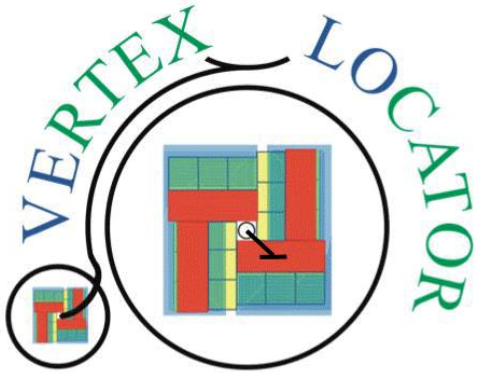
VELO Upgrade: CO_2 cooling safety system

Oscar Augusto de Aguiar Francisco

CERN

LHC machine protection panel meeting for the VELO upgrade



Outline

Modules

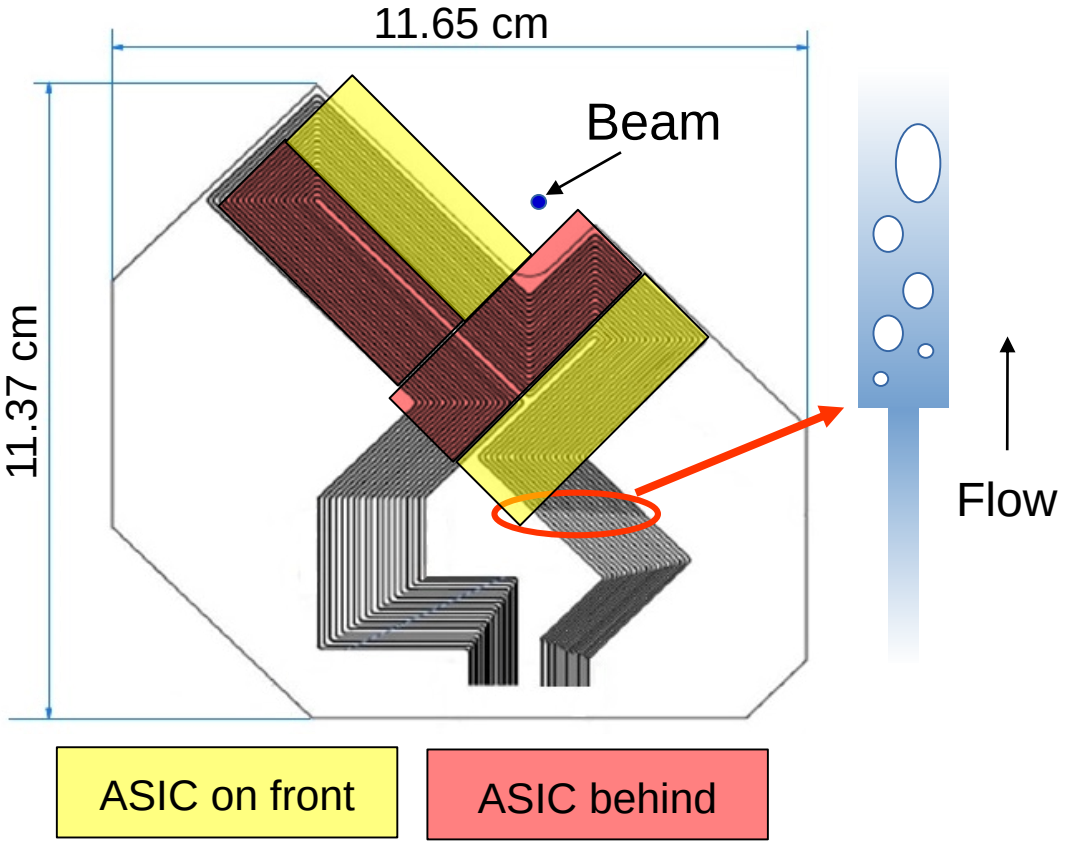
Cooling safety system

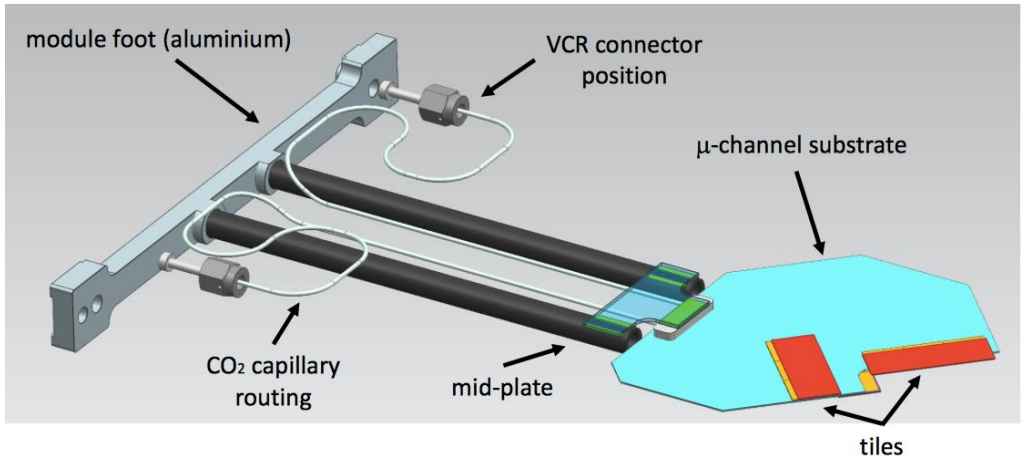
Leak detection

Summary

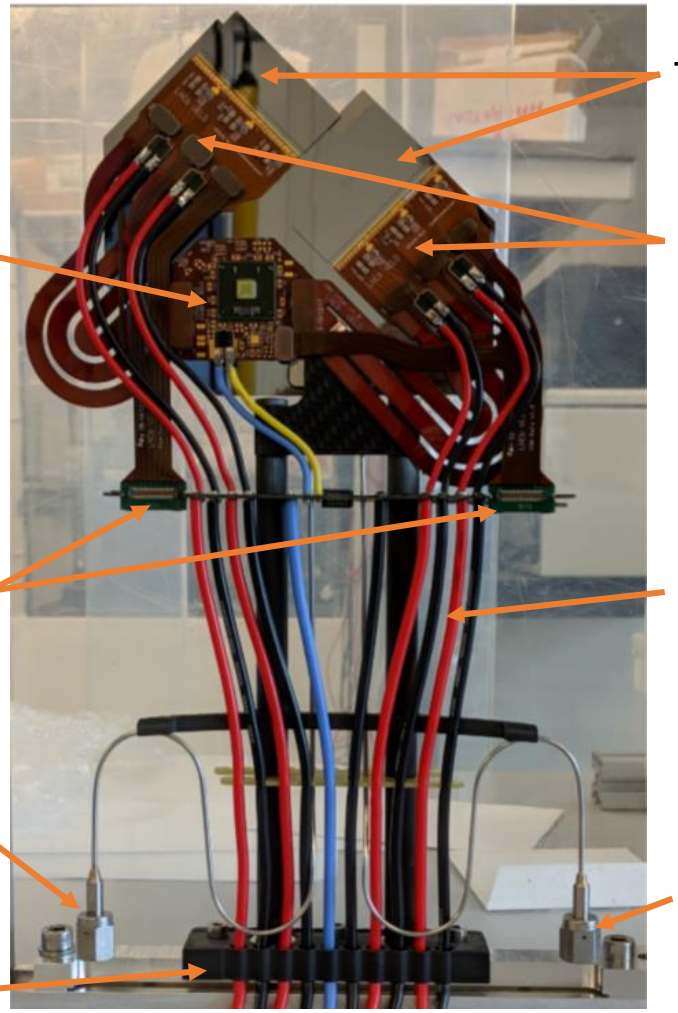
Micro-channels and first modules

- Evaporative cooling: Heat provided by electronics is absorbed by the CO_2 changing the ratio of gas/liquid
- Narrow restrictions at the entrance
  - 60 µm x 60 µm (40 mm long)
  - Prevents instabilities among the channels
- Main channels
  - 120 µm x 200 µm (~260 mm in average)
- Cooling substrate is 500 µm thick

