Studies of eco-friendly gas mixtures for RPC detectors

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ABSTRACT

In the context of climate change, one of the main contributors to global warming is the greenhouse effect. Regulations have been implemented in different areas of society to reduce or ban the use of greenhouse gases, such as TFE. Despite the fact that large-scale experiments (such as the ones held at CERN) have been excluded from these restrictions, as a scientific community, we have the duty to look for alternatives more eco-friendly to the environment. In this work we perform studies for an iRPC detector using eco-friendly gas mixtures in the context of the Phase II upgrade of the CMS detector, tested at the Gamma Irradiation Facility (GIF++) at CERN.

CMS RPC detectors

The CMS RPCs consist of double gap chambers, using a gas mixture composed of Isobutane (4.5%), Sulphur-Hexafluoride (SF6 0.3%) and TFE (95.2%). TFE and SF6 are the main contributors to the high GWP index of this mixture, therefore, the efforts to reduce or ban the usage of these components is one of the main goals of our community.

GLOBAL WARMING POTENTIAL (GWP)

In this work, a new iRPC chamber was assembled, characterized and tested using ecological gas mixtures where TFE was replaced by a mixture of HFO and CO2. In table 1 the composition of the used mixtures is summarized.

Table 1 – Gas mixture composition used by CMS RPCs and two eco-friendly mixtures (TFE is replaced by gases with lower GWP).

Component	Chemical formula	CMS	ECO2	ECO3
Sulfur hexafluoride	SF_6	0.3%	1%	1%
Isobutane	$i-C_4H_{10}$	4.5%	4 %	5%
Hypofluorous acid	HFO	-	35%	25%
Carbon dioxide	CO_2	-	60%	69%
TFE	$C_2F_4H_2$	95.2%	-	-
GWP		1485	476	527

In these candidate mixtures TFE (GWPTFE = 1430) is replaced with HFO (GWPHFO = 7), moving the working point to higher value, therefore in order to lower this HV, CO2 is added.

EFFICIENCY - MUON STREAMER PROBABILITY - EFFICIENCY at WP

Total area 51x51 cm^2 (smaller version of the iRPC Upgrade gaps), an active area of 45.5x45.5 cm^2 electrodes made out of bakelite of 1.43 mm thickness and resistivity 1.17 - 1.39 $\times 10^{10}$ Ω*cm. Gap thickness of 1.4 mm and 32 strips of 1.2 cm width. KODEL Front-end electronic with a threshold of 60 fC.

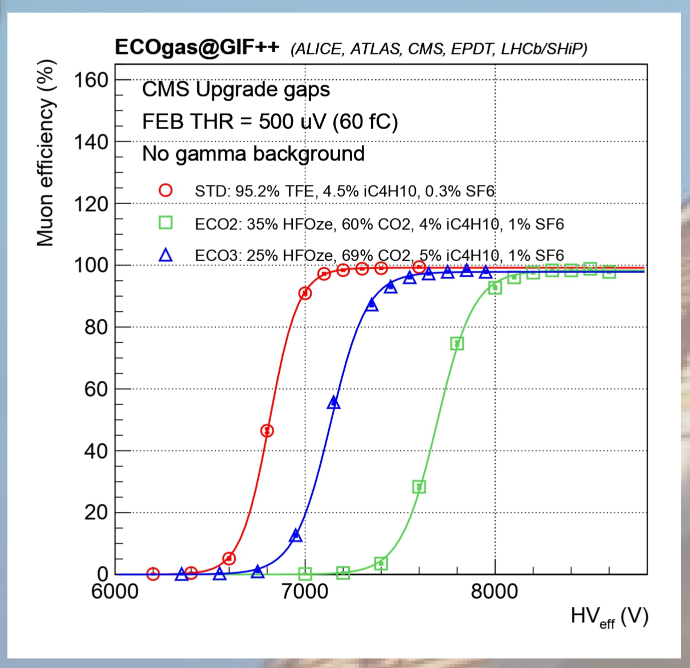

Figure 1 – Muon efficiency as a function of HV_{eff}(V) in absence of gamma radiation background. $WP_{STDmix} = 7.16$ kV, $\epsilon_{WP} = 98.1$ %, $WP_{ECO2} = 8.10$ kV, $\epsilon_{WP} = 96.8$ %, $WP_{ECO3} = 7.54$ kV, $\epsilon_{WP} = 96.3$ %.

