Mitigating Emissions in Gaseous Particle Physics Detectors: CO_2 as an Eco-Friendly Alternative for RPC Detectors

EP-DT Detector Technologies

Ștefania A. Juks[1], Mattia Verzeroli[2], Gianluca Rigoletti[3], Beatrice Mandelli[3], Roberto Guida[3]
(1) Université Paris-Saclay, (2) Université Claude Bernard Lyon I, (3) CERN

Introduction

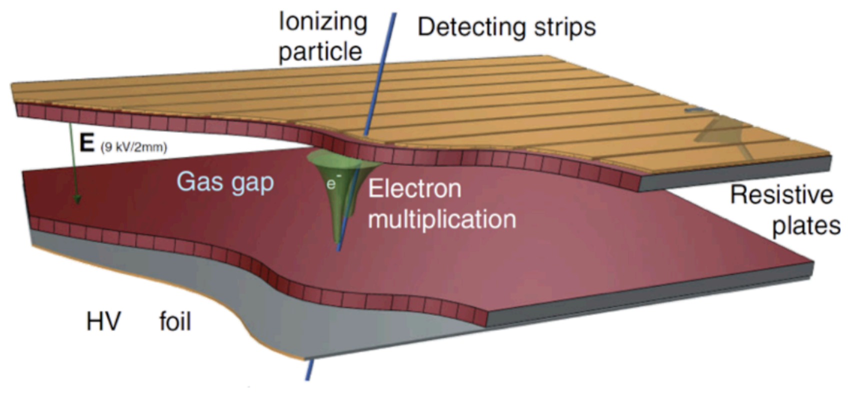
- **Sustainability** is an increasingly crucial factor in the **particle physics research community**. At CERN, it is imperative to **mitigate emissions** from our operations. Within the gas group, several **strategies** are in place to reduce the environmental impact from particle detector operation: **gas recirculation**, **gas recuperation**, and, in the long term, the **search for alternative eco-friendly gases.**

Motivation: Greenhouse Gas (GHG) Emissions must be reduced. This is driven not only by environmental concerns but also by economic and regulatory pressures. The cost of one of the gases in the mixture is increasing, its availability is decreasing, and regulations are intensifying.

Strategies
1. Recirculation
2. Recuperation
3. Alternative Gases

Resistive Plate Chamber Detectors

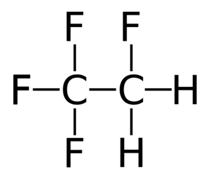
- Employed in **fast space-time particle tracking** required for the **muon trigger** at ATLAS, CMS and ALICE.
- High-Pressure Laminate Resistive Plate Chambers (**HPL-RPC**) are significant **contributors to GHG** emissions at CERN, accounting for 85% of the emissions during RUN2 [1].



Principle of Operation.

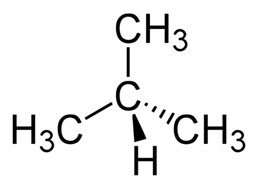
GWP: equivalent amount of CO_2 emitted (in kg).

$C_2H_2F_4$ (R-134a)



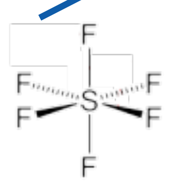
- GWP: 1430
- 95.2%

i-C_4H_{10}



- GWP: 3.3
- 4.5%

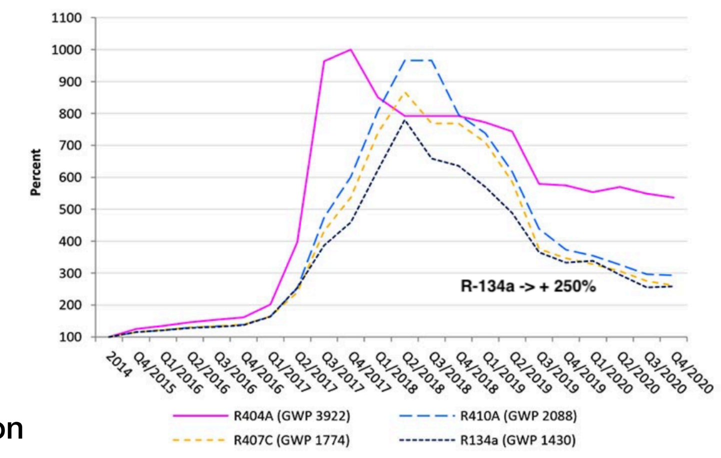
SF_6



- GWP: 22800
- 0.3%

Problem: ↗ Price ↘ Availability ↗ Regulations

- **Emissions** should be **reduced**.
- **Regulations** are intensifying -> **F-Gas** [2], **PFAS** [3].
- The **availability** is **sparse**.
- **Costs** are increasing.
- The **safety** criteria must be **maintained**:
  - Alternative gases cannot be toxic or flammable



Price trends of common refrigerants, including R-134a for which an approximate 250% increase is observable between 2014 and 2020 [4].

