# Strategies for reducing greenhouse gases emissions at the CERN LHC experiments

Gianluca Rigoletti
Supervisors: R. Guida, P. Nedelec

PhD Day, 27/01/2021, Lyon, France

# Outline

- ➔ Introduction and PhD activities
- ➔ Greenhouse gases at CERN LHC experiments
  - ◆ Greenhouses gases usage
  - ◆ Strategies for greenhouse gases reduction
- ➔ Optimization of current technologies
  - ◆ Gas Systems overview
  - ◆ Gas Control and Monitoring Systems
- ➔ Alternative gases and Resistive Plate Chambers detectors
  - ◆ Characterization of RPCs with eco-friendly gas mixtures and cosmics muons
  - ◆ Aging and impurities studies at the Gamma Irradiation Facility
- ➔ Conclusions

# Introduction

## Who am I

- Physics student, master in physics of the matter at the university of Milano-Bicocca, Italy
- CERN based, currently doing my 2nd year (but D3) of PhD
- My interests involved mainly python, pizza and hydroponics systems

## My PhD

**Goal:** *find, study, develop strategies to reduce greenhouse gases (GHGs) emissions from gas systems at CERN LHC experiments.*

***Main PhD activities***

**Gas Systems for LHC-experiments**

- Upgrades, maintenance and operation of LHC-experiments
- Gas control systems software involvement

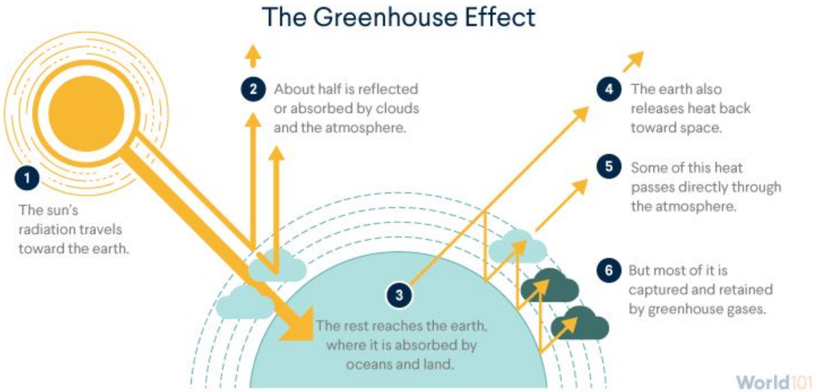
**R&D on gas systems**

- RPC performance studies with eco-friendly gas mixtures
- Live monitoring tools for dedicated setups
- Data analysis on GHG emission for specific systems

# Greenhouse gases

# Greenhouse gases

A **Greenhouse gas** (GHG) is a gas absorbing and emitting energy in the **infrared range**, causing the greenhouse effect (i.e. warming the earth surface)




**Fluorinated** gases are usually **high-GWP** gases, thus considered **GHGs**

The **global warming potential** (GWP) is a measure to quantify the "strength" of a GHG.

↓

*it measures how much energy the emissions of 1 ton of a gas will absorb over a given period of time,* ***relative to the emissions of 1 ton of CO2***.

| Gas | GWP[100] | Lifetime [years] |
|---|---|---|
| CO2 | 1 | * |
| CH4 | 28 | 12.4 |
| N2O | 265 | 121 |
| C2H2F4 | 1430 | 14 |
| CF4 | 7390 | 50000 |
| SF6 | 22800 | 3200 |

# Greenhouse gases at CERN

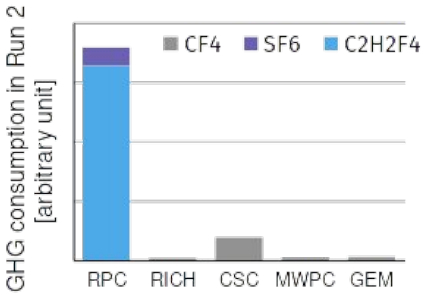
At **CERN**, several gaseous detectors use **gas mixtures** with at least one **GHG**.

The main **GHG emissions** from particle detectors are due to **fluorinated** compounds.

The main emission is coming from **C2H2F4** (R-134a), used in ATLAS, CMS and ALICE experiments

European union **F- regulation** aims at reduce the F-gas availability

*PhD goal: find, study, develop strategies to reduce GHGs emission from particle detectors at CERN LHC experiments*



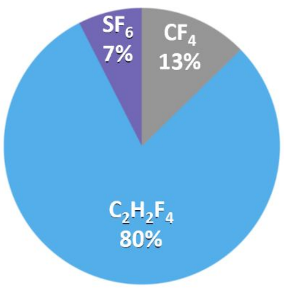
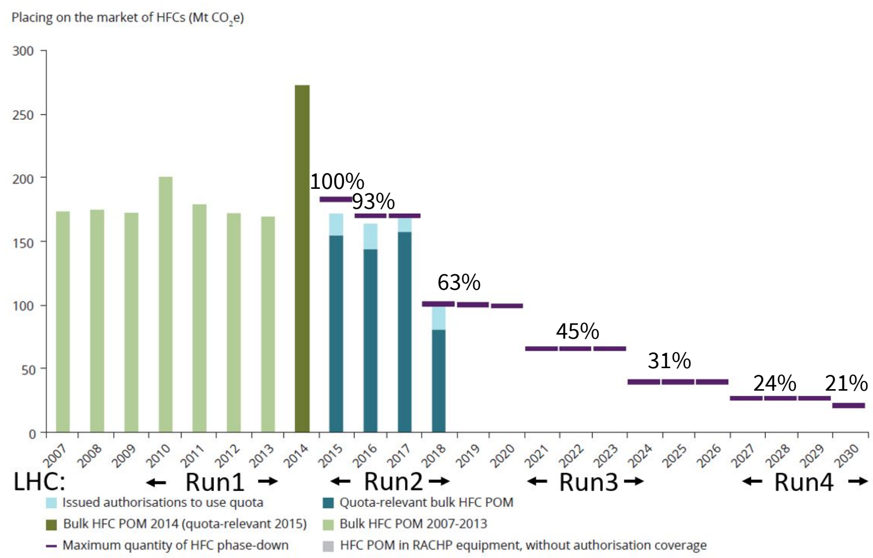



