ATLAS & CMS CO2 detector cooling upgrade project

Sustainability Accelerator Panel – P.HANF (EN-CV) & P.PETAGNA (EP-DT)

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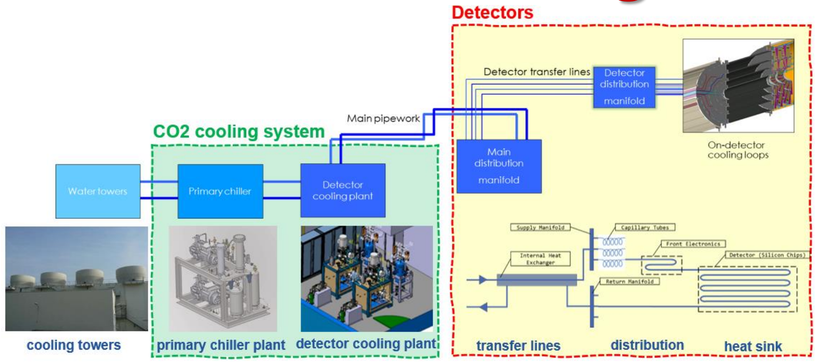
Indico 1427241

Logistic situation of an experiment (e.g. ATLAS)

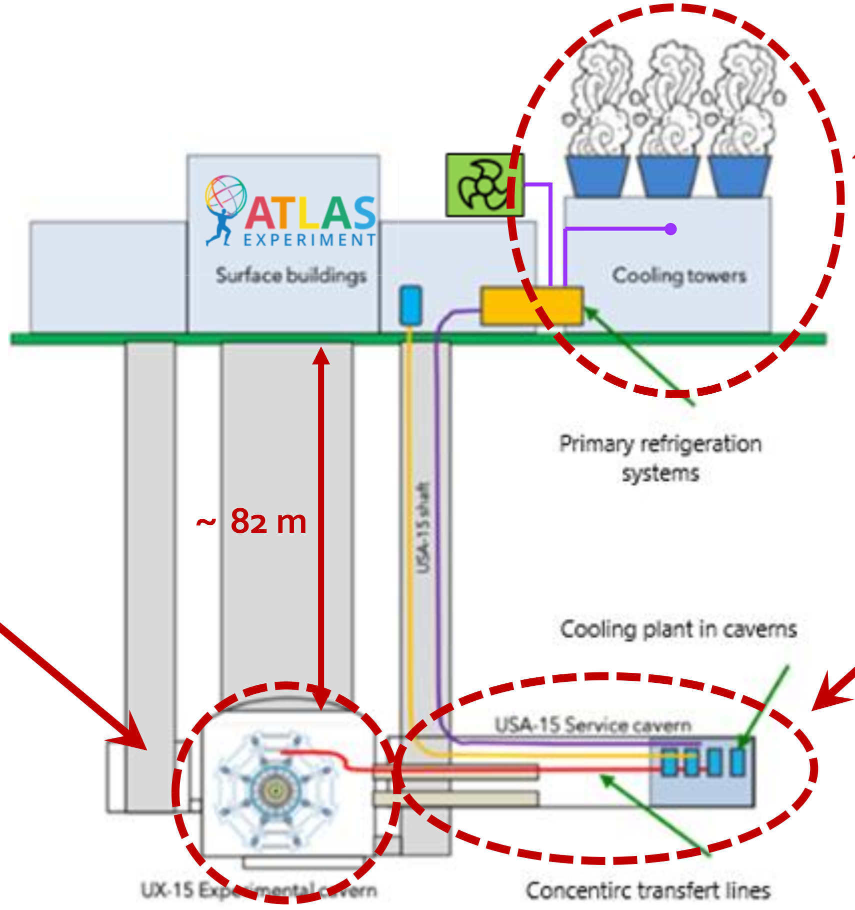
The Si detector cooling chain



Experimental cavern

- high radiation
- high magnetic field
- inaccessible during operation
- limited access during LHC shutdown

(home to the particle detectors)



Cooling towers

(final heat sink)

Service cavern

- no radiation
- no magnetic field
- accessible
- specific safety rules apply

(home to the detector cooling systems)

