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Quality related experience in CO_2 cooling systems.

Workshop on Quality Issues in Current and Future Silicon Detectors

Friday 4 November 2011

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What means quality?

- **Quality** is of course:
  - The right procedures to make reliable hardware which does not break and needs a minimum of maintenance.
- But, **quality** is as well:
  - A design approach which does not need complicated hardware, nor a complicated control.
- And in cooling systems **quality** means as well:
  - The vapor/liquid mass fraction, but that is not the scope of this QA presentation.

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CO_2 cooling projects in particle physics

- 2 CO_2 cooling systems have successfully been built for particle detectors
  - AMS-Tracker experiment on the International Space Station
  - LHCb-Velo experiment for the Large Hadron Collider at CERN
- Many future CO_2 cooling systems are under design:
  - Atlas Inner B-layer @ CERN
  - CMS upgrade pixel @ CERN
  - Belle-2 @ KEKb (Japan)
- Some are foreseen for the far future:
  - CMS upgrade tracker @ CERN
  - Atlas upgrade pixel and tracker @ CERN
  - LC-TPC for the future Linear Collider

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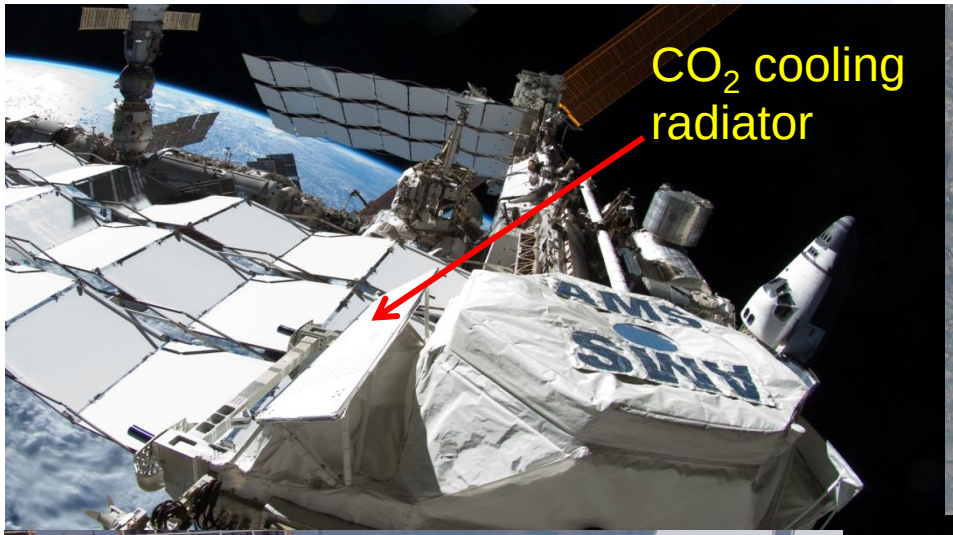
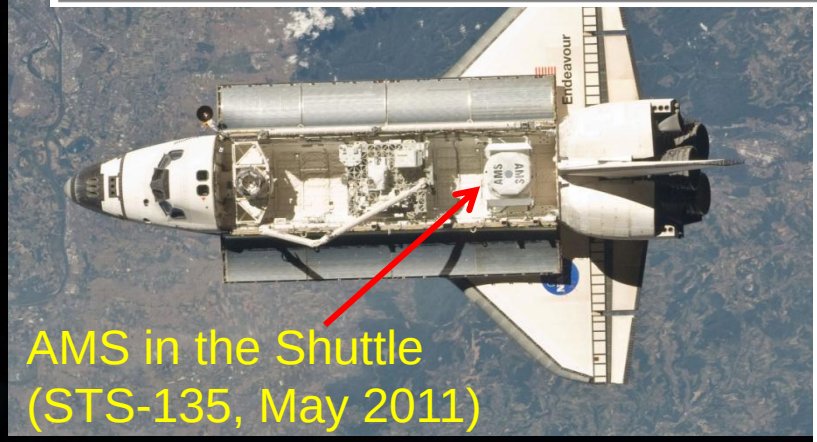
The 1st CO_2 cooling system in Space!

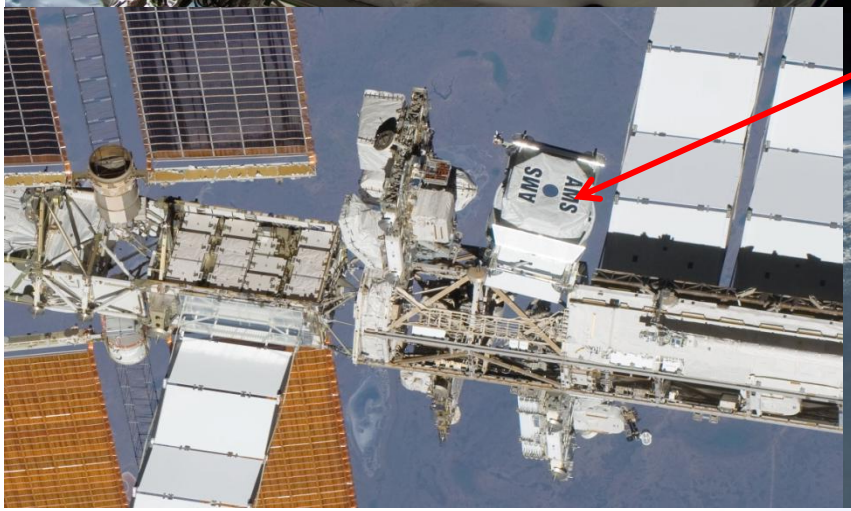
A CO_2 cooling system for Alpha Magnetic Spectrometer (AMS) Tracker Detector on the International Space station (ISS)

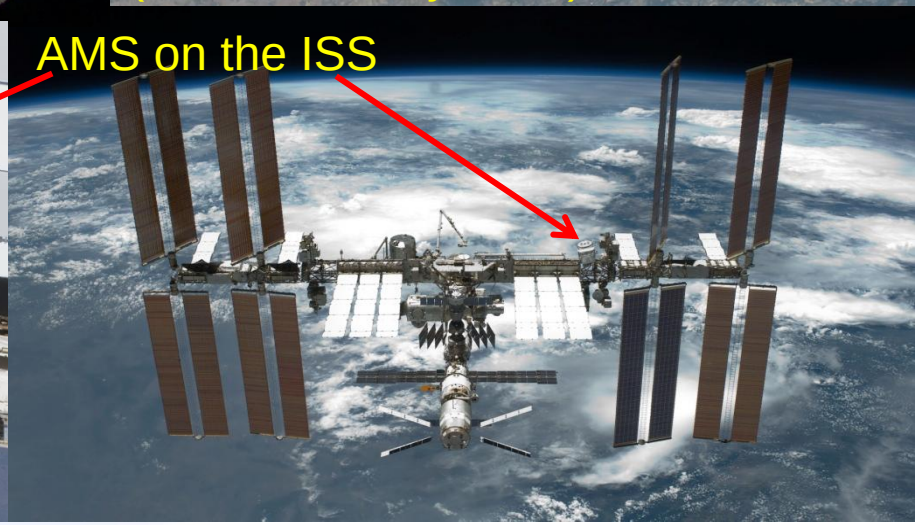
ISS sightings:

Date	Mag	Starts			Max. altitude			Ends		
		Time	Alt.	Az.	Time	Alt.	Az.	Time	Alt.	Az.
4 Nov	-1.5	18:31:43	10	W	18:34:32	29	SW	18:37:21	10	SSE
5 Nov	-2.6	17:34:12	10	WNW	17:37:19	55	SSW	17:40:27	10	SE
6 Nov	-0.4	18:13:36	10	W	18:15:45	17	SW	18:17:54	10	S









