CRYOMODULE SPL

SPL Cryomodule Conceptual Design Review

VACUUM VESSEL AND ASSEMBLY TOOLING

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Cryostat overview

Goal

Design and construct a ½-lenght cryomodule

- for the test of 4 β=1 cavities (instead of 8 in a machine type cryomodule)
- in conditions as close as possible to a machine-type cryomodule

Cryostat specific main objectives

Learning of the critical assembly phases:

- From clean room assembly of cavities to a cryomodule
- Alignment/assembly procedure

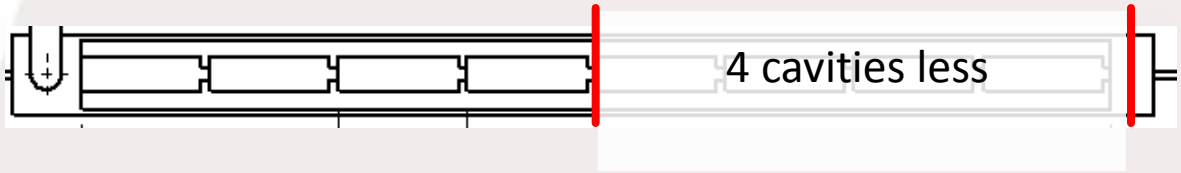
Proof of concept of "2-in-1" RF coupler/cavity supporting:

- Fully integrated RF coupler: assembly constraints
- Active cooling effect on cavity alignment

Operation issues:

- Cool-down/warm-up transients, thermo-mechanics, heat loads
- Alignment/position stability of cavities
- Cryogenic operations (He filling, level controls, RF coupler support tube cooling)

The short cryomodule design strategy



- Mechanical design
- Cryogenics (Heat loads, T and P profiles, segmented machine layout)
- Designed for 0%-2% test (for 1.7% expected tunnel slope)

Vacuum vessel and tooling design aspects

Technical solutions focus on the ½-lentgh cryomodule

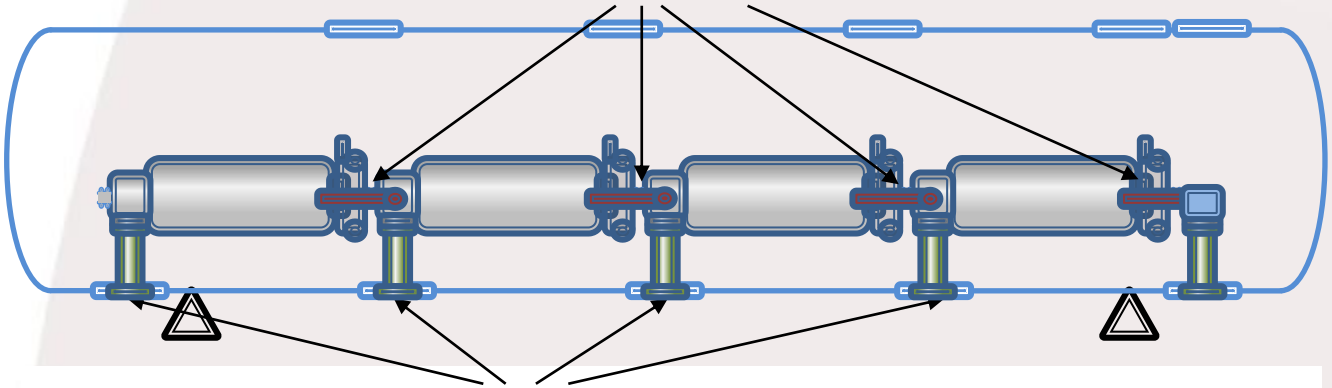
Technical solutions were developed for the full length cryomodule (more constraining environment)

Specifically the tooling for the cryostating

VACUUM VESSEL / COUPLER INTERFACE

The supporting system concept

Intercavity supports



RF coupler double-walled tube flange fixed to vacuum vessel

The RF coupler (its double-walled tube) provides:

- fixed point for each cavity (thermal contractions)
- mechanical supporting of each cavity on the vacuum vessel

The intercavity support provides:

- a 2nd vertical support to each cavity (limits vertical self-weight sag)
- relative sliding between adjacent cavities along the beam axis
- enhancement of the transverse stiffness to the string of cavity (increases the eigenfrequencies of first modes)

VACUUM VESSEL / COUPLER INTERFACE

Alignement requirements

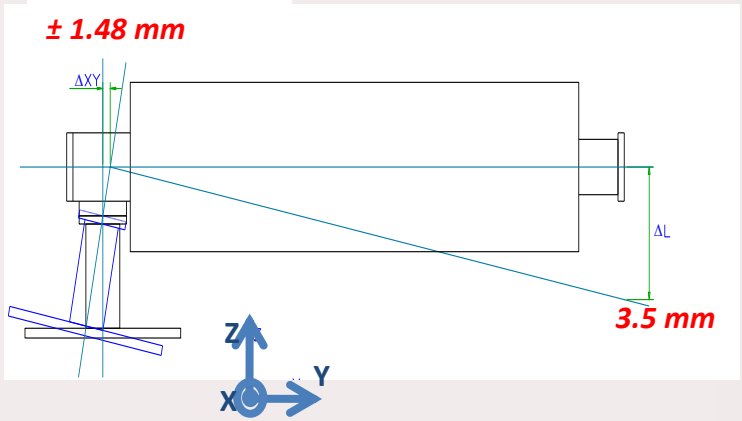
➢ Budget of tolerances :

BUDGET OF TOLERANCE			
Step	Sub-step	Tolerances (3σ)	Total envelopes
Cryo-module assembly	Cavity and He vessel assembly	**± 0.1 mm**	Positioning of the cavity w.r.t. external referential ± 0.5 mm
	Supporting system assembly	**± 0.2 mm**	
	Vacuum vessel construction	**± 0.2 mm**	
Transport and handling (± 0.5 g any direction)	N.A.	**± 0.1 mm**	Reproductibility/ Stability of the cavity position w.r.t. external referential ± 0.3 mm
Testing/operation	Vacuum pumping	**± 0.2 mm**	
	Cool-down		
	RF tests		
	Warm-up		
	Thermal cycles		

➢ Geometrical Tolerances of the assembly :

Cavity/He Vessel /Coupler/Vacuum Vessel

⇒ **ΔXY= 1.48mm / ΔZ= 3,5mm**



For each cavity, compensator component on the coupler side

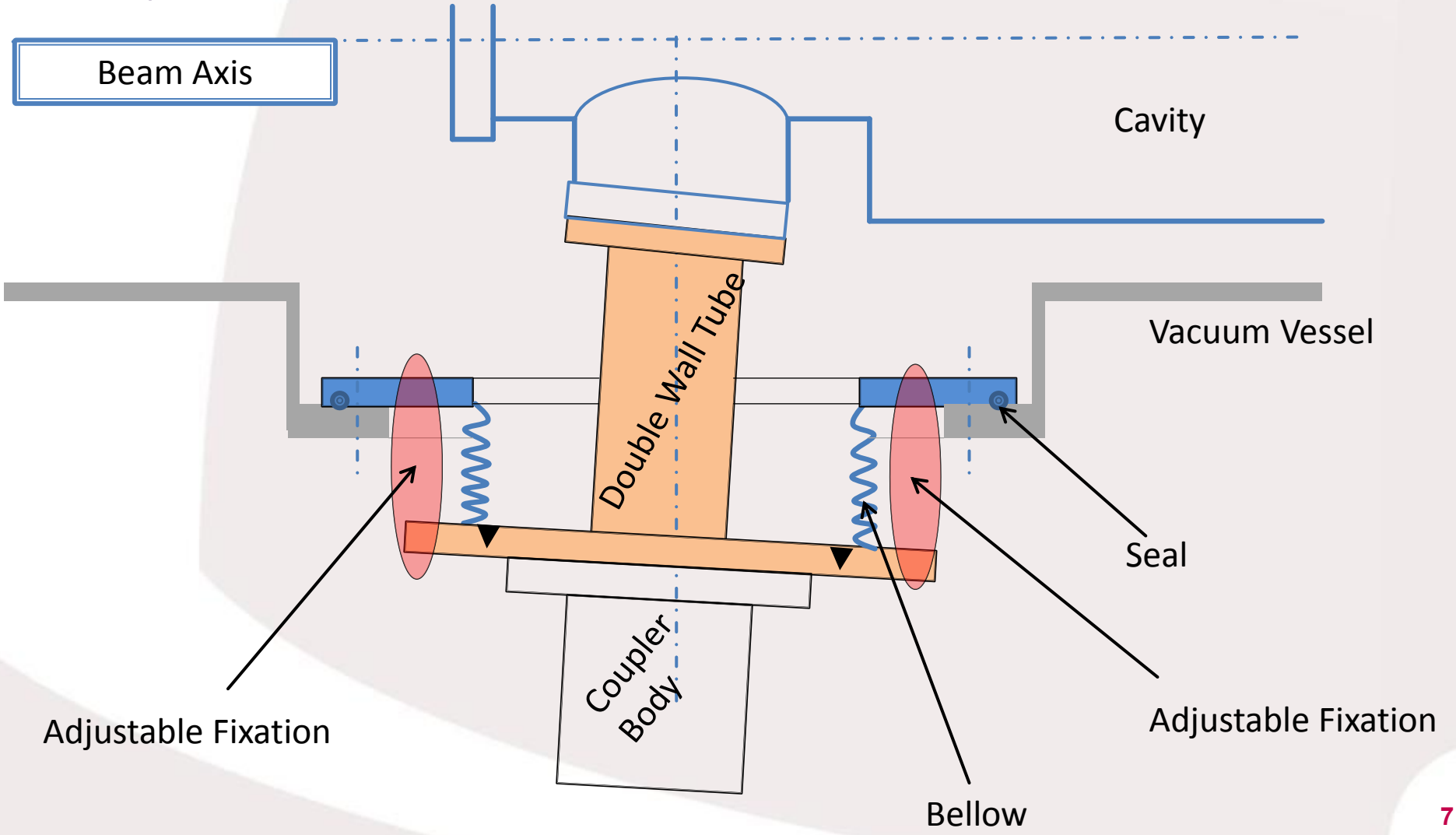
➢ To compensate the assembly tolerances (longitudinaly and angulary)

➢ Enable to support the cavities without loosing the alignment (fixed point)

VACUUM VESSEL / COUPLER INTERFACE

Coupler compensation interface with the vacuum vessel

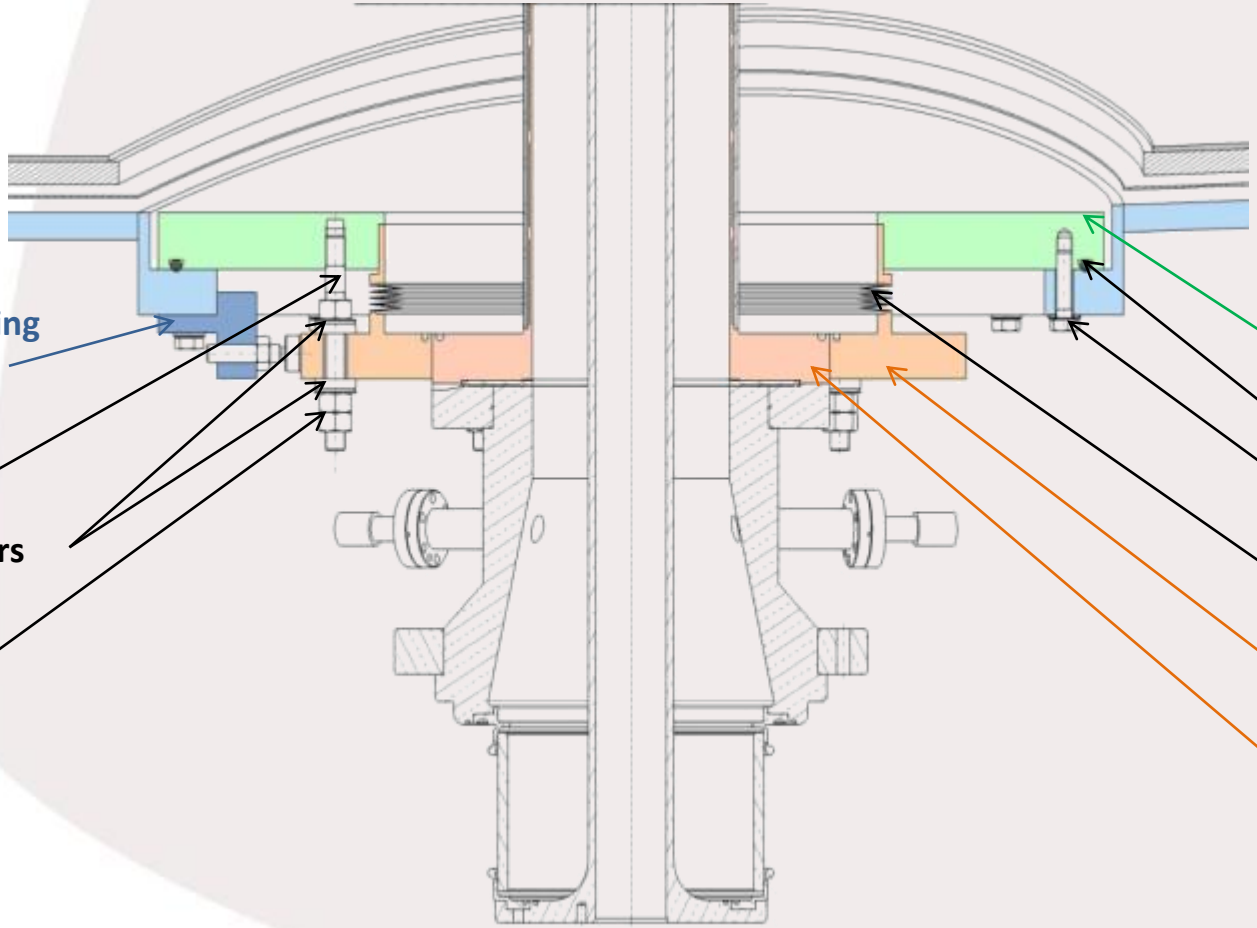
Principle scheme



VACUUM VESSEL / COUPLER INTERFACE

Coupler compensation interface with the vacuum vessel

Chosen solution



The detailed study of this interface has been done.
It will soon be constructed and tested on a mock-up by CERN.

