EP-DT
Detector Technologies

RPC2020

# R&D on gas recirculation and recuperation systems for RPC detectors

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XV workshop on Resistive Plate Chambers and Related Detectors
Rome "Tor Vergata" , 10 - 14 February 2020

# Outline

- Greenhouse gases (GHG) for particle detection
- LHC Gas Systems
- Strategies for optimizing use of GHG
- RPC case
- Conclusions

# Greenhouse gases used for particle detection

GHGs like R134a ($C_2H_2F_4$), $CF_4$, SF6, $C_4F_{10}$, … are used by several particle detector systems at the LHC experiments

| Gas | GWP - 100 years |
|---|---|
| $C_2H_2F_4$ | 1430 |
| $CF_4$ | 7390 |
| $SF_6$ | 22800 |

Due to the environmental risk, "**F-gas regulations**" started to appear.

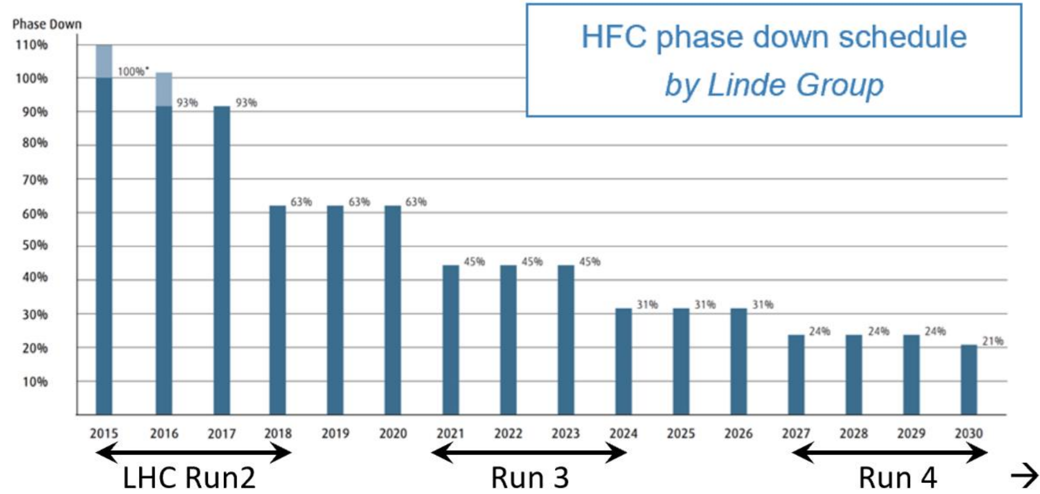
For example, the EU517/2014 is:

- **Limiting** the total amount to one-fifth of 2014 sales by 2030
- **Banning** the use of F-gases where less harmful alternatives are available.
- **Preventing** emissions of F-gases by requiring checks, proper servicing and recovery of gases.

F-gas regulations already affected **gas price** (especially for R134a in EU)

Future **availability** can also be affected (especially where replacements are available)

For the moment CERN/Switzerland seems to be not affected



# Gaseous detector systems at LHC

Very Large detector volume

- *From 10 $m^3$ up to several 100 $m^3$*

Use of many gas components

- *R134a, $SF_6$ , $CF_4$, $C_4F_{10}$, … (GHG)*
- *and many others, some expensive (Xe, …)*

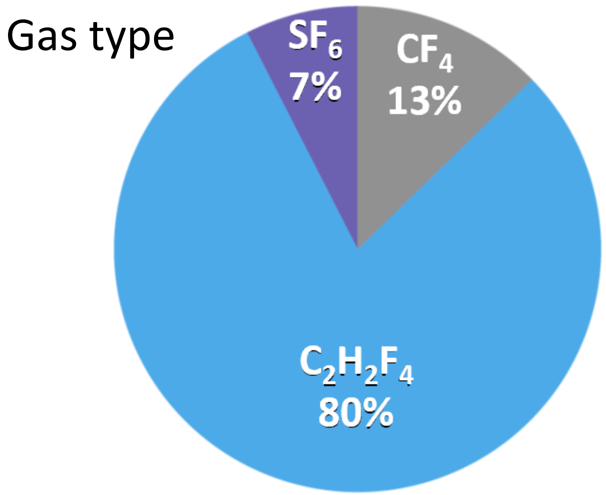
+ High mixture flow
+ Operational costs issue

