Studies on the performance of RPCs operated with R-1234ze gas mixtures

Gianluca Rigoletti, R. Guida, B. Mandelli

CERN, EP-DT R&D Days, 21/06/2022

EP-DT
Detector Technologies

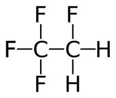
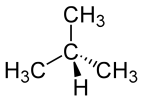
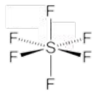
RPC emissions at CERN

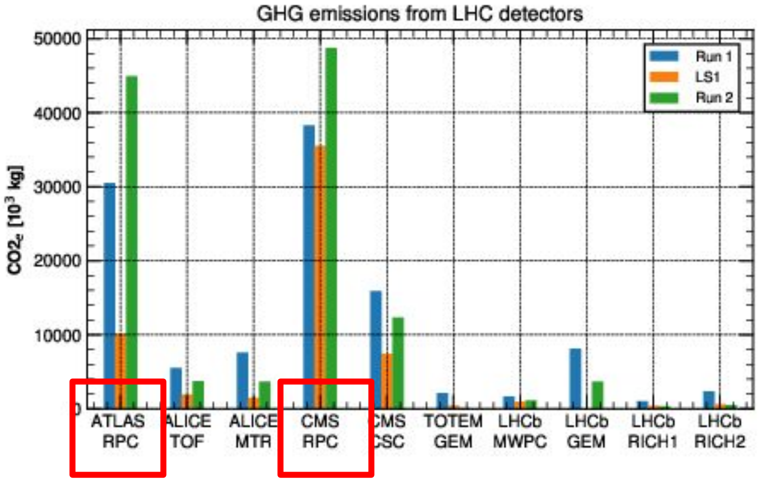
RPC accounted for **87%** of **GHG emissions** from particle detectors at LHC during Run 2

- **Leaks** at detector level + R-134a in the gas mixture, GWP 1430

Search for **alternatives** to **R-134a**:

- Hydro-Fluoro-Olefins family: **low GWP** (< 10) and **good refrigerant** properties
- **R-1234ze** identified as main alternative by refrigerant industry

R-134a	i-C4H10	SF6
~95 %	~5 %	~0.3 %
		
GWP 1430	GWP 3.3	GWP 22800



Goal:

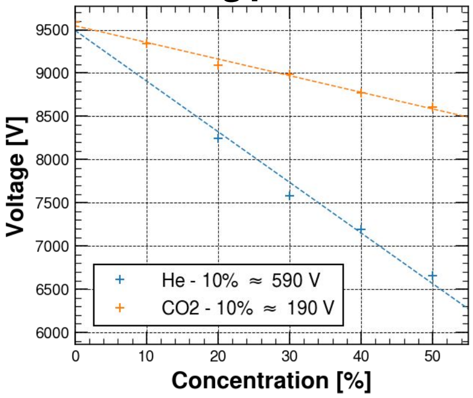
*Find a **eco-friendly** gas mixture **suitable** for **LHC** operation, that requires **no change** in the currents RPC systems (FEB, HV, Gas systems, etc.)*

Reduction of R-134a: addition of He or CO2

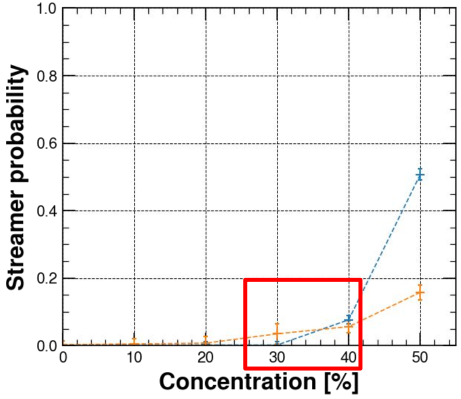
Addition of an “inert” gas to the standard gas mixture

- Best candidates are **Helium** or **CO2**
  - Availability
  - Well studied in gas detectors
  - Lower detector working point
  - Non toxic, non flammable

