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S Boi[1,2], M Abbrescia[3,4], C Avanzini[5], L Baldini[5,6], R Baldini Ferroli[7], G Batignani[5,6], M Battaglieri[8,9], E Bossini[5,6], F Carnesecchi[10,11], C Cicalò[1,2], L Cifarelli[10,11], F Coccetti[12], E Coccia[13], A Corvaglia[14], D De Gruttola[15,16], S De Pasquale[15,16], F Fabbri[7], L Galante[17,18], M Garbini[10,12], G Gemme[8], I Gnesi[12,19], S Grazzi[8,20], D Hatzifotiadou[10,21], P La Rocca[22,23], Z Liu[24], G Mandaglio[20,23], G Maron[25], M N Mazziotta[4], A Mulliri[1,2], R Nania[10], F Noferini[10], F Nozzoli[26], F Palmonari[10,11], M Panareo[14,27], M P Panetta[12,14], R Paoletti[5,28], C Pellegrino[25], O Pinazza[10], C Pinto[22,23], S Pisano[7,12], F Riggi[22,23], G C Righini[29], C Ripoli[15,16], M Rizzi[4], G Sartorelli[10,11], E Scapparone[10], M Schioppa[19,30], A Scribano[28], M Selvi[10], G Serri[1,2], S Squarcia[8,31], M Taiuti[8,31], G Terreni[5], A Trifirò[20,23], M Trimarchi[20,23], C Vistoli[25], L Votano[32], M C S Williams[10,24], A Zichichi[10,11,21] and R Zuyeuski[24].

[1]Dipartimento di Fisica, Università di Cagliari, Cagliari, Italy. [2]INFN Sezione di Cagliari, Cagliari, Italy. [3]Dipartimento Interateneo di Fisica, Università di Bari, Bari, Italy. [4]INFN Sezione di Bari, Bari, Italy. [5]INFN Sezione di Pisa, Pisa, Italy. [6]Dipartimento di Fisica, Università di Pisa, Pisa, Italy. [7]INFN Laboratori Nazionali di Frascati, Frascati (Rome), Italy. [8]INFN Sezione di Genova, Genova, Italy. [9]Thomas Jefferson National Accelerator Facility, Newport News, VA, USA. [10]INFN Sezione di Bologna, Bologna, Italy. [11]Dipartimento di Fisica ed Astronomia, Università di Bologna, Bologna, Italy. [12]Museo Storico della Fisica e Centro Studi e Ricerche "E. Fermi", Rome, Italy. [13]Gran Sasso Science Institute, L'Aquila, Italy. [14]INFN Sezione di Lecce, Lecce, Italy. [15]Dipartimento di Fisica, Università di Salerno, Salerno, Italy. [16]INFN Gruppo Collegato di Salerno, Salerno, Italy. [17]Dipartimento di Scienze Applicate e Tecnologia, Politecnico di Torino, Torino, Italy. [18]INFN Sezione di Torino, Torino, Italy. [19]INFN Gruppo Collegato di Cosenza, Cosenza, Italy. [20]Dipartimento di Scienze Matematiche e Informatiche, Scienze Fisiche e Scienze della Terra, Università di Messina, Messina, Italy. [21]CERN, Geneva, Switzerland. [22]Dipartimento di Fisica e Astronomia, Università di Catania, Catania, Italy. [23]INFN Sezione di Catania, Catania, Italy. [24]ICSC World laboratory, Geneva, Switzerland. [25]INFN-CNAF, Bologna, Italy. [26]INFN Trento Institute for Fundamental Physics and Applications, Trento, Italy. [27]Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy. [28]Dipartimento di Scienze Fisiche, della Terra e dell'Ambiente, Università di Siena, Siena, Italy. [29]CNR Istituto di Fisica Applicata "Nello Carrara", Sesto Fiorentino (Florence), Italy. [30]Dipartimento di Fisica, Università della Calabria, Rende (Cosenza), Italy. [31]Dipartimento di Fisica, Università di Genova, Genova, Italy. [32]INFN, Laboratori Nazionali del Gran Sasso, Assergi (L'Aquila), Italy.

