Evaluating the Performance and Long-Term Stability with LHC-like Background Irradiation of RPC Detectors with CO_2-based Gas Mixtures

RPC Conference 2024 - Santiago de Compostela, Spain

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11.09.2024

Outline

RPC Conference 2024

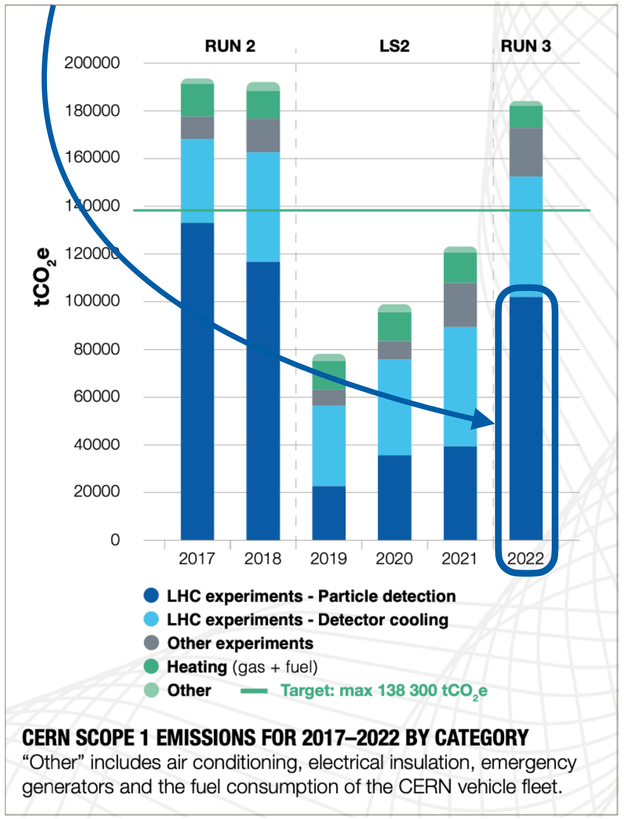
- Motivation
- Set-up & Methodology
- Reduction of R-134a consumption
- Ageing Studies for the 30% CO_2 mixture
- Summary

Motivation

CERN's Strategies to reduce GHG emissions

Context

78% of CERN's **emissions** from the use of **F-gases**
~ 180 000tCO$_2$e in 2022 alone



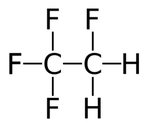
CERN SCOPE 1 EMISSIONS FOR 2017–2022 BY CATEGORY
"Other" includes air conditioning, electrical insulation, emergency generators and the fuel consumption of the CERN vehicle fleet.

(CERN Third Environmental Report, 2023)

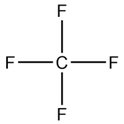
Problem

RPCs use F-gases in all major LHC experiments.

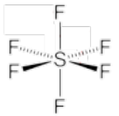
$C_2H_2F_4$ (R-134a)
- GWP: **1430**



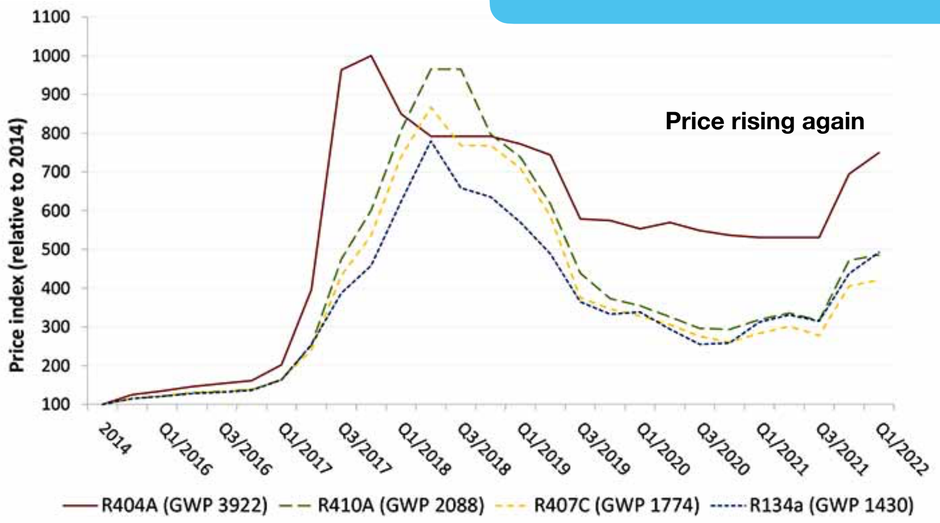
CF_4
- GWP: **7390**



SF_6
- GWP: **22800**



Emissions *Price* *Availability* *Regulations*



Mitigation strategies

Short-term
- GHG Consumption Reduction

Long-term
- Alternative Gases
- Recuperation
- Recirculation

More details in Roberto Guida's talk

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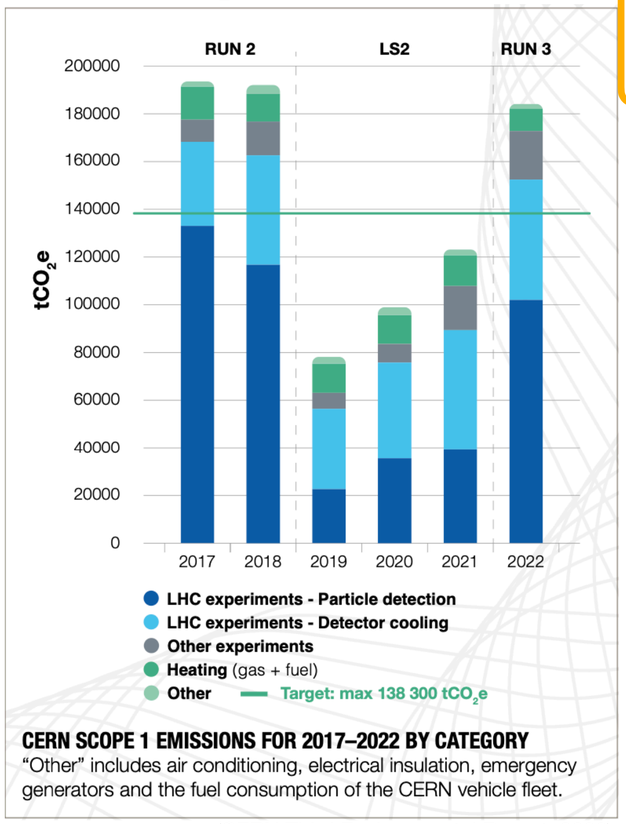

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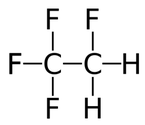

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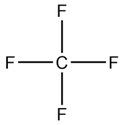

SF_6
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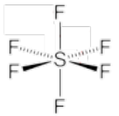
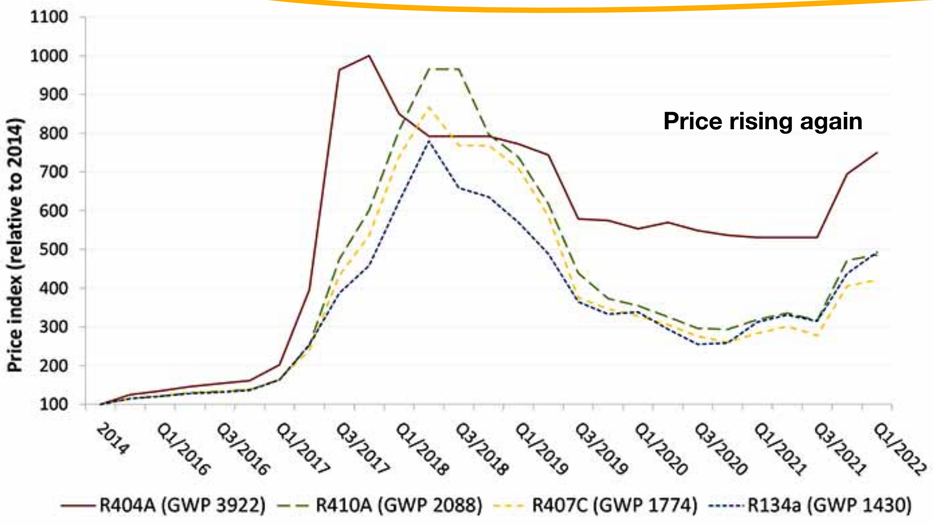


