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CO_2 Cooling Seminar

Desy Hamburg

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18 February 2011

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CO_2 Cooling Seminar

- The benefits of using CO_2 cooling.
- History of CO_2 cooling.
- Introduction to the 2PACL CO_2 circulation method.
- CO_2 cooling in the AMS-Experiment.
- CO_2 cooling in the LHCb Velo Detector
- Future applications.
- Conclusions

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Why is evaporative CO_2 cooling good for HEP detectors?

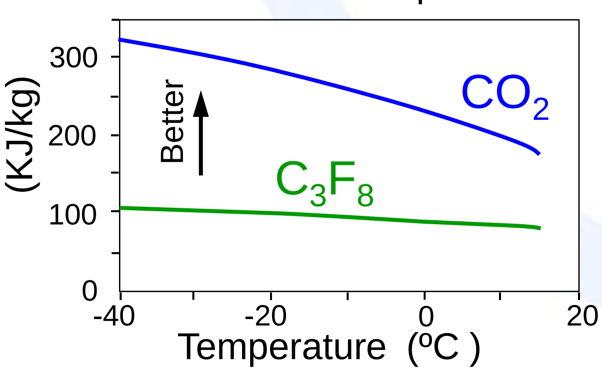
CO_2 allows small tubing

Why?

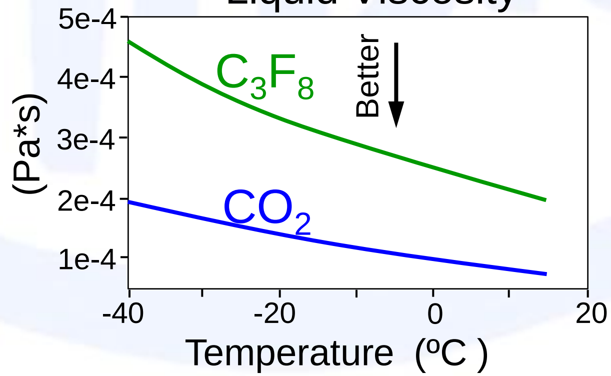
Large latent heat & Low viscosity & High pressure

- Large latent heat → Allow low flow → Low pressure drop → Lower pressure drop
- Low viscosity → Low pressure drop → Lower pressure drop
- High pressure → Allow high pressure drop
- Lower pressure drop & Allow high pressure drop → **Allow very small tubing**

Latent Heat of Evaporation



Liquid Viscosity



What happens inside a cooling tube?

Heating a flow from liquid to gas

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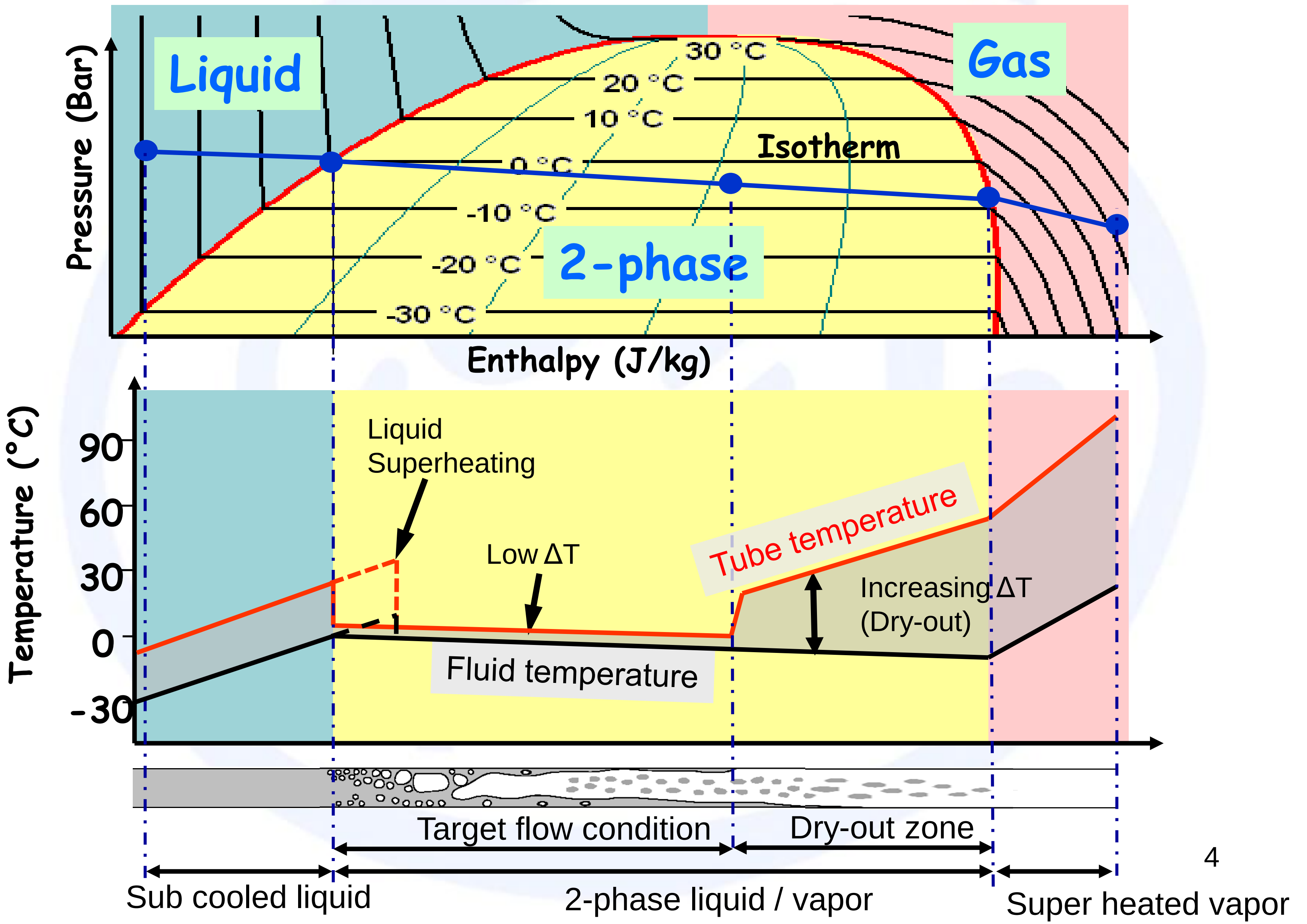

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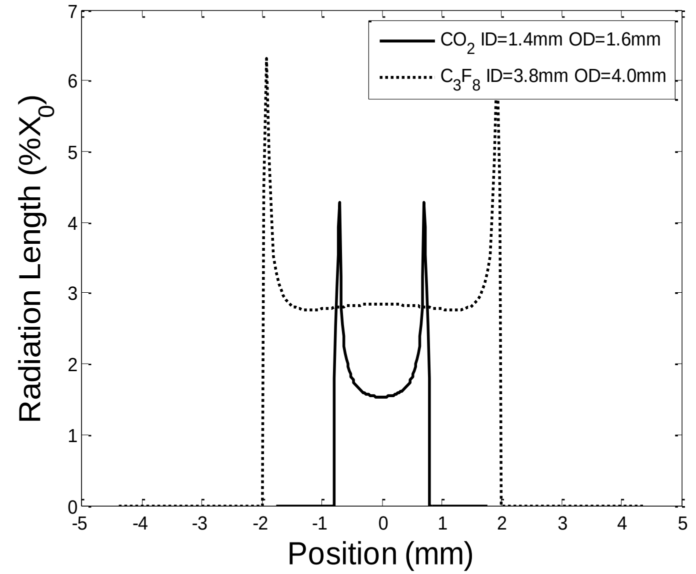
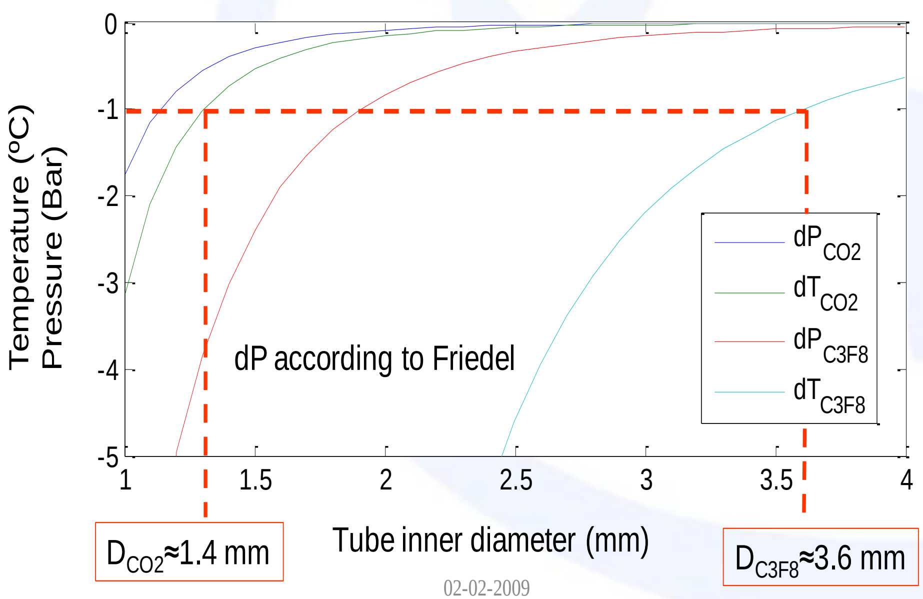
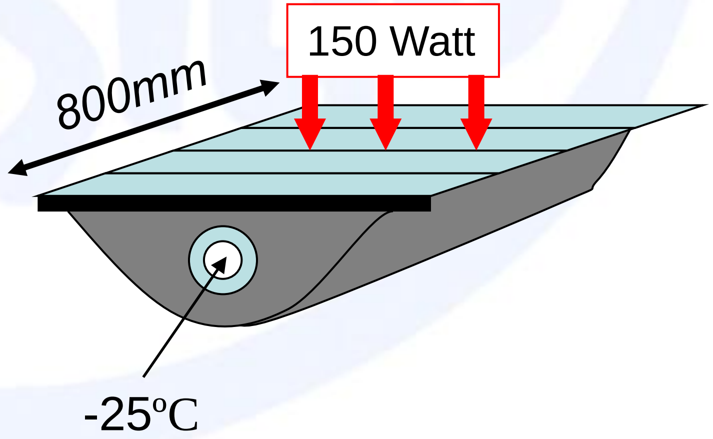
CO_2 Calculation Example

Atlas IBL stave

	CO_2	C_3F_8
Inner Diameter (D_i [mm])	1.4	3.6
Max. Design Pressure (MDP [bar])	100	15
Tube wall thickness (T_w [mm])	0.1	0.1
Relative tube mass (m_{rt} [g/m])	3.8	9.3
Fluid density (ρ_f [kg/m^3])	1054	1564
Relative fluid mass (m_{rf} [g/m])	1.6	15.9
Total relative mass (m_{rtot} [g/m])	5.4	25.2
Relative stored Energy (Q_{rst} [J/m])	15.4	15.3







CO_2 safety issues

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CO_2 has a high pressure but this does not have to be an increased safety issue.

Pressure Equipment Directive (PED):

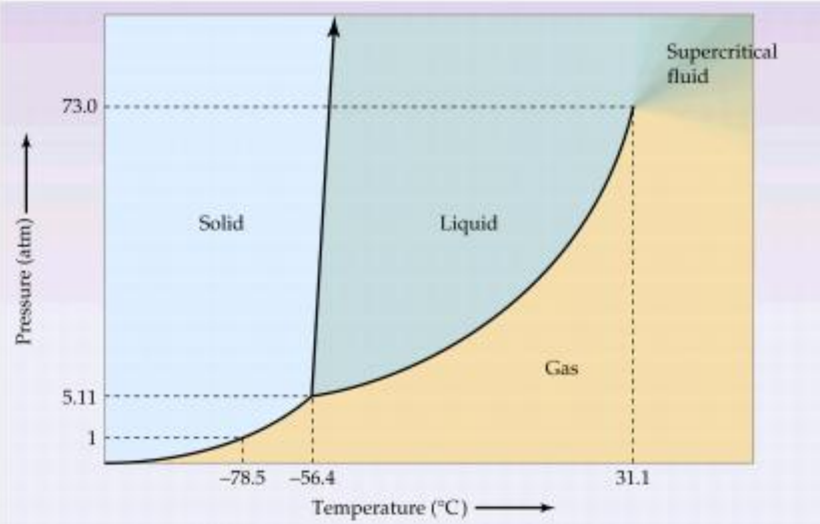
- Stored energy determines the safety class.
- Stored Energy = Pressure x Volume

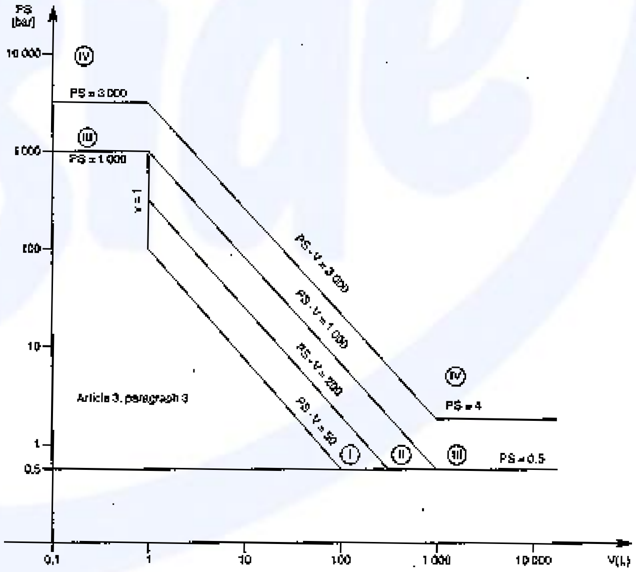
CO_2 is environmental friendly, non-toxic and cheap.

CO_2 in large concentrations is asphyxiating, be careful with venting CO_2 in unventilated small spaces.

CO_2 does not exist as liquid in atmospheric conditions. It is released as -78ºC solid. Cold burn risk.

	ID	Design Pressure	Stored energy
CO_2	1.4mm	100 bar	15.4 J/m
C_3F_8	3.6mm	15 bar	15.3 J/m





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Is CO_2 cooling new?

- **NO!** it was used in the late 19th and early 20th century and is one of the first used refrigerants.

- The high pressure of CO_2 (130 bar) was a problem for materials those days.
  - Development of low pressure synthetic refrigerants (CFC's) causing CO_2 to disappear as refrigerant.

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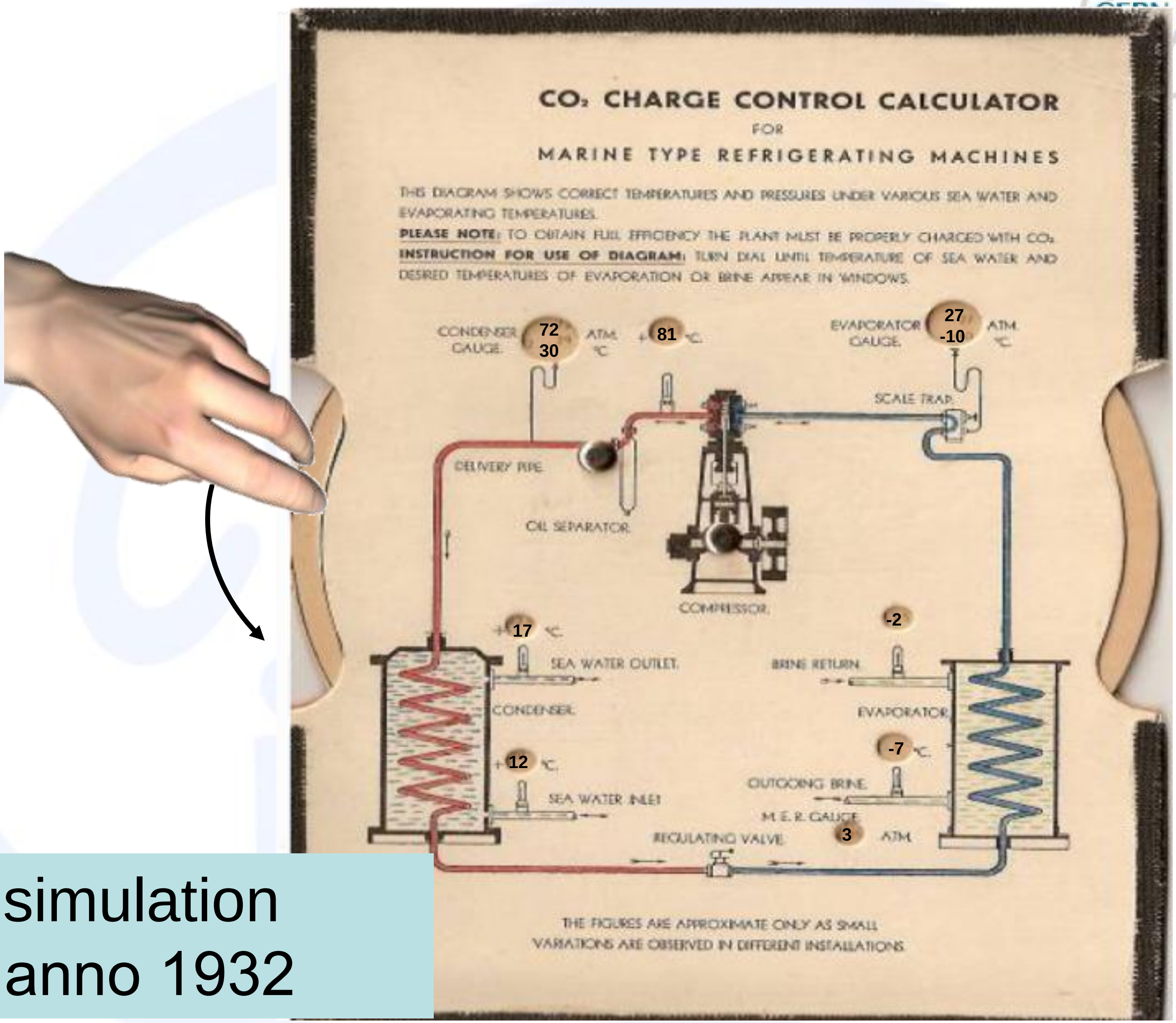