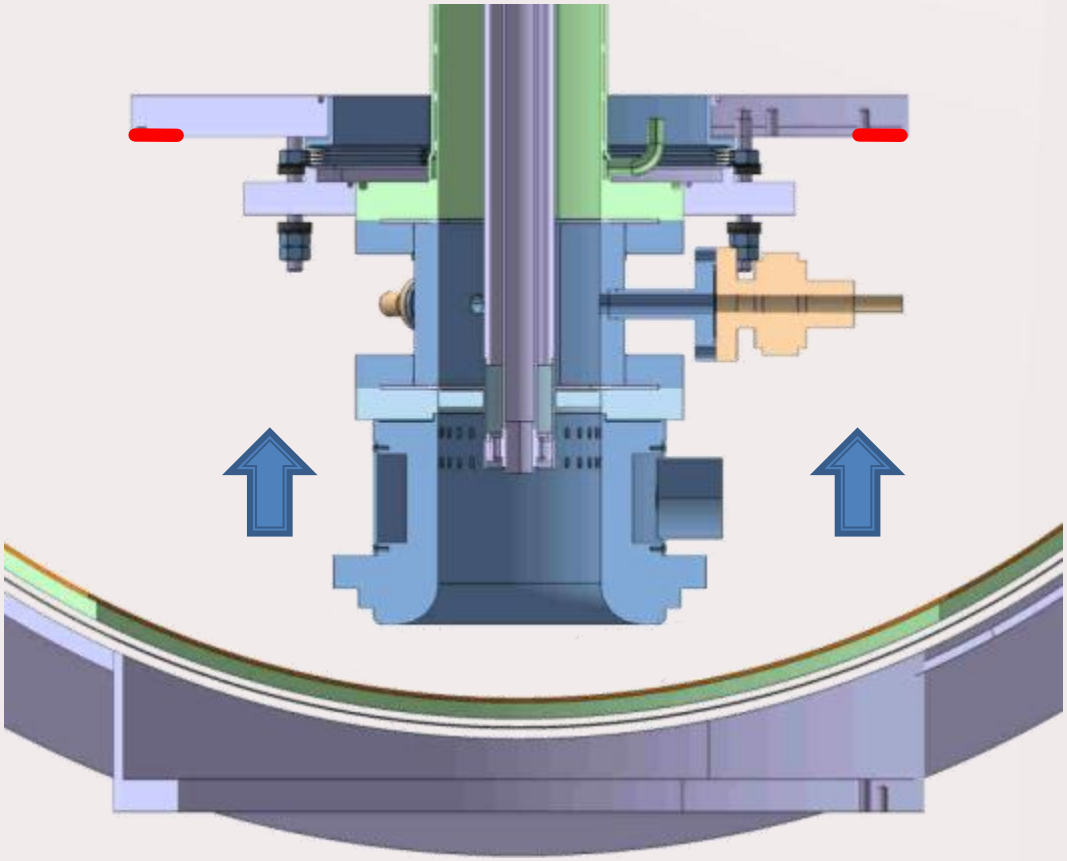
Note technique : NT-21B-004
CONCEPTION DES PALIERS SUPPORTS

VACUUM VESSEL / COUPLER INTERFACE

Coupler compensation interface with the vacuum vessel

Assembly procedure

- **Vacuum vessel lift of**



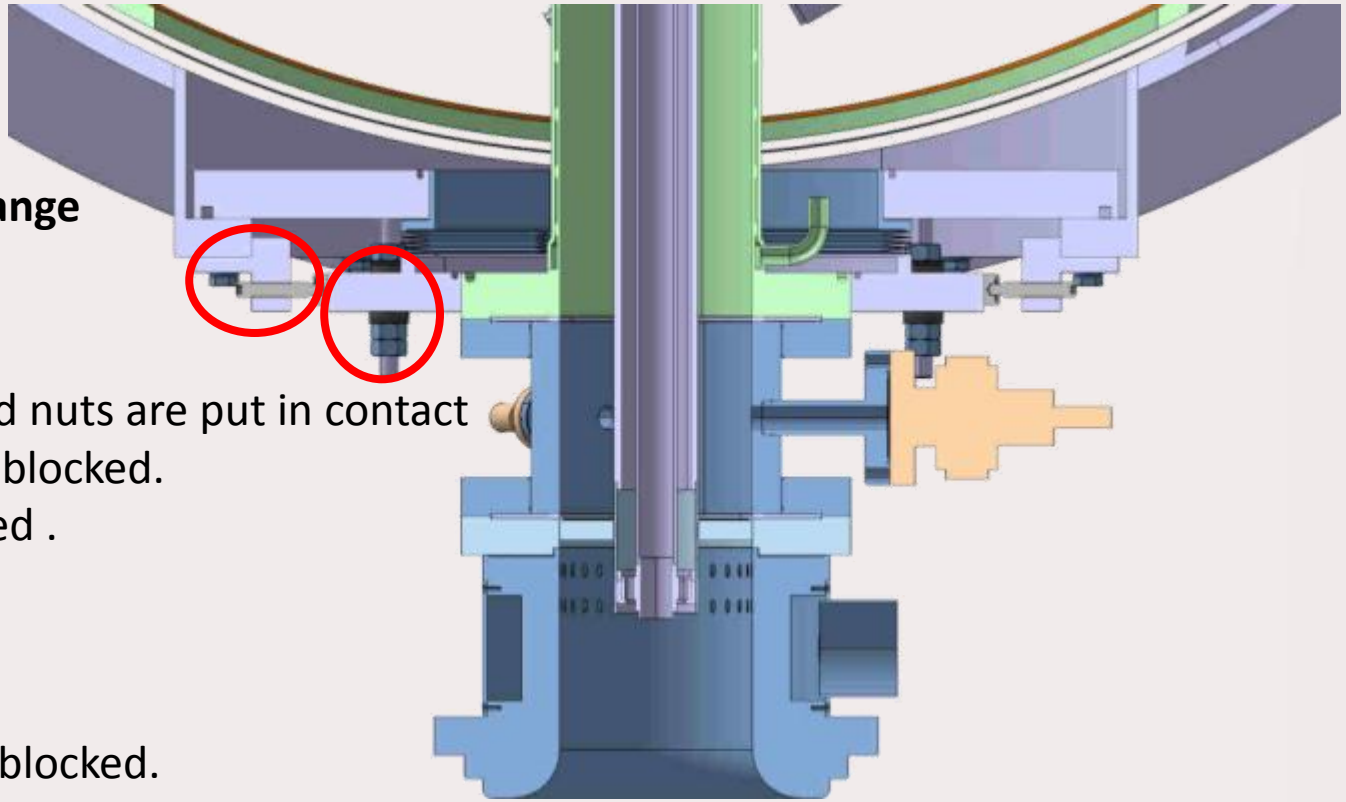
- **Contact of the 4 coupler sealing flanges to the 4 bearings of the vacuum vessel**
- **And fixing**

⇒ defaults located at the level of the 4 bearing plans are compensated by the flexibility of the bellows.

Coupler compensation interface with the vacuum vessel

Assembly procedure

Fixation of the coupler flange



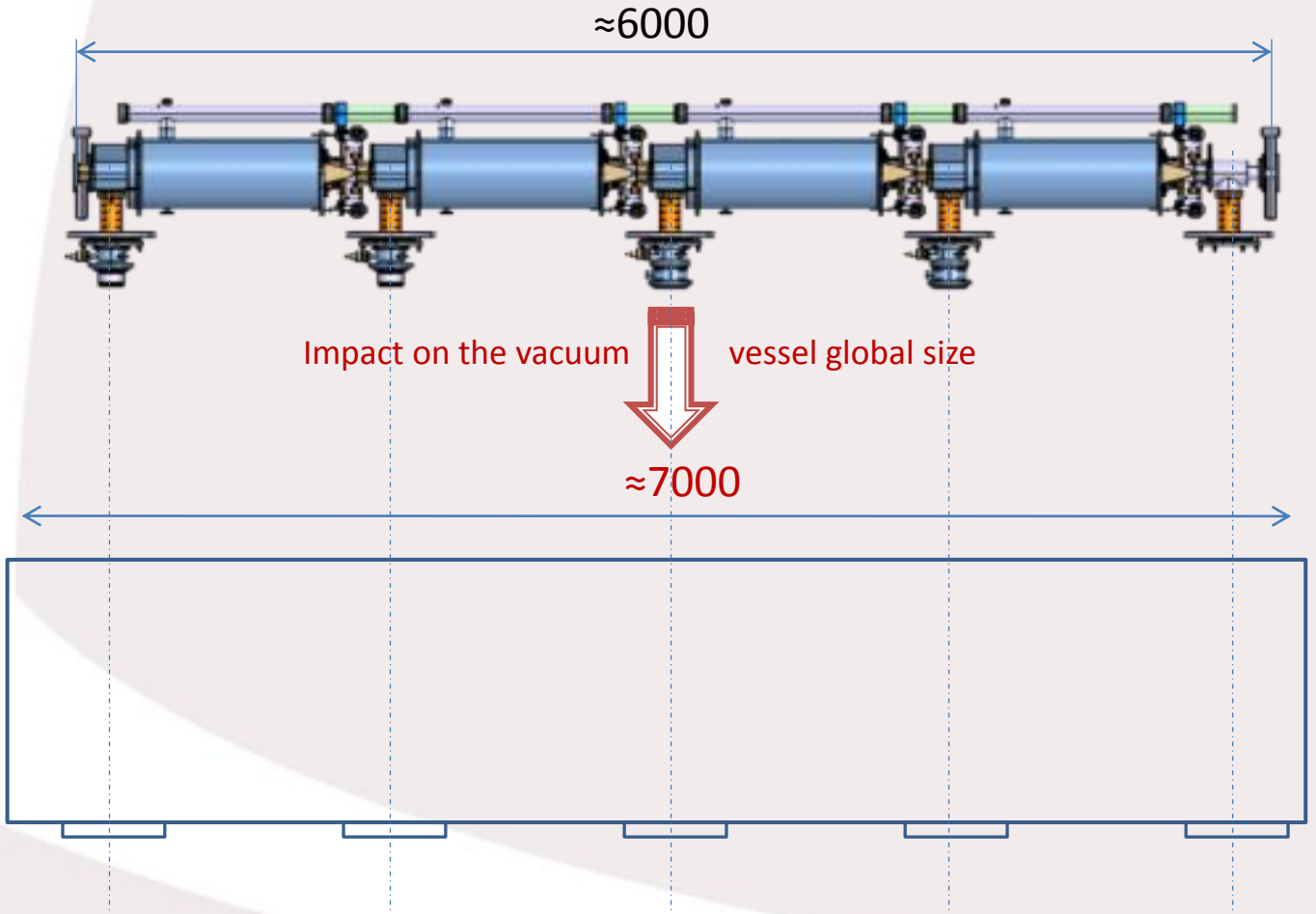
Lower curved washers and nuts are put in contact to the coupler flange and blocked.
Upper nuts can be clamped .

X,Y adjustable stops are blocked.

→ **No motion is allowed between the coupler flange and the vacuum vessel bearing (translation nor rotation).**

Constraints

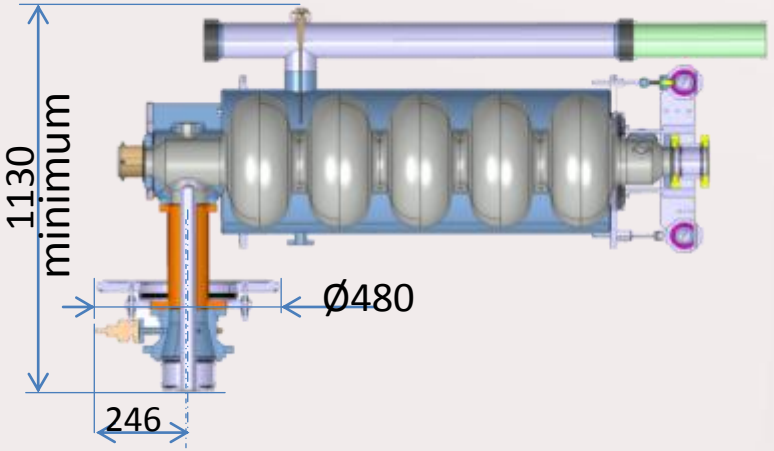
- **Constraints due to the assembly method of the string of cavities**
  - ➢ Pre-Alignment in the clean room required (interconnection bellows)
  - ➢ Cavities cleaned and filled with nitrogen (1020mbar) → 2 x valves minimum



VACUUM VESSEL DESIGN

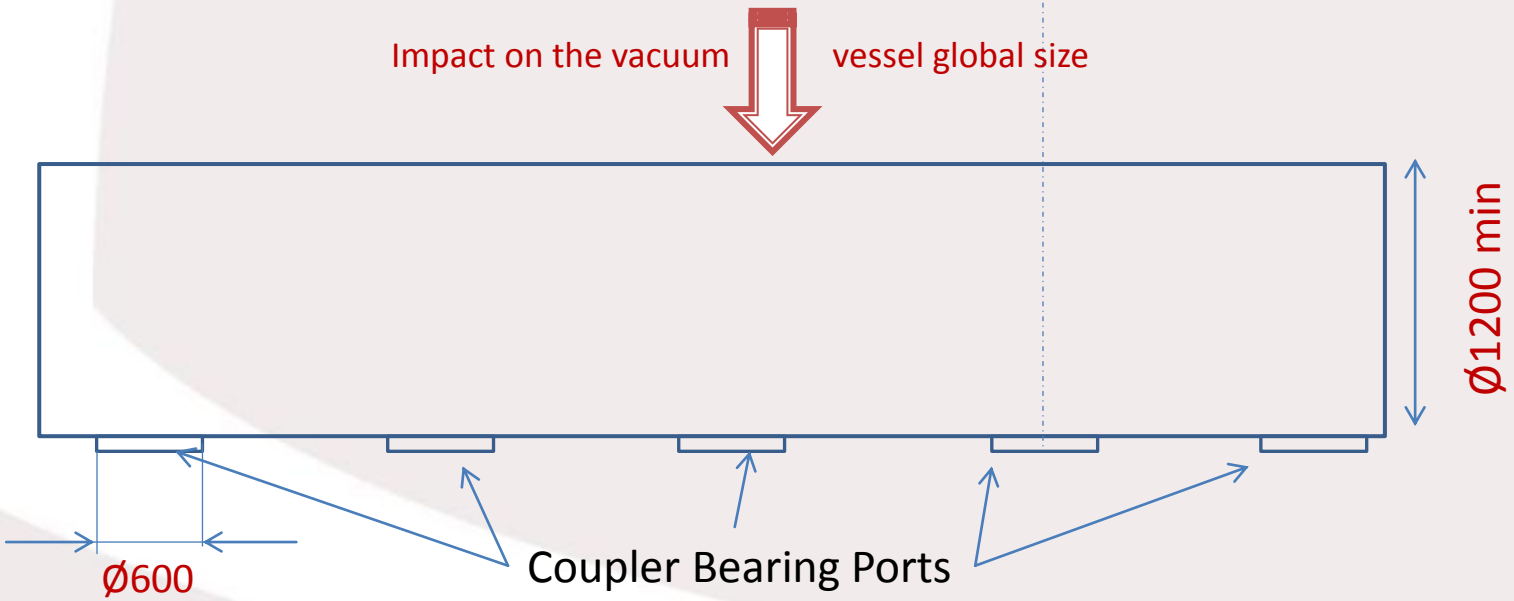
Constraints

- **Constraints due to the supporting System:**
  - Cavities supported and fixed by the lower flange of the double-wall tube of the coupler
  - Size of the power coupler
  - Size of the vacuum gauje