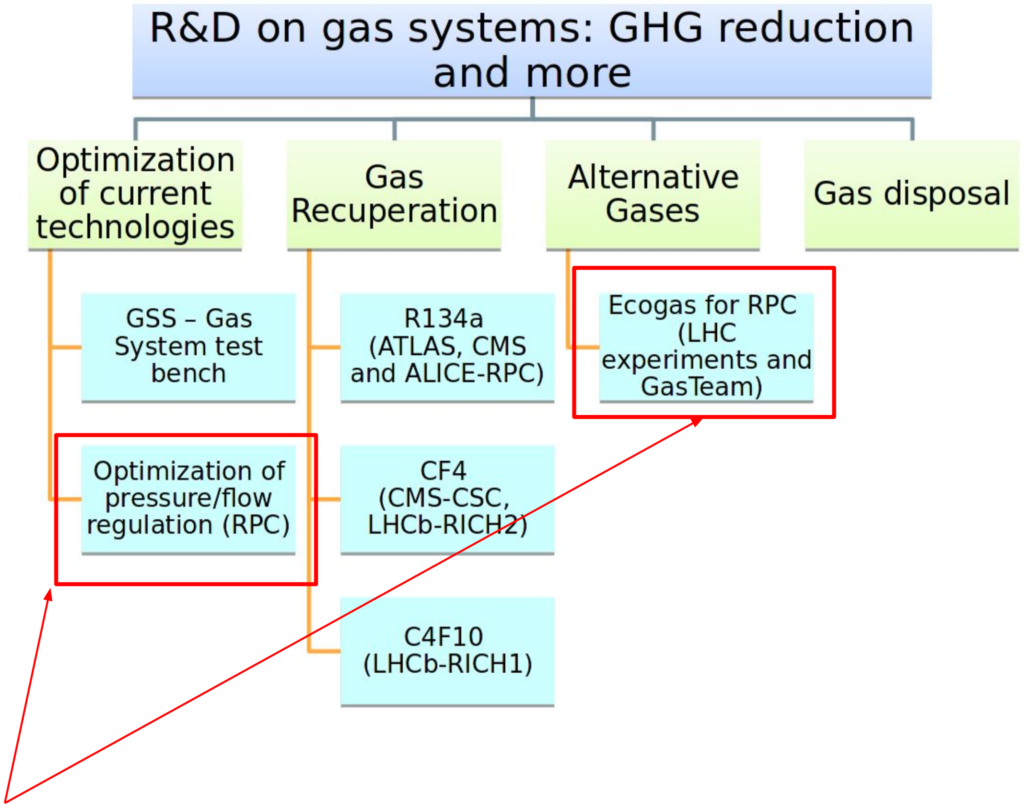

**Figure ES.1** **Progress of the EU HFC phase-down**



# Strategies to reduce GHG emissions

Four different strategies defined:

- **Optimization** of current technologies: gas recirculation, pressures and flow fine regulation
- **Gas recuperation**: extract GHGs from gas mixtures and reuse them
- **Alternative gases**: study the effects of eco-friendly gas on detectors performance
- **Gas disposal**: abatement of the gas if possible

