The EEE Project: cosmic rays, multigap resistive plate chambers and high school students

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**ABSTRACT:** The Extreme Energy Events Project has been designed to join the scientific interest of a cosmic rays physics experiment with the enormous didactic potentiality deriving from letting it be carried out by high school students and teachers. After the initial phase, the experiment is starting to take data continuously, and the first interesting physics results have been obtained, demonstrating the validity of the idea of running a real physics investigation in these peculiar conditions. Here an overview of its structure and status is presented, together with some studies about detector performance and first physics results.

**KEYWORDS:** Resistive-plate chambers; Large detector systems for particle and astroparticle physics; Particle tracking detectors (Gaseous detectors)
1 Introduction

The Extreme Energy Events Project \cite{1, 2} was conceived in 2003 by its scientific leader, professor Antonino Zichichi, and is presently carried out by Centro Fermi, in collaboration with INFN, CERN and MIUR (the Italian Ministry of Education, University and Research).

Its main scientific goal is studying the most interesting, and still partially unexplored, region of the cosmic rays spectrum, i.e. the one whose primaries are characterized by an energy $> 10^{18}$ eV. Here, issues related to the exact composition and origin, probably extragalactic, of this radiation, together with the precise shape of the spectrum (affected by presence of the Greisen, Zatsepin and Kuz’min cutoff) still hold unsolved.

A standard technique to study this radiation consists in detecting the particles arriving at ground level — essentially muons — of the Extensive Air Showers (EAS) originated by the interaction of the primaries when they enter the atmosphere. Since we are interested here to highly energetic primaries, the corresponding showers may impinge on the ground with millions of particles scattered on a several km radius area.

Therefore an elevate number of stations, distributed on a large surface, is needed. These stations, possibly, have to conjugate excellent performance in terms of efficiency, time and spatial resolution, with easiness of operation and low cost. The EEE collaboration chose to use a wider and cheaper version of the Multigap Resistive Plate Chambers (MRPCs) already in use for the Time Of Flight system of the ALICE experiment at LHC, whose characteristics and performance in dedicated beam tests, described in \cite{3}, adequately fulfilled these requirements.

Each EEE station is composed by a telescope made of three MRPCs, and the detection of EAS is performed by searching for muon events in coincidence among different stations. At regime, a network of about 100 stations all over Italy is foreseen.

In addition to EAS of extreme energy, the EEE network will allow studying also other interesting phenomena. For instance, a systematic study of the single muon flux and its variations, correlated with the relevant environmental parameters, could be carried on. Also a search for very long distance correlations, which up to now has never been performed, could be approached.
Figure 1. Layout of a MRPC used for the EEE experiment.

The innovative aspect of the experiment is that the stations are located in Italian high schools — plus two at CERN, and one each at Bologna and Catania INFN sections — and are operated by teachers and students of these schools, and that, moreover, the detector themselves have been built at CERN by the same teachers and students. The chambers were then sent to their institute of destination and the final installation and commissioning was performed by mixed teams under the supervision of experts and researchers from scientific institutions [4].

All this closely joins in the very same activity important didactic aspects deriving from taking direct part to a real scientific experiment, with the interest of performing a research in an advanced field of investigation.

2 Construction and characteristic of the stations

The MRPCs developed for the EEE Project (see figure 1) are characterized by six gas gaps each, 300 µm thick, obtained by separating glass plates, 80 × 160 cm² in dimensions, by means of commercial nylon fishing lines used as spacers. The outer glass plates are coated with resistive paint, and act as high voltage electrodes, while the inner ones are left electrically floating. The gas mixture is C₂H₂F₄/SF₆ mixed in 98/2 proportions, flowing at a typical rate of 2–3 l/h.

Standard operating voltage ranges around 18 ± 20 kV, so that the chambers operate in avalanche saturated mode, and the relative signals are induced on 24 copper strips (per chamber) glued on two vetronite plates placed on top and bottom of the glass outer electrodes. Signals are sent to NINO-ASIC chips based Front End electronics [5], amplified, discriminated and subsequently acquired by means of multi hit TDCs. Since readout strips lie longitudinally on the chambers, one coordinate (x) of the muon impact point is given by the difference of the signal arrival times at the two strip extremities, while the other (y) is directly obtained from the position of the fired strip.