Working point shift



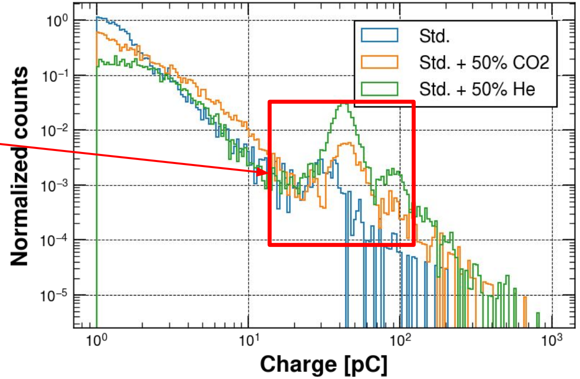
Streamer contamination



Detector performance with cosmic muons

- Working point decreases (~**590 V/**10% of He, **190 V** / 10% of CO2)
- **Low** streamer probability up to **30-40**% of He/CO2. Streamer probability increases at higher concentrations
- Helium usage represent an issue for LHC operation → **CO2** used as **main candidate**

Charge distribution



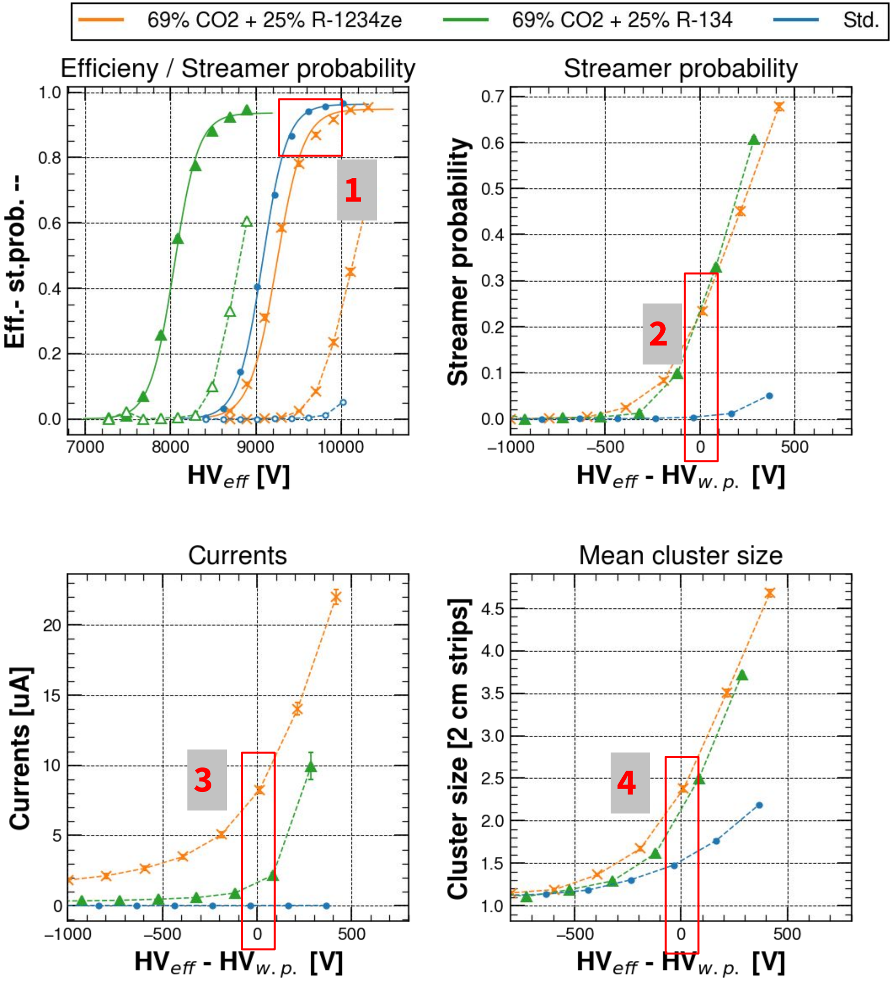
R-1234ze vs R-134a

R-1234ze cannot be replaced 1:1 to **R-134a**:

- Working point **> 12 kV**, not allowed by HV systems and detector design

R-1234ze vs **R-134a** properties when used in similar gas mixtures (CO2/i-C4H10/SF6 69/5/1) and cosmic muons:

1. **R-1234ze** increases working point
2. **Streamers** are **similar** between the two gases → **higher** streamers than **std. gas mixture** due to high presence of CO2 / low presence of fluorinated gas
3. **R-1234ze** currents are higher than **R-134a** ones → possible higher drop of efficiency at high rates
4. **Cluster size similar** between the two gases, but higher than **std. gas mixture** → charge transversal size increase due to high concentration of CO2



R-1234ze + R-134a with muon beam and gamma background

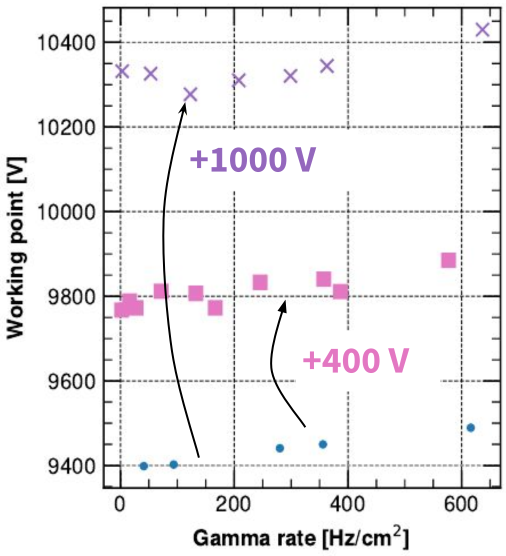
R-1234ze + R-134a + 50% CO_2

- Working point around **1 kV** higher than std.
- **2%** more of **efficiency drop** at 500 Hz/cm2
- Currents at 500 Hz/cm2 up to **80%** higher

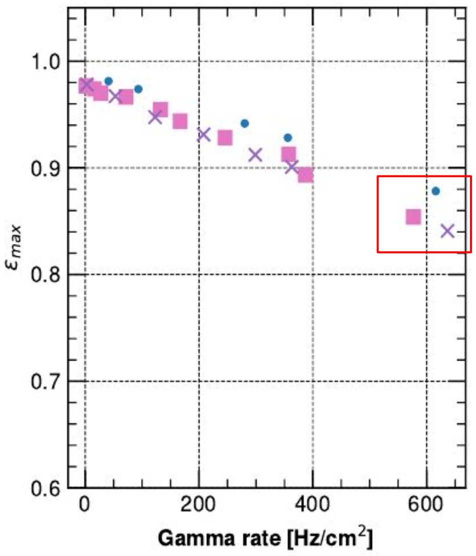
R-1234ze + R-134a + 30% He

- Working point around **400 V** higher than std.
- **2%** more of **efficiency drop** at 500 Hz/cm2
- Currents up to **50%** higher at 500 Hz/cm2

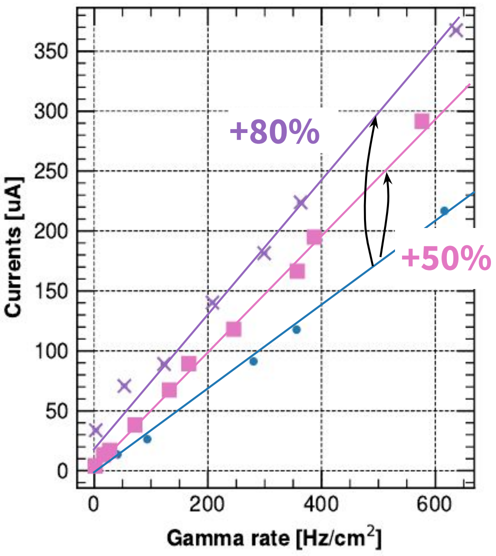
Working point shift



Efficiency drop



Currents



Impurities studies: setup and methodology development

R-134a and **R-1234ze** break under electric field and gamma irradiation → **HF** production → detector inner surface possible damage

