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New Eco-gas mixtures for the Extreme Energy Events MRPCs: results and plans

The EEE collaboration

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ABSTRACT: The Extreme Energy Events observatory is an extended muon telescope array, covering more than 10 degrees both in latitude and longitude. Its 59 muon telescopes are equipped with tracking detectors based on Multigap Resistive Plate Chamber technology with time resolution of the order of a few hundred picoseconds. The recent restrictions on greenhouse gases demand studies for new gas mixtures in compliance with the relative requirements. Tetrafluoropropene is one of the candidates for tetrafluoroethane substitution, since it is characterized by a Global Warming Potential around 300 times lower than the gas mixtures used up to now. Several mixtures have been tested, measuring efficiency curves, charge distributions, streamer fractions and time resolutions. Results are presented for the whole set of mixtures and operating conditions, focusing on identifying a mixture with good performance at the low rates typical of an EEE telescope.

Keywords: Particle tracking detectors - Gaseous detectors - Resistive-plate chambers - Timing detectors

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1 Introduction

The Extreme Energy Events (EEE) [1] experiment is a strategic project led by the italian Museo Storico della Fisica e Centro Studi e Ricerche "Enrico Fermi" (Centro Fermi [2]), carried on in collaboration with INFN, CERN and MIUR, aiming at the detection and analysis of highly energetic cosmic rays. The experiment consists of a network of 59 muon telescopes, based on the Multigap Resistive Plate Chamber (MRPC in the following) technology, and already produced relevant observations in the field [3–8]. Due to its wide coverage over the Italian territory (more than 10 degrees both in latitude and in longitude, covering an area larger than 3×10^5 km²), the EEE network is the largest MRPC-based system for cosmic rays detection. Details on the detector performances can be found in [9–11]. The current MRPCs are six gas gaps detectors, 300 μ m each. The chambers are filled with a mixture made of 98% tetrafluoroethane and 2% sulfur hexafluoride and are operated in avalanche mode at a continuous flow of 2 l/h and atmospheric pressure. A new bunch of 27 MRPCs have been produced in 2017 for the observatory upgrade: they are again 6 gaps MRPCs with a thinner gap size of 250 μ m [9].

Recent EU regulations set an upper limit for the "Global Warming Potential (GWP)" allowed in gas-operated devices [12]. The mixture presently adopted in the EEE telescopes has a GWP around 1990, demanding for the search of an alternative. In order to provide a gas mixture satisfying the EU restrictions, several gas mixtures have been explored, that will be presented in the following sections. These tests represent the first study in this direction performed on MRPCs operated at low rate, as the one typical of cosmic muons detection with these devices (100 Hz/m²).

2 Tests performed

The tests have been performed by detecting and tracking cosmic muons with one of the telescopes of the EEE network installed at CERN (CERN-01). The setup used is shown in Fig. 1: the three chambers of CERN-01 - represented in yellow - are operated with the nominal mixture and provide the trigger for the event acquisition. Good events are represented by muons crossing its three

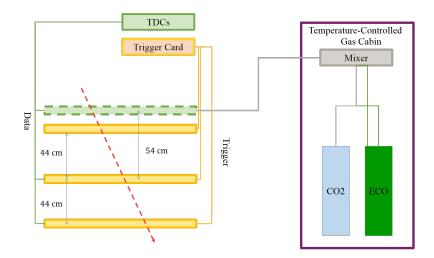


Figure 1. Experimental setup.

chambers. Events readout is then performed on the two bottom-most chambers of CERN-01 and on the chamber under test, positioned on the top of the telescope and represented in green. The latter is operated with the mixture under test, provided by an external mixer. Different combinations have been explored, as reported in Tab. 1.

2.1 Pure R1234ze

The dominant component of the EEE nominal mixture is the tetrafluoroethane $(C_2H_2F_4)$, with a GWP=1430. In recent years, the tetrafluoropropene $(C_3H_2F_4)$, coming in two allotropic forms, generally labeled as R1234yf, and R1234ze, of which R1234ze has been used, since the other is slightly flammable), has emerged as a good substitute for the former, thanks to its sensibly lower GWP=6. The first mixture analyzed was composed of 100% R1234ze. In Fig. 2, the efficiency and the streamer fraction obtained with the R1234ze are shown, in comparison with the nominal ones. The streamer fraction has been evaluated as the ratio between the number of hits with a high cluster size (≥ 5) and the total number of hits. The new gas shows excellent quenching properties

Tested Mixtures		
Pure R1234ze		
R1234ze (90%) + CO ₂ (10%)		
R1234ze (80%) + CO ₂ (20%)		
R1234ze (50%) + CO ₂ (50%)		
R1234ze (95%) + SF ₆ (5%)		
R1234ze (98%) + SF ₆ (2%)		
R1234ze (99%) + SF ₆ (1%)		
CO ₂ (100%)		
CO ₂ (98%) + SF ₆ (2%)		

Table 1. Tested gas mixtures.

(streamer component stays below 5% in the whole range) and exhibits a stable efficiency plateau; however, the latter is reached at a $HV_{eff}^{-1} \approx 21 \text{kV}$, at the limit of the operability regime for the EEE MRPCs.

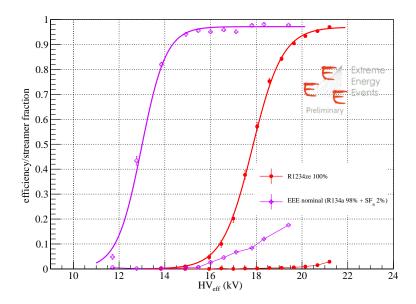


Figure 2. Efficiencies and streamer fraction for the nominal EEE gas mixture and one made of R1234ze.

