Cooling in HEP Vertex and Tracking Detectors

VERTEX 2011

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A question

- What is a High Energy Vertex or Tracking detector from a cooling system point of view?

An answer

- Based upon the CMS tracker:
  - A heat load of about 35 kW
  - Distributed along more than 4000 meter of tube with a diameter of about 2 to 3 mm
  - Often at temperatures of -20°C or even lower
  - With 50 meter long supply and return lines
- In General:
  - Very similar to this CMS example

The goals

- Reliable cooling with minimal temperature gradients
- The minimal amount of material inside the detector active volume
- Temperatures between -40^{o}C and +20^{o}C

Engineering issues

- Radiation
  - Limits choice of coolants and components
- Magnetic field
  - Limits choice of components
- System is often inaccessible during long periods of time, a year or years
  - Fewer (active) components is always better
  - Active components in accessible places
- Various solutions at LHC

ALICE - SPD

- 2-Phase system using C_4F_{10}
- Operating temperature +15°C
- Operating pressure 1.9 bara
  - Low pressure, requires larger return pipes, not
  - a problem when space is available
- Uses chilled water as primary cold source

ATLAS - SCT

- 2-Phase system using C_3F_8
- Operating temperature -25^{o}C
- Operating pressure 1.7 bara
  - Low pressure, requires larger return pipes
- Advantage: warm supply and return pipes
    - Disadvantage: this requires carefully controlled heaters
- Uses a C_3F_8 vapor compression cycle as primary cold source, not an industrial standard

CMS Tracker

- Single phase system using C_6F_{14}
  - Single phase requires larger supply/return lines, due to higher mass flow
- Operating temperature -20^{o}C
- Operating pressure 6 – 9 bara
- Simple design
- Uses industrial standard R507a chiller as primary cold source

LHCb - VELO

- 2-Phase system using CO_2
- Operating temperature -30^{o}C
- Operating pressure 14 bara
- System designed for maximum simplicity and robustness
- Uses industrial standard R507a chiller as primary cold source

Why is evaporative CO_2 cooling good for HEP detectors?

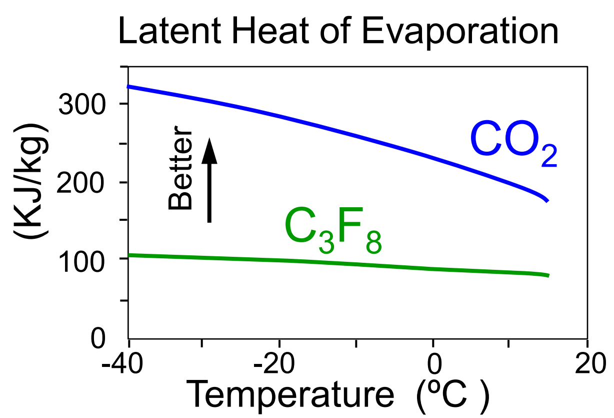
CO_2 allows small tubing

Why?

Large latent heat

Allow low flow

Low pressure drop



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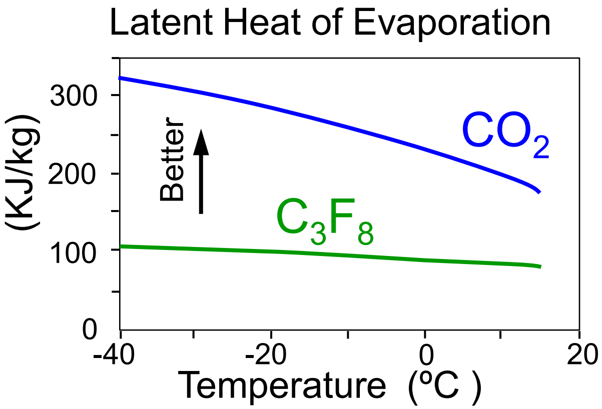
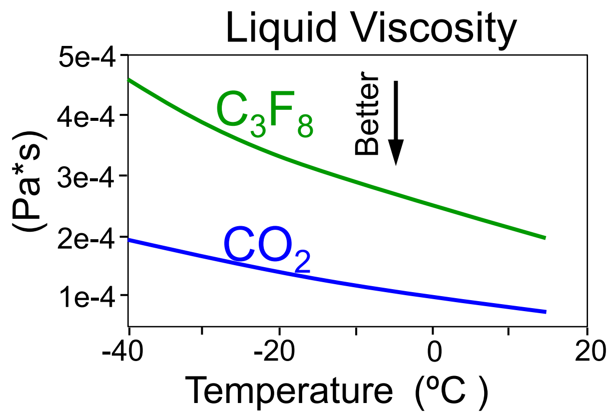




Why is evaporative CO_2 cooling good for HEP detectors?

CO_2 allows small tubing

Why?

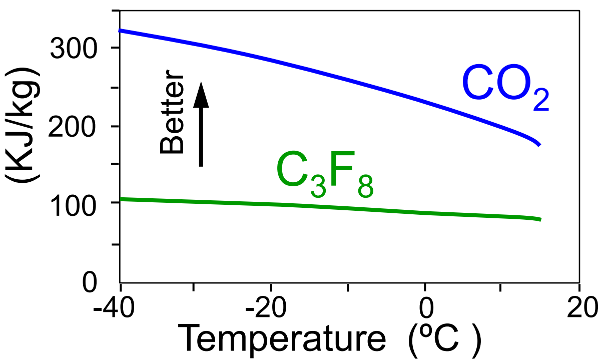
Large latent heat & Low viscosity & High pressure

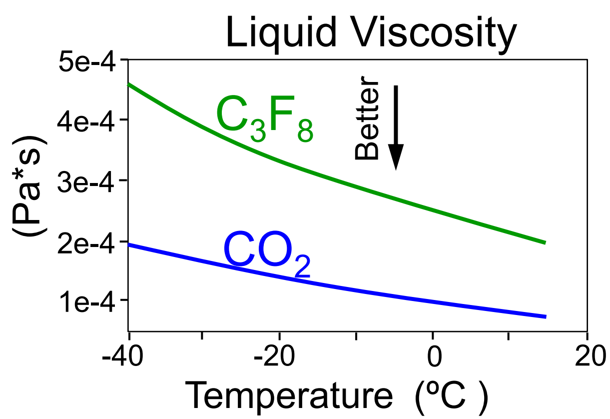
- Large latent heat → Allow low flow → Low pressure drop → Lower pressure drop
- Low viscosity → Low pressure drop → Lower pressure drop
- High pressure → Allow high pressure drop → Allow very small tubing
- Lower pressure drop → Allow very small tubing

Allow very small tubing

But with very high heat transfer capability!