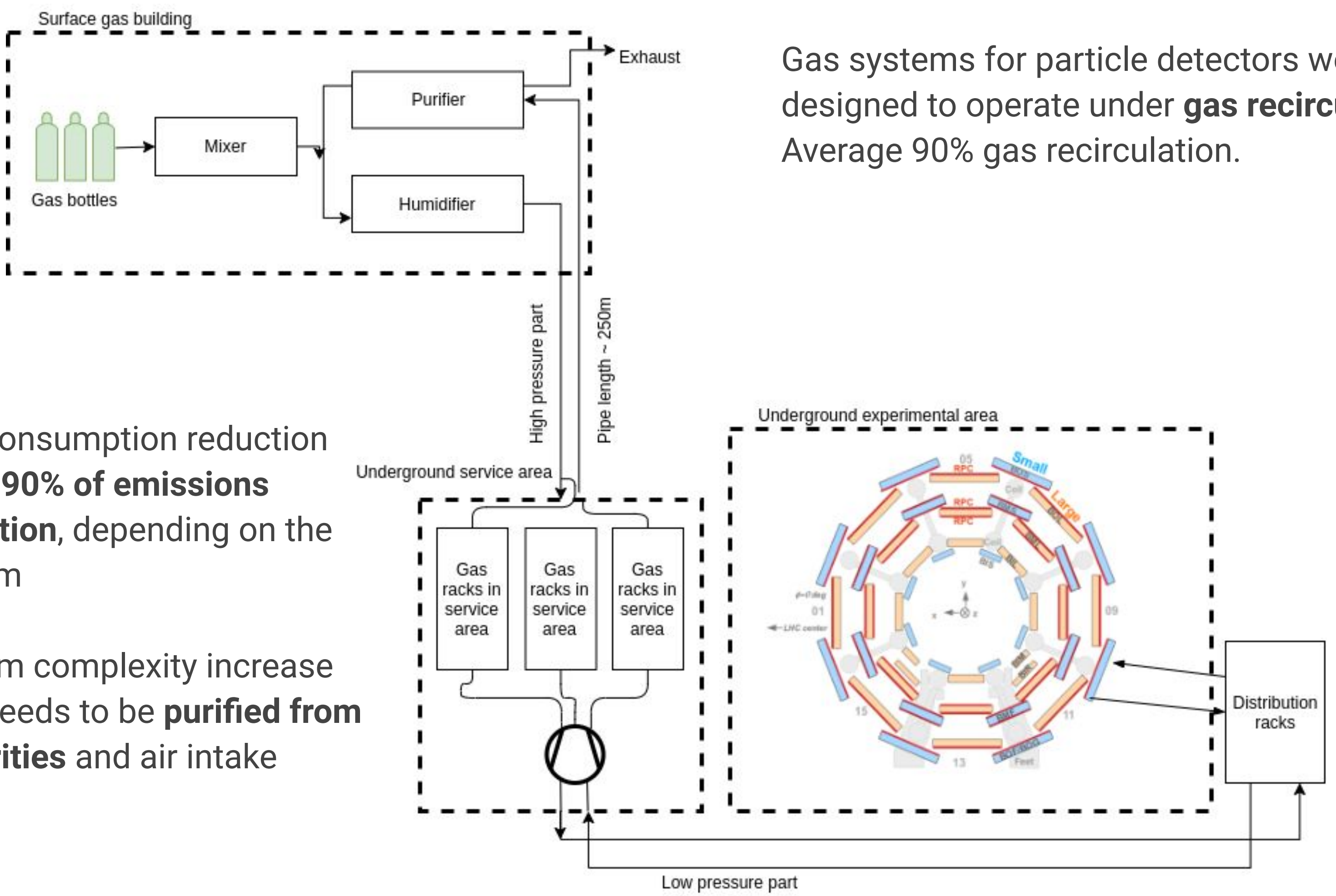



Main PhD activities

# Optimization of current technologies

# Gas System overview

*Schematic view of an LHC gas system*




Gas systems for particle detectors were designed to operate under **gas recirculation**. Average 90% gas recirculation.

**Pros**:

- Gas consumption reduction
- **Up to 90% of emissions reduction**, depending on the system

**Cons:**

- System complexity increase
- Gas needs to be **purified from impurities** and air intake

# Optimization of current technologies

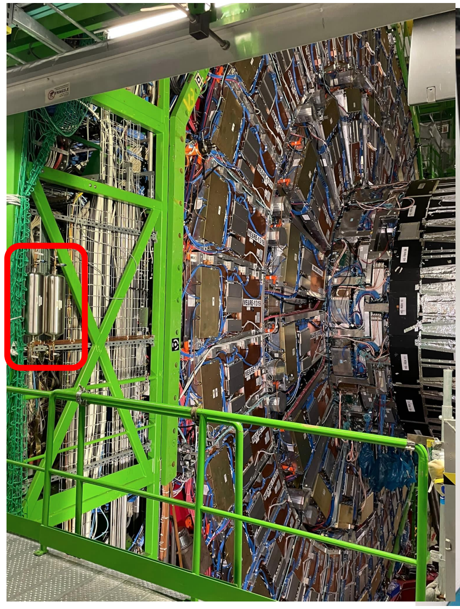
**Hardware optimization**

- Optimization of **single modules**:
  - Drawings, CADs collection
  - Piping, layout organization
- Proper checks and maintenance on **existing equipment**
  - Ex: pump membranes and mass flow controllers check
- Installation of **new components** in the gas systems
  - E.g. regulation valves for pressure control
  - E.g. filters for dust, micro particles

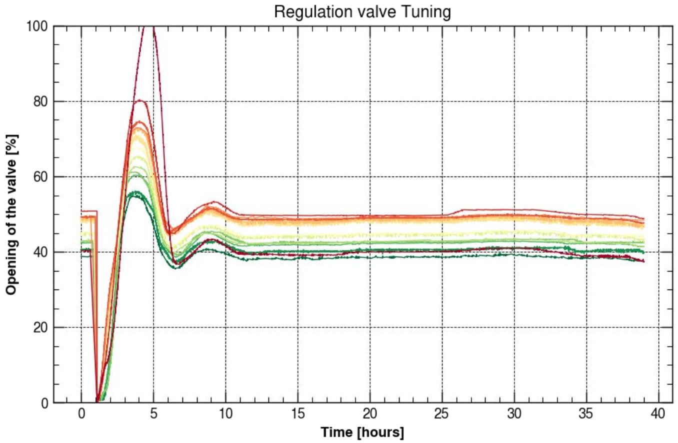
**Software optimization**

- Parameters tuning:
  - **P.I.D.** values of regulation valves
  - Flow and pressure setpoints
- Alarms and notifications to the operator:
  - Thresholds
  - Severity levels
  - Timers, hysteresis and so on
- Archiving and data retrieval
  - Optimize the number of stored data point
  - Improve offline and online data retrieval tools

