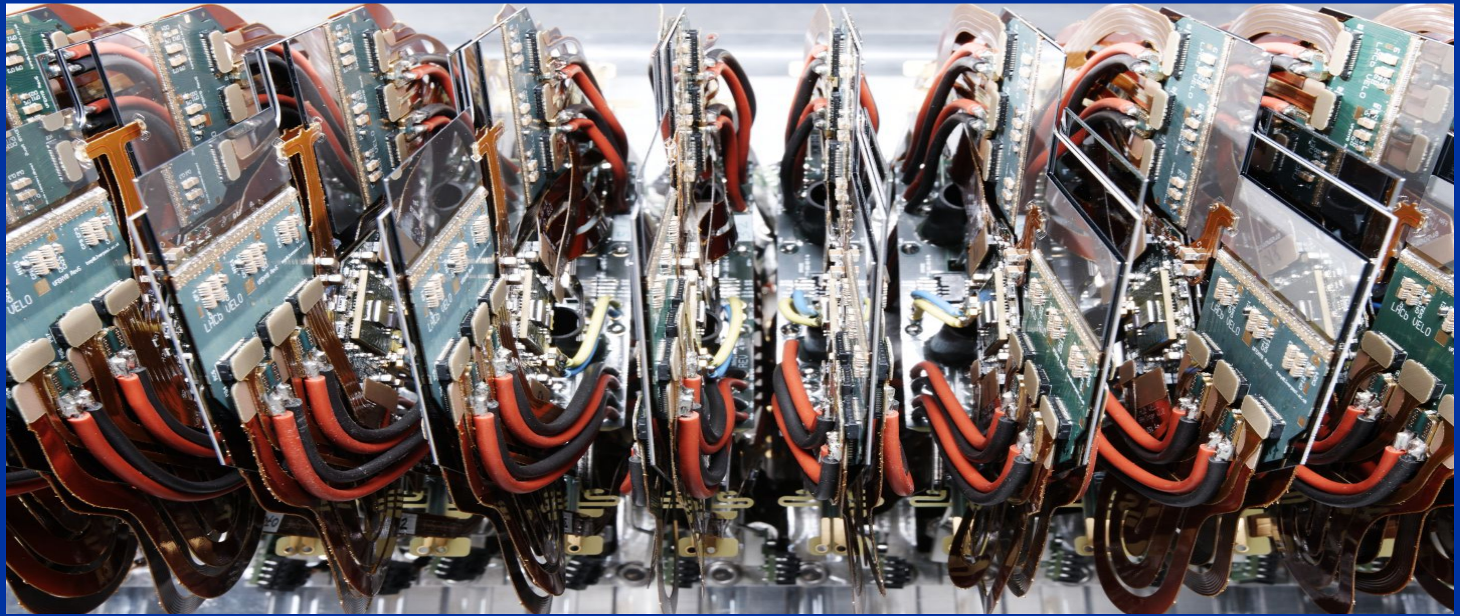


Status and plans for the LHCb VeLo motion system re-validation

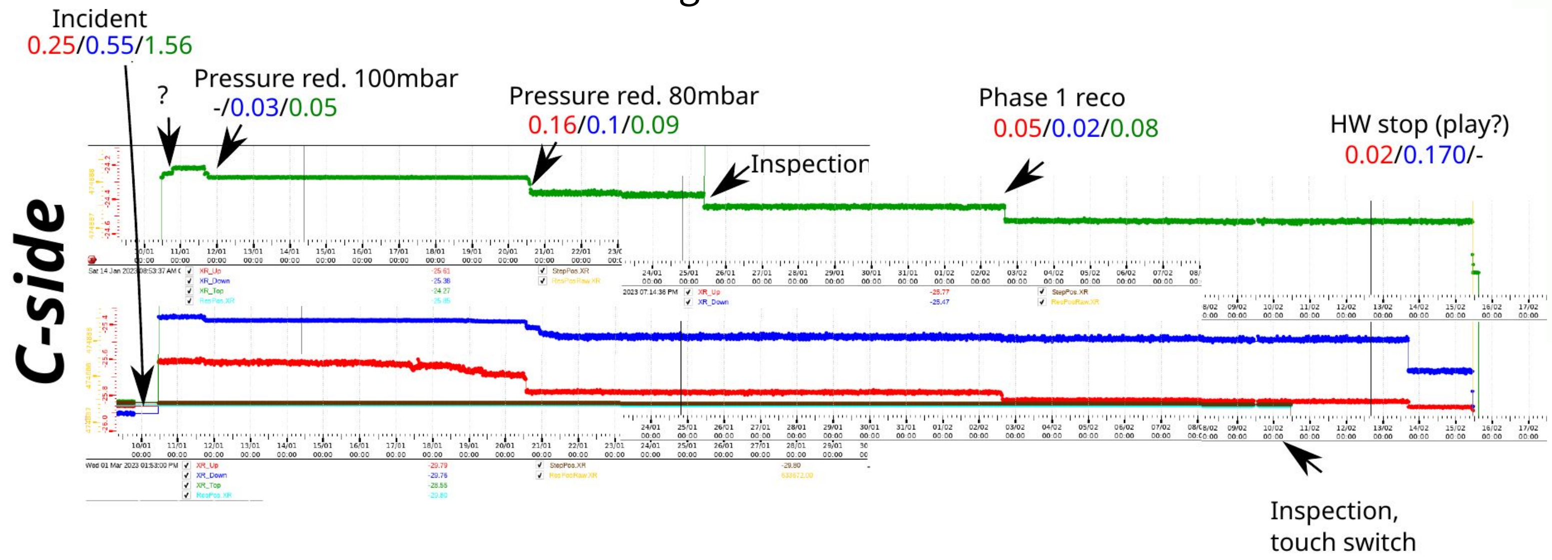
Victor Coco (CERN) for the VELO Group

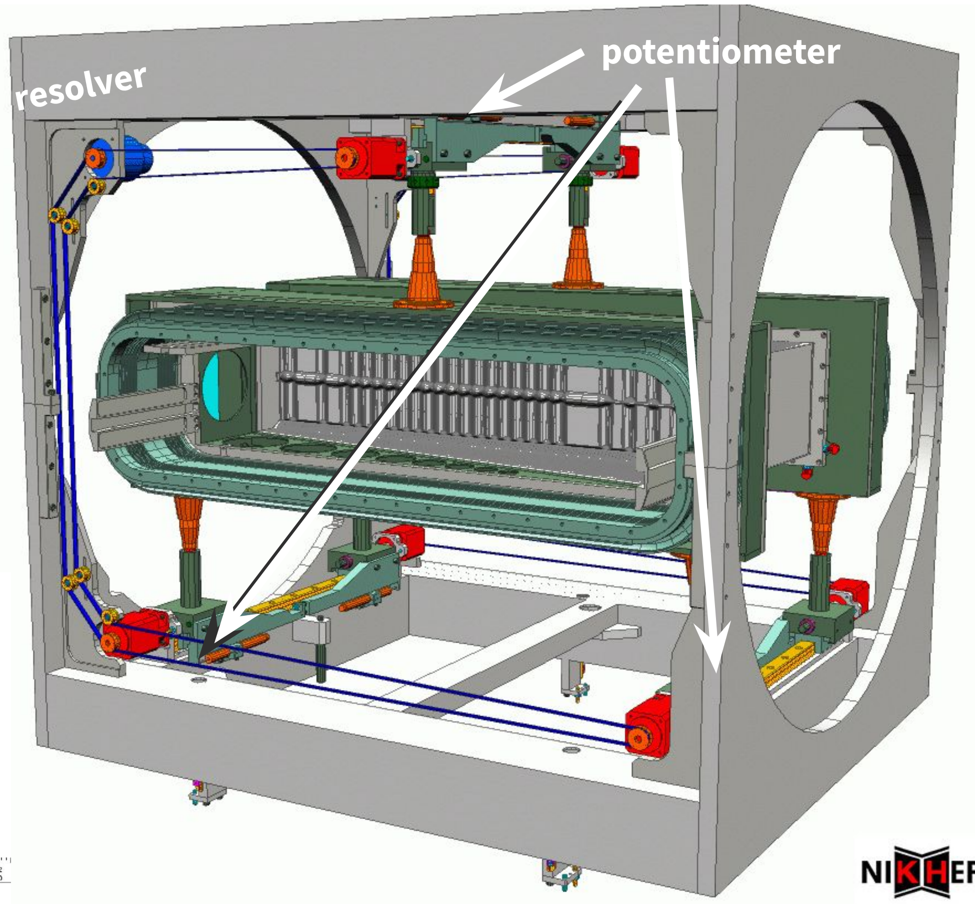
with inputs from Vacuum group (CERN TE-VSC), LHCb Tech. Coord

R. Dumps, W. Byczynski, F. Sanders, K. Bridge, X. Pons

Motion system behaviour during event

- **Movement seen on the motion system during the event.**
  - monitoring was unfortunately OFF during event (all control/monitoring machines were down in preparation for the AUG test)
  - Pressure difference pulled on the two halves
  - Movement seen on the potentiometer (ie mvt of the detector support cart)
  - No significant movement on the resolver (1 step C side, 4 A side, ie few um)
  - position relaxed with rebalancing the pressure
  - all indicate the movement seen on potentiometer is propagated to the VELO
  - beamline reconstruction will give clear answer.

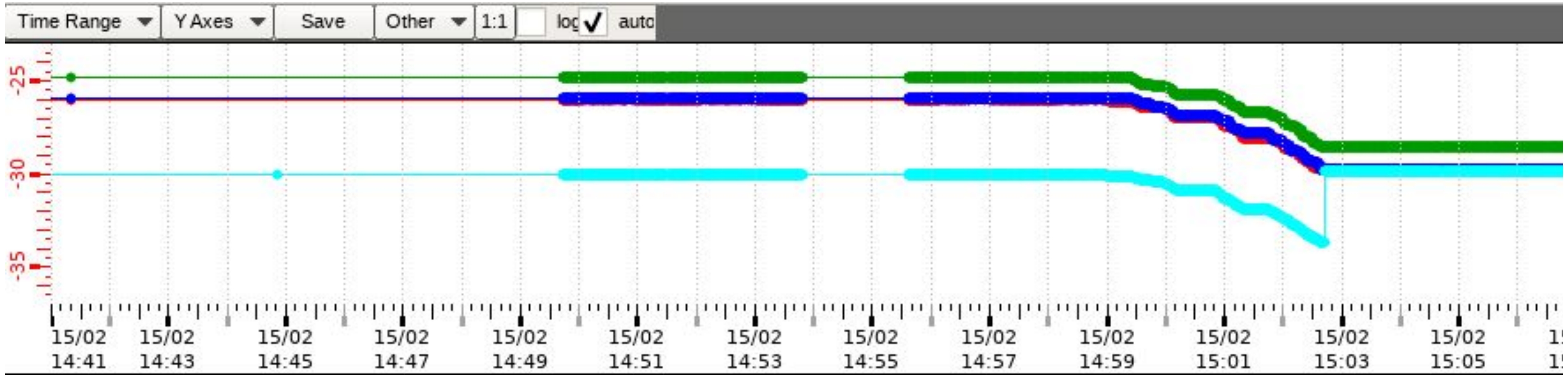


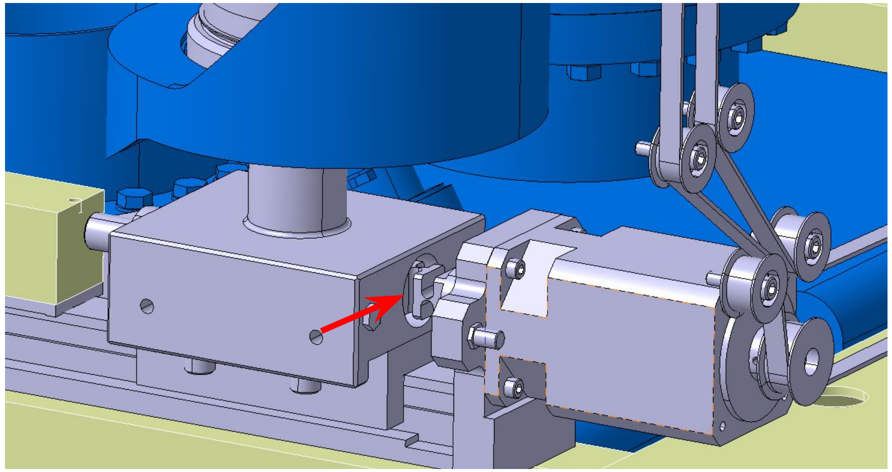


R. Dumps, W. Byczynski, F. Sanders, K. Bridge, X. Pons

Test and investigation

- **Good response of the system during test**
  - small movement between -26/28mm and -29.8/29.8mm
  - residual displacement of the top support by 1.25(0.9)mm on C(A)-side





- **Hypothesis is deformation of the coupling piece**
  - stress test on-going, significant elastic deformation and deformation by more than 1mm seen, data to be further analysed and quantified
- **Re-qualification procedure to be defined**
  - inspection of coupling pieces need to be done with half closed
  - only possible after tomography: with one foil open and one closed closest approach ~1-2mm ie risk of collision

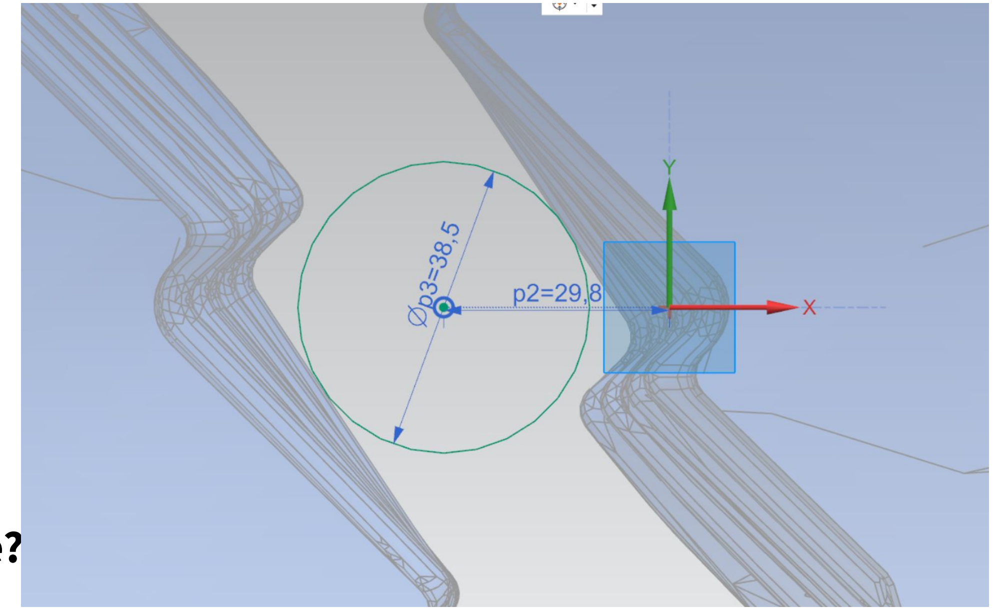
⇒ HW and SW limits on the motion system for now

Impact VELO open or partially closed

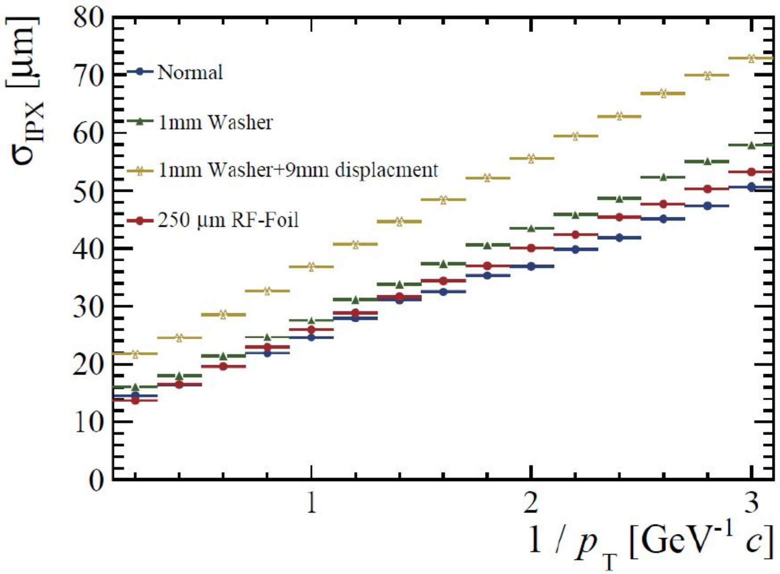
J. Haimberger, F. Sanders, M. Morrone (TE-VSC)

- **Aperture with VELO in open position from 49mm to 38.5mm**
- **Fully open VELO has reduced overlap with LHCb acceptance**
  - ~50% coverage in ϕ, 1.5<η<3.8 [to be refined with simulations]
  - can do most of the remaining VELO calibration / commissioning
- **If we can re-qualify the motion system, could close to ~10mm**
  - ~70% coverage in ϕ, for 2.<η<4.2
  - can do most of the remaining VELO calibration / commissioning and support most of the global commissioning
  - open the possibility of a 2023 physics program
- **If we can't, could consider moving once to the closest of minimal aperture?**

