High Luminosity LHC

CRAB CAVITIES

CRYOMODULE REVIEW

VACUUM TANK DESIGN

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on behalf of the Crab Cavity Collaboration

10/11/2015

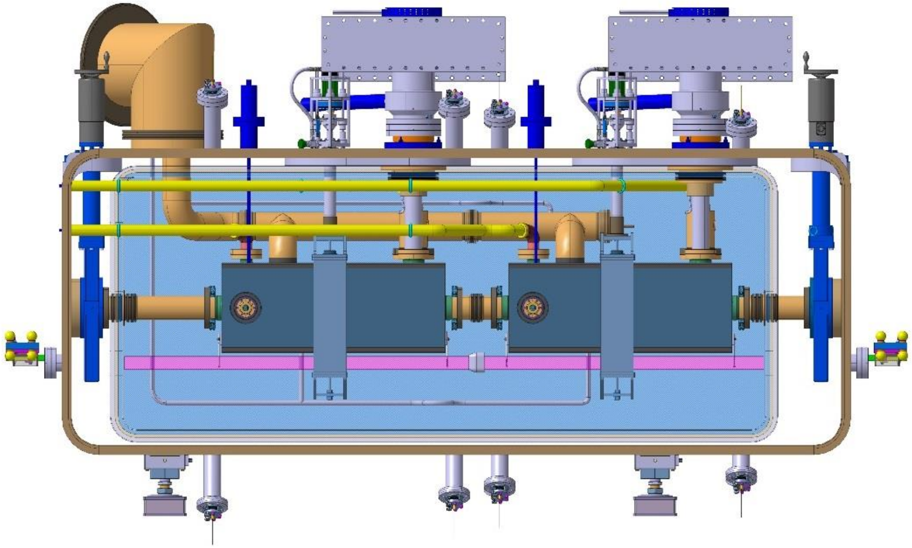
The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

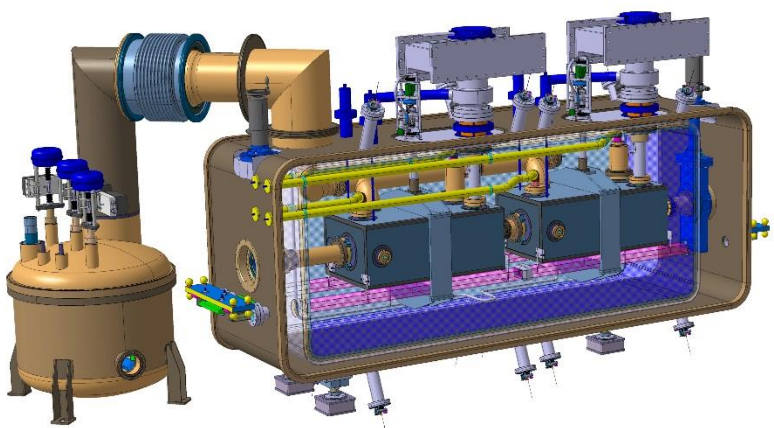
Previous design review

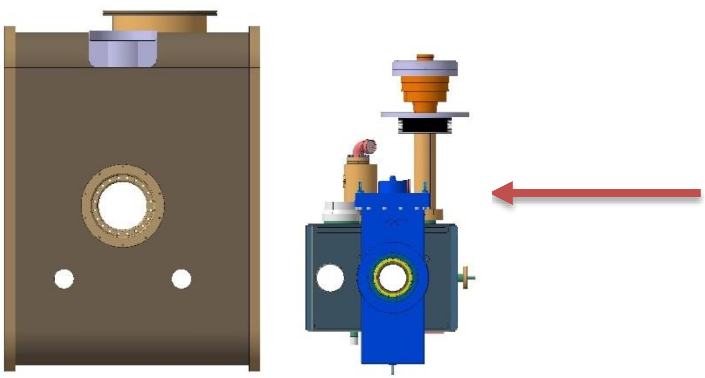
1 – Lateral insertion

Advantages :
Simplicity of conception / manufacturing
Large openings

Disadvantages :
Vacuum valves inside vacuum tank
Overall dimensions
Insertion of thermal screen and MLI very complex
Heavy side doors (~300kg)





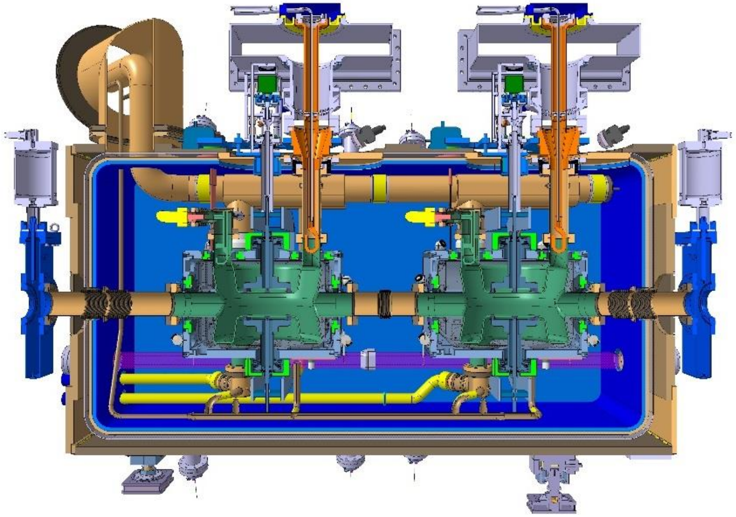


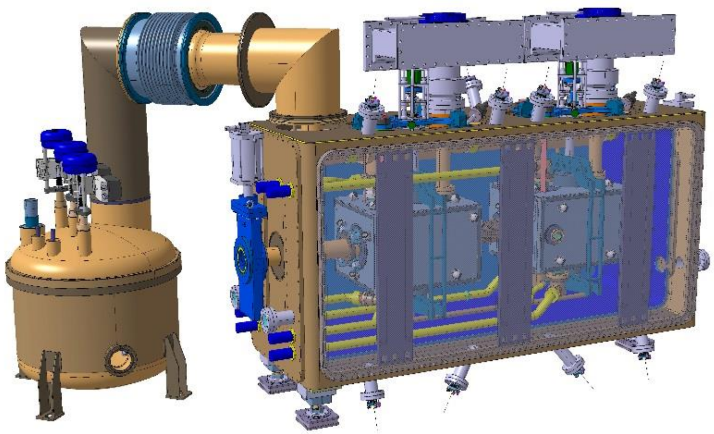
Previous design review

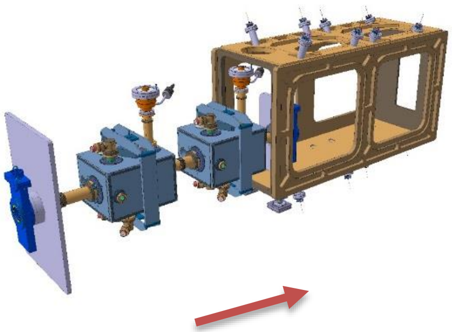
2 – Longitudinal insertion

Advantages :
Externalization of valves
Simplification of assembly sequence
Overall size reduced

Disadvantages :
Limited space available for assembly
Vacuum tank less rigid compare to other solutions
Multiplication of large size sealing
Insertion of thermal screen and MLI very complex

