CO_2 cooling experience in the LHCb Vertex Locator

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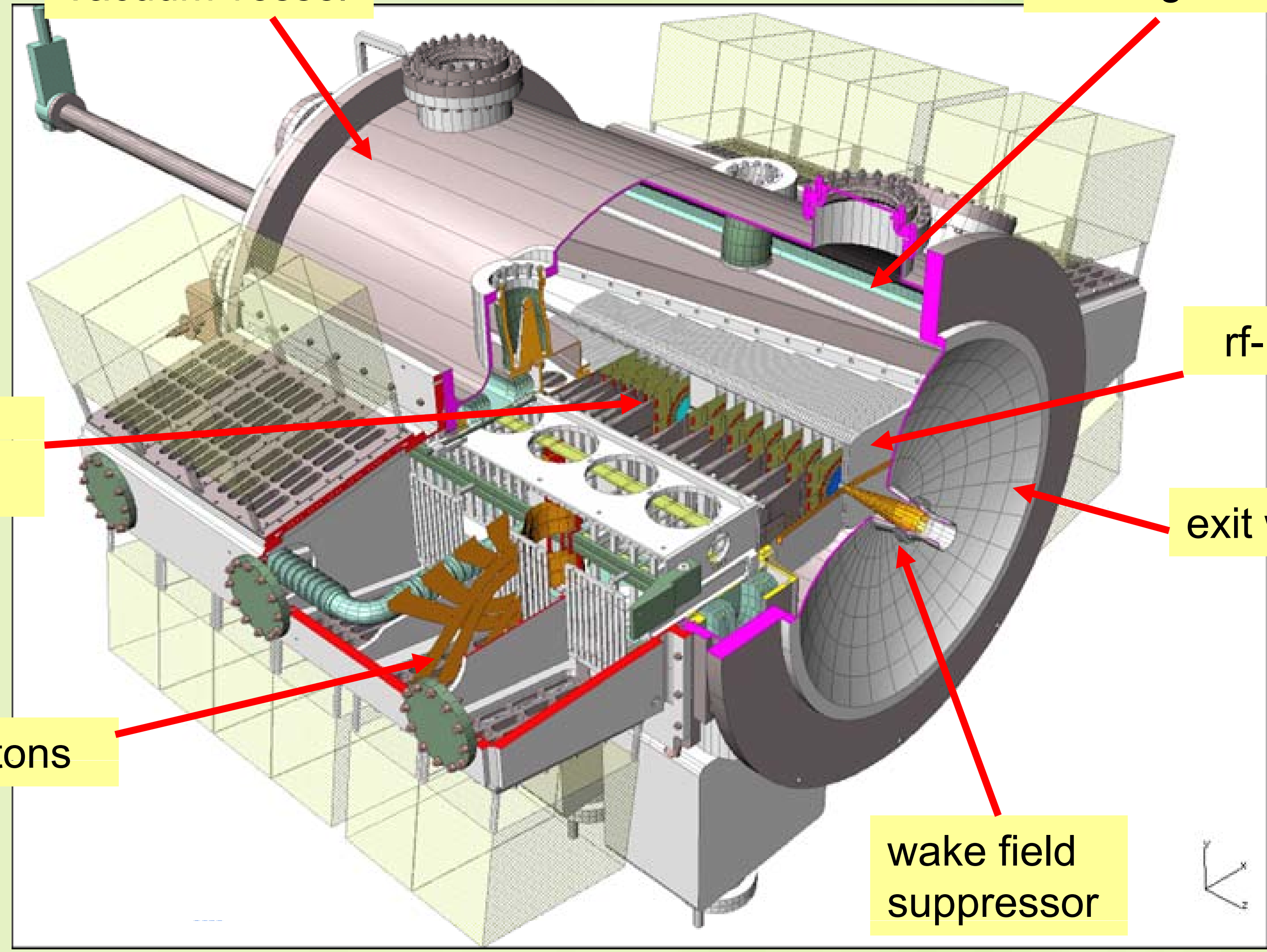
Vertex 2007 Lake Placid 24/09/2007

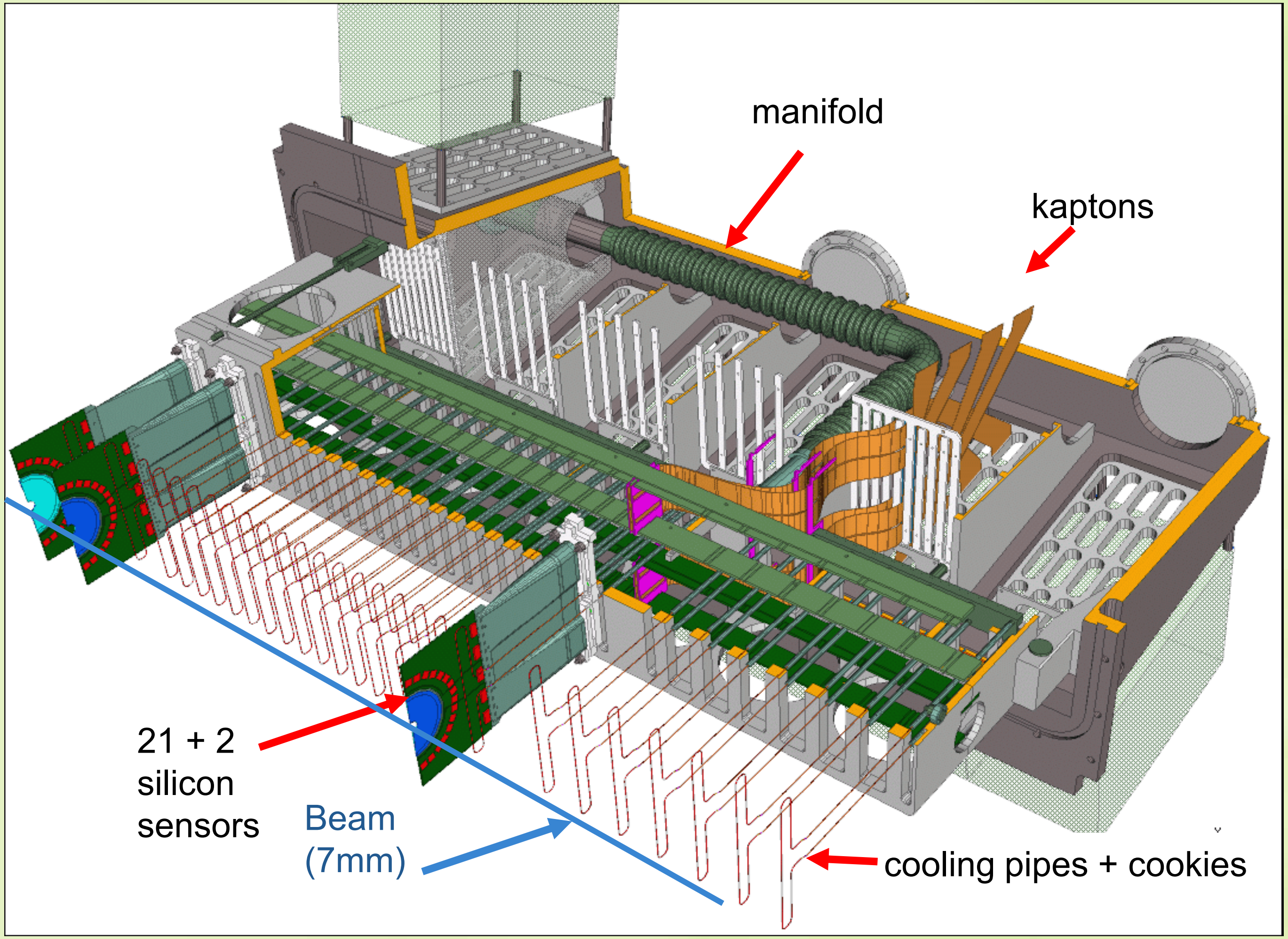
Outline

- VeLo Introduction
- VELO CO_2 Cooling system
- Evaporator Lab performance
- Cooling plant operation
- Major challenges
- Final Cooling plant performance
- Module Thermal performance
- Conclusions

VErtex LOcator



VELO detector half



VELO cooling requirements

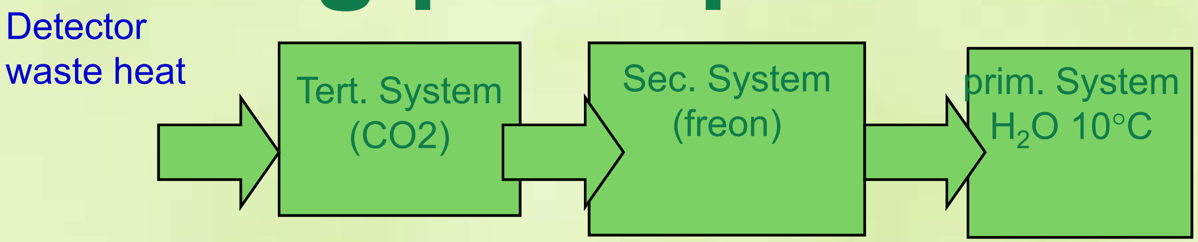
- Harsh non-uniform radiation environment
  - avoid thermal runaway in silicon
  - hold reverse annealing
  - radiation hard refrigerant

