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Highlights on Searches for Environmentally Friendly Gases in the CMS RPC System

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The Resistive Plate Chambers (RPC) of the Compact Muon Experiment (CMS) experiment at the Large Hadron Collider (LHC) operates with a gas mixture composed of 95.2% of $C_2H_2F_4$, a greenhouse gas with high Global-Warming Potential (GWP). In recent years, several eco-friendly alternatives, such as hydrofluoroolefins (HFOs), have been investigated to identify sustainable replacements that preserve the detector performance. Another promising approach is to partially replace $C_2H_2F_4$ with CO_2, reducing the mixture's GWP by 30–40%. These studies are being performed at the CERN Gamma Irradiation Facility (GIF++), which replicates the radiation conditions expected during the High-Luminosity Phase-2 data taking at the Large Hadron Collider (HL-LHC), using an 11.5 TBq gamma source and a muon beam. Updated results are presented on the performance of two 1.4 mm double-gap RPC chambers operating with various alternative gas mixtures under high-rate gamma irradiation. Results are also presented on RPC aging studies with these alternative gas mixtures, providing a deeper insight into the long-term performance and stability for the future of the RPC muon system.

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1. Introduction

Resistive Plate Chambers (RPCs) are widely used in particle physics experiments, as in the Compact Muon Solenoid (CMS), at CERN. Currently, the RPCs operate with a gas mixture containing a large amount of $C_2H_2F_4$ — a greenhouse gas with a Global Warming Potential (GWP) of 1430 [1]. Given the present policies at CERN to decrease the greenhouse gas emissions, alternative gas mixtures are being studied at the Gamma Irradiation Facility (GIF++), which simulates LHC Phase-2 conditions with a gamma radiation source and a muon beam. This paper presents results on the performance of two 1.4 mm double-gap RPC chambers with various alternative gas mixtures in a high gamma background, and future aging studies are discussed.

2. Resistive Plate Chambers and experimental setup

Each RPC chamber has 2 detector layers where gas gaps are filled with a mixture containing 95.2% $C_2H_2F_4$, 4.5% i-C_4H_{10}, and 0.3% SF_6. Between the two gaps lies a readout strip plane connected to an adapted front-end board with charge threshold of 60 fC. When a voltage difference is applied across the electrodes, a traversing particle initiates an avalanche and the resulting charge is induced on the strips, providing position and timing measurements of the detected particle. For the LHC Phase-2 upgrade, a new generation of improved RPCs (iRPCs) will be installed in the forward regions of CMS.

The system is set up at GIF++ bunker, where an 11.5 TBq ^{137}Cs source is combined with a high-energy (100 GeV/c) muon beam. Studies are performed using two iRPC-like chambers, which were tested with different alternative gas mixtures, under a muon beam and a different gamma irradiation rates, that are comparable to those expected in CMS during HL-LHC operations. The environment parameters, as temperature, pressure and humidity are constant monitored, as well as high voltage and gap current. Stable parameters and performance are essential for doable operation in GIF++ with perspectives to CMS in Run 4 and onwards. The complete description of the chambers geometry and experimental setup can be found in Ref. [4].

3. Alternative gas mixtures and detector performance

The alternative gas mixtures can be categorized into two groups. The first group ("MIX" group of Table 1) involves a partial substitution of $C_2H_2F_4$ by CO_2. This approach is regarded as a mid-term strategy, given that ATLAS, another multi-purpose experiment at LHC, has been employing MIX1 since 2023 in order to reduce the emission of $C_2H_2F_4$ and no degradation in the system was observed so far [7]. In this scenario, the SF_6 component is augmented by up to 1% to ensure that cluster size and streamer probability remain within specified requirements, as demonstrated in Ref. [2]. As SF_6 also presents high GWP, we incorporated in the tests the MIX3, with only 0.5% of this gas. The second group ("ECO" group in Table1)

entails a complete replacement of $C_2H_2F_4$ with hydrofluoroolefin (HFO)-1234ze, an industrial gas characterized by a low GWP. SF_6 is similarly increased for the aforementioned reasons, and CO_2 is incorporated to reduce the operating voltage point, as indicated in Ref. [3].

Figure 1 shows the measured efficiency vs. high-voltage (HV) for CO_2-based mixtures. The results show only a minor drop in efficiency as CO_2 percentage was increased, limiting this partial

Mixture	$C_2H_2F_4$	HFO	CO_2	i-C_4H_{10}	SF_6	CO_2e (g/l)
STD	95.2	0	0	4.5	0.3	6824
MIX1	64	0	30	5	1	5650
MIX2	54	0	40	5	1	5000
MIX3	64.5	0	30	5	0.5	4940
ECO2	0	35	60	4	1	1522
ECO3	0	25	69	5	1	1519
GWP	1430	7	1	3	22800	-
$\rho(g/L)$	4.68	5.26	1.98	2.69	6.61	-

Table 1: Alternative gas mixtures used in RPCs detectors at GIF++. STD is the standard gas mixture used in CMS. "MIX" is the group of CO_2-based gas mixtures and "ECO" is the group with HFO instead of $C_2H_2F_4$. The $\rho(g/L)$ is the gas density [5].

replacement to 40%, as confirmed by studies with other types of RPC detectors [2]. The efficiency drop with the increase of background rate is show to be similar for all tested mixtures. All CO_2-based mixtures show a lower working point (WP) compared to the standard gas mixture due to the lower global density of the mixture.

