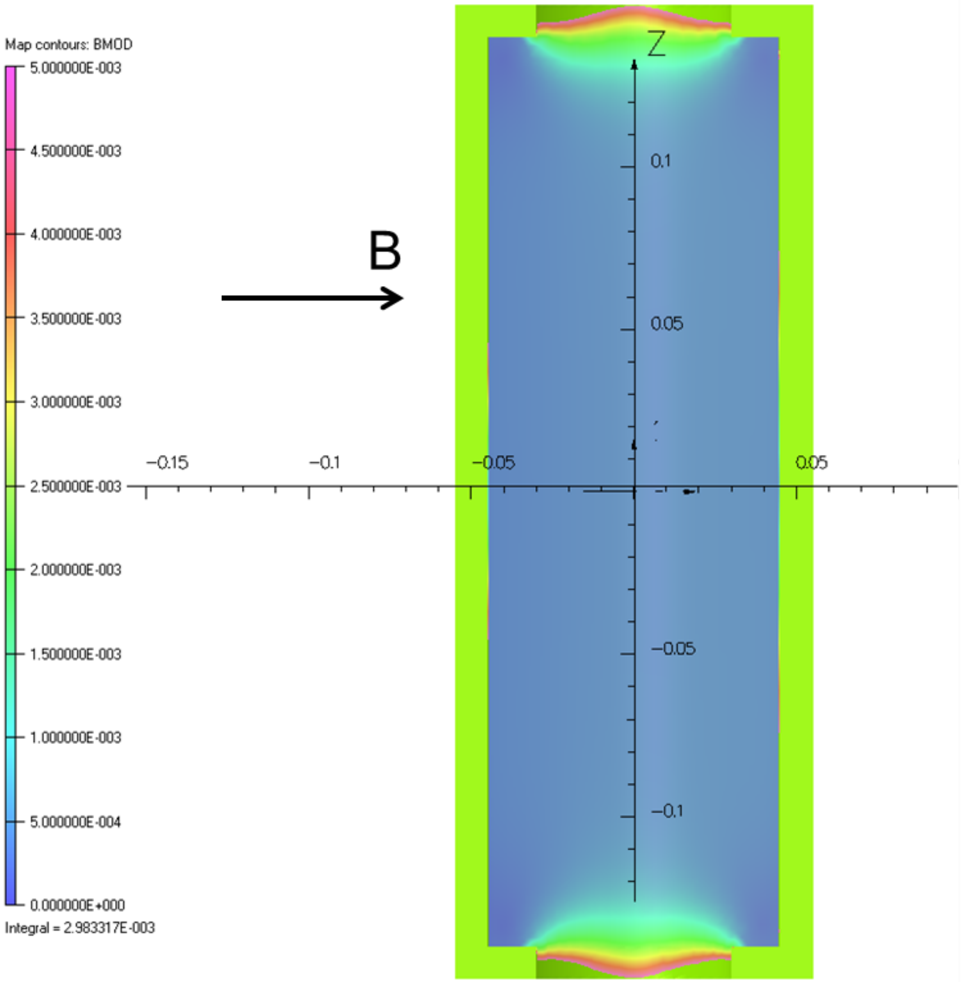
M. Masuzawa, K. Tsuchiya and A. Terashima, KEK, Tsukuba, Japan
A. Dael, O. Napoly and J. Plouin, CEA, Saclay, France

Proceedings of SRF2013, Paris, France

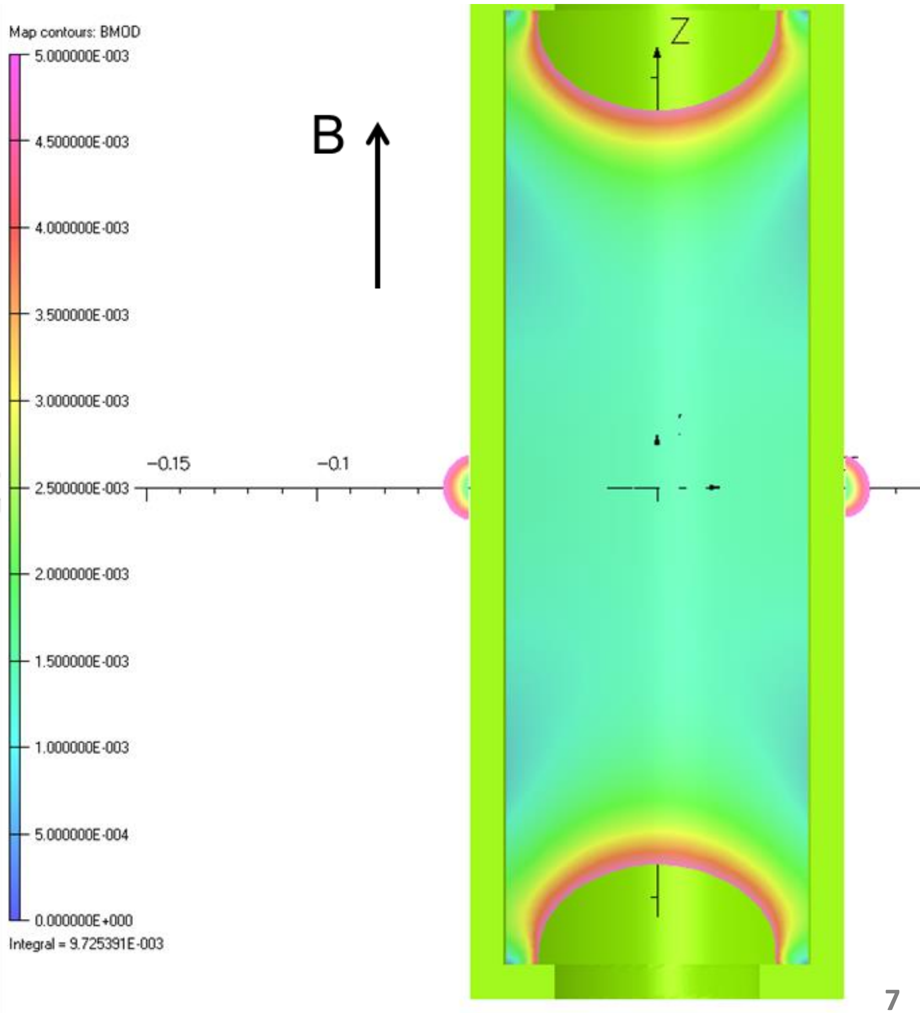
Magnetic shielding effect is anisotropic

- A cylinder is twice as effective against radial field as against axial field.

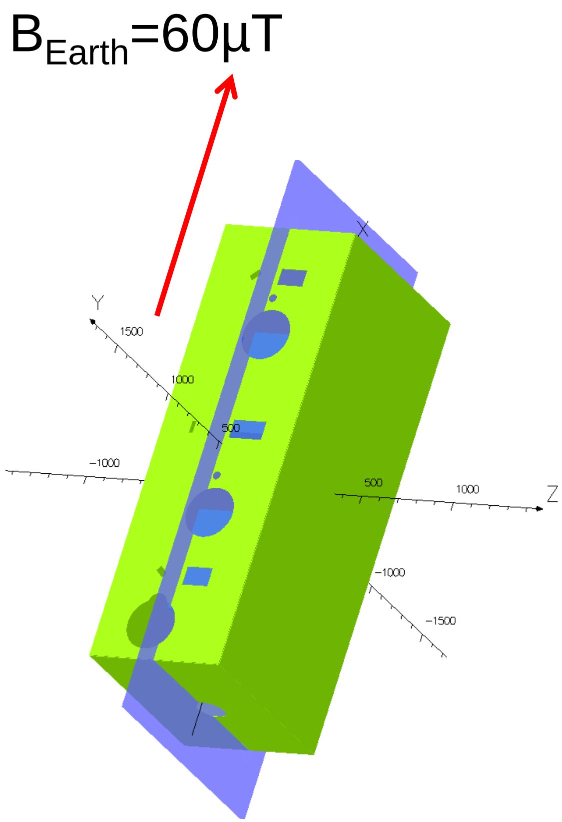
The external field is radial

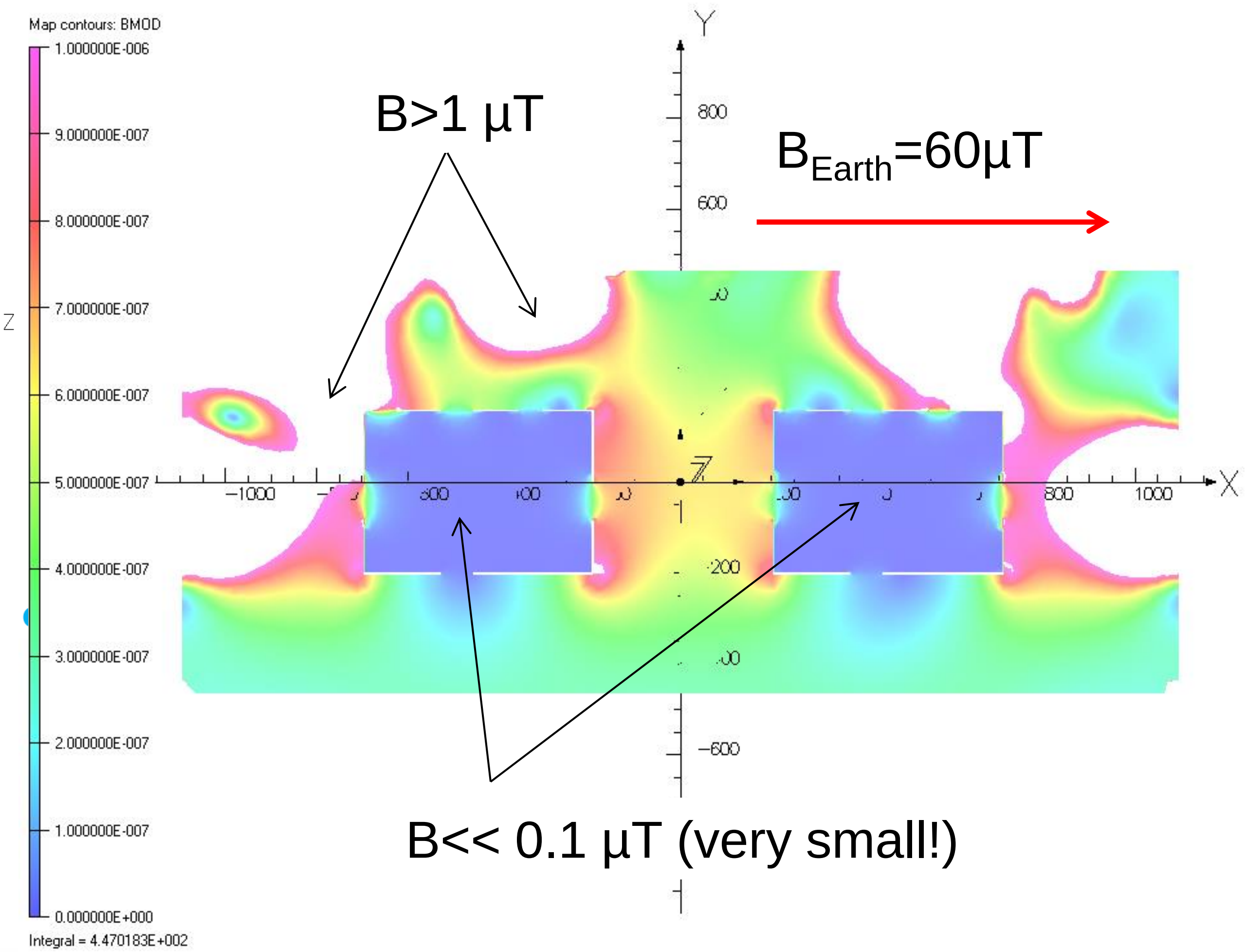


The external field is axial



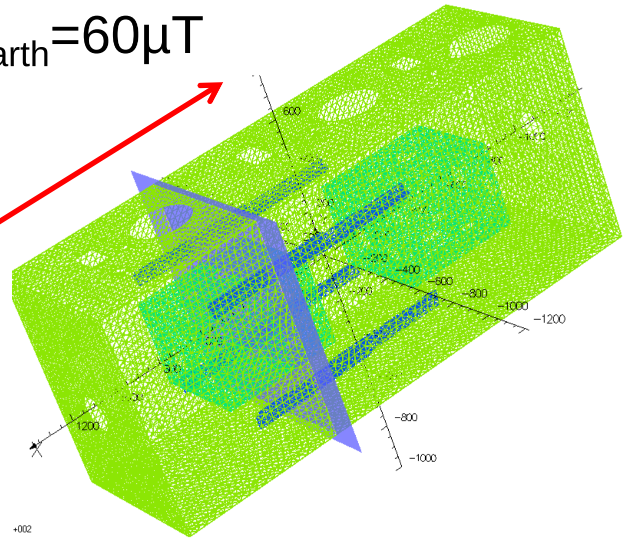
Performance: the field is parallel to the long side