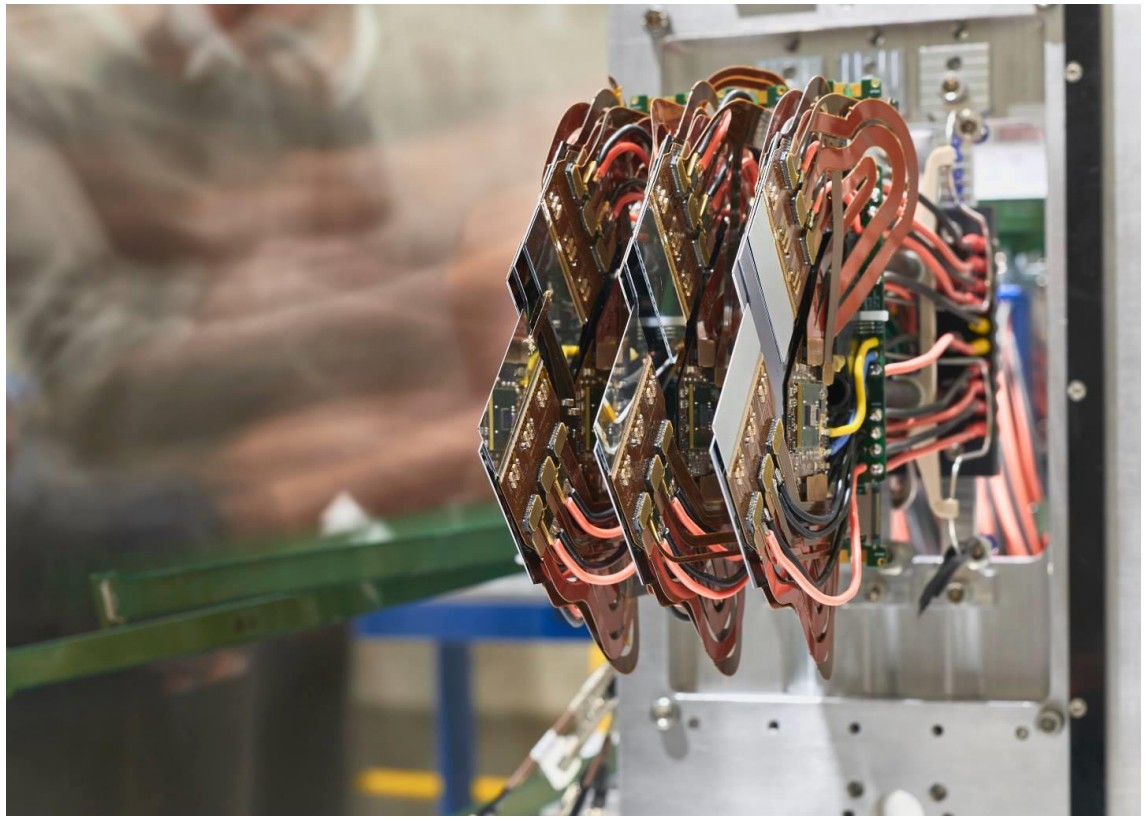




Micro-channels and first modules

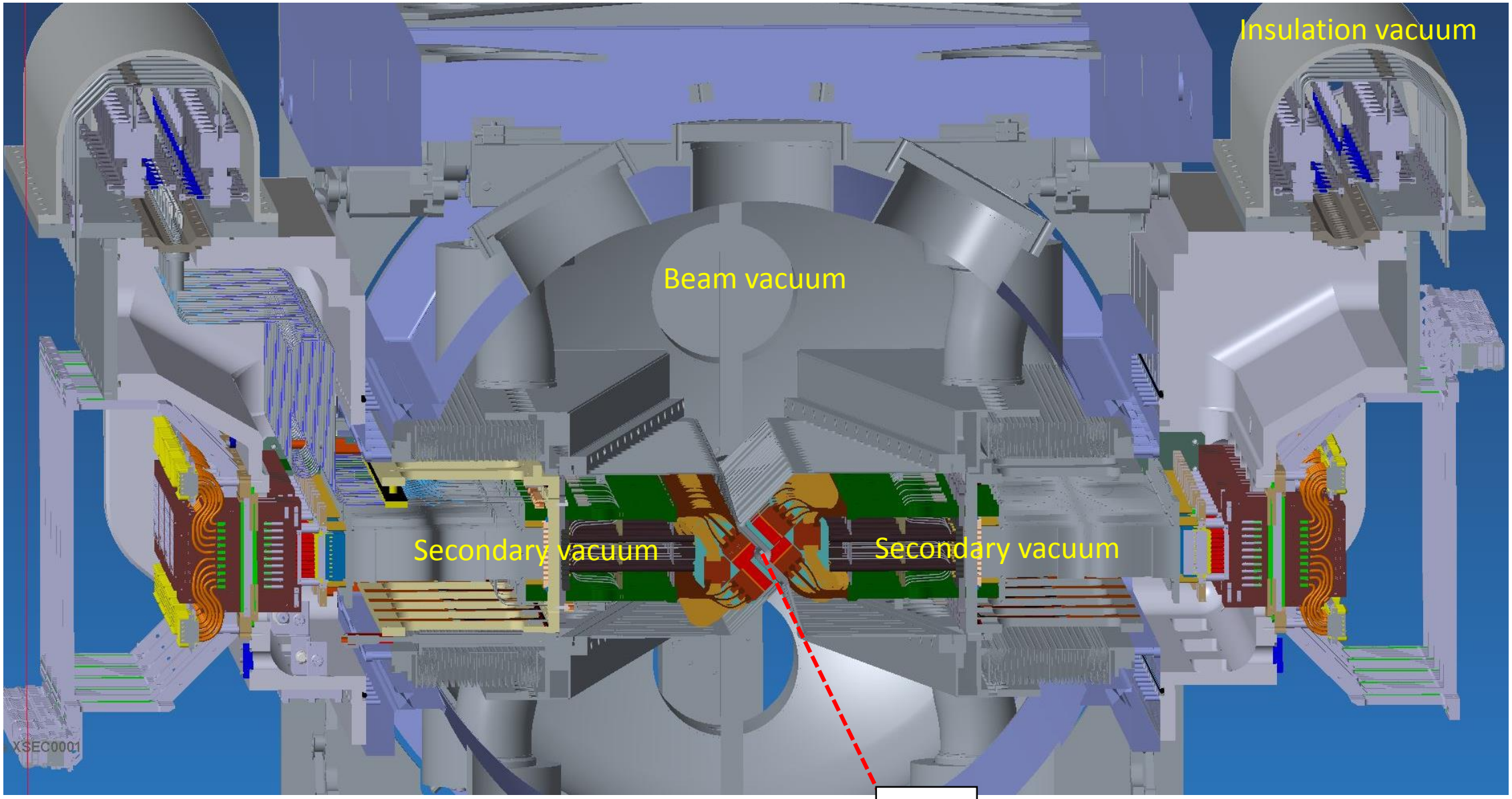


Successful testbeam with three modules



Julien Ordan, 2018

Full 3D design



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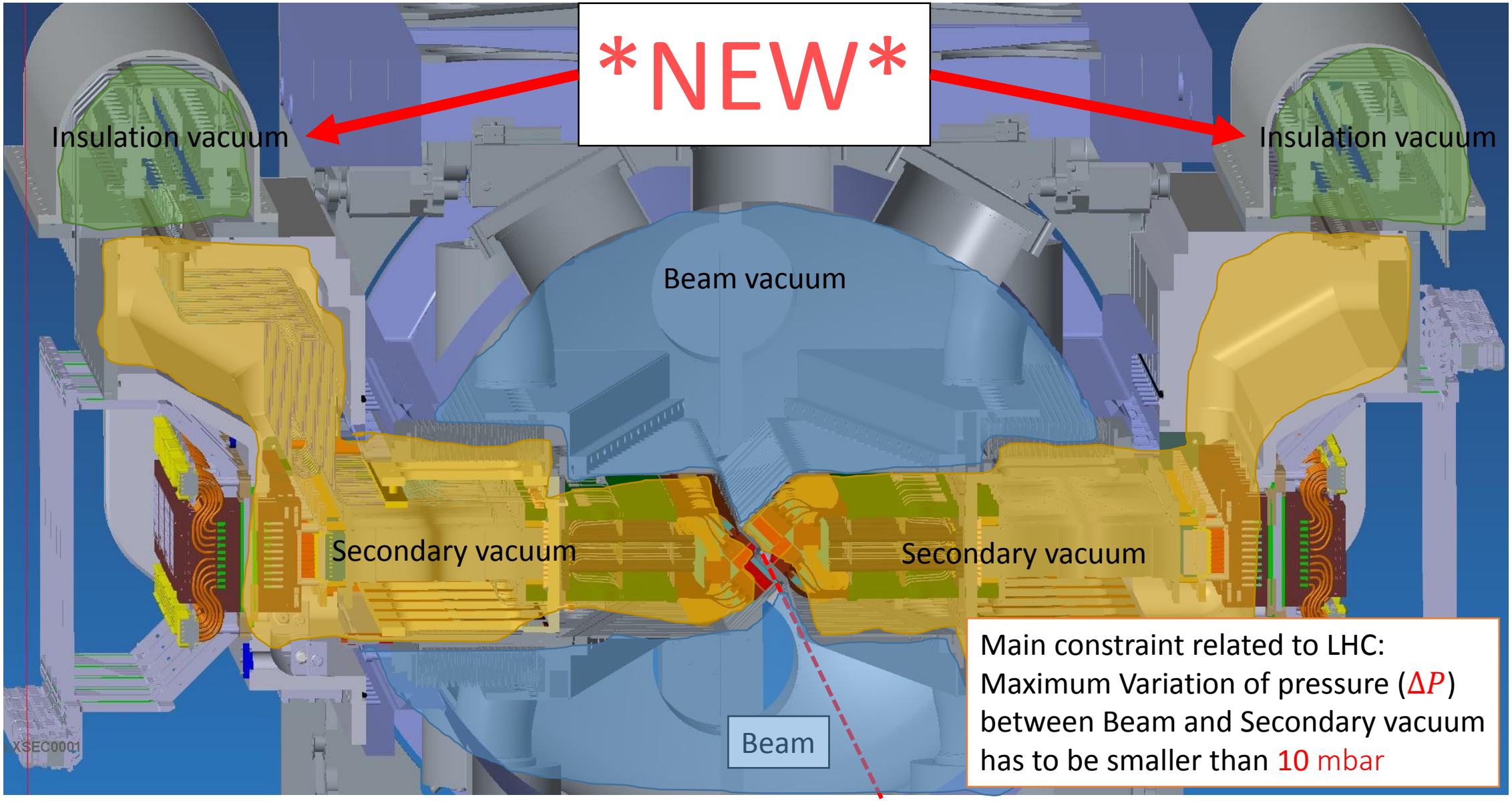


Main constraint related to LHC:
Maximum Variation of pressure (ΔP) between Beam and Secondary vacuum has to be smaller than 10 mbar

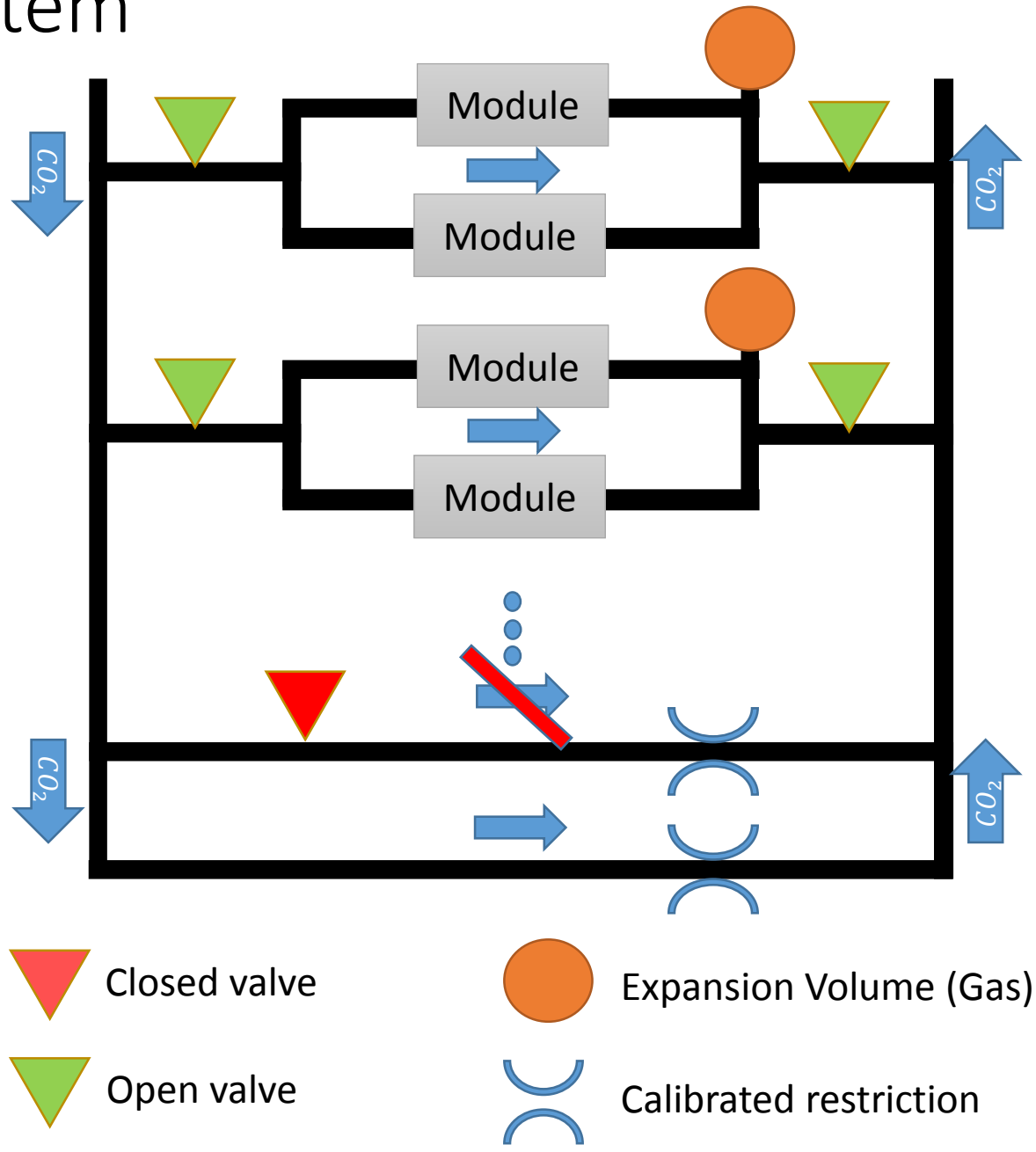
Insulation Vacuum and safety system

- Minimize the pressure raise in case of leaks
- An expansion volume is necessary to close the valves and prevent pressure build up while the system warms up

Two bypasses:

1) Always open to ensure minimum flow to keep the distribution lines cold
2) Divert the flow if the safety system is activated in such way that the variation of pressure over the detector is the same

If activated, LV and HV will be inhibited on the modules (no cooling).



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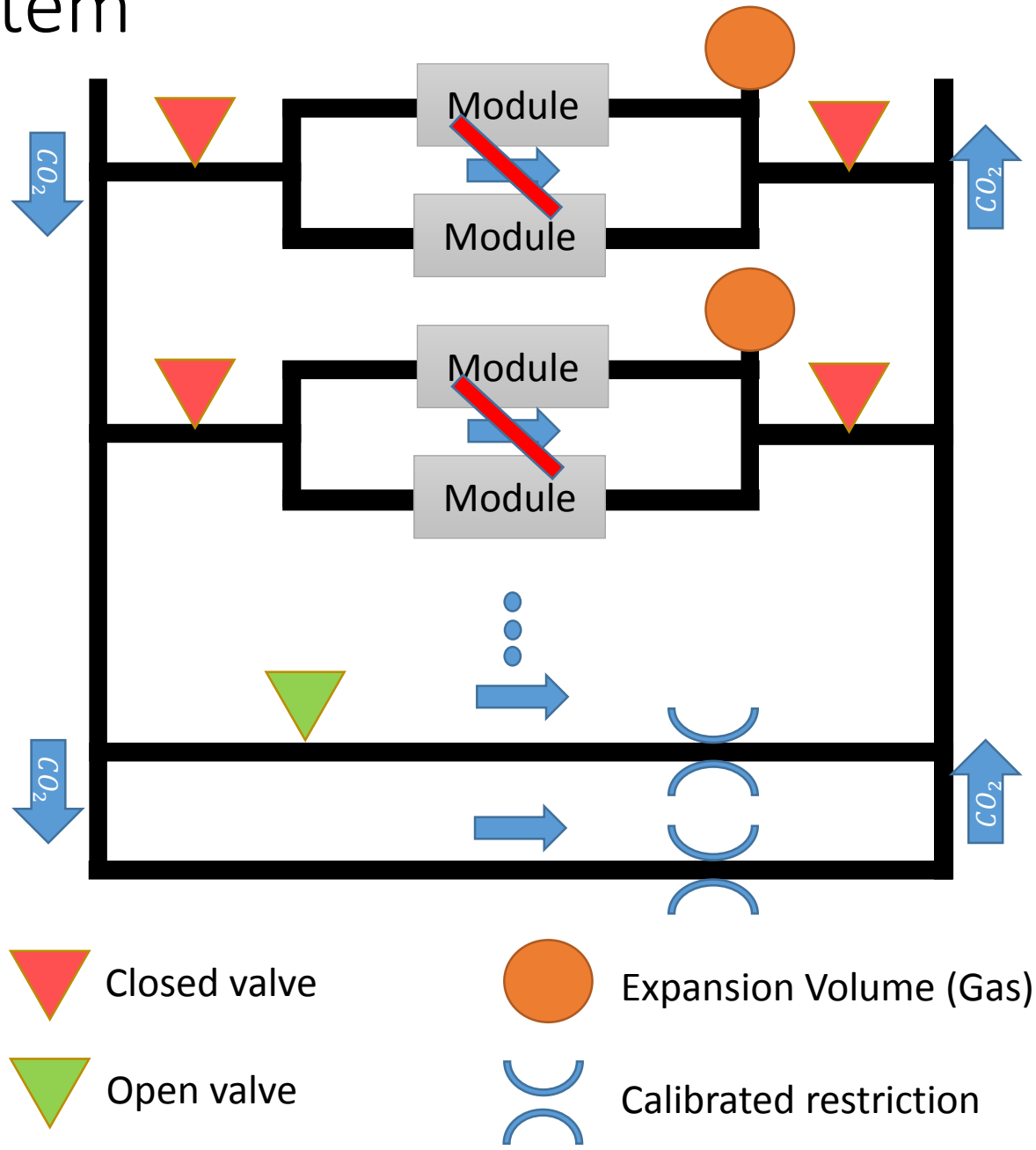


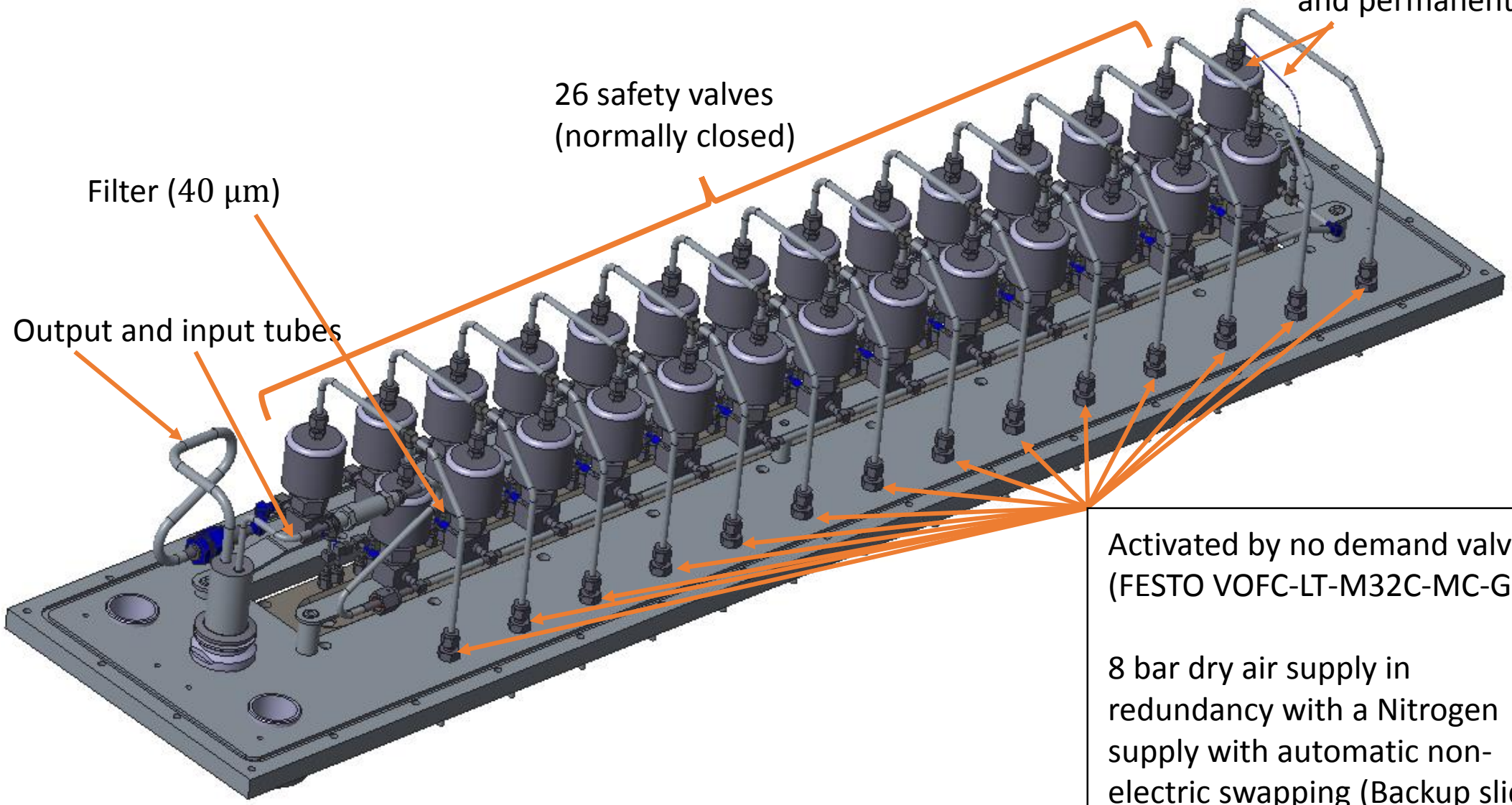
Isolation Vacuum (Safety system) – 3D design