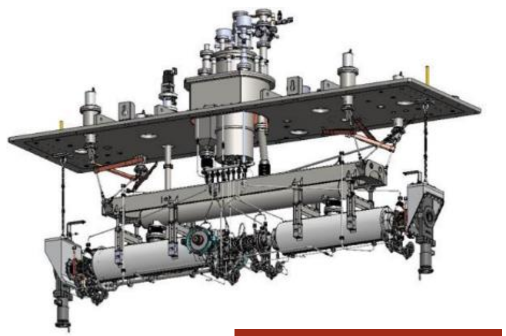




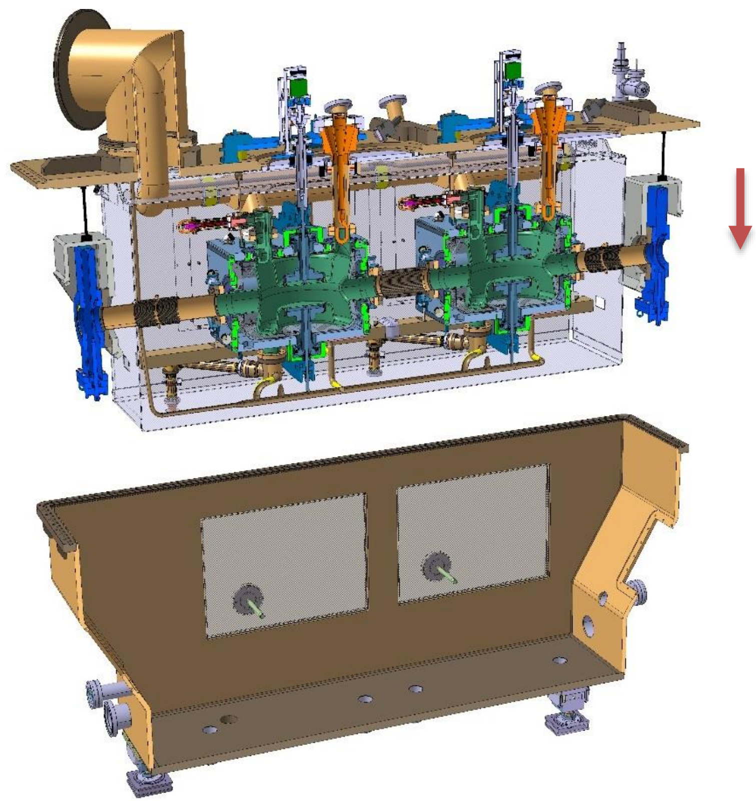


Chosen design : Vertical assembly

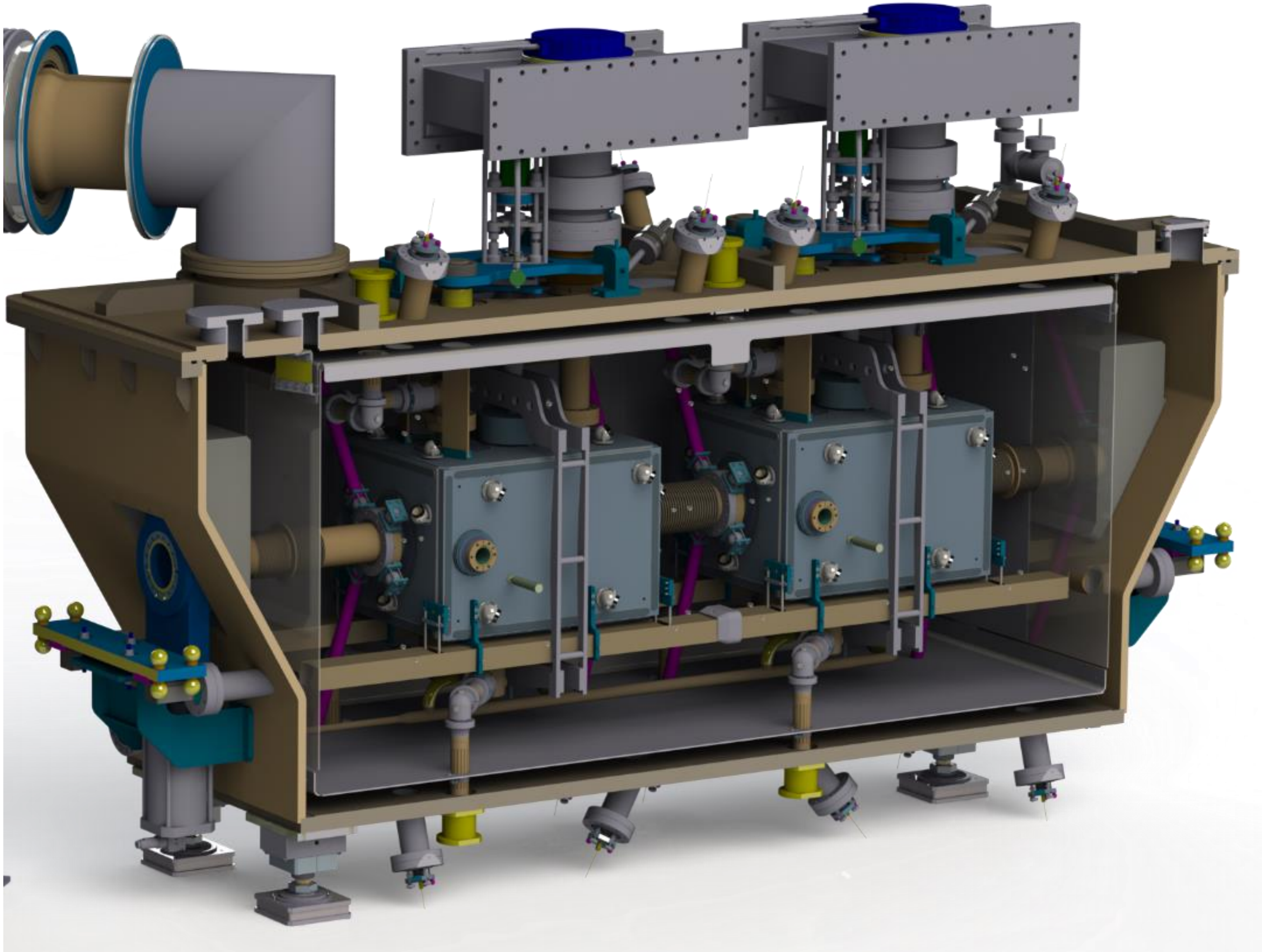
Design from Triumph
Advanced Rare IsotopE Laboratory **(ARIEL)**



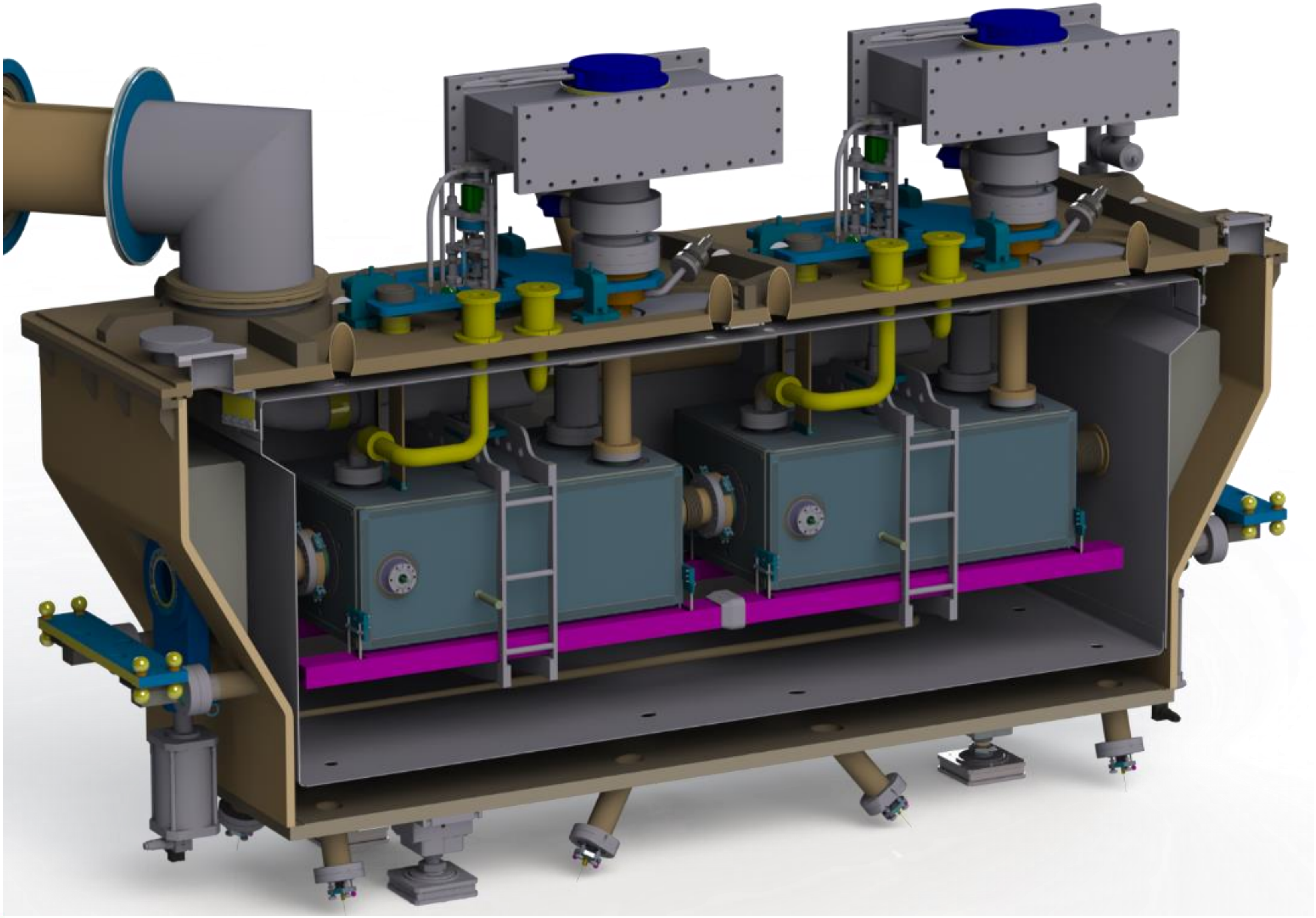
Advantages :
Externalization of valves
Suppression of large openings
Vacuum tank more rigid
Simplification of assembly sequence
Space available for assembly