Emissions → ***Price*** → ***Availability*** → *Regulations*

Less R-134a used, implies



Mitigation strategies

Short-term

GHG Consumption Reduction

Focus of this talk

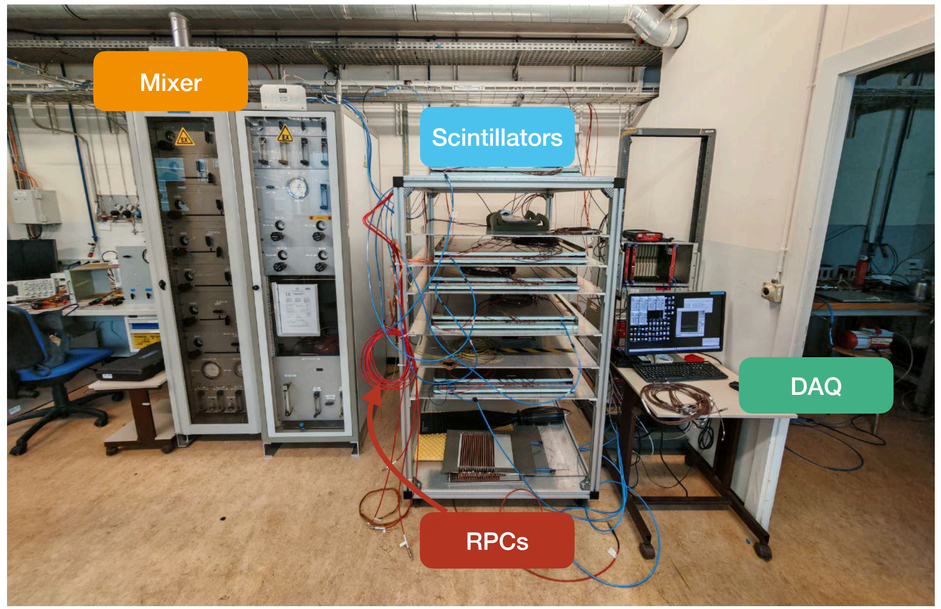
- addition of an inert gas to the mixture
- **reduced amount of gas** needed
- **reduced costs**
- **reduced emissions**

-> possibly reduce even further the SF$_6$ concentration

Set-up and Methodology

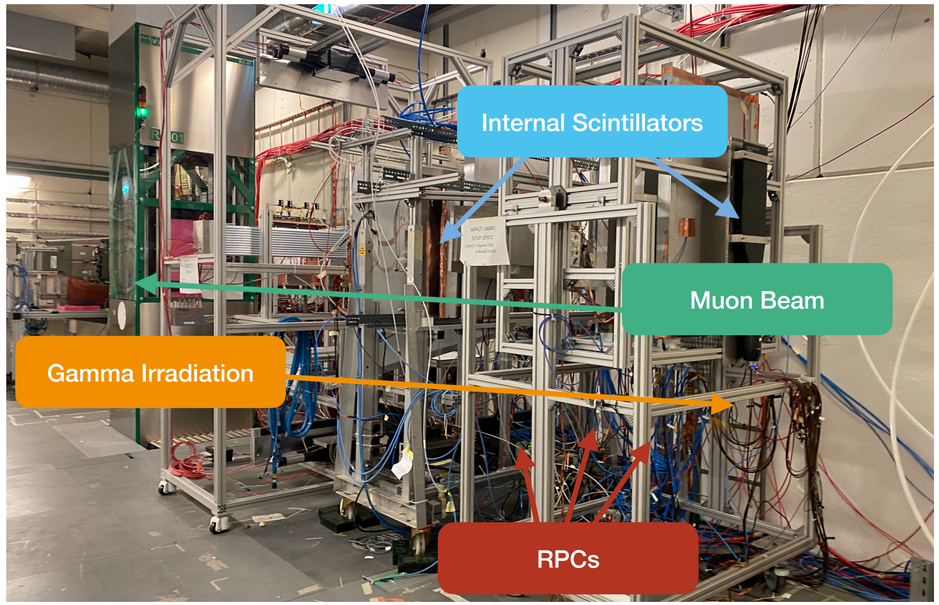
Lab256 & GIF++

- Testing new gas mixtures with cosmic muons
  - Gas mixing Unit
    - Up to 6 components
  - RPC detectors
    - 2mm gap, high pressure laminates (HPL), strip size between 2-2.5cm



Test Beams Campaigns

Ageing Tests



- Performance studies under LHC-like conditions with muon beam
  - ^{137}Cs, 12.5TBq irradiator
    - Pb Filters are used to regulate the gamma background intensity
  - DAQ
    - CAEN digitizer V1730, resolution 0.12mV, sampling 500MS/s

Detector and Mixture Characterisation

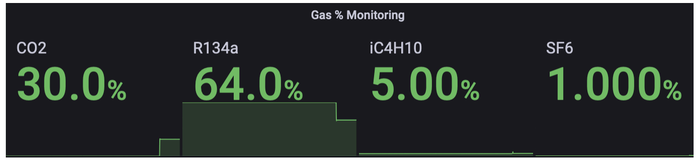
Set-up and Methodology

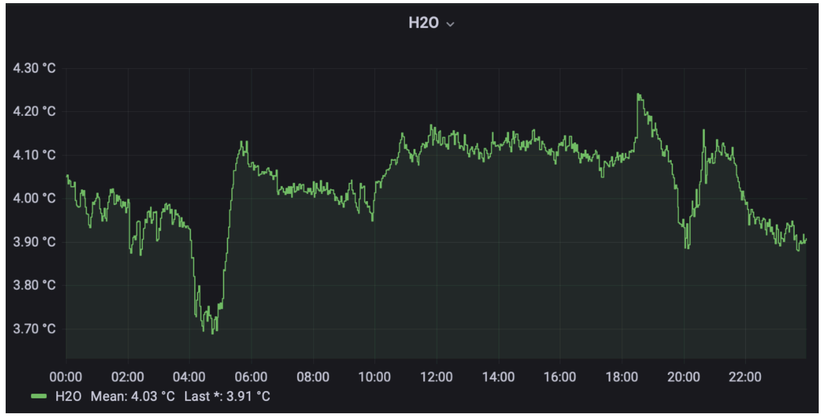
Dedicated Gas Control System

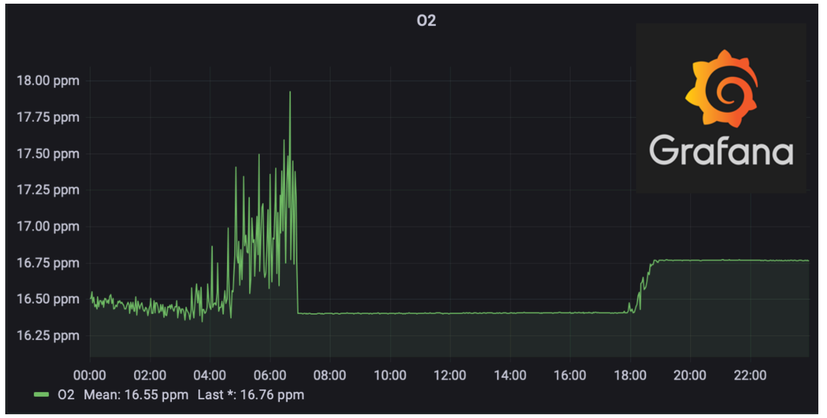
Monitoring includes various metrics:

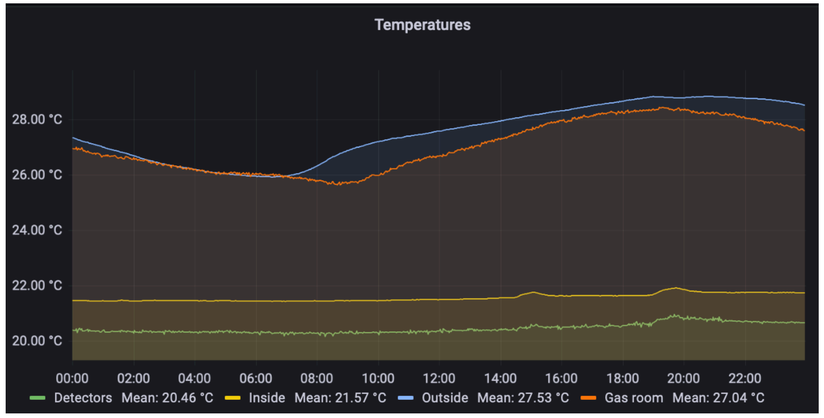
- oxygen,
- humidity,
- dose
- environmental parameters
  - temperature
  - pressure,
- gas flow measurements.

