# AIDAinnova 3rd Annual Meeting

Luca Contiero, Camila Pedano

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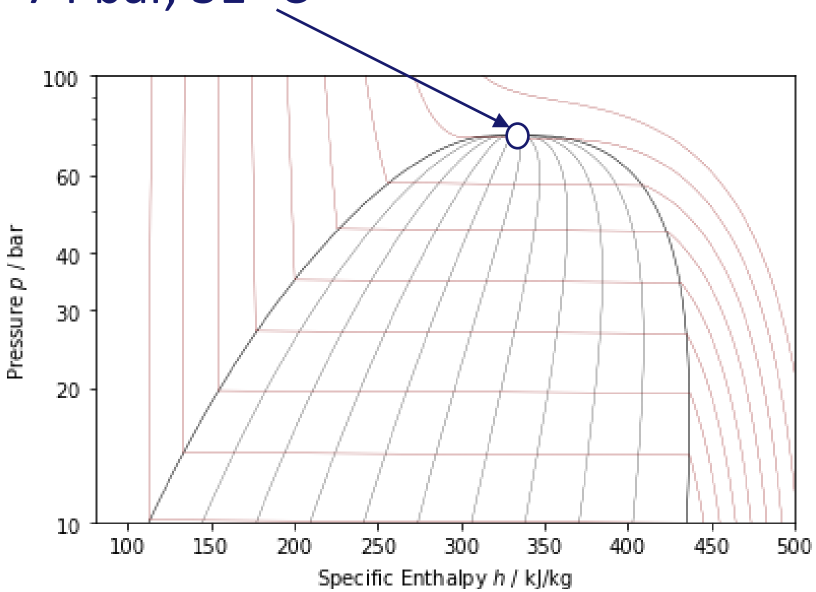
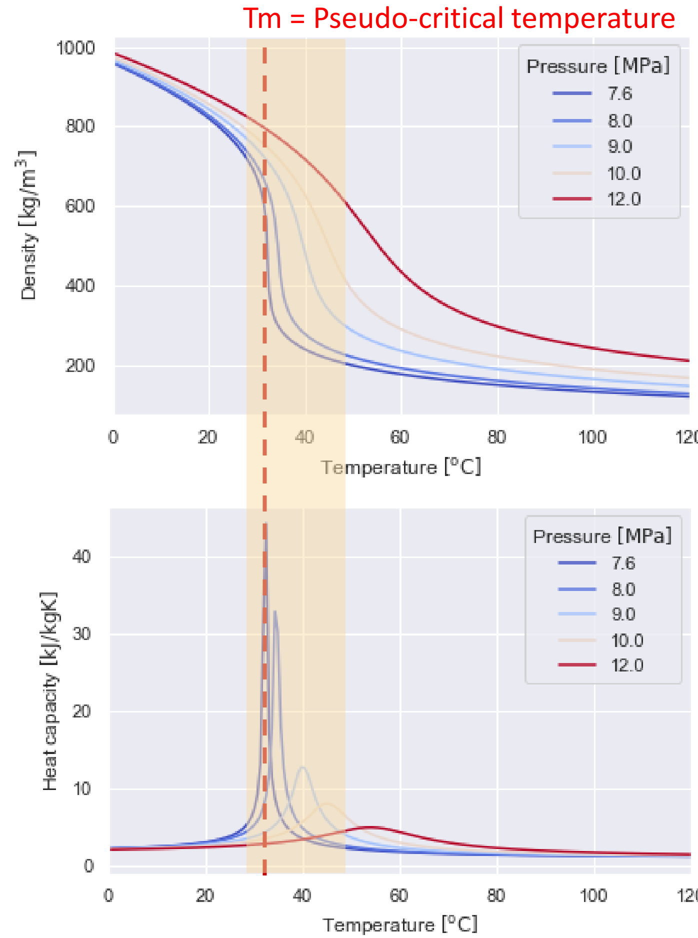
# The supercritical condition

- At subcritical: discontinuities
- Above critical value: change is continuous
  - T<Tc liquid-like fluid
  - T>Tc vapor-like fluid
- Critical point of carbon dioxide:
  74 bar, 31 °C




Temperature of interest for room temperature detector cooling (+31 to +45 °C)



# $CO_2$ project

Low radiation
Ambient temperature

Detector environment

High radiation
Significantly cold temperature

Provide precision measurements of thermal-fluidic properties of sCO2 in the range of temperatures of interest for possible ultra-light future detectors operating in environments with low radiation levels.

Aim

Design a completely new cycle and provide a precise strategy to move from the warm to the cold area without any thermal shocks on the detector