CO_2 cycle simulation "software" anno 1932

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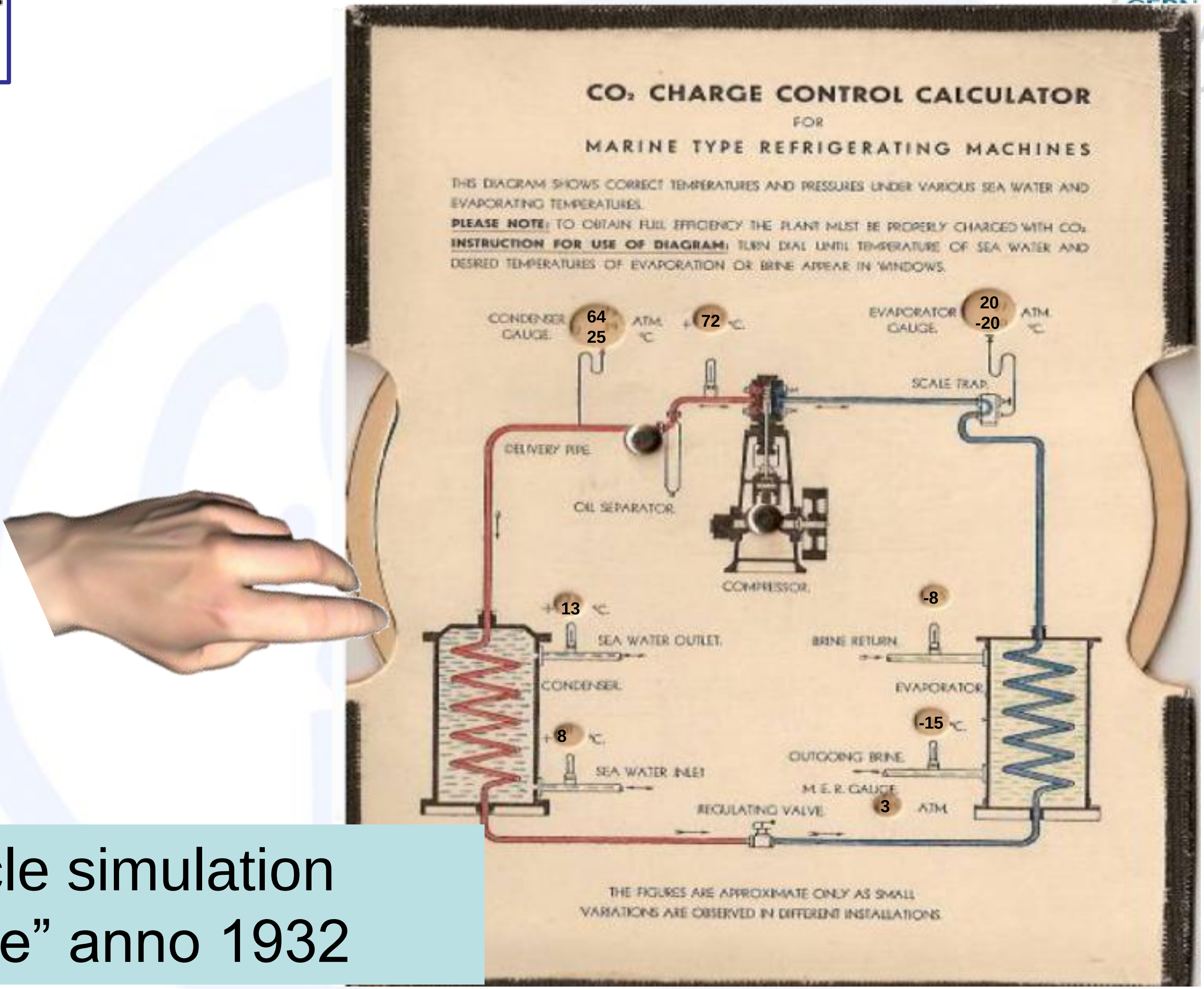
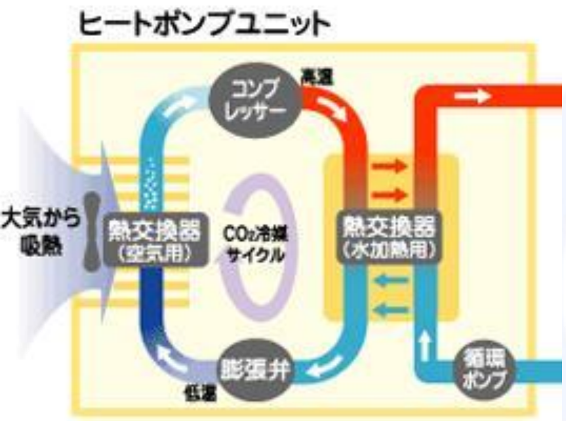


CO_2 cycle simulation "software" anno 1932

The last 12 years CO_2 is reintroduced as "green" refrigerant. Now CO_2 is getting standard again.

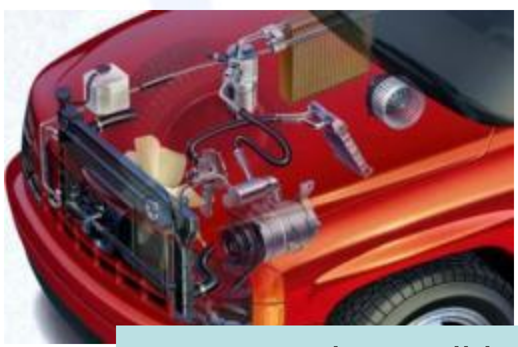
Soon your beer at home will be cooled with CO_2 too…

Japanese "ecocute" for tap water heating



CO_2 cooled ice creams

Super market CO_2 cooling plant



CO_2 Car air-conditioning

CO_2 cooled ice skating rink in Haarlem

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CERDEC team earns Secretary of the Army Environmental Award

CO_2 cooling is SO GREEN that the even the Hummer guys won a environmental prize because of their CO_2 air-conditioning.

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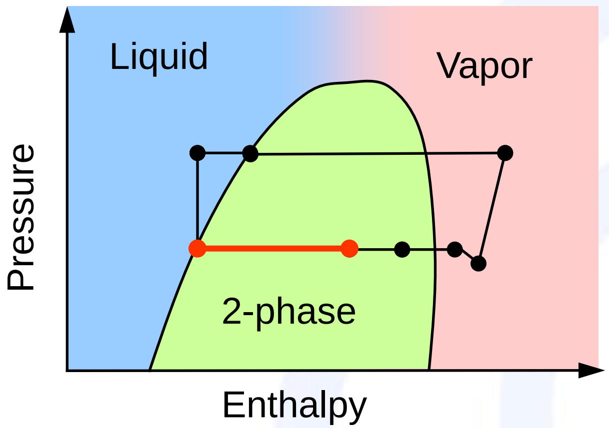
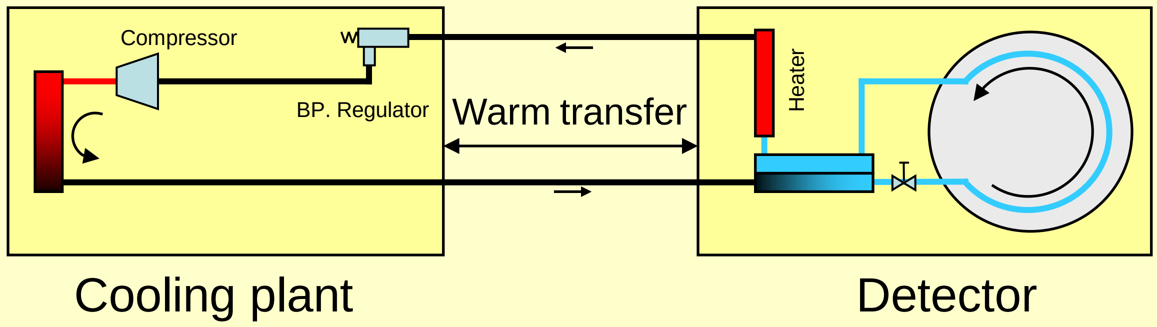
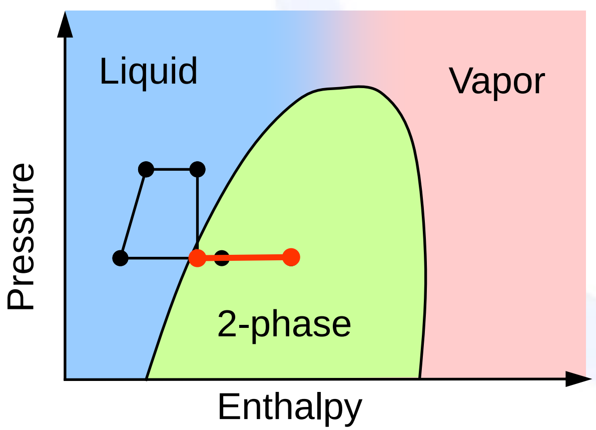
How to get the ideal 2-phase flow in the detector?



Traditional method: (Atlas)

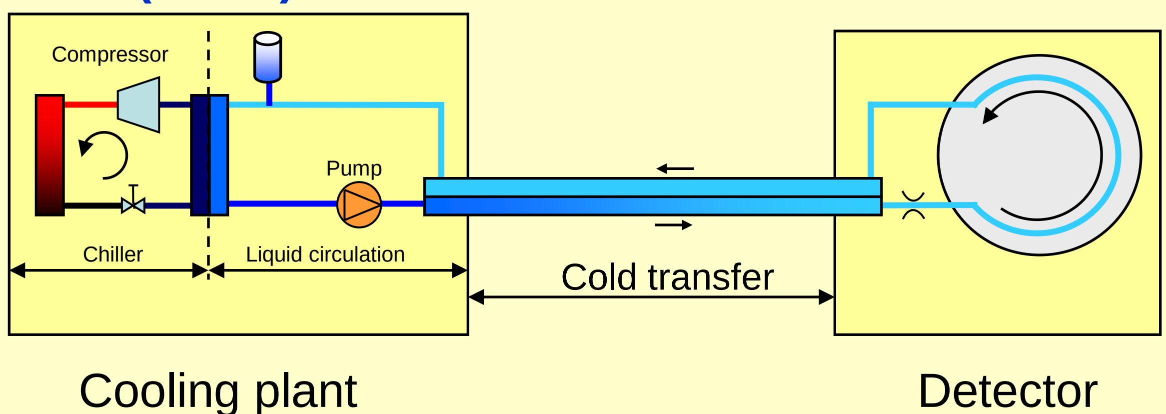
Vapor compression system





2PACL method: (LHCb)

Pumped liquid system



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CO_2 systems in HEP

- 2 CO_2 cooling systems have been developed for HEP detectors so far.
  - AMS-TTCS (Tracker Thermal Control System)
    - Q= 150 watt
    - T=+15ºC to -20ºC
  - LHCb-VTCS (Velo Thermal Control System)
    - Q=1500 Watt (2 parallel systems is 750 W)
    - T= +8ºC to -30ºC
- Both systems are based on the **2PACL** principle invented at Nikhef

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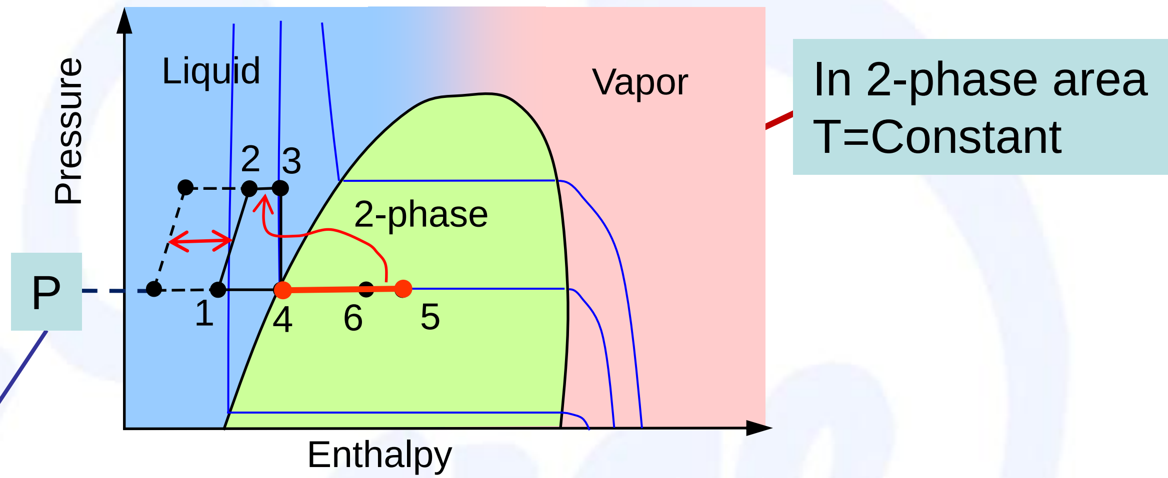
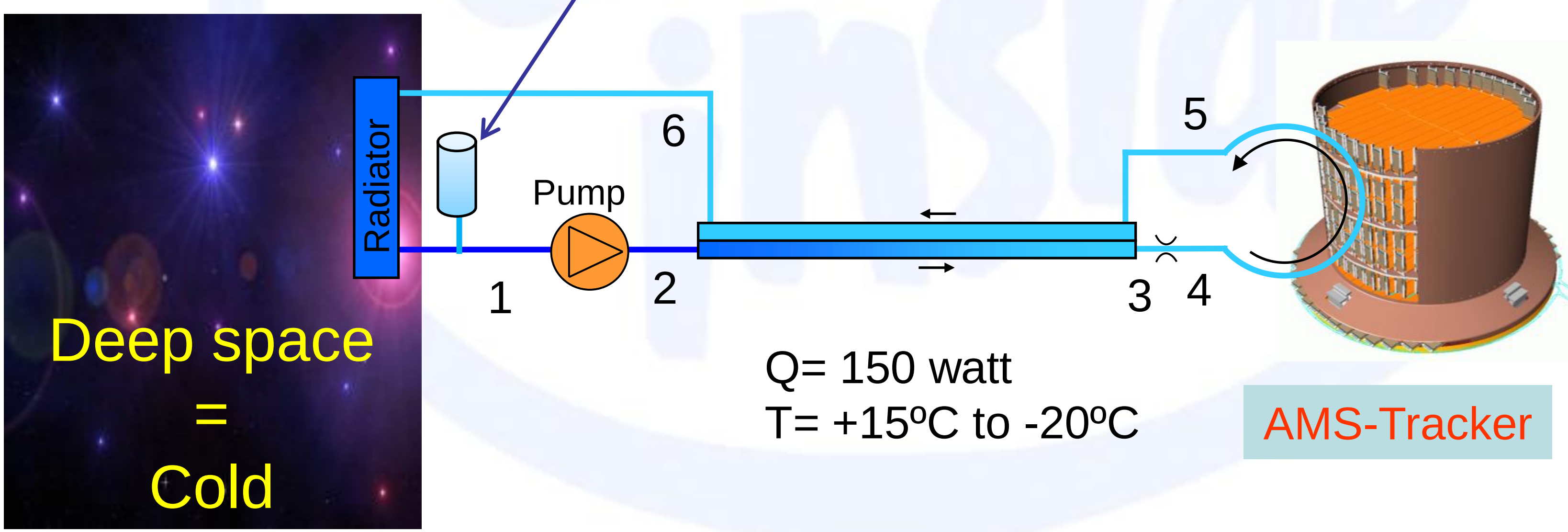
2-Phase Accumulator Controlled Loop (2PACL)

- 2PACL was developed for the AMS-TTCS
- 2PACL also implemented in LHCb-VELO





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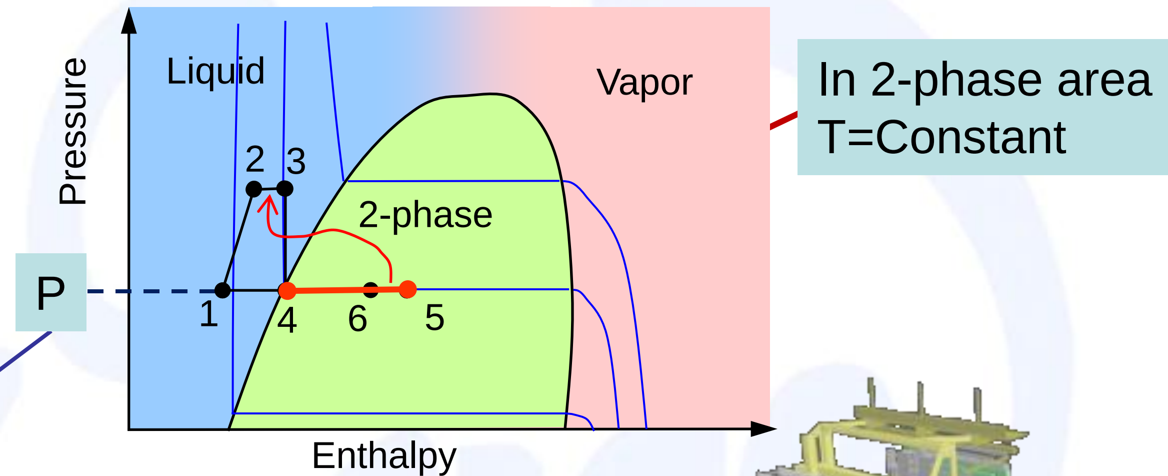

