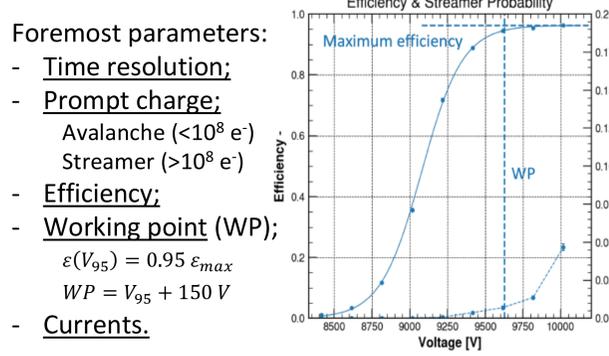
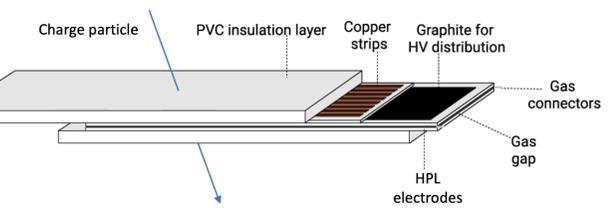
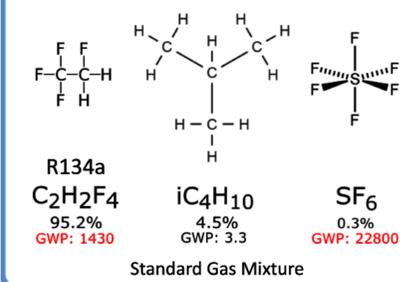


Introduction

Due to leaks at the detectors level, RPC detectors dominate CERN GHG emissions:

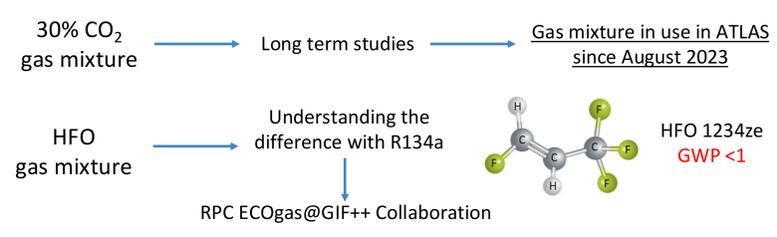
- **Large area**
5000 m²/experiment
- **Large volume**
15 m³/experiment
- **High Global Warming Potential:**



R134a Alternatives

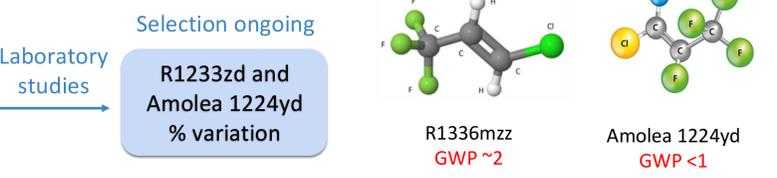
- He
- Ar
- R32
- N2
- CO₂ **selected**
- HFO1234ze...
- + market available

The goal is to find an eco-friendly gas mixture that is compatible with the current LHC RPC systems and that allows to have a good detectors performance

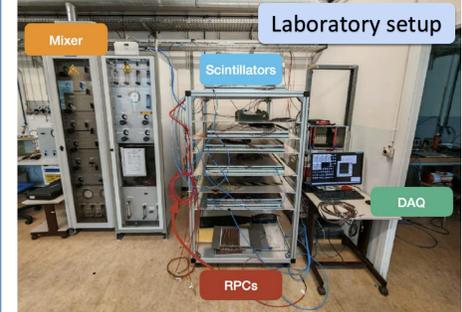


SF₆ Alternatives

- Amolea 1224yd
- Novec 4710
- R1233zd
- R1336mzz

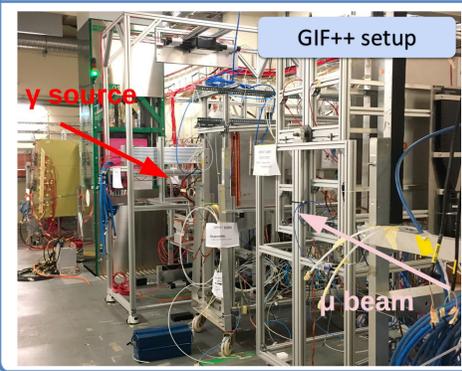


Setup: Laboratory and Gamma Irradiation Facility



Four, 2 mm gap, 70x100 cm² RPCs detector commissioned in January 2025.
Mixer unit up to 6 gas components, with humidifier module and parallel detector flushing;
V1730 and DT5730 CAEN digitizer (14-bit at 500 Ms/s, V_{pp} = 1 V) are used for the signal readout.

