Recent results and performance of the multi-gap resistive plate chambers network for the EEE Project

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The EEE collaboration

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ABSTRACT: The Extreme Energy Events (EEE) Project is devoted to the study of Extensive Atmospheric Showers through a network of muon telescopes, installed in High Schools, with the further aim of introducing young students to particle and astroparticle physics. Each telescope is a tracking detector composed of three Multi-gap Resistive Plate Chambers (MRPC) with an active area of $1.60 \times 0.80 \, \text{m}^2$. Their characteristics are similar to the ones built for the Time Of Flight array of the ALICE Experimentat LHC. The EEE Project started with a few pilot towns, where the telescopes have been taking data since 2008, and it has been constantly extended, reaching at present more than 50 MRPCs telescopes. They are spread across Italy with two additional stations at CERN, covering an area of around $3 \times 10^5 \, \text{km}^2$, with a total surface area for all the MRPCs of $190 \, \text{m}^2$. A comprehensive description of the MRPCs network is reported here: efficiency, time and spatial resolution measured using cosmic rays hitting the telescopes. The most recent results on the detector and physics performance from a series of coordinated data acquisition periods are also presented.

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

Contents

1 The EEE Project

The Extreme Energy Events (EEE) Project [1, 2] is an experiment for the detection at ground of Extensive Air Showers (EAS), produced by the impact with the atmosphere of high-energy primary cosmic rays, with energy greater than 10^{11} eV up to 10^{18} eV and above. In particular it aims to reveal and investigate EAS from Ultra High Energy Cosmic Rays (UHECR), that were originated from extra galactic sources and should be affected by Greisen Zatsepin Kuzmin (GZK) cut. The detection of an EAS is operatively achieved by detecting coincidences in time among secondary muons at ground level, recorded at the different sites of the EEE network. It consists of tracking detectors, namely telescopes, synchronized by means of GPS modules, based on three layers of Multi-gap Resistive Plate Chambers (MRPCs) of large area, hosted in Italian High Schools, in INFN Sections, and at CERN. A picture of an EEE Project laboratory inside a school building is shown in figure 1. The network is organized in clusters of 2, 3 and 4 telescopes within the same town, and single telescope stations.

The inhomogeneous grid of telescopes allows a multiple, thrilling approach to the study of cosmic rays: *a single detector* the EEE telescope is a high precision tracking detector that can study the flux of secondary cosmic muons, their arrival directions and upward-going particles; *a telescopes cluster* in the same town, it can study the properties of the EAS in which muons are originated; eventually *an array*, using sites far apart, makes it possible to investigate time correlations between different EAS events.

The EEE Project also joins its scientific interest with a powerful outreach action [1, 3, 4]. High school students are introduced to high energy physics both with the participation to the detector assembly at CERN and the involvement with their teachers and researchers from the scientific institutions in the operation and monitoring of the EEE stations.
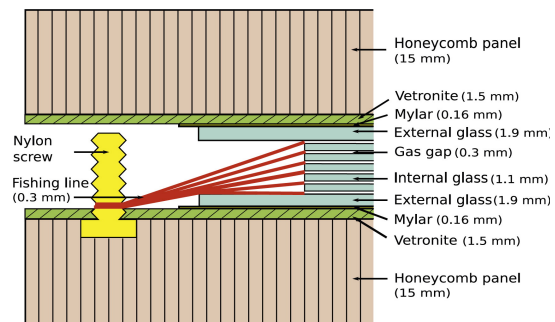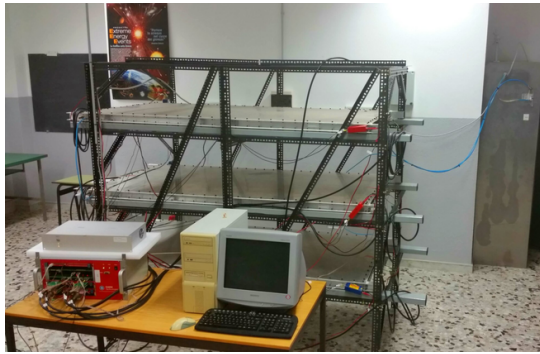
Figure 1. Picture of a MRPCs telescope station located at ITIS *Galileo Ferraris*, a high school in Savona.