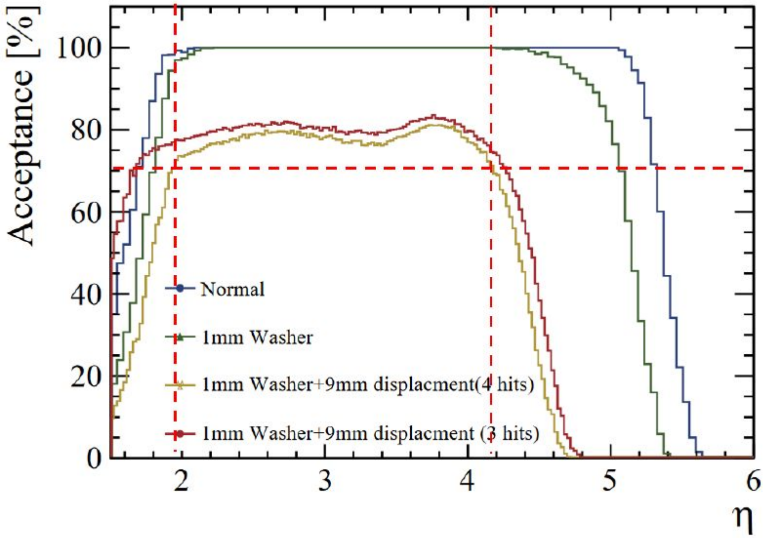
Simulated deformation



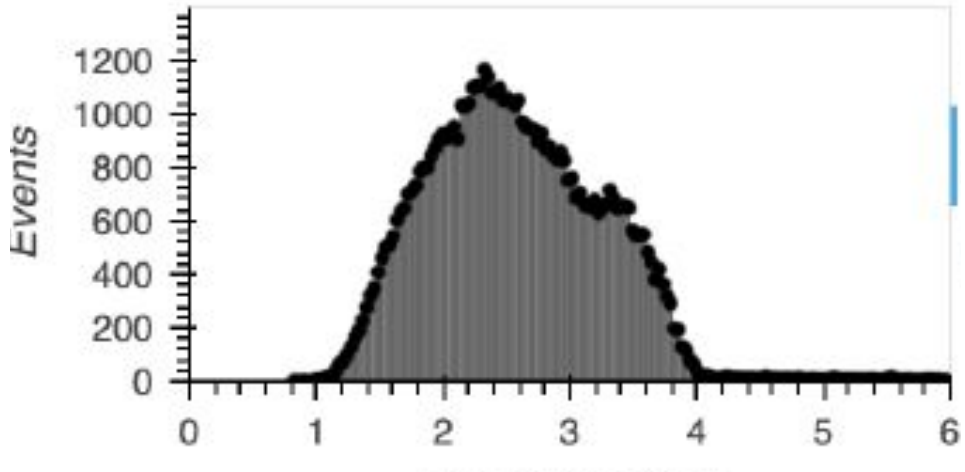
IP @10mm



Efficiency loss due to phi-gap @10mm



Pseudo rapidty distribution in pp collision in 2022 in open position



Status and Plans

- **Not planning to close the VELO before:**
  - inspecting the coupling piece (need tomography before doing inspection)
  - asses if VELO can be moved safely

    ⇒ for the moment motion is limited both in hardware and software.
- **On-going investigation**
  - study of the system, test of the pieces that could have been damaged
  - tomography and measurement of the beamline position will provide more information

- **Possible outcomes are:**
  - motion system is re-qualifiable:
    - max closing will be driven by the deformation
    - we should re-discuss at that point the closing strategy
  - motion system can be moved to “minimal aperture” position (1 move), but not reliable enough to open/close at every fill
    - Exact “minimal aperture” position depends on the exact deformation (need tomography beforehand)
  - motion system cannot be moved safely
    - VELO remains open for 2023

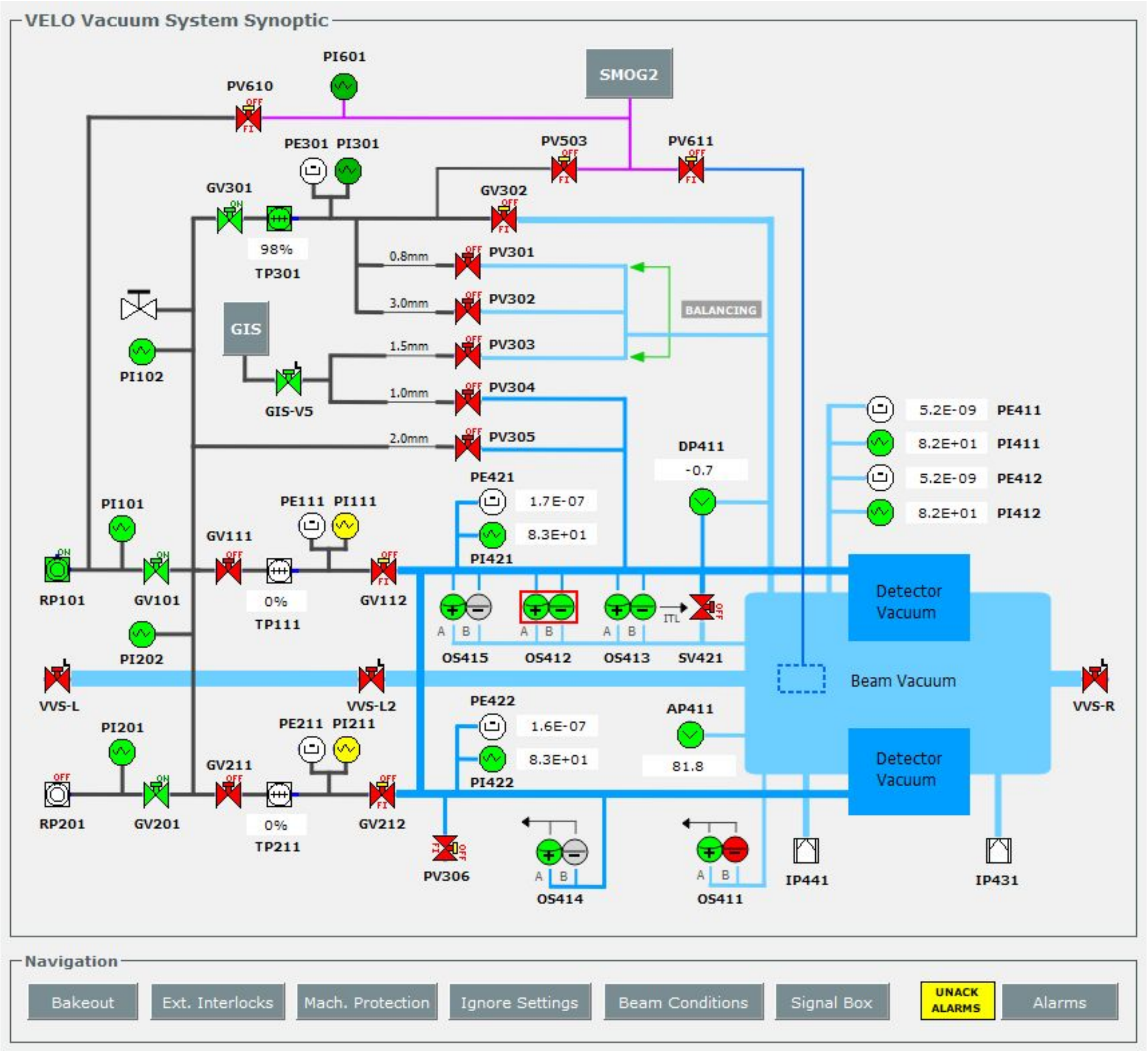
BACKUP

more information on the incident timeline, on the RFFoil simulation and

About the VELO vacuum system

- **A set of pressure switches ensure:**
  - Safety of the foil: at **+/-10mbar** ΔP the valve between beam and detector volume opens
  - Activation of the balancing system: at **+2/-5mbar** ΔP the GIS pumps/inject ultra-pure Neon in the beam volume
  - Triggering of the CO_2 safety system: at **-6mbar** ΔP, the valve allowing circulation of CO_2 within the detector to be closed (in parallel with an algorithm detecting fast rise of the pressure)
  - the beam volume or detector volume pressures wrt. atmosphere trigger warnings

- **A set of pressure gauges ensure the monitoring of the volumes**
  - Under low to ultra-low vacuum a set of Pirani and Penning gauge provide vacuum levels.
  - When vented a capacitive gauge (baratron) is reading Neon pressure in primary volume (absolute calibration issues because of radiation).
  - A ΔP capacitive gauge is providing precise differential pressure measurement between beam and detector volume
  - Detector volume is equipped with pressure gauges (but not part of the vacuum system, instead target measurement of fast rate change for pressure above 2-3mbar, as part of the CO_2 safety system)
  - Implemented and controlled by the Vacuum group based on RunI & II design



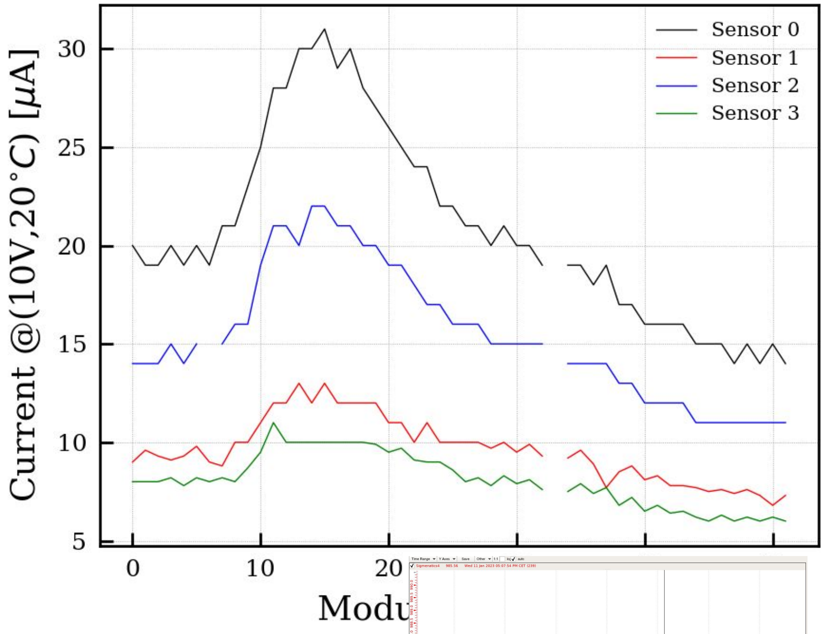
VELO Vacuum incident

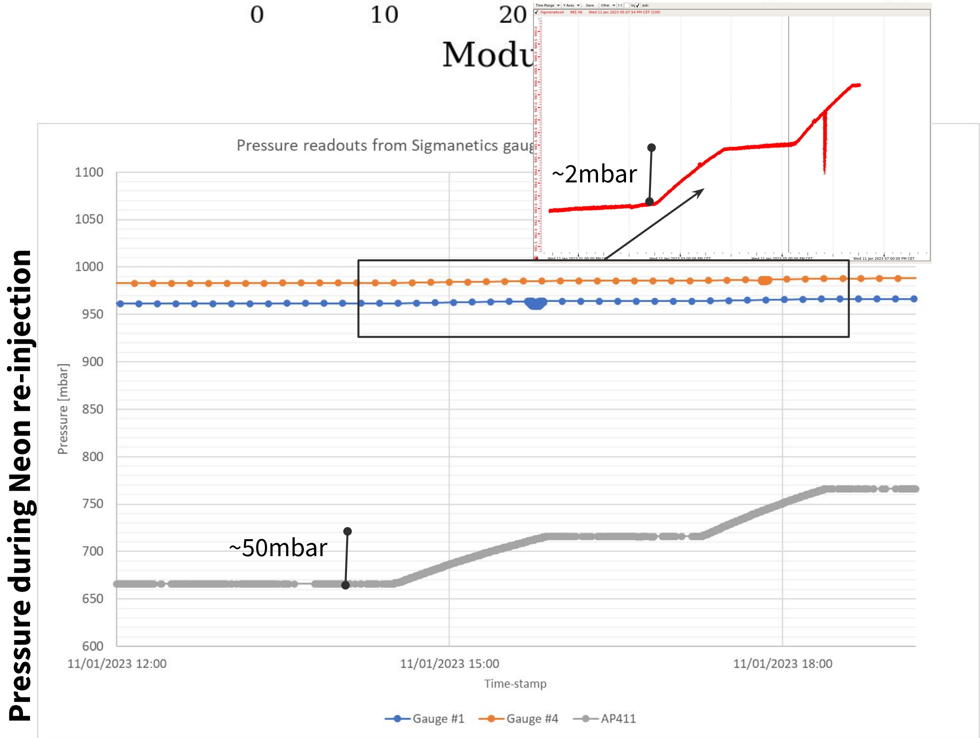
- **No CO2 leak**, ie the microchannels are OK.
- **Cooling has been stopped**
- Fine to stay warm (beneficial annealing not yet saturated)
- **Sensors are OK**, current consistent expected increase from radiation+temperature

⇒ **primary goal is to keep the detector safe**

- The day after the event had **no direct pressure measurements**
- **Re-injected 2 times 50mbar to reduce over-pressure**.
- At that point:
  - work from TE-VSC to get back pressure switch readout and pressure measurements
  - fear of buckling in the detector direction while relaxing
  - no effect from creep expected

⇒ **needed to assess whether or not is it safe to go back to balancing**





RF-foil deformation studies

work from LHCb VELO Nikhef team and CERN TE-VSC

Simulations of the boxes deformation

- **Aim to estimate the deformation and assess possible risk for the detector to relax pressure difference:**
  - half-box simulation compared to measurements @ Nikhef to validate the model
  - full box simulation to estimate the situation in the VELO

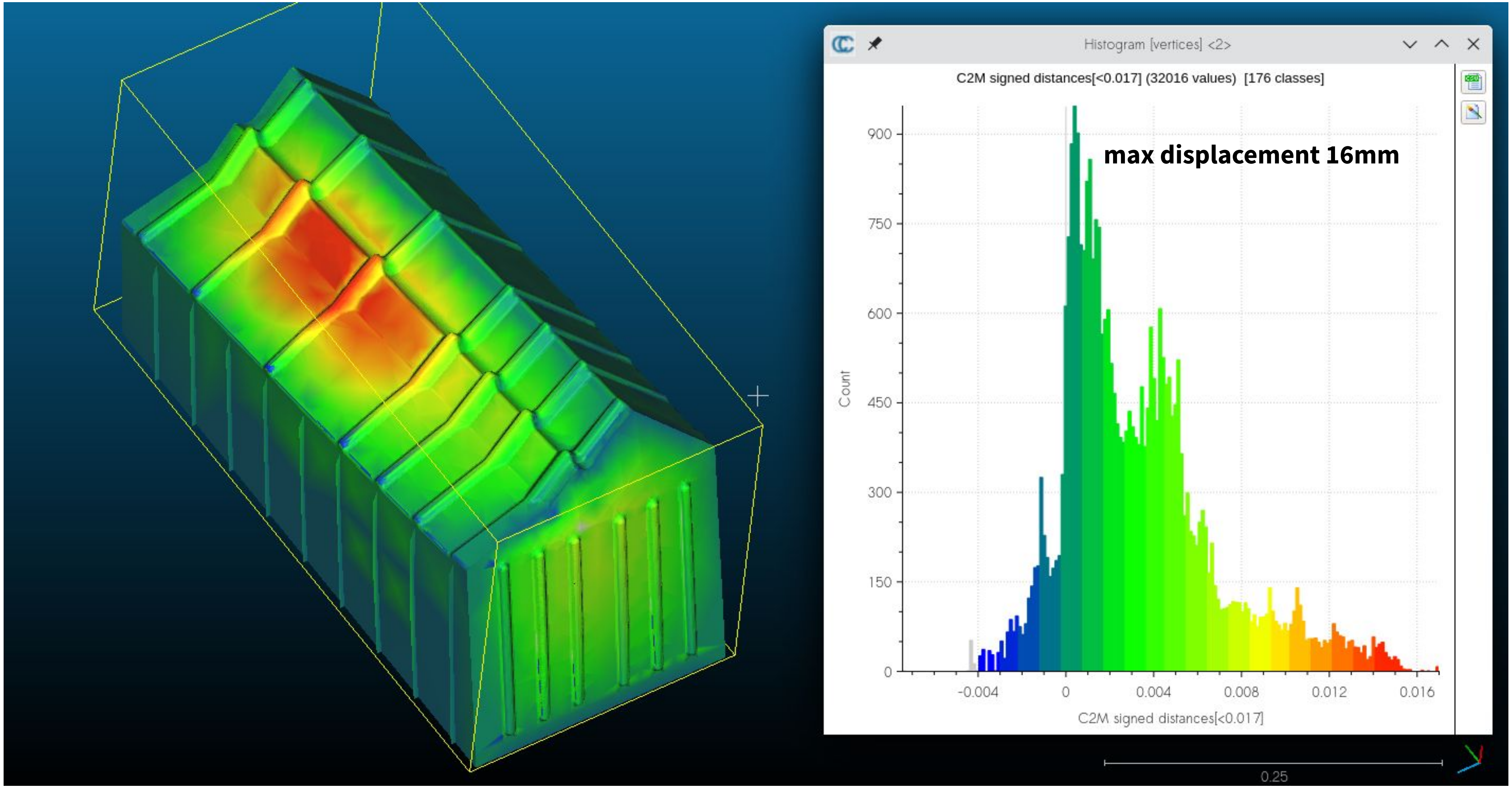
- **Elasto-plastic simulation with COMSOL**
- **Material properties "assumptions":**
  - For the half box no material certificate (ie no measurement of the elastic limit), but estimation @120MPa, and simulation done @140MPa (worse agreement)
  - For the full box material certificate gave 134MPa

- **Reproduced the pressurisation cycle**
  - 0→ -200mbar → 0mbar in step of 10mbar
  - 0mbar → 2mbar → 12mbar → … to check impact of underpressure

