CERN and the Environment Town Hall meeting Emissions

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CEPS
CERN Environmental Protection Steering Board

GHG Emissions - Scope 1

Scope 1: direct emissions resulting from an organisation's facilities and vehicles.

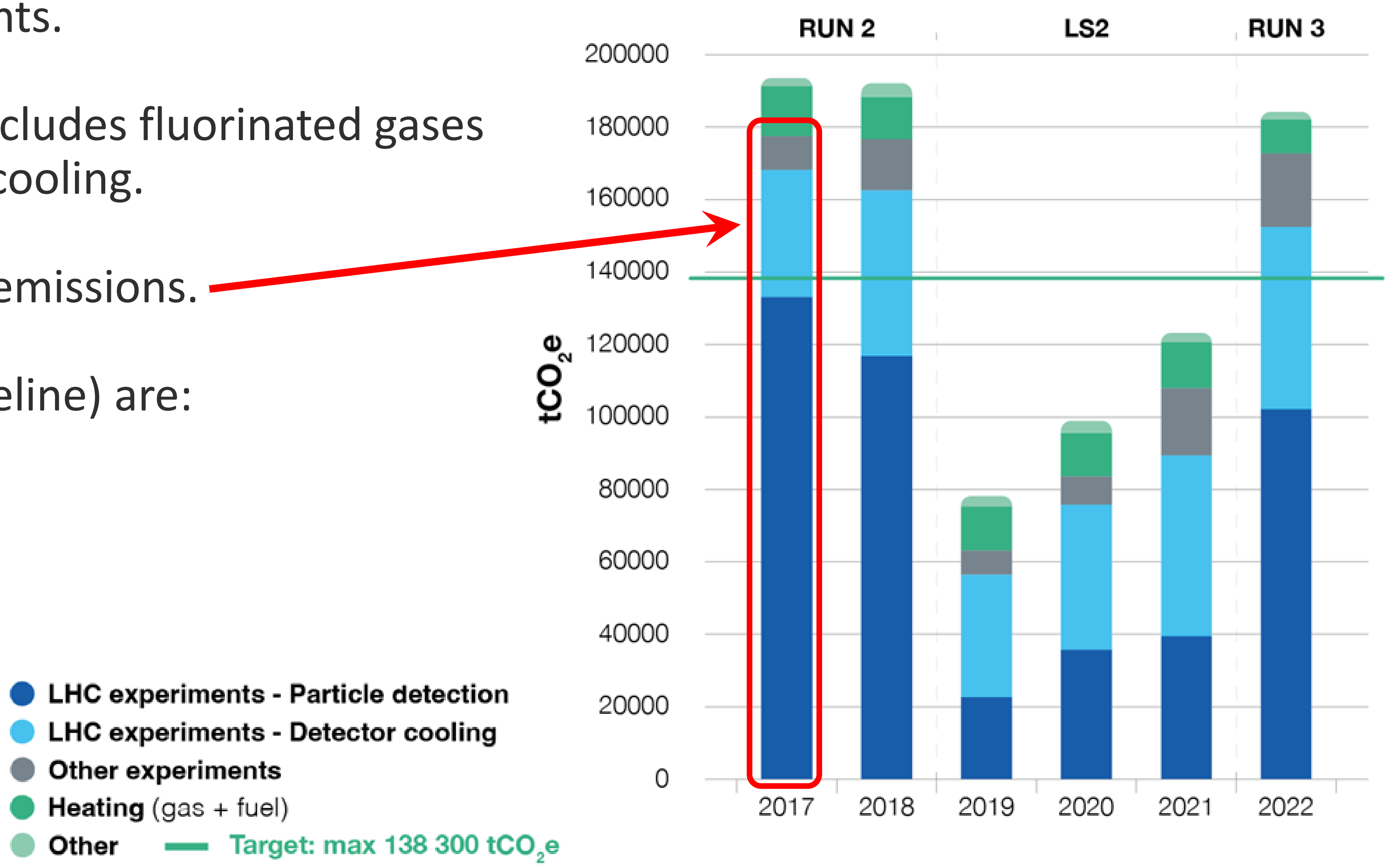
Approximately 90% come from the experiments.

A wide range of gas mixtures is used which includes fluorinated gases (F-gases) for particle detection and detector cooling.

This account for about 78% of CERN Scope 1 emissions.

