Efficiency comparison of MRPC muon detectors with novel gas mixtures

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Abstract

The goal of our study was to perform a comparative analysis of new gas mixtures to be used in the Multi Resistive Plate Chambers (MRPC) type muon detectors of the Extreme Energy Events (EEE) project [1]. Effort was made to eliminate the use of the standard mixture (tetrafluoroethane-sulfur exafluoride) currently in use, in order to reduce its emission into the atmosphere because of its effects as strong greenhouse gas with a Global Warming Power (GWP) about *1900* times higher than carbon dioxide [2]. In general, we found that using a 40% tetrafluoropropane-60% carbon-dioxide combination would produce efficiency curves most similar to the those of the standard mixture.

1 Introduction

Extreme Energy Events is a project undertaken in collaboration with INFN and Centro Fermi. It involves a network of *59* independent cosmic ray telescopes spread across high schools in Italy. Each EEE detector is comprised of three MRPC layers with a relative distance around *50cm* in order to extrapolate each passing particle's trajectory [3]. Our analysis focused on data recorded by the BOLO-01 and CERN-01 detectors, comparing their efficiency in detecting secondary cosmic rays while using the following gas mixtures: Standard (98% tetrafluoroethane-2% sulfur exafluoride), 40% tetrafluoropropane-60% carbon-dioxide, 100% tetrafluoropropane. These new gases were chosen as most suitable as they are in conformity with our safety, cost, spatial and temporal resolution standards. The efficiencies were studied as a function of HV (voltage level of the detector). The new mixtures must perform with a similar electric tension to the standard one. If not, expensive hardware modifications would be required [4].

2 Measuring efficiency

Efficiency is defined as follows:

$$\eta = \frac{n_{det}}{n}$$

where n is the total number of detectable particles expected to pass through the telescope's volume and n_{det} is the number of particles that has been successfully detected. In order to accurately measure efficiency and minimize the effect of noise and scattering on computations, several cuts had to be performed on the raw dataset. The criteria adopted to decide whether to accept or discard an event as random noise were Time of Flight (TOF) acceptance and geometrical acceptance: if the TOF of an event is between *2ns* and *8ns*, it is regarded as real, if not, it will be discarded. In addition, geometrical acceptance only takes into consideration the particles whose trajectory intersects all of the three chambers, the events that adhere to both these filtering criteria will be considered as the total number of detectable particles. Out of these, the number of detected particles is calculated through further filtering: the detected coordinates on the bottom layer must fall in a 5cm range from the expected ones.

3 Data standardization

A key element of our study was the standardization of the high voltage as it allowed to compare data from different sources and conditions, eliminating the influence of pressure and temperature on the efficiency values. Using the following formula, high voltage has been regularized with a reference pressure P_{ref} of *1010 mbar* and a reference temperature T_{ref} of *293.15 K*:

$$HV_{ref} = HV \frac{P_{ref}}{P} \frac{T}{T_{ref}}$$

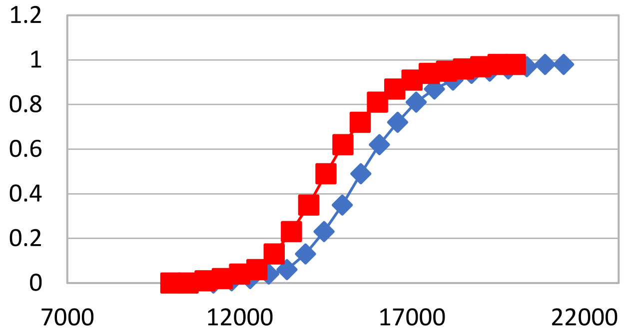

Fig. 1

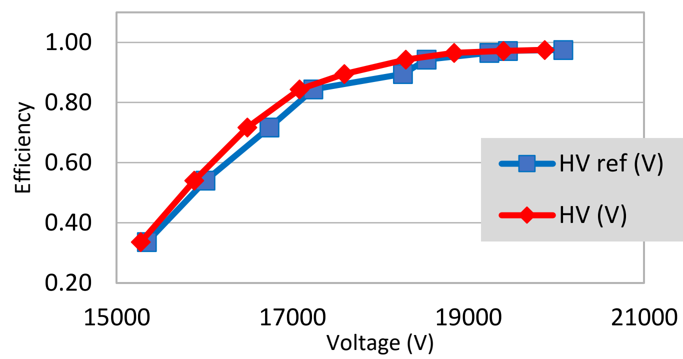

Fig. 2

Standardized and non-standardized efficiency values for the CERN-01 (*Figure 1*) and BOLO-01 (*Figure 2*) datasets using the standard gas mixture is shown as a function of voltage values.

4 Efficiency comparison

A standardization procedure was performed on all datasets for both telescopes. *Figures 3,4* show the efficiency values as a function of voltage levels in MRPC plates of CERN-01 and BOLO-01 respectively. A qualitative similarity can be observed between efficiency curves of both detectors.