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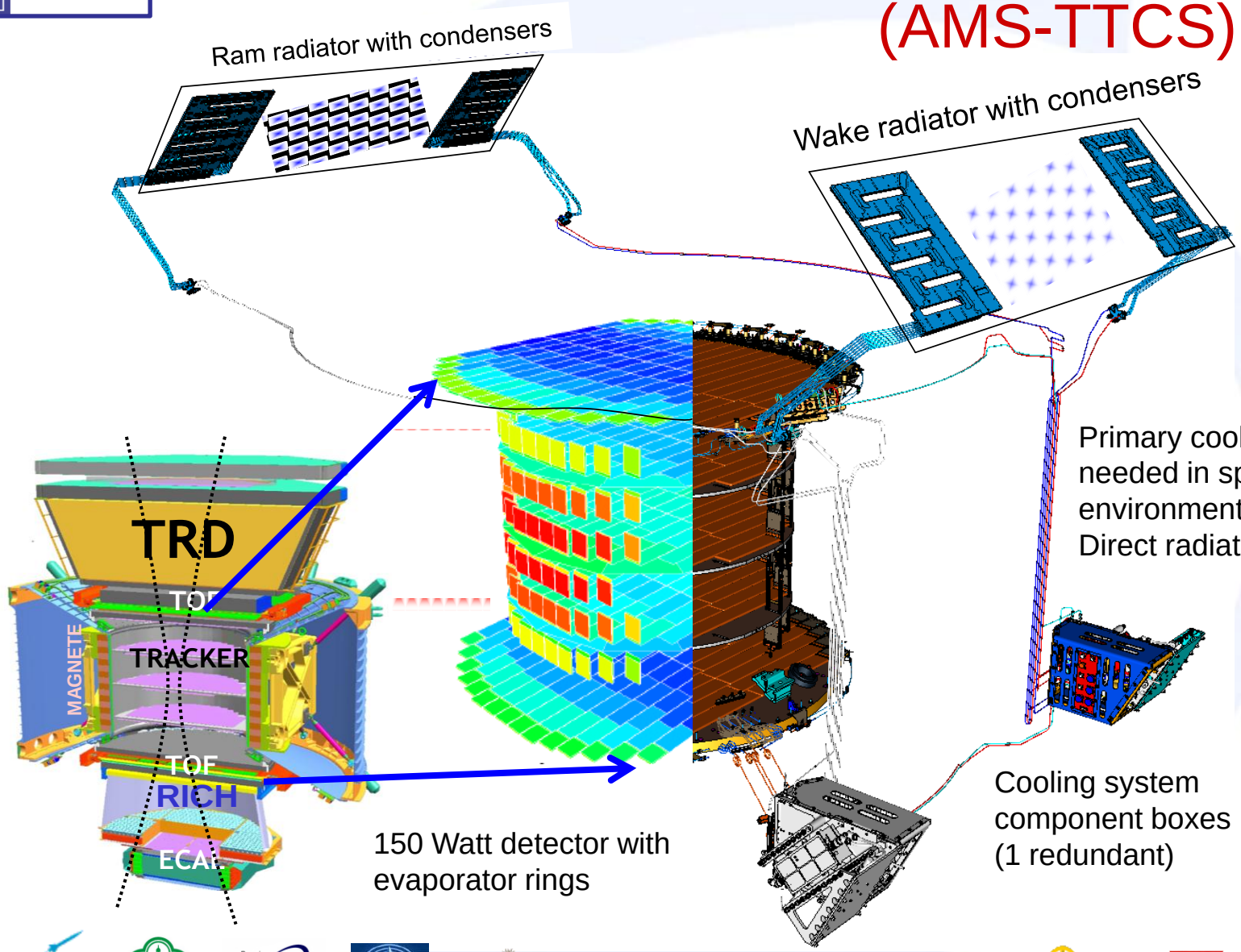
AMS-Tracker Thermal Control System (AMS-TTCS)



LHCb-Velo Thermal Control System (LHCb-VTCS)

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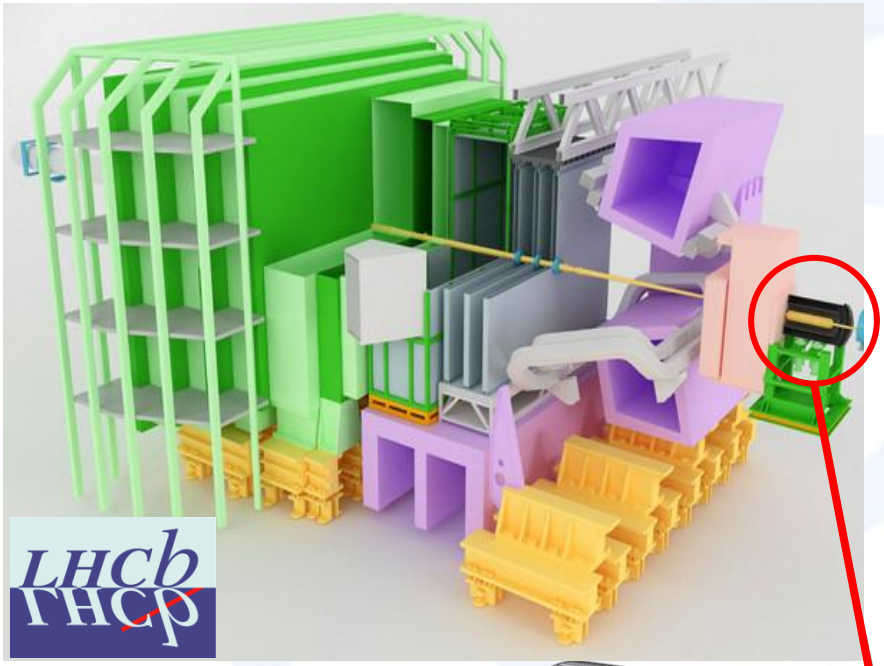
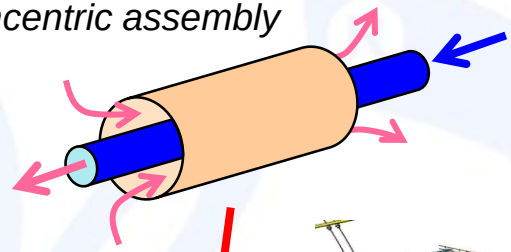