Figure 2 shows the currents and the efficiencies of CO_2-based mixtures before and after irradiation. The current is shown to be around 20% higher for CO-$_2$ based mixtures compared to the standard one, which may imply faster aging. Since 2023, aging studies are being developed in GIF++ and, as shown in Figure 2, after 40 mC/cm^2 of integrated charge, no degradation has been observed. The drop in efficiency for high rates (around 2kHz/cm^2) are associated with the electronics prototype used for the tests, as described in Ref. [4], while for moderate rates and results are similiar with irraditaion.

4. Conclusions

Initial findings from a prototype of the iRPC utilizing CO_2-based gas mixtures indicate comparable efficiency and a reduced working point when compared with the standard mixture. However, due to the 20% higher current, long term investigation is being performed. The total expected integrated charge at the end of HL-LHC is 300 mC/cm^2 [1], and so far we have integrated only 40 mC/cm^2, representing about 4% of total value with a safety factor of 3.

As in CMS we have a $C_2H_2F_4$ recuperation system with 80% of efficiency [8] and a gas leak permanent repair procedure [9], both in operation since 2023, we will achieve CERN mitigation policy of GWP gases expected by the end of Run 3 and keep ongoing with longevity studies with CO_2-based mixtures to decide in the near future if we CMS-RPC system operation can handle the mixture change.

References

[1] CMS Collaboration,"The Phase-2 Upgrade of the CMS Muon Detectors", CERN-LHCC-2017-012, https://cds.cern.ch/record/2283189.