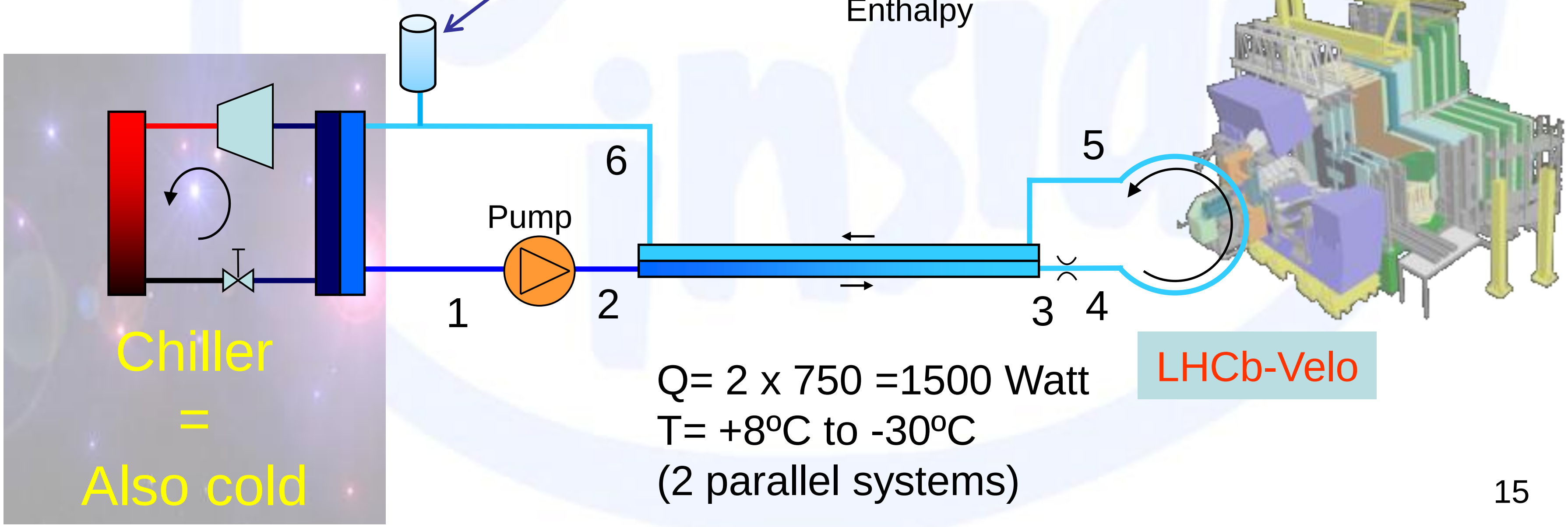

2PACL Operation

From start-up to cold operation

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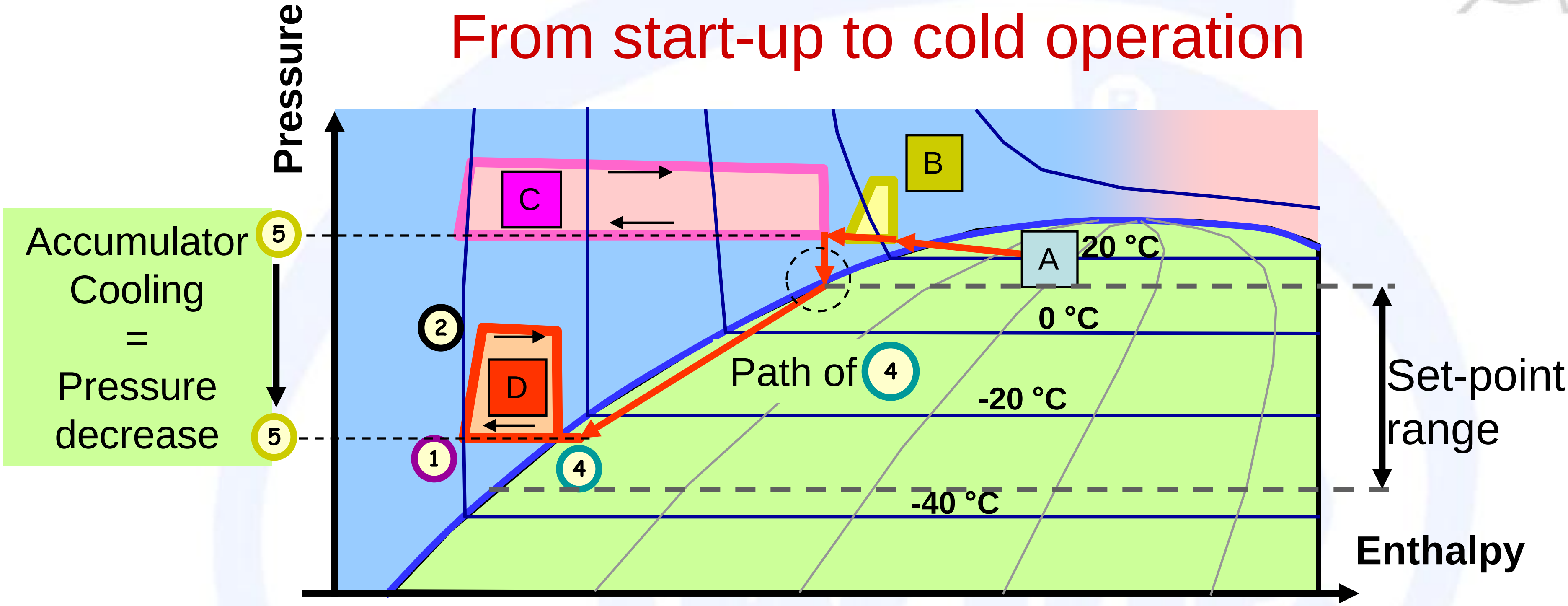

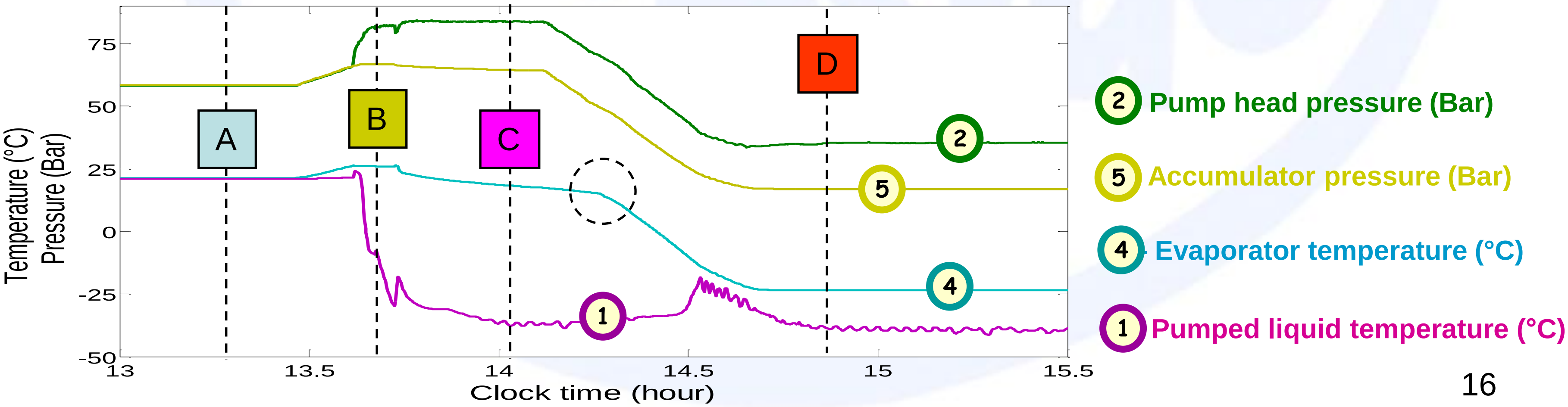

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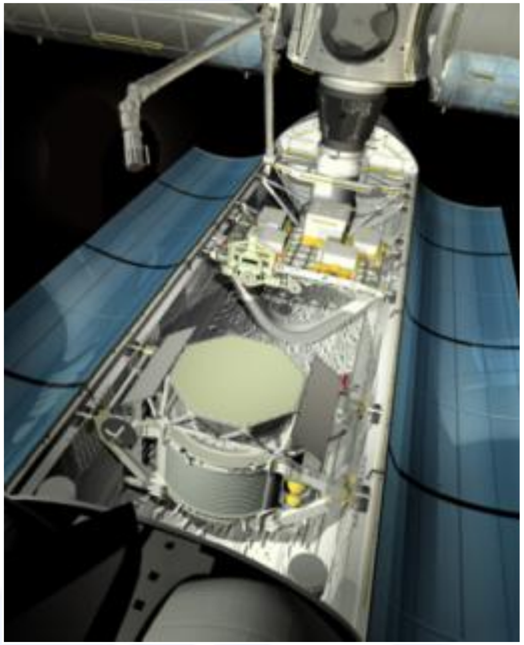
Alpha Magnetic Spectrometer



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AMS-Detector Ready for flight STS-134 *(19 April 2011)*

UNIVERSITÉ DE GENÈVE

CARLO GAVAZZI SPACE SpA

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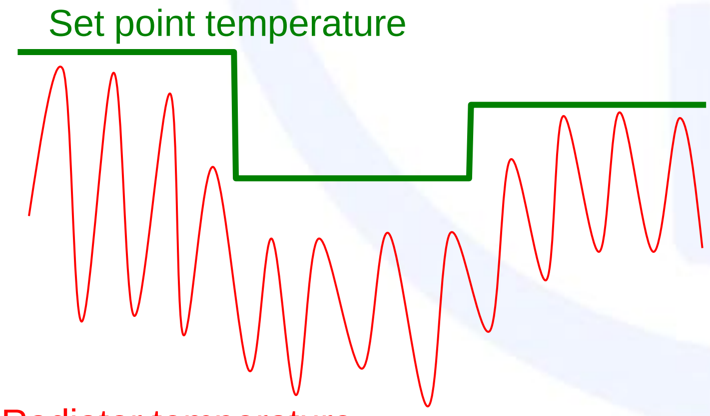
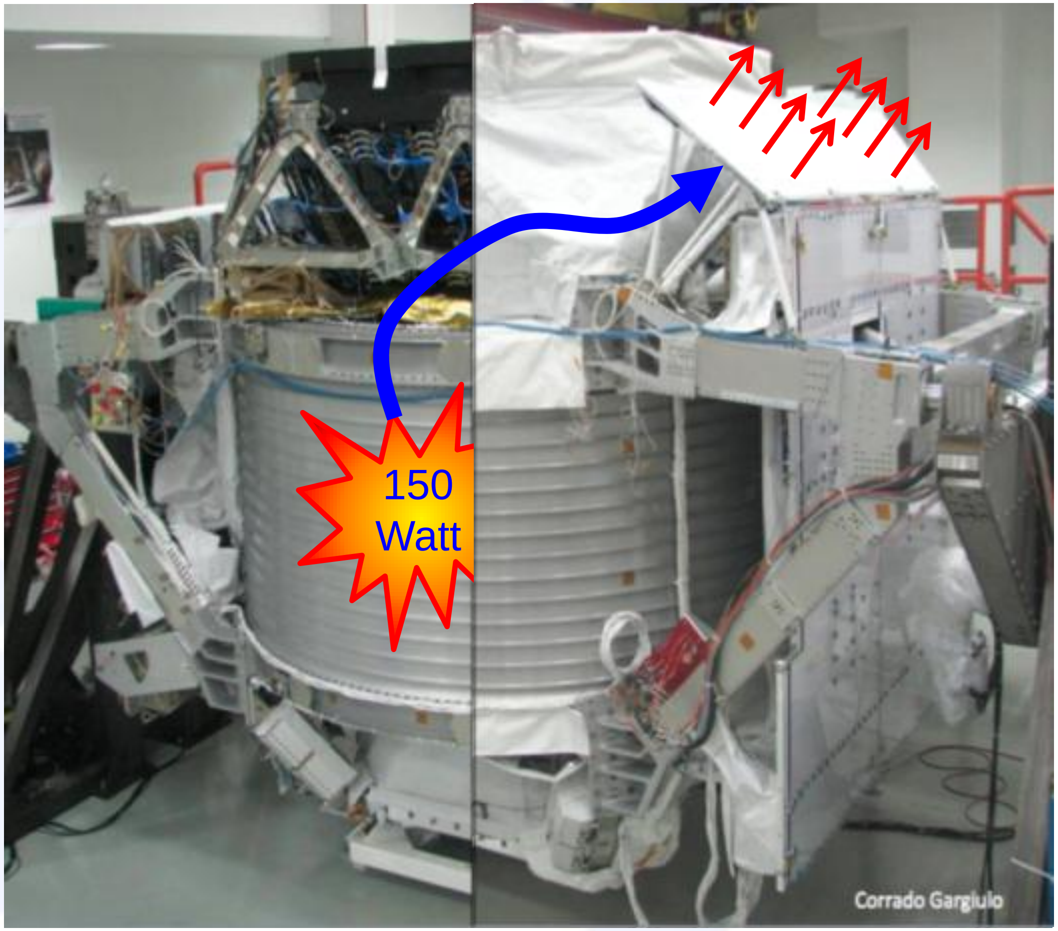
Tracker Thermal Control system (TTCS)

- TTCS: Bringing the 150 Watt from the insulated detector center to the external radiator panels.
- Keeping the detector temperature stable <3ºC over orbit.
- Evaporator set-point between -20ºC and +15ºC (Depending on seasonal temperature.





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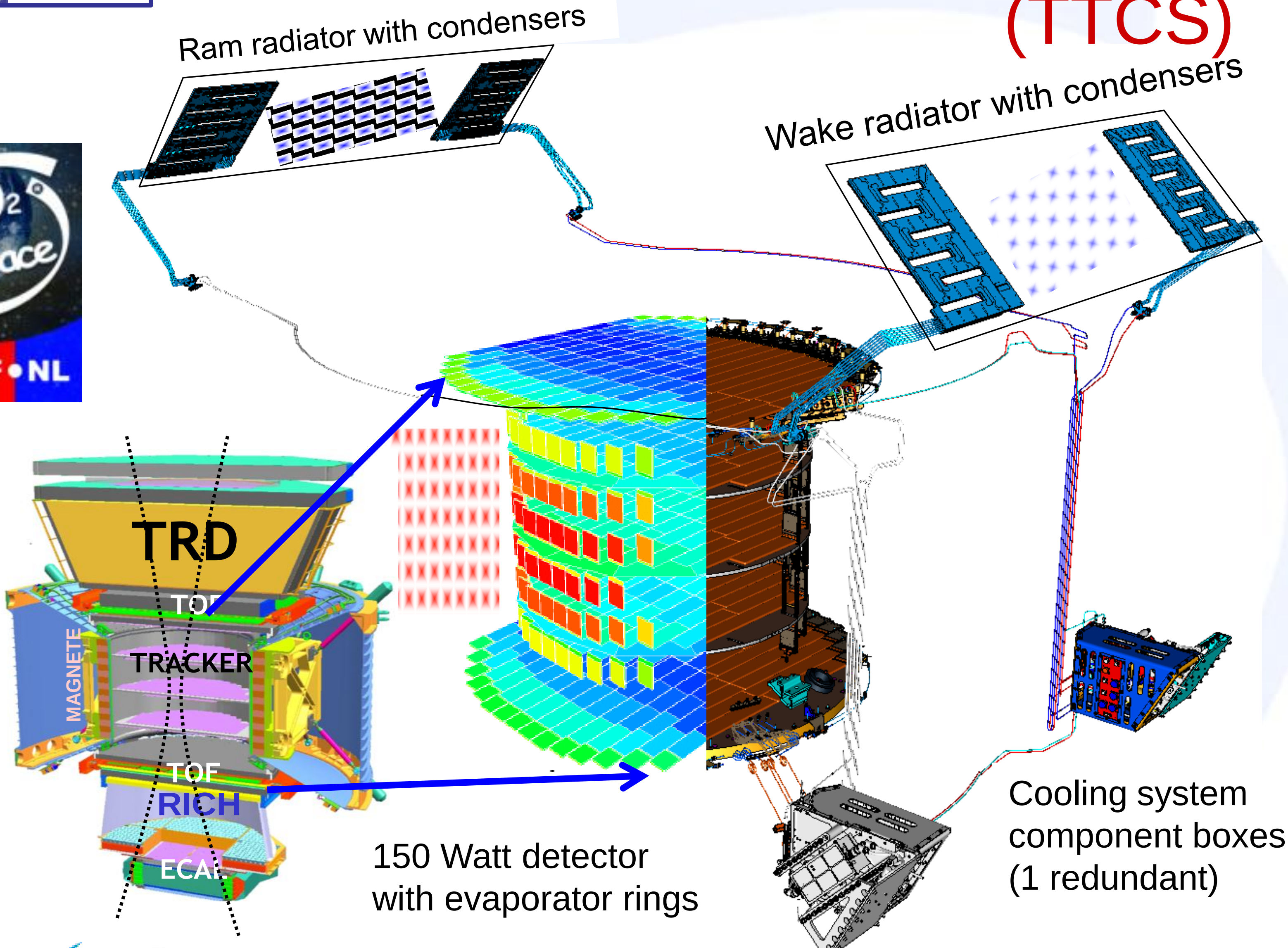
Tracker Thermal Control system (TTCS)



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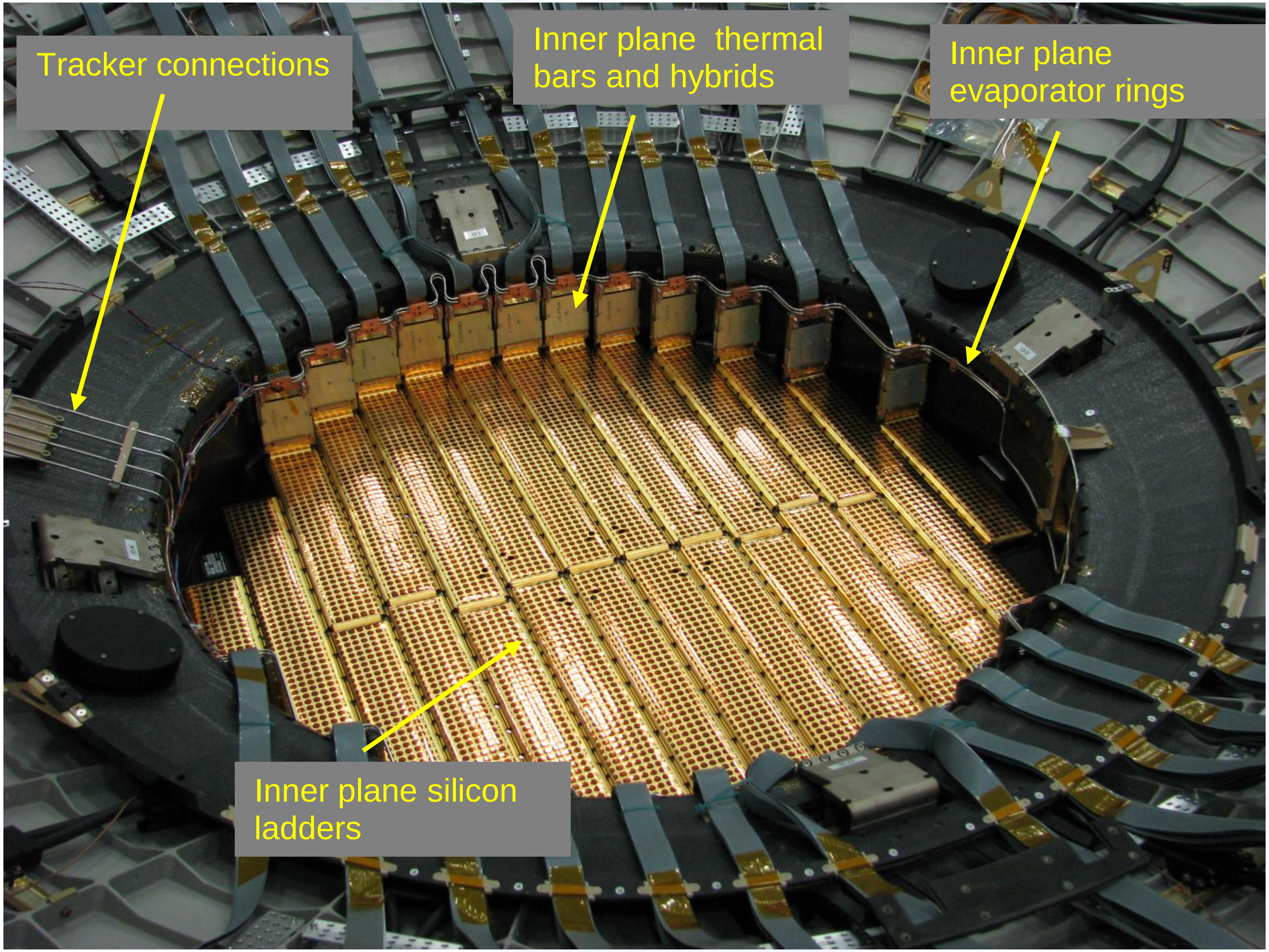
AMS-Tracker with CO_2 cooling rings.