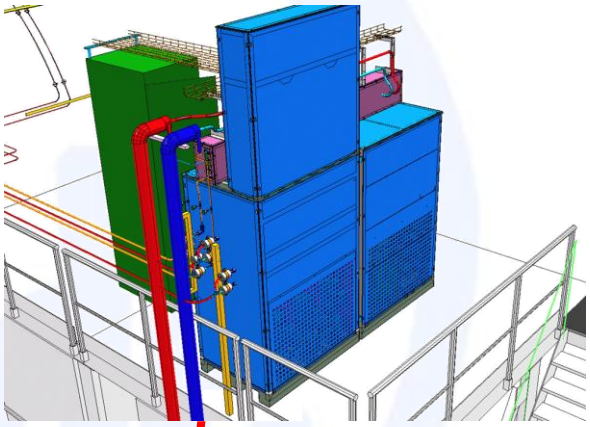
Transfer tube

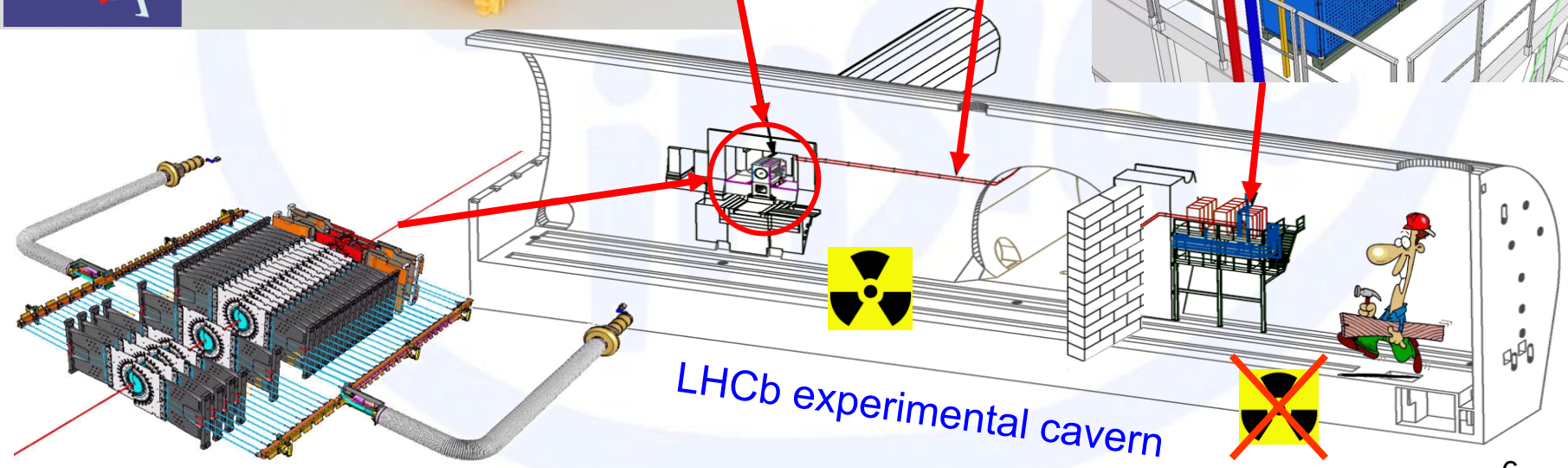
Concentric assembly



Cooling Plant

All active hardware





Cooling capacity: 1.5 kW@-30°C

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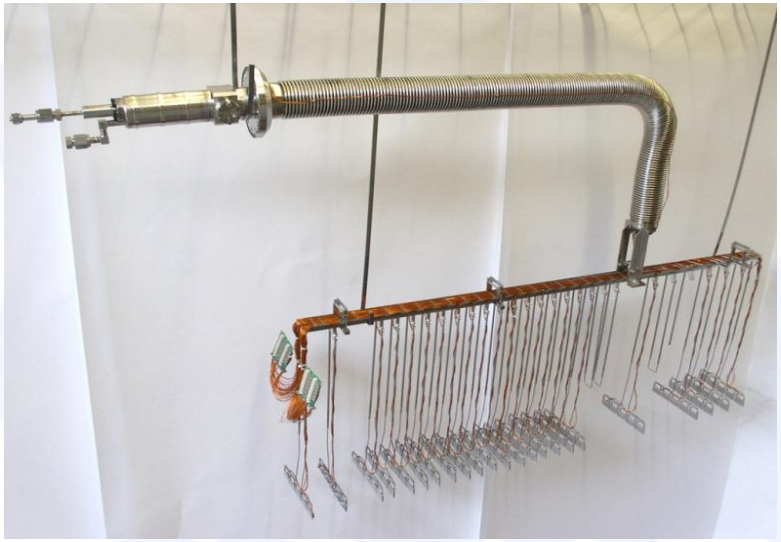
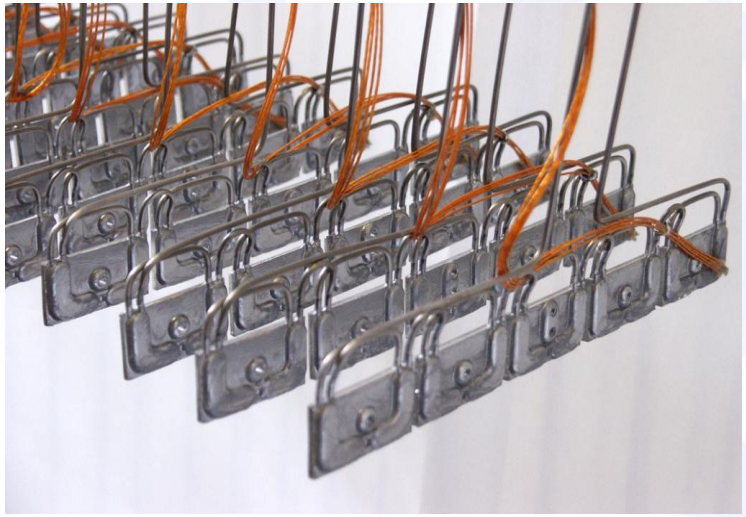
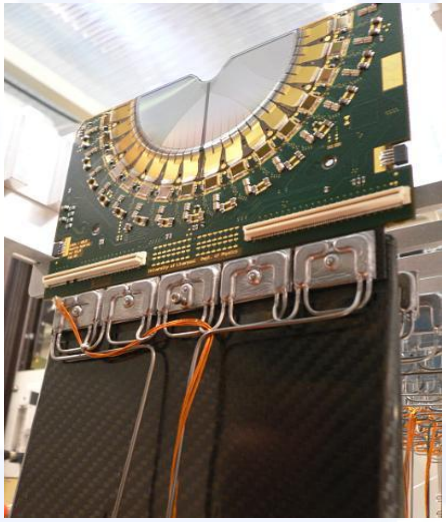
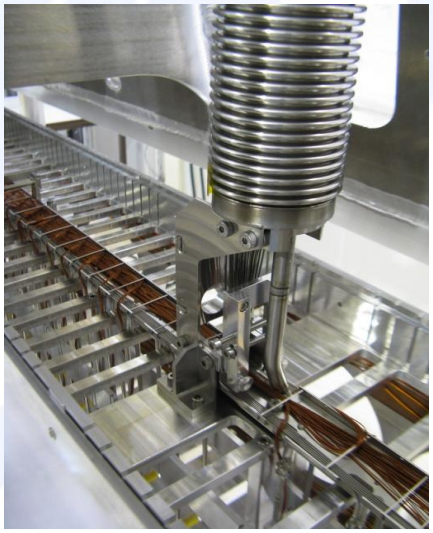
VTCS Evaporator
(Inside LHC vacuum system)









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Quality approach in CO_2 cooling systems

- The applied quality rules in the current CO_2 systems in HEP come from the AMS experiment and are therefore directly related to NASA space standards.

- Although lots of people think that “space” means exotic technologies; the opposite is true:
  - Space hardware must be as simple as possible!
  - Nicely explained in the payload construction manual:
    - Simplified Design Options for STS Payloads

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Just some nice recommendations from this NASA manual:

JSC-2054
Revison -

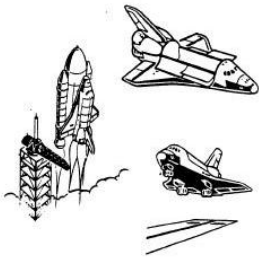
Simplified Design Options for STS Payloads

Loads and Structural Dynamics Branch Report

Structures and Mechanics Division
Engineering Directorate

April 1988

David A. Hamilton



NASA
National Aeronautics and Space Administration

Lyndon B. Johnson Space Center
Houston, Texas

Keep things simple:

Appendix B - Design Considerations

B1. The following comments relative to structural design were provided by P. D. Smith of the Structural Mechanics Branch.