Alternatives:

- R-1234ze (HFO)
- R-1224yd, the Amolea
- R-1336mzz
- R-236fa
- Novec™ 4710

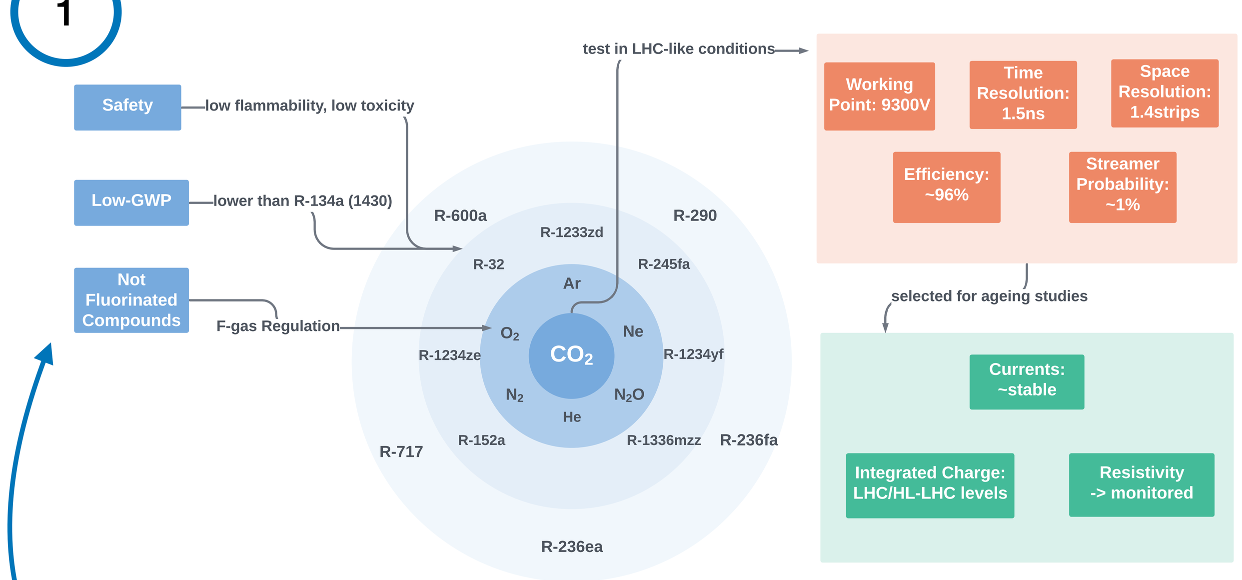
For R-134a consumption reduction

For the eco-friendly search

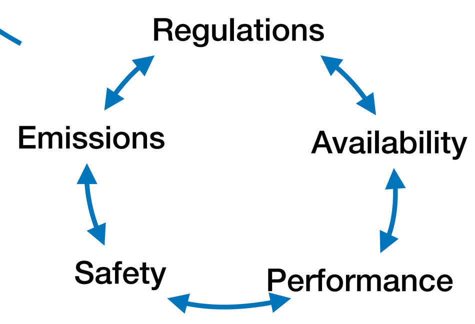
CO_2, He, Ar, N_2, N_2O, Xe, O_2, Ne

Set-Up & Methodology

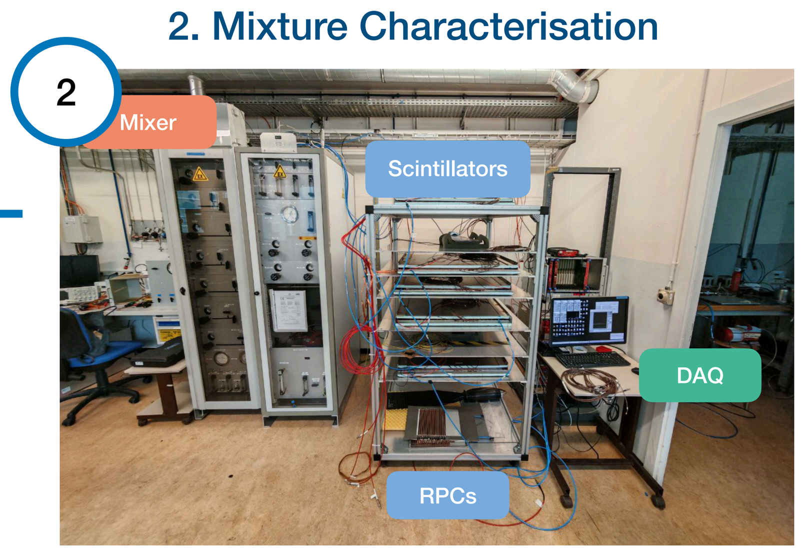
Standard Mixture Parameters



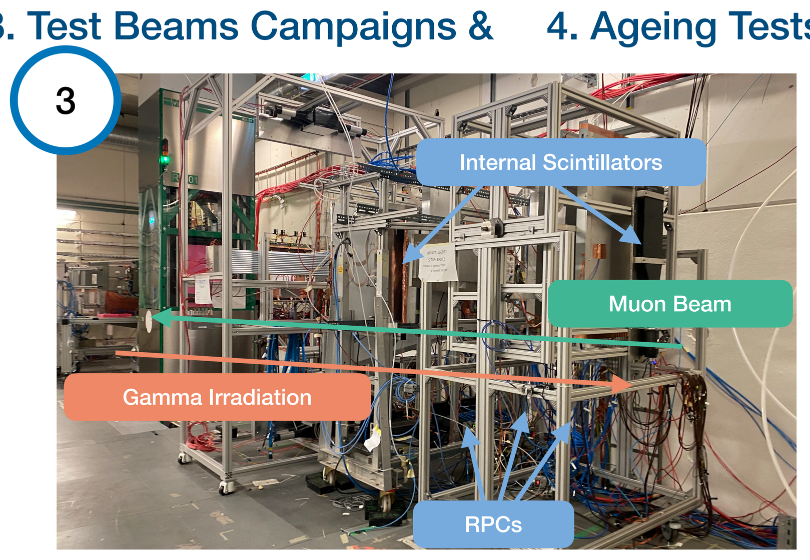
1. Market Research



2. Mixture Characterisation



3. Test Beams Campaigns & 4. Ageing Tests



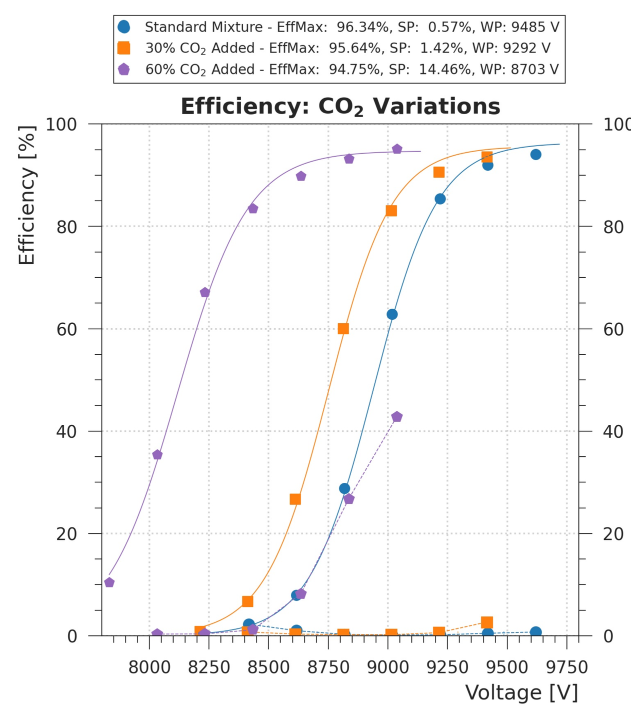
RPC Set-up at GIF++.

Alternative Mixture

Constraints:
- The RPCs under testing are 2mm HPL-RPCs with strip sizes varying between 2 and 2.5cm.
- Choosing an alternative gas is **NOT trivial**.
- The new mixture **cannot induce any changes** in the LHC current systems:
  - High Voltage (HV) Modules
  - Front-end Electronics
  - Detectors.

- **Chosen gases** go forward for a **performance check**.
- The mixture is **initially tested** in our **laboratory** compared to the standard gas mixture checking the efficiency, streamer probability, working point, time and spatial resolution and more.
- **At** the Gamma Irradiation Facility (**GIF++**), we check the mixture's **experimental parameters** with the ^{137}Cs source that mimics the background radiation of the LHC experiments.
- Outside the testing periods, the gas mixture undergoes **ageing studies**.