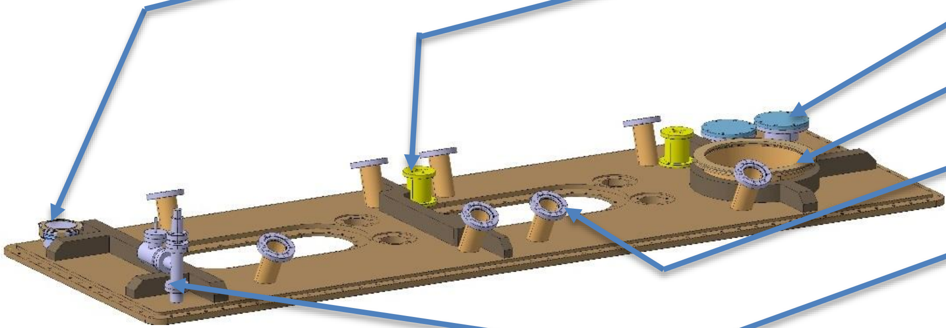
Cryomodule overview (DQW)

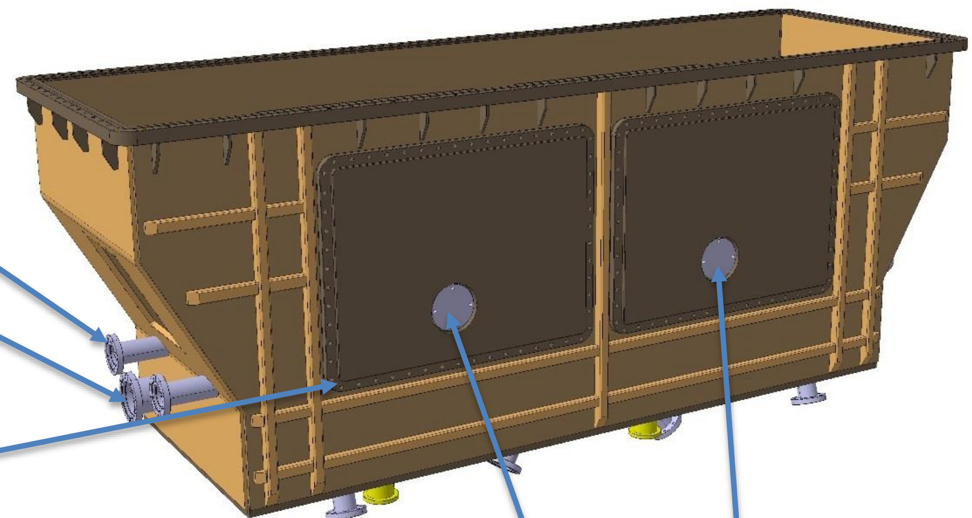


Cryomodule overview (RFD)



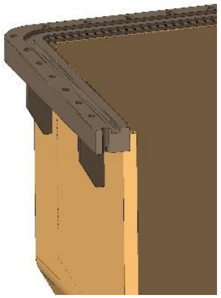
Connections

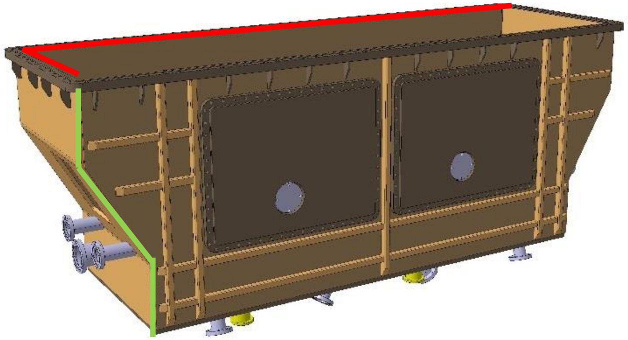




Welds interfaces

Flange





Flat sides

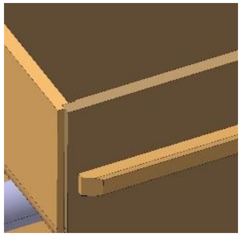


Table 17-4 — Classification of welded joints

g) Flanges and pads

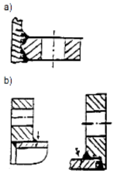
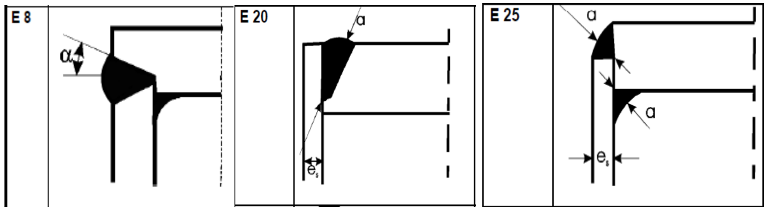
7.2	welded flange	a) b) 	71 80 63	63 63 63	Full penetration weld: — as welded — if weld toe dressed Partial penetration welds	F2.1 to F2.3

Table A-3 — Pressure bearing welds - Flats ends



FE calculations

Overview

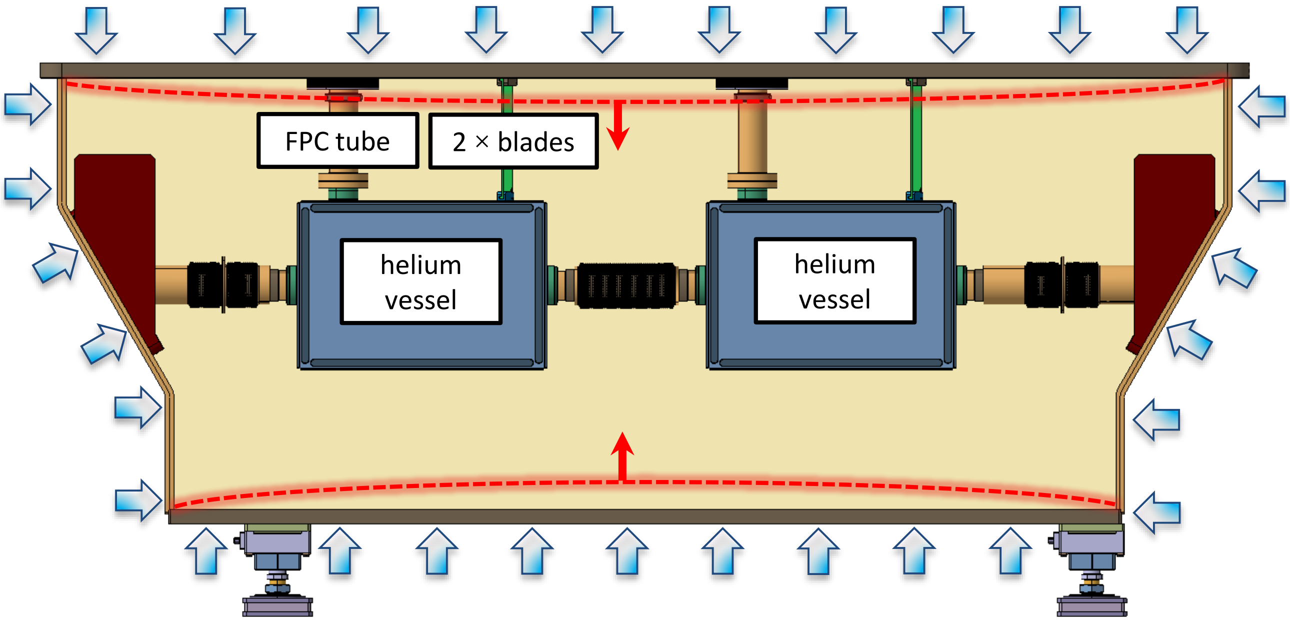
Objectives of the FE calculations:

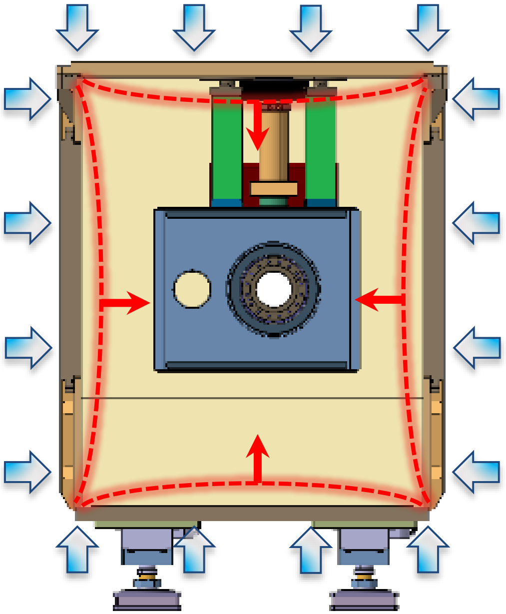
- Minimize the vessel deformation.
- Optimize the mass.
- Verify the stress level.
- Assess the structure against buckling.