Bypass valve (Normally open) and permanent bypass

26 safety valves (normally closed)

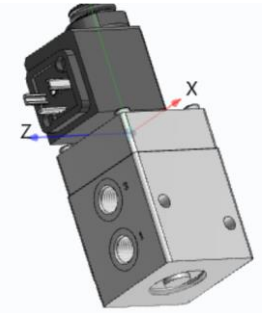
Filter (40 µm)

Output and input tubes



Activated by no demand valve (FESTO VOFC-LT-M32C-MC-G14)

8 bar dry air supply in redundancy with a Nitrogen supply with automatic non-electric swapping (Backup slide)



FESTO

Pressure in the secondary volume in case of leaks

- Scenario with the failure of one cooling loop containing two modules

- Considerations:
  - The CO2 inside the tubes/module is on the liquid state
  - During operation, the CO2 will be boiling (gas/liquid)
  - The CO2 in the expansion reservoir is on the gas state

- The reaction time was not considered on this exercise!
  - In discussion with the LHCb vacuum group
- The CO2 solidification slows down the leak rate (neglected)
- The suction of the vacuum pump was neglected

- Total CO2 in the loop:

$$m_l = \rho_{lCO2_{-35C}} \times V = 1096.5 \frac{\mathrm{kg}}{\mathrm{m}^3} \times 5.5\, ml = 6.03\, g$$

$$m_g = \rho_{gCO2_{+20C}} \times V = \frac{194.2\mathrm{kg}}{\mathrm{m}^3} \times 5.5\, ml = 1.07\, g$$

Pressure in the secondary volume in case of leaks

- Total pressure using ideal gases equation:

$$P_{leak} = m_T \times \frac{RT}{44V} = 7.1\ g \times \frac{8.31 \times 10^{-2} L.bar.K^{-1}\ mol^{-1} \times 300K}{600\ L \times 44\ g\ mol^{-1}}$$

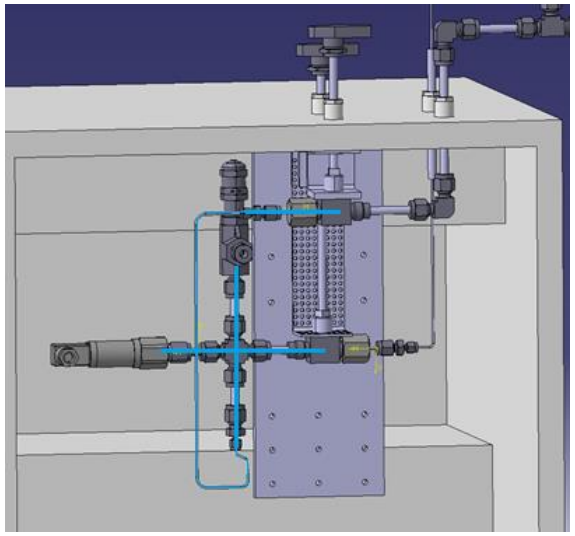
$$P_{leak} = 6.70\ mbar$$

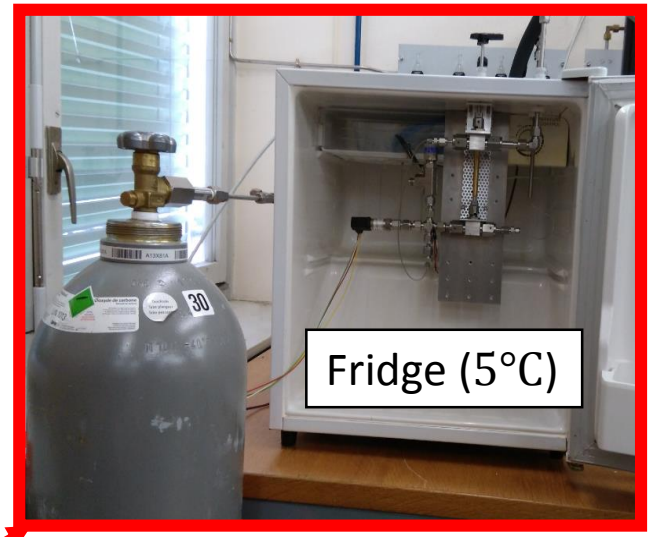
Baseline is to use a container made using a standard 10 cm long tube with of ½" outer diameter pipe (ID 1.0922 mm):

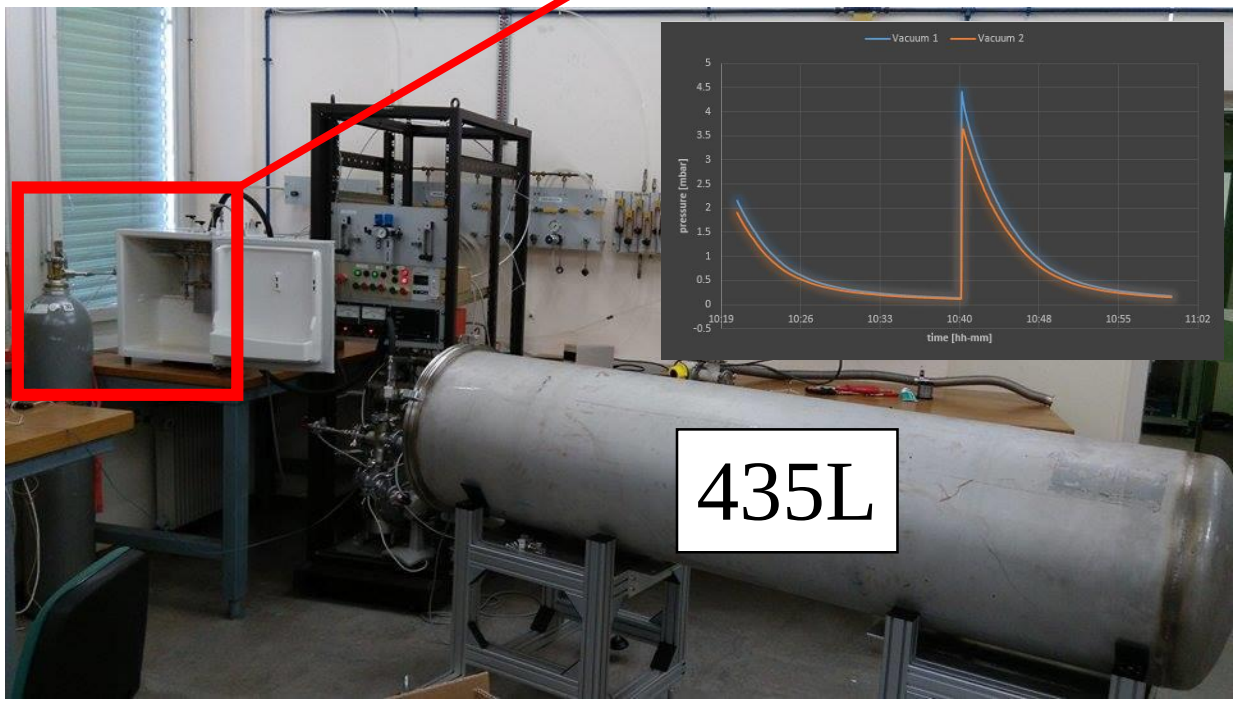
- Expansion volume would be ~8.2 ml for the expansion volume (1.6g CO2)
- Total mass of 7.63 g
- $P_{leak} = 7.2\ mbar$ (Safety margin of 38% with respect to 10 mbar)

Experimental test #1

Capillary length [cm]	Pipes volume	CO2 mass [g]	Total volume (L)	CO2 Liquid density [kg/m3]	Max. Pressure [mbar]
100 (Fully liquid)	4.35161	4	435	895.9	4.5
VELO Upgrade Liquid(Scaled)	5.5	6.03075	600	1096.5	5.05
VELO Upgrade Gas (Scaled)	8.2	1.59244	600	194.2	1.33
VELO Upgrade total (Scaled)	13.7	7.62319	600	-	6.38







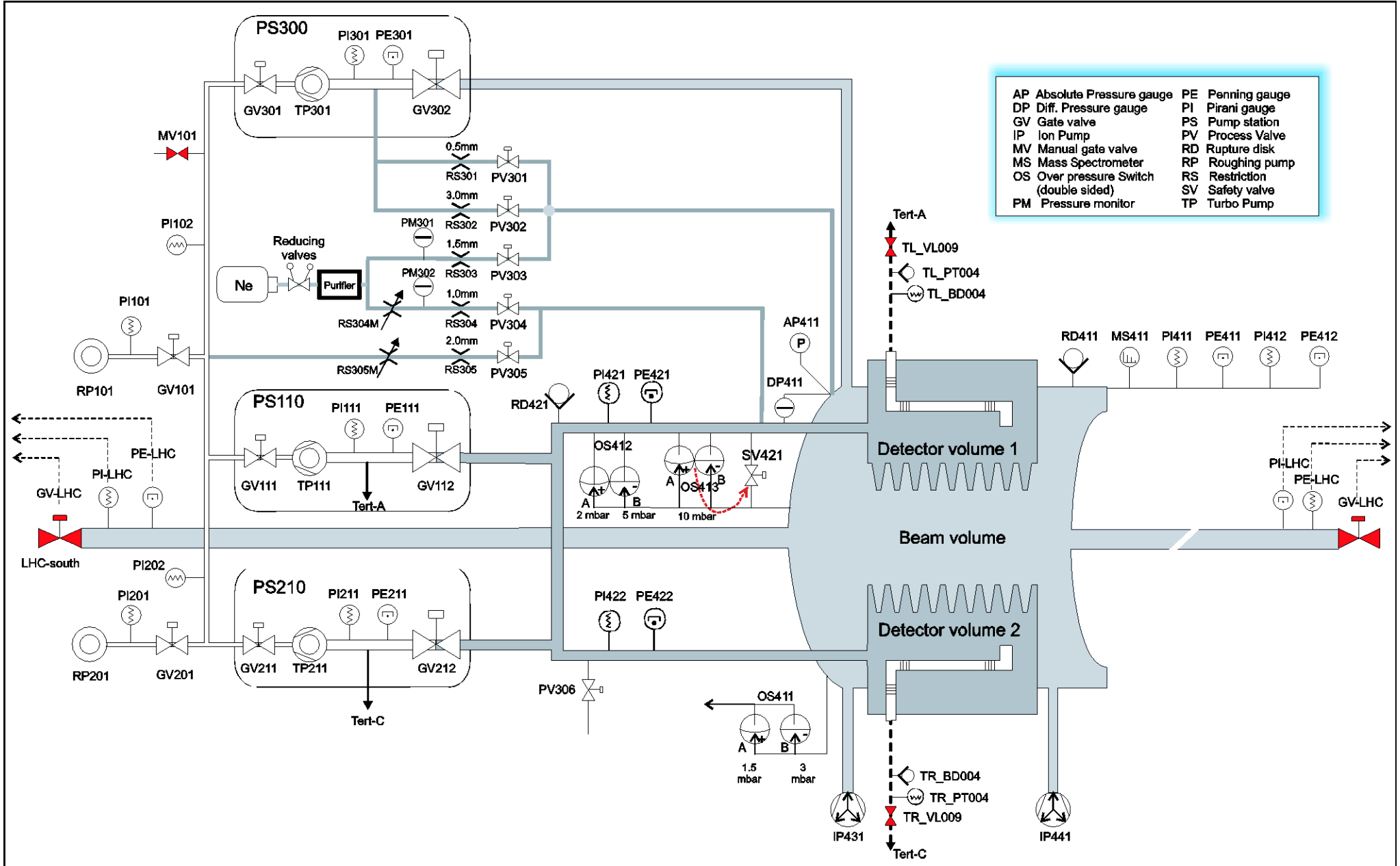
The reaction time was neglected!

Takes into account the pump speed (Adixen?)

