Performance of eco-friendly alternative gas mixtures in CMS iRPC detector in the HL-LHC environment

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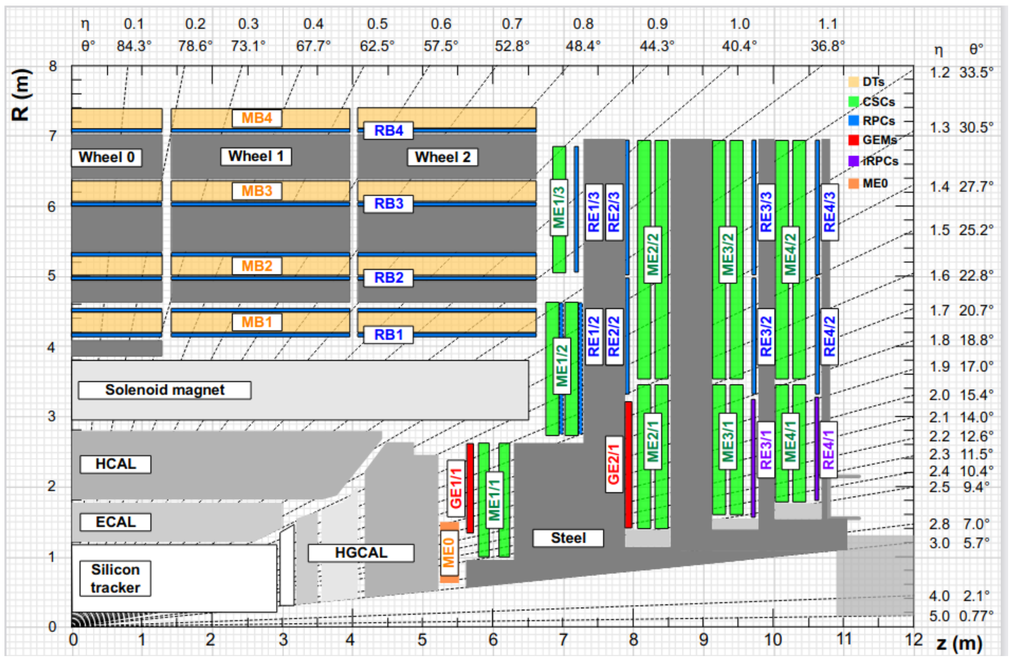
on behalf of the CMS Muon Group

1 Introduction

The Compact Muon Solenoid (CMS) is one of two general-purpose experiments at the Large Hadron Collider (LHC) at CERN. The muon system's Resistive Plate Chambers (RPCs), which are gaseous detectors in the barrel and endcaps, operate in avalanche mode for position and timing measurements. For the Phase-2 upgrade of CMS, improved RPCs will be installed in the forward region of the Muon System [1].



Schematic longitudinal view of one quarter of the CMS detector with the different subsystems which compose the Muon Detector. Existing RPC chambers are represented in blue. The locations of new improved RPC stations (RE3/1 and RE4/1) are indicated in violet.

The RPCs use a gas mixture of 95.2% $C_2H_2F_4$, a greenhouse gas with a Global Warming Potential (GWP) of 1430. Alternative gas mixtures are being studied at the CERN Gamma Irradiation Facility (GIF++), which simulates LHC Phase-2 conditions with a 12 TBq radiation source and muon beam. This poster presents the performance of two 1.4 mm double-gap RPC chambers with various alternative gas mixtures in a high gamma background and discusses future aging studies. Due to the unavailability of official Front-End Boards (FEBs) for iRPCs in CMS, a customized FEB with a 60 fC charge threshold is used.

2 Alternative Gas Mixtures for RPC detectors

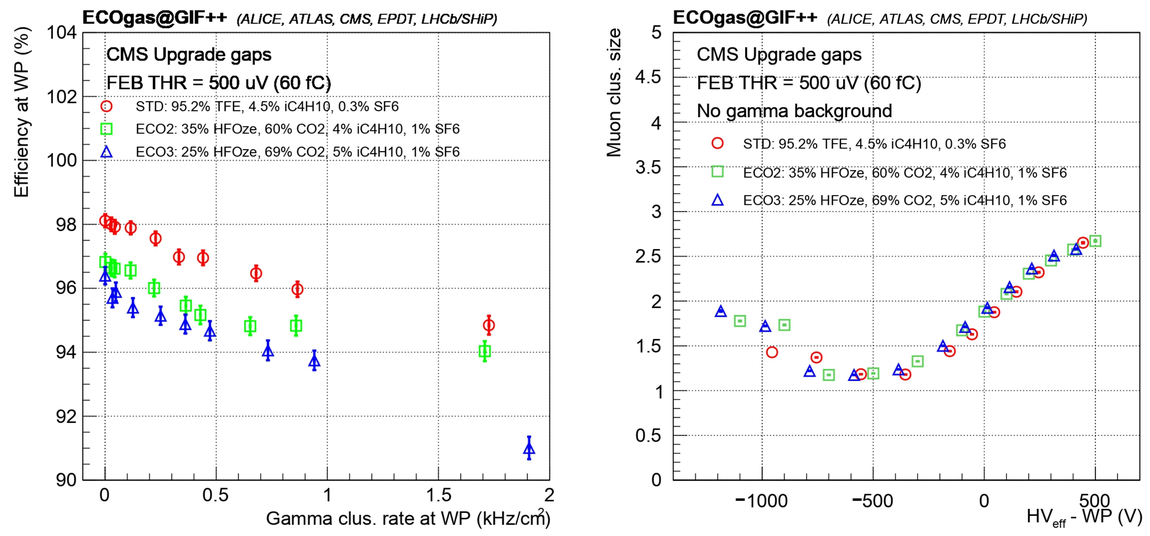
The alternative gas mixtures can be grouped into two sets. The first set (MIX in the table below) partially replaces $C_2H_2F_4$ with CO_2. This is considered a mid-term plan, as ATLAS has been using MIX1 since 2023. In this case, the SF_6 component is increased up to 1% to maintain cluster size and streamer probability within requirements, as shown in previous studies [2]. The second set (ECO in the table below) completely replaces $C_2H_2F_4$ with HFO-1234ze, a low-GWP industrial gas. SF_6 is also increased for the same reasons, and CO_2 is added to lower the working point, as shown in previous studies [3].