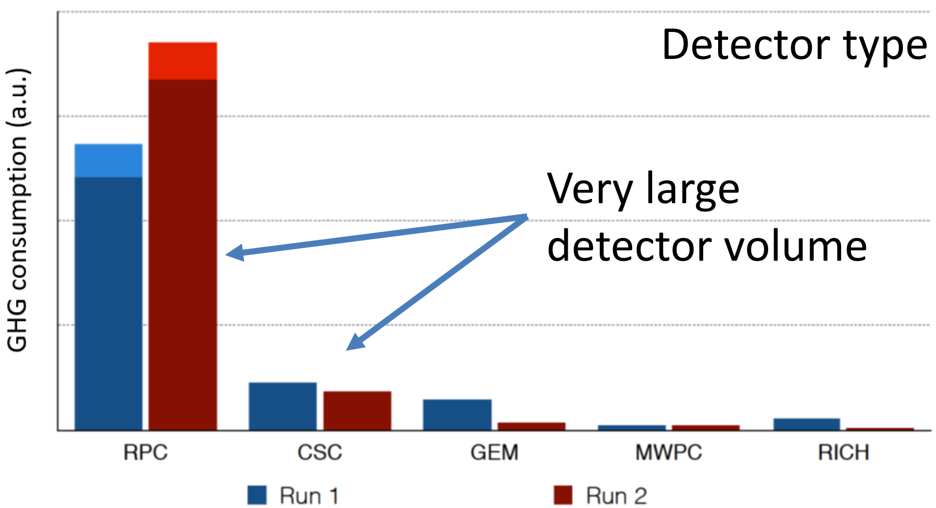
→ **Need of optimizing gas usage**

A lot of work already from the design phase

→ otherwise operational costs due to gas consumption would have been huge

***Relative contribution of GHGs used at LHC experiments***

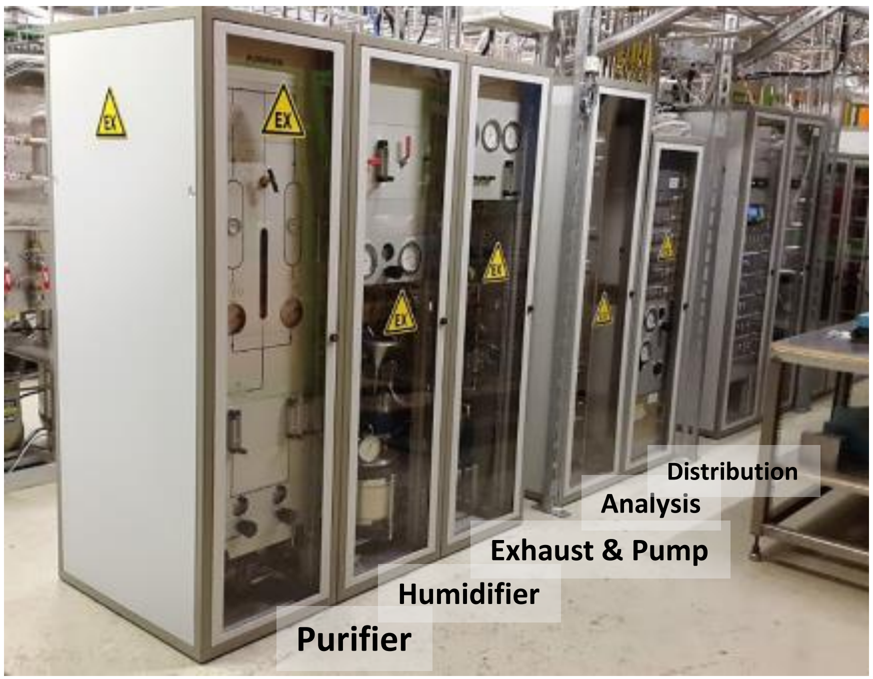


# Gas systems for LHC experiments

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




Keywords:

- **Modularity**
  - Gas systems are made of functional modules
  - Simplifies maintenance, operation, training of personnel, …
- **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, …)

# GHG Optimization Strategies

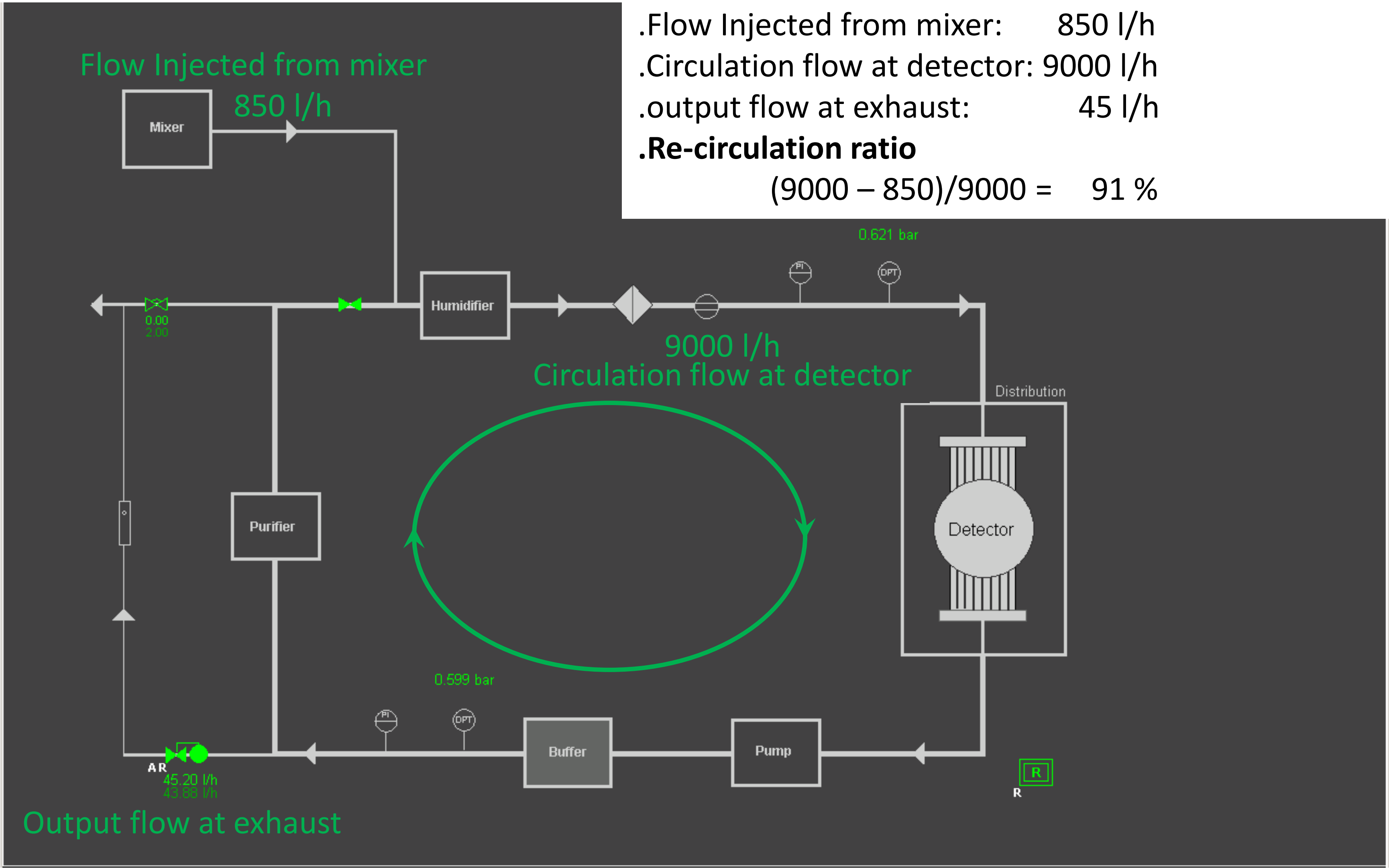
- How to reduce greenhouse gas usage
  - Optimization of current technologies
    - Optimization of present gas recirculation systems
  - Gas Recuperation
    - R134a (ATLAS, CMS and ALICE-RPC)
    - CF4 (CMS-CSC, LHCb-RICH2)
    - C4F10 (LHCb-RICH1)
  - Alternative Gases
    - Ecogas for RPC (LHC experiments and GasTeam working group)
  - Gas disposal
    - Destruction of GHGs

Program supported/funded by CERN Environmental Protection Steering board

# Gas recirculation systems

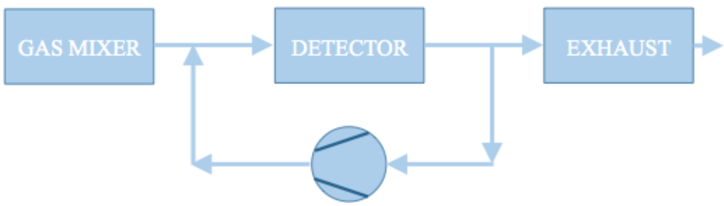
Gas recirculation system: Terminology and Flow balance

.Flow Injected from mixer: 850 l/h
.Circulation flow at detector: 9000 l/h
.output flow at exhaust: 45 l/h
**.Re-circulation ratio**
(9000 – 850)/9000 = 91 %



# Optimization of current technologies

- First step done at the early design phase:
  - Most of the systems were 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 gas)
- Sophisticated 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 and LHCb-GEM