*Dummy chambers for pressure control*



*Layout of a distribution rack*



# Gas Control and monitoring Systems

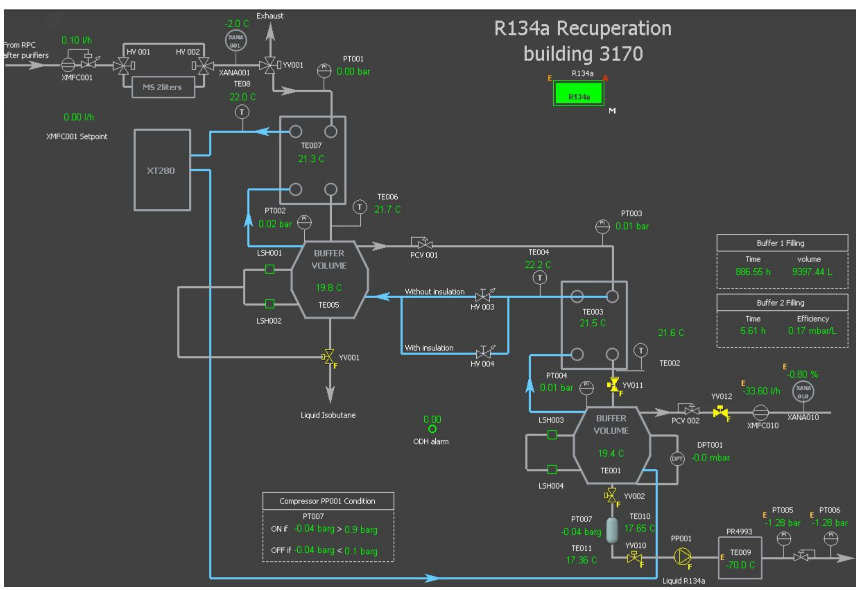
**Gas control systems** (GCS) allow to monitor and control the plant providing gas to detectors.

**Main features:**

- Built on by CERN industrial control + Siemens SCADA software
- Common Human Machine Interface for operators -> Ease of use

**Monitoring systems: technologies involved**

- SCADA: WinCC-OA
- PLC programming: Schneider electric
- Web
  - Devops: Openshift
  - Time series databases: InfluxDB
  - Dashboarding: Grafana
- Analysis: python with its ecosystem




*WinCC-OA: monitor and control*

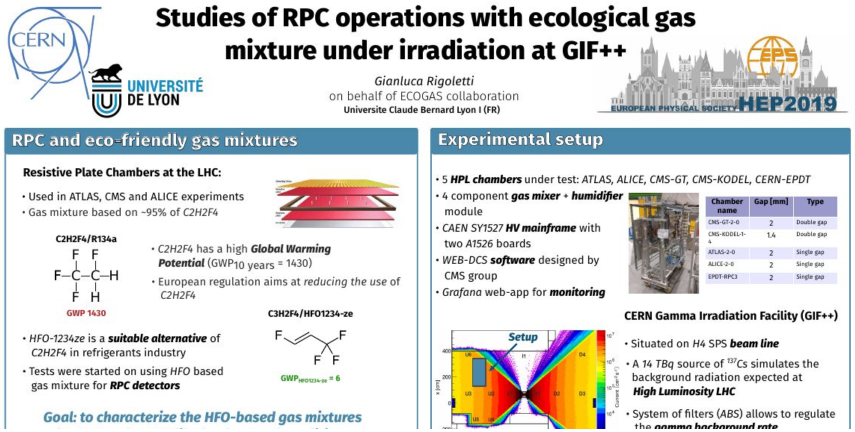

*Grafana: monitor*

# Alternative gases and Resistive Plate Chambers detectors

# Alternative gases

Detector **performance** characterization with of **eco-friendly** gas mixtures.

Few detectors are studied: mainly **Resistive Plate Chambers** (RPCs) because of their emissions and **Gas Electron Multipliers** (GEM).




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

**Pros**

- Reduction in GHGs emissions
- **Gas system complexity remains the same**
- Possibility to operate detectors at **higher flow rates** if needed

**Cons**

- **Long term studies** are required to validate detectors operation
- Eco-friendly gas price and availability
- **Performance gains**/loss still **not clear**

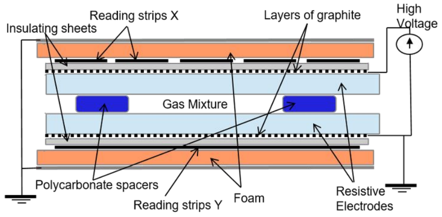
# Resistive Plate Chambers (RPCs) at LHC

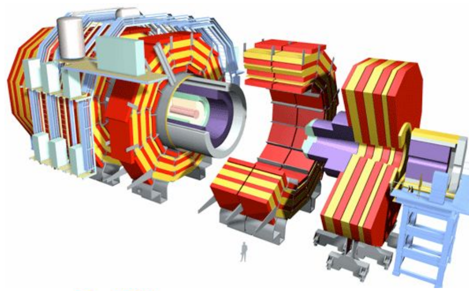
RPCs: gaseous particle detectors employed in **ATLAS**, **CMS** and **ALICE** experiments