Vacuum

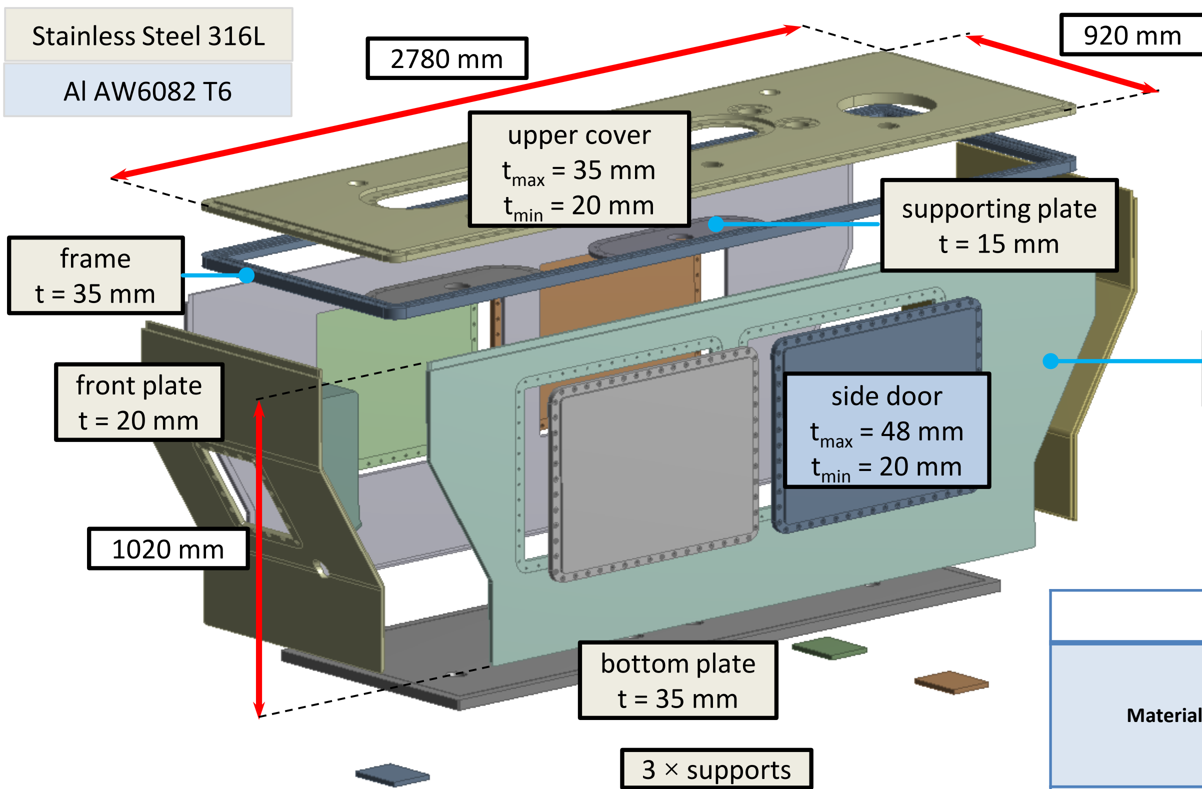
Atmospheric pressure

Gravity





FE model



Key components of the vacuum vessel.

FE model of the vessel includes:
- 600 components,
- 478 bolted joints,
- 24 welded joints,
- frictional contacts.

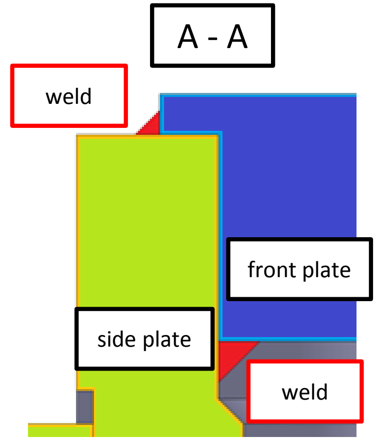
The detailed model was required to properly capture the vacuum vessel structural response.

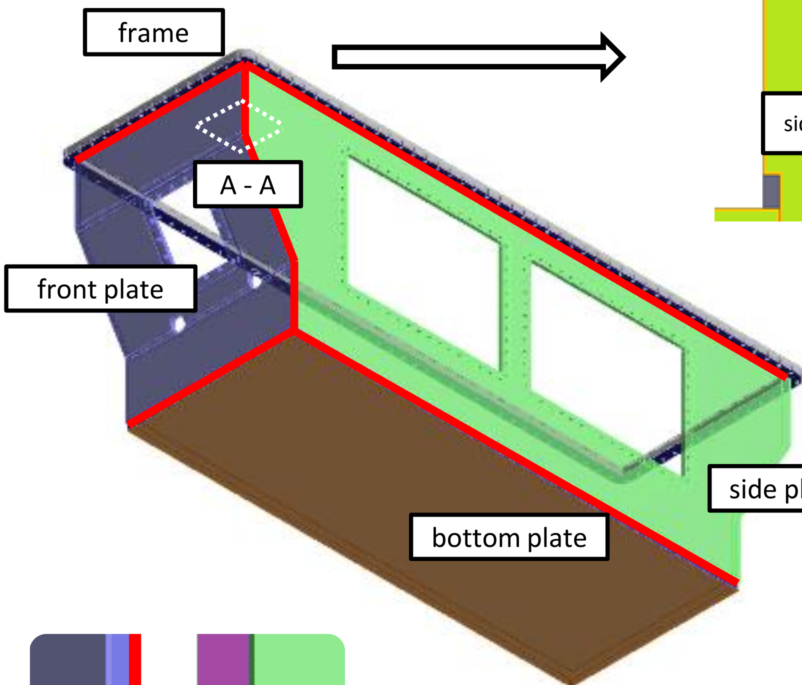
Physical properties at temperature 20°C [1]					
Material	Poisson's ratio	Elastic modulus	Density	$R_{p0.2}$	Max allowable $R_{p0.2}/1.5$
	-	[GPa]	[kg/m³]	[MPa]	[MPa]
Stainless Steel 316L	0.27	193	7950	225	150
Al AW6082 T6	0.33	69.5	2710	240	160

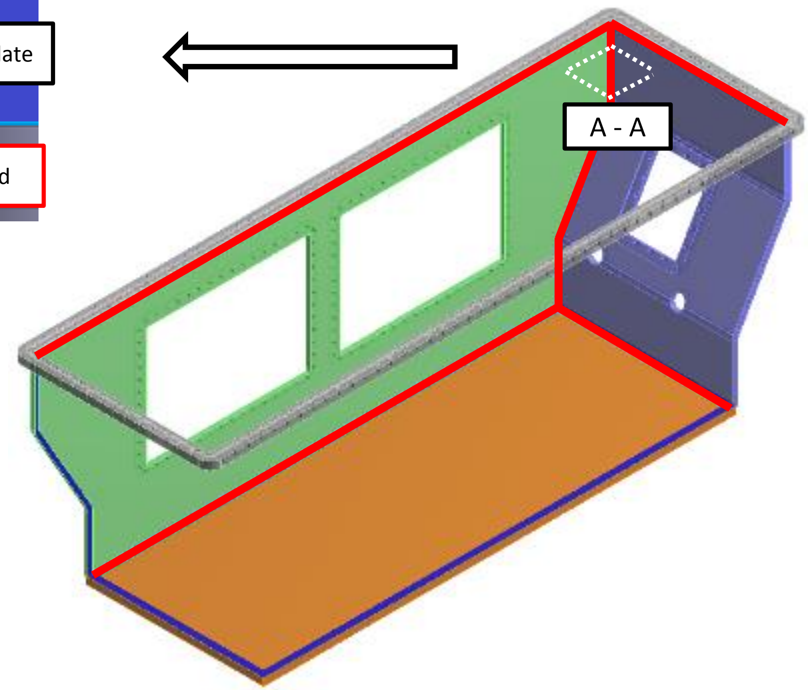
[1] Materials and Ansys Library for Design Office, EDMS 1291793.

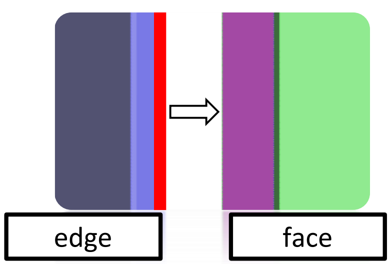
Welds

Vacuum vessel welded from the interior and exterior.





