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EEE - Extreme Energy Events: an astroparticle physics experiment in Italian High Schools

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Abstract. The Extreme Energy Events project (EEE) is aimed to study Extensive Air Showers (EAS) from primary cosmic rays of more than $10^{18} eV$ energy detecting the ground secondary muon component using an array of telescopes with high spatial and time resolution. The second goal of the EEE project is to involve High School teachers and students in this advanced research work and to initiate them in scientific culture: to reach both purposes the telescopes are located inside High School buildings and the detector construction, assembling and monitoring - together with data taking and analysis - are done by researchers from scientific institutions in close collaboration with them. At present there are 42 telescopes in just as many High Schools scattered all over Italy, islands included, plus two at CERN and three in INFN units. We report here some preliminary physics results from the first two common data taking periods together with the outreach impact of the project.

1. The Physics and the Project

There are particles in the Universe with an energy much higher than the highest energy available at the biggest accelerators: these are the Extreme Energy Cosmic Rays, whose energy (5 10^{19} eV, about 8 joule) is ten million times higher than the present LHC collision energy (13 10^{12} eV). How can they arrive at our atmosphere without losing energy because of scattering from the photons of the cosmic microwave background? What is their origin? Which are the mechanisms which give them such acceleration? The EEE project's goal is to contribute to answering these questions by measuring the very low flux of these particles and their origin in the Universe detecting the ground muon component of the produced Extensive Atmospheric Showers (EAS) by an array of telescopes scattered throughout Italy.

To reach the second goal of the project - *"to bring Science to the heart of the young"* - the telescopes have been located in High School buildings to have students and teachers involved in the detector assembling and data taking, monitoring and analysis. This innovative project - the first and still only one in Italy to have both a scientific *and* an educational goal - was proposed in 2003 by Professor Antonino Zichichi [1] [2] and is coordinated by the *Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi - Rome* in close collaboration with MIUR, the Italian Ministero dell'Università, dell'Istruzione e della Ricerca, INFN and CERN. In 2004 it was a *"pilot project"* with just 7 schools, in 2015 it is an *"Experiment"* with 42 telescopes in as many Italian High Schools plus two at CERN and three in INFN units, across an overall area of $\approx 0.5\ 10^6 km^2$. The Italian schools are grouped in geographical areas ("clusters") to be followed by one or more researchers belonging to the closer INFN unit.

2. The Telescopes

Each telescope [3] (see figure 1) is made of three Multigap Resistive Plate Chambers (MRPC) [4], which provide the three points (sketched in yellow in the figure) to get the muon incoming direction and its time of flight between the planes. An external GPS antenna provides the "UTC" time stamp to be associated with each event, information needed to identify muon tracks detected by far-away telescopes as belonging to the same Extended Shower, that is coming from the same primary cosmic ray. Other components of the telescope are the front-end electronics (located at the chamber short sides), the TDC (Time to Digital Converter) modules and the trigger card (all in the VME crate) and the low-to-high voltage converters (the red boxes attached at the right side of the chambers in the picture). Care has been taken to use non-flammable gas: a mixture of freon ($C_2F_4H_2$), at 98%, and SF_6, at 2%.

3. The data taking periods

After some years of single telescope data taking, in the fall of 2014 there was a one month long *Pilot-run* involving the simultaneous and, for the first time, completely automatic acquisition and data storage at the *INFN-CNAF* computer center in Bologna [1] , from 23 telescopes. After this successful test, there was a second common run (*RUN-1*) in which two thirds (35) of the