E-mail: `stefano.boi@ca.infn.it`

Abstract. The Extreme Energy Events experiment (EEE) is a cosmic ray observatory made of about 60 muon telescopes based on Multigap Resistive Plate Chamber (MRPC) detectors. The EEE experiment has two main targets: a scientific and a dissemination. The EEE collaboration has also developed a large set of portable scintillator-based detectors, named Cosmic Box (CB), mainly used for educational purposes. The CB allows students to perform cosmic ray counting measurements in several environments. CBs are made of two 15 x 15 x 1 cm scintillators read by two 3 x 3 mm^2 SiPMs operated in coincidence. Three CBs were deployed in Nuraxi Figus and Seruci coal mine to perform an underground measurement of the cosmic muon flux attenuation. High school and university students were directly involved in all the stages of the measurements: from the preliminary measurements to the on-site work and data analysis.

1. Introduction

The Extreme Energy Events project (EEE) is a joint experiment by *Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi* (CREF) and *Istituto Nazionale di Fisica Nucleare* (INFN) which aims to the study of cosmic rays [1]. It has two main targets: a scientific and a dissemination. An array of about 60 muon telescopes made of three Multigap Resistive Plate Chambers (MRPC) detectors is installed in several Italian high schools. Figure 1 shows the involved high schools, while figure 2 shows a telescope installed in a high school laboratory. With this observatory, the EEE collaboration is able to perform several physics measurements on secondary cosmic rays. A few examples can be found in refs. [2–4]. The peculiar laboratories in which telescopes are installed give the possibility to involve high school students in all these activities. In this way, the EEE project is not only a scientific experiment but also a dissemination opportunity. Every EEE student follows lectures on cosmic rays, covering items such as their discovery and importance, their nature and properties (composition, energy spectrum,..) and how to detect them. They are also introduced to widely used analysis software tools, as C++ and ROOT [5]. The schools with a detector are in charge of the daily checks on the system. The students, under their teacher supervision, have to check the voltage of the chambers, verify the DAQ and data transmission, verify the gas system and fill an online logbook. In the event of an anomaly, they report it on the logbook and contact their local responsible, who instruct them how to correct the anomaly if the intervention can be easily performed by the students or the teacher. Schools without the detector usually cooperate with schools hosting a telescope in several ways. In some cases, they share the laboratory and the daily shifts. During monthly online meetings they report their results to the entire collaboration. A general meeting in presence is also organized yearly when it is possible.

The EEE collaboration also developed a portable scintillator-based detector to be used as support for the MRPC telescopes characterization, to perform field measurements outside the laboratories and to participate to dissemination events. The detector is called Cosmic Box (CB) (fig 3). Three CBs have been used to perform underground muon flux measurements at Nuraxi Figus and Seruci mine in Sardegna, Italy. Four measurements have been performed at the moment: one at the surface and three underground. Some high school and university students were involved in all the stages of the experiment. The preliminary measurements and preparation were made with the help of university students, while the on-site installation and movement of the detectors underground were made with the help of high school students from Sardegna and Lombardia.

2. The Cosmic Box

The Cosmic Boxes (CB) are portable scintillator detectors. They are composed of two plastic scintillator planes of 15 cm x 15 cm x 1 cm, installed inside a plexiglass box. The distance between the two planes can be modified between 10 cm and 25 cm. Each scintillator is read by a pair of silicon photomultipliers (SiPM) installed in one of the scintillator corners, operated in coincidence. Technical specifications of the scintillators and the SiPMs are reported in Table 1. Three custom PCB have been developed for this detector. Two boards, one per scintillator, are used to supply the power to the SiPM and to perform the readout and discrimination of their signals. A motherboard is used to manage the voltage distribution, the coincidences between the

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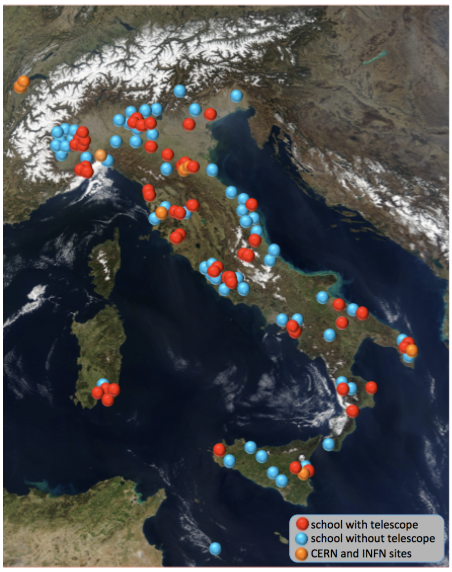


Figure 1: EEE laboratories. Red dots are schools with a telescope installed, blu dots are participating schools without a telescope, orange dots are INFN and CERN laboratories.