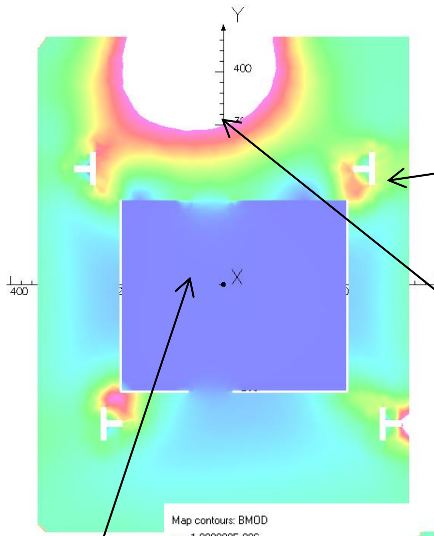


Performance: the field is parallel to the long side II

B_{Earth}=60µT

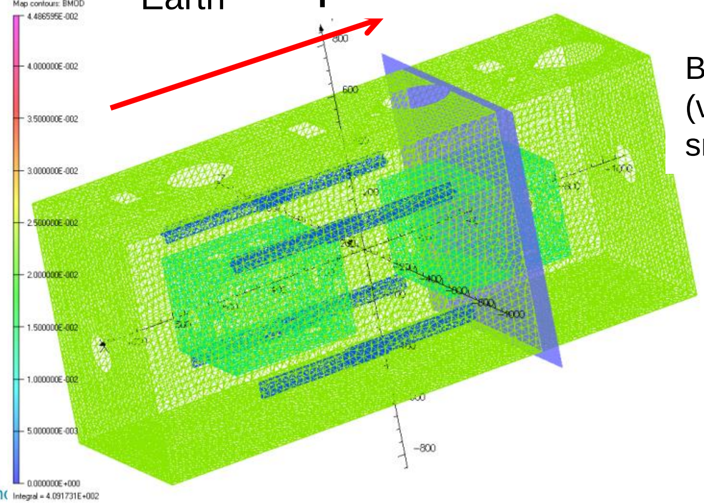


Invar gives localised enhancement but does not effect field within cryoperm.

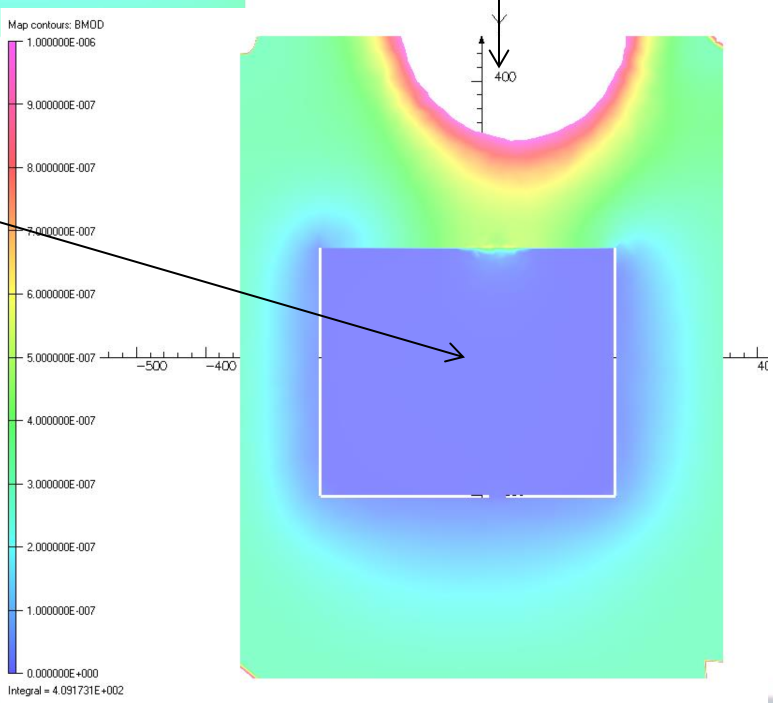


B>1 µT

B_{Earth}=60µT

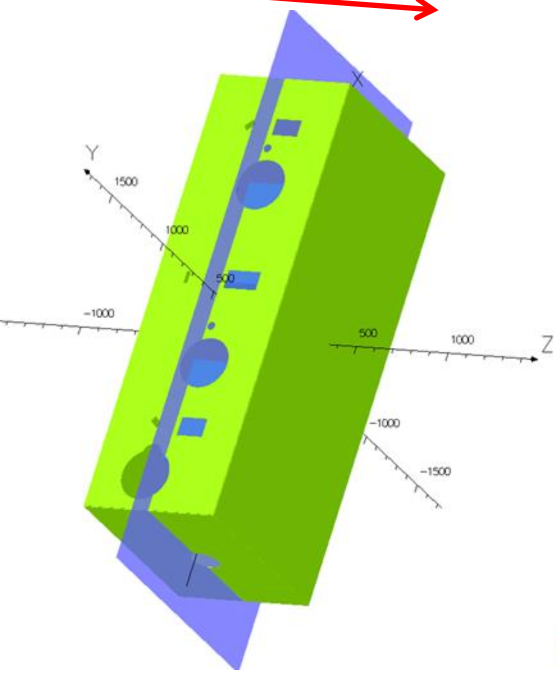


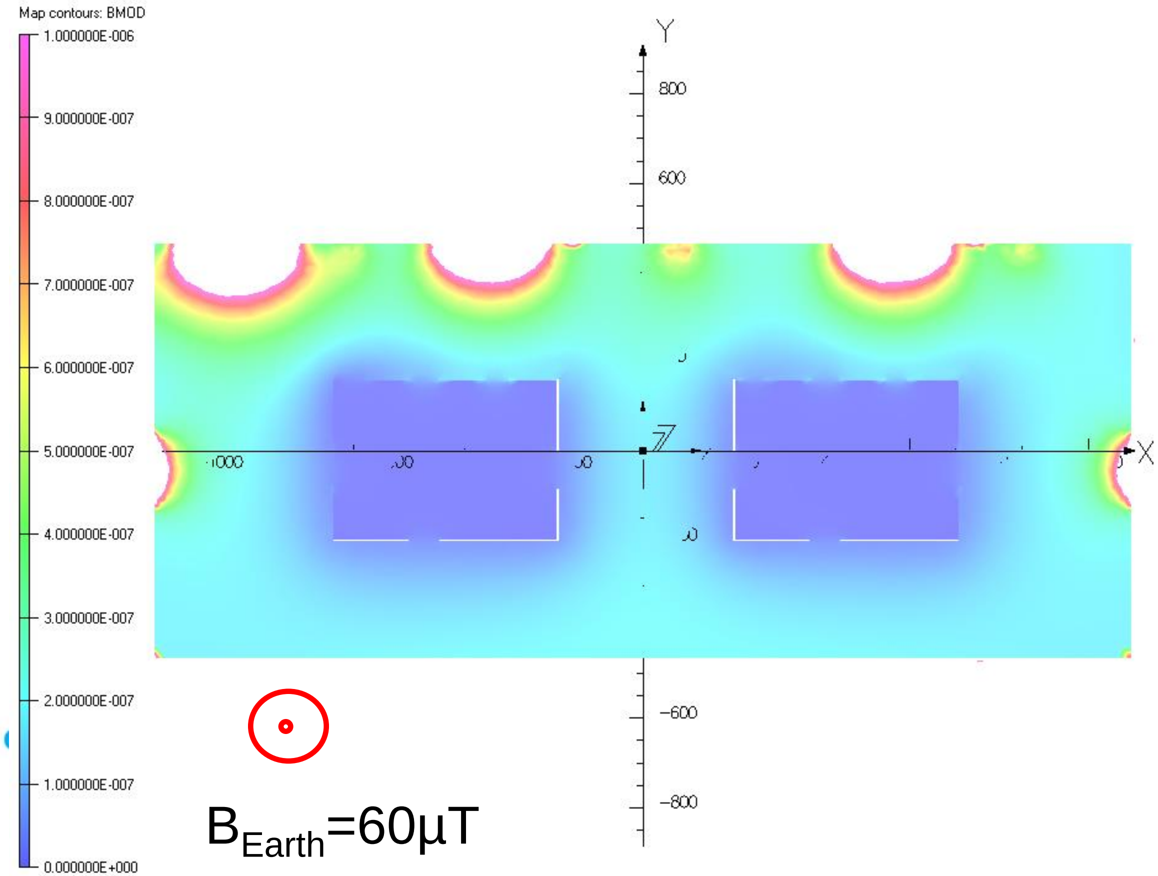
B<<0.1 µT (very small!)



Performance: the field is parallel to the short side

B_{Earth}=60µT



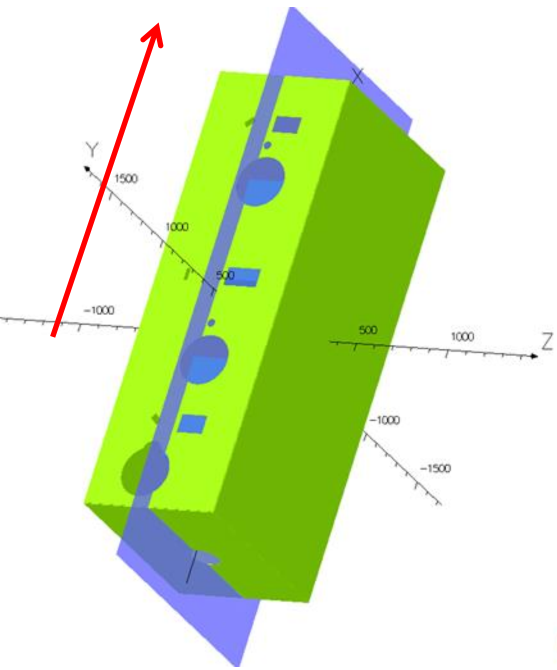


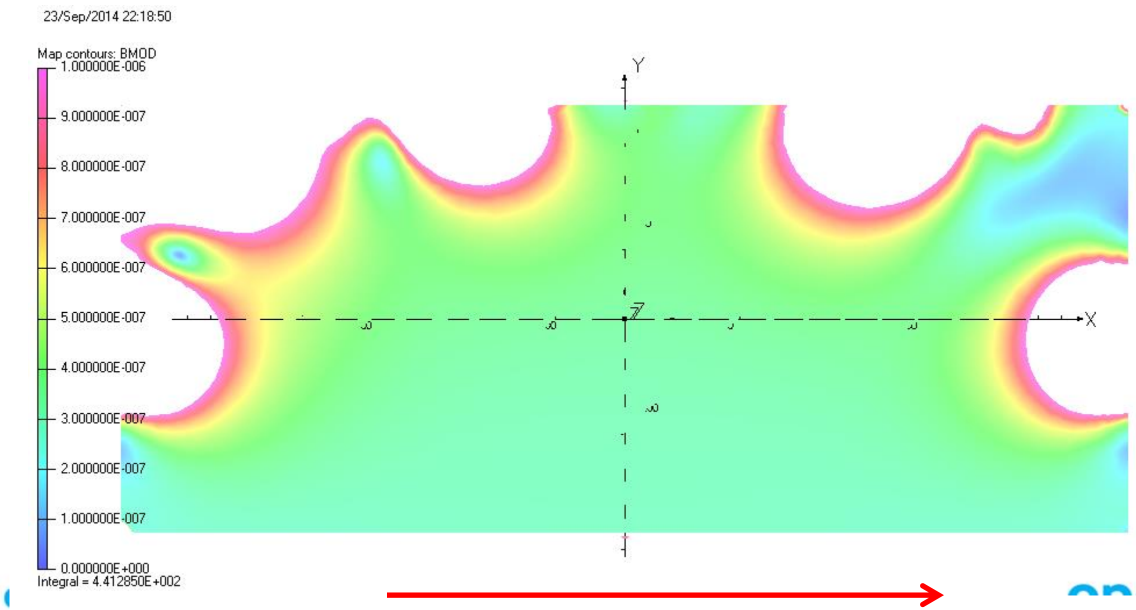
B_{Earth}=60µT

As expected (and similar to the case of a single cylinder) this field configuration is easier for the shield to deal with. Field penetration from the apertures is much weaker.

Single layer: the field is parallel to the long side

B_{Earth}=60µT





B_{Earth}=60µT

A single-layer shield is within spec **(~0.5 µT**) at the cavity locations, but this gives a limited factor of safety.

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Single- vs double-layer solution

- Both solutions meet the specification, however, a single-layer solution offers little room for error (3dB) therefore gives increased risk.

