Simulations of the LHCb VeLo RF foil deformation due to 200 mbar pressurisation

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Outline

- Context
- Elastoplastic FEM model
- Half box VELO
  - Simulations vs dedicated tests
- VELO
  - Simulations vs observations
- Conclusions

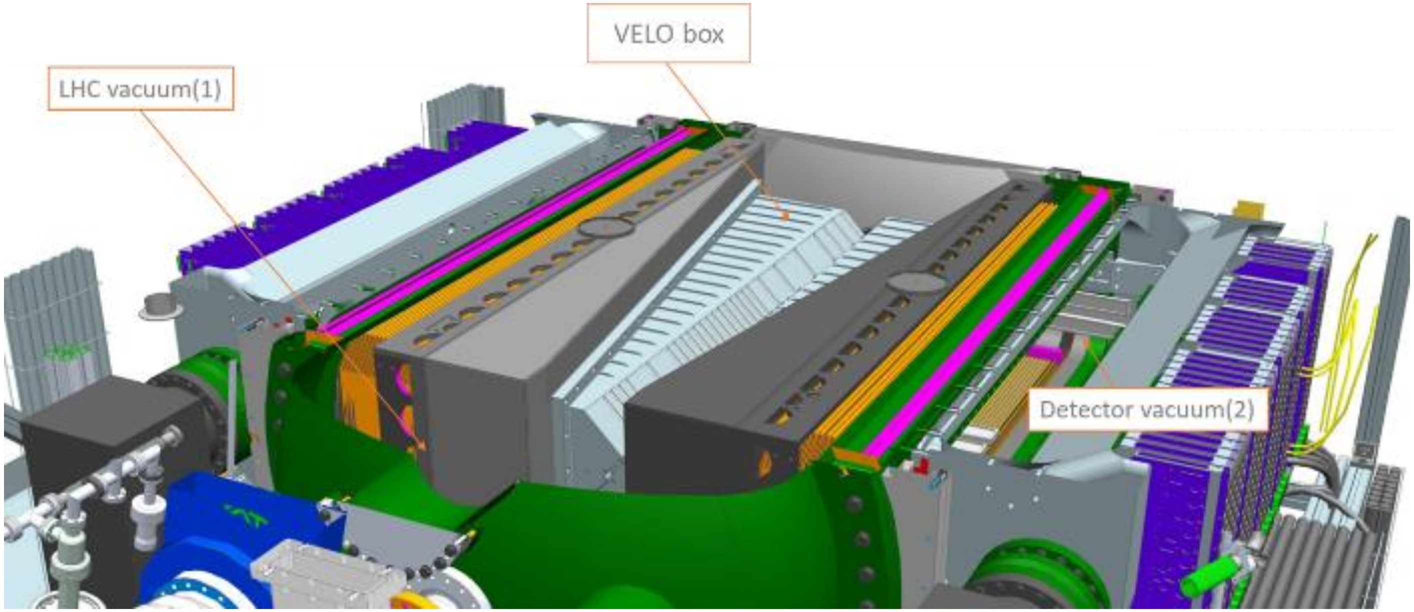
Context

The LHCb VErtex LOcator (VELO) detector is enclosed within a vacuum aluminium box, also known as an RF box or foil, which separates the detector vacuum from the LHC beam vacuum.

To prevent permanent deformations, the maximum differential pressure admitted between the two volumes is 15 mbar.

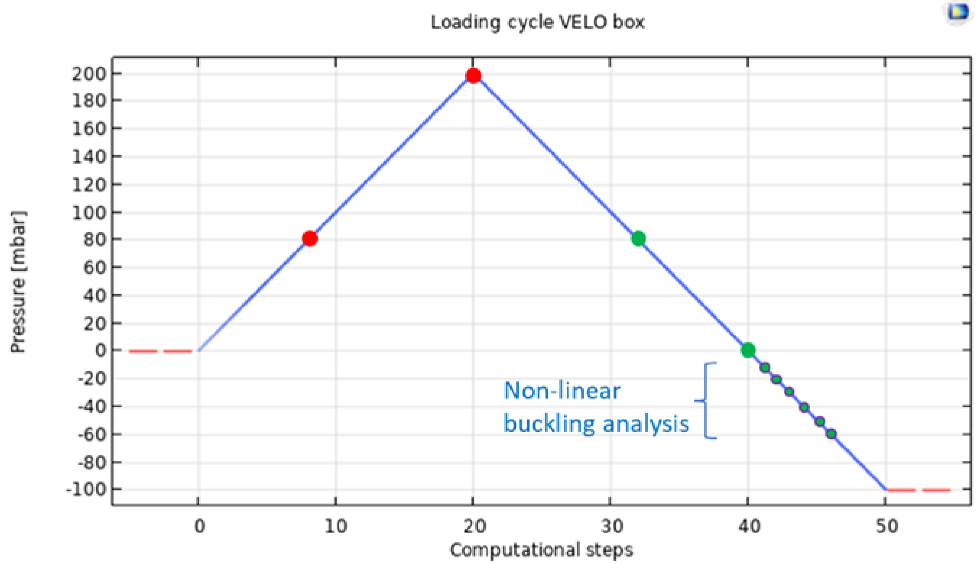
In January 2023, the VELO box experienced a differential pressure of about 200 mbar.

Highly non-linear simulations were conducted to predict the deformations related to such pressurization, and linear and non-linear buckling analyses were also performed to assess local and global instabilities.



Elastoplastic FEM model

- Highly non-linear model developed in COMSOL Multiphysics.
- The box undergoes large deformations.
  It is then geometrically nonlinear → the load distribution and stiffness of the structure change considerably during the loading phase.
  Hence, loading steps every ΔP=10 mbar.
- Bilinear elastoplastic behaviour included in the model to estimate residual deformations.
- Loading phase up to 200 mbar and unloading phase down to -50 mbar (see figure on the right).
- Isotropic hardening considered in the model.
- Shell elements used to discretize the geometry (3 elements through the thickness to model plasticity).



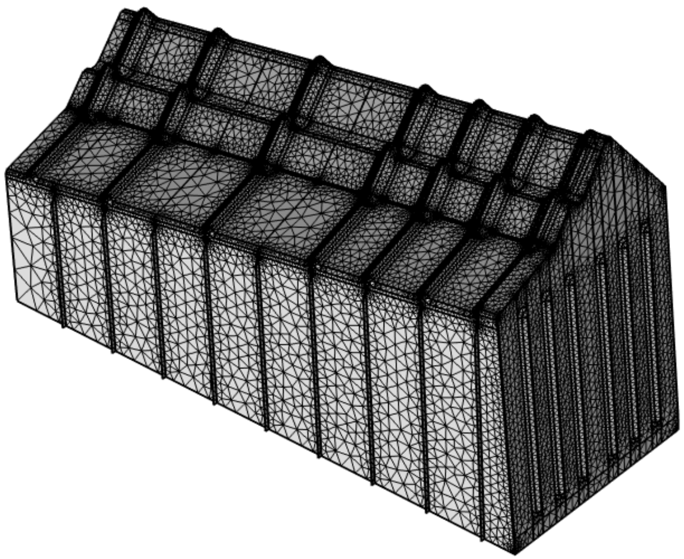
Typical loading cycle of the VELO box. The results are shown for the pressure increase (red points) and for the pressure decrease (green points) up negative pressures (outside pressure higher than internal one).