CERN's objectives of reduction wrt 2018 (baseline) are:

- **Horizon 2025: -28% by the end of Run 3**
- **Horizon 2030: -50%**



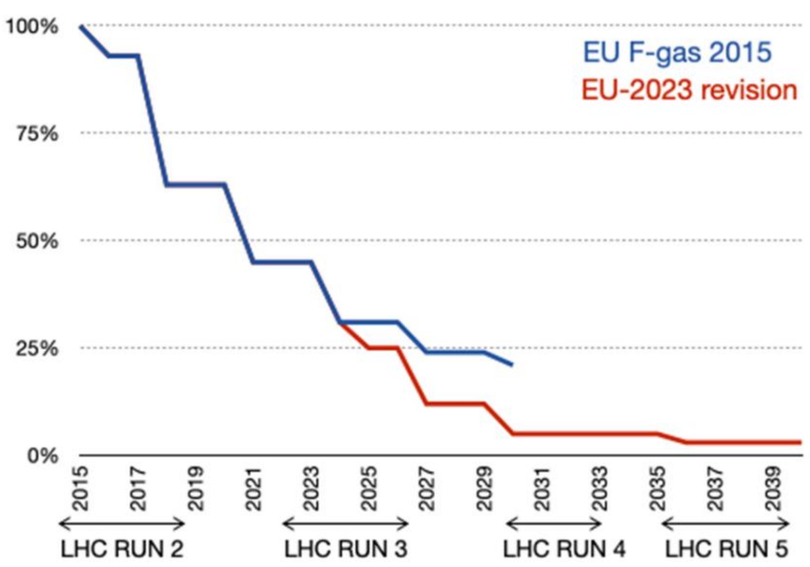
CERN F-gas policy

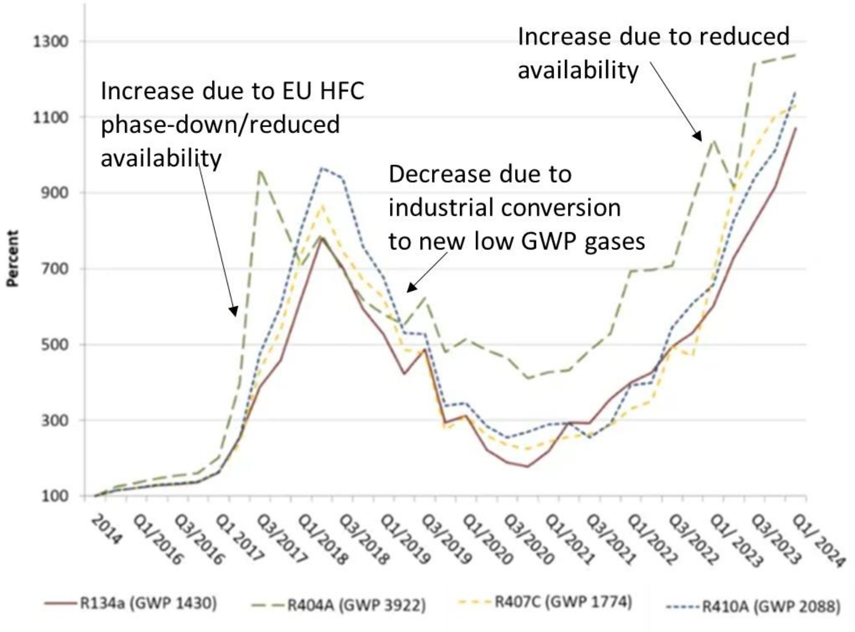
CERN has adopted an F-gas policy which is in line with the content of "F-gas regulations"

For reference, the key principles of EU517/2014 are:

- **Limiting the total amount** of the most important F-gases that can be sold from 2015 onwards. By 2030, it limits the use to 1/5 of 2014 sales
- **Banning the use of F-gases** in new equipment where less harmful alternatives are available
- **Preventing emissions of F-gases** from existing equipment by requiring checks, proper servicing and recovery of gases

The new EU Regulation (2023) calls for the total elimination of HFCs by 2050



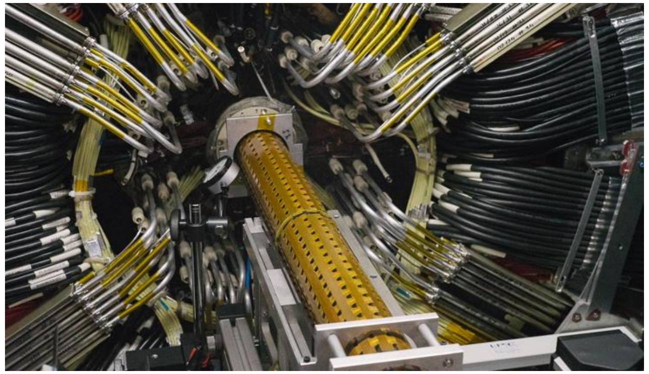


Also important to consider new regulations concerning PFAS

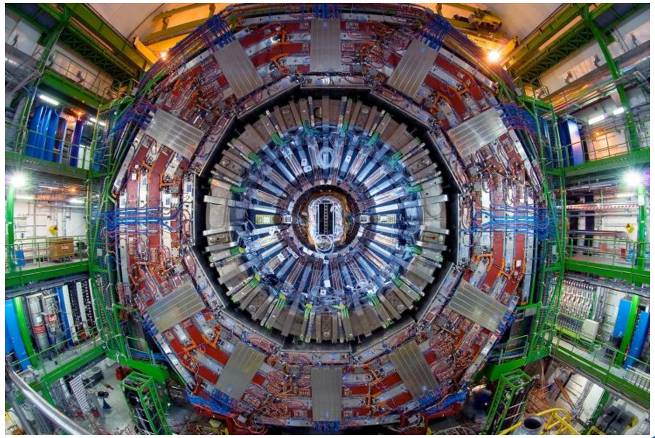
Where/why are GHGs used at CERN?