Mixture	$C_2H_2F_4$	HFO	CO_2	i-C_4H_{10}	SF_6	GWP_{mix}
STD	95.2	0	0	4.5	0.3	1485
MIX1	64	0	30	5	1	1529
MIX2	54.5	0	40	5	1	1353
MIX3	64.6	0	30	5	0.5	1337
ECO2	0	35	60	4	1	476
ECO3	0	25	69	5	1	527
GWP	1430	7	1	3	22800	-
$\rho(g/L)$	4.68	5.26	1.98	2.69	6.61	-

Table 1: Different alternatives gas mixtures used in RPCs detectors at GIF++. STD is the standard gas mixture used in CMS. MIX are the group of CO_2-based gas mixtures and ECO are the gas mixtures with HFO instead of $C_2H_2F_4$.

2.1 HFO/CO_2 mixtures

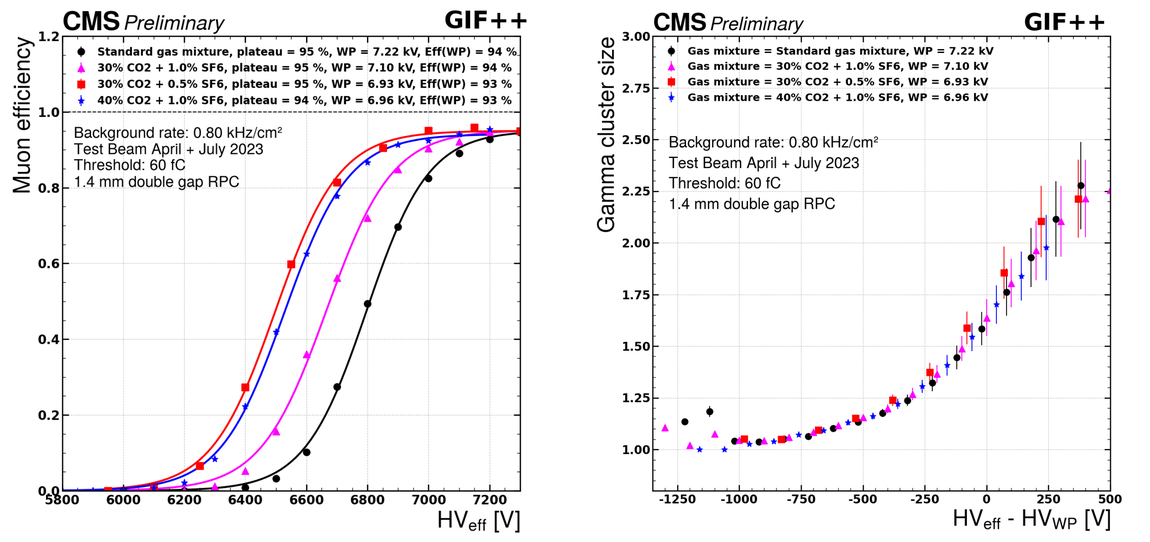
The efficiency shows about 2% reduction when HFO/CO_2 replaces $C_2H_2F_4$ in the absence of background, with similar slope drops observed as gamma background intensity increases. The working points for the eco-friendly mixtures were calculated and found to be higher. The muon cluster size is similar for all mixtures studied.



Efficiency as a function of background gamma rate (left) and muon cluster size for standard gas mixture and different HFO-based mixtures (right).

2.2 $C_2H_2F_4$ /CO_2 mixtures

The working point (WP) is raised by adding SF_6 but lowered by adding CO_2, as expected. None of the tested mixtures showed dramatic efficiency degradation at the WP for 800 Hz/cm^2 background rate. The gamma cluster size at a rate of 800 Hz/cm^2 is similiar for all the mixtures tested.



Efficiency curve for standard gas mixture and different CO_2 based gas mixtures with a background rate around 800Hz/cm^2 (left) and the gamma cluster size for the same rate (right).

3 Conclusion

The results summarized here represent the initial performance evaluation of alternative gas mixtures for improved RPC operation in CMS during the High Luminosity LHC Phase. Among the proposed eco-friendly HFO/CO_2-based mixtures, the one with 35% HFO (ECO2) showed the most promise based on its efficiency, despite having a relatively high, but not excessive, working point compared to the standard mixture (STD). Additionally, similar muon cluster size and efficiency drops were observed. The $C_2H_2F_4$/CO_2-based mixtures showed good shape, comparable with the STD in terms of efficiency curves; however, further research is needed to understand the implications of higher current density observed during the study. Both prototypes began an irradiation campaign in September 2023 using ECO2 and MIX3 for extended longevity studies. No degradation in the chambers has being observed so far.

References

[1] Colaleo, A. (2015), et al. *CMS Technical Design Report for the Muon Endcap GEM Upgrade*, CERN-LHCC-2015-012, CMS-TDR-013 https://cds.cern.ch/record/2021453.

[2] Rigoletti, G. et al. *Performance studies of RPC detectors operated with $C_2H_2F_4$ and CO_2 gas mixtures* Nucl. Instruments Methods Phys. Res. Sect. A: Accel. Spectrometers, Detect. Assoc. Equip. 1049, 168088 (2023).

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

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