For more information please see technical report on VELO deformations (EDMS N° 2820818 *in approval [1]*).

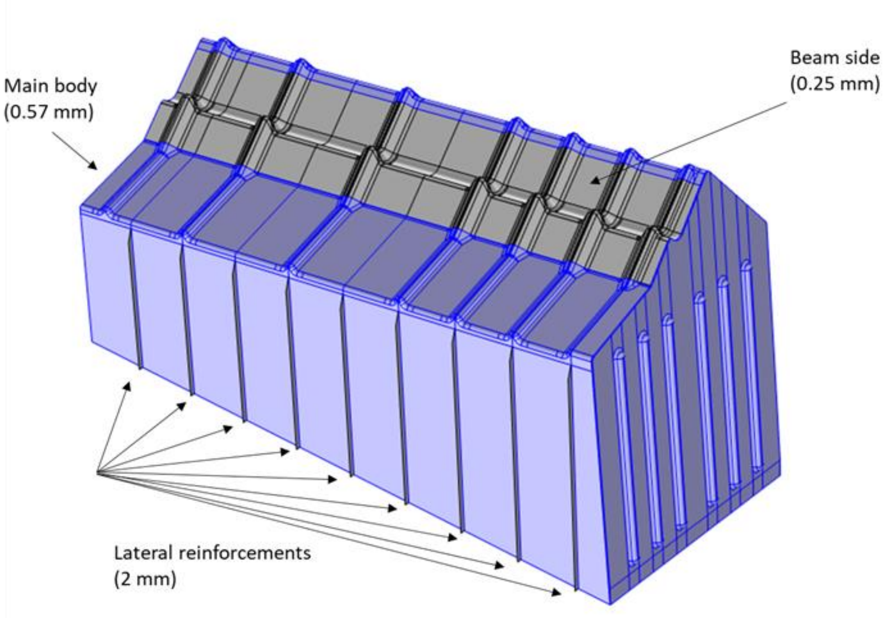
Half VELO box

The FEM model was benchmarked on a half RF box that was developed as an initial prototype by Nikhef.

The half box was used for a dedicated overpressure test up to 200 mbar.

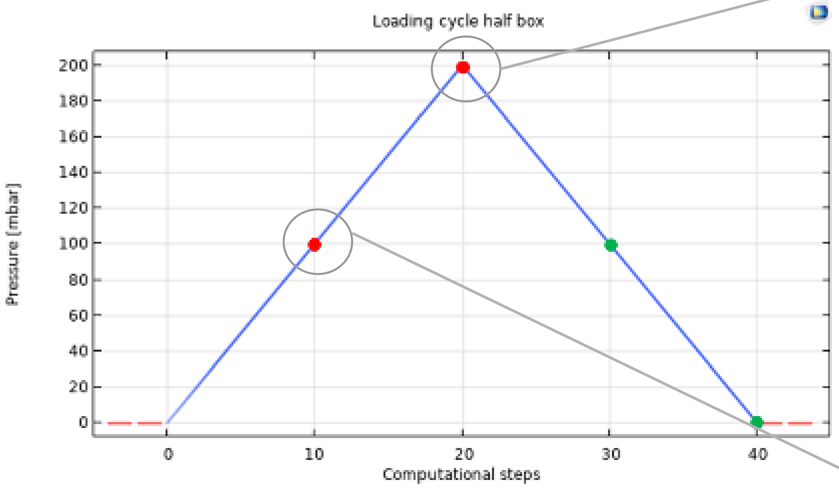


Half box was discretised with around 40 k triangular shell elements

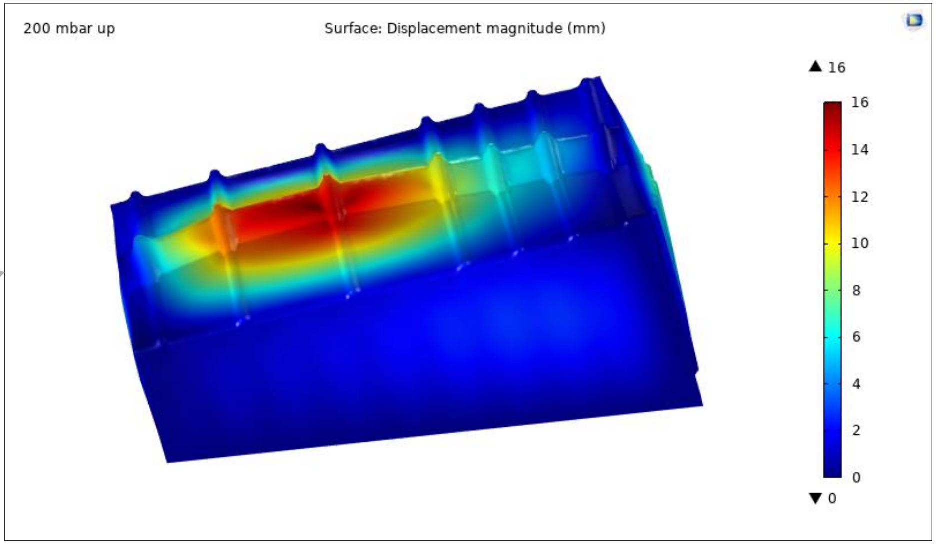


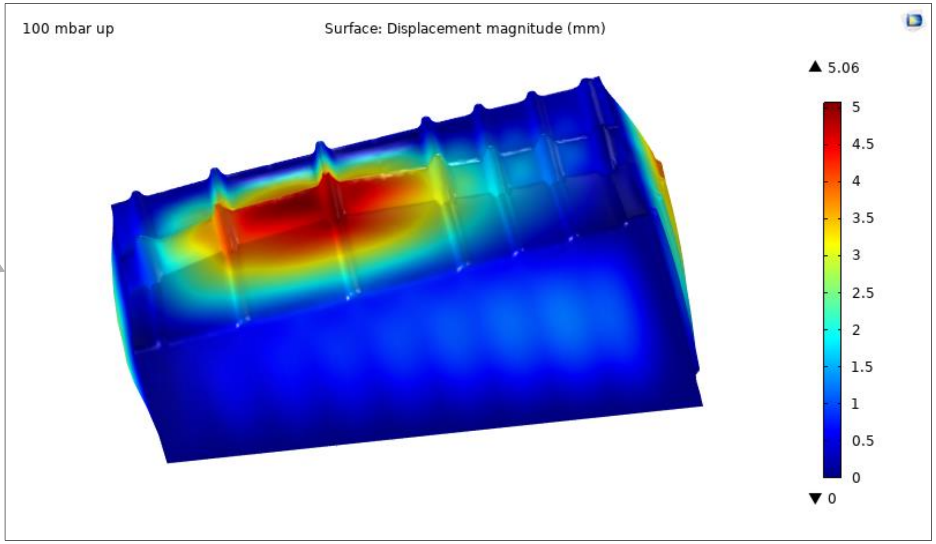
Thicknesses of the half box model. The main body (in blue) is 0.57 mm thick; the beam side (in grey) is 0.25 mm while the lateral reinforcements are 2 mm thick

