IL NUOVO CIMENTO **47 C** (2024) 262
DOI 10.1393/ncc/i2024-24262-1

COMMUNICATIONS: SIF Congress 2023

Eco gas mixtures for the MRPCs cosmic ray telescopes of the EEE Project

C. RIPOLI(1)(2)

(1) *INFN, Gruppo Collegato di Salerno, Sezione di Napoli - Napoli, Italy*
(2) *Dipartimento di Fisica "E. R. Caianiello", Università degli Studi di Salerno - Salerno, Italy*

received 31 January 2024

Summary. — The Extreme Energy Event (EEE) Project is a cosmic ray physics experiment with outreach and educational purposes. The experiment is designed to study high energy cosmic rays through the detection of the Extensive Air Shower's (EAS) muon component. The array of muon telescopes is based on Multigap Resistive Plate Chambers (MRPC) syncronized via GPS in order to correlate the information collected by different telescopes. The Project involves 70 schools from all over Italy with an intensive outreach program: students can actively contribute and participate in the EEE research activities. The EEE Collaboration is leading an ecological transition to replace the existing gas mixture with an eco-friendly one. Having shown encouraging results, the new eco-gas mixture —based on $C_3H_2F_4$ and Helium— has already been deployed in some of the telescopes allowing the restart of data taking.

1. – Introduction

The Extreme Energy Event (EEE) Project is a cosmic ray physics experiment supported by Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi (CREF) and the Italian National Institute for Nuclear Physics (INFN). The EEE Project has two main goals that come together: research and education. The scientific aim is to study cosmic rays by detecting and tracking secondary muons using Multi Gap Resistive Plate Chamber (MRPC) detectors; the educational one is to involve young students of secondary school in high energy physics ("*Science inside schools*") [1] with an intensive outreach program. Teachers and students, supported by researchers, are engaged in the detectors construction and maintenance, data taking and data analysis.

The project started in 2004 at CERN and then the pilot phase was initiated in 2005 with a few stations taking data. It has been continuously extended and the amount of Italian high schools involved in the experiment has been growing constantly over time. Coordinated data taking periods have been performed since 2014 during each school year, providing a huge number of candidate muon tracks. In 2017, the EEE Collaboration decided to start an important upgrade program, aiming to extend the network and to improve the system [2]. Since few years the EEE Collaboration is fully involved in an ecological transition to reduce the Green House Gases (GHG) emissions and it started to investigate environmentally sustainable alternatives to replace the standard mixture used to flux the chambers [3]. Nowadays several stations are fluxed with the eco-friendly gas mixture based on trafluoropropene $C_3H_2F_4$ and Helium (He) with satisfactory performance according to the physics aims of the experiment [4].

2. – Research: the EEE physics items of interest and the experimental setup

The EEE detectors array is the largest MRPC-based distributed system spanning a larger than $10^5\,\mathrm{km}^2$ area, with characteristics similar to the ones built for the TOF array of the ALICE experiment at LHC. It consists of 61 muon telescopes, each equipped with a GPS module in order to synchronize the EEE stations. The telescopes are organized in local clusters and single telescope stations distributed all over the Italian territory and installed mainly in high schools buildings but also at universities and research centres (fig. 1).

The EEE array allows to measure time-correlated events between telescopes placed in the same city [5] or located hundreds of kilometers apart to detect individual EAS or coincidence between two different correlated EAS [6, 7], respectively.

The detector performance and the statistics collected by the EEE telescopes allow a large variety of studies, ranging from the measurements of the local muon rate and the observation of variations in time of the rate of cosmic muons correlated with astrophysical events (usually called "Forbush" decreases) [8] to the search for anisotropies in the sub-TeV energy region [9].

Each EEE telescope is made up of 3 MRPCs specifically designed to combine good tracking and timing capabilities (fig. 2). Each chamber with an area of $(0.82 \times 1.58)\mathrm{m}^2$ consists of six $300\,\mu$m gas gaps ($250\,\mu$m in the new chambers built in the EEE upgrade phase since 2017) obtained by stacking glass sheets; 24 cathode and anode readout copper strips are mounted on both sides of the stack of glass plates laid out to collect the signals induced by particles, providing two-dimensional information.