  } Temperature silicon sensors ~-5ºC at all times → cooling temperature of -25ºC

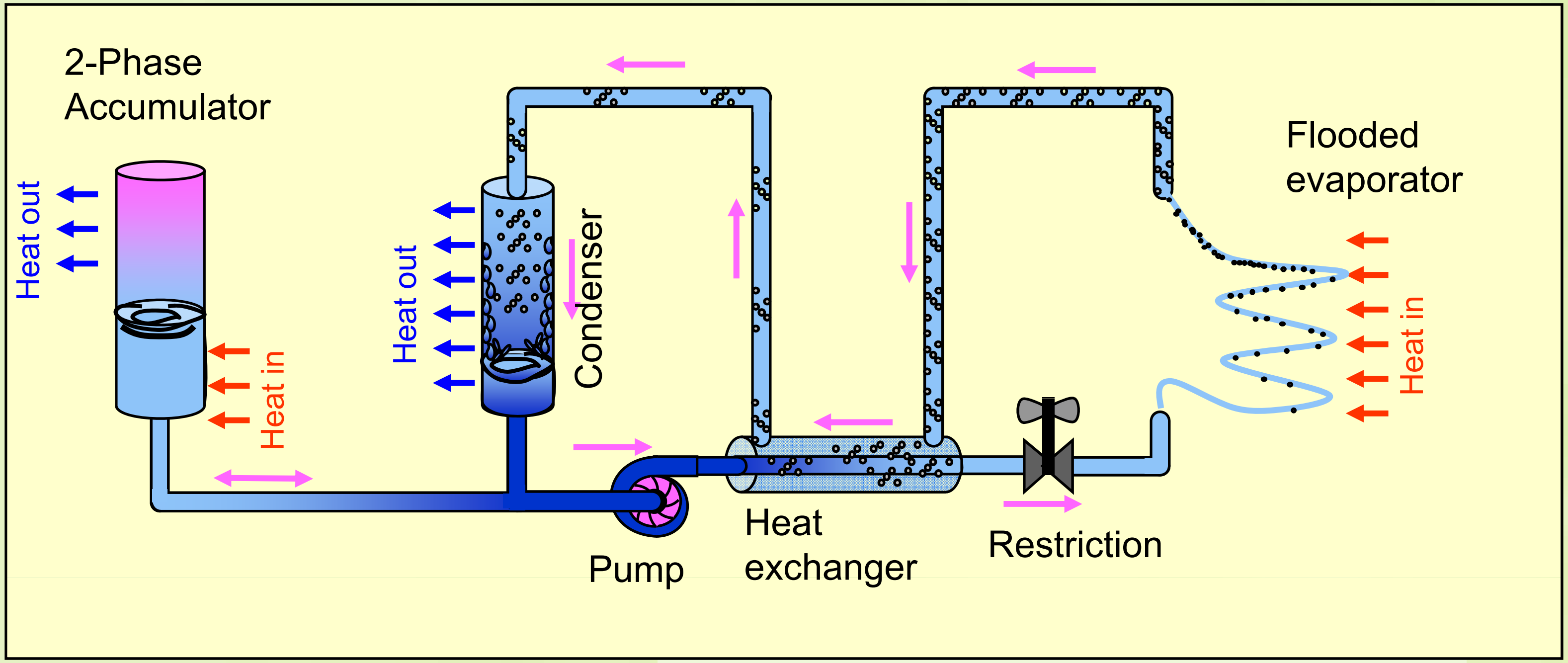
- Vacuum
  - Direct contact between cooling and module
  - No connections but failsafe orbital welds
- In LHCb acceptance → low mass system
- No mechanical stress on the module
- Cooling capacity up to 800W/half