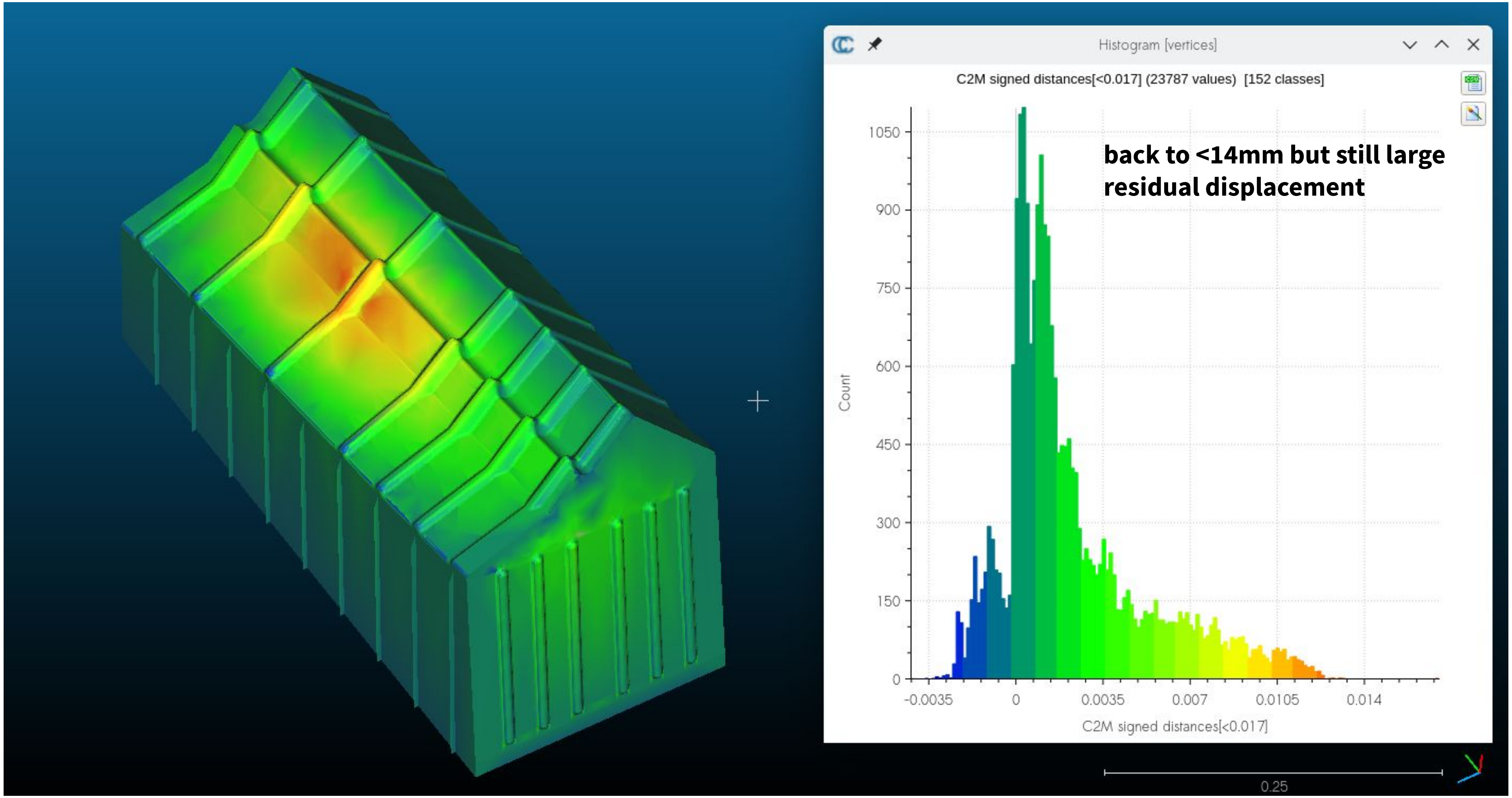
- **Linear and non-linear buckling analysis**
  - to try an assess if the foil could deform back in a "uncontrolled" way
  - no back buckling seen @ Nikhef on the small foil

- **Rather lengthy simulation (up to 17h) performed by M. Moronne and C. Garion (TE-VSC) starting from studies done by J. Van Dongen (Nikhef)**

Simulations of the half box @-200mbar

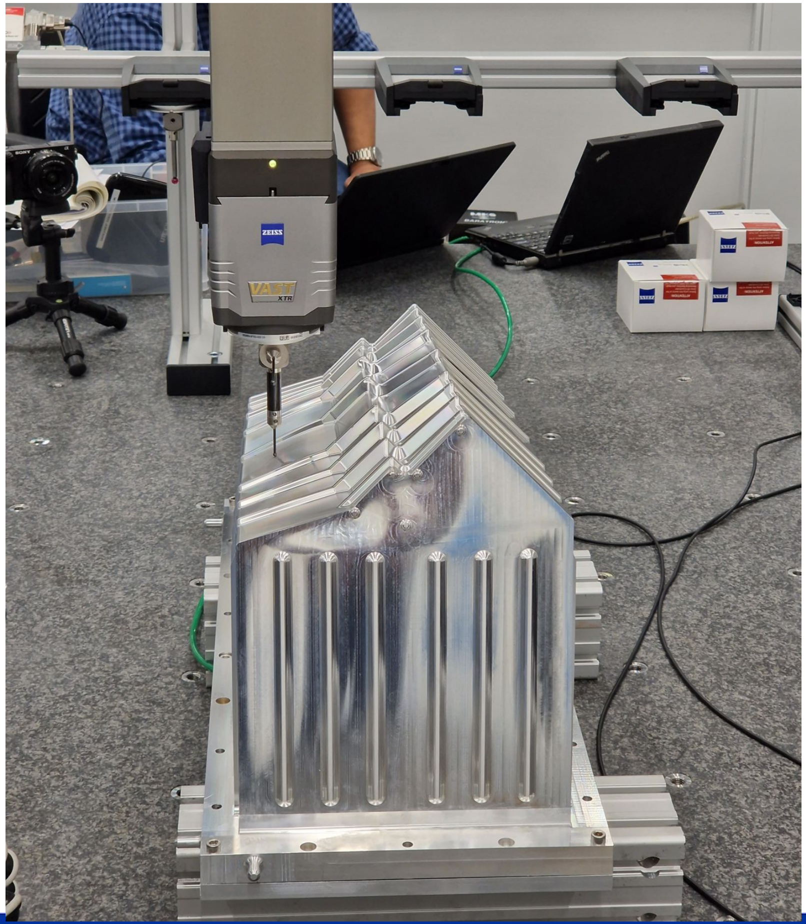


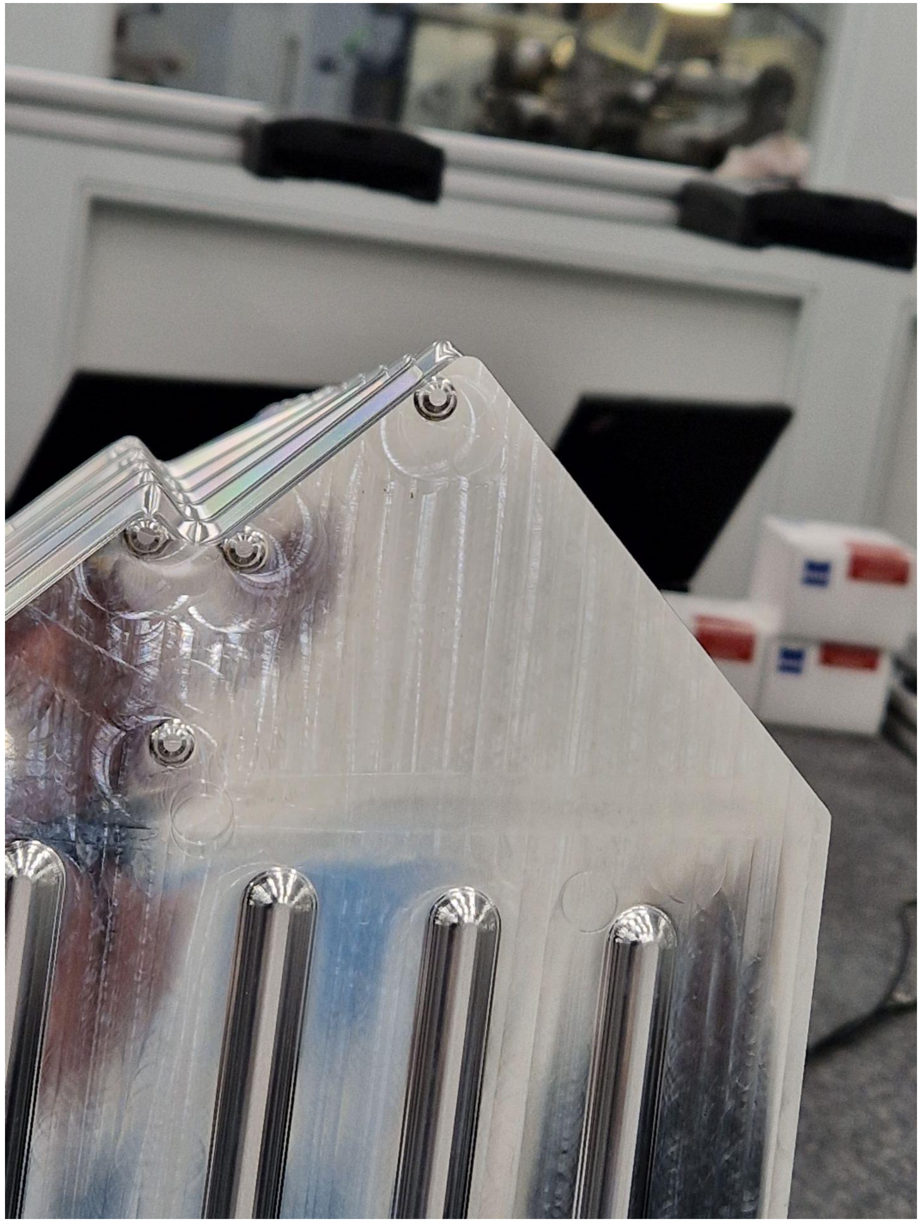
Simulations of the half box back to 0mbar



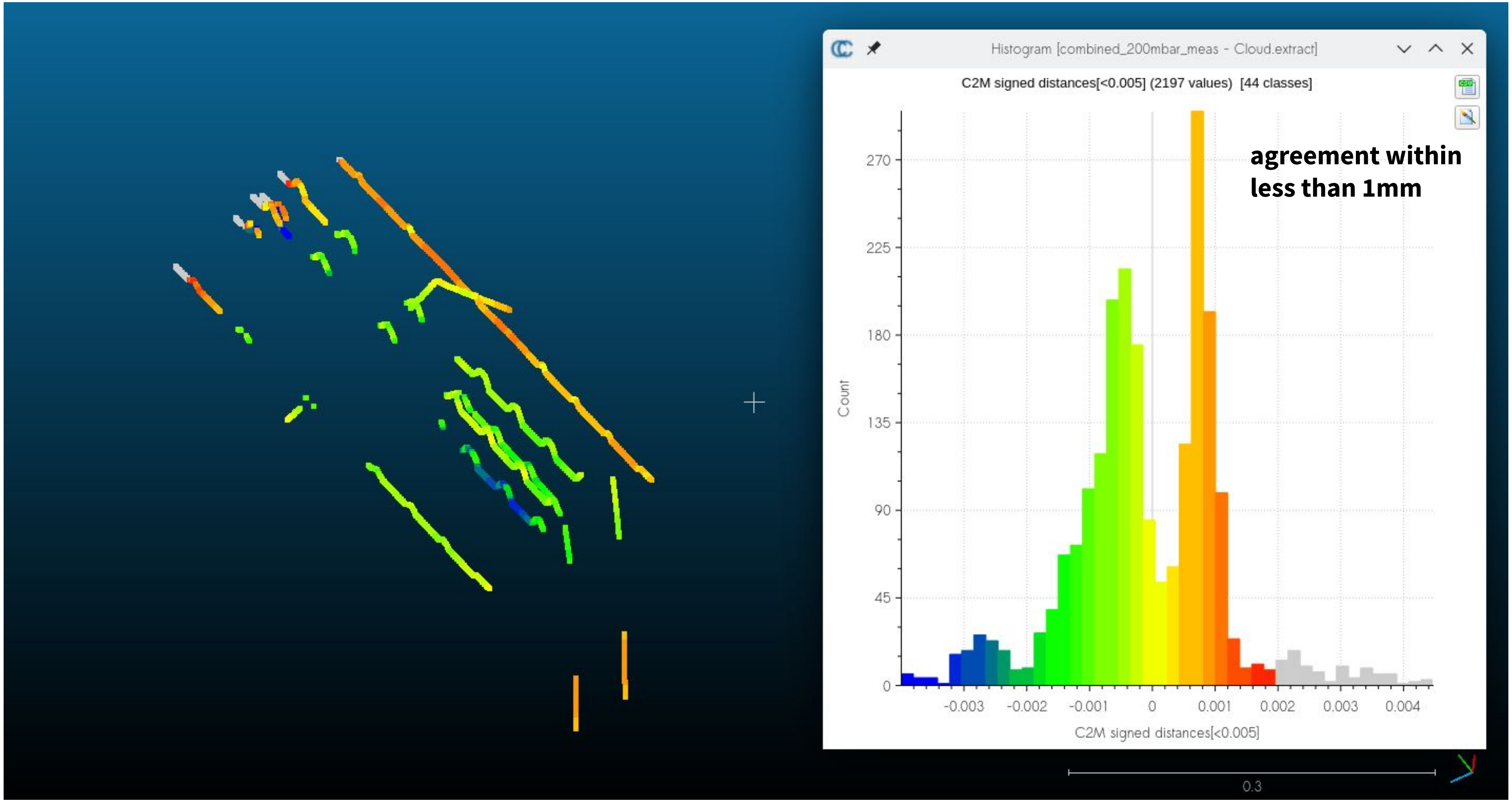
Measurements at Nikhef

- Half box, 500 µm thick with central thinned/etched part to 250 µm, torlon coated
- Pressure cycle: 0 → 200mbar → 0 → -11mbar → -25mbar
- Used to validate simulations