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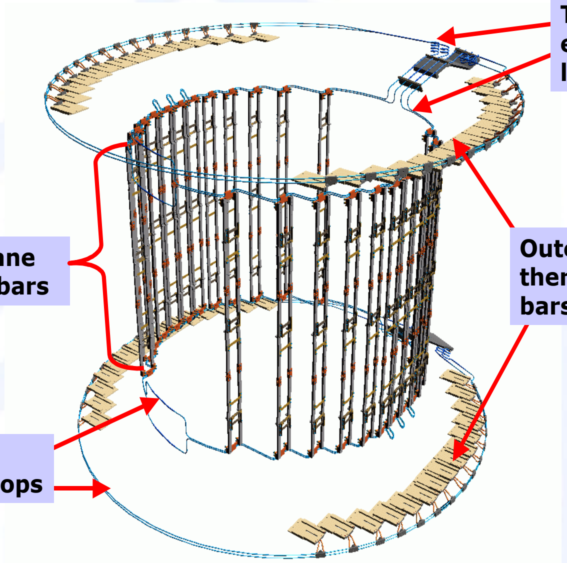
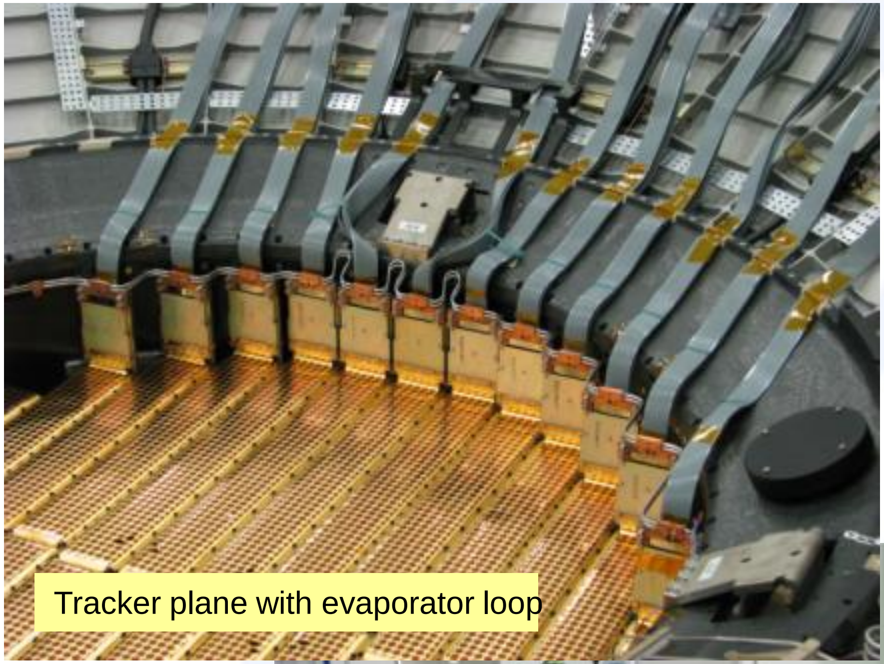
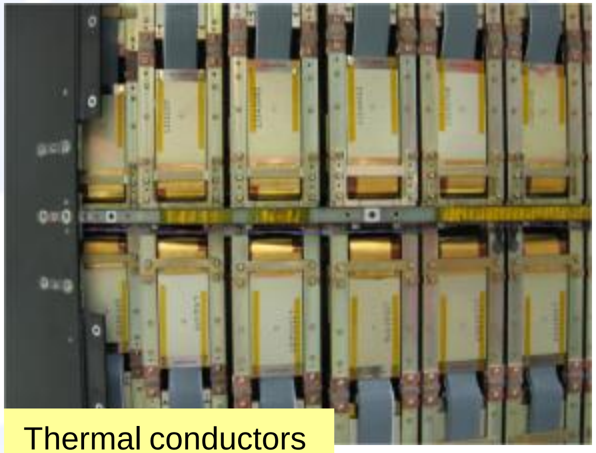
TTCS Evaporator system




Tracker plane with evaporator loop


Welding of the evaporators


Thermal conductors

TTCS Schematics

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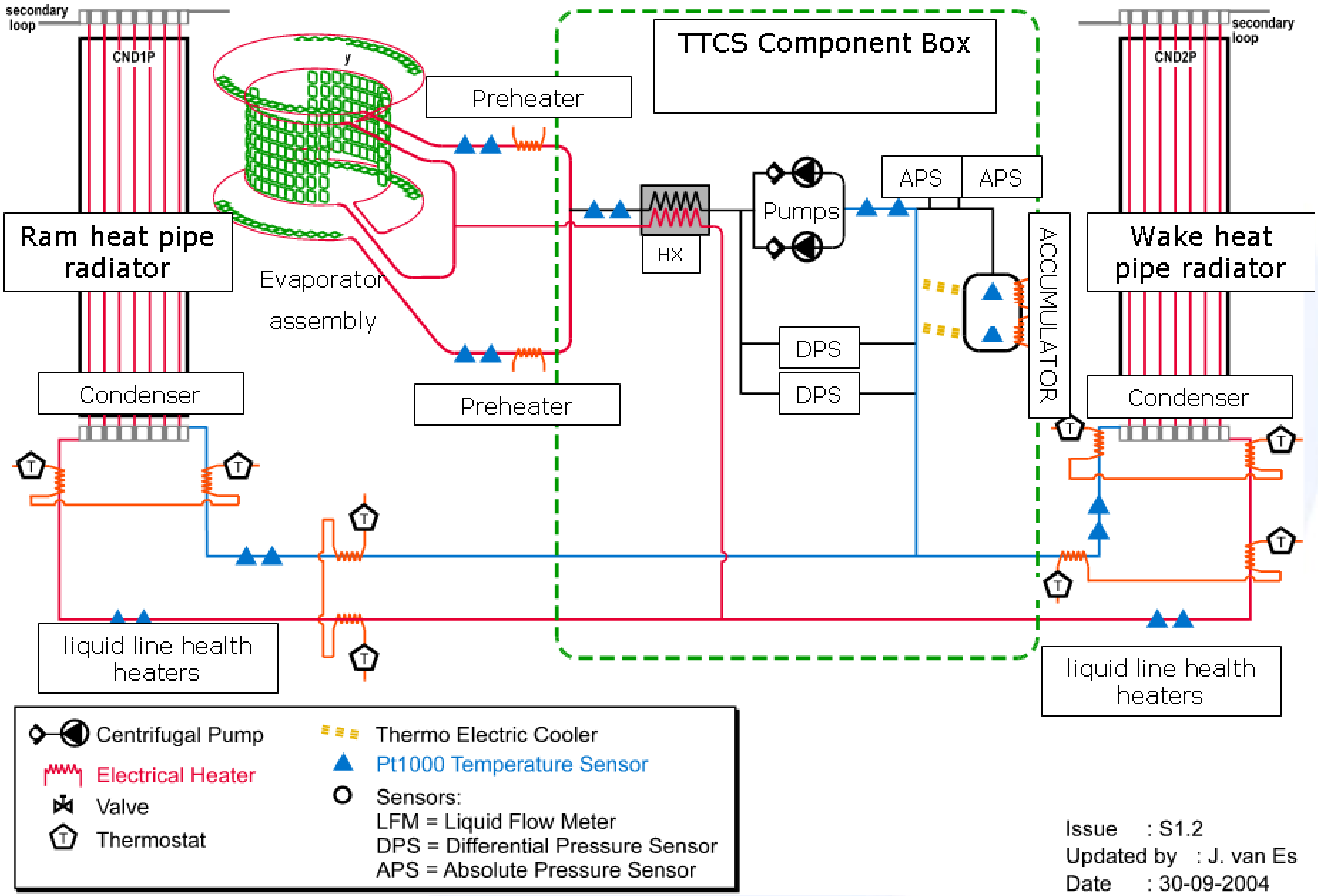

Issue : S1.2
Updated by : J. van Es
Date : 30-09-2004

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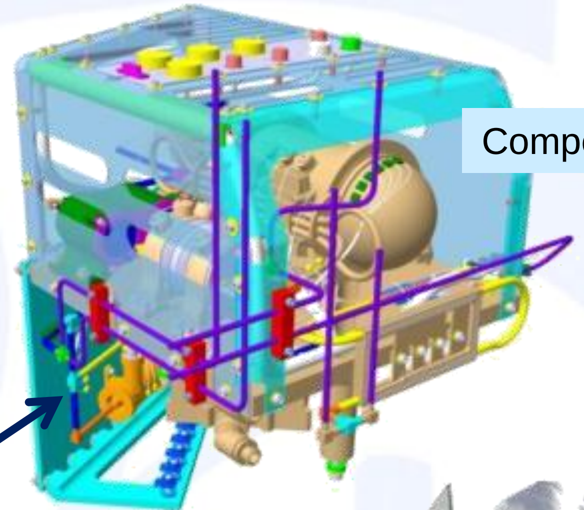
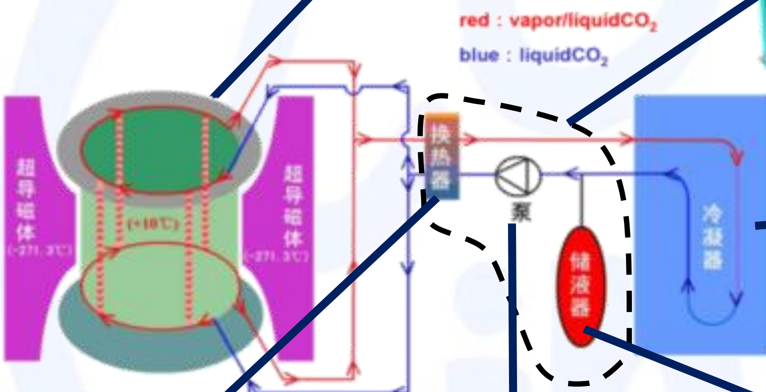
TTCS Components

Evaporator section



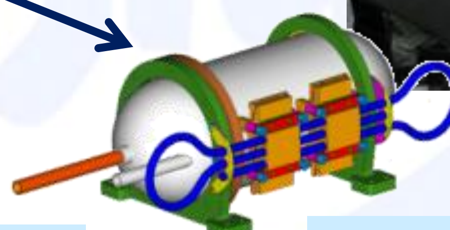
Component box



Condenser and radiators

Heat exchanger

Centrifugal pump



Accumulator

AMS-02 NLR 中山大學 INFN CASC UNIVERSITÉ DE GENÈVE NIKHEF MIT CARLO GAVAZZI SPACE SpA

TTCS Engineering Model Test Results

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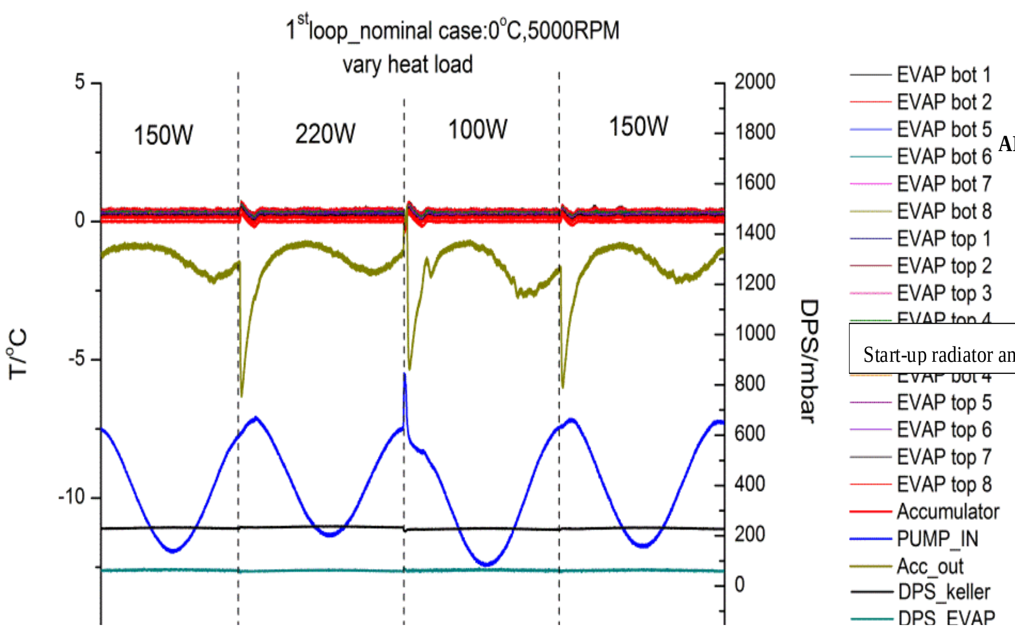
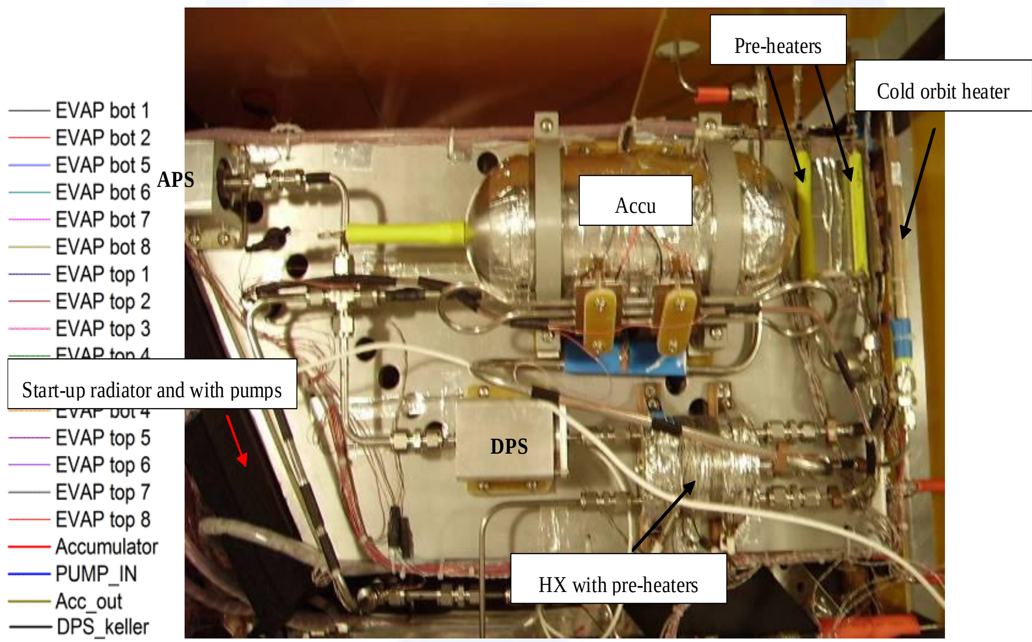
- The TTCS installed in AMS can only be tested in vacuum.
- All the functional tests have been done with an engineering model.





Thermal stable operation with varying heat loads & varying orbital conditions

AMS Thermal Vacuum Tests @ ESA-Estec in the LSS

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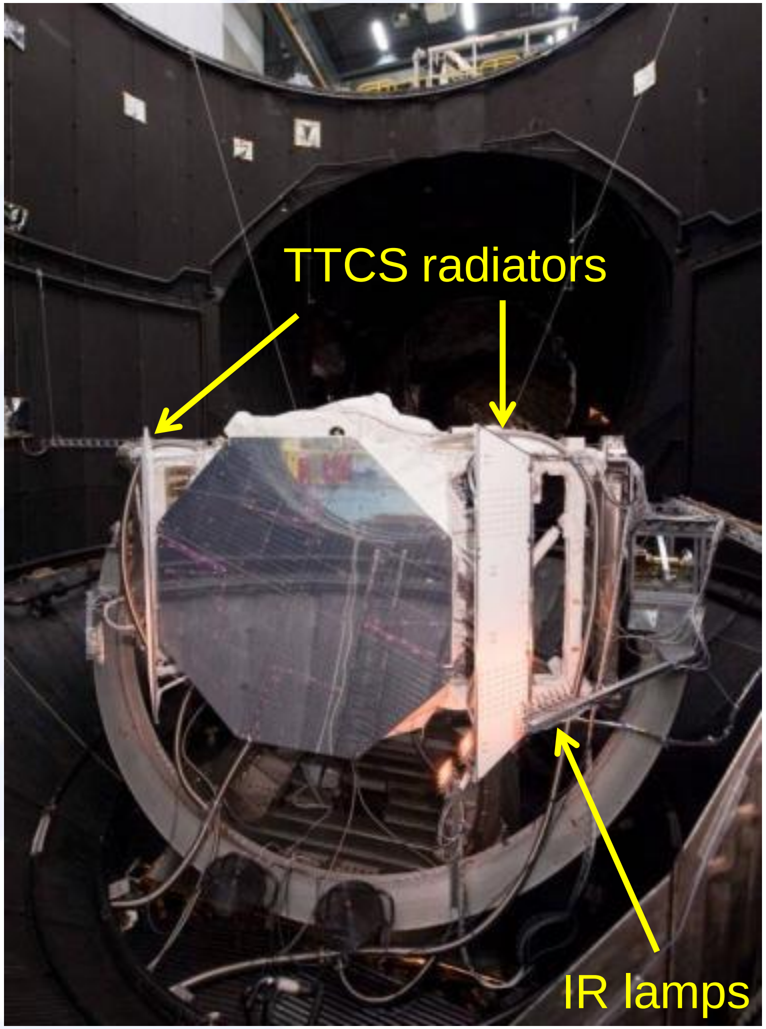
- In April 2010 the TTCS was tested in AMS in the Large Space Simulator (LSS) at ESA-Estec.
- The LSS is a large vacuum chamber with nitrogen cooled walls to simulate the cold of space.
- The TTCS was tested under different wall temperatures.
- Orbital variations were simulated with IR heaters facing the radiator panels.