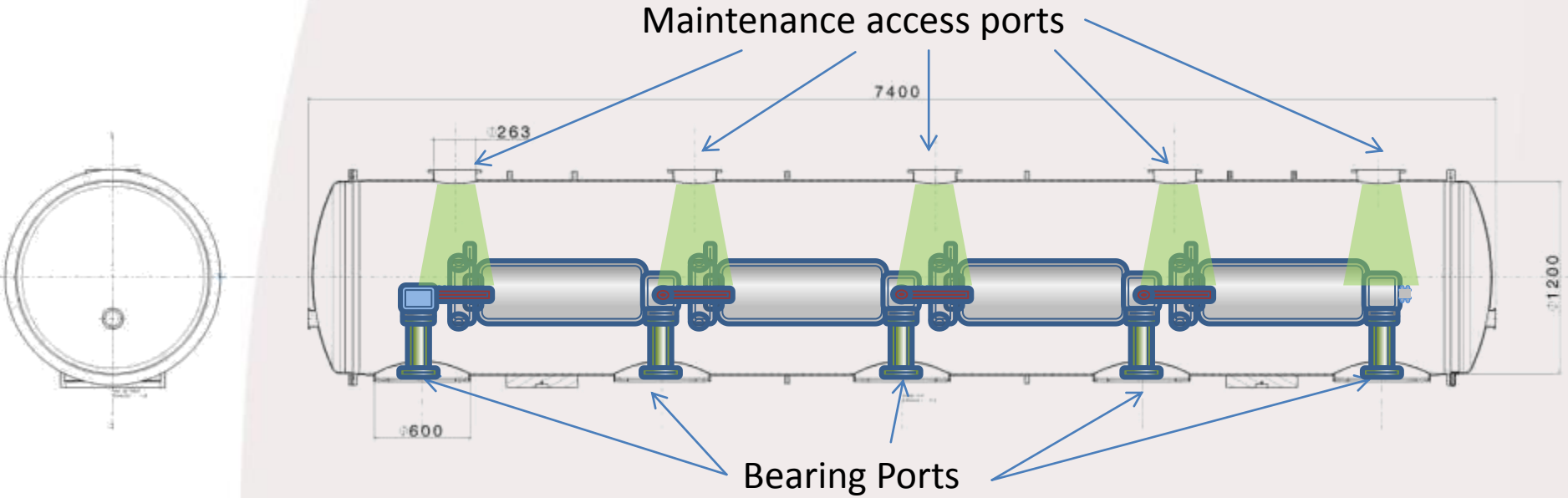
Outer part of the coupler disassembled

Impact on the vacuum vessel global size

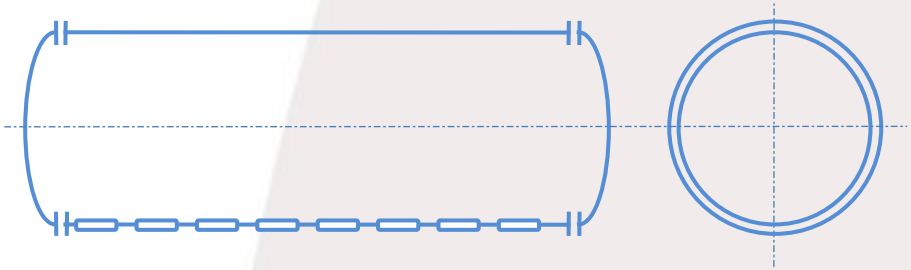


Requirements

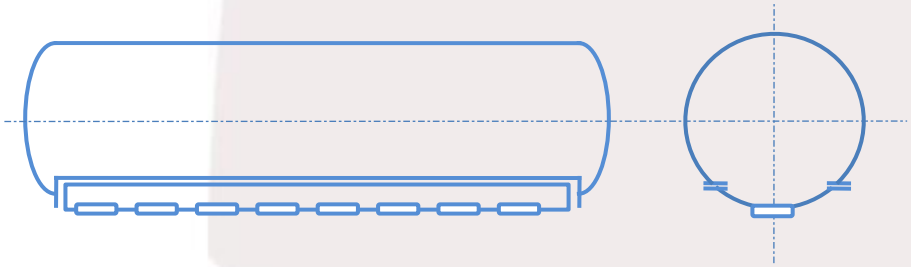
Maintenance aspects : Access to the tuner, the HOM, without decryostating



Different concepts



Cylindrical vacuum vessel (LHC type)



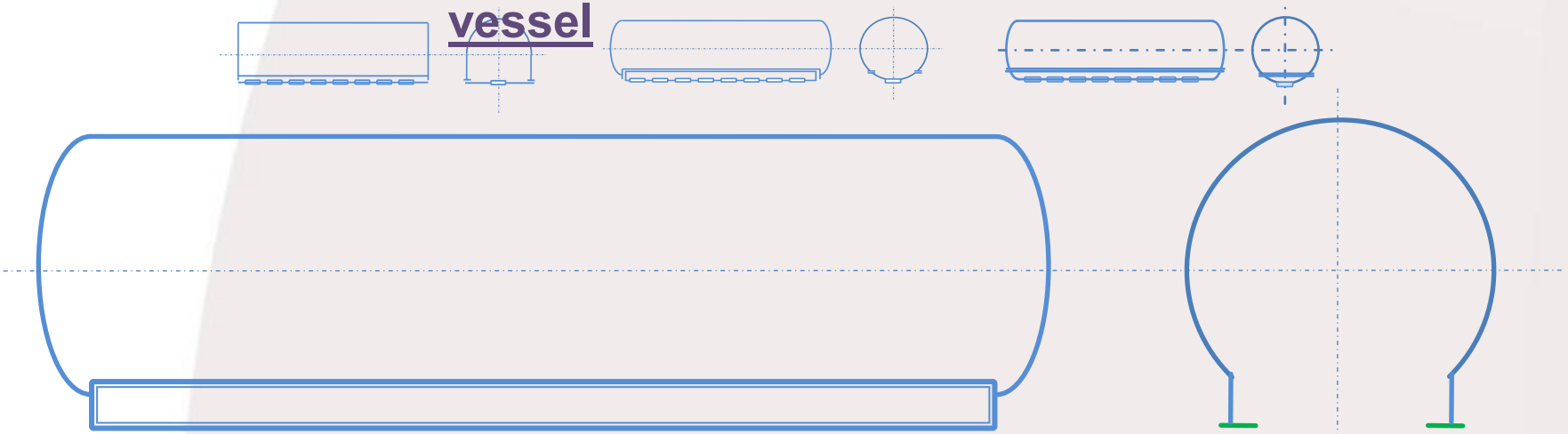
Vacuum vessel with longitudinal aperture

- Bottom cover
- Top cover

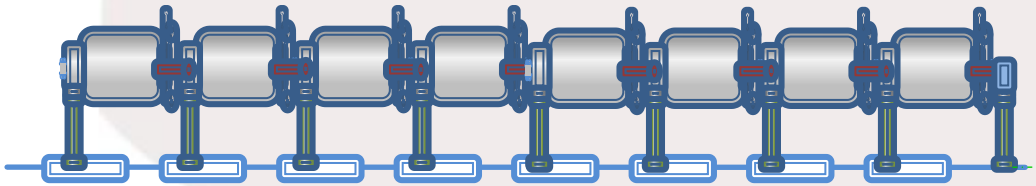
VACUUM VESSEL CONCEPTS

Different concepts

Removable bottom cover vacuum vessel



Sealing interface



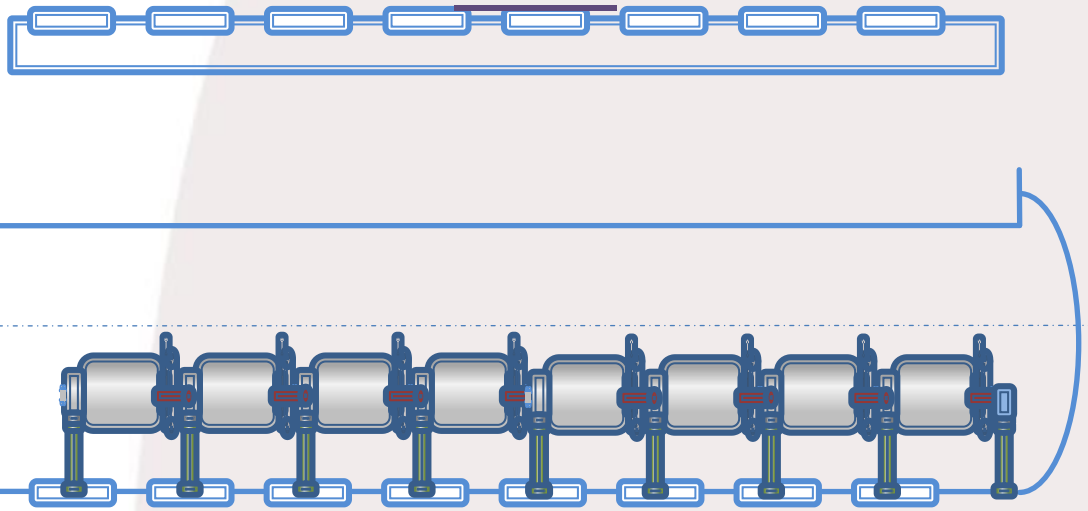
Reference plane
(→ Great stiffness required)

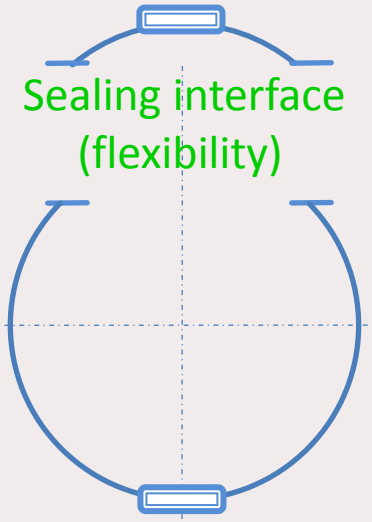
Those two functionalities are here difficult to achieve
(tight tolerances required during construction)

VACUUM VESSEL CONCEPTS

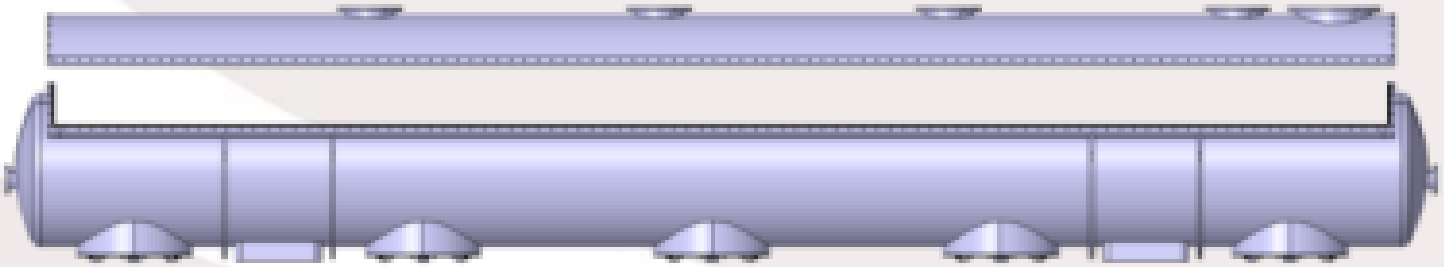
Different concepts

Removable top cover vacuum vessel



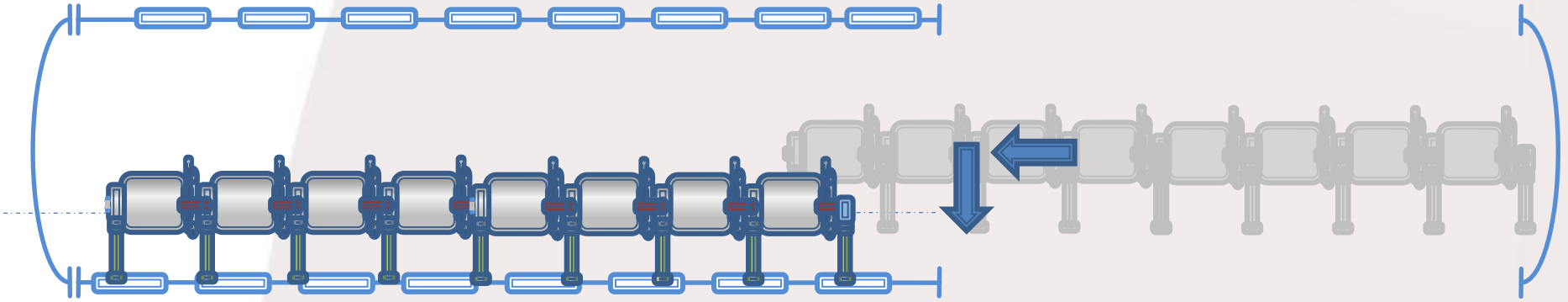


Reference plane
(→ Large stiffness required)