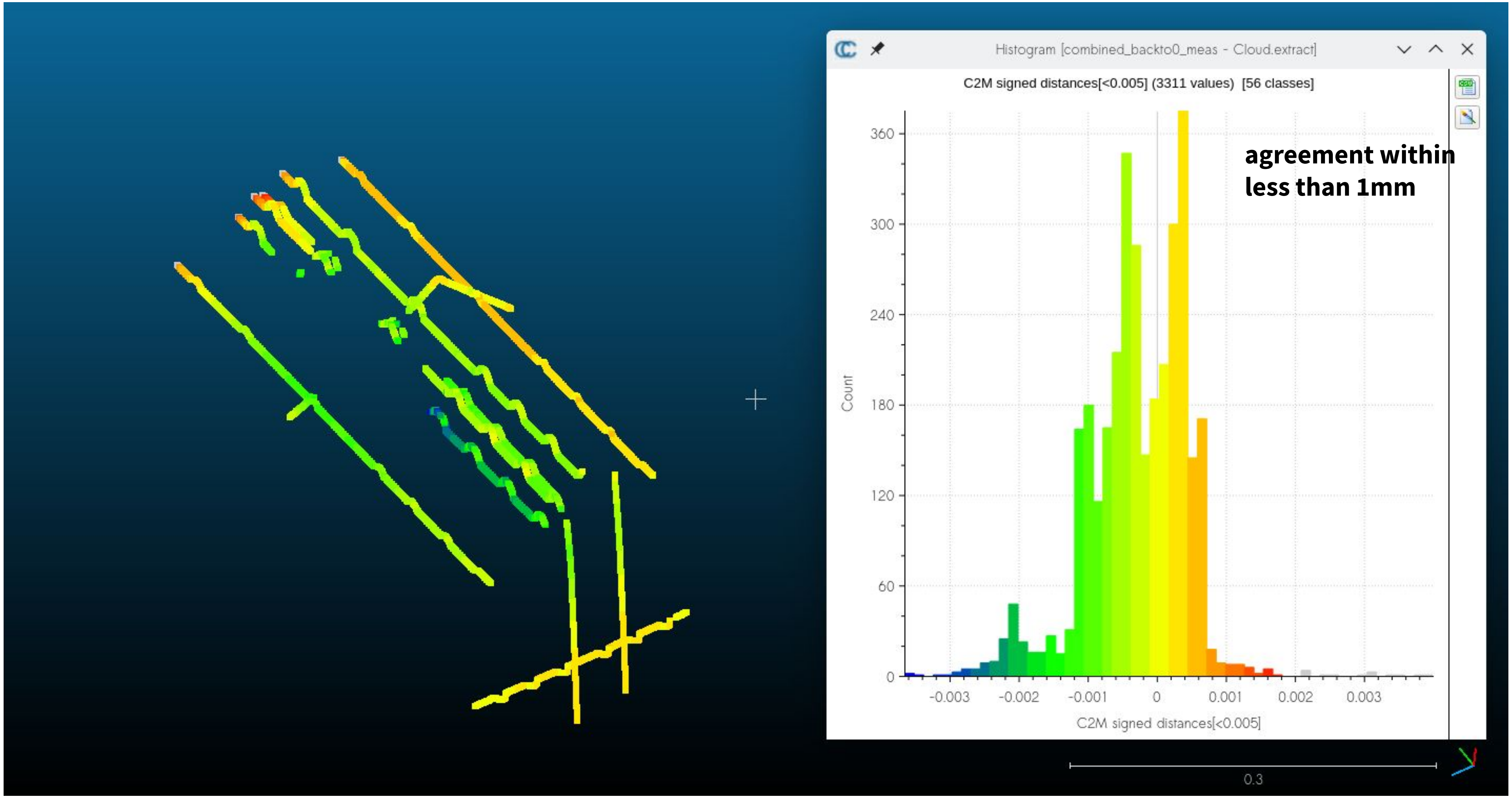




Simulations of the half box

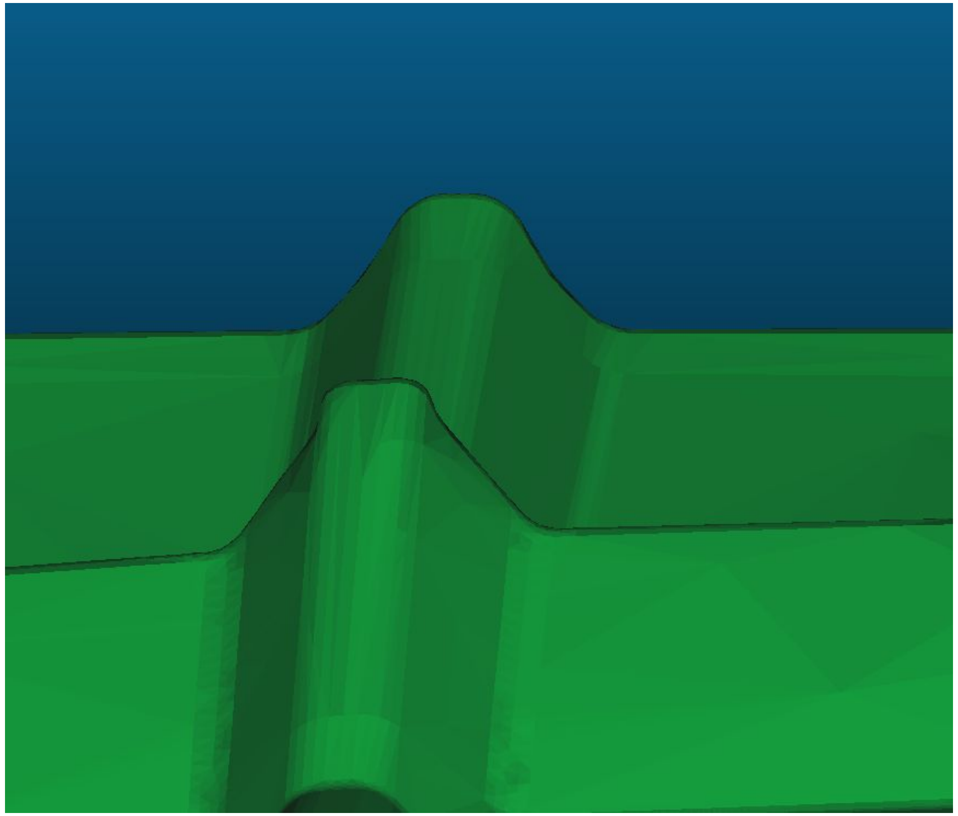


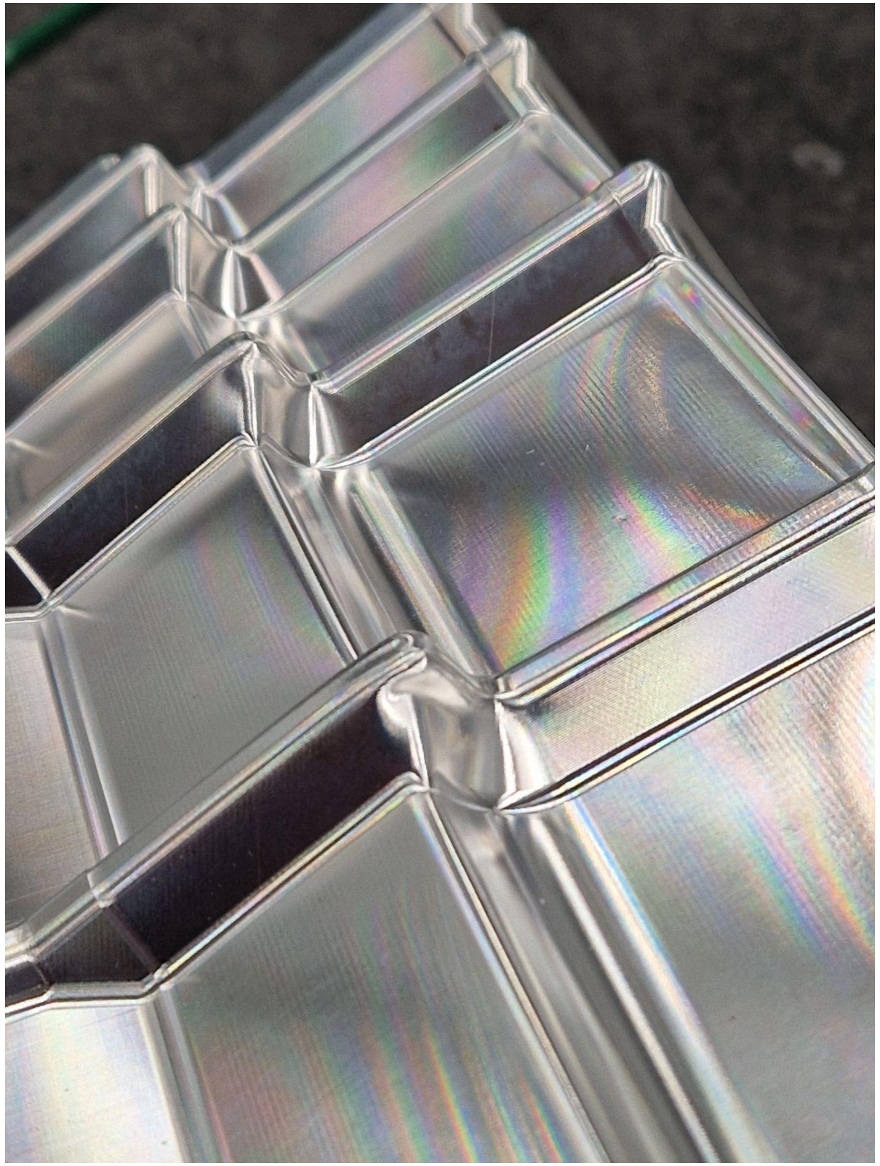
Simulations of the half box



Simulations of the half box

- **Local buckling reproduced in simulation**
  - here with coarse mesh at the same place
  - more detailed “pinching” with smaller mesh on the large foil





Validity of the model

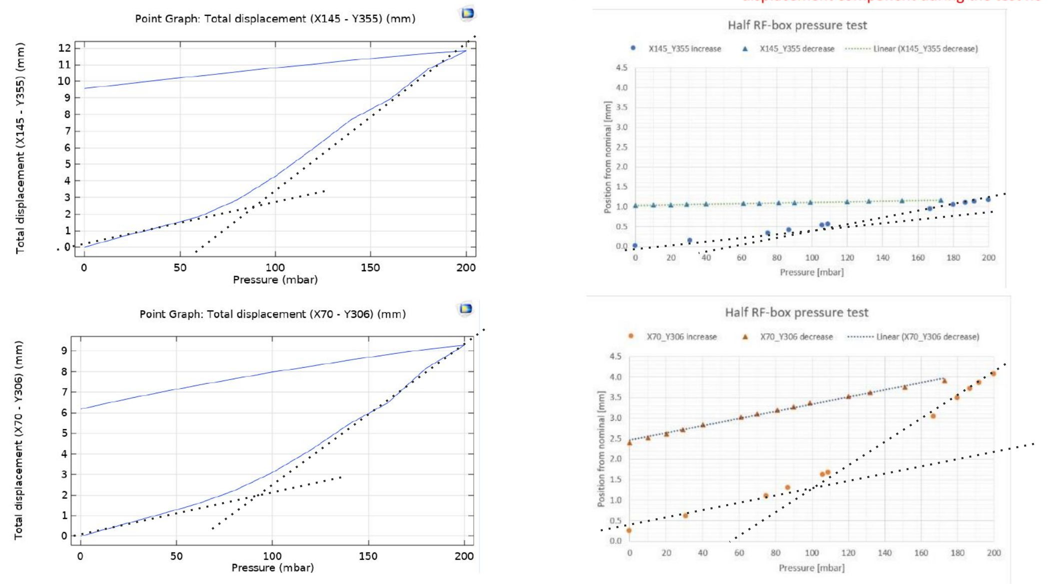
- **Measurement within 0.5-1mm of the simulations**
- **Better agreement on 5 points using 120MPa elastic limit compared to 140MPa elastic limit**
  ⇒ no unknown for the full box model thanks to the certificate (134MPa)
- **End of linear regime (displacement vs DP) in good agreement meas. vs. simulation**
  - note that the measured displacement is a projection of the full displacement (ie. proportionnal to but not equal)
- **Overall behaviour similar:**
  - elastic up to 70-80mbar, plastic deformation and then elastic back to 0mbar

Consensus within the group that the simulations of the deformation are a good representation of reality
+ deformation away from detector give further safety

From slide 11 results
@ Sy= 120 MPa

FEM / test comparison on the short RF foil
-Pressure vs displacement -

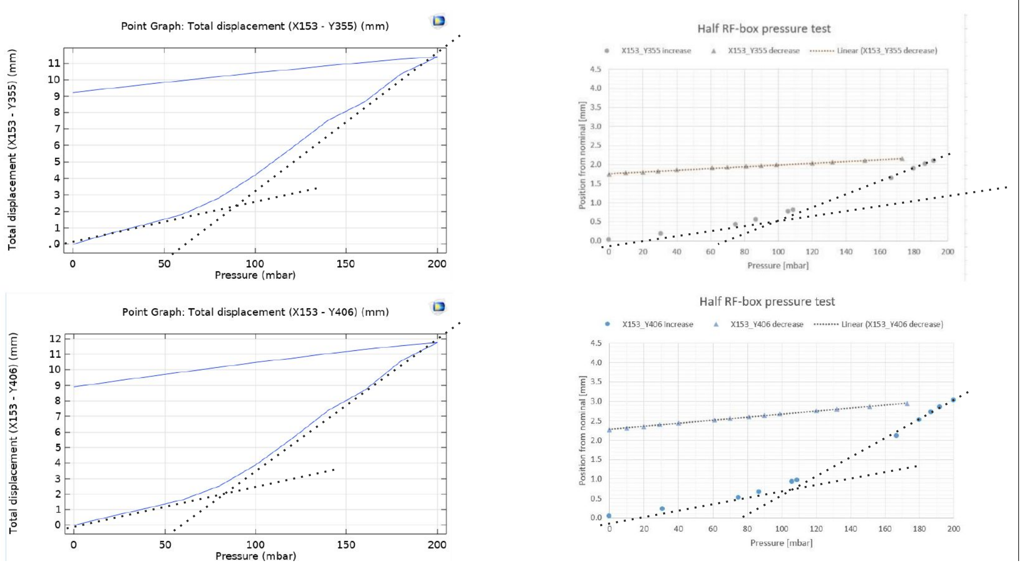
Only the slope should be compare
displacement component during the test no



From slide 11 results
@ Sy= 120 MPa

FEM / test comparison on the short RF foil
-Pressure vs displacement -

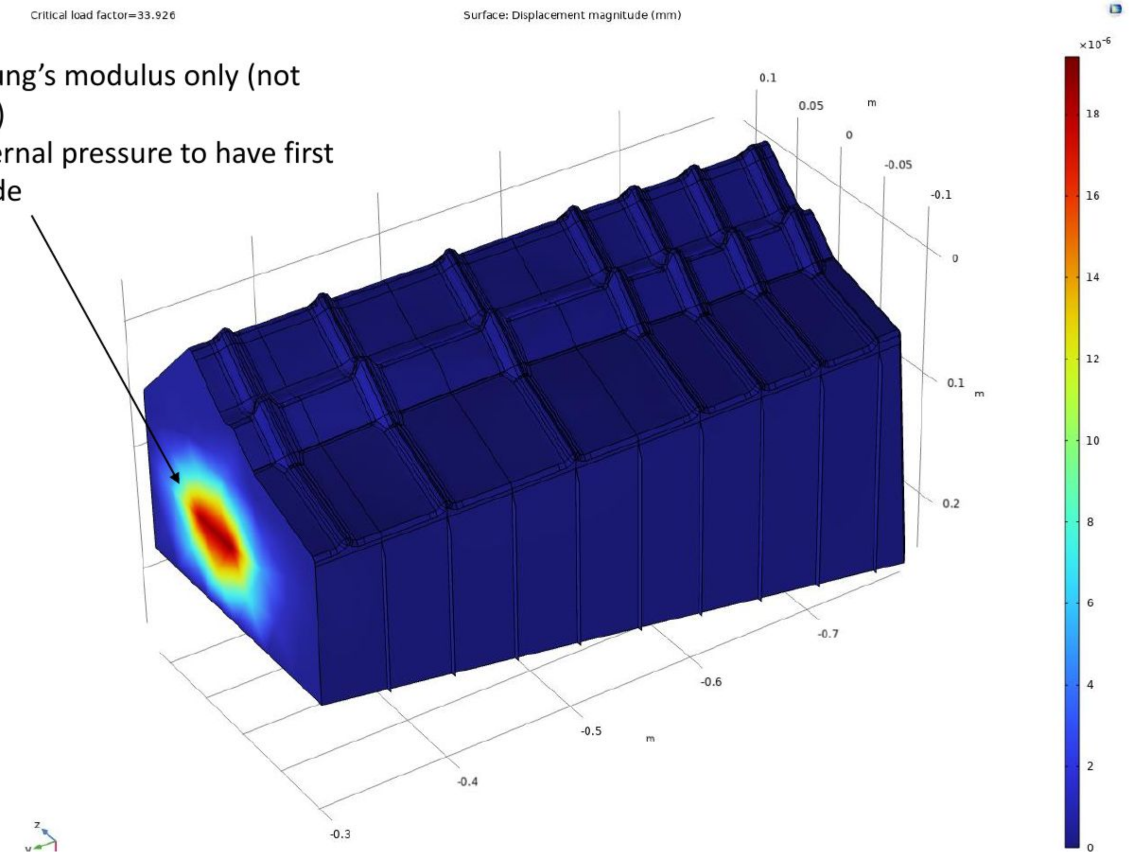
Only the slope should be compared:
displacement component during the test not identified



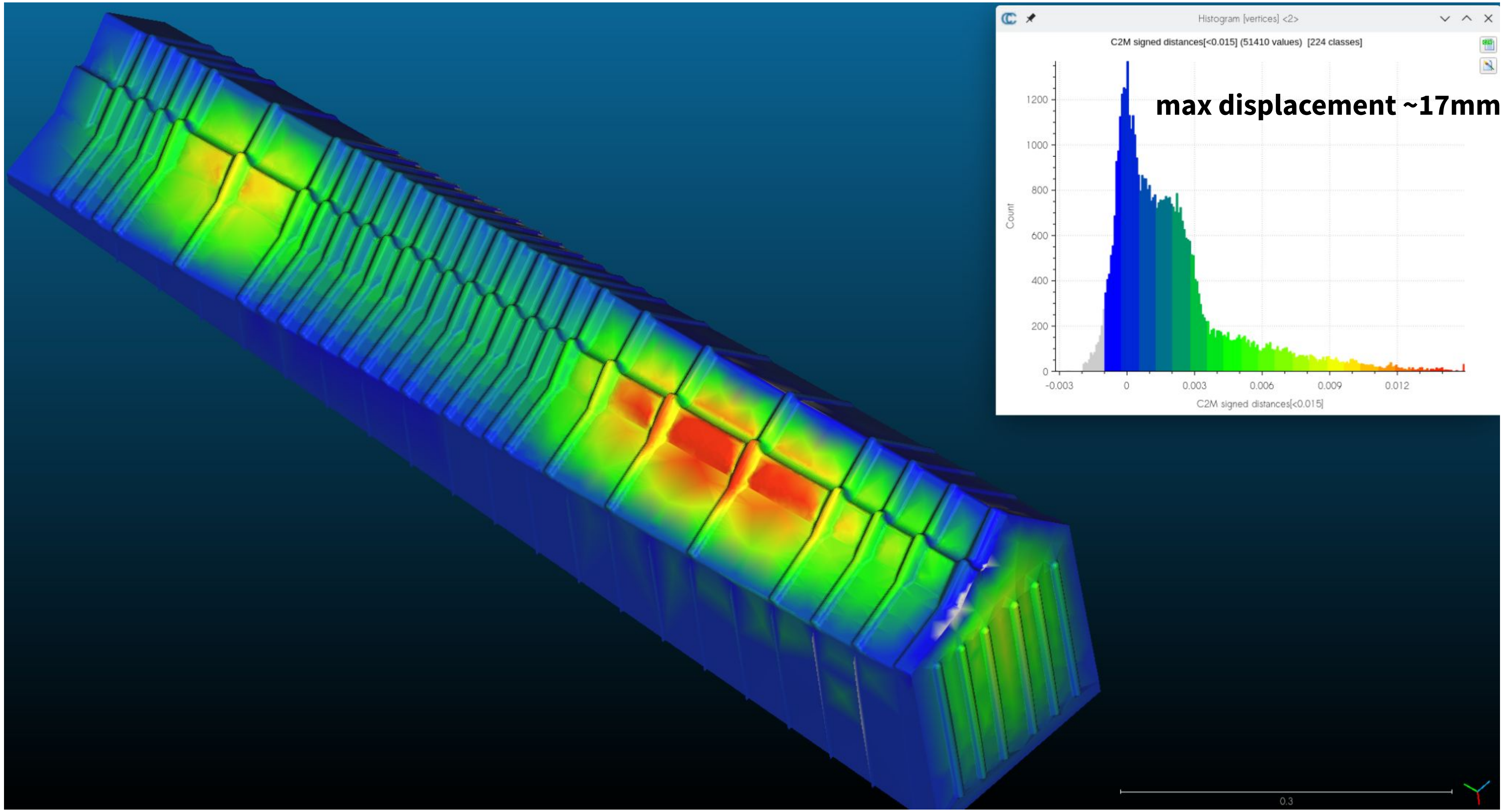
Half box buckling simulation
linear buckling analysis

- **Linear buckling analysis to see if sudden movement could happen when going in underpressure**
- **No buckling mode on the top side**
- **Bucking seen on the large flat side after 34mbar**
    - Linear buckling analysis thought to underestimate the effect
- **At Nikhef went down to +25mbar, no “brutal” buckling, can feel with finger that pushing there deforms, but in an “elastic” way**