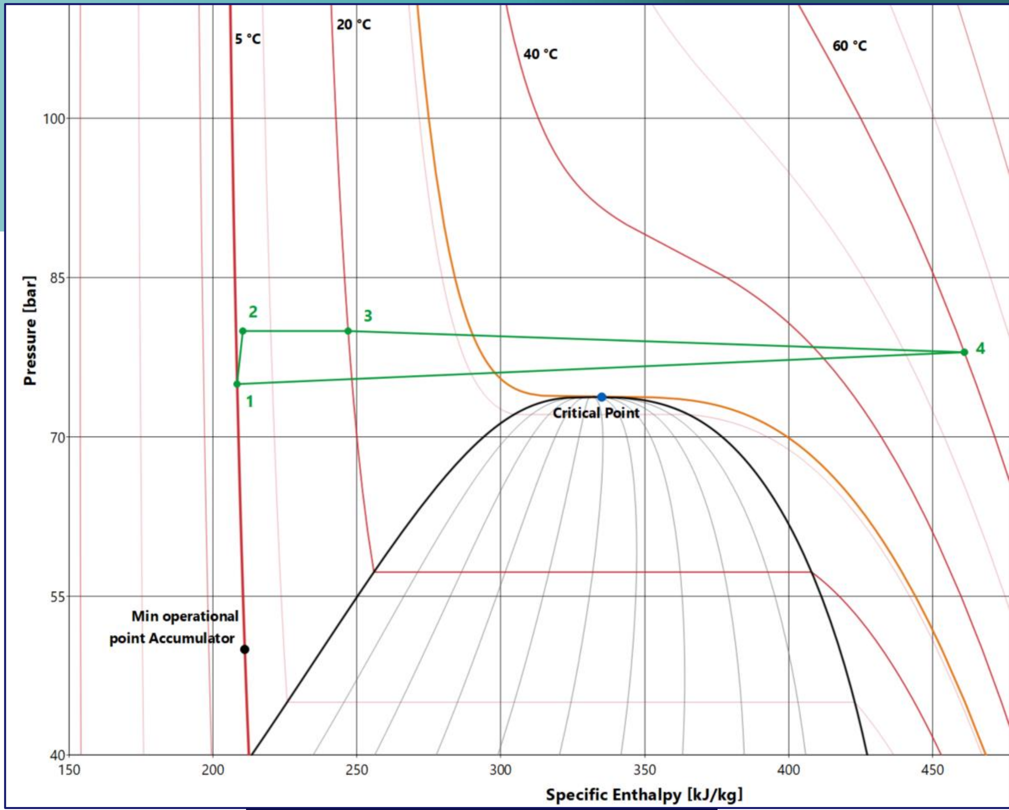
$CO_2$

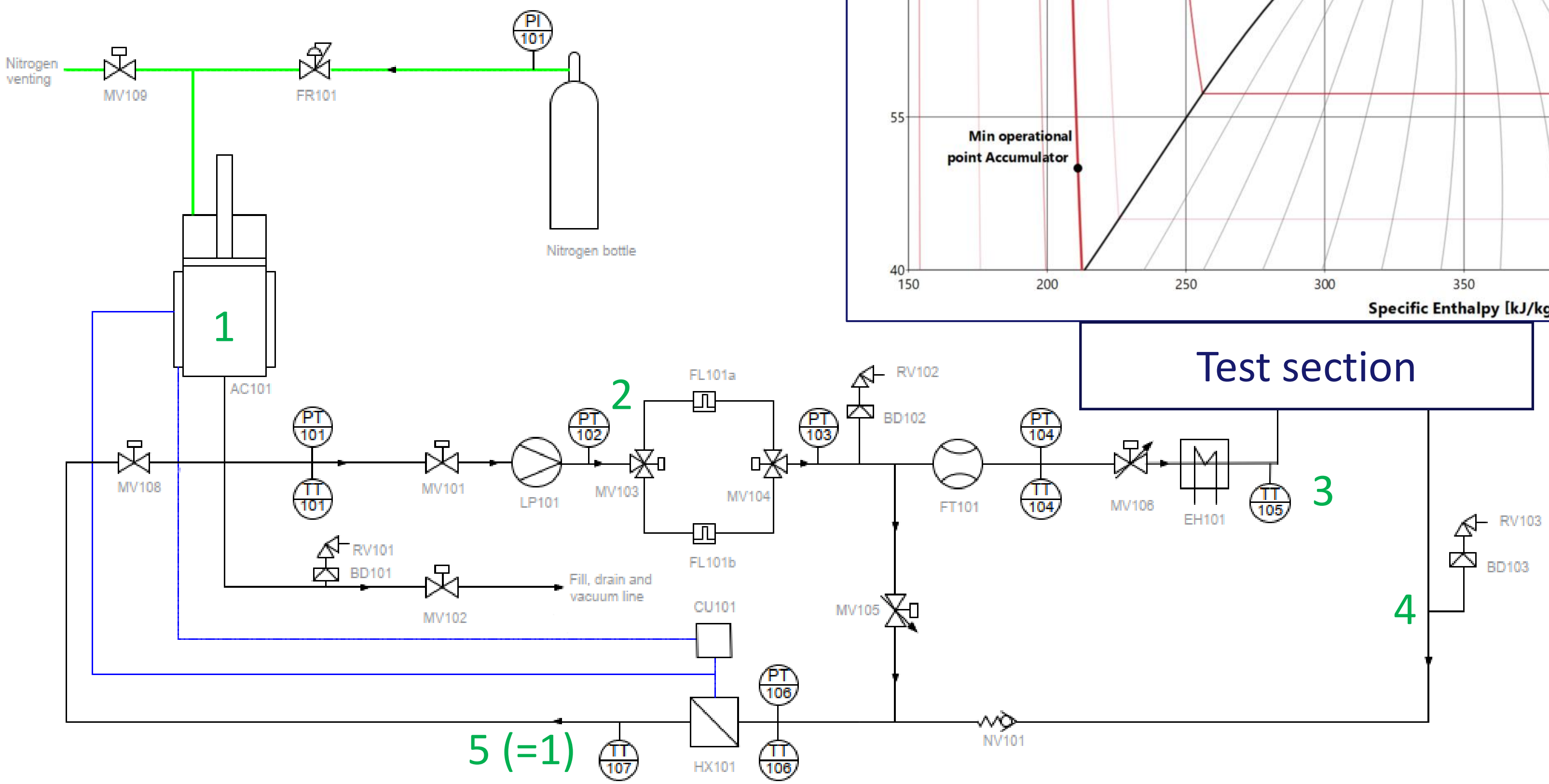
Fluid

Kr

# Process and cycle

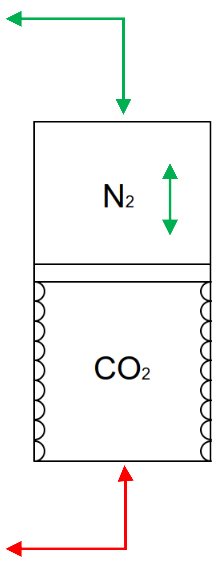
The pressure-enthalpy diagram on the right shows the thermodynamic cycle described in the P&ID



# The accumulator concept

- Until now, $CO_2$ two-phase cooling at CERN has been based on a two-phase accumulator where the temperature of the refrigerant can be controlled by means of the pressure – two phase equilibrium.
- Above the two-phase equilibrium region this is not an option.
- A new concept for an accumulator needs to be conceived – pressure and temperature are **independent variables.**




The accumulator is the **center** of the process, its main tasks are:

- Giving pressure to the fluid
- Fluid storage
- Attenuate oscillations

**Working principle**

Gas side (top, green) is filled with Nitrogen gas. Carbon dioxide, at the bottom side in red, will be pressurized by adding or removing gas charge.

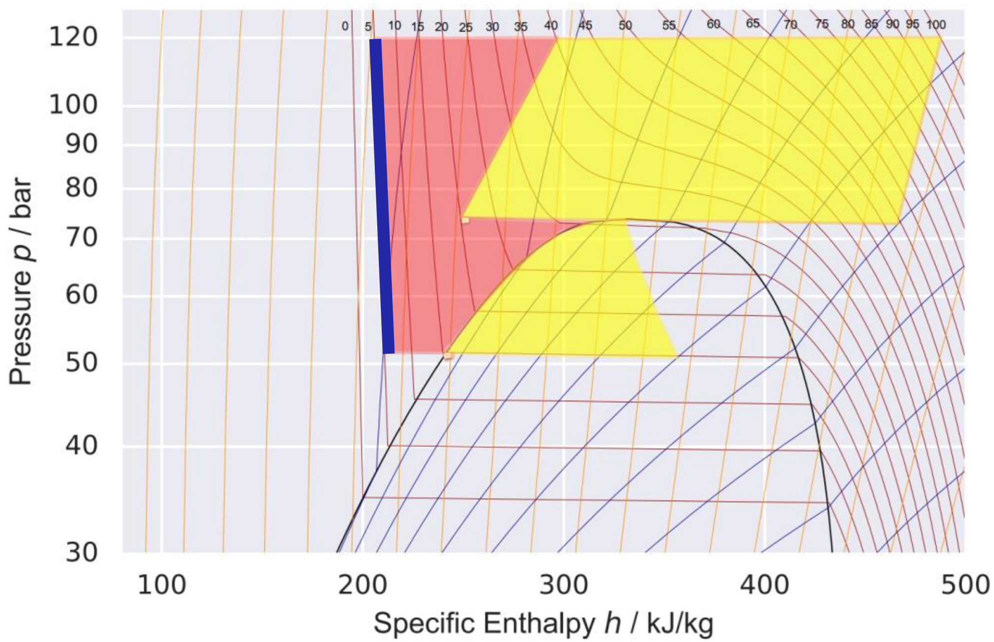
**Choice of accumulator type based on fluid and system requirements**