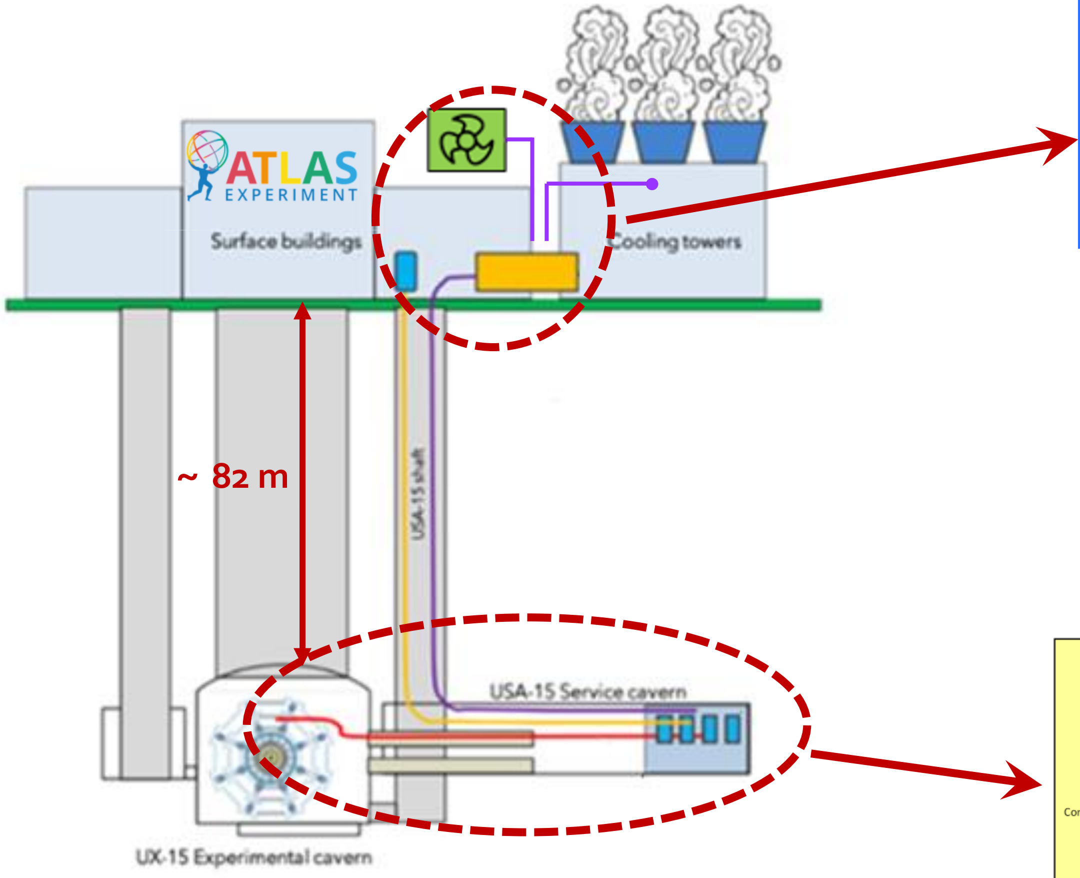
Detectors cooling requirements

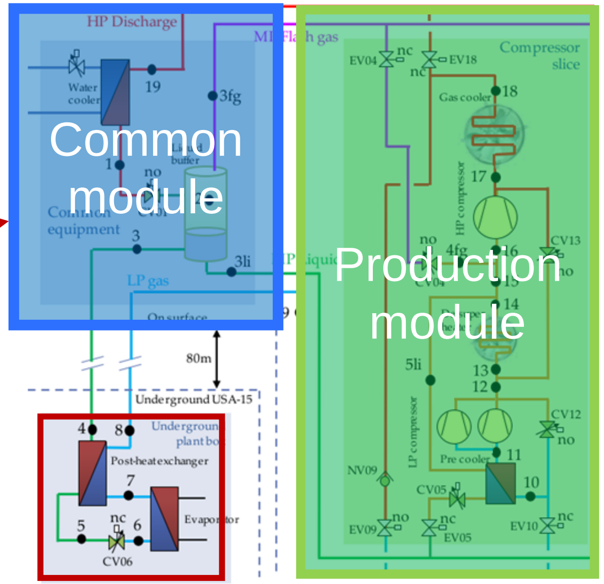
- Typical lifespan of the order of 10 to 15 years
- **Absolute reliability (system available 24/24 7/7 over the lifespan)**
- Stability in time (typically better than ±1K)
- **Saturation temperature in the detector << 0 °C**
- Low T gradient (max few K) along a cooling loop
- **Environment in the cavern: high magnetic field**
- Environment in the cavern: high radiation (**no oil contamination in the fluid**)