Gas used	Reason to use	Detector
R410a (GWP 1430)	Cool down to prevent self-heating and annealing behaviour	Silicon detector
R404a (GWP 22800)		
R23 (GWP 12400)		
C_3F_8 (GWP 8830)		
C_6F_{14} (GWP 9300)		
R134a (GWP 1430)	Containment of charge Rate capability	Resistive Plate Chamber
SF_6 (GWP 22800)		
CF_4 (GWP 7390)	Mitigation of ageing effects	Cathode Strip Chamber
		Multi Wire Proportional Chamber
	Time resolution	Micro Pattern Gaseous Detector
	Cherenkov radiator	Cherenkov detector
C_4F_{10} (GWP 8860)		

Detector cooling

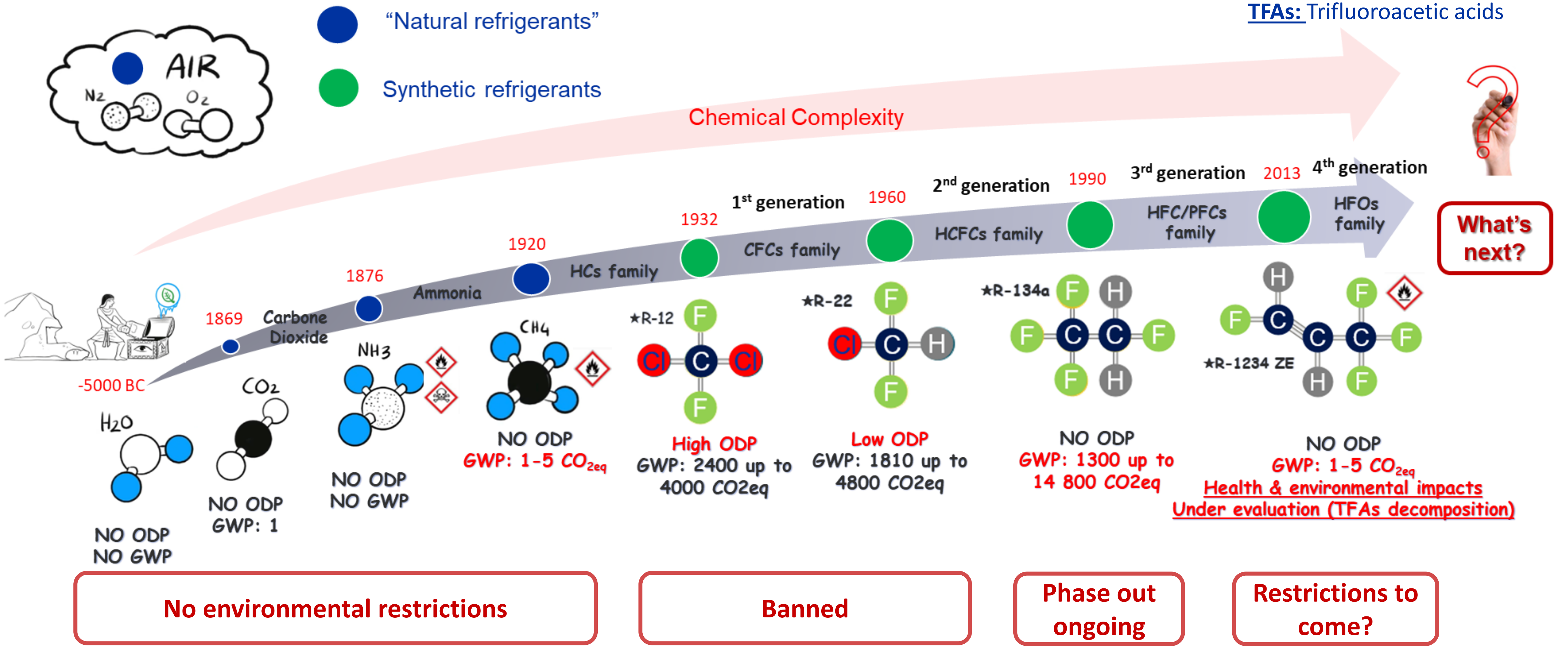


Particle detection



Refrigerant families and history

ODP: Ozone depletion potential
GWP: Global Warming Potential
PFAS: "Forever chemicals"
TFAs: Trifluoroacetic acids