VELO Thermal Control System based on CO_2 Evaporator

The CO2 cooling principle

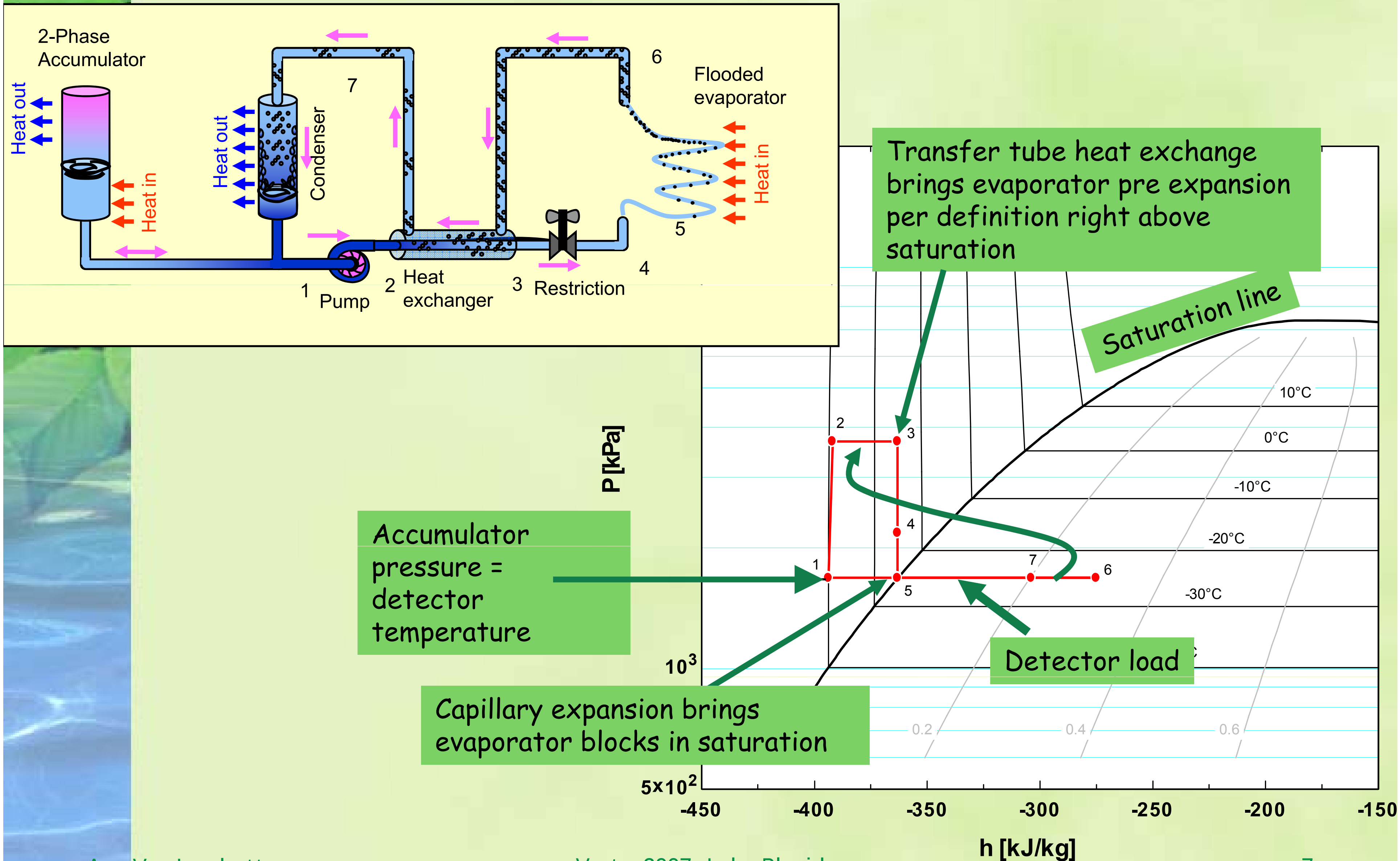


Tertiary System: two-phase accumulator controlled system

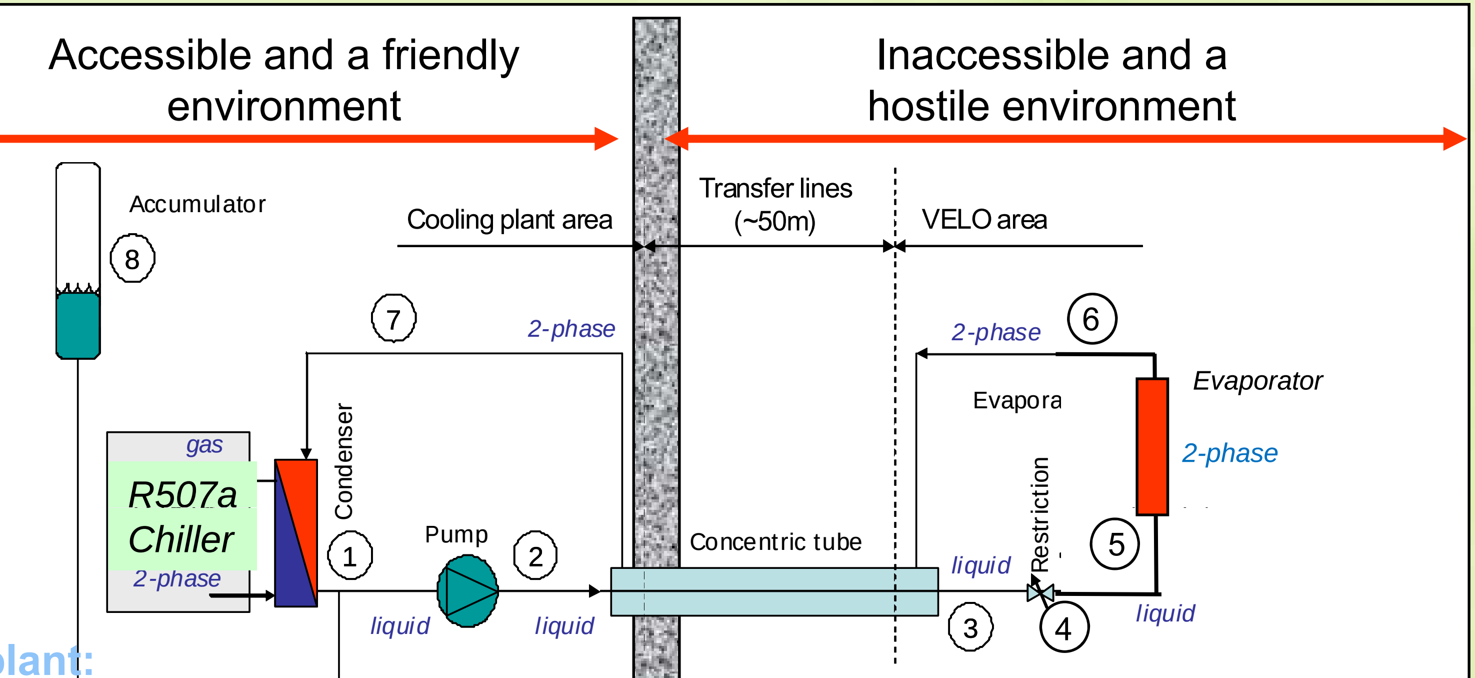


No local evaporator control,
evaporator is passive in detector

The CO2 cooling cycle



The implementation



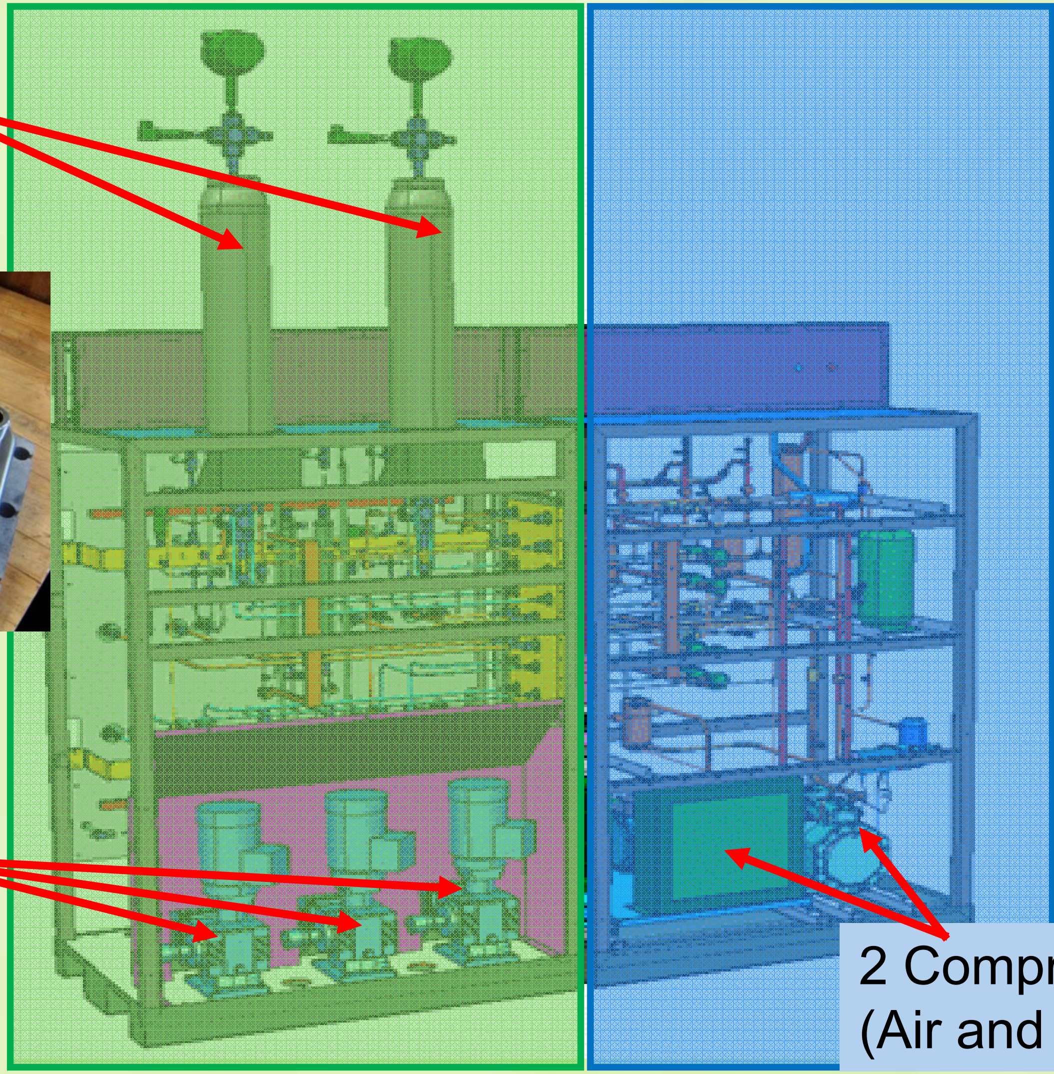
Cooling plant:

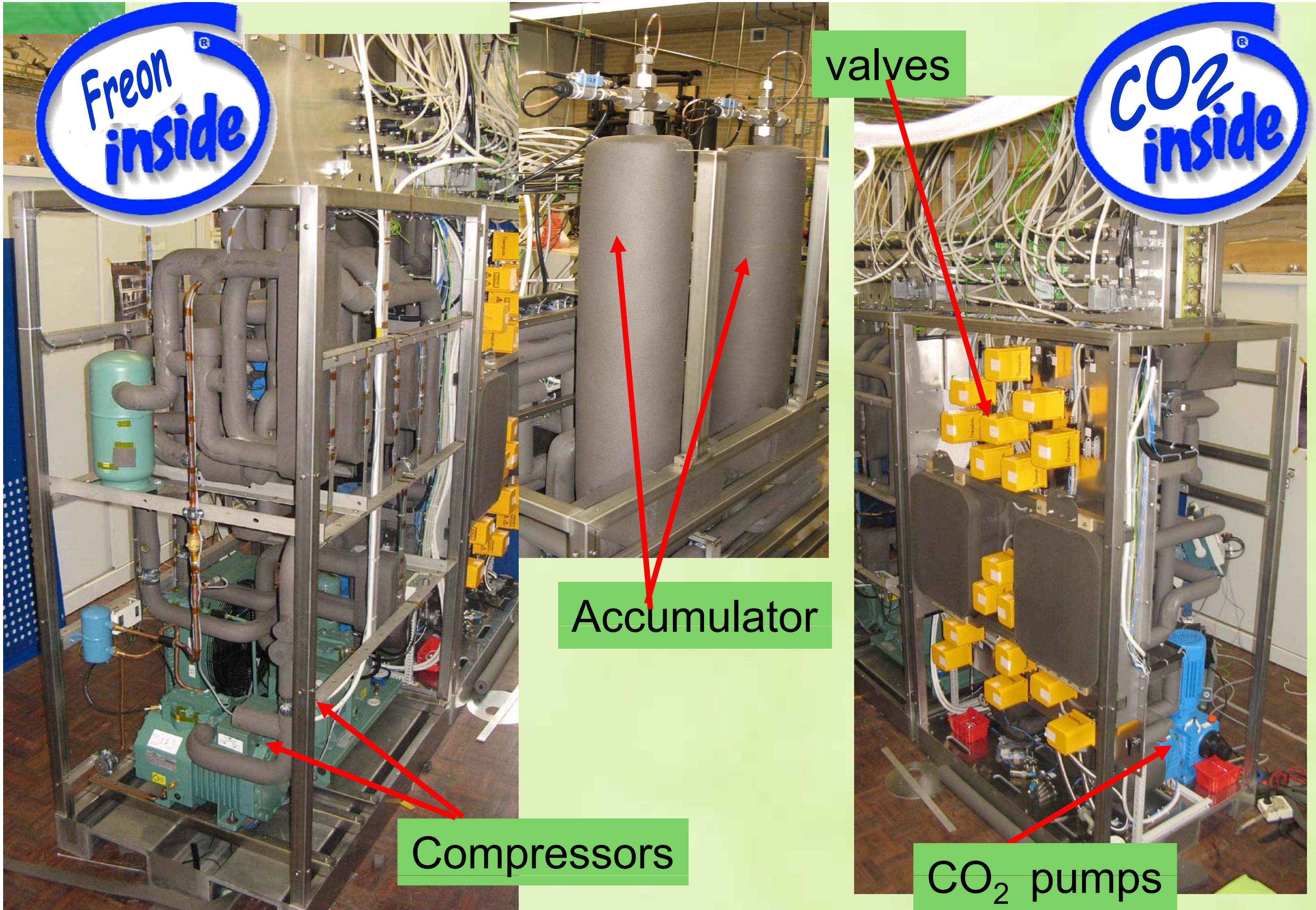
- **Sub cooled liquid CO_2 pumping**
- **12.5 kg CO_2 per half**
- **CO_2 condensing to a R507a chiller**
- **CO_2 loop pressure control using a 2-phase accumulator**
- **Redundancy with spare pump and backup chiller**
- **Control of the system by Siemens PLC**

Evaporator :

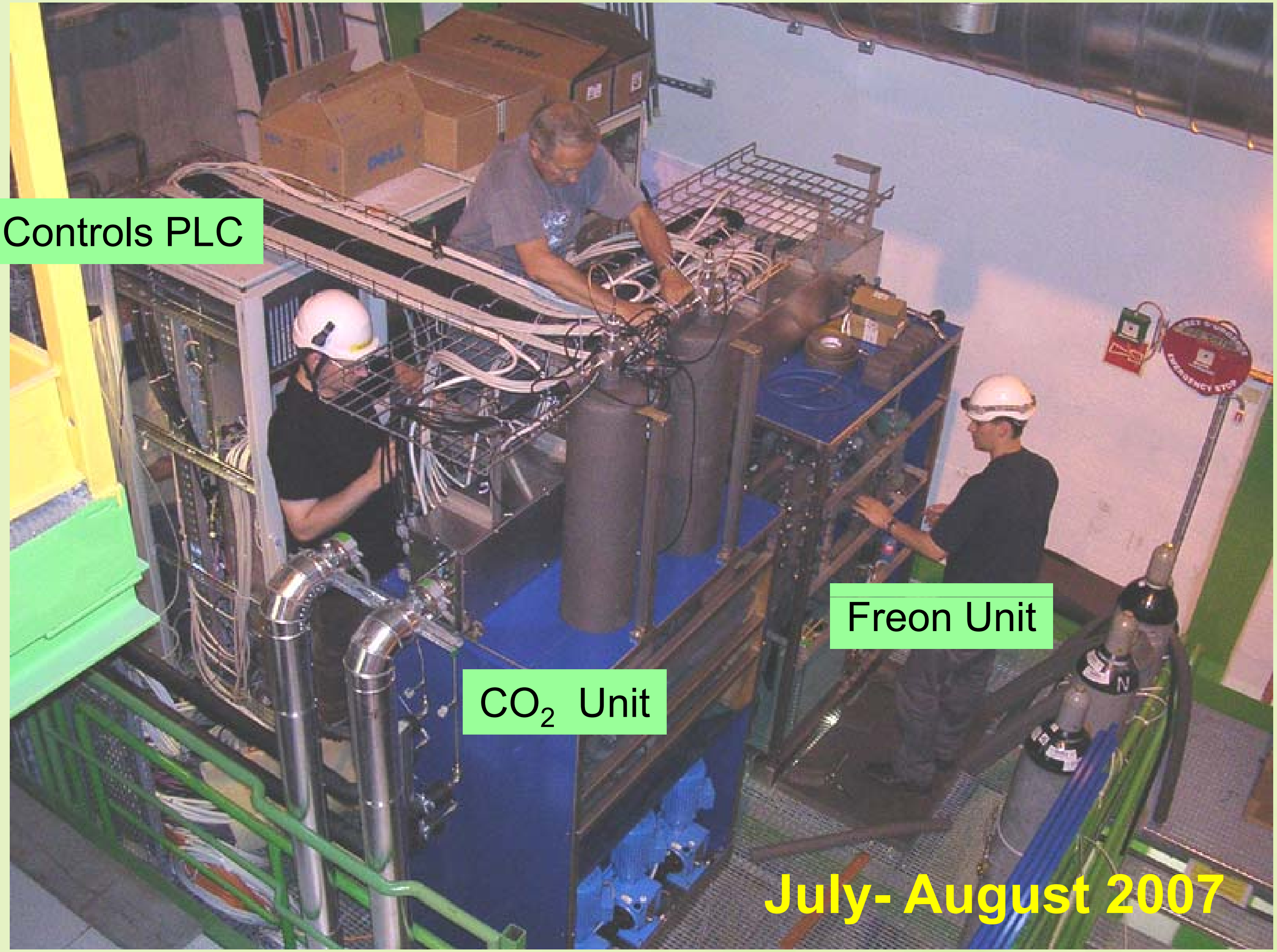
- **VTCS temperature ≈ -25ºC**
- **Total Evaporator load ≈ 0-1600 Watt**
- **Completely passive**