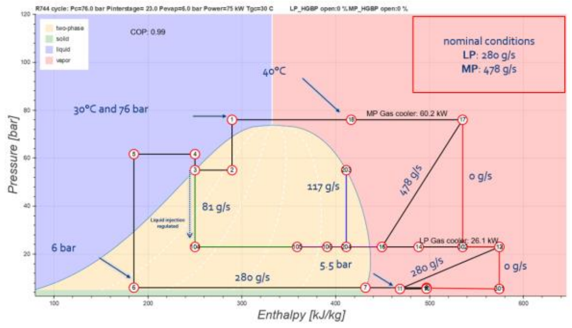
Related challenges

1. **Extremely low temperature needed** at the cooling plant to maintain performances of silicon sensors;
2. **Integration on site** Stong limitations associated with regards to the current underground facilities
3. **Operation & Modularity of the needs with an high T°C stability** from 0-100%
4. **Distribution of the Coolant to the internals of the detectors** Hundreds of micro channels

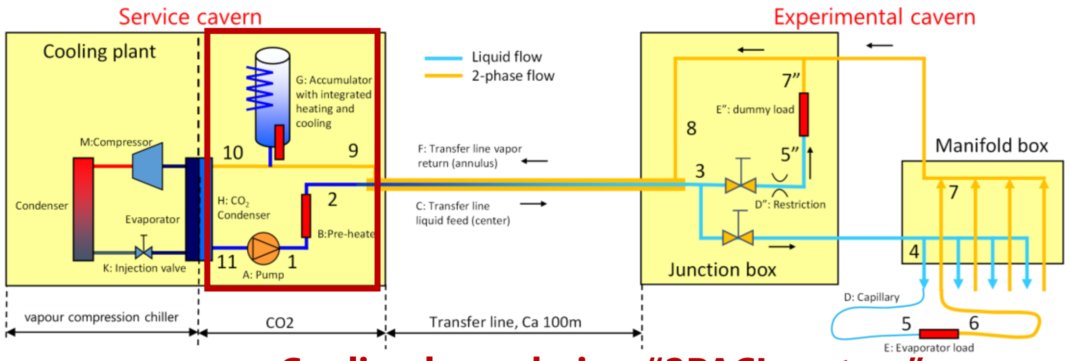
The new detector Cooling system architecture (e.g. ATLAS)







Refrigeration production choice: "R744 Primary system"



Cooling loop choice: "2PACL system"

LHC Cooling systems : current status and objectives

Secondary circuit "cooling loop"

CO_2 - "2-PACL" technology

RUN 1
- LHCb Velo 1kW@-30 °C, 2 plants

RUN 2
- LHCb Velo 1kW@-30 °C, 2 plants
- ATLAS IBL 1.5 kW@-35 °C, 2 plants
- CMS Pixel 15 kW @-25 °C, 2 plants

RUN 3
- LHCb Velo II 2kW@-35 °C, LHCb UT 5kW@-30 °C – 2 plants
- ATLAS IBL 1.5 kW@-35 °C, 2 plants
- CMS Pixel 15 kW @-25 °C, 2 plants

RUN 4
- ATLAS Pixel End cap (PEC), ATLAS Pixel barrel (POB), ATLAS Pixel Inner system (PXI), ATLAS Strip end cap (SEC), ATLAS Strip barrel (SRB), ATLAS HGTD – **380 kW@-53ºC**, 1 plant
- CMS Outer tracker (OT), CMS Inner Tracker (IT), CMS Barrel Timing layer (BTL), CMS Calorimeter end cap (CE, CMS Endcap timing layer (ETL) – **750 kW@-53ºC**, 1 plant

Others

Run 1:
- ATLAS ID 62kW@-25 °C: C_3F_8 direct evaporation, 7 compressors
- CMS Pixel 10 kW @-20 °C, CMS Strip 65 kW @-30 °C, CMS Preshower 26 kW@-25 °C – C_6F_{14} single-phase, 5 plants