# ALICE-RPC gas system upgrade

Much smaller wrt ATLAS and CMS-RPC systems

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

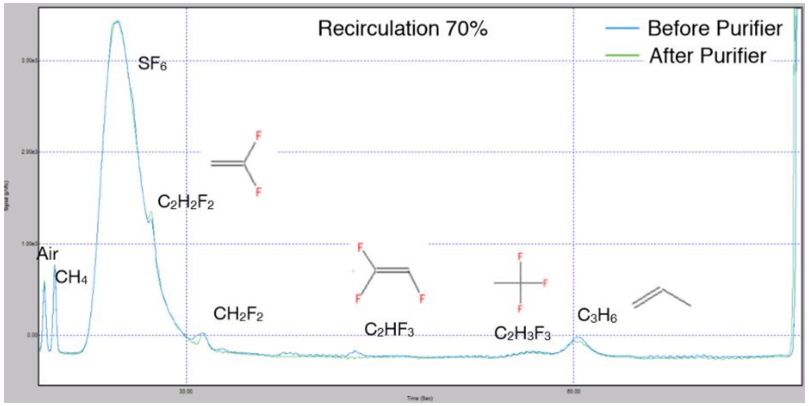
**From Run1 to Run2: 75% GHG reduction**

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)]

# ATLAS and CMS RPC gas systems

GHG usage is dominated by the large RPC systems of ATLAS and CMS

- mixture recirculation almost at design level (85-90% as validated during ageing test)

Optimization of gas system beyond original design to cope with observed detector fragility:

-Start-up procedure (after “long” stop)

-Gas system upgrade to minimize any pressure/flow fluctuation

-Different regulation parameters for start-up and run phases

-Tight warning limits

-Monitoring tools to quickly spot correlation between development of leaks and any operation

-Gas recuperation plant

-Tools for periodic check of gas system tightness

-Minimize impact of cavern ventilation

More critical situation for ATLAS-RPC due to:

-appearing of new leaks at start-up after shutdown (Xmas or LS)

-significant increase of leaks during run (from 2012 and in particular from 2015)

**Positive effects already visible:**

**→ Reduced leak developments at start-up**

**→ Pressure regulation improved by 70% where modification implemented**

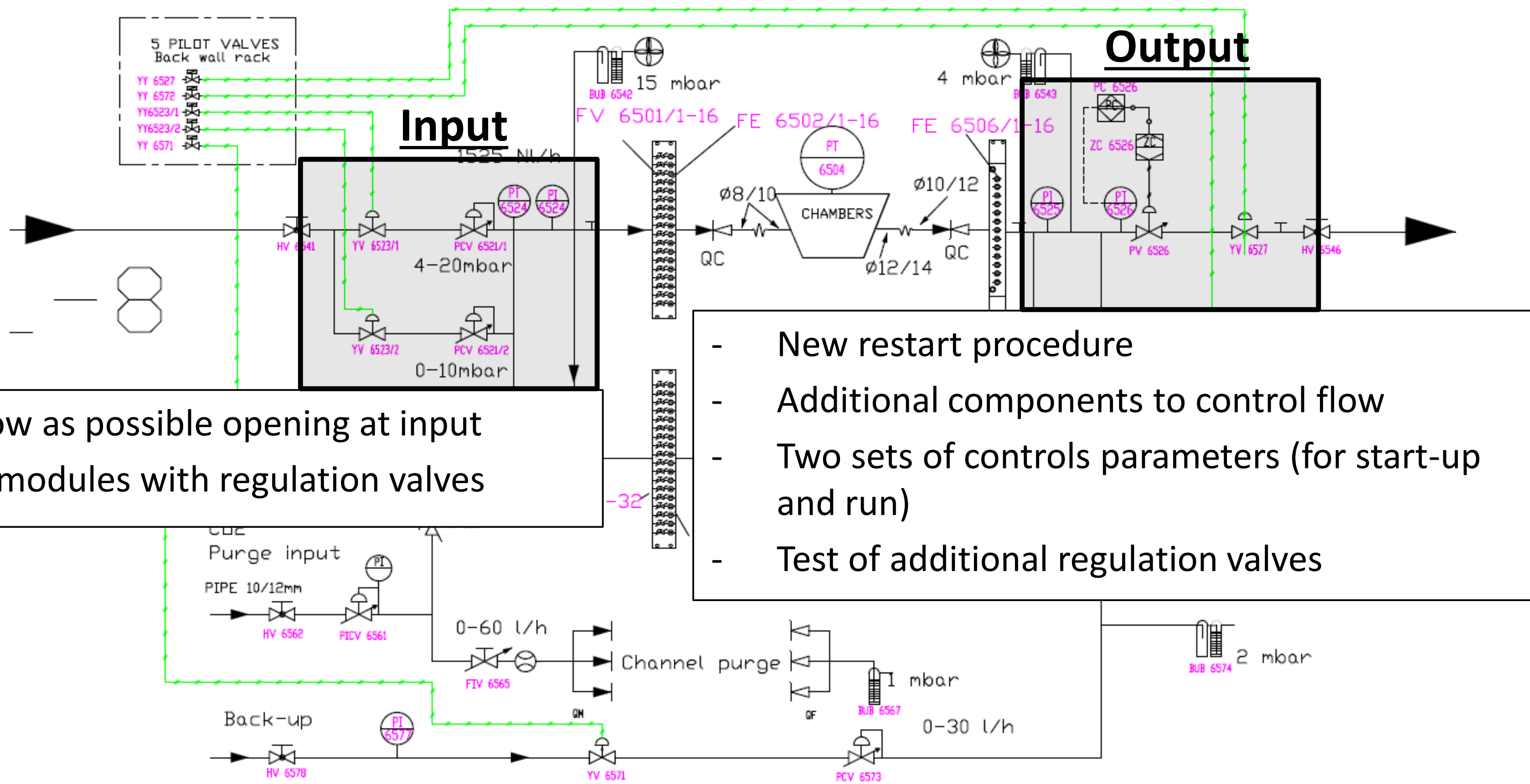
# RPC Gas system upgrade

Goal: minimize any chamber pressure/flow fluctuation

from some 0.1 mbar to < 0.1 mbar

Work on **mixture distribution modules**

one example: Distribution module




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

- New restart procedure
- Additional components to control flow
- Two sets of controls parameters (for start-up and run)
- Test of additional regulation valves