Half VELO box



Total displacements at 100 mbar (up) and 200 mbar (up)



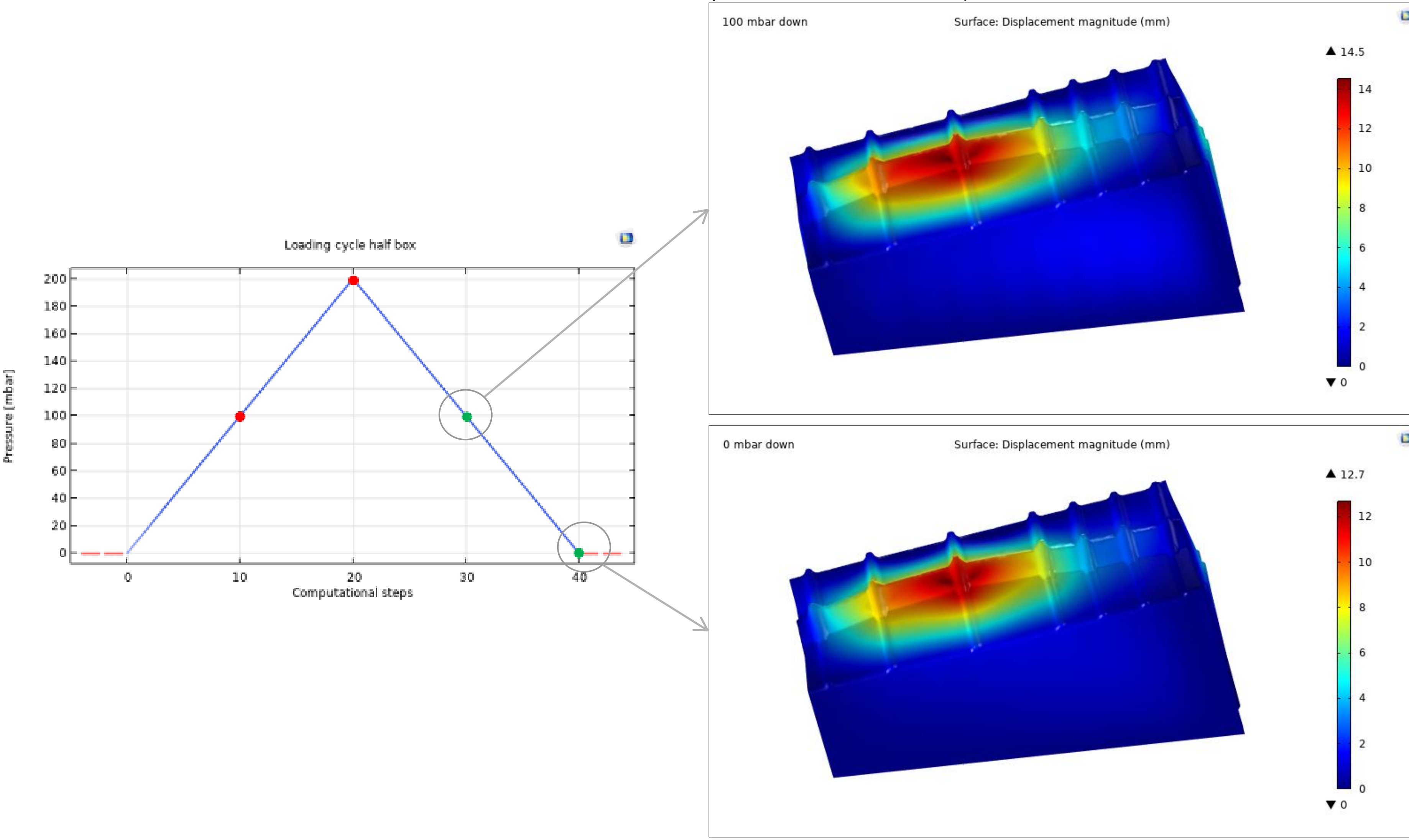


Simulation results presented on 16/01/2023 [1]

CERN

Half VELO box

Total displacements at 100 mbar (down) and 0 mbar (down – permanent deformations)

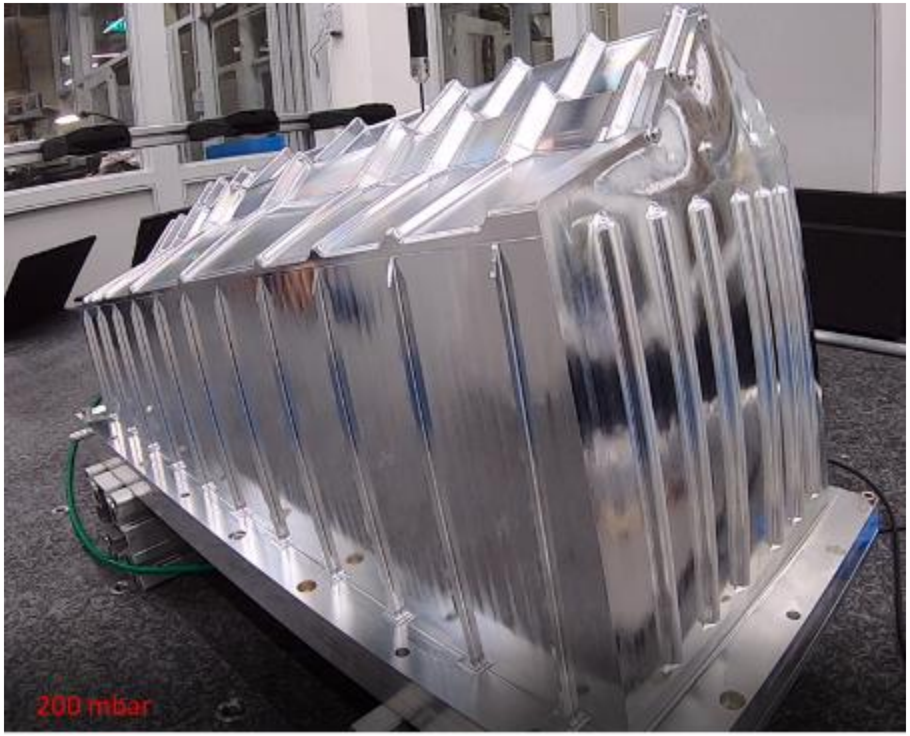


Simulation results presented on 16/01/2023 [1]