2.2 Mixtures of CO₂ and R1234ze

A natural choice to lower the operating high-voltage of tetrafluoropropane gas mixtures is to add CO_2 . Being the GWP of CO_2 the reference value to define the global warming potential of other gases, *i.e.* $GWP_{CO_2}=1$, no limitations in the addition of this gas derive from ecological regulations. As a consequence, different CO_2 percentages have been tested, ranging from a minimum of 10% to a maximum of 50%, in combination with R1234ze. Fig. 3 shows the results obtained with the different combinations. While the high voltage needed to reach the plateau is sensibly lowered with respect to the pure R1234ze case and a stable working region can be identified, the presence of CO_2 produces a noisy configuration, with the streamer component getting too high when entering the efficiency plateau. However, a possibile working point at 17 - 18 kV for the $R1234ze(50\%) + CO_2(50\%)$ mixture can be identified, despite the relatively high streamer percentage.

2.3 Mixtures of R1234ze and SF₆

In order to minimize the streamer component, the addition of a gas with good quenching properties is needed. Toward this direction, alternative mixtures have been tested, composed of R1234ze and SF₆. However, due to the high global warming potential of the SF_6 (GWP_{SF_6} =23900), its amount has to be kept very limited. Fig. 4 shows the results obtained exploring different compositions. On

 $^{^{1}}HV_{eff} = HV \times \frac{p_0}{p} \frac{T}{T_0}$, with p_0 =1000 mbar and T_0 =298.15 K representing standard temperature and pressure, and p_0 and p_0 and p_0 being the ones in the detector room.

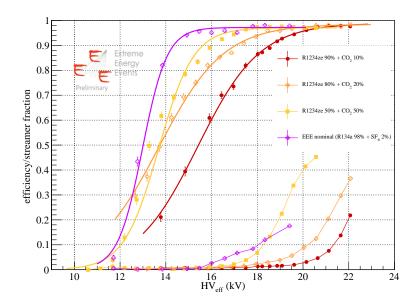


Figure 3. Efficiencies and streamer percentage for the different mixtures of CO₂ and R1234ze tested.

the one hand, the presence of SF_6 confirms its quenching capability, with a streamer component at the level of a few percent; however, it is demanding in terms of operating voltage, since the efficiency plateau is reached only for very high HV_{eff} values, at the limit of the allowed operating conditions for the EEE MRPCs. The data trend allows, however, to identify a possible strategy: since the SF_6 is very effective as a quencher already at very low percentage, and since the diminishing of the amount of SF_6 shifts toward lower operating voltages the efficiency plateau, a further combination can be explored, *i.e.* a mixture R1234ze (99.5%) + SF_6 (0.5%), that would fulfill EU regulations and with a working region where the HV_{eff} is not too high. This will be done in the near future.

2.4 Mixtures of CO_2 and SF_6

Combining the information collected with the previous studies, a further combination has been tested, with mixtures based on CO_2 and SF_6 . In principle, the excellent quenching properties of SF_6 and the low operating voltage allowed by CO_2 could provide an optimal configuration, with both HV_{eff} and streamer percentage kept very low. The results are shown in Fig. 5: while the plateau is reached at a very low voltages, the streamer component is diverging. Furthermore, the efficiency turns out to be too low, so this combination has to be discarded.

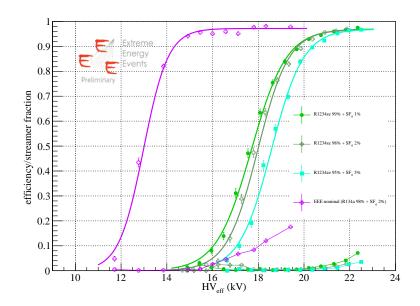


Figure 4. Efficiency and streamer fraction for the R1234ze and SF₆ mixtures tested.

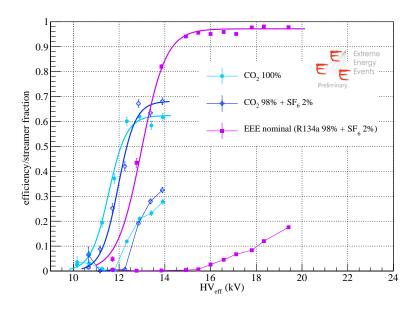


Figure 5. Efficiency and streamer probability for the CO₂ and SF₆ mixtures tested.

3 Conclusions

Fig. 6 summarizes the efficiencies and streamer components of the most promising mixtures, *i.e.* $R1234ze(50\%) + CO_2(50\%)$ and $R1234ze(99\%) + SF_6(1\%)$. In the near future, some of the EEE stations will be equipped with these mixtures, and telescope performances and stability will be investigated on a long-term perspective. In addition to it, further tests have been planned, that will

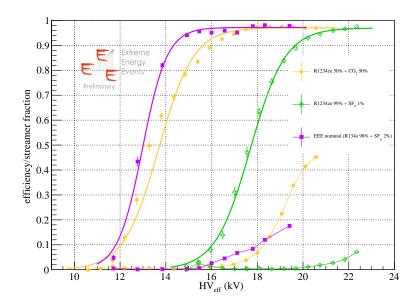


Figure 6. Most promising mixtures tested: efficiencies and streamer percentage.

explore alternative gases and mixtures such as CF3I, $R1234ze(99, 5\%) + SF_6(0, 5\%)$, R1234ze + He.

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