Run 2 / Run 3:
- ATLAS ID 62kW@-25 °C: C_3F_8 direct evaporation, thermosiphon
- CMS Strip 65 kW @-30 °C, CMS Preshower 26 kW@-25 °C – C_6F_{14} single-phase, 4 plants

Total installed cold cooling power: 164 kW (CO_2 0.6%) (Run 1–2)

Total installed cold cooling power: 177 kW (CO_2 13%) (Run 3)

Total installed cold cooling power: 1130 kW (Run 4)

Primary circuit "Refrigeration production"

R404a/R507a

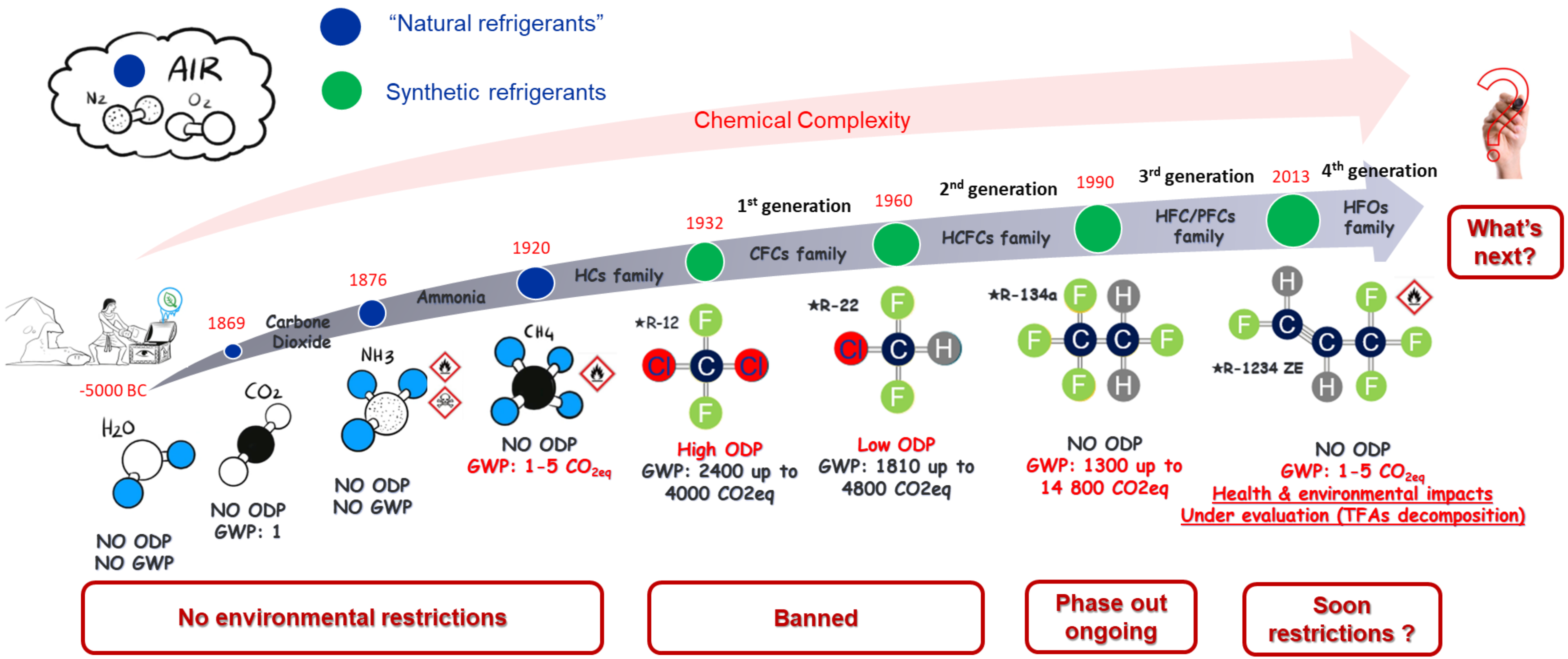
R404a/R507a & R448a

From few kW to 1MW+ of cooling & refrigeration technology installed on the LHC in 15 years !!!