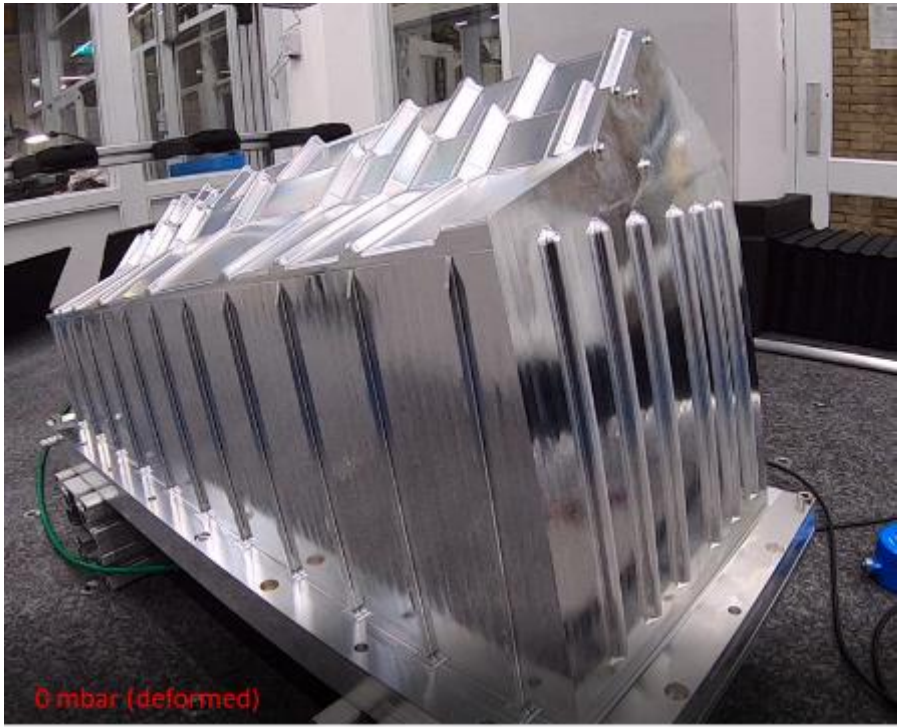
Half VELO box

Test: pressurisation up to 200 mbar

The half box was pressurised up to 200 mbar and a taster mounted on a robotic arm measured the displacement over multiple paths at different pressure values.



Half box with an overpressure of 200 mbar wrt atmospheric pressure.



Half box in equilibrium with the external pressure. Permanent deformations are visible.

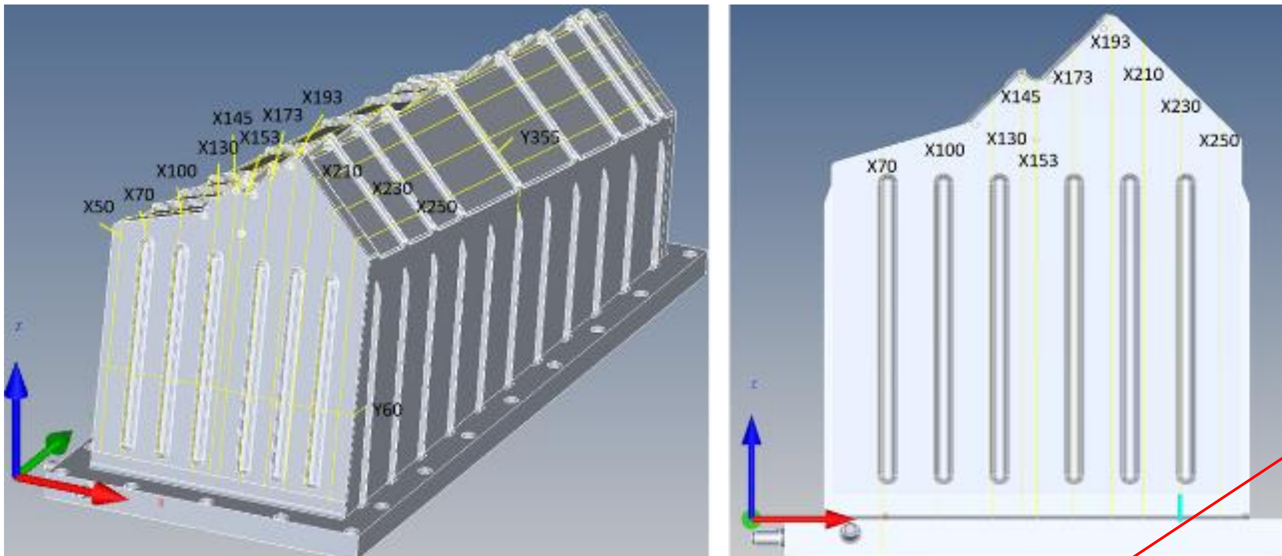
Courtesy of Nikhef

Test results presented on 17/01/2023 [1]

Half VELO box

Comparison with test

The displacement (z-component) at the taster paths intersections was measured by Nikhef and compared with simulation data:
- A close agreement, **within 1 mm**, was found between test and simulation, apart from one point (due to local buckling effect);
- The pressure of the transition from elastic to macroscopic plastic behaviour is around **70 -80 mbar** both for test and simulation.



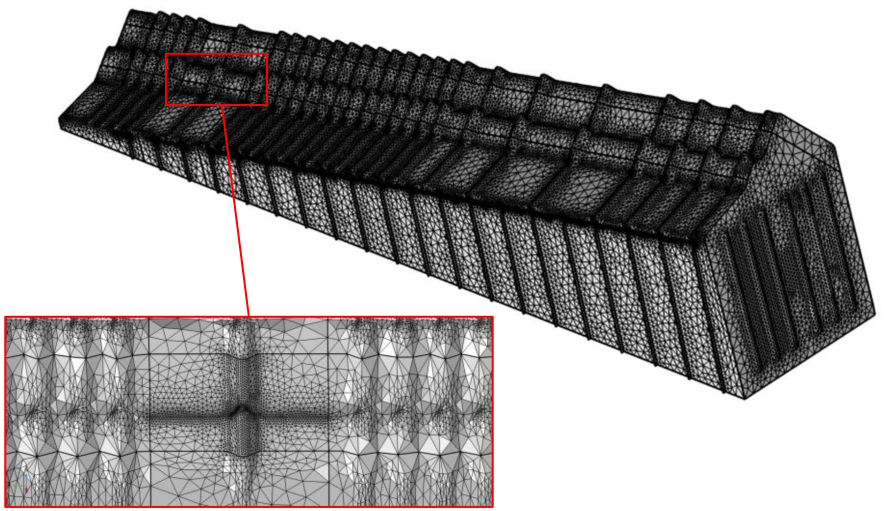
Taster paths of the half box.

		Pressure: up to 200 mbar				Pressure: back to 0 mbar			
Intersection of perpendicular taster lines		Test done at Nikhef			Simulation	Test done at Nikhef			Simulation
Description	Location	Measured z [mm]	Nominal z [mm]	Δ z [mm]	Δ z [mm]	Measured z [mm]	Nominal z [mm]	Δ z [mm]	Δ z [mm]
Top rib short side	X145-Y355	208.1966	201.9524	6.2442	10.1	207.3915	201.9524	5.4391	8.1
Center surface between ribs low side	X70-Y306	165.3618	159.3343	6.0275	5.5	162.8571	159.3343	3.5228	3.6
Valley rib interaction trajectory	X153-Y355	207.6169	196.7828	10.8341	9.6	205.3806	196.7828	8.5978	8
Center surfacebetween ribs high side	X230-Y405	182.8914	181.9116	0.9798	0.65	182.54	181.9116	0.6284	0.5
Valley between ribs interaction trajectory	X153-Y406	189.9338	180.6112	9.3226	9.1	187.5423	180.6112	6.9311	7.1