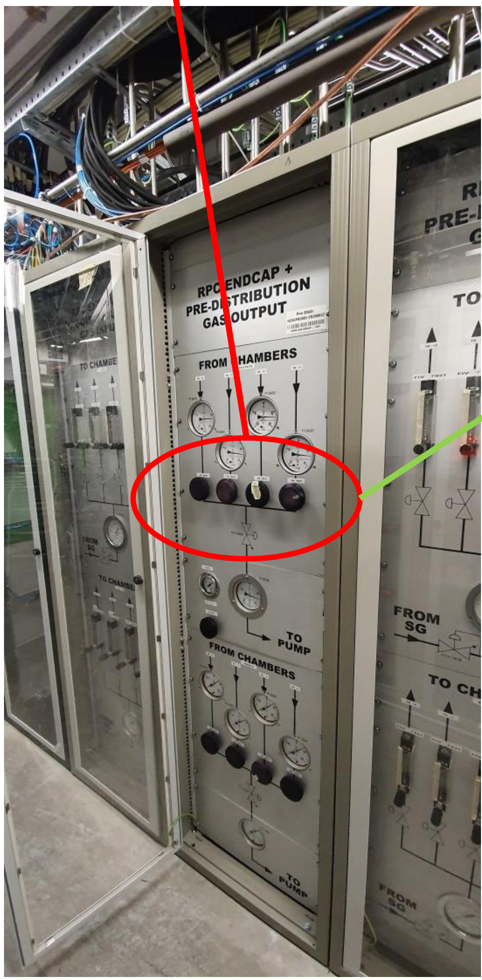
# CMS RPC gas systems

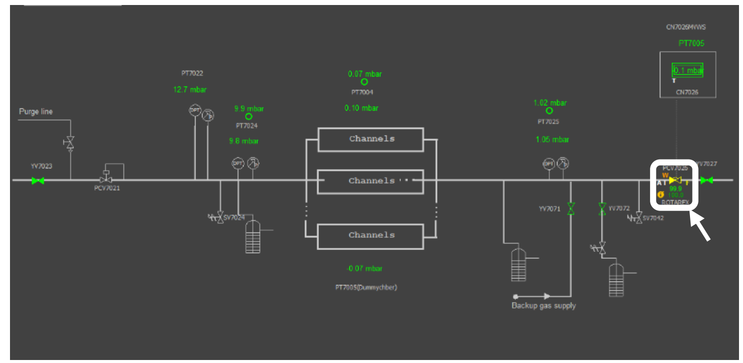
High granularity at distribution ([Gas mixture quality for CMS RPC]() RPC2020 talk)

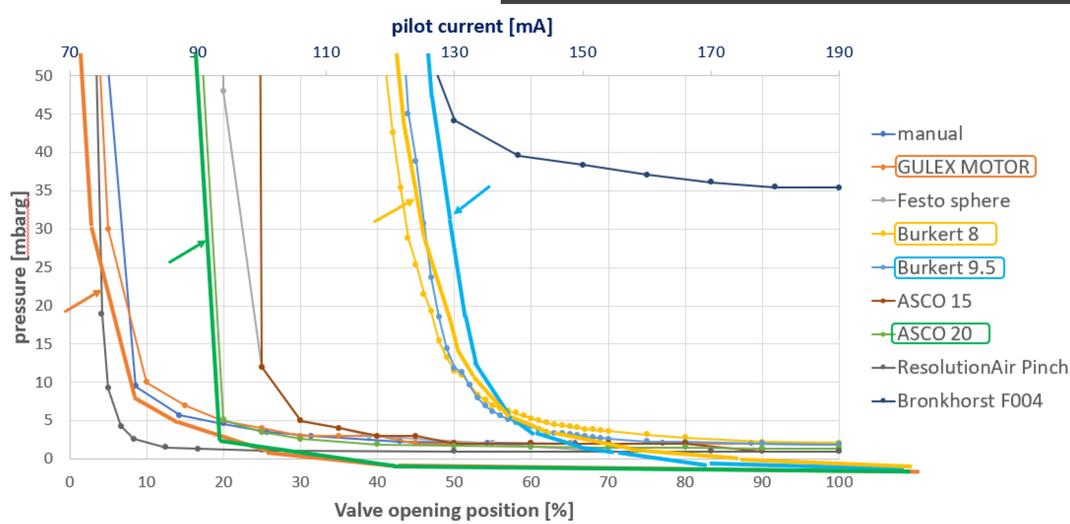
Manual valves present to equalize pressure between different detector zones

→ make difficult pressure regulation

- About 10 different models tested in lab
- 4 installed at CMS for test (other under evaluation in lab)



# ATLAS and CMS RPC gas systems

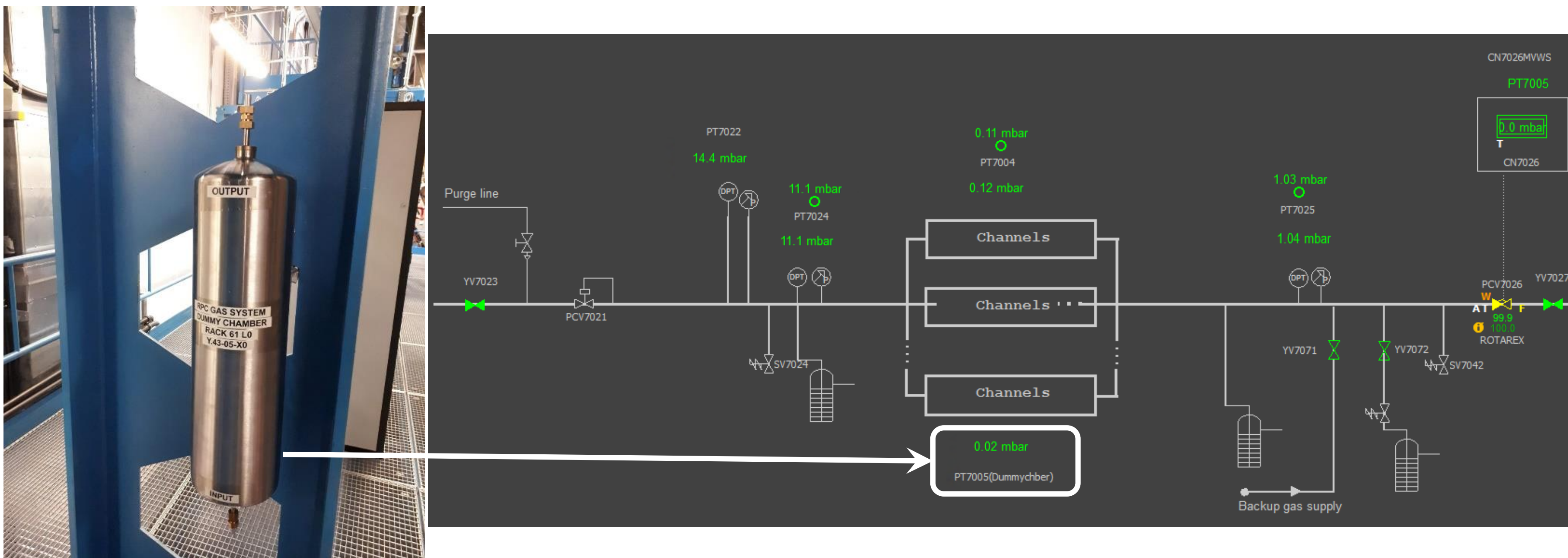
Detector pressure regulation is done sensors at rack level