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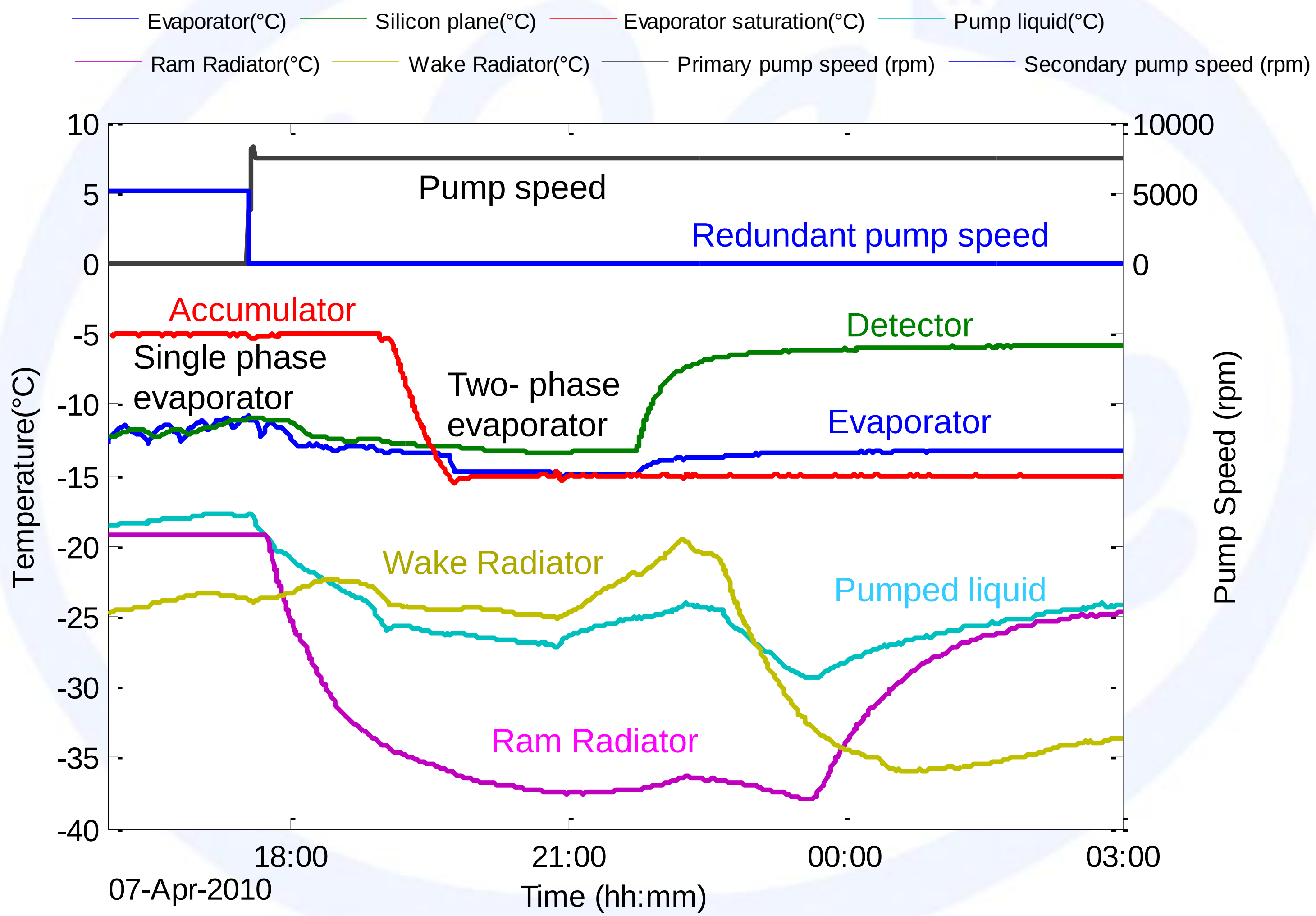
TTCS Test results from the LSS vacuum :
Transient performance



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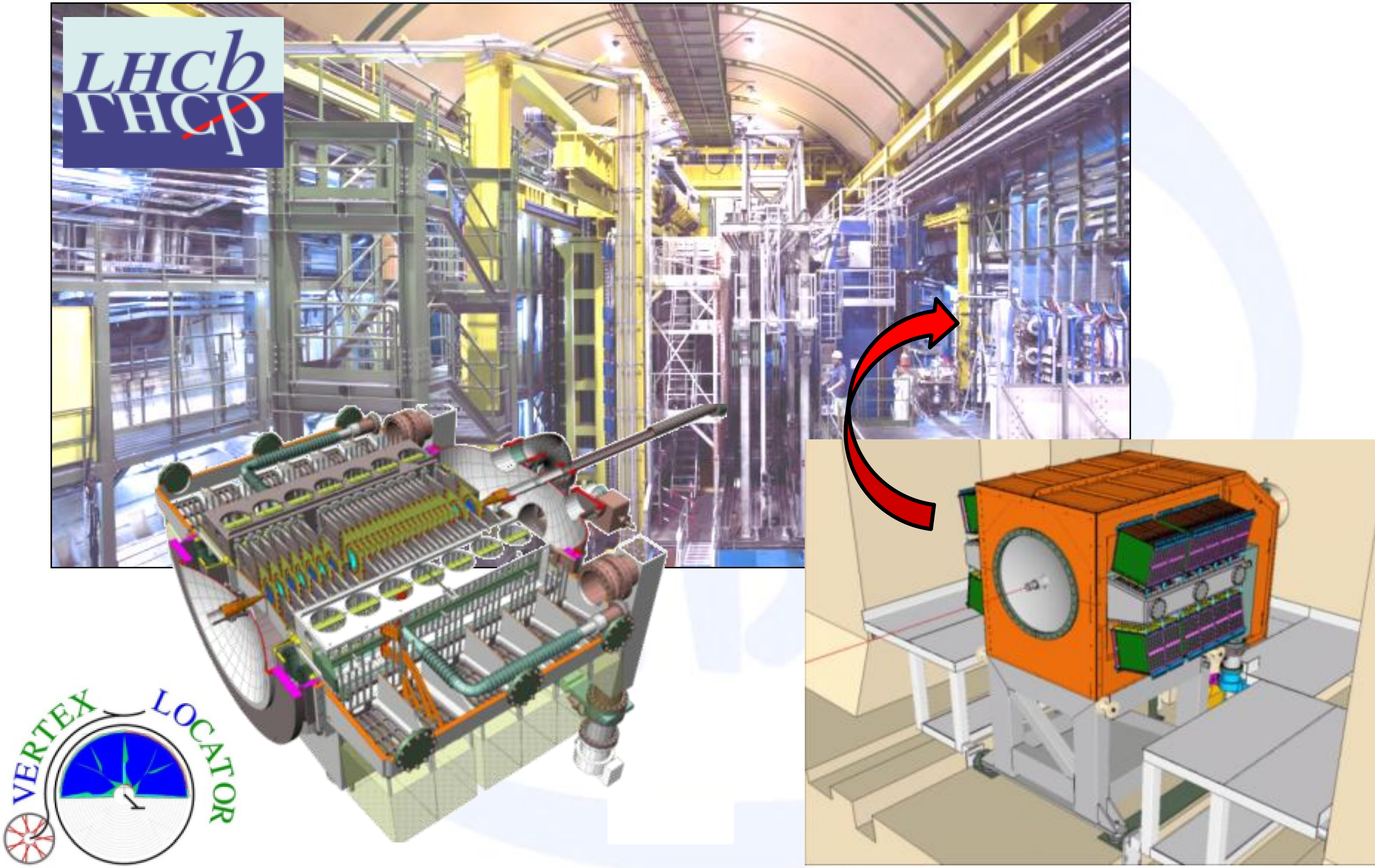
LHCb Detector



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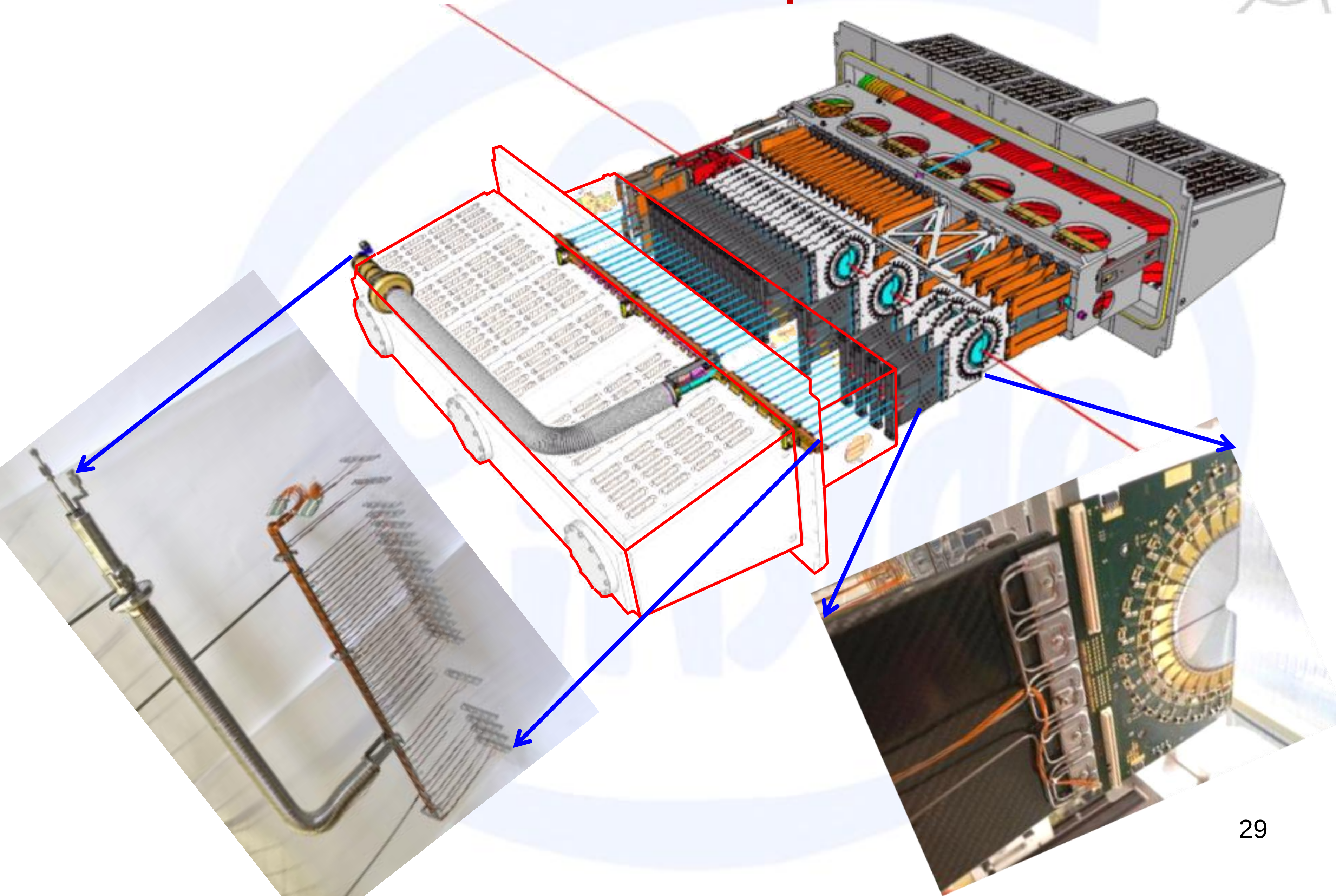
VTCS Evaporator



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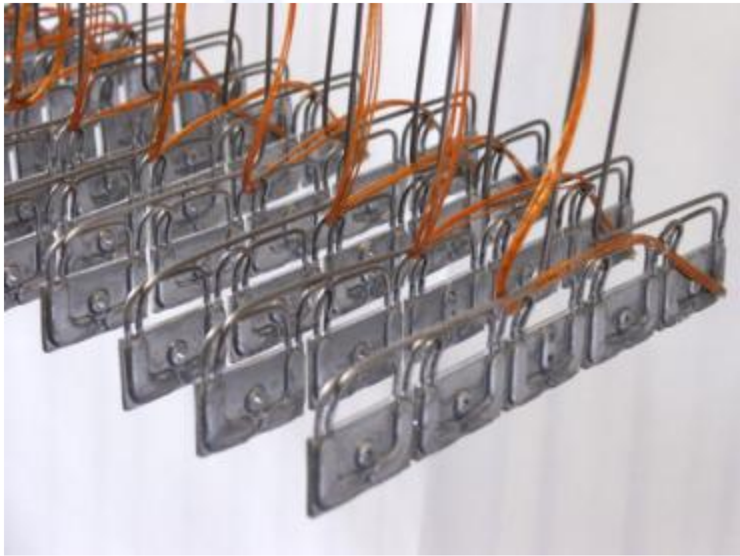
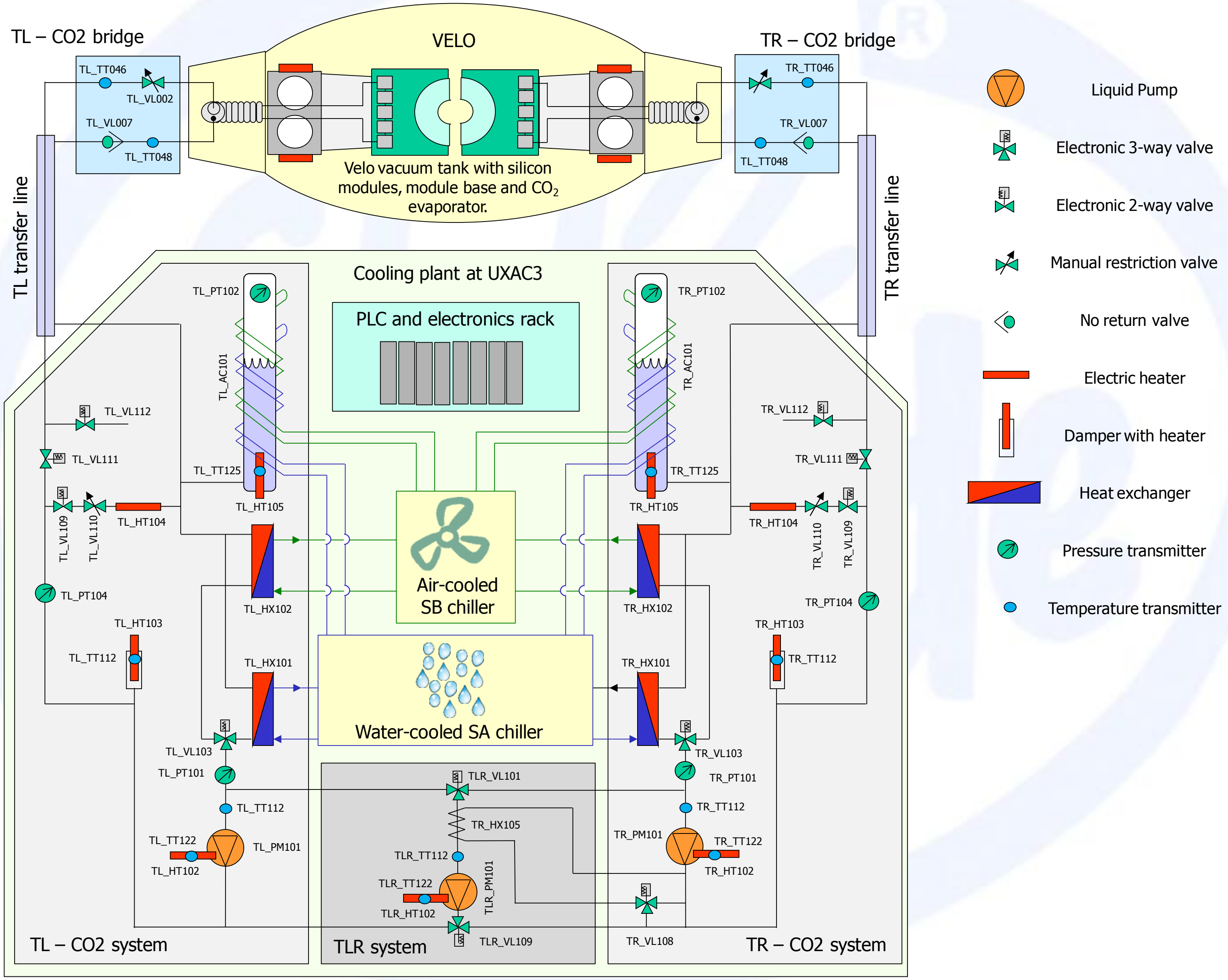
VTCS Evaporator



VTCS Schematics



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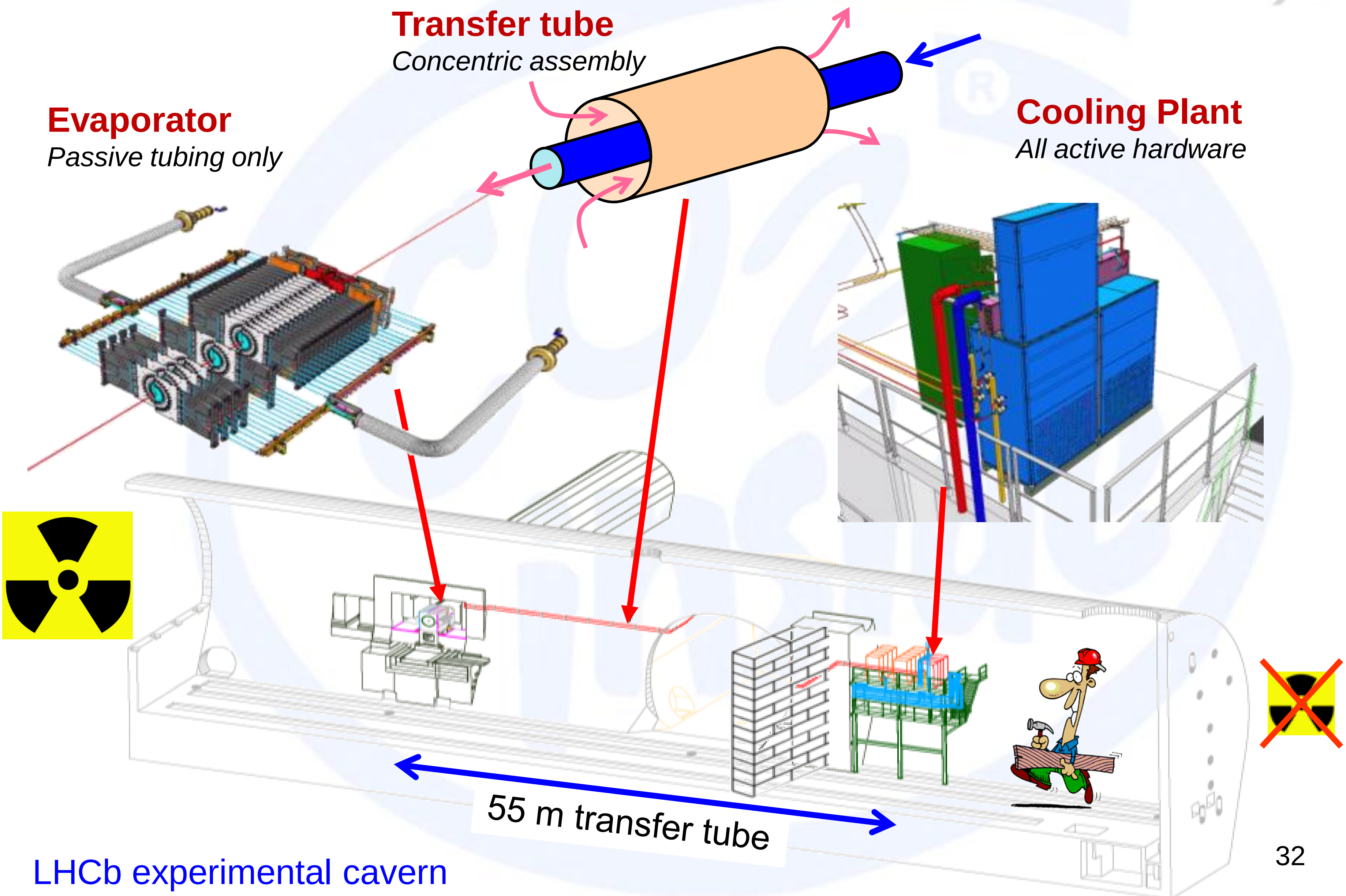
VTCS Locations