VELO leak detection

- Dedicated pressure sensors:
  - Penning: 10^{-11} mbar < p < 10^{-4} mbar
  - Pirani: 10^{-4} mbar < p < 1 bar
  - Absolute Baratron: 1 mbar < p < 1 bar
- Possibility to analyze the variation of pressure over time but it is challenging
- Additional pressure sensors on the vacuum system side could also inform us about leaks (redundancy)
- Membrane switches (+10 mbar) which give almost instantaneous response (no processing time)

VELO Vacuum system



LHCb Vertex Locator

EDMS No: 901534 Version 1.1

Date 08-01-2009

LHCb vertex vacuumsystem

National institute for subatomic physics Amsterdam

Date: 19-03-2008

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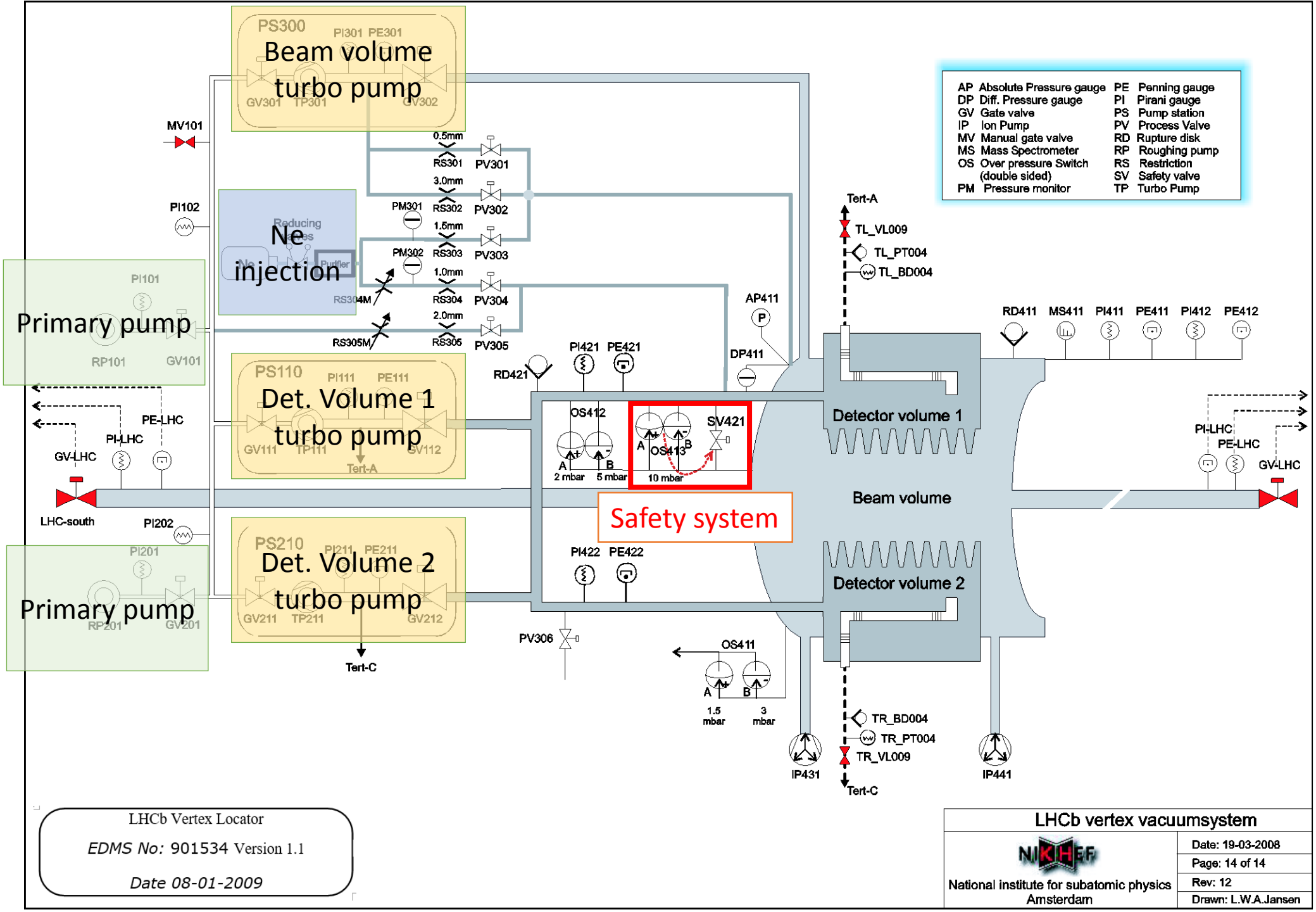
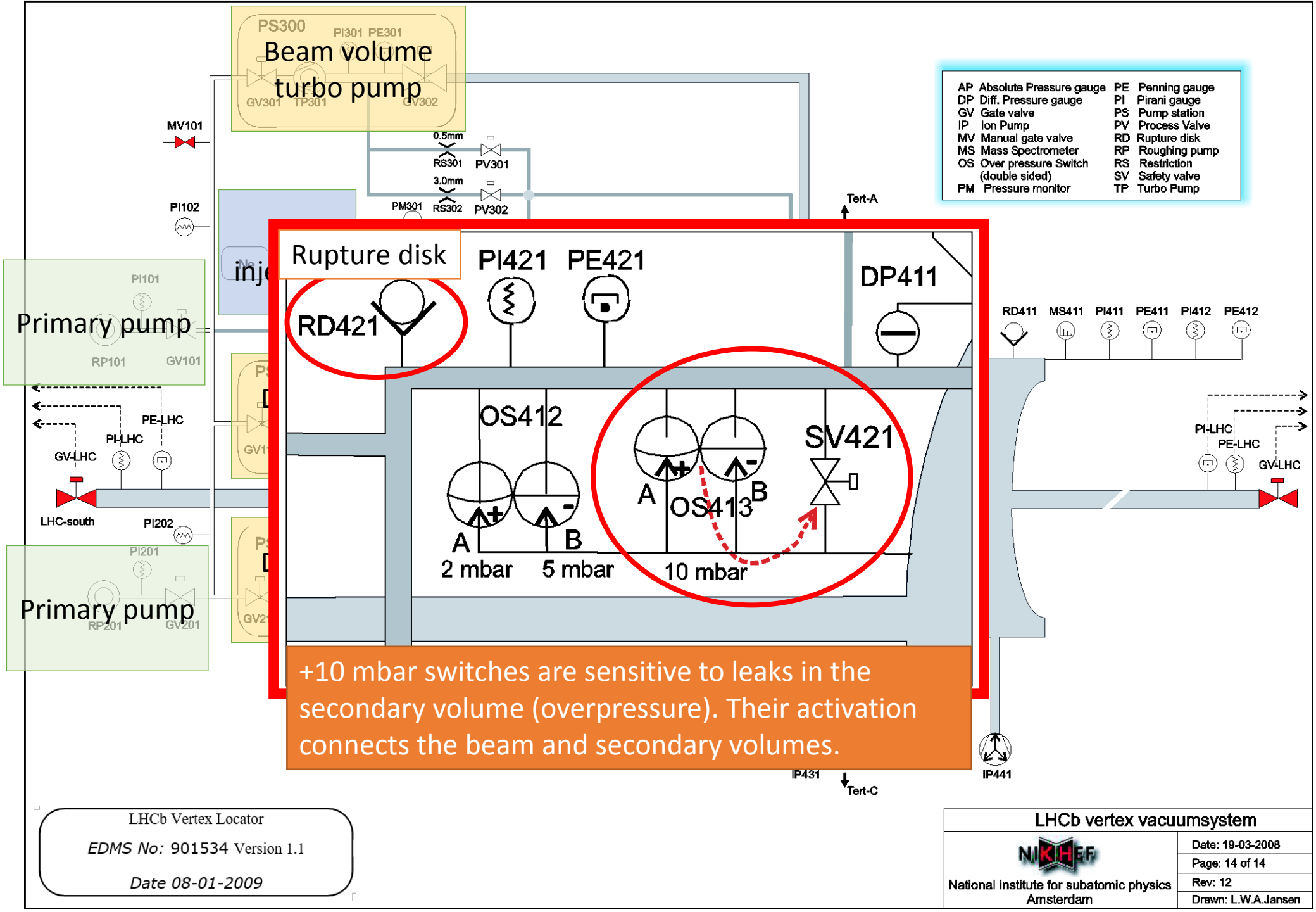
Rev: 12

Drawn: L.W.A.Jansen

VELO Vacuum system



VELO Vacuum system



Summary

The first protection against unlikely leaks are the two shutoff valves that can isolate every two modules from the cooling plant and mitigate pressure increase in the secondary vacuum.

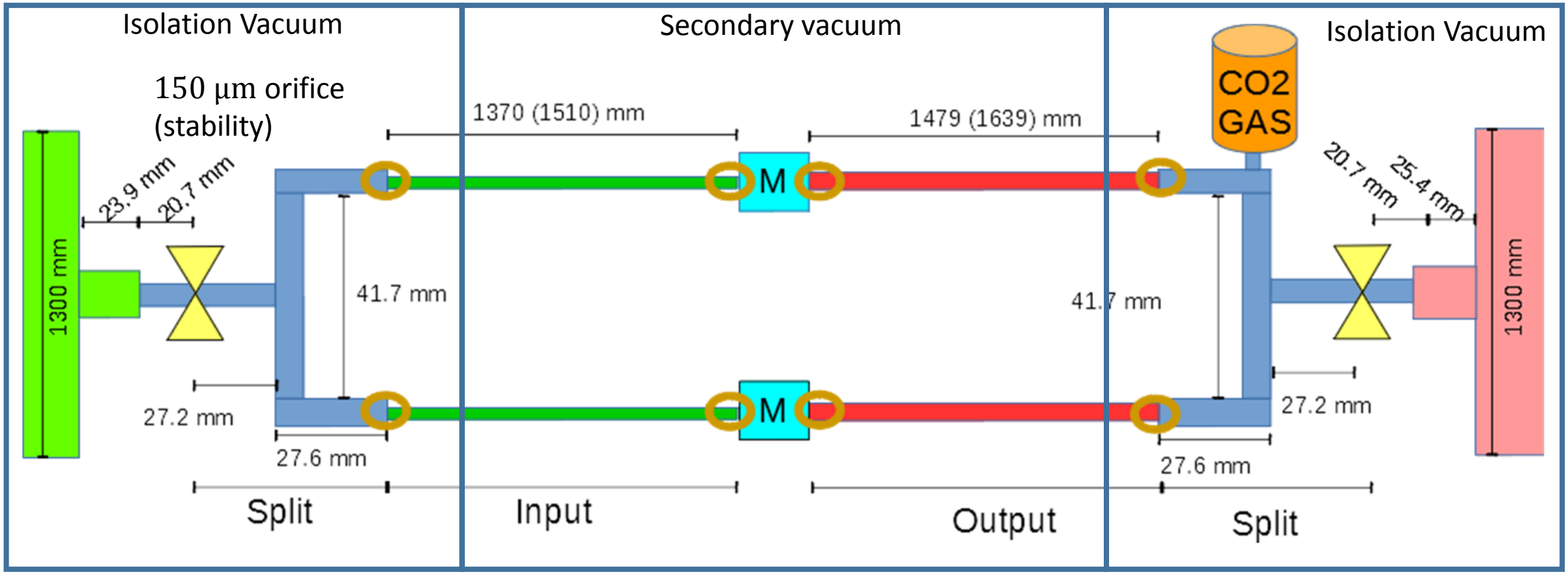
The second protection is the connection of beam and secondary volumes to prevent the RF plastic deformation/rupture if $|\Delta P| > 10\ mbar$

The CO_2 present in the cooling loops (ignoring the reaction time) would increase the pressure in the secondary volume by 6.38 (6.70) mbar

The redundancy of the leak detection mechanism can be achieved by signals provided by the vacuum system and additional pressure sensors

Thank you!!!

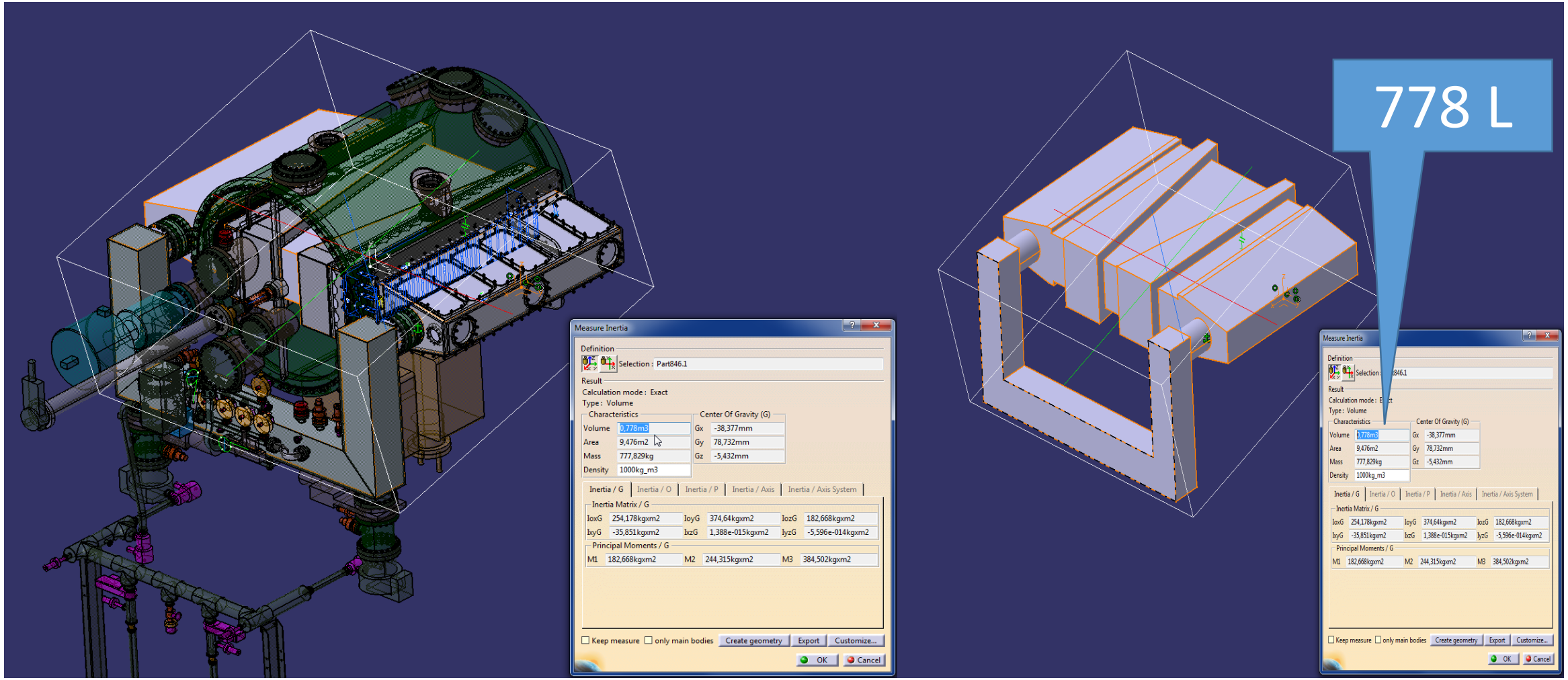
One branch of the cooling system



1/8" (ID 1.397 mm)
1/16" (ID 0.5715 mm)
1/16" (ID 1.2 mm)
1/4" (ID 6.223 mm)
VCR connector 1/8" (~5mm)