The data acquisition system makes use on VME standards, and the DAQ program is LabView based and runs on a PC connected to the VME crate by means of a CAEN USB-VME bridge.
module. Since the main goal of the EEE network is to detect coincidences in time among stations located at different positions, each event acquired must be provided with the relative time stamp; this is given by a Hytec Global Positioning System (GPS) VME module integrated in the system and readout by the DAQ program.

Since EEE stations operate in high schools, particular attention has been put on safety issues. For instance, the gas mixture does not contain any flammable component, like, for instance, isobutane, which is routinely used with this kind of chambers. High voltage is provided by small DC/DC converters of the EMCO-Q series, providing an output voltage up to ±10 kV when powered with 0–5 V, packed in small boxes and connected directly to the electrodes of the detector (see figure 2).

Another peculiar aspect of the EEE network lies in the fact that the stations are under direct control of the students and teachers of the schools involved in the experiment. Nevertheless, from time to time some intervention or monitoring by the researchers, usually located in the nearby universities or local INFN sections, are needed. This is the reason why most of the subsystems of the EEE telescopes are directly monitorable or controllable from remote. To reach this aim, for instance, the Lecce group of the EEE Project collaboration developed a suitable device to supply the high voltage for the MRPCs and the low voltage for the related Front End electronics (LV/HV). This device is interfaced with the DAQ PC and controlled by means of a dedicated software, and, since the PCs are permanently online, the LV/HV system can be continuously monitored from remote. A block diagram of the HV-LV system developed for the EEE telescopes is shown in figure 3, while a picture of the panel of the relative control software is shown in figure 4.

Moreover, it is important to keep under control the quality of the events taken, to be sure that the acquisition is running smoothly and the detector performance remains stable in time. A complete suite of online and offline monitoring programs has been set up for this important task, and is standardly used by teachers and students during their periodic checks of the stations.
Also an event display, based on java technology and therefore easily portable on different operating systems, has been developed. As an example of its potentialities, the first event acquired by the Liceo “A. Scacchi” in Bari, one of the schools recently joining the network, is shown in figure 5. The three orthogonal projections of the MRPCs, with indicated the strips fired and the computed positions along them, together with the reconstructed muon track, are displayed.
3 Experimental results

One of the challenges of the EEE Project was to obtain results of scientific validity when operating the EEE stations not in scientific laboratories, but in high schools. At the moment, the EEE collaboration has produced about 12 papers and around 20 contributions to conferences, mostly related to detector issues or the experiment structure and commissioning.

The most important parameter of the stations to keep under control is chamber efficiency. This cannot be monitored continuously, since the trigger requirement of the EEE stations during normal operation needs at least one signal coming from each of the six front-end boards in each event, and therefore must be measured in dedicated periods. For this purpose, each chamber is in turn excluded by the trigger, and the line joining the two points of the remaining chambers is extrapolated onto the chamber under examination, searching for a hit there nearby. Efficiency vs. HV, measured in this way, for the three chambers located at the EEE station of Altamura is reported in figure 6, showing that it is above $\sim 90\%$ in all cases; since for these measurements just the coincidence between two chambers is required, an efficiency slightly lower than the one measured in dedicated beam tests is expected; nevertheless it remained stable in about three years of operation.

Figure 7 shows the strip multiplicity distribution for the EEE station in the Istituto Tecnico “E. Fermi” in Frascati, i.e. the number of contiguous strips fired on each chamber associated to the passage of a particle. Most of the events show a single strip fired when the cosmic muon crosses the RPC plane. A small fraction of events have 2 or more strips fired, and this is usually related to the crossing of the muon at the edge between two neighboring strips.

Another important parameter to measure is the spatial resolution of the MRPC chambers used for the EEE experiment. It is computed by using the difference between the estimated position of
Figure 6. Efficiency vs. HV of the three chambers located at the EEE station of Altamura.

