New RPC Gas Mixtures for Sustainable Operation in the CMS Experiment

16th Pisa Meeting on Advanced Detectors, 2024

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1. Introduction

The current operation of the Resistive Plate Chamber (RPC) system within the CMS experiment involves approximately 95% tetrafluoroethane ($C_2H_2F_4$, TFE). However, in response to concerns about climate change, the European Union has instituted regulations to phase down and limit the production and usage of fluorinated greenhouse gases (GHGs) [1]. Within this framework, collaborative efforts within the RPC EcoGas@GIF++ Collaboration have been dedicated to investigating novel ecological gas mixtures based on tetrafluoropropene ($C_3H_2F_4$, HFO-1234ze) to ensure the sustainable functionality of RPCs. This poster will delve into the performance outcomes derived from improved RPC (iRPC) gas gaps operating on HFO/CO_2-based mixtures as ecologically viable alternatives, particularly in anticipation of the High Luminosity LHC phase. Additionally, the utilization of TFE/CO_2 mixtures has been explored as a pragmatic strategy to swiftly alleviate gas-related operational costs.

2. Gaseous mixtures candidates

Mixture	TFE %	HFO %	CO_2 %	i-C_4H_{10} %	SF_6 %	GWP_{mix}
STD	95.2	0	0	4.5	0.3	1485
ECO2	0	35	60	4	1	476
ECO3	0	25	69	5	1	527
MIX1	64	0	30	5	1	1529
MIX2	54.5	0	40	5	1	1353
MIX3	64.5	0	30	5	0.5	1337
GWP	1430	7	1	3	22800	-
Density (g/L)	4.68	5.26	1.98	2.69	6.61	-

STD: CMS mixture, ECO*: HFO/CO_2-based mixtures and MIX*: TFE/CO_2-based mixtures

3. RPC prototypes and experimental set-up

To study the performance of each mixture, two twin RPC prototypes were utilized: one flushed with HFO/CO_2-based mixtures and the other with TFE/CO_2-based mixtures. The prototypes were equipped with iRPC gaps in a double-gap layout, maintaining the readout copper strips in between. The iRPC gaps are constructed with High Pressure Laminated electrode material, featuring a thickness of 1.43 mm, bulk resistivity of 1.17-1.39 $\times 10^{10}$ Ωcm, and a gas gap of 1.4 mm. For signal readout, KODEL Front-end electronics and a CAEN VME multi-hit TDC V1190 were employed.
The performance study was conducted at the CERN Gamma Irradiation Facility, which can combine muon beam and gamma background with varying intensities using a 12.5 TBq ^{137}Cs source and a series of attenuation filters [2]. Both prototypes were positioned in the upstream irradiation field, approximately 3-4 meters away from the source. The muon trigger for data acquisition was set up by the coincidence of four scintillators: two located inside the irradiation bunker and two positioned outside.

4. Methodology

The study was carried out by applying high voltage scan with each mixture at different gamma background intensities and in absence of background (source OFF). The applied high voltage is corrected for temperature and atmospheric pressure variations, to maintain the effective high voltage (HV_{eff}) constant over time, according to the following equation, used by the CMS collaboration [3]:

$$HV_{app} = HV_{eff}\left[(1-\alpha)+\alpha\frac{P}{P_0}\frac{T_0}{T}\right] \tag{1}$$

where P_0 and T_0 are reference values (293.15 K and 990 mbar) and α is an empirical parameter set to 0.8.
The efficiency data points were interpolated using the logistic function reported in equation 2:

$$\varepsilon(HV) = \frac{\varepsilon_{max}}{1+e^{-\beta(HV-HV_{50})}} \tag{2}$$

where the free parameters are: ε_{max}, which represents the asymptotic maximum efficiency (plateau efficiency); β, which is related to the steepness of the efficiency curve, and HV_{50}, which represents the voltage where the efficiency reaches 50% of its maximum. These values are used to compute the voltage corresponding to the Working Point (WP), according to the definition used by the CMS collaboration [4]:

$$\text{WP} = \frac{\log 19}{\beta} + HV_{50} + 150\text{ V} \tag{3}$$

The average gamma cluster charge was estimated by the equation 4:

$$< q > = \frac{I}{\gamma_{rate}\cdot A} \tag{4}$$

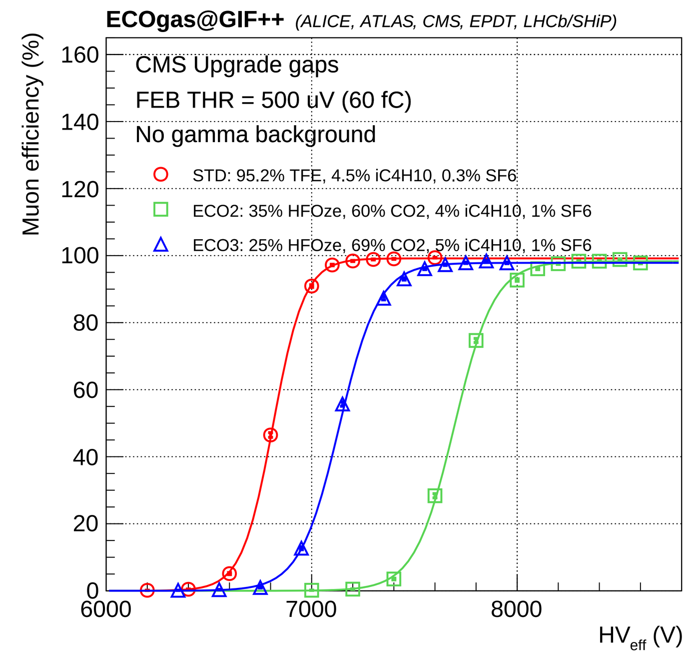
where $\frac{I}{A}$ is the mean current density between both gaps and γ_{rate} is the gamma cluster rate. Finally, the time resolution was calculated by the Time of Flight of muons with orthogonal tracks between both prototypes (flushed with the same mixture for this scope).

7. Conclusions

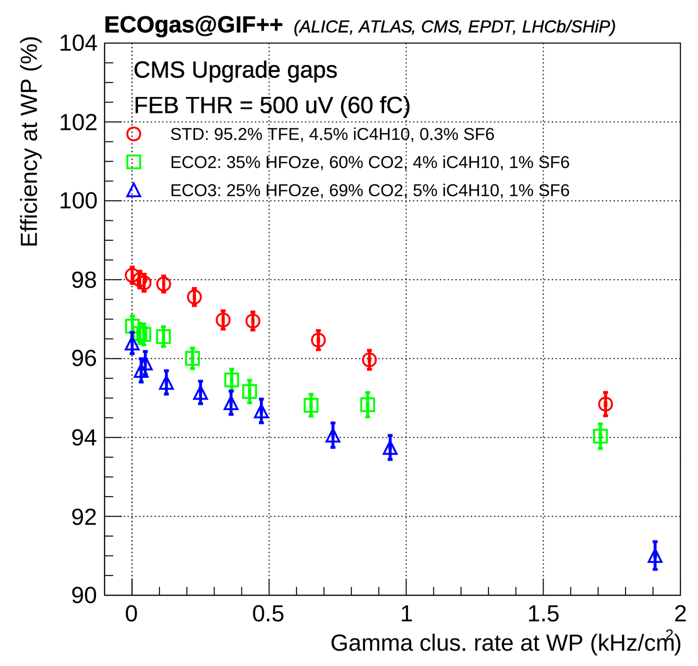
The results presented summarize the initial performance analysis of alternative candidate mixtures aimed at improved RPC operation in CMS to face the High Luminosity LHC Phase.
Among the proposed ecological mixtures (HFO/CO_2-based), the mixture containing 35% HFO (ECO2) was selected as more promising based on its efficiency value results, despite the estimation of a relatively high but not dramatic Working Point compared to the standard mixture (STD). In addition, similar average gamma cluster charges and efficiency drops were observed with increasing background levels.
The TFE/CO_2-based mixtures show good agreement with the STD regarding efficiency curves; however, further investigation is needed into the consequences of higher current density.
Both prototypes commenced an irradiation campaign in September 2023 using ECO2 and MIX3 (containing 30% CO_2 and 0.5% SF_6), respectively, for additional longevity studies.