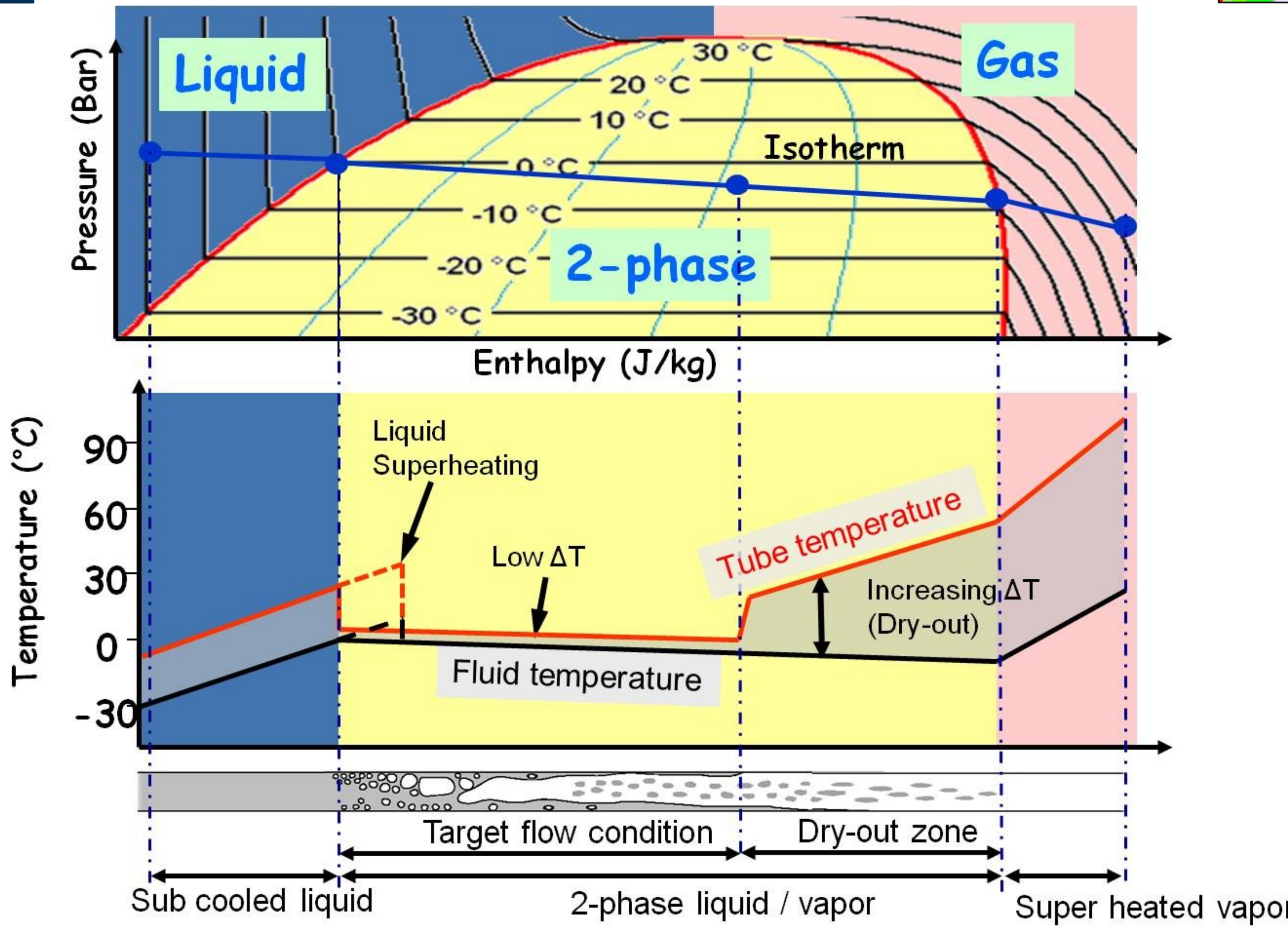
Latent Heat of Evaporation



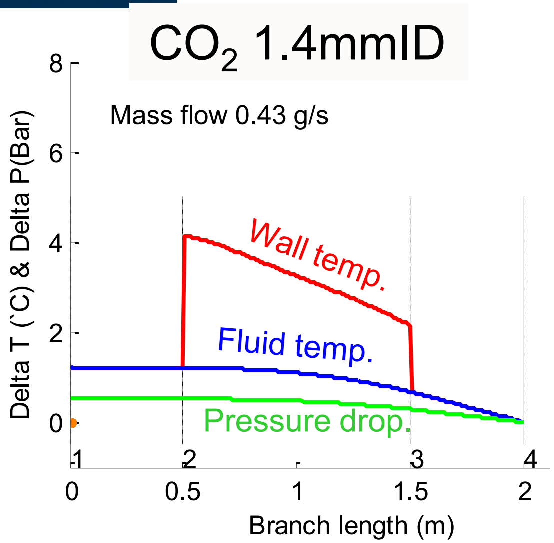


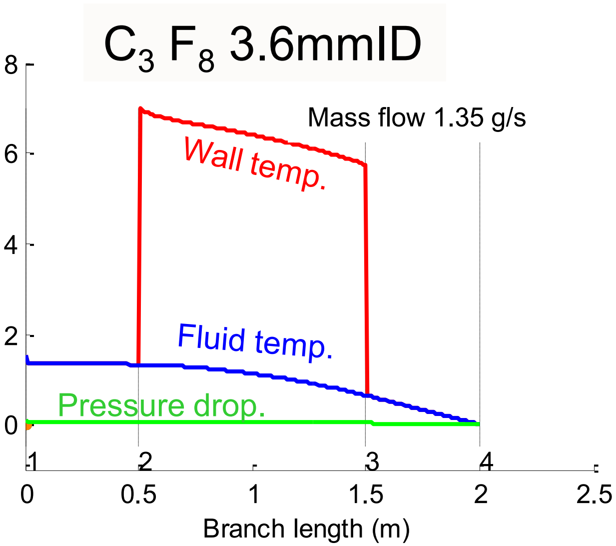
What happens inside a cooling tube?

Heating a flow from liquid to gas



Comparison between evaporative CO_2 and C_3F_8 in a cooling tube

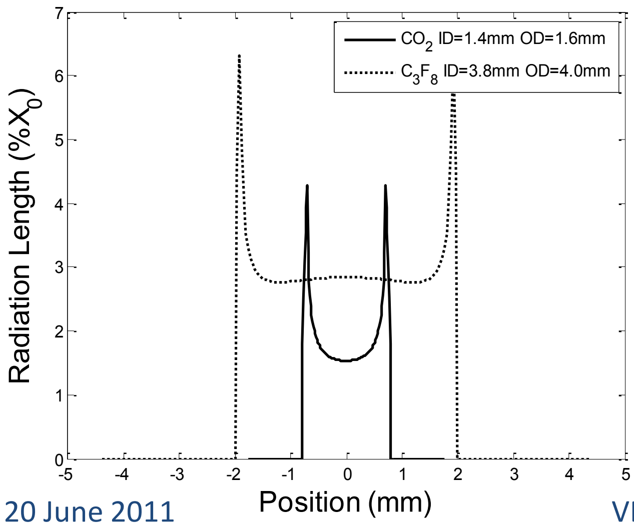


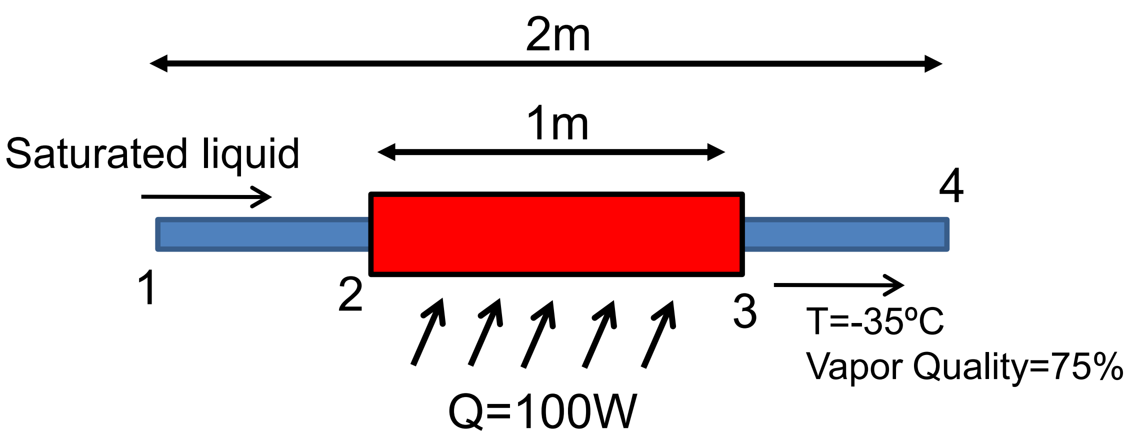


1.4mm (CO_2) and 3.6mm (C_3F_8) give more less the same temperature gradient along the pipe.