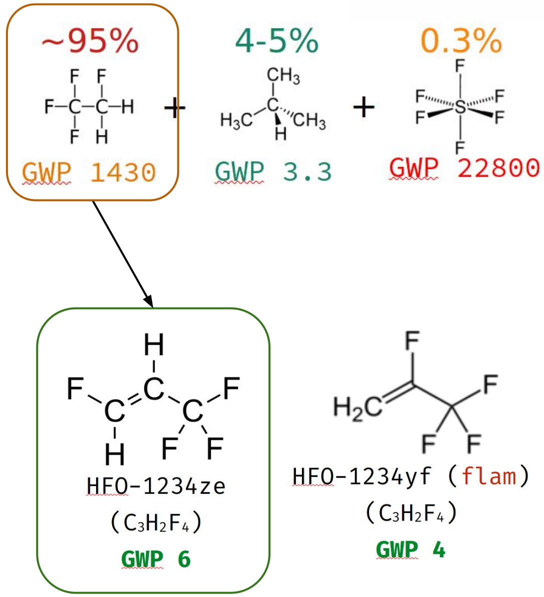
The gas mixtures is made out of 2 or 3 main components: **$C_2H_2F_4$(R-134a)**, **i-$C_4H_{10}$** and **$SF_6$** with a gas mixture of **GWP**$_{[100]}$ ~ **1400**

The **presence of leaks** at detector level in ATLAS and CMS results in a considerable **GHG emissions** due to **R-134a.**

The refrigerant industry started using Hydro-Fluoro-Olefins (**HFO**s) gases as **R-134a alternative**.



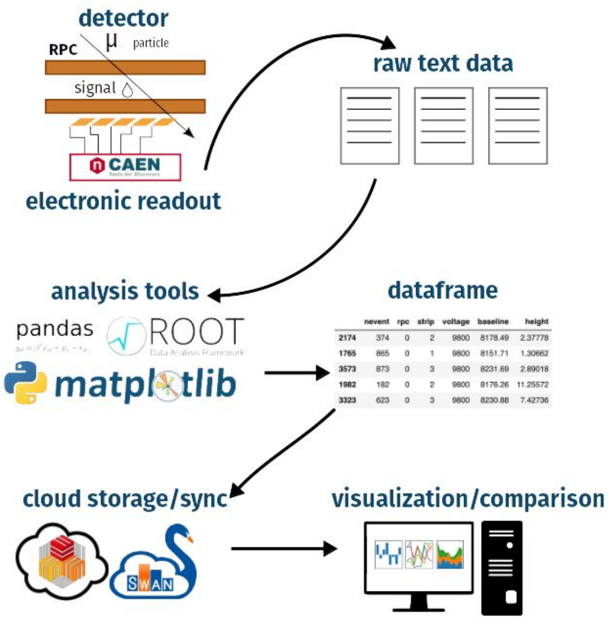



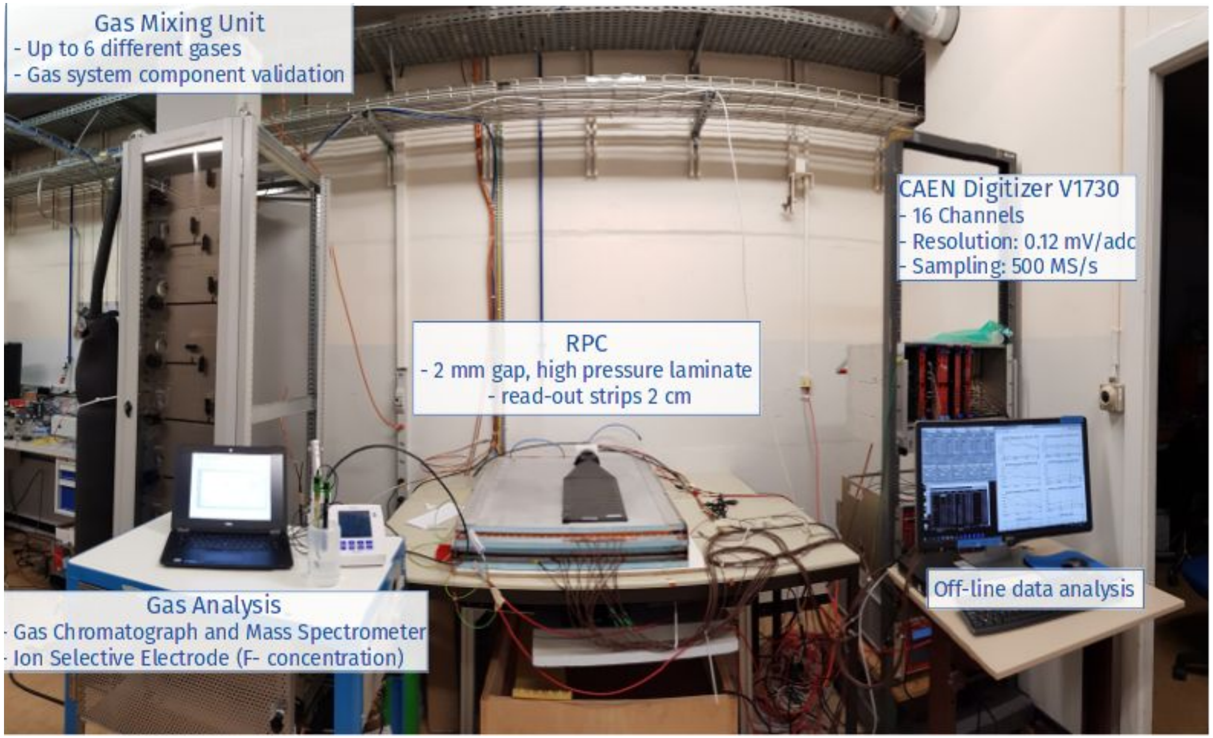



*Goal: find and **eco-friendly** gas mixture **compatible** with the current ATLAS and CMS RPC **systems** (i.e. requires no change in the HV cables, FE electronics, gas system etc.)*