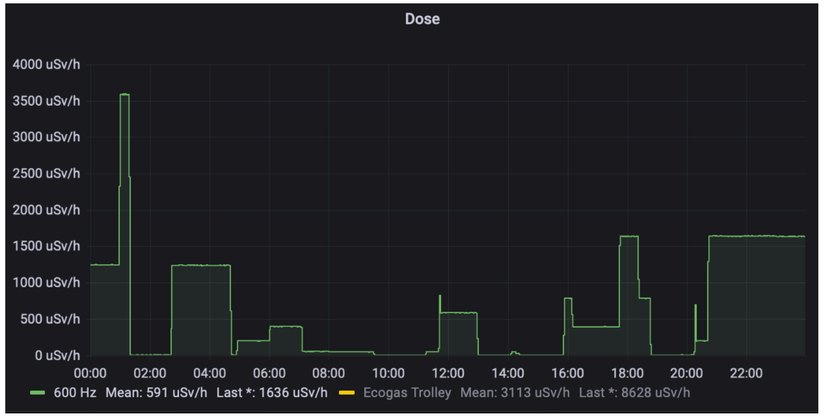
Data is continuously recorded.









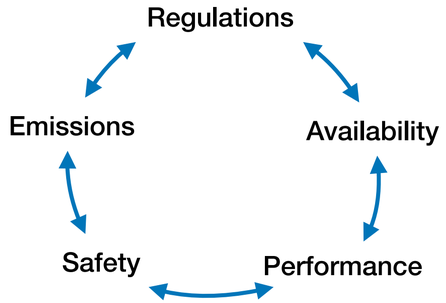


Reduction of R-134a consumption

Addition of CO_2 to the Standard Gas Mixture

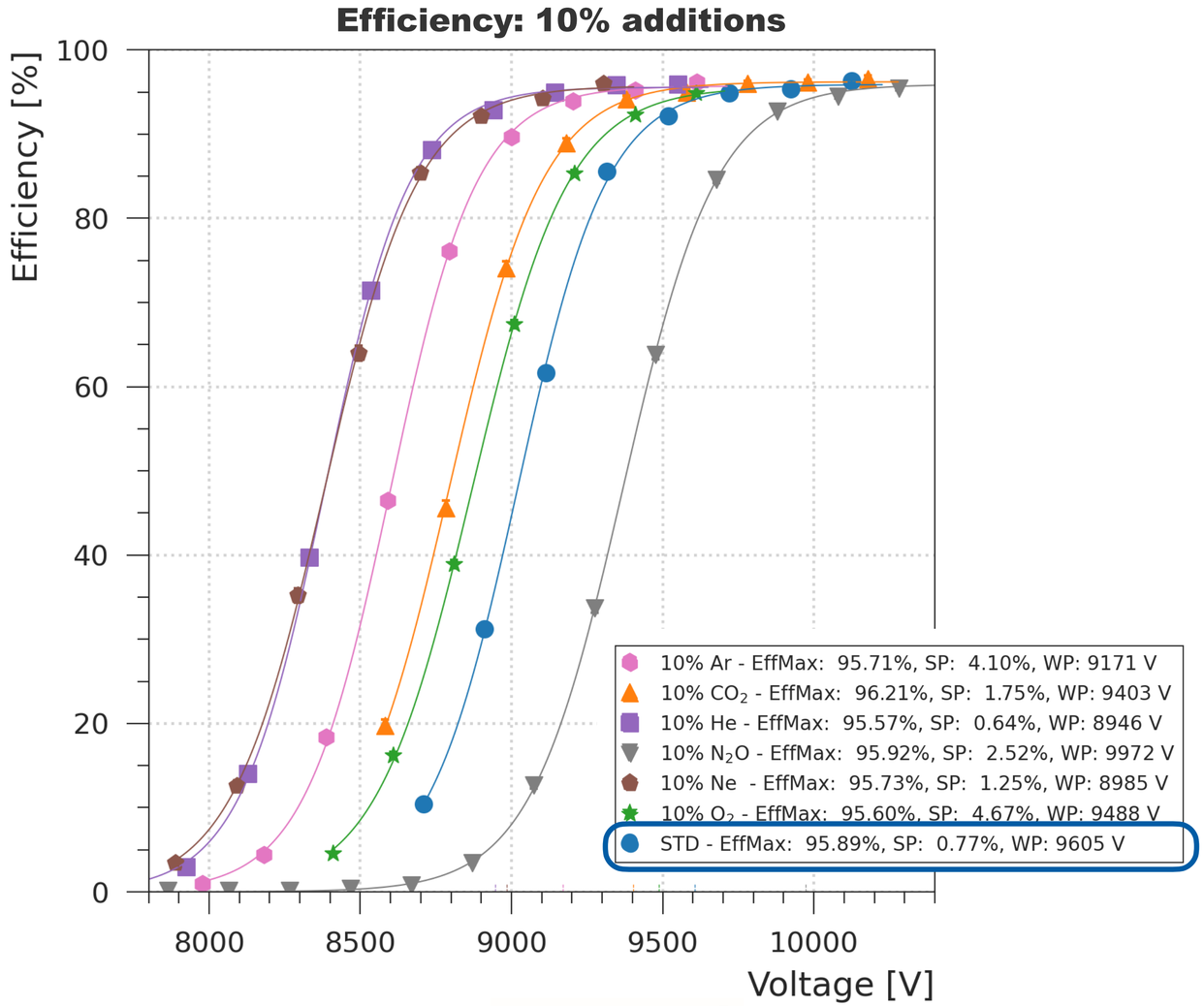
Constraints:

- 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 (FEE)).



For R-134a consumption reduction: CO_2, He, Ar, N_2, N_2O, Xe, O_2, Ne.

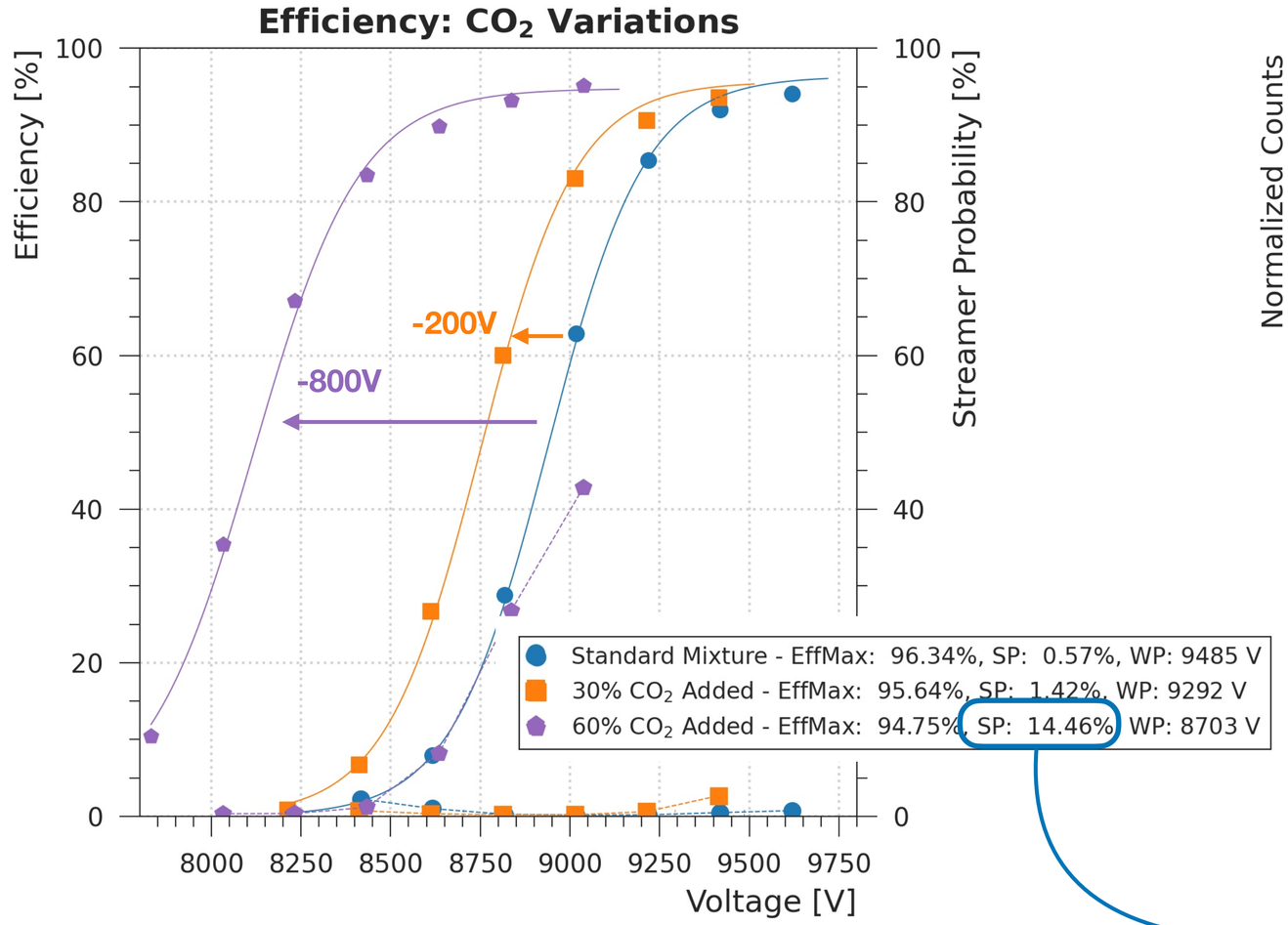
- Out of Ar, CO_2, He, N_2O, Ne and O_2, **CO_2 proved to be the best option (given the constraints)** to reduce the consumption of R-134a.
  - Ar, N_2O and O_2 increase the streamer probability
  - He and Ne reduce the working point, but He cannot be used out of safety considerations and Ne is expensive
  - CO_2 reduces the working point and increases the streamer probability but within operating limits -> making it a suitable choice