→ Weight of hydrostatic column is 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

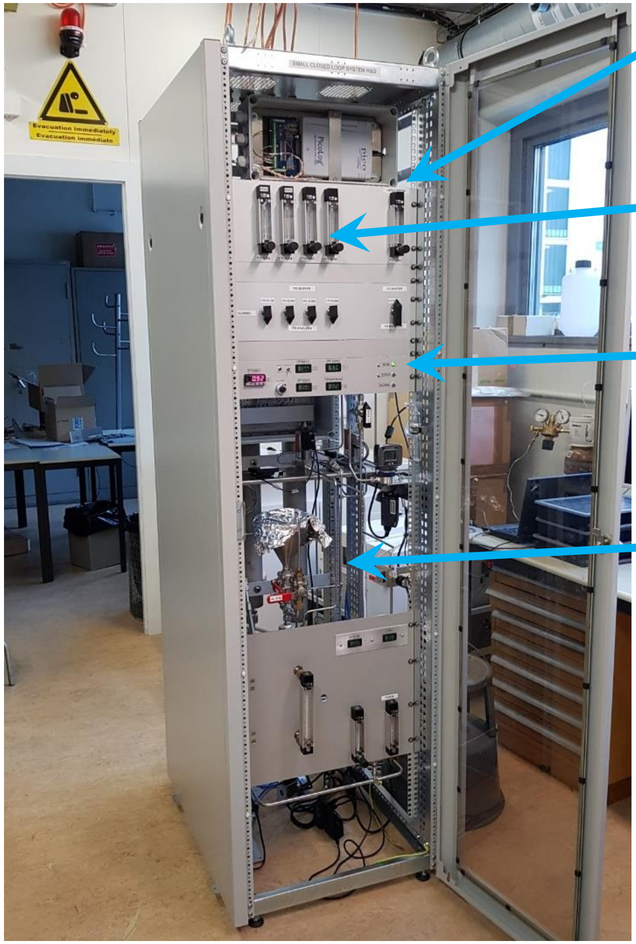
- Installation of volumes that simulates detectors ("dummy RPC") is on-going



# “Lab size” gas systems

Sometimes lab test are using relatively high gas quantity if compared with large LHC systems: example from GIF++ tests, EEE telescope, …

Development of Recirculation system for laboratory applications



Fresh input from mixer

Distribution to detectors

Monitoring of pressure, $O_2/H_2O$, temperature, atmospheric pressure

Humidifier

["A portable gas recirculation unit" JINST 12 T10002]()

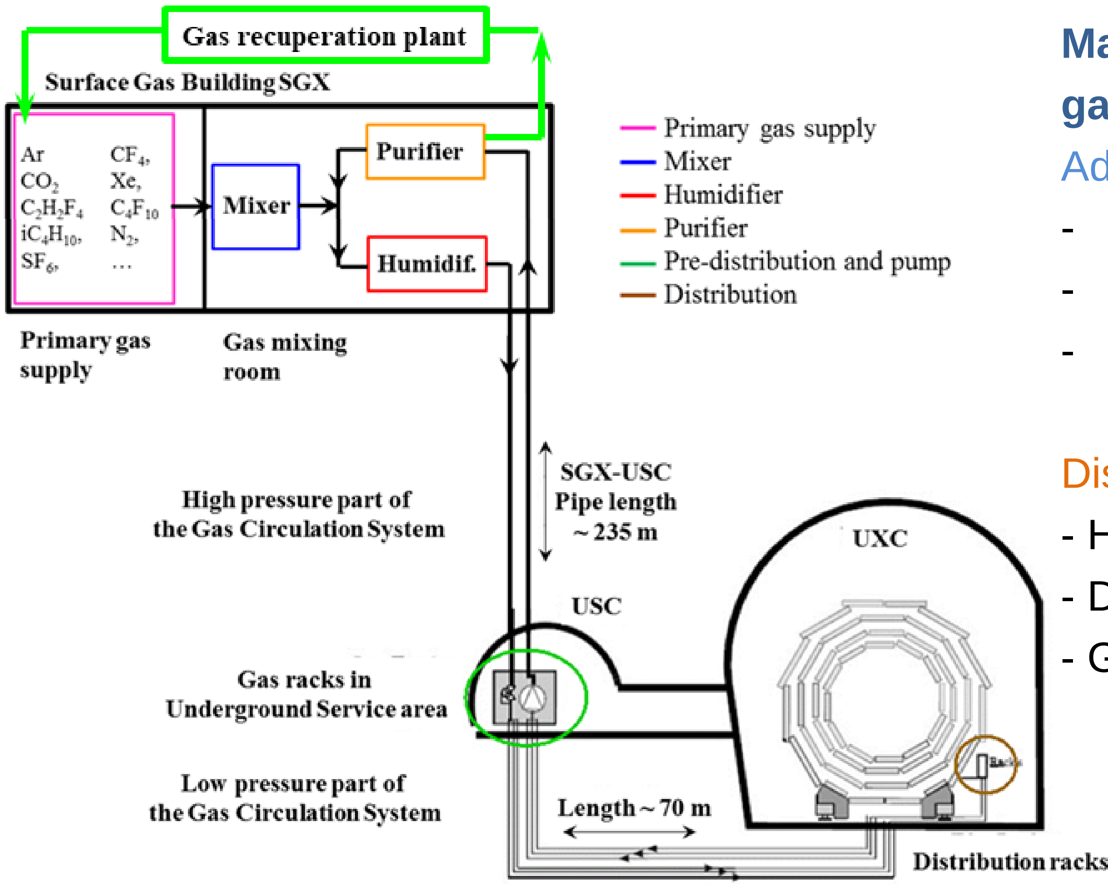
# GHG Optimization Strategies

How to reduce greenhouse gas usage
(not only for RPC)

- Optimization of current technologies
- **Gas Recuperation**
- Alternative Gases
- Gas disposal

# 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
- Keep impurities like N2 under control
- Operation at lower detector pressure

Disadvantages:

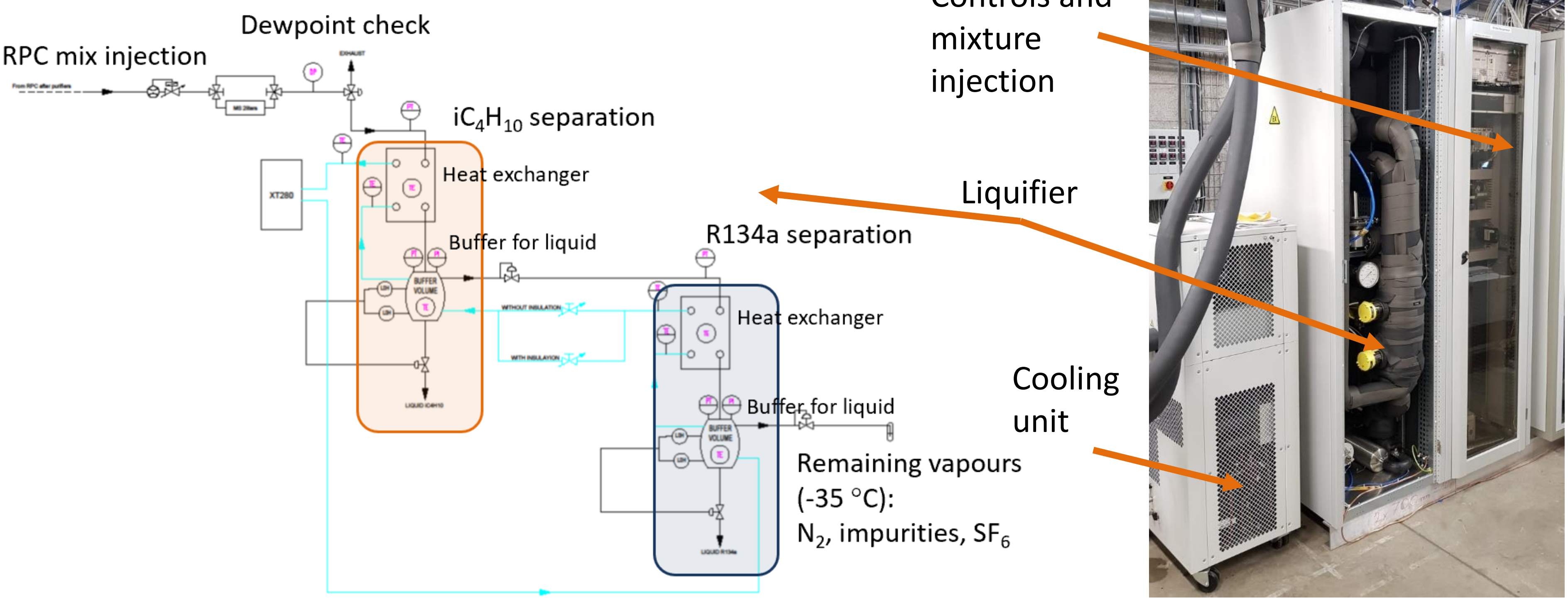
- Higher level of complexity
- Dedicated R&D
- Gas mixture monitoring fundamental

# Gas recuperation: R134a

Dec2018: Prototype0 was tested connected to ATLAS-RPC with low (100 nl/h) input flow

- Results very encouraging:
  - Very high efficiency (close to 100 %)
  - air/$N_2$ removed to same level of new R134a
  - recuperated R134a was very clean

ATLAS-SGX1



# Gas recuperation: R134a

Dec2019: Prototype0 is now connected to CMS-RPC. Test just started.

Goals:

- Run at higher flow (500-1000 nl/h)
- Test R134a compression and storage
- Re-use recuperated R134a for RPC gas system operation

CMS-SGX5

Recuperation prototype

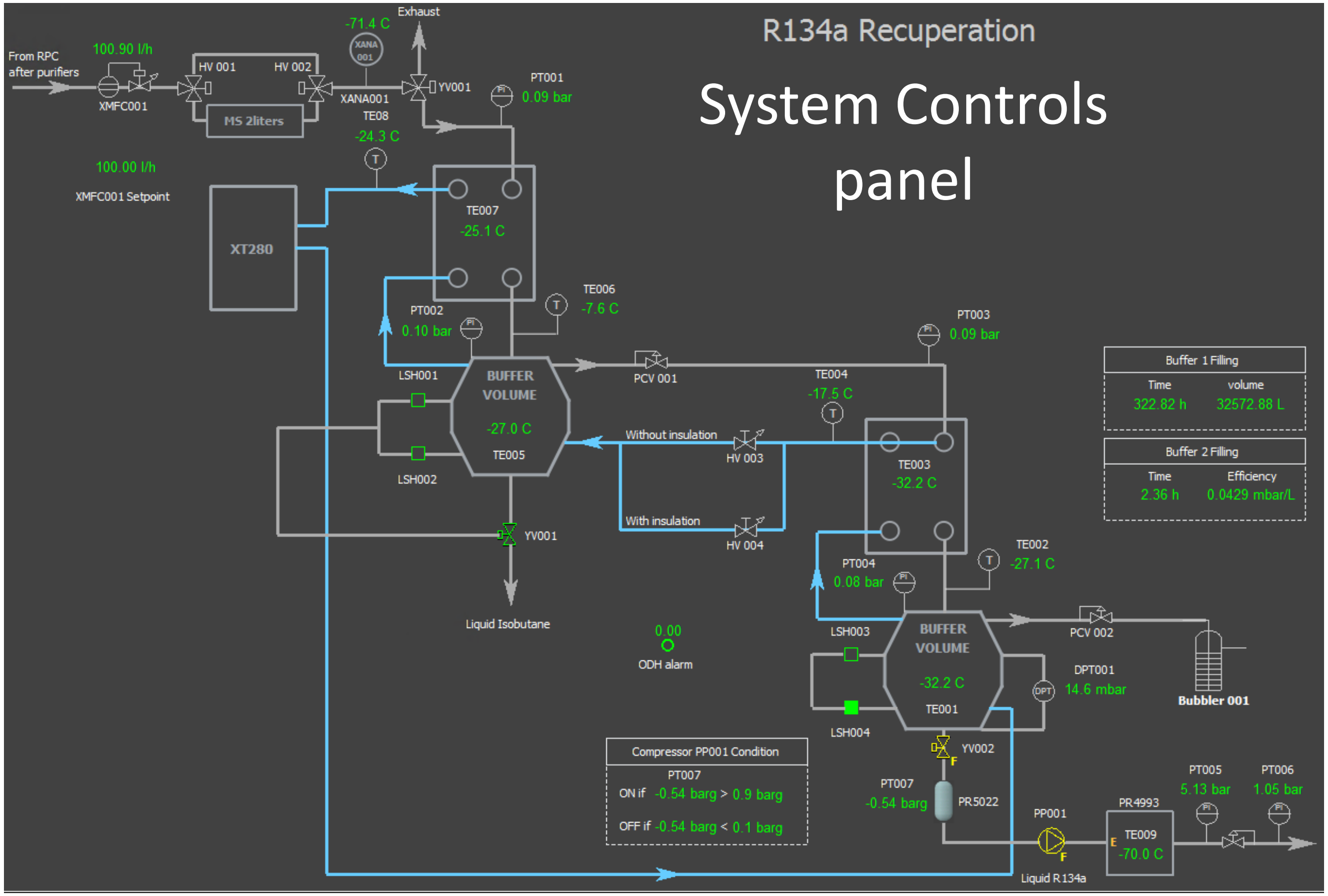
Compressor

Storage for re-use

# Gas recuperation: R134a

Dec2019: Prototype0 is now connected to CMS-RPC.