5. Performance results operating with HFO/CO_2-based mixtures

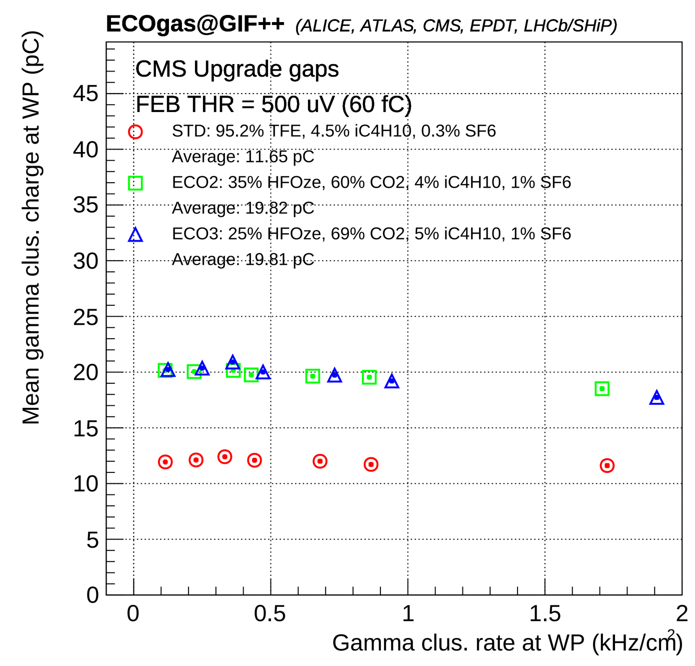
The efficiency shows around 2% loss when HFO/CO_2 replaces TFE in absence of background, and similar slope drops are observed once increasing gamma background intensity. The WPs were calculated resulting in higher values for the eco-friendly candidates. The mean gamma charge was estimated at around 40% greater for the alternative mixtures while the time resolution shows them faster than the STD.



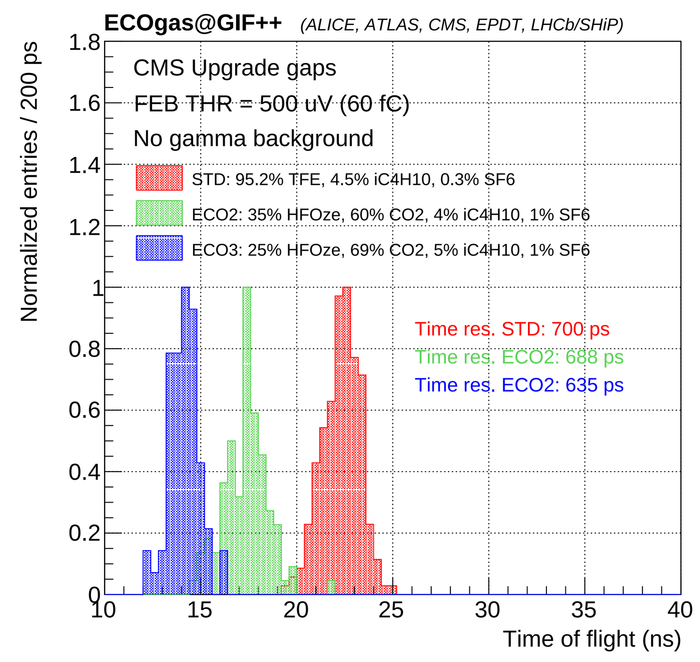
Efficiency in absence of gamma background, using the STD (WP = 7.16 kV, ϵ_{WP} = 98.1%), ECO2 (WP = 8.10 kV, ϵ_{WP} = 96.8%) and ECO3 (WP = 7.54 kV, ϵ_{WP} = 96.3%) mixtures.



Efficiency at WP as a function of the gamma cluster rate measured at the associated value.



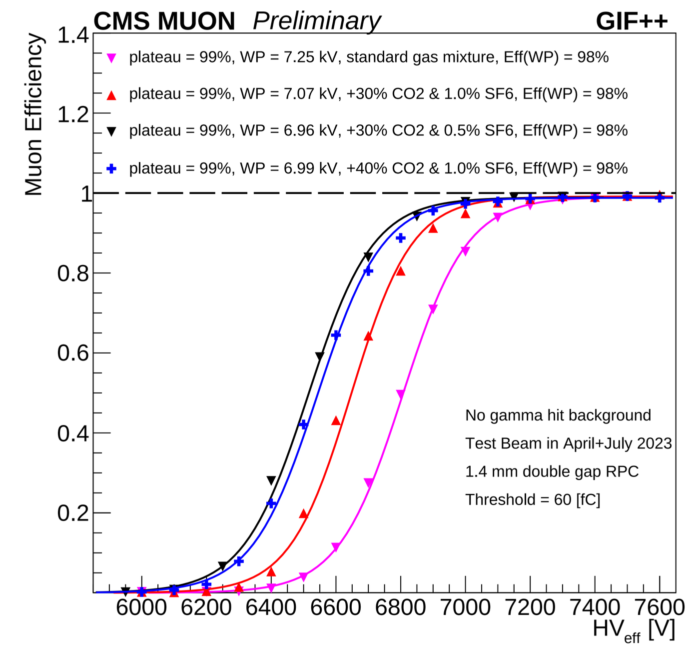
Average gamma cluster charge at WP as a function of the gamma cluster rate measured at the associated value.