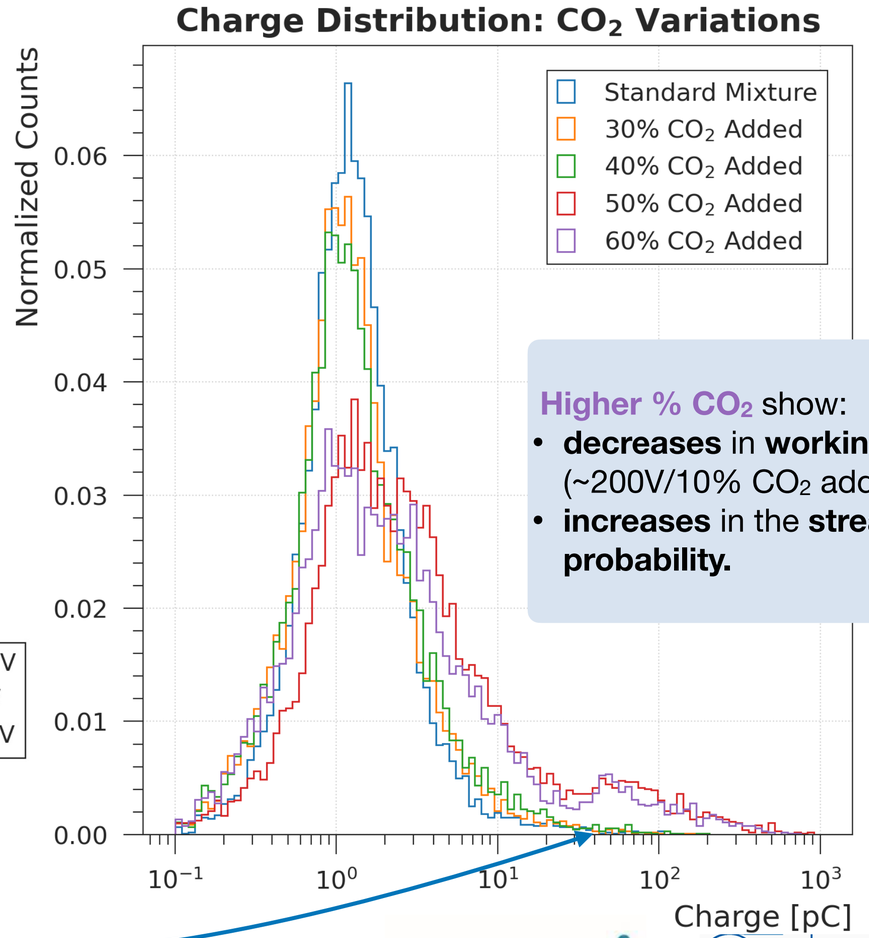


Addition of CO_2 to the Standard Gas Mixture

Concentration tuning

Muon Beam Parameters





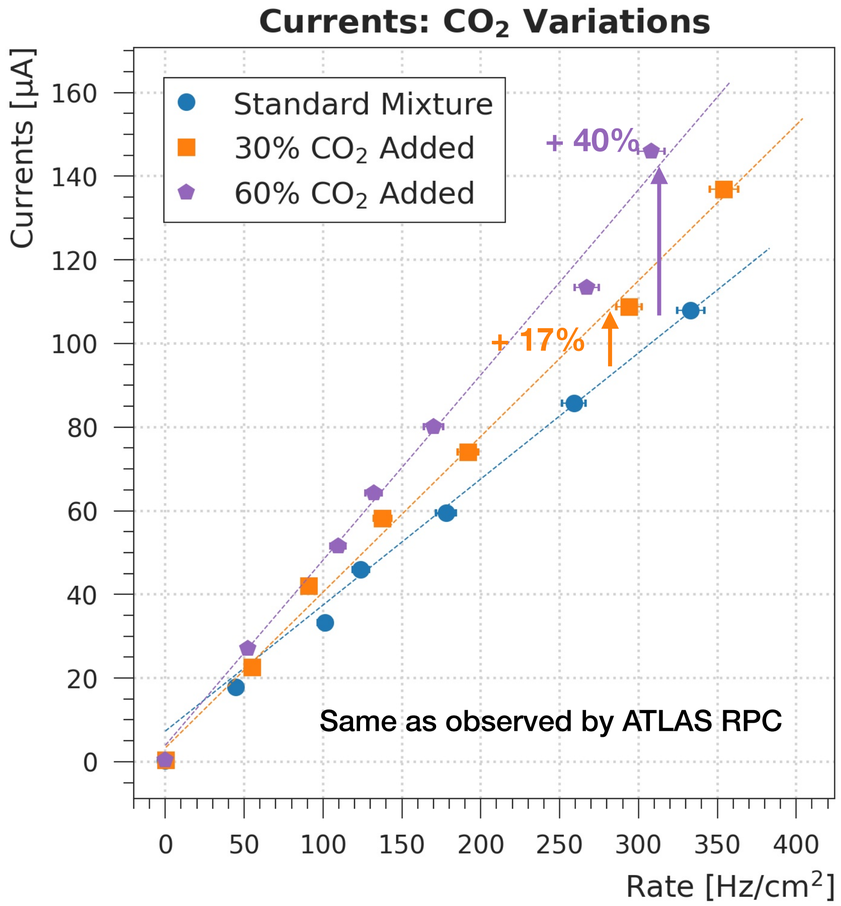
Higher % CO_2 show:

- **decreases** in **working point** (~200V/10% CO_2 added)
- **increases** in the **streamer probability.**

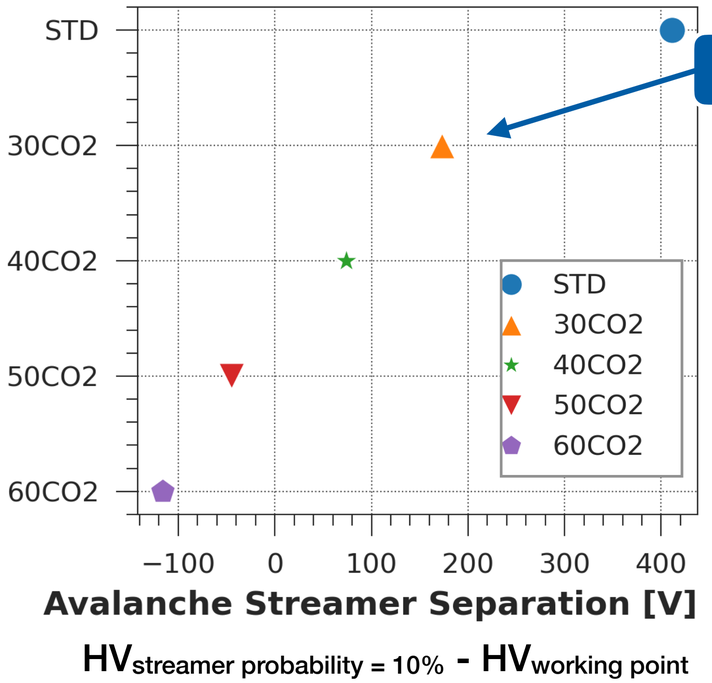
Addition of CO_2 to the Standard Gas Mixture

Concentration tuning

Gamma Background Parameters



- **Higher % CO_2** show **increases** in the **currents.**
- The standard mixture shows the highest separation (400V) between the avalanche and streamer regions.
- **30% CO_2 + 64% R-134a + 5% iC_4H_{10} and 1% SF_6** shows the **closest performance to the standard gas mixture**.