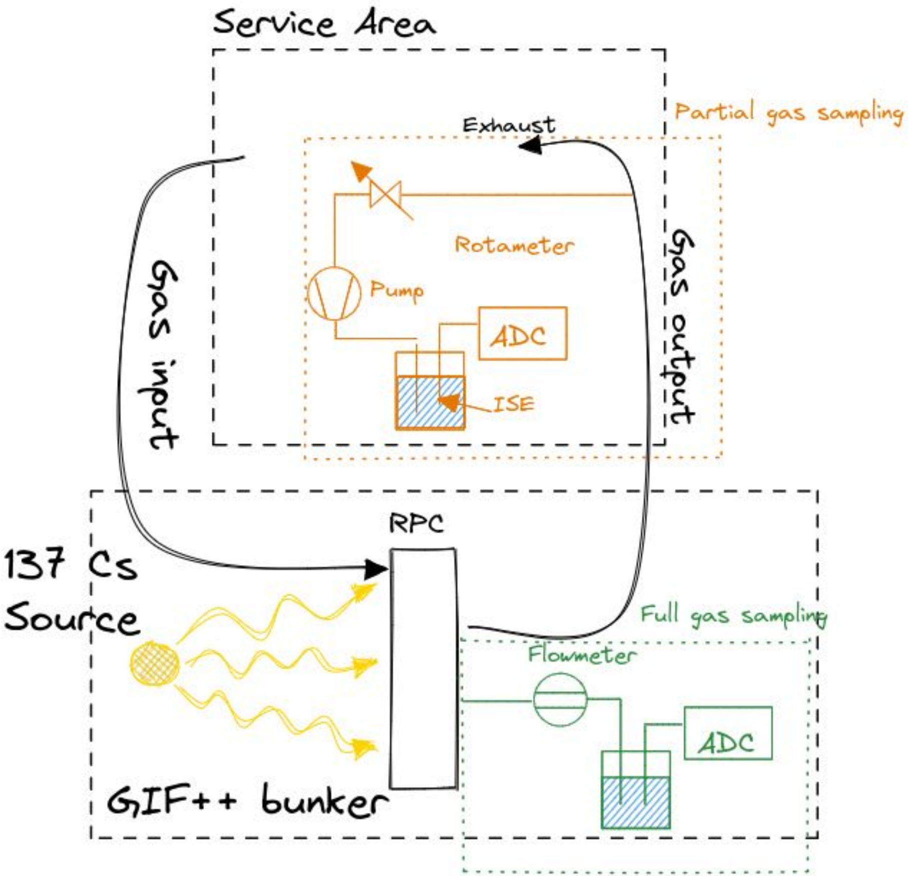
Studies on HF production

- **Gas** analyzed at the **output** of the detector irradiated and operated at working point with different gas mixtures
- **Ion Selective Electrode** technique employed: gas is sampled into a F- capturing solution, the **concentration** of **HF** is measured

Setup and methodology development

- **Partial** gas sampling or **full** gas sampling → Both have pros and cons
- **Optimization** of the existing **methods**: increase the **accuracy** of measurement by improving parameter **monitoring** and measurements **procedure**
- **Tests** on **hardware** components for optimal measurements: long lasting electrodes, mass flow meters, stirrers, etc.

The setup and methodology will be used by the RPC ECOGAS @ GIF++ collaboration (AIDA Innova WP 7.2)



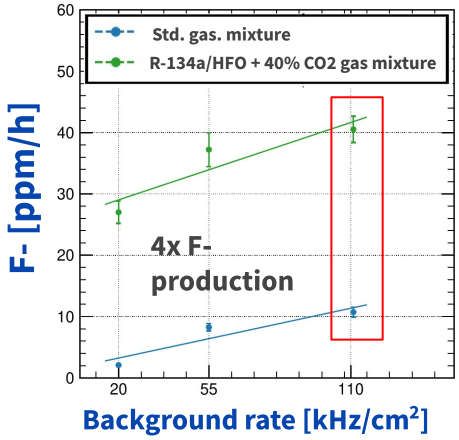
Impurities studies: HF production of different gas mixtures