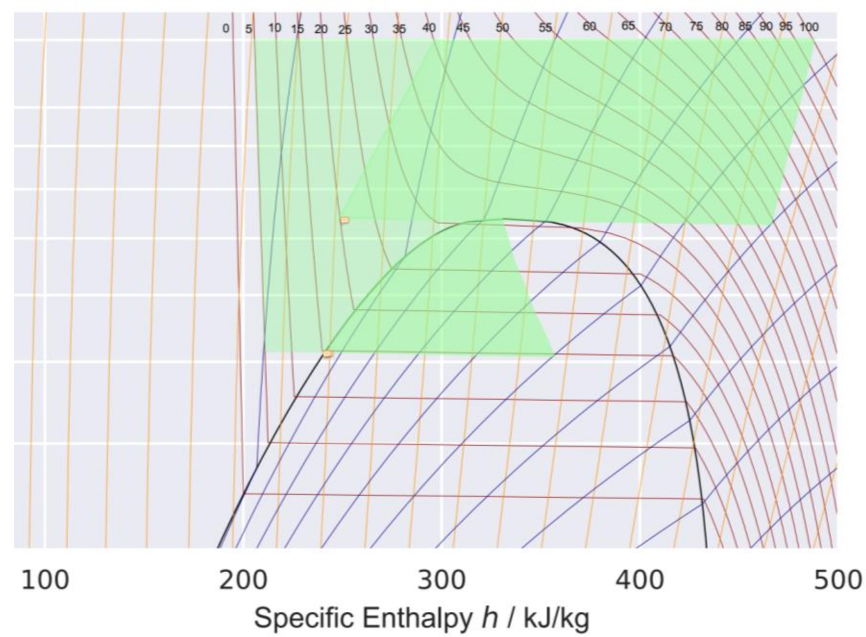
a. Piston: presence of oil
b. Bladder: bladder is generally made of rubber, there can be leakage of $N_2$ to $CO_2$ side
c. Diaphragm: diaphragm generally made of rubber
d. Bellow: best choice!

# Operating conditions

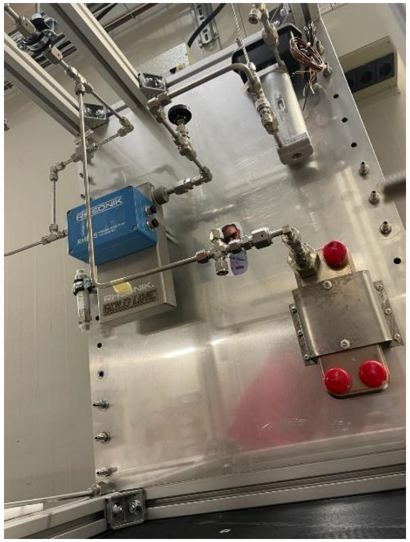
- In **dark blue** the operating conditions of the accumulator.
- In **red** the range covered by the pre-heater
- In **yellow**, area tested in the test section
- In **green**, area covered by heat exchanger

| | |
|---|---|
| **Flow configuration** | Up, down, horizontal |
| **Diameter [mm]** | 1-3 |
| **Mass flux [kg/m²s]** | 500-1200 |
| **Heat flux [kWm²]** | Enough to cover yellow |



# Status of test rig



# Testing plan

| Task | Timeline |
|---|---|
| Finishing construction and Data Acquisition System | April-June 2024 |
| Commissioning | June 2024 |
| Start of experimental campaign | Summer 2024 |

# Krypton project

Low radiation
Ambient temperature

Detector environment

High radiation
Significantly cold temperature

Provide precision measurements of thermal-fluidic properties of sCO2 in the range of temperatures of interest for possible ultra-light future detectors operating in environments with low radiation levels.

Aim

Design a completely new cycle and provide a precise strategy to move from the warm to the cold area without any thermal shocks on the detector