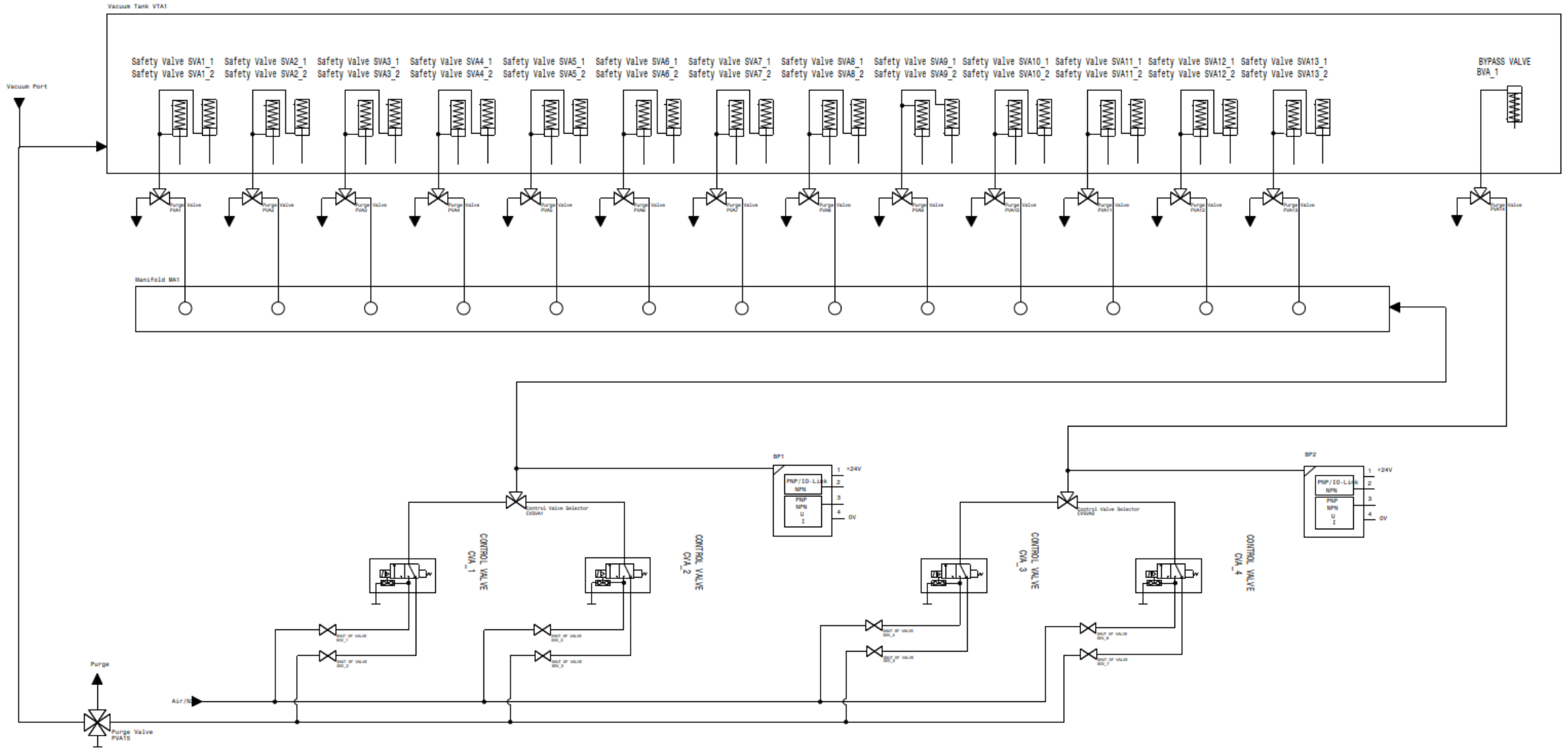
3/8" (ID 9.398 mm)
Same volume between the valves
M 2x320 mm 1/16 " to the connector in the module (Microchannels – Input + output)

Total secondary volume

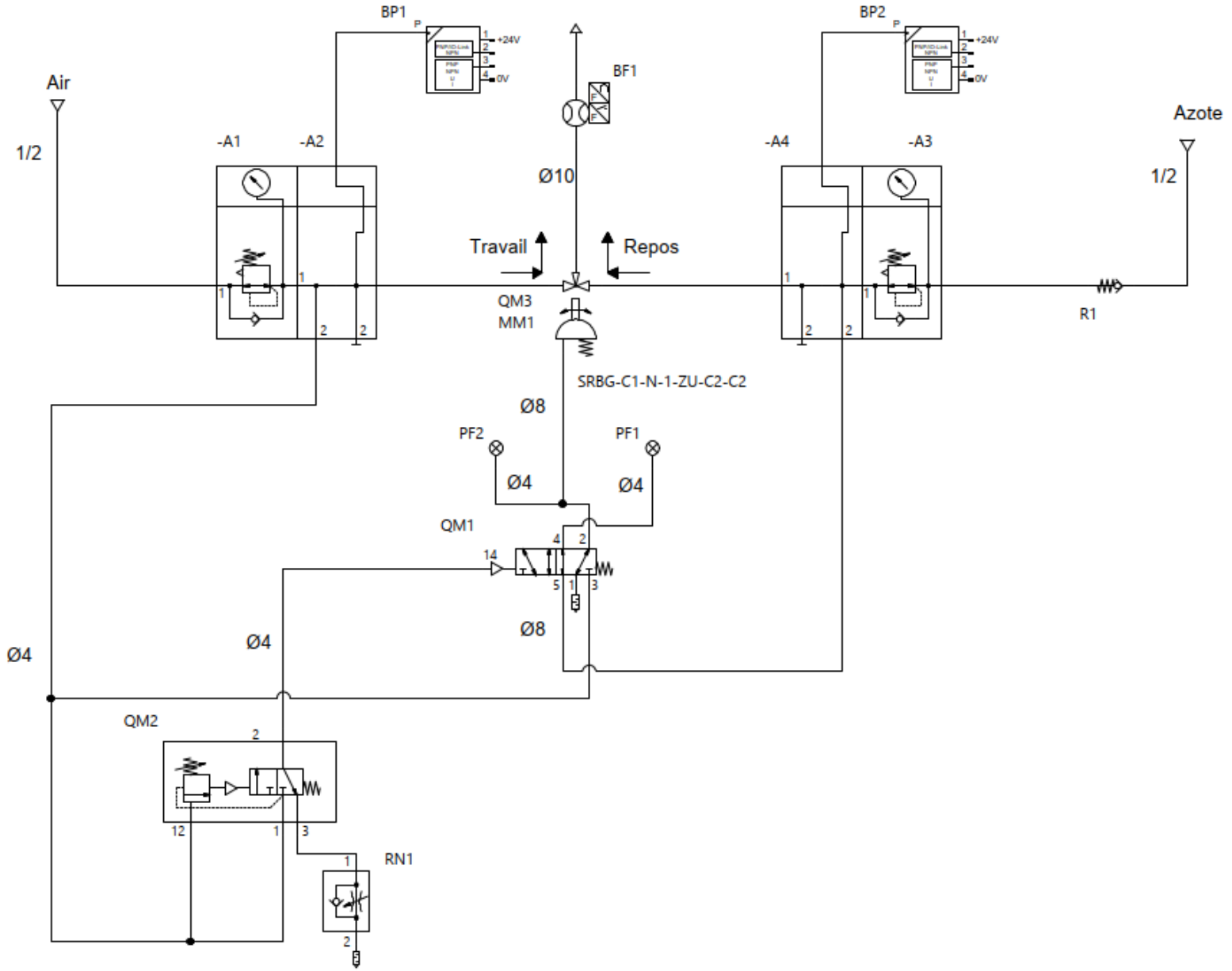


Due to the cables, modules and mechanics, we are assuming that the effective volume is 600 L.

Shutoff valves trigger system



High pressure gas redundancy system



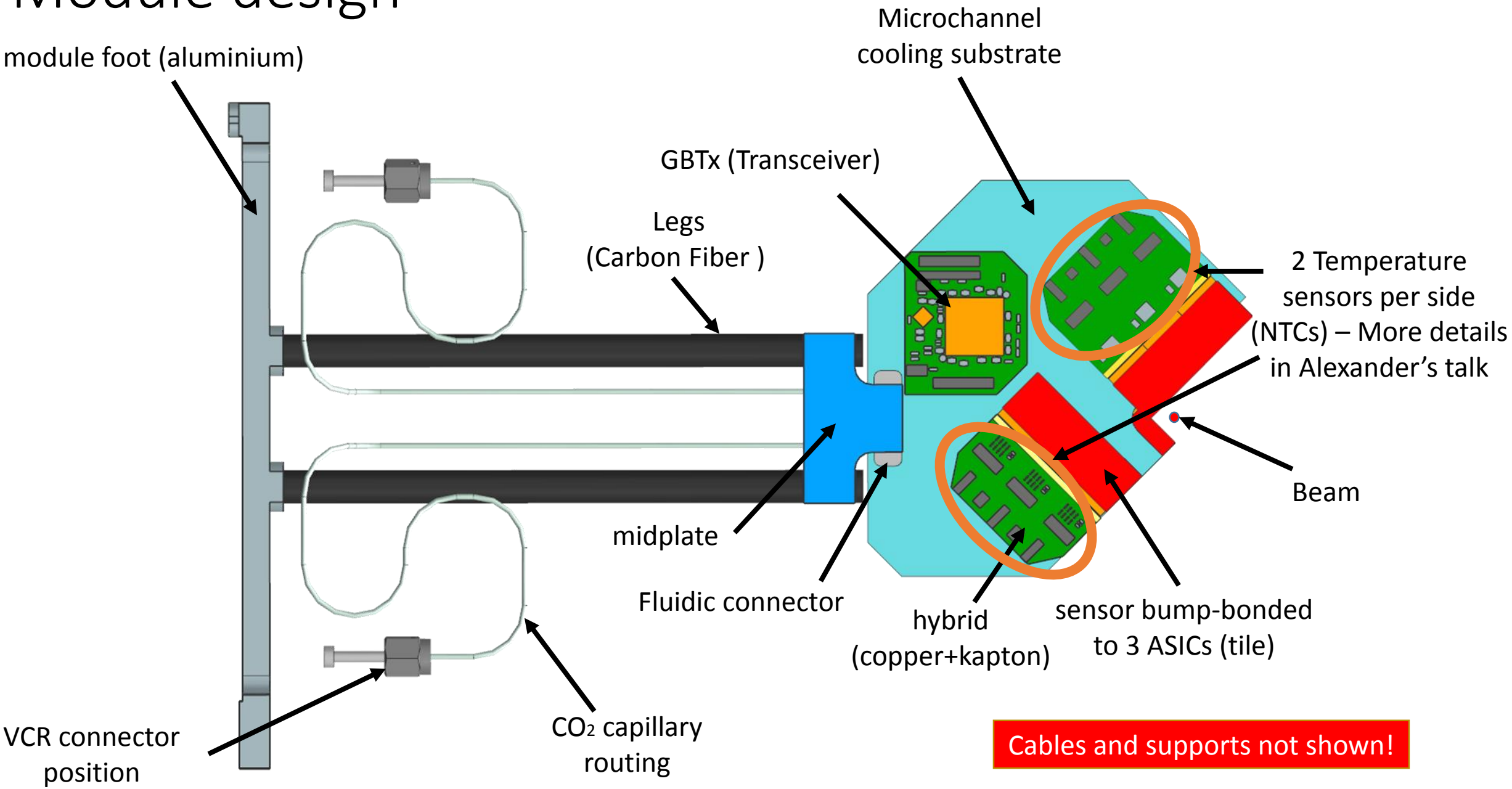
Pressure in the secondary volume in case of leaks

- Assuming 30% vapour quality in the return line when the modules are on:
  - 1.179 ml of liquid becomes gas at -35C
  - Total mass becomes: 1.6g + 4.74g + 0.037g = 6.38g
  - 10 cm expansion volume as in previous slide
  - Total pressure using ideal gases equation:

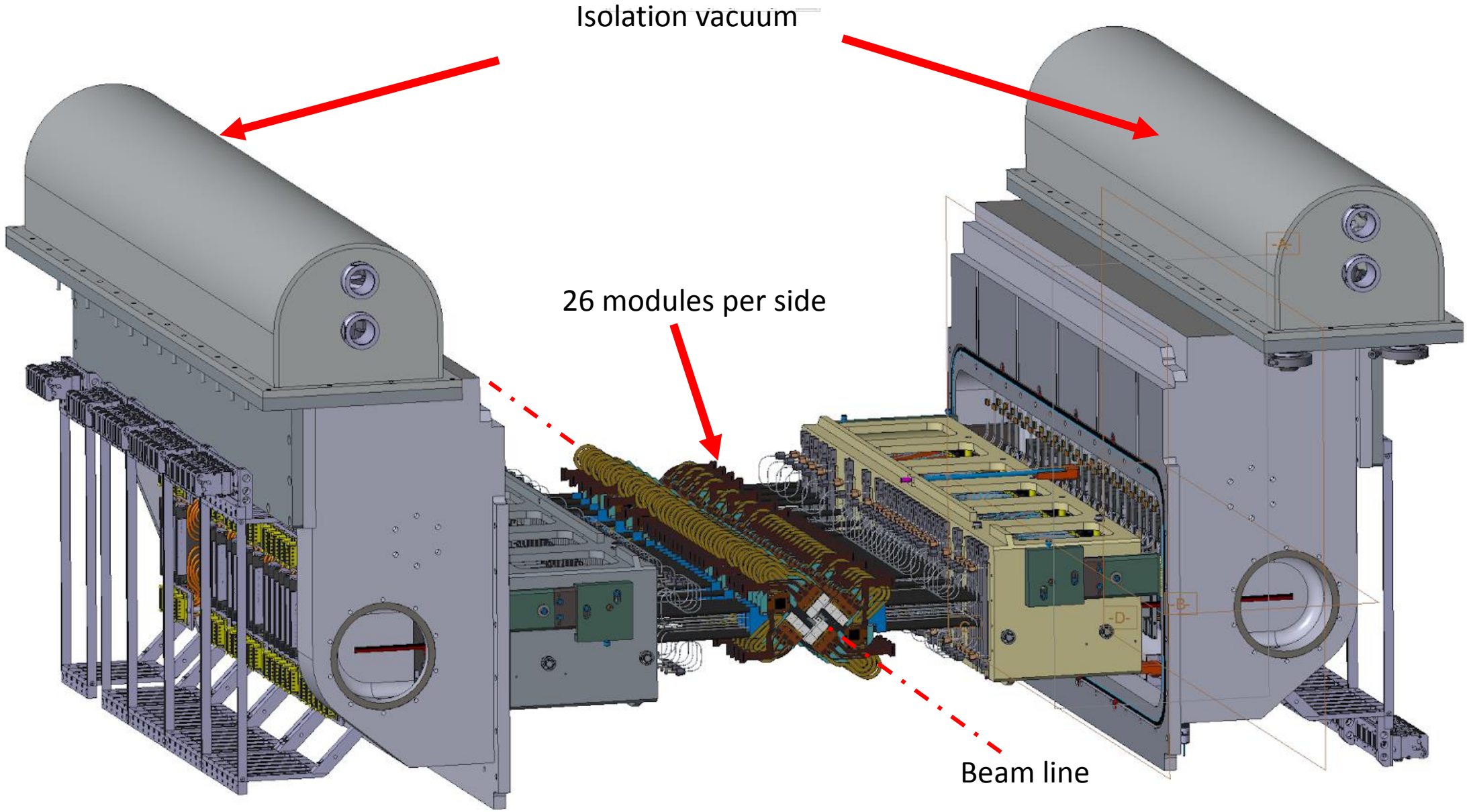
$$P_{leak} = m_T \times \frac{RT}{44V} = 6.38\ g \times \frac{8.31 \times 10^{-2} L.bar.K^{-1}\ mol^{-1} \times 300K}{600\ L \times 44\ g\ mol^{-1}}$$

