EP-DT
Detector Technologies

R&D strategies for optimizing the greenhouse gas consumption at the CERN LHC experiments

R. Guida, B. Mandelli, G. Rigoletti
CERN EP-DT

Outline

- Greenhouse gases (GHGs) for particle detection
- CERN Strategies for optimizing GHGs usage
  - Results, new projects and plans
- Conclusions

Gaseous detector systems at LHC

- Very Large apparatus: detector volume from < 1 m^3 up to several 100 m^3
- High mixture flow
- Operational costs issue

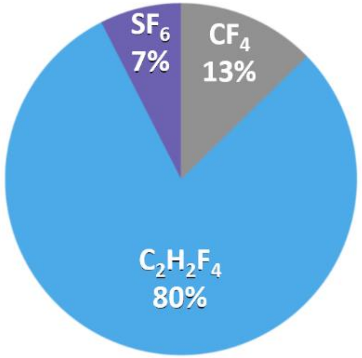
→ ***Optimization of gas usage needed! A lot of work already from the design phase.***

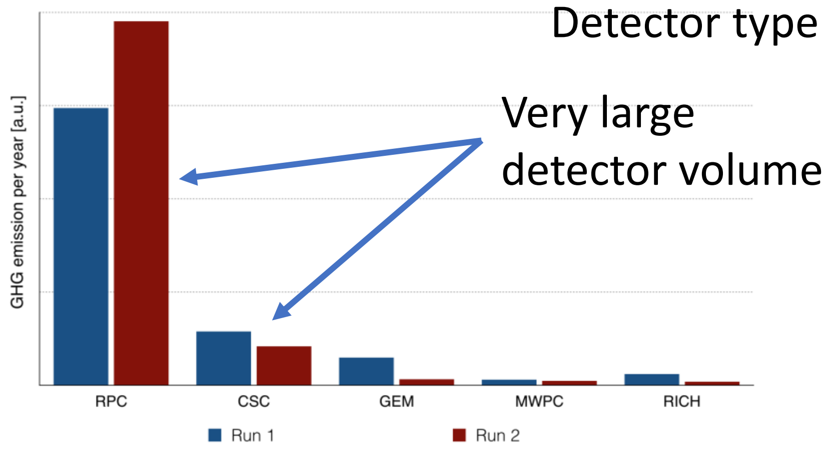
Nowadays increased attention on GHGs emissions: F-gas regulation aims in limiting emissions, GHGs availability, price, …

GHGs used at LHC experiments *and their relative contribution to emissions:*

GHGs like R134a ($C_2H_2F_4$), CF_4, SF_6, C_4F_{10}, … are used by several particle detector systems at the LHC experiments because **needed to achieve specific performance**

Gas	GWP - 100 y
$C_2H_2F_4$	1430
CF_4	6500
SF_6	22800

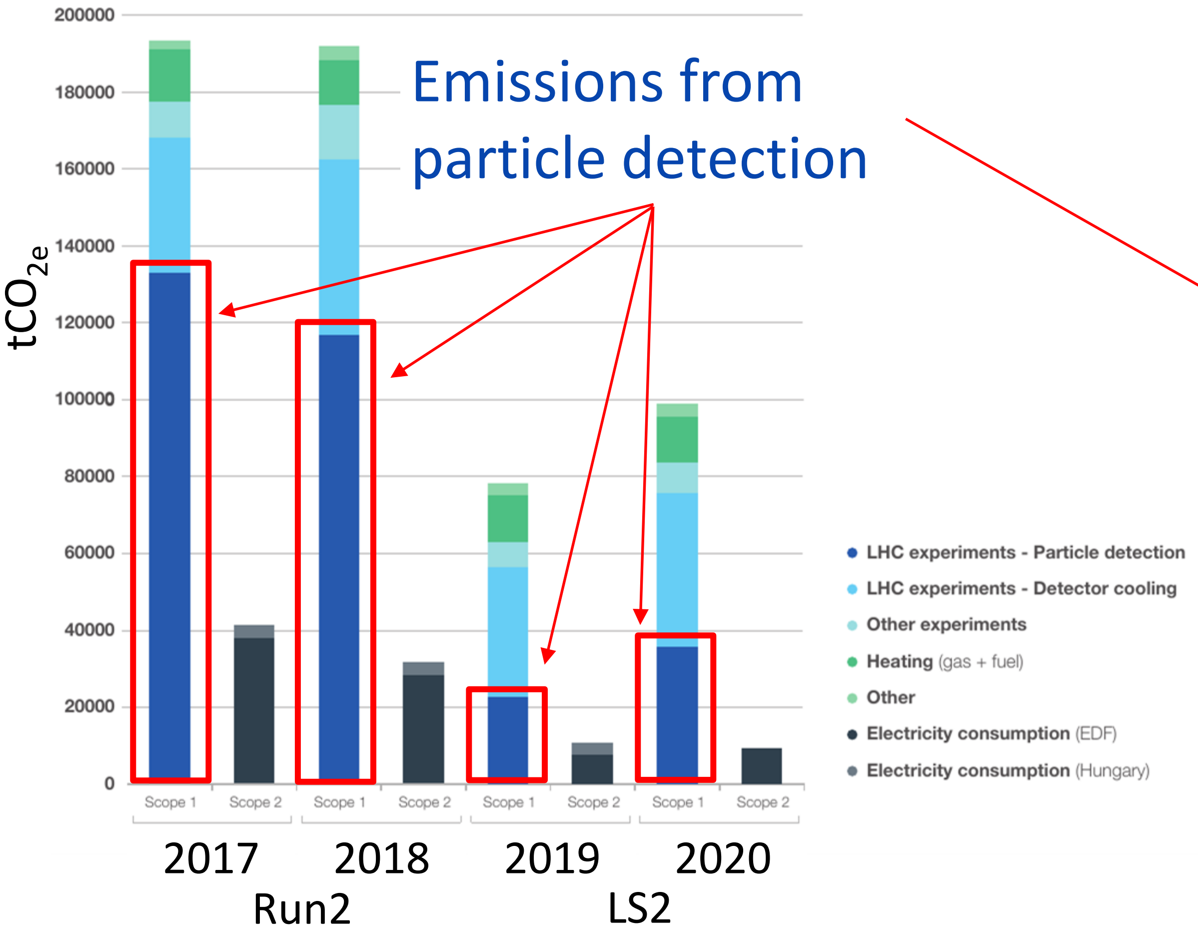




Of course, GHG usage in particle research is negligible wrt other activities.
However, GHG optimization is mandatory and it can secure operation over the LHC run period and reduce costs.

Greenhouse gas usage

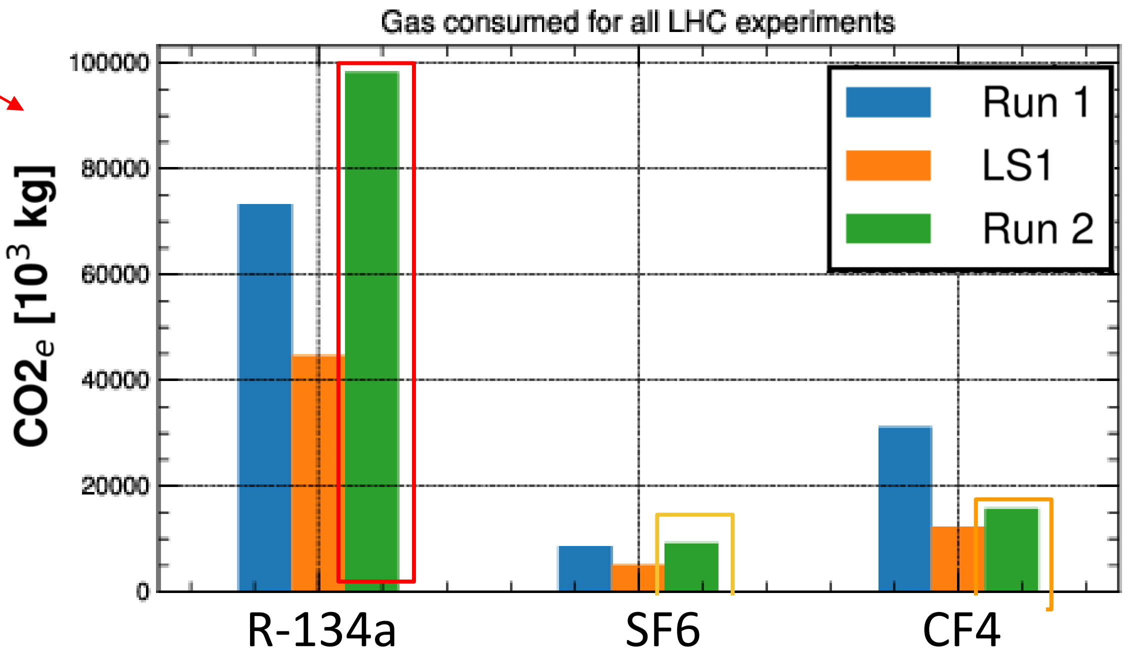
- [CERN Environment Report 2019-2020](#)
- [2021: CERN's Year of Environmental Awareness.](#)
- [CERN Environment workshop: 12 and 13 October 2022](#)



Total CERN emissions during 1 year of Run 2 ~ **200 000 tCO2e**

~ 50% from particle detectors → mostly due to leaks and operation

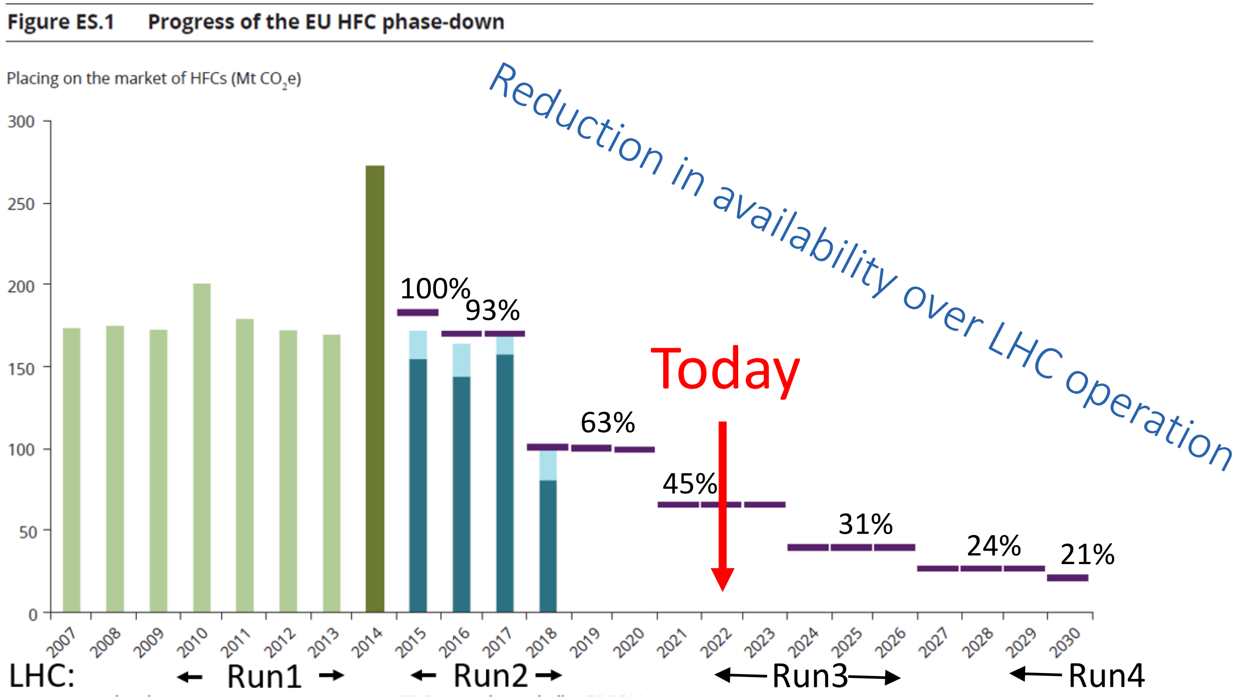
- **$C_2H_2F_4$/R-134a** biggest contributor → leaks from RPC detector
- **CF_4** → due to operation of CSC and RICH systems
- **SF_6** → Related to RPCs as R-134a



Greenhouse gas regulation

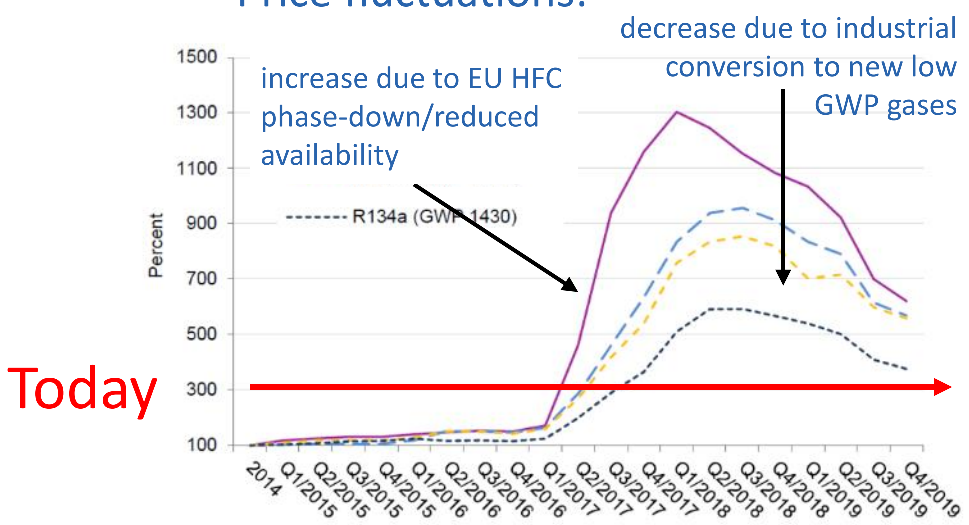
Due to the environmental risk, "**F-gas regulations**" started to appear. For example, the EU517/2014 is:

- **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.



HFC phase down: effects on HFC availability and prices

Price fluctuations:



Sources: European Environment Agency, Fluorinated greenhouse gases 2019 report
Öko Recherche report, March 2020 J. Kleinschmidt et al.

Goal: reduce F- gases consumption and emissions from particle detectors

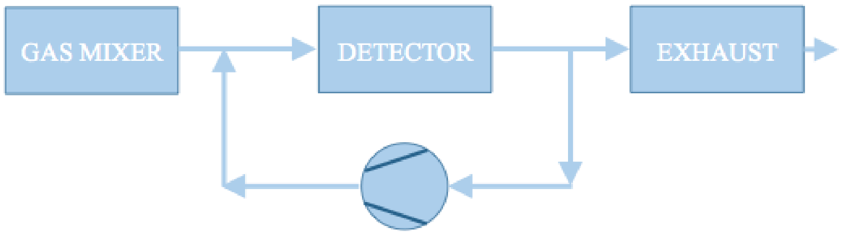
GHG Optimization: CERN Strategies

How to reduce greenhouse gas usage

- **Optimization of current technologies**
  - Gas recirculation
  - Particular attention to operation
  - Improved controls and monitoring
- **Gas Recuperation**
  - Membrane separation
  - Pressure swing
  - Cryogenic/cold separation
- **Alternative Gases**
  - New eco-friendly gases, HFOs, …
- **Gas disposal**
  - GHGs destruction

Optimization of current technologies

- All gas systems are designed to recirculate the gas mixture: average 90% gas recirculation → 90% reduction of consumption



Advantages:

- Reduction of gas consumption

Disadvantages:

- Complex systems
- Constant monitoring (hardware and mixture composition)
- Use of gas purifying techniques

- The remaining 10% is what we started to address from LS1. It is needed to compensate for:
  - Leaks at detector: 85 % (mainly ATLAS and CMS RPC systems)
  - 15% N_2 intake (CMS-CSC, LHCb-RICH1, LHCb-RICH2)

- Two remaining open mode systems upgraded to gas re-circulations from Run1 to Run2:
- ALICE-MTR: from Run1 to Run2: 75% GHG reduction
- LHCb-GEM: from Run1 to Run2: 90% GHG reduction

  → *For both detector systems:* ***Original investment largely paid back by gas cost saving during few years of operation***

- and laboratory setups:
- 2013: Development of "A portable gas recirculation unit" JINST 12 T10002
- 2020: Development of Gas recirculation systems for RPC detectors: from LHC experiments to laboratory set-ups - RPC2022

ALICE-Muon Trigger RPCs/MID

Mixture: **$C_2H_2F_4$ 89.7%, SF_6 0.3%**, iC_4H_{10} 10%

Detector volume: 300 liters (much smaller wrt ATLAS and CMS-RPC systems)

Therefore originally designed in open mode → upgraded to gas recirculation in 2015