Figure 2. Basic design of the MRPC internal structure.

2 The MRPCs cosmic ray network

2.1 The MRPCs telescope stations

The MRPCs used in the EEE Project [5, 6] have six gas gaps of $300\,\mu$m, obtained interleaving two glass plates of $164 \times 85 \times 0.19\,\mathrm{cm}^3$, coated with resistive paint, with five floating glass plates ($158 \times 82 \times 0.11\,\mathrm{cm}^3$), by means of commercial fishing line. Their basic layout is shown in figure 2. The external glasses, with a volume resistivity of $\sim 10^{13}\,\Omega$cm, act as dielectric plates, and two vetronite panels insulate 24 pairs of copper strips, the readout electrodes. Two honeycomb panels, 15 mm thick, ensure the rigidity of the structure which is enclosed in an aluminum box. These wide active area MRPCs are mounted horizontally on a metallic frame with vertical distances ranging between 0.3 and 1.0 m depending on the stations (figure 1). They are continuously flushed, $\sim 3\,$l/h at atmospheric pressure, with a 98% of $C_2H_2F_4$ (R134A) and 2% of SF_6 gas mixture, and operate in avalanche mode with a typical voltage around 18 kV supplied by DC/DC converters.

When an ionizing particle passes through the chamber, a electron avalanche is generated inside each gas gaps. The sum over all the gaps induces a signal on the electrode strips. From the hit strips a differential signal is transmitted to the two front-end boards (FEAs) equipped with NINO ASIC amplifier/discriminator [7] mounted at the ends of the chamber. From the FEAs LVDS pulses are fed into two TDCs and into a trigger card sitting inside a VME crate.

A six-fold coincidence of the OR signals from both FEAs of the three MRPCs generates the data acquisition trigger (MRPCs triple coincidence).

The absolute time of each event is recorded by means of an external Global Positioning System (GPS) module, in order to get the event UTC time stamp and to correlate the information collected by different telescopes. A weather station completes the muon telescope station with the aim of measuring the local value of temperature and pressure, since they both influence the secondary cosmic ray flux at ground and the gas density in the MRPC.

The data acquisition chain is controlled by a LabView program running on a PC connected to the VME crate via an USB-VME bridge.

2.2 The coordinated data acquisition

For the first time at the end of 2014, the EEE telescope network tested a simultaneous and completely automatic acquisition and data storage at the central computer facility of the INFN, the *Centro Nazionale Analisi Fotogrammi* CNAF [8]. At present all the network station data are transferred and stored at CNAF, where events are analyzed and particle tracking procedure is implemented. The PC of each EEE station is connected by means of a BTsync client [9], a peer-to-peer software to synchronize data folders in real time. In November 2014 a first coordinated data taking, Pilot Run (2 weeks) was performed, with several telescopes running simultaneously. Afterwards a large number of telescopes of the EEE array partecipated in Run1 (45 days), which lasted from February to April 2015. A new combined data taking, Run2, started in October 2015 and lasted until end of May 2016. More than 40 telescopes were involved and Run2 has already reached its goal, achieving 15×10^9 events in 7 months.

3 The EEE Multi-gap Resistive Plate Chambers performance

3.1 The single MRPC performance

The performance of a single MRPC was measured at the CERN Proton Syncrotron facility. A detailed report of the set-up and the beam-test results has been already described in [10]. The chamber efficiency vs high voltage was measured, with the value at plateau reaching 100%. Time resolution, obtained as the σ of the arrival time distribution of the signal at the strip ends, is 141 ps, without corrections. A value of 70 ps can be obtained, implementing corrections for pulse width, slewing corrections, and taking into account the scintillators time jitter. Spatial resolution, measured along the strip length, the long chamber side, by two TDCs is 94 ps, that corresponds to a resolution of ~ 8 mm.