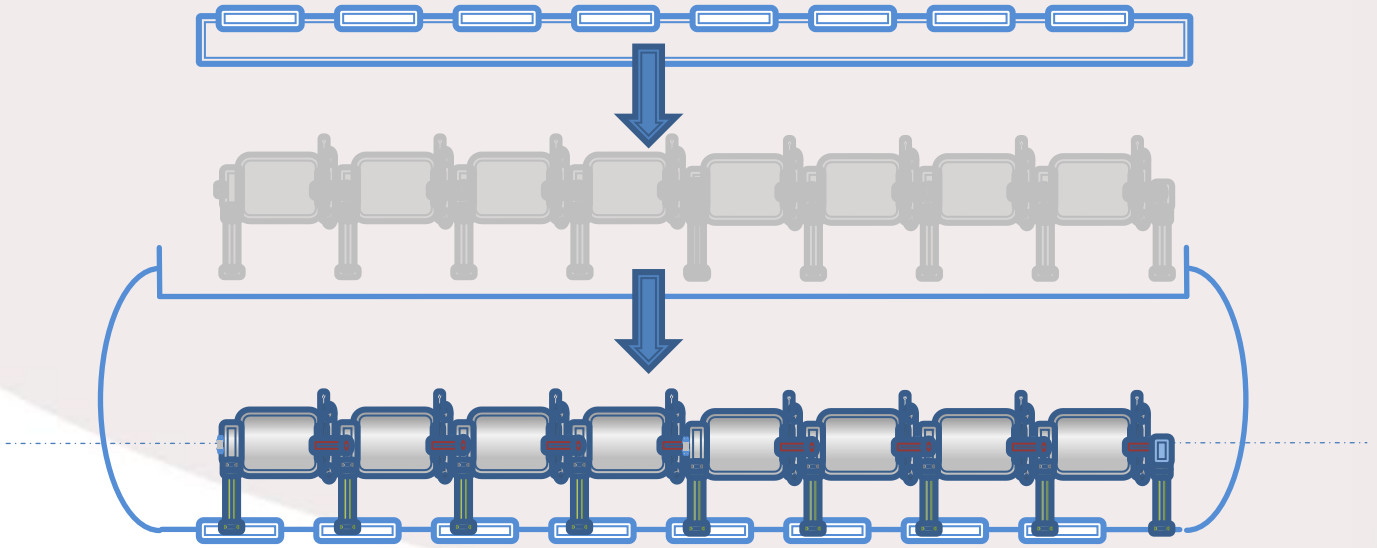


CONCEPTUAL CRYOSTATING TOOLING

- **Horizontal cryostating**

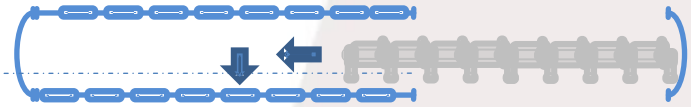


- **Vertical Cryostating**

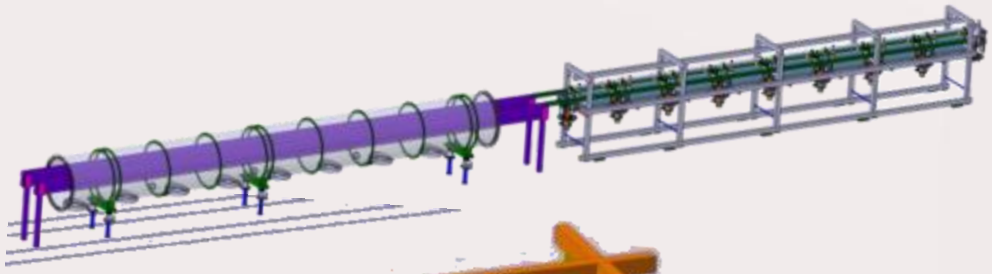


CONCEPTUAL CRYOSTATING TOOLING

➢ Horizontal cryostating Tooling Studies

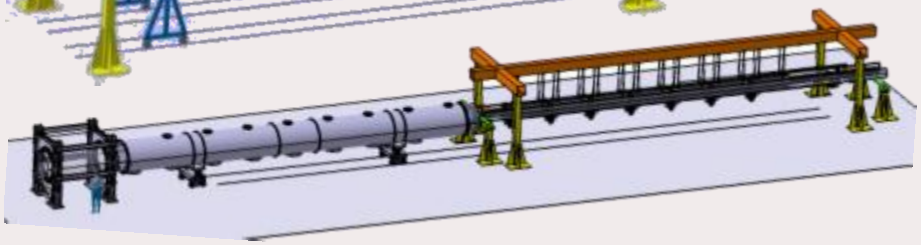


Mobile Frame tooling

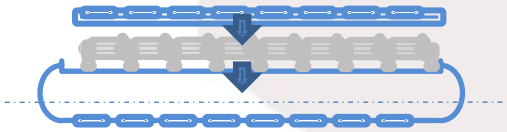


Mobile Trolley Tooling

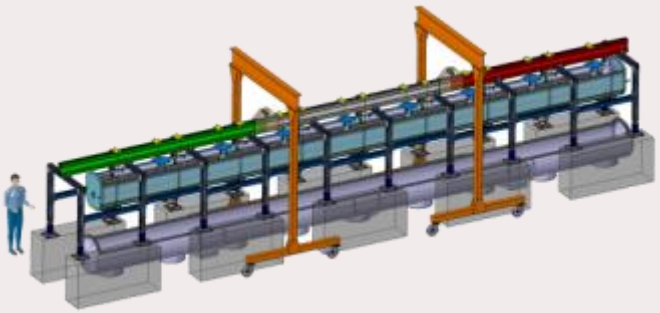
Cantilever Tooling



➢ Vertical Cryostating Tooling Study

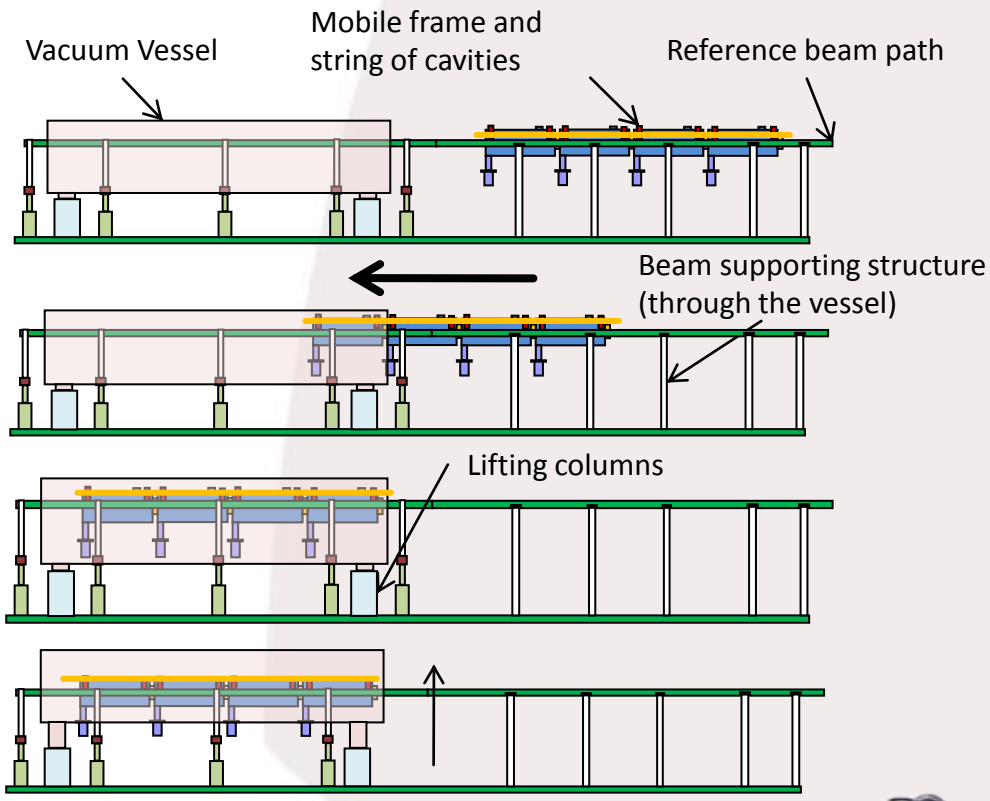


Vertical Cryostating Tooling



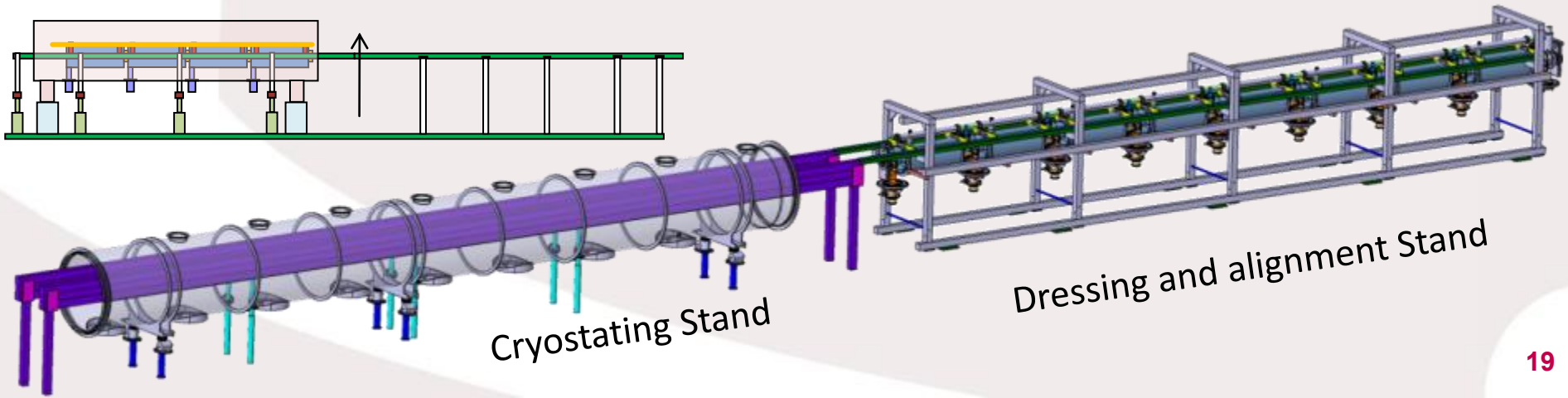
CONCEPTUAL CRYOSTATING TOOLING

Mobile frame tooling



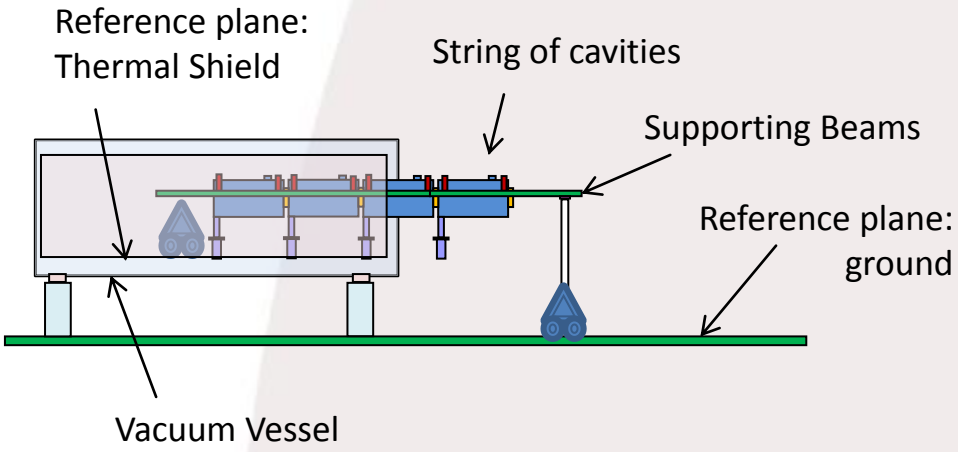
- Translation of the string
+
- Beam straightness
+
- Beams twist

- Probable lost of alignment during translation



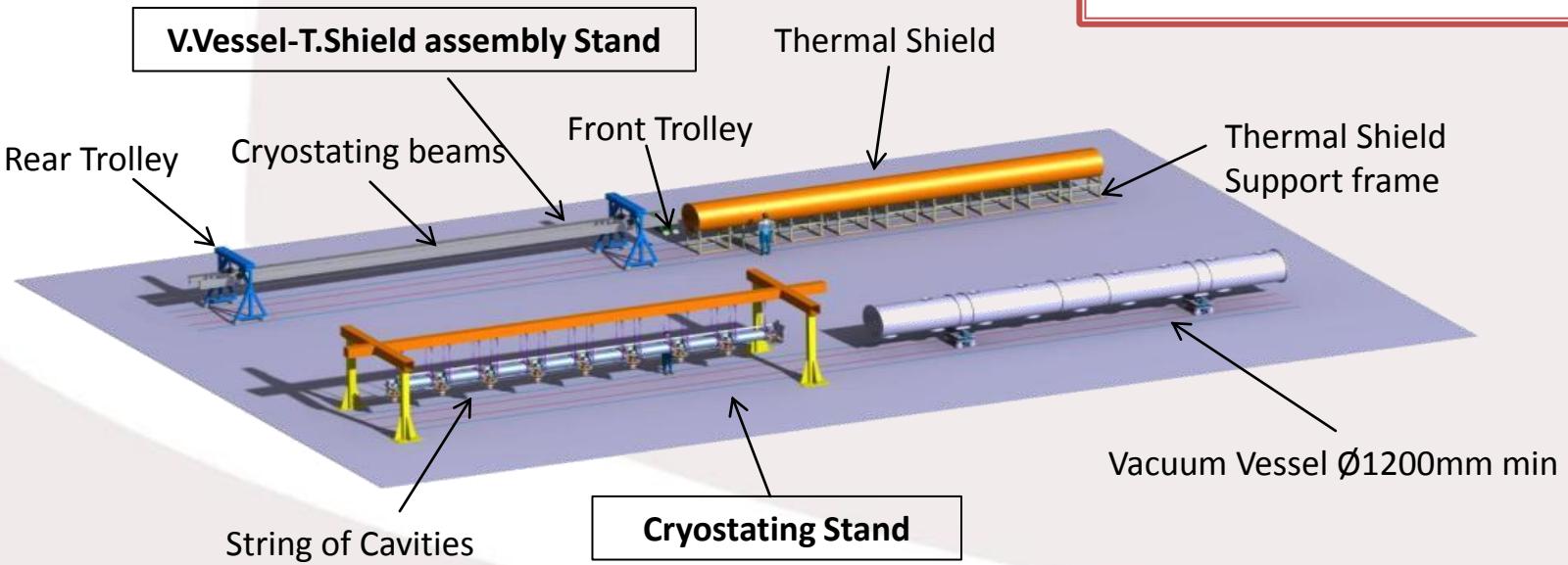
CONCEPTUAL CRYOSTATING TOOLING

Mobile trolley tooling



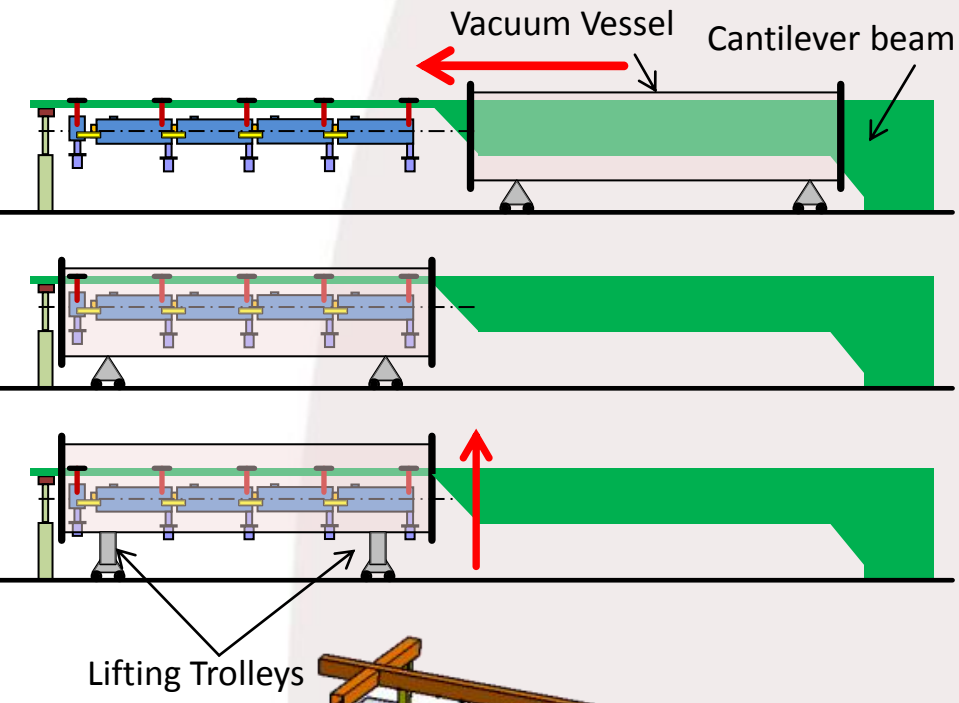
- Translation of the string
+
- Rolling way into the thermal shield
+
- Rolling way on the ground