[1] where data are sent via BitTorrent Sync

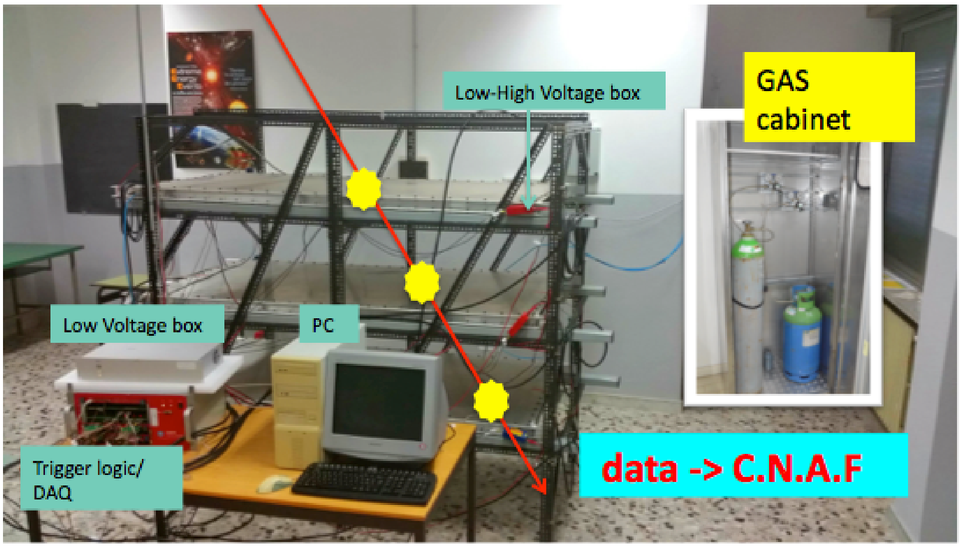

Figure 1. The EEE telescope at ITIS Galileo Ferraris in Savona.

EEE telescopes were ready to efficiently take data and over 5 billion events have been collected in about three months (February-April 2015). All the raw data from the running telescopes are regularly sent to CNAF [5] - on a run-by-run basis - where they are *"quality monitored"* and the outputs - together with the raw data - are put on a web page which researchers and students can freely access to perform their own data monitoring and analysis.

4. Physics outcomes

When telescopes take data in a *"stand alone"* mode, as well as during the common run periods, it is important to study the cosmic ray flux variations as a function of the atmospheric pressure. This easy relation can also be obtained by the students and is needed to apply the relative correction when studying the cosmic ray flux variations due to other effects, such as the coronal mass ejections occurring on the solar heliosphere: the "Forbush effect" or GCRD (Galactic Cosmic Ray Decrease). The first EEE result - the first to be obtained by a "scientific-educational" experiment - was published in 2011 [7] and other variations were observed in 2012 (figure 2), 2014 and 2015 showing that the EEE array has the capability of becoming a stable monitor for these effects over a broad surface and an angle of more than 10^0 in latitude and longitude [8].

The much sought coincidences between telescopes located in different schools at various distances have been seen both at short (hundreds of meters) and long (more than one kilometer) distances; figure 3 shows the time differences - as measured using the GPS information - of events between two telescopes in Cagliari and in Savona, 520 meters and 1180 meters apart respectively. Thanks to the very good chamber time resolution, not only can we measure the muon time of flight but we can also select a small sample of events with negative velocity: these events follow by 2.2 μs a downgoing muon and they are the upgoing electrons coming from the muon decay. Figure 4 shows the time difference (log scale) between two consecutive events versus particle velocity: the blob at the lower left corner is the event sample we are interested in. In figure 5 we show the two reconstructed tracks of one of these events.

The distributions of secondary cosmic muons were also measured by the MRPC Telescopes of the EEE Project, spanning a large angular and temporal acceptance through its sparse sites, to test the possibility to search for local anisotropies at the sub-TeV scale over long runs [9].

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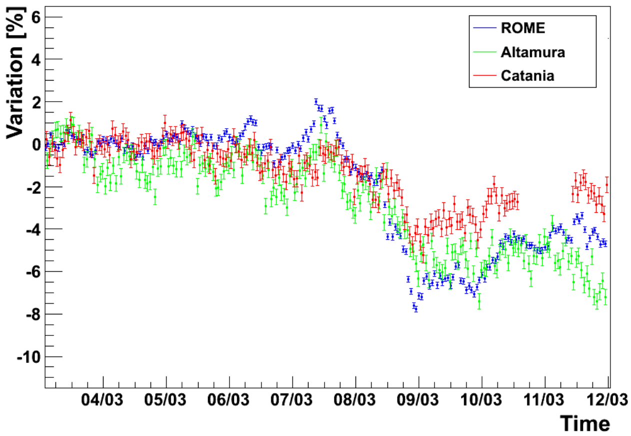

Figure 2. Time variation of the measured cosmic-ray flux as observed by two EEE telescopes in 2012, corrected for atmospheric pressure variation. In the same plot the corresponding neutron flux, as measured by the Rome neutron station [6] is also shown.