The cooling plant

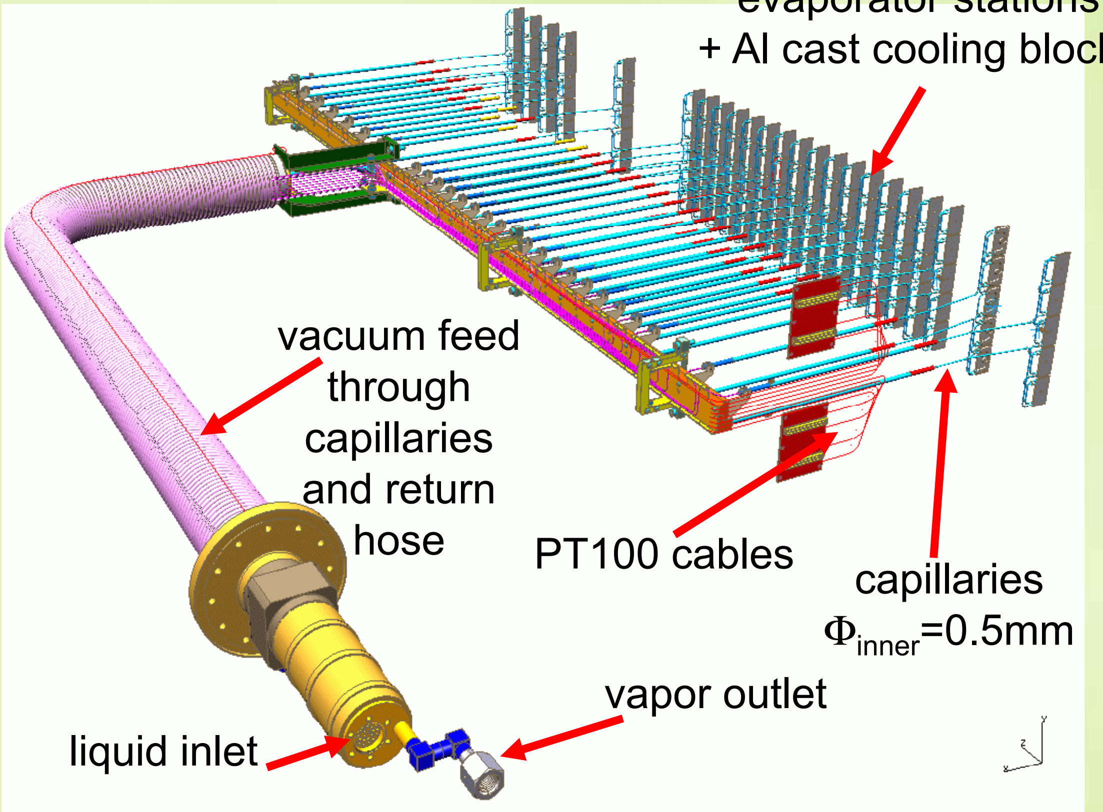



Freon inside
valves
CO_2 inside
Accumulator
Compressors
CO_2 pumps

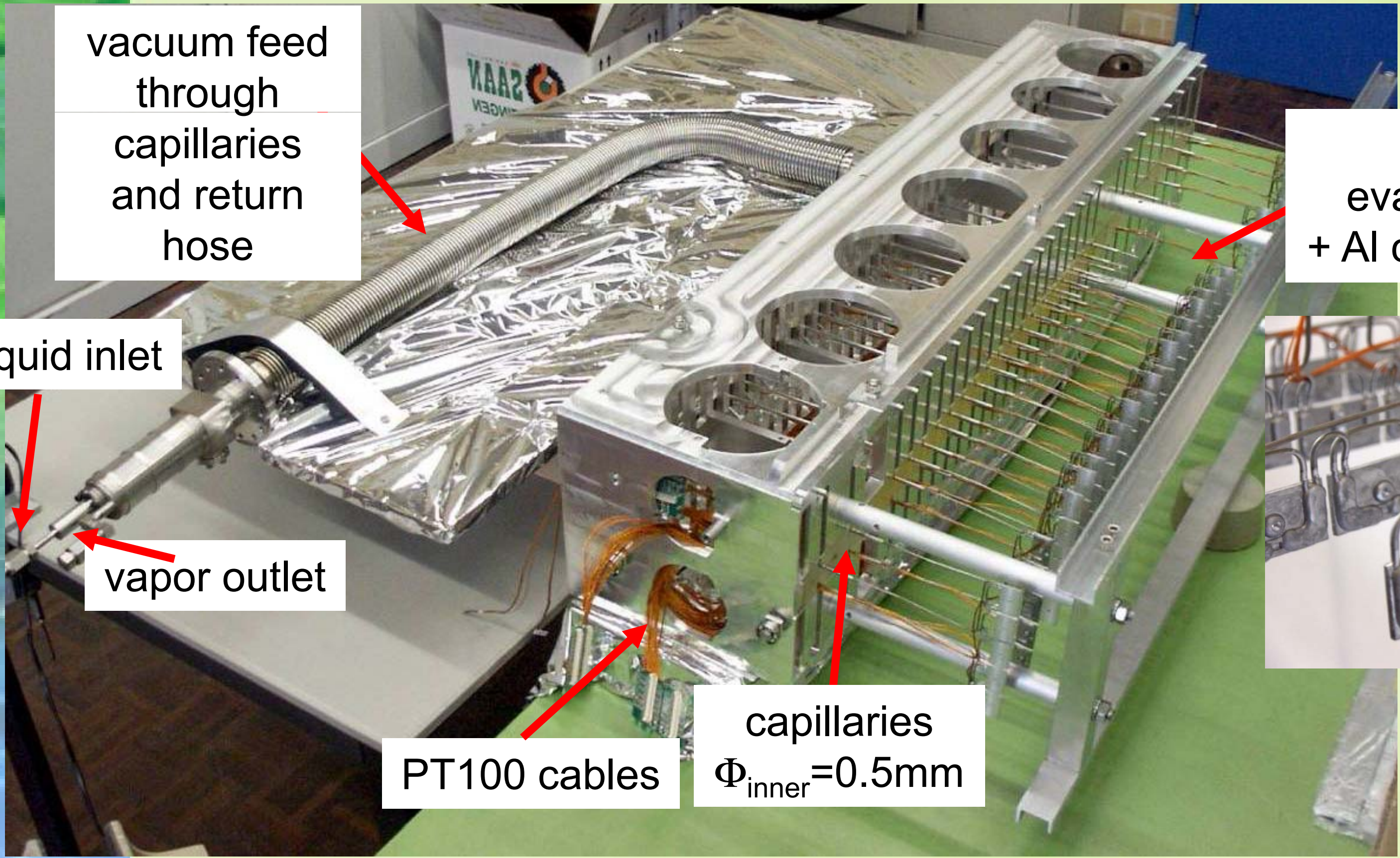
Installation at CERN

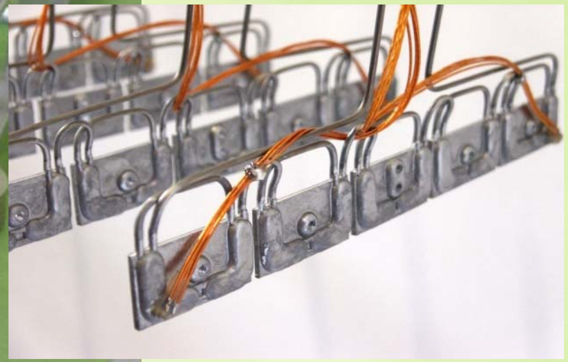


The Evaporator

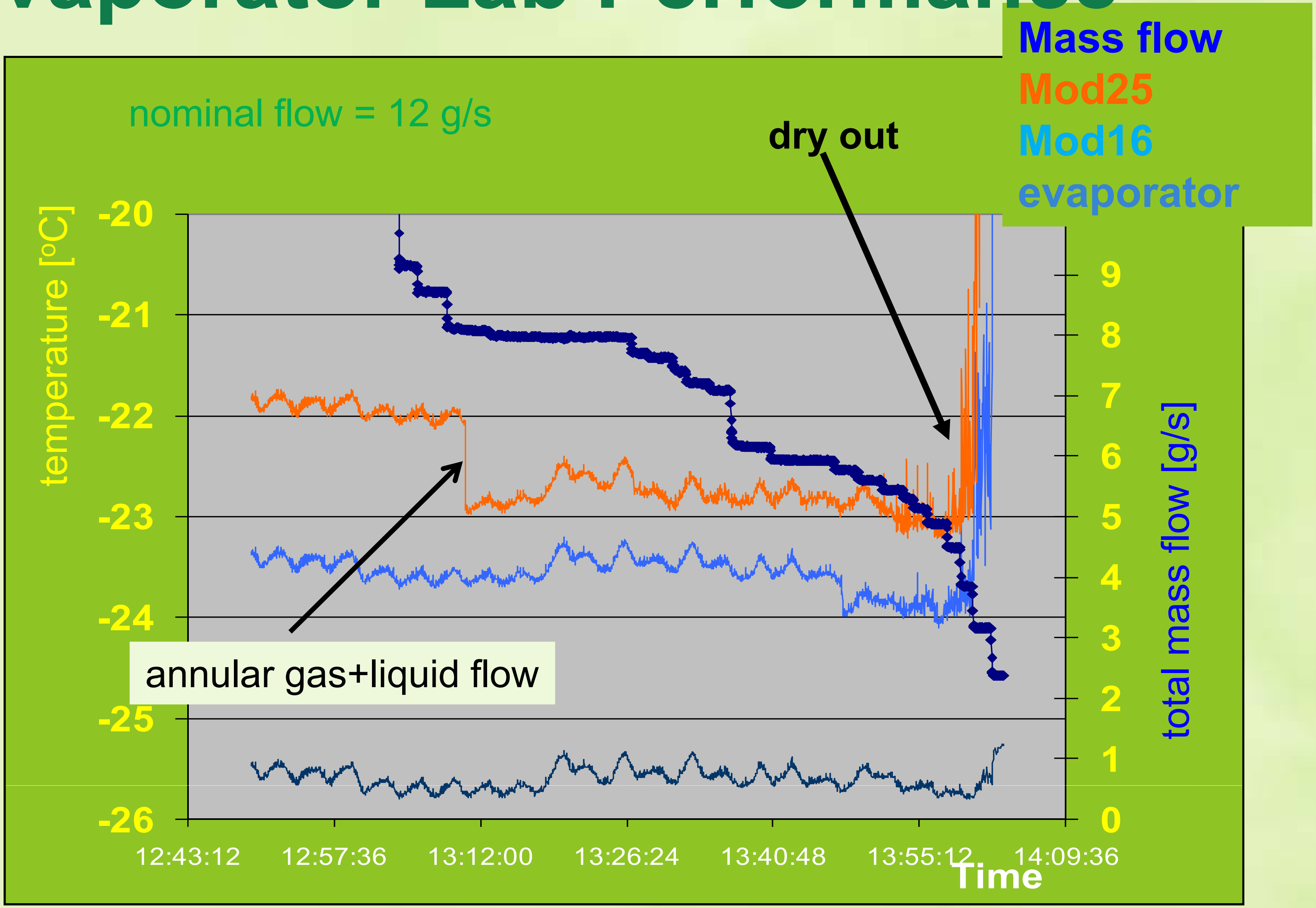


The Evaporator



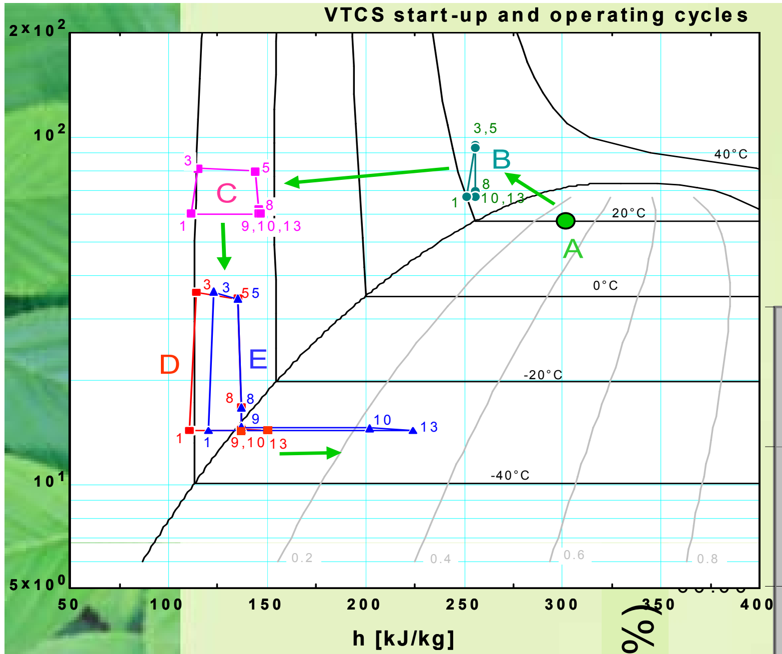


Evaporator Lab Performance

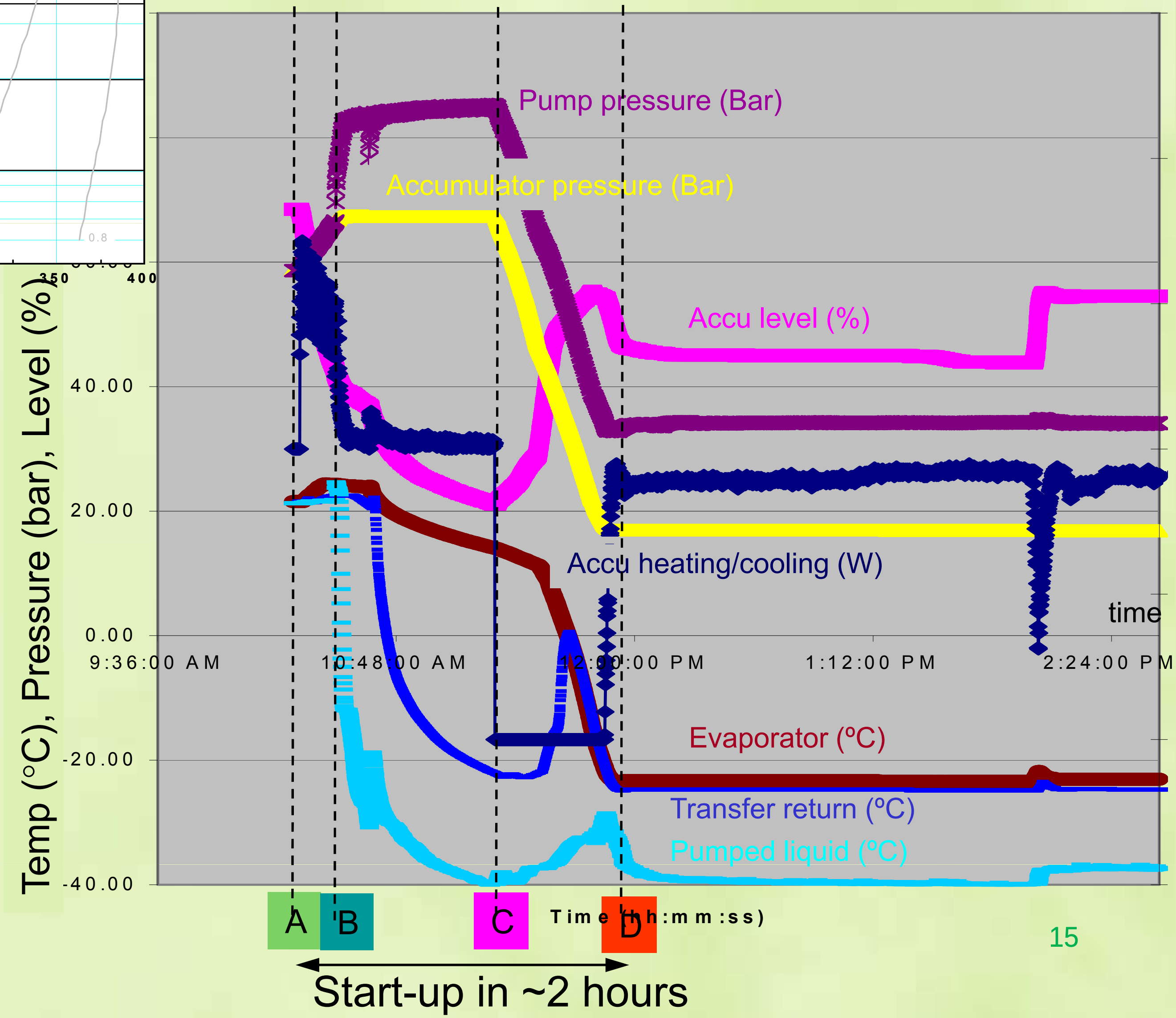


heat load 1.4x nominal

Operation: start-up



From room temperature to set-point of-25 ºC



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Major Challenges

Hardware concerns

Pumps

• problems for cold start-up → sphere valve secured by a spring