1. Make the structure simple. Many aircraft/spacecraft designers get carried away by thinking exotic missions require exotic hardware, when in reality exotic missions succeed when simple structure is provided. Visualizing a "how would I design this at home" approach is sometimes helpful. Structural design is basically "connect the head bone to the neck bone, etc." Do not over do it.

Use your common sense:

Computer Programs

Computer programs are not a substitute for good basic judgment. Final reactions should be checked for summations at all forces; for this principle still holds even in the high technology age. Plot results and

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From space standards to earth applications

- The LHCb CO_2 cooling is based on the lessons learned in AMS.
- The LHCb quality requirements were high:
  - Evaporator hardware is inside the LHC vacuum
    - Extreme leak tightness requirements,
    - Inaccessible
    - Both are similar to the requirements of AMS in space.
  - As we were used in designing and building according to the AMS rules, the philosophy was applied to the entire LHCb-Velo cooling system.
- This quality philosophy seems to work well
  - The LHCb-VTCS has run since 2008 almost continuously without major problems.

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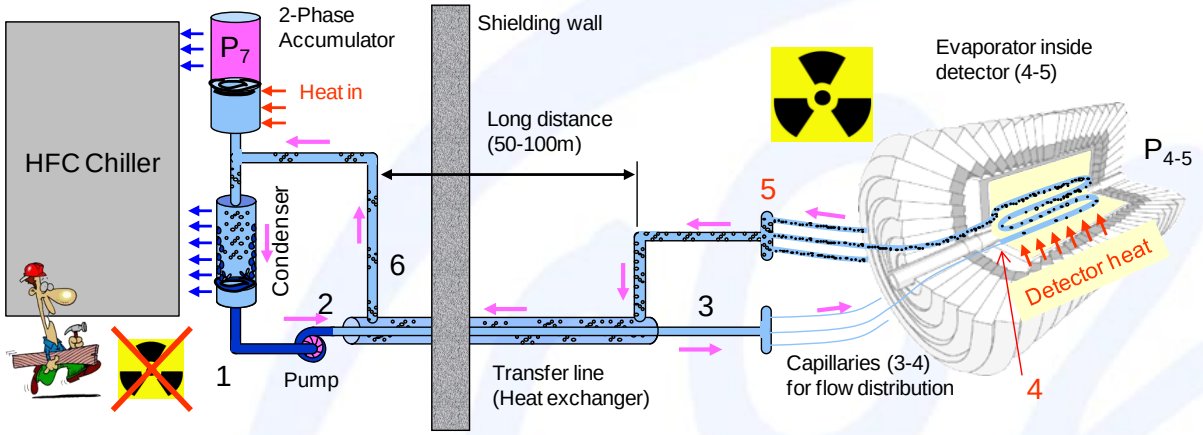
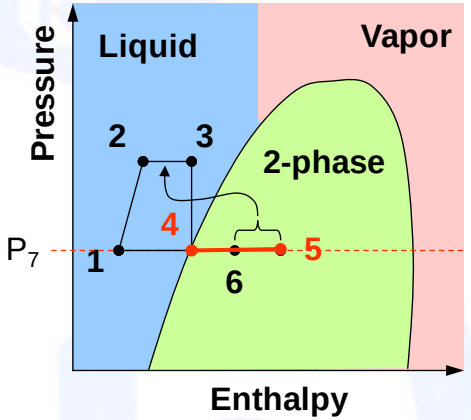
Quality starts with a simple concept.





The 2-Phase Accumulator Controlled Loop (2PACL)

- For AMS the 2PACL method was invented
  - Simple to operate, self stabilizing cooling system.
  - Minimum amount of actuators and control.
- 2PACL successfully applied in LHCb-Velo.
  - Passive in detector cavern
  - All active components in the distant accessible cooling plant
  - 1 primary control (P7 accumulator pressure = detector temperature)

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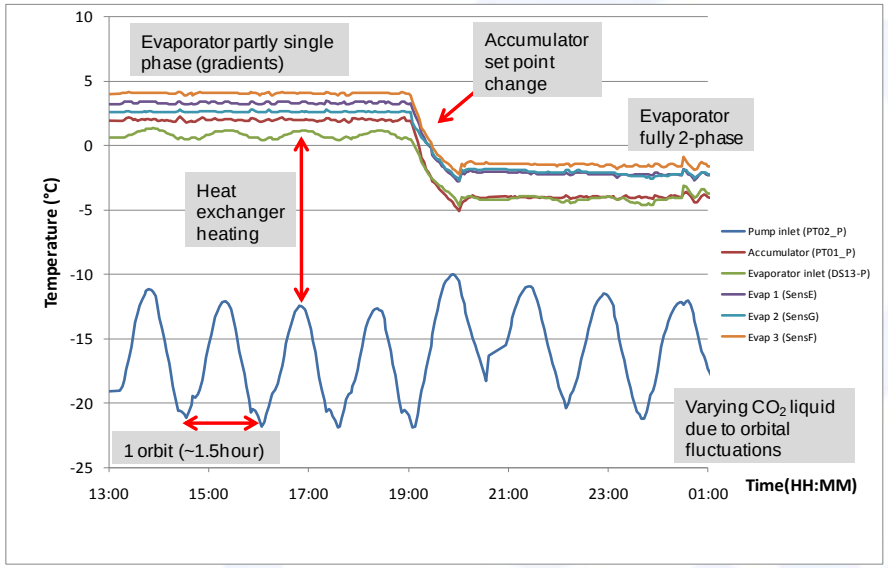
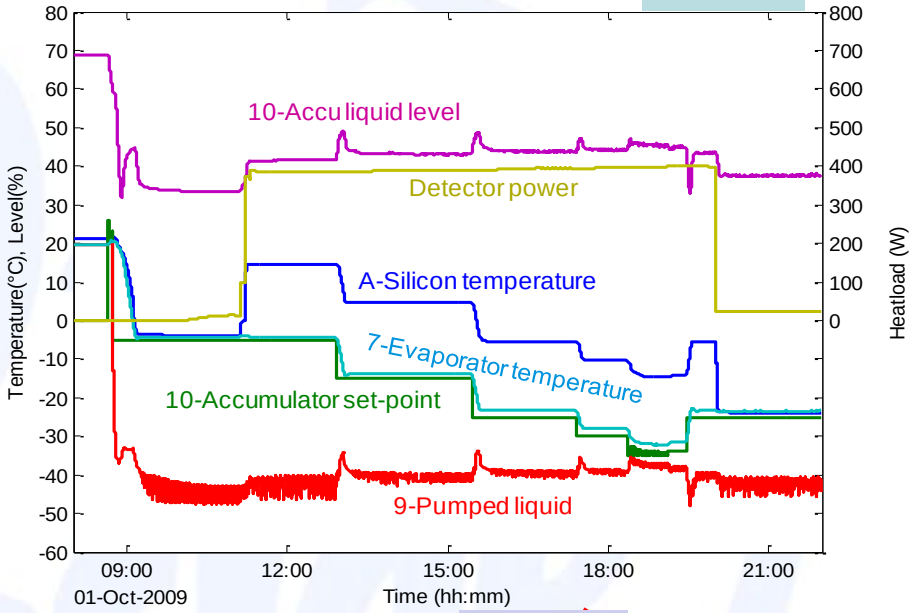
AMS TTCS and LHCb-VTCS 2PACL performance