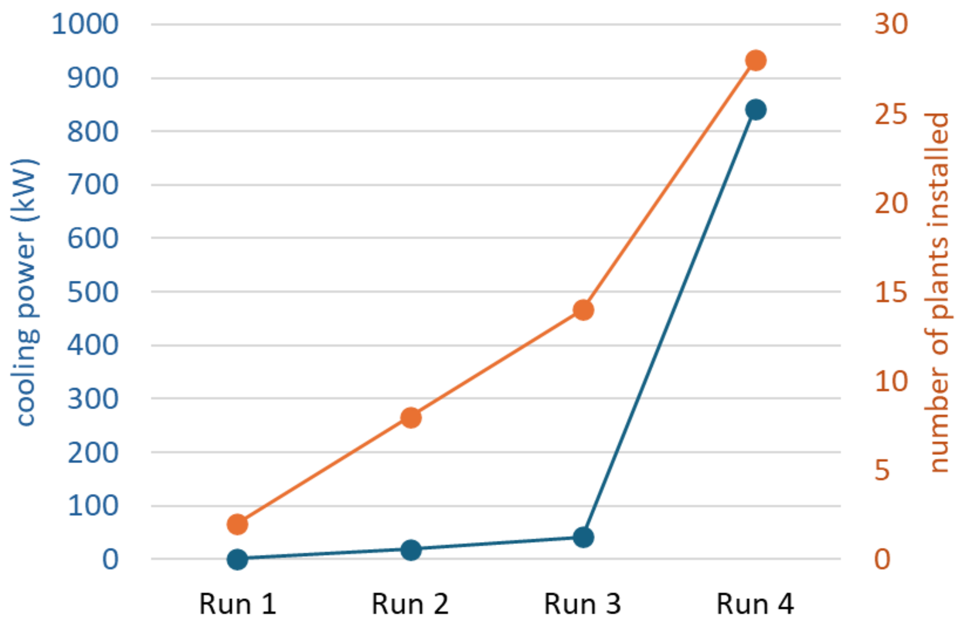
Strategies: detector cooling

The CO_2 systems' higher operating pressures presented early challenges compared to other commercial refrigerants, now solved thanks to technological developments.

Why CO_2 and not another fluid?

- High reduced pressure
  → High vapour/liquid density ratio → low boiling flow pressure drops
- Low viscosity
  → low liquid flow pressure drop → smaller pipe diameter
- Low surface tension
  → small bubble size → high heat transfer coefficient
- High latent heat of evaporation (specific enthalpy)
  → can absorb large heat quantities