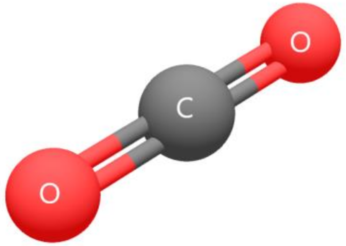
Why CO2 and not another fluid?

ODP: Ozone depletion potential
GWP: Global Warming Potential
TFAs: Trifluoroacetic acids being part of the PFAS “forever chemicals”

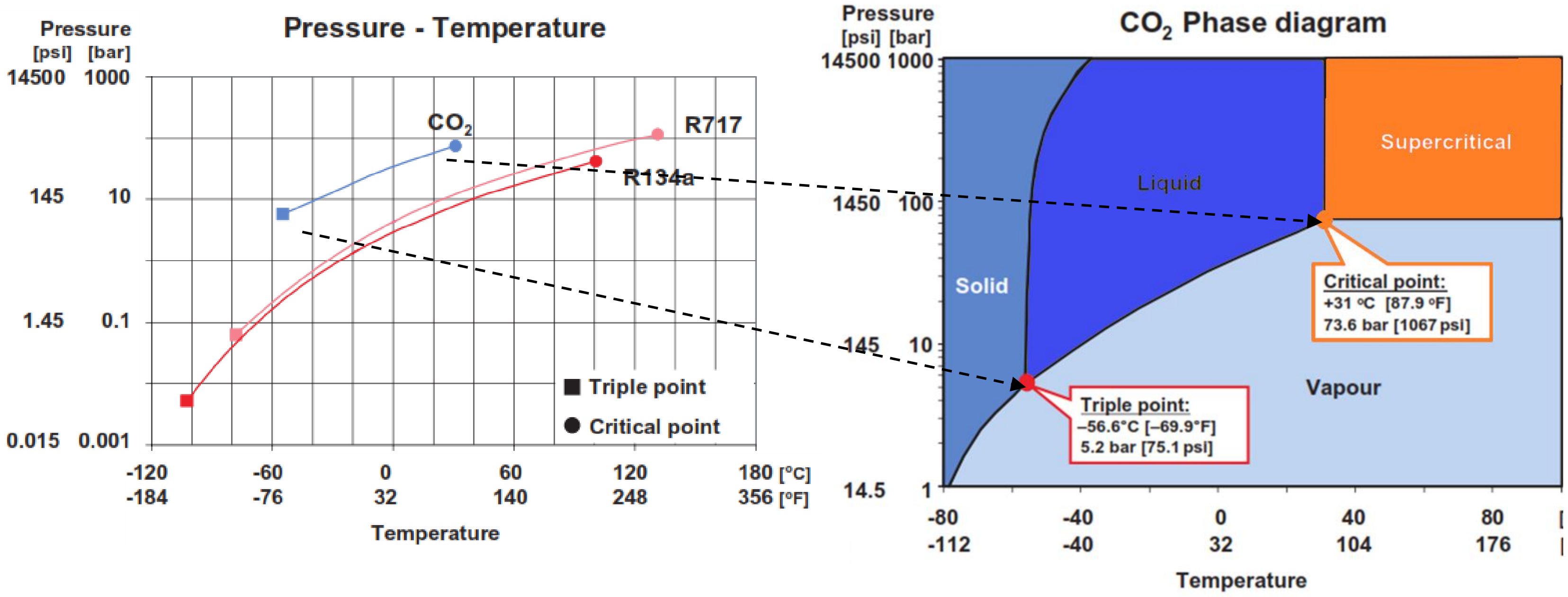
1. CO2 as refrigerant History & Families