2019 Measurements

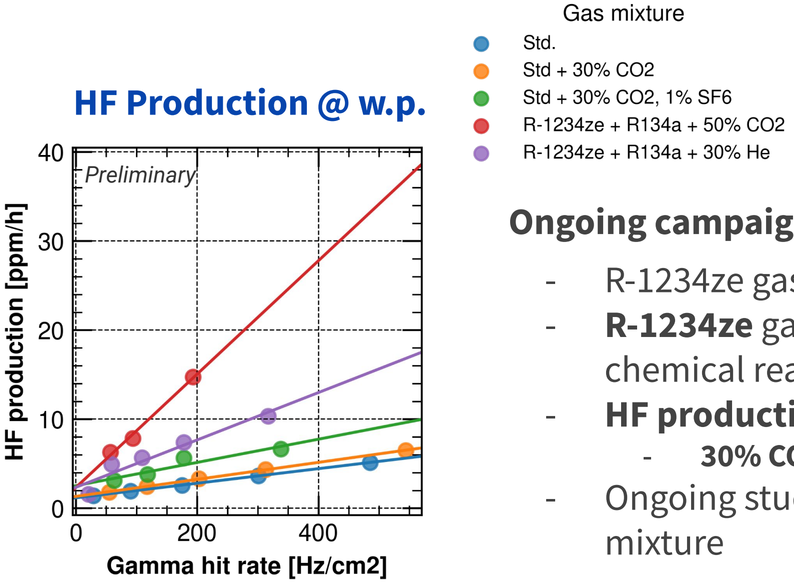
- Comparison between **standard** and **R-1234ze/R-134a + CO2** gas mixture
- Detector operated at **w.p.** and **different** background **rates**
- **R-1234ze** gas mixture produced around 4 times more HF than std. gas mixture

G. Rigoletti et al 2020 JINST 15 C11003

HF Production @ w.p.



HF Production @ w.p.



Ongoing campaign

- R-1234ze gas mixtures and Std. + CO2 gas mixtures
- **R-1234ze** gas mixtures have the **highest HF production** → R-1234ze higher chemical reactivity
- **HF production** is **not proportional** to amount of **F-gases** in the mixture:
    - **30% CO2** + R-134a produces the **same amount** of HF as the **std.** gas mixture
- Ongoing studies to understand **correlation** between **HF** and gases in the mixture

Usage of CO2 for R-134a reduction

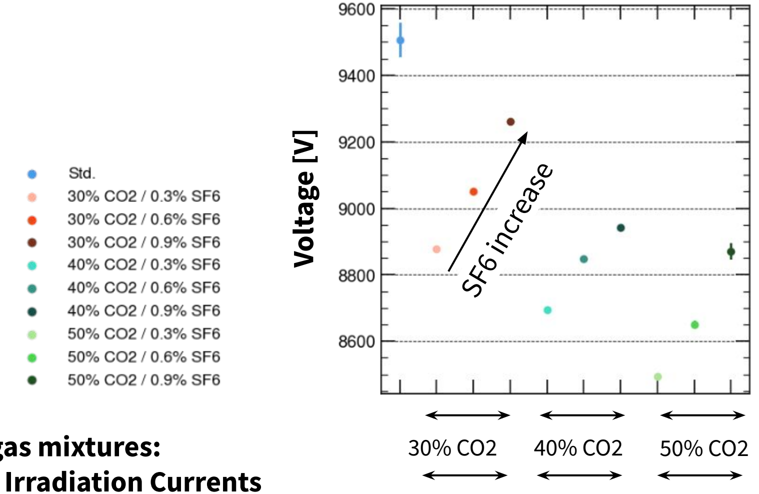
The simple addition of CO2 **could mitigate** R-134a consumption on the mid-term:

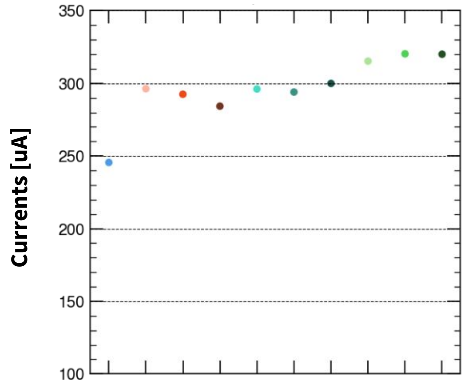
- 30% of CO2 shows **lower streamer probability** and **lower current increase w.r.t to R-1234ze** (~ + 20%)
- 30%+ of CO2 may require **SF6** concentration **to be increased** → increases **detector's plateau** of avalanche operation
- Aging studies required: **CO2/R-134a** expected to be **similar** to **standard** gas mixture (no additional F- pollutants)