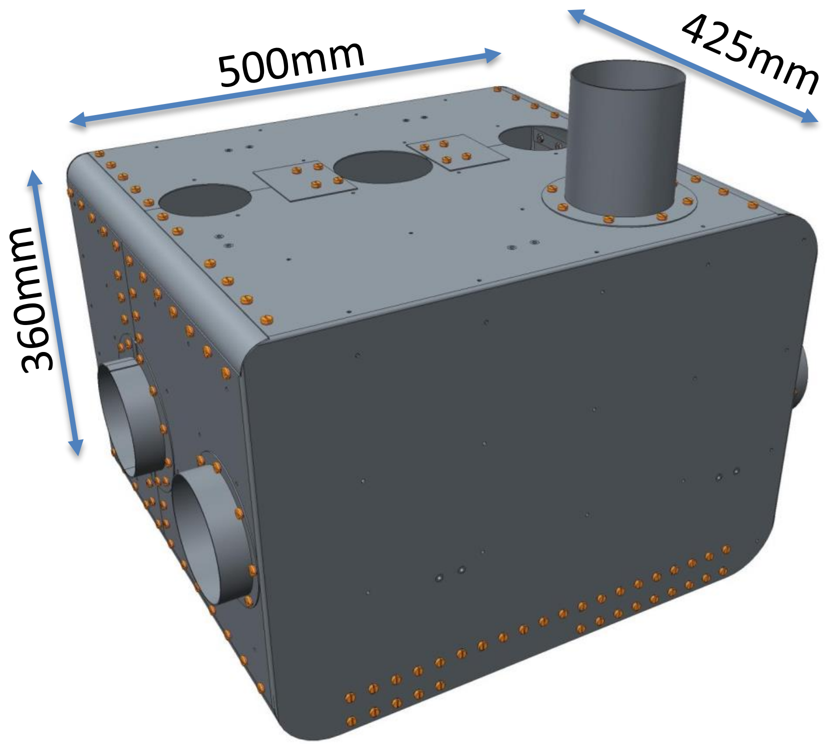
- Model limitations and assumptions:
    - Magnetic properties: The shielding materials are only known from public-domain sources only. Variations are possible from one batch to the next one. Developing our own measurement capability is important.
    - Environment: feromagnetic materials in the vicinity of the shield will greatly enhance the field locally, we need magnetic survey data for SPS.
    - Last-minute changes to the outer shield: Bigger apertures, added holes.

- However, use of a double-layered shield mitigates these risks.

Cryogenic Magnetic Shield Assembly

- Internal to helium vessel gives several benefits;
  - Shield is 'tighter' to cavity giving better shielding performance
  - It allows smaller clearance holes around penetrations.
  - It allows for more freedom in the inter-cavity support system design.
- DQW Crab Cavity - Cold Magnetic shield
- Inside Helium Vessel
- Shielding mass ~10.5kg
- Supported off Helium Vessel

Design by Niklas Templeton and Erin Nolan (Edinburgh University)



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Reasons for close fitting shield…

- To maximise the distance from helium vessel weld regions
  - Therefore minimising the heating of the shield during welding which would reduce the permittivity of the shield.

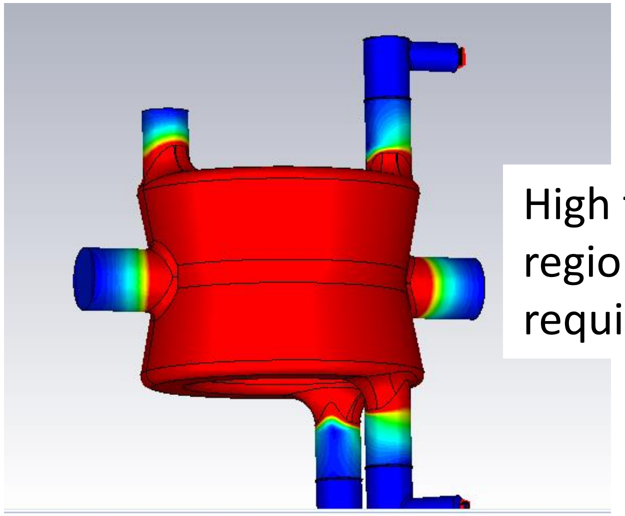
- The shielding factor is inversely proportional to the shield diameter (if approximated to a cylinder): $A \approx \frac{\mu t}{d}$

A - attenuation factor of a perpendicular field

μ – magnetic permeability

T – wall thickness

d - diameter

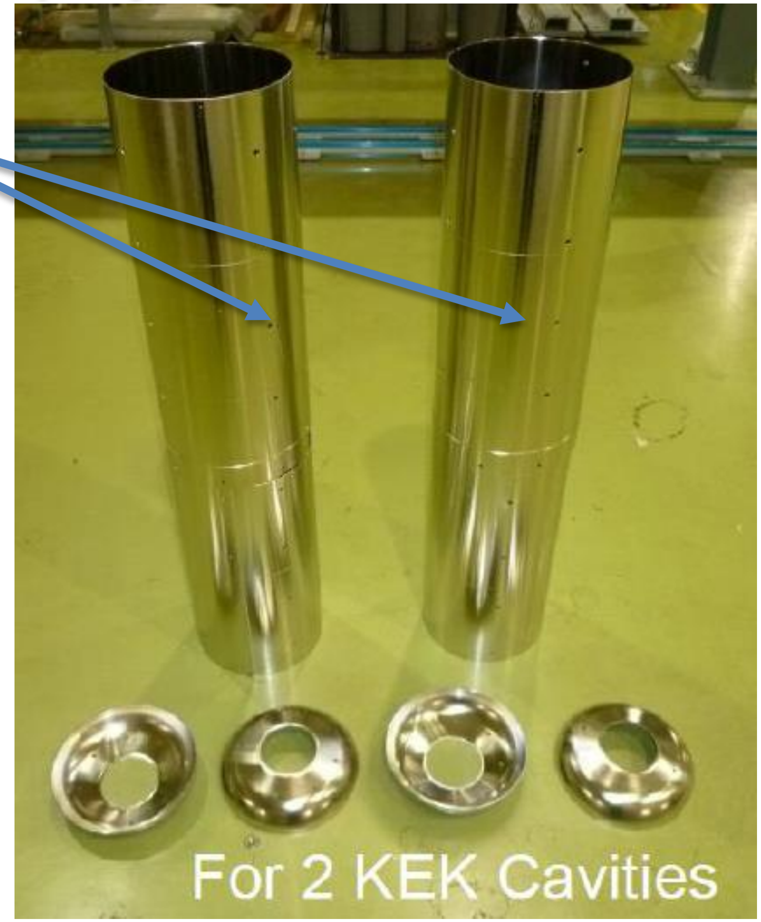


Reference - F. Pobell, *Matter and Methods at Low Temperatures*. Springer-Verlag, third ed., 2007.

KEK Cavities

- 1 mm thick Aperam Cryophy

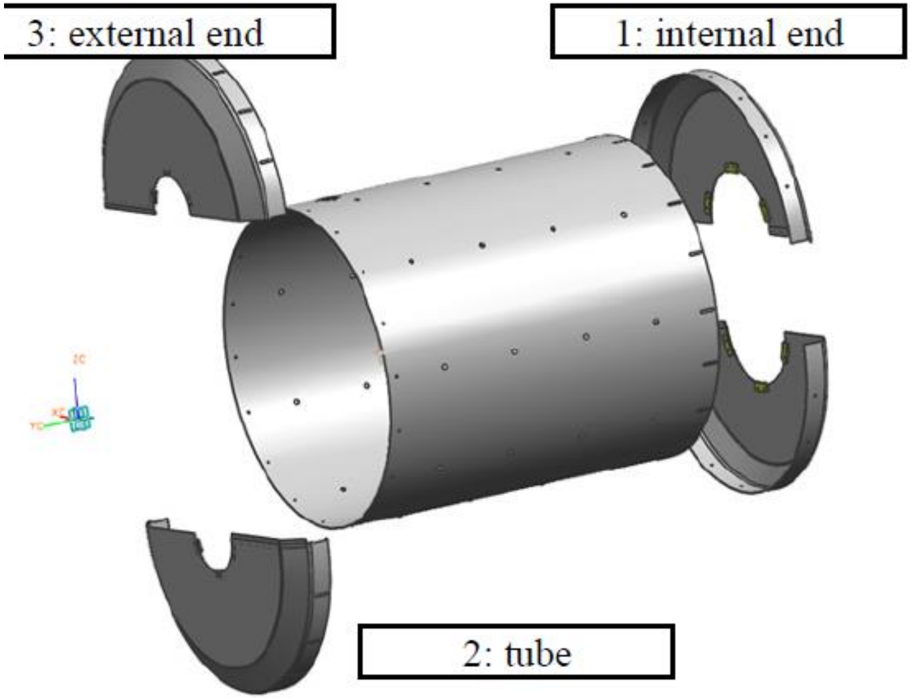
Ø3mm helium flow holes



Reference - Magnetic shields inside and outside LHe tank in S1-Global cryomodule assembly at KEK, E. KAKO (KEK), 2011 Dec. 07

TRASCO elliptical cavities coaxial cold tuner

- 1 mm thick “CRYOPERM 10”
- The shield is supported at the cavity tubes by means of small G10 blocks
- 3 mm diameter holes on the shield tube allow He gas flow during cooling.

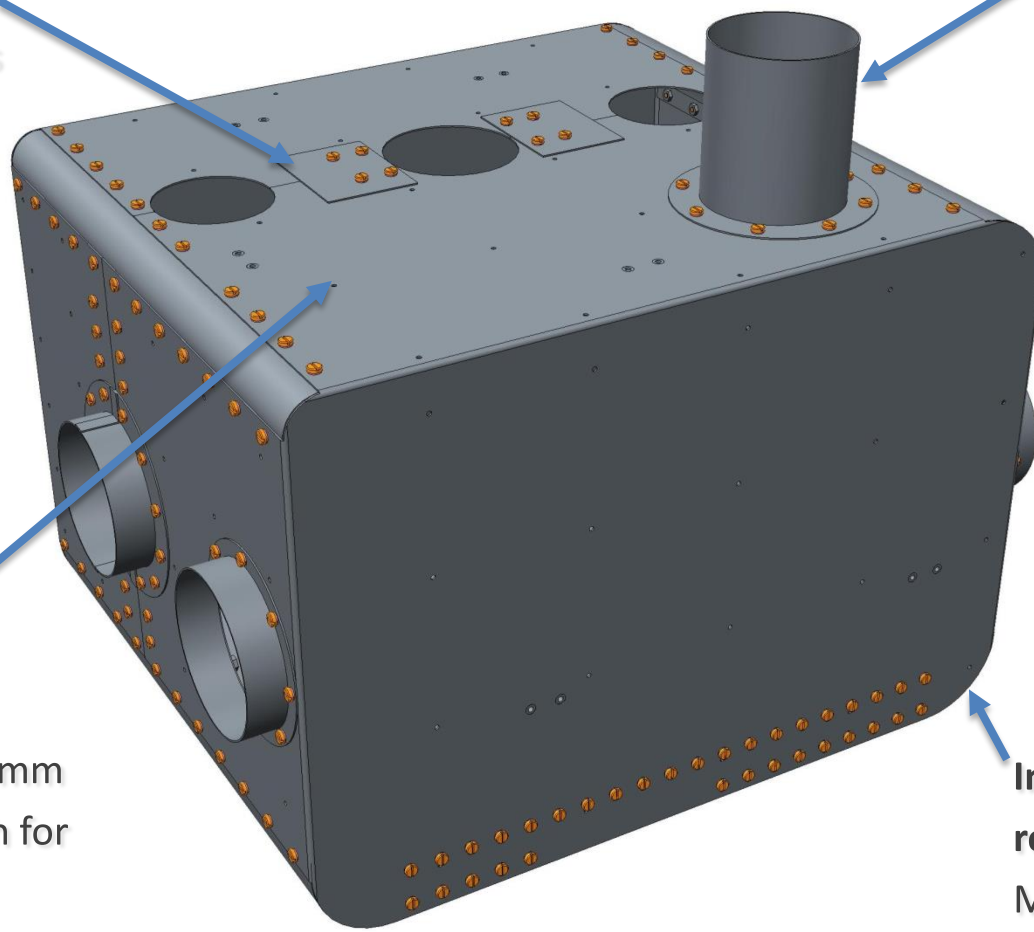


Reference - Magnetic shields inside and outside LHe tank in S1-Global cryomodule assembly at KEK, E. KAKO (KEK), 2011 Dec. 07

Cryogenic Magnetic Shield Assembly

Additional Cover Strips
Overlapping joints allows magnetic flux to follow a continuous low-reluctance path