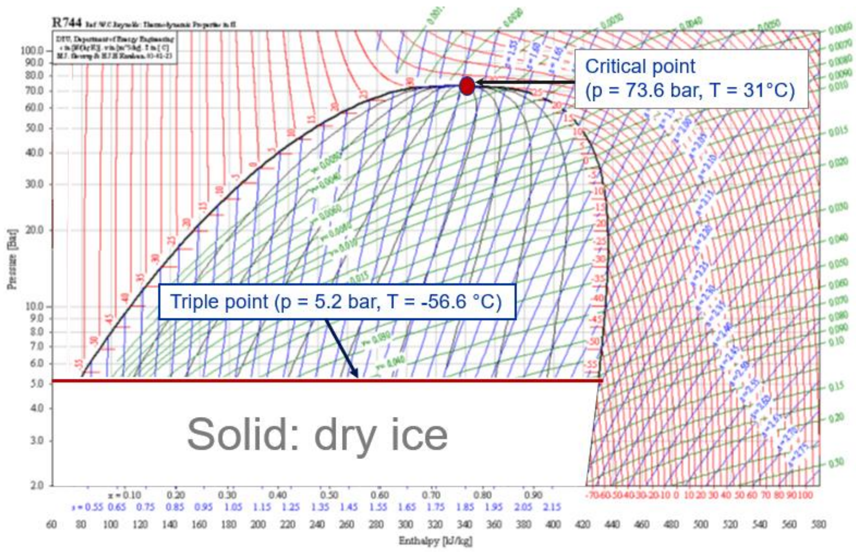


Why CO2 and not another fluid?



2. CO2 thermodynamical properties

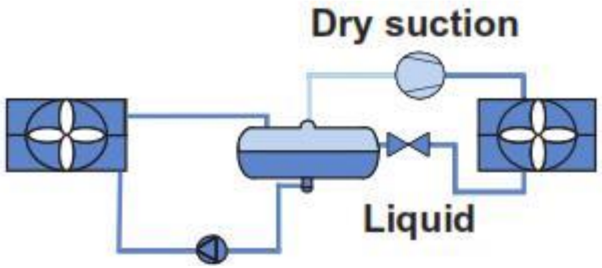




GOOD QUALITIES AS REFRIGERANT:

- High reduced pressure
- High vapor/liquid density ratio
- Low viscosity
- Small surface tension (=small bubble size, i.e. high heat transfer coefficient)
- High latent heat of evaporation (specific enthalpy) (=can absorb large heat quantities)

Why CO2 and not another fluid?



3. CO2 Optimized design & ressources management

Piping sizing

	Refrigerant			R 134a		R 717		CO_2	
	Capacity	kW	[TR]	250	[71]	250	[71]	250	[71]
"Wet return" line	ΔT	K	[F]	0.8	[1.4]	0.8	[1.4]	0.8	[1.4]
	Δp	bar	[psi]	0.0212	[0.308]	0.0303	[0.439]	0.2930	[4.249]
	Velocity	m/s	[ft/s]	11.0	[36.2]	20.2	[66.2]	8.2	[26.9]
	Diameter	mm	[inch]	215	[8.5]	133	[5.2]	69	[2.7]
	Area "Wet return"	mm²	[inch²]	36385	[56.40]	13894	[21.54]	3774	[5.85]

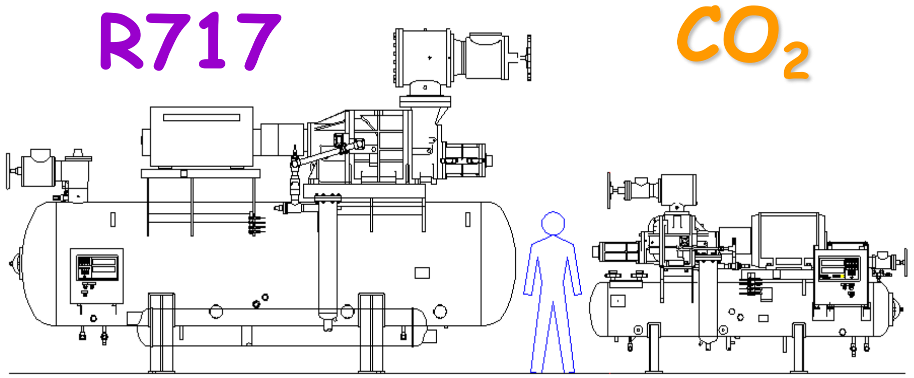
"Liquid" line	Velocity	m/s	[ft/s]	0.8	[2.6]	0.8	[2.6]	0.8	[2.6]
	Diameter	mm	[inch]	61	[2.4]	36	[1.4]	58	[2.3]
	Area "liquid"	mm²	[inch²]	2968	[4.6]	998	[1.55]	2609	[4.04]
Total pipe cross section area	Area "Wet return"	mm²	[inch²]	39353	[61.0]	14892	[23.08]	6382	[9.89]
Liquid cross section area		%		8		7		41	