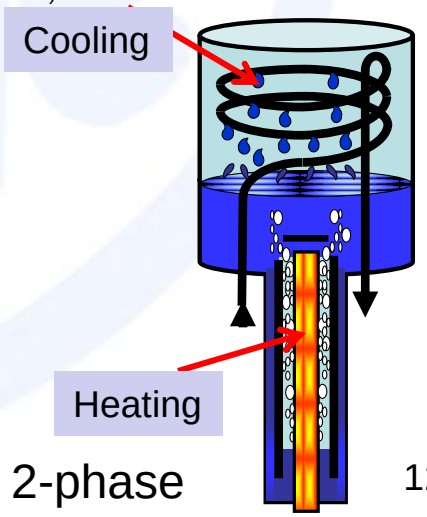
AMS in space



LHCb



- Accumulator control is main controlled item.
  - A combined cooling / heating control
    - AMS: Electrical heating and radiation cooling
    - LHCb: Electrical heater / freon injection
- Other controls are not critical for a stable temperature in the detectors.
  - AMS:
    - Some small heaters
  - LHCb:
    - Chiller: capacity control with injection valves and compressor frequency inverter
    - Heaters: Vibration damper heater and pump oil heater
- All controls and actuators are simple industrial standards in LHCb, accumulator is only homemade object



2-phase accumulator

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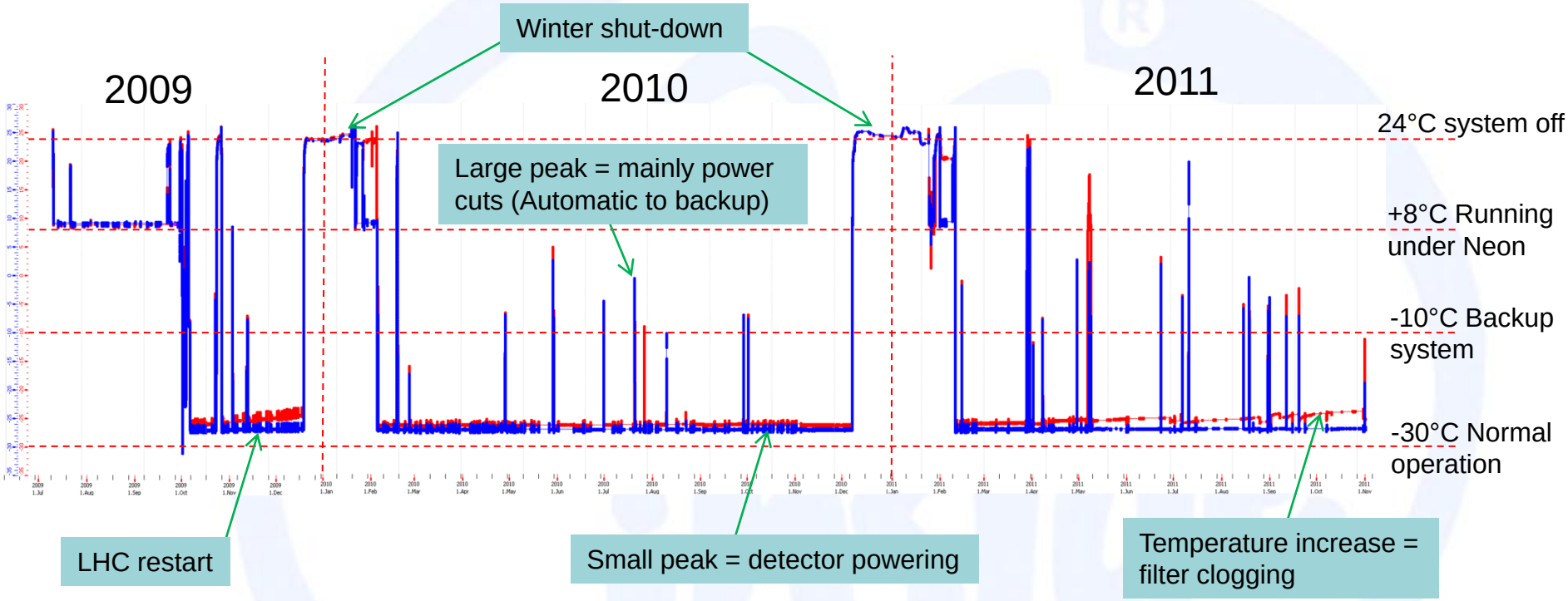
LHCb-VELO long term performance



- LHCb-VTCS runs without major problems since 2008.
  - 2008 commissioning phase
  - From 2009 continuous switched on (see plot), -30°C since Oct 2009.

- Problems experienced
  - Insulation leakage (replaced part of the insulation in shut-down Jan 2011)
  - 1 clogging filter in the TR system causing a slow increase of the temperature (red line)
    - Replaced in shut-down Jan 2010, due to replace next week again
  - 1 leak was observed in the chiller and repaired (industry production fault)

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Applied quality and safety rules in future CO_2 systems.

- **For pressure safety we are obliged by law to follow the PED (Pressure Equipment Directive)**
- For dangerous aspects in cooling systems we have developed strict rules:
  - Heater safety: 2 fault redundant
    - 1 hardware interlock
    - 2 software interlock levels
      - Warning: Switch off individual heater
      - Alarm: Switch off all heaters (to protect against sensor swap)
  - Trapped liquid safety:
    - Automatic valves actuated by pressure measurement
    - Relieve valve or burst disc
- For QA related aspects of the CO_2 system we follow basic rules as gained from previous experience
  - Orbital welding
  - Swagelok VCR connectors
  - Keep it simple approach
  - Design for insulation
- For control we are following for future systems the PVSS-UNICOS approach from the LHC cryogenics.

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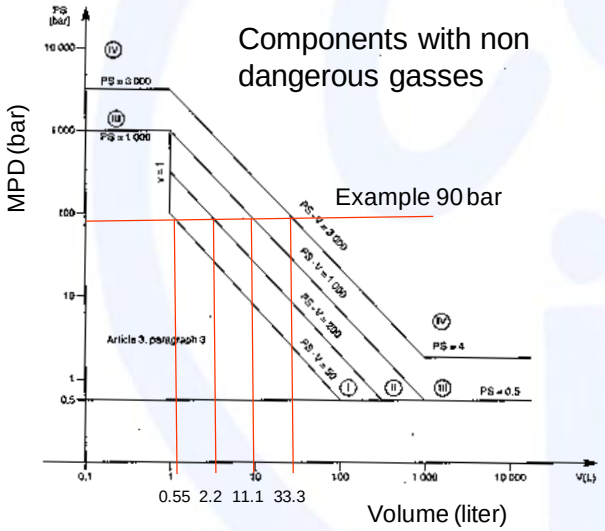
PED Classification (1)

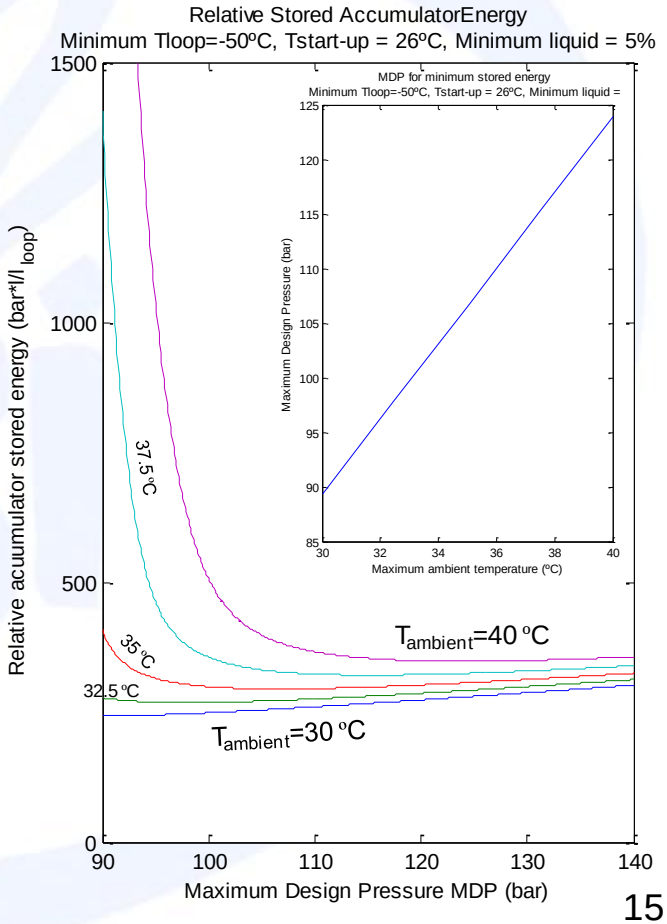
(Pressure Equipment Directive)