• pump-membrane failure as result of vacuuming → pump filling now done by flushing.

• pump discharge burst discs replaced by spring relieves

Heat exchanger

• from food industry (no mixing between coolants) + reinforced to withstand 200bar

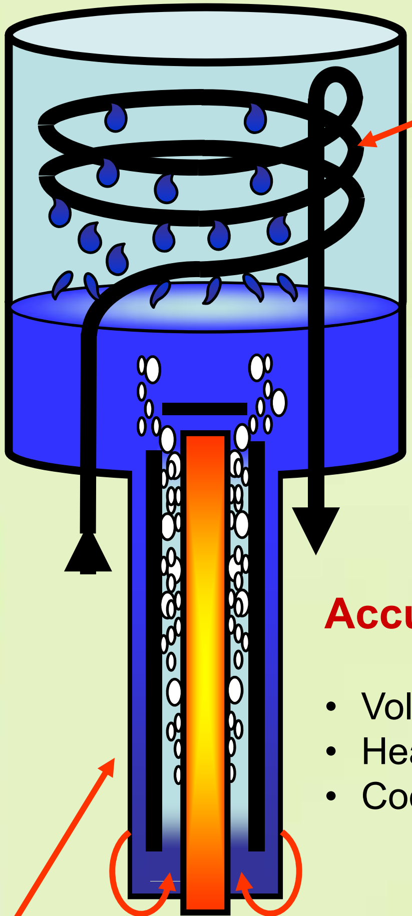
Safety Procedures

Accu working pressure 130bar, V =14l → European directive for high pressure vessels → CE certification

PLC control loops

Accu control see next slides

VTCS Accumulator Control

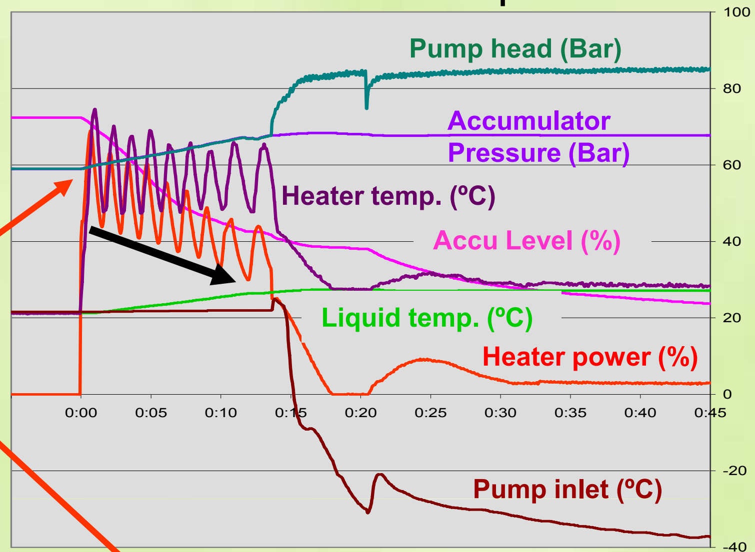


Cooling spiral for pressure decrease *(Condensation)*

Decrease heater power near critical point to prevent dry-out

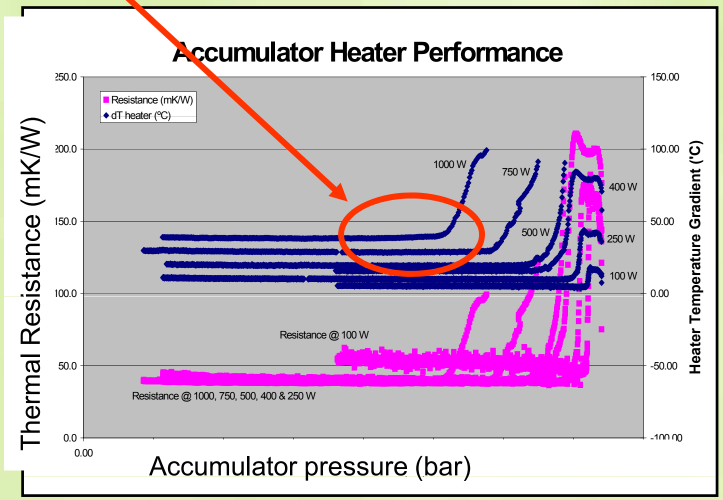
Thermo siphon heater for pressure increase *(Evaporation)*