Gas mixture selection studies with cosmic muons to study detector's performances with the new gases.

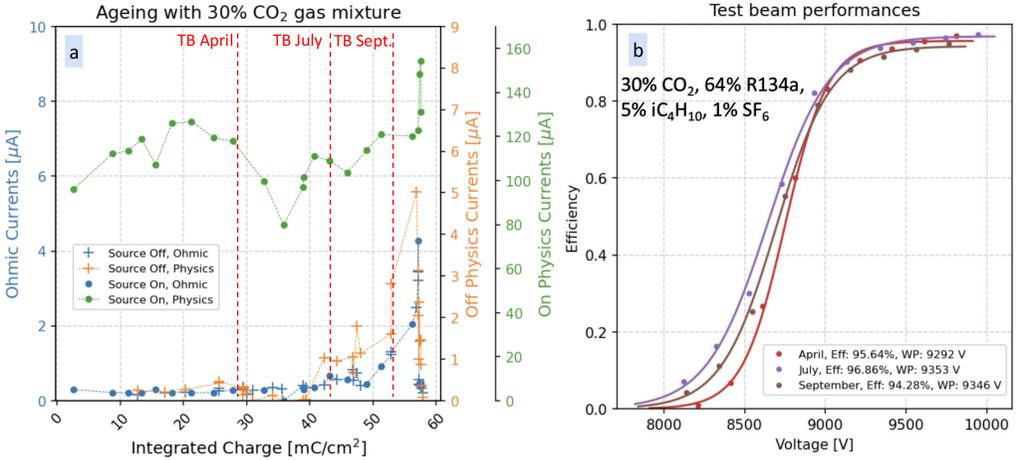


Detector operated in an LHC-like environment using a 12 TBq ¹³⁷Cs source, with adjustable attenuation filters, for **aging studies**. 3 detectors at 400 Hz/cm², 2 detectors at 100 Hz/cm².

Muon beam provided by SPS three times per year -> **Performance Monitoring:**
Detectors are tested under varying irradiation backgrounds, using CAEN digitizers.

Studies with LHC-like background irradiation for both **long-term ageing** and **test beam performances** for new gas mixtures.

Aging studies with 30% CO₂ Gas Mixture – GIF++

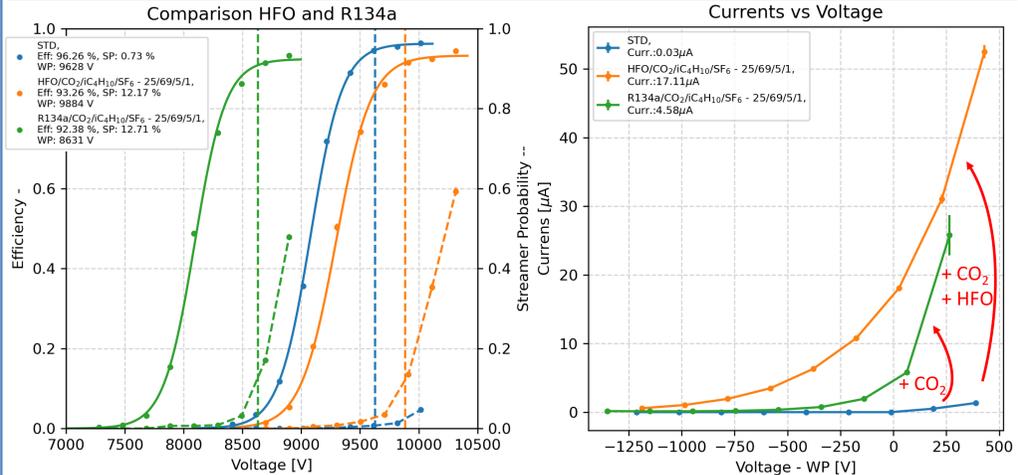


Detector Operation: Background irradiation of 400 Hz/cm², operative voltage of 9000 V, working with 50% of the maximum efficiency.

(a) **Ohmic and physics currents** (with/without irradiation) show no increase up to 40 mC/cm². Beyond this, currents rise but nearly recovered without irradiation. This effect likely relates to detector construction rather than aging effect.

(b) **Efficiency curves**, measured at different integrated charge levels during the test beam periods, show no significant performance changes up to 56 mC/cm² (ATLAS RPC RUN3 25 mC/cm²).