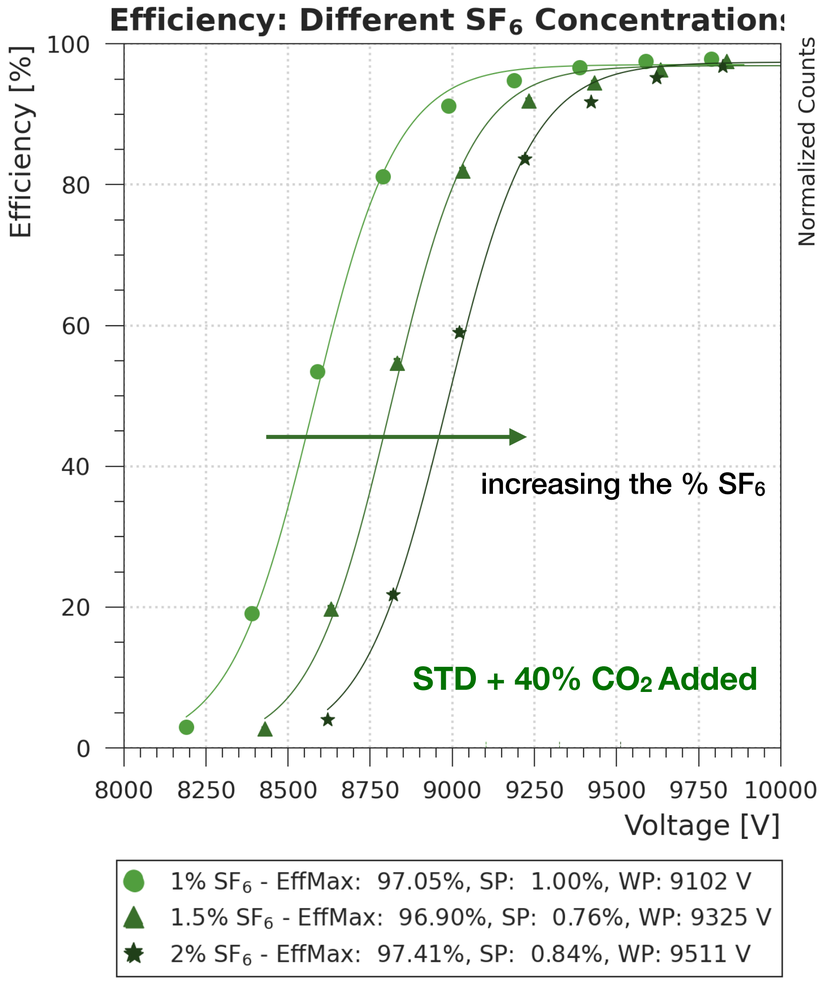


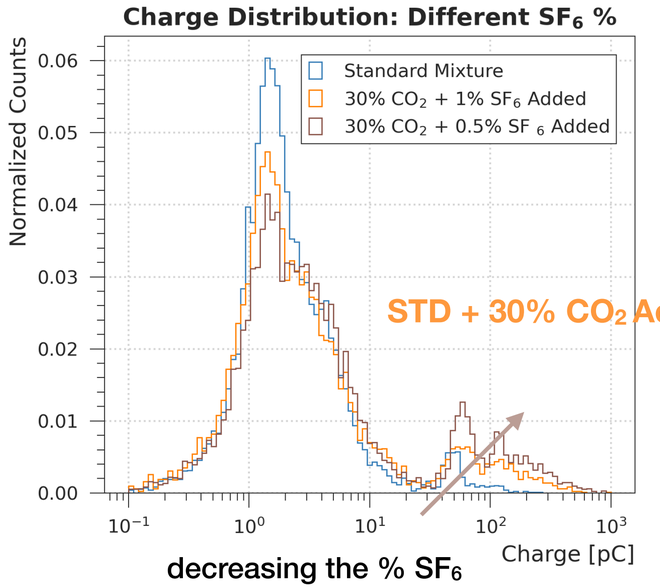
Gas mixture selected by ATLAS RPC

More details in **G.Rigoletti (2023),** ***Performance studies of RPC detectors operated with C2H2F4 and CO2 gas mixtures***

Addition of CO_2 to the Standard Gas Mixture

Fine-tuning the SF_6 concentration

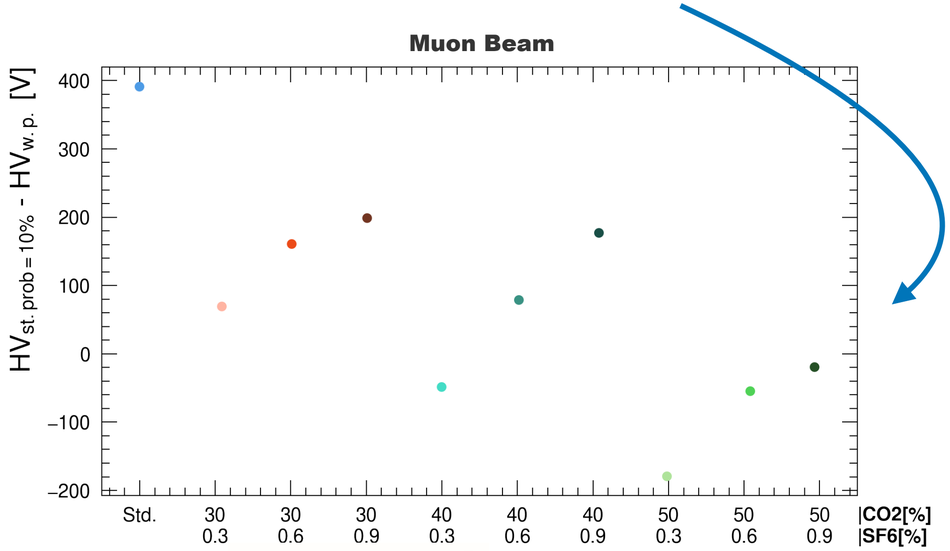




- **40% CO_2 + 1, 1.5 and 2% SF_6** were tested
  -> **higher % SF_6** show **decreased streamer probability**, while the **working point increases**

- **30% CO_2 + 0.5 and 1% SF_6** were tested
  -> both the **avalanche and streamer charge** are **similar** and there is a small separation between them