- PED classification for CO_2 systems.
- Stored energy = MDP x Volume
  - MDP = Relieve pressure
  - MDP= (P @ TenvMax or P+dPpump)x110%
  - PTP = 1.43 x MDP

MDP = Maximum design pressure, PTP = Proof Test Pressure



Stored energy of accumulator in case of fluid storage (worst case).



Find minimum for stored energy

(Not necessarily at lowest pressure)

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PED Classification (2)

Category	Design	Fabrication	Commis-sioning	PED Module	Applicable to volumes @ MDP=90bar
Art. 3.3				Good practice	V≤0.55 Liter Dn≤ø32 mm
I				A	0.55<V≤2.2 L DN≤ø100mm
II			Notified Body control	A+A1	2.2<V≤11.1 L DN≤ø250mm
III	Notified Body control	Approved fabrication procedure	Notified Body control	B1+F	11.1<V≤33.3L DN>ø250mm
IV	Notified Body control	Approved fabrication procedure	Notified Body control	G	V>33.3L

The higher the PED class, the larger notified body involvement

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- For QA related aspects of the CO_2 system we follow basic rules as gained from previous experience
  - Orbital welding
  - Swagelok VCR connectors
  - Keep it simple approach
  - Design for insulation

- For control we are following for future systems the PVSS-UNICOS approach from the LHC cryogenics.

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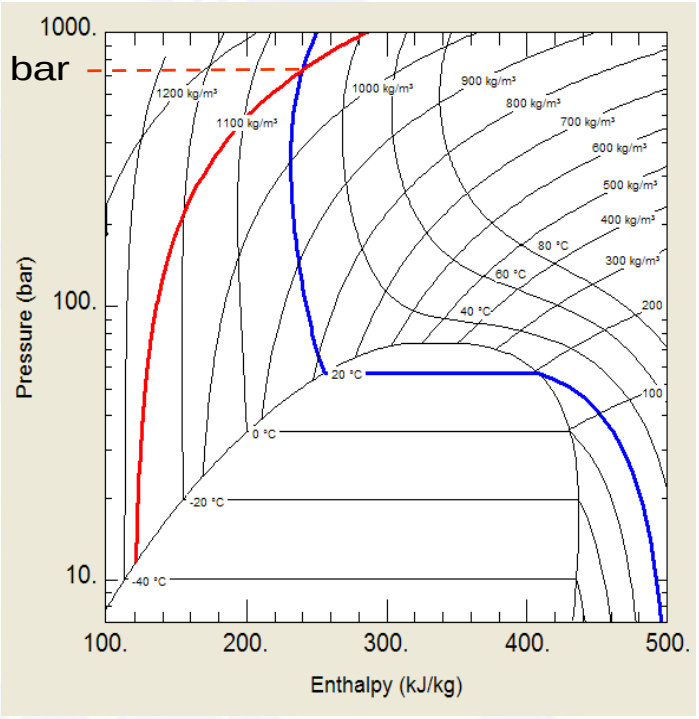
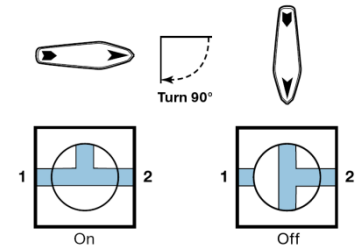
Trapped liquid

- Trapped cold liquid is a real danger in a cooling system.
- Be careful with introducing too many valves
- Don’t use valves with dead volumes
- Every volume needs a relieve
- AMS-TTCS has no valves, only liquid trap possible in frozen condenser
  - MDP=3000 bar for condenser!
- LHCb-VTCS has burst discs at each volume + controlled valves to avoid liquid trap
  - MDP=135 bar (Swagelok burst disc)





Ball valve with T-hole

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For QA related aspects of the CO_2 system we follow basic rules as gained from previous experience

- **Orbital welding**
- **Swagelok VCR connectors**
- **Keep it simple approach**
- **Design for insulation**

- For control we are following for future systems the PVSS-UNICOS approach from the LHC cryogenics.

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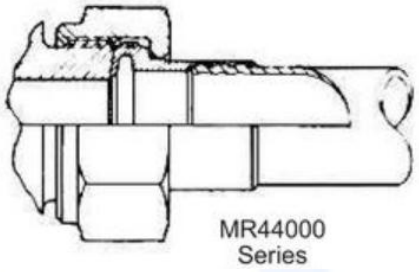
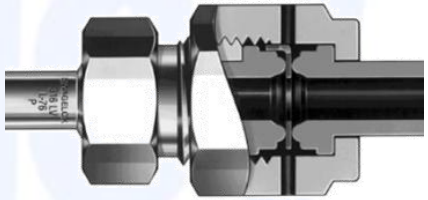
Quality aspects of pipe connections


Orbital weld, the perfect weld

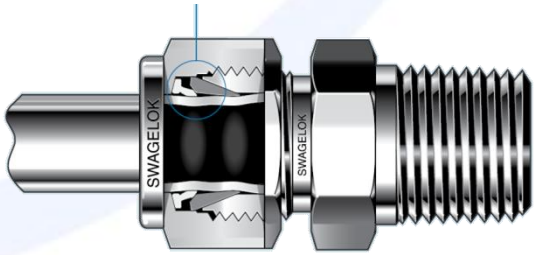
- Only serious joining techniques were used:
  - Vacuum brazing
    - (No flux=No corrosion)
  - Orbital welding.
    - Automatic procedure also in small spaces
  - Reliable connectors:
    - Space qualified Dynatube for AMS
    - Swagelok VCR connectors for “earth” use
  - Not all connectors are meant for disassembly!
    - Swagelok tube fittings deform the pipe and can easily damage the connection forever.
    - The use of these connectors is okay for 1 time assembly only



Dynatube diaphragm connector


Swagelok VCR connector with replaceable seal (Multiple use)

- No leakage problems have been observed in the LHCb CO_2 system
  - Last refill (2x12 kg) in January 2010, system was empty for maintenance reasons



Swagelok tube fitting connector (limited use)

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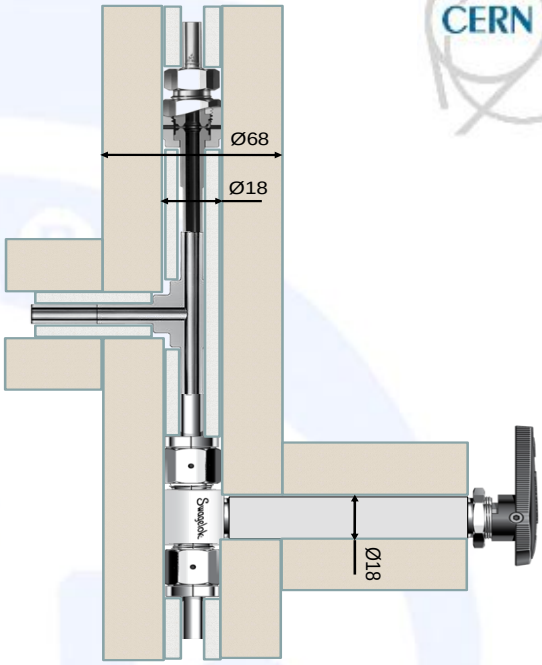
Insulation