Figure 7. Strip multiplicity as measured at one of the EEE telescopes located in Frascati.

the particle hit on a plane, determined by joining with a line the hits on the other two planes, and the actually measured hit on the plane under study. This is shown in figure 8, where the difference has been already normalized to the actual number of uncertainty sources. The discrete structures along the y direction are due to the conductive strips pitch and size. For the x direction, the value of 9.568 cm/ns for the actual speed of the signal along the strips has been used; the RMS values obtained (∼1.45 cm) correspond to a time resolution of ∼1.45 cm/9.568 cm/ns ∼150 ps. The value is in agreement with the expectations for the TDCs chip declared resolution (∼100 ps), with a factor √2 due to the time difference between two chips for measuring the x coordinate.
Muon trigger rate is also constantly kept under control and its trend is extensively studied over long periods of time in order to investigate fluctuations in the muon rate due to periodic effects (cycles with periods of 11 years, one year, 27 days, one solar day or semi-diurnal variations) as well as exceptional events, such as magnetic storms and large solar flares. The detected muon rate is affected by environmental conditions, because of the barometric effect related to muon absorption in the atmosphere, and because changes in gas pressure have a direct impact on the avalanche development inside the MRPC [6, 7]. This effect is evident in figure 9, that shows the trend of the atmospheric pressure (top) and the muon rate (middle) as measured by one of the EEE telescopes in Catania, over a limited period of 8 days. This telescope operates at a constant ambient temperature, thus making negligible the dependence of the MRPC efficiency on the temperature. Therefore, a correction factor — in this case of around 0.26%/mbar — was applied to the measured rate to remove this dependence; the corrected rate is shown in the bottom plot of figure 9 and it shows a much more stable behavior with respect to the uncorrected measured rate, as expected.

Of course, studies related to detector behavior were not the only ones produced by the EEE collaboration. In particular, the capability of detecting EAS with the EEE stations was definitely put in evidence when the first coincidences between different stations have been recorded, opening the way to obtain interesting physics results. Due to the expected frequency for observing coincidences, the first data came from the closest stations of the experiment, only about 200 m apart, and located at L’Aquila, whose results were already published [8].

Obviously, the search for coincidences among nearby telescopes is still going on, being the main goal of the EEE Project. In this case it is essential that the telescopes among which the coincidences are searched for should be operated with the maximum duty cycle possible.

Among others, in the town of Bologna three EEE telescopes have been running since some years with a very satisfactory duty cycle. They are located at Liceo “E. Fermi”, Liceo “L. Galvani” and at Bologna INFN laboratory. The periods during which all the three telescopes were taking data and the search for threefold coincidences is possible are shown in figure 10. Due to their rather large mutual distance (> 1.5 km), in this particular case for the moment the coincidence peak is not distinguishable from the background deriving from accidentals. Anyhow, the EEE collaboration is acquiring more and more data and searching for coincidences among stations located closer to each other.
Just as an example, here are reported some results obtained by the EEE stations in Cagliari. These are installed at Liceo “Michelangelo” and Liceo “Pacinotti”, located 520 m apart, and are characterized by a 70 cm distance between the MRPCs in each telescope, with an average acquisition rate of 20 Hz in the first telescope and 31 Hz in the second. A preliminary analysis was performed to search for events correlated in time in the two detectors, on a 14 days long run, processing data with the EEE standard reconstruction software, and then analyzing them with a software implemented to search for events with a time delay less than 10 µs. The distribution of the time differences between the events in the two telescopes as measured by the GPS is reported in
Figure 10. Time periods useful for threefold coincidences search for three EEE telescopes located in Bologna; also the corresponding measured rates are reported.

Figure 11. Preliminary results of muon coincidences observed between the two telecopes located at Cagliari.

figure 11, and it shows a clear coincidence peak. A more sophisticated analysis is now under way with a larger data sample, and, moreover, since recently a third telescope begun to take data, at a distance of roughly 2 km from the other two, this should also reduce the background and enhance the peak.