Despite of the smaller heat exchange area CO_2 has a lower temperature gradient to the fluid.

The gain in radiation length is significant





CO_2 and safety

CO_2 has a high pressure (10-100bar) but this does not have to be an increased safety issue.

Pressure Equipment Directive (PED):

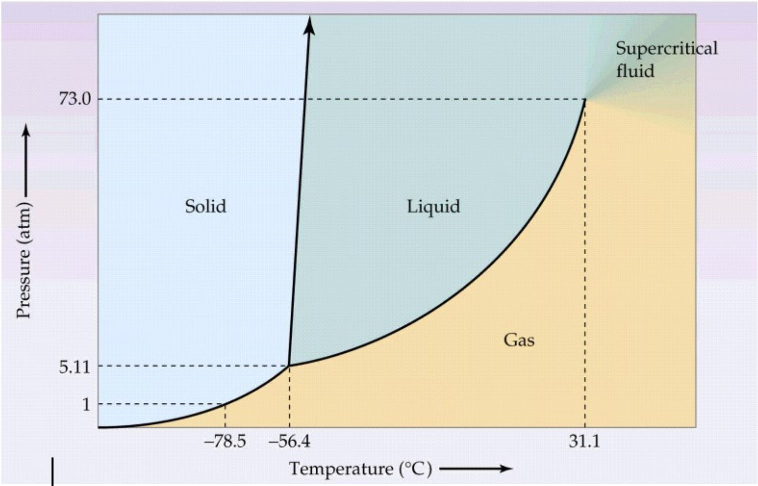
- Stored energy determines the safety class.
- Stored Energy = **Pressure x Volume**

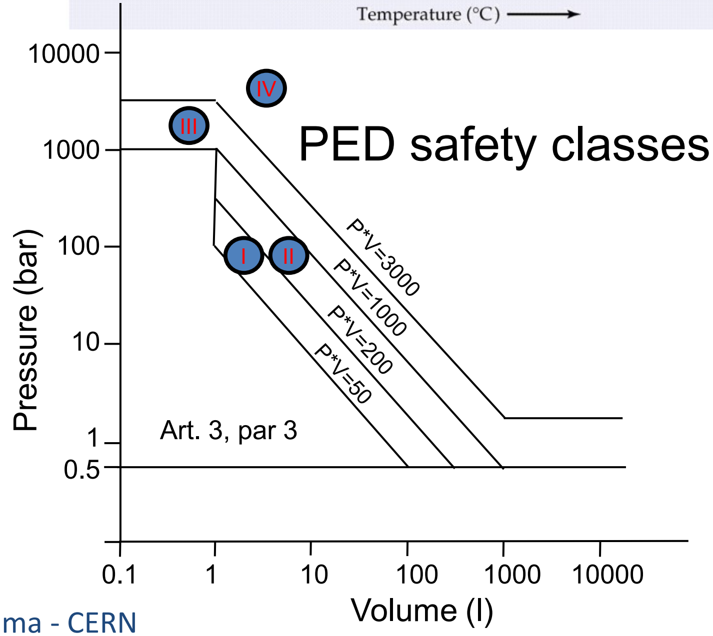
CO_2 is environmental friendly, non-toxic and cheap.

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

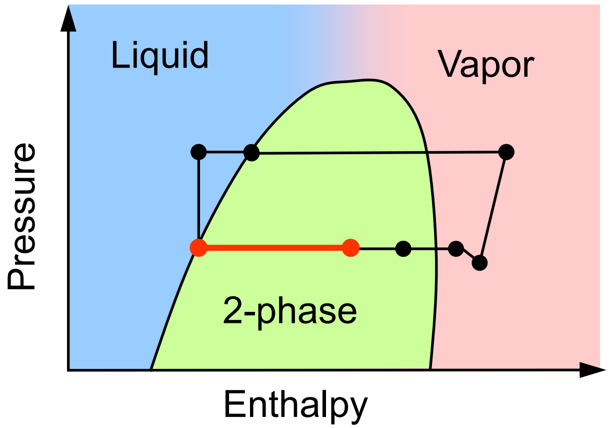
CO_2 does not exist as liquid in atmospheric conditions. It is released as -78ºC solid (Like a fire extinguisher). => Cold burn risk.

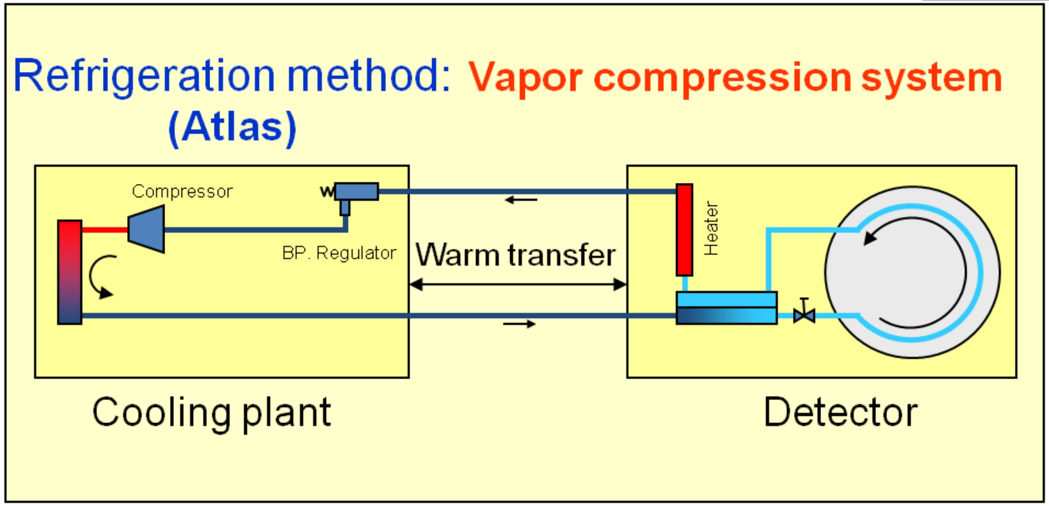
	ID	Design Pressure	Stored energy
CO_2	1.4mm	100 bar	15.4 J/m
C_3F_8	3.6mm	15 bar	15.3 J/m

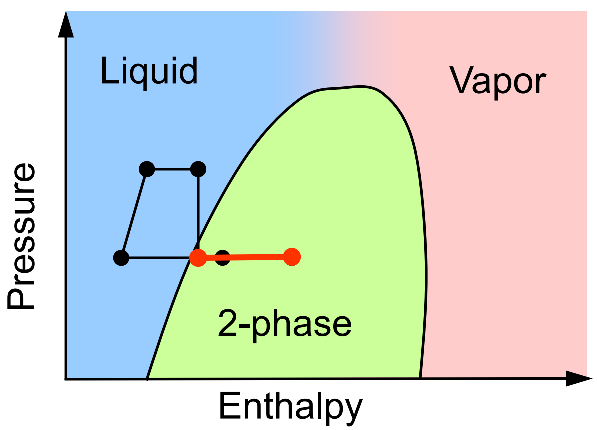


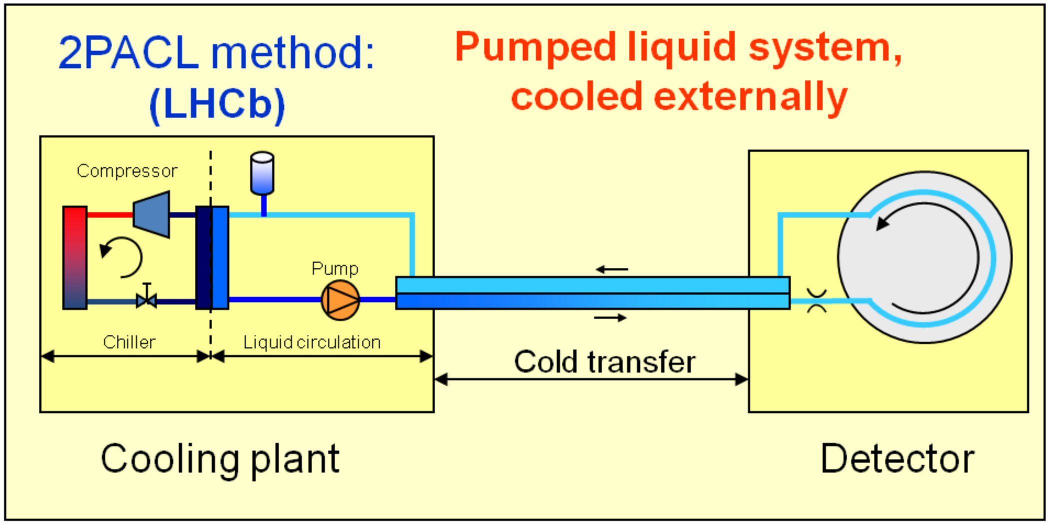


How to evaporate liquid CO_2 in a detector?