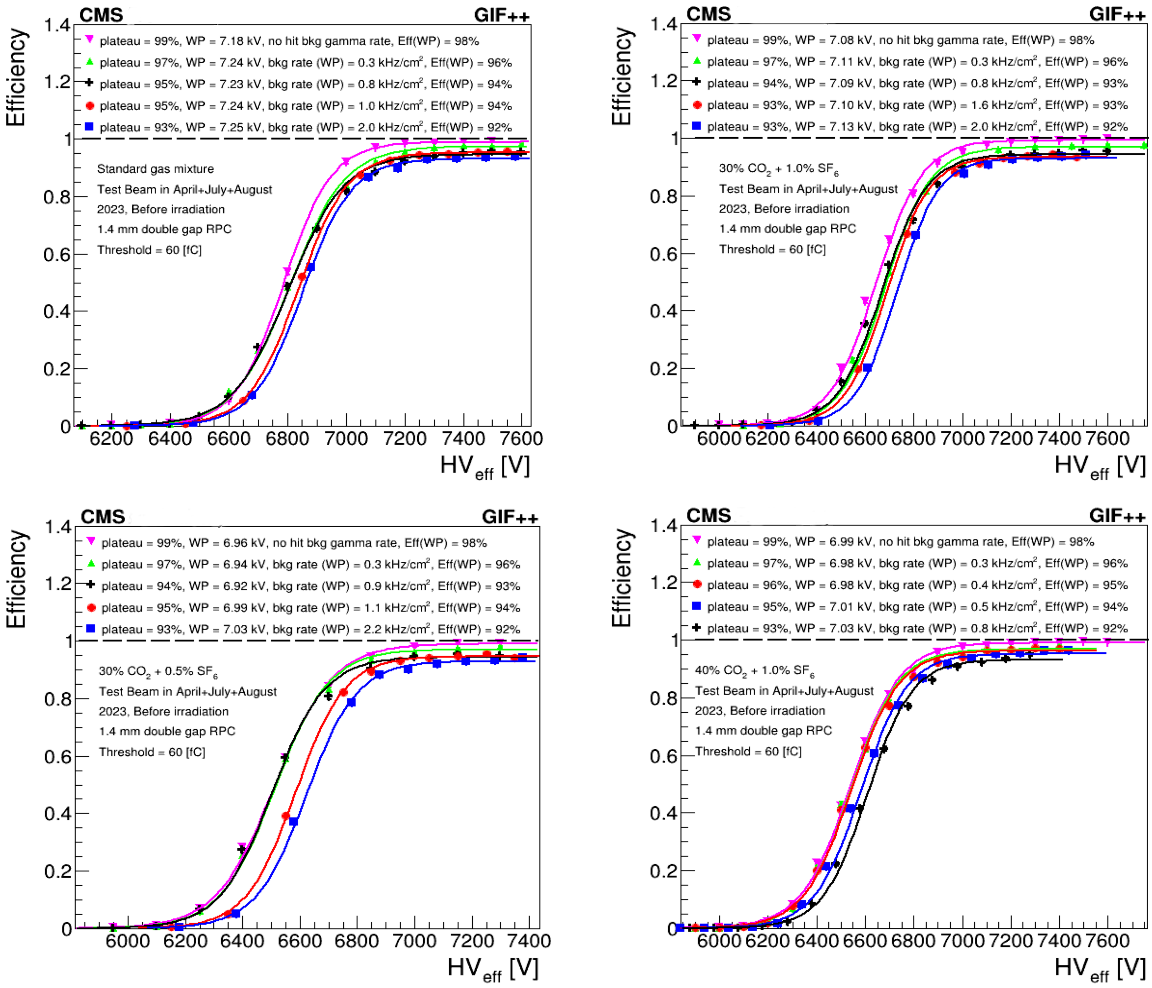

Figure 1: Efficiency plots for different gas mixtures at different gamma background rates. On top left, the standard gas mixture is presented, while the CO_2-based mixtures (30-40% with 1% of SF_6) are shown on top right and bottom right, respectively [6]. On the bottom left the performance of a mixture with 30% CO_2 and less SF_6 (0.5%) is shown since as we decrease the amount of $C_2H_2F_4$, the GWP is driven by SF_6. Uncertainties are too small hence they are not seen in the plots.

[2] G. Rigoletti *et al.*,"Towards sustainable RPC detectors: Exploring CO2-based gas mixtures for CERN LHC experiments", Nucl. Instrum. Meth. A **1075** (2025) 170331, https://doi.org/10.1016/j.nima.2025.170331.

[3] B. Quintanilla, J. R *et al.*, "Efficiency studies of RPC detectors with eco-friendly gas mixtures in high radiation rate environments", 2022, https://cds.cern.ch/record/2824927.

[4] J. P. Pinheiro *et al.*, "Performance and longevity of CO_2 based mixtures in CMS improved Resistive Plate Chambers in the HL-LHC environment", Nucl. Instrum. Meth. A **1076** (2025) 170451, https://doi.org/10.1016/j.nima.2025.170451.

[5] RPC ECOGas@GIF++ Collaboration *et al.*, "High-rate tests on Resistive Plate Chambers

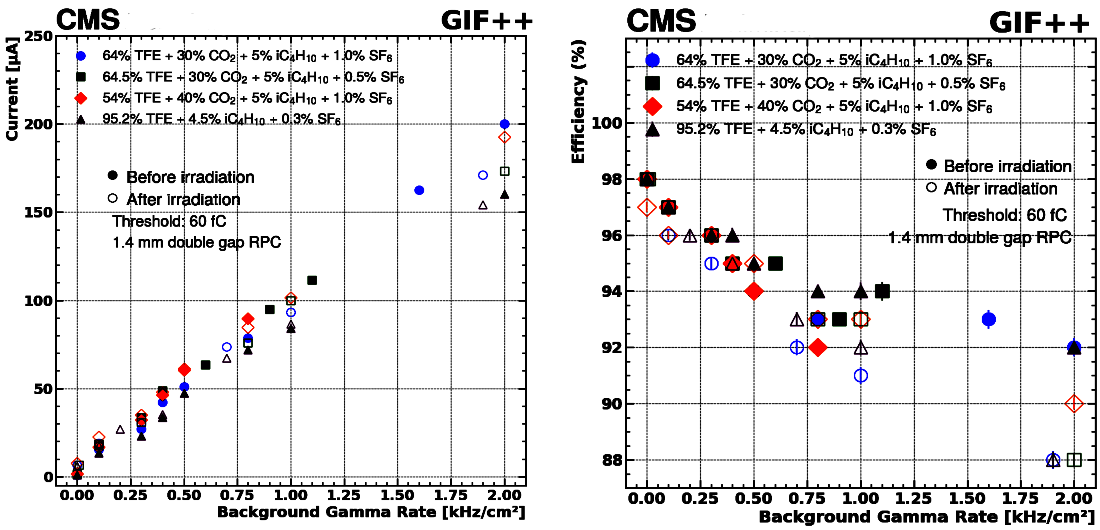

Figure 2: These plots show current and efficiency drop with gamma rate before (filled dots) and after (open dots) the irradiation period [6], where the total integrated charge was 40 mC/cm^2.

operated with eco-friendly gas mixtures", European Physical Journal C **84** (2024) 300, https://doi.org/10.1140/epjc/s10052-024-12545-8.

[6] CMS Collaboration,"CO-2-based mixture for iRPC detector studies", CMS-DP-2024-113, https://cds.cern.ch/record/2916753.

[7] E. Ballabene *et al.*, "Performance of ATLAS RPC detectors and L1 Muon Barrel Trigger with a new CO_2-based gas mixture", Nucl. Instrum. Meth. A **1076** (2025) 170482, https://doi.org/10.1016/j.nima.2025.170482.

[8] M. C. Arena *et al.*, "Recuperation systems for fluorinated gases at the CERN LHC experiments", Nucl. Instrum. Meth. A **1068** (2024) 169789, https://doi.org/10.1016/j.nima.2025.169789.

[9] J. P. Pinheiro *et al.*, "CMS RPC Detector consolidation and preparation for new chambers installation for Phase II upgrade programme", PoS ICHEP2024 **957** (2025), https://doi.org/10.22323/1.476.0957.