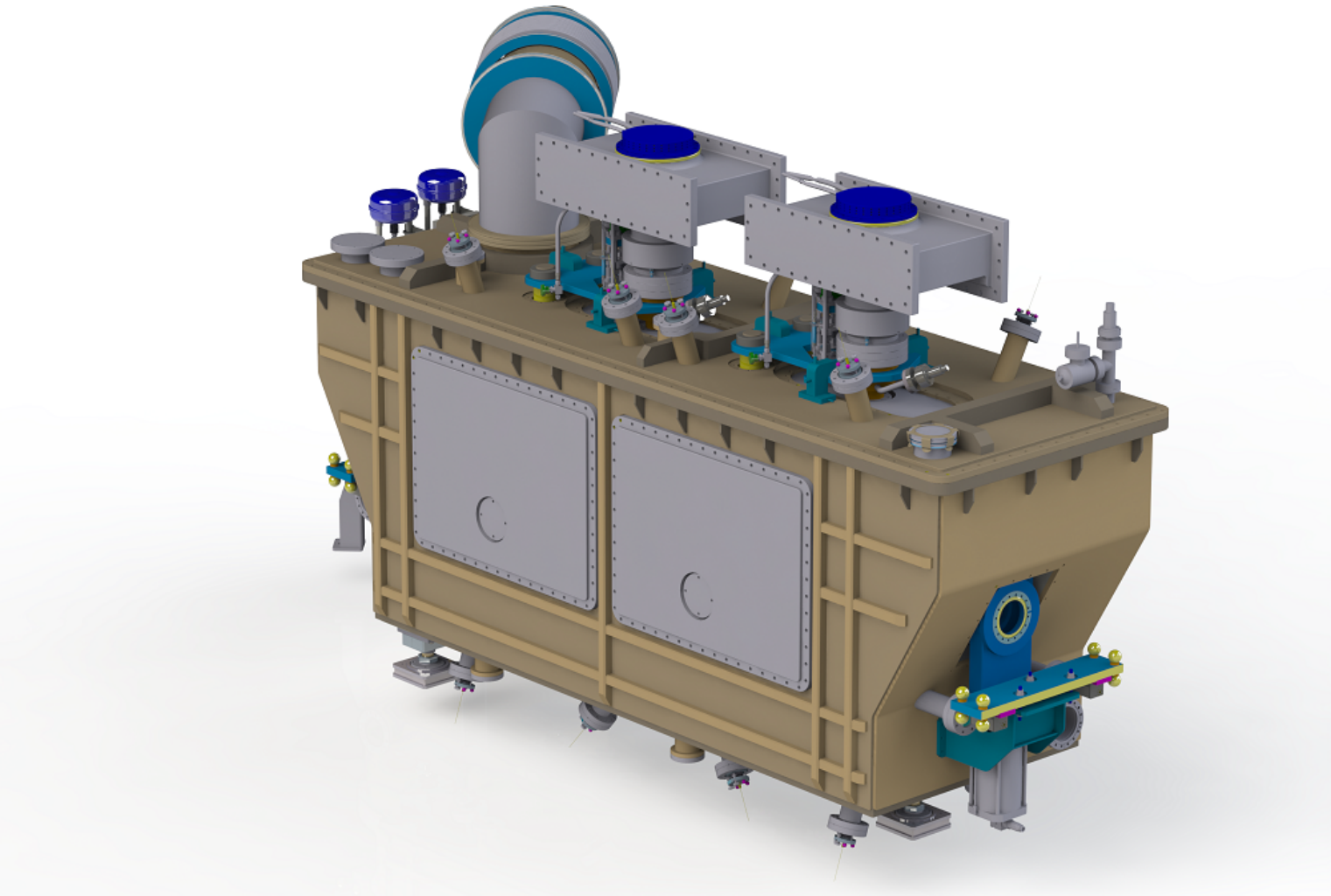
Helium Vessel Design, Prototyping and Tests

Carlo Zanoni on behalf of the
Crab Cavity Collaboration

Outline

1. Introduction and main functions
2. Design concept and material choice
3. Stress assessment
   - Loads and allowable stress
   - Bolts and welds model
   - Results
4. Prototype
   - Status
   - Future plans
   - Lesson learned
5. Conclusion

Introduction



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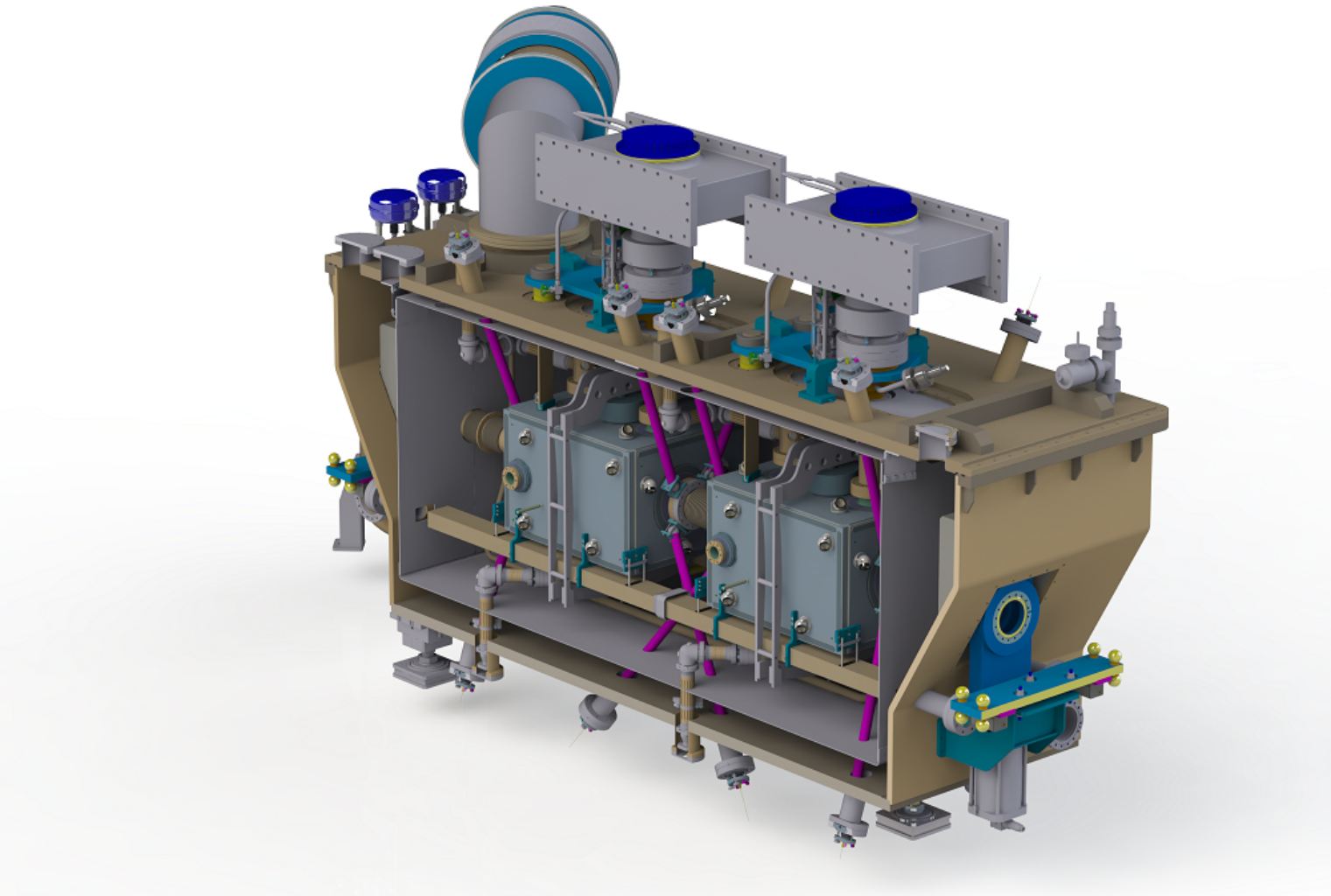

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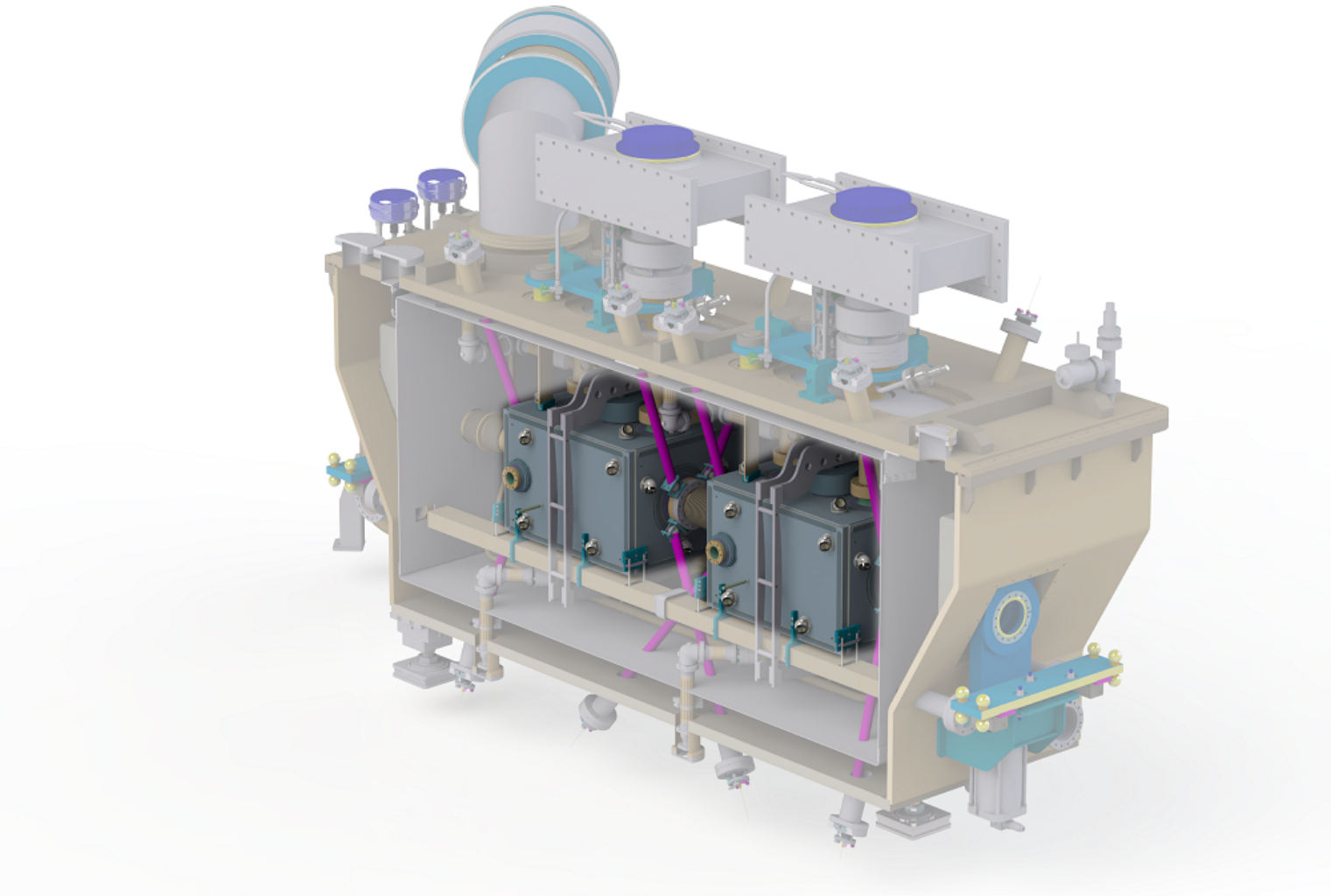