From Run1 to Run2: 75% GHG reduction

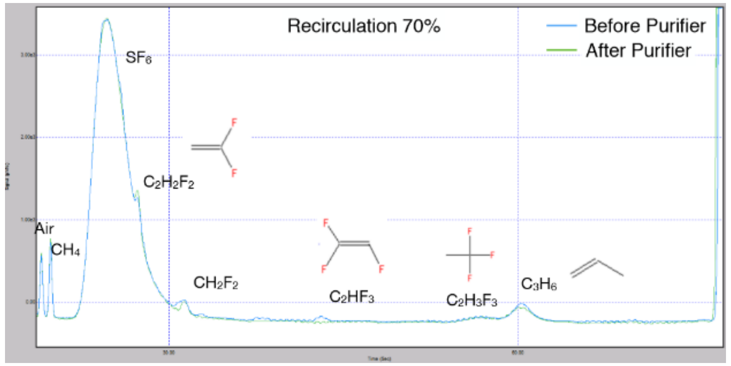
Original investment already largely paid back by gas cost saving during operation

RPC operated in slightly different conditions (higher pulse charge):

→ Impurities due to fragmentation of main gas components are visible

→ Closely monitored

→ Detector performance are not affected by gas recirculation



More details in
Gas mixture monitoring for the RPC at LHC (RPC2018)

LHCb-GEM example

mixture: **CF_4 40%**, Ar 45%, CO_2 15%
Detector volume: ~ 50 liters (but very high flow needed by the detector)
→ R&D for operation of large GEM detector systems with gas recirculation

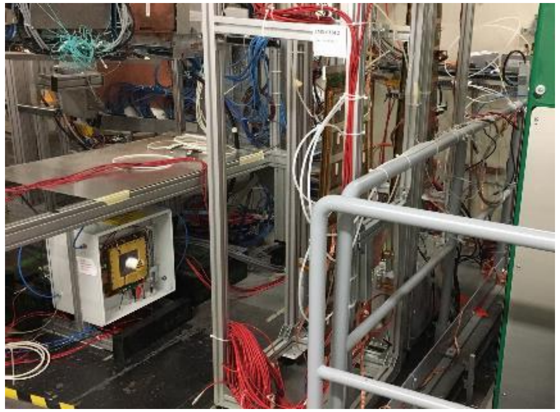
From Run1 to Run2: 90% GHG reduction

2013: Development of small gas recirculation systems for R&D
Started test in lab with radioactive source (GEM never operated in recirculation before)

2016-…: Validation continued at CERN Gamma Irradiation Facility

2016-…: LHCb-GEM upgraded to gas recirculation

"A portable gas recirculation unit" JINST 12 T10002



Gas mixture purification studies

Original investment already largely paid back by gas cost saving during operation

LHCb-GEM detector operation became more stable thanks to less frequent replacement of CF_4 cylinders

ATLAS and CMS RPC systems

Nowadays GHGs usage for particle detectors @ LHC is dominated by the large ATLAS and CMS RPC systems:

mixture recirculation is already almost at design level (85-90%) and today it is limited by leaks at detector level

Further optimization requires:

- **Fixing leaks at detector level**
  - Huge ongoing effort of RPC detector communities (ATLAS and CMS)
  - but critical/fragile gas connectors are extremely difficult to access
  - Good technical progress
- **Gas system upgrade to minimize any pressure/flow fluctuation**
  - → Goal: new upgrades to cope with observed fragility of some detector components
  - → Positive effects already visible at end of Run2:
    - Reduced leak developments at start-up
    - Pressure regulation improved by 70%
- **Minimize impact of cavern ventilation (tests in collaboration with EN-CV)**
- **Look for other external causes (vibrations, …)**
- **Detector R&D to validate higher recirculation fraction**
- **Tools to check detector and gas system tightness**

Optimization strategies

Optimization of gas systems → **Helps reducing gas emissions** / → **Affects detector performances**

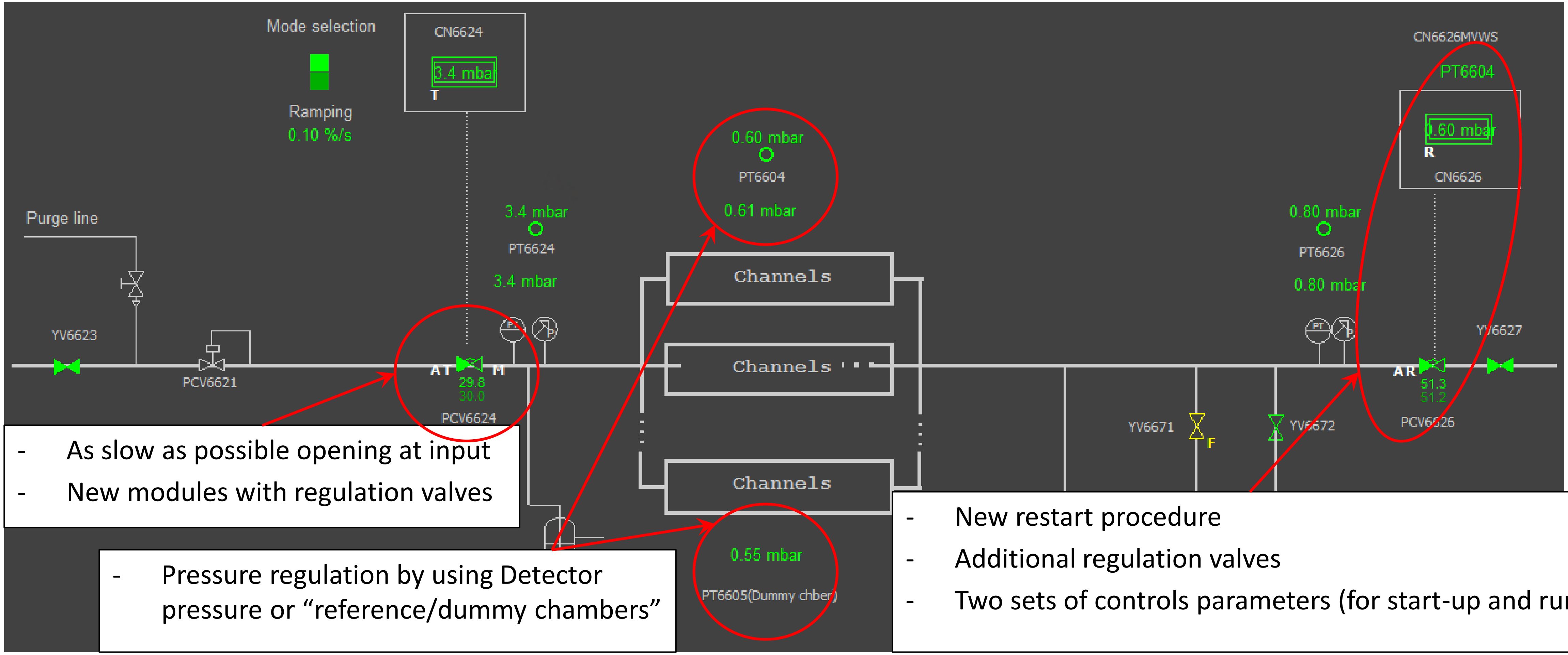
	Optimization strategy	Technical implementation	Goal	Examples
Direct effects	**Gas recirculation**	Mixture recirculation systems	Consumption reduction, detector performance	RPC, RICH, CSC, …
	Flow, Pressure regulation	Automatic regulation, PID controllers	Detector stability, leak reduction	RICH detectors, RPC leaks
	Software upgrades	Additional control features	Operation stability	All LHC gas systems during LS2 upgrades
Indirect effects	**Monitoring**	HMI, Control panels, dashboards	Anomaly detection	Impurities intake, malfunctioning of gas component
	Offline analysis	Data analysis	Deeper understanding of the dynamics	System startups, additional regulation valves when needed

Examples: RPC Gas system upgrade

Goal: minimize any chamber pressure/flow fluctuation to cope with observed fragility of some detector components

from some 0.1 mbar to ~ 0.1 mbar: **not an easy challenge**

Example of upgrades on **mixture distribution modules:**



- As slow as possible opening at input
- New modules with regulation valves

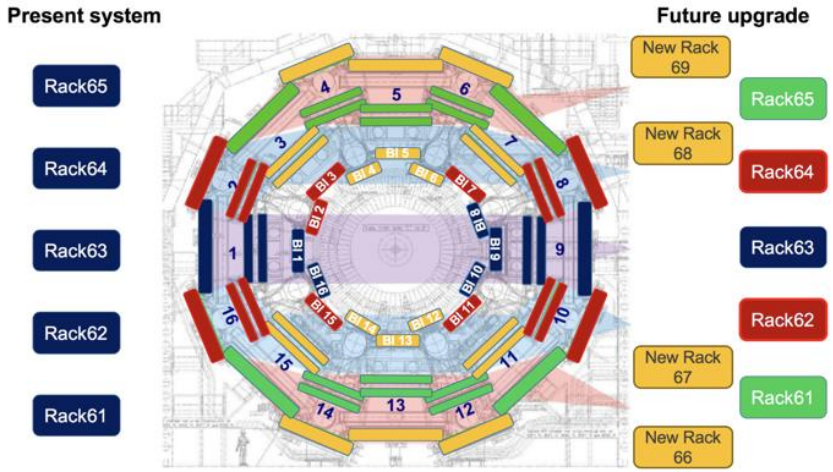
- Pressure regulation by using Detector pressure or “reference/dummy chambers”

- New restart procedure
- Additional regulation valves
- Two sets of controls parameters (for start-up and run)

Examples: ATLAS – RPC gas system

4 New distribution racks (i.e., from 5 to 9 modules):

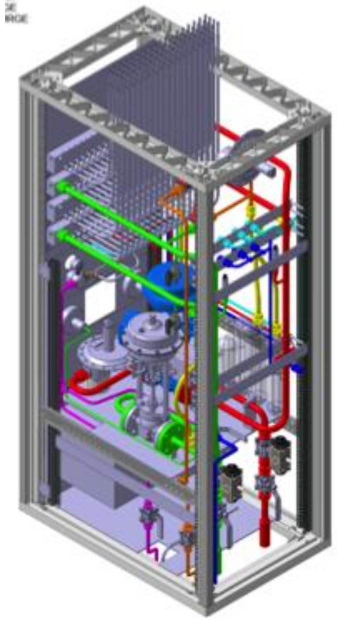
- To minimize hydrostatic pressure effect
- for the addition of new channels needed for upgrade



Upgrade of existing racks:

to minimize any chamber/flow fluctuation from some 0.1 to ~0.1 mbar

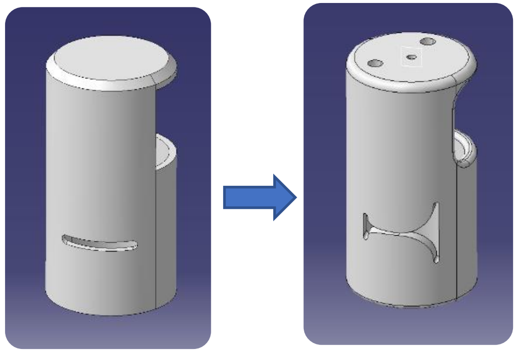
From design to installation:



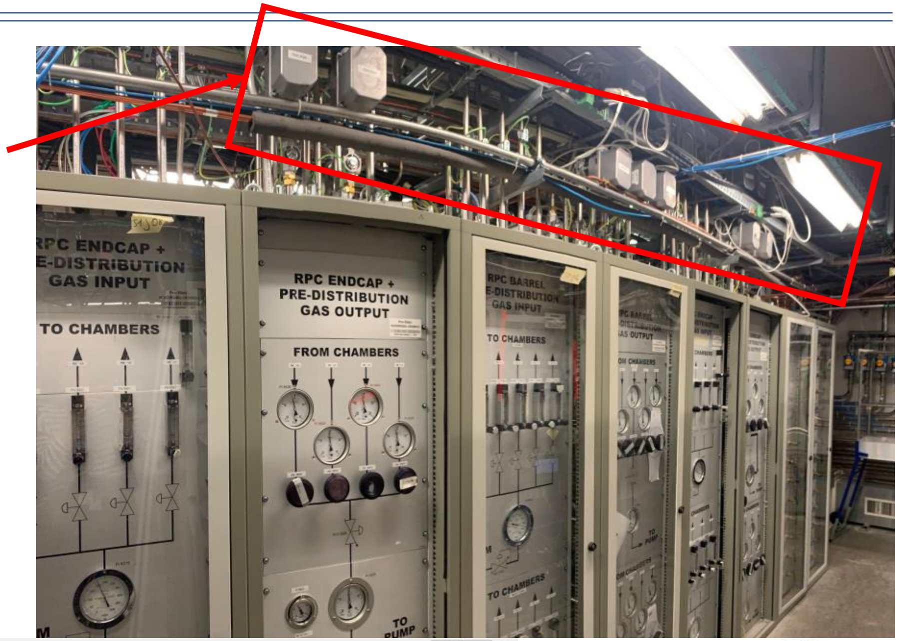
Examples: CMS – RPC gas system

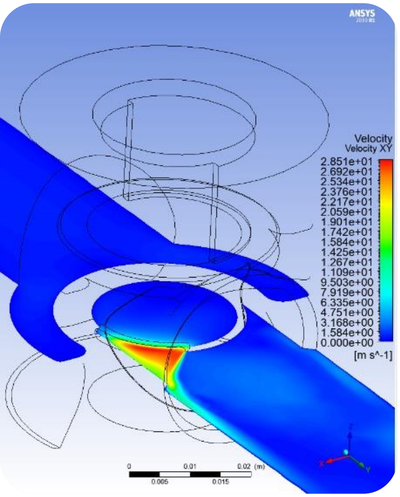
Many tests performed in laboratory and at CMS

- One valve selected: ECONEX
- Valve seats specific for distribution module:
  - Different in BARREL and ENDCAP
  - **R&D to improve/design seat shape**

