# The EEE project - Science in schools: state and results

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## Abstract

The Extreme Energy Events (EEE) project is an extended array for cosmic rays survey. It was conceived by Antonino Zichichi and supported by the Museo Storico della Fisica e Centro Studi e Ricerche "Enrico Fermi" with the collaboration of the European Organization for Nuclear Research (CERN), of the Istituto Nazionale di Fisica Nucleare (INFN) and of the Italian Ministry of Education, University and Research (MIUR). This experiment is aimed to study cosmic rays of extreme high energy, and related phenomena. To achieve this goal, a network of nearly 50 muon telescopes has been installed in high schools, distributed throughout the Italian territory, either as single stations or clusters. During the second coordinated run of data taking, which ended in May 2016, 25 billion muon tracks were detected and reconstructed. This huge amount of data, allows us to undertake various studies: the dependence of the local muon flux on solar activity; the sky anisotropy on sub-TeV scale; event correlations, due to EAS, between clustered telescopes at distances from a few hundred meters to over a kilometre. The status of the project and some results will be presented.

*Keywords*: Multigap RPC, EAS detection, Muon detection, Forbush decrease

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## 1. The EEE Project

The main scientific goal of the EEE project [1,2] is the detection of extensive air showers (EAS) produced by the impact of primary cosmic rays on the Earth's atmosphere, by the use of a sparse array of telescopes installed over the Italian territory. The EEE network allows the investigation of several aspects of cosmic ray radiation, from the measurement of the local muon flux to the identification of EAS with telescopes located in the same area, to the search for correlations at long distance. The EEE project has an important role in introducing a large number of high-school students to the methods of particle and astroparticle physics. Teams of students are directly involved in the construction, installation, operation and data analysis of the experiment, under the supervision of researchers from scientific institutions.

## 2. Detector and Performance

The design of the EEE telescope allows to detect muons from EAS with high efficiency (up to 92%) and tracking resolution. Each telescope is composed of three MRPC chambers of 160×80 $cm^2$ size, filled with a mixture of C2F4H2 (98%) and SF6 (2%) and operated in avalanche mode [3].

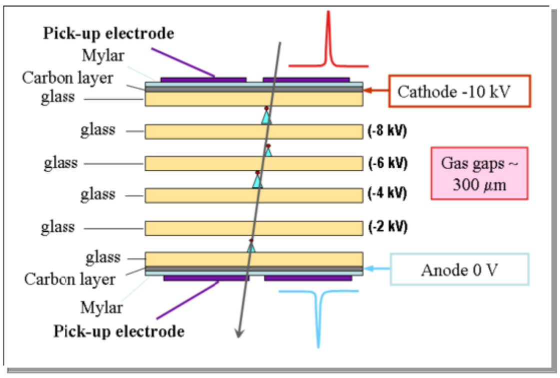


Figure 1 - EEE MRPC cross section.

Each EEE chamber has 24 pick-up strips, with readout at the two ends. A VME-based data acquisition includes a trigger card, 144 TDC channels and a GPS unit for remote synchronization. Each MRPCs telescope is provided with a weather station for measuring outdoor/indoor temperature and pressure to study the secondary cosmic ray flux variation, correlated with meteorological parameters and solar activity. The coordinates of particle impact point are determined from fired strip (Y) and the comparison of the arrival times of the signals at the opposite ends in each strips (X).

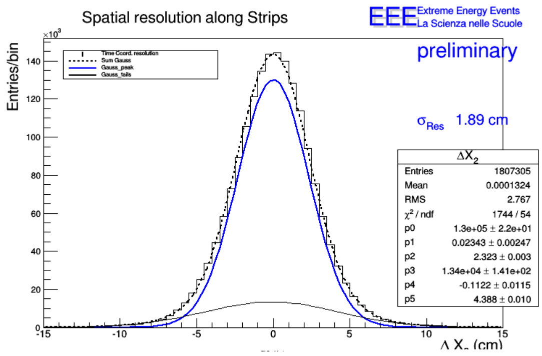


Figure 2 - ΔX distribution of one EEE telescope

The TDCs are operated with a 100 ps bin width, so that strip dimension and time difference provide an overall spatial resolution of 1.9 cm along strips and 1 cm in short direction; measured time resolution is 210 ps [4].