$$P_{leak} = 6.02\ mbar$$

Module design



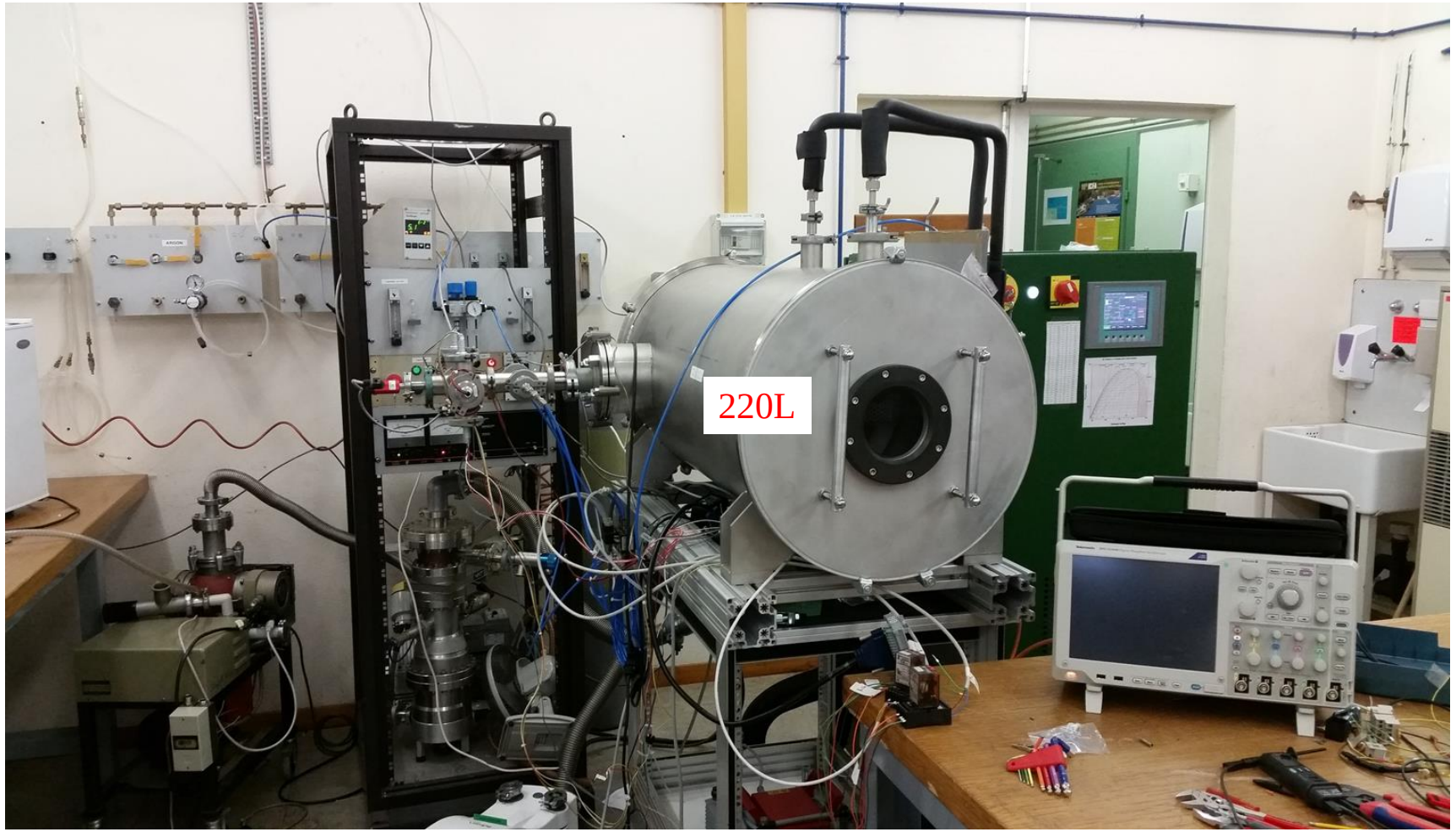
Modules, mechanical supports and Isolation vacuum



Experimental tests

- Summary of results:
  - Up to 6 m x 1 mm ID capillary with pure liquid CO2 (up to 7.6 g) release in a vacuum chamber with volume 435l -> maximum pressure 4 mbar with the pump running
  - Up to 50 cm x 1 mm ID plus additional components (4.55 ml volume) released in a vacuum chamber of 220 l -> maximum pressure of 5.8 mbar with reaction time of ~ 433 ms and vacuum pump running
  - Failure of the safety system test in a volume of 220 l -> Pressure stabilized at 15 mbar with the vacuum pump running (CO2 solidification)

Safety system setup



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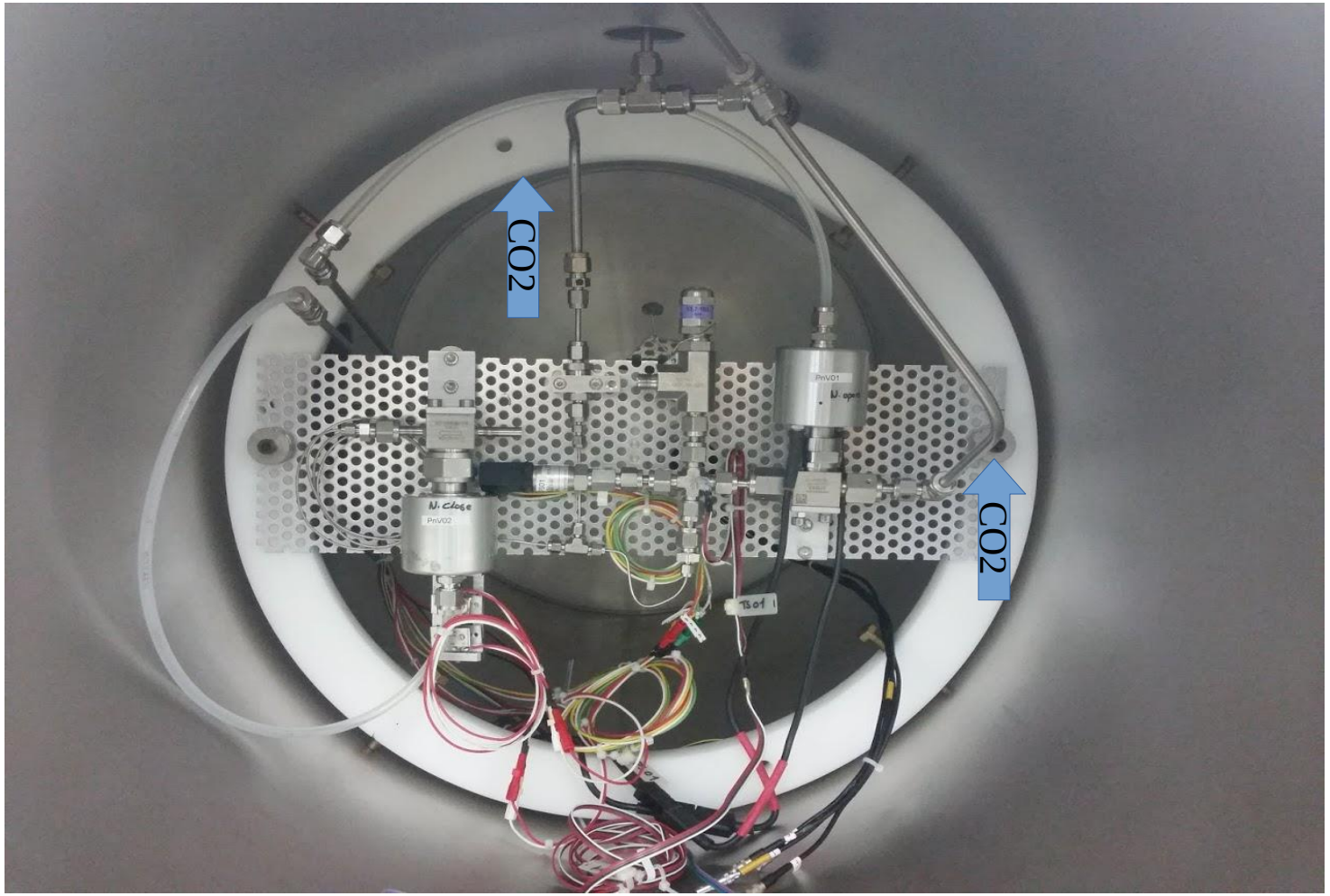
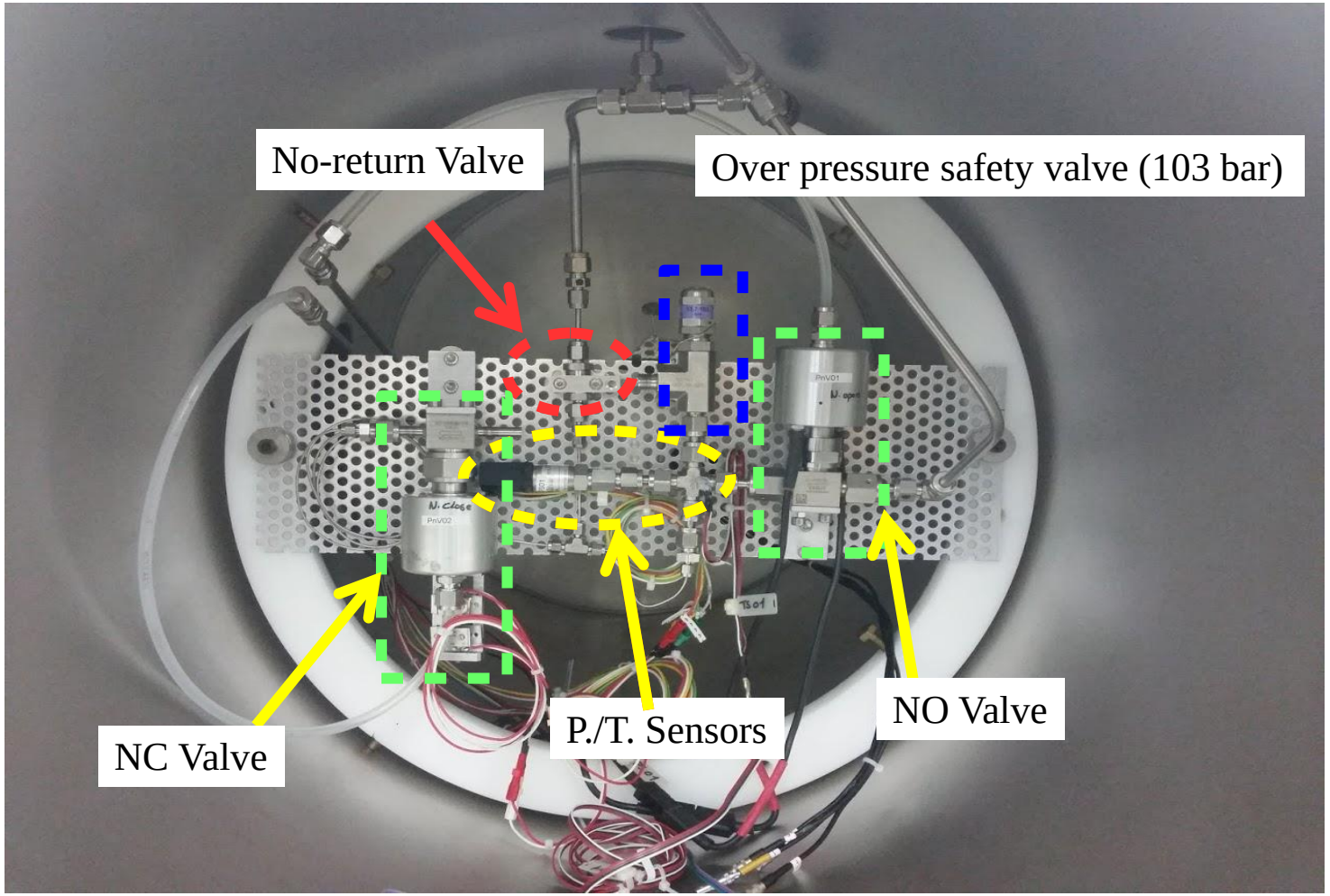
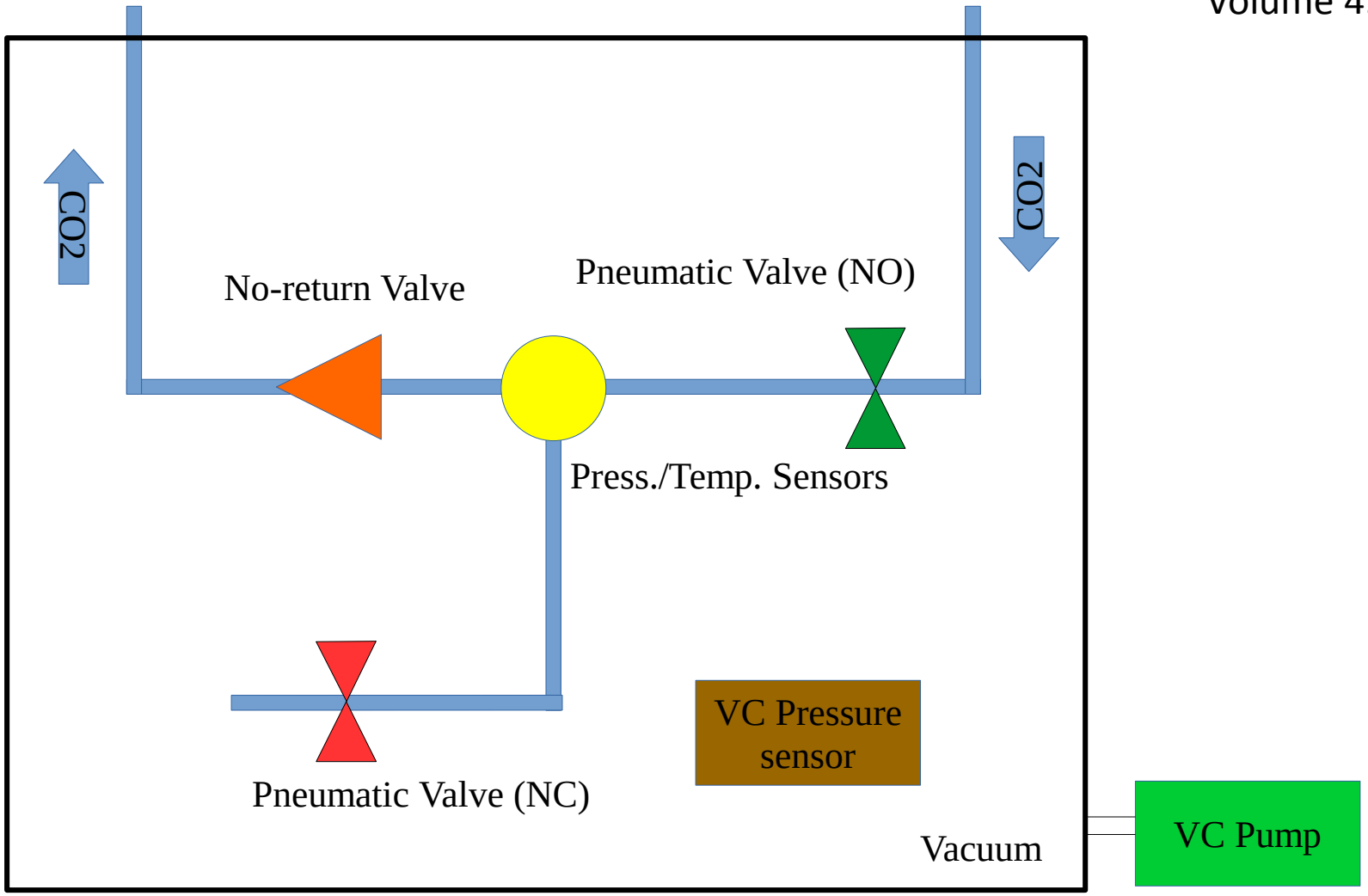