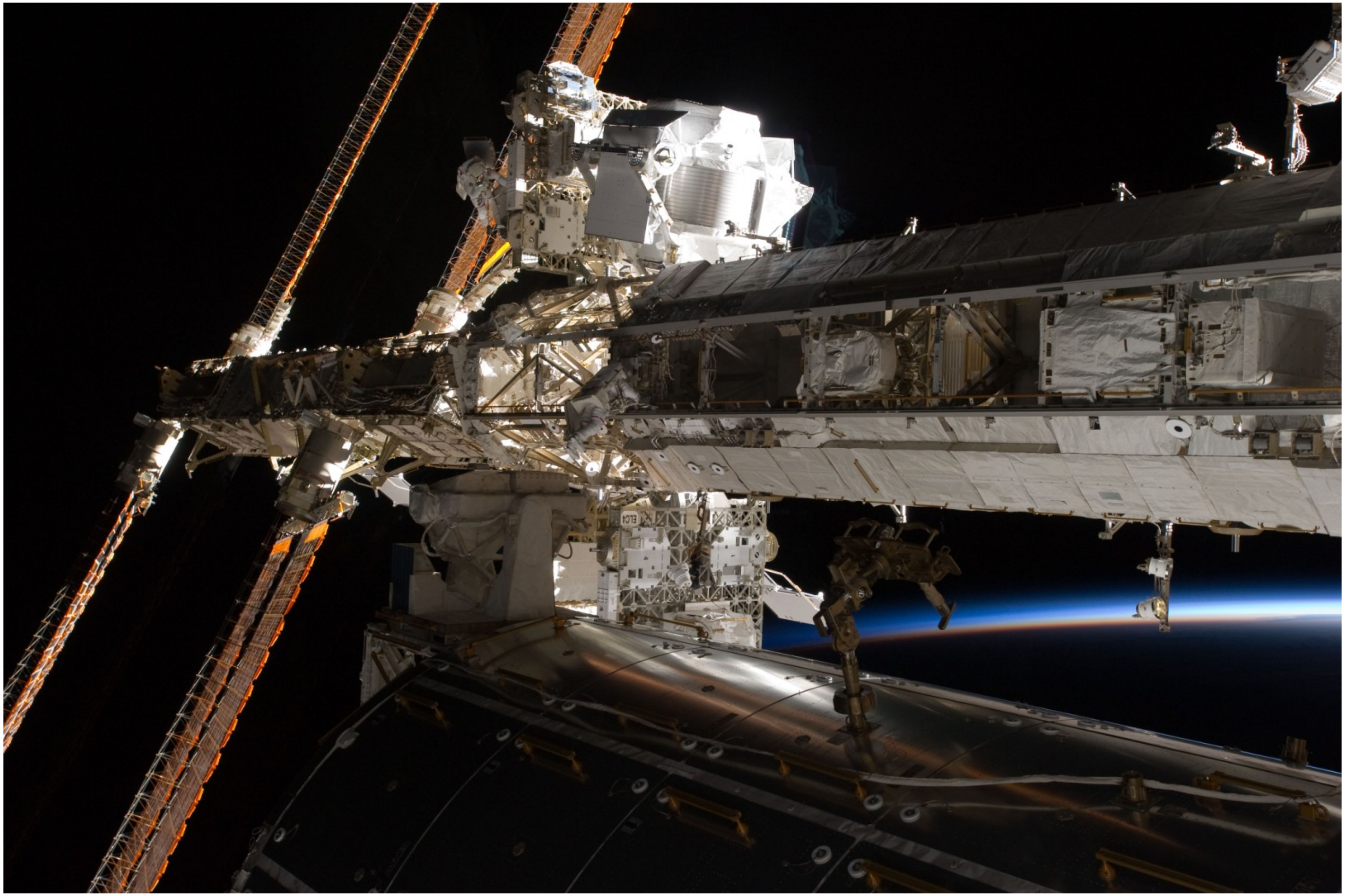




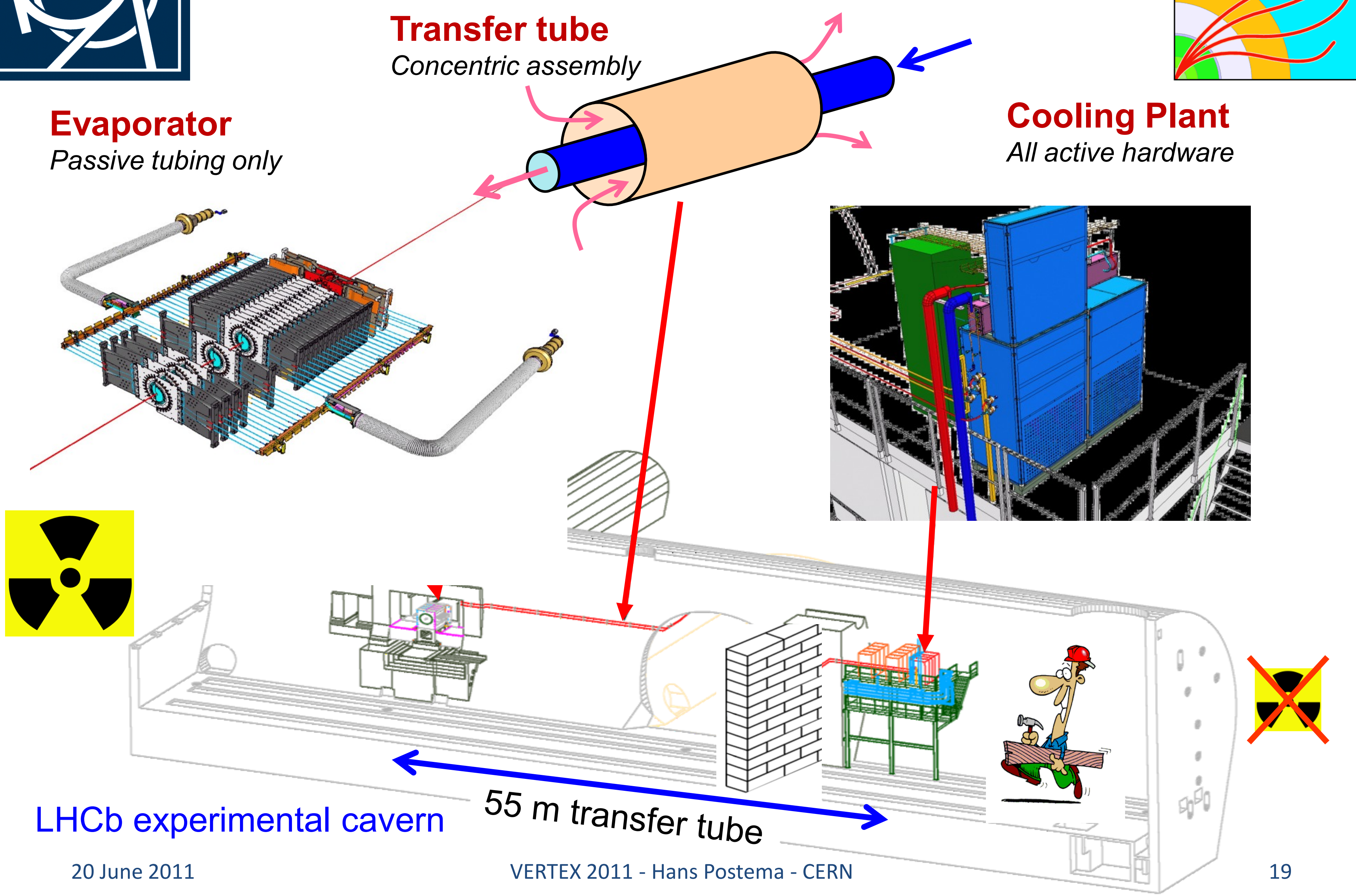
CO_2 systems in HEP

- 2 CO_2 cooling systems have been developed for HEP detectors so far.
  - AMS-TTCS (Tracker Thermal Control System)
    - Q= 150 watt
    - T=+15°C to -20°C
    - Operating in space since 20 May 2011
  - LHCb-VTCS (Velo Thermal Control System)
    - Q=1500 Watt (2 parallel systems of 750 W)
    - T= +8°C to -30°C
    - Operating at -30°C since 3 years!
- Both systems are based on the **2PACL** principle invented at NIKHEF

AMS on the ISS



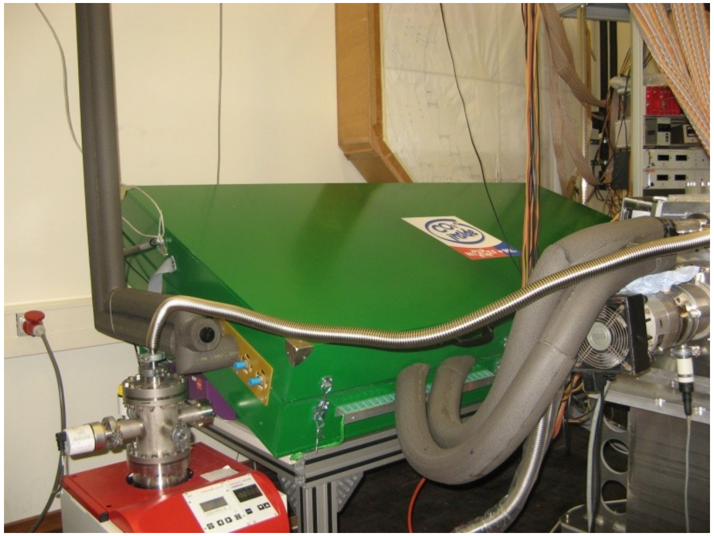
VTCS Locations