- Probable loss of alignment during translation



CONCEPTUAL CRYOSTATING TOOLING

Cantilever tooling



➢ Translation of the Vacuum Vessel

No Loss of alignment

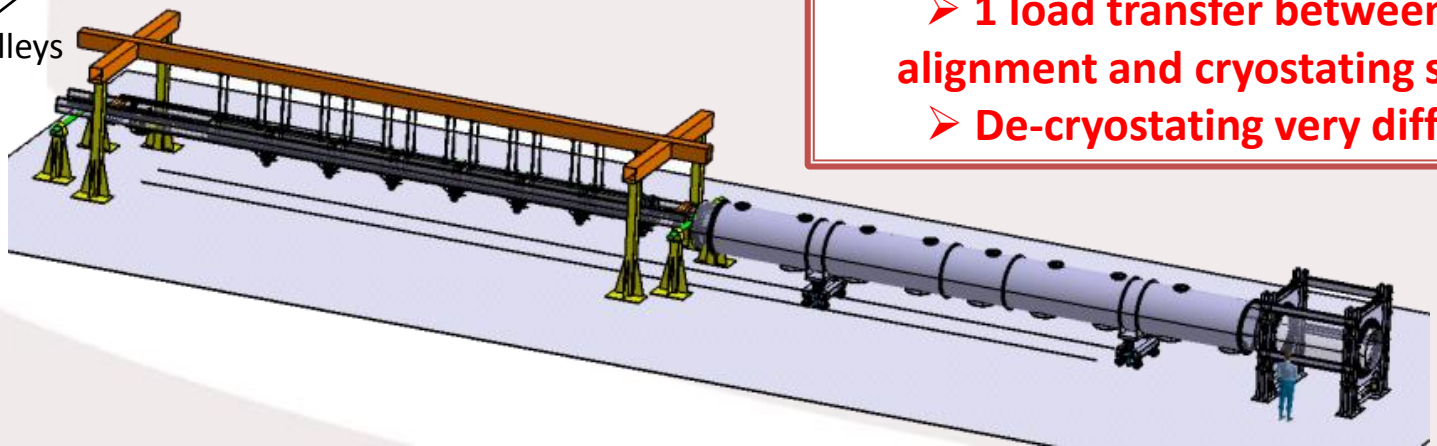
➢ Beam deflection ~ 50mm

+

➢ Beam size → no space arround cavities

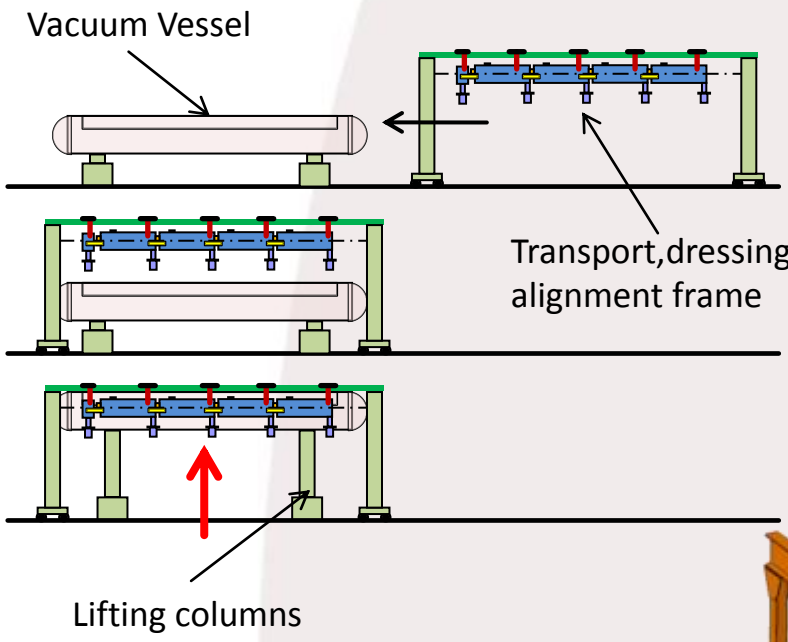
➢ 1 load transfer between the alignment and cryostating stands

➢ De-cryostating very difficult



CONCEPTUAL CRYOSTATING TOOLING

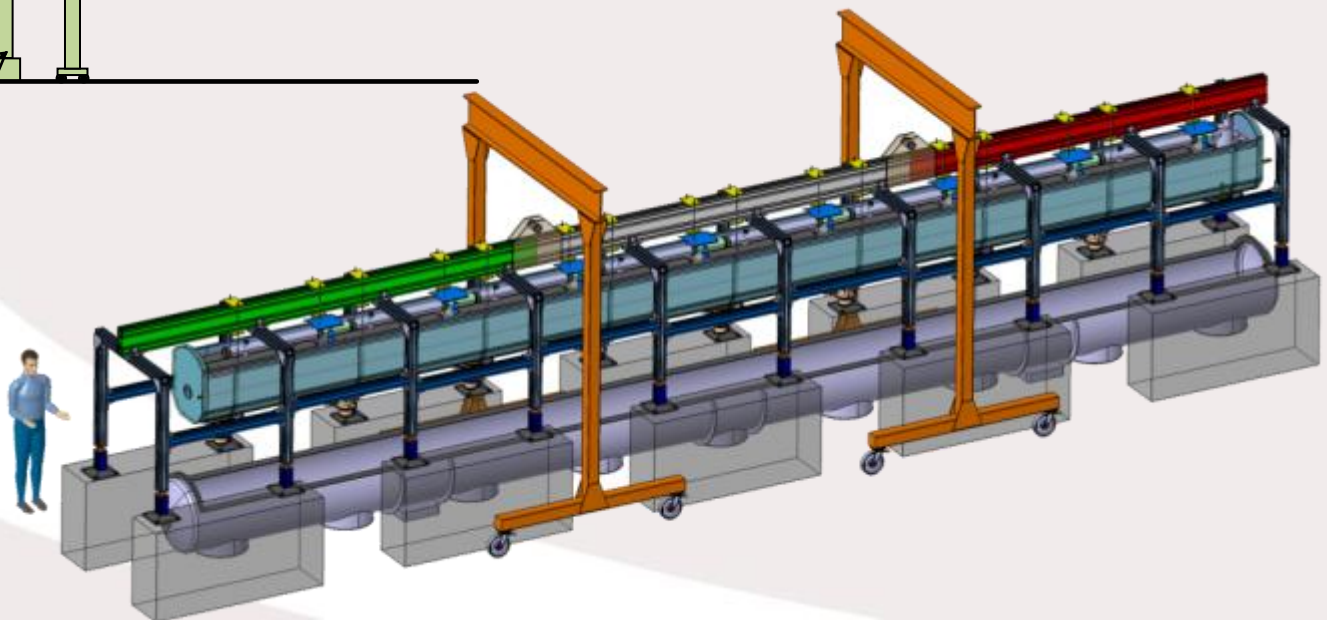
Vertical cryostating tooling



➢ Vertical Translation of the Vacuum Vessel

No Loss of alignment

➢ Top Opened Vacuum Vessel



CONCEPTUAL CRYOSTATING TOOLING

Comparison of cryostating toolings

<table>
<tr><th>Impact on :</th><th>Mobile frame tooling</th><th>Mobile trolley tooling</th><th>Cantilever tooling</th><th>Vertical cryostating tooling</th></tr>
<tr><td rowspan="2">Vacuum vessel design</td><td colspan="3">Cylindrical Vessel Ø1200mm min</td><td rowspan="2">Cylindrical Vessel Ø800
with top aperture
Top cover Ø900</td></tr>
<tr><td>6 DN160 ports added for beams supporting system</td><td colspan="2">-</td></tr>
<tr><td>Cryomodule</td><td>beams to cavity supports permanently installed</td><td>-</td><td>beams to cavity supports permanently installed</td><td>-</td></tr>
<tr><td>Thermal shield</td><td colspan="3">-Cylindrical Ø1040mm
-Insertion tooling needed
-5 x Ø600mm aperture for coupler flange insertion
⇒ 5 x Ø600mm closing cover with passive cooling (thermal contact only)</td><td>2 parts with active cooling</td></tr>
<tr><td rowspan="2">Alignment</td><td colspan="2">Probable lost of alignment during translation</td><td>Restricted access to inter-cavity connections</td><td rowspan="2">working Height of 2m</td></tr>
<tr><td colspan="3">- Restricted visibility of the alignment targets
- Restricted visibility for alignment verification after cryostating</td></tr>
<tr><td>Load Transfert</td><td colspan="3">2</td><td>1</td></tr>
<tr><td>Size</td><td colspan="3">≈35m</td><td>≈15m</td></tr>
<tr><td rowspan="3">Tooling complexity</td><td colspan="3">Beams removal</td><td rowspan="3">Long Stroke jacks needed for the VV lifting</td></tr>
<tr><td colspan="2">Beams straightness (reference)</td><td rowspan="2">-Specific tooling needed to offset the beams deflection
- Cantilever lifting tooling
- De-cryostating very difficult due to the beams deflection</td></tr>
<tr><td>Beams twist</td><td>- Beams deflection
- Rolling way onto the thermal shield
- Rolling way on the ground</td></tr>
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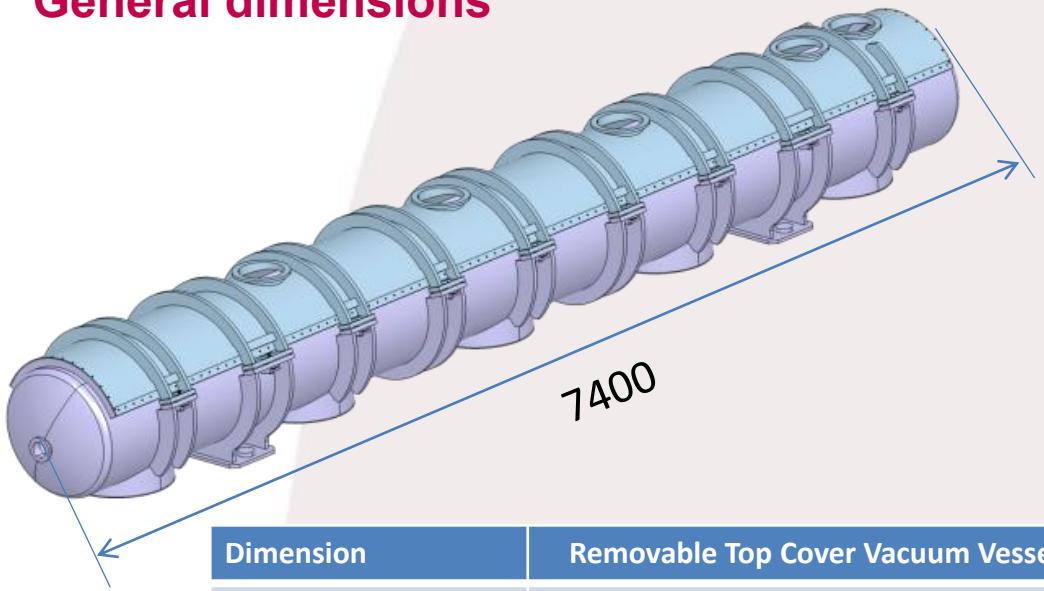
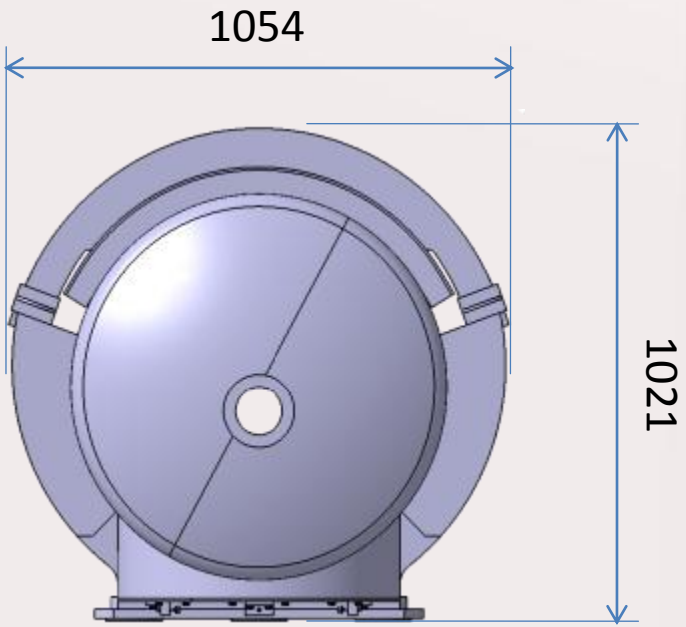
REMOVABLE TOP COVER VACUUM VESSEL

General dimensions

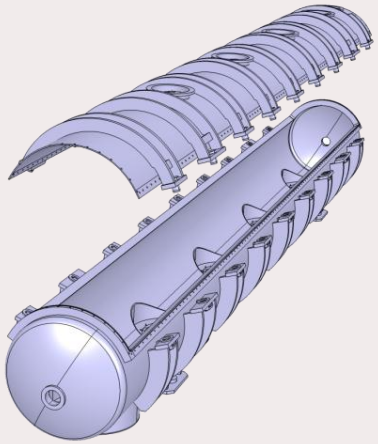




Dimension	Removable Top Cover Vacuum Vessel
Length (mm)	7400
Height (mm)	950
Thikness (mm)	10 (tube) and 6 (Top Cover)
Material	Steel and Stainless steel for flanges
Weight (ton)	2.4
Diametre (mm)	800/900
Number of openings	2 + 5 + 5 (2 beam flanges+ 5 coupler bearings ports + 5 access ports)
Number of Supports	2

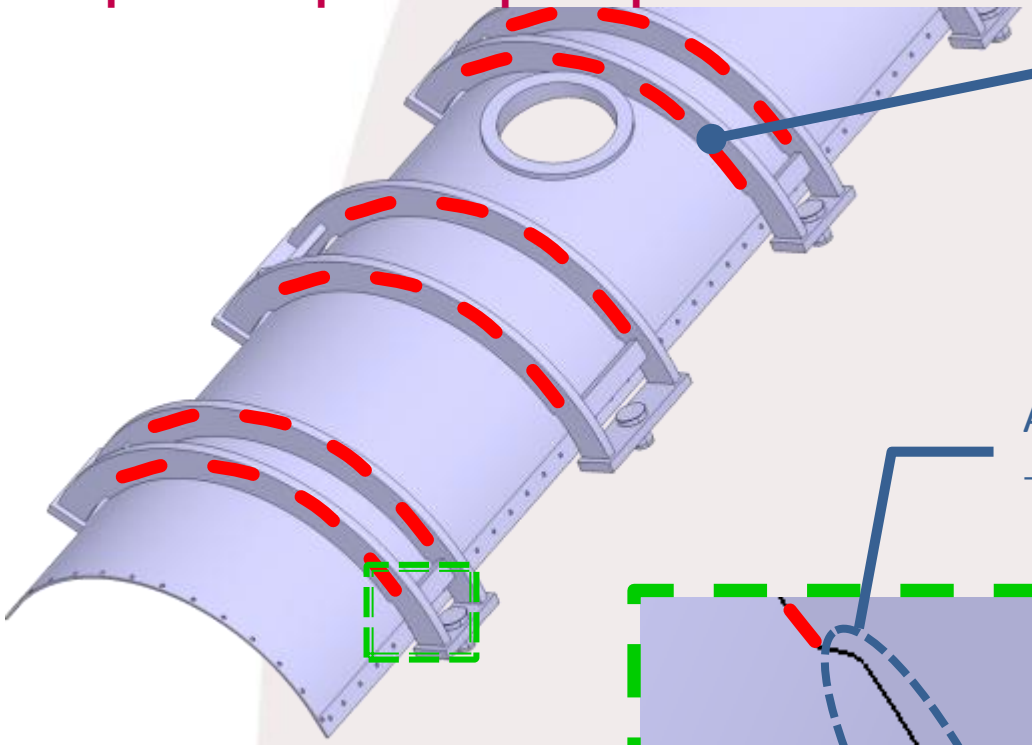
Smaller diameter

⇒ Easier maintenance access



REMOVABLE TOP COVER VACUUM VESSEL

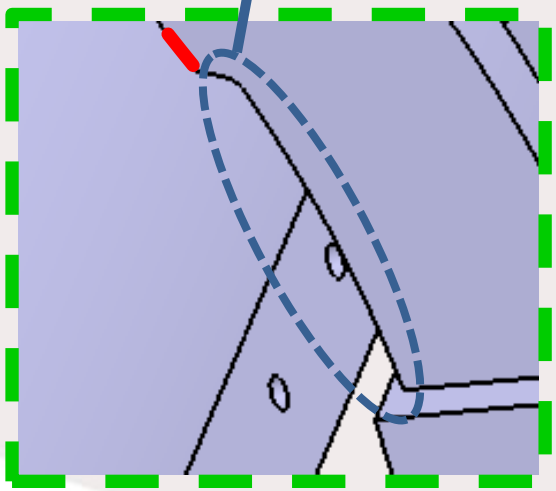
Proposed Top cover principle

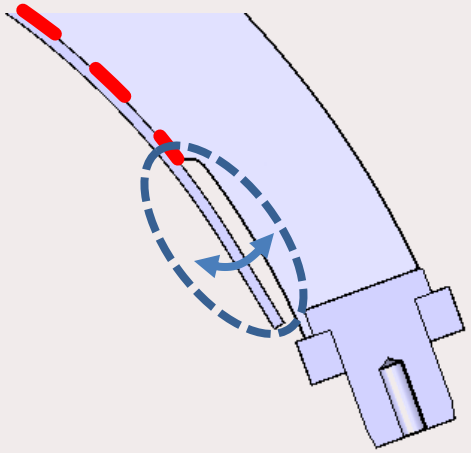


Pairs of half rings partially welded → stiffness

Weld seam

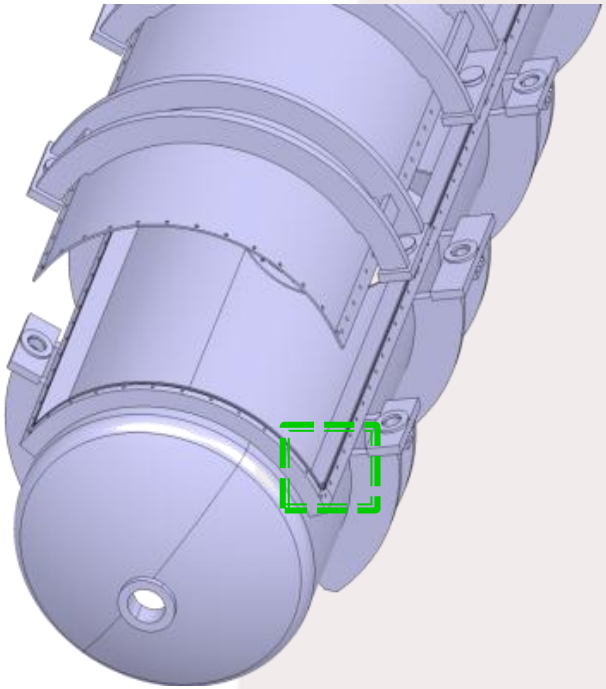
Area not welded
→ Flexibility of the top cover sealing zone