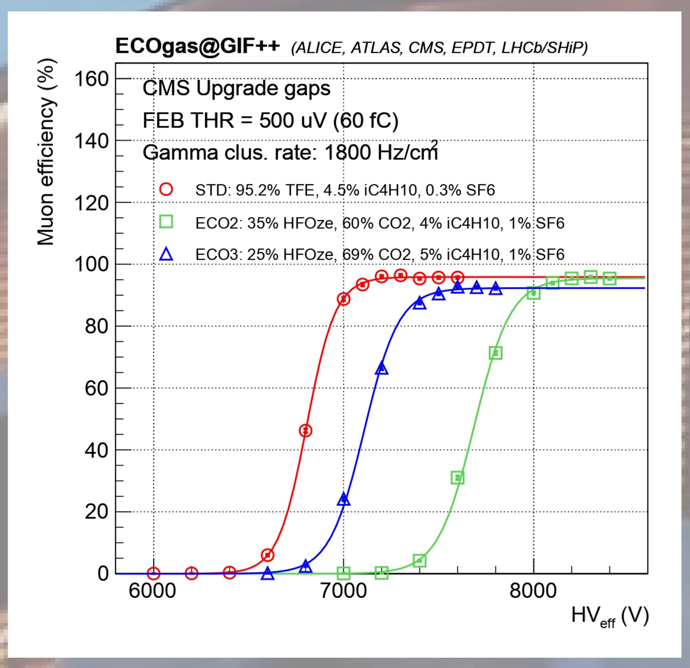

Figure 2 – Muon efficiency as a function of HV_{eff}(V). Gamma cluster rate of $1800 Hz/cm^2$. $WP_{STDmix} = 7.18$ kV, $\epsilon_{WP} = 95.1$ %, $WP_{ECO2} = 8.12$ kV, $\epsilon_{WP} = 94.1$ %, $WP_{ECO3} = 7.53$ kV, $\epsilon_{WP} = 91.4$ %.

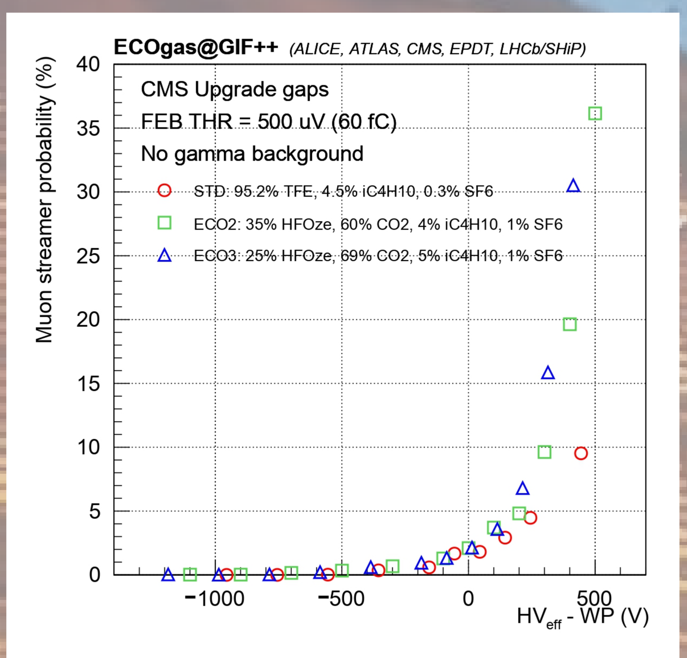

Figure 3 – Muon streamer probability at the WP (STPWP) as a function of HV_{eff} - WP (V) without gamma background. $STPWP_{STDmix} = 1.9$ %, $STPWP_{ECO2} = 3.2$ %, $STPWP_{ECO3} = 2.1$ %. Streamers are assumed as the muon cluster size greater than 4 strips.