# Eco-friendly gases performance studies

RPCs **performance** studied with **eco-friendly** gas mixtures and **cosmics muons** on a dedicated setup




Dedicated **data acquisition system** and
**Data analysis pipeline** written for studying the detectors

# Alternatives to R-134a: HFO-1234ze

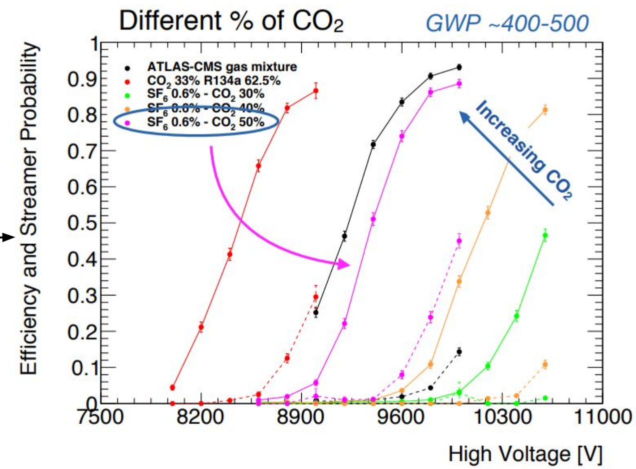
The **working point** of the detector with HFO replaced to R-134a is > 12 kV, **not suitable for LHC**

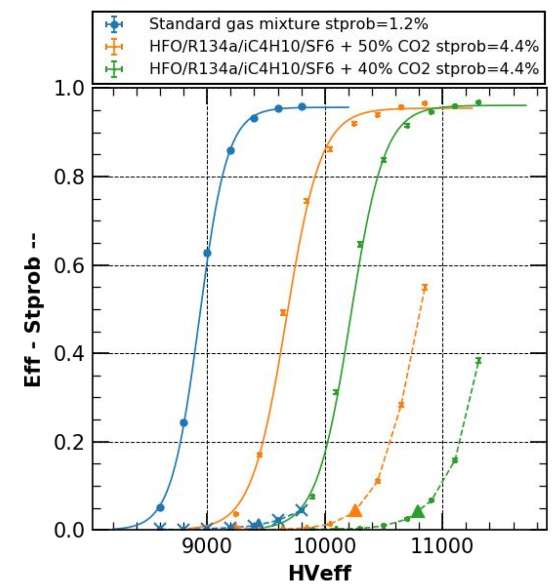
An addition of a gas lowering the working point is required: **4-components gas mixtures** with **$CO_2$** were studied

A small fraction of **R-134a** is needed to mitigate streamer fractions and stabilize the detector performance -> **5-component gas mixtures**

2 selected **HFO-based** gas mixtures:

| Gas mixture | Working point [V] | St. Prob. [%] | Pulse charge av [pC] | Pulse charge st [pC] | Cluster size [#/2cm] | Time resolution [ns] |
|---|---|---|---|---|---|---|
| Standard | 9440 | 1.2 | 0.8 | 10.1 | 2 | 1.9 |
| HFO/ R134a/ iC4H10/SF6 + 50% CO2 | 10260 | 4.4 | 1.1 | 14.7 | 2.3 | 2 |
| HFO/ R134a/ iC4H10/SF6 + 40% CO2 | 10790 | 4.4 | 1.1 | 11.8 | 2.2 | 1.8 |