Ongoing CO_2 projects

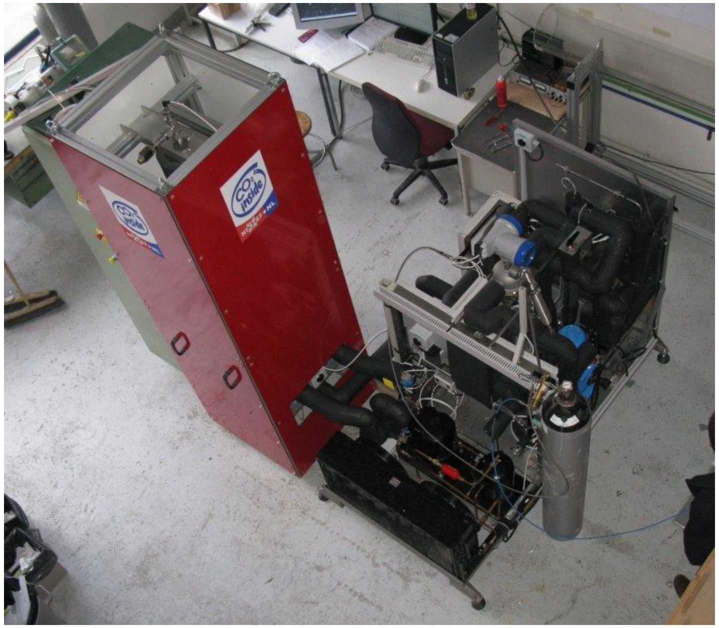
- CO_2 cooling development for upgrade detectors:
  - Atlas IBL
  - CMS-pixel replacement
  - Atlas and CMS upgrade silicon detector
  - Belle-2 detector at KEK
- Maintain CO_2 cooling platforms for testing. At CERN/Nikhef the following systems are operational and are open to external customers:
  - Nikhef 2PACL system
  - CERN Cryolab 2PACL system
  - CERN B187 test setup
- Test systems under development:
  - CERN-DT / Nikhef 1kW system
  - CERN-DT 100W system

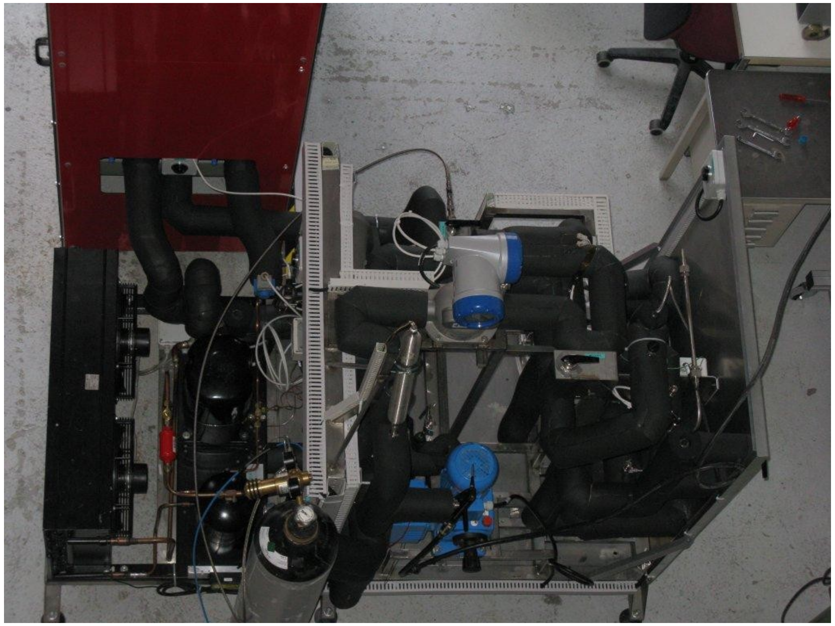
Operational: Nikhef CO_2 2PACL test system