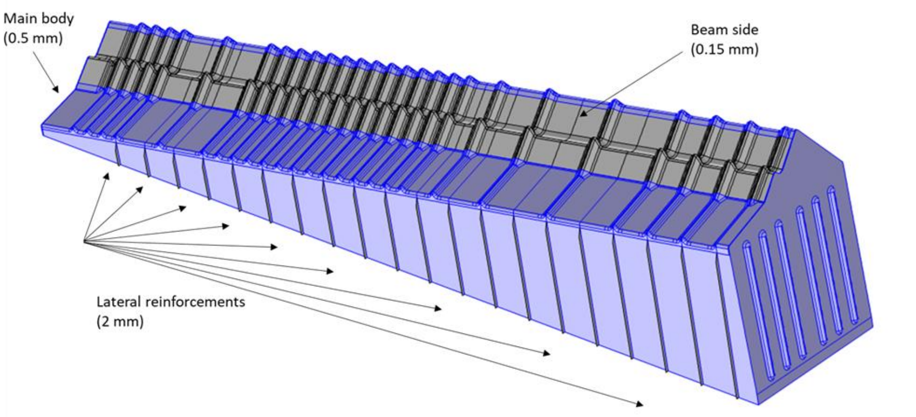
Comparison between simulation and test

Half VELO box

After the benchmark with the half box, the model was used to estimate the deformation of the VELO box.



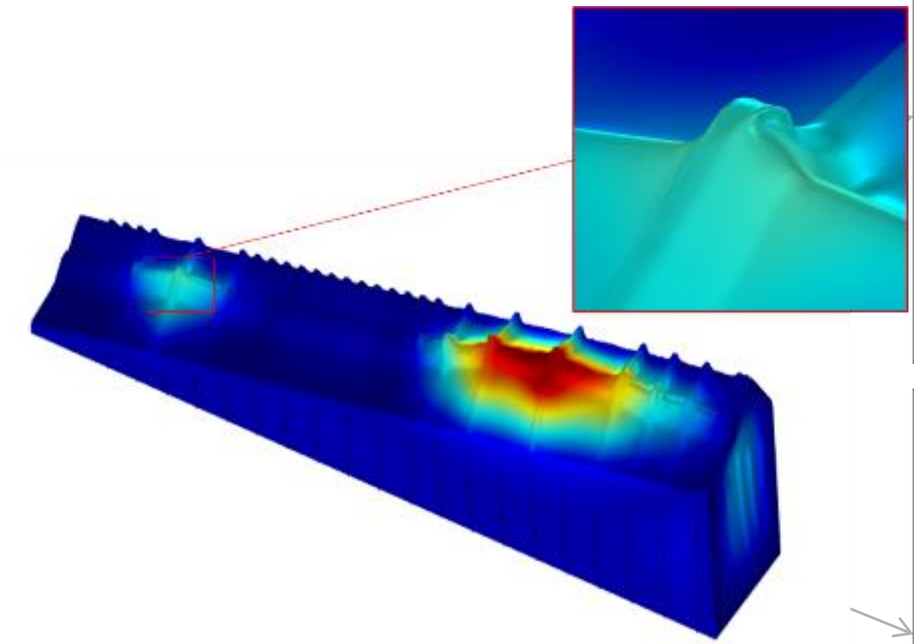
Half box was discretised with around 73 k triangular shell elements. In the red box local mesh refinement to capture local buckling phenomena observed during the test.

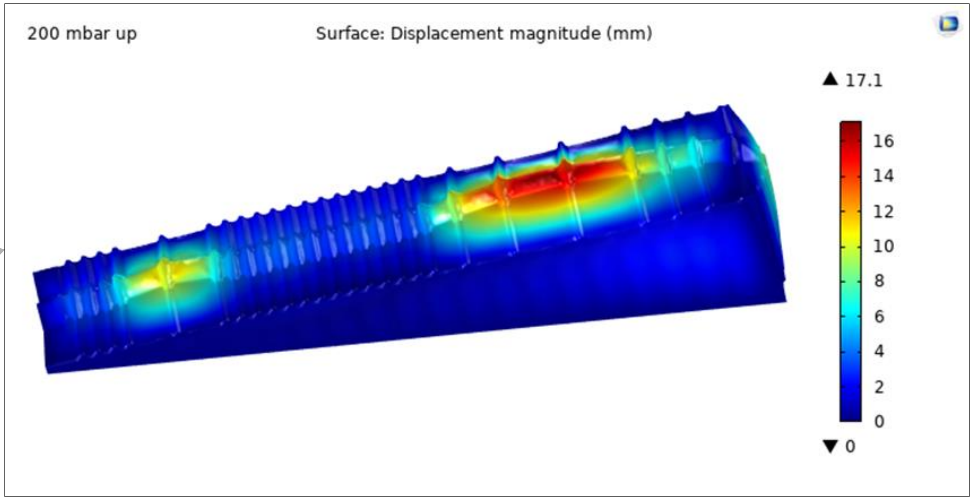


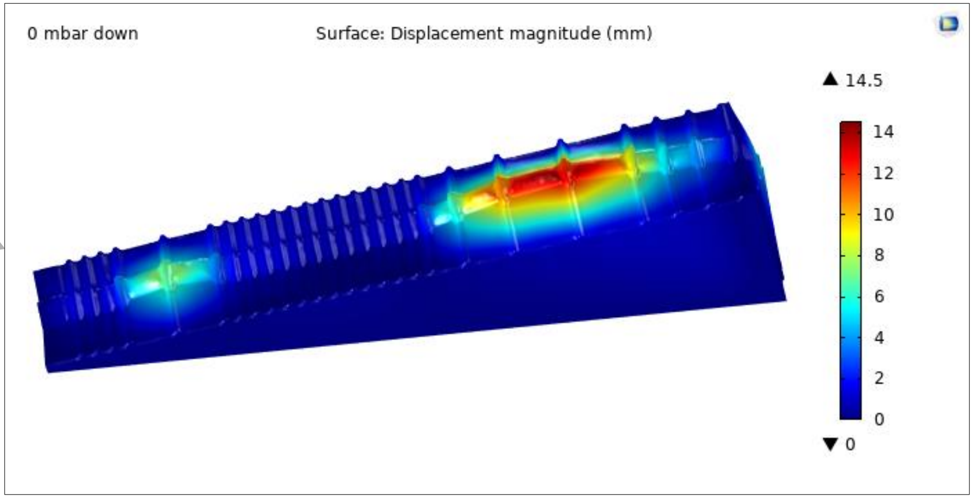
Thicknesses of the VELO box baseline model. The main body (in blue) is 0.5 mm thick, the beam side (in grey) is 0.15 mm while the lateral reinforcements are 2 mm thick (the etching non uniformity was considered).