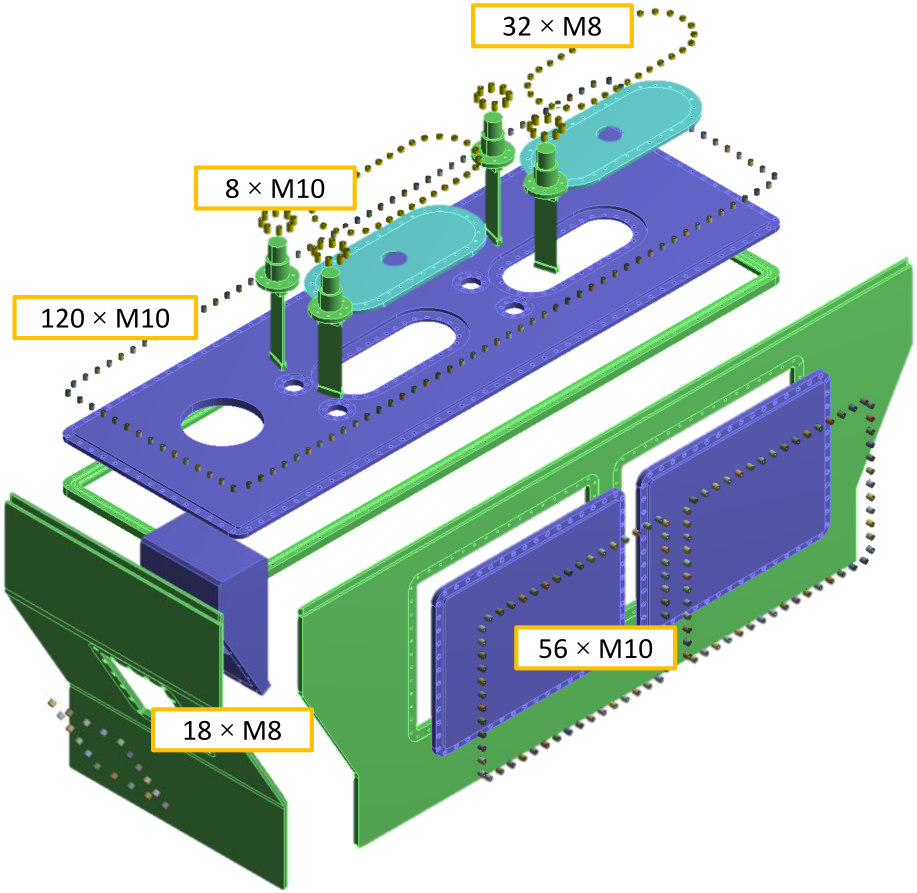




Weld definition in ANSYS by edge to face contacts.

The same weld configuration for pairs:
- front plate → side plate,
- front plate + side plate → bottom plate,
- front plate + side plate → frame.

Bolts



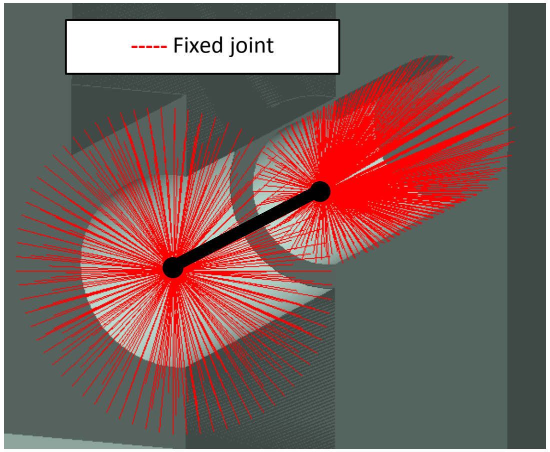
Bolt preload:

- 35 kN (M10),
- 22 kN (M8).

Coefficients of friction μ:

- 0.32[1] (316L – 316L),
- 0.3[1] (Al – 316L).

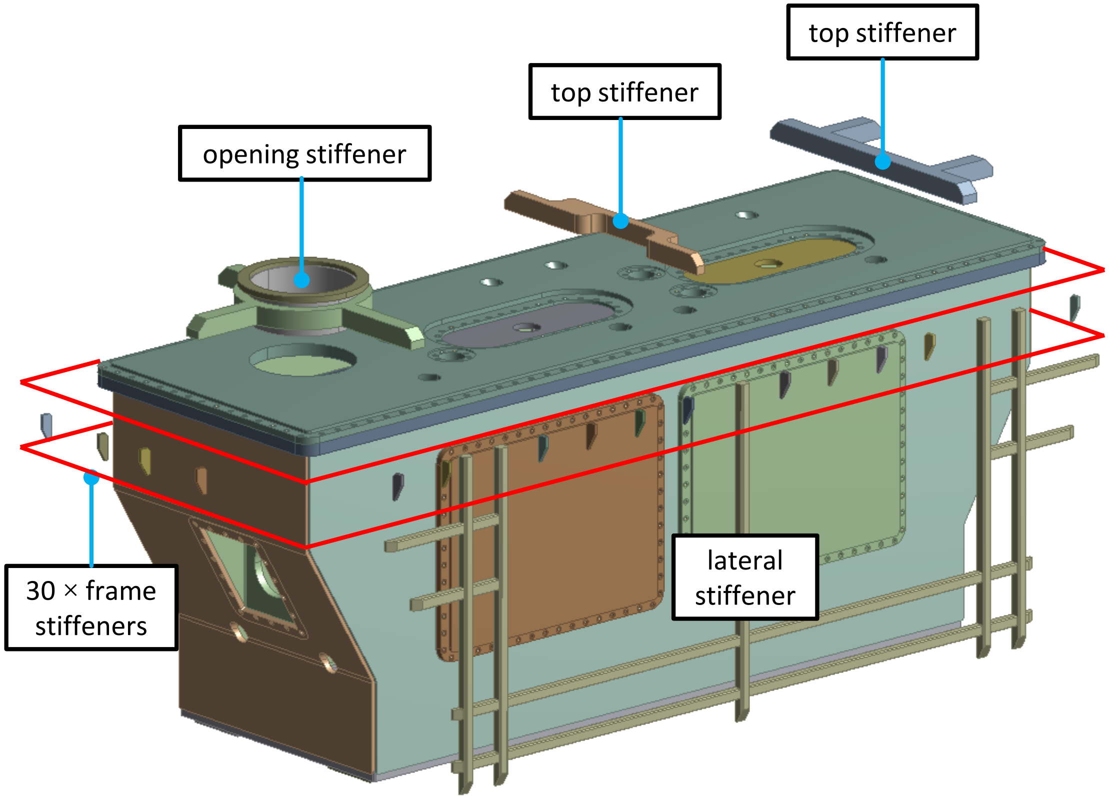
Total number of bolts: 476.
Bolt properties calculated according to the VDI 2230-2.

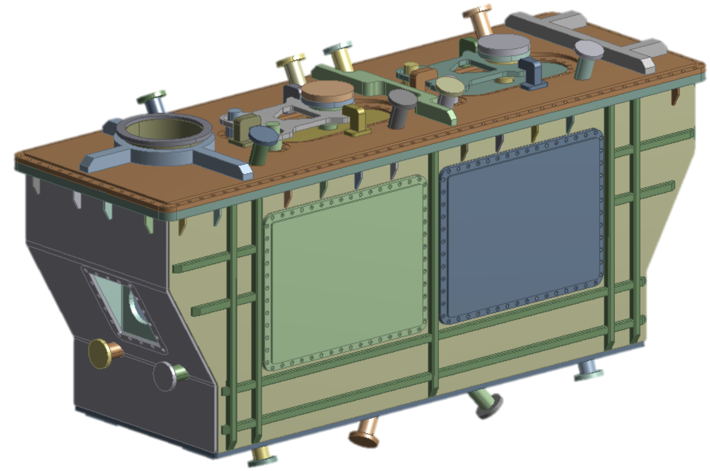


Bolt definition in ANSYS.
Beam attached by a spider net to the bearing face and screw hole.

[1] J. C. Burton, P. Taborek and J. E. Rutledge, Temperature dependence of friction under cryogenic conditions in vacuum. Tribology Letters, Vol. 23, No. 2, August 2006

Stiffeners





Final version of the FE model.

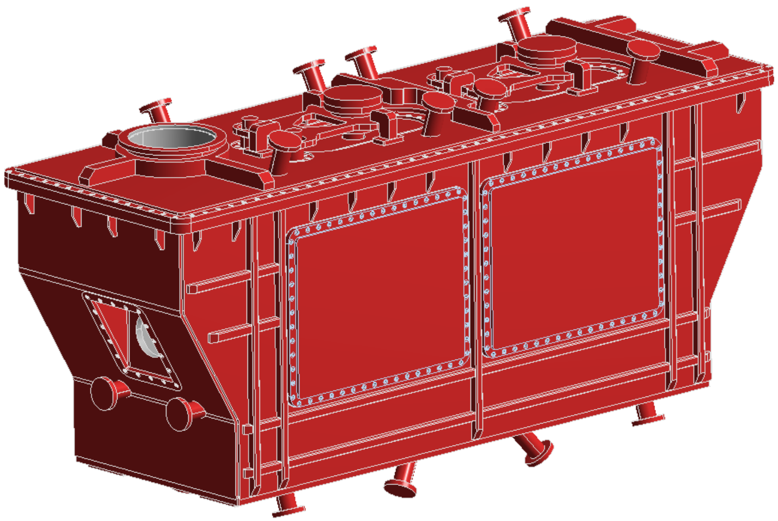
≈ 2600 kg

- The additional stiffeners encompassing the frame and top stiffeners added.
- The lateral stiffeners were added to increase the stiffness of the vessel and minimize deformation of the plates.