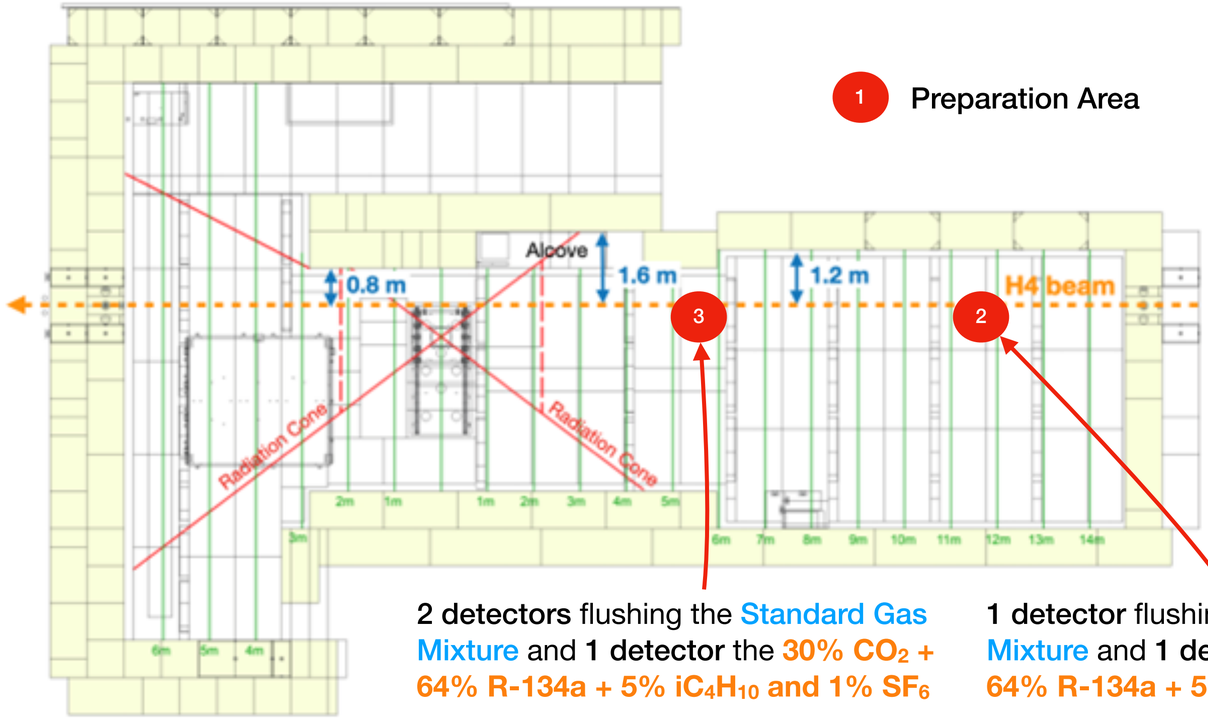
- Given all tested combinations, **increased % SF_6 increase the avalanche streamer separation**, while **increased % CO_2 reduce** it.



Ageing studies for 30% CO_2 Added

At GIF++

- Three set-ups:
  1. No irradiation
  2. LHC conditions
     ~100Hz/cm²
  3. HL-LHC conditions
     ~350Hz/cm²
- Detectors are **continuously irradiated** ~working point.
- The detectors are **checked with weekly high voltage scans** with the irradiation source off and on
  - Current behaviour observed

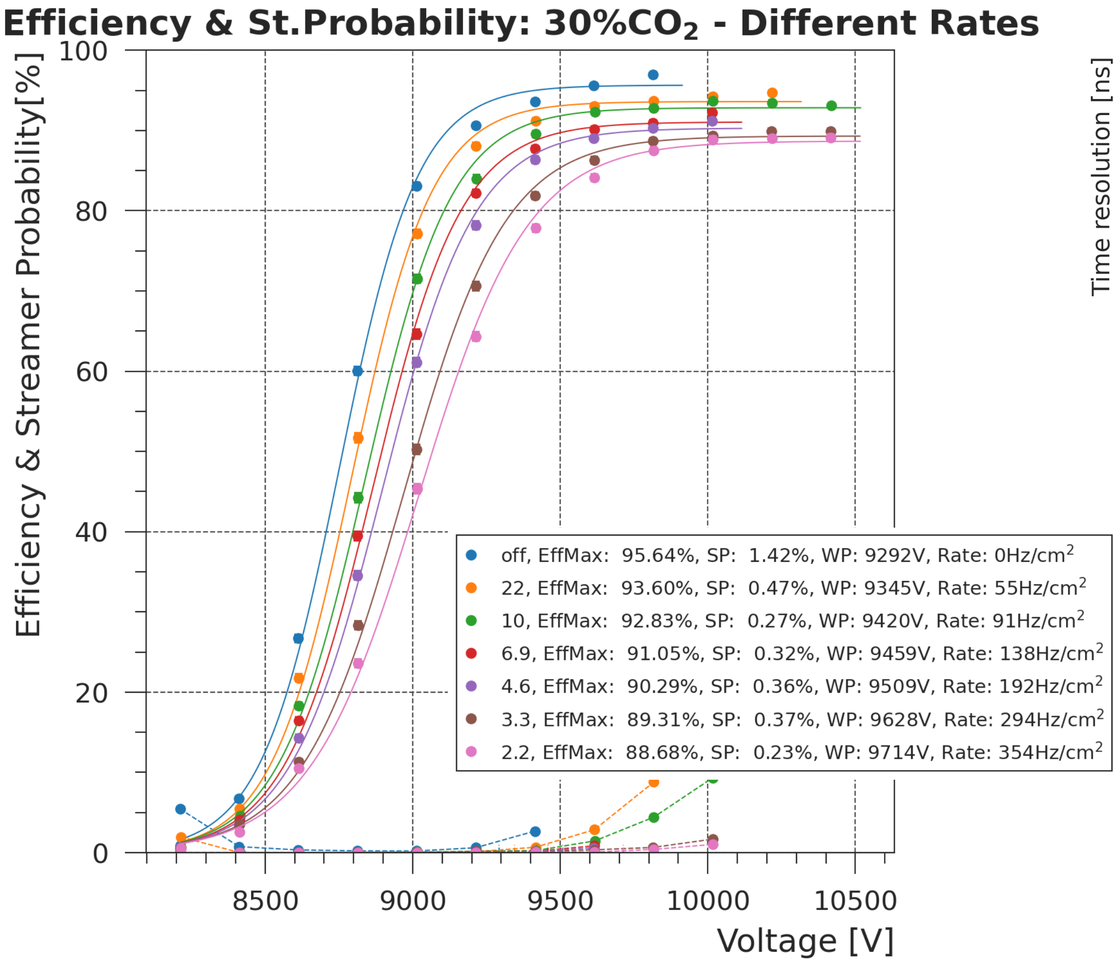


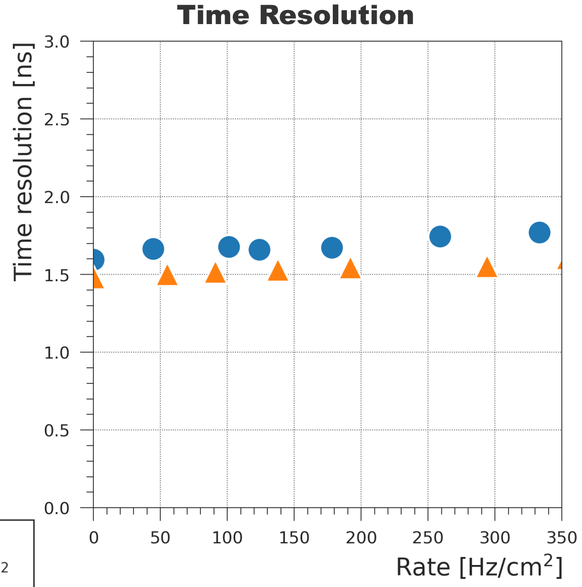
2 detectors flushing the Standard Gas Mixture and **1 detector** the **30% CO_2 + 64% R-134a + 5% iC_4H_{10} and 1% SF_6**

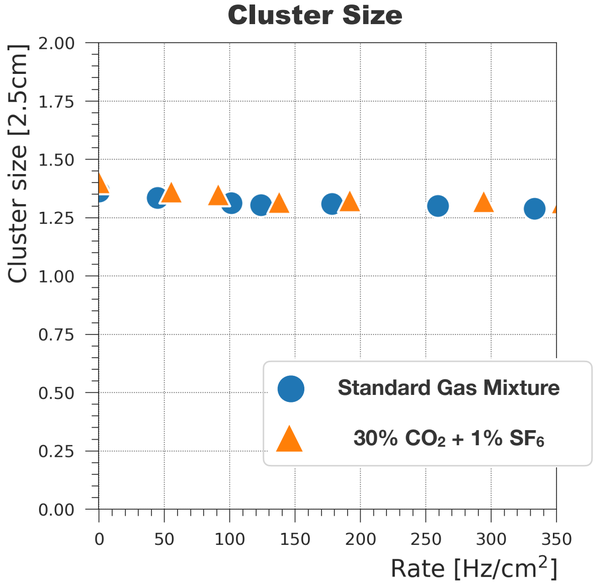
1 detector flushing the Standard Gas Mixture and **1 detector** the **30% CO_2 + 64% R-134a + 5% iC_4H_{10} and 1% SF_6**