It was observed that the most promising between the two novel mixtures based on tetrafluoropropane (ecofreon), is 40% tetrafluoropropane-60% carbon-dioxide, as it can provide maximum accuracy to the detector under similar operating voltages as the standard mixture. While pushing voltage further on the scale would seemingly be convenient in order to improve efficiency of the detector, it should be taken into consideration that higher voltages result in more prominent instrumentation noise and false readings, it was therefore chosen to keep voltage levels of EEE telescopes in the rapidly climbing region of the curves (*16000-20000 V*) [5].

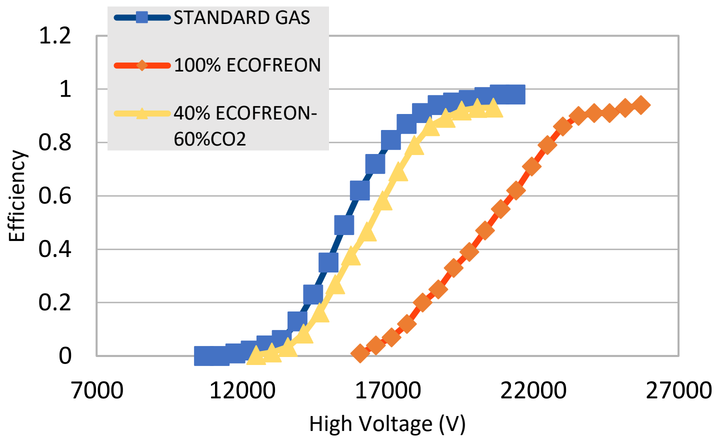

Fig. 3

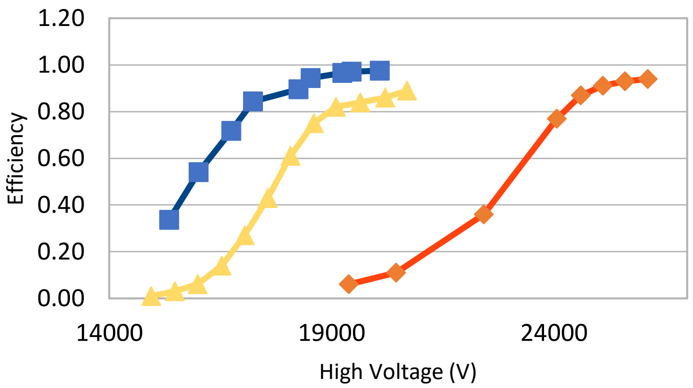

Fig. 4

5 Further studies

The given dataset also made it possible to perform further studies. A computer code was developed to fit the angle from normal of the events considered as successfully detected in a gaussian probability density function. *Figure 5* shows the results of the last study, it is possible to notice how the mean value ($\sigma = 22.77^o$) is not centered between the maximum angle ($\theta = 54.45^o$) and the minimum ($\theta = 0^o$). This result was thought to be the result of the atmosphere's influence on the muon flux to the Earth's surface, additional confirmation is given by the histogram in *Figure 6*, it shows the evident influence of the incidence angle on the number of events associated with it. As expected, an anticorrelation was observed between the angle from normal and the events, such phenomena was intuitively explained by thinking of the vertical path as the shortest one, that gives particles in a wider range of energies the ability to survive until detection by the MRPC plates.

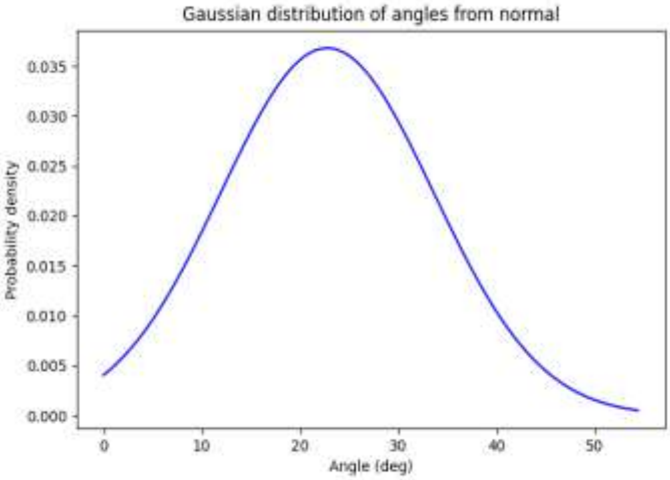

Fig. 5

Fig. 6

6 Conclusions

Our study concluded that an ionizable gas mixture composed by a 40% of tetrafluoropropane and a 60% of carbon-dioxide produces acceptable efficiency values at the voltage ranges already provided by the hardware implemented in each EEE detector [6]. The more desirable efficiency curve experimentally obtained at BOLO-01 and CERN-01 by mixing tetrafluoropropane with carbon-dioxide is due to carbon-dioxide's negative effect on scattering phenomena.

We are looking forward to further improve and test the angle extrapolation methods and cuts used to compute the results in *Figure 5*, additional investigation regarding these will be possible as soon as EEE detectors are brought back online after a long shutdown to student's activities caused by the COVID-19 pandemic. [7]

References

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