3.2 The telescope performance measured using cosmic rays

The efficiency versus HV curves for each telescope are measured, inside school buildings, before and after a coordinated data taking, to test the stability of the chambers. Two scintillators are placed above and below the detectors, providing the trigger on cosmic muons passing through the 3 chambers. Thus several tests have been performed in several towns with equivalent results [4–6]. An example is shown in figure 3. All the measurements showed at a plateau above 18 kV an efficiency higher than 90%, also in the older EEE stations, built in 2007. This value is compatible with that measured on a single chamber in a test beam. Time and spatial resolution for the MRPCs telescope have been measured with cosmic muons in the EEE stations, during the Run2 period. The resolutions are obtained by studying the distributions of the impact time and the impact point of a cosmic particle in the three MRPCs. The limit for the spatial and time resolution depends on the strip pitch, 3.2 cm and on the time bin (100 ps) of the TDCs that provide the signal arrival time measurement. The track events are reconstructed at CNAF. The hits on the chambers are selected as particle events by means of the variable χ^2: the quadratic sum of the three-dimensional distances between the hit position and the best fit track. The *Good* track events are chosen with $\chi^2 < 10$. The impact time in each MRPC is reconstructed as the average of the signal arrival times at the strip ends (left and right). A study of the performance from the whole array is in preparation.
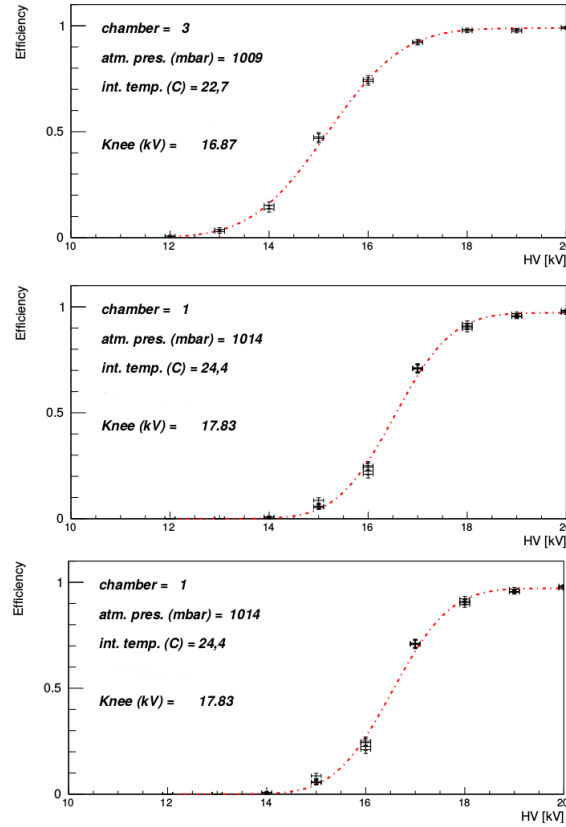
Figure 3. Efficiency vs. HV, for the MRPCs telescope located at Catanzaro. The figure shows in each MRPC a detection efficiency plateau ∼ 95% for HV values above 18 kV.

In particular we show here, as an example, data collected from a telescope in Torino. We have studied the distribution of the quantity in figure 4 by using the hit times of the top and bottom chambers to predict the hit time in the middle chamber. If we assume the same time resolution for the three MRPCs, it can be calculated as $\sigma_{T_{\text{res}}} = \sqrt{\frac{2}{3}}\, \sigma_{\Delta T_2}$, and its value is 207 ps. No time or charge correction was implemented. The Y−cordinate particle impact point, along the short side of the chamber, is defined by the fired strips, while the X−coordinate along the strip direction is reconstructed as the difference of the signal arrival time at the strips ends, measured by the TDCs. $X_{\text{ch}} = \frac{T_{\text{left}} - T_{\text{right}}}{2\, v_{\text{strip}}}$. The spatial resolution, as for the time resolution, has been studied by extrapolating the top and bottom chamber hit position onto the middle chamber, assuming the same resolution for each MRPC. A strip calibration has been applied, and the distribution along the strip direction is shown in figure 5. The distribution data fit presents two Gaussian contributions, that are being investigated and the convolution sigma $\sigma_{Y_{\text{res}}\text{Tot}}$ is ∼ 2.00 cm. The spatial distribution obtained along the short side is 1.0 cm, in agreement with the strip pitch constraint $\sigma_y = 3.2\,\text{cm}/\sqrt{12} = 0.9\,\text{cm}$.