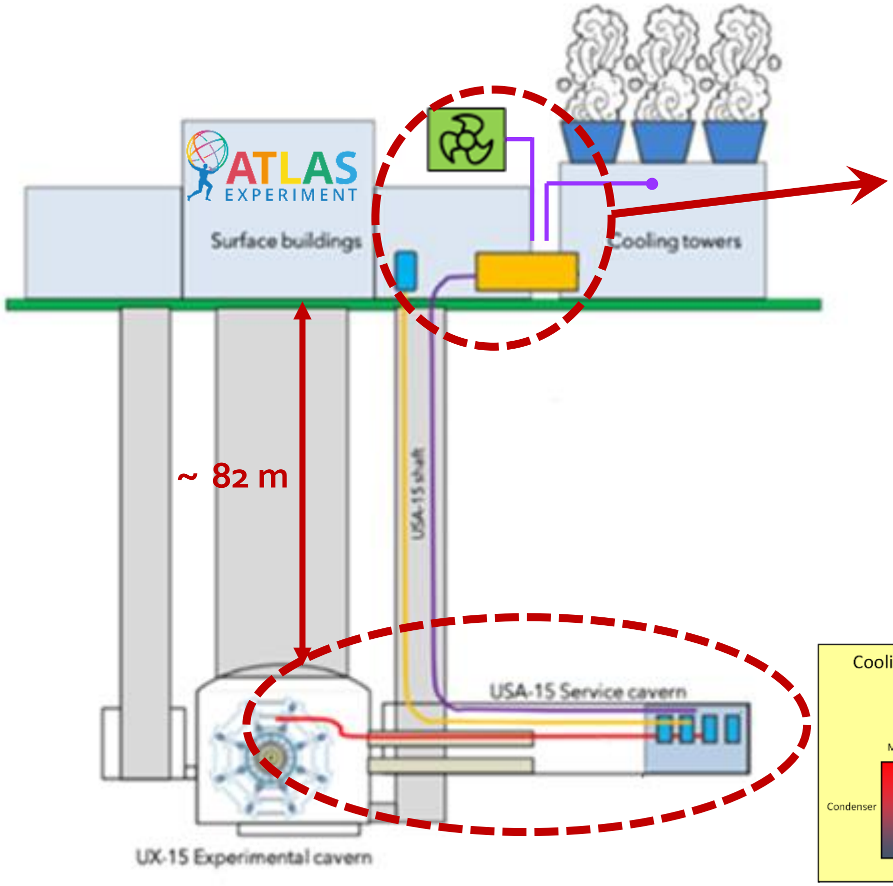
CO_2 cooling systems evolution at CERN



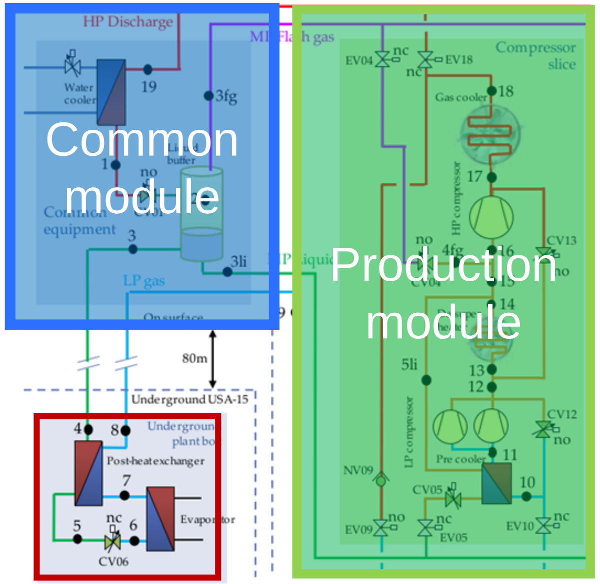
❑ CO_2 cooling will bring about a reduction of direct emissions of some 40 ktCO_2e/year

✓ ***This will allow CERN to achieve its objective at horizon 2025***

The new detector cooling architecture



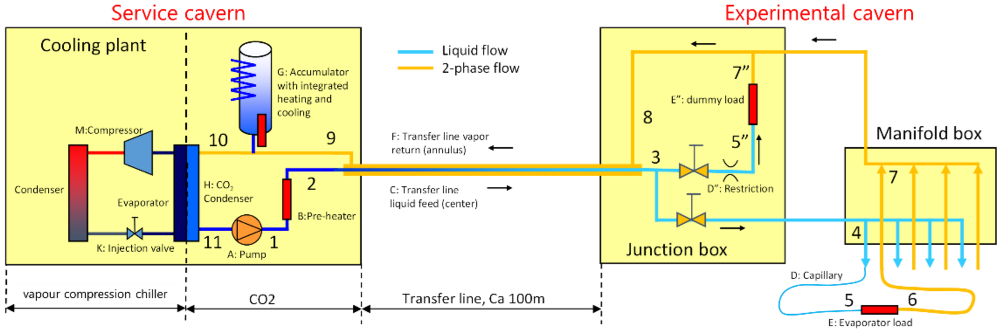
Refrigeration production choice: "R744 Primary system"



First set (out of 11) of R744 chillers being installed @ CMS

First (out of 15) CO_2 2PACL loop received @ CERN

Cooling loop choice: "2PACL system"



Particle detection: why do we have GHG emissions?

GHGs are used because needed to achieve specific detector performance and/or long-term stability

- ➢ R&D for "new" ecofriendly gases

Each gaseous detector has a dedicated gas system that can recycle the gas mixture up to 100% limiting the emissions almost to zero

Limiting factors to gas recirculation are:

❑ Leaks at detector level (about 70% of total emissions)

Mainly concerning ATLAS and CMS RPC detectors

- ➢ Leak repair campaigns

❑ Detector design constrains (about 20% of total emissions)

Air intake at detector level and/or accumulation of impurities under radiation

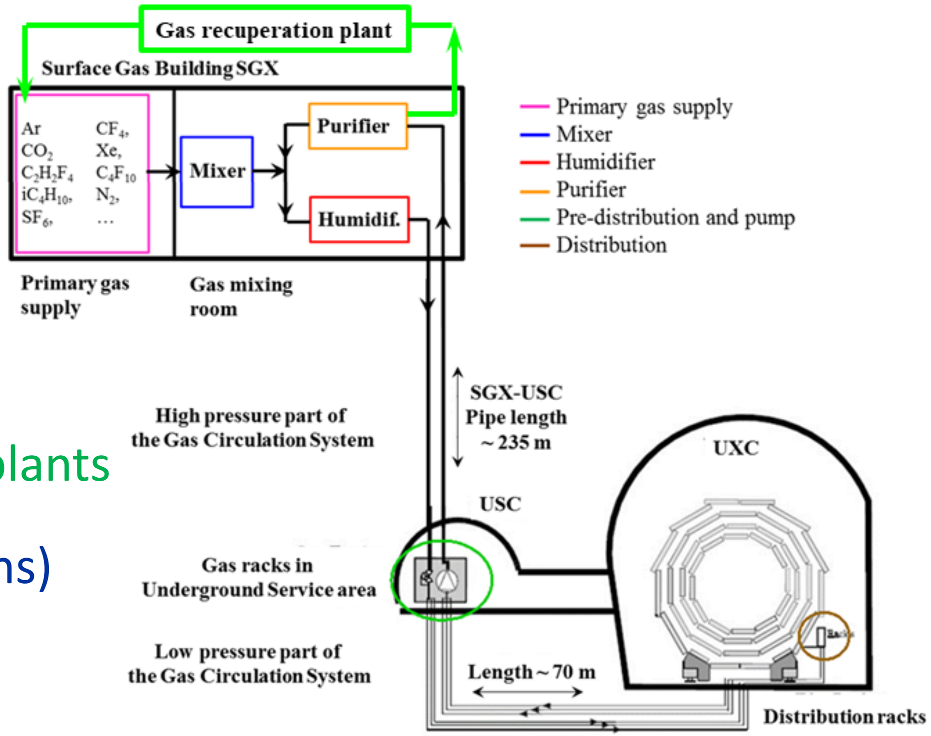
- ➢ Gas systems optimization and development of gas recuperation plants