Tubular Shielding
Prevents field penetration through openings



Helium Holes
Shield peppered with Ø3mm holes on 50-100mm pitch for helium transfer

Increased curvature & rounds
More effective at containing channelled magnetic flux

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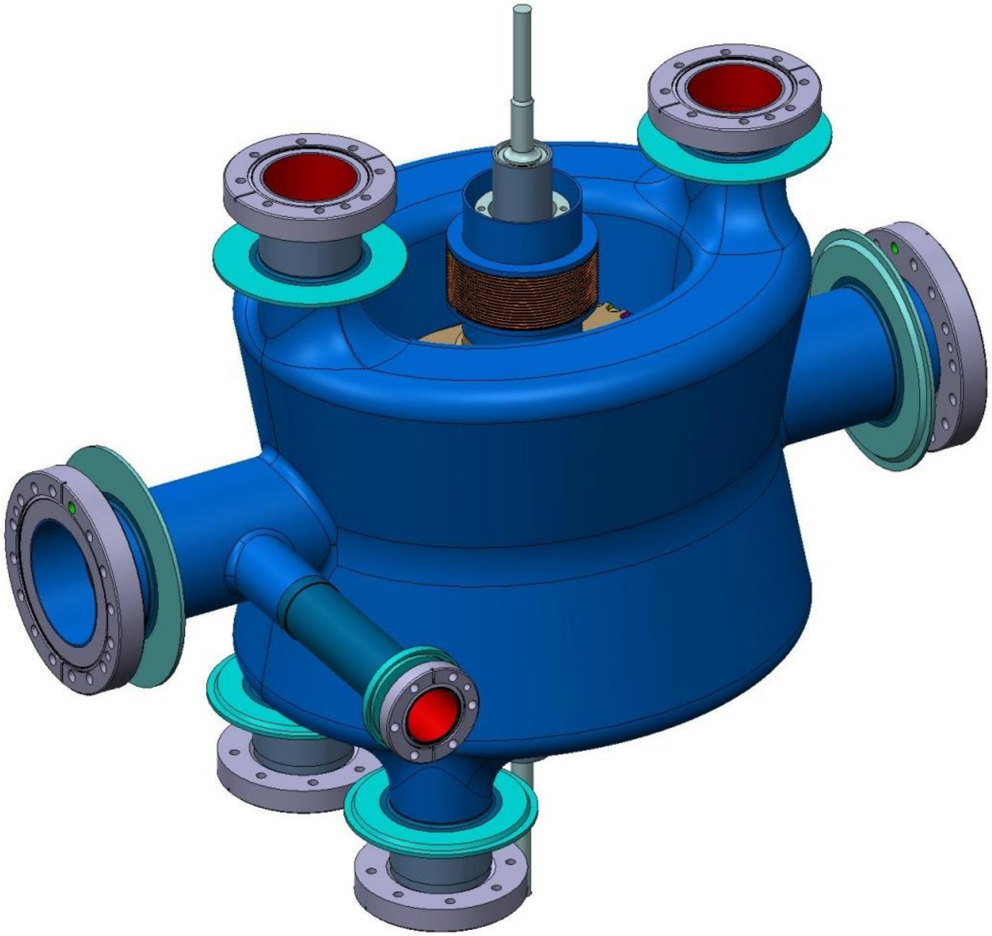
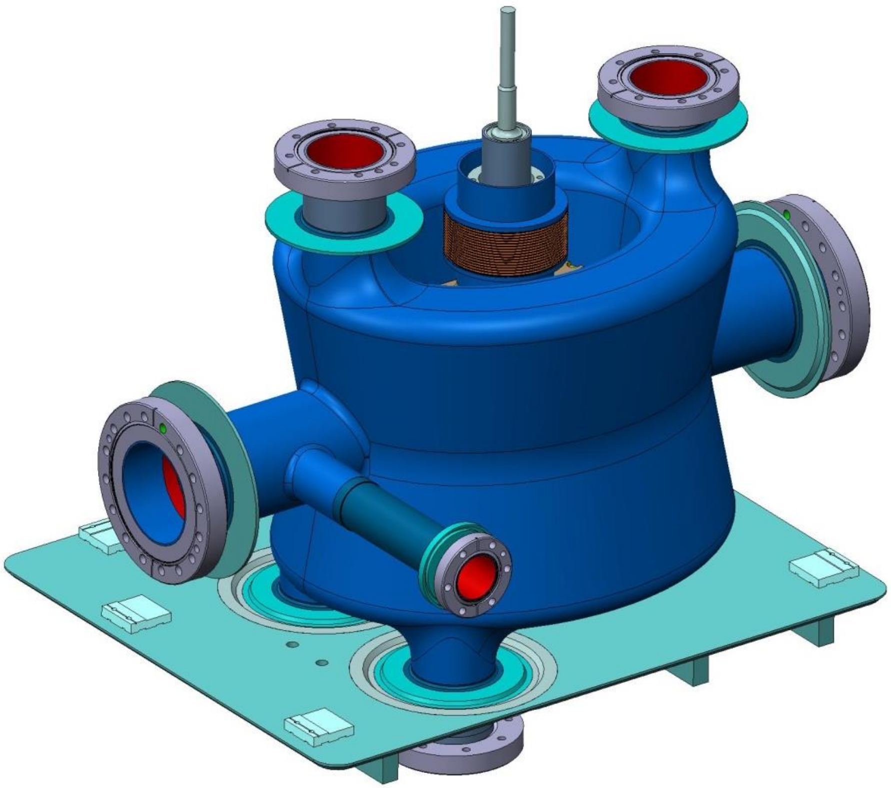
Assembly Procedure

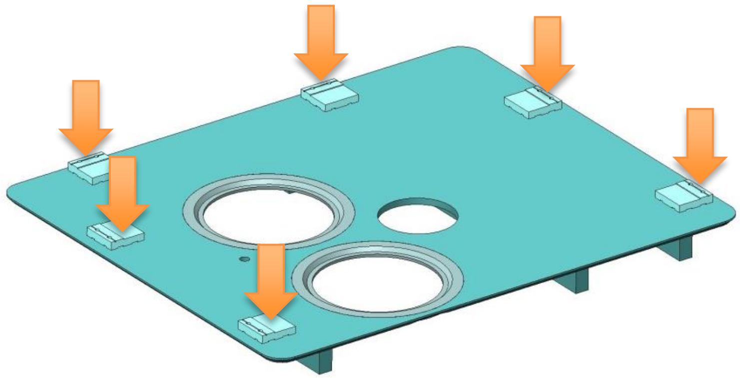


DQW Cavity assembly

Assembly Procedure

→ Pre-drilled vented pads are welded to the base eliminating the need and risk of tapping the Helium vessel.



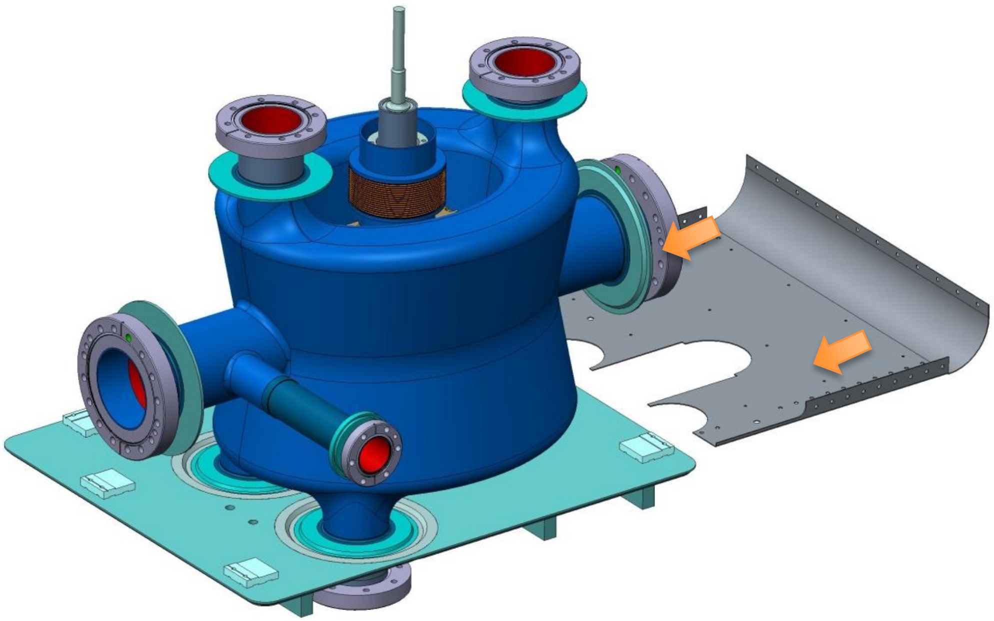


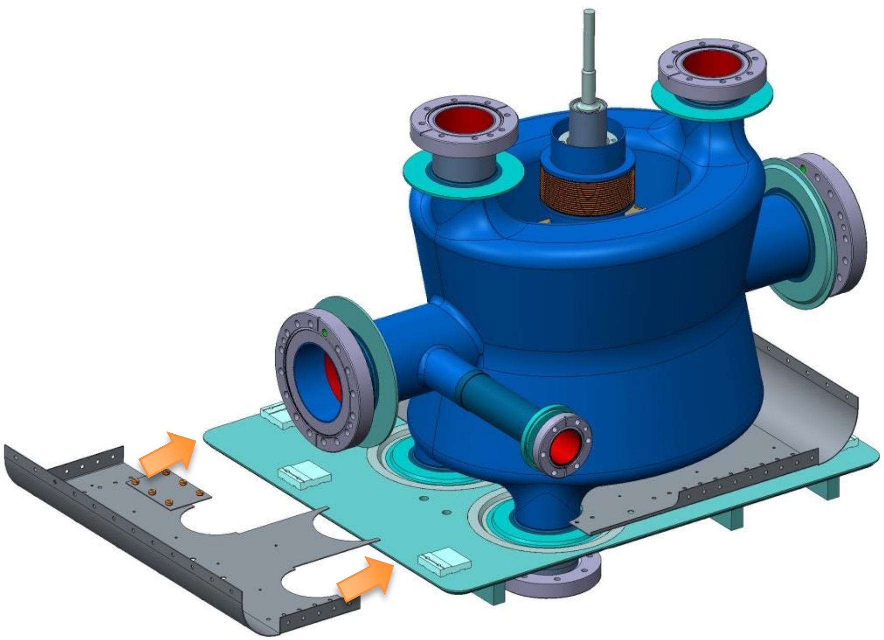
→ The cavity would then be welded to the base.

→ Mounting off the Helium vessel will reduce the risk of any vibration in the cryoperm transferring to the cavity.

Assembly Procedure

→ Lower sections of the magnetic shielding would then slide in to place from each side.