## 3. CNAF and Data Taking

Until the second half of 2014 the data of the single or cluster stations were collected and analysed using local computing resources. From the second half of 2014, also due to the large amount of data being collected, CNAF-Bologna has been involved in the collection and data analysis for all the EEE telescopes. Each school is connected to CNAF by means of a Btsync client, a peer-to-peer software to synchronize data folders in real time. Data are transferred and stored at CNAF where events are analysed and tracking procedure is implemented [5]. Good events are selected by means of cuts on the $\chi 2$ calculated for the hit positions in the three chambers, on cuts of the time of flight of the particles between the upper and the lower chambers and on the track length. Also the polar and azimuthal angles of the fitting track are reconstructed. The involvement of CNAF had permitted to implement a coordinated Run system on the entire network. Three coordinated data taking Runs have been completed and one is in planning:

- Pilot-Run (27/10-14/11/2014), $10^9$ candidate tracks;
- Run-01 (02/03- 30/04/2015), $5x10^9$ candidate tracks;
- Run-02 (07/11/2015-20/05/2016), $15x10^9$ candidate tracks and 43 stations participating;
- Run-03 will start in October 2016 with objective to double total statistic.

The creation of a single database allowed us to create a comprehensive monitoring system, in a web site, with easy accessibility also from students. On this web site [6], all can immediately check the status of each telescope.

## 4. Physics Results

### 4.1 Coincidences

The relative distance, between the various telescopes in the EEE network, range from a few hundred meters, for clusters of 2–4 telescopes in the same city, to more than 1000 km for the farthest stations. To correlate muons detected in different telescopes, GPS synchronization is used.

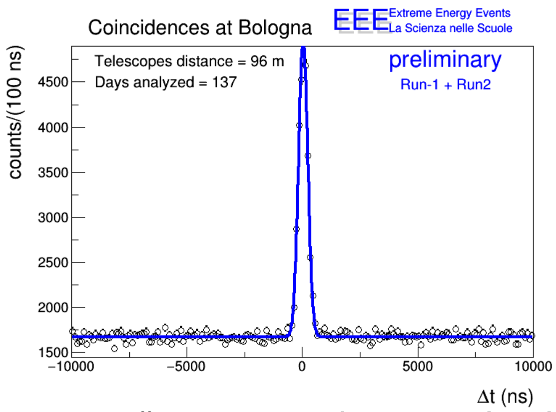


Figure 3 - Difference time spectrum between muons detected with two telescopes in Bologna at a relative distance of 96 m.

The difference in the arrival time of muons to two telescopes depend on their relative distance, as well as on the orientation of the incoming tracks [7]. This was taken into account for a proper analysis of the coincidence events.

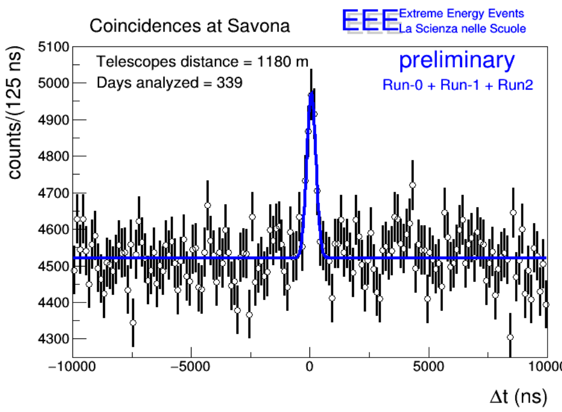


Figure 4 - Difference time spectrum between muons detected with two telescopes in Savona at a relative distance of 1180 m.

The coincidence rate between two telescopes clearly decreases with the increasing relative distance, requiring a larger statistics to be collected in order to identify the coincidence peak. In the current analysis, we were able to see coincidences between distant telescopes up to a distance of 1.2 km (see figure 4).

### 4.1 Forbush Decrease

An important transient variation of the cosmic ray flux observed at Earth, denoted as Forbush decrease, is caused by solar flares and their associated interplanetary disturbances. The study of Forbush decreases is usually carried out by means of neutron monitor stations which are distributed throughout the world.