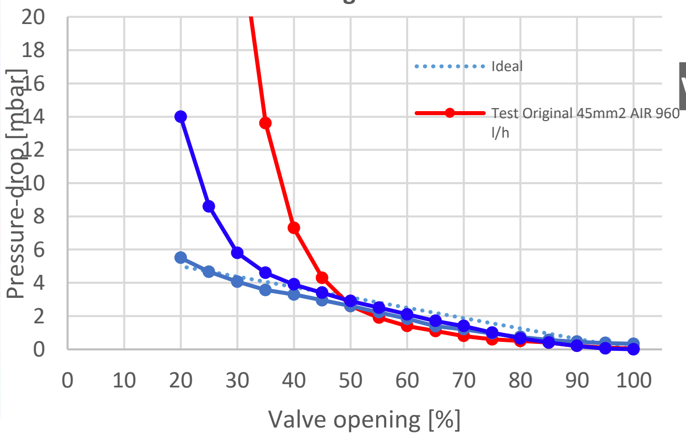


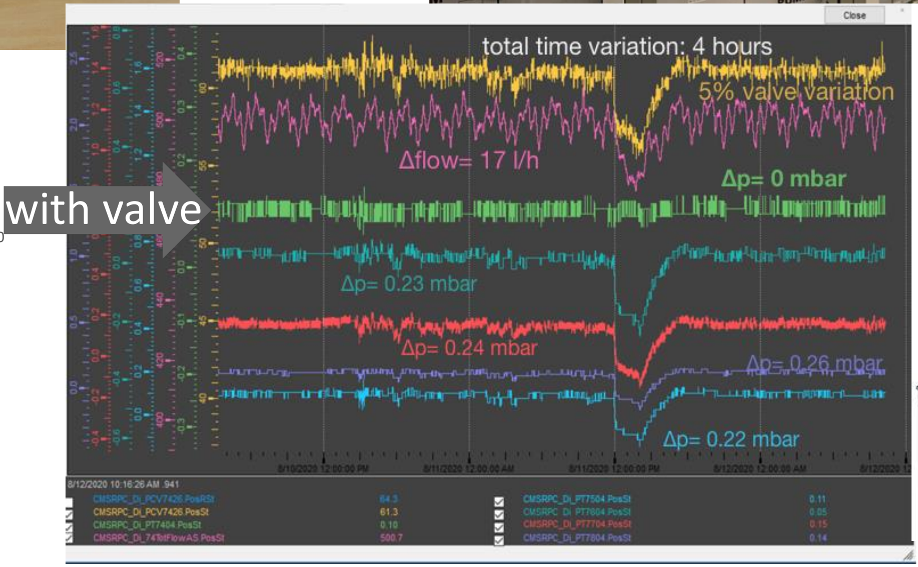
Valves installed

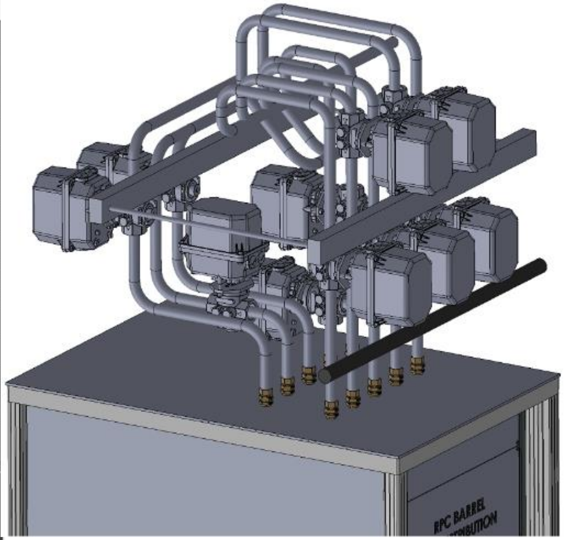




M. Busato







Examples: ATLAS and CMS – RPC gas systems

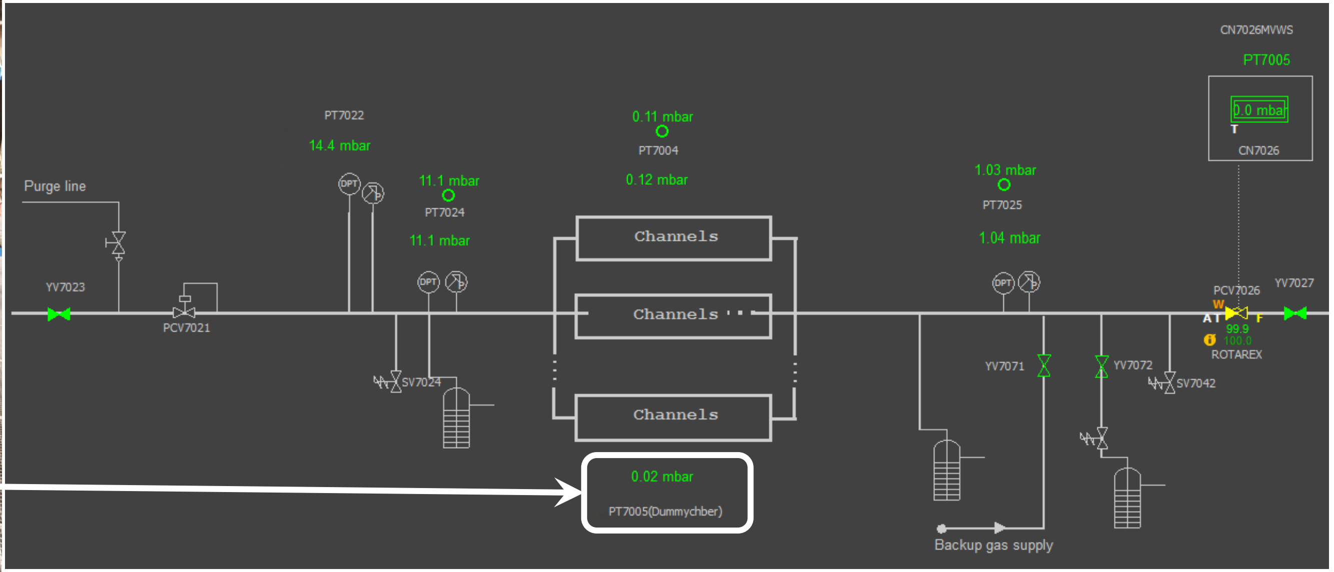
Detector pressure regulation was done using sensors at rack level:

- Weight of hydrostatic column was not taken into account
- Particularly critical during fill and emptying phases
- Pressure sensors already present at detector level cannot be used due to risk of detector leak presence/development

→ Installation of volumes that simulates detectors (reference sensors/"dummy RPC")

→ Extremely useful during detector filling after shutdown (when mixture hydrostatic pressure is changing significantly)

→ Minimize over-pressure at chamber level

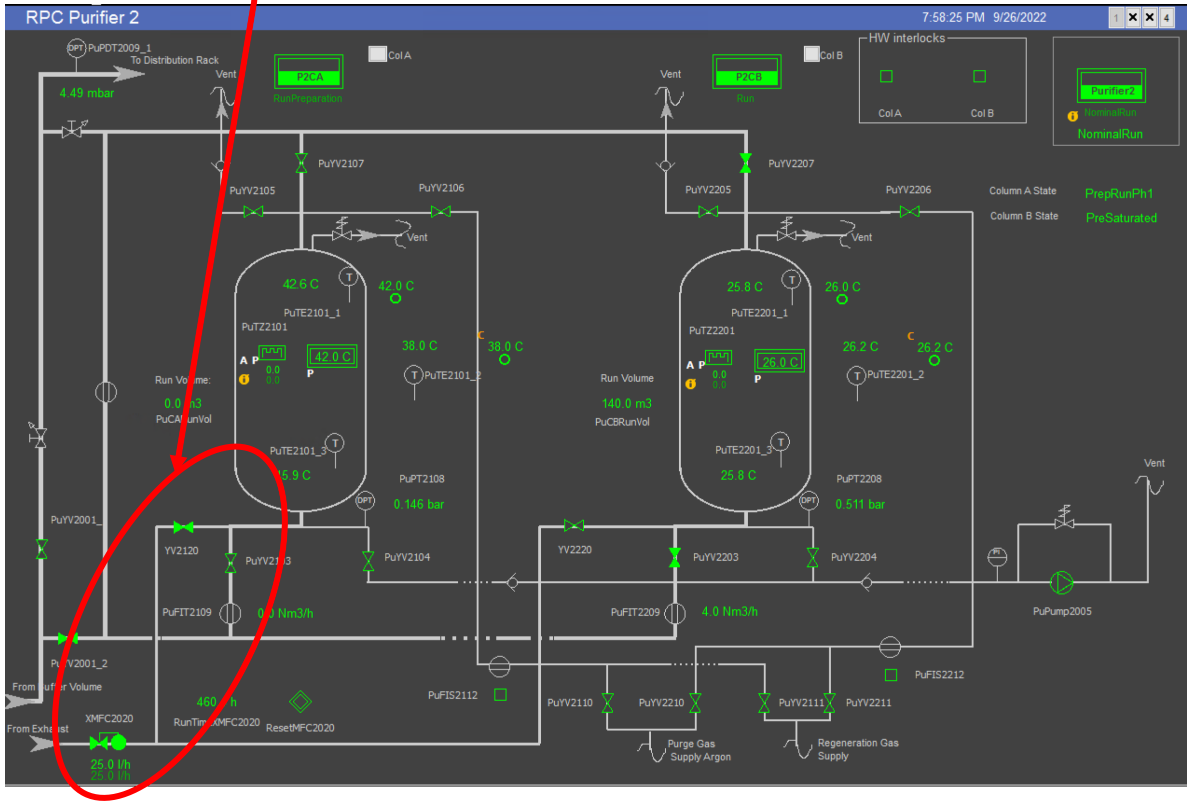


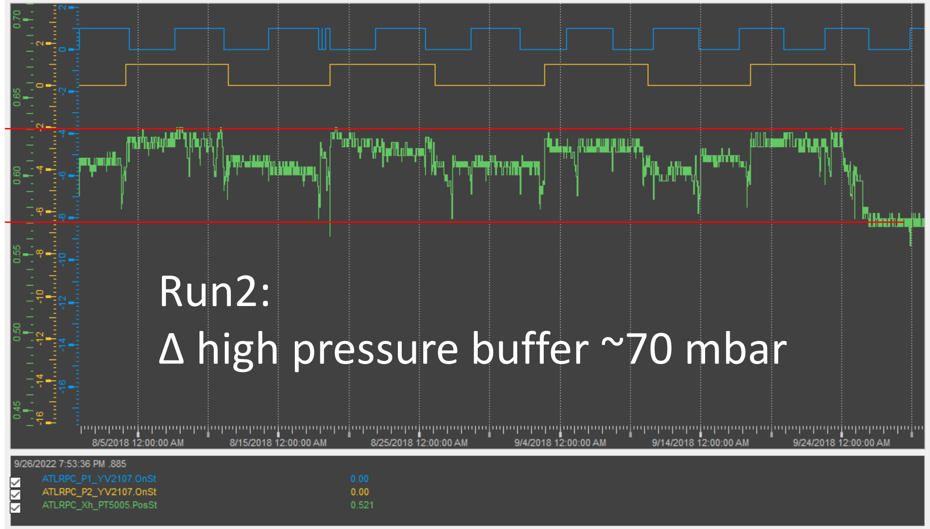
Examples: ATLAS and CMS – RPC gas systems

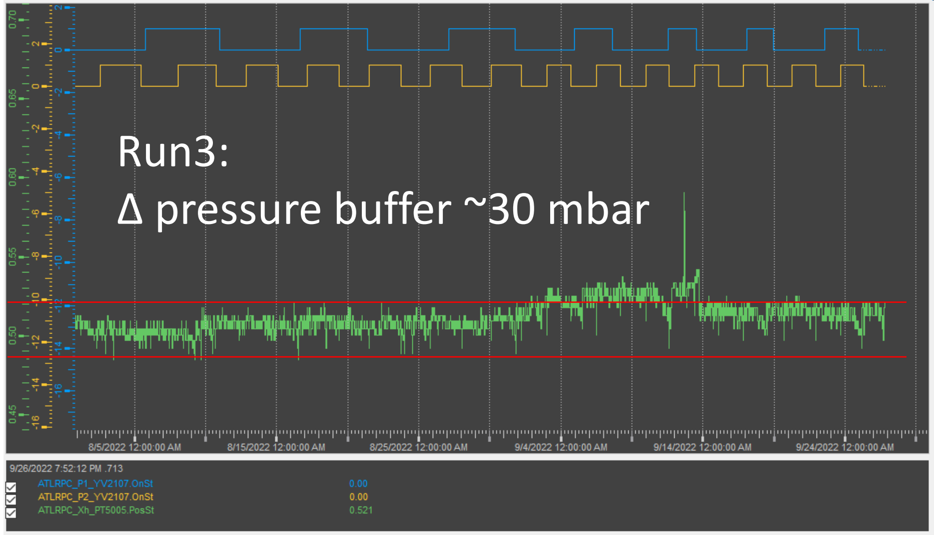
Upgrade of purifier modules

→ Smoother change to run conditions:

modification of preparation for run phases



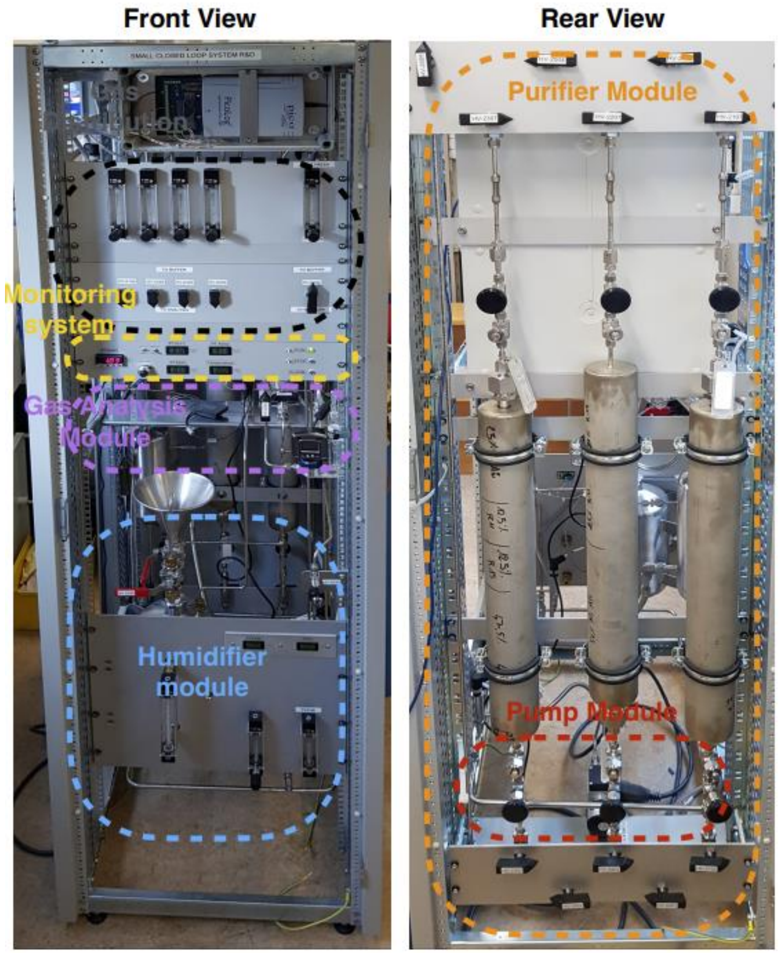




"Lab size" gas systems

Sometimes lab test are using relatively high gas quantity if compared with large LHC systems:
example from GIF++ tests (RPC, CSC, GEM), test beam activities (CALICE RPC-SDHCAL), EEE telescope, …

Development of Recirculation system for laboratory applications



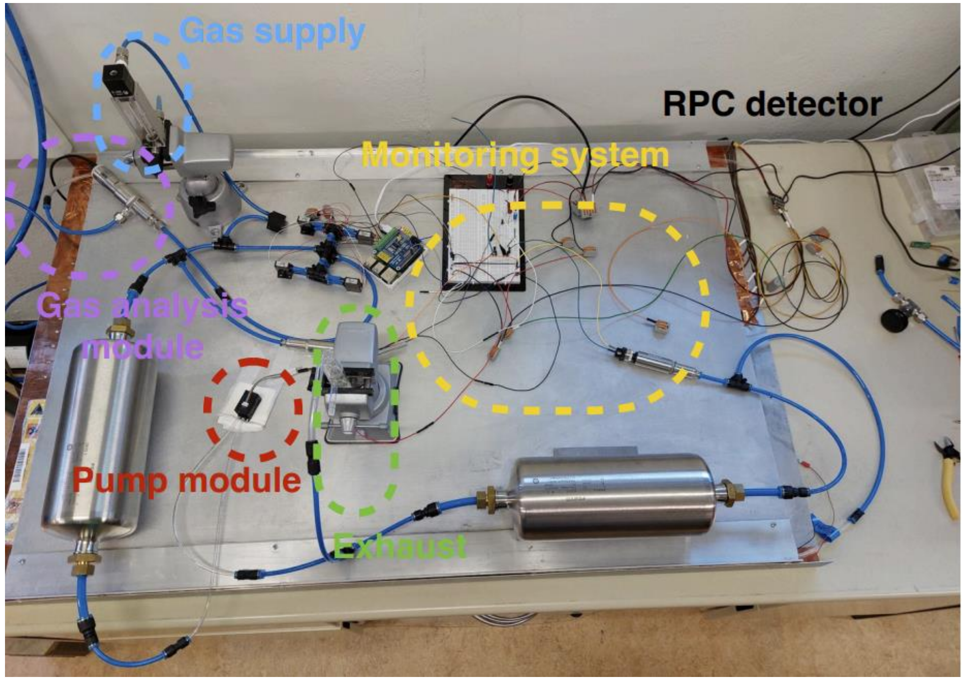
- 2013: Development of ["A portable gas recirculation unit" JINST 12 T10002]

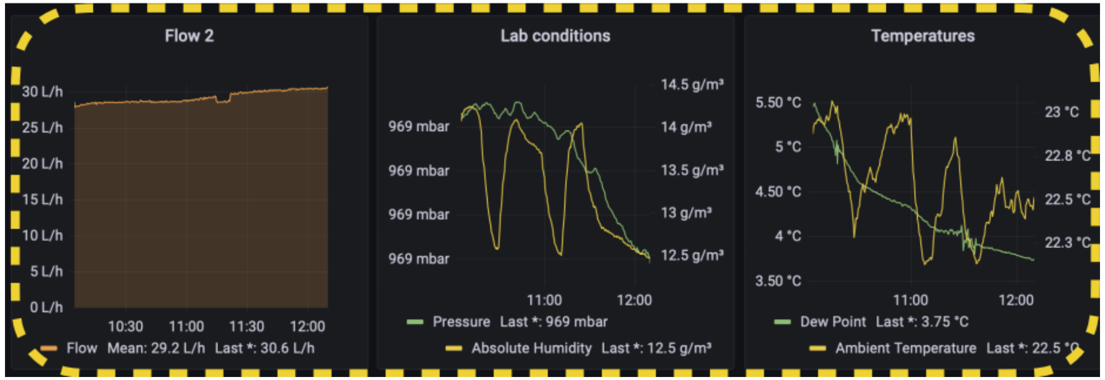
- ~10 detectors
- ~100-200 l/h
- One single rack can contain the full system
- Control system based on simple PLC
- Monitoring system based on Grafana
- Possible to have some parameters controlled remotely
- Few sensors
- Five gas systems already produced and in use