L_{eqv} = 50 [m] / 194 [ft] - Pump circ.: n_{circ} = 3 - Evaporating temp.: TE = –40[°C] / –40[°F]

Compressor displacement

Refrigerant			R 134a		R 717		CO_2	
Refrigerant capacity	kW	[TR]	250	[71]	250	[71]	250	[71]
Required compressor displacement	m³/h	[ft³/h]	1628	[57489]	1092	[38578]	124	[4387]
Relative displacement	-	-	13.1		8.8		1.0	

Evaporating temp.: TE = –40[°C] / –40[°F]
Condensing temp.: TE = –15[°C] / –5[°F]



Why CO2 and not another fluid?

4. Environmental performances: Targeted carbon footprint on direct emission

ATLAS Savings: about 20 000Teq CO2/year

CMS Savings: about 20 000Teq CO2/year

ATLAS Current Status Primary loop

Refrigerant	Refrigerant familly	GWP potential	Circuit or equipment	Cooling power (kW)	Refrigerant mass (kg)	Direct emission (eq TCO2)
R410a	HFC	[illegible]	ATLAS Chiller USA15[(1)]		3	0
R404a	HFC	[illegible]	ATLAS Chiller 160 kW Thermosiphon[(1)]		180	271
R23	HFC	14800	ATLAS Chiller 2 60 kW Thermosiphon[(1)]		40	0
R134a	HFC	[illegible]	ATLAS TILE TEST (186/9a)		2	0
R134a	HFC	[illegible]	ATLAS TILE TEST (186/9c)		2	0
R134a	HFC	1430	ATLAS SR1 Mono 2 Primary		[illegible]	0

[(1)] will be decommissionned and replaced by the R744 Primary loop during LS3

271 eqTCO2

ATLAS Current status Secondary loop

Refrigerant	Refrigerant familly	GWP potential	Circuit or equipment	Cooling power (kW)	Refrigerant mass (kg)	Direct emission (eq TCO2)
C2F6	PFC	[illegible]	ATLAS SR1 Blend Secondary 2[(1)]		[illegible]	0
C3F8	PFC	8830	ATLAS SR1 Blend Secondary[(1)]		[illegible]	0
C3F8	[illegible]	8830	ATLAS Evap UX15[(1)]		[illegible]	5890
C3F8	PFC	8830	ATLAS SR1 Evap*		80	0
C3F8	PFC	8830	ATLAS 60 KW Thermosiphon[(1)]		1500	362
C6F14	PFC	9300	ATLAS Brine Thermosiphon[(1)]		6500	4650
C6F14	PFC	9300	ATLAS Cables UX15		3340	2325
C6F14	PFC	9300	ATLAS SR1 Mono Secondary		50	0
C6F14	PFC	9300	ATLAS TRT UX15[(1)]		3000	9300
C6F14	PFC	9300	ATLAS SR1 Mono 2 Secondary		100	500

[(1)] will be decommissionned and replaced by the R744 Primary loop during LS3

20201.6 eqTCO2

ATLAS R744 Primary loop forecast

Refrigerant	Refrigerant familly	GWP potential	Circuit or equipment	Cooling power (kW)	Refrigerant mass (kg)	Direct emission (eq TCO2)
R744	Natural	1	ATLAS Pixel End cap (PEC) ATLAS Pixel barrel (POB) ATLAS Pixel Inner system (PXI) ATLAS Strip end cap (SEC) ATLAS Strip barrel (SRB) ATLAS (HGTD)	380	1200.00	0.2

ATLAS CO2 "2PACL" secondary loop forecast

Refrigerant	Refrigerant familly	GWP potential	Circuit or equipment	Cooling power (kW)	Refrigerant mass (kg)	Direct emission (eq TCO2)
CO2	Natural	1	ATLAS Pixel End cap (PEC) ATLAS Pixel barrel (POB) ATLAS Pixel Inner system (PXI) ATLAS Strip end cap (SEC) ATLAS Strip barrel (SRB) ATLAS (HGTD)	380	12000.00	2.4

2018 Data from LHC operation

Why CO2 and not another fluid?