$CO_2$

Fluid

Kr

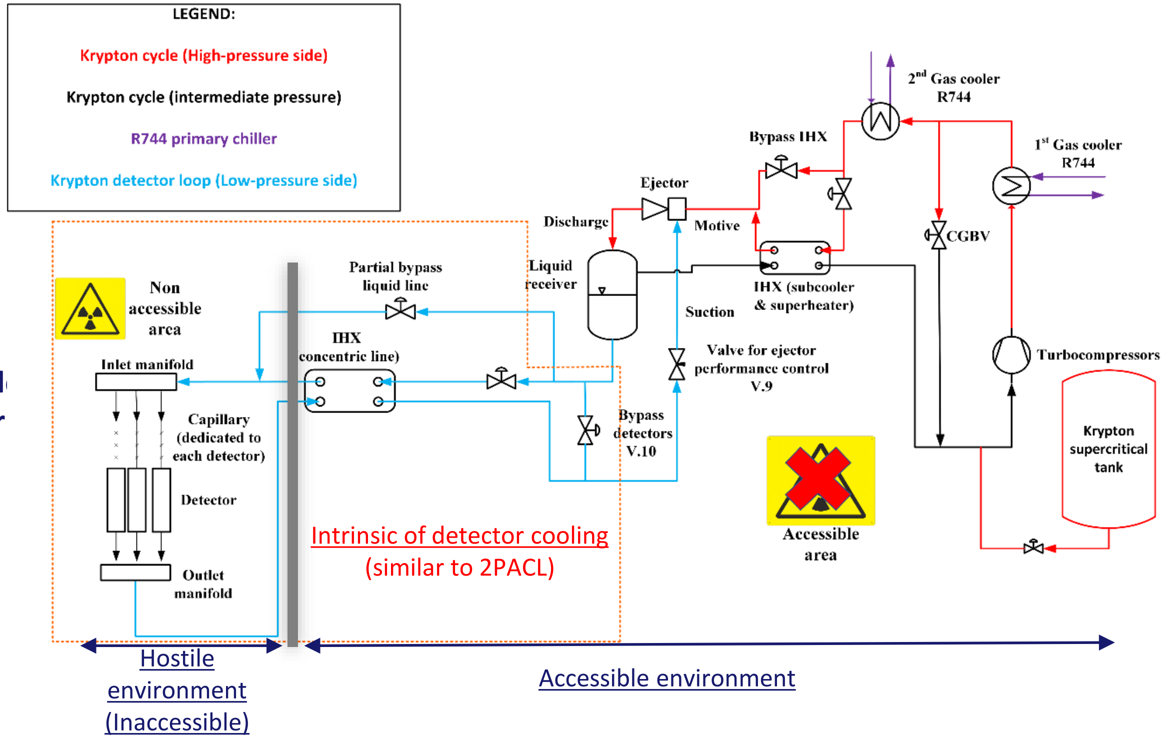
# A recap from last year's meeting

- Description of target and framework:
  - Design of the new cooling system for the Phase III Upgrade of the Large Hadron-Collider in the range -60 down to -80°C

**Krypton cooling based on an ejector-supported system**

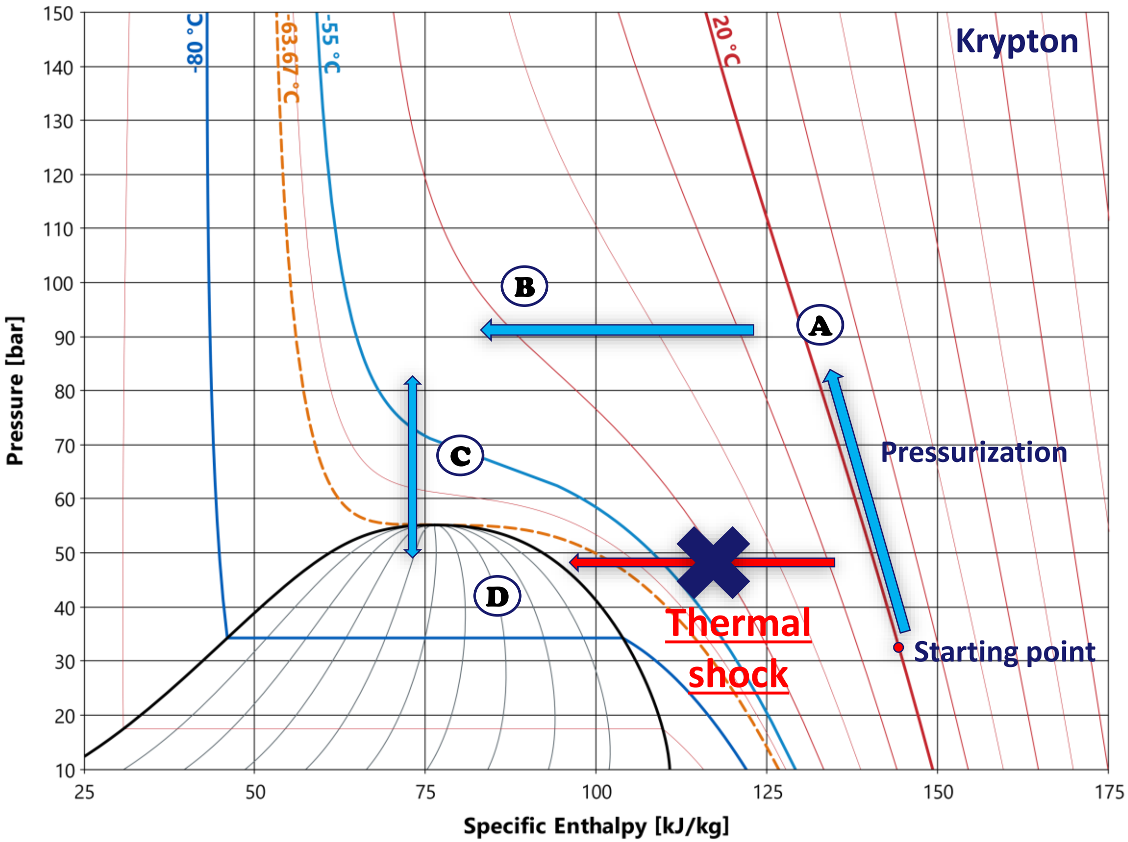
**Aims:**

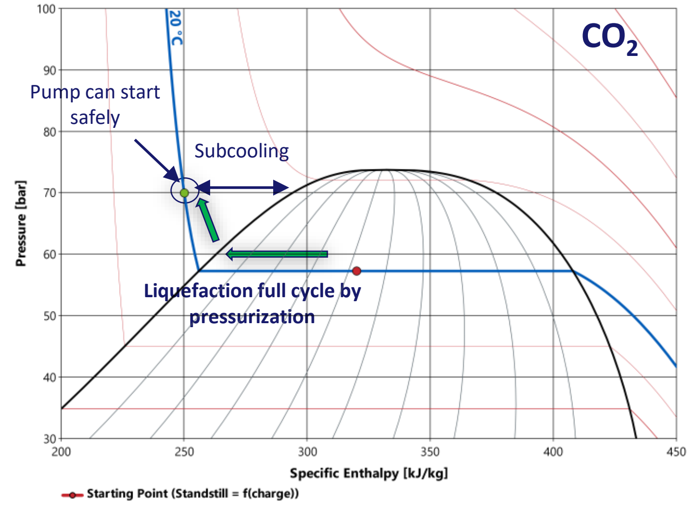
1) **Design a completely new cycle** and provide a **precise strategy** to move from the warm to the col area **without any thermal shocks** on the detector
2) Test of fluid performance (HTC – Δp) and **fluid scaling with $ScCO_2$** (PhD Camila Pedano)




- From last year:
  - Dynamic modelling of the cycle (almost completed) & test-rig building finished
  - Development of the control strategies to handle different transients

- Challenges with Krypton cooling:




- Starting temperature (20 degC) in gas/supercritical phase

Four different scenarios to be investigated:

- Startup (A)
- Supercritical cooldown (B)
- Supercritical operation (C)
- Transcritical operation (D)

# System's transients

- Ejector ("pump without moving parts") takes over the 2PACL pump


**Ejector working principle**

**Global description of an ejector**

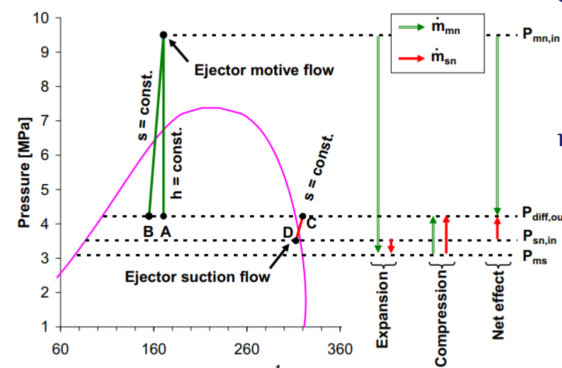
Two parameters are normally used to measure two separate effects:

1) Mass entrainment ratio

$$\Phi_m = \frac{m_{secondary}}{m_{primary}}$$

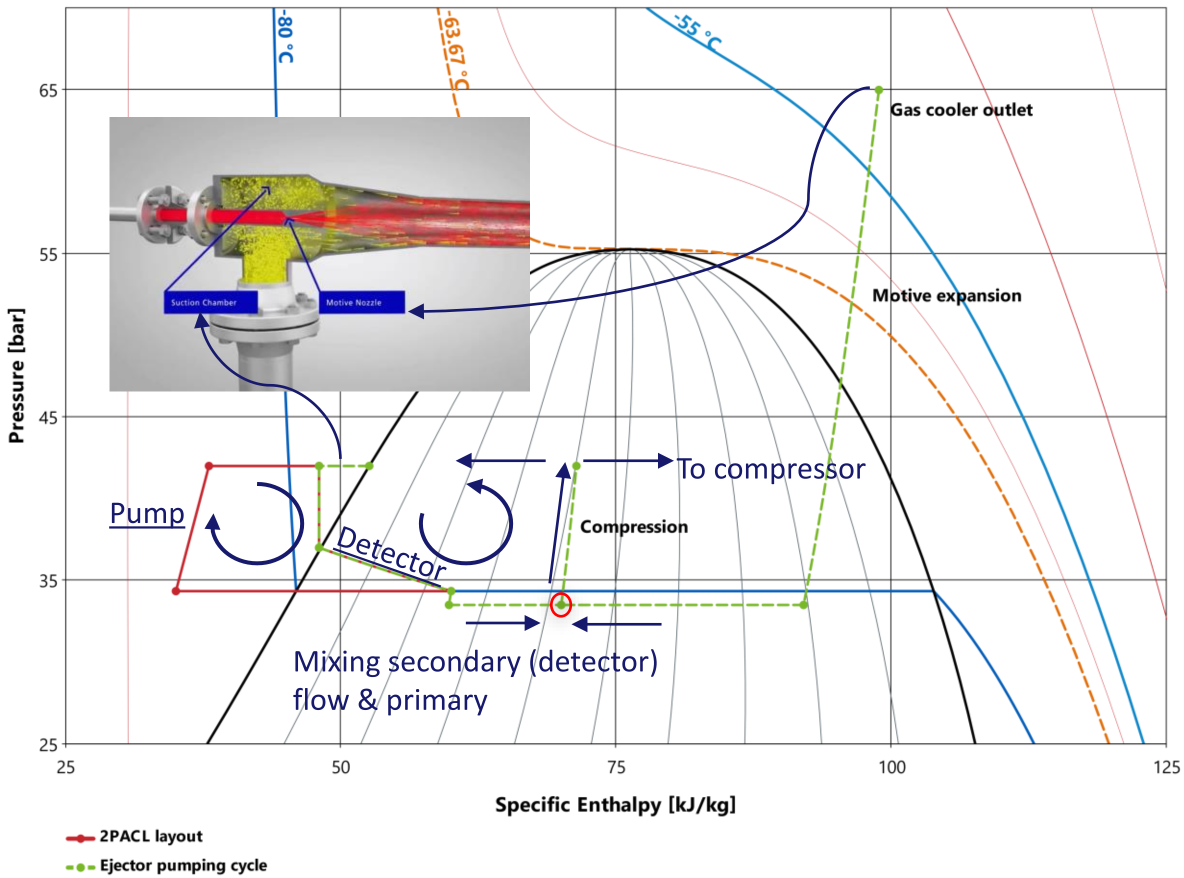
2) Pressure lift

$$P_{lift} = P_{outlet} - P_{secondary}$$




$$\eta_{ej} = \frac{m_{sec}}{m_{prim}} \frac{h_c - h_d}{h_a - h_b}$$

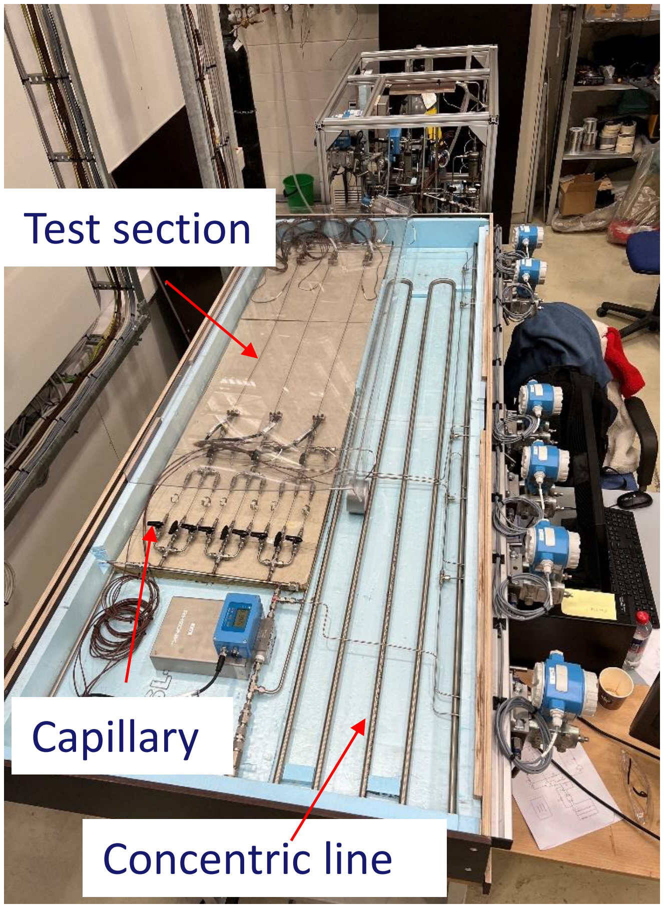
# Ejector as flow regulator



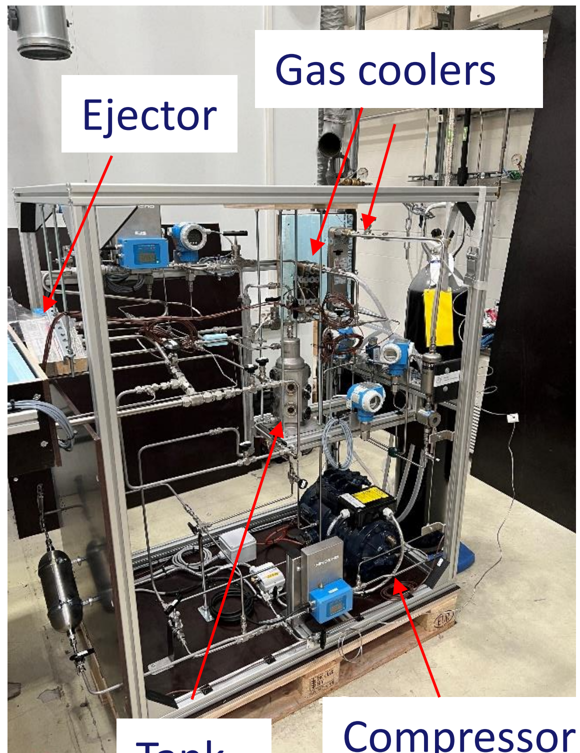

- Pumping loop coupled with a vapor compression cycle
- Compressor provides necessary driving flow to the ejector
- Pumping capacity ejector:
  - Adjustable via change motive conditions
  - Linked with design detector loop