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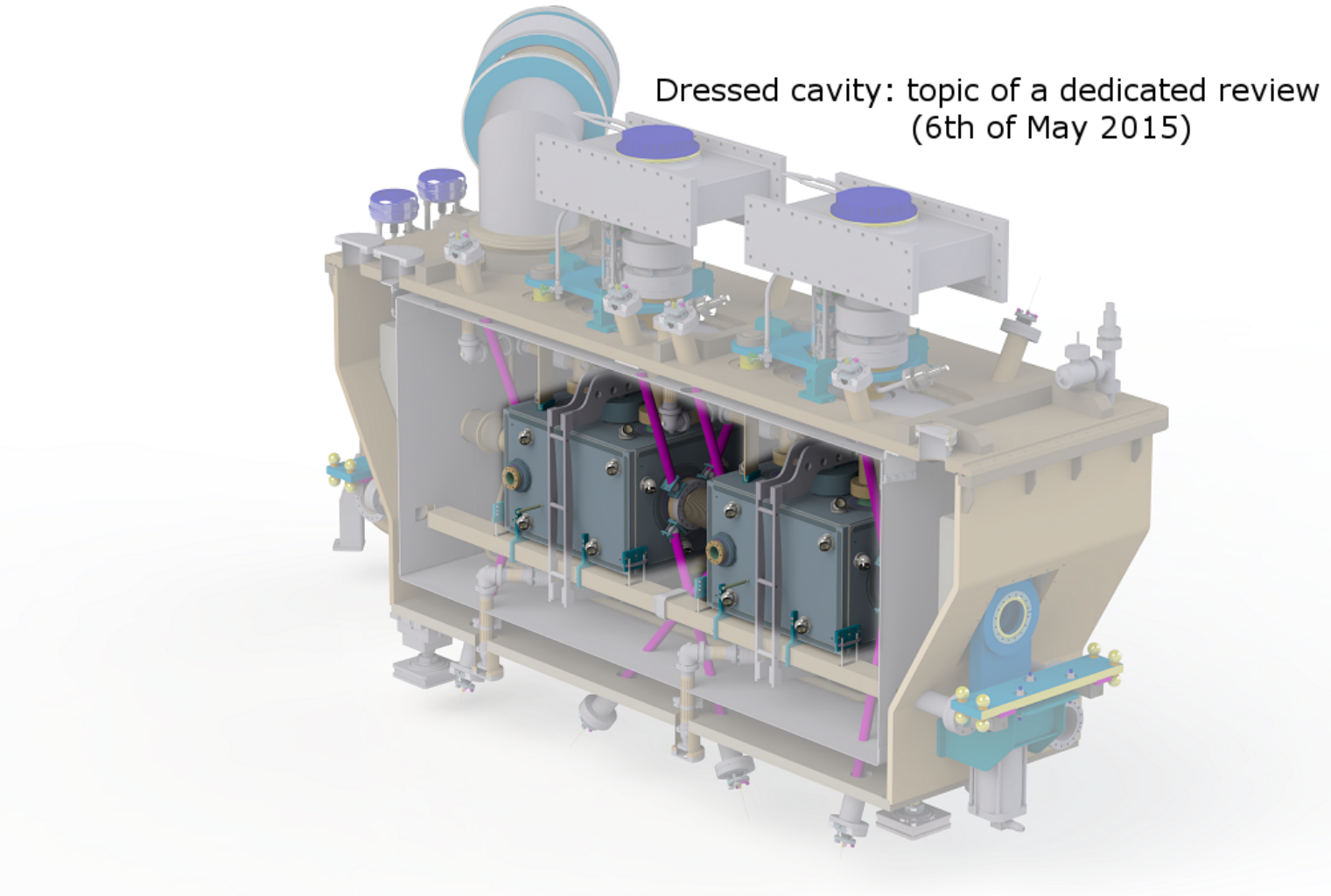
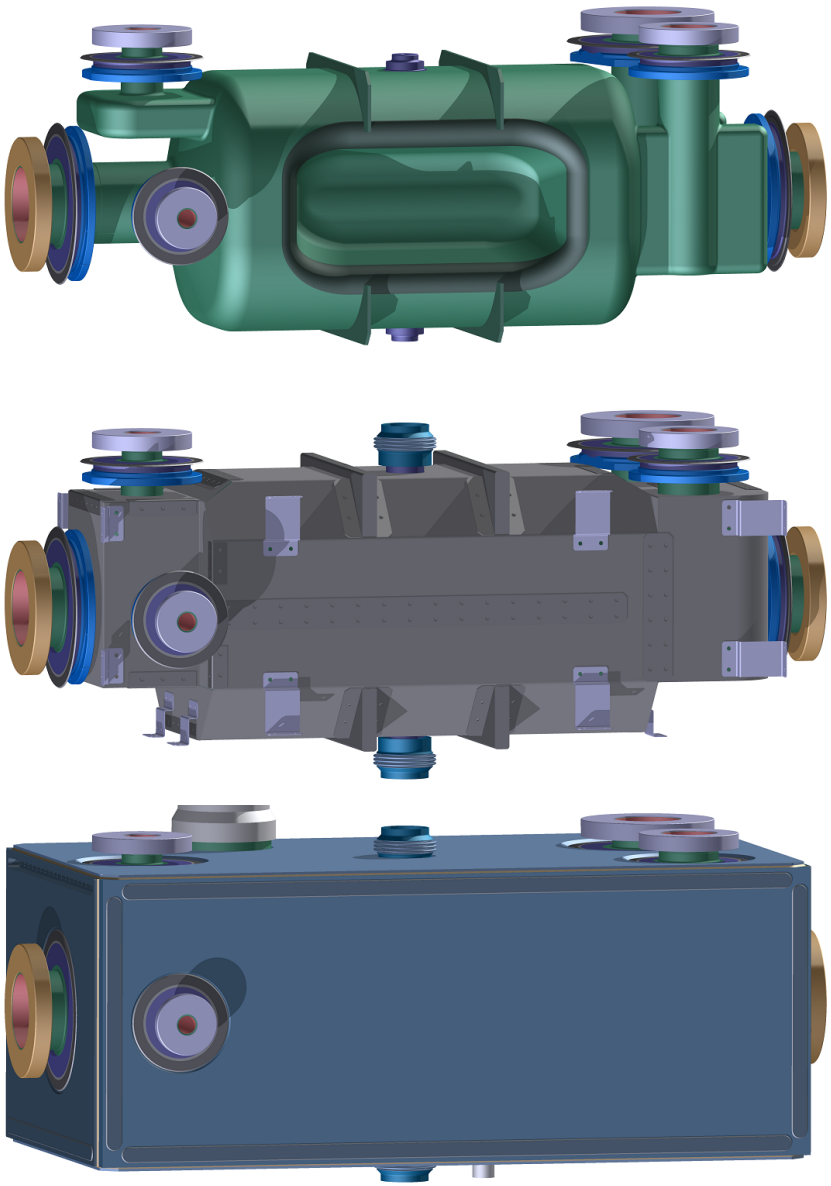
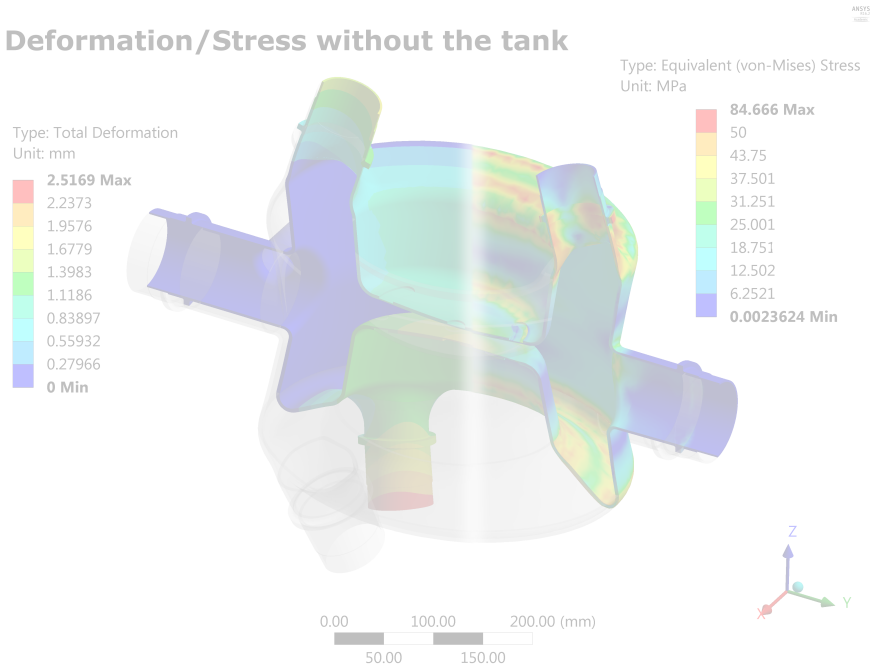