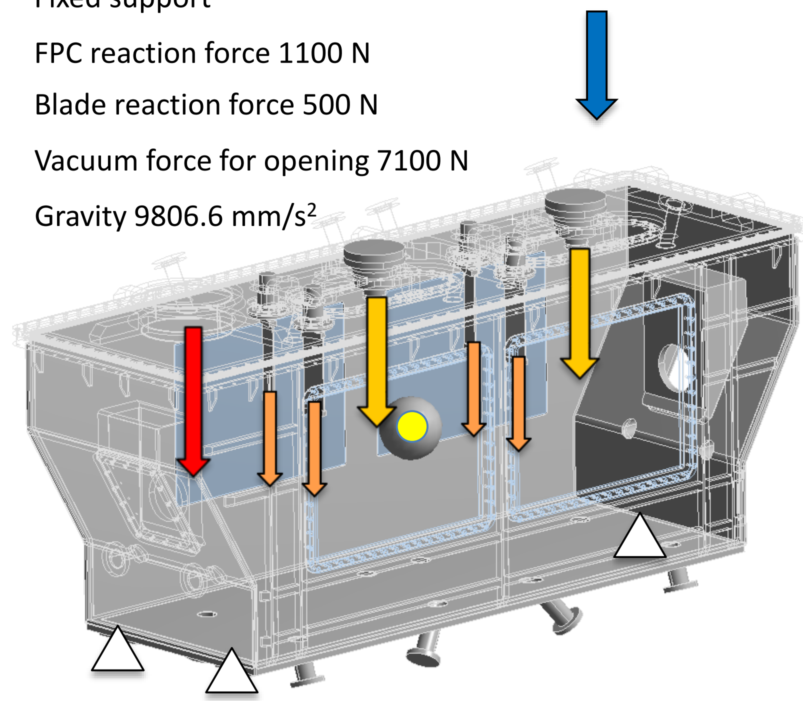
Loads and BCs

Load on the top plate	
Weight [kN]	Vacuum force [kN]
9.5	161.3

Pressure 0.1 MPa



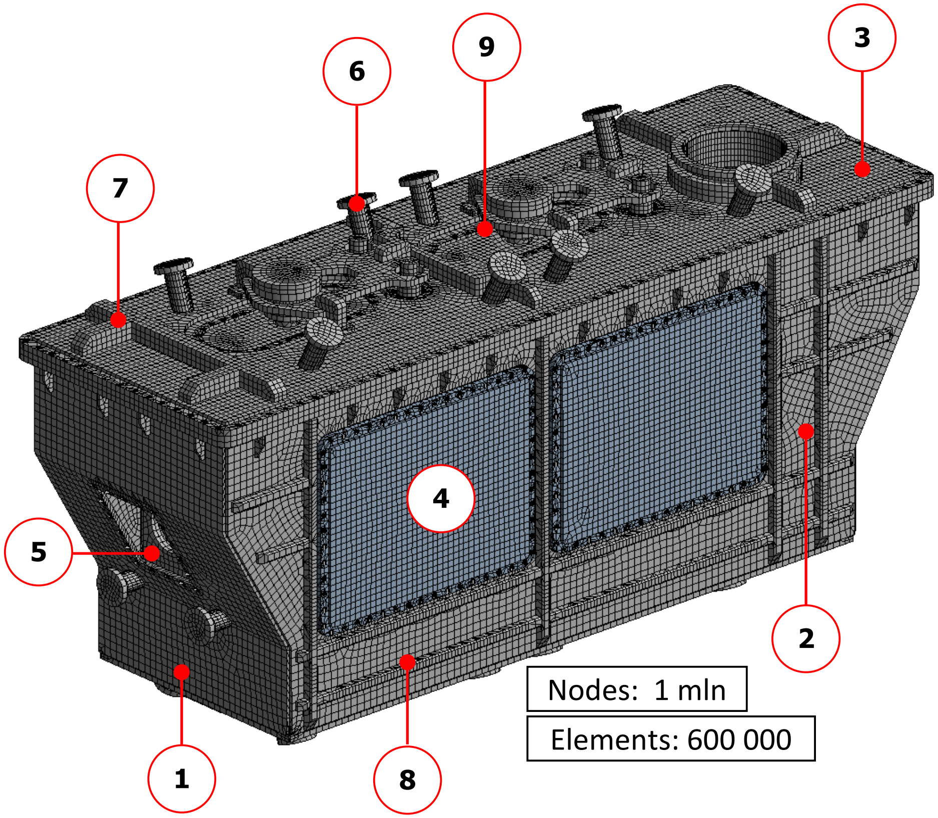
- Total mass of the magnetic and thermal shields 180 kg
- Fixed support
- FPC reaction force 1100 N
- Blade reaction force 500 N
- Vacuum force for opening 7100 N
- Gravity 9806.6 mm/s^2



- ➢ Differential pressure 0.1 MPa assigned to the external faces of the vacuum vessel.
- ➢ The helium vessels replaced by corresponding reaction forces extracted from the related calculation.
- ➢ CoG for the magnetic and thermal shields defined and the coresponding mass attached to the top plate.

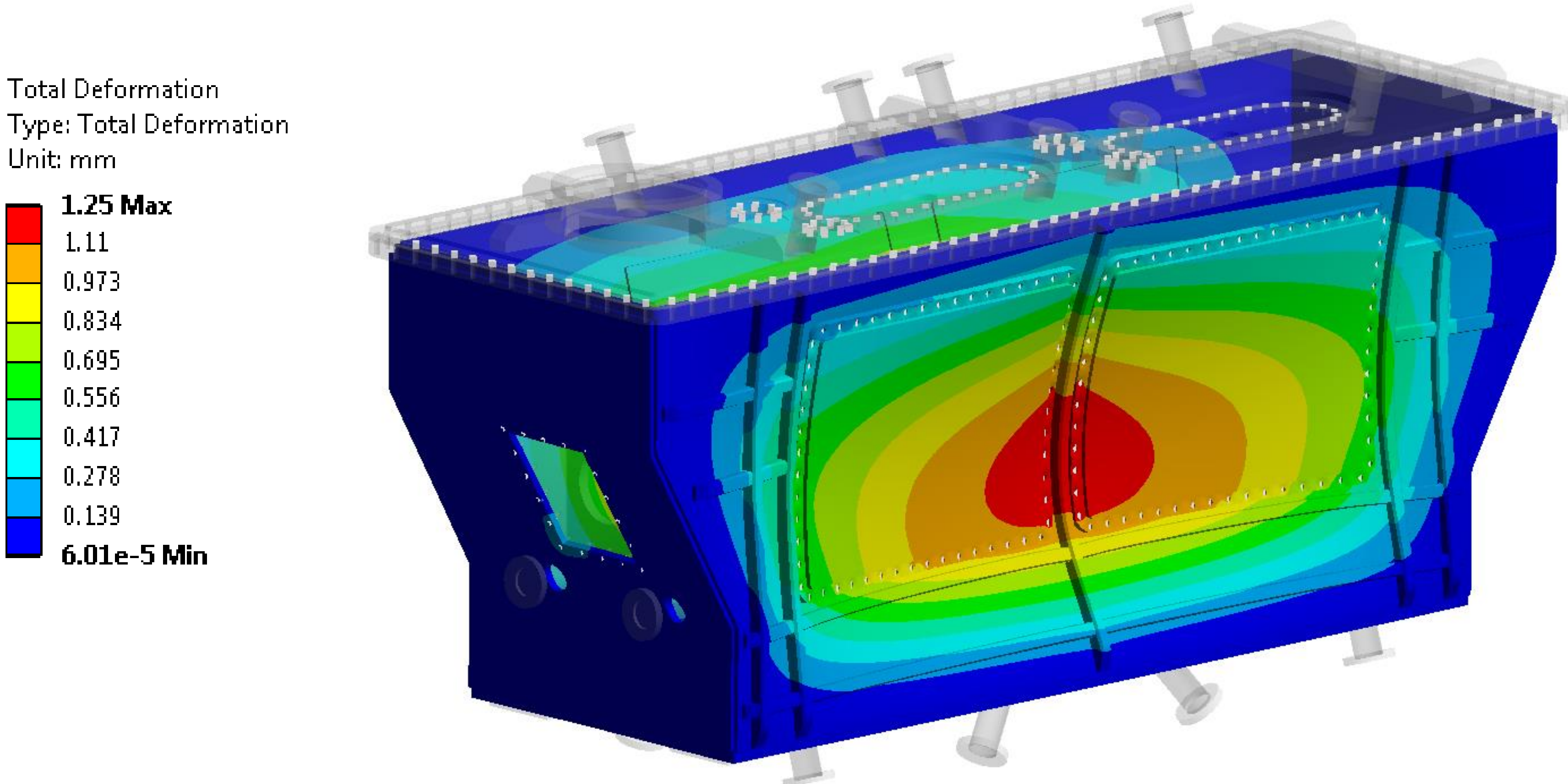
Mesh

Mesh convergence test performed to select the most reasonable size in order to obtain trusted results.