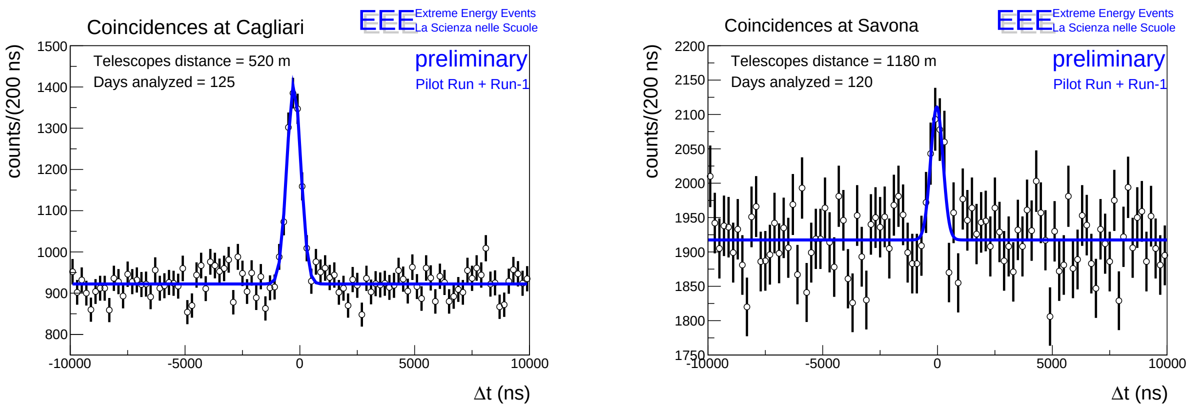

Figure 3. The time difference between events detected by two telescopes at a distance of 520 meters in Cagliari (at left) and 1180 meters in Savona (at right).

5. Outreach outcomes

Once a school is selected to enter the EEE Collaboration, a group of 5-7 students, together with one or two of their teachers, go to CERN, where they are taught how to assemble an MRPC chamber and, in a week, they build all three chambers that will form their telescope. Back at school, the researchers set up the telescope, make all the needed connections to the gas system and the electronics, check the signals and make sure that all these activities are followed and understood by the students. Before taking any official data the students measure the chamber efficiency with the help of two ancillary scintillation counters and get familiar - sometimes for the first time - with real signals generated by cosmic rays. In this first part, meetings and seminars are arranged to introduce students to particle and astroparticle physics, to data handling and analysis and - very important - to monitoring the data taking and the data quality; for this purpose, during the official runs, they organize themselves in groups and take shifts, every day, to write an official e-logbook and check what cannot be remotely checked; in

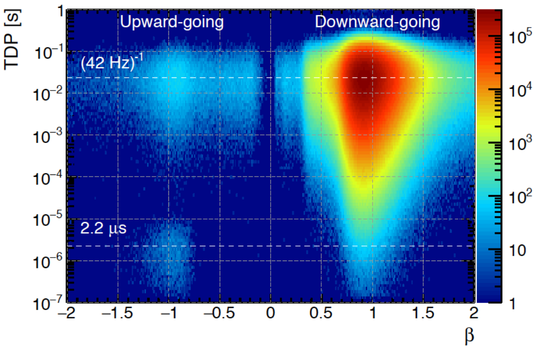

Figure 4. The time difference (log scale) between two consecutive events versus second particle velocity (beta).

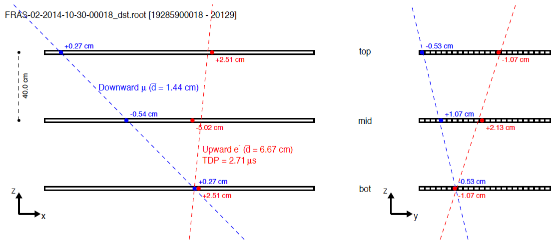

Figure 5. A two-view display of a *muon decay event* as reconstructed by the analysis program.

fact, even if all schools are remotely accessible there might be local problems which cannot be solved remotely (i.e. empty gas bottle replacement, PC turned off by local thunderstorm,..): in these cases students' help is essential. Some schools, triggered by this project, develop some side activities by themselves like building a cloud chamber, taking a portable cosmic ray detector up to the mountains, to verify - and measure - the increasing value of the flux with respect to altitude, organizing trips to various INFN Laboratories - usually Frascati and Gran Sasso - or setup official *"EEE openings"* with the presence of Professor Zichichi, getting wide local media coverage. Every few months or so, there are topical seminars for the students of the schools belonging to the same "cluster". Besides, at least once a year, there is a general meeting of all the schools: the last one, held in Erice in December 2014, saw the attendance of 47 schools and more than 80 students.

In all these years the EEE project has involved part-time more than 60 researchers, technologists and technicians and - only in the last three years - more than 100 teachers and $\approx$ 500 students. Besides we can say that more than 20000 students and their families and friends had one or more contacts with EEE events or activities.

6. Conclusions

Thanks to all the involved High School people (teachers, students, really ALL), the EEE project has been very successful and its unique "$hands-on$" approach has allowed students to learn not only new physics topics but also a *team-work* methodology which will be useful in their future work. More High Schools are ready to enter this project - they will be 52 in total by the end of 2016 - and even more are in the waiting list.

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