Main functions



- hosts and stiffens the cavity
- contains 2 K helium
- supports magnetic shield and tuning



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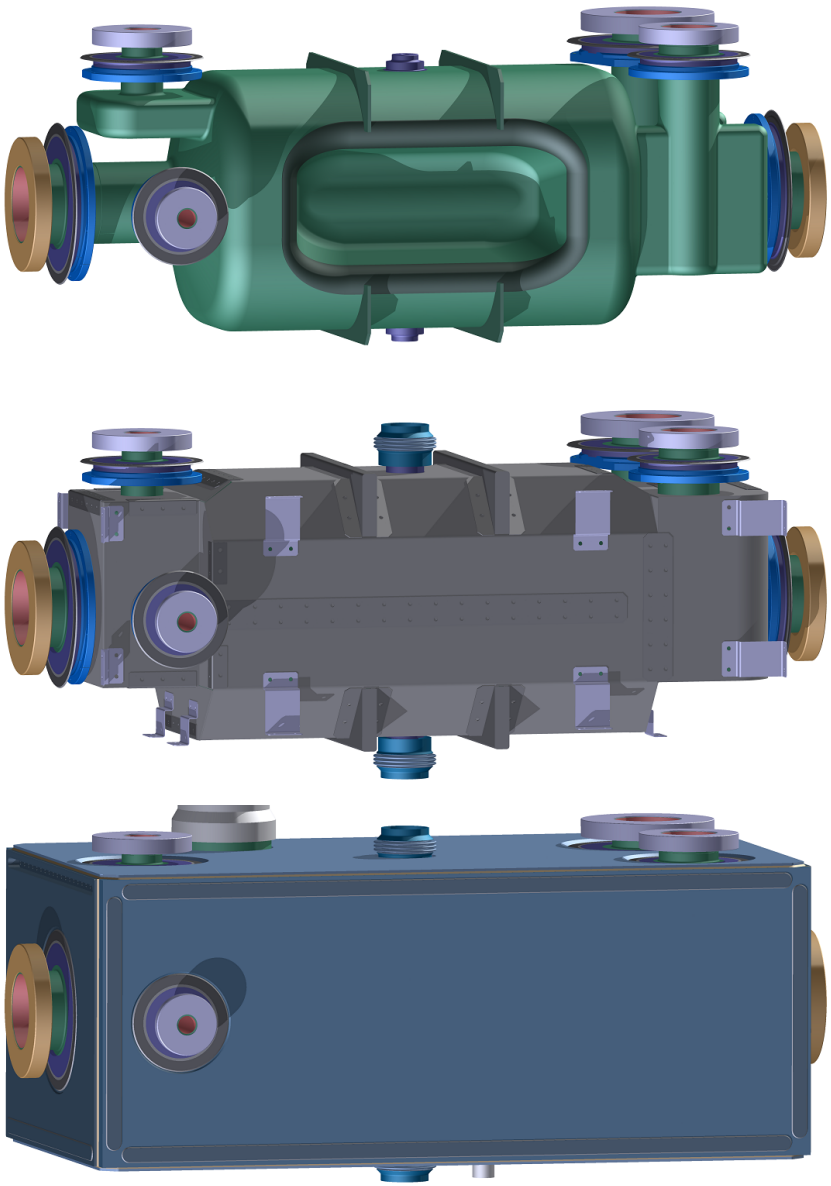

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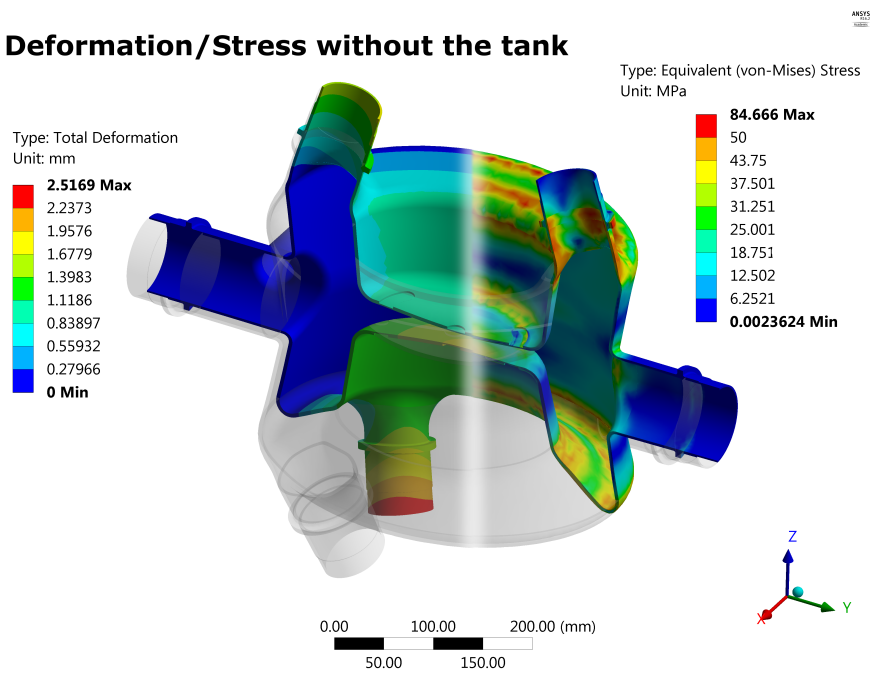
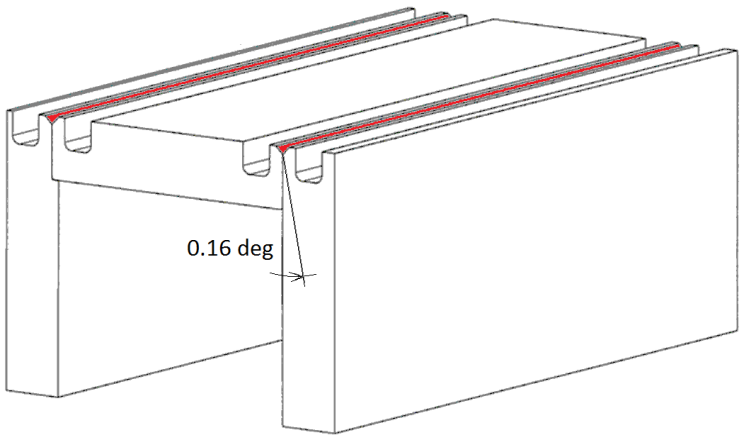


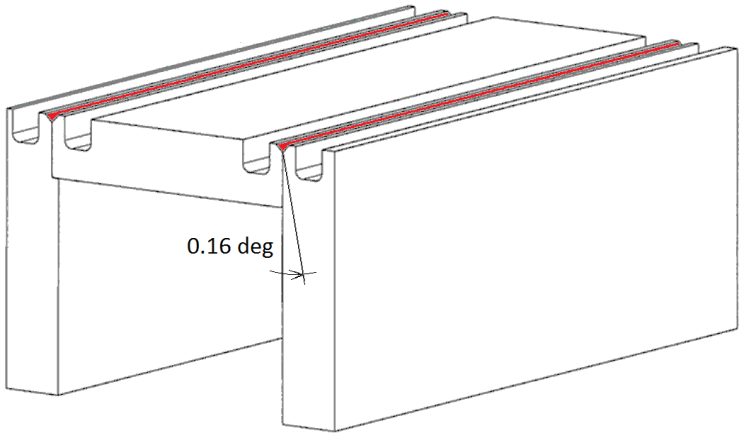
Design concept



- thick (3+ mm) welds would determine high deformations at cavity interface
- thin welds alone would allow large deformations of the plates when pressure is applied

- structural loads carried by a large set of bolts between the plates
- 1.5 mm welds at interfaces for leak tightness

Design concept



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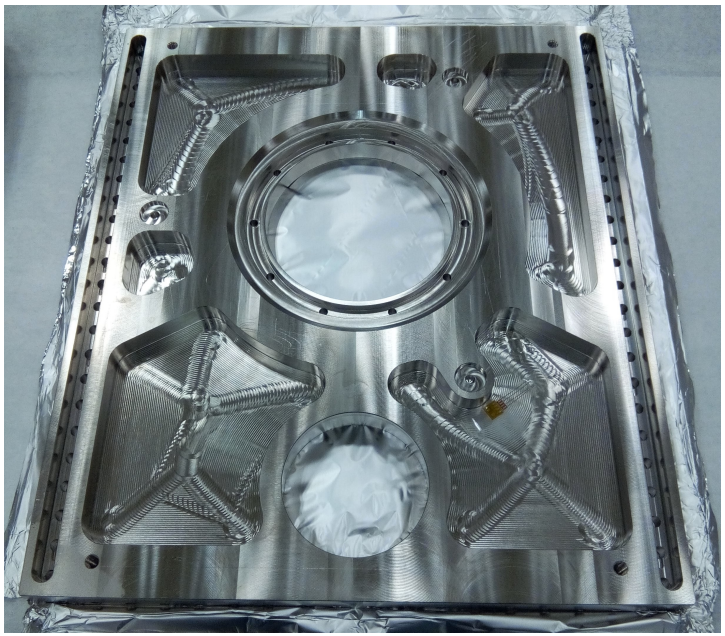
Material selection