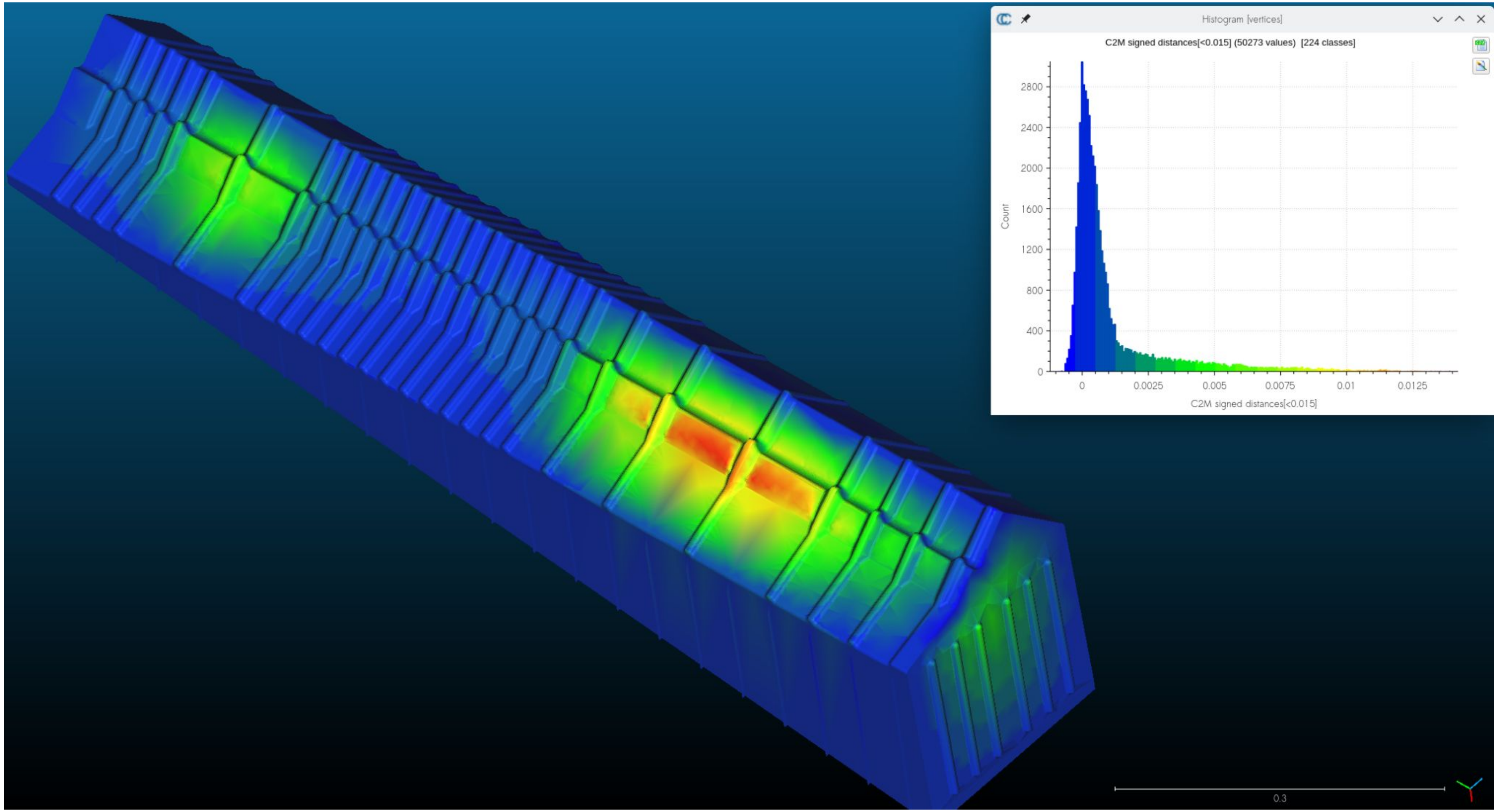
- Based on Young’s modulus only (not conservative)
- 34 mbar external pressure to have first buckling mode



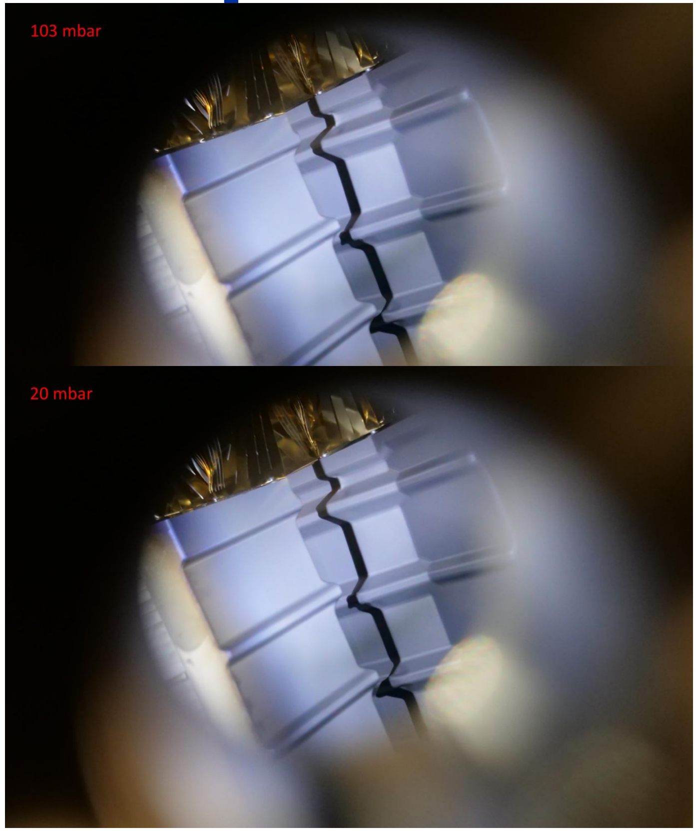
Full box simulation
elasto-plastic deformation simulation @ -200mbar



Full box simulation
elasto-plastic deformation simulation @ 0mbar



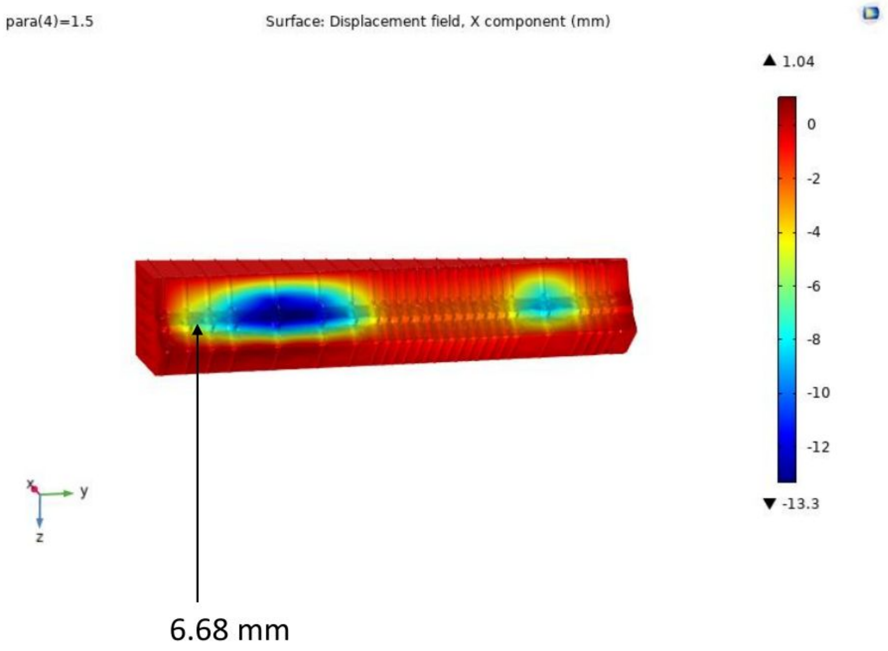
Comparison with view port



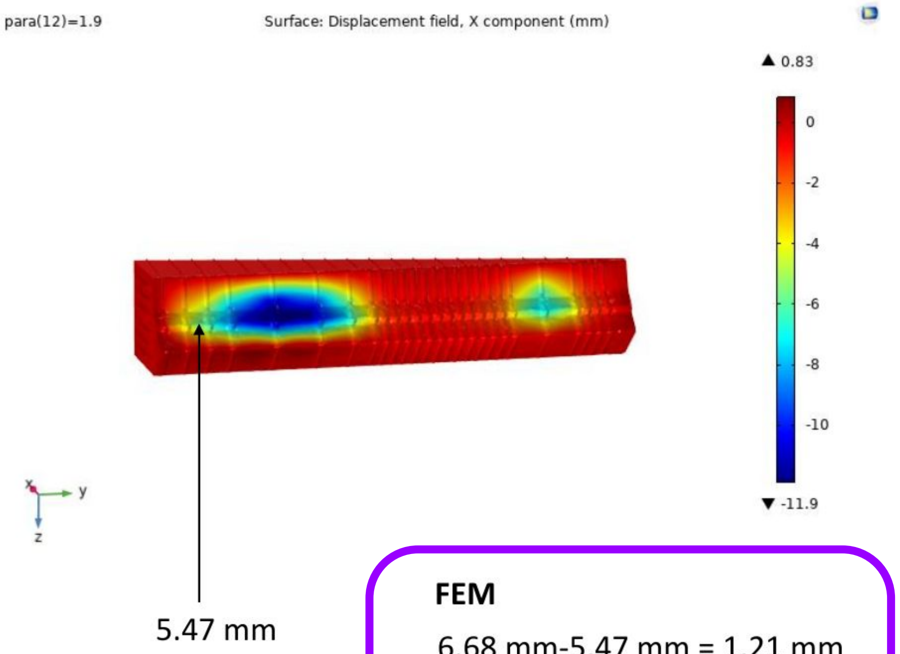
Net displacement (derived from mapping): 1.96 mm- 0.85 mm= 1.11 mm

Important:
x displacement = perpendicular to view port

100 mbar



20 mbar



FEM

6.68 mm-5.47 mm = 1.21 mm

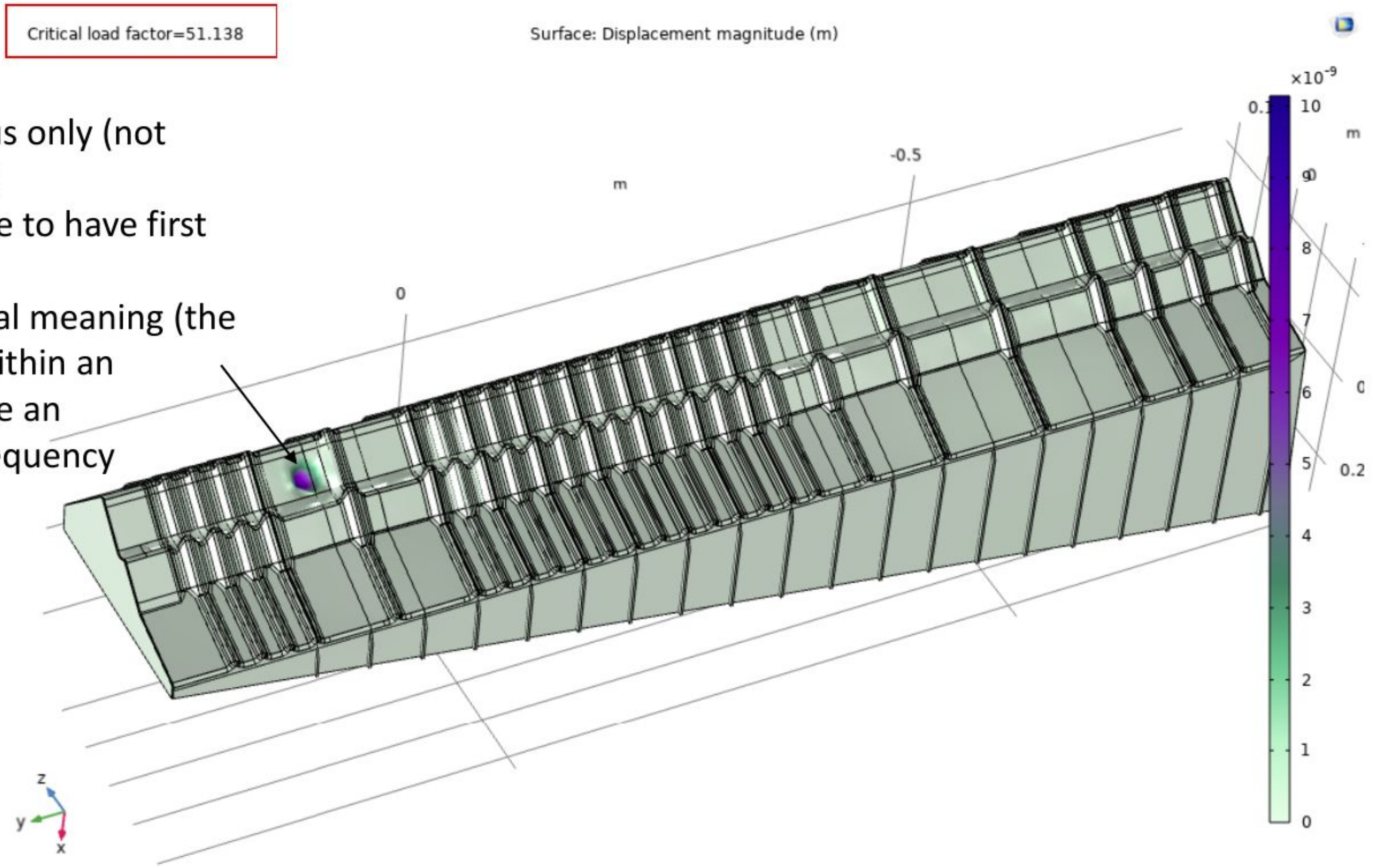
VELO images

1.96 mm- 0.85 mm= 1.11 mm

Full box simulation

Linear buckling analysis

- **Same linear buckling analysis show deformation possible on the flat part of the foil ie far from the modules**



- Based on Young's modulus only (not conservative, can be less)
- 51 mbar external pressure to have first buckling mode
- The legend has no physical meaning (the shape is only known to within an arbitrary scale factor, - like an eigenmode in an eigenfrequency analysis)

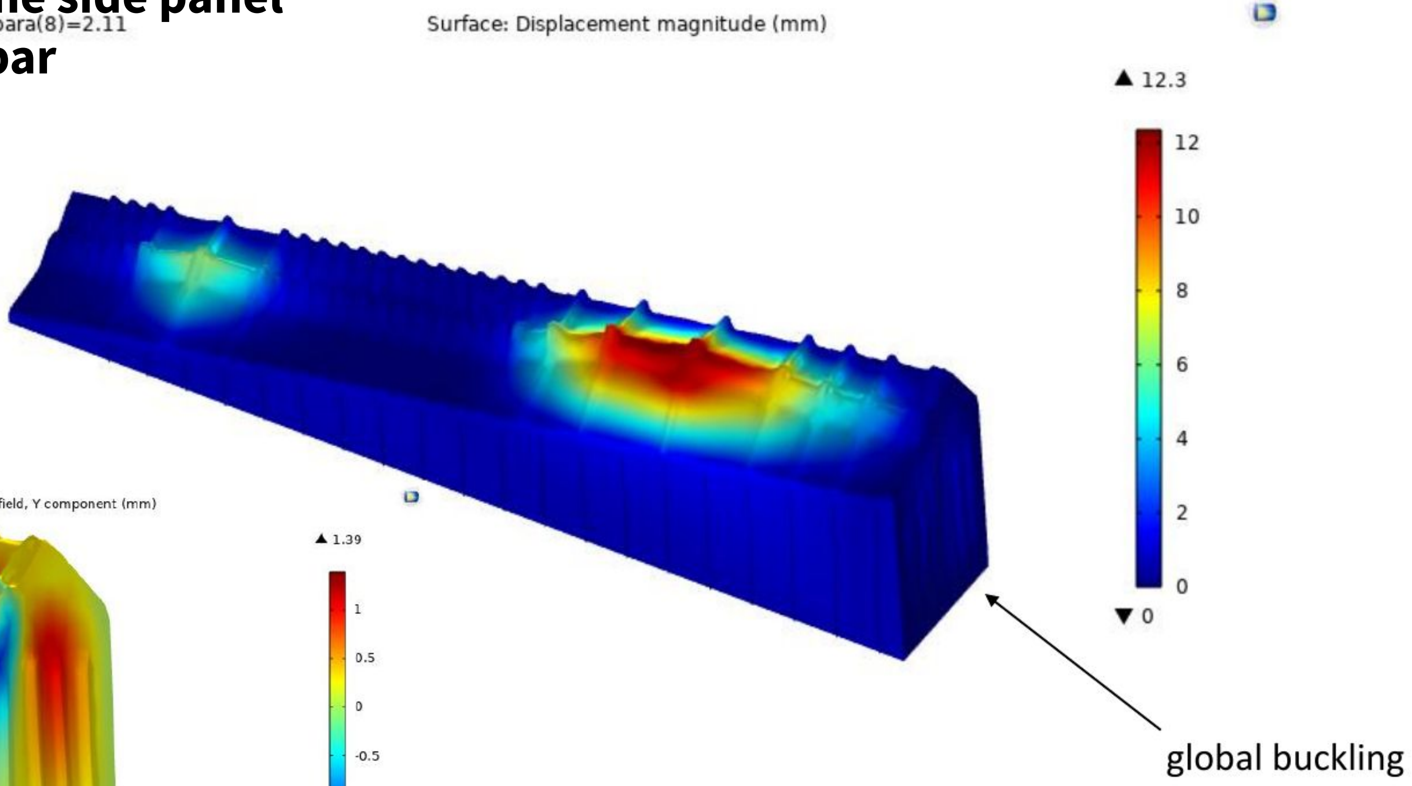
Full box simulation

Non-linear buckling analysis

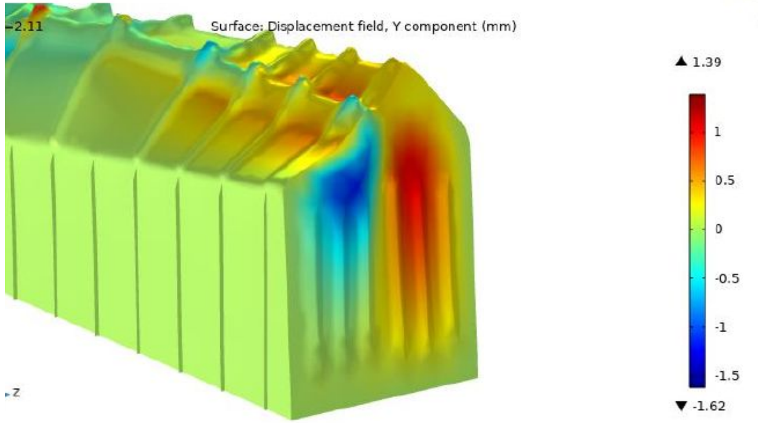
- **More refined non-linear buckling analysis**
- **Buckling happening around +20mbar on the side panel**
- **Smooth deformation @+2mbar and +12mbar**
- **REMINDER: Safety limit @+10mbar**