- 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

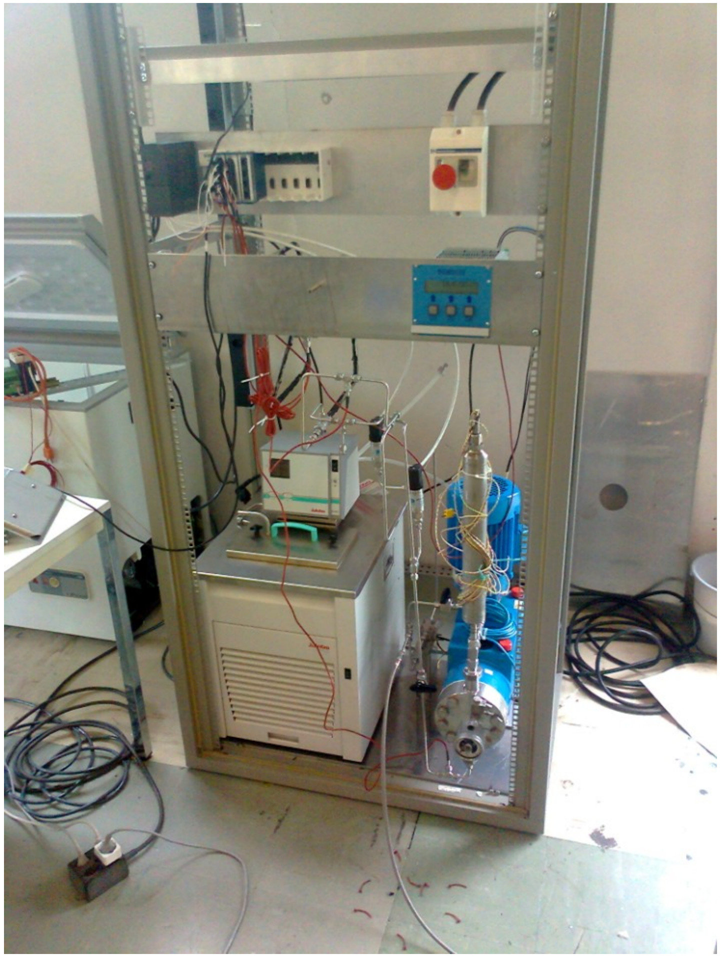
Operational:
CERN-Cryolab 2PACL test system

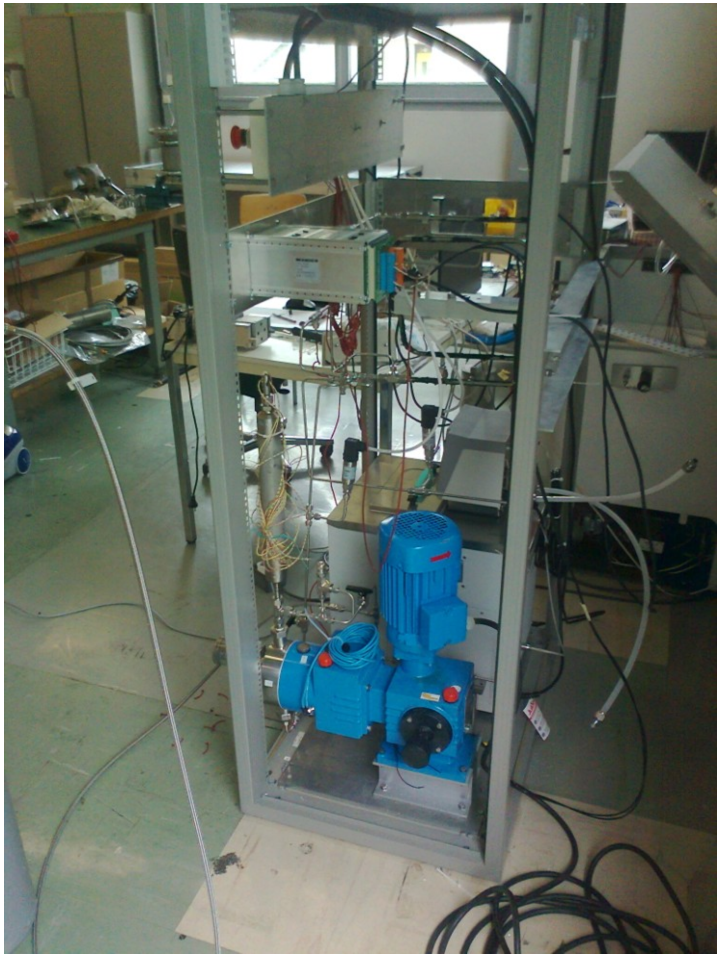




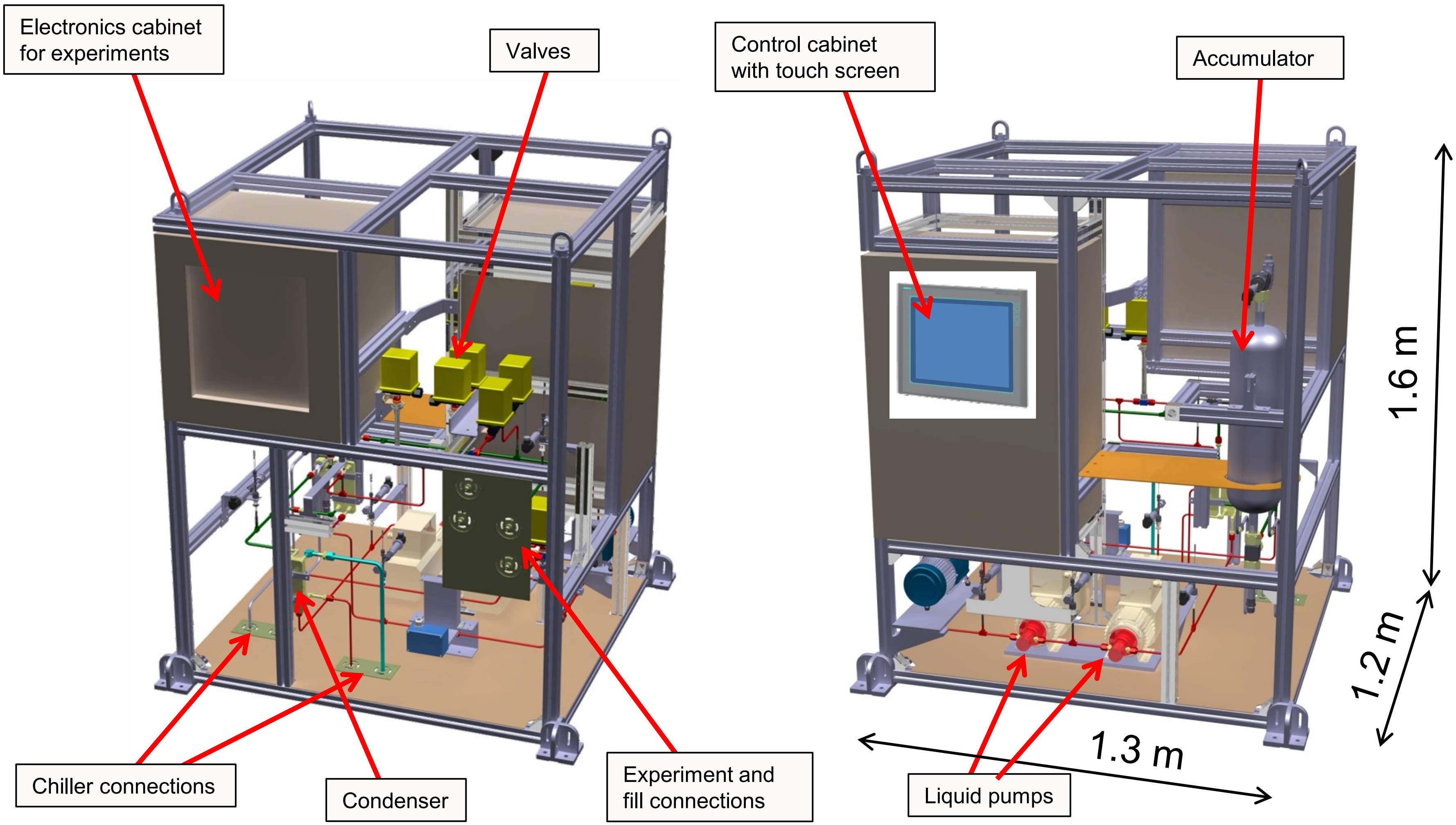
- Capacity 0 W to 2kW
- 27 Liter accumulator for large volume experiments.
- Temperature range +25°C to -40°C
- Small (150 Watt) and large experiment outlet.