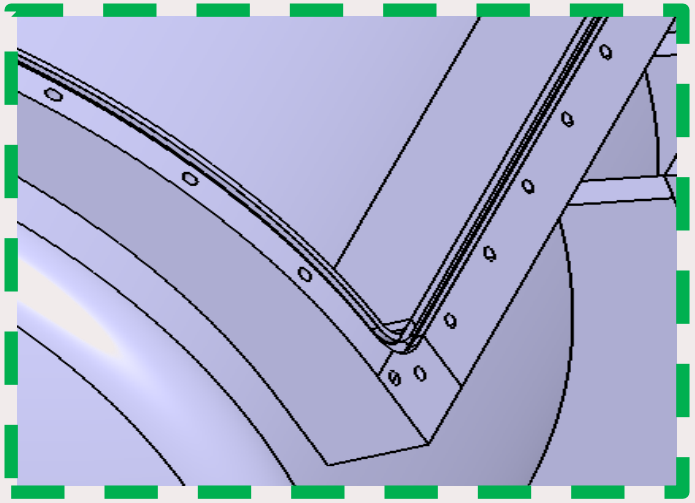


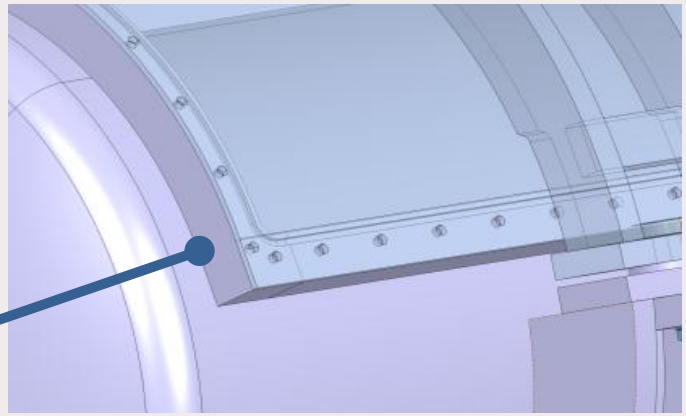


REMOVABLE TOP COVER VACUUM VESSEL

Top cover sealing







Sealing flange

Sealing (prototype):

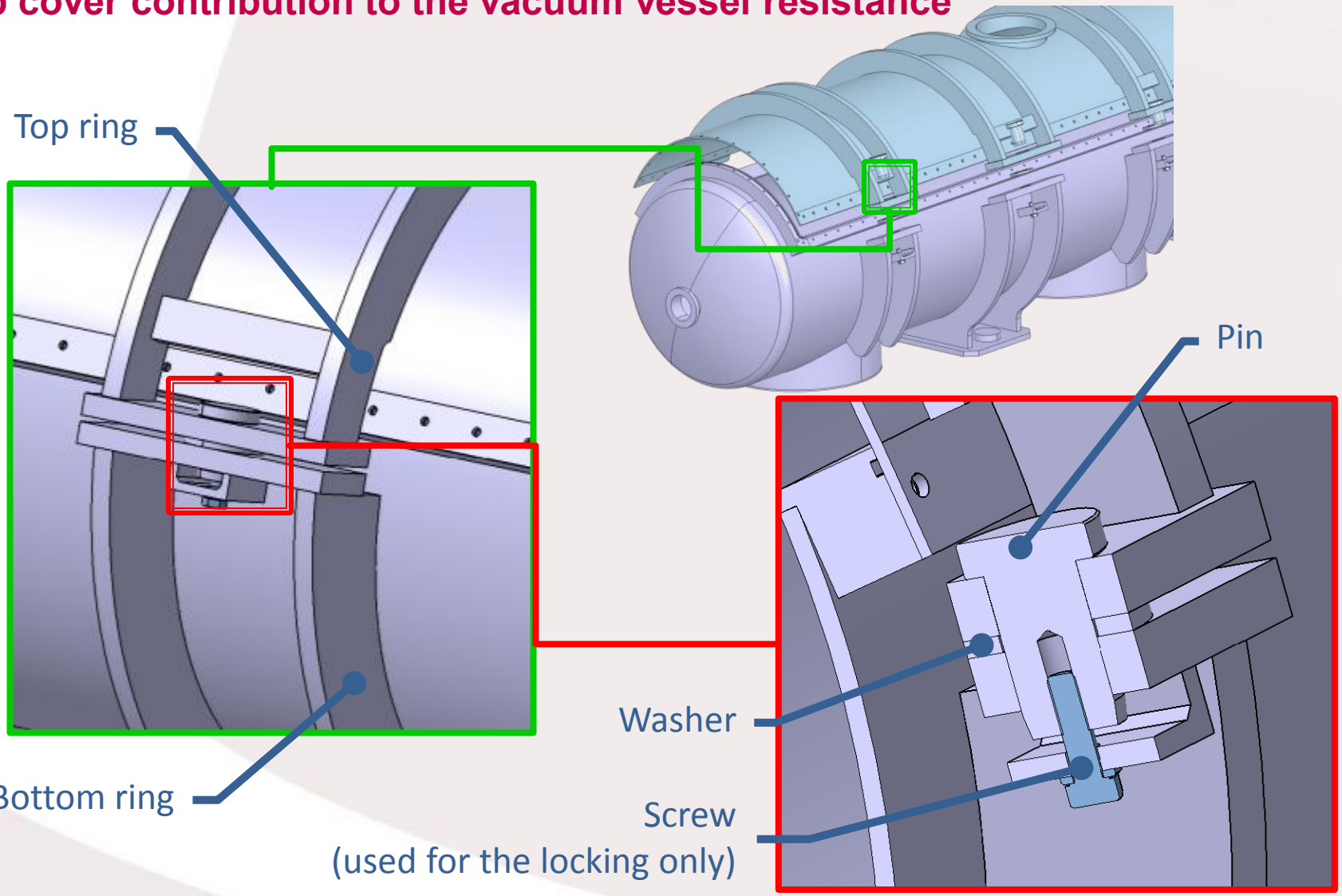
• Polymer seal placed in a groove made in the flange of the vessel main part.

• Screws will provide sufficient deflection of the cover for the seal compression.
(they are not used to contribute to the vacuum vessel strength)

This solution may be "easily" replaced by a sealing weld, making welding lips on the vessel flange and on the top cover

REMOVABLE TOP COVER VACUUM VESSEL

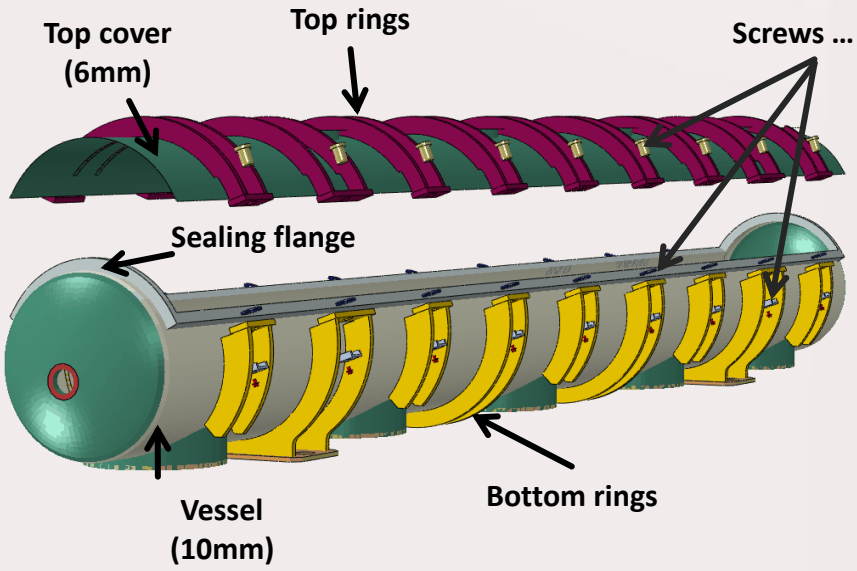
Top cover contribution to the vacuum vessel resistance



REMOVABLE TOP COVER VACUUM VESSEL

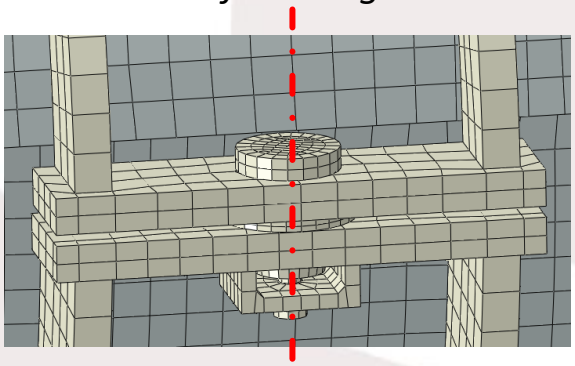
Computations of different loadings

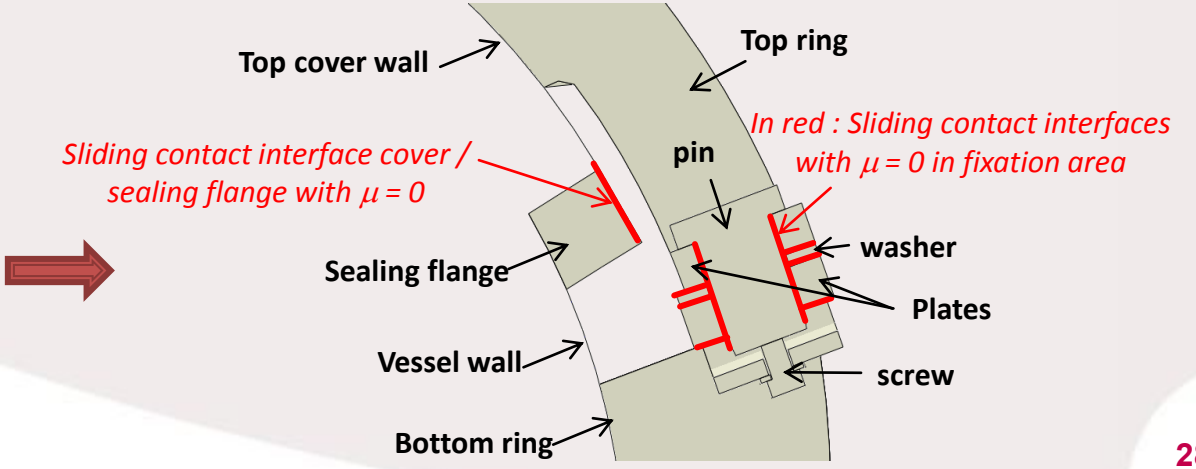
WEIGHT OF THE VACUUM VESSEL	2860 Kg
Decomposition by components :	
Vessel (with fixation flanges of coupler)	1160 Kg
Sealing flange	300 Kg
Top cover	350 Kg
Top rings (9 double rings)	395 Kg
Bottom rings (9 double rings) with two feet	610 Kg
18 fixations (screws, pins, washers)	46 Kg



Modelisation of the interfaces :

Fixation of the rings :

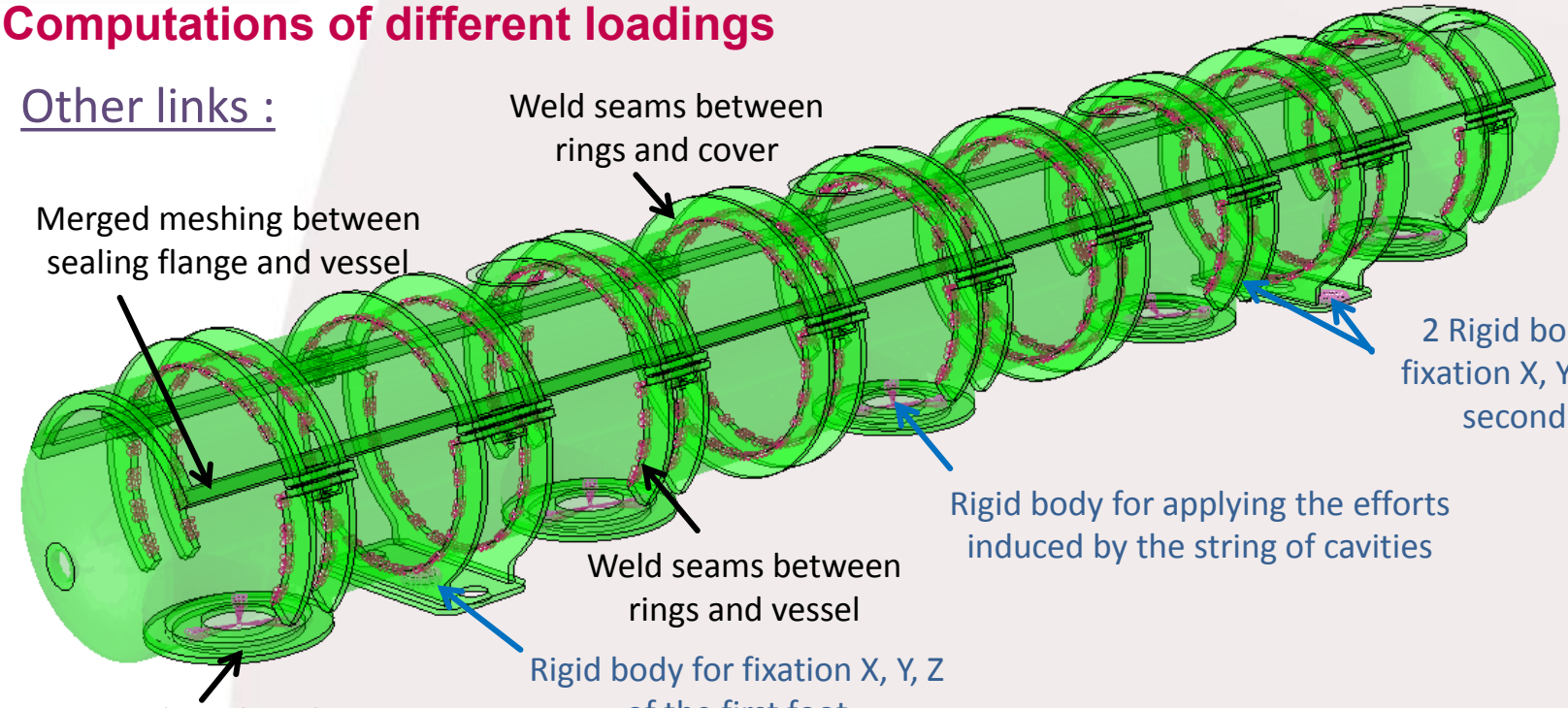




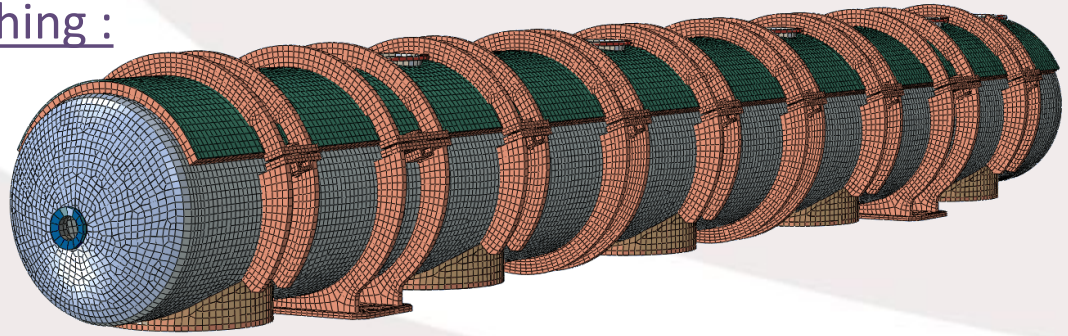
REMOVABLE TOP COVER VACUUM VESSEL

Computations of different loadings

Other links :