❑ Small experiments and laboratory setups (about 10% of total emissions)

Small installations where gas recirculation was difficult to implement

- ➢ Development of new small scale gas recirculation systems

Gas recirculation and recuperation systems

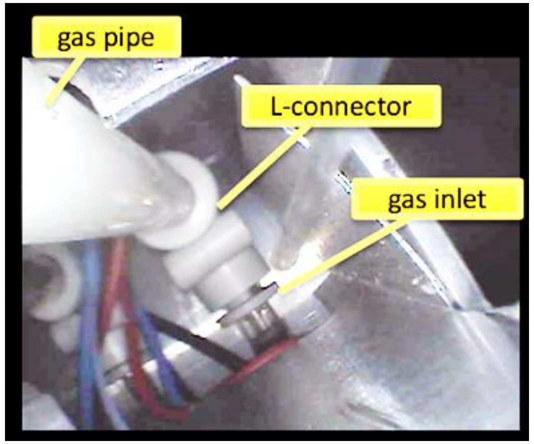


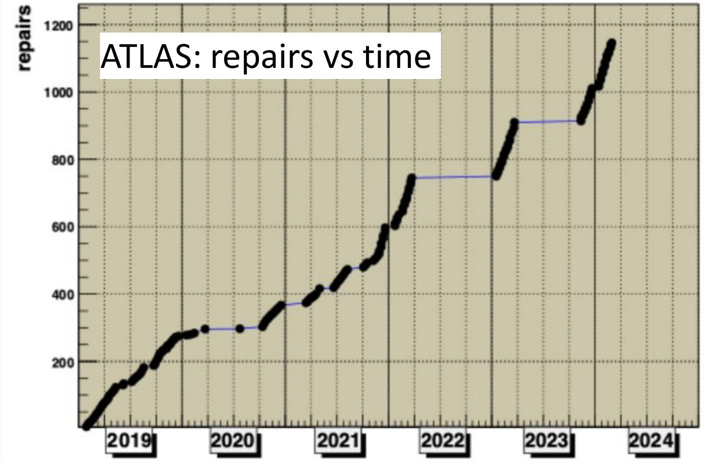
RPC leaks issue and repair campaigns (from ATLAS and CMS RPC teams)

8000 gas inlets in total per experiment, often with very difficult access

Development of leaks: reasons

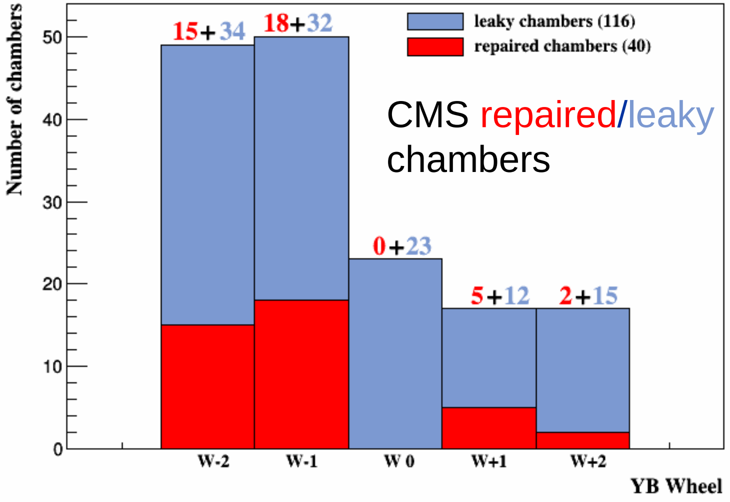
- Gas inlets tend to crack due to inborn fragility
- LD Polyethylene pipes became brittle/deteriorated





Works done during LS2

- Massive repair campaign
- Gas recirculation system to minimise pressure fluctuations to <~0.1 mbar
- Non-return valves installed at the chamber output (ATLAS)



Gas leak repair campaigns

- Planned during next YETSs and LS3
- Standard repair technique: gluing or replacement of cracked gas inlets or pipes
  - Trigger holes will be addressed first: fundamental to restore the trigger capability
- Resin injection in service boxes to consolidate gas inlets (ATLAS)

Gas recuperation plants

System designed to extract the valuable component from the gas mixture for recuperation and reuse allowing for a further reduction of gas emissions

Complexity:
Gas mixtures used are so specific that industrial systems do not exist

- ❑ **New system developed for $C_2H_2F_4$ (RPC detector systems)**
  - ✓ Emissions reduced by 15 ktCO_2e/year (CMS RPC during 2024)
- ❑ **Substantial improvements of existing systems for CF_4 and C_4F_{10}**
  - ➢ Potential reduction of emissions by 1.5 ktCO_2e/year
- ❑ **Development of other recuperation plants (SF_6 and new R134a)**
  - ➢ Potential reduction of emissions by 5-6 ktCO_2e/year

R134a recuperation plant installed at CMS

Reducing GHGs consumption also ensures detector operation is less subject to market crisis affecting price and availability

Ecofriendly alternatives for particle detectors

New ecofriendly liquids/gases have been developed for industry as refrigerants and HV insulating medium.