- Good insulation is very important.
  - Moisture seal function more important than heat leak.
- Design the cooling plant for easy insulation.
  - Complicated geometries are hard to insulate vapor tight.
  - LHCb plant was designed too tight
  - Future systems are designed for easy insulation
- LHCb suffered a lot from bad insulation
  - Bad experience with Armaflex NH
    - CERN standard as it is non flammable
    - Ageing problem material seem to dry out
    - Closed cell becomes open cell = > water absorbing sponge
  - Part of the insulation replaced with Armaflex AF (special CERN permission)
  - Still forming ice in places inside the cooling plant which could not be repaired.
    - Not problematic, but not elegant.
- Investigation of vacuum insulation inside detectors for future systems
  - IBL transfer line

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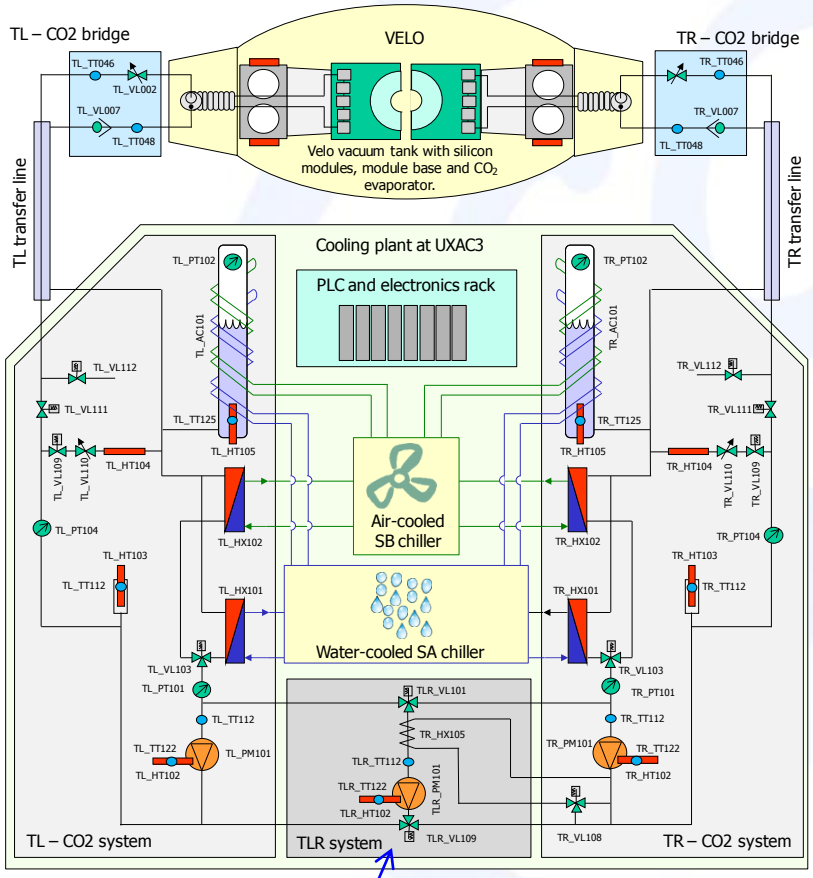
Redundancy approach

LHCb-VTCS



Shared spare pump

- Adding redundancy is not always adding reliability.
- LHCb pump redundancy was shared between 2 systems.
  - Added complexity of valves was under estimated.
  - Each valve increases the complexity more then linear.
  - Full proof PLC program was a complex task
- Better approach:
  - A simple system without local redundancy.
    - No extra valves!
  - Have a spare simple system ready (AMS approach)
  - Switch over to system B incase of problems
    - Also easy for maintenance
  - Less risk of trapped liquid
  - Atlas upgrade idea:
    - 6 identical systems of 20kW +x spare unit(s)
    - Instead of a single 120kW plant with internal redundancy
- LHCb-VTCS backup procedures all in PLC
  - No user interaction required.

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  - Orbital welding
  - Swagelok VCR connectors
  - Keep it simple approach
  - Design for insulation

For future system control we are following the PVSS-UNICOS approach adopted from the LHC cryogenics.

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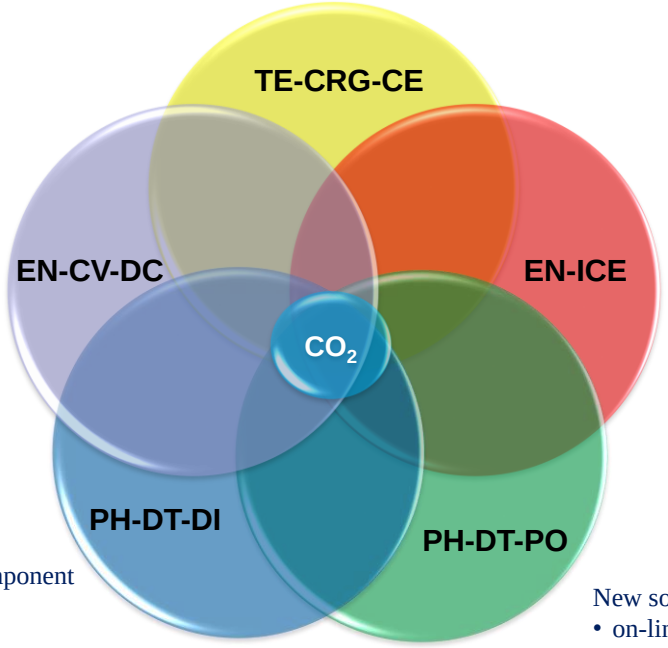
Control logic approach (1)

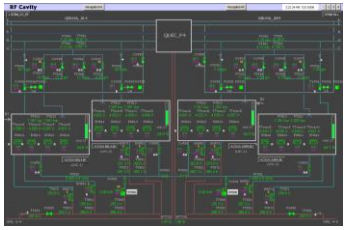
Standardization approach

Industrial electrical components
Control hardware equipment
Electrical diagnostic tools
Siemens PLC standard



Schneider PLC standard

UNICOS framework
IEC61512-1 standard
PVSS



Recipes component

New software components:
- on-line pressure enthalpy diagram
- one button PVSS system start/stop