Fig. 1. – EEE Project map. In red and light blue schools with and without the telescope, respectively. In orange research centres equipped with telescopes [10].

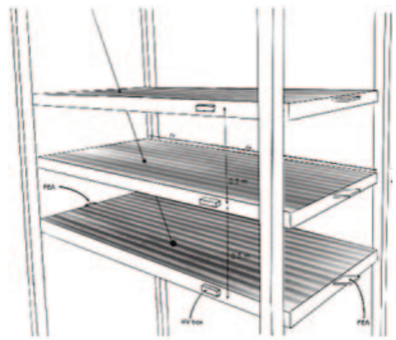

Fig. 2. – Sketch of a EEE telescope [6].

When a cosmic muon crosses the chamber the y coordinate (short side) is determined by the strip on which the signal is induced, while the x coordinate (long side) is determined by measuring the difference between the arrival time of the signal at the two ends of the strip (fig. 3).

The 24 readout copper strip electrodes ($180\,\text{cm} \times 2.5\,\text{cm}$ spaced by 7 mm) are mounted on both sides of the stack of glass plates, so that the signal (the sum of all gas avalanches in all the gaps) is a differential signal of the cathode and anode strips. Two front-end (FEA) boards placed at the two edges of the chamber read the signal given by each strip. The signals are digitized at both edges of the strip by a fast discriminator, with an output signal duration which depends on the total input charge. A schematic top view of a chamber is shown in fig. 4, the FEAs for the read-out of the strip signals are placed on the short sides, the gas inlets and outlets and the high voltage connectors are located at the ends of the longer side. High voltage to the chambers is provided by a set of DC/DC converters, with the output voltage roughly 2000 times larger than the driving low voltage. The total HV applied on the chambers is typically in the range 18–20 kV for the chambers (avalanche mode). Deeper details on the detector can be found in [10, 11].

The data collected by each station are sent to the computing facility of the INFN, the CNAF center, where they are stored, reconstructed and made available for analysis [12].

3. – Education: EEE outreach activities

The EEE Project was born with the educational mission to involve students in a scientific high energy physics experiment. The students can actively take part in all the

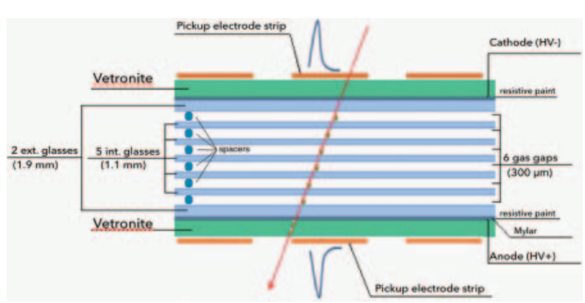

Fig. 3. – Front view of a EEE chamber [10].

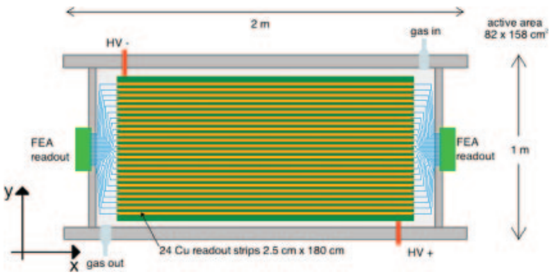

Fig. 4. – Top view of one of the EEE chambers [10].

stages of the experiment, from the construction of the chambers at CERN and the installation in high-schools, to continuous detectors monitoring and data taking with the telescopes. During the year students attend masterclasses, physics lectures and joint discussions on data analysis and their interpretation, taking part to plenty of local, national and international activities. It is worth mentioning the two main annual appointments: the International Cosmic Day (ICD) and the International Muon Week (IMW).