# Current status test-rig

***Detector loop***



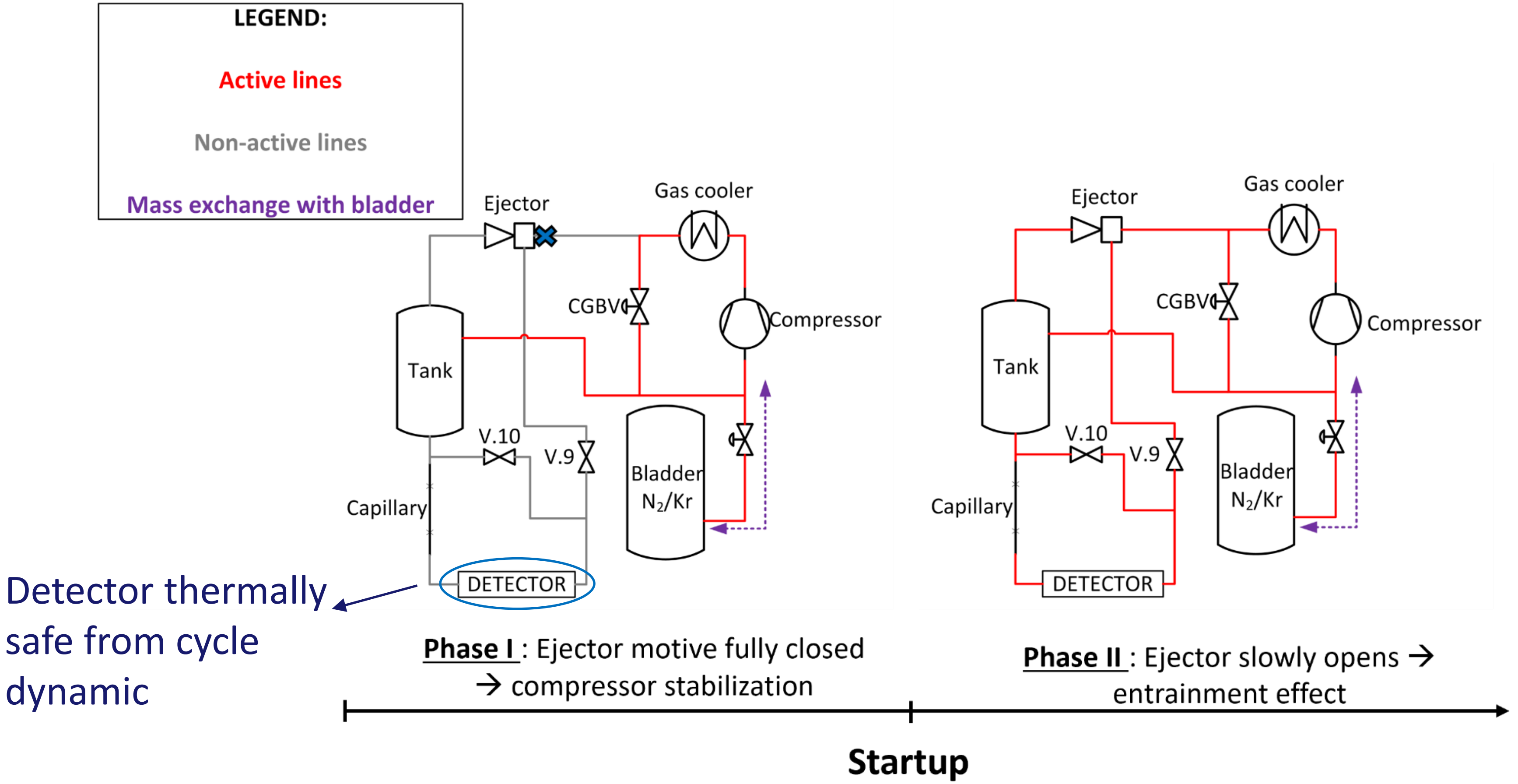

***Compressor loop***



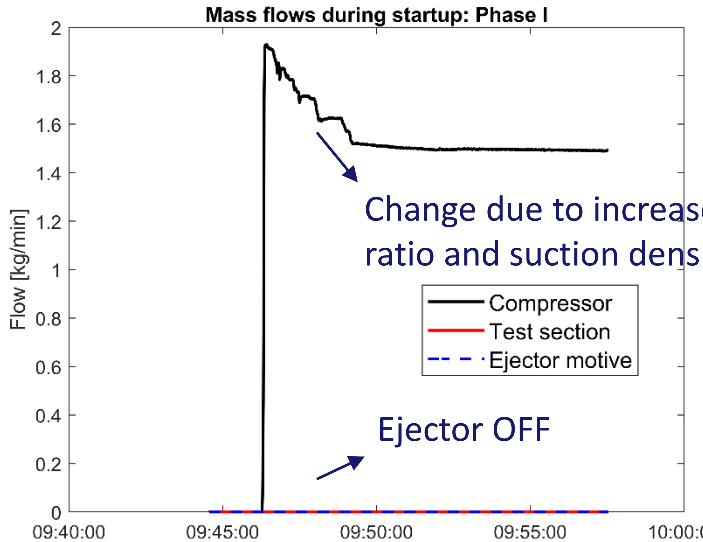

Electric cabinets

# Dynamic model as virtual test bench for control strategies

- Dynamic model in Modelica provides good insights on cycle behavior
- Startup and cooldown concept tested during commissioning phase