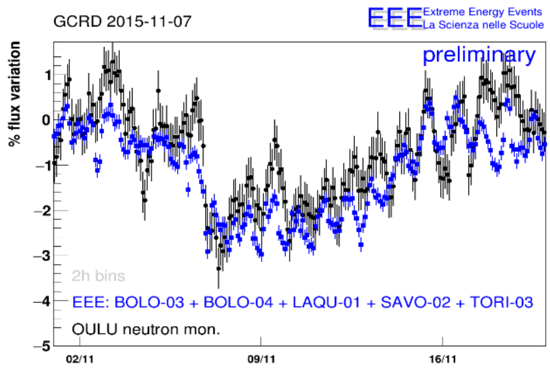


Figure 5 - Data comparison of Forbush decrease between EEE-Telescopes and OULU Neutron Monitor in 2015.

The first observations of Forbush decrease by EEE telescopes was in February 2011 [8] with a small number of stations. Observations were repeated in subsequent years, with the contribution of a larger number of stations in operation [9]. Local values of temperature and pressure influence both cosmic ray flux at the sea level and gas density in the MRPC. Once the period in which a solar event occurred has been identified, the data containing variation of cosmic rays flux are selected, corrected for pressure and temperature, and compared with data from neutron monitors, such as the Oulu in Finland or Moscow in Russia [8,9]. The data of our network seem in good agreement with the data taken by neutron monitor (see figure 5).

### 4.2 Anisotropy

Small but measurable anisotropies in the arrival distribution of cosmic rays, due to large-scale effects as well as local magnetic field features, may be evidenced. The array of EEE telescopes allows to look for small anisotropies in a wide portion of the equatorial sky.

To study anisotropies, the coordinates of muon track events are transformed from local (θ, ϕ, t) to equatorial coordinate (Right Ascension, Declination) to take into account Earth motion.

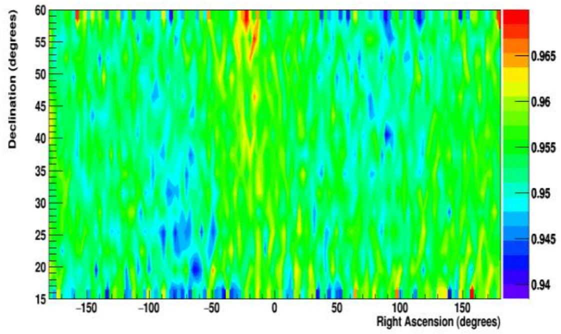


Figure 6 - Combined result from EEE sites with some anisotropy

Data are corrected for acceptance and time exposure day-by-day by the scrambling method [10]. A set of ~$10^9$ EEE events from 23 EEE sites and from different periods has been analyzed (see figure 6). Integrated data show some evidence of small anisotropies (few $10^{-3}$ ).

### 4.3 Up-going Events

The MRPC telescopes can discriminate between down-going and up-going tracks, and between high and low β particles.

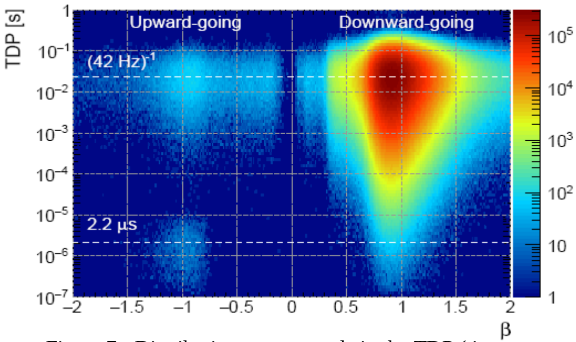


Figure 7 - Distribution event sample in the TDP (time difference to previous event)-β plane. Positive/(negative) β values correspond to downward/(upward)-going

Out of the ~$1,3 \times 10^8$ events with a good reconstructed track, about $7 \times 10^4$ (or 1/1000) feature a negative β, i.e., they are upward-going [11]. Two separate populations of upward-going relativistic particles, with β close to -1, are clearly identified (see figure 7). One is characterized by a TDP (time difference to previous event) of the order of μs. Relativistic up-going electrons are produced from the decay of downward-going muons stopping in the lowermost part of the telescope or in the ground immediately below it. About 6% of the sample, the downward-going parent muon triggers the telescope and can be tagged. Muon decay is identified in 0.005% of all EEE events.

## 5 Conclusion

Since the beginning of the EEE project, both the individual telescopes and the telescope clusters have successfully combined an outreach and educational activities for students with scientific research. This research is continuously improved thanks to the increasing involvement of CNAF, to the expansion of the network of telescopes and to the increase of the data taking period. This is a clear indication of the excellent performance of EEE the network.

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