Setup in Building 187





1kW - CO_2 Cooling unit mechanical design



1kW CO_2 unit components

CE/PED certified accumulator arrived at CERN

Construction at Nikhef has started

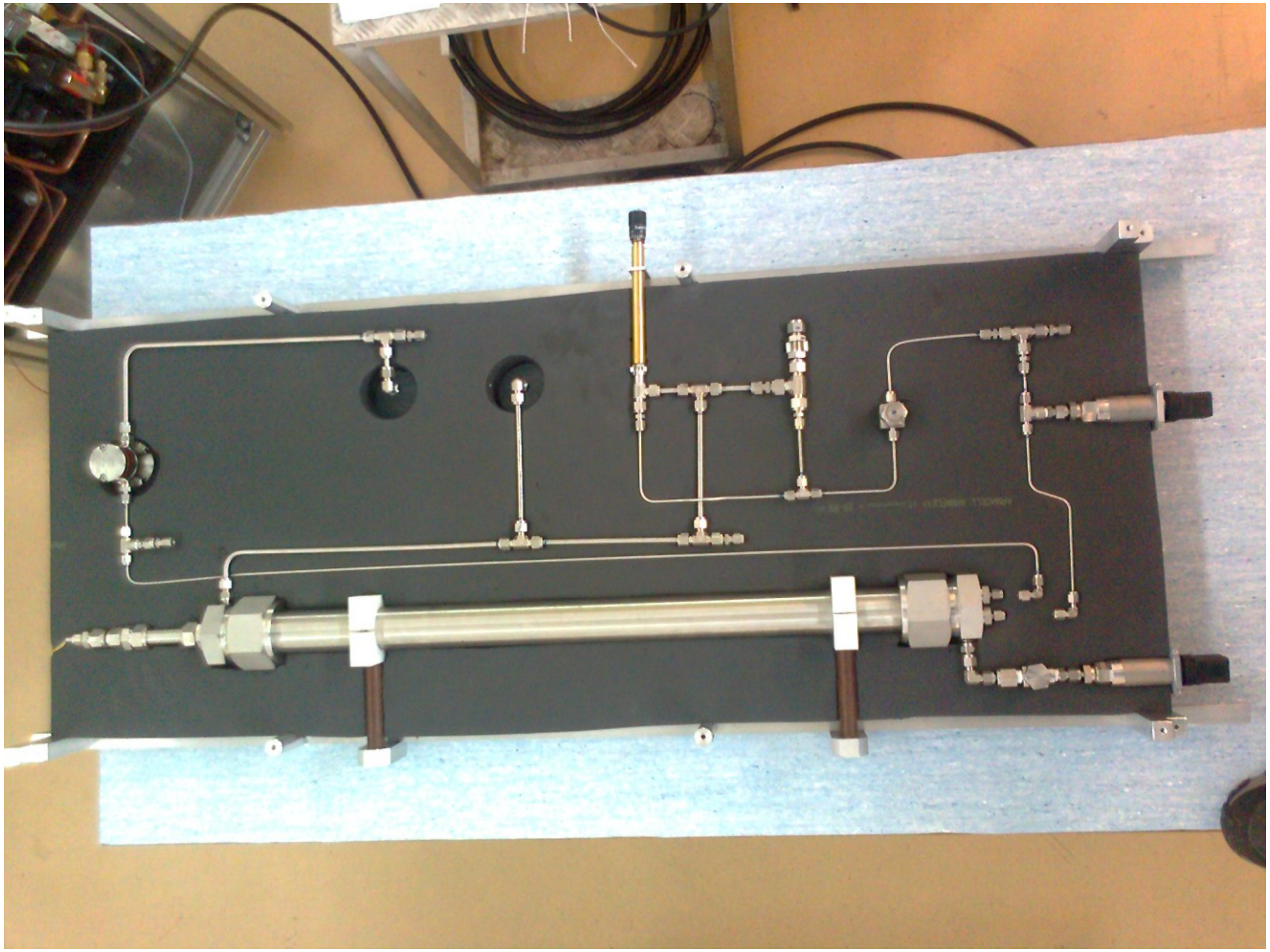
1kW plant at NIKHEF

Latest news:
Assembly completed since a few days

100 Watt I-2PACL CO_2 unit

- Nominal design capacity
  - 100W@-40° C
  - Higher capacity at higher temperatures
- New simplified 2PACL concept called Integrated 2PACL (I-2PACL).
  - Integrated functionality of several components to reduce costs.
- Cheaper and easier to build.
  - Less components and controls
- 2D piping layout, easy to insulate in between removable foam layers
  - Easy access to all insulated components
- 2 prototypes under manufacturing
  - LHCb velo
  - Atlas IBL or Pixel
- Small CO_2 volume.
  - PED Class 1 (No notified body required)
- 3m flexible concentric hose connection to experiment.

2D piping layout



Easy access to all insulated components

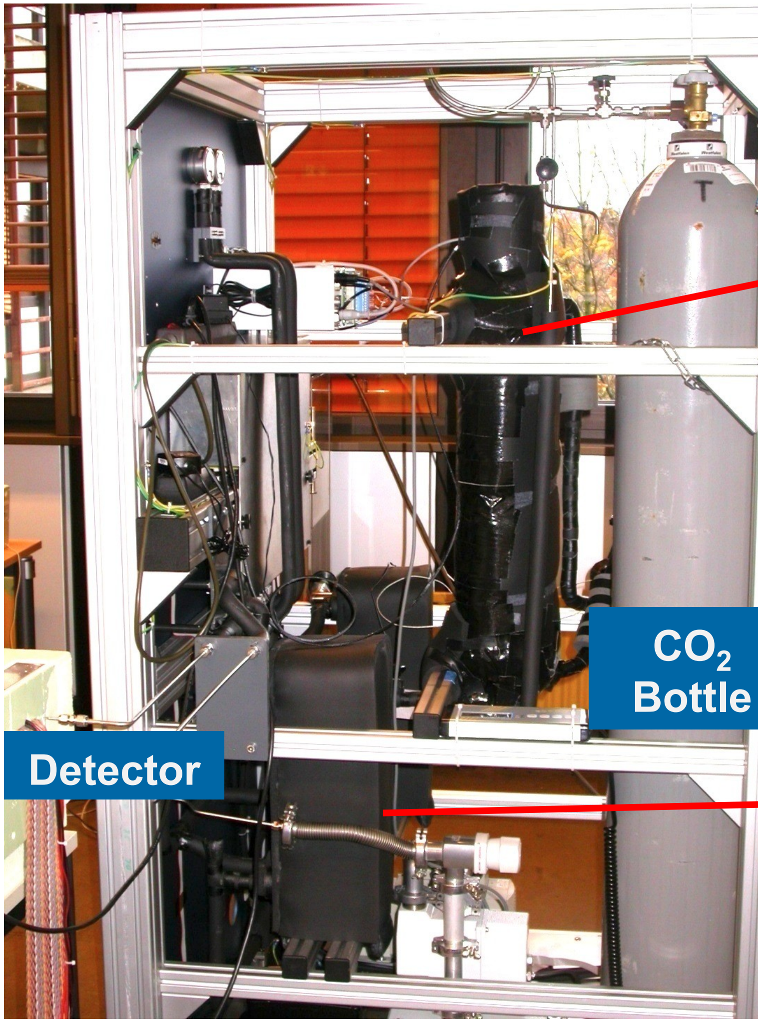
CO_2 Collaboration

- CERN-CMS
- CERN-Cryolab
- CERN-CV
- CERN-DT
- EPFL Lausanne
- Fermilab
- HEPHY Vienna
- IPNL-Lyon
- KEK Japan
- NIKHEF
- NLR Amsterdam
- Karlsruhe University
- MPI Muenchen
- PSI Villingen
- RWTH Aachen
- SLAC