Test ongoing. Not straightforward to re-find setting with new components (compressor, storage, …)

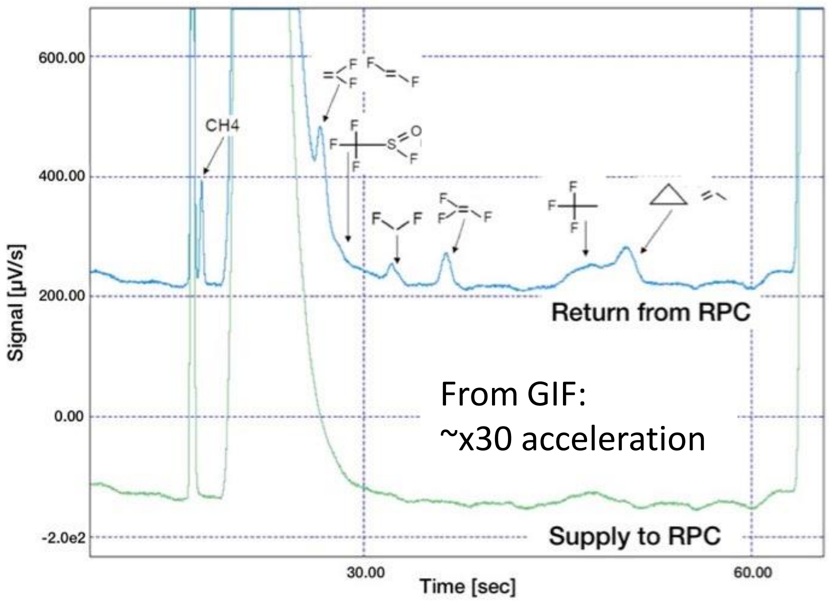


# Gas recuperation: R134a

**From Run2 to Run3**
**Potential 90% GHG reduction**

Next steps:

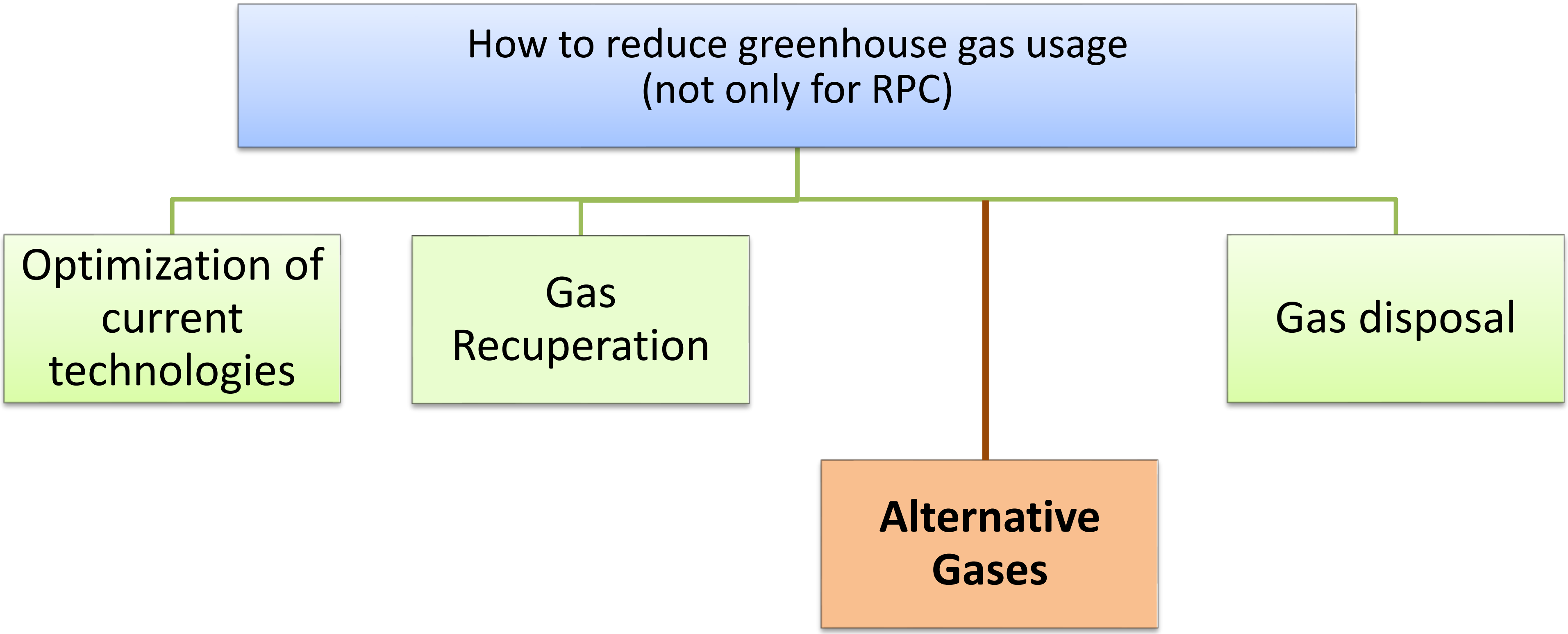
- Separation study of specific RPC impurities (i.e. not only N2): to be evaluated before Run 3




| Molecule | Boiling point (°C) | Molecule | Boiling point (°C) |
|---|---|---|---|
| C2H2F4 | -26 | C2H2F2(e) | -42 |
| iC4H10 | -12 | CH2F2 | -51 |
| SF6 | -64 | CHF3 | -84 |
| | | C2HF3 | -51 |
| CH4 | -161 | C2H3F3 | -47 |
| C2H4F2 | -117 | C3H6 (propene) | -33 |
| CF4SO | 110 | C3H6 (cyclopropane) | -47 |
| C2H2F2(z) | -20 | | |