- 20-30 kCHF

“Lab size” gas systems

Development of Recirculation system for ~1-2 detectors – 20-30 l/h



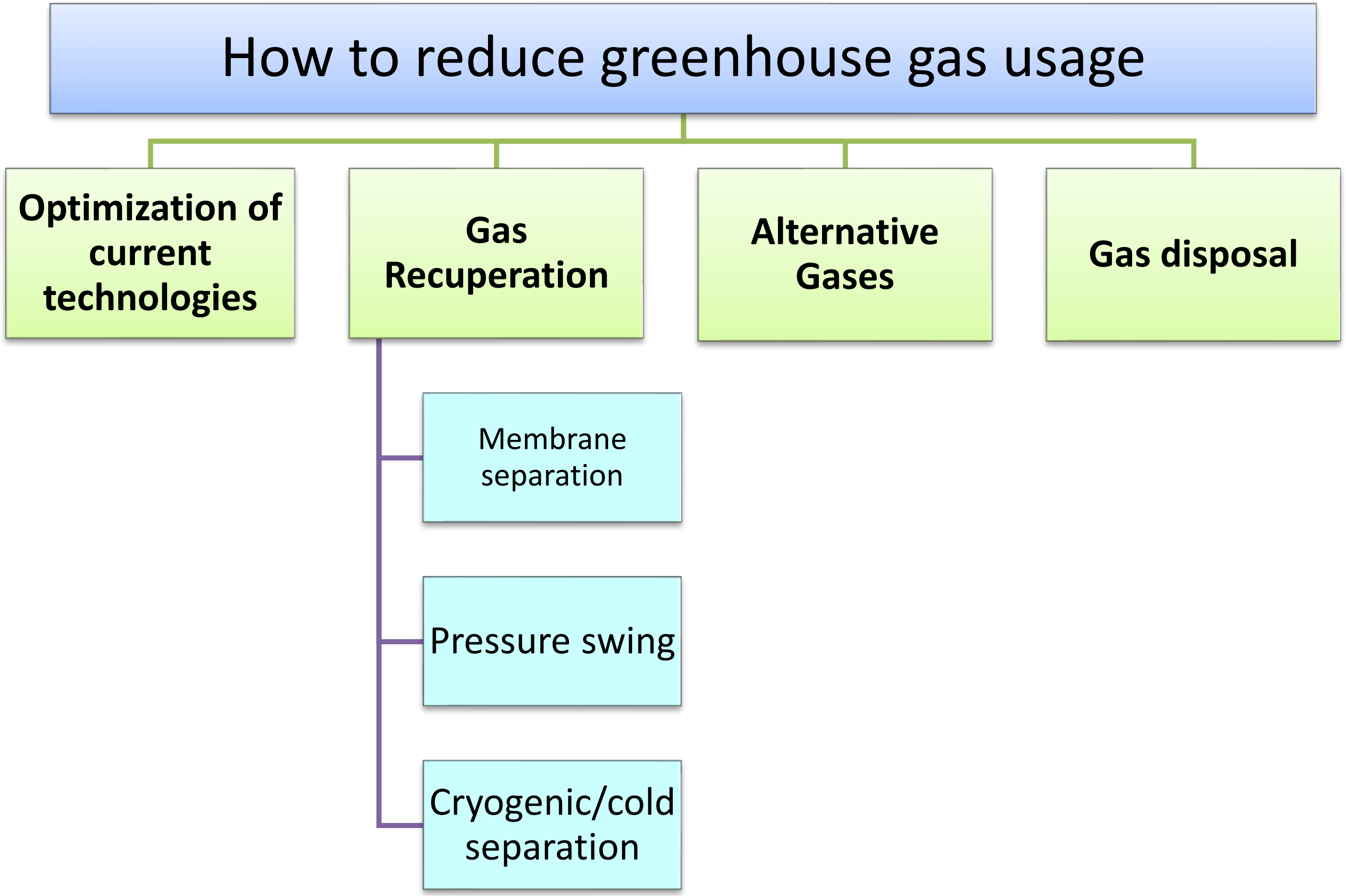


- 2019: Development of [Gas recirculation systems for RPC detectors: from LHC experiments to laboratory set-ups - RPC2022]

  - It should fit in a small box
  - Monitoring system based on RaspBerry PI and Grafana
  - Manual (optional remote) control
  - Limited number of electronic sensors
  - Very cheap components

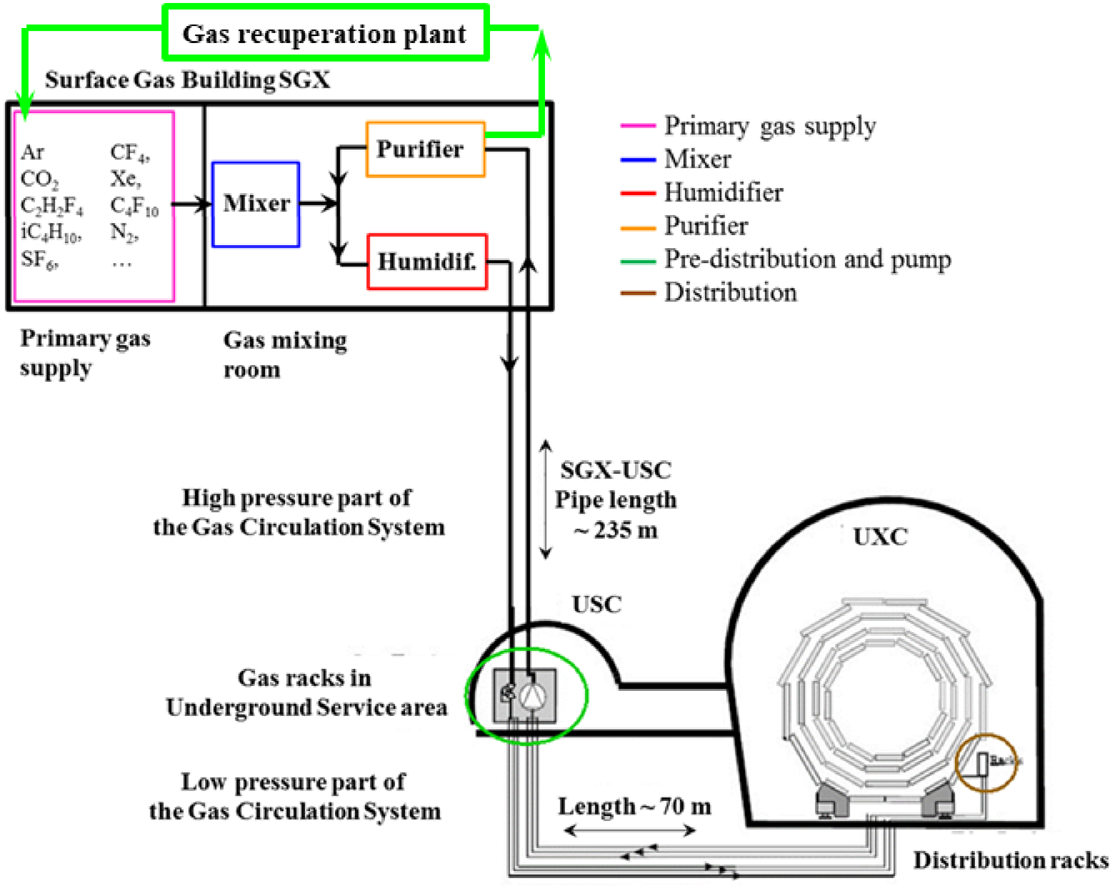
  - 1-2 kCHF

GHG Optimization Strategies



Gas systems and recuperation

Possibility to recuperate a single gas component from exhausted mixture



Many LHC gas systems already with gas recuperation

Advantages:

- Further reduction of gas consumption

Disadvantages:

- Higher level of complexity
- Dedicated R&D
- Gas mixture monitoring fundamental

- ***Ongoing R&D aims in testing the feasibility for new recuperation systems*:**
  - **R134a for ALICE-RPC, ATLAS-RPC, CMS-RPC, ALICE-TOF**
- ***and substantial improvements of existing systems:***
  - **CF_4 for CMS-CSC, LHCb-RICH2**
  - **C_4F_{10} for LHCb-RICH1**
- Recuperation will be effective only if leaks at detector level will be reduced
- R134a recuperation can drastically decrease GHG consumption
- R&D costs for first R134a recuperation system can be potentially paid back with one year of operation

Gas Recuperation: the R134a case

2018: Prototype0 tested in ATLAS-RPC (100 nl/h)

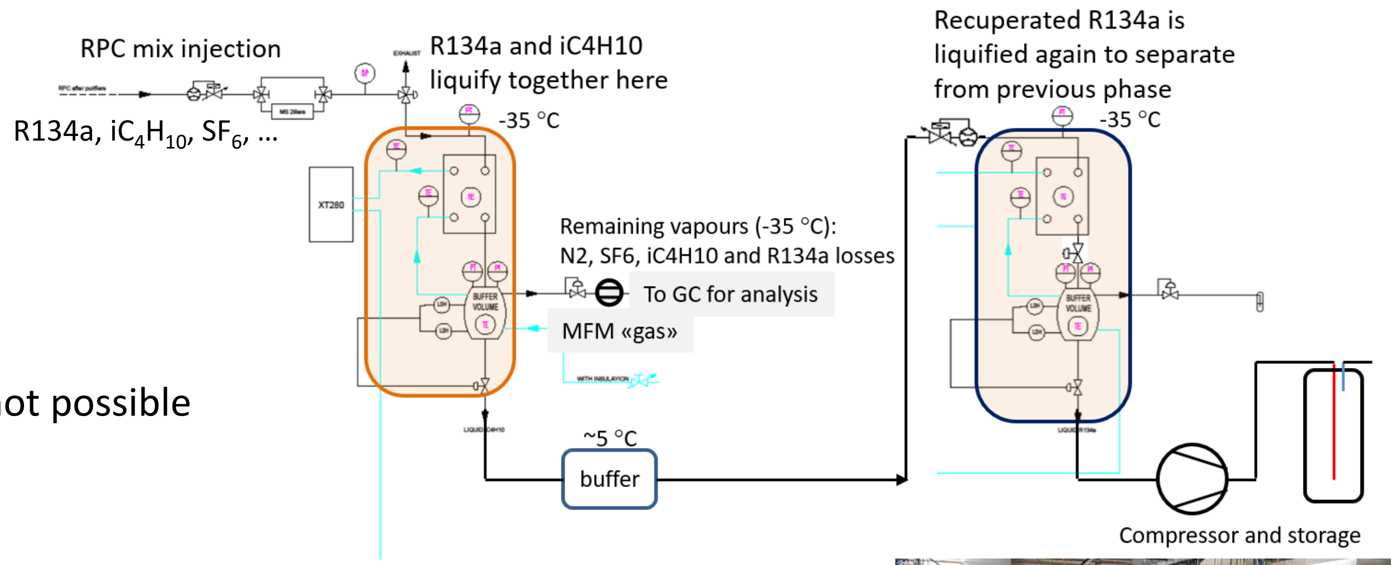
- encouraging results, air/N2 and iC4H10/SF6 removed

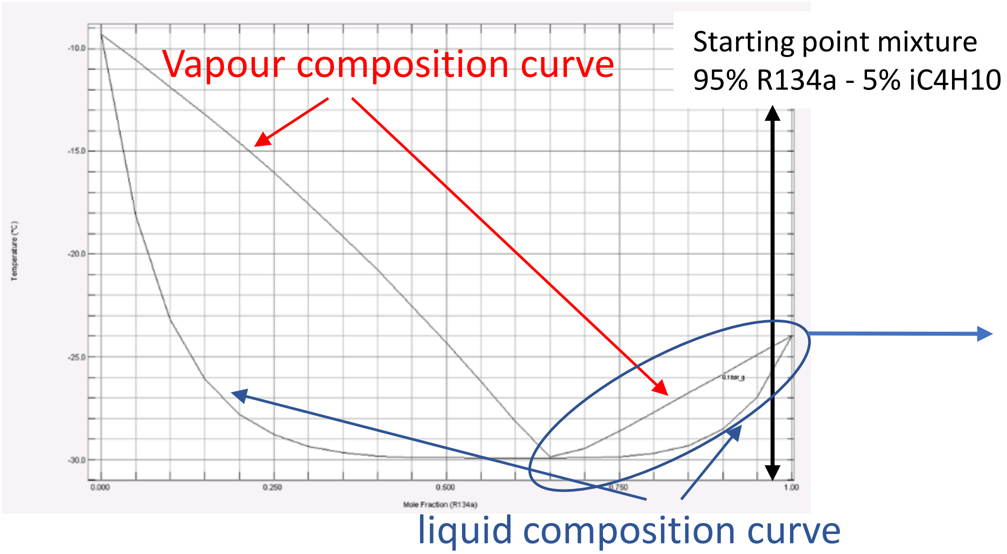
2019: Prototype0 moved to CMS

2020: test restarted at CMS with CMS-RPC

- R134a/iC4H10 form an **azeotrope**

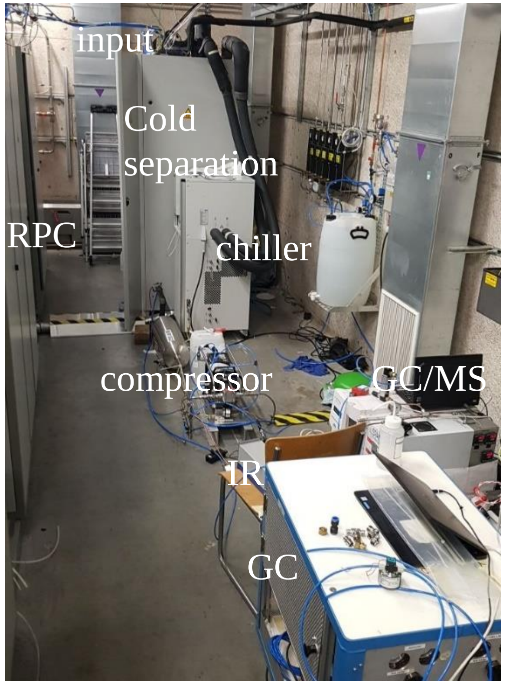
→ simple separation thanks to difference in boiling points is not possible





R134a/iC4H10 remaining mixture is totally liquefied and it is sent to buffer at 5 °C:

- azeotropic mixture is slowly heats up
- liquid is enriched of pure R134a
- vapour of azeotrope which escapes from exhaust

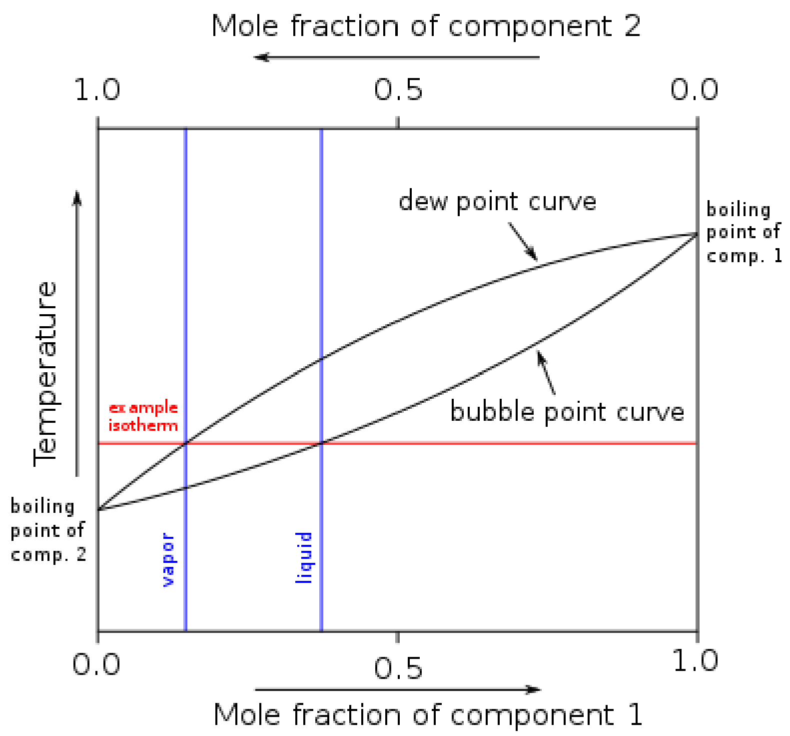


Gas Recuperation: the R134a case

Ideal mixture:

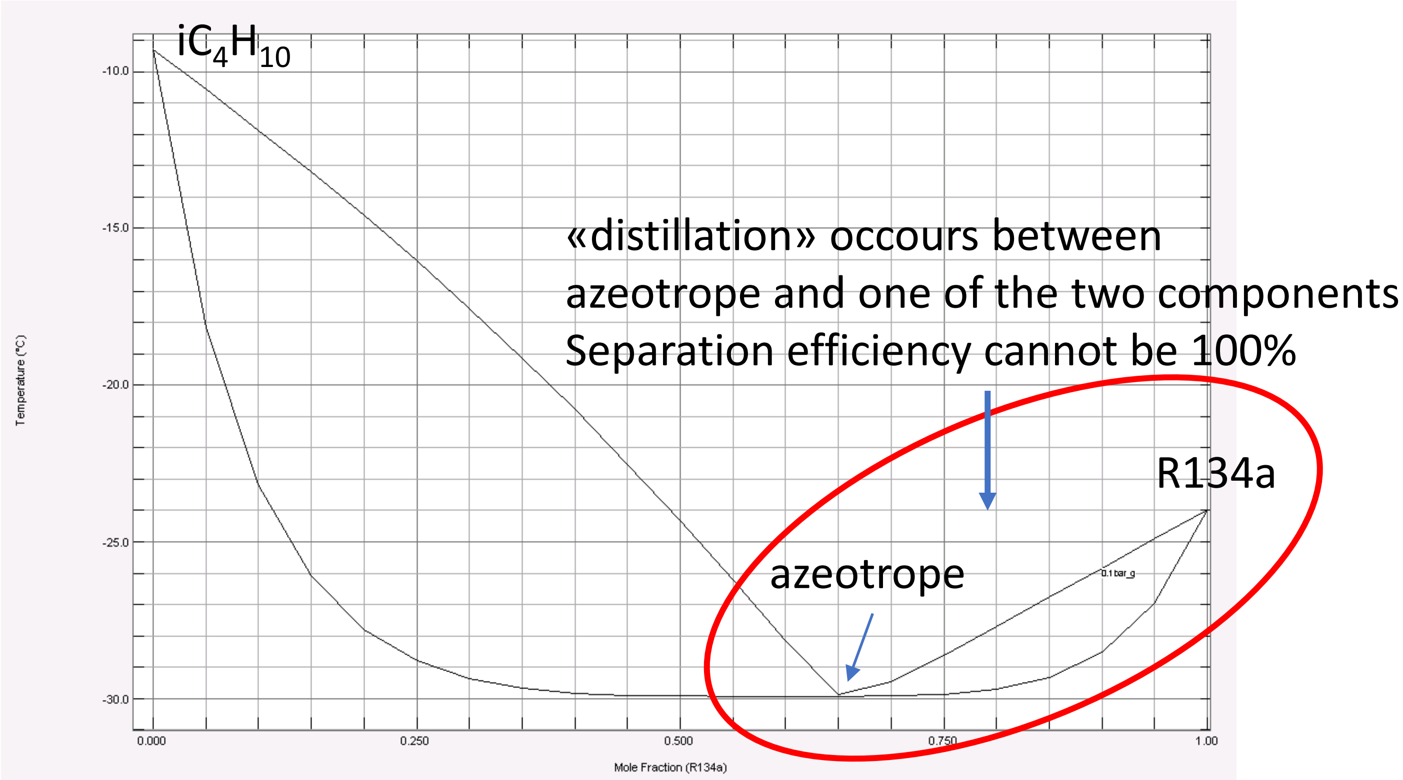
Two boiling termeratures (component1 and component2)

No other min/max for vapour and liquid curves



Azeotropic mixture:

In the boiling temperature vs composition plot is present a min or a max



Gas Recuperation: the R134a case

Status (Master Thesis F. Cambiè, D. Burragato, M. Di Toma)

collaboration with:

- **Chemistry department University of Pavia, Italy**
- **Politecnico of Torino, Italy**

- **Input flow tested up to 600 l/h**
- **Good R134a quality with good recuperation efficiency (~80% limit due to azeotrope)**
  - **Contaminants: air and SF6 (<50 ppm) and iC_4H_{10} (close to detection limit)**
- Integration of compressor unit and storage of recuperated R134a completed

Tests still needed

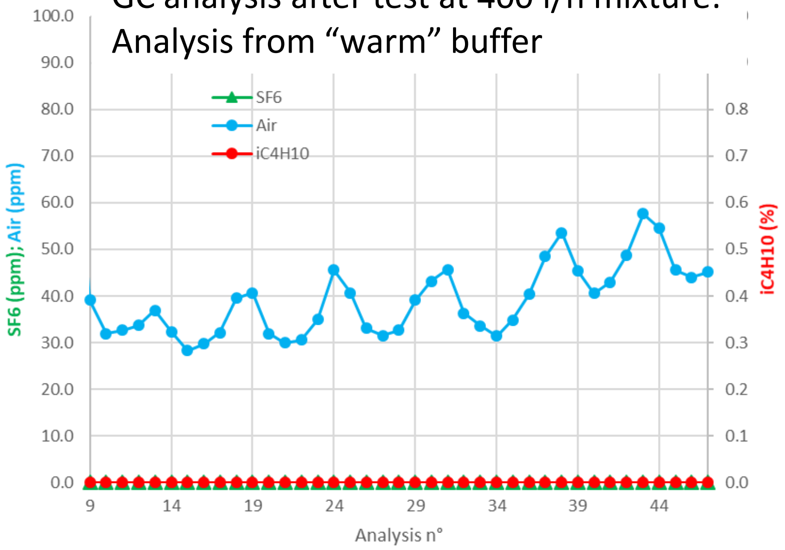
- **Input flow up to 1000 l/h**

  Azeotrope can be a problem for high flow
- **Re-use of recuperated R134a in mixer: March/April-2023**
- **Separation studies of possible RPC impurities: 2023**
- **R&D for possible recuperation of SF_6 (timescale to be defined)**

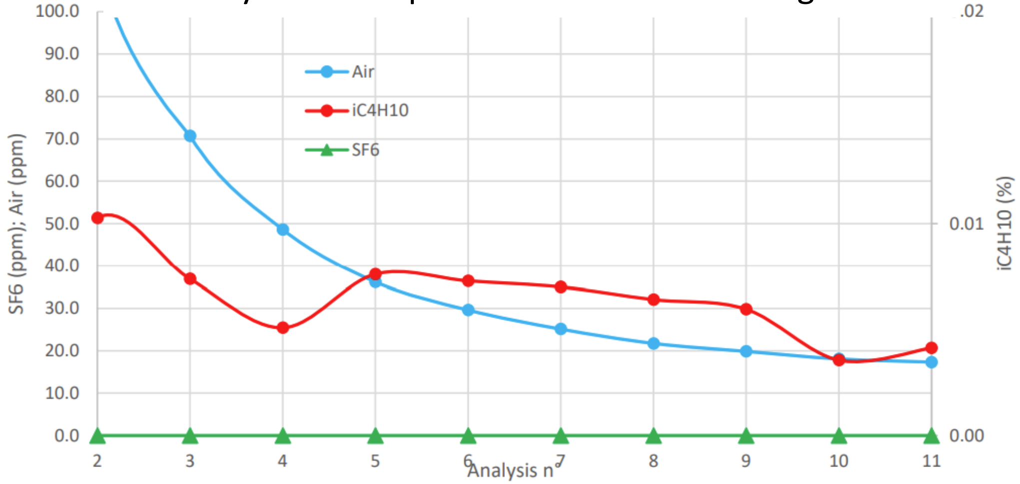
Final system

- Construction of a second prototype: end-2022
  - It should be very similar to final system
- Final recuperation system: construction end of 2023
  - ...if satisfactory results from second prototype

GC analysis after test at 400 l/h mixture:
Analysis from "warm" buffer

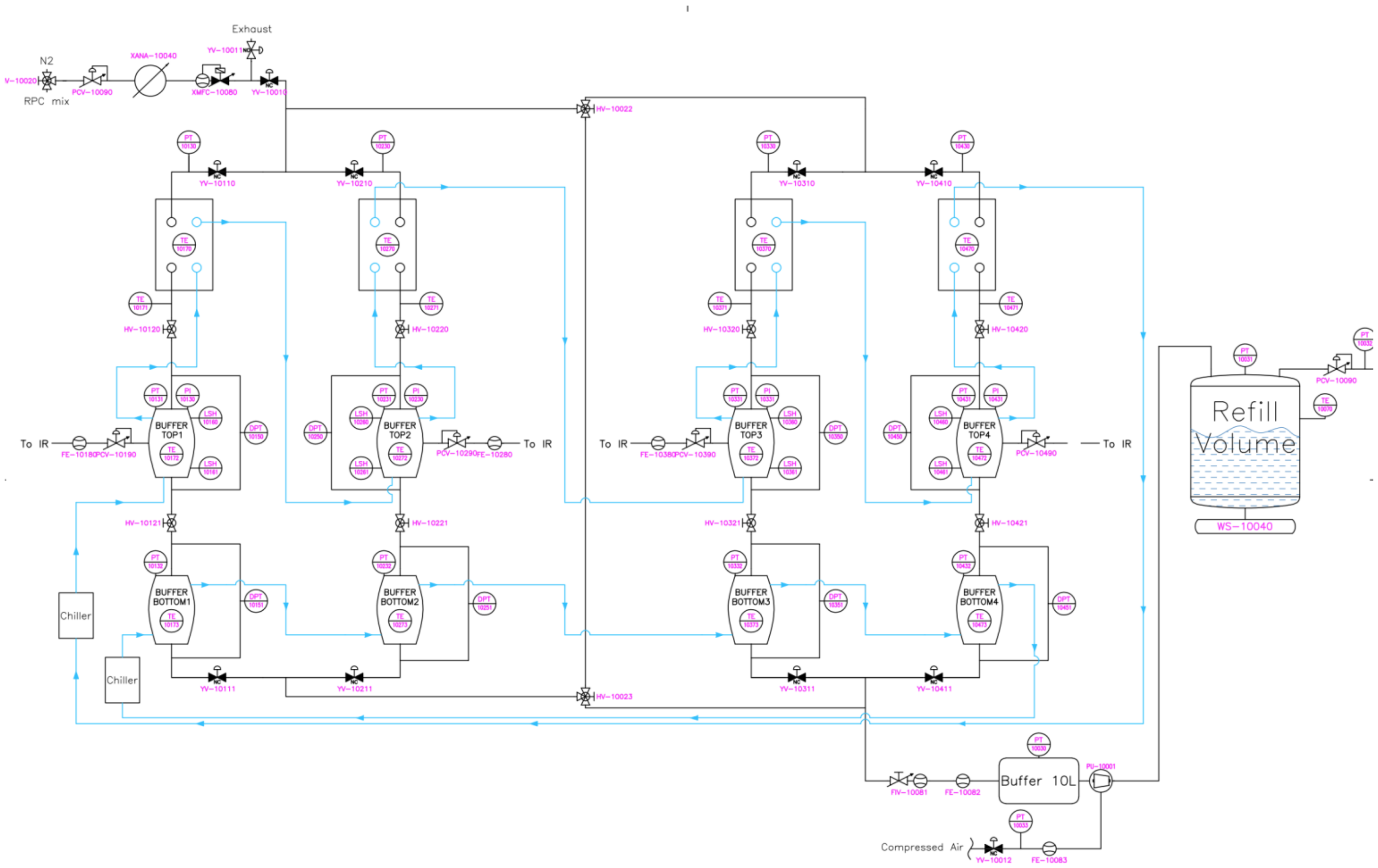


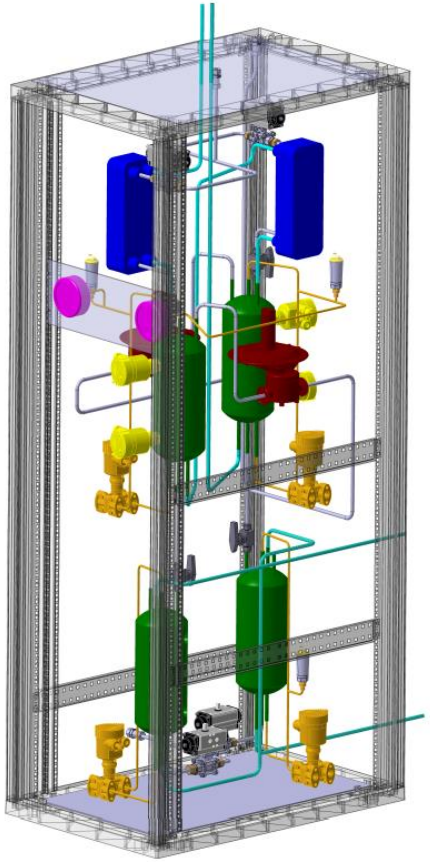
GC analysis of recuperated R134a from storage bottle



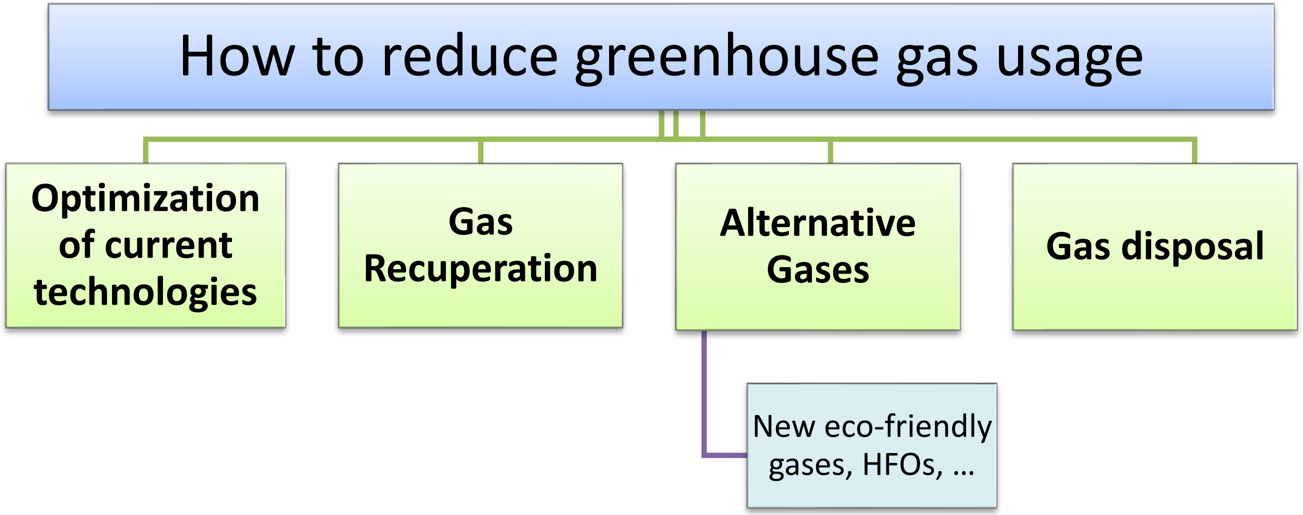
Gas Recuperation: the R134a case

Construction of the second prototype: installation expected at CMS January-February 2023





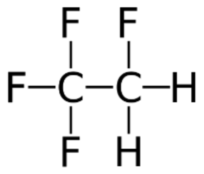
GHG Optimization: CERN Strategies



Possible alternatives to GHG gases

New eco-friendly liquids/gases have been developed for industrial applications as refrigerants and HV insulating medium…

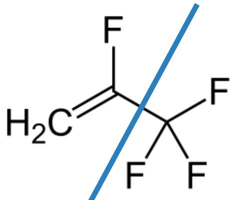
→ many gases tested, but not straightforward for detector operation. Best options:



R134a ($C_2H_2F_4$)

GWP 1430

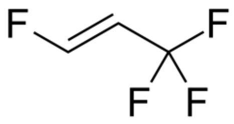
Hydro-Fluoro-Olefin (HFO)
- C=C double bond
- fluorine-containing
- hydrogen-containing



HFO-1234yf

($C_3H_2F_4$)

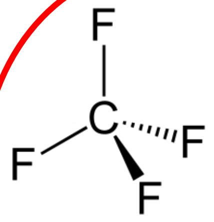
GWP 4 flammable



HFO-1234ze

($C_3H_2F_4$)

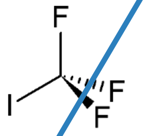
GWP 6



R14 (CF_4)

GWP 5700

?