VTCS Cooling plant

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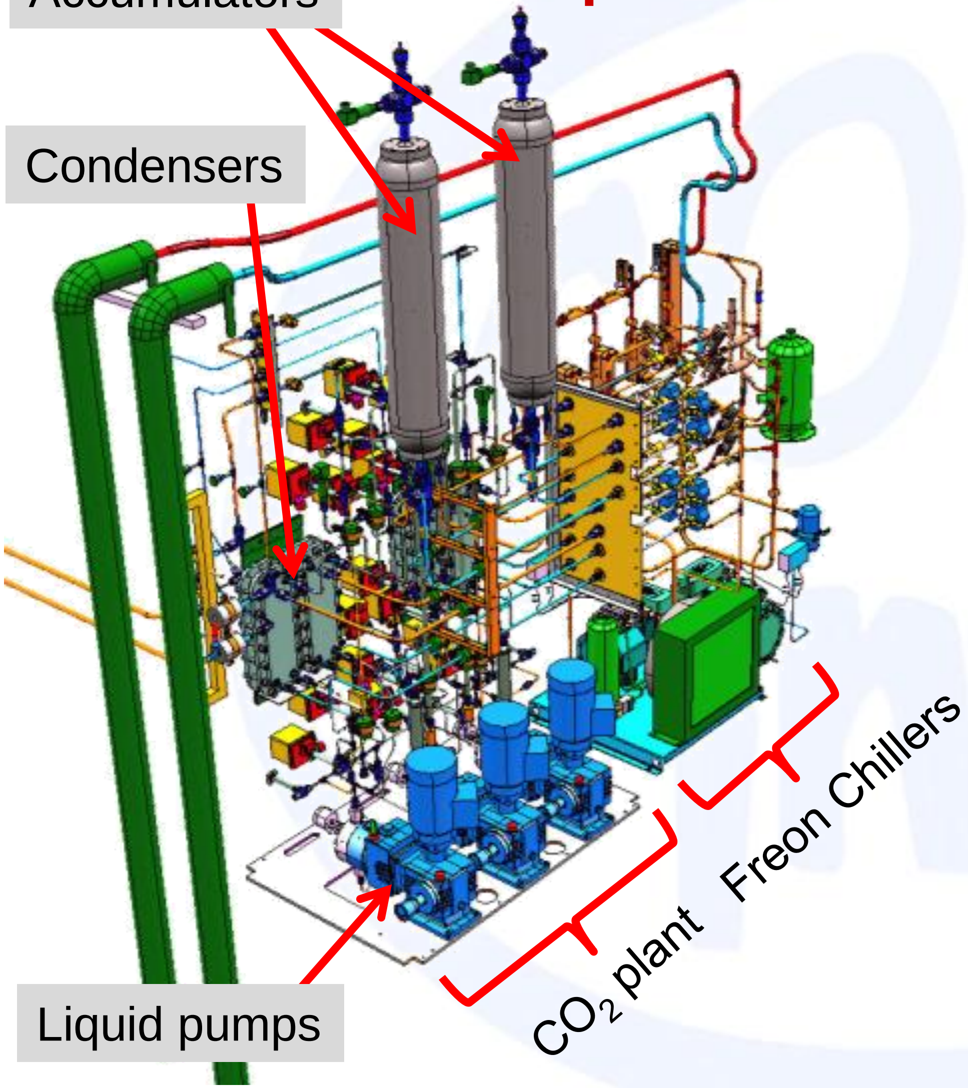

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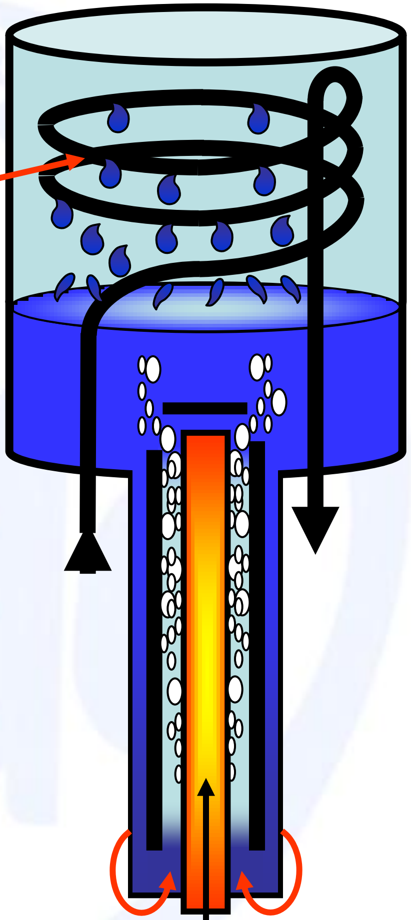
VTCS Accumulator

Cooling spiral for pressure decrease *(Condensation)*



Thermo siphon heater for pressure increase *(Evaporation)*

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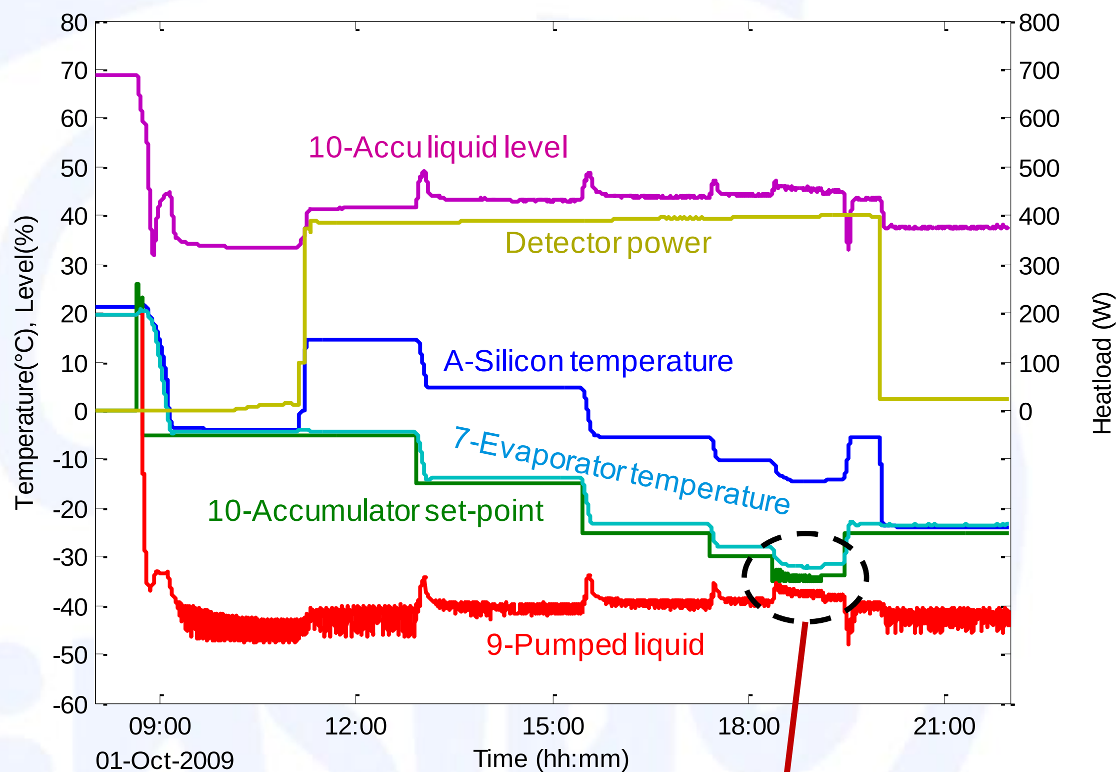
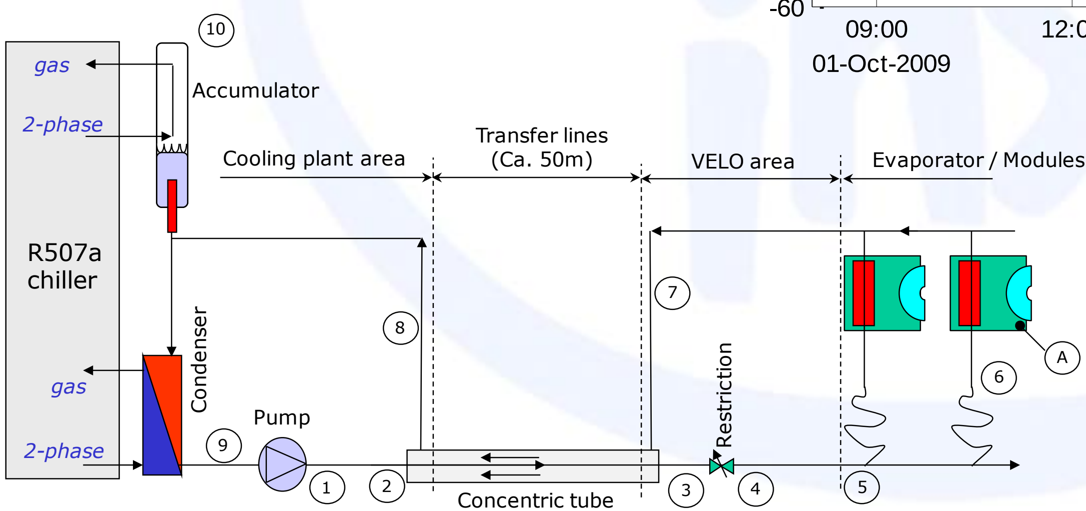
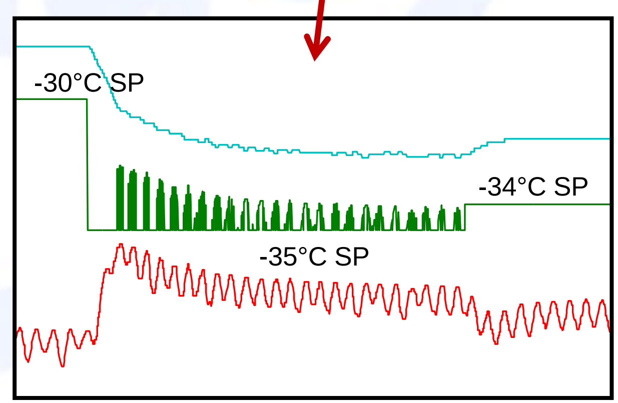
VTCS Commissioning results:
Start-up and operation

Start–up of the VTCS during October 2009 commissioning:

8:40 - Start-up with set-point -5°C
11:10 - Detector switched on
12:50 – Set point to -15°C
15:30 - Set point to -25°C
17:10 - Set point to -30°C
18:20 - Set point to -35°C (System Limit)
19:10 - Set point to -34°C
19:30 - Set point to -25°C
20:00 - Detector Switched off







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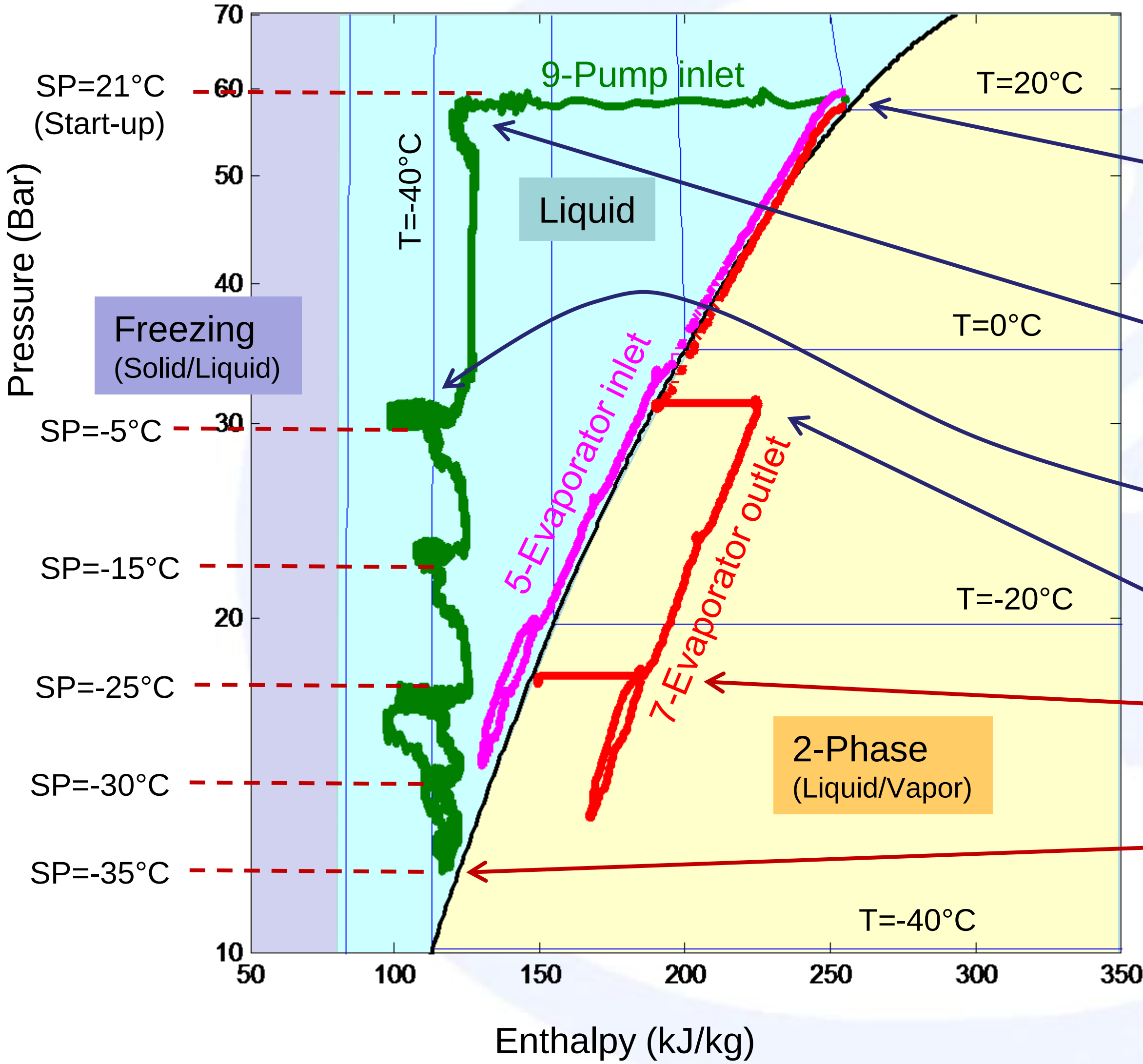
VTCS Commissioning results:

Start-up and operation in the PH-diagram



Start-up sequence

1. Increase pressure to make liquid.
2. Pump at high pressure and cool down in liquid mode
3. Lower pressure to desired set-point
4. Power-up detector

Switch-off detector

Lowest possible set-point (liquid approaches saturation line)