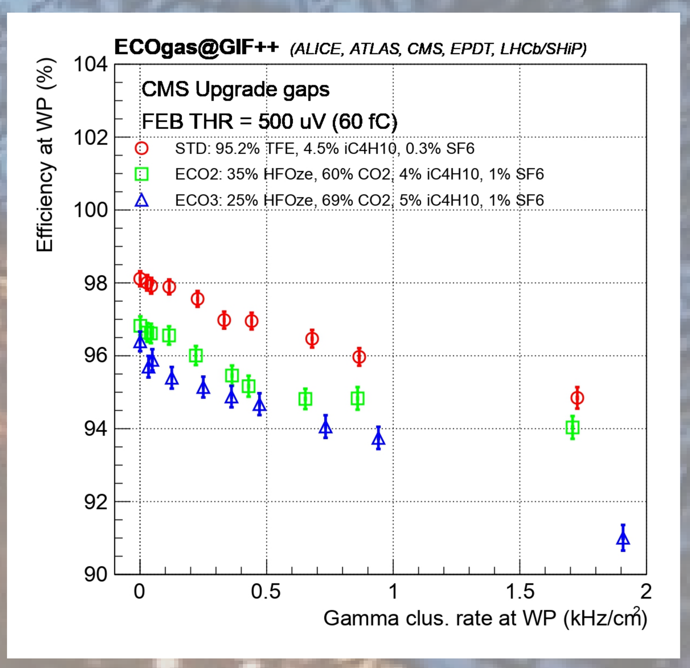

Figure 4 – Muon efficiency at WP as a function of the gamma cluster rate. Similar trend for all mixtures at higher gamma cluster rates. Lower efficiencies with eco-mixtures probably due to lower production of primaries.

MUON CLUSTE SIZE - WP - MEAN GAMMA CLUSTER CHARGE

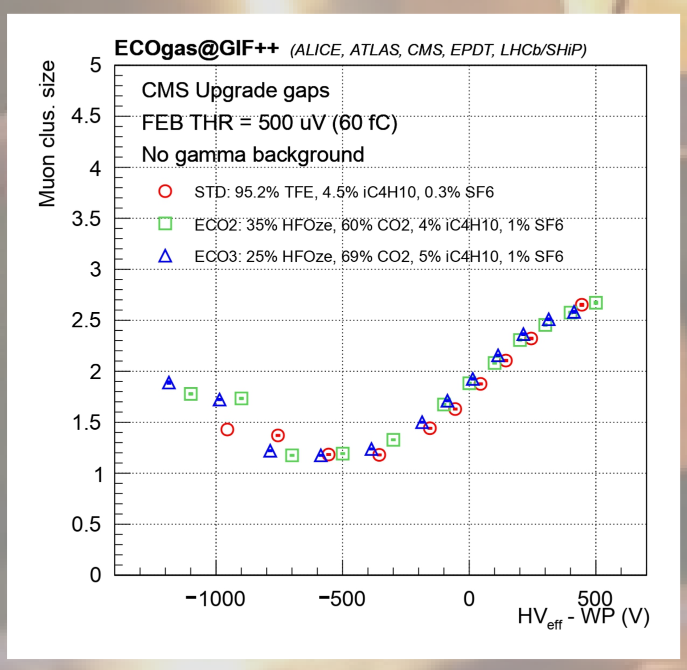

Figure 5 – Muon cluster size as a function of HV_{eff} - WP (V) without gamma background.

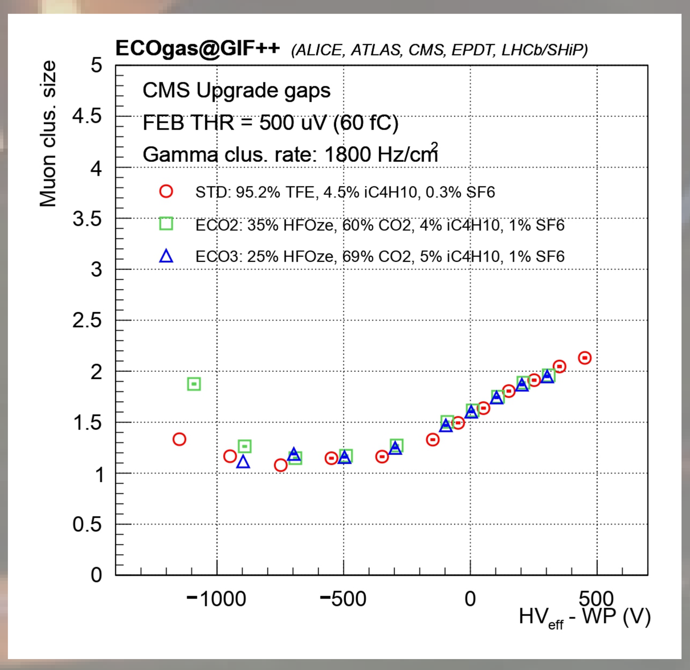

Figure 6 – Muon cluster size as a function of HV_{eff} - WP (V). Gamma cluster rate $1800 Hz/cm^2$.