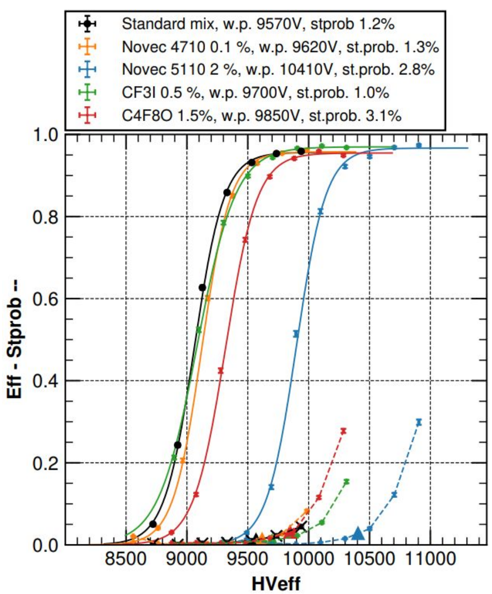


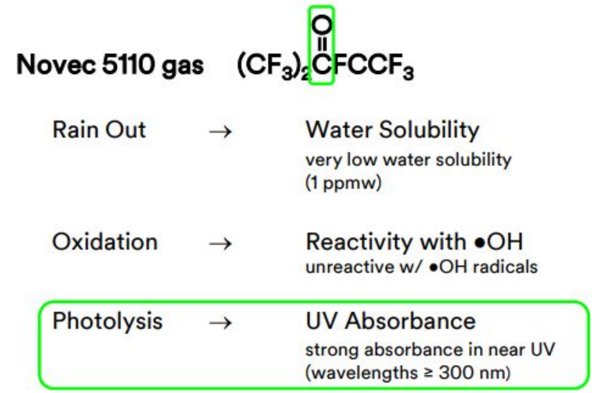



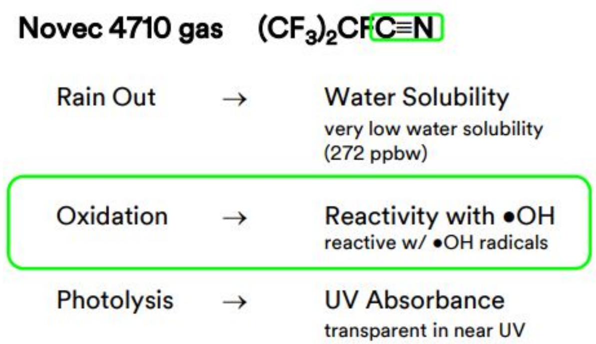
# Alternatives to SF6

**Alternatives to $SF_6$** were tested and they are still under study:

- $CF_3I$: GWP = 0, **good** performance but **toxic**
- Novec 5110: GWP < 1, discrete performance but **boiling point** at 26 °C
- Novec 4710: GWP 4700, **excellent performance** but may react with **water**
- $C_4F_8O$: GWP ~ 8000, poor performance




*John G. Owens, 3M, Greenhouse Gas Emission Reductions from Electric Power Equipment through Use of Sustainable Alternatives to SF6*

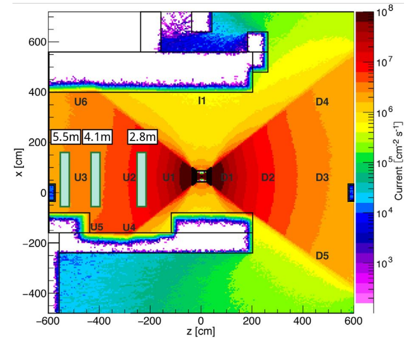
# Gamma Irradiation Facility

**Long term study** of RPCs performance with eco-friendly gas mixture started.

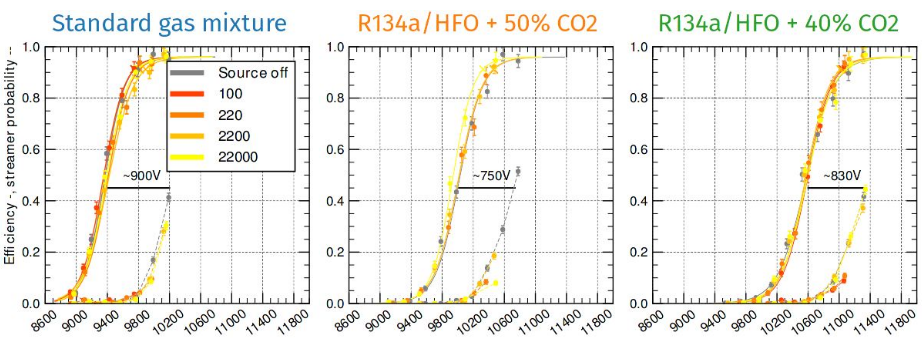
***Goal: characterize performance with***

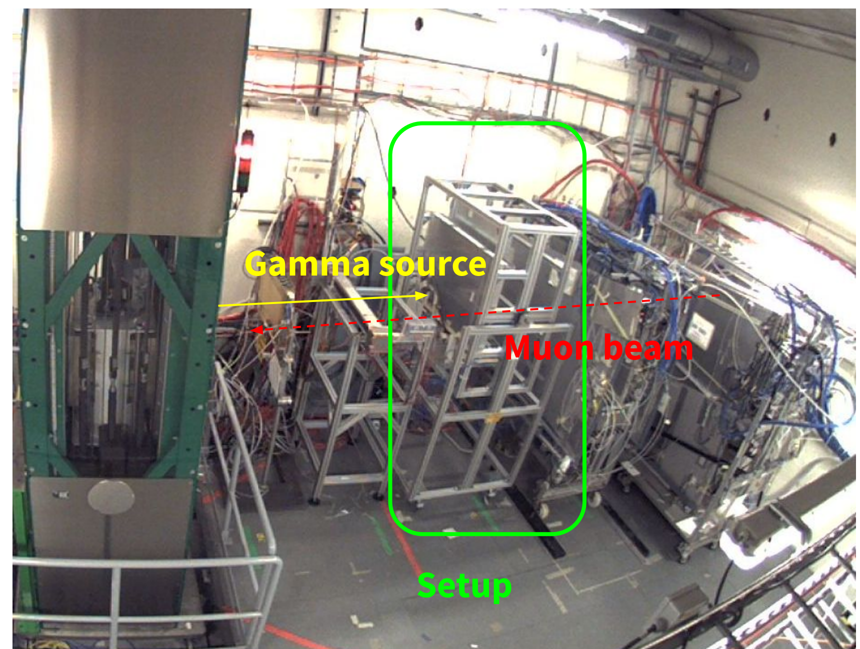
- eco-friendly gas mixtures
- LHC-like conditions:
  - Background radiation
  - Gas recirculation

| ABS | Gamma Rate [kHz/cm²] |
|---|---|
| 100 | 55.3 |
| 220 | 41.2 |
| 2200 | 3.75 |
| 22000 | 0.774 |