Ageing studies for 30% CO_2 Added

Test Beam Parameters



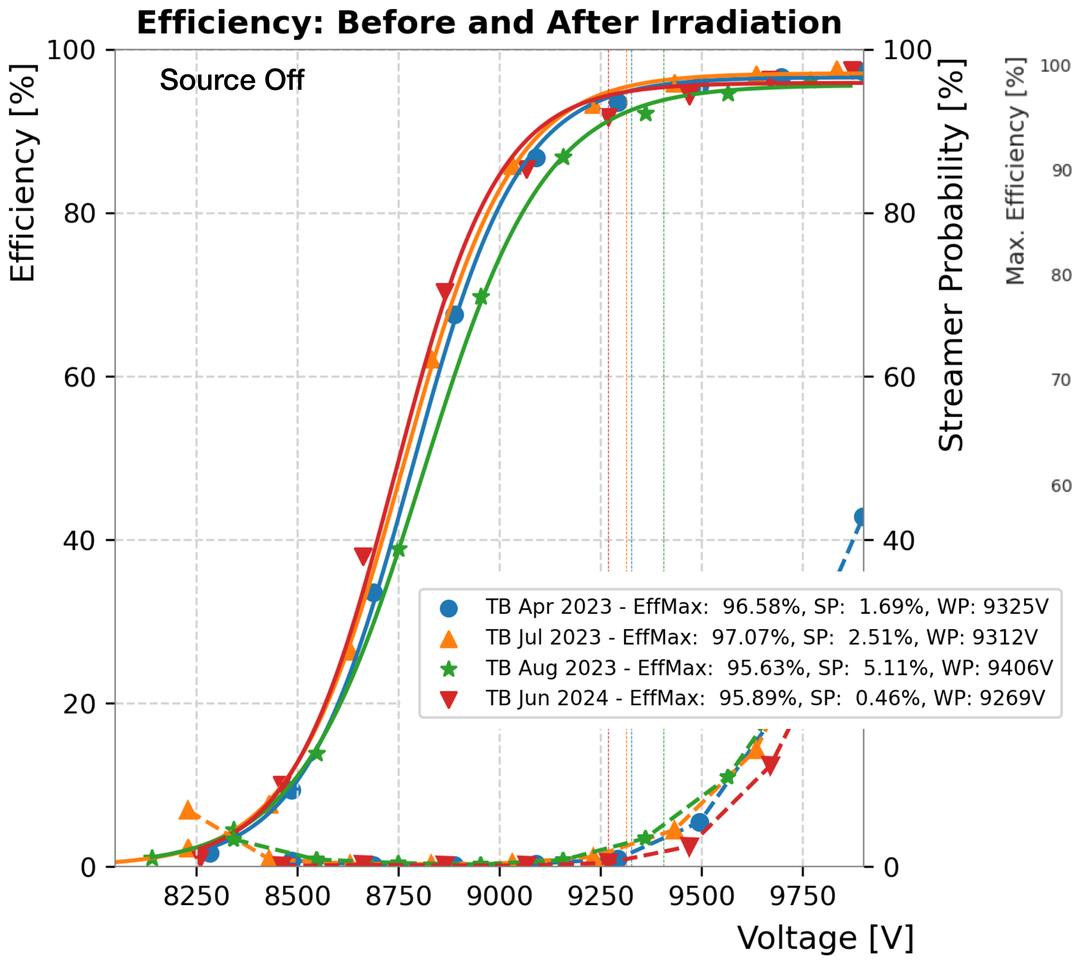


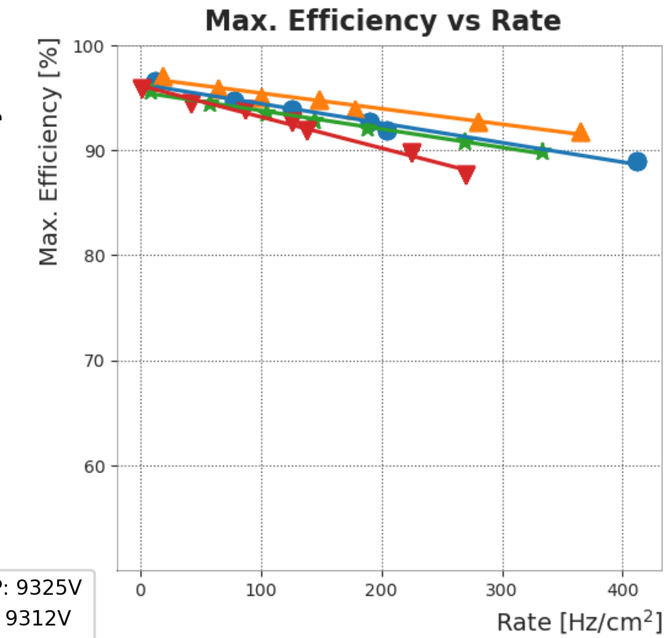


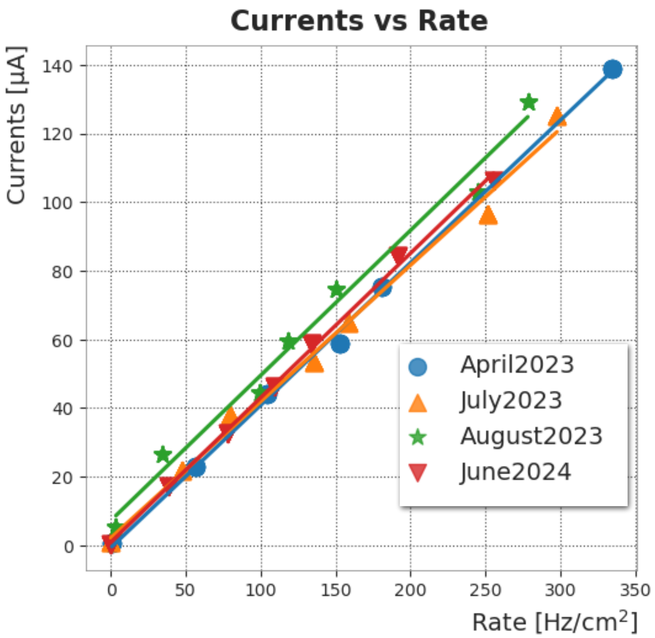
- During test beam campaigns, we assess the **detector's initial parameters for different rates** (6 different ABS filters).
- Parameters like: **efficiency, streamer probability, time and spatial resolution** are recorded, all compared to the performance of the Standard Gas Mixture.

Ageing studies for 30% CO_2 Added

Before & After Irradiation







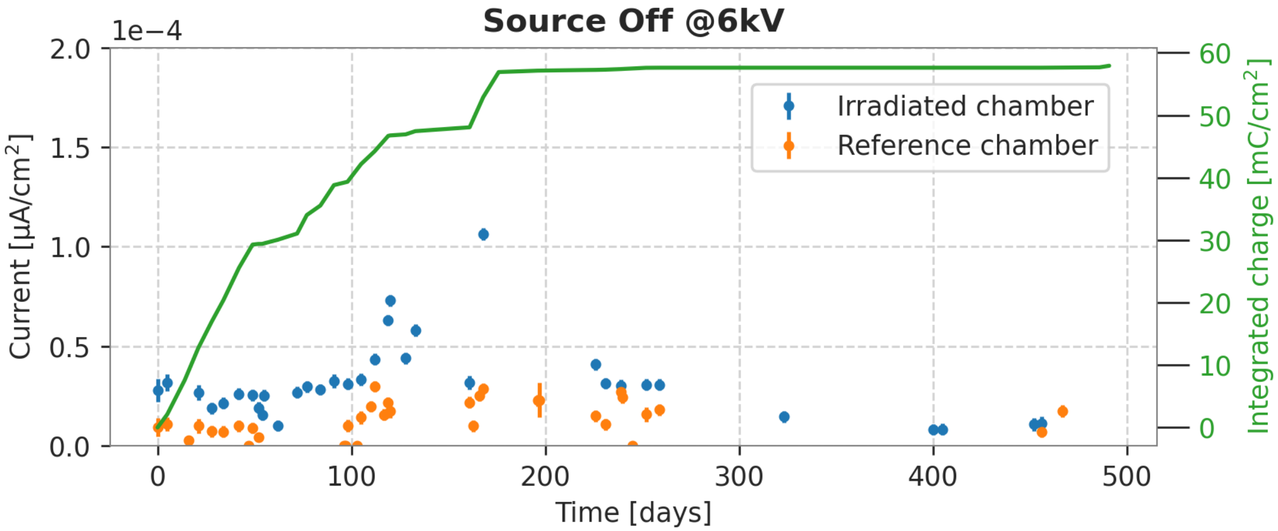
30% CO_2 + 64% R-134a + 5% iC_4H_{10} and 1% SF_6 was validated for the ATLAS experiment, being now in use for a year.