2PACL Start-up



Accumulator Properties:

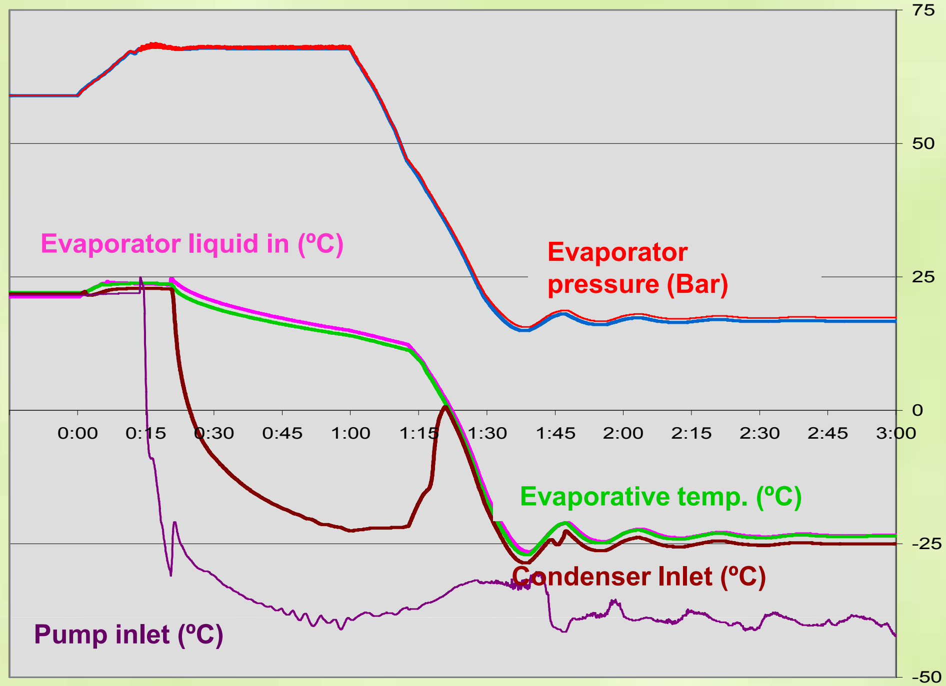
- Volume 14.2 liter (Loop 9 Liter)
- Heater capacity 1kW
- Cooling capacity 1 kW



VTCS Accumulator Control

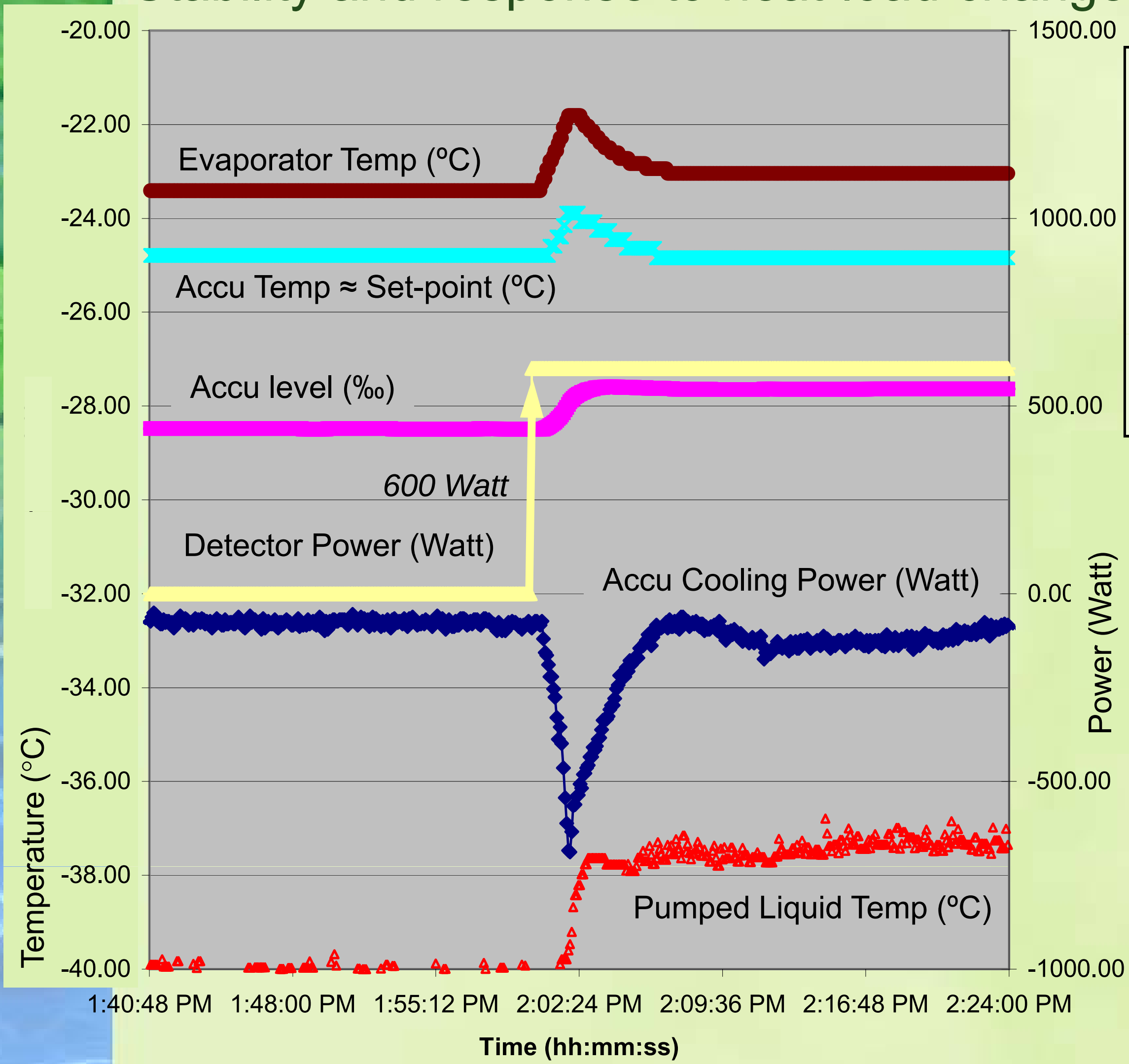
Accu PID control loop not adequate → temperature oscillations of a few degrees

Needed tuning of PID control loop to solve problem



VTCS Evaporator performance

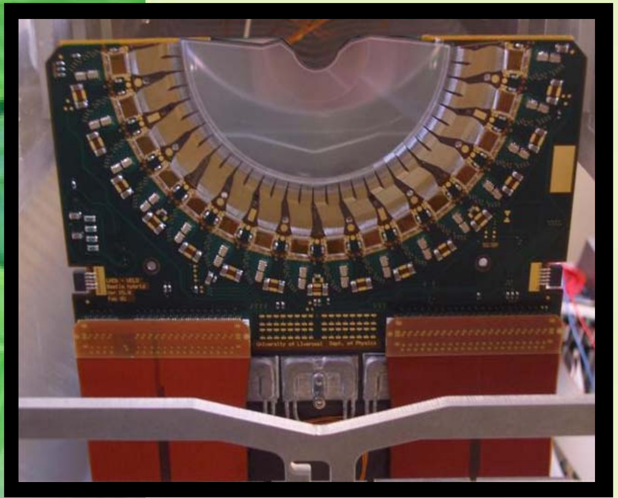
Stability and response to heat-load changes

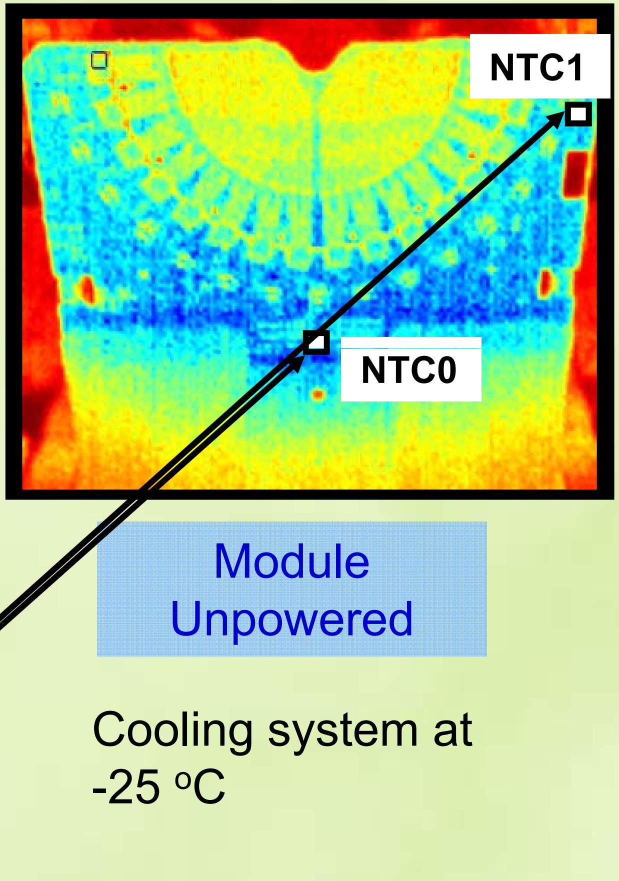


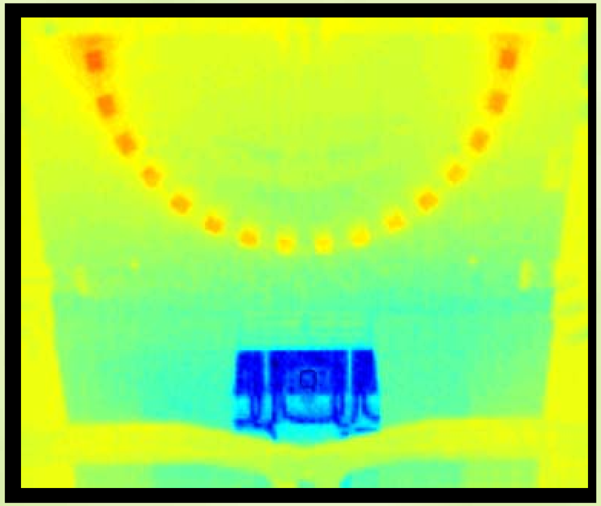
@Setpoint =-25ºC:
Accumulator temp: -24.8ºC
Evaporator temp(No Load): -23.4ºC
Evaporator temp(600 W Load):-23.0ºC
Stabilization time from 0 to 600 Watt: ca. 7min
Temperature stability: <0.25ºC