As expected the performance for a single MRPC is better than that measured during Run2. During the test beam conditions are ideal: the beam was centered in the middle of the strips, two pairs of scintillators were used to provide the trigger, TDCs with 25 ps bins were used. The test beam results indicate excellent performance achievable by the MRPC detectors. When used with secondary cosmic rays many factors can affect these results. The electronic noise, strip
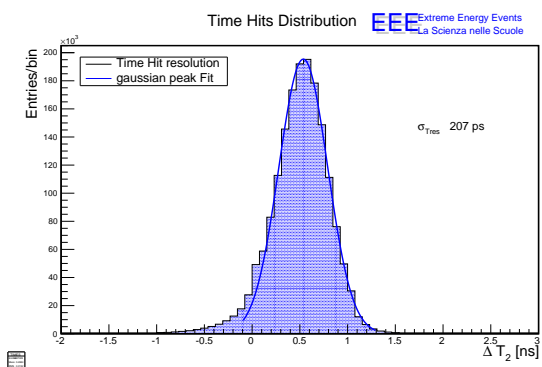
Figure 4. Time distribution obtained as $\Delta T_2 = \frac{T_{Bot}+T_{Top}}{2} - T_{Mid}$, the time resolution is calculated as $\sigma_{T_{res}} = \sqrt{\frac{2}{3}}\,\sigma_{\Delta T_2}$. Data from a telescope in Torino.
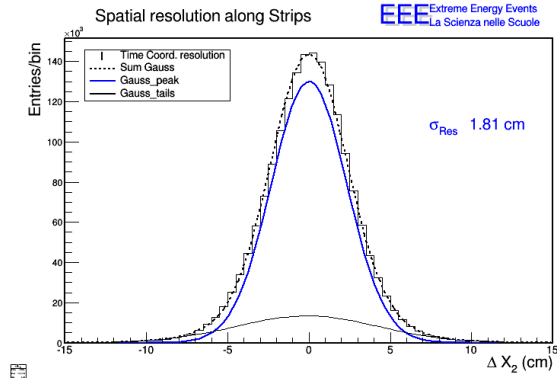
Figure 5. Spatial distribution along the strip direction obtained as $\Delta X_2 = \frac{X_{Bot}+X_{Top}}{2} - X_{Mid}$, the spatial resolution is calculated as $\sigma_{X_{res}} = \sqrt{\frac{2}{3}}\,\sigma_{\Delta X_2}$. Data from a telescope in Torino.

miscalibration or multiple scattering, can produce a larger resolution, and we can expect that the hit time calibrations and the time slewing corrections will reduce and optimize these values [11].

4 Recent Physics Results

Preliminary results from the Pilot Run and Run1 on main topics such as EAS detections and studies of the cosmic ray flux, have been reported in [12–14, 16]; two studies on the anisotropies research for the low energy primaries [17], and the upward-going particles [18] have been already published. Here we report briefly the most recent results.

Galactic Cosmic-ray Flux decreases The EEE telescopes monitor the secondary cosmic rays flux, with a selective sensitivity to the muon component. Thus the network is able to detect the galactic cosmic-ray flux decreases (GCRDs) associated to solar phenomena as Coronal Mass Emissions — the *Forbush* decreases, or solar flares, that take place over few hours [19, 20]. The MRPCs particle rate is normalized applying a barometric coefficient evaluated in each station, and the high sensitivity of the telescopes allows to detect this rapid variations, ∼ 5%, behaving as a solar monitor array with wide coverage and with precise timing. The EEE network observations are generally highly correlated with neutron monitor stations, as in figure 6, although these are more sensitive to low-energy primaries, whereas muons detected in the EEE telescopes originate from events of higher energy in the atmosphere. A GCRD, observed during the Run2, is shown in figure 7 in comparison with the Oulu Neutron Monitor data.