Non-linear buckling analysis

22 mbar

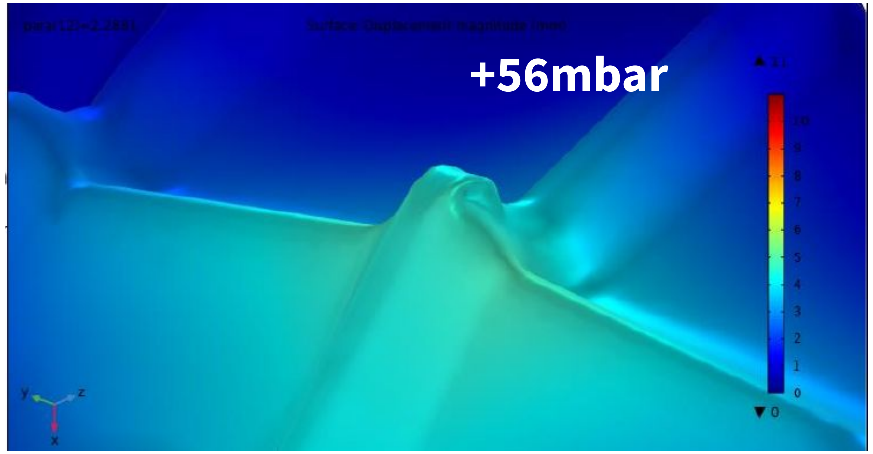


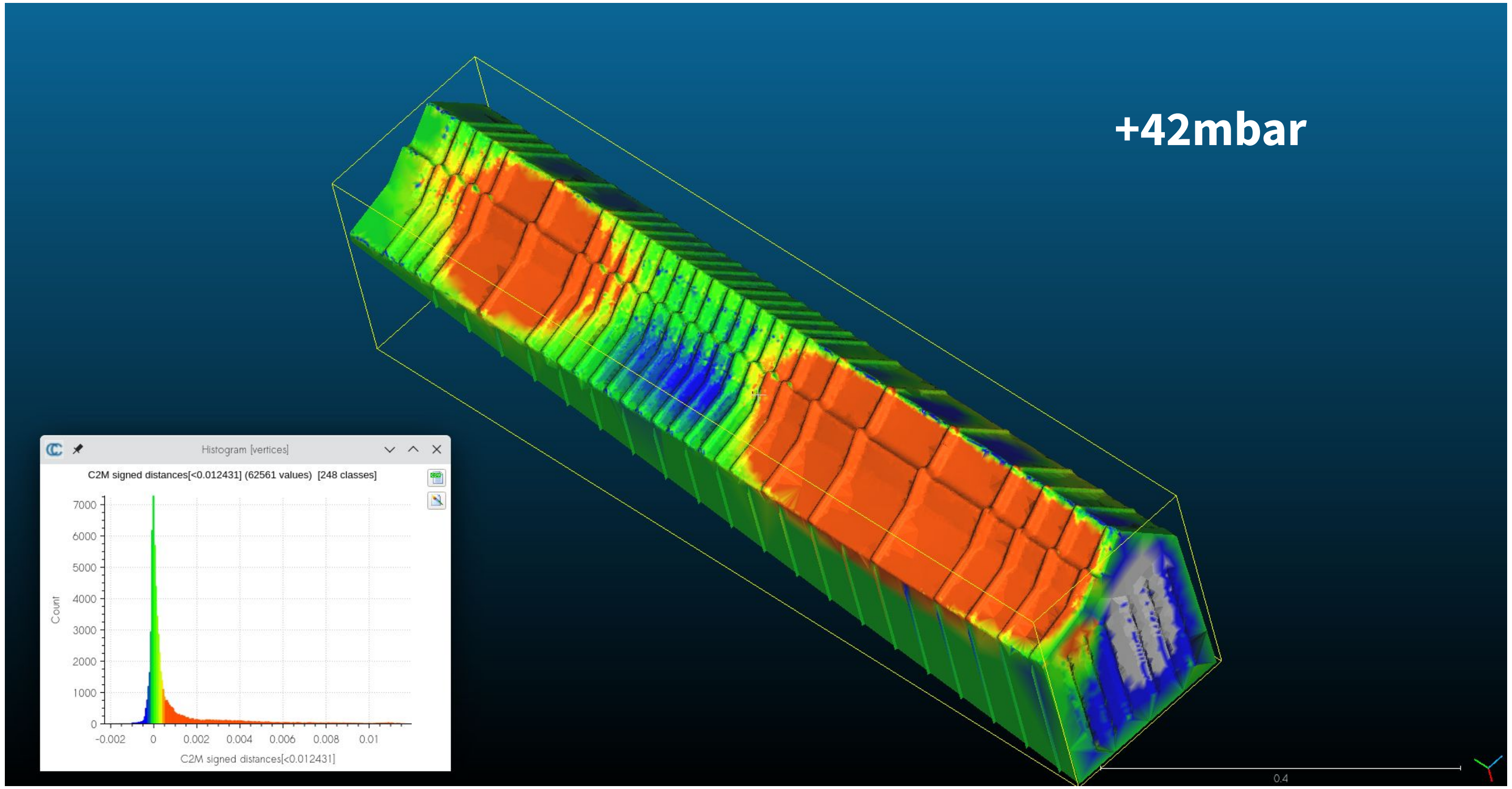
- Non-linear buckling analysis;
- Geometry updated every DP=10 mbar;
- Pressure from DP= -2 to -62 mbar;
- Elastic limit= **134 MPa**;
- Young's modulus = 70 GPa;
- Isotropic tangent modulus = 1.5 GPa;
- No kinematic hardening considered;
- Dimensions: main body 0.5 mm, lateral ribs 2mm, beam envelope 0.18 mm
- Computational time ~ 17 h



Full box simulation
Non-linear buckling analysis

- **REMINDER: Safety limit @+10mbar**
- **At +42mbar some part with negative displacement (still within <1mm of the nominal foil close to sensor slots)**
- **At +56mbar strong local buckling and instabilities**





Recommendation

- **On the basis of the simulation and measurement @ Nikhef, there is a consensus that:**
    - **it is safe to go to 0mbar with the detector in**
    - **it is safe to go to +2mbar with the detector in**
    - **Everything indicates it should be safe to go to +10mbar with the detector in BUT if there is a safe way to avoid it, until we either replace the foil or remove the detector it should be considered**
        - the fact the -10mbar switch is working indicate the +10mbar should be working.
        - we could make sure that no operation leading to fast pressure change is performed (ie no change of temperature during Neon operation this year), add software alarms if the +3 or +4mbar is reached, and constant monitoring during venting and pump down (slow changes that allow to react by stopping the procedure).
        - 3 possibilities:
            - go to +2mbar, remove the detector, finalise with +10mbar, put back the detector (not recommended unless we change the foil)
            - **go to +2mbar, keep the detector in, operate without risking +10mbar until we change the foil**
            - **go to +10mbar if previous point is not achievable**

Incident Analysis

Sequence of Events

The following is a condensed sequence of the events that ultimately led to the over pressurization of the Detector Volume and subsequent deformation of the RF Foil. For a more detailed account you may consult the following EDMS document (https://edms.cern.ch/document/2820759/1).

Night of January 09-10, 2023

LHCb VELO Team – Warm up of the detector prior the AUG test (VELO is currently in Balancing Mode under ultra-pure neon). First time activity, detector warmup has never been tested in terms of gas balancing.

23h11 - Warm up of the detector starts

- Differential pressure on the detector side starts to increase (initial value -3.4mbar).

23h25 – Differential Pressure between Detector and Beam vacuum reaches -5mbar

- Detector volume is over pressurized compared to the Beam volume.
- Vacuum Control System correctly compensates with standard balancing cycle (+2/-5mbar), injecting neon into the beam volume.
- Pressure differential stays above 5 mbar, Balancing System keeps injecting neon.

Sequence of Events

Slides from Rodrigo Ferreira (TE-VSC) @ LMC #456

23h41 – Differential pressure reaches -6.8mbar (exceeded limit of -5mbar)

- VELO team stops the warming cycle and contacts TE-VSC (**J. Sestak**).

00h00 – TE-VSC performs remote diagnostic of the system and shares findings with LHCb

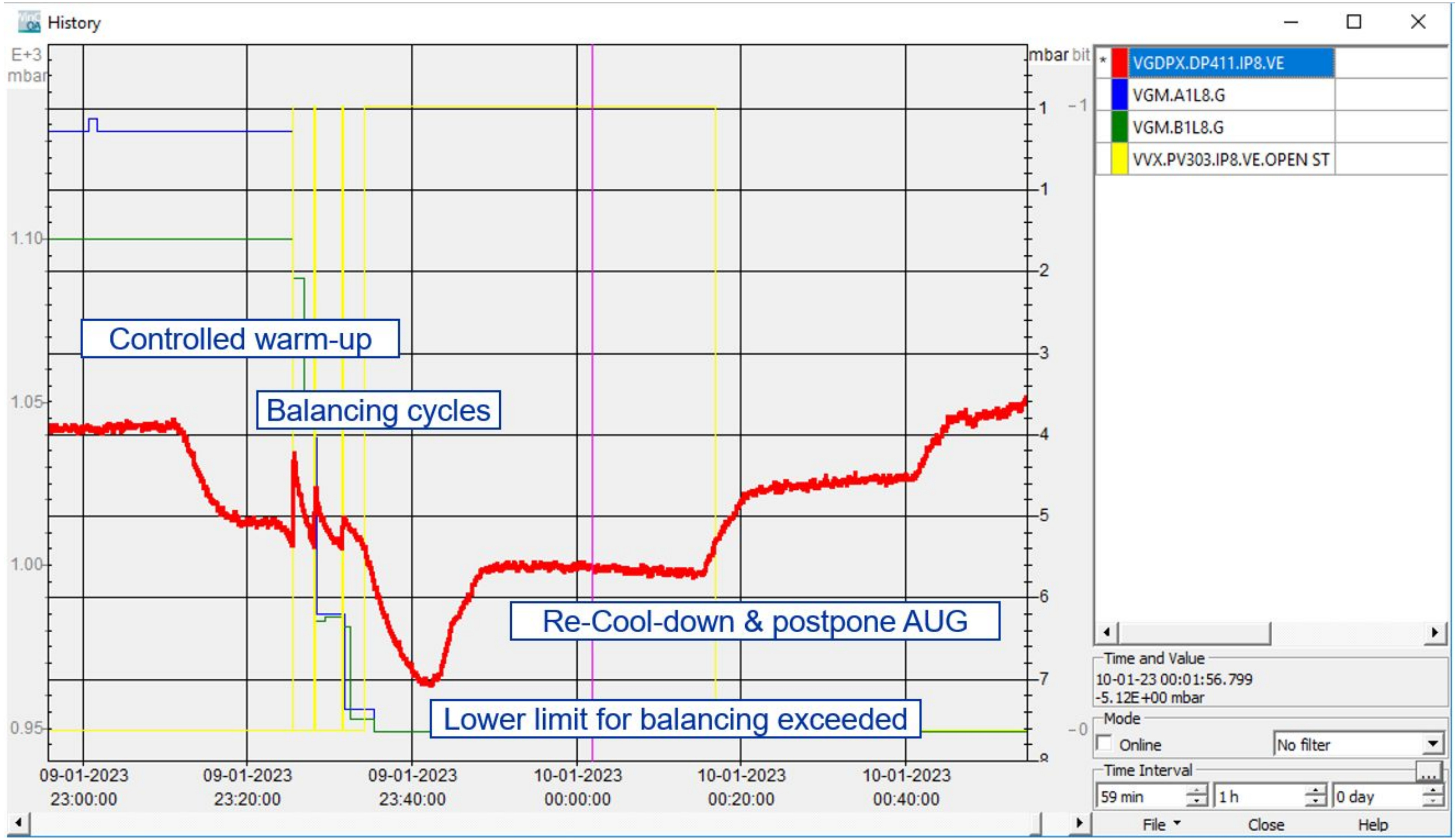
- It was verified that the warmup of the Detector Volume caused a pressure increase that the Balancing System cannot cope with (at the current pressure setting on the injection line)
- Quantity of gas needed to compensate DP on the Beam vacuum volume (injected by the balancing process) requires manual readjustment of the manometer setpoint on GIS neon bottle (which can only be done on-site by a VSC expert)
- TE-VSC requests to stop the warm-up, revert the temperature and wait for the morning.
- TE-VSC requests the postponing of AUG tests planned for the morning of 10/01/2023. LHCb VELO team agrees and will propagate the message towards the LHCb TC.

00h20 – LHCb VELO team reverts warm-up of the detector

- Detector is cooled back down to the original temperature
- Stable differential pressure of -2.4 mbar is achieved around 2 AM

Sequence of Events

Slides from Rodrigo Ferreira (TE-VSC) @ LMC #456



Sequence of Events

Slides from Rodrigo Ferreira (TE-VSC) @ LMC #456

Morning of January 10, 2023

6h22 – Dry air supply is stopped, and cooling stops as a result

- Dry air supply is stopped remotely by EN-CV as a preparatory action prior to the AUG test
- Loss of dry-air supply results in the shutdown of the cooling plant
- Detector starts warming up to ambient temperature in an uncontrolled way
- A fast differential pressure increase due to gas expansion is experienced in the Detector Volume

6h23 - DP between detector and beam vacuum volume reaches -5mbar

- Balancing system correctly starts to compensate the DP by neon injection
- Pressure keeps rising in the Detector volume, but the pressure of the injection system has not yet been increased, so the balancing system is unable to keep up
- The increase in differential pressure continues rapidly, at around 1 mbar/10s (with the Detector volume becoming more over pressurized)

Sequence of Events

Slides from Rodrigo Ferreira (TE-VSC) @ LMC #456

6h24 – DP reaches -8.8 mbar and the Overpressure Safety System is triggered (start of the failure)

- Differential pressure hits the threshold of the pressure switch used in the Safety System (10 mbar by specification, but around 9 mbar in reality).
- At this point the Safety System should have opened the Overpressure Safety Valve. In reality, the relay used to read the pressure switch is faulty (a hidden failure, only detectable by proof testing) and short-circuits the power supply.
- The combined resistance of the wiring (around 5 Ohm) is high enough that the power supply does not totally shutdown but the voltage drops from **24V** to **9.8V**.
- Due to the failure of this relay the safety system fails to actuate the safety valve and equilibrate the pressure differential between the two volumes (the closed pressure switch status is never read).
- Additionally, the low voltage of the power supply causes a second problem in the control system.

Sequence of Events

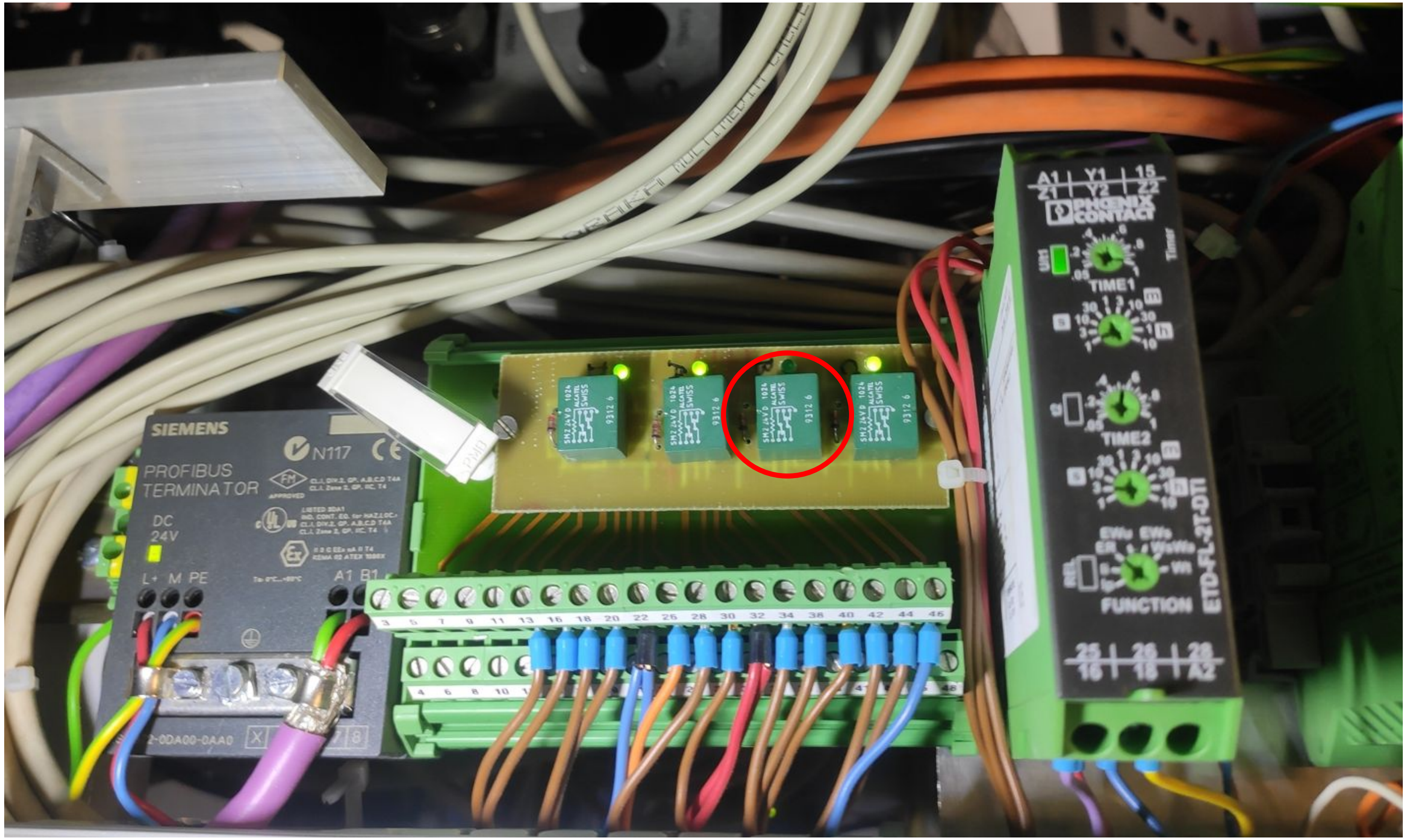
Slides from Rodrigo Ferreira (TE-VSC) @ LMC #456

Optocouplers and mechanical relays have very different operational thresholds. Optocouplers typically require significantly higher turn-on and hold-on voltages compared to equally rated relays.