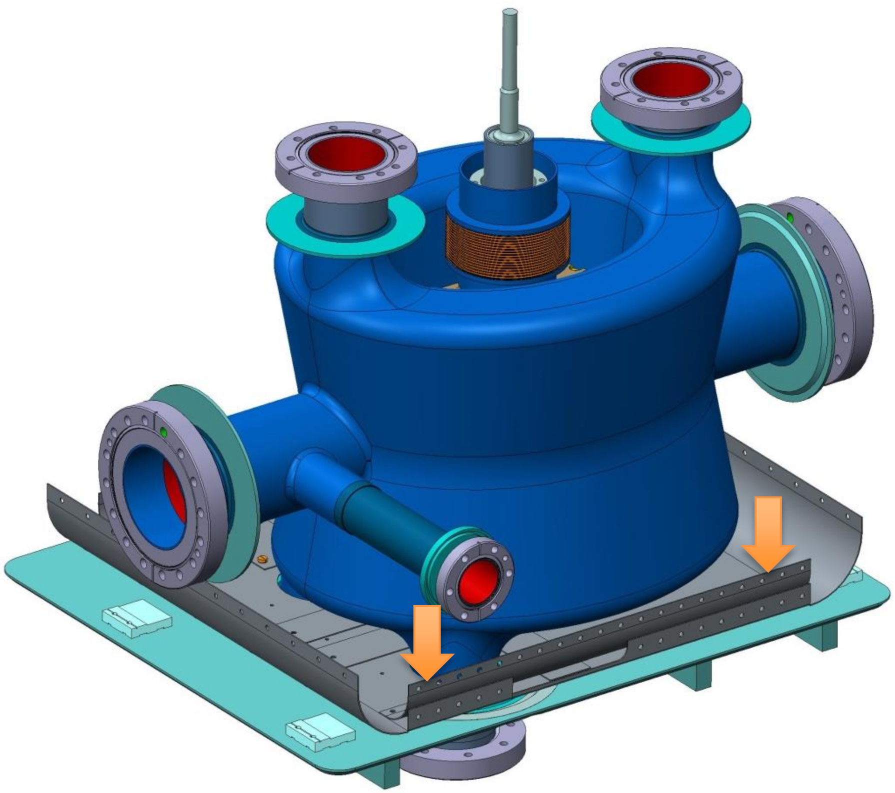


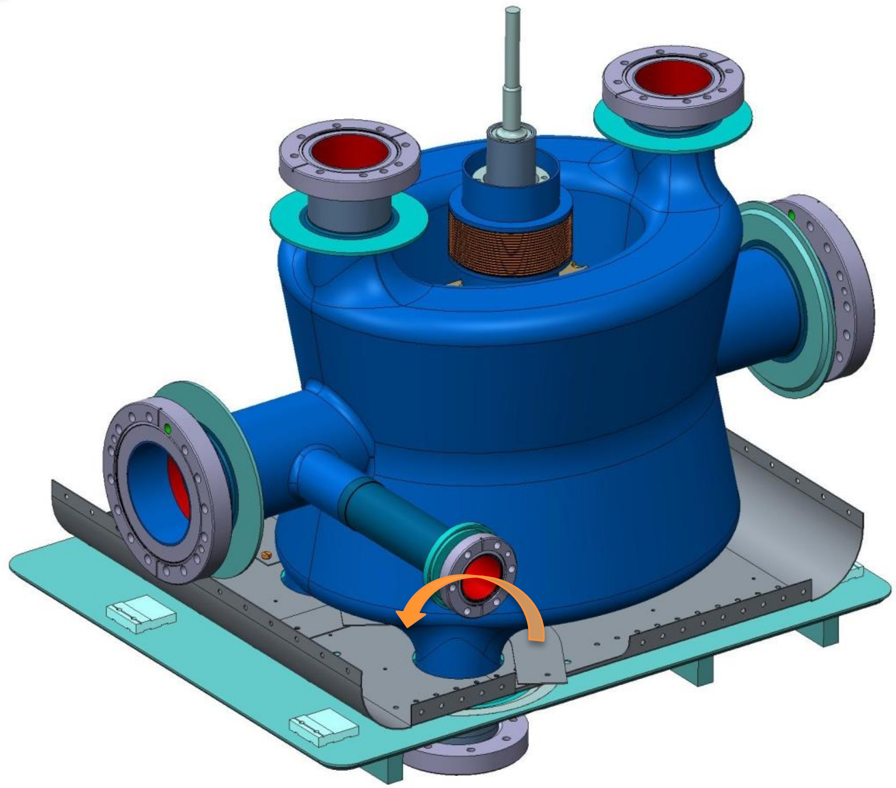


→ The cover strips would then be screwed together.

Assembly Procedure

→ The cover strip between the 2 lower pieces is slid around into place.
→ The piece is curved so that the screws to hold them down can be accessed.





→ Additional curved strips connect the two lower pieces and the side walls.

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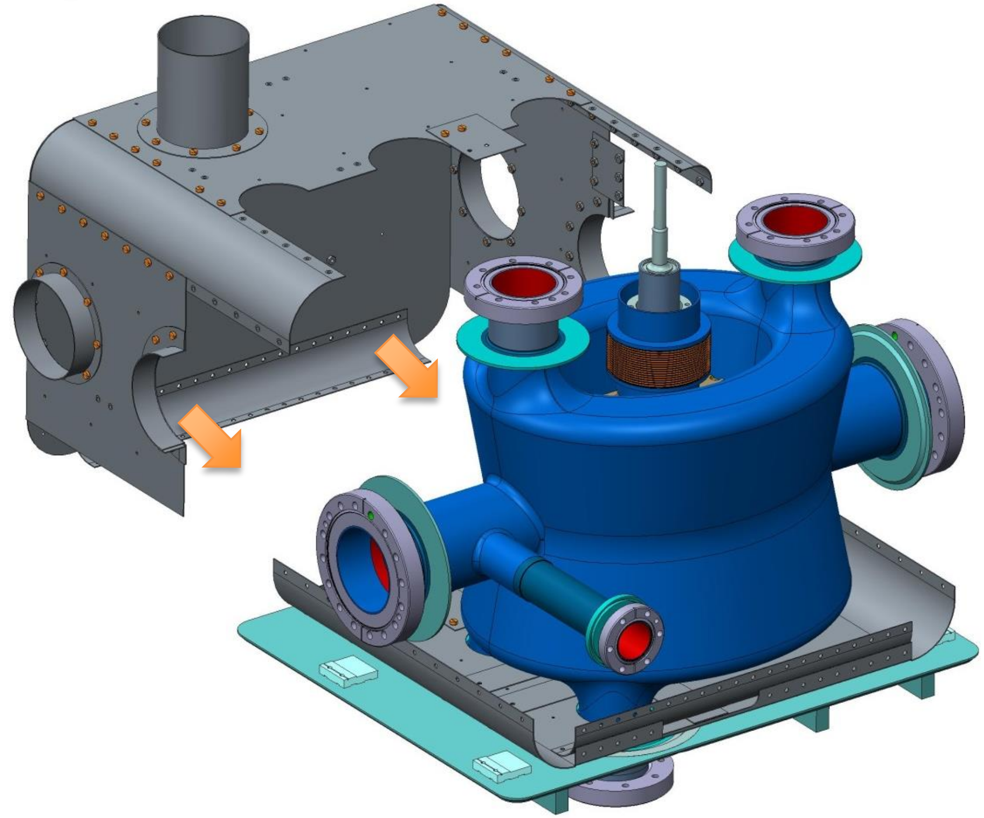
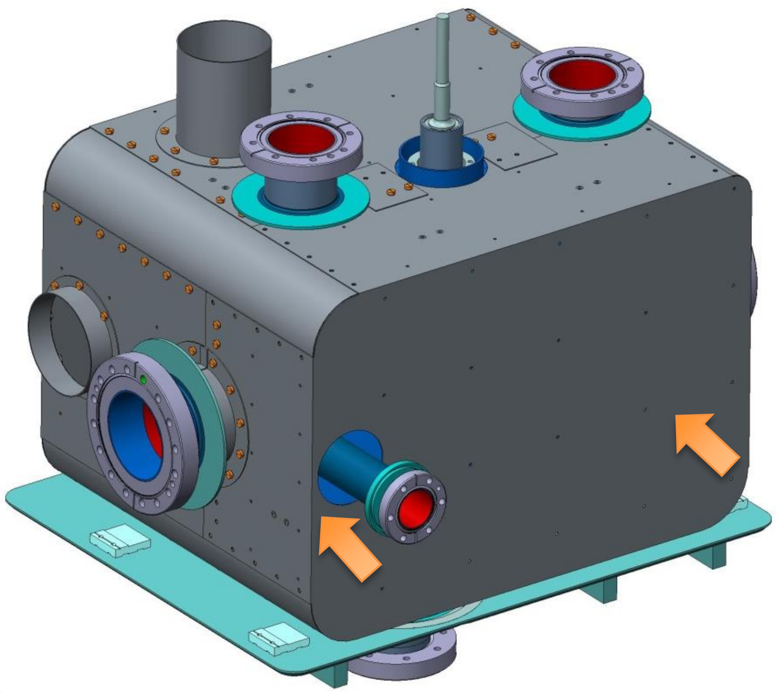
Assembly Procedure

→ Upper sections of the magnetic shielding would then slide in to place from each side perpendicular to the lower pieces.





→ Final cover strips are added and shield assembly is fastened.

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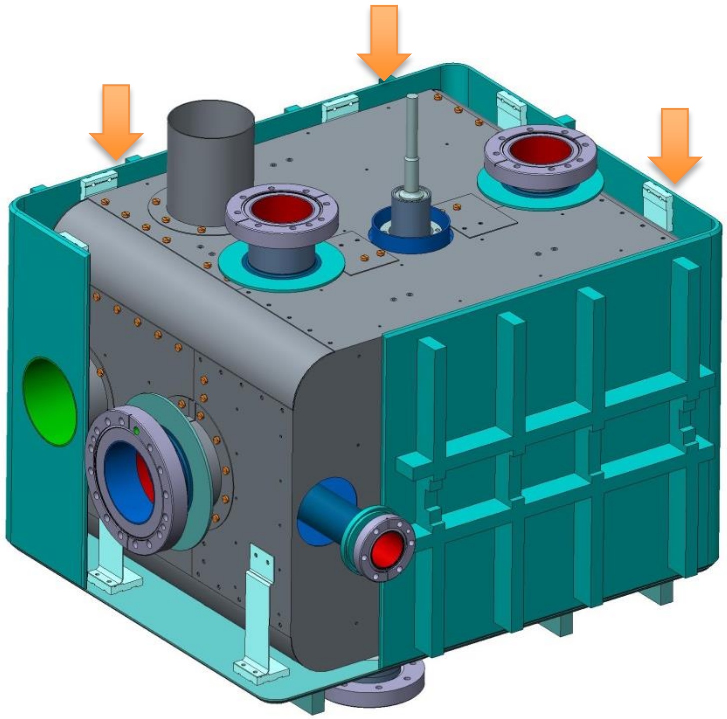
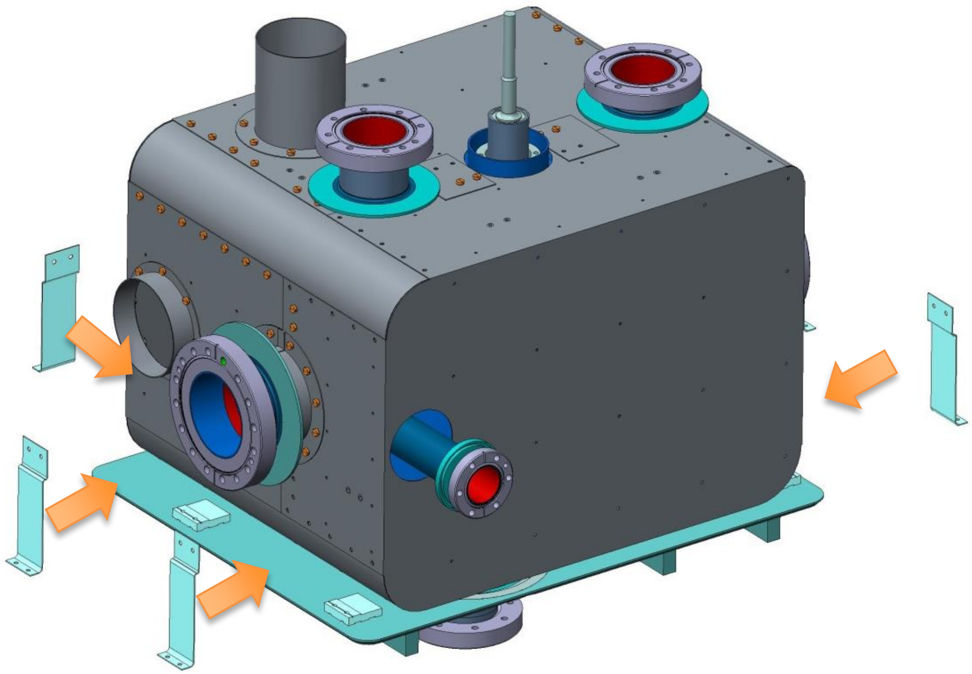
Assembly Procedure

→ The lower 1mm thick grade 2 Ti brackets can be brought in from the side and screwed onto the magnetic shielding and the pads below.

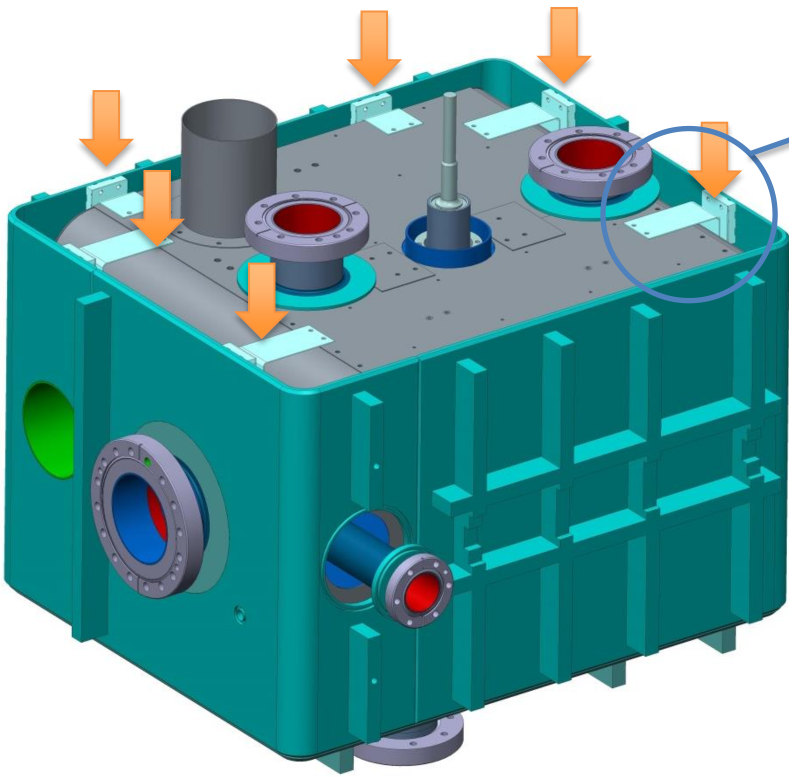


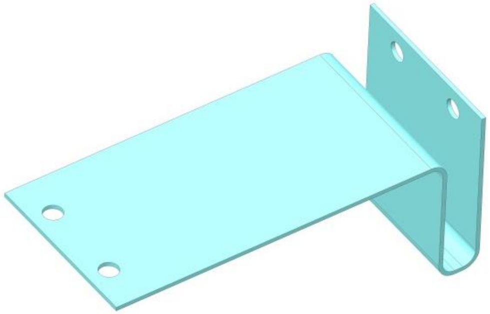


→ The helium vessel side pieces, pre-welded with bracket mounts, are positioned into place. The dummy beam pipe could also be welded now.