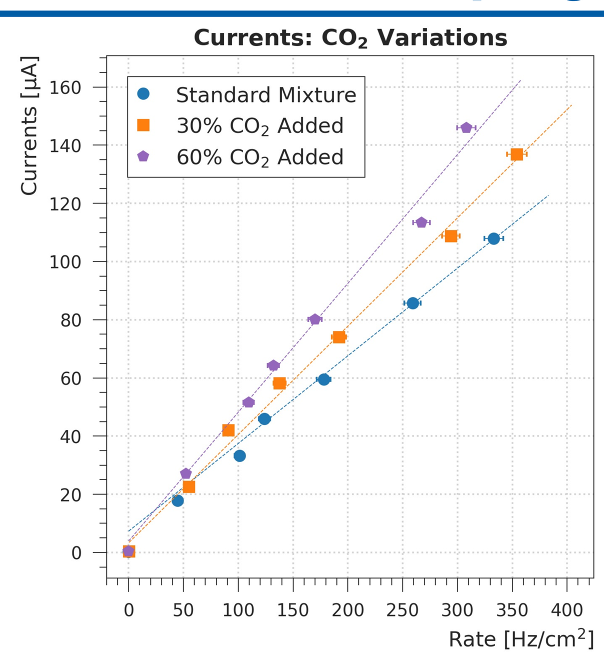
Results

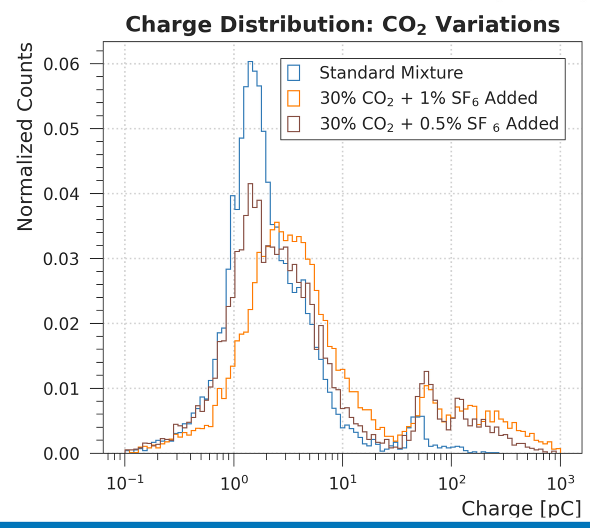


- Out of O_2, N_2, N_2O, CO_2, He and others, **CO_2 proved to be the best option (given the constraints)** to reduce the consumption of R-134a.
- **30% CO_2 + 64% R-134a + 5% iC_4H_{10} and 1% SF_6** shows the **closest performance to the standard gas mixture**.
- Higher % CO_2 show **increases** in the **streamer probability and currents.**
- **Reducing** further **to** only 0.5% of SF_6 **could** represent a further tuning that would **lower the mixture's GWP.**

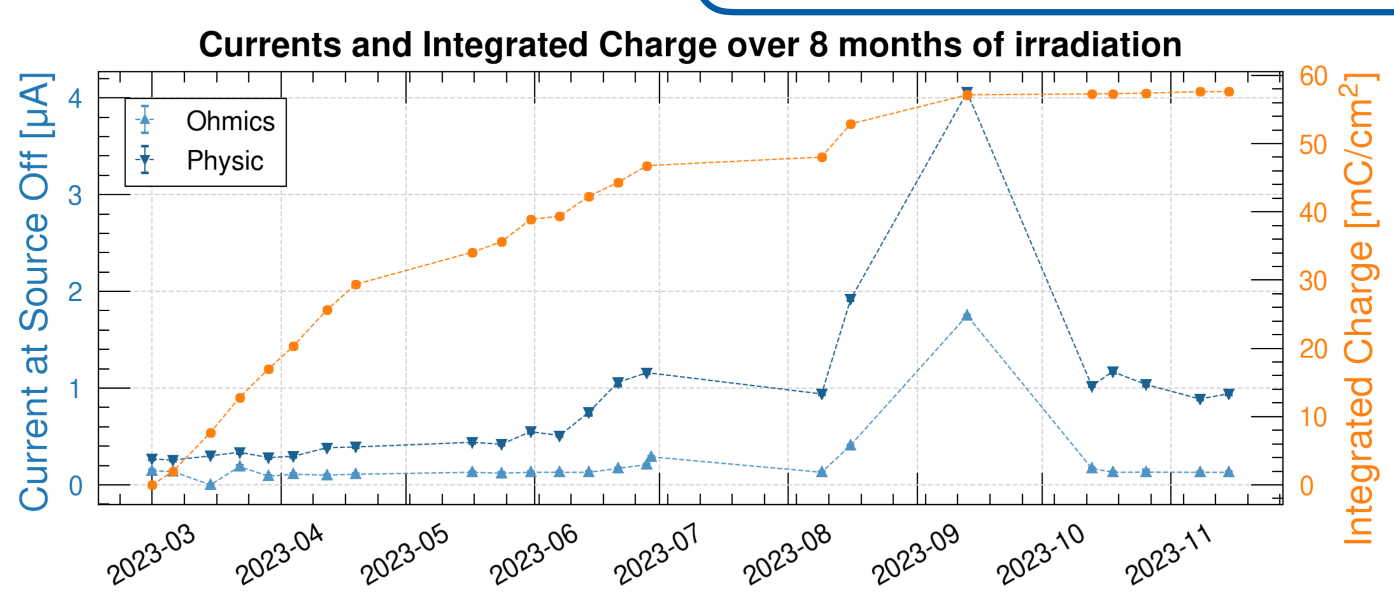
The mixture was validated for the ATLAS experiment, being now in use since August 2023 [5].