5. Environmental performances: Targeted carbon footprint on <u>indirect emission</u>

1. Detailed technical bench mark benchmark to list potential efficient compressor candidates
   ➔ **from 2018 to 2020**

2. Refrigeration concept development and performances evaluation on test benches
   ➔ **from 2020 to 2023**

3. Validation and implementation of the final solution based on a **Total Cost of Ownership** approach on the LHC lifetime operation (2042)
   ➔ **from 2023 to 2026**

➔ **Despites more expensive, CERN went for the most efficient proposed solution!**
18% energy savings representing a total of 162 MWh on a monthly base for ATLAS + CMS

Why CO2 and not another fluid?

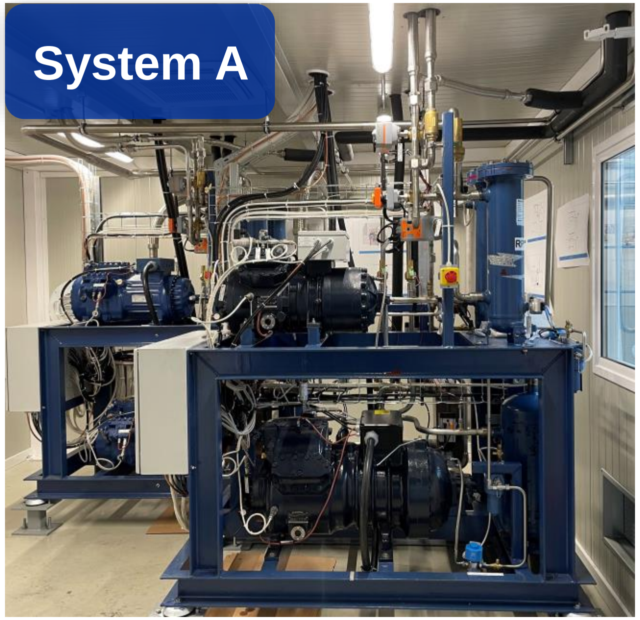
6. Environmental performances: Targeted carbon footprint on indirect emission

Possibility of non-negligible subsidies of the Program ECO21 from SIG aiming to reduce energy consumption with any kingd of simple, fast solutions ➔

Valid for any kind of retrofit, optimisation of refrigeration, cooling and ventilation systems

Under evaluation

Up to 40 CHF by TCO2 eq saved on a yearly based going until the life time expectation of the system!!

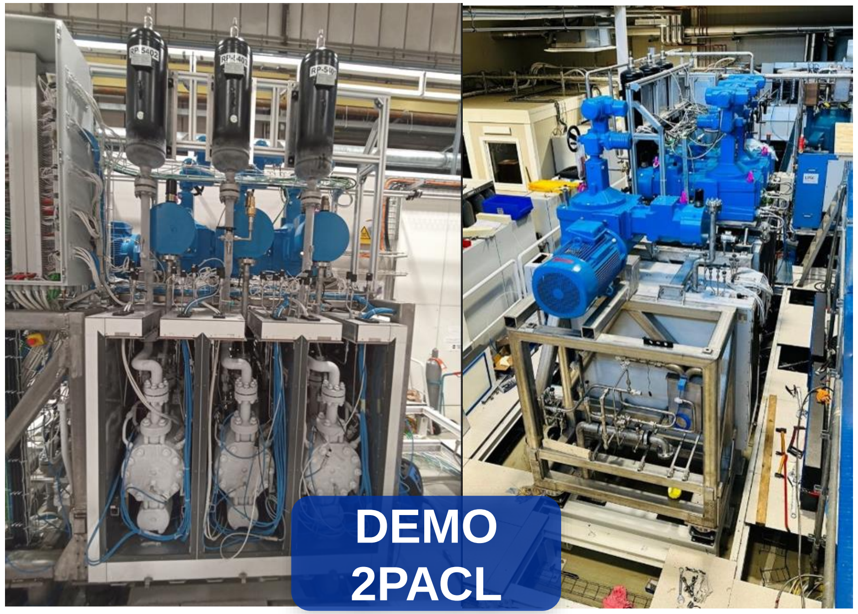

System A


System C


Construction workshop


System B


CMS Final System site
compact
Under Construction


DEMO 2PACL

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