Complexity → not straightforward for detector operation

~20-30 years ago, it was time to get rid of ODG gases
There was not the level of awareness of the risk of using GHGs
(gaseous detectors were conceived with these gases)

ODG
Ozone Depletion

R13B1 ($CBrF_3$)
ODP 10
GWP 6900

→

GHGs
Greenhouse gases

R134a ($C_2H_2F_4$)
ODP 0
GWP 1430

→

"ECO" gases

Hydro Fluoro Olefines (HFO)
3M™ Novec™
- PFAS

HFO with Chlorine
ODP 0
GWP < 10

→

Natural gases

CO_2
Hydrocarbons
…
ODP 0
GWP 1

Now it is time to address the usage of GHG worldwide and the potential threat of PFAS

New detector collaborations are addressing this recent new challenge for gaseous detectors:

ECOGAS@GIF++ collaboration for RPC gas mixture, DRD1, new detector design, new FEB, …

Ecofriendly alternatives for particle detectors

Two different challenges:

Present: find an ecofriendly mixture for currently installed detectors

Constraints: not possible to change FEB, geometry, HV cables, …

Today's mitigation strategies:

Dilution of currently used mixture with a neutral gas

- ✓ ATLAS RPC introduced 30 % CO_2 in 2023
- ✓ LHCb RICH2 introduced ~10% CO_2

Addition of ecofriendly gases to currently used mixture

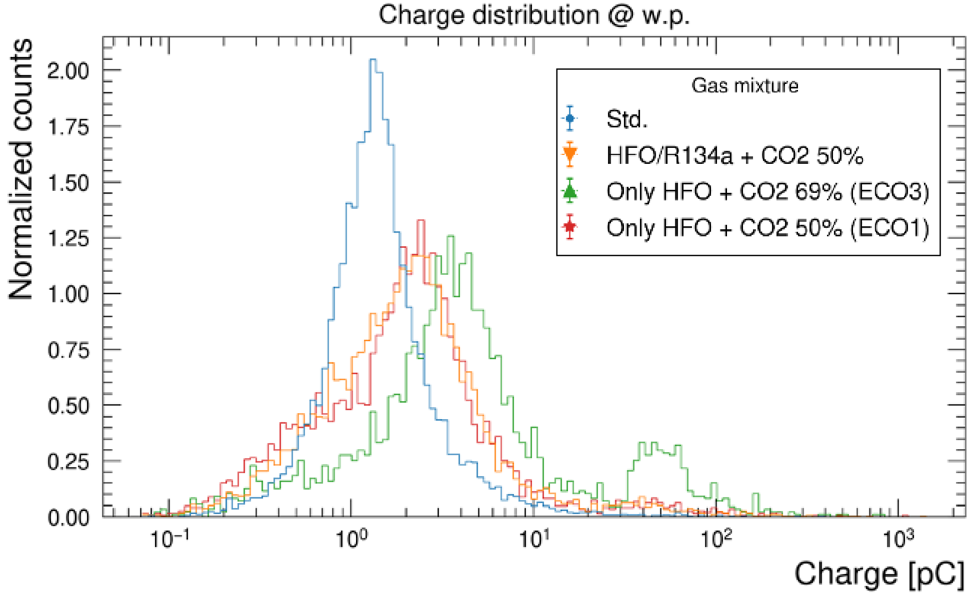
- ❑ HFO with addition of CO2/R134a most promising, but detector performance affected
- ❑ Cl-HFO shows good performance
- ❑ In both cases long-term effects to investigate

Future: find ecofriendly gas mixtures for future detectors

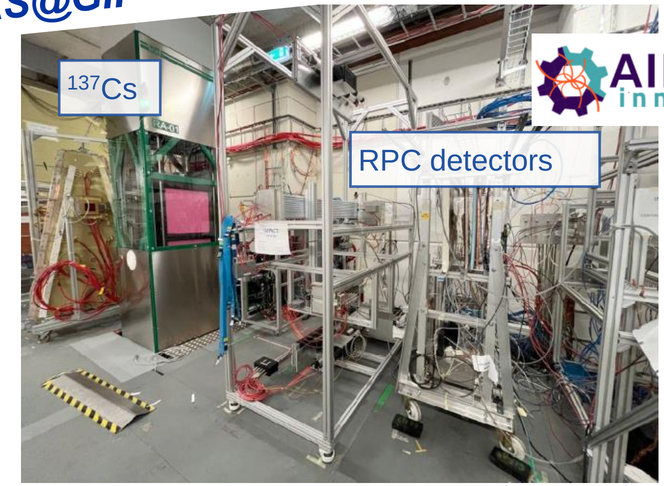
Advantages: possibility to design the detectors already with new gases

New FEB, new geometry, suitable cables, …

More leak tight vessel/detectors would allow using Hydrocarbons



ECOGAS@GIF++ collaboration



Particle detection: where are we today?