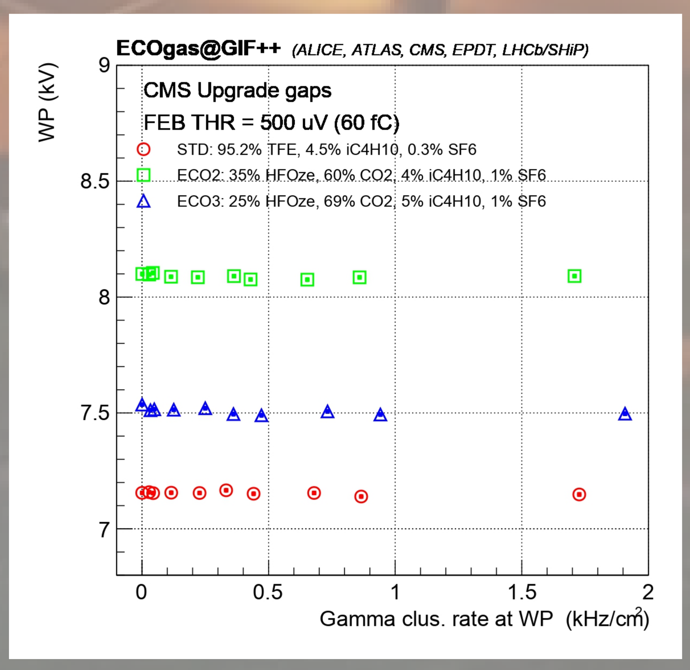

Figure 7 – Working Point (WP) as a function of the gamma cluster rate. Shift in the WP between the mixtures, highest for ECO2 candidate followed by ECO3. Constant behaviour due to low electrode resistivity, in combination with the small gap area.

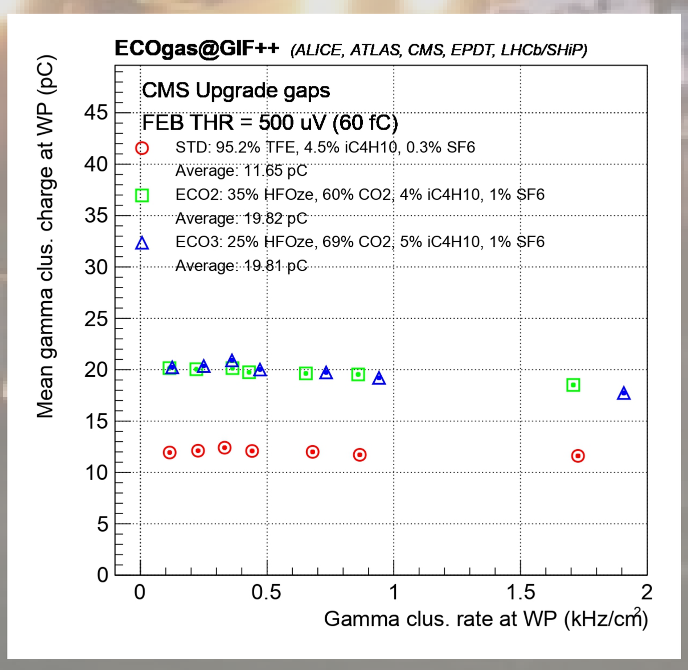

Figure 8 – Mean gamma cluster charge at WP as a function of the gamma cluster rate. The values are estimated using the average current of both gaps and the gamma cluster rates. The average charge with ecological candidates is about 70% higher than with STD mixture.

CONCLUSION

New iRPC chamber using CMS Upgrade gaps (1.4 mm gap thickness and 1.43 mm electrode thickness) was built for studies of aging with ecological mixtures. The RPC (within ECOgas@GIF++ collaboration) started the irradiation campaign by mid September 2023 with eco-mixtures for further aging studies. This will clarify the suitability of these kind of mixtures for future operation.

ACKNOWLEDGMENTS

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