Meshing :



Simulated loadings :

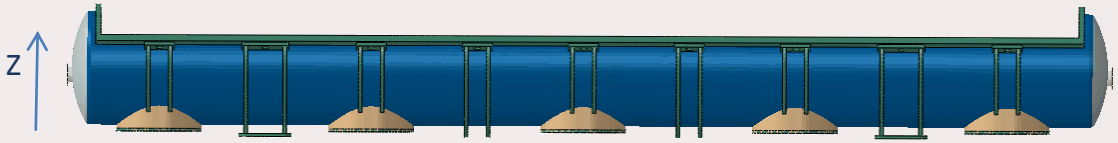
- Gravity
- External pressure
- Handling
- Buckling

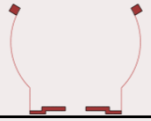
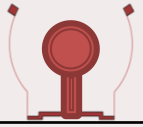
REMOVABLE TOP COVER VACUUM VESSEL

Loading: weight (string of cavities + vacuum vessel)

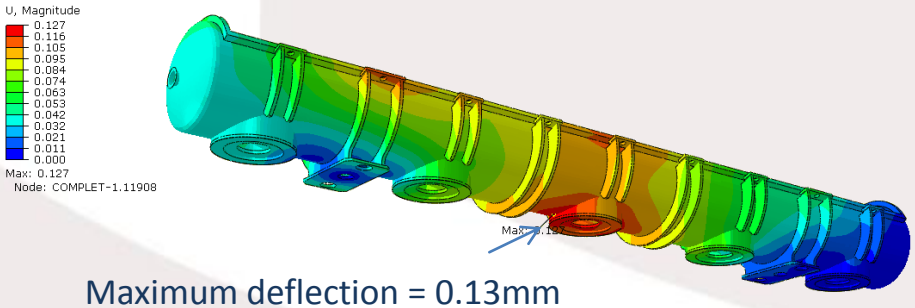
Open vessel

Displacement in Z axis of each bearing (mm) :

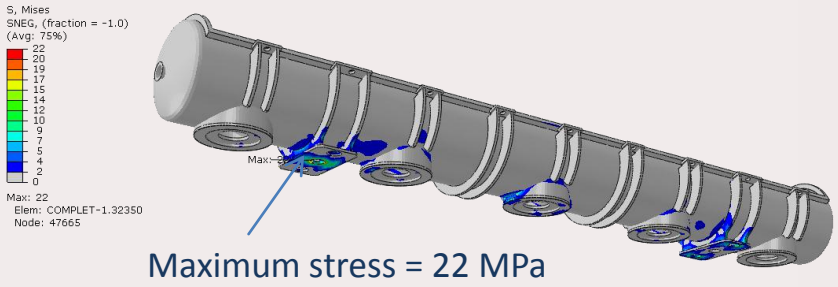


Configuration	Bearing 1	Bearing 2	Bearing 3	Bearing 4	Bearing 5
Open vessel without cavities 	-0.03	-0.04	-0.07	-0.03	-0.006
Open vessel with cavities 	**-0.04**	**-0.06**	**<u>-0.12</u>**	**-0.06**	**-0.008**

Results in configuration Open vessel with cavities :



Maximum deflection = 0.13mm



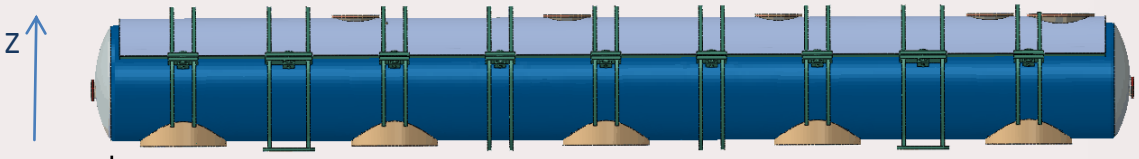
Maximum stress = 22 MPa

REMOVABLE TOP COVER VACUUM VESSEL

Loading: weight (string of cavities + vacuum vessel)

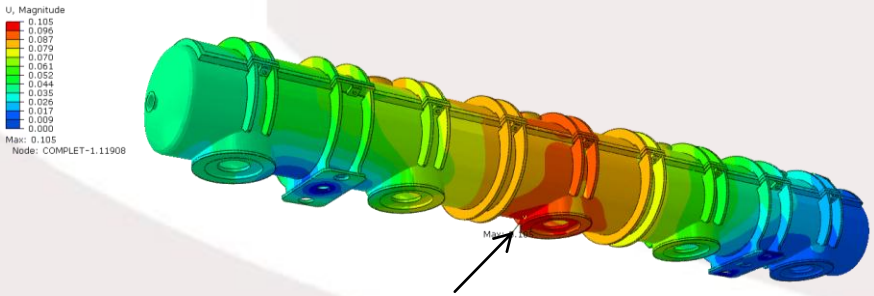
Closed vessel

Displacement in Z axis of each bearing (mm) :

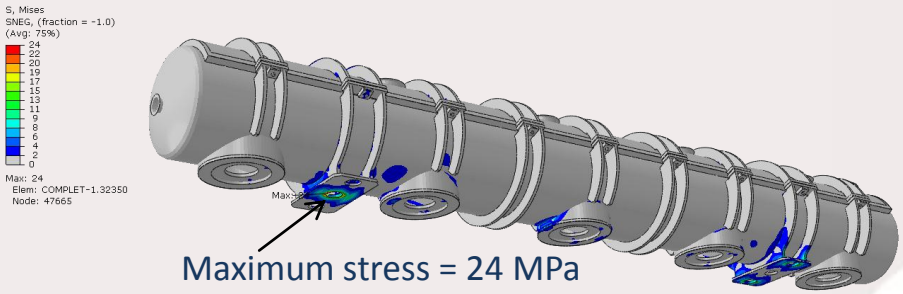


Configuration	Bearing 1	Bearing 2	Bearing 3	Bearing 4	Bearing 5
Open vessel with cavities 	-0.036	-0.063	-0.117	-0.060	-0.008
Closed vessel with cavities 	**-0.036**	**-0.059**	**-0.098**	**-0.054**	**-0.016**

Results in configuration Closed vessel with cavities :



Maximum deflection = 0.11mm

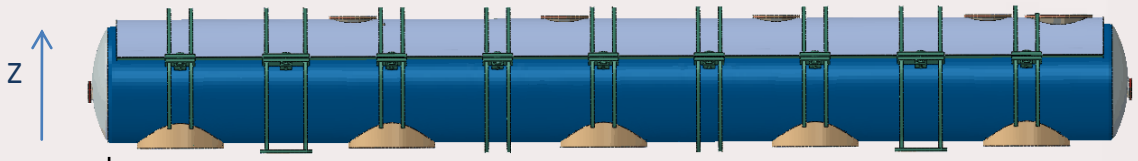


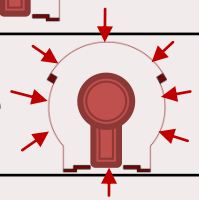
Maximum stress = 24 MPa

REMOVABLE TOP COVER VACUUM VESSEL

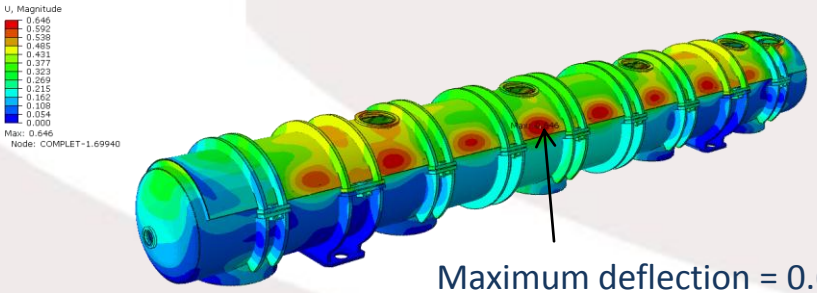
Loading: external pressure of 1 bar (vacuum simulation)

Displacement in Z axis of each bearing (mm) :

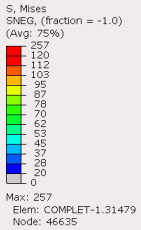


Configuration	Bearing 1	Bearing 2	Bearing 3	Bearing 4	Bearing 5
Gravity 	-0.036	-0.059	-0.098	-0.054	-0.016
Gravity + external pressure 	0.057	-0.076	-0.175	-0.069	0.066
Only external pressure	**0.093**	**-0.017**	**-0.077**	**-0.015**	**0.082**

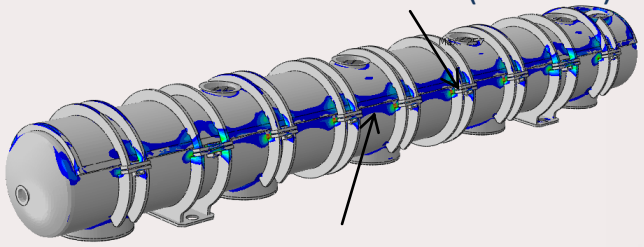
Results in configuration Gravity + external pressure :



Maximum deflection = 0.65mm



Maximum stress = 260 MPa (washers)



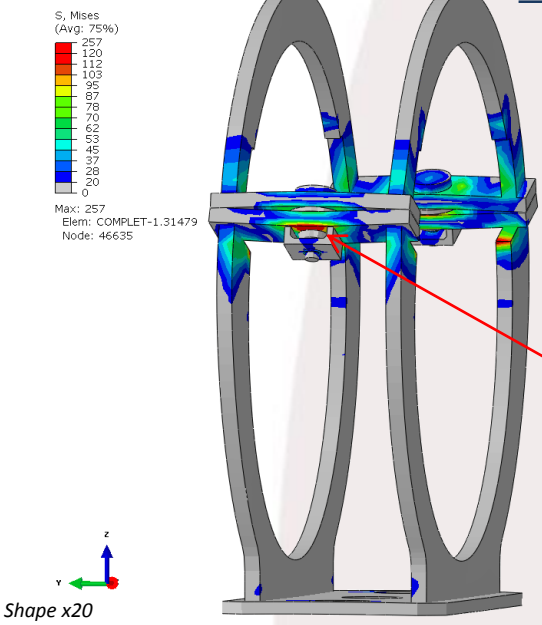
Maximum stress = 120 Mpa (vessel)

REMOVABLE TOP COVER VACUUM VESSEL

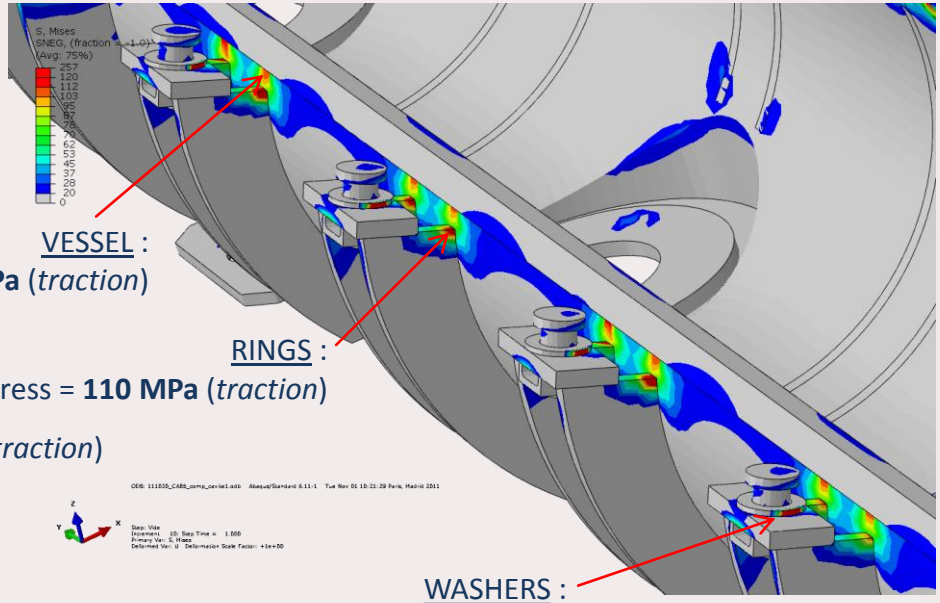
Loading: external pressure of 1 bar (vacuum simulation)

Results in configuration Gravity + external pressure :

Von Mises stresses :



Shape x20



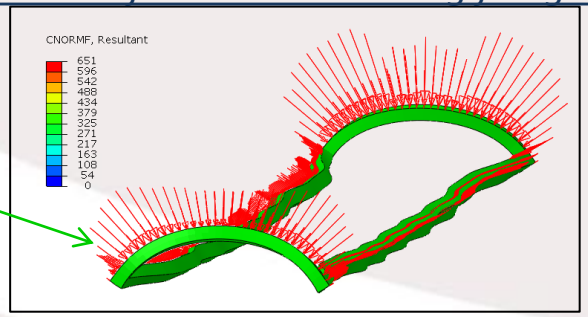
VESSEL :
Max stress = **120 MPa** (*traction*)

RINGS :
Max stress = **110 MPa** (*traction*)

PLATES:
Max stress = **130 MPa** (*traction*)

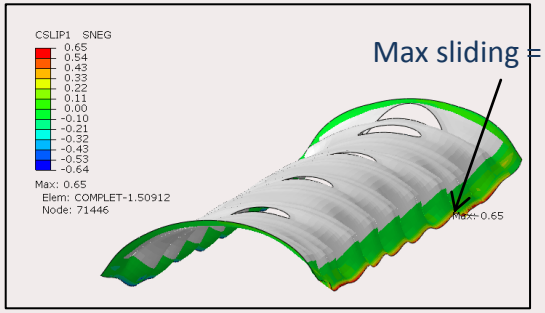
WASHERS :
Max stress = **260 MPa** (*compression*)

Contact force on the sealing flange :



Contact is maintained all around the flange

Sliding of the top cover :

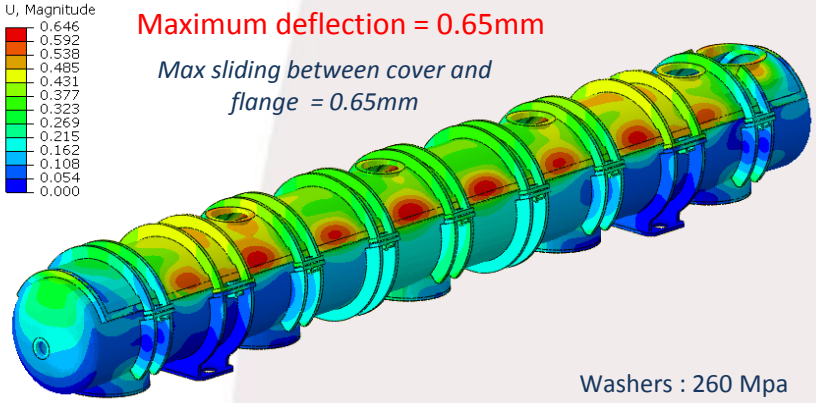


Max sliding = 0.65mm

REMOVABLE TOP COVER VACUUM VESSEL

Why so many rings ?