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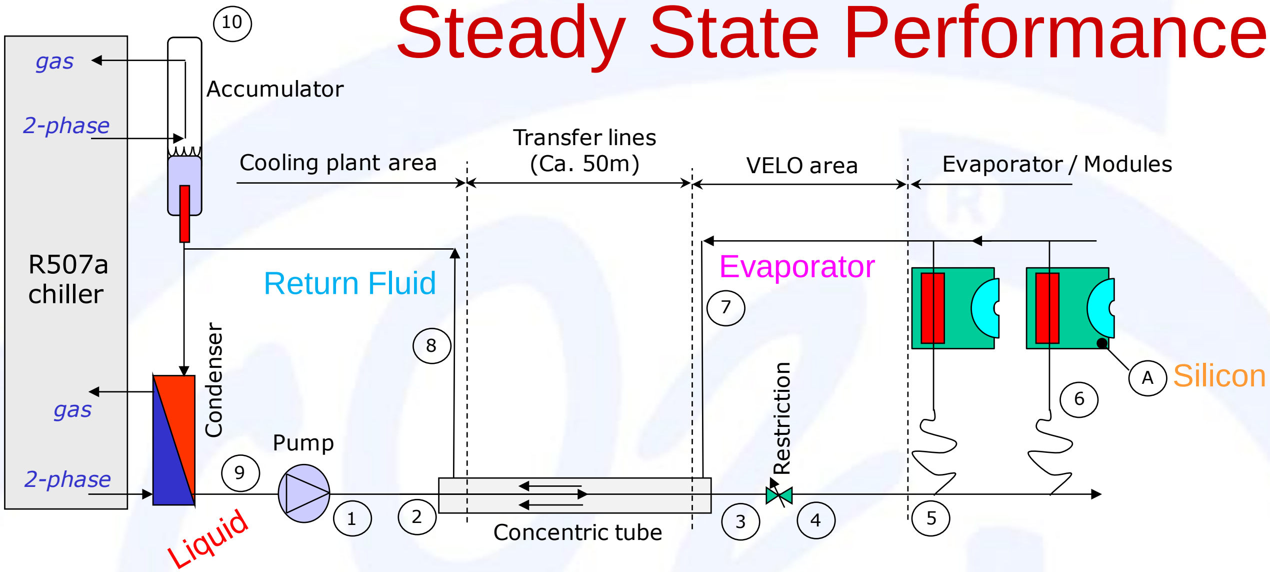
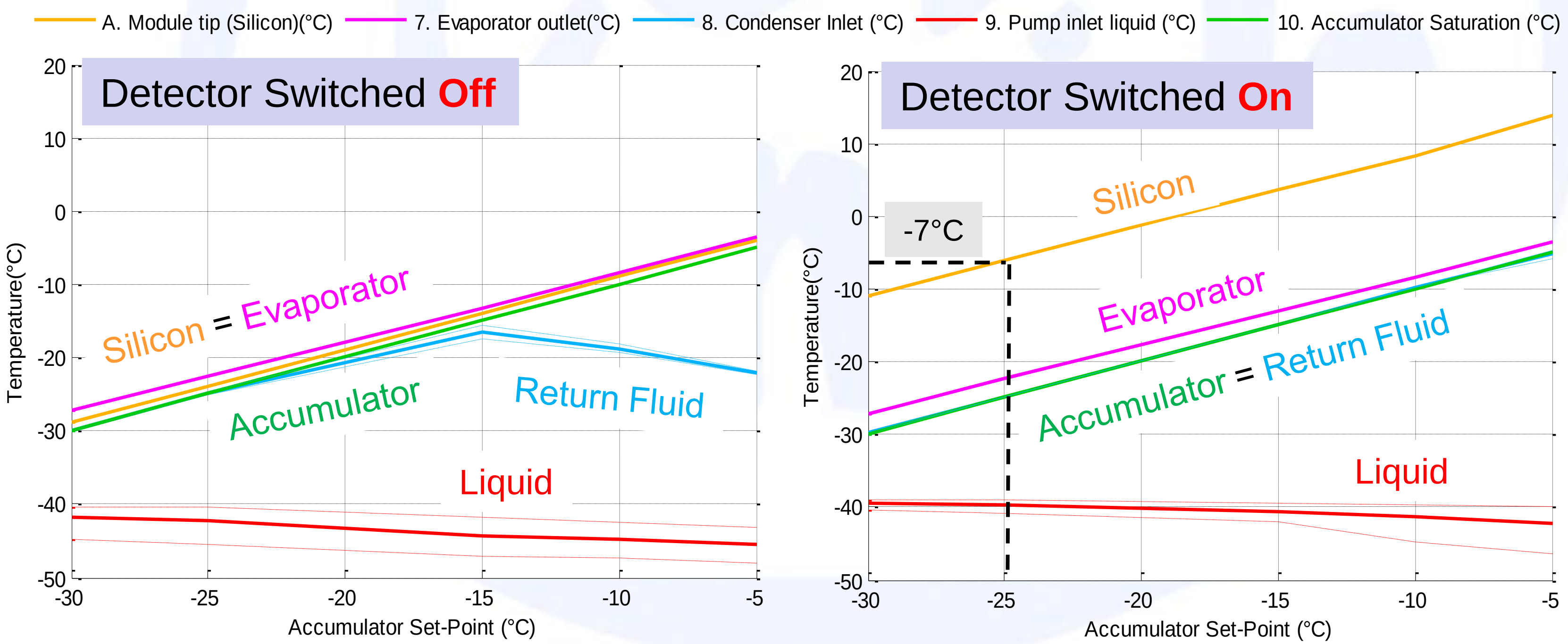
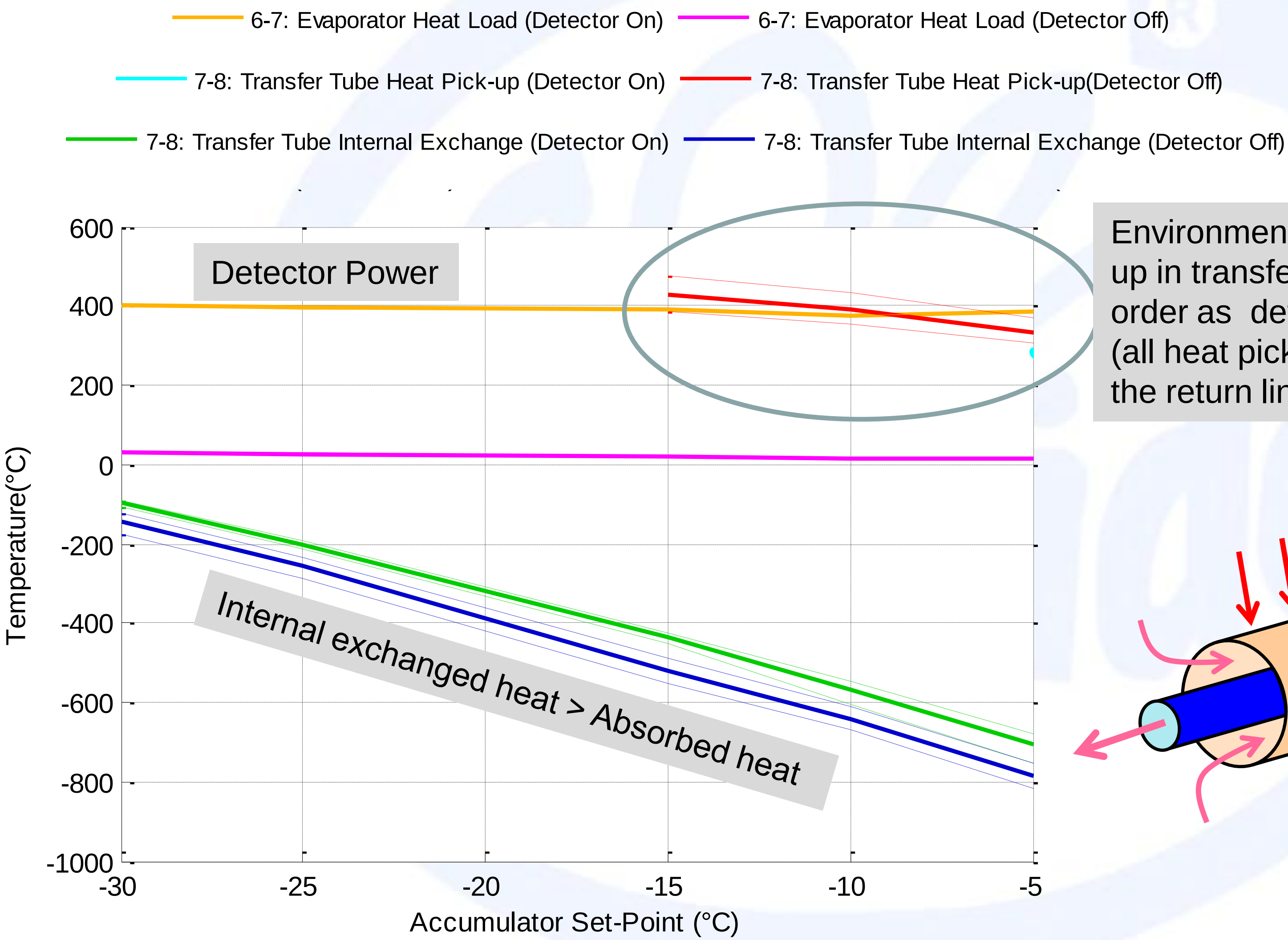
VTCS Commissioning results:
Steady State Performance

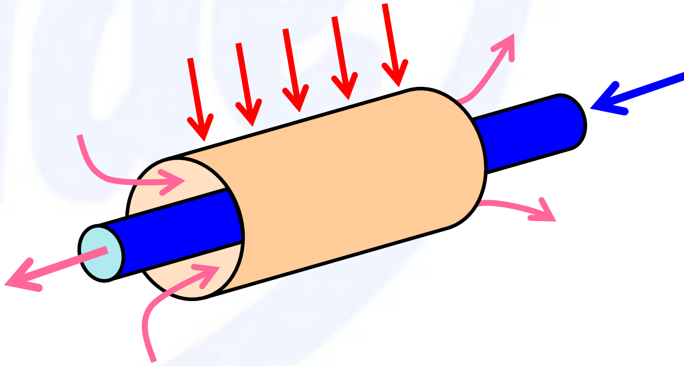




VTCS Commissioning results:
Heat loads



Environmental heat pick-up in transfer line same order as detector power. (all heat pick-up only in the return line)



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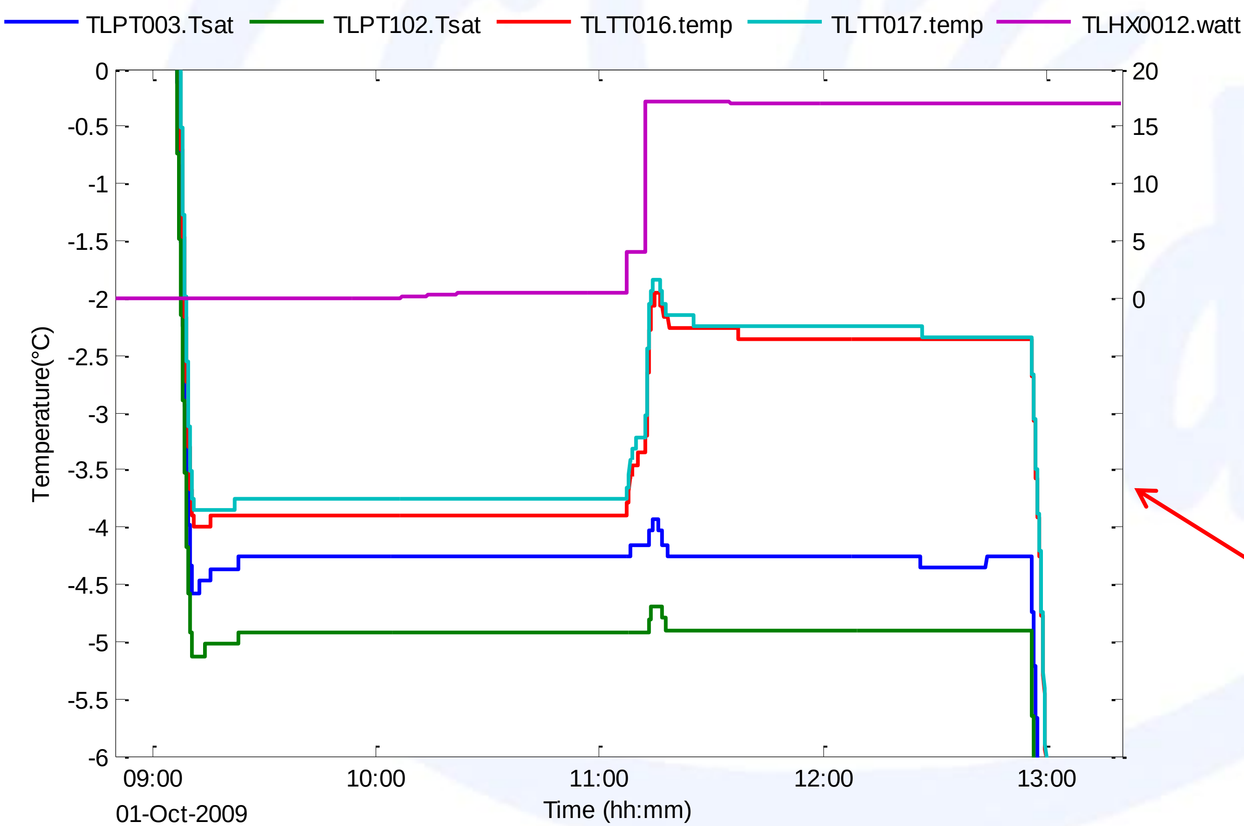
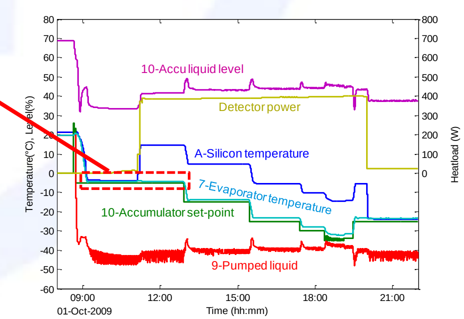
VTCS Commissioning results:
Thermal Stability

The 2PACL is a very high precision temperature control method.
The Velo evaporator is controlled from 60m distance.
The stability <0.1°C; reaction time immediate (pressure control)

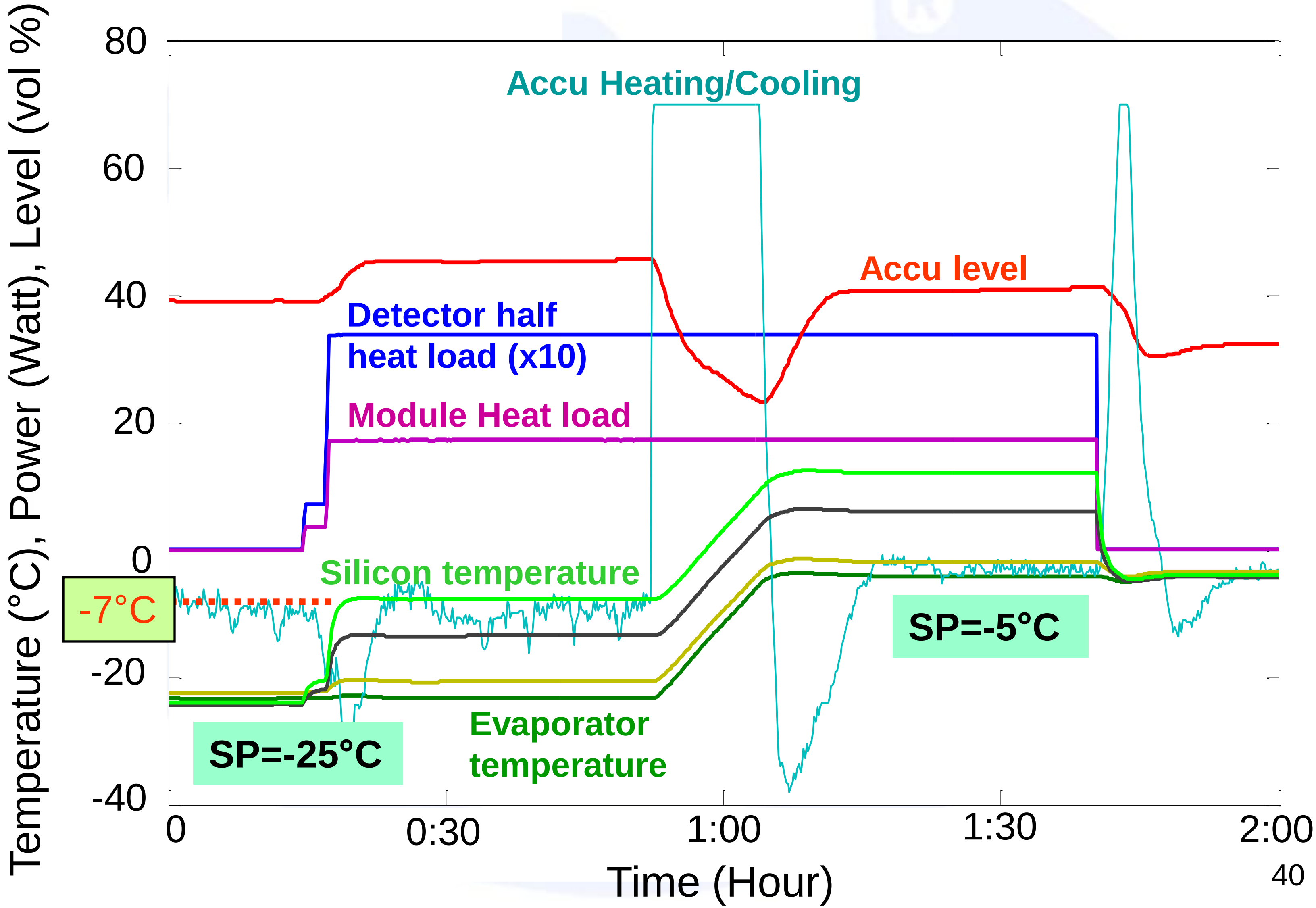
(Note: Chiller is fluctuating ~8°C, Temperature archiving 0.1°C)





Accumulator response

(powering up and down and a temperature change)



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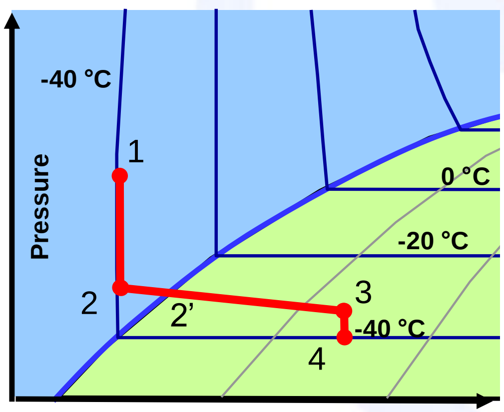
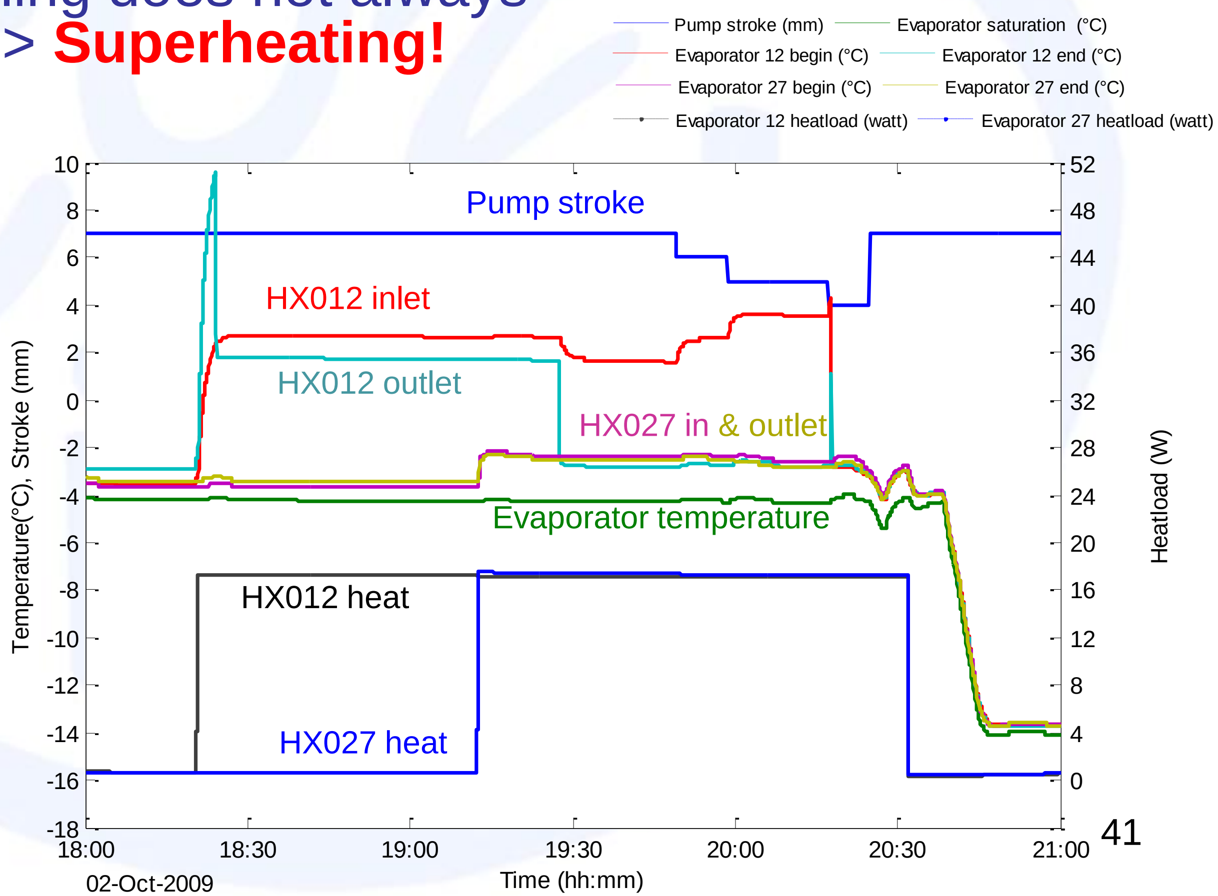
VTCS Commissioning results: Superheating

- An interesting phenomenon is observed, which needs attention for future systems. Sometimes the liquid is slightly sub cooled and boiling does not always start immediately => **Superheating!**





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Future CO_2 cooling projects

- CO_2 cooling is foreseen for the following experiments:
  - Near future:
    - Atlas Inner B-layer (IBL) detector: 2013 (1.5kW@-40ºC)
    - CMS-pixel detector: 2014 (9kW@-20ºC)
    - Belle-II pixel vertex detector: 2014 (1.2 kW@-35ºC
    - XFEL R&D: 2011 (1.2kW@-15ºC)
  - Atlas silicon detector upgrade
    - Atlas silicon detector upgrade: 2020 (180kW@-40ºC)
    - CMS silicon detector upgrade: 2020 (100kW@-25ºC)
    - International Linear Collider TPC: 20xx (2kW@+20ºC)
- Any more CO_2 cooling projects that we are not aware off? Please tell me.