RPCs studied with both muon beam and gamma irradiation during test beam




https://doi.org/10.1088/1748-0221/15/05/c05004

# Impurities study

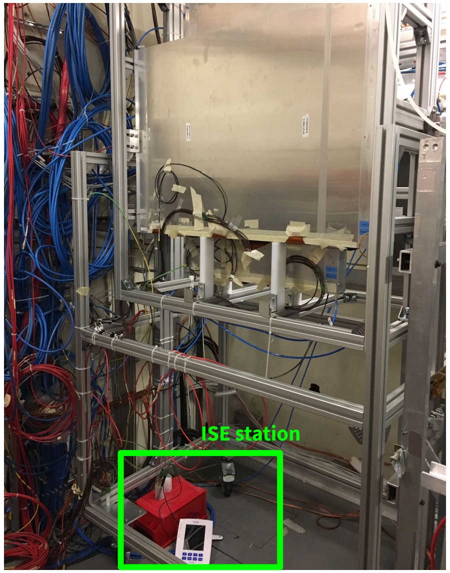
Under the effect of high background radiation and electric fields **Freons** (HFO, R-134a) **molecules break** into **fluorine radicals**.

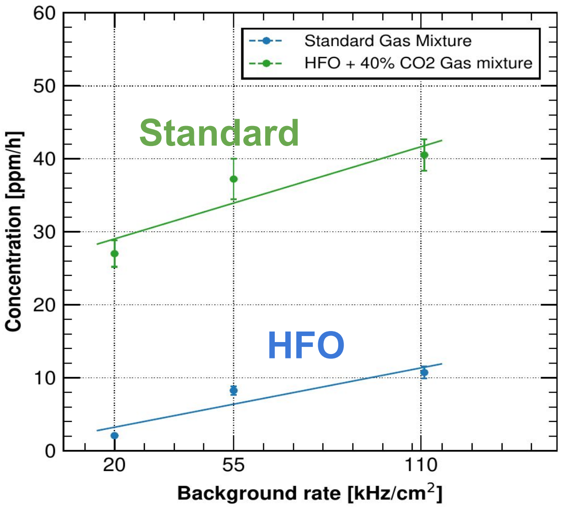
F- radicals may react with water vapour contained in the RPC gas mixtures and could form **fluoridric acid (HF)**

**HF could damage surface of the electrodes** of the detectors

A dedicated test was conducted to measure the **rate of HF production** by irradiating 2 RPC and measuring the HF with Ion Selective Electrodes (ISE) stations.

***We found out that HFO molecules are breaking ~10 times more easily than R-134a molecules***




https://doi.org/10.1088/1748-0221/15/11/C11003

# Conclusions

**Several strategies** for GHG emissions reductions

**Different activities** involvement

**LHC Gas Systems upgrades:**

- Mechanical and software upgrades, **maintenance**, operation and **optimization** of gas systems
- **Several LHC gas systems** to operate on (~ 30 systems)

**R&D on Gas Systems**

- Lot of RPC detectors and **gas mixtures** to test
- **Long term studies** progressing
- **Several challenges** posed by new gases under test

Thank you!

# Backup

# Optimization of current technologies

**Hardware optimization**

- Fine tuning of flow and pressure on the detectors and in the gas system
- Proper checks and maintenance on existing equipment
- Installation of new components in the gas systems

**Software optimization**

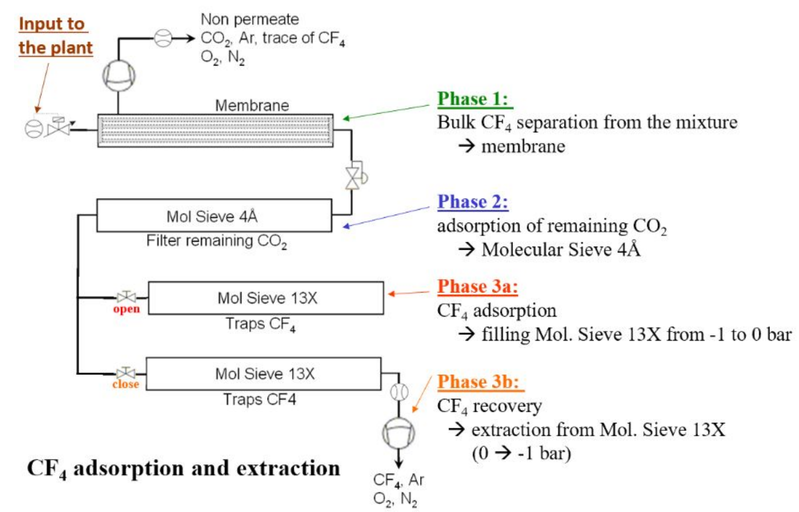
- 

openstack
docker
Red Hat OpenShift Online
Bronkhorst®
pandas
Grafana
influxdb
Schneider Electric
WinCC OA
SIEMENS

# Gas recuperation systems

Several detectors using **expensive** or **GHGs** in their gas mixture: RPCs, ALICE-TRD, ATLAS-TRT, CMS-CSC, LHCB-RICH1, etc.

**Gas components** can be **extracted** from the gas mixture and **stored** in the bottles




*CMS-CSC CF4 recuperation*

**Pros:**

- Cost reduction, GHGs reduction
- **Reduce impurities** that can't be purified by recirculation systems (mostly N2)
- Allows to operate the gas system with a high "fresh" flow

**Cons:**

- **Increase in system complexity**
- It works only under particular conditions (pressure, flow, etc.)
- Different recovery techniques are required for different gas and gas mixtures (membrane separation, pressure swing, cyogenic distillation, etc.)