Recently, during last February 2011, a class X2 solar flare, followed by an important Coronal Mass Emission (CME) gave origin to a Forbush decrease recorded by some of the stations of the Neutron Monitor Network (NMN). Two stations of the EEE network saw a similar decrease in the muon rate, with an intensity profile clearly comparable to the ones observed by the stations of the NMN [9].
This kind of observations are intrinsically interesting, since X-class flares can trigger even blackouts on Earth, or, in general, affect the space weather conditions close to our planet. To our knowledge, this has been the first observation of a Forbush decrease performed by means of detectors installed in high schools, outside of scientific laboratories, and, for this particular event, the first to be published. Nevertheless, the results obtained show an overall quality comparable to the ones obtained in professional observatories. Recently, the EEE network detected another solar flare, happened in March 2012, whose data are still under analysis and will be the subject of a forthcoming paper.

4 Conclusions

The EEE experiment is an innovative approach both to scientific research and scientific communication. Its stations, located in high schools all over Italy and at CERN, acquire data almost continuously, and their operation relies on the incredible enthusiasm shown by students and teachers.

In addition to its invaluable didactic functions, EEE produces interesting physics results; its detectors show a performance, in terms of efficiency and time resolution, comparable to the one characteristics of similar detectors installed at the LHC experiments.

The first coincidences among nearby stations have already been recorded, demonstrating the possibility of effectively revealing Extensive Atmospheric Shower using the EEE array. Finally, the detection of the February 2011 Forbush decrease has opened up new and interesting possibilities to use the EEE network also for studying the solar activity and its effects on the cosmic ray muon flux on Earth.

Acknowledgments

Nothing of what has been described here would have been possible without the hard work, passion, and dedication of all the students and teachers involved in the EEE Project. They have been building the MRPC detectors at CERN, and helped setting up the telescopes at the sites; the collaboration relies on their day by day work for operating the stations and collecting high quality data. To them all goes the warm acknowledgment of the whole EEE scientific community.

A Schools involved in the EEE Project

In the following a list of the italian Schools which have been contributing to the EEE Project, and a map showing their locations in the national territory are reported.
Figure 12. Map of the Schools involved in the EEE Project.

Table 1. List of Italian Schools contributing to the EEE Project.

| School Name                  | City          |
|------------------------------|---------------|
| Liceo “Cagnazzi”             | Altamura (BA) |
| Liceo “A.B. Sabin”           | Bologna       |
| Liceo “L. Galvani”           | Bologna       |
| Liceo “L.B. Alberti”         | Cagliari      |
| ISTIT “S. Cannizzaro”        | Catania       |
| Istituto “Villa Sora”        | Frascati (RM) |
| Polo Liceale “G. Marconi”    | Grosseto      |
| ISTIT “Amedeo d’Aosta”       | L’Aquila      |
| Liceo “G. Palmieri”          | Lecce         |
| Liceo “G. Banzi Bazoli”      | Lecce         |
| IIS “L. Nobili”              | Reggio Emilia |
| Liceo “Chiabrera”            | Savona        |
| ISTIT “G. Ferraris”          | Savona        |
| Liceo “Galileo Ferraris”     | Torino        |
| Liceo “A. Volta”             | Torino        |
| Liceo “S. Staffa”            | Trinitapoli (BT) |
| Istituto Nautico “Artiglio”  | Viareggio (LU) |
| Liceo “A. Scacchi”           | Bari          |
| Liceo “E. Fermi”             | Bologna       |
| Liceo “Pacinotti”            | Cagliari      |
| Liceo “Michelangelo”         | Cagliari      |
| Liceo “E. Fermi”             | Catanzaro     |
| ITIS “E. Fermi”              | Frascati (RM) |
| Liceo “B. Touschek”          | Grottaferrata (RM) |
| Liceo “A. Bafile”            | L’Aquila      |
| ITIS “E. Fermi”              | Lecce         |
| Liceo “G. Marconi”           | Parma         |
| Liceo “G. da Procida”        | Salerno       |
| Liceo “O. Grassi”            | Savona        |
| ISTIT “E. Alessandrini”      | Teramo        |
| Liceo “Giordano Bruno”       | Torino        |
| Liceo “M. d’Azeglio”         | Torino        |
| Liceo “E. Barsanti”          | Viareggio (LU) |
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