CF_3I

GWP 0.4 toxic

Very difficult challenge for already installed detectors where it is not possible to change of FEB electronics, HV system, etc

However, in any case to be considered

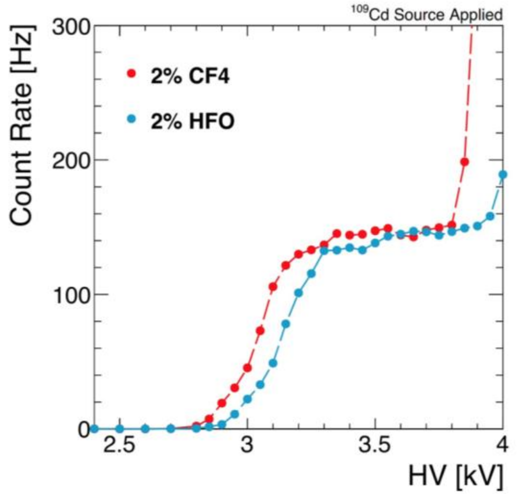
- Long-term operation (to evaluate possible aging issues)
- No flammability or toxicity of the gas mixture

Possible CF_4 replacements

CF_4 is used in different types of particle detectors to prevent aging, to enhance time resolution or because of its scintillation photon emission

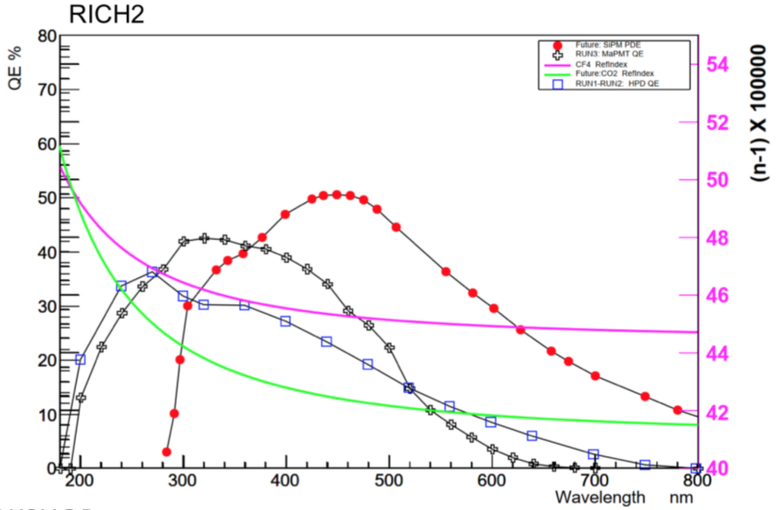
CMS CSC studies (K. Kuznetsova)

- CF_4 is a source of fluorine radicals to protect against anode ageing
  - Now 10% CF_4 in CSC gas mixture
- Two possibile approaches to reduce GHG consumption (beyond the recirculation and recuperation systems)
  - **Decrease the CF_4 concentration**: preliminary results show that 5% could be safe for operation
  - **CF_3I and HFO1234ze not best candidates**
  - Look for other alternatives to CF_4 on-going



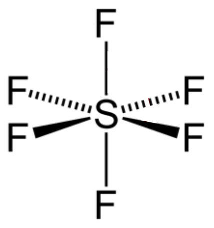
LHCb RICH studies (S. Easo and O. Ullaland)

- RICH detectors use either CF_4 or C_4F_{10}
  - Necessary for good refractive index
- Replacement of C_4F_{10} with **C_4H_{10}**
  - Refractive index matches very well
  - But C_4H_{10} flammable
- Replacement of CF_4 with **CO_2**
  - Under investigation
- Use of SiPM to reduce the chromatic error and increase the yield



Alternatives to SF_6

6 F

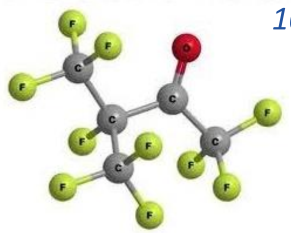


SF_6

GWP 23900

- Chemical inertness: extremely stable
- Exceptionally long lived in the atmosphere
- Excellent dielectric property
  - SF_6 x 2.5 than Air
- Non-flammable and toxic
- Gaseous form
- No major reactions
  - Ok with H_2O, Cl and acids

10 F



3M™ Novec™ 5110

($CF_3C(O)CF(CF_3)_2$)

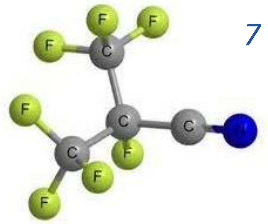
GWP <1 - Atm. lifetime 15 days

High boiling point: 27 C

Sensitive to UV radiation

Higher HV working point

7 F



3M™ Novec™ 4710

($(CF_3)_2CFCN$)

GWP 2100 - Atm. lifetime 30 years

It may react with H2O

4 F

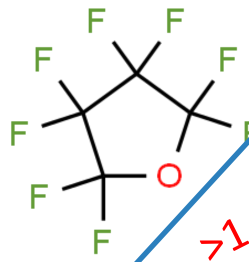
AMOLEA™ HFO-1224yd

(CF_3-CF=CHCl)

GWP <1 - Atm. lifetime 20 days

Presence of Cl (and recent bad experience at CMS)

8 F



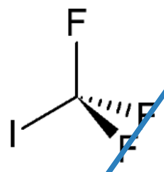
C_4F_8O

GWP 8700

Atm. lifetime >3000 years

>1.5% needed
No gain in GWP

3 F



CF_3I

GWP 0.4

Atm. lifetime 6 days

toxic

Not only detector performances….

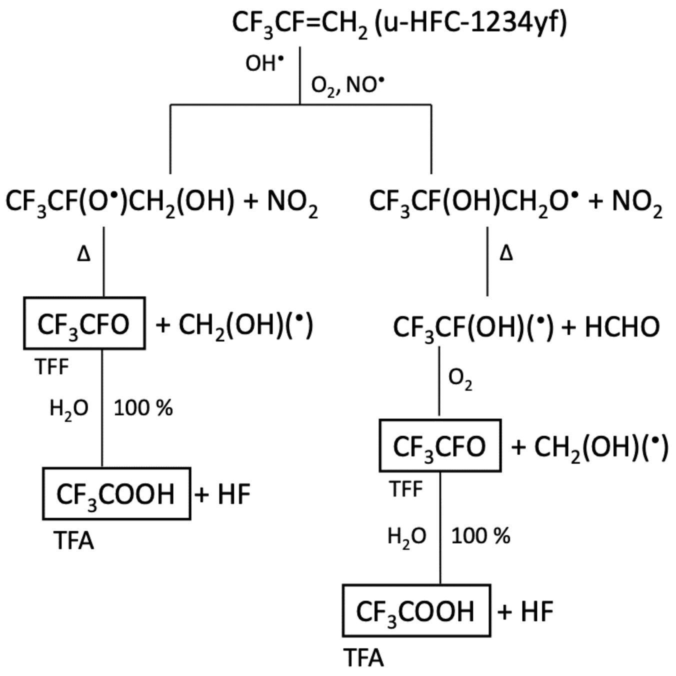
Two factors identify the greenhouse gases and their effects on climate: the radiative efficiency and lifetime in the atmosphere

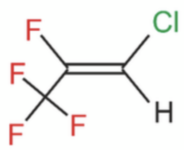
The lower are the GWP and the lifetime, the easier is the creation of sub-products

Do these sub-products have an impact on detector lifetime?

Three factors determine the atmospheric lifetime

Rain out	→	Water solubility
Oxidation	→	Reactivity with OH
Photolysis	→	UV absorbance

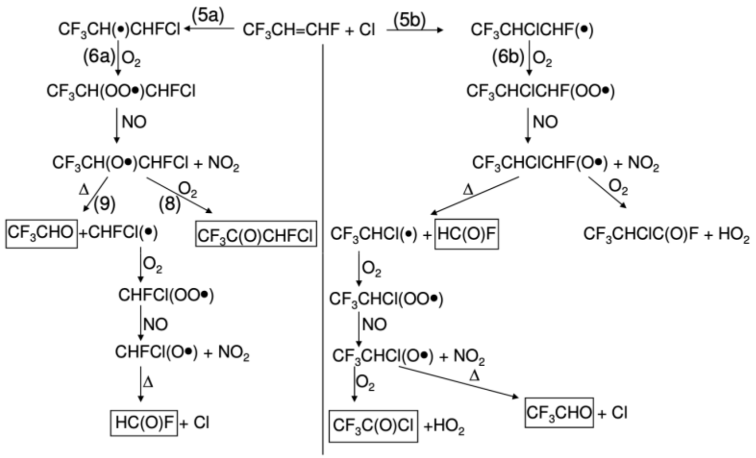




HFO-1224yd

Degradation products:

TFA, CO2, HF, HCl



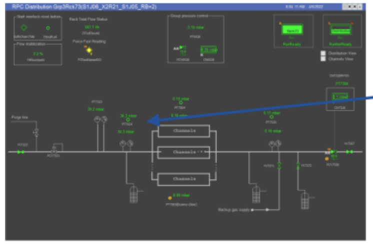
Hydrofluoric Acid (HF)

HFO produces much more HF than R134a in RPC detectors

Trifluoroacetic acid (TFA)

- HFO1234ze is estimated to break down into TFA at less than 10%, whereas R-1234yf will break down into TFA at 100% (R134a at 21%)
- TFA highly soluble: no formation of insoluble salts
- Phytotoxic

Observation with ppm of HCFC:



Increase of input pressure

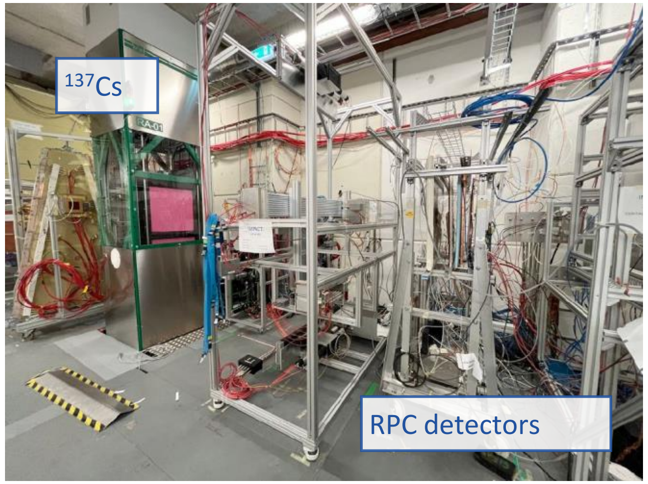
presence of white dust at detector input!

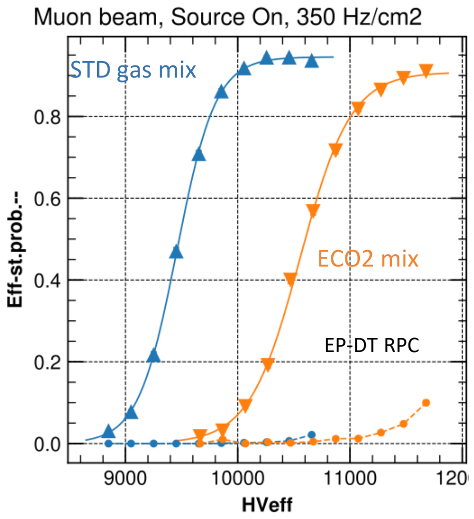
Long-term studies with HFO gas mixtures

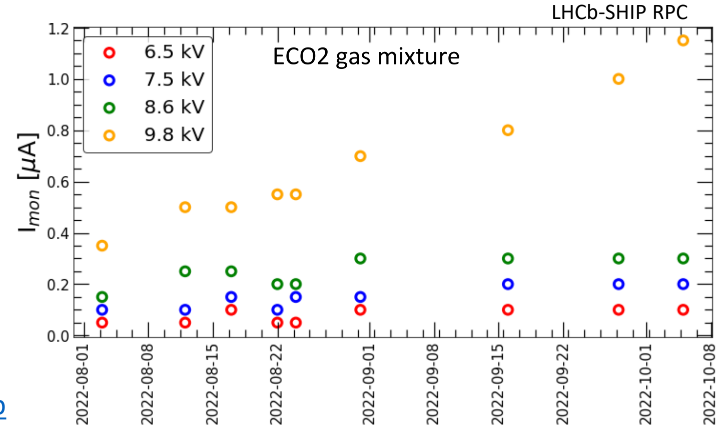
RPC long-term operation with eco-friendly gas mixtures under high background radiation and possible ageing effects must be investigated

Creation of the ECOGAS@GIF++ collaboration: *a joint effort between CERN Gas Team, ALICE, ATLAS, CMS, LHCb-SHIP RPC communities*

- Set-up at CERN Gamma Irradiation Facility (GIF++)
  - 12.2 TBq ^{137}Cs and H4 SPS beam line
- Several RPCs under test from different experiments
- Detector performance studies
  - At different back-ground radiations
  - For different gas mixtures and for different types of RPCs
- Long-term performance studies
  - Irradiation of RPCs to accumulate an equivalent charge of the HL-LHC Phase
  - Fundamental for the validation of new eco-friendly gas mixtures
- Three gas mixtures under study
  - CO_2 50-70% + HFO 45-25% with~5% iC_4H_{10} and 1% SF_6







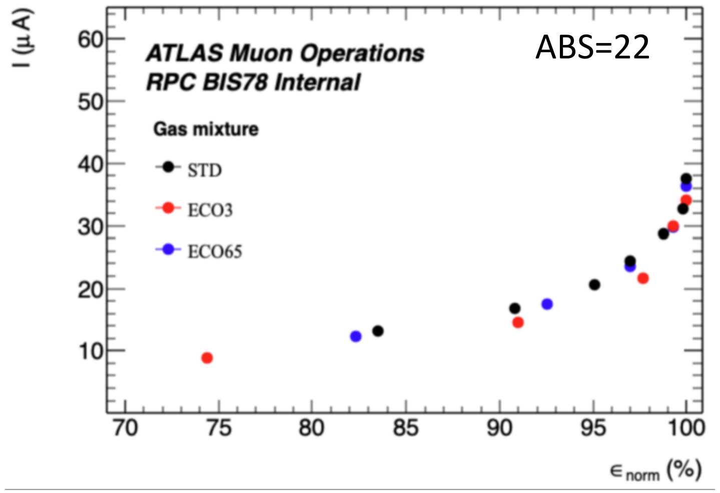
Results presented in RPC2022 workshop

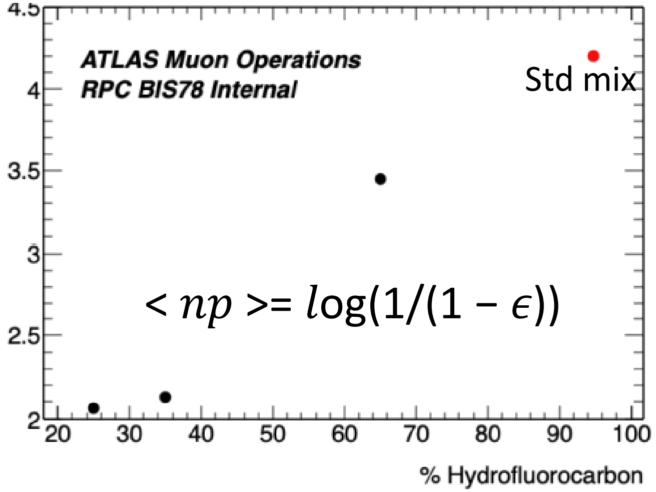
ATLAS and CMS - RPC upgrade programs: new detectors & FEB

New detectors for Run3 (ATLAS-BIS/BI)

- Triplet (3 single gaps; 1 mm gas gap)
- Very effective Faraday cage allowing to operate with low noise and trigger on 2/3 coincidence
- New FEB with new chip:
  - Low noise
  - Allowing threshold as low as 1 fC
    - → from 30 to 3 pC per photon count
      - → Increased rate capability (x10)
      - → Low ageing (÷10)
- 3 independent singlets providing 3D+time
- Combined σ_t 160 ps

Mixtures from ECOGAS@GIF collaboration: ECO3 = 25%HFO/70%CO2/4%ISO/1%SF6
ECO2 = 35%HFO/60%CO2/4%ISO/1%SF6
ECO65 = 65%HFO/30%CO2/4%ISO/1%SF6





New detectors for Run3 (CMS-iRPC)

- double gap (1.4 mm gas gap)
- new FEB:
  - PETIROC2C re-designed
  - Threshold < 50 fC
  - TDC σt 20 ps
  - TDC and detector σt ~ 160 ps
    - → position resolution of ~1.6 cm

From:
CERN EP Seminar: Summary of RPC workshop
RPC 2022 workshop: Overview:
Exploring the performance limits of the new generation of ATLAS RPCs
XVI Workshop on Resistive PlaCMS iRPC FEB development and validation

Conclusions

GHGs usage in particle detectors

F-gas regulation

- Due to the environmental risk, “F-gas regulations” started to **limit the GHGs usage** (EU case)
- **availability** and **price** are today critical for old F-gases

Detector design

- It is fundamental to look not only at detector performance but also at the **infrastructure**
- New generation detectors should **limit the risk of developing leaks**
- If detectors are tight, gas consumption can be limited thanks to **gas recirculation and recuperation systems** (useful not only for GHGs but also for any expensive gases)

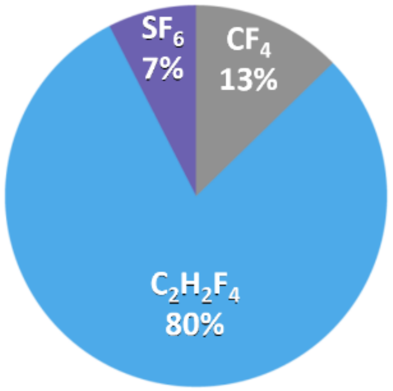
Strategies for GHG usage optimization

Optimization of current technologies

- Particular attention to gas system and detector operation
- Gas systems upgrade beyond original design
- Improved/higher gas recirculation