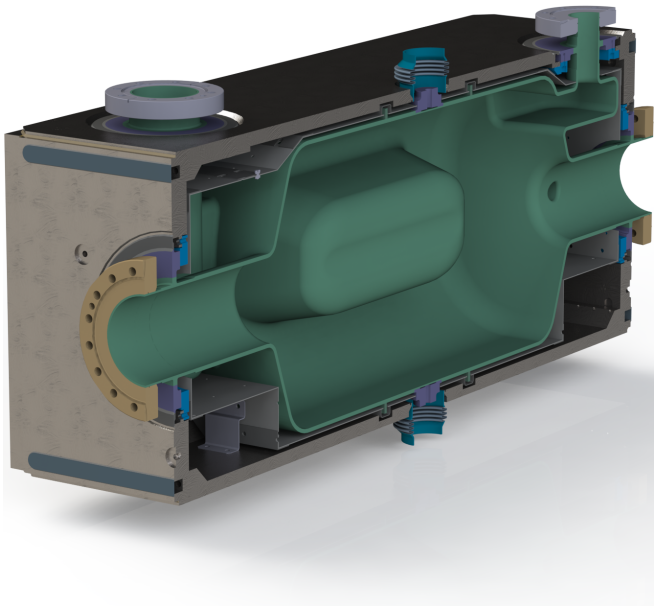
St. steel (316LN): well known material, but thermal expansion 2 x niobium

Titanium gr.2: thermal expansion $\approx$ niobium, but some extra complexity for welds

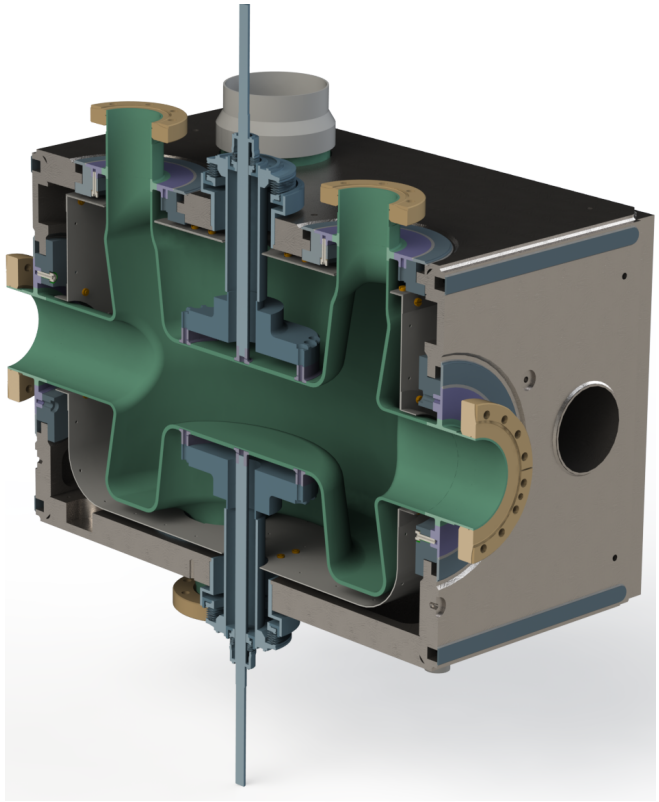


Geometry

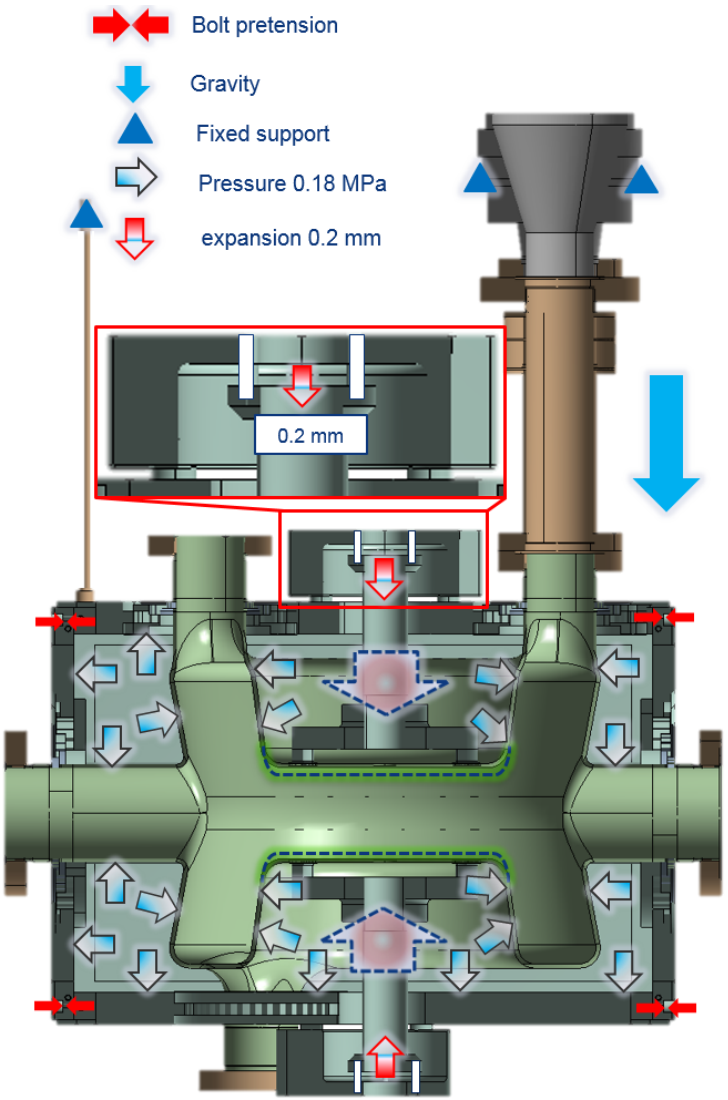
- cavity
- tuning
- (+pretuning for DQW)



- helium tank
  - 6 Ti plates
  - bolts (covered for tightness)
  - 1.5 mm welds
  - NbTi interface with cavity



Strength assessment: loads and allowable stress



Material	$Rp_{0.2}$ [MPa]	$Rp_{0.2}/1.5$ [MPa]
Nb (RRR 300)	75	50
Nb55Ti	480	320
Ti grade 1	200	134
Ti grade 2	280	187
Ti grade 5	830	554
St. steel (316LN)	280	187

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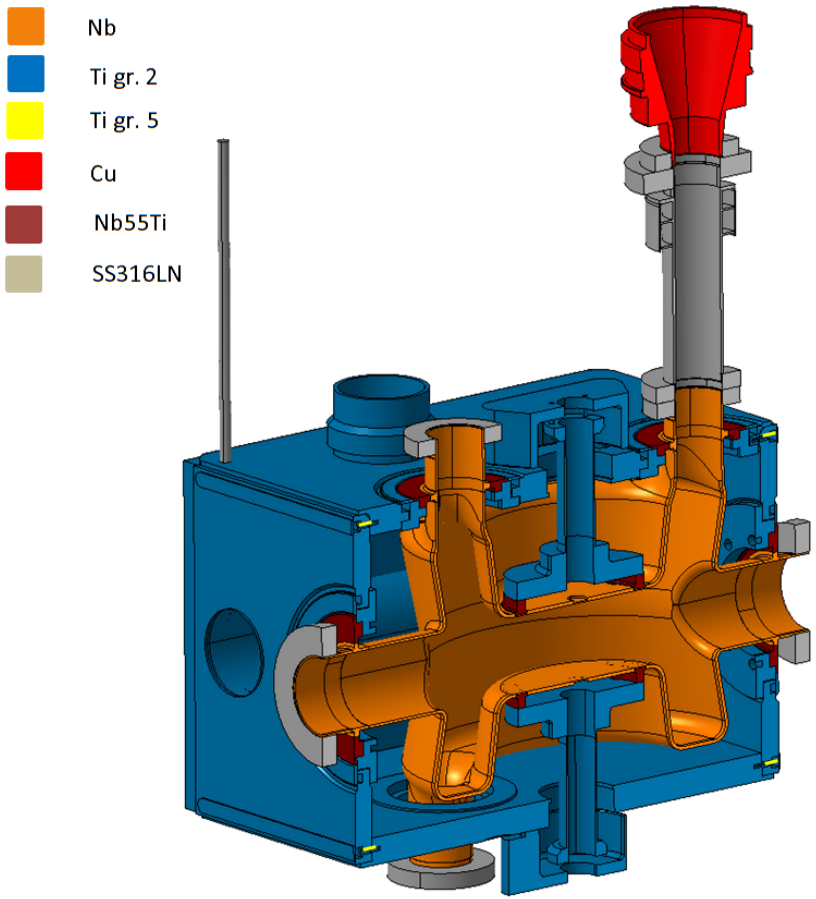