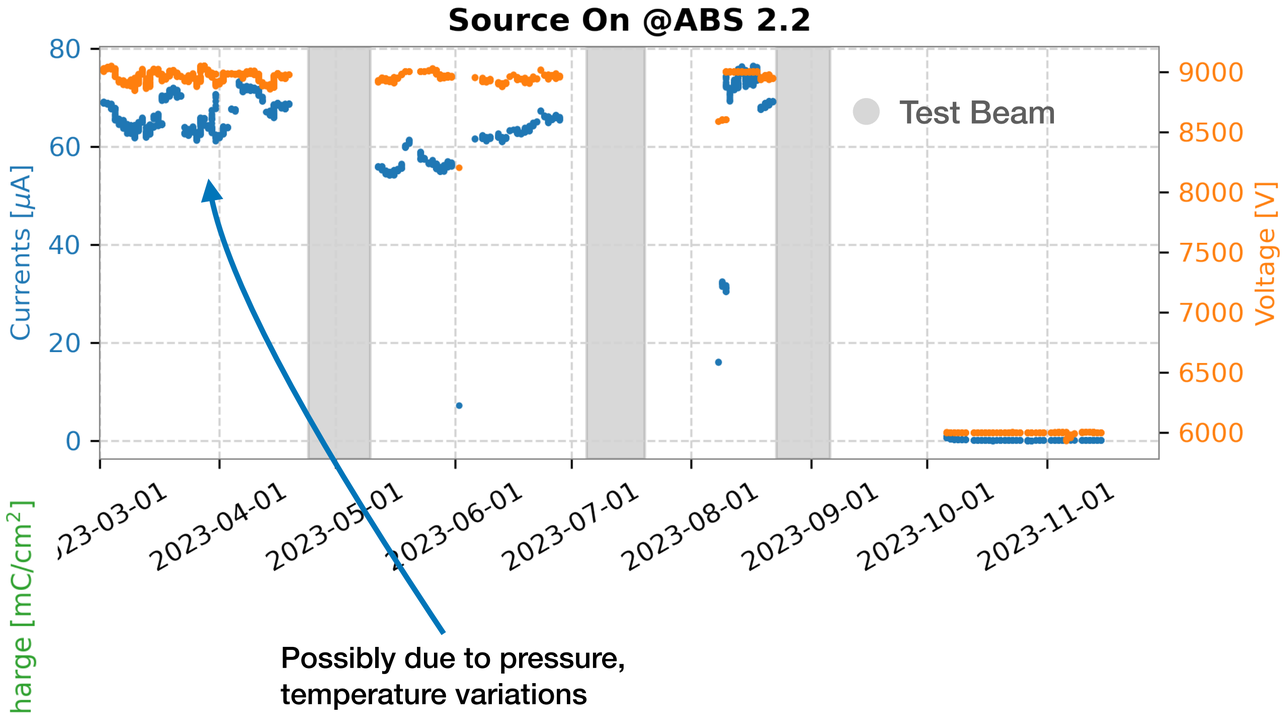
Ageing studies for 30% CO_2 Added

Before & After Irradiation

- **~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.

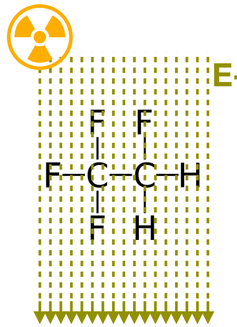




The mixture is continuing ageing tests at the moment at the Gamma Irradiation Facility (GIF++).

Gas Analysis

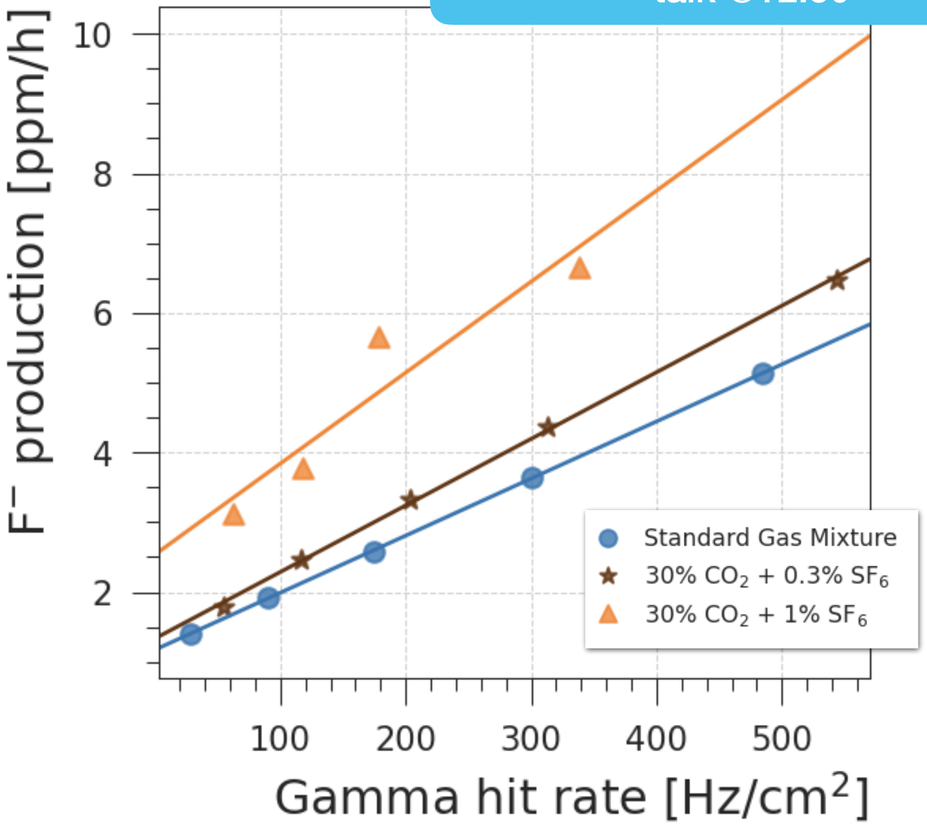
Ion Selective Electrode (ISE) Measurements



HFC- Radicals + F-*

*Together with the water molecules from the mixture, HF- radicals can be created.

More details in Mattia Verzeroli's talk @12:50



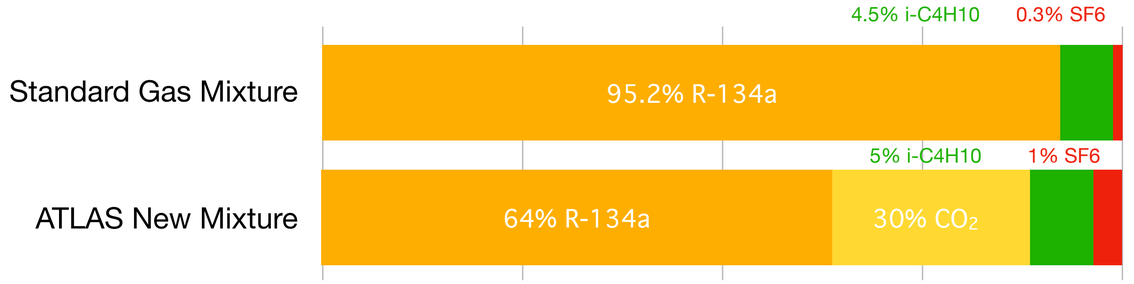
- **ISE** Measurements are used to **determine the F- concentrations** of different solutions.
- During measurements, **all parameters not directly investigates are kept fixed (gas flow, the solution's volume, same electrode reading method).**
- Adding 30% CO_2 to the Standard Gas Mixture, with the same amount of SF_6 shows a slight increase in the F- production (still under investigation).
- 30% CO_2 and increased % SF_6 added seems to produce more impurities.

Summary

Conclusions and Future Developments

- For R-134a reduction consumption, CO_2 is the best choice.
- The **addition of 30% CO_2 with 1% SF_6 shows the closest performance to the Standard Gas Mixture.**
- 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**.



In ATLAS, for one year, reducing the R-134a consumption saved ~100kCHF

- The mixture is **under ageing studies** to continue integrating the amount of charge predicted **for the ATLAS RPC certified operation** of the 2mm gaps.
- **Fine-tunings are checked** for the mixture
  - **increasing** the fraction of added CO_2 to 40%
  - **reducing the SF_6** amount to continue reducing the emissions.
- More measurements will be performed for impurities production to refine the methodology and further studies are ongoing.

Thank you!