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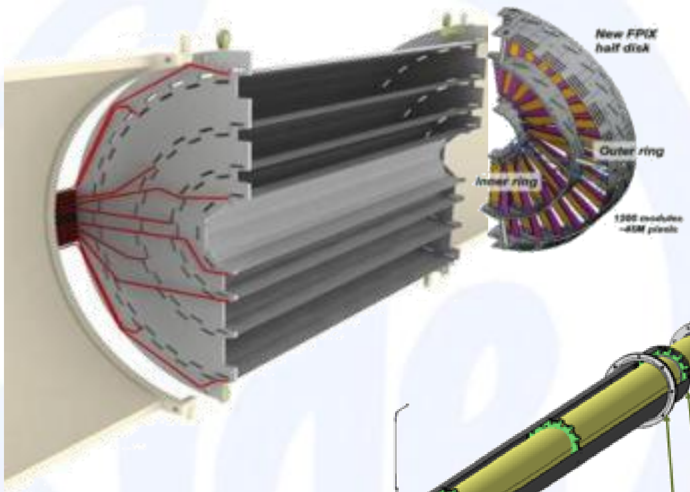
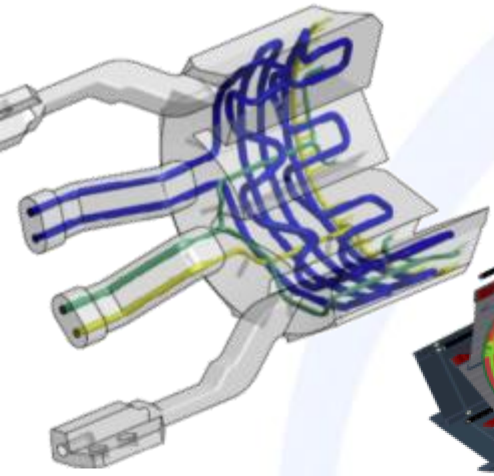
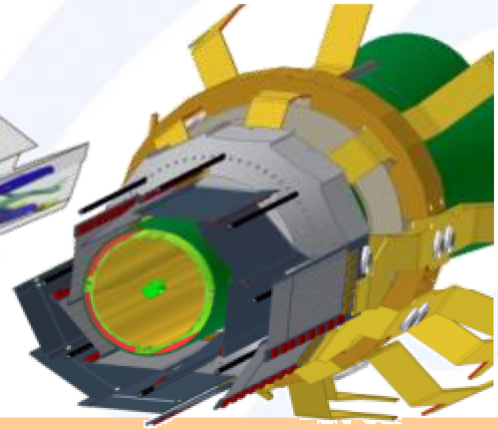
Near future CO_2 challenges

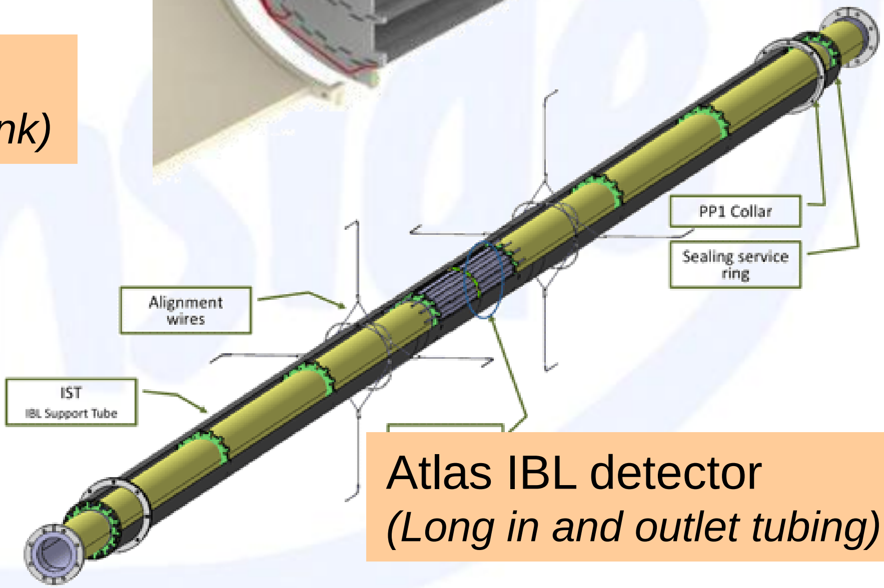
CMS pixel detector
(Extreme small diameter tubing @ small dP allowed)







Belle-II pixel detector
(Rapid Prototyping heat sink)



Atlas IBL detector
(Long in and outlet tubing)

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CO_2 research plants

- To support the research on CO_2 cooling plants are constructed all over the world. At CERN/Nikhef the following systems are operational:
  – Nikhef 2PACL system
  – CERN Cryolab 2PACL system
- Systems under development:
  – CERN-DT / Nikhef 1kW system
  – CERN-DT 100W system

Operational:
Nikhef CO_2 2PACL test system

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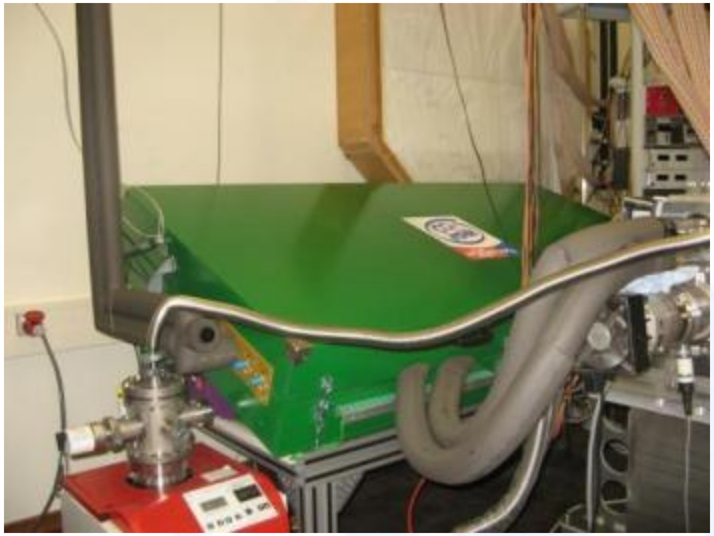

- Capacity 1kW
- Evaporative temperature range: -40ºC to +25ºC
- Universal test box for experiments
- Pre set-up temperature sensors and pressure sensors.
- Controllable power supply
- Automatic scanning connected experiments

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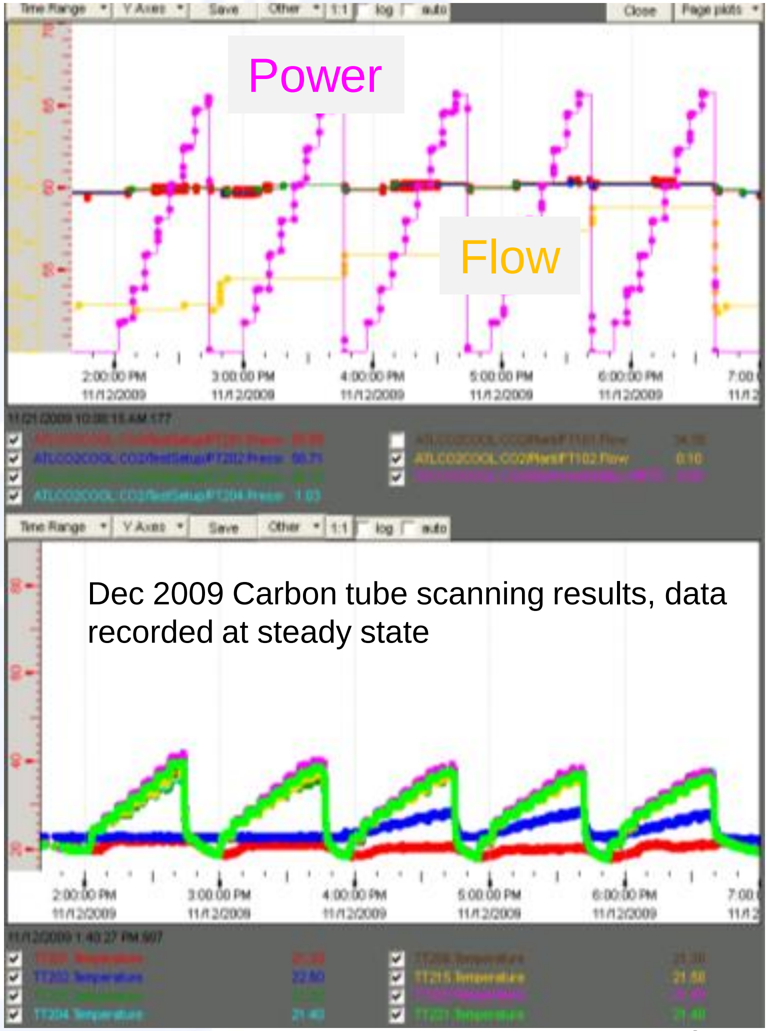
PVSS Automated scanning

- Easy test procedure. Steady state data recorded after each setting change.
- Able to change:
  - Outlet pressure (Evaporative Temperature),
  - Inlet enthalpy (Inlet temperature)
  - Mass flow
  - Power
- Several structures have been tested and analyzed.
- Tests fully protected to overheating.



Dec 2009 Carbon tube scanning results, data recorded at steady state

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Operational:
CERN-Cryolab 2PACL test system

- Capacity 0 W to 3kW
- 27 liter accumulator for large volume experiments.
- Temperature range +25ºC to -45ºC (To be verified in upcoming commissioning)
- Small (150 watt) and large experiment outlet.

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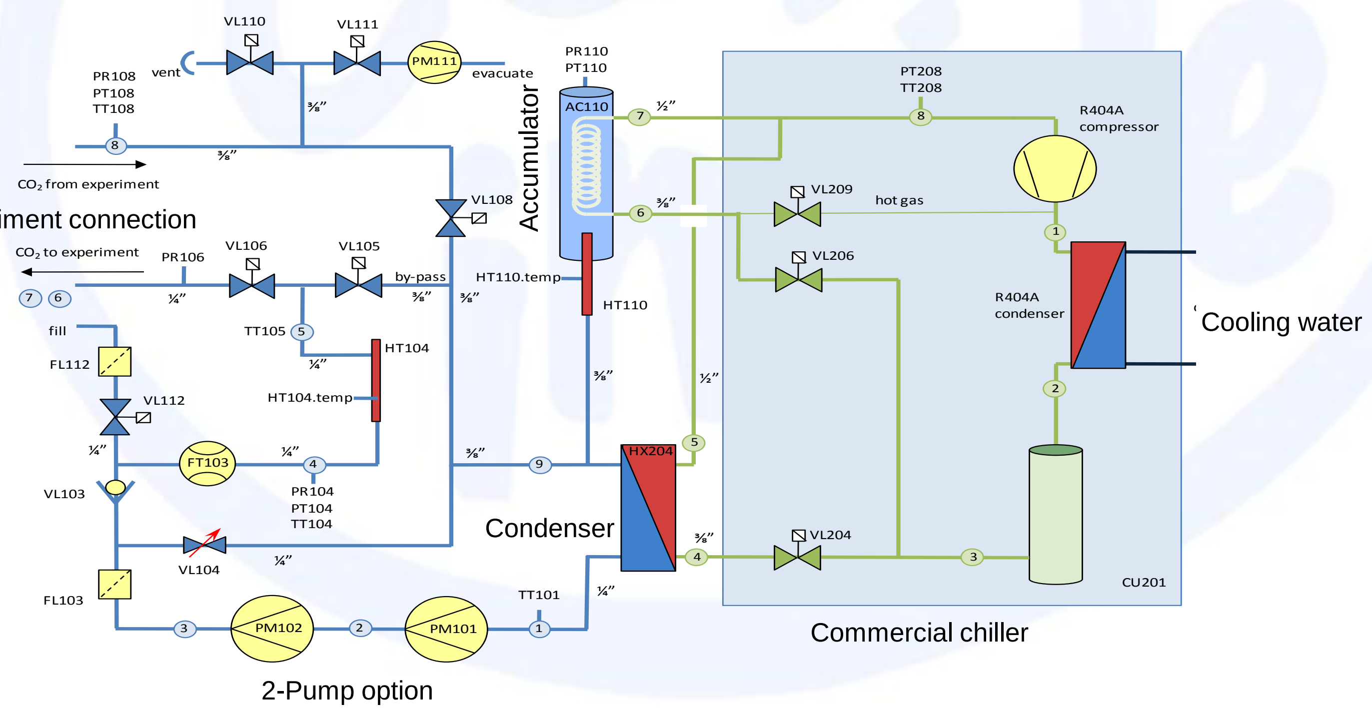
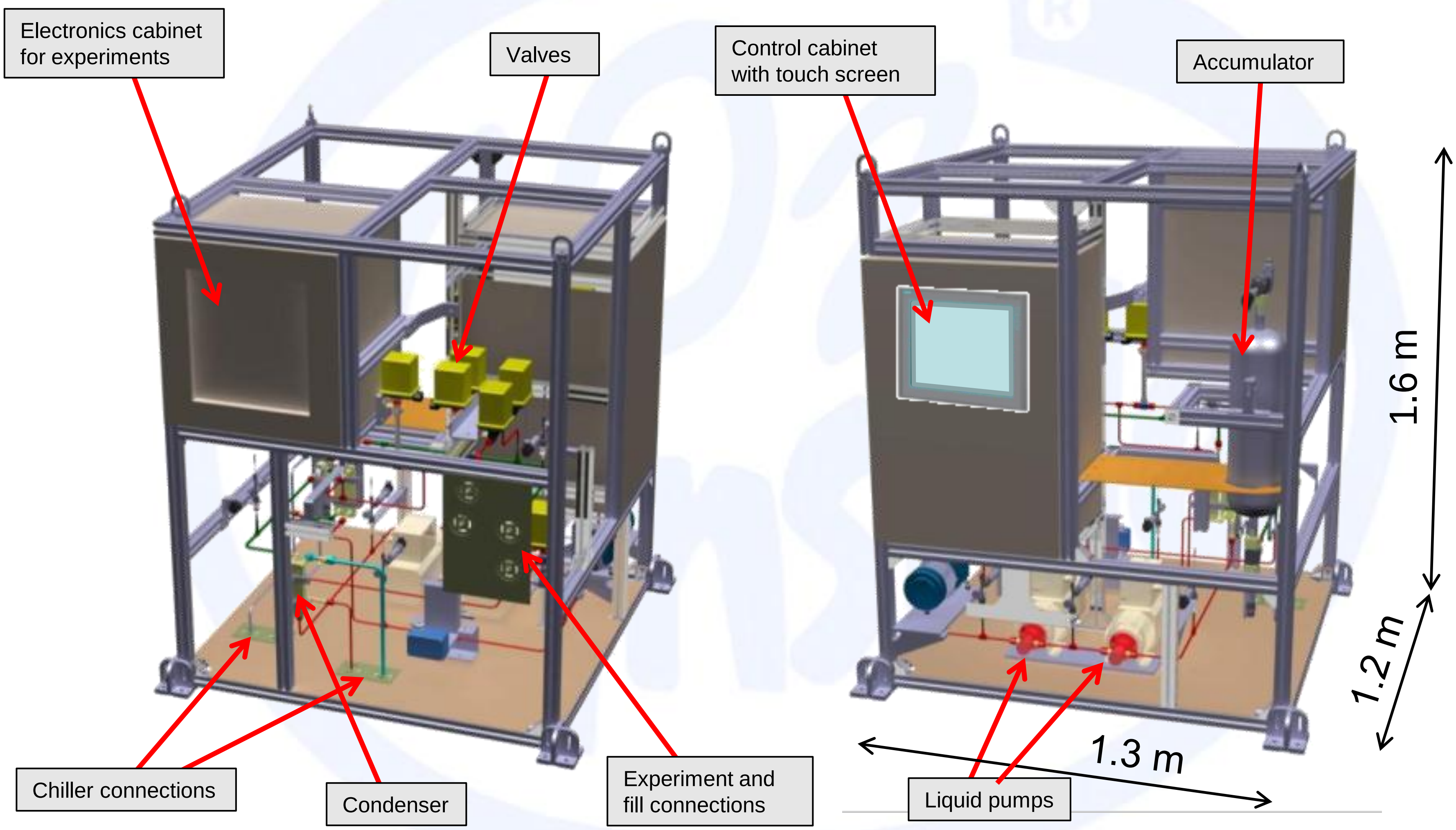
Under development:
CERN / Nikhef 1kW Unit Schematics.

- Common CERN-DT / Nikhef development.
- User friendly system, designed for series production to distribute among labs.
- Project can use additional collaborators.
  - If you want to invest money and man power in CO_2 cooling, please consider joining this collaboration and benefit from the 12 years of CO_2 cooling knowledge.
- Base design for future cooling plants (IBL, XFEL)



CO_2 Cooling unit mechanical design



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Conclusions

- CO_2 cooling is the future for particle physics cooling.
- CO_2 cooling seems also very beneficial for other scientific instrument cooling.
- 2PACL technology is interesting as a system principle (high stability, easy to operate).
- If you plan to invest money and manpower in CO_2 cooling, consider to join the CERN/NIKHEF 1kW unit development.