VELO box

Total displacements at 200 mbar (up) and 0 mbar (down-permanent deformations)



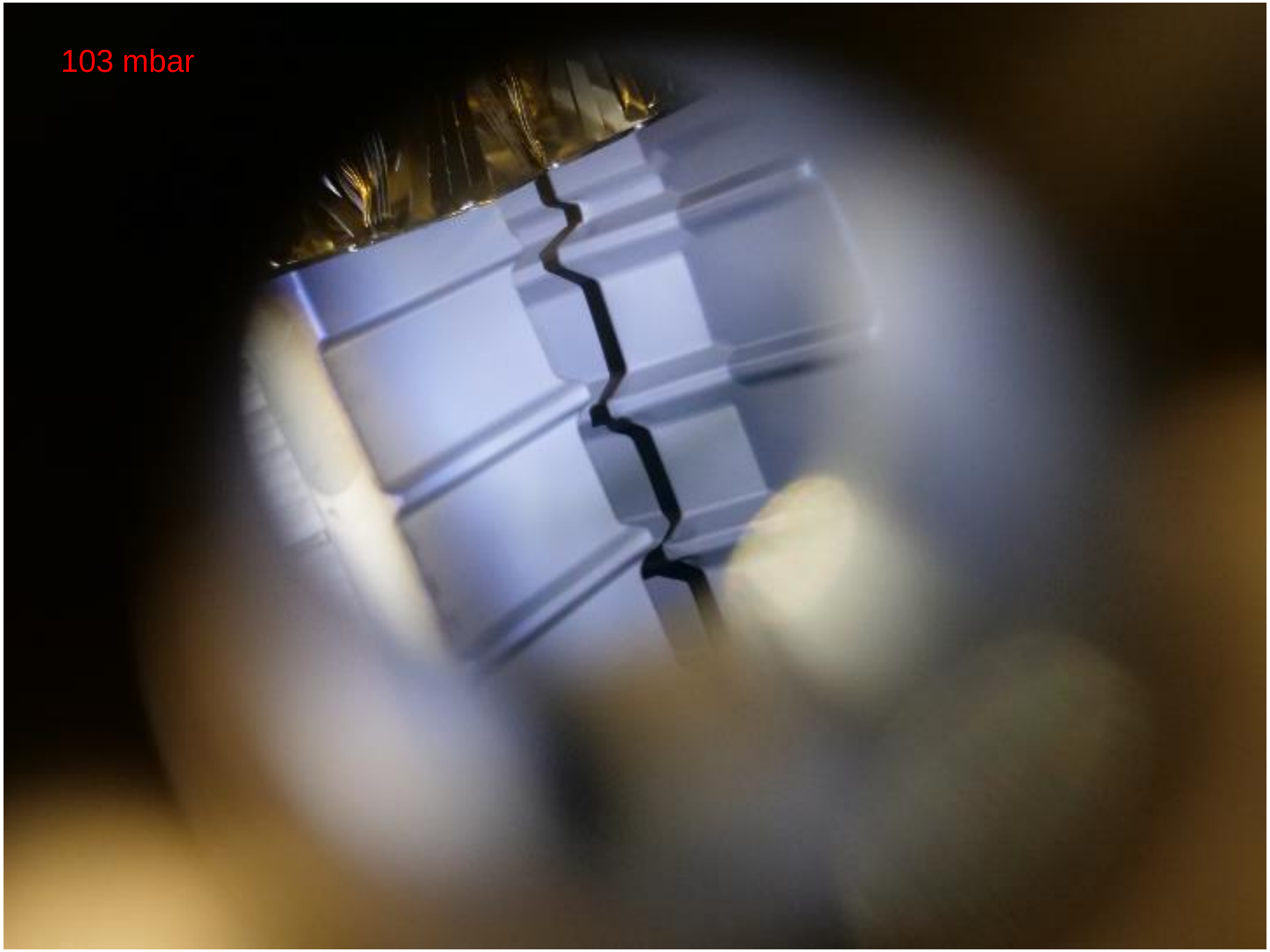




Local buckling appear at around 100 mbar thanks to local mesh refinement.