- Test possibility of $SF_6$ recuperation

# GHG Optimization Strategies



# Alternative gases

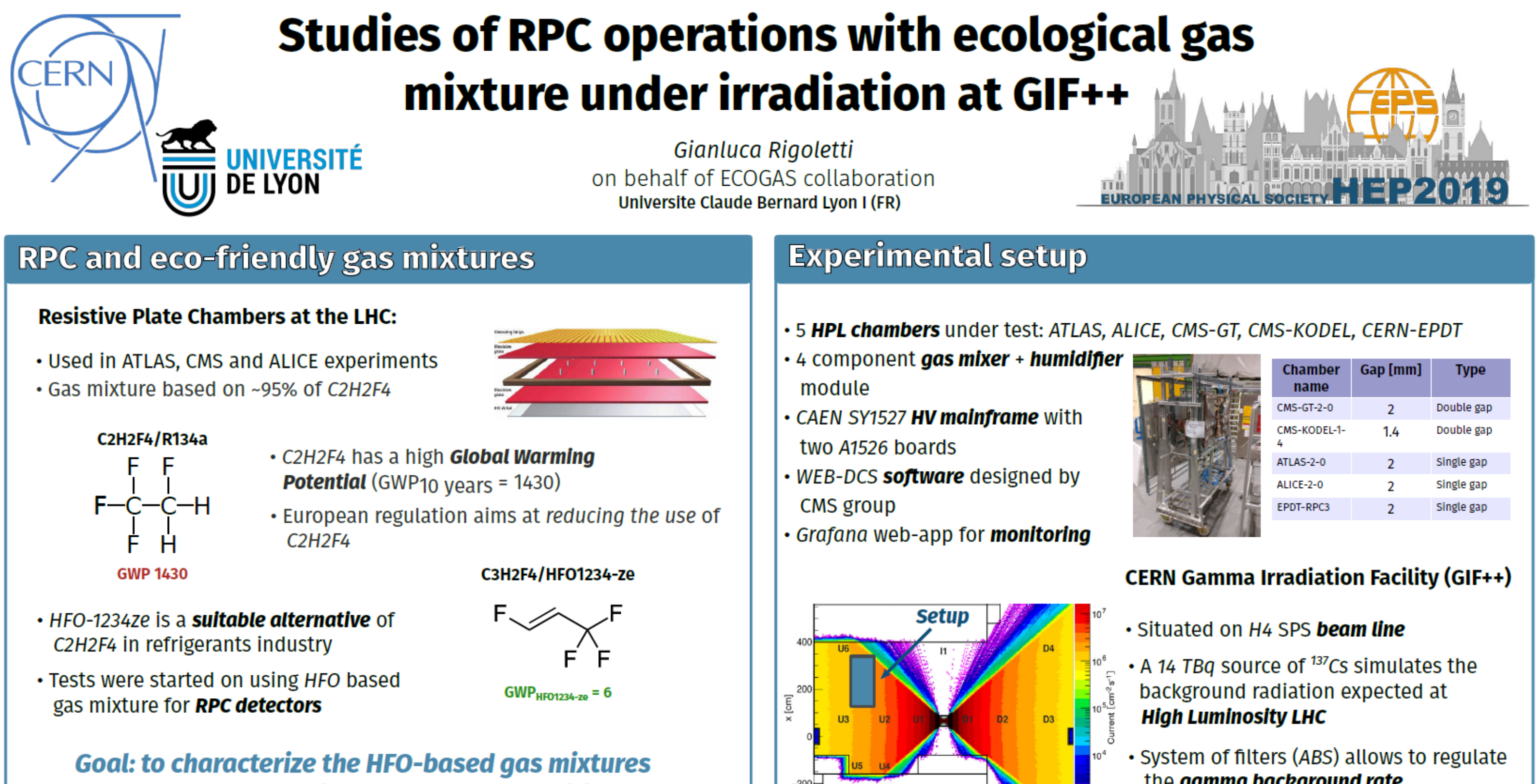
A lot of R&D ongoing

Common working group for the RPC community of ALICE, ATLAS and CMS experiments

One common setup at CERN-GIF++

Results presented at EPS2019 conference

https://indico.cern.ch/event/577856/contributions/3420164/



## Studies of RPC operations with ecological gas mixture under irradiation at GIF++

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on behalf of ECOGAS collaboration
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EUROPEAN PHYSICAL SOCIETY HEP2019

### RPC and eco-friendly gas mixtures

**Resistive Plate Chambers at the LHC:**

- Used in ATLAS, CMS and ALICE experiments
- Gas mixture based on ~95% of *C2H2F4*

C2H2F4/R134a

GWP 1430

- *C2H2F4* has a high ***Global Warming Potential*** ($GWP_{10\ years}$ = 1430)
- European regulation aims at *reducing the use of C2H2F4*

C3H2F4/HFO1234-ze

$GWP_{HFO1234-ze}$ = 6

- *HFO-1234ze* is a ***suitable alternative*** of *C2H2F4* in refrigerants industry
- Tests were started on using *HFO* based gas mixture for ***RPC detectors***

***Goal: to characterize the HFO-based gas mixtures***

### Experimental setup

- 5 ***HPL chambers*** under test: *ATLAS, ALICE, CMS-GT, CMS-KODEL, CERN-EPDT*
- 4 component ***gas mixer*** + ***humidifier*** module
- *CAEN SY1527* ***HV mainframe*** with two *A1526* boards
- *WEB-DCS* ***software*** designed by CMS group
- *Grafana* web-app for ***monitoring***

| Chamber name | Gap [mm] | Type |
|---|---|---|
| CMS-GT-2-0 | 2 | Double gap |
| CMS-KODEL-1-4 | 1.4 | Double gap |
| ATLAS-2-0 | 2 | Single gap |
| ALICE-2-0 | 2 | Single gap |
| EPDT-RPC3 | 2 | Single gap |

**CERN Gamma Irradiation Facility (GIF++)**

Setup

- Situated on *H4 SPS* ***beam line***
- A *14 TBq* source of $^{137}Cs$ simulates the background radiation expected at ***High Luminosity LHC***
- System of filters (*ABS*) allows to regulate the ***gamma background rate***

# GHG Optimization Strategies

How to reduce greenhouse gas usage
(not only for RPC)

Optimization of current technologies

Gas Recuperation

Alternative Gases

**Gas disposal**

# 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 one company available to take PFC/HFC based mixture for disposal: but extremely expensive

# Conclusions

*R&D program aims in developing systems allowing to optimize GHG usage:*

- For many gases used today there is no “easy” replacement available
- Availability and price of used GHGs can be affected (one more good reason for optimizing consumption)

*Four strategies identified:*

- **Optimization of current technologies**
  - Particular attention to gas system and detector operation
  - Gas systems development beyond original design
  - The specific case of ATLAS and CMS RPC detector systems
  - Improved/higher gas recirculation
  - Controls, Purifier and other module upgrades (here only example of distribution was presented)
  - Development of small gas recirculation system for laboratory application

- **Gas recuperation plant**
  - Recuperation system for R134a, $SF_6$ will be effective if leaks at detector will be reduced
  - R&D costs for R134a recuperation system is well justified by running costs
  - R134a recuperation prototype0 showed good performance (both quality and efficiency)

# Conclusions

- **New eco-gases**
  - HFO1234ze promising but difficult for already installed detectors (many constrains)
  - Many tests ongoing everywhere
  - New common effort: joint EcoGas collaboration for RPC at GIF++
  - However, it does not look for tomorrow

- **GHGs abatement/disposal**
  - Commercial systems exist. Adopted when gases cannot be reused.
  - Quite heavy infrastructures required
  - Gas availability can become a real problem in the future it is always better to minimize consumption

*Optimized gas systems, new recirculation plants, … are*

- Nevertheless increasing complexity for operation
- Development and application of strict maintenance and operation procedures

# Optimization of gas consumption