In order for students to be more engaged each year the EEE Collaboration proposes the "*Cosmic box contest*". The Cosmic Box (CB) is an user-friendly portable scintillator-based muon telescope that can be operated with a single or double coincidence trigger and it is provided with a display to monitor the acquisition rate. Students are asked to submit research projects proposals, where they can suggest new investigations and measurements using this detector. Each project is evaluated by a team of EEE researchers and the best ones are awarded with a CB, that can be used for a given amount of time to carry on the proposed measurement. The awarded school teams have the possibility to present their analysis during the monthly meeting, scheduled by the EEE Collaboration (Run meeting). One of the most successful projects was focused on the study of muon flux variation with altitude. Schools from all over Italy carried out measurements across different altitudes ranging from $-20\,\mathrm{m}$ under ground level to more than $2000\,\mathrm{m}$ above sea level. After performing the measurements, they prepared a detailed report to discuss the collected data and expected statistics. They also investigated the influence of the atmospheric conditions on the cosmic ray flux, monitoring atmospheric temperature and pressure of the places where they performed the measurements [13].

Another interesting project merging a scientific aim with the outreach mission is *PolarquEEEst* experiment, started in 2018. The project is devoted to perform measurements of cosmic rays flux at extreme latitudes using the so-called POLAR detectors, based on scintillators coupled to SiPMs. The permanent installation at Ny-Ålesund of three detectors allows to study different kinds of correlations between the muon rate at ground and atmospheric/astrophysical effects [14]. As per EEE Project tradition POLA detectors were assembled at CERN by Italian, Norvegian and Swiss high school students. Data from the PolarquEEEst mission available for students analyses are used also in EEE masterclasses.

In recent years schools have also been involved in the ecological transition of the project with the aim to promote a deeper understanding of this phase and to raise awareness among young students about this crucial topic. Since telescopes are installed mainly in schools building, students have the opportunity to study the efficiency of chambers fluxed with the new eco-friendly mixture and installed in their school.

A bi-annual in presence meeting is planned; in the last two years a first meeting in presence focused on the Ecological Transition of the EEE Project, took place in Erice (Sicily) at Ettore Majorana Foundation and Centre for Scientific Culture in November 2021: *"1st Meeting of the EEE Project after COVID shutdown"*. The students had the opportunity to attend seminars and the Masterclass: *"Ecogas per le stazioni EEE - Analisi dati su miscele ecologiche"*, analyzing long-term data acquired by telescopes fluxed with the new ecogas mixture [15].

The last in presence meeting took place at INFN National Laboratory of Legnaro (PD) in November 2023, where in addition to several seminars on applied physics, participants performed the efficiency measurements on one chamber of the LNLE-01 muon telescope installed there. The measure is particularly interesting in this delicate transitional phase, it will be published including the students and the teachers that took part in it in the authors list.

4. – The ecological transition

Since 2015 the EEE Collaboration has undertaken strategies to reduce the EEE telescopes gas injection in the atmosphere. The gas flow has been reduced and the monitoring of the rate before and after the flow reduction shown a great stability [16].

The *standard* gas mixture fluxed (at a continuous flow of 2 l/h and atmospheric pressure) in EEE MRPCs was made of 98% of tetrafluoroethane ($C_2H_2F_4$) and 2% of sulfur hexafluoride (SF_6), both classified as GHG.

A gas is characterized by a specific index: Global Warming Potential (GWP) to quantify its impact as GHG, the value is normalized to CO_2 which has a value equal to 1. The GWP of the EEE standard mixture comes from the combination of the values of its components: 1430 and 23600 for $C_2H_2F_4$ and SF_6, respectively. The resulting value, 1880, is still allowed for research activities but out of the range suggested by the EU regulations [17] that ban gases with an index greater than 150. Neverthless, the EEE Collaboration decided to pursue a path to reduce the muon telescopes GHG emissions identifying a new ecological mixture to replace the previous one.

Besides having a lower GWP the new eco-friendly gas mixture has to be compatible with current hardware; each telescope is equipped with only two flowmeters so just a binary mixture is eligible, the MRPCs can operate with a bias voltage up to 20 kV so the mixture has to be characterized by a working point up to this value. Furthermore it has to satisfy the safety requirements neither flammable or toxic and compared to the previous one, it needs to have similar performance and a lower GWP.