Safety system setup

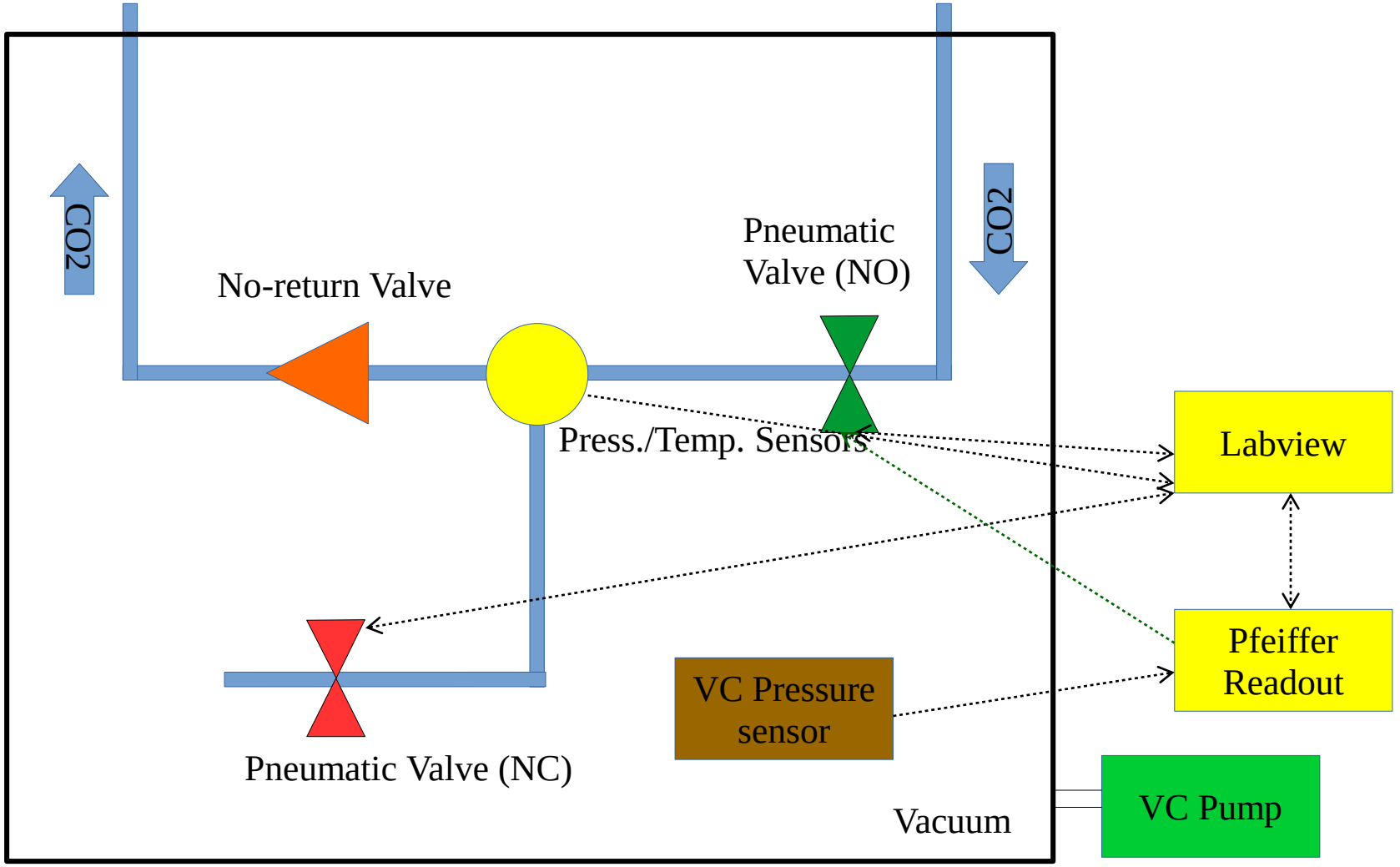


Safety system test

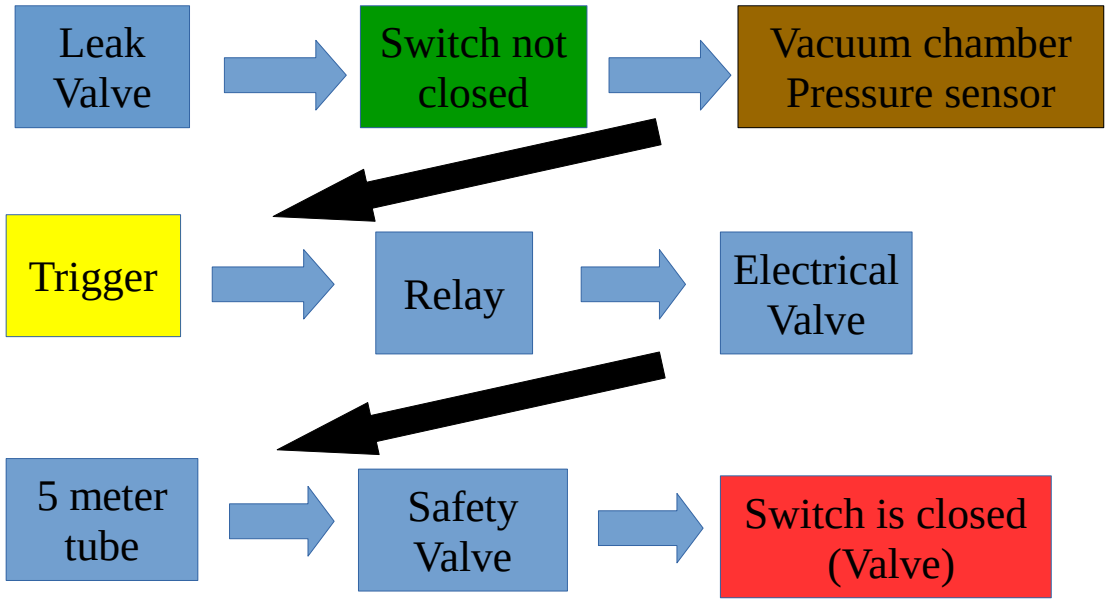
Volume 4.55 ml

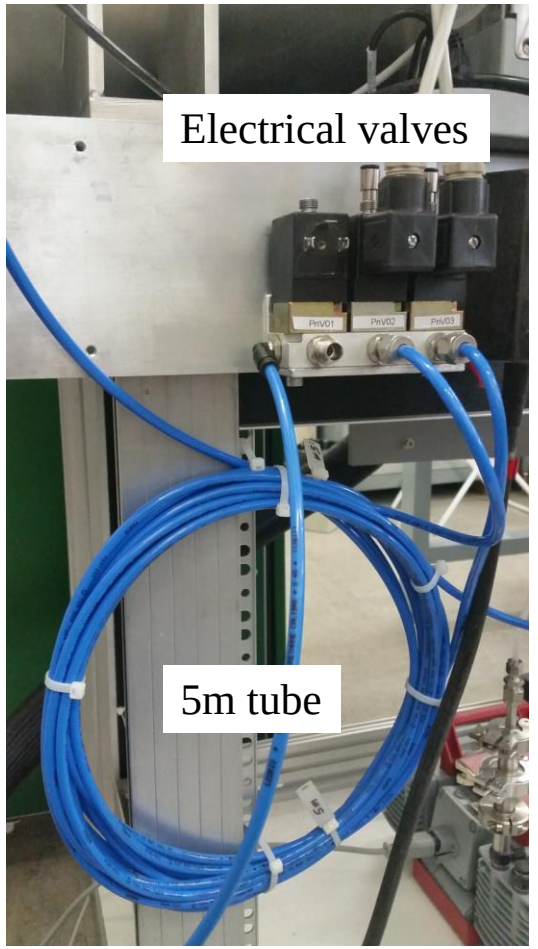


Safety system test

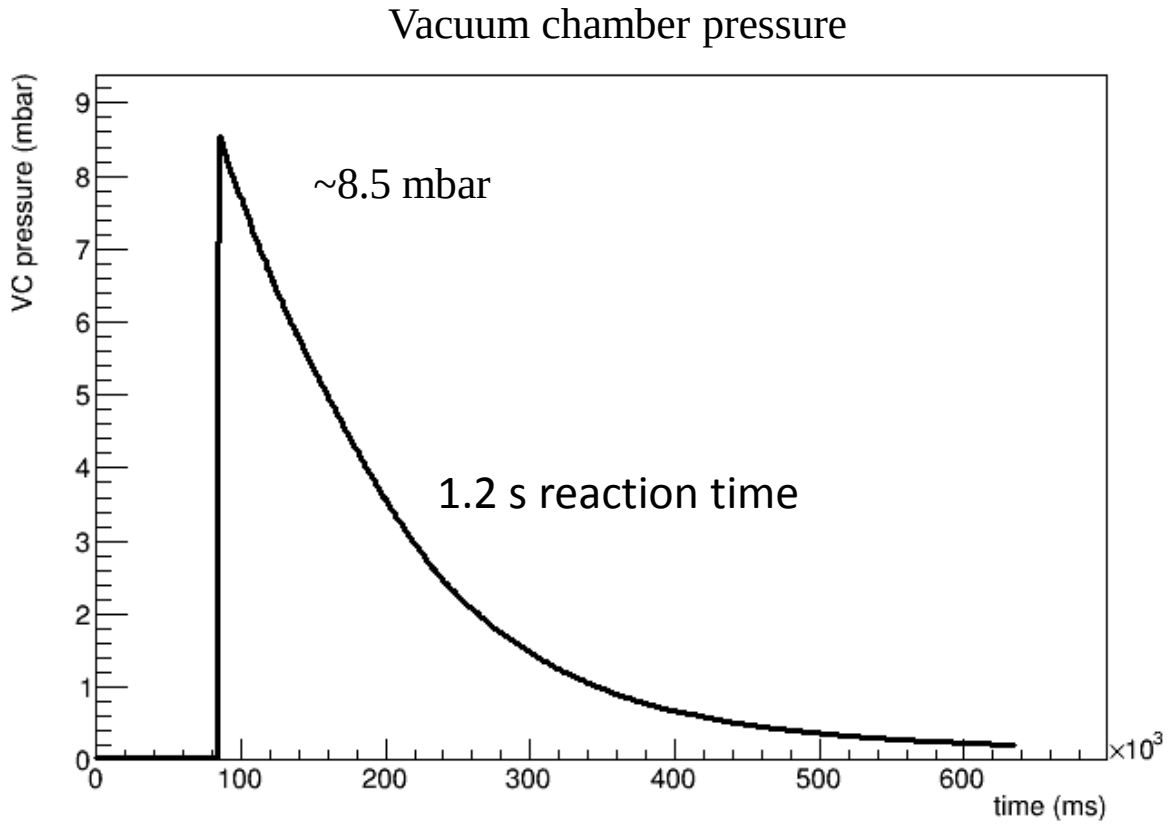


Activation chain



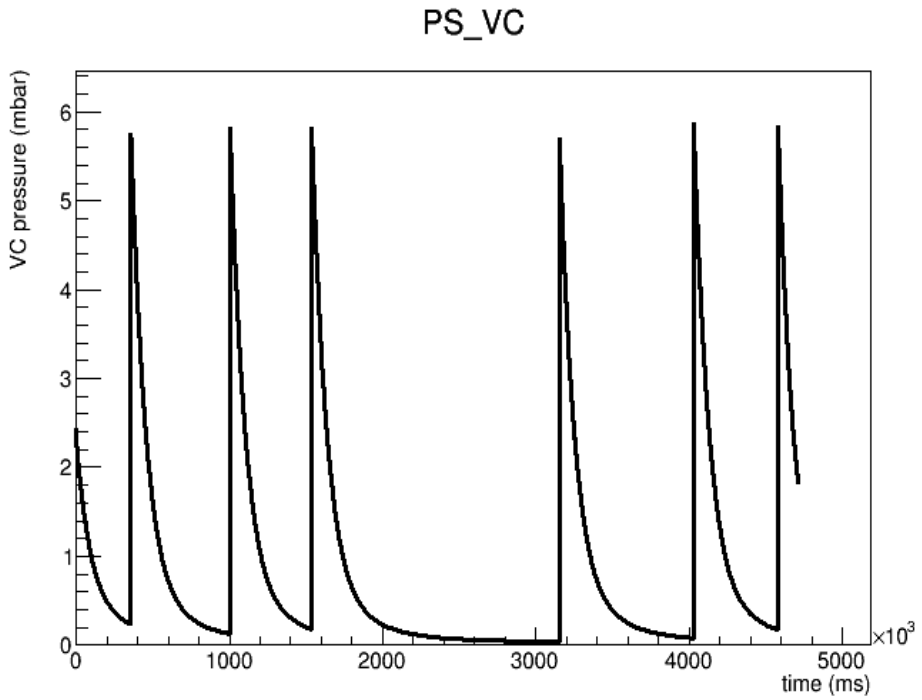


Safety system test (Labview)