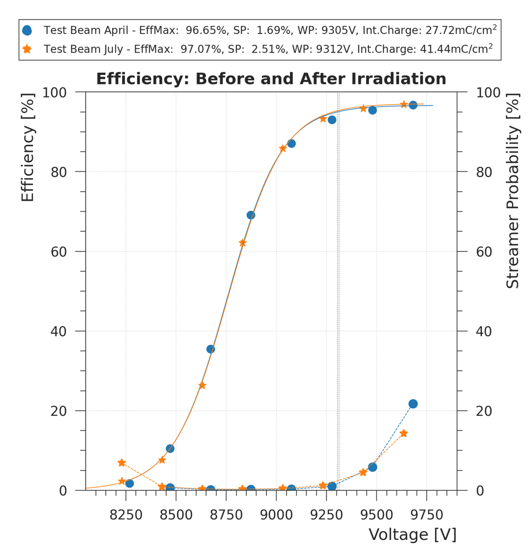
2. Test Beam Campaigns





3. Ageing Tests





Aim
- **Integrate** the amount of charge predicted for the **10 years ATLAS RPC certified operation** of the 2mm gaps: **~300mC/cm²** and for the High-Luminosity LHC (**HL-LHC**) phase: **~840mC/cm.**
- **~60mC/cm²** of **charge** were up **to now integrated -> validated the mixture for RUN3**
- No significant signs of deterioration in the performance were observed, when checking between test beam campaigns.

4 The mixture is undergoing ageing tests at the moment at the Gamma Irradiation Facility.

Conclusions

- The **30% CO_2 + 64% R-134a + 5% iC_4H_{10} and 1% SF_6**, now **in use in the ATLAS experiment**—allowed for a **30% decrease in the R-134a** required and a **15% reduction in CO_2e emissions.**
- The **mixture is under ageing studies** to continue **integrating the amount** of charge **predicted for the 10 years ATLAS RPC certified operation** of the 2mm gaps: **~300mC/cm²** and the High-Luminosity LHC (**HL-LHC**) phase: **~840mC/cm²**.
- **Fine-tunings** to the mixture, like **increasing the fraction of added CO_2** to 40% and **reducing the SF_6 amount**, are considered to continue reducing the emissions.
- **Studies on alternative gases are continuously ongoing.**

References

[1] CERN (2021), 'Vol. 2 (2021): Cern environment report, 2021'. https: // doi. org/ 10. 25325/ CERN-Environment-2021-002
[2] EU (2014), 'Eu legislation to control f-gases'. https: // climate. ec. europa. eu/ eu-action/ fluorinated-greenhouse-gases/ eu-legislation-control-f-gases_ en
[3] ECHA (2023), 'Annex xv restriction report - echa'. https: // tinyurl. com/ annexecha3032
[4] Post, C. (2021), 'Hfc prices stable despite increased demand'. https: // tinyurl. com/ coolingpost
[5] Rigoletti, G., Guida, R. and Mandelli, B. (2023a), 'Performance studies of rpc detectors operated with c.sub.2h.sub.2f.sub.4 and co.sub.2 gas mixtures'. 10. 1016/ j. nima. 2023. 168088.