Investigation of correlations between **performance** and **environment**:

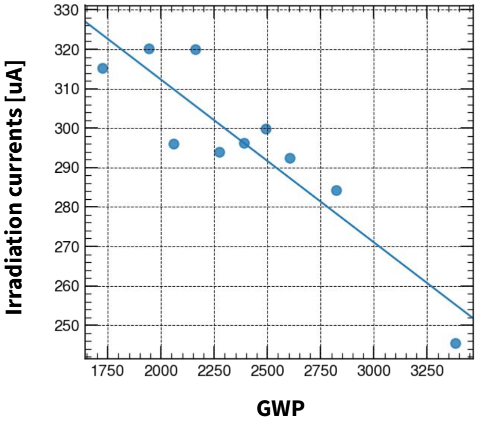
- Lower R-134a amount → higher GWP reduction
- Difficulty: **lower GWP** gas mixture seem to have **higher currents** → under investigation

Working points





CO2/SF6 gas mixtures: GWP reduction vs Irradiation Currents



Conclusions

R-1234ze studies with cosmic muons and muon beam

- **CO2** added to the gas mixture to **lower** the **working point**
- High amount of **CO2** increases **currents** and **streamers**
- **R-1234ze/CO2** shows **similar streamer** contamination but **higher currents** than equivalent **R-134a/CO2** gas mixture
- **No R-1234ze** gas mixtures were found to **match standard gas mixture** performance:
  - **R-134a + R-1234ze** could be a compromise between GWP and performance

Impurities studies

- Ongoing studies on the improving **methodology** and **setup**
- **Preliminary tests** performed on R-1234ze, CO2 and He gas mixtures
  - **R-1234ze** produces **more HF** than **R-134a** → confirmed 2019 results
  - **Non linear** HF **production**: adding 30% of CO2 to std. mixture does not reduce HF production

CO2 gas mixtures

- **CO2** to R-134a could help **lowering GWP** and reduce GHG consumptions
  - CO2 ionization properties are well studied → simulations possible
  - GWP can be reduced by 30-50%
- **R-134a/CO2** gas mixtures show **lower currents** increase than **R-1234ze/CO2** ones
- **SF6** concentrations may need **to be adjusted** depending on the **CO2 amount**