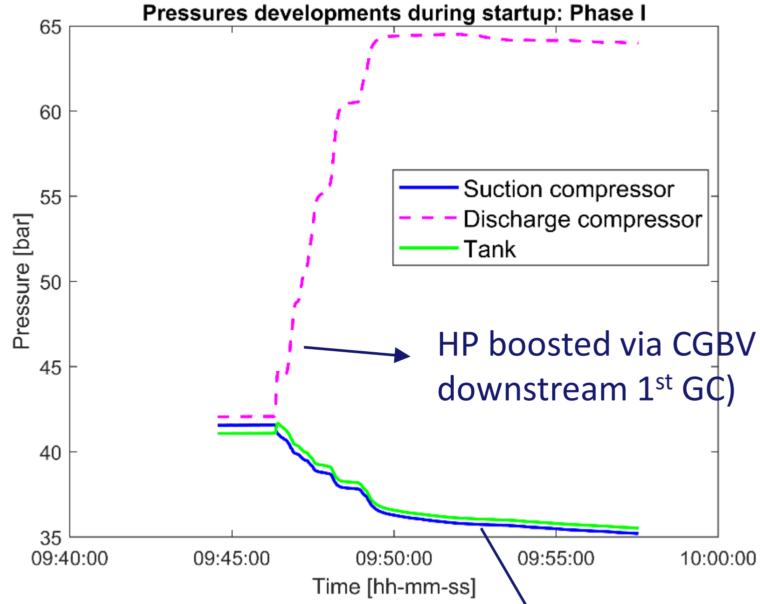


# Preliminary test with $CO_2$: startup (Phase I)




Change due to increase pressure ratio and suction density

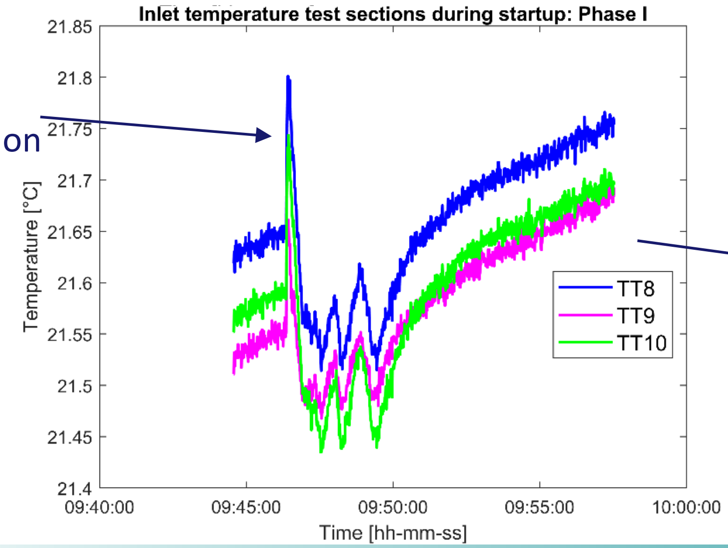
Ejector OFF




HP boosted via CGBV (valve downstream 1st GC)

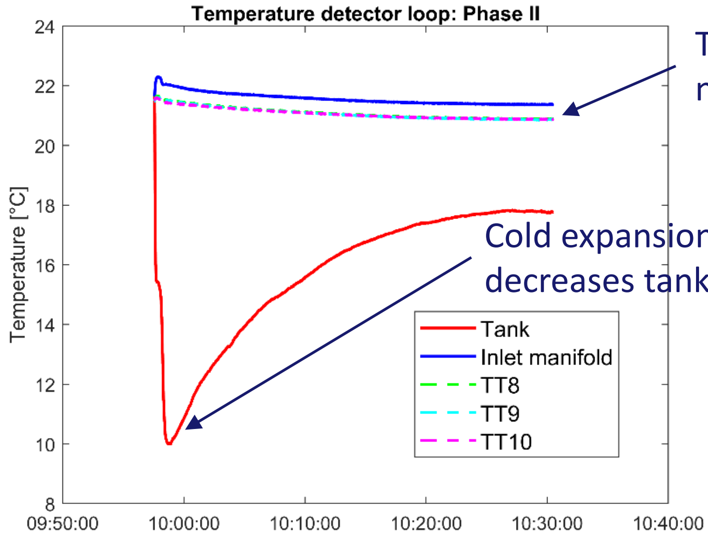
Low pressure decreases due to mass movement towards HP side