6h24 – Issue in the Balancing System

- The voltage of **9.8V** that is now being output by the pressure switch power supply is **not enough to actuate the optocouplers** used to read the Balancing Pressure Switches
  - All optocouplers open, meaning that the control system now **falsely** reads the **Beam Volume as over pressurized** (OS412A Open).
- The same **9.8V** are, however, **enough to keep the mechanical relays closed**.
  - The relay used to read the status of the pressure switch power supply remains closed, so the system **falsely** reads the **power supply status as being OK**.
- The software is designed to deal with a fault such as this. By design, the **PLC interlocks all balancing valves in case of a Power Supply failure** (i.e. nothing is actuated if the values of the pressure switches cannot be trusted). But because the supply status was still reported as OK, the Balancing system actuated as normal.

Sequence of Events



Safety System Relay Assembly (faulty relay marked in red)

Sequence of Events

Slides from Rodrigo Ferreira (TE-VSC) @ LMC #456

While the pressure in the Detector continues to rise with the warm up, the PLC reads the following status:

- The status of the PSU is OK, so it can trust the pressure switch status (**false**)
- OS412B is Open, so the Beam volume is not underpressured anymore (**false**)
- OS412A is Open, which indicates a Beam Overpressure (**false**)

The balancing system acts according to what it sees: it proceeds to pump the beam volume in an effort to equalize a perceived differential Beam **overpressure** (while in reality it is the Detector volume that is **overpressurized** due to the uncontrolled warmup of the detector volume).

6h25 – DP between detector and beam vacuum volume reaches -9.8 mbar

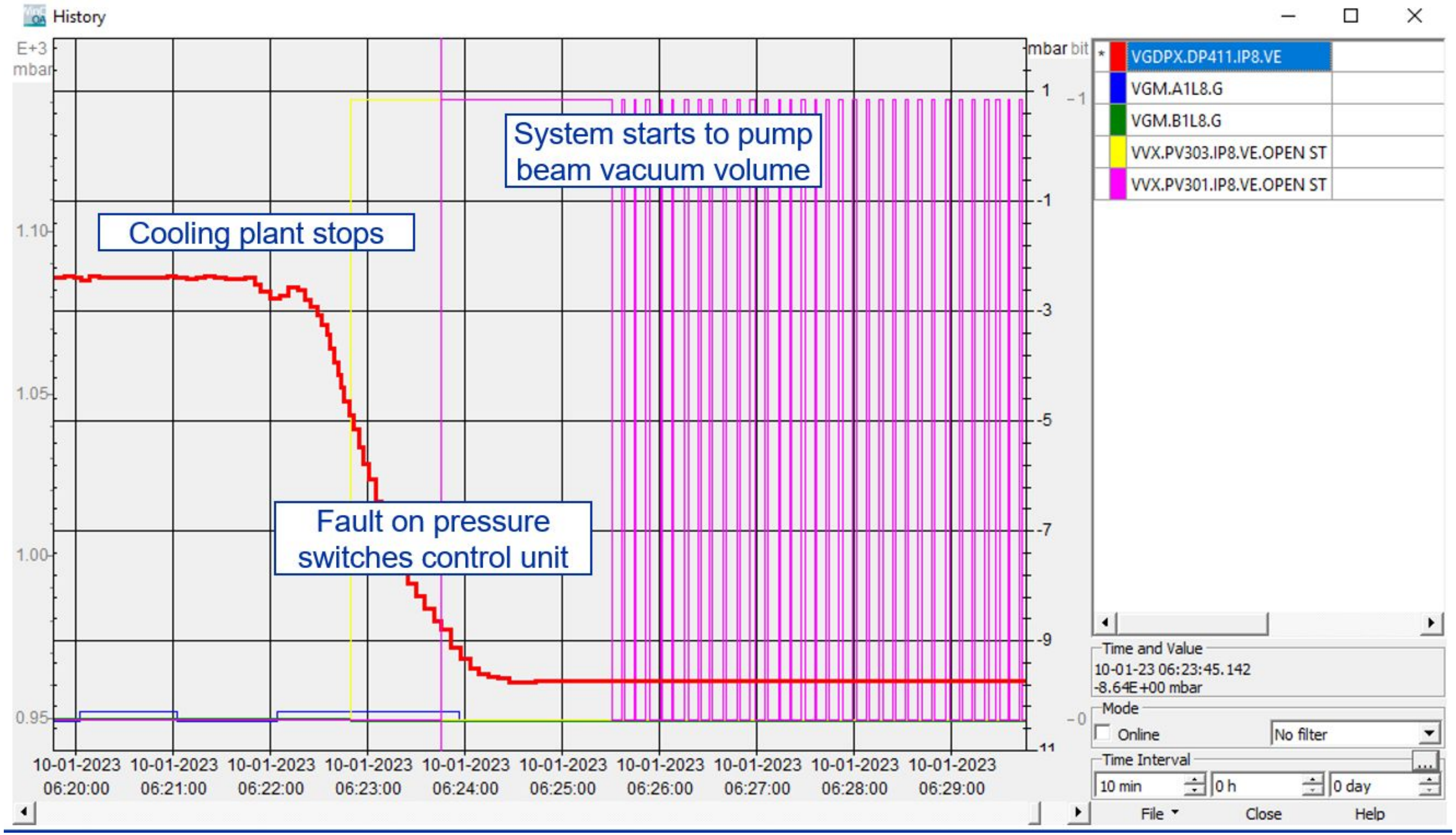
- Differential Gauge reading freezes (for an unknown reason, given that the differential pressure continued to increase and the gauge is rated at -133/133 mbar)

6h36 – LHCb VELO team contacts VSC piquet (as the expert is unavailable)

- Situation is unclear, so it is decided to meet at CERN to analyse the situation

Sequence of Events

Slides from Rodrigo Ferreira (TE-VSC) @ LMC #456



Slides from Rodrigo Ferreira (TE-VSC) @ LMC #456

Sequence of Events

7h05 – TE-VSC analyses the system status on the SCADA and tries to make sense of it

- The instrumentation shows entirely inconsistent information (and thus cannot be trusted):
  - OS414 and OS411 indicate that **both volumes are over pressurized** in relation to atmosphere
  - Absolute pressure measurement gauges indicate we are **around 650 mbar** in the Beam
  - Pressure switch OS412A indicates a Beam **overpressure > +2 mbar**
  - Differential pressure measurement reads **-9.8 mbar of Beam under pressure**
  - Safety pressure switches indicate that we are **within the -10/+10 mbar range**
- **SV421 is closed** and the safety system did not trigger
- **Beam Vacuum is being pumped via PV301 by the Balancing System**
- The **power supply** for the **pressure switches** is **working properly**

9h43 – TE-VSC stops automatic Balancing

- After considerable internal discussion, TE-VSC stops automatic balancing process
- Pumping of the Beam Volume through PV301 is stopped
- Ongoing discussions between the LHCb VELO team and VSC experts

Final Status

Slides from Rodrigo Ferreira (TE-VSC) @ LMC #456

12h00 – **TE-VSC inspects VELO and VELO control racks**

- VELO elliptical head zone is inspected (rupture discs control, safety valve physical status)
- VELO control racks are inspected and the issue with the power supply is identified

16h30 – TE-VSC performs measurement using Gas Injection System line

- Neither the Absolute nor the Differential Baratron gauges can be trusted at this point
- Pressure gauge on the GIS line is used to measure Beam volume pressure, confirming the drop to be around 180 mbar.
- Gauges on the VELO Detector vacuum volume indicate a pressure increase of approximately 40 mbar compared to before the event
- **This means the differential pressure between Beam Vacuum volume and Detector Vacuum volume would be in the range ≈ 200 – 220mbar.**

Miscelaneous

Changing the foil

	Pre installation of paths for trolleys to pass on stairs, runners on corners, extension platform on A side	1d	
1.1	Venting ---	1d	
1.2	Cooling disconnection	4h	
1.3	cooldown period to be discussed with RP	0h	
1.4	dismount non VELO items (RP sensor..)	30m	
1.5	Electronics dismounting and storage	3d	
1.6	Prepare for the Removal of the VELO detectors – Check rails and pulley system, configure crane perpendicular to detector	0hrs	Preperation work to be done in advance - 2-3 hrs work
1.7	Installation rails and skates (A side)	2hrs	
1.8	Move detectors 4 mm down	2hrs	
1.9	Open service flanges	1hr	
1.10	Disconnect detector from tank flange	2hrs	
1.11	A side: Disconnect base, Retract fully, attach flanges, sliding guide, lifting bracket, extract	4hrs	
1.12	A side: Lift and rotate VELO detector into transport trolley	2hrs	
1.13	A side: Install heater/blind flanges	1hr	
1.14	Deinstallation rails and skates (A side)	1hr	
1.15	A side: Put blind flange/dust cover	1hr	
1.16	A side: VELO trolley extraction	1hr	Supervision only - Work done by riggers
1.17	Reconfigure crane for C side removal	2hrs	
1.18	Installation rails and skates (C side)	2hr	
1.19	Disconnect detector from inside structure	2hr	
1.20	Retract fully, attach flanges, sliding guide, lifting bracket, extract	4hr	
1.21	C side: Lift and rotate VELO detector into transport trolley	2hrs	
1.22	C side: Install heater/blind flanges	1hr	
1.23	C side: Put blind flange?	1hr	
1.24	C side: VELO trolley extraction	1hr	Supervision only - Work done by riggers
1.25	Reconfigure crane for eliptical head removal	2hr	

	Re-installation of paths on stairs and corridors for trolleys to pass, extenstion platform for A side	
3001	Check rails and pulley system, reconfigure crane	1d
3.1	C side Dismount heater/blind flange	1h
3.2	C side Installation rails and skates	2h
3.3	C side bring trolley onto platform	3h
3.4	C side lift and rotate detector onto skates	2h
3.5	C side insert detector, connect base	1h
3.6	C side install heater flanges	1h
3.7	C side close service flange	1h
3.8	C side remove trolley	1h
3.9	A side Dismount heater/blind flange	1h
3.10	A side Installation rails and skates	2h
3.11	A side bring trolley onto platform	3h
3.12	A side lift and rotate detector onto skates	2h
3.13	A side insert detector, connect base	1h
3.14	A side install heater flanges	1h
3.15	A side close service flange	1h
3.16	A side remove trolley	1h
3.17	Install bosch profile and platform	5h
3.18	Install local box	4h
3.19	Cooling connection	2h
3.20	Leak test	1h
3.21	Insertion of readout boards	
3.22	Connection of LV/HV cables	
3.23	Connection of temp/data cables	7d
3.24	Connection to VSS, check of safety system	3d
3.25	SMOG temp cabling (can be done in parallel)	1d
3.26	Reinstallation PLUME	1w
3.27	Reinstallation BCM/RMS	1d
3.28	Fine tuning PLUME monitoring fibres Alcove	1d
3.29	Fine tuning PLUME monitoring fibres Balcone	1d
3.30	Reinstallation Moedal	
3.31	Dismantle platform, access paths for trolleys	4h

A3 needs neg coating: Spare "cigar" to be prepared, swapped with C1 in tank under N2, tooling provided. Time estimate: 3w
Wakefield suppressors: Procedure assumes WFS can be preserved by cutting mushrooms (upstream and SMOG). Spares to be produced for downstream (under investigation)
Complete dismount of Moedal panels and support frames to be done in advance
C side platform needs to be made large enough for all operations???? TBC

		comment	time		material	tools
2.1	Venting	already done as part of Task 1	6h	1	Assuming the GIS is prepared for venting (depends if we vent with Neon or N2O2 mixture)	
2.2	Remove local box		4h	2		
2.3	Remove VELO bosch profile platform		1h	2		
2.4	dismount PLUME	already done as part of Task 1	3d	5		
2.5	Dismount everything between tunnel wall and velo (BCM, RMS)		1d	6		
2.6	Removal of the vacuum sector A1L8.X (VELO upstream) and bl	Special authorisation is needed due to IT8L cryo status	1d	7	Wall plug plate (LHCb built one during the LS2)	
2.7	Remove vacuum equipment in front of elliptical head		1d	8		
2.8	Disconnection of the Upstream WFS from the elliptical head		1h	9	Special tool from INFN to disenga	storage in "surface buffer"
2.9	Disconnect elliptical head	need work from vacuum group beforehand	4h	10	where does ellliptical head stay d	Must be well protected!
2.10	Dismount SMOGII part 1	SMOG team + TE-VSC team	1h	10	Disconnection of	the SMOG2 services - access on the top of the VELO
2.11	Disconnect WFS from Foil	procedure to be tested (cutting mushroom or WFS)+open flange	2h	10		
2.12	Remove heater/detector blind flanges	are they there? or just dust cover (also where is the dust cover)	1h	11		Dust covers are with the TE-VSC
2.13	Install infrastructure for RF box replacement	trolleys	1h	11		
2.14	Disconnect bellow and remove bumpers		2h	11		
2.15	Prepare motion system and remove gear belt		2h	11		
2.16	Fix bellows with PVC tool	due to no access from exit foil side need to redefine procedure..	2h	12		needs preparation/rehearsal with jig...
2.17	Fix 2 RF boxes together		1h	12		
2.18	Lift off center frame		2h	12		
2.19	Install lifting frame for RF boxes/bellows	wrap lifting frame in foil to protect from paint chips	1h	12		
2.20	Remove RF boxes/bellows with lifting frame		2h	12		
2.21	Seal Vac-tank to avoid dust, cover over VELO		2h	13		
2.22	Move RF-boxes/bellows to convenient place		30m	13		
2.23	Detatch RF-boxes/bellows, check quality of bellows		2h	13		
2.24	Connect new boxes on old bellows		1h	13		
2.25	Install SMOG2 part 2		8h	14		
2.26	Align SMOG Part 2		1d	15		
2.27	Refurbish coupling to motion system	(no need if inspection is good, we have 2 spares to replace all w	0m	16	2 of 6 available	
2.28	Soldering of PT100 connectors (can be done in parallel)		4h	16		
2.29	Replace WF suppressor in exit foil	(no WFS, need minimal 2, would like to have better tooling for in	2h	17	please consider	that the UX85-1 chamber must be fixed after UTto avoid any move
2.30	Reinstall RF boxes in velo		4h	17	6 CF100 special rings (6 in hand, might order spares)	
2.31	Reinstall center frame		2h	17		
2.32	Remove fixation between 2 boxes/bellows		10m	17		
2.33	Install protection for round shape bellows		20m	17		
2.34	Alignment of motion system		1d	18		
2.35	Test motion system control		4h	19		
2.36	ROMER arm foil measurement		1d	20		
2.37	Exchange of the ion pumps of the VELO tank	Better to do this before the SMOG intervention as once the SMC	1d	21		
2.38	Install SMOG Part 1			22		
2.39	Alignment SMOG Part 1		2d	23		
2.40	Recheck motion system		1h	24		
2.41	Install heater/blind flanges	Flanges with heater setup to be installed at this point	1d	24		
2.42	Install elliptical head		4h	25	helicoflex (would like to order 3)	
2.43	Reinstall vacuum equipment on the elliptical head		1d	26		
	Pump-down for Leak check #1		1d			
2.44	Leak check #1 (CERN Vac)	Should be done prior the upstream part installation. This step co	2d	29		
2.45	Venting		1d	30		
2.46	Installation of A1L8.X upstream vacuum sector (CERN Vac Job)		1d	31		
2.47	Connect suppressor to RF-boxes at exit window side		1h	32		
	Final pump-down of the IP8.X before bake-out		1d			
2.48	Leak check #2 (CERN Vac Job)	Final leak detection before the bake-out	4h	32		
2.49	Connect equipment for VELO bake-out		1d	33		
2.50	Install vacgroup bake-out equipment, do bake-out, remove bake	4d installation of bake-out, 4d removal; process 5 days (+weeke	14d	47	Please bear in mind that the final RGA scans can be only done 48h after the room temperature. M	
2.51	Venting with ultra-pure neon for detector installation		1d	48		
2.52	Take off VELO heater/blind flanges	System must be vented after the bake-out	4h	49		

Task lists collected for

- Detector Extraction
- RF foil replacement
- Detector Insertion

To be supported by:

- Coating of box C1 (A3 is ready)
- Manufacture of spare WFS (one spare exists but has minor tear, will aim to preserve WFS in place)
- Preparation of dedicated tooling for the particular circumstances
- RP plan to match radioactive environment
- Full support from other SDs (SMOG,PLUME, BCM, RMS…)
- Bakeout compromise (exclude RICH1)

No showstoppers identified!