Temperatures stable without pressure change

Module Cooling







Module
Unpowered

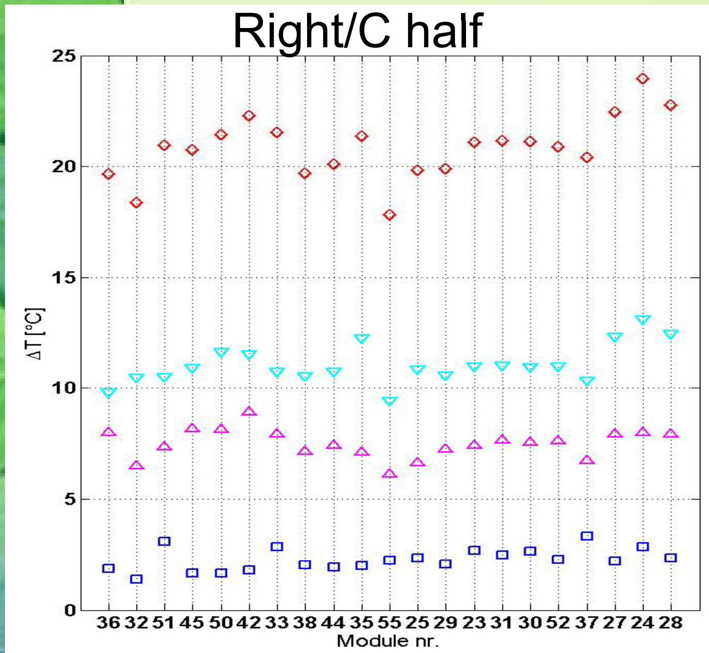
Module
Powered

Cooling system at -25 ^{o}C

Total Chip Power : ~19W

2 NTCs to monitor temperature on hybrid

Module Cooling & Performance

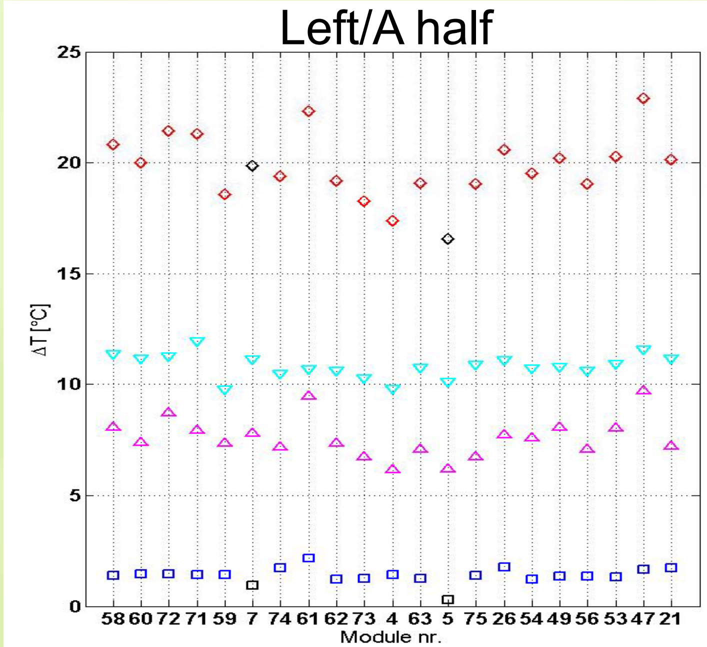


ΔT(Setpoint – NTC1)
Cooling system to silicon

ΔT(Cool. Cookie-NTC0)
Transfer cool-module

ΔT(NTC0-NTC1)
Module performance

ΔT(setpoint-cool. Cookie)



$\langle T_{silicon} \rangle$ with setpoint of -25°C:

(-4.2 ± 1.4) °C

Min. -7.2 °C Max. -1.0 °C

$\langle T_{silicon} \rangle$ with setpoint of -25°C:

(-5.2 ± 1.5) °C

Min. -8.4 °C Max. -2.1 °C

Measurement conditions not exactly as! final system (vacuum, not all modules cooled simultaneously, …)

Small variations in power consumption, modules assembly, evaporator stations → variations in ΔT

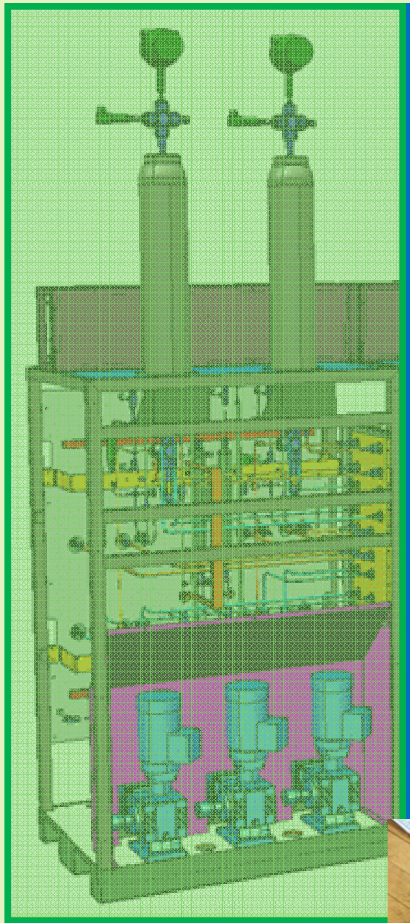
Conclusions

- All stringent requirements met
  - Setpoint temperatures go down to ~ -35°C
  - System proves stable operation:
    - without loads/with loads up to 800W
  - Module thermal performance + CO2 cooling at -25 °C
    → All modules at all times below 0°C
  - Low mass system without mechanical stress on module
  - Redundancy built in
- VELO CO_2 cooling system is installed and commissioned
- PLC control successful
  - all routines implemented
  - 1 button start/stop for main system

Looking forward to enter the final commissioning phase with the VELO installed!