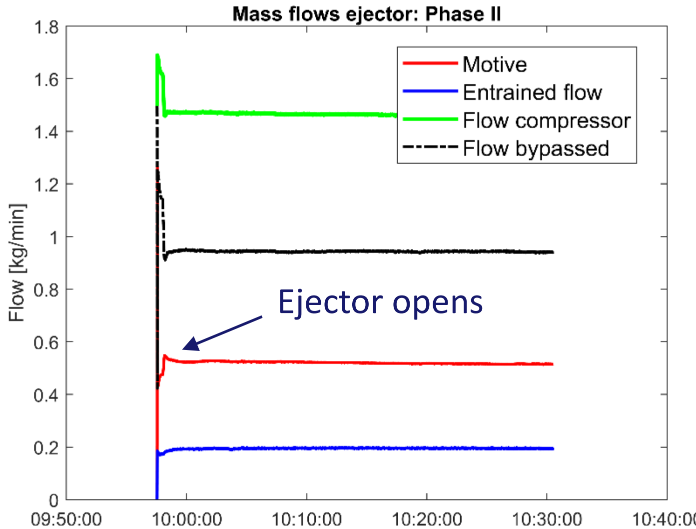
Peak when compressor is on



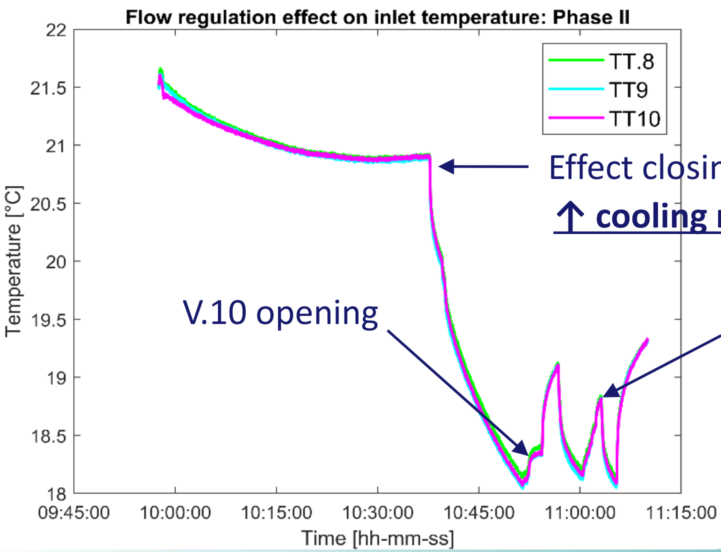

Temperature remains nearly constant during the stabilization of the compressor

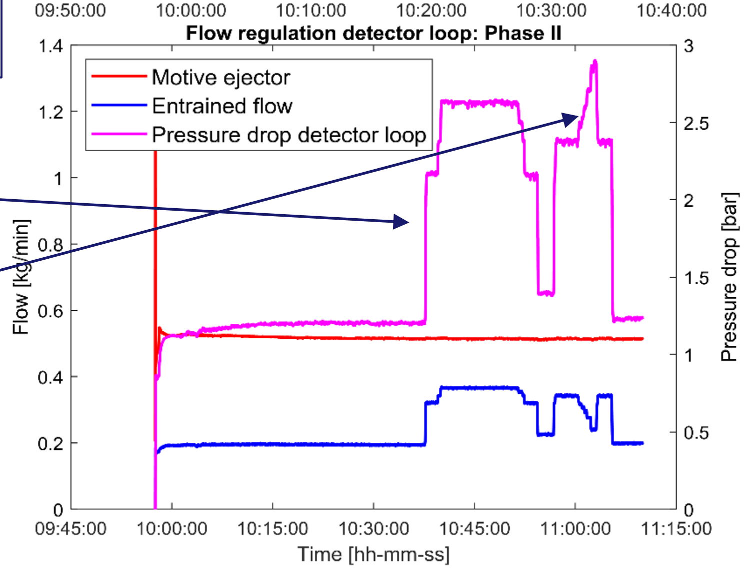
# Preliminary test with $CO_2$: startup (Phase II)



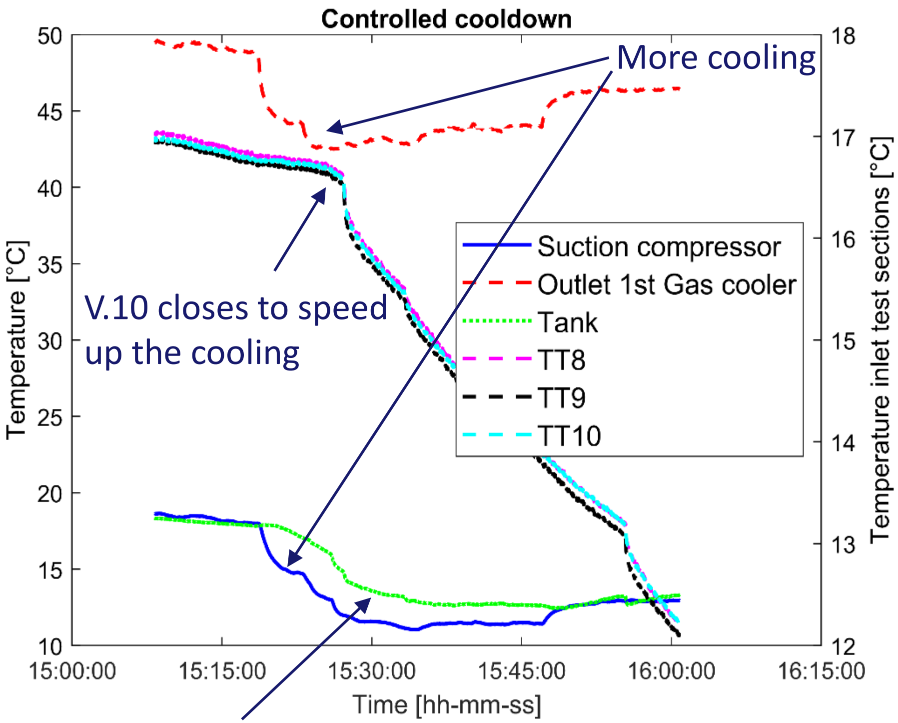



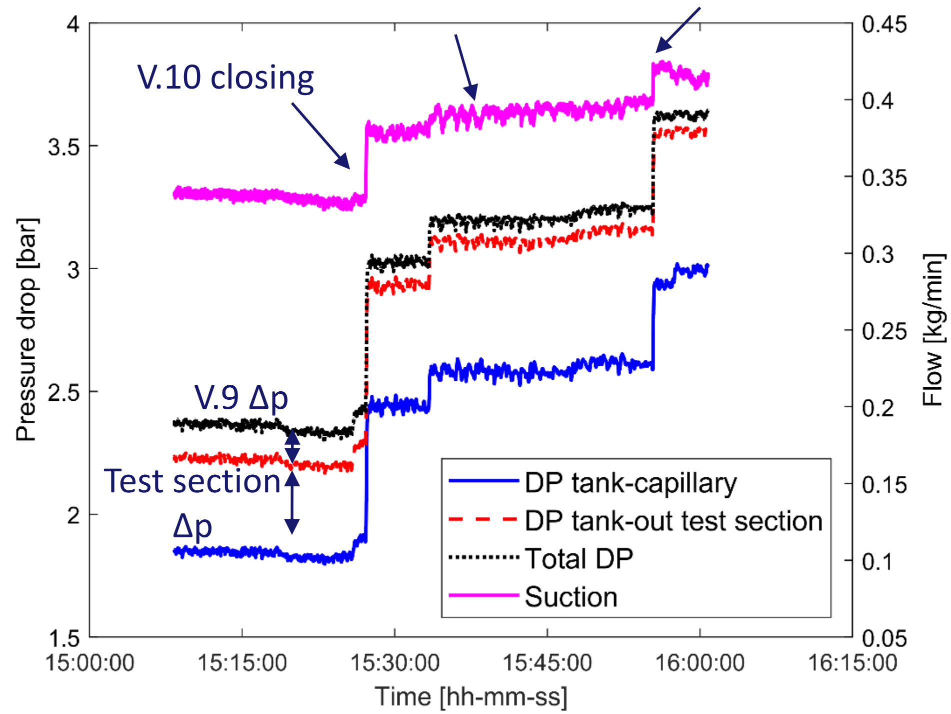

V.9 & V.10 acts as double flow protection



# Preliminary test with $CO_2$: Cooldown




Expansion motive decreases temperature in the tank → Tank T ↓ with some time delay = f(inertia)

- **<u>Temperature decreases by ≈ 4 K in 30 mins</u>** → cooling speed under control, can be increased/decreased according to ejector capacity – OD valve – Cooling power 1st gas cooler

# Testing plan

| Planning the experimental test to prove the cooling concept | | |
|---|---|---|
| **Task** | **Purpose** | **Timeline** |
| Commissioning of the system with $CO_2$ | Testing components functionality and interlocks of the system | *Done* |
| Preliminary tests with $CO_2$ in gas phase | Warm gas phase , *focusing on startup and thermal stability at the test section level* (detectors). Due to limited size of the system *no possible to test safely two-phase without external bladder* | *Done* |
| Start testing with krypton at NTNU | Tests to evaluate compressor performance (critical) before moving the rig to CERN | End of April – May 2024 |
| Test with krypton at CERN | Real tests considering the ideal layout involving a cold primary chiller with $CO_2$ and a bladder tank to sustain system's pressure during cooldown | Under discussion |