Impact on UT can be minimised by timing of mounting of C side platform (cabling completion)

Some parallelisation possible, but estimate of 3.5 months probably reasonable

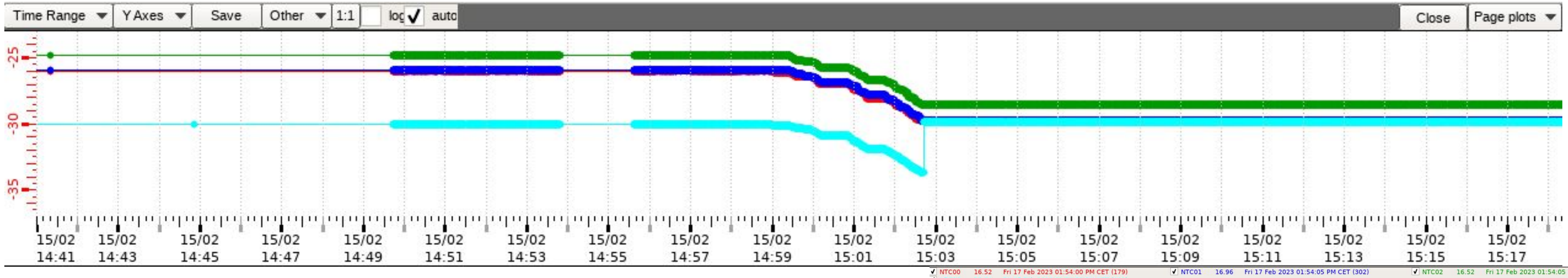
Options for recovery

- **Without incident time to physics :**
    - 2 months of no beam + 4-6 weeks with beam to finalise the work of last year (ie. ~6-8weeks with beam)
- **[1] Changing the foil this YETS.**
    - **PRO:** possibly PbPb in 2023 with VELO ready. Ready day 1 on 2024
    - **CONS:** one missing spare RFBox ie. risk of running with tube and no VELO, less time to prepare. Delay is delay direct delay to LHC/GPD (ie. schedule should not be contracted). Reduced time for global commissioning with VELO.
    - **pre-requisite:** spare WFS, tooling for dismounting VELO, agreement of the LHC for X (6?) weeks delay, LHCb agreement
- **[2] Operate with deformed foil this year and change foil in 2023/2024 YETS:**
    - **PRO:** by 2024 calibration finalised should be ready almost day 1, allows global commissioning with VELO.
    - **CONS:** no data with fully closed VELO
    - **pre-requisite:** motion system OK to go to 10mm (otherwise have to stay open), LHCb agreement
- **[3] Remove the VELO, and change the foil next year:**
    - **PRO:** safest of all the options
    - **CONS:** no VELO calibration in 2023 is 4-6 weeks needed in 2024 / no velo or long tracks during 2023.
    - **pre-requisite:** tooling for dismounting VELO, LHCb agreement

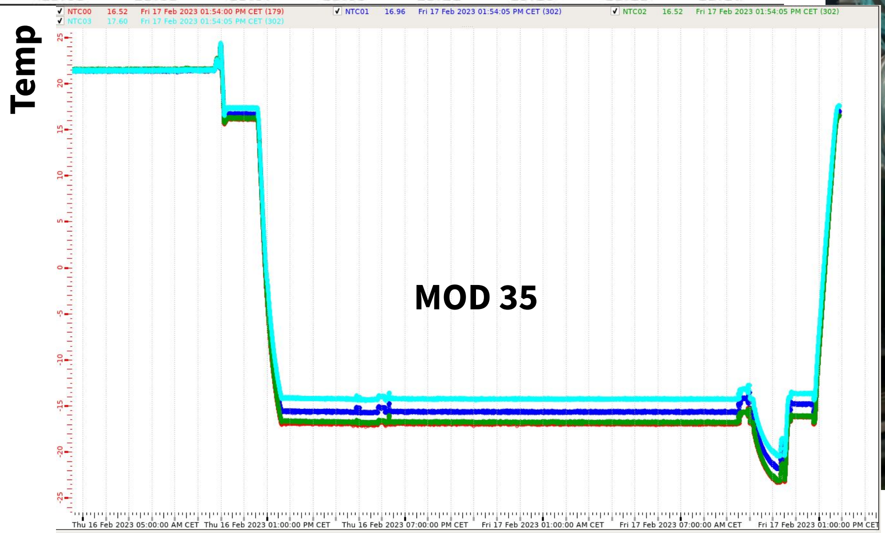
Provided the pre-requisite are fulfilled (some VELO, some LHCb, some LHC), the VELO group is ready to follow those routes

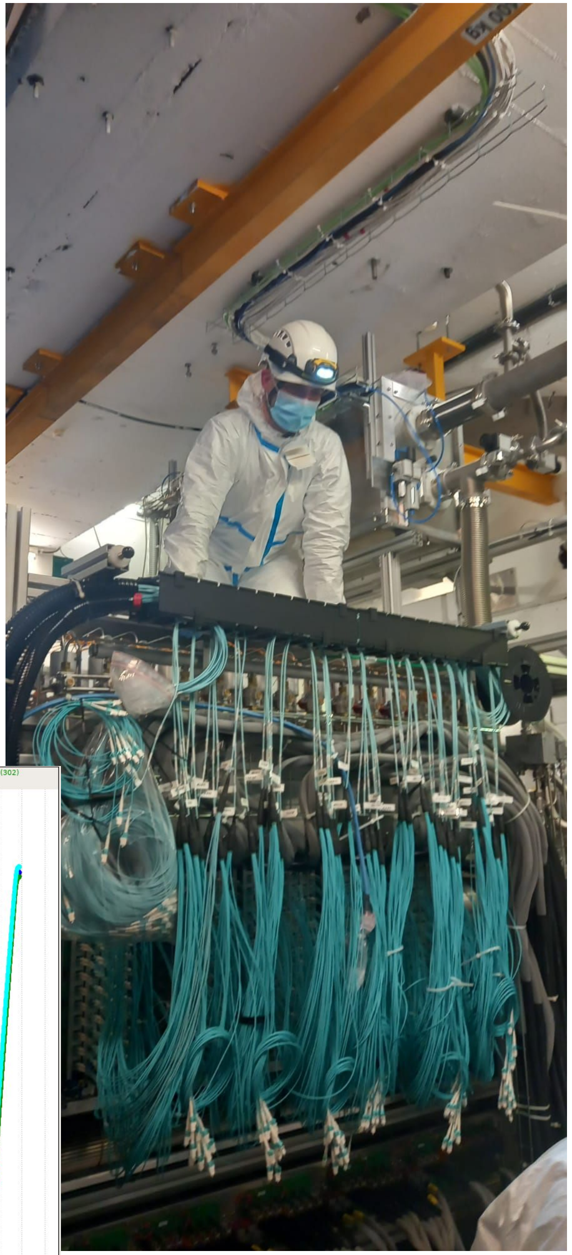
Recovery status
Velo side

- **10/02 change gasket on Mod35**
- **13/02 install hardware limit on the motion**
- **14/02 TE-VSC put back vacuum**
- **15/02 retracted the VELO fully (from 28mm and 26mm to fully open 29.8mm)**



- **16/02 cooled down the VELO and tested electronics:**
  - cooling OK
  - config+data path OK
  - sensors OK
- **17/02 tested cooling property of Mod35, all OK, warm-up and vent CO_2**

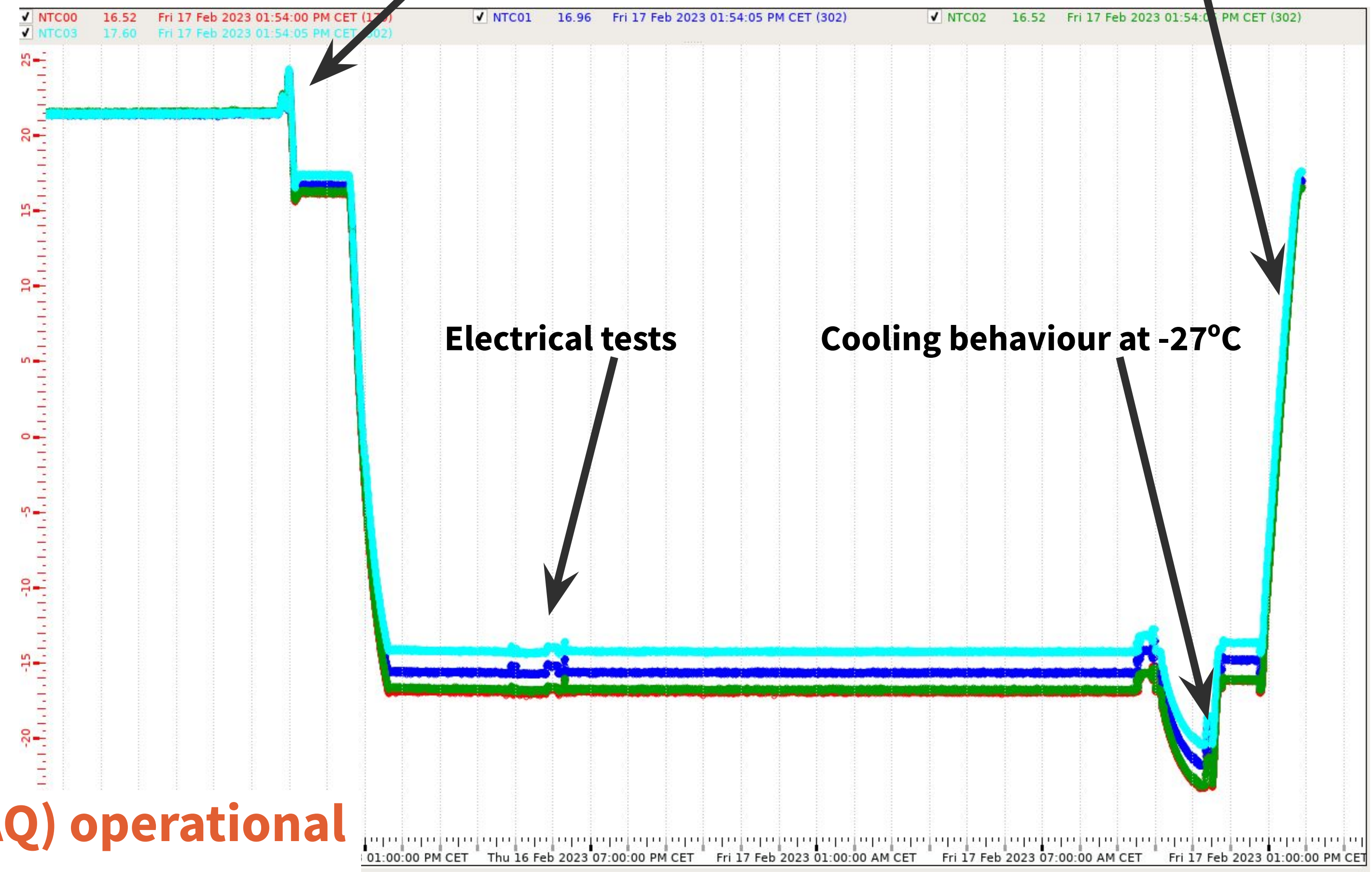




Phase 2 recovery
13/02-17/02 [VELO side]

E. Lemos, W. Byczynski, R. Dumps, N. Jurik, S. deCapua, G. Zunica

- **Cooled down the VELO to -20°C** [main chiller in maintenance]
- **Module 35 tested down to -27°C**
  - module was left OFF in 2022 as cooling performances were sub-optimal
  - restriction gasket changed on 10/02
  - tested with full load ⇒ OK
- **VELO electronics response tested:**
  - configured the detector, ie tested LV, and slow control path as well as basic VELOpix functionalities
  - PRBS generation to test DAQ links
  - Detector OK [full analysis to come]
- **High voltage:**
  - More voltage points taken [20,50,140-200V]
  - No misbehaving sensors, full annealing analysis to follow

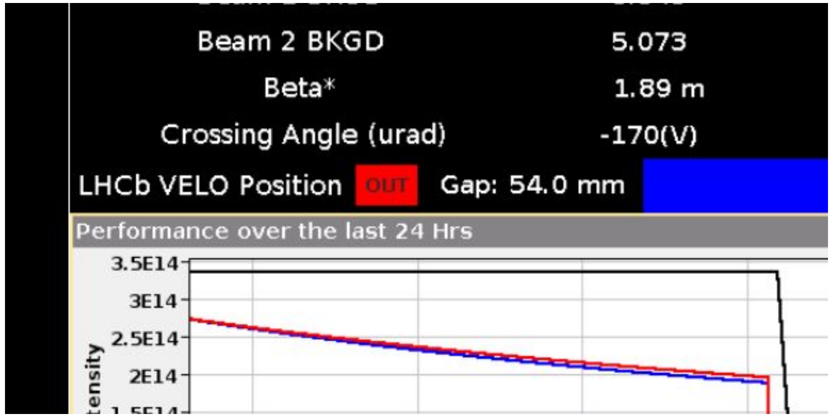


⇒ Cooling, sensors and electronics (ECS/DAQ) operational

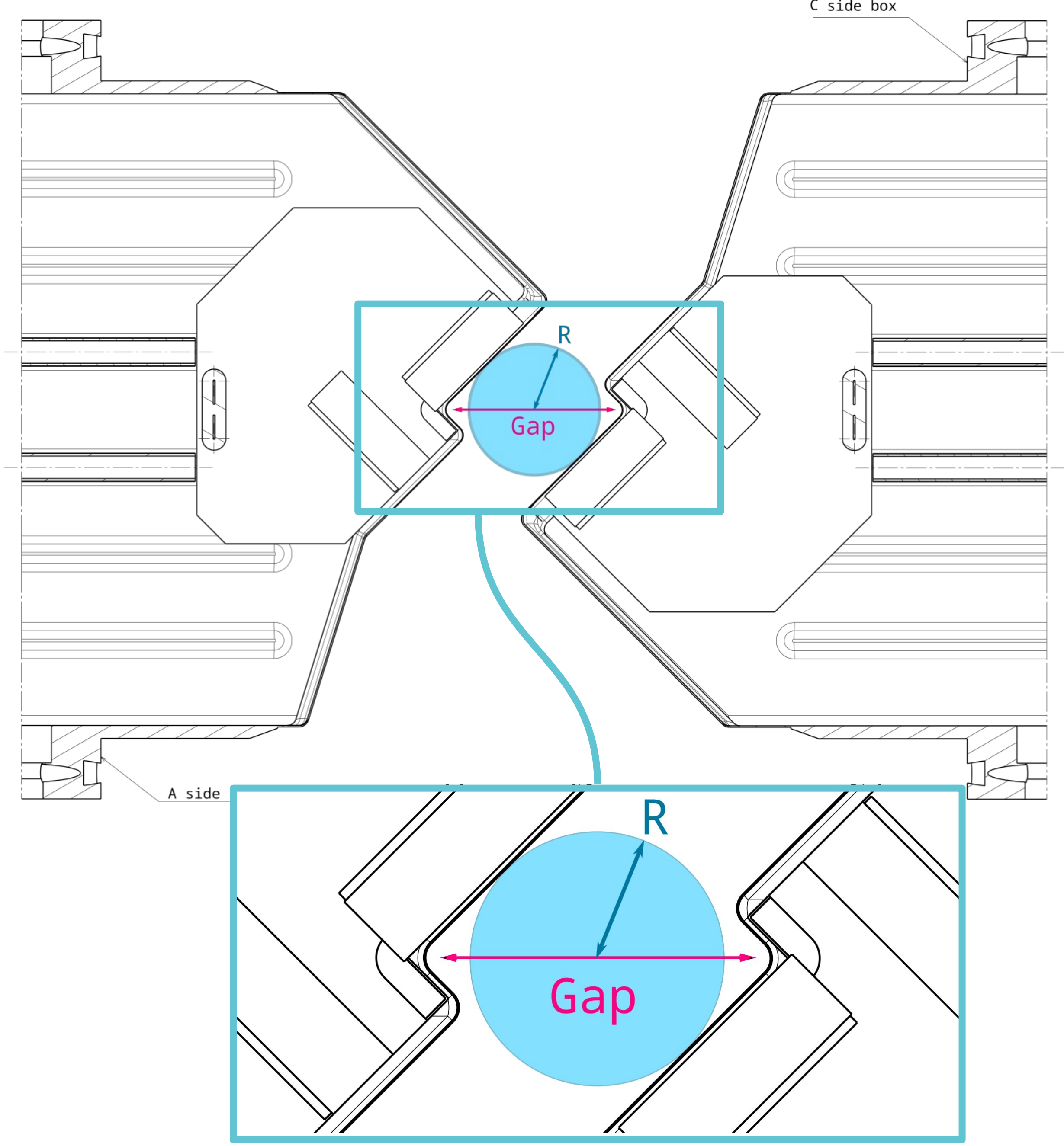
Closing vocabulary

- **Half position is the distance of the half wrt. the beam position**
  - in garage position centered over reference orbit
  - while moving centered on reconstructed beam
- **The Gap is the sum of A and C side positions**

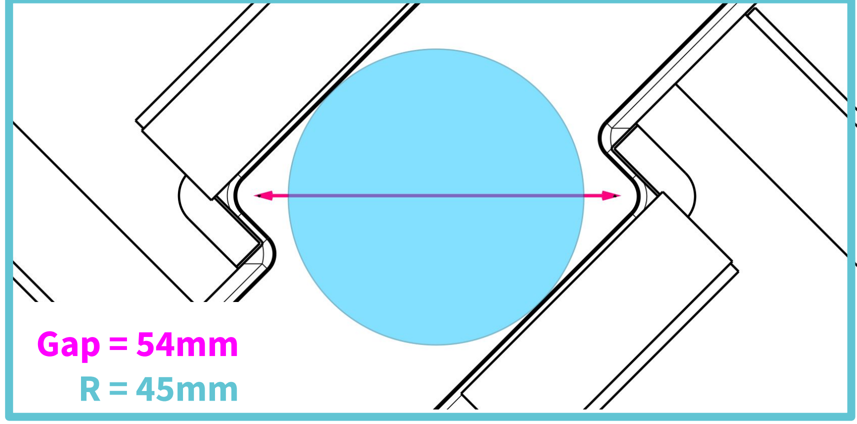
LHC operation page



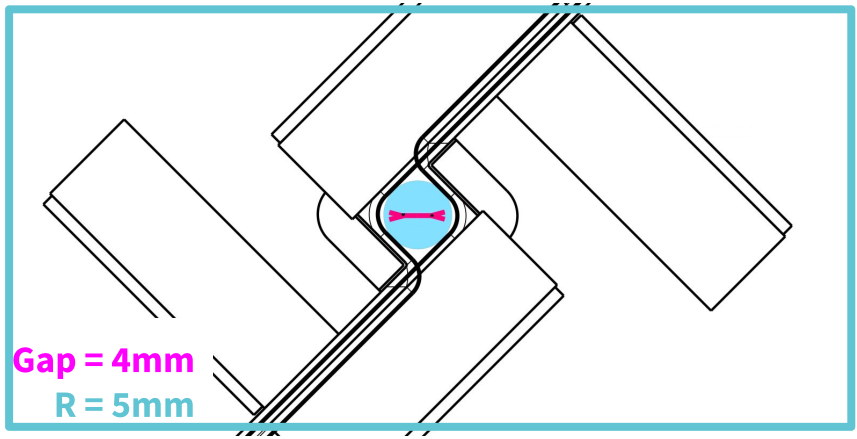
- **The minimal radial aperture R, is the minimal aperture seen by the beam when the VELO is centered on the interaction point**



Opened VELO



Partially closed VELO



Closed VELO