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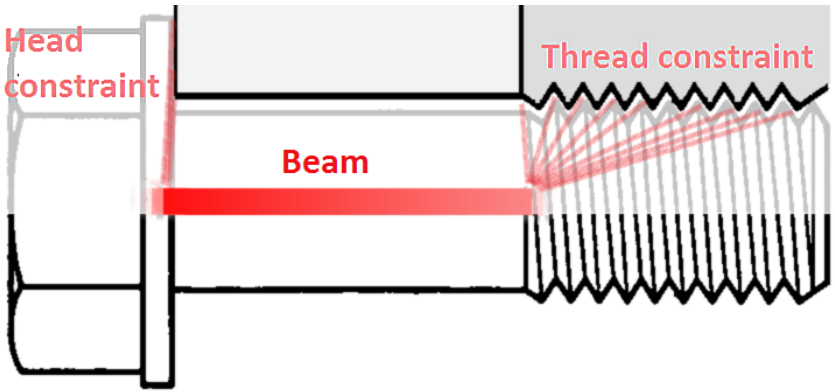
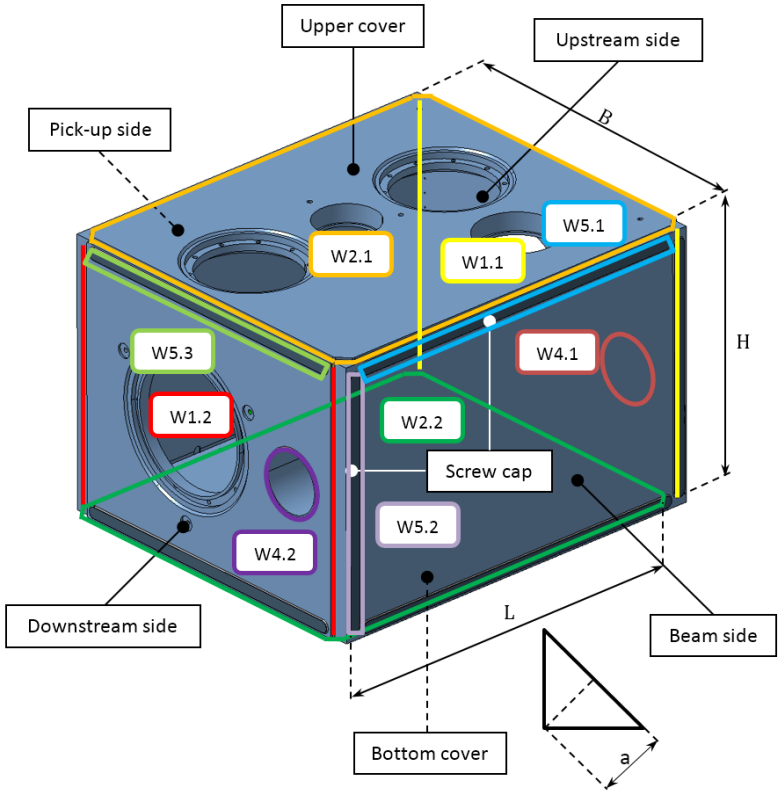
Strength assessment: bolts and welds

Bolt model:

- beam
- extremities constrained
- cross section properties according to VDI 2230:2
- length = distance between head and first thread in the plate

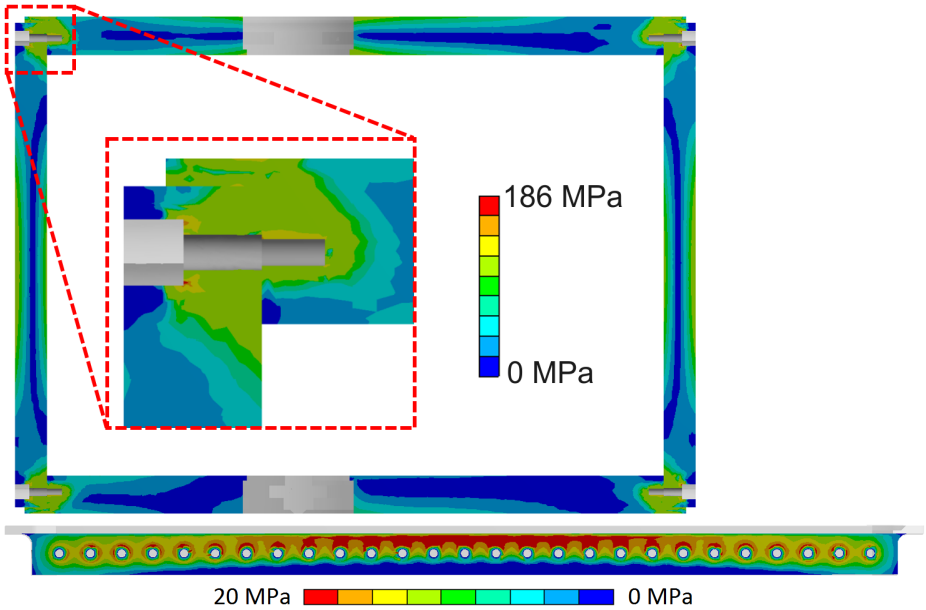




Welds:

- no fatigue
- average stress on each weld assessed

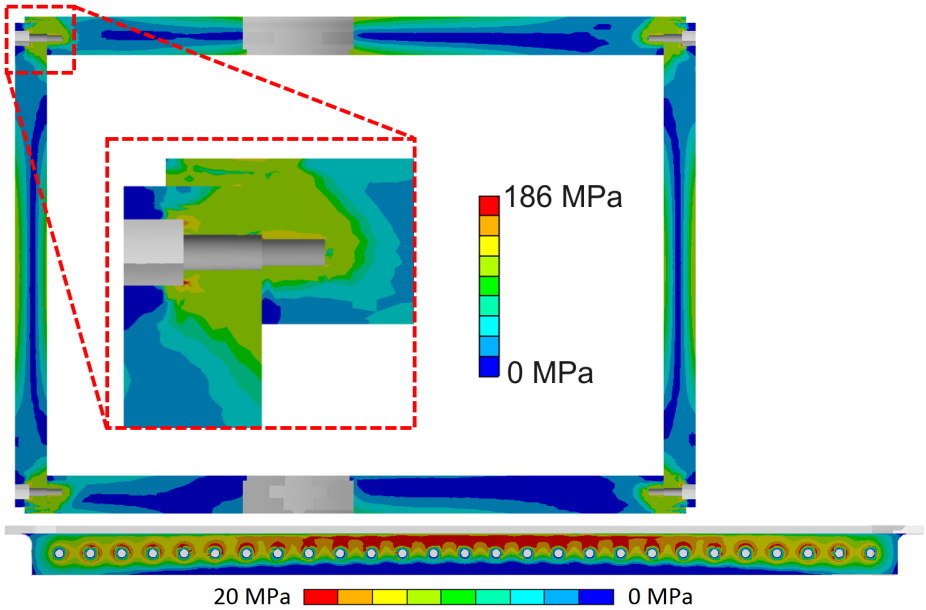
Strength assessment: results



Cavities:

- ANSYS stress intensity > 50 MPa
- analysis of linearized stress according to EN13445-3 ✓

Strength assessment: results



Cavities:

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Strength assessment: results (bolts)

DQW:

Name	Units	Bolts	Bolts + Welds
Preload	[N]	4500	4500
Max axial force	[N]	4650	4655
Max bending moment	[Nmm]	3430	1630
Max shear force	[N]	525	245
Equivalent stress	[MPa]	620	480
Proof stress	[MPa]	830	830
Safety factor	-	1.34	1.74

The friction between plates is not taken into account (very conservative assumption)

Strength assessment: results (bolts)

RFD:

Name	Units	Bolts	Bolts + Welds
Preload	[N]	4500	4500
Max axial force	[N]	4705	4787
Max bending moment	[Nmm]	3838	2516
Max shear force	[N]	750	495
Equivalent stress	[MPa]	632	531
Proof stress	[MPa]	830	830
Safety factor	-	1.31	1.56

The friction between plates is not taken into account (very conservative assumption)

Strength assessment: results (welds)

Weld	Material	$R_{p0.2}$ [MPa]	Stress [MPa]	Allowable stress (= 0.7·$R_{p0.2}$/1.5) [MPa]	Safety factor
W1.1	Ti gr. 2	280	22.10	131	5.91
W1.2			26.74		4.89
W2.1			34.33		3.81
W2.2			14.89		8.78
W3.1.1			26.66		4.90
W3.1.2			24.17		5.41
W3.1.3			23.85		5.48
W3.1.4			26.57		4.92
W3.2.1			33.10		3.95
W3.2.2			33.89		3.86
W4.1			12.63		10.35
W4.2			11.90		10.98
W5.1			11.83		11.05
W5.2			10.60		12.33
W5.3			11.79		11.08
W6.1.1			15.33		8.55
W6.1.2			13.90		9.42
W6.1.3			13.94		9.39
W6.1.4			14.06		9.32
W6.2.1			14.37		9.12
W6.2.2			14.46		9.06

Prototype: goal

1. confirm the tank structural **resistance**
2. verify the **geometry** is good for assembling/welding
3. test the **assembly** procedure
4. test **welding** procedure and welds quality
5. verify **leak tightness** along a load cycle representative of real conditions
6. verify bolts do not loose **preload** during a load cycle
7. **validate FE** model with an estimate of the force on bolts, stress/strain and displacement on few tank locations