Assembly Procedure

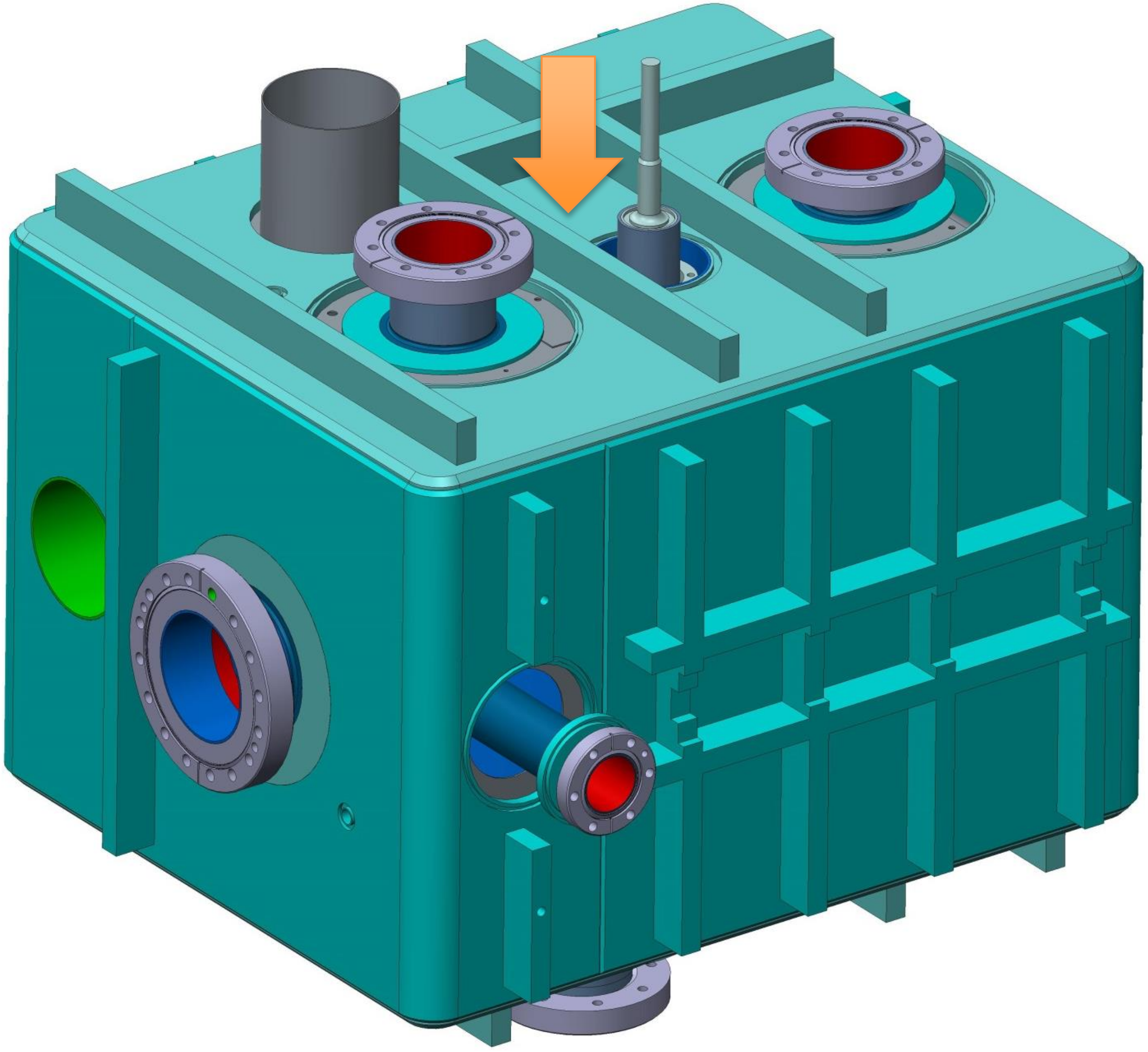
→ The remaining side helium vessel piece is welded in place and top brackets are fastened.





→ 1mm thick Grade 2 Titanium brackets connect the shield to the He Vessel. Brackets support the cryoperm whilst the ‘u’ bend feature allows flexibility for thermal contraction

Assembly Procedure



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Thermal and Structural Analysis - Mesh

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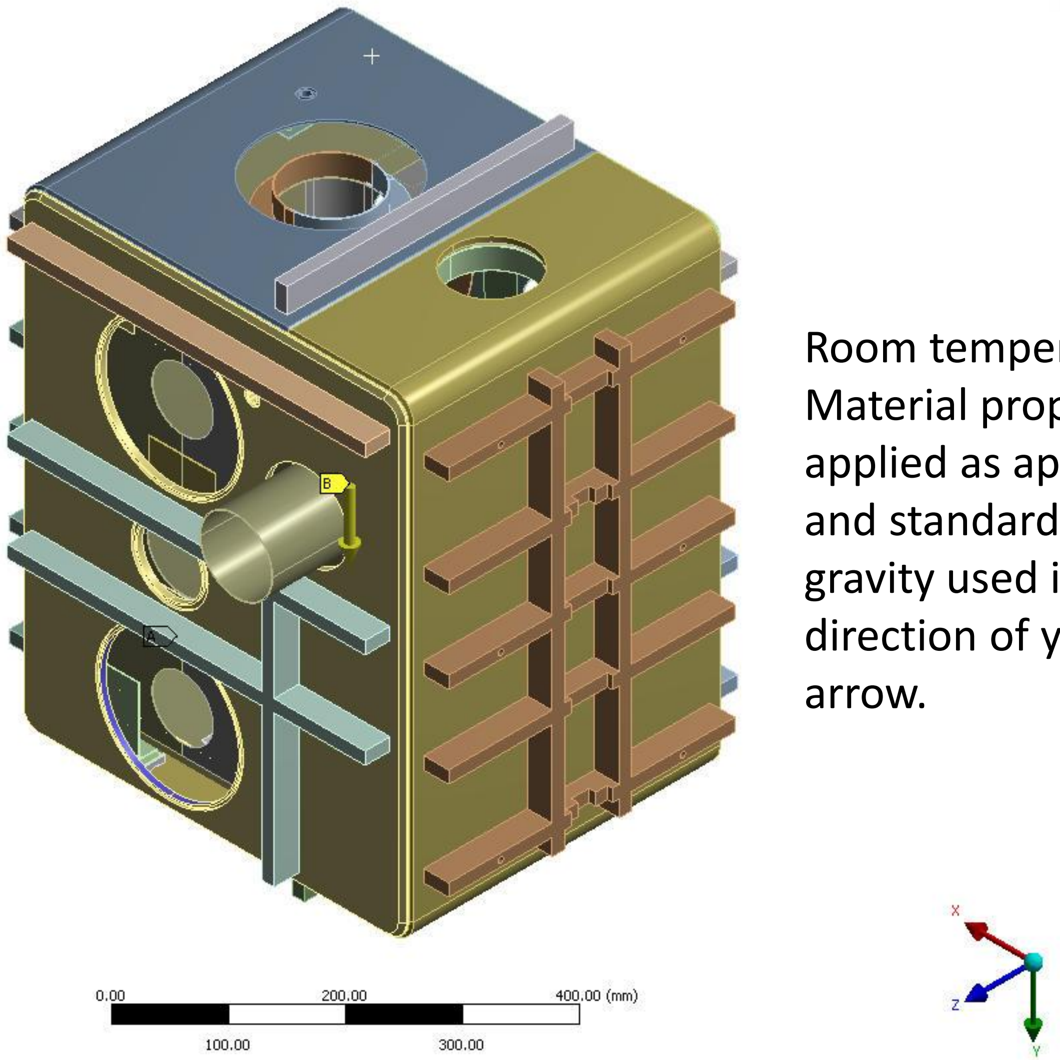
1. Vertical Self Weight Boundary Conditions

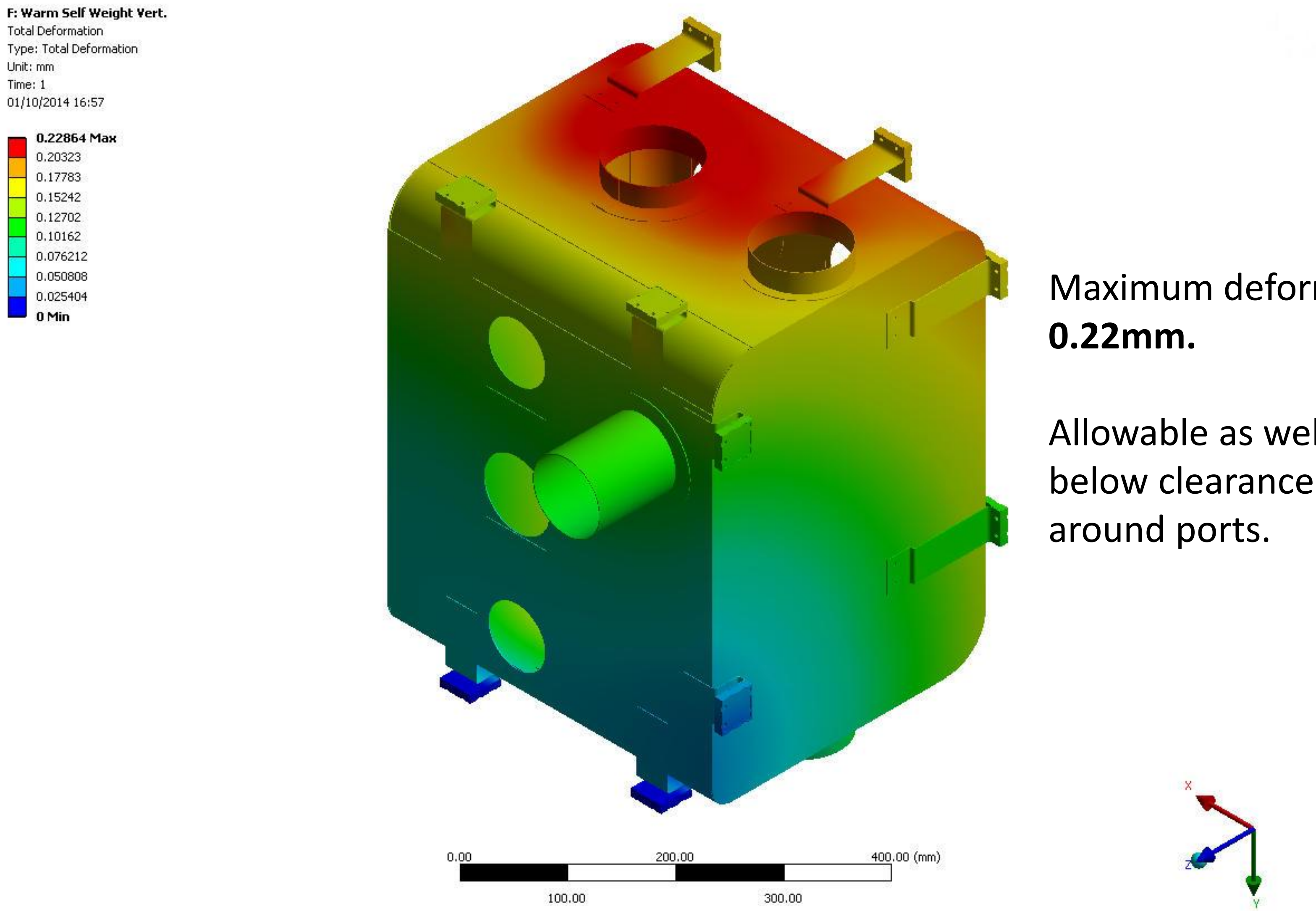
i.e. to re-create the conditions of a post process, such as re-performing the HPR or BCP.