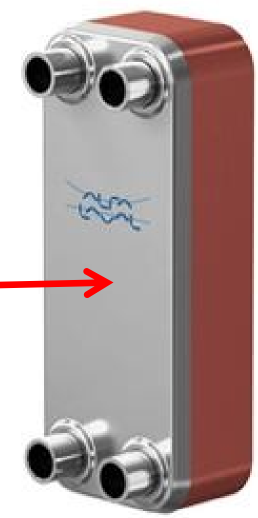
More CO_2 cooling plants

- RWTH Aachen – working cooling plant
- IPNL Lyon – working cooling plant
- Fermilab – starting operation of plant
- CERN-CV plant at Atlas pit under construction

CO2 plant at RWTH-Aachen

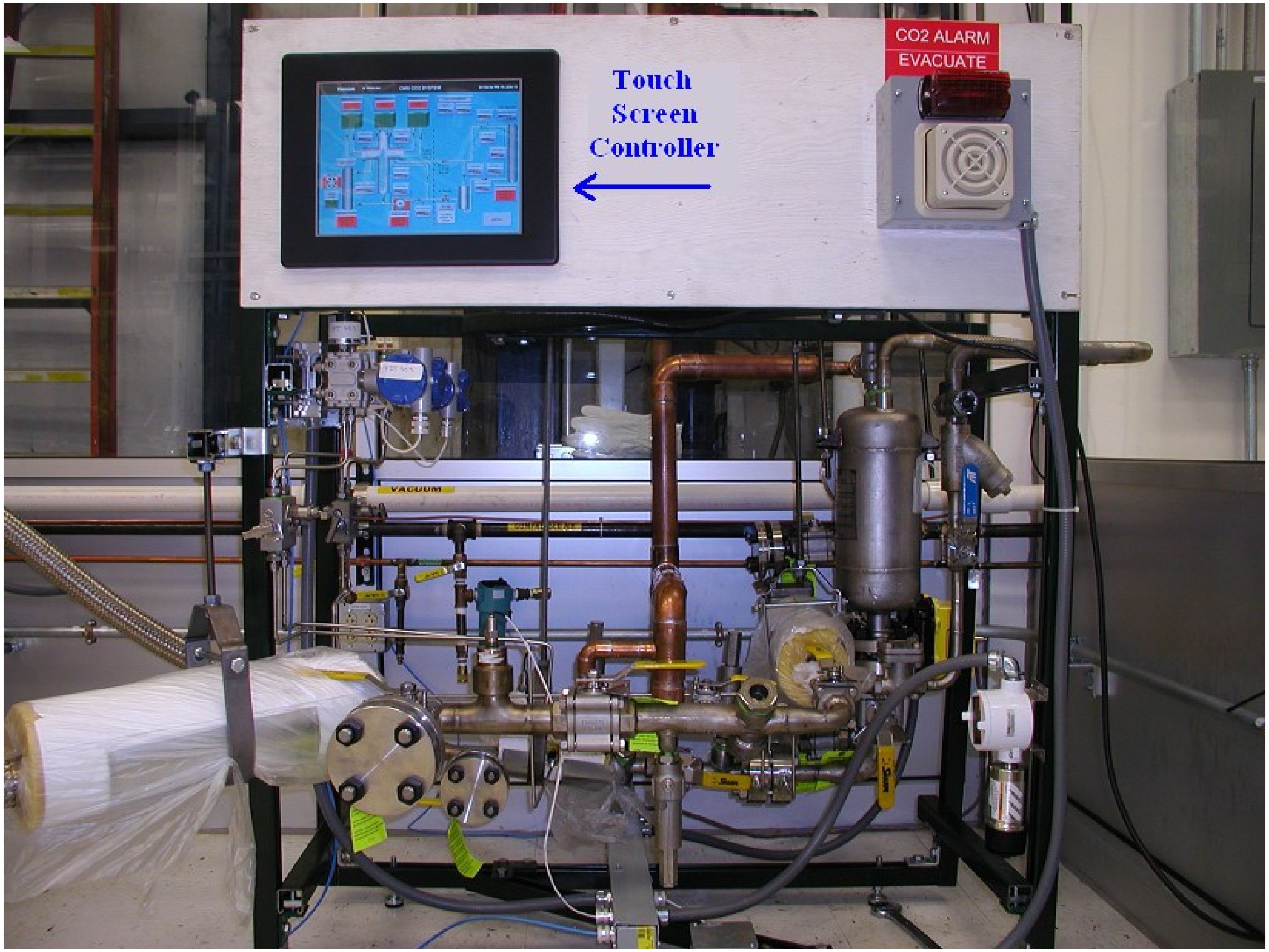


Expansion Vessel

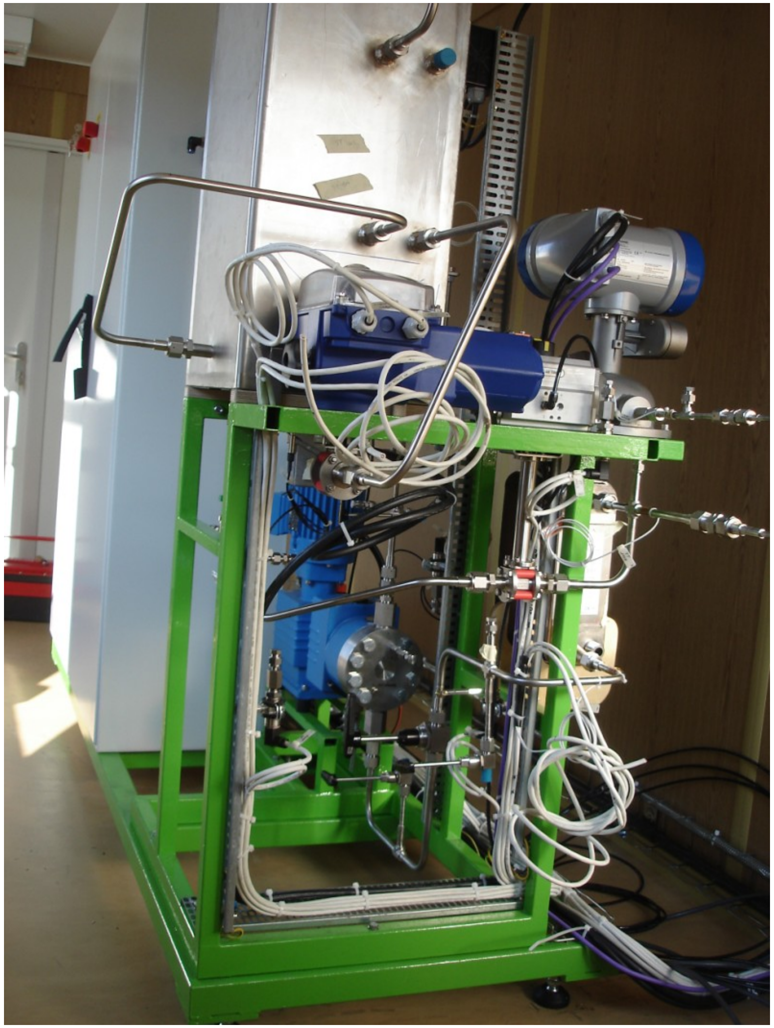


Heat Exchanger

Fermilab CO_2 plant



Plant at Atlas SR1



Cooling Success

- Not only a matter of selecting the right fluid
- A concept that uses the maximum amount of industrial experience and industrial technology assures maximum reliability
- Design the system keeping the very limited access in mind.
- Only components of outstanding quality should be used, fluids can be expensive, refurbishments too

Conclusions

- CO_2 cooling can be the optimal solution for VERTEX and Tracking detectors
- A successful and reliable cooling system requires:
  - A well chosen concept
  - A simple and excellent design
  - High quality components and manufacturing
- Albert Einstein: "everything should be made as simple as possible, but no simpler"