Thank you

Backup

Usage of CO2 for R-134a reduction

GWP reduction w.r.t to STD gas mixture

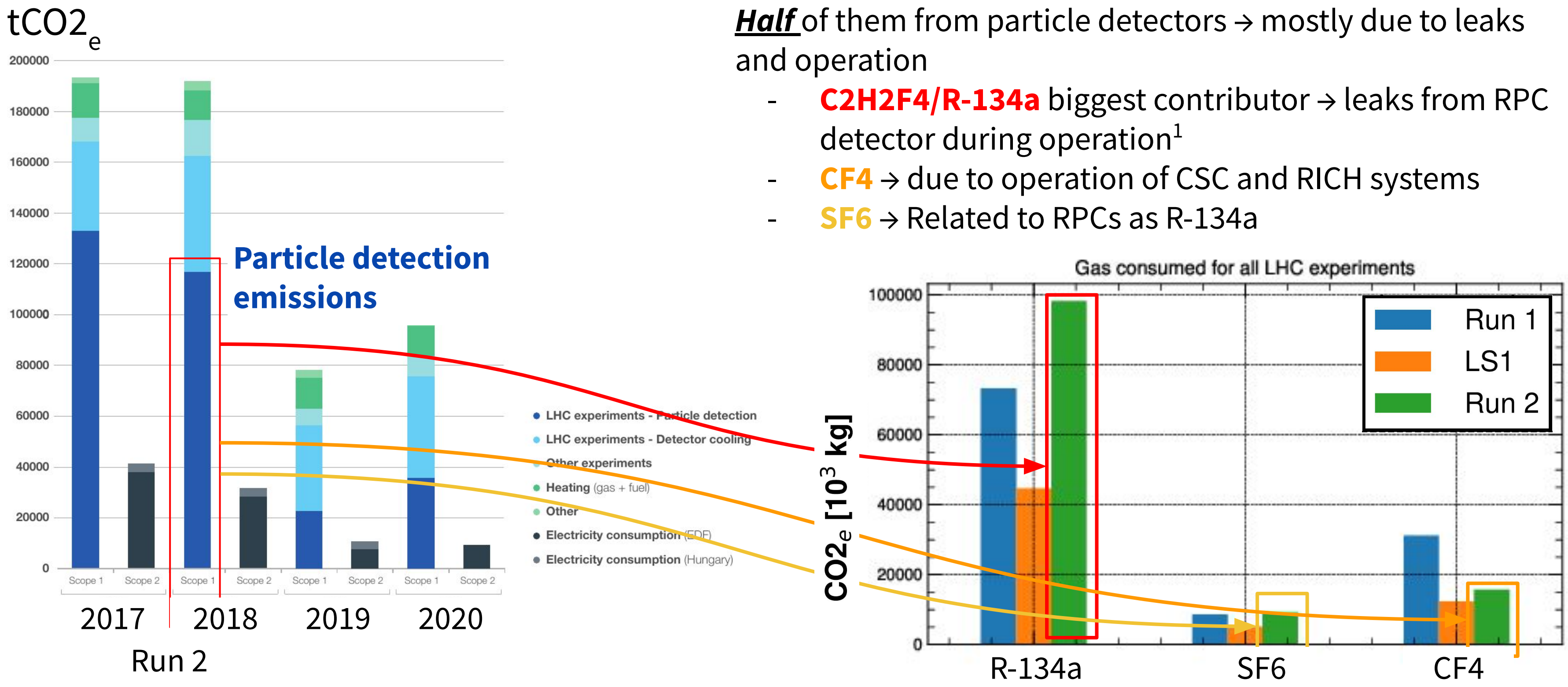
SF6\CO2	30 %	40 %	50 %
0.3 %	29.4 %	39.2 %	49 %
0.6 %	23 %	32.8 %	42.6 %
0.9 %	16.6 %	26.4 %	36.1 %

Greenhouse gases emissions from RPCs

https://hse.cern/environment-report-2019-2020

CERN emissions during 1 year of Run 2 ~ **240 000 tCO2e**
Half of them from particle detectors → mostly due to leaks and operation

- **C2H2F4/R-134a** biggest contributor → leaks from RPC detector during operation[1]
- **CF4** → due to operation of CSC and RICH systems
- **SF6** → Related to RPCs as R-134a



[1] *Reparation of leaks campaign performed in CMS and ATLAS*

Safety-Environment-Performance

Safety:

Safety first for LHC operation. Due to gas leaks and currents design:

- Gas mixture must not be **flammable**
- Gas components should not have **high toxicity levels**

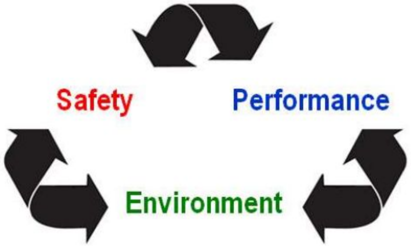
Tradeoff between **flammability** and **GWP**. Lowering GWP by:

- Replacing F with Cl or H:
  - Shortens atmospheric lifetime
  - Increases flammability limit
- Adding C=C bound:
  - Increases reaction with O_2

Performance:

RPC **short** and **long** term **performance** shouldn't be affected

- Good **quenching** gases required for **high rate** capability
- **Radiation-hard** gases required to minimize **impurities** affecting long term performances



Environment:

GWP represents the **main** environmental concern

GWP is related to Infrared absorption over time. **Low-GWP** gases have short **atmospheric lifetimes**:

- Water solubility → Rain out
- OH^- reactivity → Oxidation
- UV absorbance → Photolysis