Conclusions

Recuperation of R134a can drastically decrease GHG consumption



Gas recuperation plant

- **Gas recuperation will be effective only if leaks at detector level will be reduced**
- R&D costs for R134a recuperation system is well justified by running costs
- R134a recuperation prototype0 is more complicated than expected but showed good performance:
  - ~ 80% recuperation efficiency and good gas quality
- Consolidation of existing plants (CF4, C4F10) ongoing:
  - CMS-CSC-CF4 recuperation efficiency increased to 70%
  - LHCb-RICH2-CF4 installed
  - LHCb-RICH1-C4F10 design ongoing

New eco-gases

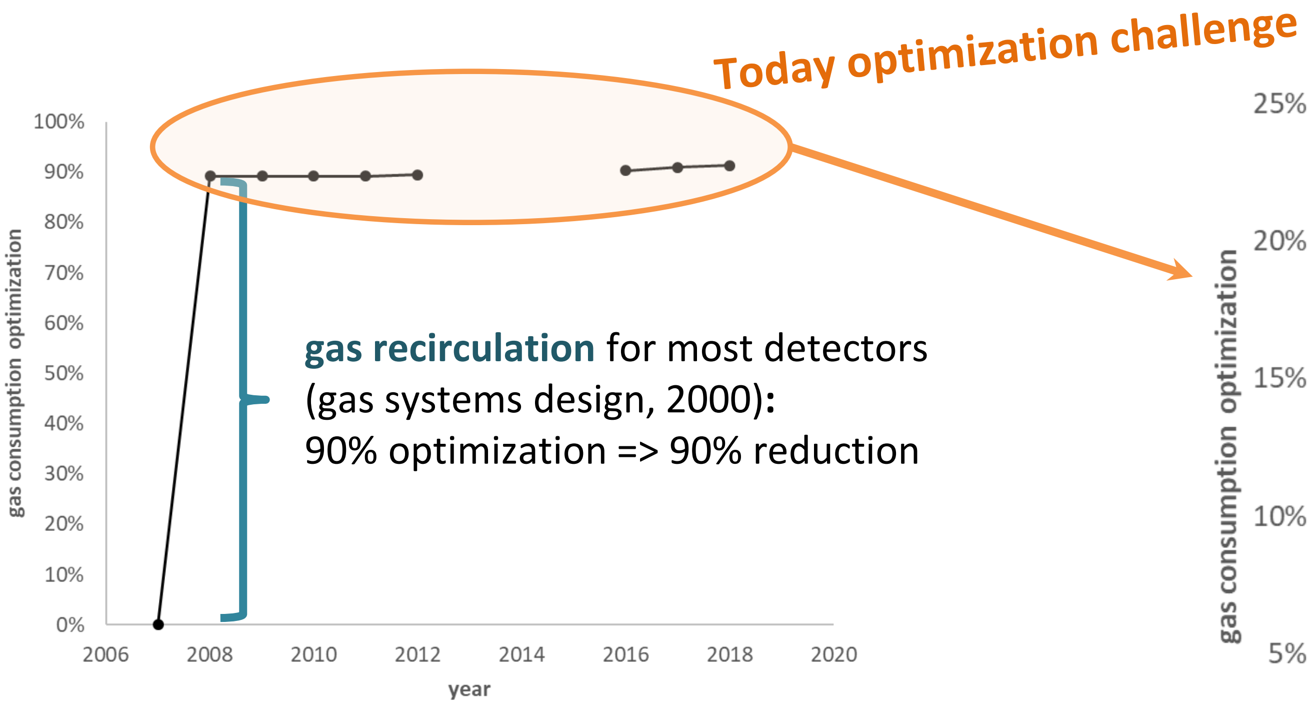
- New low-GWP gases can easily break
  - **Sensitive to UV, humidity and oxidation**
  - HF, TFA sub-products are produced and their effects on long-term operation need to be evaluated
- **Missing cross-section to perform simulation studies**
  - Dedicated measurements needed
- R-1234ze, NOVEC, … are currently the main fluorinated alternative but:
  - For 2 mm gas gap RPC, the addition of a 4th mixture components (CO2, ?) is needed to maintain reasonable HV working point
  - availability and price are still a matter of concern
  - long term operation in high radiation environment to be studied
- **New generation detectors and electronics seems to be more compatible with new eco-friendly gases** than old-generation 2 mm gas gap RPC
  - Upgrades for LHC experiments (ATLAS and CMS RPC Phase2 upgrades)

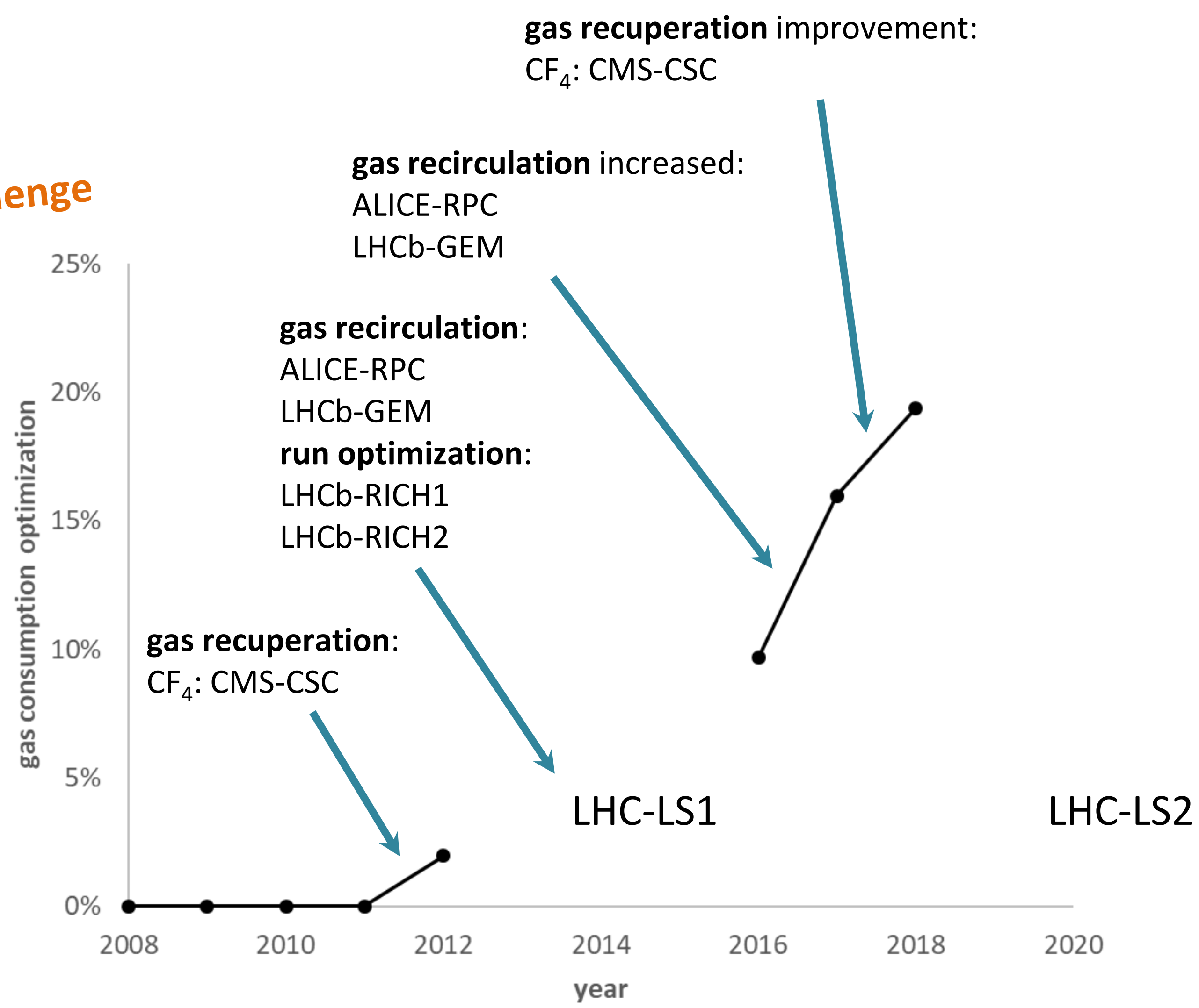
Conclusions

GHGs abatement/disposal

- Commercial systems exist. Adopted when gases cannot be reused.
- Heavy infrastructures required (CH_4+O_2 supply, Waste water treatment)
- Since availability/price can become a real problem in the future it is better to optimize consumption
- Destruction in external companies: more expensive than Gas abatement system.

Optimization of gas consumption





Spare Slides

GHG equivalent emissions

Run 2 emissions from F-gases ~ 130 000 tCO2e

Geneva emissions 2019 ~ 2 650 000 tCO2

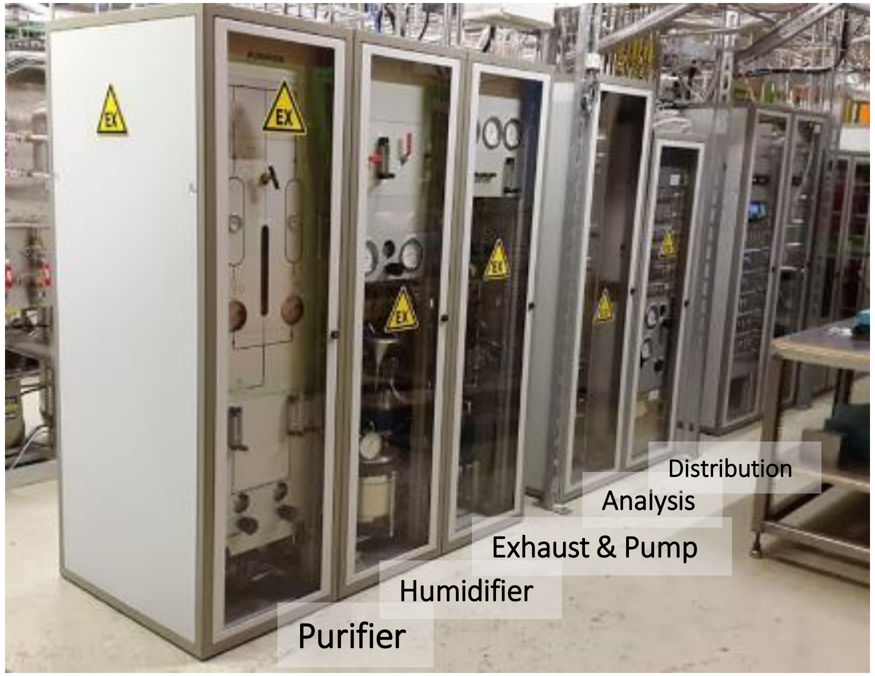
Switzerland emissions 2018 ~ 39 637 007 tCO2e

CERN contribution ~ 5% of Geneva, 0.3 % of Switzerland GHG emissions

https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Gas systems for LHC experiments

- Gas system for detector at LHC experiments:
  - Very large apparatus
  - Mixing the different gas components in the appropriate proportion
  - Distributing the mixture to the individual chambers
- Gas systems are made of several configurable functional modules (*building blocks*):
  - Simplifies maintenance, operation, training of personnel, …



Three keywords for such a large infrastructure:

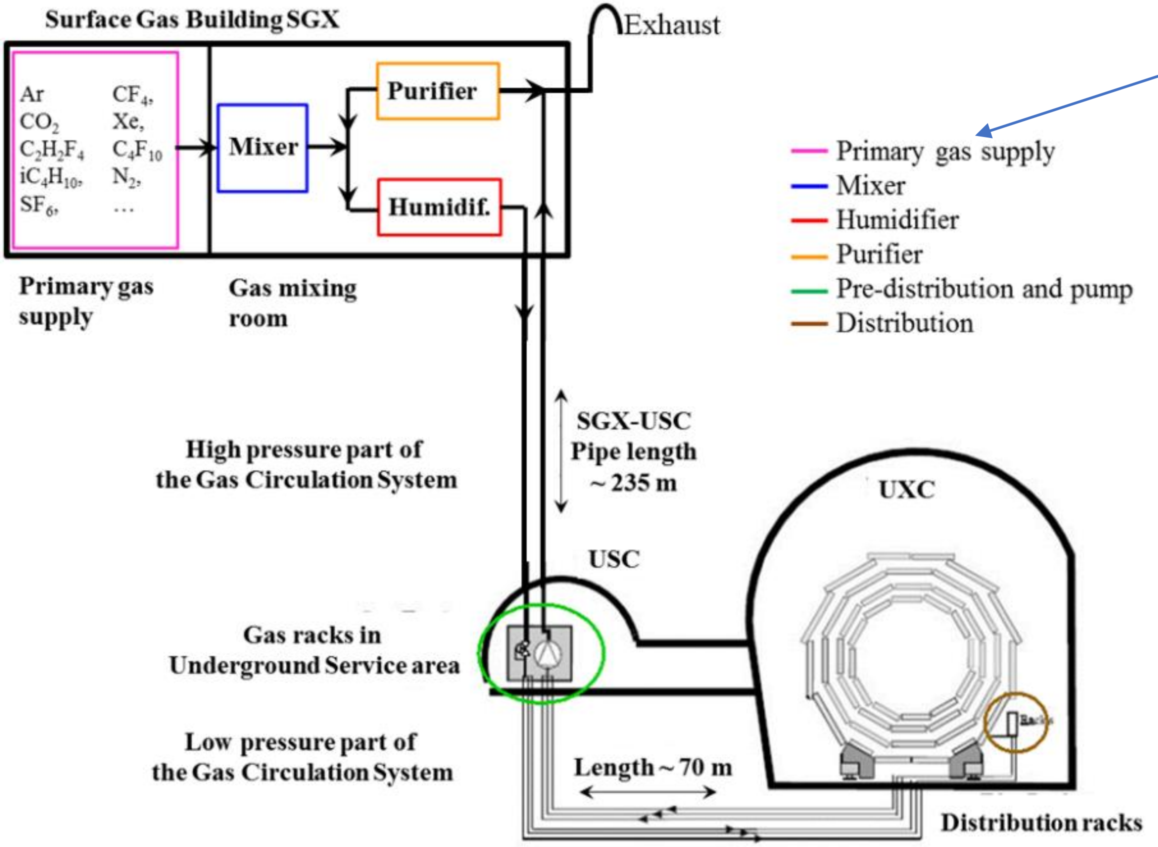
- Reliability
  - LHC experiments are operational 24/24 7/7
  - Gas systems must be available all time
- Automation
  - Large and complex infrastructure
  - Resources for operation
  - Repeatability of conditions.
- Stability
  - Detector performance are strictly related with stable conditions (mixture composition, pressures, flows, …)

Gas systems for LHC experiments

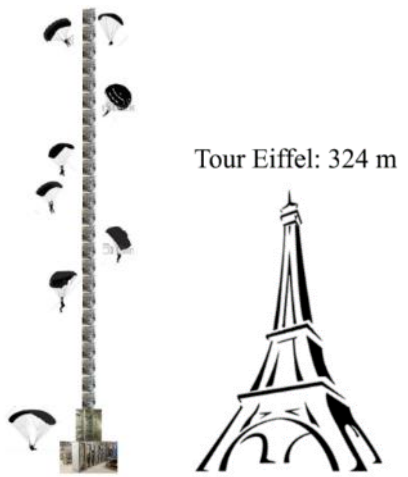
Gas systems extend from the surface building to the service balcony on the experiment following: a route few hundred meters long.