The main gas choice to substitute the *standard* mixture is the tetrafluoropropene $C_3H_2F_4$ characterized by a significantly lower GWP, just 6. A large number of mixtures based on $C_3H_2F_4$ with the addition of different percentages of He have been tested in order to find the best mixture to use in the EEE MRPCs at the same operating voltage as the standard mixture, without affecting the detectors performance or requiring any hardware change. The identification of the new eco-friendly mixture has been driven by the results of an extensive set of tests: efficiency curves as a function of the applied voltage have been measured to find the best working point. The data acquired compared with the data collected with the standard mixture show a good rate stability and no degradation in terms of cosmic track reconstruction. The eco-friendly gas mixture made of 50% of $C_3H_2F_4$ and 50% of He is currently used reducing the emission of greenhouse gases in the atmosphere and providing similar detectors performance. The satisfactory results carried out in laboratories (CERN, INFN and univeristies) and confirmed also in less controlled environments (school buildings) demonstrate that EEE telescopes can operate with this new eco-friendly mixture and the long-term data taking is ongoing. On the basis of these results, all the EEE detectors will be progressively operated with the new eco-gas mixture.

5. – Conclusions

The EEE experiment is a unique project that over the years is carrying on its scientific and educational purposes. The physics goal of the experiment is to detect and to study secondary muons on the Earth surface generated by primary cosmic rays interaction in atmosphere. High school students are involved in the Project through plenty of local, national and international physics outreach activities. They have the opportunity to experience all the steps of the EEE physics research. The EEE Collaboration is actively involved in a transition phase to replace the gas mixture in the MRPCs with an ecological one. The new eco-mixture ($C_3H_2F_4$ + He) shows a lower GWP with respect to the previous one and provides similar detector performance complying with the project requirements. Currently several muon telescopes of the array take data with the eco-friendly gas mixture made of $C_3H_2F_4$ + He. More and more telescopes are gradually restarting the data taking with the eco-friendly mixture leading to the first extended detectors array working with this ecological gas mixture. Indeed a complete restart of the whole EEE array fluxed with the new gas mixture is foreseen. From the educational point of view the EEE Collaboration aims to enhance the offer of outreach events in order to involve ever more young students in the EEE Project and to raise awareness among them about this transitional phase.

* * *

I warmly acknowledge all the members of the EEE Collaboration for the scientific discussion and contribution. I would also like to thank CREF and INFN for their support.

REFERENCES

[1] Zichichi A., *Progetto "La Scienza nelle Scuole" - EEE (Extreme Energy Events)* (Società Italiana di Fisica, Bologna) 2004.
[2] EEE Collaboration (Abbrescia M. *et al.*), *JINST*, **14** (2019) C08005.
[3] EEE Collaboration (Ripoli C. *et al.*), *PoS*, **EPS-HEP2021** (2022) 739.
[4] EEE Collaboration (Abbrescia M. *et al.*), *Nucl. Instrum. Methods A*, **1055** (2023) 168431.
[5] EEE Collaboration (Abbrescia M. *et al.*), *2009 IEEE Nuclear Science Symposium Conference Record (NSS/MIC)* (IEEE) 2009, p. 439.
[6] EEE Collaboration (La Rocca P. *et al.*), *PoS*, **ICRC2021** (2021) 292.
[7] EEE Collaboration (Abbrescia M. *et al.*), *J*, **4** (2021) 838.
[8] EEE Collaboration (Abbrescia M. *et al.*), *Eur. Phys. J. Plus*, **126** (2011) 1.
[9] EEE Collaboration (Abbrescia M. *et al.*), *Eur. Phys. J. Plus*, **130** (2015) 187.
[10] EEE Collaboration (Abbrescia M. *et al.*), *JINST*, **13** (2018) P08026.
[11] EEE Collaboration (Abbrescia M. *et al.*), *JINST*, **14** (2019) C08005.
[12] EEE Collaboration (Noferini F. *et al.*), *Nucl. Instrum. Methods A*, **824** (2016) 329.
[13] EEE Collaboration (Ripoli C. *et al.*), *PoS*, **TAUP2023** (2023) 322.
[14] EEE Collaboration (Noferini F. *et al.*), *PoS*, **ICRC2023** (2023) 232.
[15] EEE Collaboration (Garbini M. *et al.*), *PoS*, **ICHEP2022** (2022) 380.
[16] EEE Collaboration (Ripoli C. *et al.*), *J. Phys.: Conf. Ser.*, **2374** (2022) 012152.
[17] Council of European Union, Council regulation (EU) No. 517/2014 (2014).