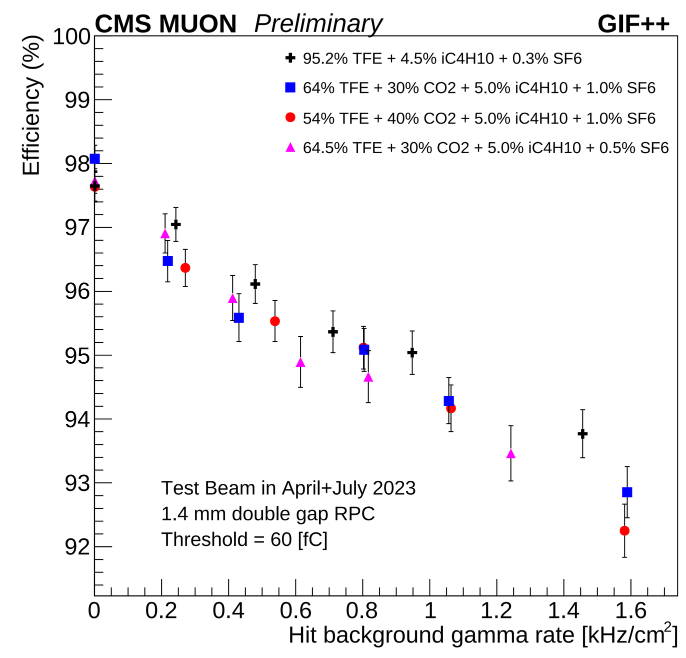
Average gamma cluster charge at WP as a function of the gamma cluster rate measured at the associated value.

6. Performance operating with TFE/CO_2-based mixtures

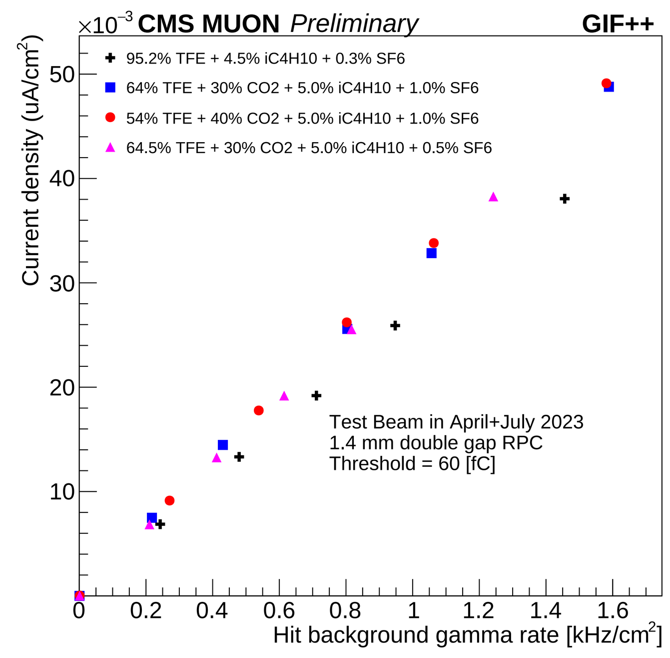
The WP is increased by the addition of SF_6 but decreased by the addition of CO_2. There is no degradation of the efficiency at the WP for any of the tested mixtures in absence of gamma background. The efficiency drop with the background gamma rate is similar for all mixtures while the mixture with 40% of CO_2 (MIX2) shows a drop of 2% of efficiency when the gamma rate is close to 1.5 kHz/cm^2. Therefore, the current density shows values 20% higher for the TFE/CO_2 based mixtures.



Efficiency in absence of gamma background.



Efficiency at WP as a function of the gamma cluster rate measured at the associated value.



Average current density at WP as a function of the gamma cluster rate measured at the associated value.

8. References

[1] Council of European Union. *Council regulation (EU) no 517/2014*. 2014.

[2] D. Pfeiffer, G. Gorine, H. Reithler, et al. "The radiation field in the Gamma Irradiation Facility GIF++ at CERN". In: *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 866 (2017), pp. 91–103. ISSN: 0168-9002. DOI: https://doi.org/10.1016/j.nima.2017.05.045. URL: https://www.sciencedirect.com/science/article/pii/S0168900217306113.

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[4] M. A. Shah, R. Hadjiska, A. Fagot, et al. "The CMS RPC detector performance and stability during LHC RUN-2". In: *Journal of Instrumentation* 14.11 (Nov. 2019), p. C11012. DOI: 10.1088/1748-0221/14/11/C11012. URL: https://dx.doi.org/10.1088/1748-0221/14/11/C11012.