1 gas system = ~ 10 active modules

LHC gas systems = 30 systems =
= 300 modules



LHC gas systems modules > 500 m



Combined Gas Systems and Detector R&D

Concerning *Optimization of current technologies* for reduction of GHG usage

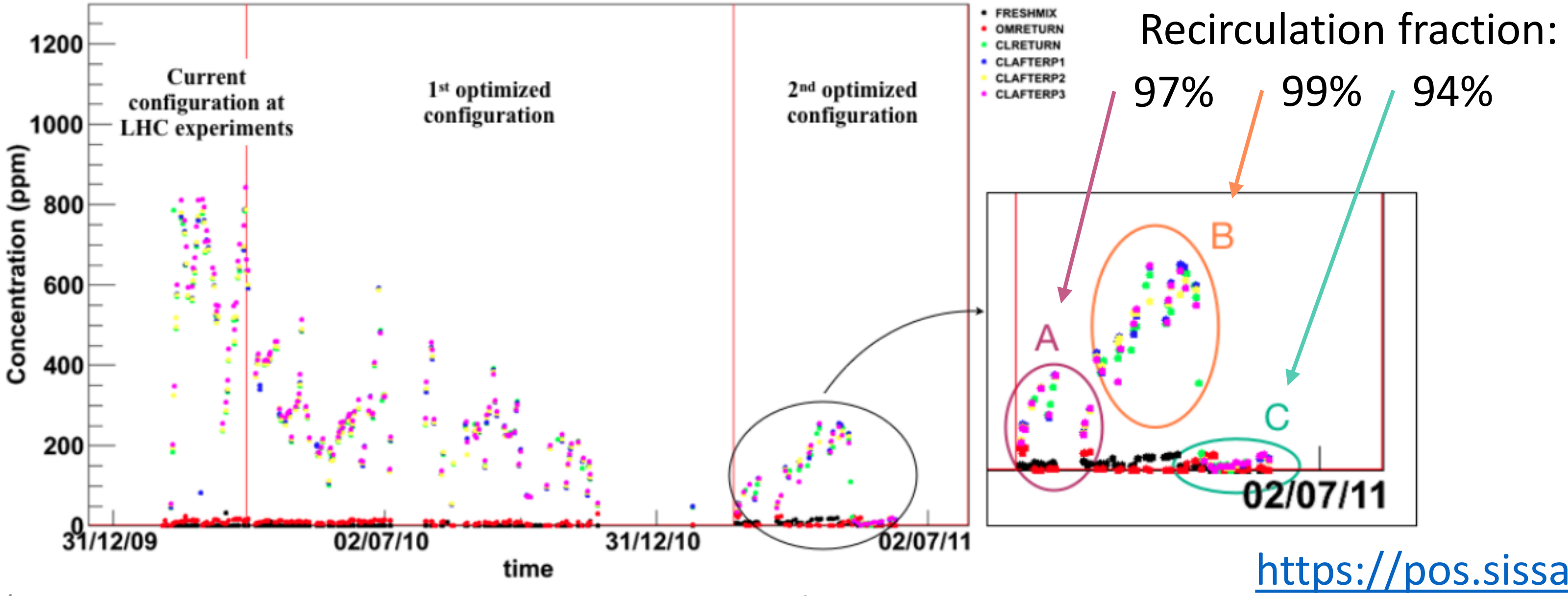
→ RPC operation at higher recirculation fraction

Today mixture recirculation is limited at about 85%

Detector validated up to 90%

What about recirculating more? Only short test performed in the past (2011) up to 97-99%

Gas recirculation and impurities in past test

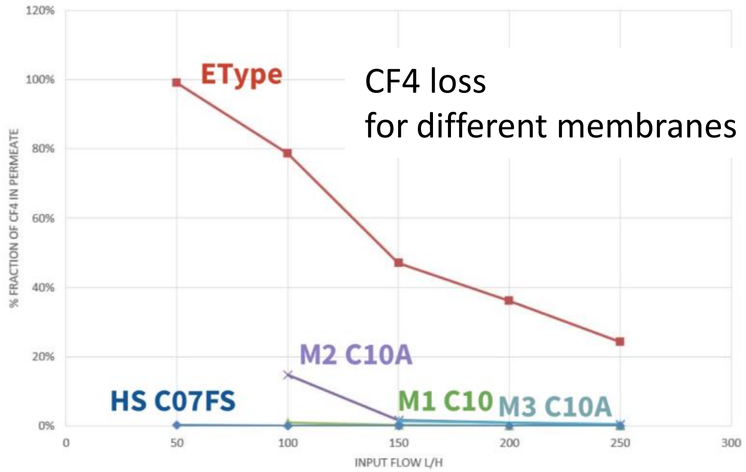


https://pos.sissa.it/159/029/pdf

CSC CF4 Recuperation Plant: recent R&D studies

Membrane module

- **Search and characterization of new membranes**
  - Membranes used in industry to recuperate CO_2
  - For different flow and with different sensitivity
- **Characterization of existing membranes to improve CF_4 loss**
  - Impact of different permeate side pressures for Ar, CO_2, O_2, N_2 extraction
  - Impact of input flow fluctuations on the membrane efficiency
  - Monitoring and fine tuning of membrane parameters

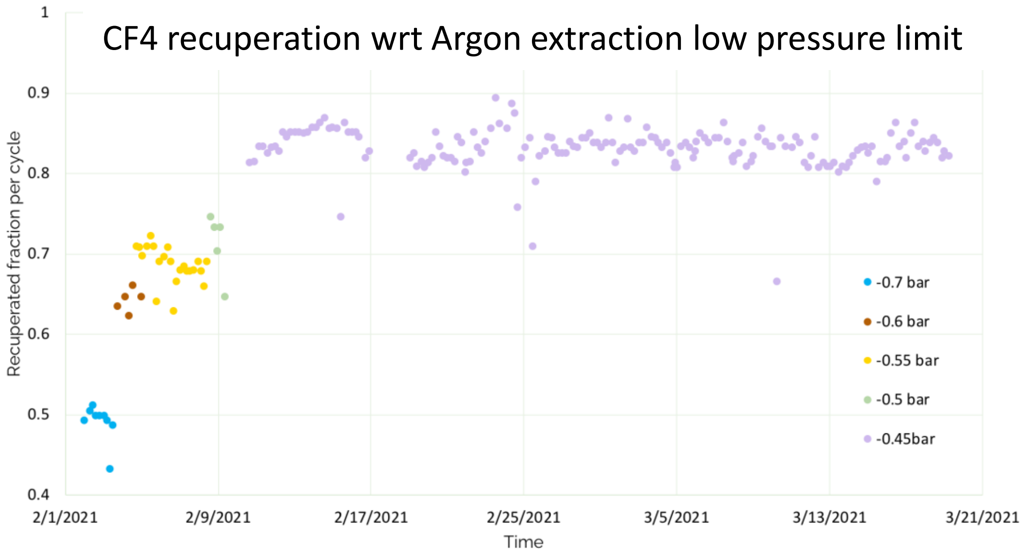


CF_4 adsorption module

- Pressure-swing method
- **Timing/optimization of run parameters**
  - Example: Ar extraction low pressurelimit
- Characterization of recuperated gas during full cycle
  - GC analyses for recuperated and exhaust gas

→ ***CF4 recuperation efficiency increased to about 70%***

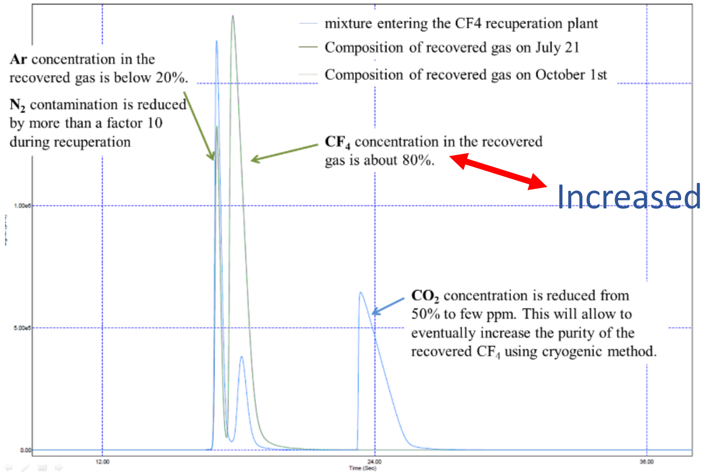
- and more studies still ongoing
- improvements possible thanks to additional resources
- Need of dedicated qualified personnel



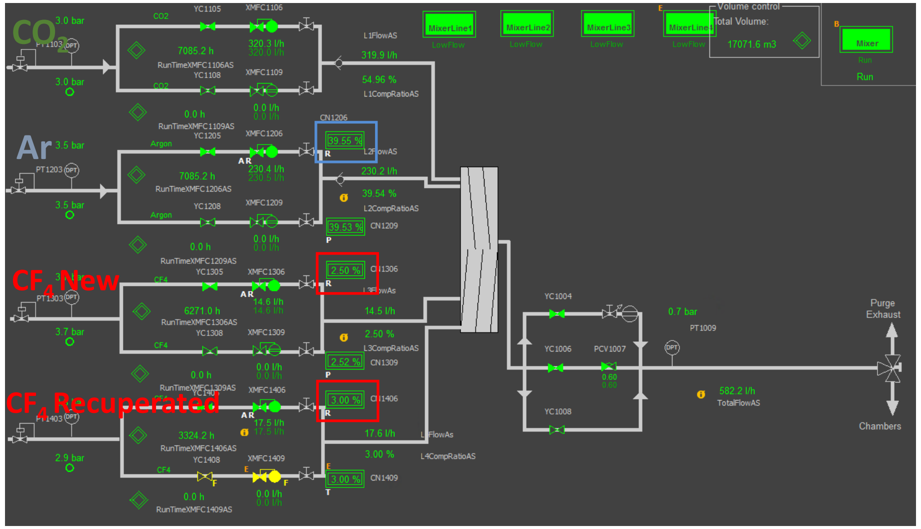
Gas recuperation: monitoring quality of recuperated gas

Complexity of using a recuperated gas: mixture quality monitoring ensuring good composition and avoiding ageing

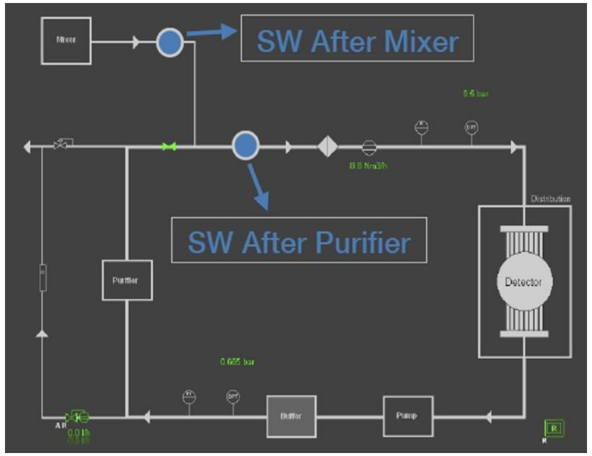
Quality of recuperated CF_4 is monitored: with **GC analysis**

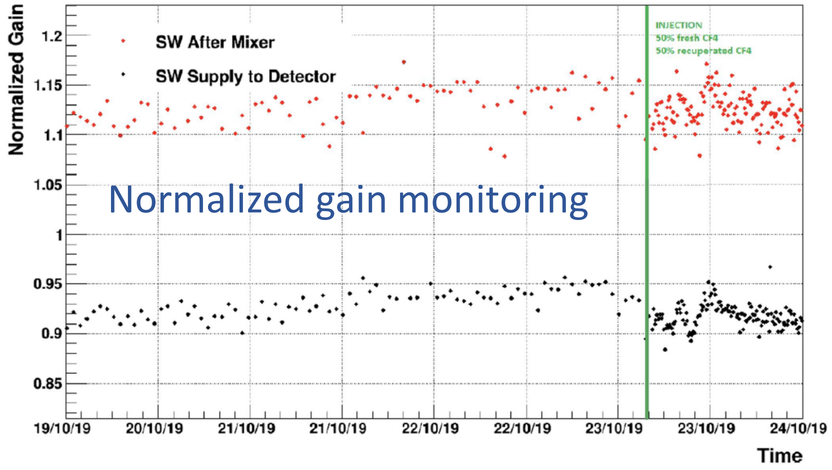


Mixed injection of CF_4 50% recuperated and 50% new



and with gas mixture monitoring: **Single Wire Chambers**

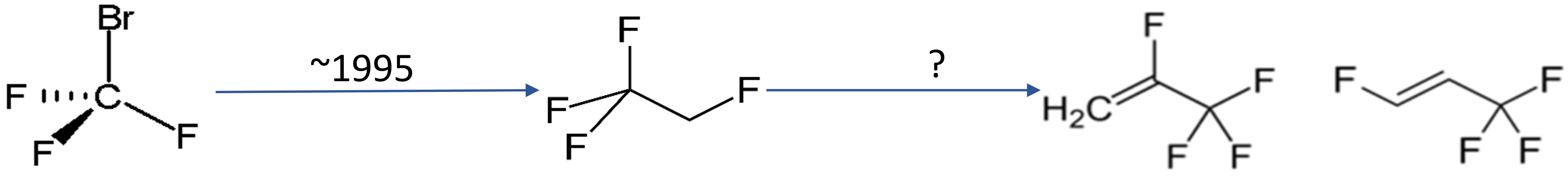




Alternative Gases

New low GWP gases alternative to R134a are already available on the market and used by industry

It is not the first time this happens in particular detection:



R13B1		R134a		HFO1234yf	HFO1234ze
($CBrF_3$)		($C_2H_2F_4$)		($C_3H_2F_4$)	($C_3H_2F_4$)
ODP* 10	→	ODP 0		ODP 0	ODP 0
GWP 6900	→	GWP 1430	→	GWP 4	GWP 6

HFOs refrigerant properties are well known while studies of ionisation processes just started…

R&D studies are ongoing. *Main constrain is coming from need of maintaining current infrastructures (HV cables, Front End electronics) very difficult to access for replacement.*

More details on Thursday, Detectors for Future Facilities session:
[“Performance studies of RPC detectors operated with new environmentally friendly gas mixtures in presence of LHC-like radiation background”]

*The Ozone Depletion Potential (ODP)

GHG abatement system

In case all studies on recuperation will not bring to efficient recuperation plants, industrial system able to destroy GHGs avoiding their emission into the atmosphere have been considered

Abatement plants are employed when GHG are polluted and therefore not reusable.

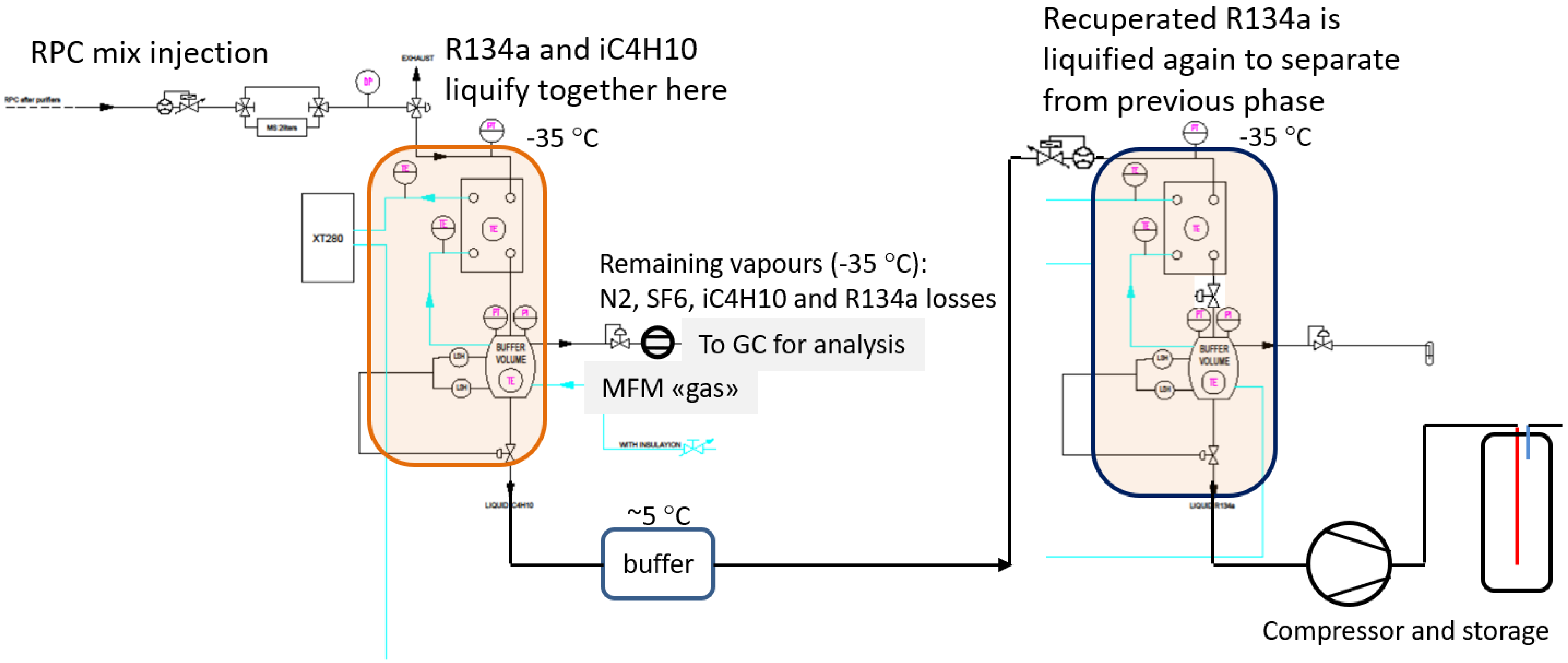
Quite heavy infrastructure required:

- CH_4/city gas + O_2 supply + N_2 supply
- Waste water treatment
    - PFC/HFC are converted in CO_2 + HF acid dissolved in water
    - disposal of remaining waste/mud

Joint CMS and EP-DT gas team is studying the feasibility

Found also companies available to take PFC/HFC based mixture for disposal:

but extremely expensive


RPC mix injection
EXHAUST
R134a and iC4H10
liquify together here
-35 °C
XT280
Remaining vapours (-35 °C):
N2, SF6, iC4H10 and R134a losses
BUFFER
VOLUME
To GC for analysis
MFM «gas»
WITH INSULATION
~5 °C
buffer
Recuperated R134a is
liquified again to separate
from previous phase
-35 °C
BUFFER
VOLUME
Compressor and storage