Prototype: status

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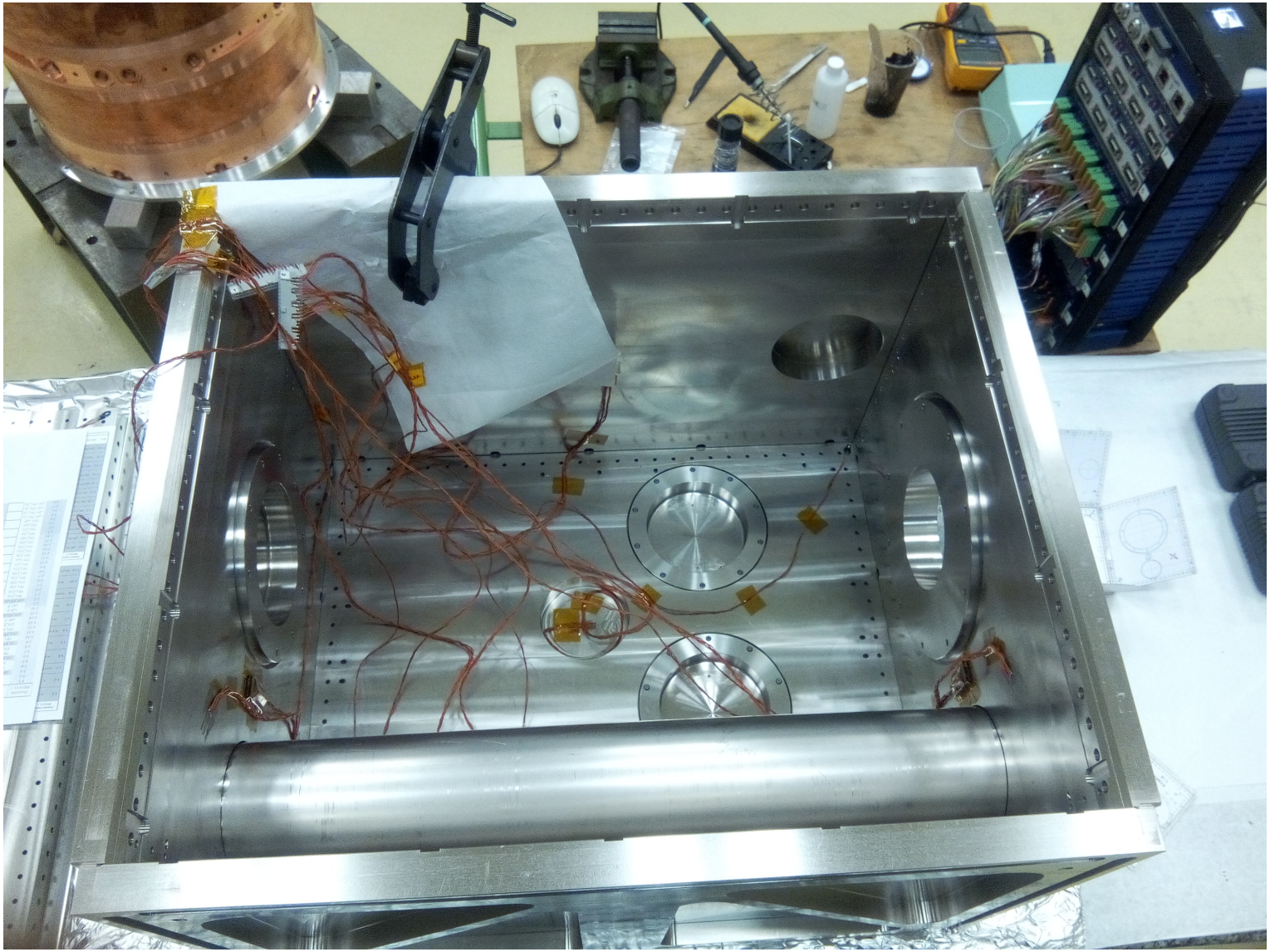

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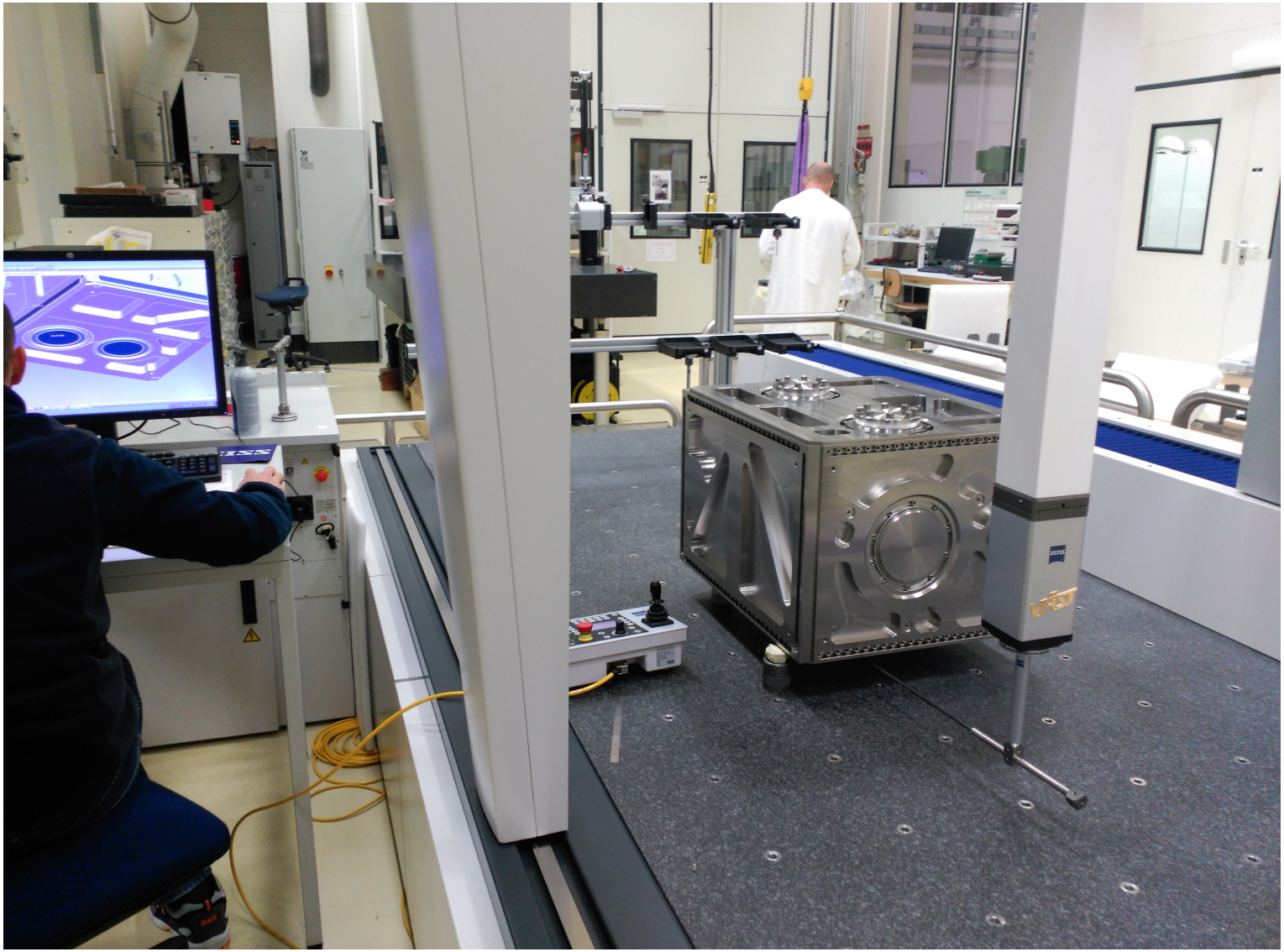

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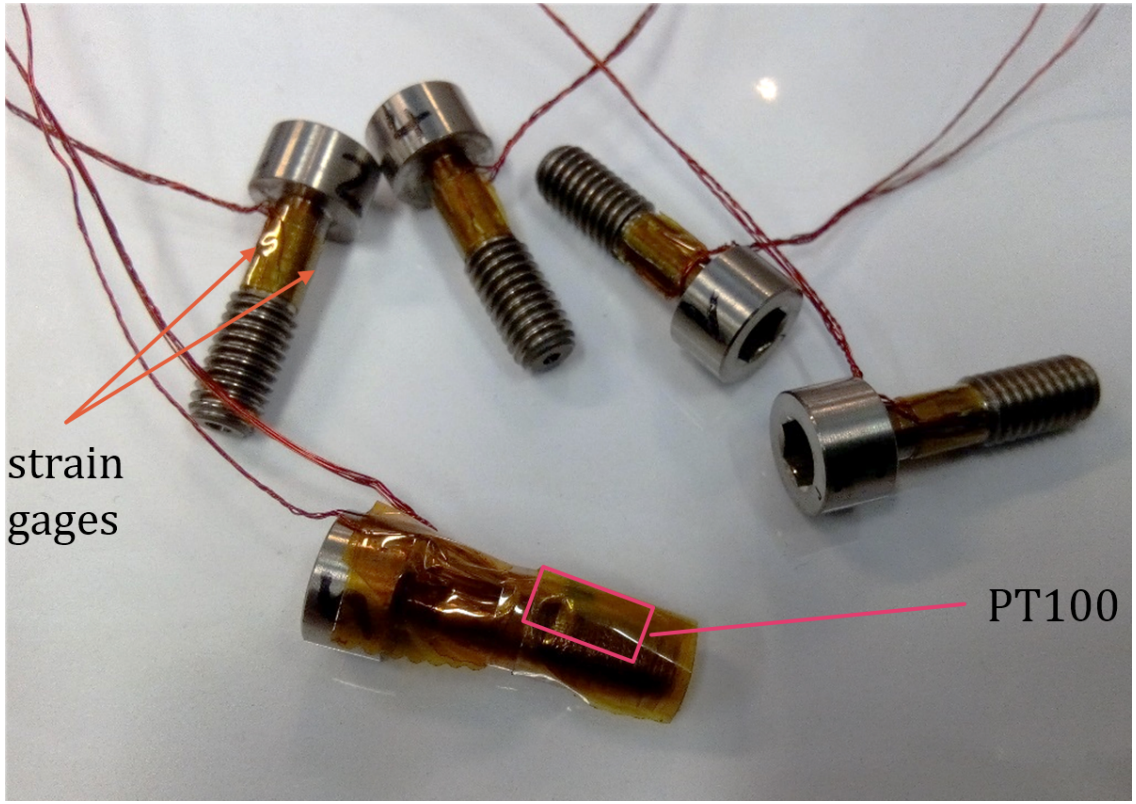
Prototype: sensors

- strain gages on screws
- strain gages on tank
- temperature sensors
- displacement sensors