Upward-going events The MRPCs telescope can provide the event Time of Flight, between the bottom and the top chambers, the particle track length, and thus a rough value of the particles speed β. Upward going events can be discriminated from downward going by mean of the β value. Upward going events are observed in EEE telescopes, as a population of ∼ 1/2000 of the downward going particle detected. Most of them could be explained as relativistic electrons coming from the muon decay. A fraction of them can be generally highly correlated with a "parent" muon passing
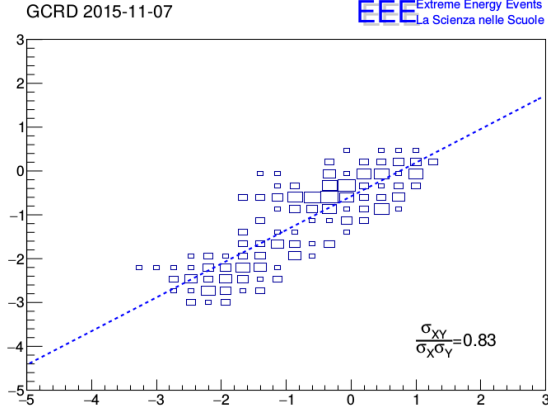
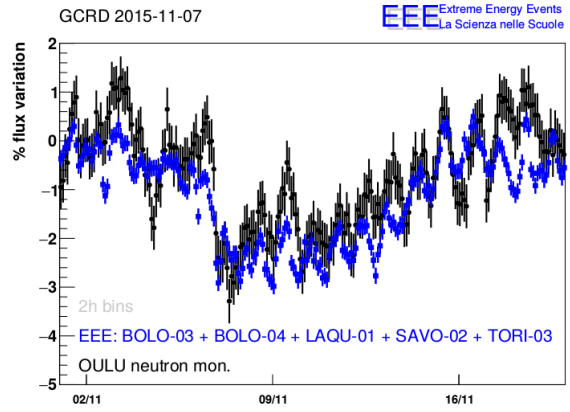**Figure 6**. The plot shows the excellent correlation between OULU and EEE percentage flux variation.

Figure 7. GCRD on the date 07 11 2015 - muon decrease observed with 5 EEE telescopes, compared to neutron rate from the Oulu station.
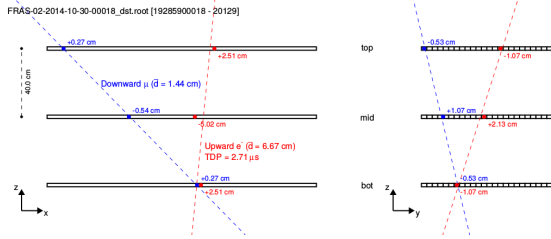

Figure 8. Event display of two tracks, separated in time by $\sim 2.7\,\mu$s. The downward-going candidate muon (in blue) and the upward-going candidate electron (in red).
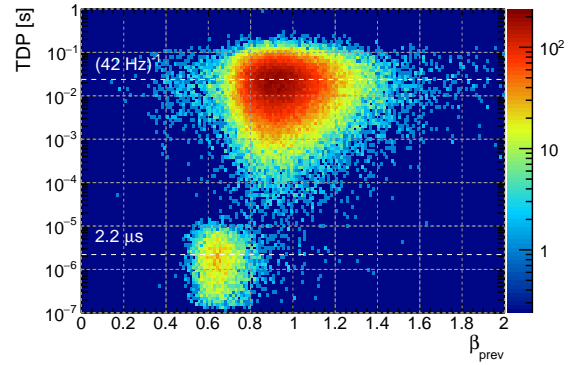

Figure 9. Distribution of the delay between the upward track and the previous downward event — TDP vs. β of the previous event. The telescopes rate is ~ 42 Hz.

through the telescope by means of the time delay respect to previous events [18]. As shown in figure 8 a downward going parent-muon stopping in the bottom chamber, or in the ground below it, decays. It generates an upward going electron-daughter, that triggers the chambers. The two events are discriminated in time with a delay equal to the muon lifetime $\tau \sim 2\mu$s. In figure 9 the up going electron-daughter time delay, the Time Difference to the Previous event (TDP) vs the parent-muon β are plotted. As expected, the parent-muon energy is lower than non-correlated events energy.

5   Summary

The EEE Project successfully combines its scientific results with an educational approach. During the Run2, more than 500 young students and 100 teachers have been involved in the project. Every year new schools join the project, thus the MRPCs network continuously increases its surface coverage.

The EEE telescopes efficiency shows the inherent, durable, stability of the MRPCs, and the time and spatial resolution in the reconstructed tracks show good preliminary results that time calibration could improve.

In April 2016 the project has reached a great goal: since the Pilot Run 20 billion of events had been collected at CNAF, and the EEE scientific collaboration is already planning the next coordinated *run*, Run3. The performance confirms the EEE Project's capability of studying the EAS main proprieties, as shown by the recent physics results. The increase of the data opens up possibilities for more detailed studies of cosmic ray physics.

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