This vertical self weight is the worst case condition for the supports.



Room temperature Material properties applied as appropriate and standard earth gravity used in direction of yellow arrow.

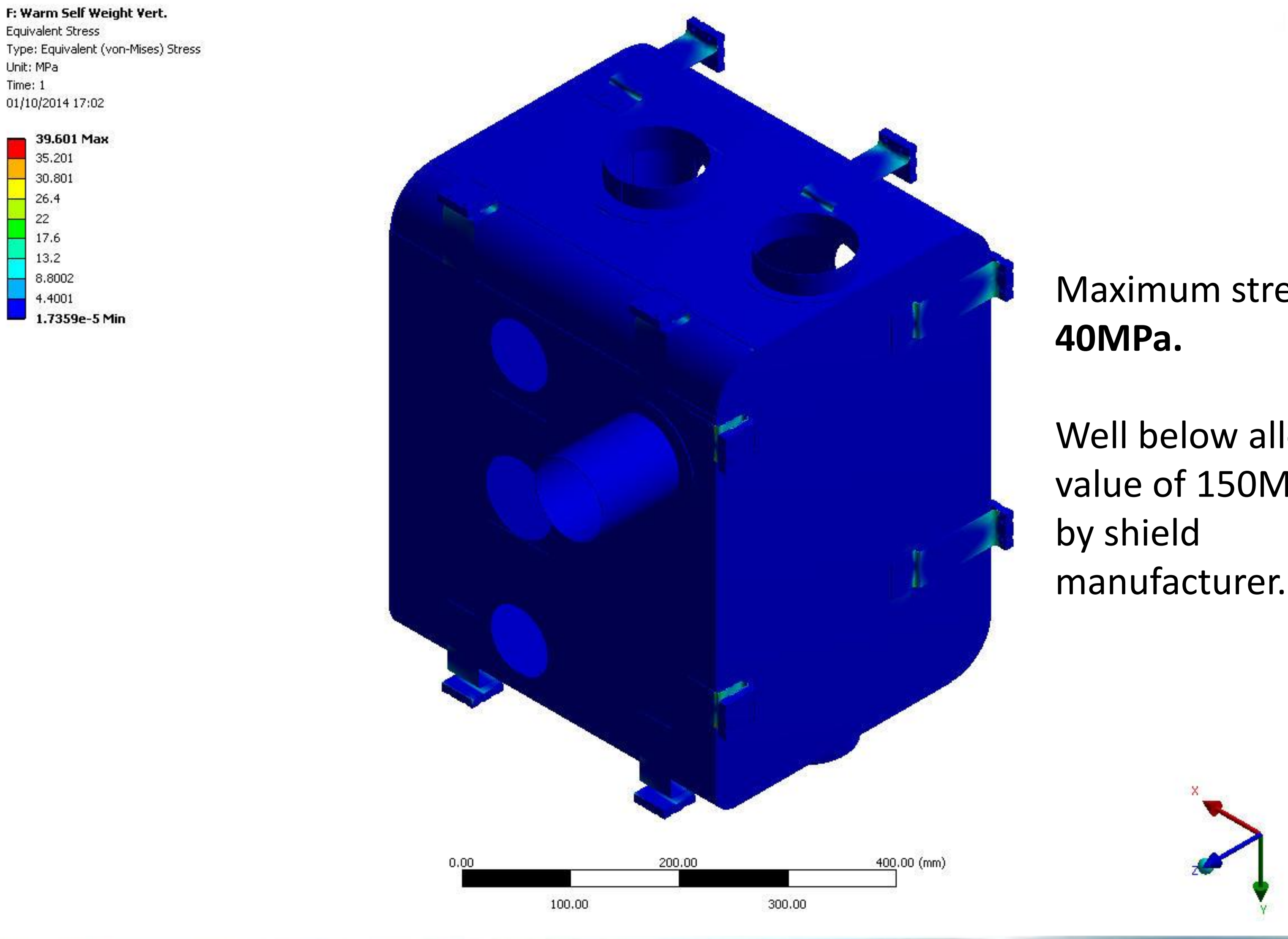
1. Vertical Self Weight Deformation



Maximum deformation **0.22mm.**

Allowable as well below clearances around ports.

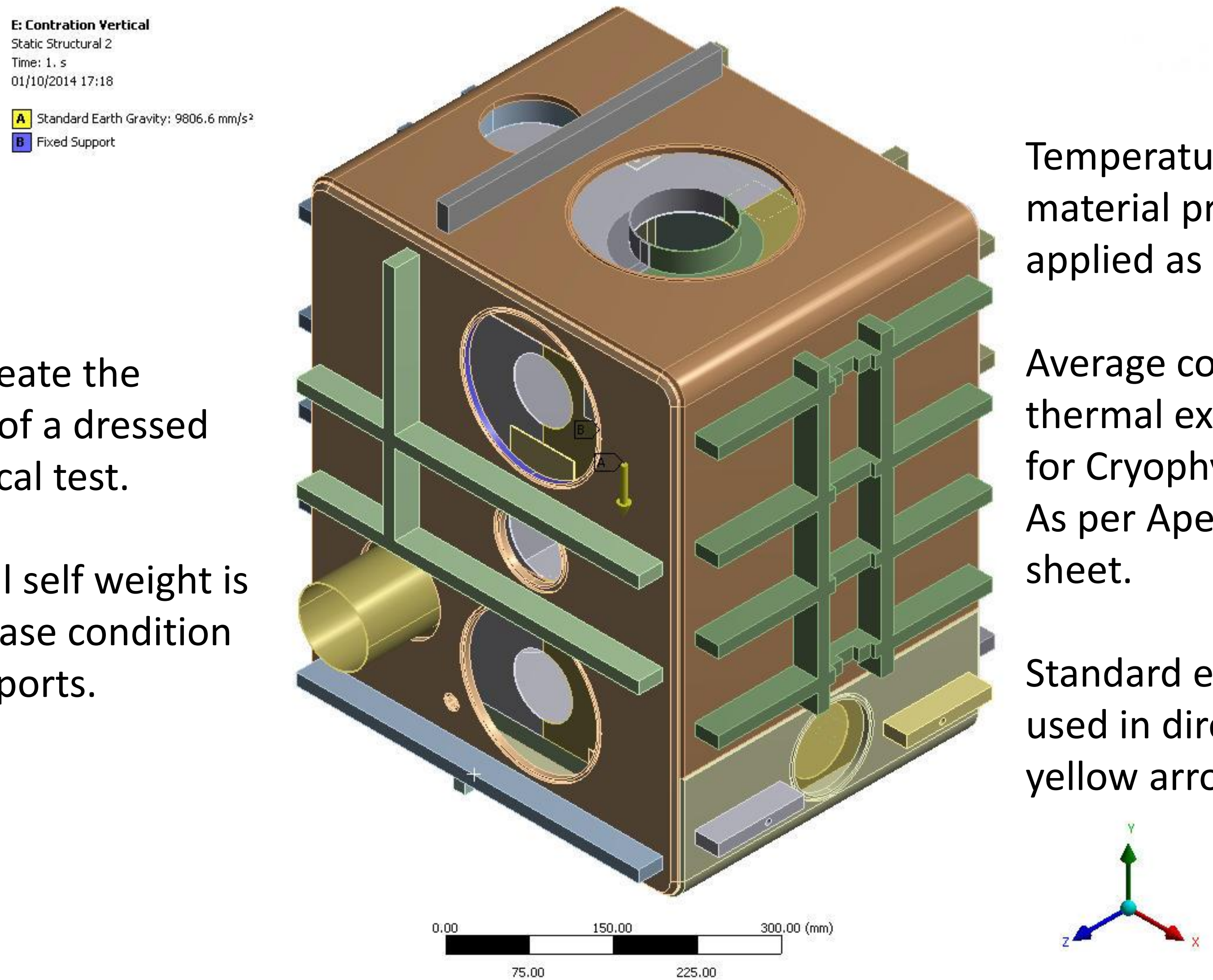
1. Vertical Self Weight Stress



Maximum stress **40MPa.**

Well below allowable value of 150MPa given by shield manufacturer.

2. Cold + Vertical Self Weight BCs



i.e. to re-create the conditions of a dressed cavity vertical test.

This vertical self weight is the worst case condition for the supports.

Temperature varying material properties applied as appropriate.

Average co-efficient of thermal expansion used for Cryophy of $8e^{-6}$/K As per Aperam data sheet.

Standard earth gravity used in direction of yellow arrow.

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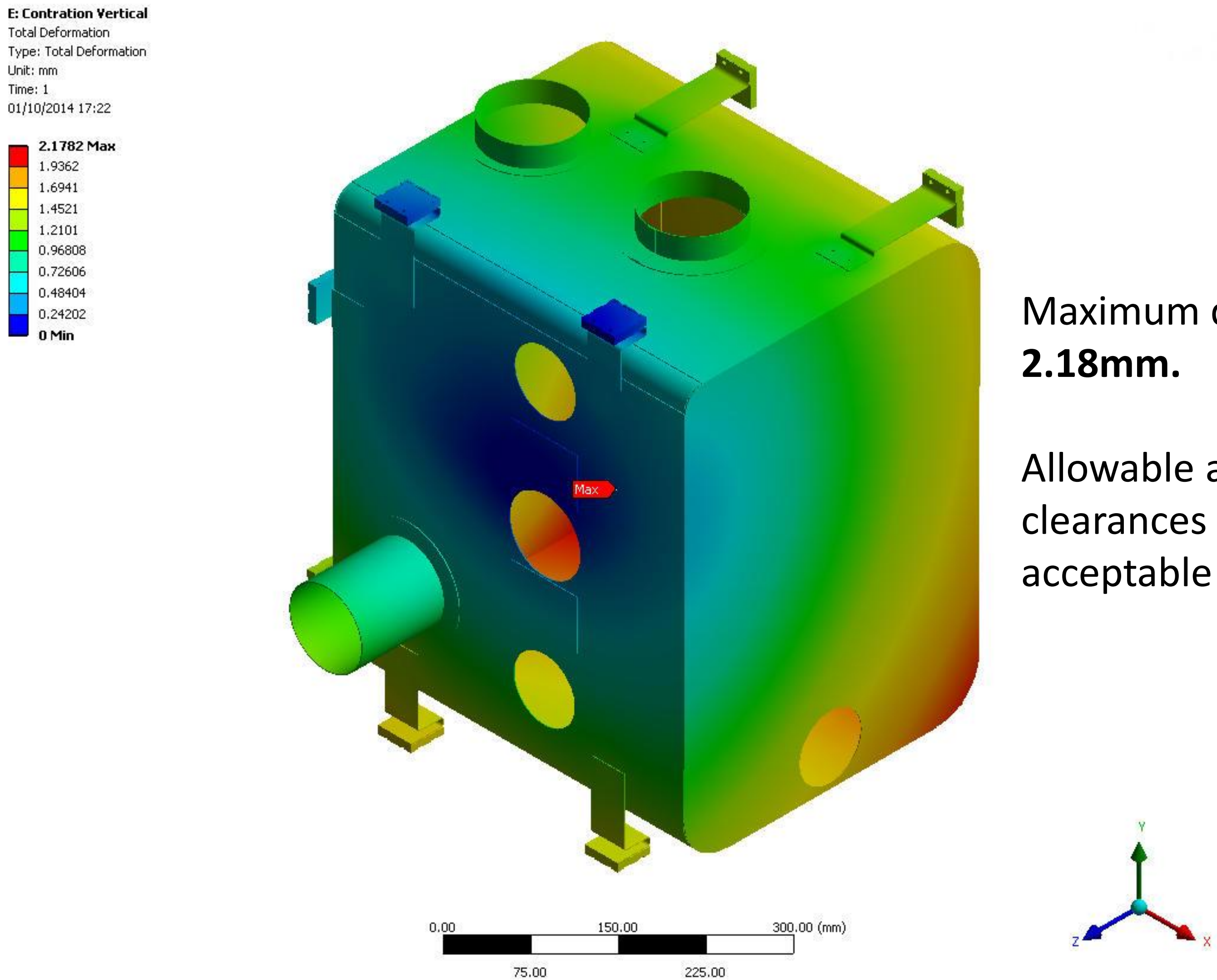
2. Cold + Vertical Self Weight Deformation



Maximum deformation **2.18mm.**

Allowable as clearances stay within acceptable limits.

2. Cold + Vertical Self Weight Stress

Stress above allowable value of 150MPa for Cryophy is red.

There are no stresses above the allowable in the magnetic shield.