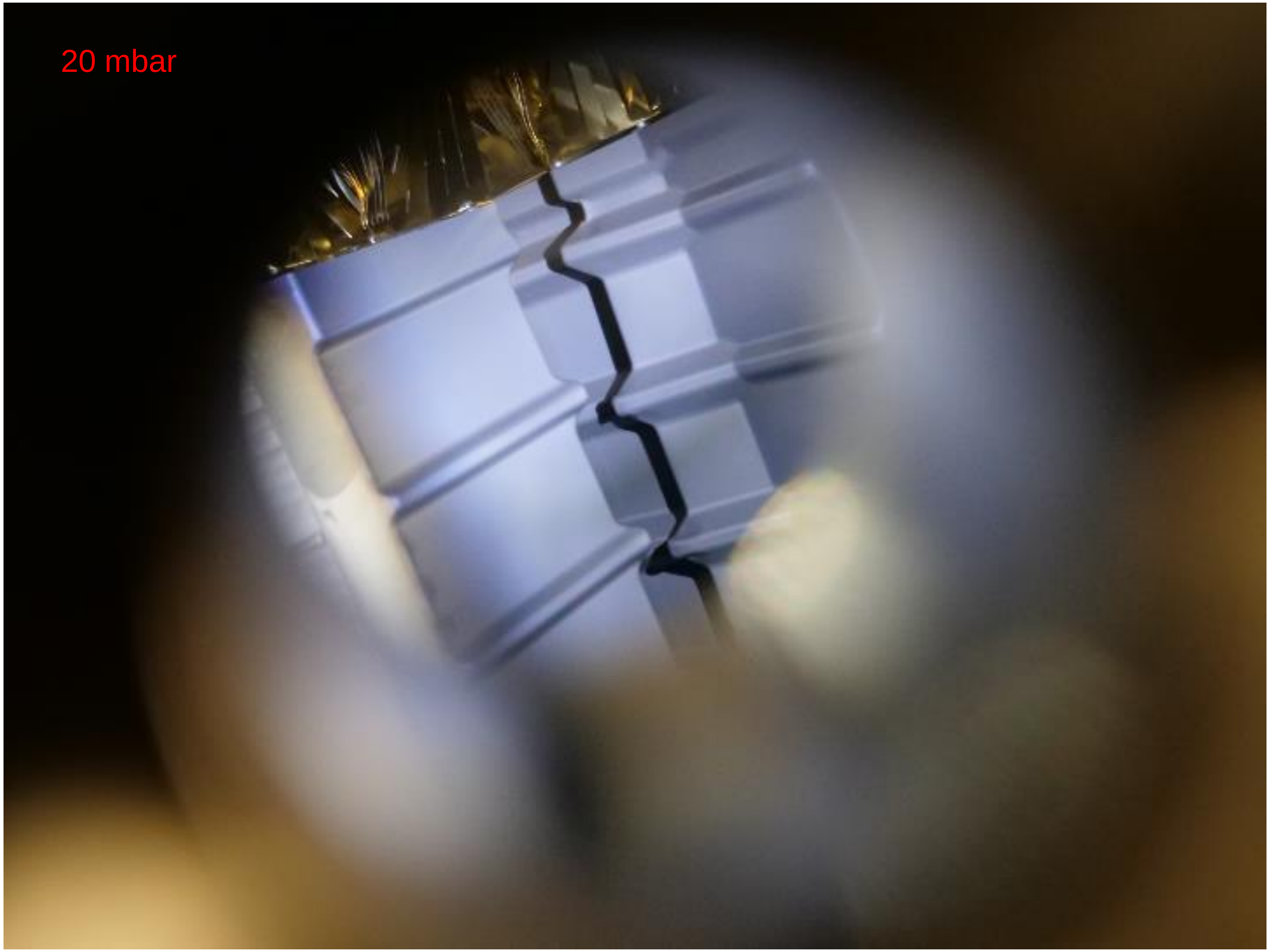
VELO box

Qualitative comparison with images from VELO viewport



VELO box

Qualitative comparison with images from VELO viewport



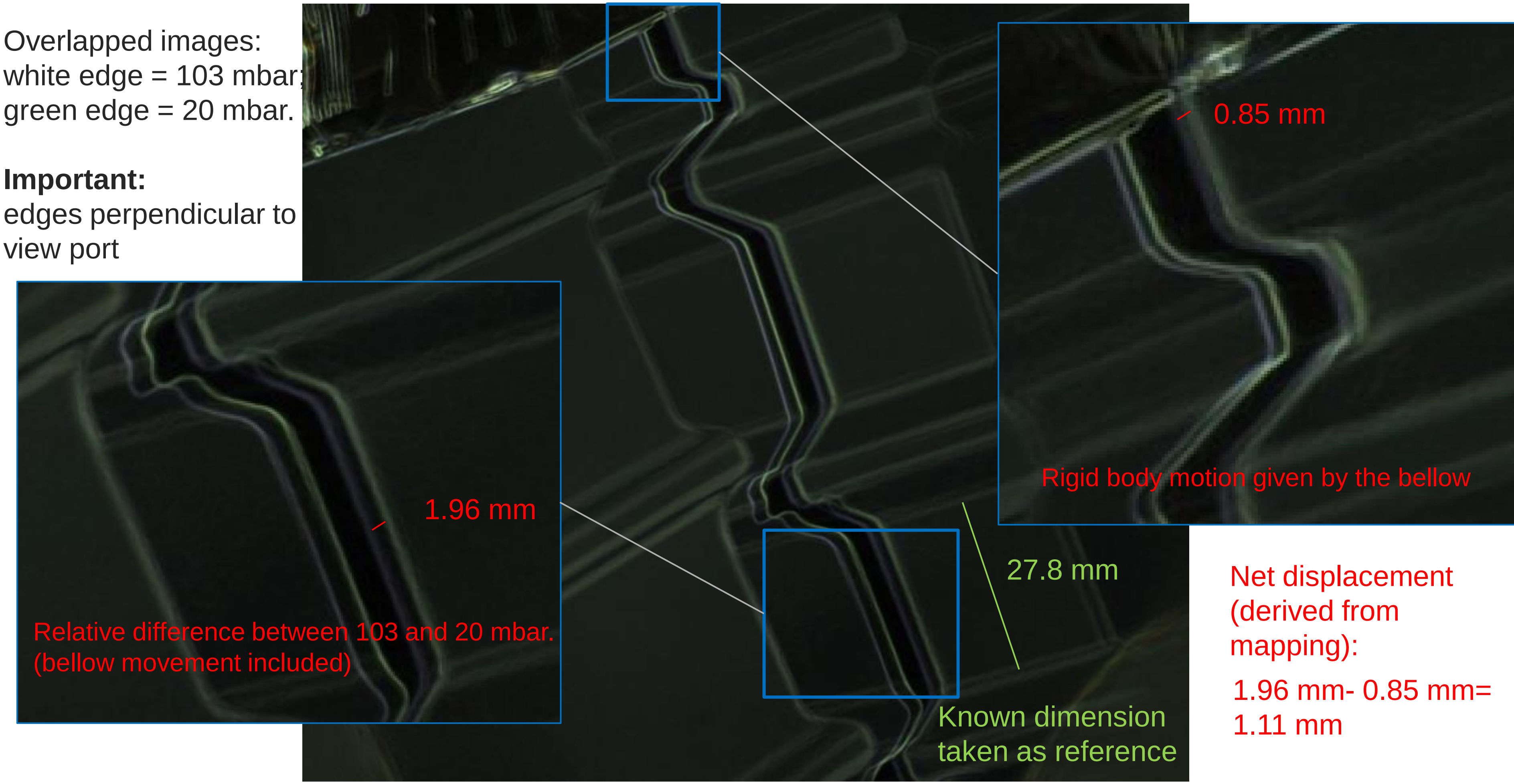
VELO box

Qualitative comparison with images from VELO viewport

Rough estimation VELO displacement between 2nd and 3rd rib

Overlapped images:
white edge = 103 mbar;
green edge = 20 mbar.

Important:
edges perpendicular to view port



Net displacement (derived from mapping):