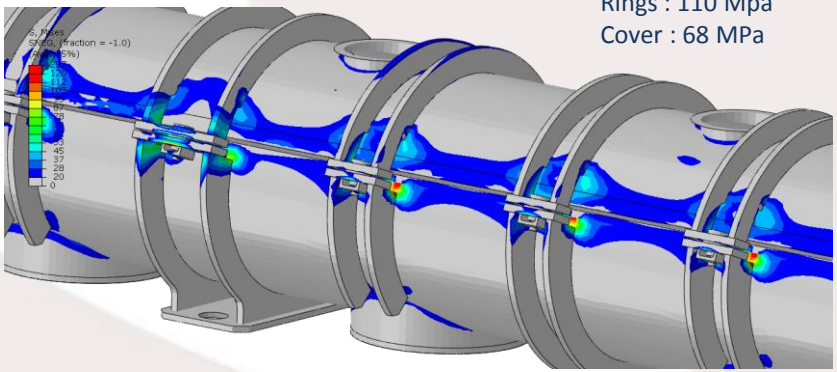
vacuum simulation



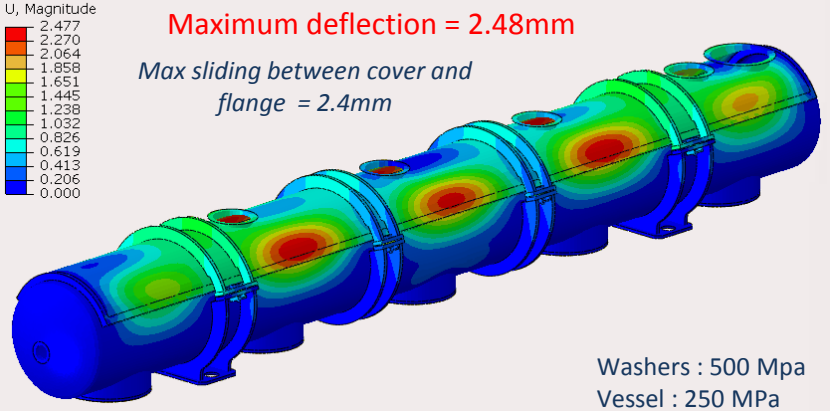
Maximum deflection = 0.65mm

Max sliding between cover and flange = 0.65mm

Maximum stresses :



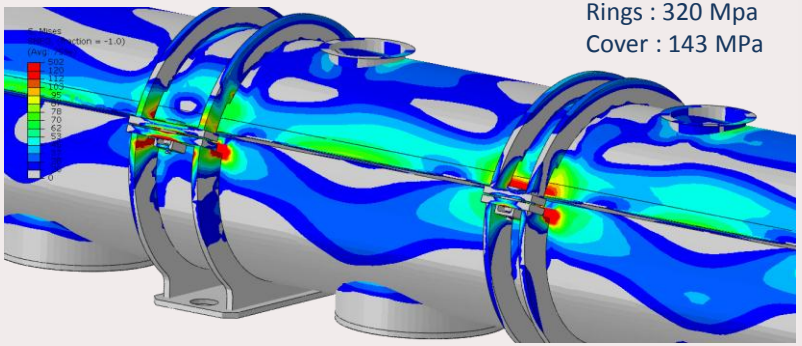
Washers : 260 Mpa
Vessel : 110 MPa
Plates : 130 Mpa
Rings : 110 Mpa
Cover : 68 MPa



Maximum deflection = 2.48mm

Max sliding between cover and flange = 2.4mm

Maximum stresses :

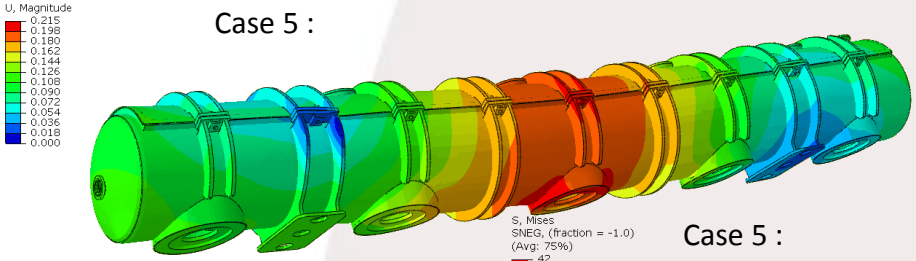


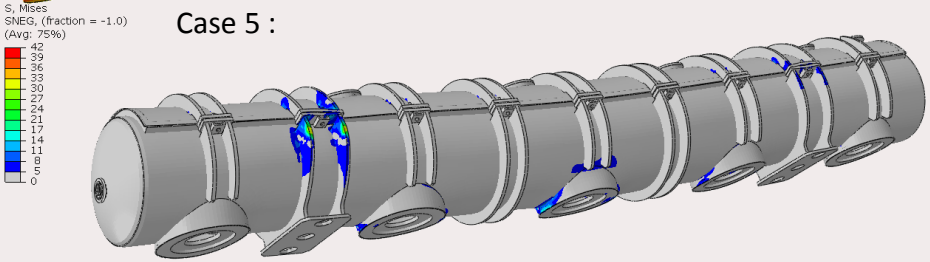
Washers : 500 Mpa
Vessel : 250 MPa
Plates : 350 Mpa
Rings : 320 Mpa
Cover : 143 MPa

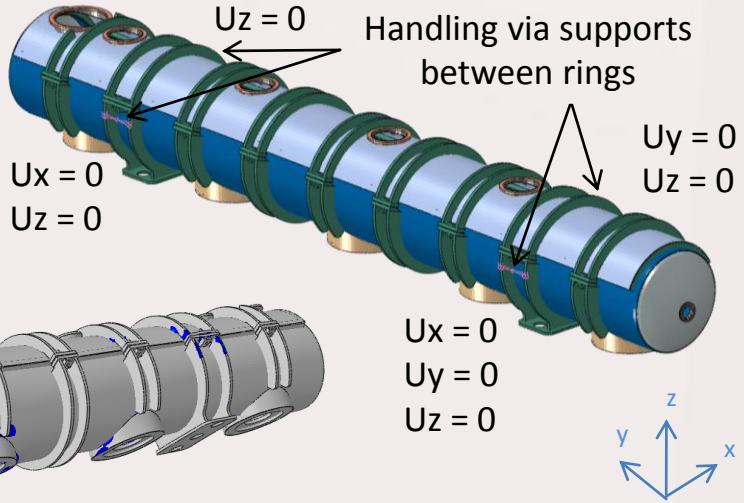
- High local stresses
- Significant sliding between cover and flange

REMOVABLE TOP COVER VACUUM VESSEL

Handling





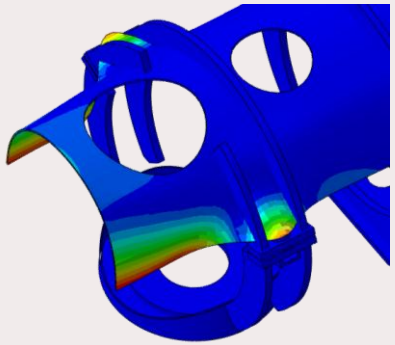


case	Acceleration	Max stress (Mpa)	Max displacement (mm)	|Δz| max between coupler bearings
1	X : 0.5g / Z : -1g	15	0.11	0.1
2	Y : -0.5g / Z : -1g	32	0.14	0.13
3	Z : -1.5g	33	0.18	0.18
4	Y : 0.5g / Z : -1g	29	0.16	0.16
5	X : 0.5g / Y : -0.5g / Z : -1.5g	42	0.22	0.22
6	X : 0.5g / Y : 0.5g / Z : -1.5g	29	0.21	0.20

REMOVABLE TOP COVER VACUUM VESSEL

Buckling

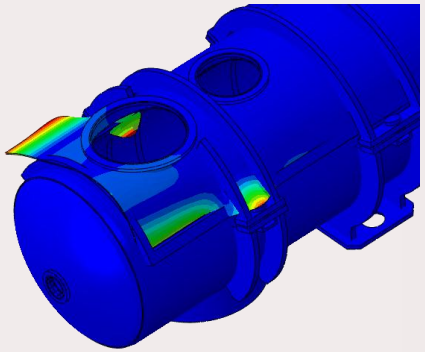
Mode 1 : 3.91 (⇔ Critical pressure : 0.39 MPa)



Hypothesis for buckling simulation :

- No contact between cover and vessel
- No screw between cover and vessel

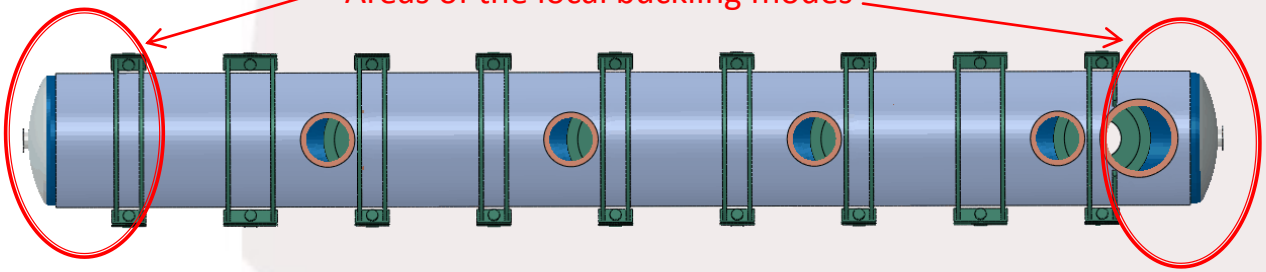
Mode 2 : 3.93



Computation of the first 20 buckling modes :

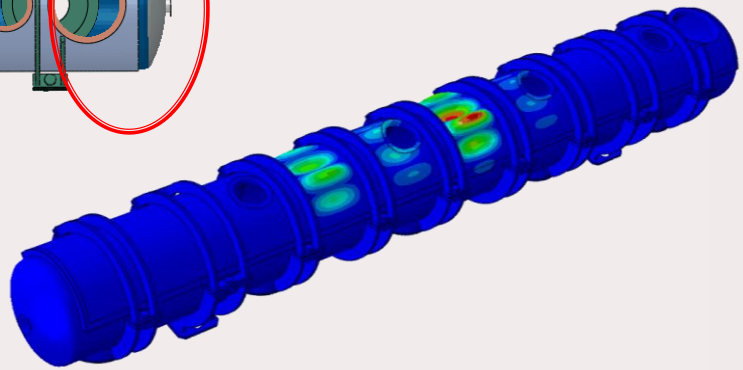
Only local buckling modes on the cover

No global buckling mode found until a min critical value of 1MPa.



Hypothesis for buckling simulation :

- Nodes are linked between the cover and the vessel



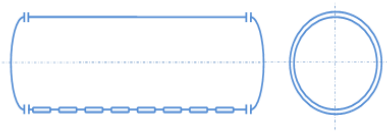
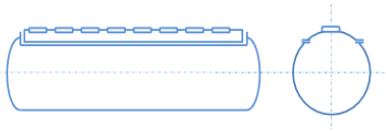
Mode 1 : 42 (⇔ Critical pressure : 4.2 MPa)

REMOVABLE TOP COVER VACUUM VESSEL

Fabrication aspects

A company was consulted to verify the possibility (and cost) of constructing this vacuum vessel.

NB: The company (CMI) is currently in charge of 3 vacuum vessels (being 9, 10 and 11m length) for the triplets update of the LHC.

Dimension	Circular VV (LHC) 	Cylindrical VV with Top cover 
Diametre (mm)	1 350	1 200
Thickness (mm)	12	15 - 6
Material	Low carbon steel	Low carbon steel
Length (mm)	12 700	12 900
Price (€HT)	159 835	187 523
Duration (month)	7	9
Length (mm)	7 700	7 050
Price (€HT)	123 885	135 393
Duration (month)	6	8

Vacuum vessel with a top opening seems feasible.

Coupler / vacuum vessel interface

An interface was designed:

compensating the coupler flange position tolerances;

supporting the mass of the string of cavities;

insuring the sealing of the vacuum vessel bearings.

This interface will be tested on a mock up at CERN.

CONCLUSION

Vacuum vessel

A vacuum vessel with a top opening and a top cover is proposed.

It may allow:

the vertical cryostating of the string of cavities by use of a dedicated tooling which was conceptually studied

providing the better probability of keeping the alignment of the string of cavities during cryostating

making easier the alignment diagnostic within the vacuum vessel

The proposed top cover combines high stiffness and flexible behaviors for the purpose of bringing together sufficient mechanical strength and a dismountable tight interface.

Preliminary computations exposes that this vacuum vessel may be sufficiently strength to induce on the one hand small deflections of the bearings interfaces during vacuum, handling and, one the other hand, to buckling.

Finally a preliminary consultation with a company have indicated that this vessel could be constructed (at a cost a bit more important than a cylindrical vacuum vessel)

THANK YOU FOR YOUR ATTENTION

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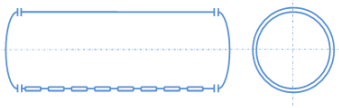
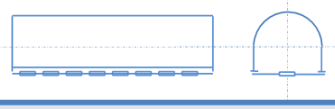
REMOVABLE TOP COVER VACUUM VESSEL

Fabrication aspects

Dimension	Circular VV (LHC)	Tunnel VV	Cylindrical VV with bottom opening	Cylindrical VV in two parts
				
Diametre (mm)	1 350	1 020	1 200	1 200
Thickness (mm)	12	15	10	15
Material	Low carbon steel	Low carbon steel	Low carbon steel	Low carbon steel
Length (mm)	13 000	13 000	13 000	13 000
Price (€HT)	163 000	205 242	195 000	189 524
Duration (month)	6	7.5	9	8
Length (mm)	6 500	6 500	6 500	6 500
Price (€HT)	113 000	135 721	125 000	132 788
Duration (month)	6	7	8	7