Component	Size [mm]	Name	Description	DoF
1	25	SOLID186 SOLID187	SOLID186 3-D 20-node hexahedral solid element with quadratic displacement behaviour SOLID187 3-D 10-node tetrahedral solid element with quadratic displacement behaviour	UX, UY, UZ
2				
3	20			
4				
5				
6				
7				
8				
9	15			
bolts	1	BEAM188	3-D 2-node linear beam element	UX, UY, UZ, ROTX, ROTY, ROTZ

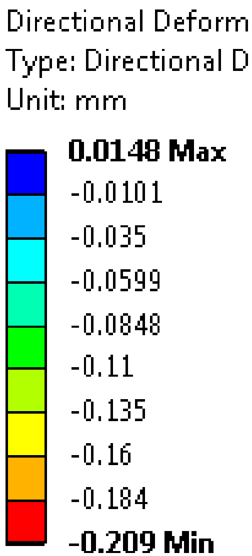
Deformation of the lateral plates



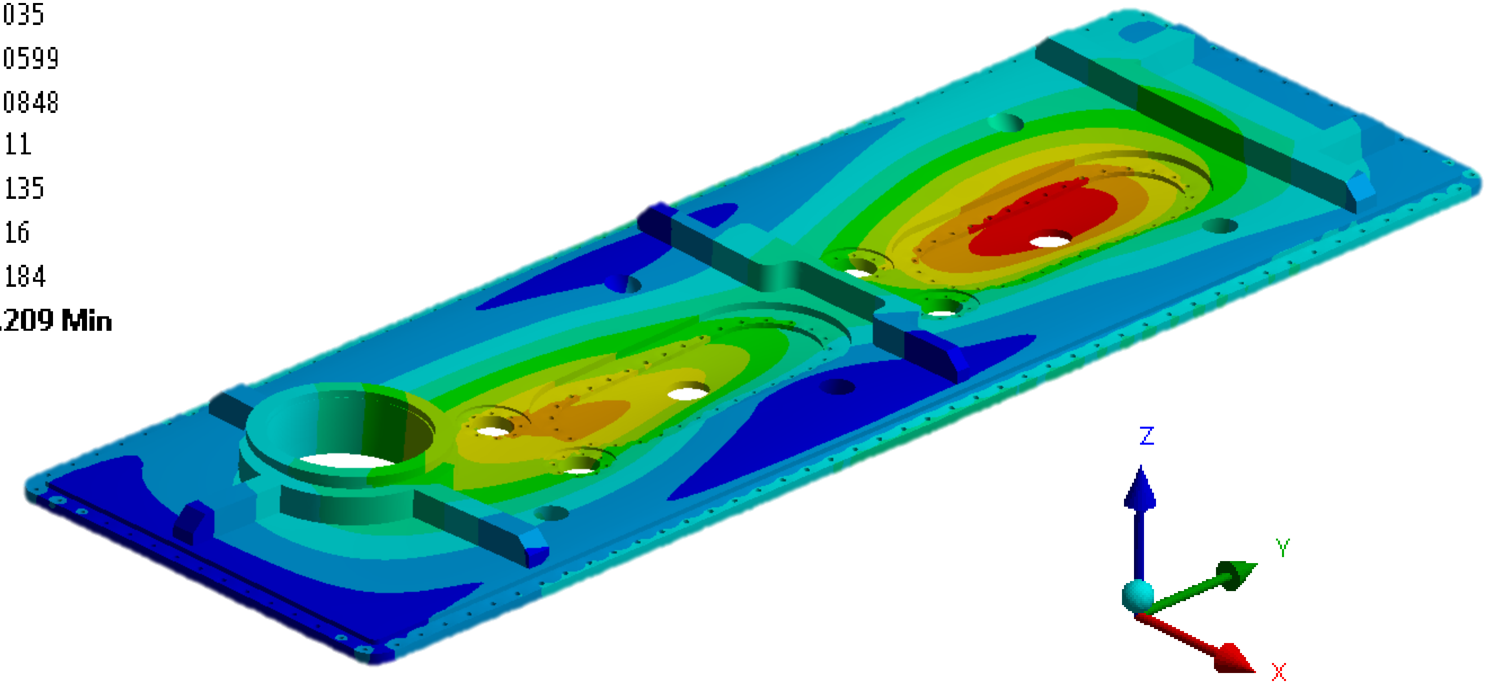
Zoom × 100

The maximum value is 1.25 mm and is located in the middle of the side plate. That deformation may be reduced slightly using thicker plates, however it increases the total mass. Therefore the trade-off between the deformation and total mass was made.

Vertical deformation

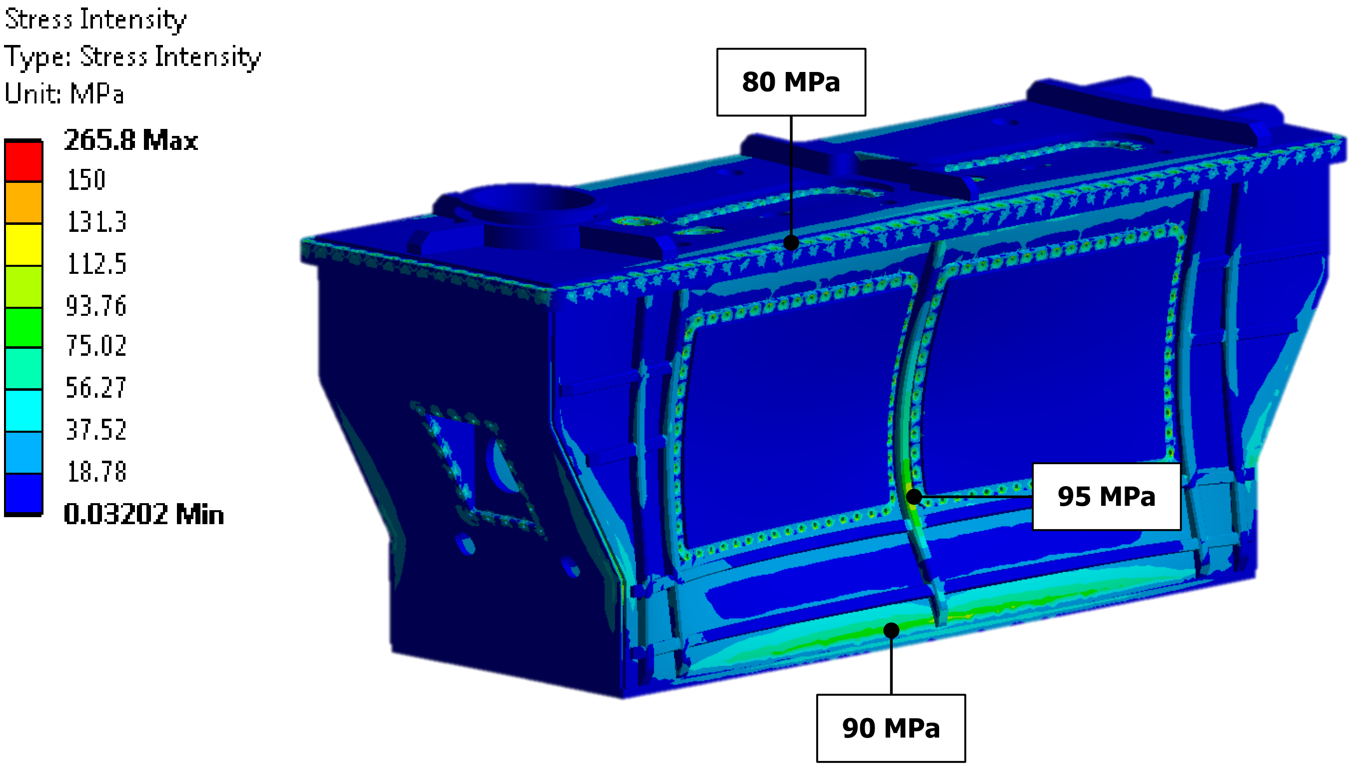


The maximum value is 0.21 mm and does not change significantly when increasing the lateral stiffness.