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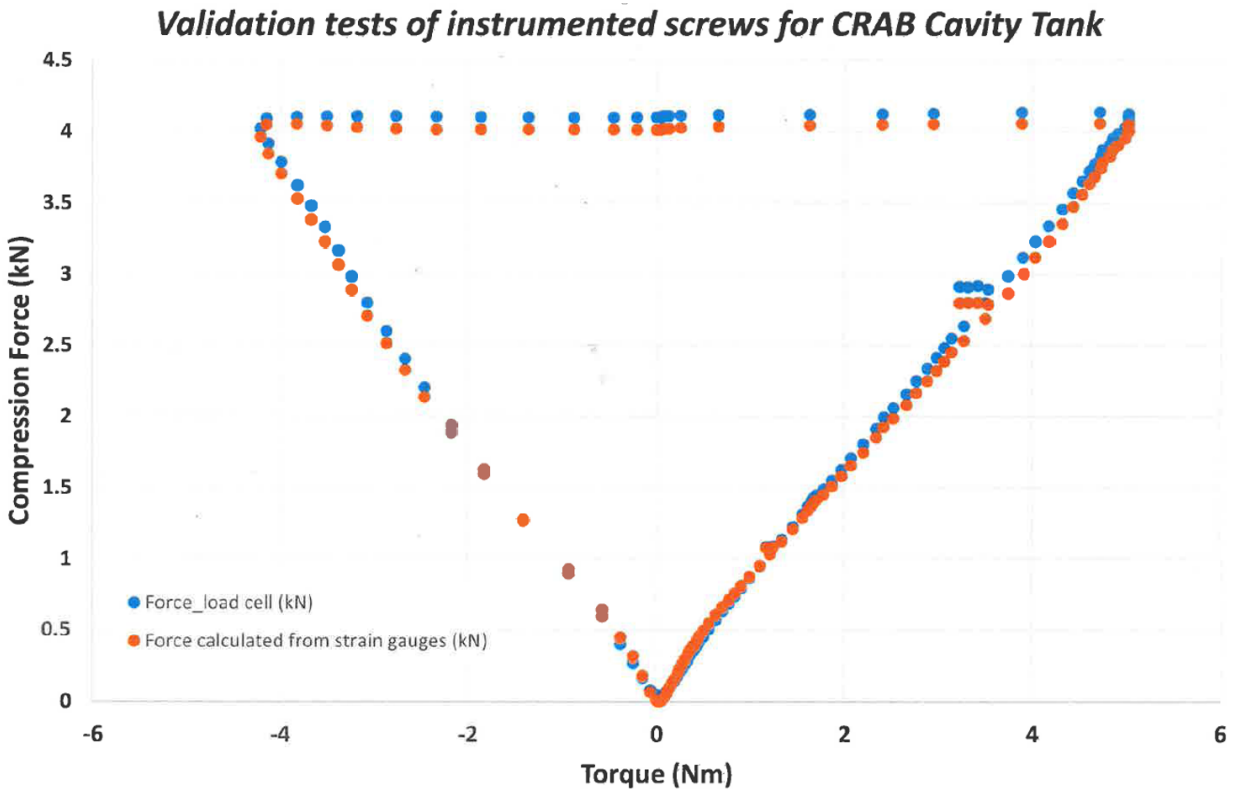

Prototype: planning

1. **fabrication, assembly and welding**
2. leak tightness test
3. dimensional control
4. pressure test
5. leak tightness test
6. dimensional control
7. thermal cycle test
8. leak tightness test
9. dimensional control

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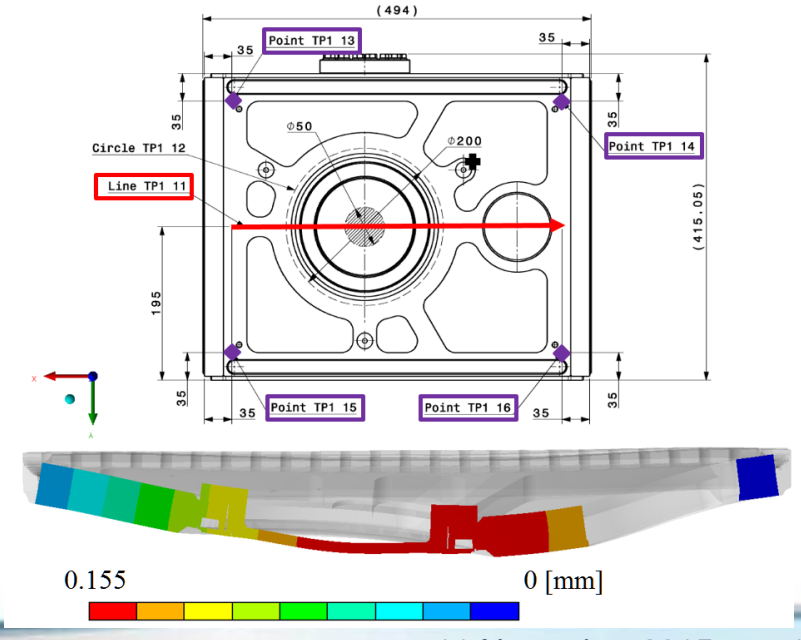
Pressure test:

- $\Delta p = 2.6$ bar
- strain in few tank/bolts locations monitored
- displacement of few tank positions monitored too



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Thermal cycle test:

- 300 K → 80 K (5 cycles)
- strain in few tank/bolts locations monitored

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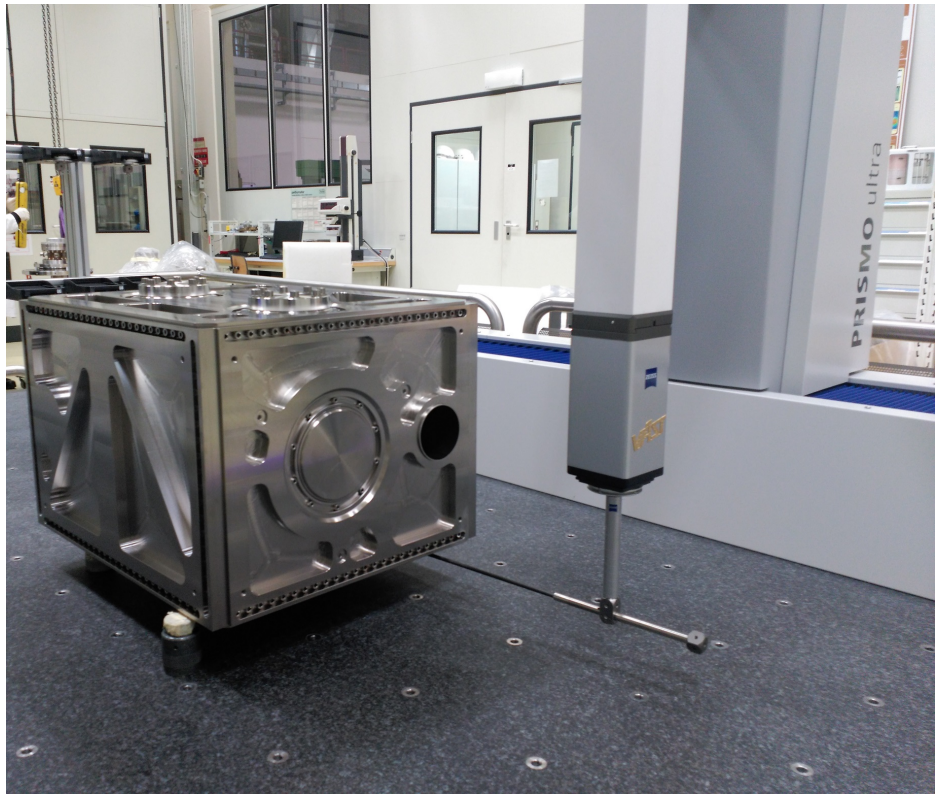

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Success criteria:

- **assembly procedure** is feasible and welding does not induce excessive deformations
- mechanical **strength** sufficient
- no **leaks**
- no substantial relaxation of bolts **preload**

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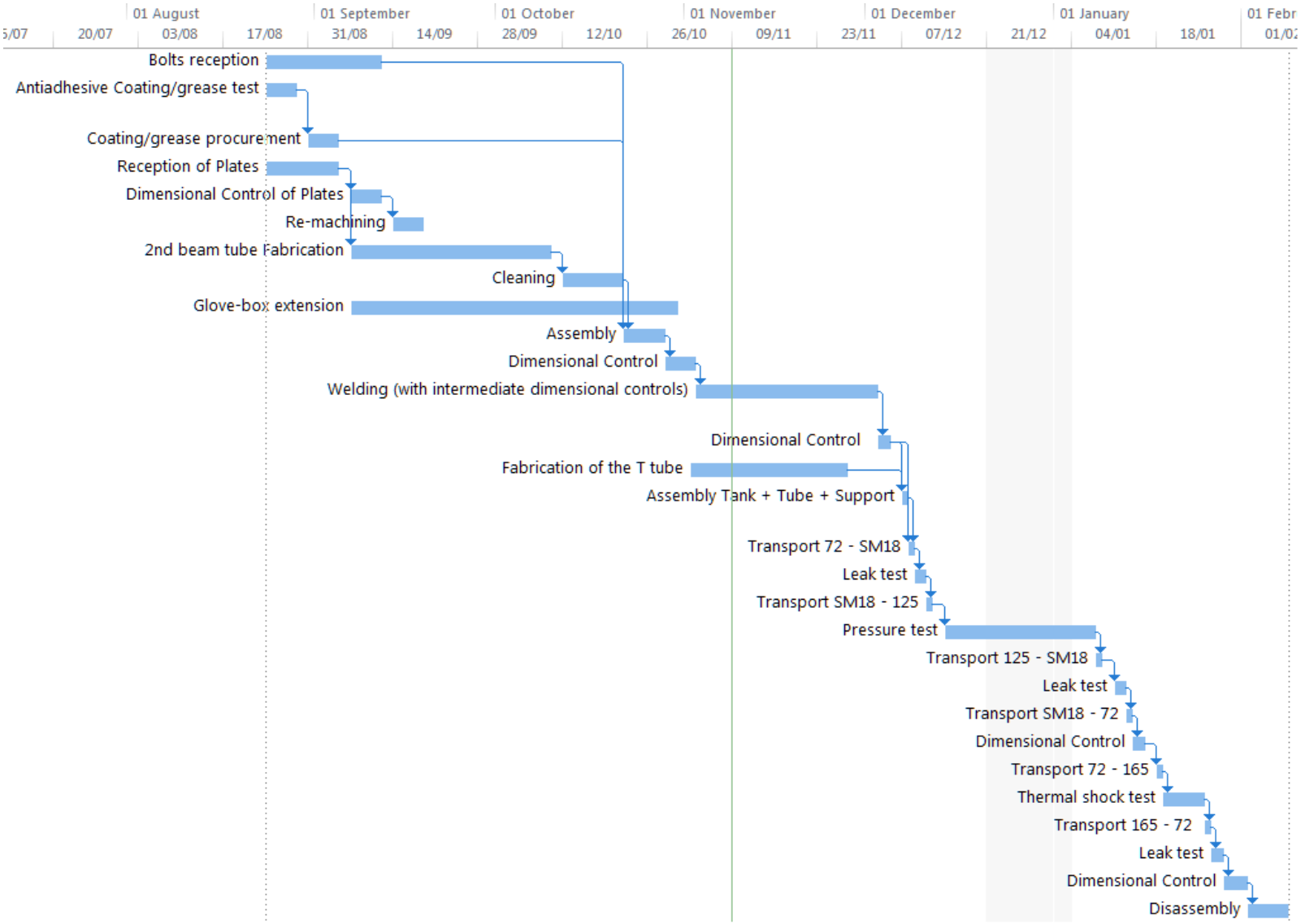