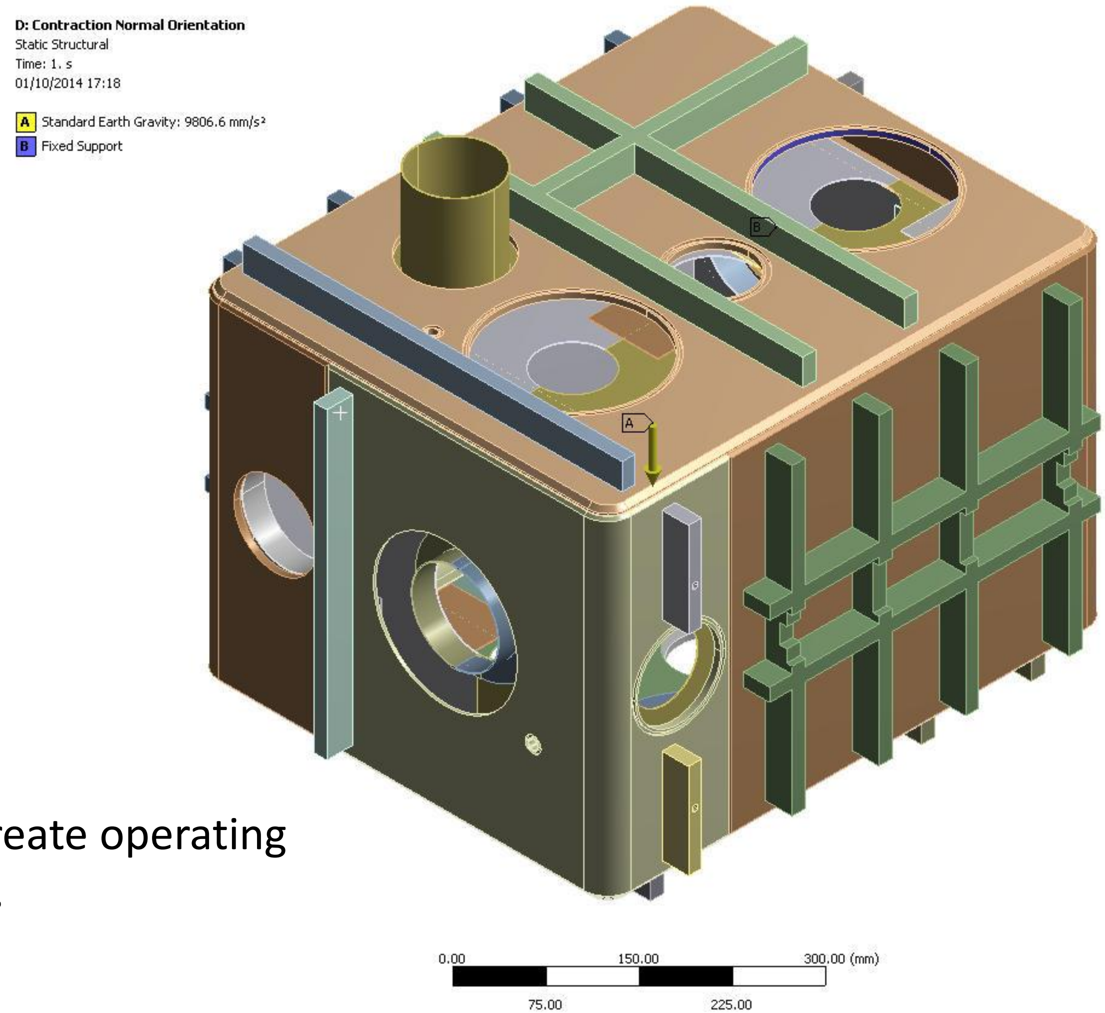
Maximum stress **446MPa.**

This occurs in the grade 2 Ti supports and pads. This is close to the acceptable limit for grade 2 Ti at 2K.

We will investigate this further, as we may mount to internal ribs.

Another option is using Grade 5 Ti which has far higher yield strength.

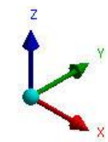
3. Cold + Horizontal Self Weight BCs



Temperature varying material properties applied as appropriate.

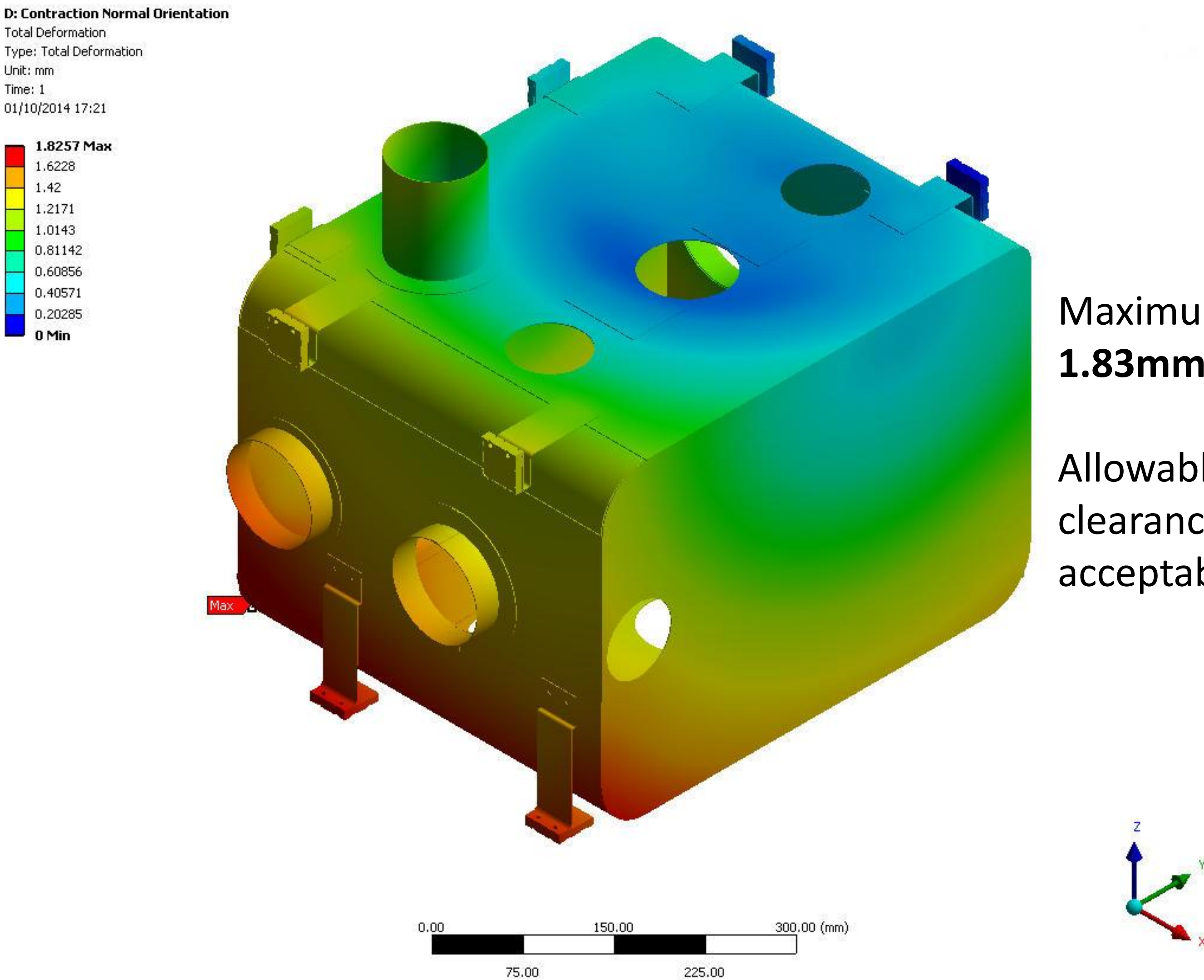
Average co-efficient of thermal expansion used for Cryophy of $8e^{-6}$/K As per Aperam data sheet.

Standard earth gravity used in direction of yellow arrow.



i.e. to re-create operating conditions.

3. Cold + Horizontal Self Weight Deformation



Maximum deformation **1.83mm.**

Allowable as clearances stay within acceptable limits.

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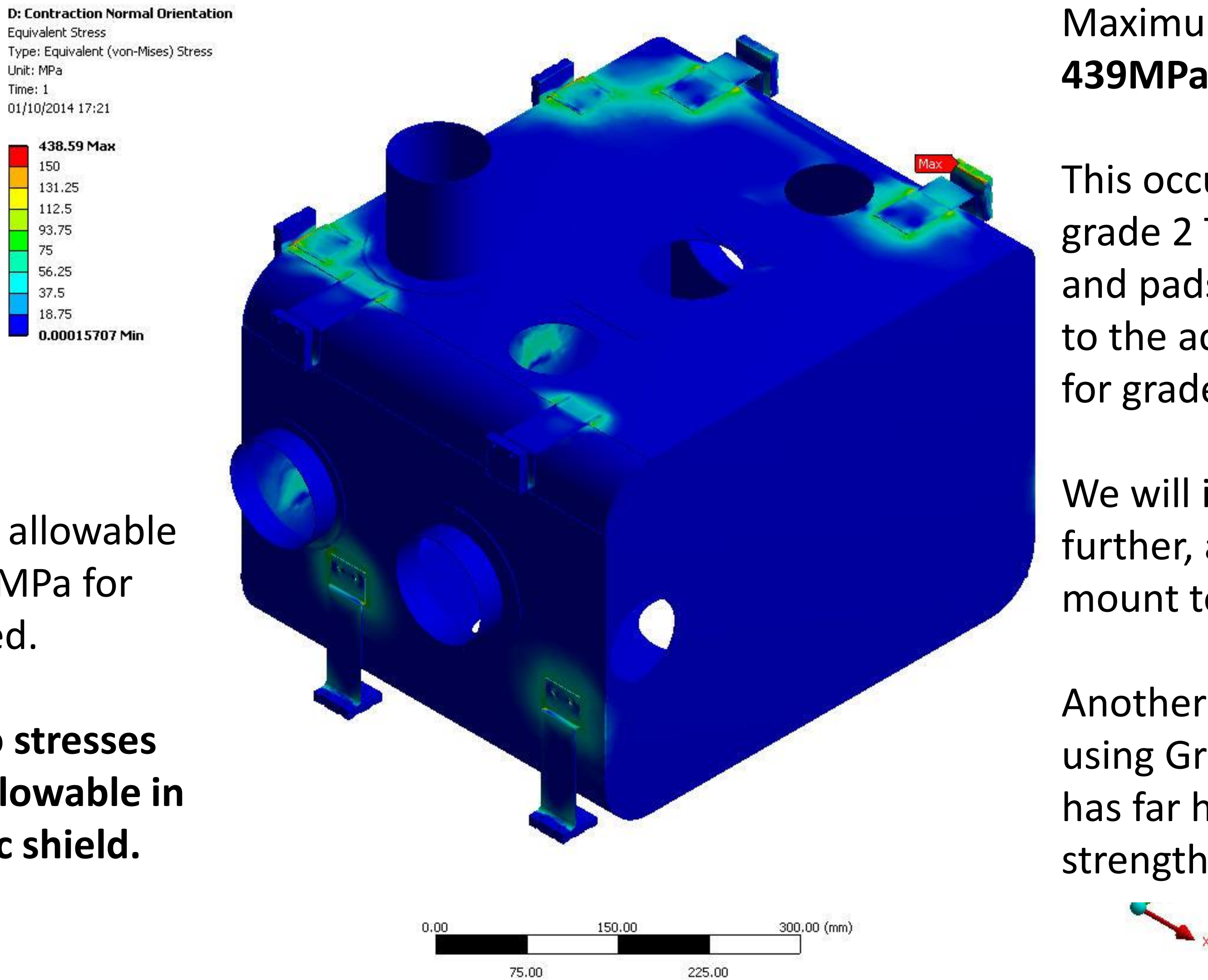
3. Cold + Horizontal Self Weight Stress



Maximum stress **439MPa.**

This occurs in the grade 2 Ti supports and pads. This is close to the acceptable limit for grade 2 Ti at 2K.

We will investigate this further, as we may mount to internal ribs.

Another option is using Grade 5 Ti which has far higher yield strength.

Stress above allowable value of 150MPa for Cryophy is red.

There are no stresses above the allowable in the magnetic shield.

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Conclusions and further work

- A double layered magnetic shielding solution has been developed in Opera to meet the requirements for the SPS module with contingency.
- An internal cold shield is envisaged primarily for better magnetic shielding performance.
- Mechanical design of the shielding is almost complete.
- FEA has been used to assess cool down stresses and stiffness of flexure supports under self weight.
- The support system appears to work well. This design, however, may need to be slightly modified to suit changes in the helium vessel design.
- We can now use what we have developed for the DQW cavity to produce a design for RFD.