Zoom × 100

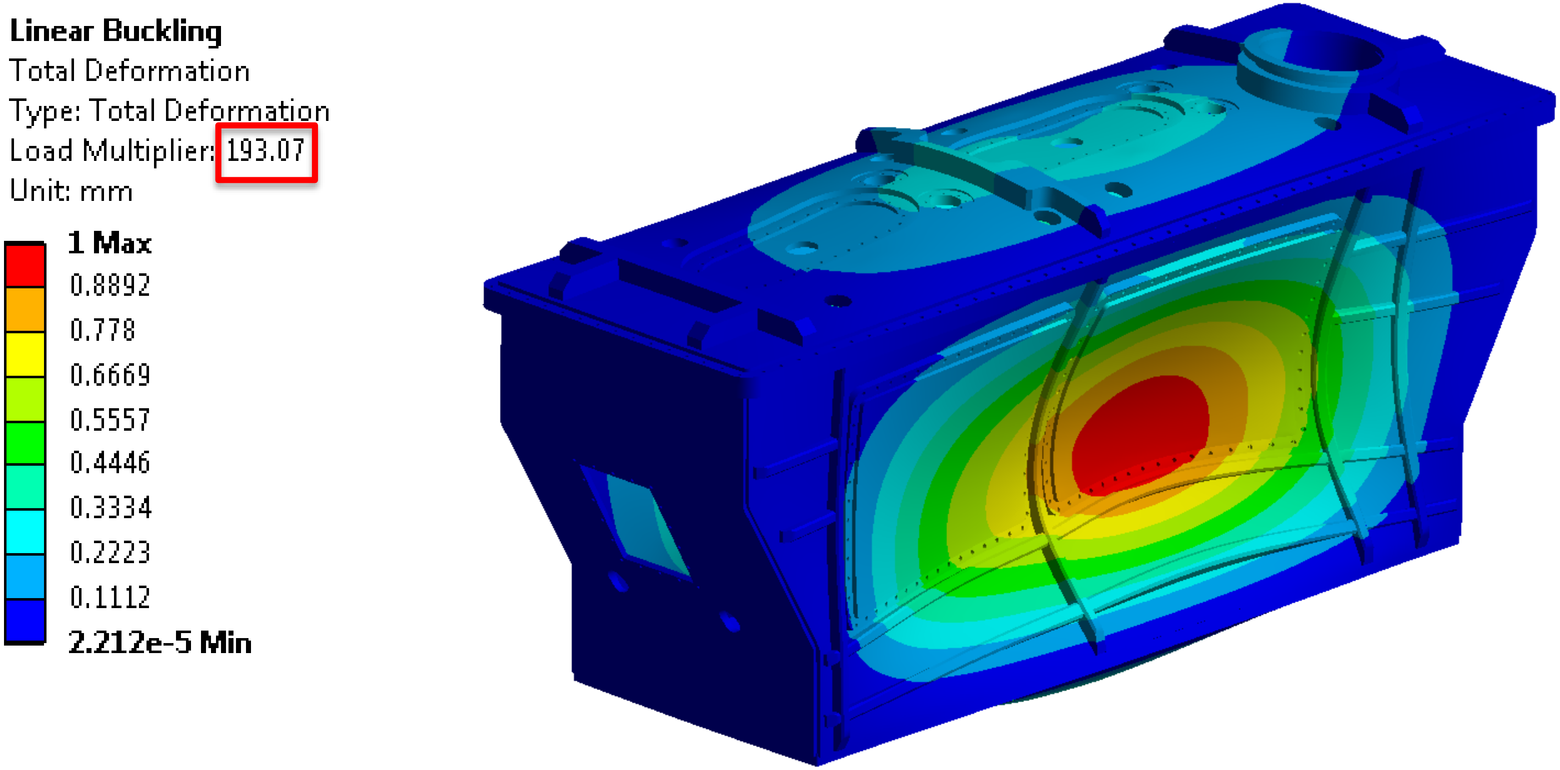
Stress intensity



Peak stresses.

- ➢ The regions with stress higher than acceptable are coloured in red. The mesh refinement resulted in even higher stress and since they are localized and occur close to the weld contacts and screw holes, they were classified as peak stresses.
- ➢ The overall stress level for the vacuum vessel is lower than acceptable value.
- ➢ The stress intensification occurs on the lateral stiffener, under the bolt heads and the bottom of the side plates.

Buckling



The pre-stressed structure was extracted from the structural calculations.
The lowest buckling factor for the vacuum vessel is 193 and proves the structure stability.

Conclusions

- The FE calculations have demonstrated the satisfactory structural performance of the vacuum vessel.
- A detailed model was prepared and verified to obtain the most realistic results.
- The lateral and vertical deformations are acceptable, however there is still space for improvement.
- The stress level is under control. The peak stresses were found as a result of the mesh distortion and contact definition.
- The buckling analysis showed that the vacuum vessel is safe and under the operating load buckling will not occur.

High Luminosity LHC

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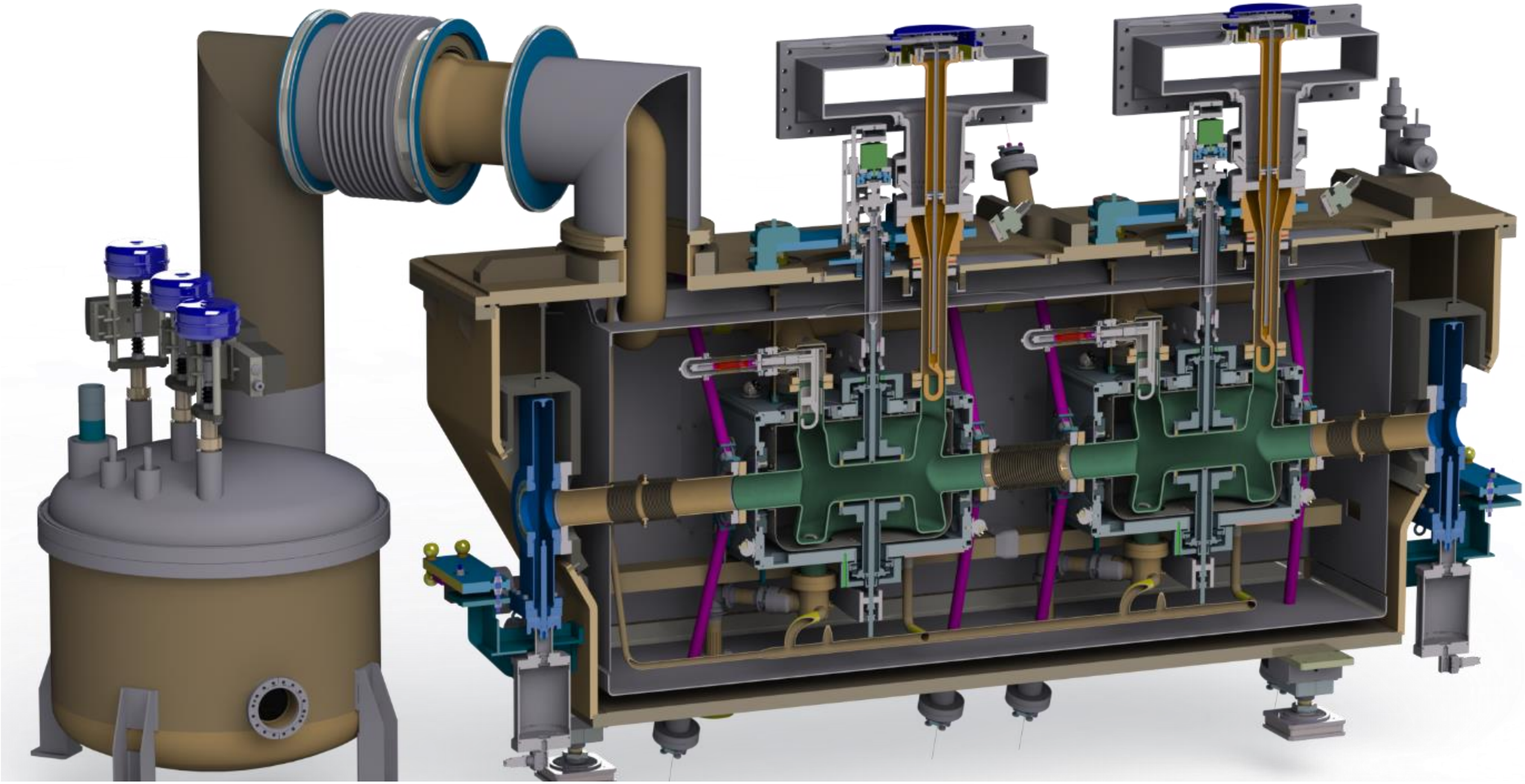
DQW section view



High Luminosity LHC

RFD section view