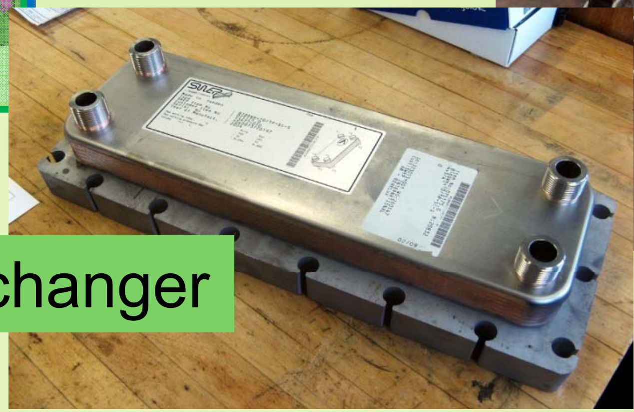
Back Up Slides

The cooling plant: CO_2 unit



CO_2-part

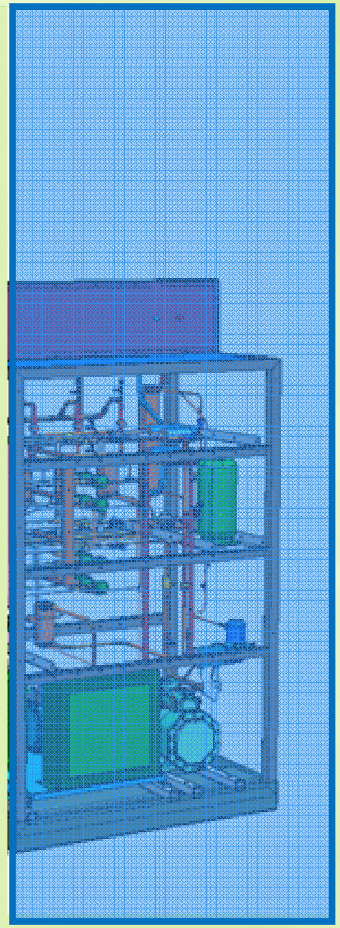
Accumulator



Heat exchanger

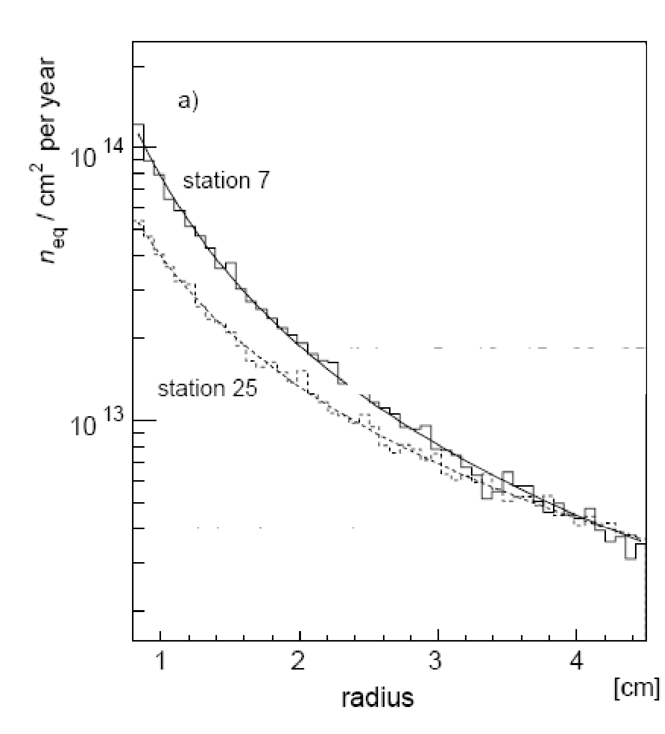
3 CO_2 pumps

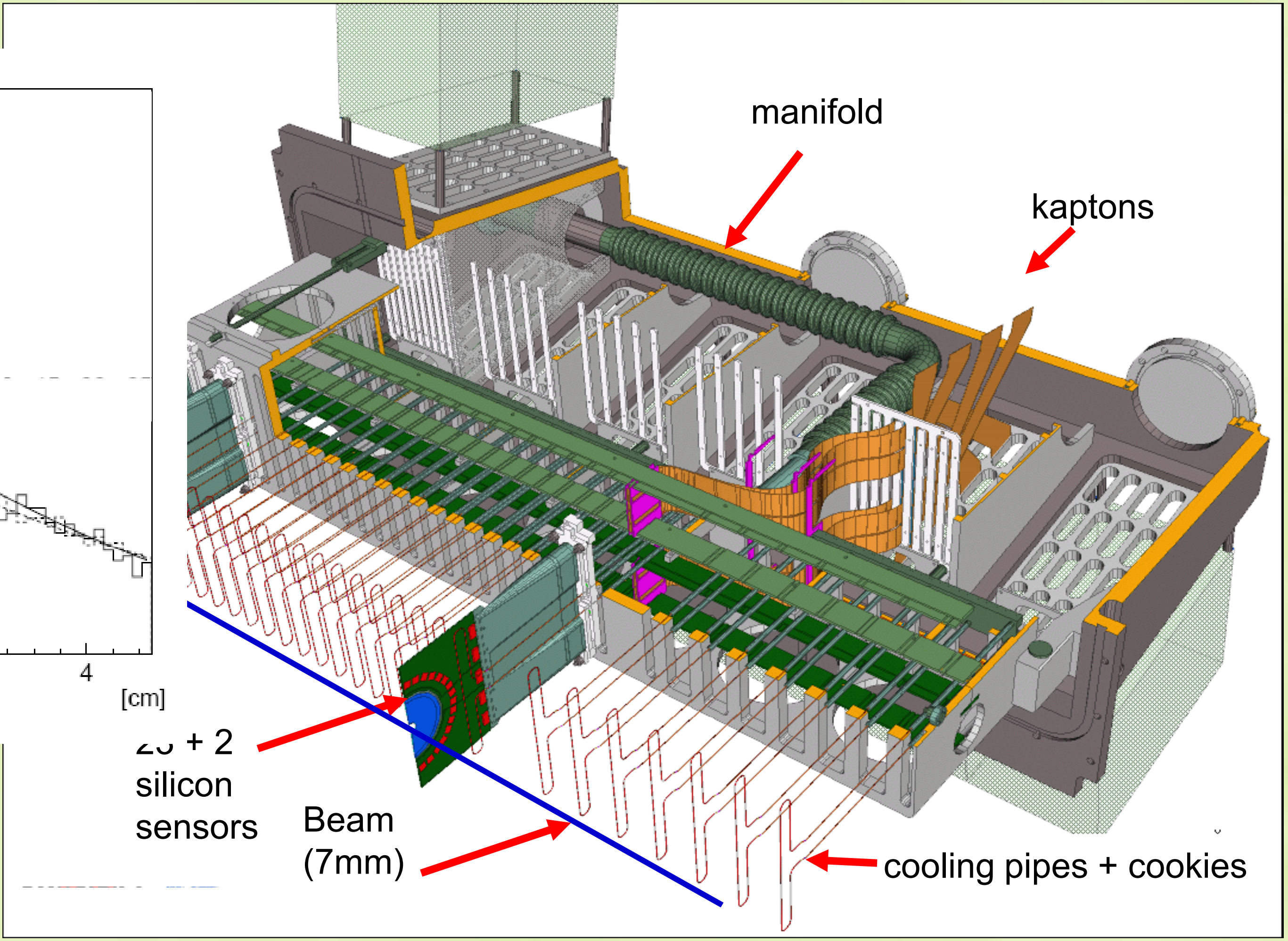
The cooling plant: Freon unit



2 Compressors
(Air and water chiller)

VELO detector half





Stand-alone test results of the VTCS cooling plant

(No external evaporator, cooling over by-pass)

Main chiller performance

- **Dynamic range of main chiller works properly.**
- **Full operational range (0 to 1800 Watt) possible in evaporator range (-25°C to -30°C)**
- **Isolation needs improvement around injection valves**
- **CO_2 condensers/ Freon evaporator works beyond expectation**

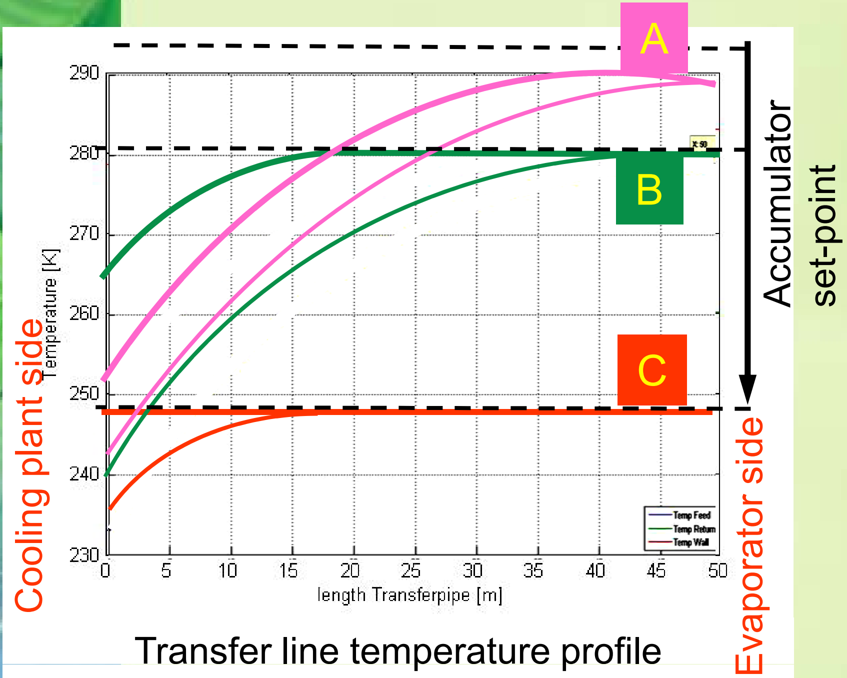
  (Hardly no dT between Freon and CO_2)

Back-up chiller performance

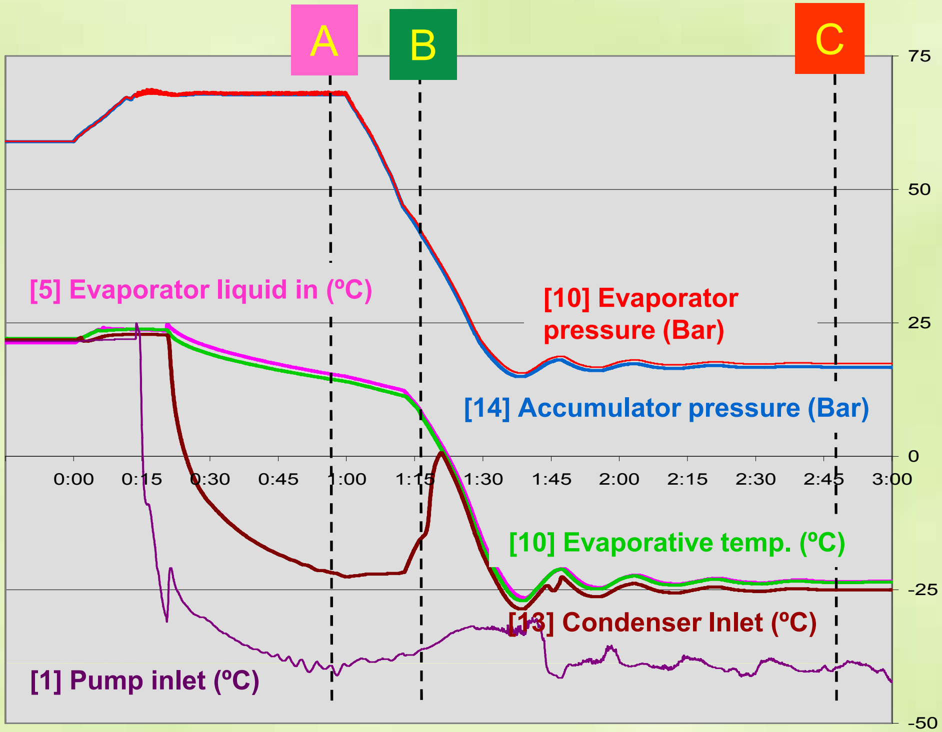
- **Able to maintain an un-powered CO_2 evaporator at -10°C**

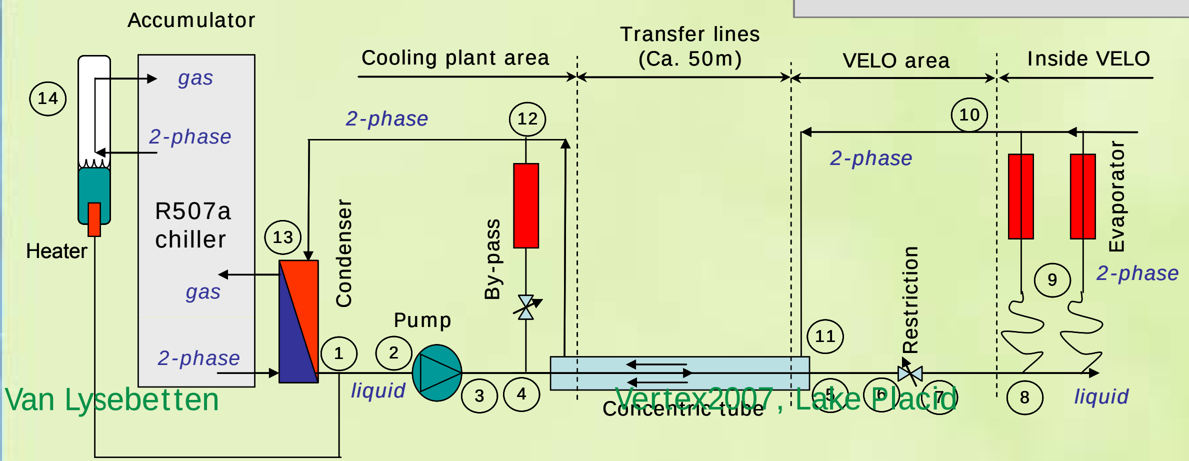
Transfer line Operation

(Internal heat exchanger)



Transfer line temperature profile





A: Condenser and evaporator single phase

B: Evaporator 2-phase, condenser single phase

C: Both evaporator and Condenser 2- phase