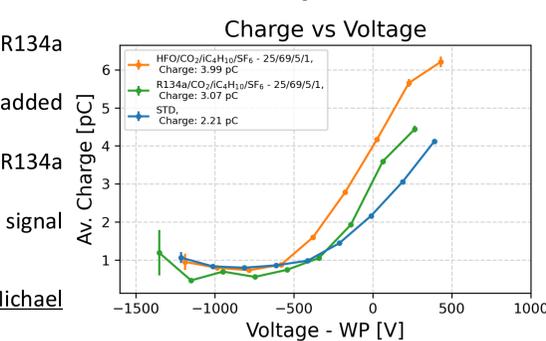
HFO as R134a alternative - Laboratory



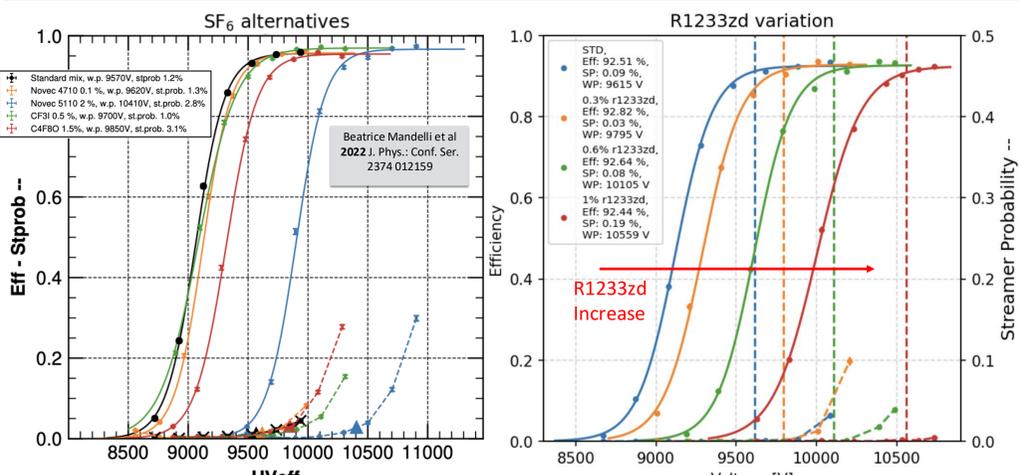
Test to compare R134a and HFO behaviors:

- 3% lower maximum efficiency for both R134a and HFO mixture wrt STD;
- Increased current observed when CO₂ is added to STD;
- Further current increase when replacing R134a with HFO;
- This current increase is also reflected in signal charge.

-> RPC ECOgas@GIF++ Collaboration: [See Michael poster](#) (RPC ECOgas@GIF++ Collaboration).



SF₆ Alternatives - Laboratory

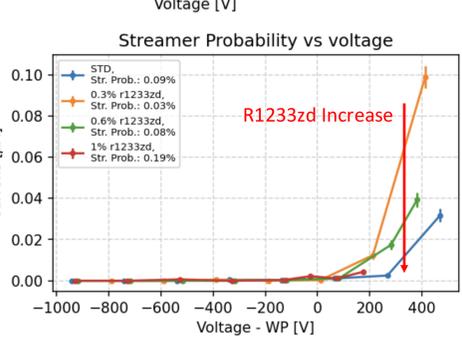


In the **past years**, several alternative to SF₆ were explored: Novec 4710 and 5110, CF₃I, Amolea 1224yd;

Now focusing on the research of other alternatives and deepening previous studies;

Evaluation of **R1233zd** as complete substitution for SF₆ in the **STD gas mixture**:

- + 350 V increase for each 0.3% R1233zd added;
- Similar streamer probability at WP for all the gas mixtures but different increases vs HV.



Conclusions

- **CERN F-Gas Policy:** CERN has adopted an F-gas policy aligned with European F-gas regulation, which limits the total amount of key F-gases that can be sold from 2015 onward and banning their use when eco-friendly alternatives are available. The European F-gas regulations has already impacted gas costs and availability, highlighting the need to find sustainable replacements.
- **CO₂ as R134a partial replacement:** The similar performance of the gas mixture with 30% CO₂ substitution to R134a wrt STD, has allowed ATLAS RPC detectors to adopt this mixture, reducing emissions by 7.5 ktCO₂e per year. The performance results were confirmed through an aging campaign together with ATLAS and CMS.
- **HFO as R134a alternative:** In recent years, the behavior of HFO-based mixtures has been studied compared to the standard one. HFO is a promising candidate; the addition of CO₂ helps reduce the WP. Long term ageing tests are currently on going -> RPC ECOgas@GIF++ Collaboration.
- **SF₆ Alternatives:** Several alternatives to SF₆ have been studied in the past. Current efforts focus on investigating new options and deepening previous studies. R1233zd was tested in STD with promising results; 0.6% R1233zd shows similar streamer probability to the STD with a working point only ~ 500 V higher.