Alarm diagnostic

From Lukasz Zwalinski's seminar talk 11-10-11

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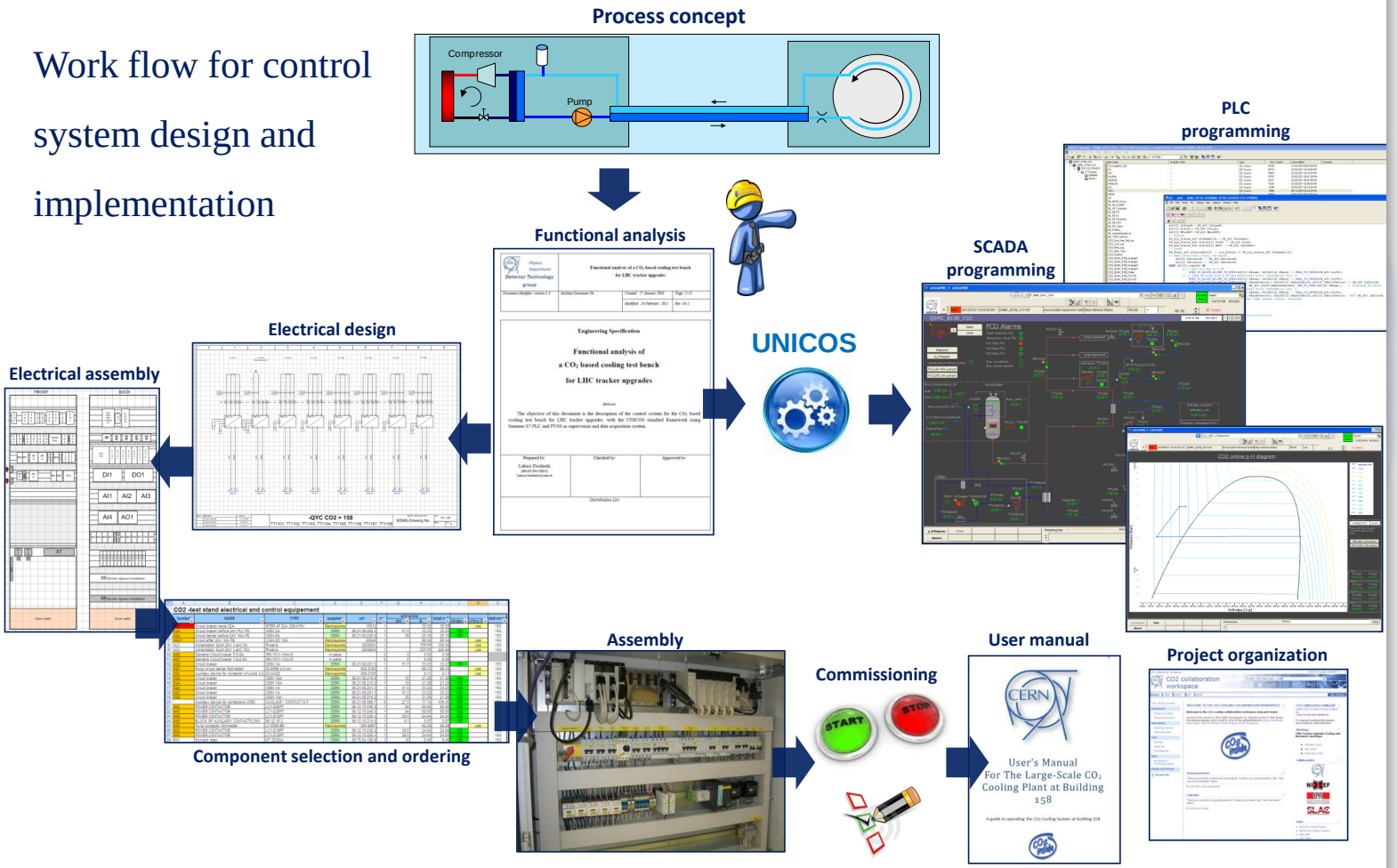
Control logic approach (2)

Control system design and implementation

Work flow for control system design and implementation



From Lukasz Zwalinski's seminar talk 11-10-11

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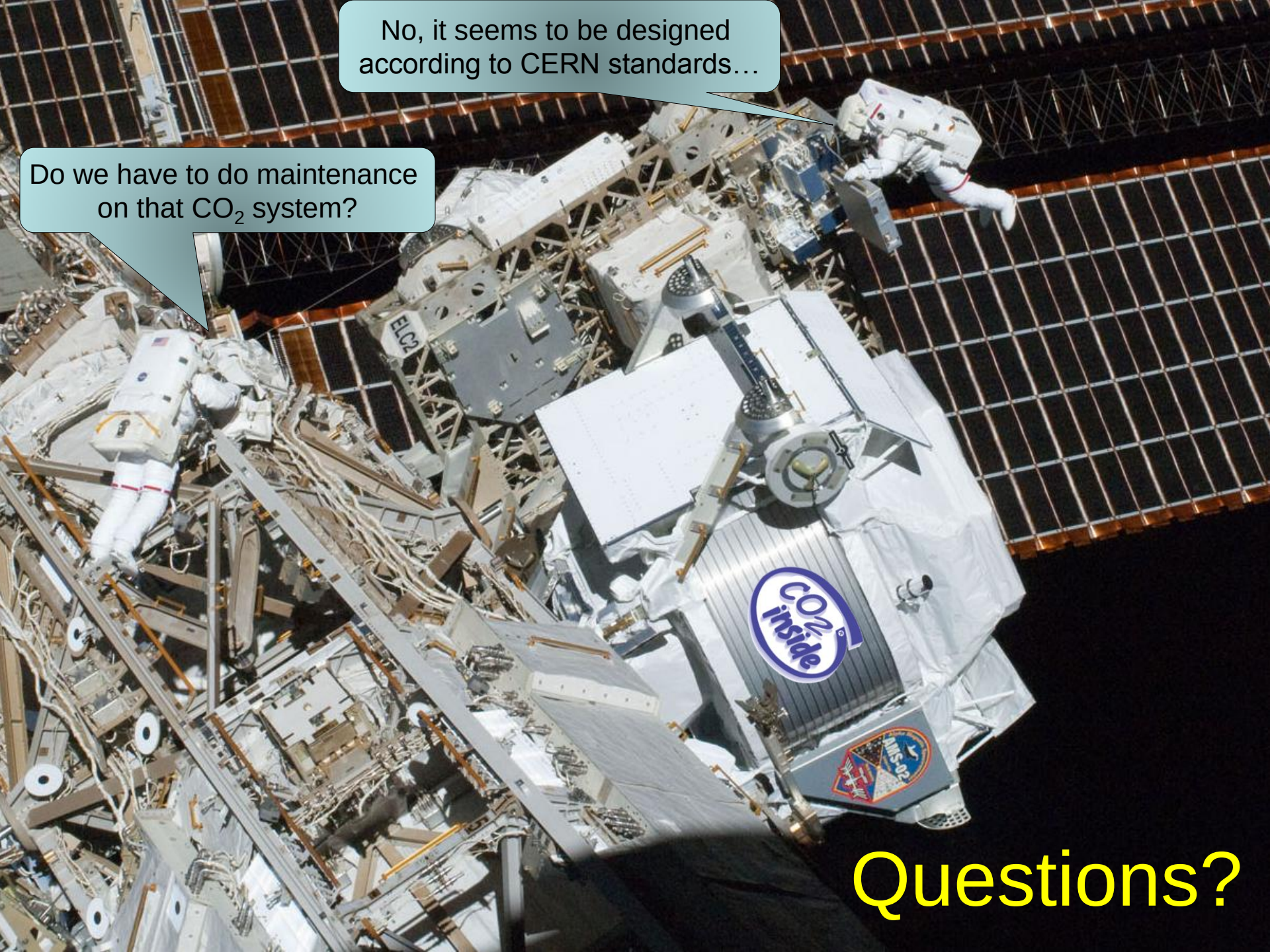
Conclusions

- Quality means:
  - A simple conceptual design.
  - The use of reliable industrial components
  - Common sense
  - A simple redundancy approach

- Aerospace QA philosophy inherited from AMS seem to be a good way to go for CO_2 cooling systems
  - No major problems in LHCb
    - Okay, except for the insulation, but a space standard for foam didn't exist…….(bad excuse!)


No, it seems to be designed according to CERN standards…
Do we have to do maintenance on that CO_2 system?
ELC2
CO2 inside
Questions?