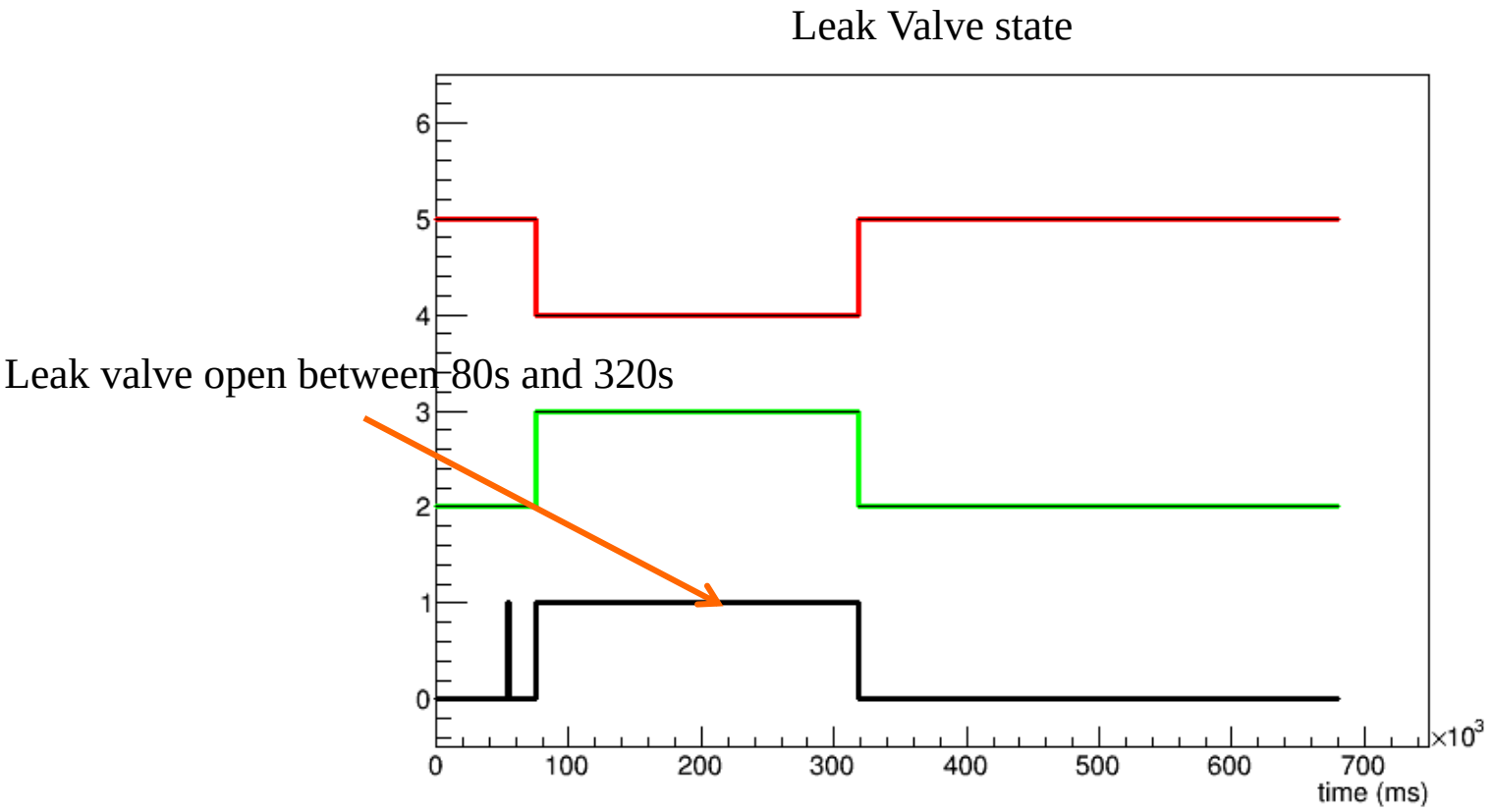


Safety system test (Pfeiffer)

- The Pfeiffer readout can be used to trigger the pneumatic valve (faster)
- Trigger set to 1 mbar threshold
- TRACI: -15C
- Maximum pressure: ~5.8mbar
- Faster reaction time (433ms)

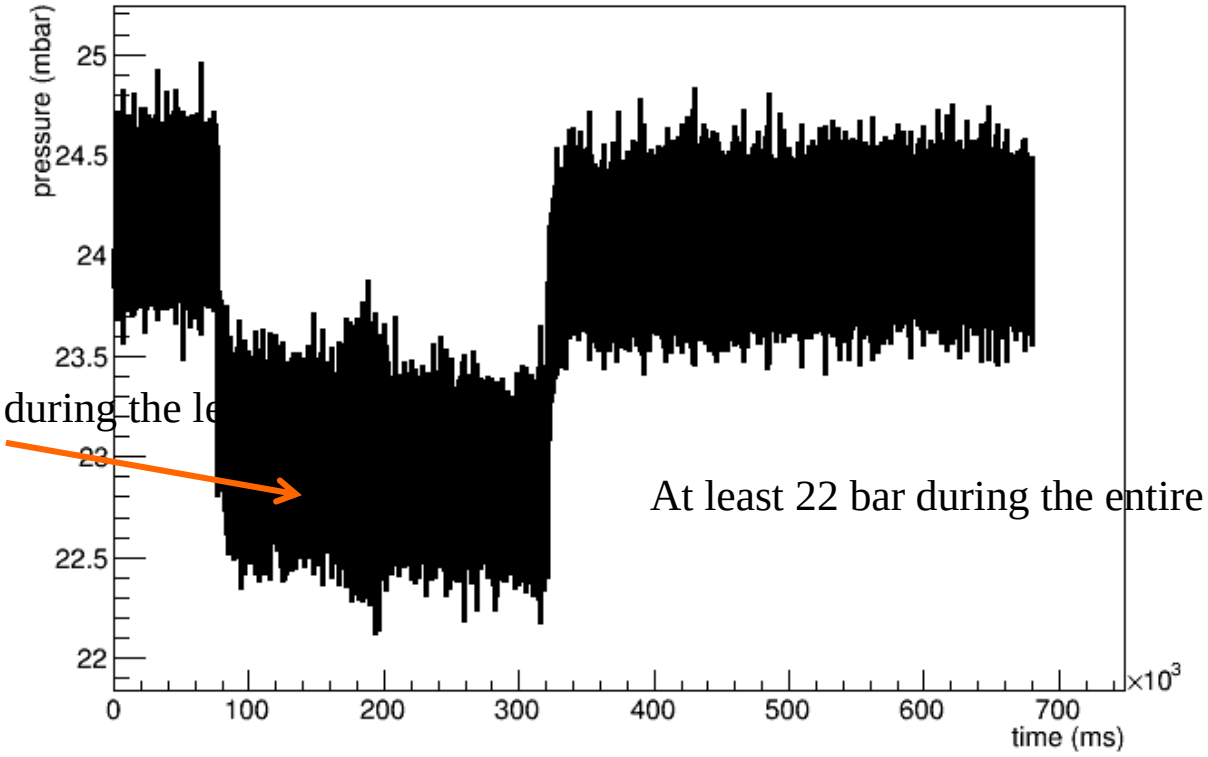


Safety system failure test



Safety system failure test

Pressure inside the tube

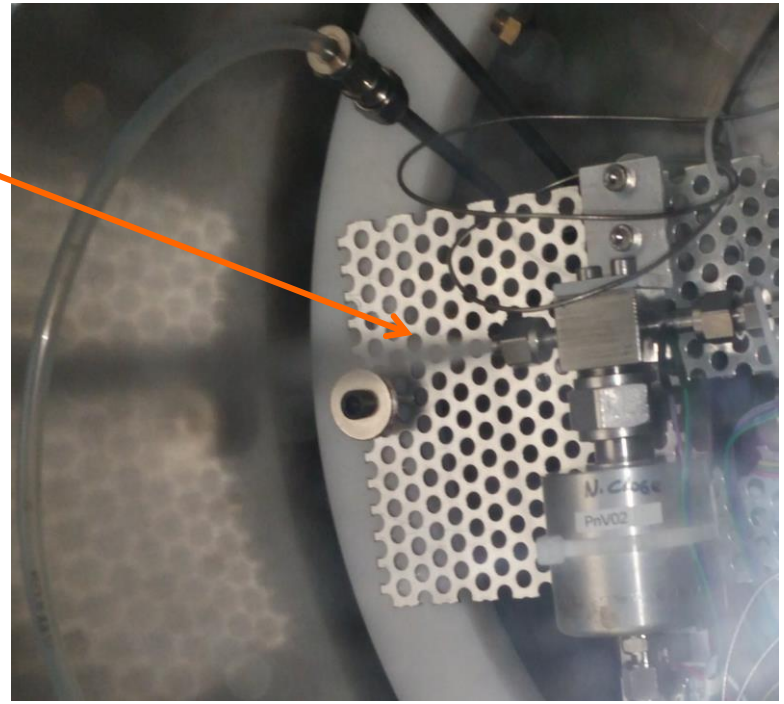


Pressure dropped during the le

At least 22 bar during the entire test

Safety system failure test

CO2 Leak

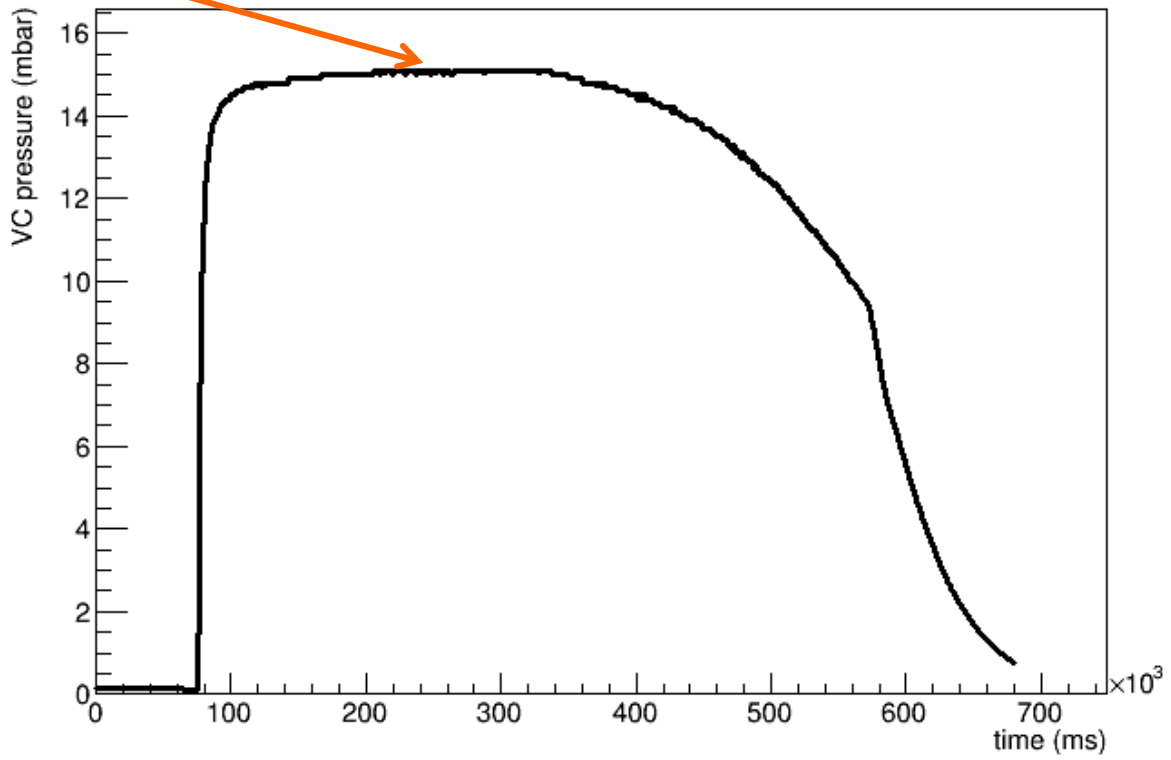


The leak was not continuous

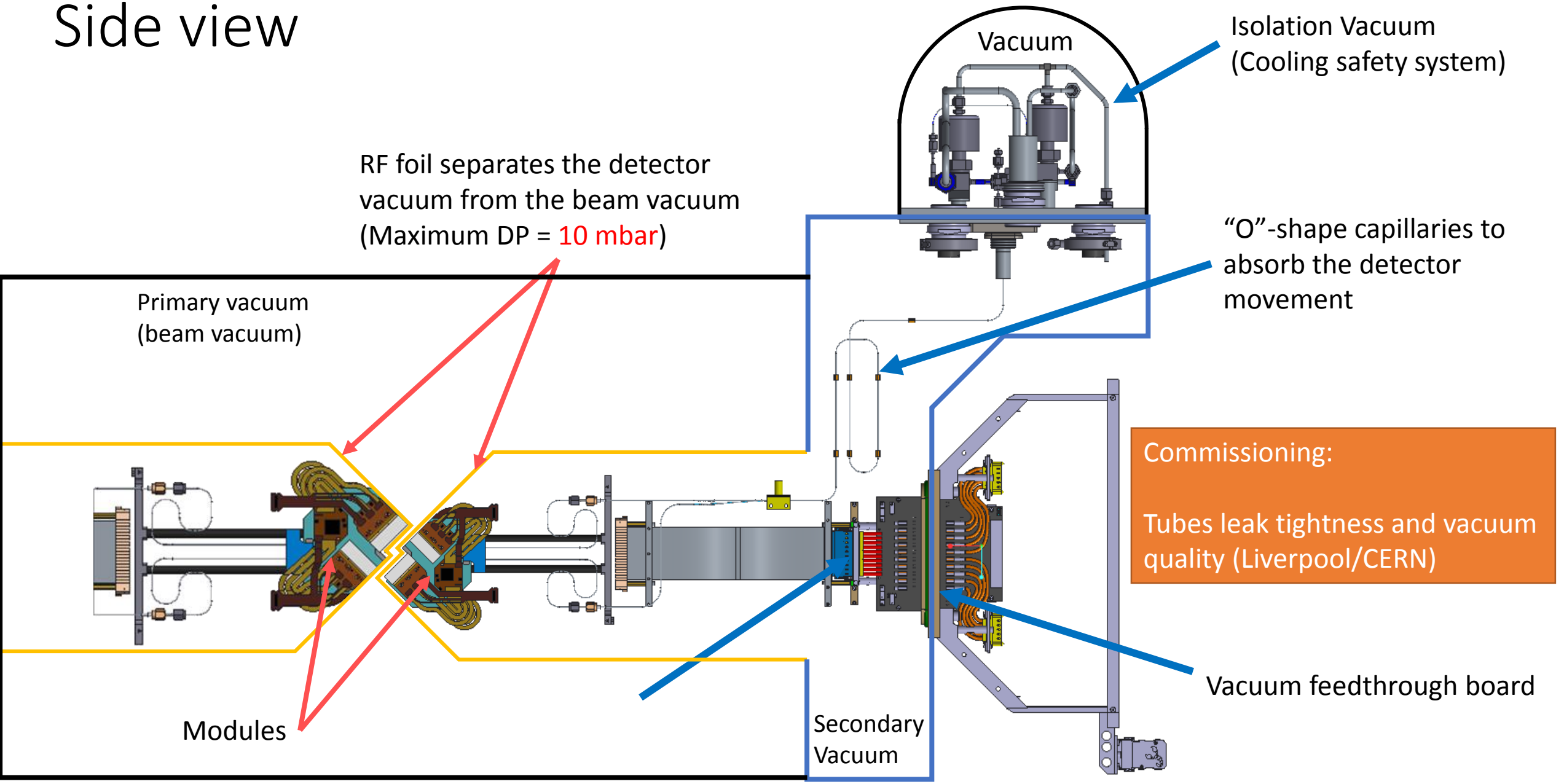
Safety system failure test

Dry ice formation inside
the tubes greatly reduce the leak

Vacuum chamber pressure



Side view



*Most of the cables are not in the drawing