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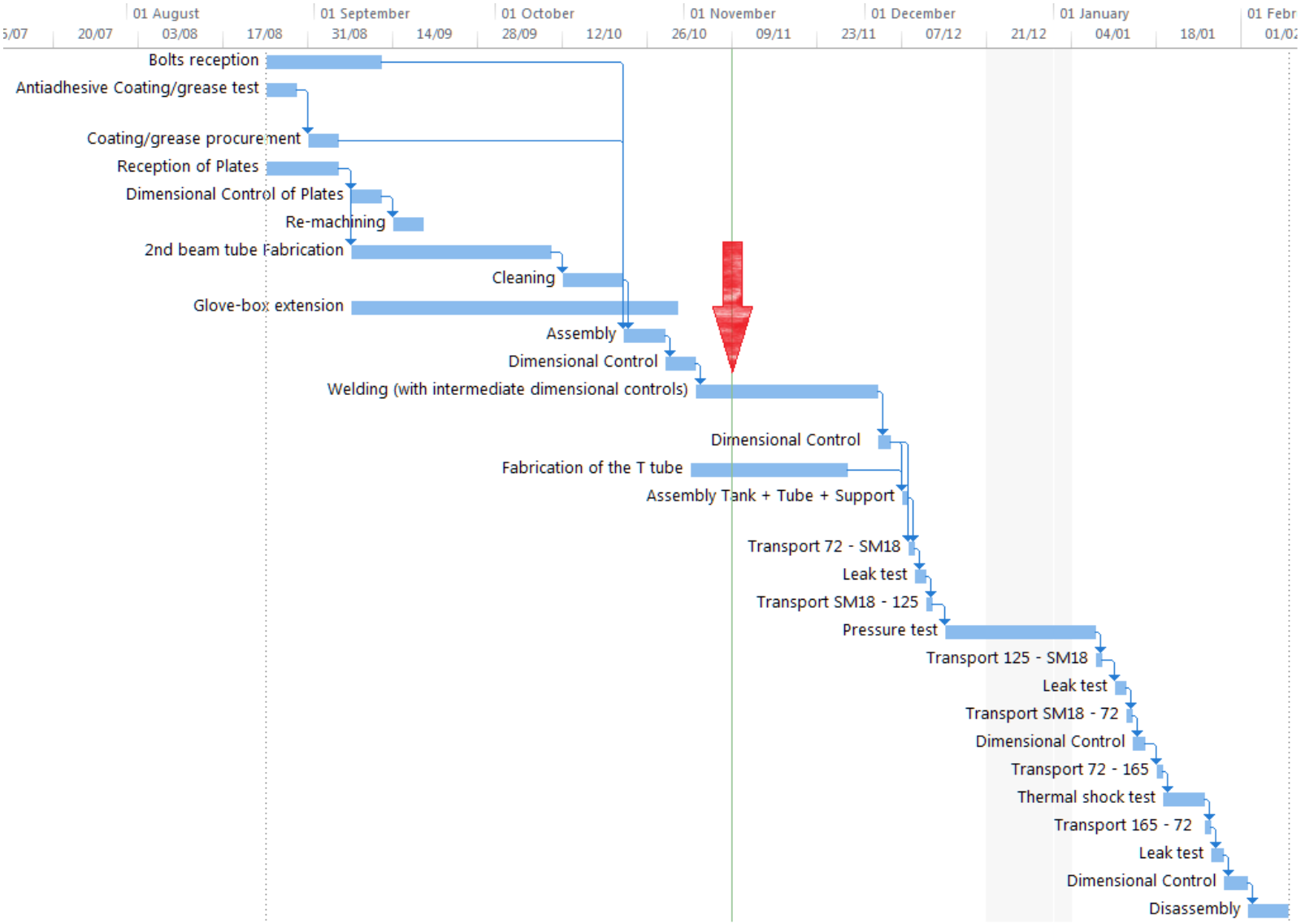
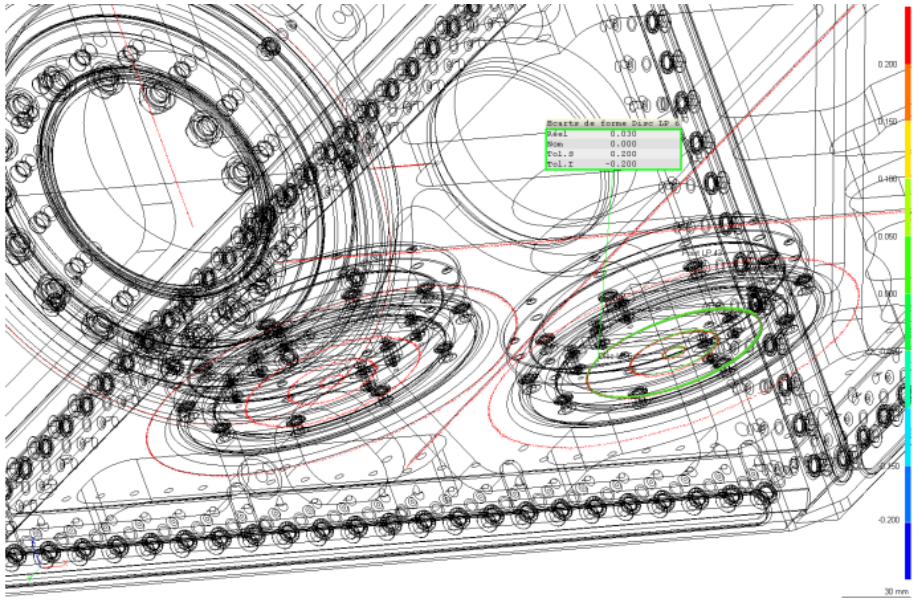


Prototype: lesson learned (in process...)

- small details in the geometry for better accommodation of some welds
- preload in screws well below expectations
- welding process has an impact on the installed sensors that is larger than anticipated

...everything under investigation and precious for SPS!



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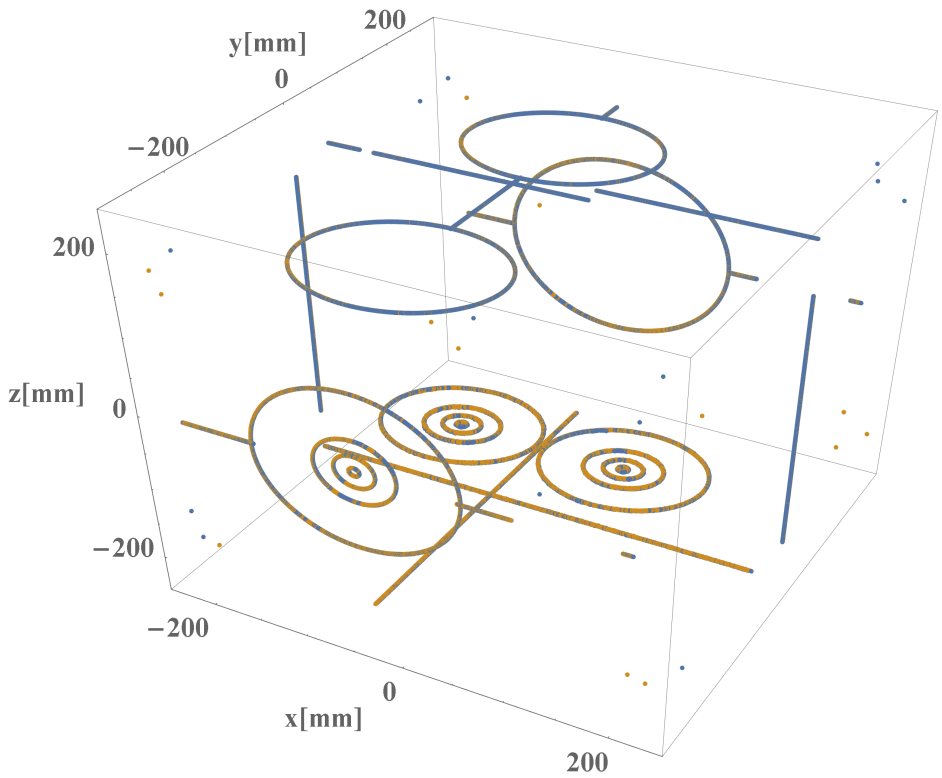

Summary and conclusions

- tank is key element for cavity *strength*
- design based on *bolts + welds* (superficial, just for tightness)

- stress in tank very **low**
- stress in cavity **acceptable** everywhere
- **bolts** have a **reasonable margin factor** even with largely conservative assumptions
- **welds** have a **large margin factor**

- design to be validated by means of a *prototype* (status: welding)
- some unexpected effects, but all info precious for SPS

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Merci pour votre attention !
Grazie per l'attenzione!