Run 1 to Run 2:

Several gas system upgrades and an increased attention on GHGs usage

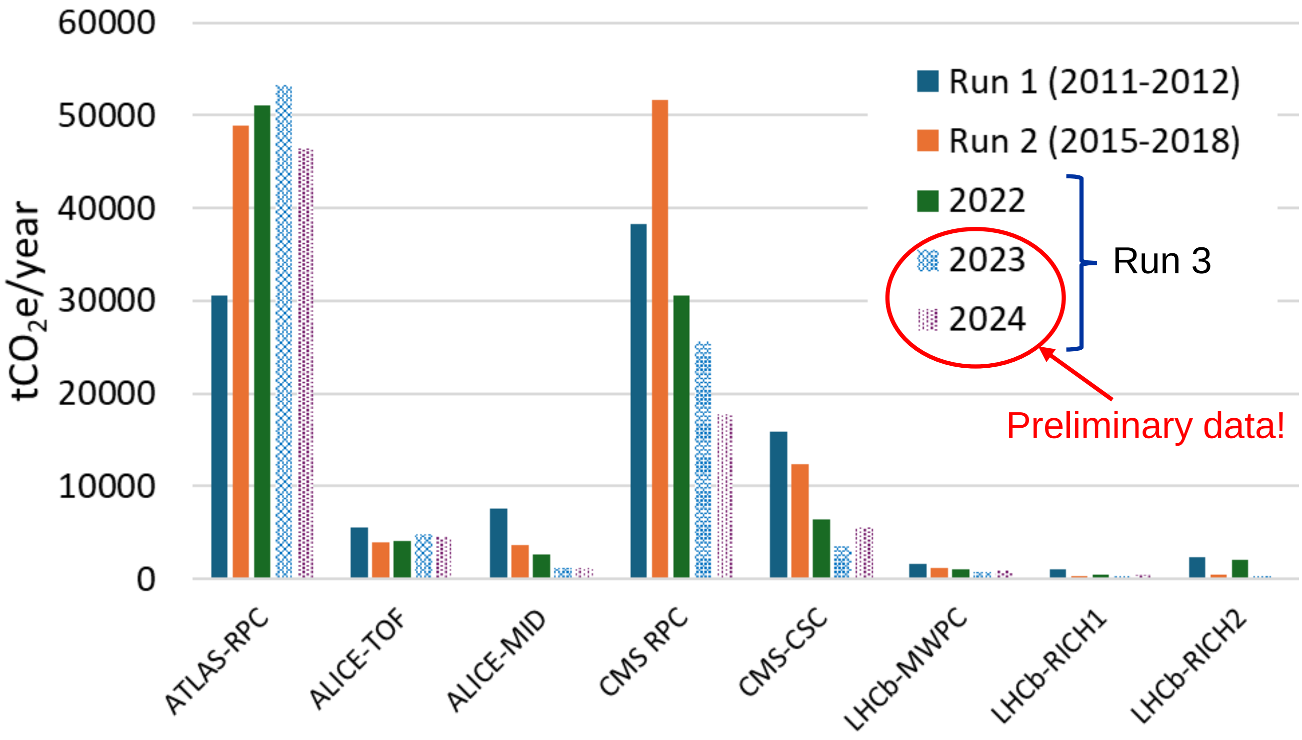
-40% GHG emissions excluding ATLAS and CMS RPC systems

ATLAS and CMS RPC systems: +35% increase of GHG emissions due to development of new leaks

Run 3 (preliminary):

ATLAS RPC started to use mixture "diluted" with 30% CO_2 → -7.5 ktCO_2e/year somehow compensated the appearance of new leaks

CMS RPC uses R134a recuperation plant and disconnected leaking chambers → -20 ktCO_2e/year but 15% of detectors disconnected



Conclusions

F-gas policy

- CERN F-gas policy is in line with “F-gas regulations” which aim to **limit the GHG usage**
- Decreasing the consumption makes detector operation less subject to crisis affecting price and availability

Detector cooling

- CO_2 is a natural refrigerant with outstanding properties down to -50 °C
- Studies ongoing for lower temperatures (< -60 °C) with Krypton

Particle detection

- Mitigation strategies are based on gas recirculation, gas recuperation and mixture dilution with inert gases
- Massive campaigns should address the leak problem in the ATLAS and CMS RPC during the upcoming (E)YETS/LSs
- Challenging to have a “full” replacement of currently used GHGs still during the HL-LHC operational period

Detector design

- It is fundamental to look not only at detector performance but also at the infrastructure
- More leak-tight vessel/detectors would allow using hydrocarbons or expensive ecofriendly gases

Horizon 2025: -28% by the end of Run 3

✓ Almost achieved considering the move to CO_2 cooling and the improvements in particle detection systems

Horizon 2030: -50%

❑ Requires continuous developments and improvements in particle detection (and a constant leak rate)

- Development of new gas recirculation and recuperation plants ongoing for GIF++, ALICE, ATLAS, CMS home.cern