1.96 mm- 0.85 mm= 1.11 mm

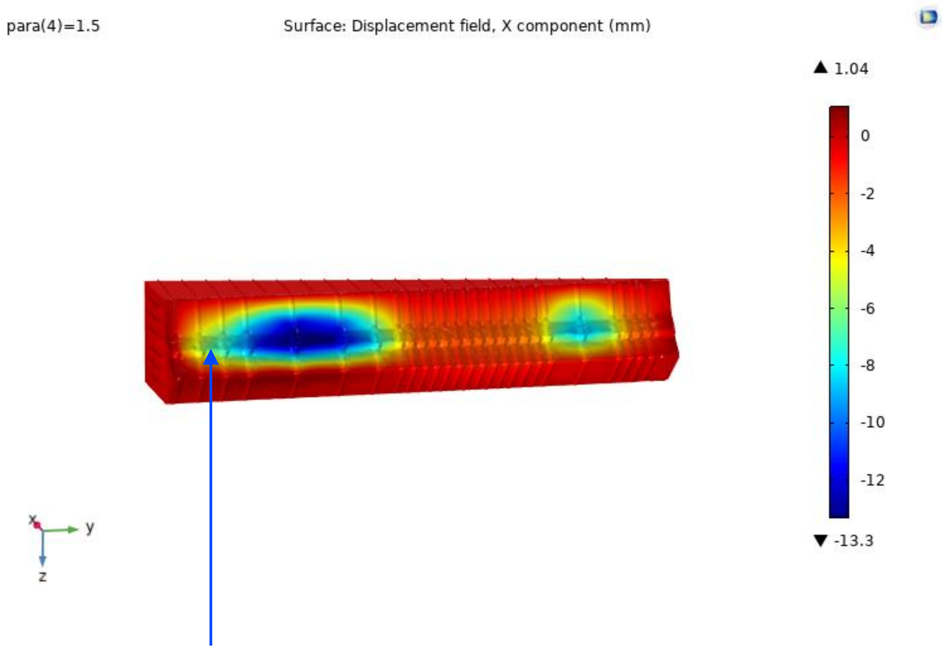
VELO box

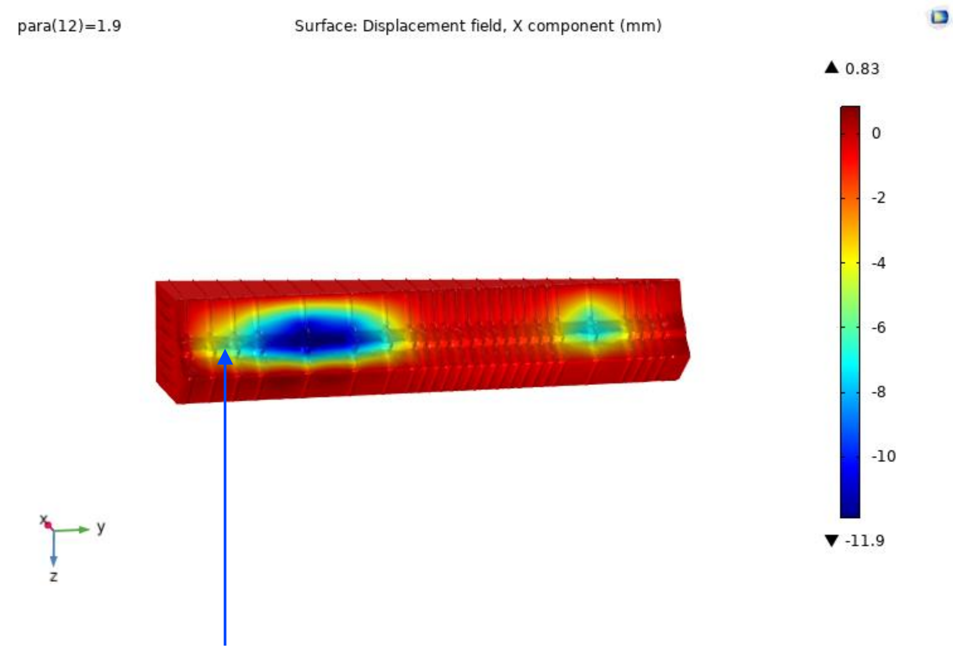
Qualitative comparison with images from VELO viewport

Rough estimation VELO displacement between 2nd and 3rd rib

100 mbar

20 mbar





6.68 mm

5.47 mm

FEM vs **VELO images**

6.68 mm - 5.47 mm = 1.21 mm

1.96 mm - 0.85 mm= 1.11 mm

Conclusions

- Highly nonlinear and computationally expensive simulations (up to around 30 h) developed to predict the deformations of the VELO box;

- Close agreement, within 1 mm, between the dedicated test of the half box and simulations, which allowed to benchmark the FEM model;

- Large permanent deformations expected in the VELO box: 14.5 mm towards beam vacuum;

- Local buckling phenomena captured in the simulations at around 100 mbar for the most loaded ribs thanks to dedicated mesh refinement;

- View port images of the VELO box in good agreement with simulations (rough comparison but the only possible one).

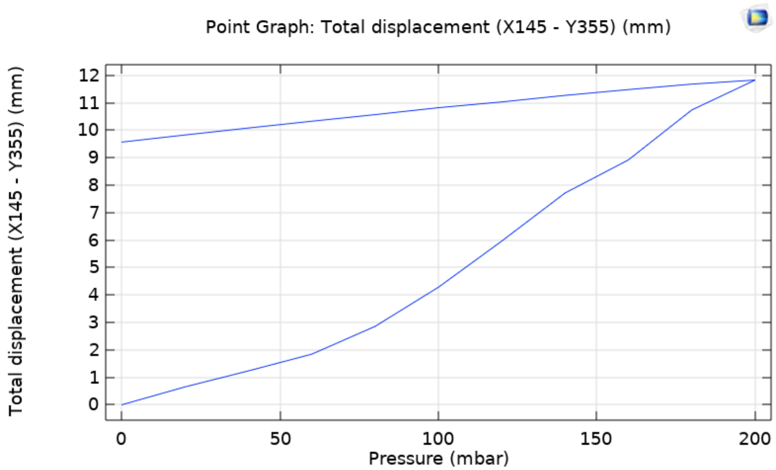
Thank you!!

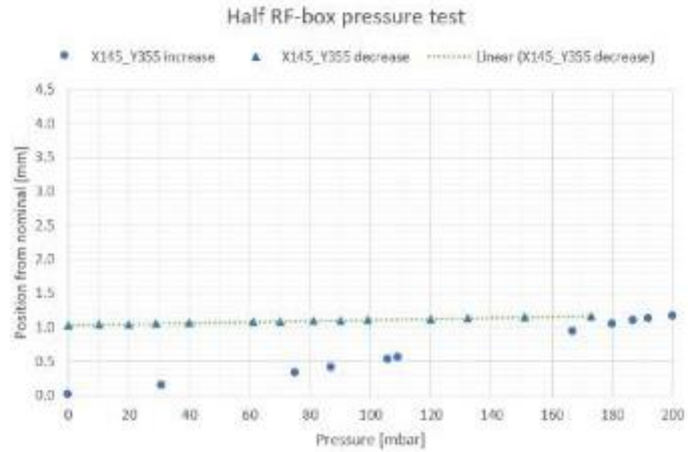
Extra

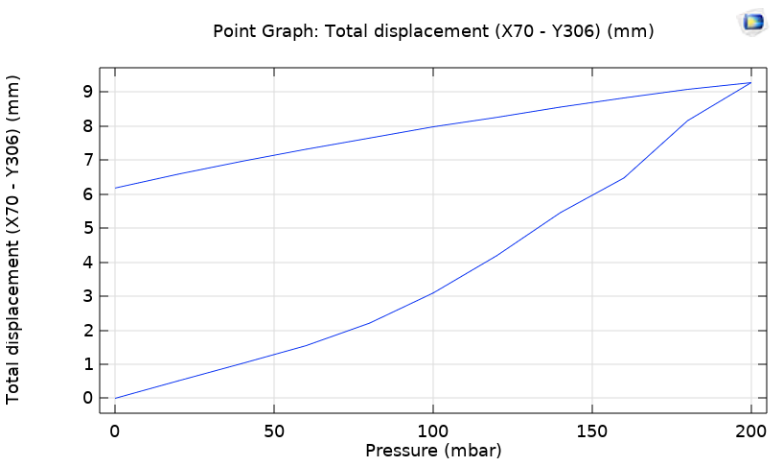
FEM / test comparison on the half box

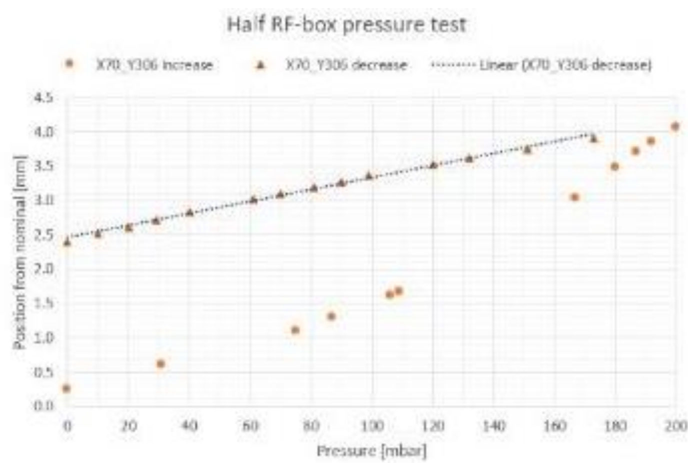
-Pressure vs displacement -

Only the slope should be compared:
displacement component during the test not identified









FEM / test comparison on the half box

-Pressure vs displacement -

Only the slope should be compared:
displacement component during the test not identified