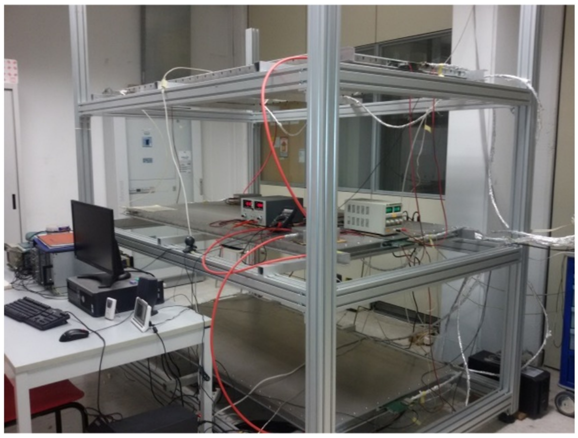


Figure 2: A view of one of the EEE telescopes installed inside a high school.

two planes and to provide a shaped output signal. The output is provided with a front display and with LVDS signals from a rear connector. The display allows to read the single scintillator or the coincidence counts. The rear connector provides LVDS signals for bottom scintillator, top scintillator and coincidence events. The power input can be provided both with a 5V wall adapter or with a common smartphone power bank. A 20 Ah power bank can provide enough power for two days of continuous acquisition, allowing using the detectors outside the buildings and making them a good choice for outside measurements and dissemination events.

Table 1: Scintillator and SiPM specification

Scintillators	
Productor	Eljen Technology
Model	EJ-200
Polymer Base	Polyvinyltoluene
Density (g/cm^3)	1.023
Photoefficiency (ph./MeV)	10000
Attenuation Length (cm)	380
Emission wavelength (nm)	425
Silicon photomultipliers	
Productor	ADVANSID
Model	NUV3S-P
Pixel width (μm)	40
Fill factor	60%
DCR (kHz/mm^2)	100

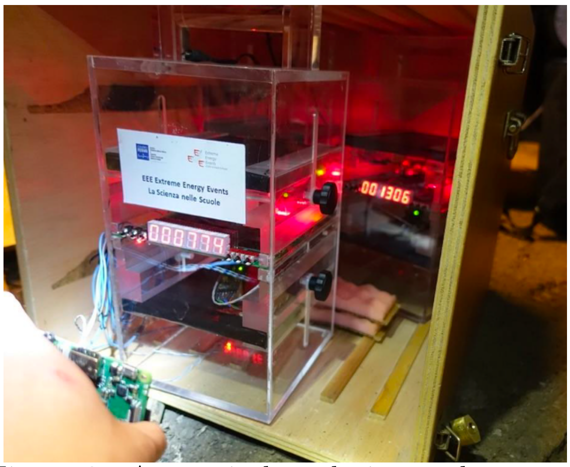


Figure 3: A cosmic box during underground measurements.

For the measurements presented in this work, three CBs were used. The system is equipped with a Raspberry Pi for data acquisition. The LVDS coincidence signals from the CBs is level adapted and acquired by the GPIO of the Raspberry Pi. The computer is equipped with a RasClock module, to provide a stable clock, and with the BME280 environmental sensor. For each CB the timestamp of the top-bottom coincidence events is written. Barometric pressure, temperature and humidity are also recorded to check the environmental stability and possibly correct the fluctuations of the SiPM. Since the internet network is not available underground, data were recorded on an SD card and recovered manually. The power supply is provided by the electrical system of the mine, but a UPS has been used for backup.

3. Dissemination impact

The CBs were designed by EEE researchers and have been assembled by high school students from Torino. EEE researchers took care of the supervision during the production process, the technical characterization and the SiPM discrimination threshold tuning.

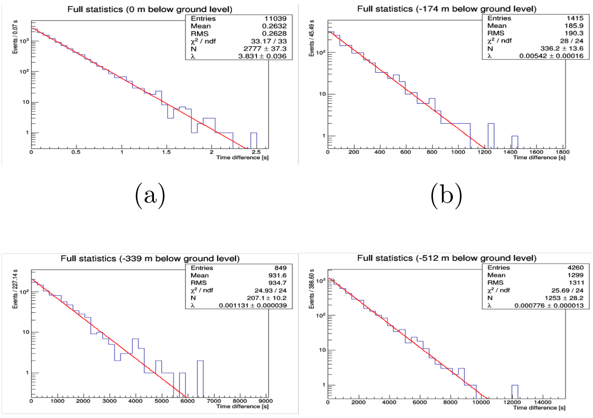
Before the underground measurements, the preliminary studies, which have foreseen also preliminary measurements at about 100 m underground, were prepared and conducted by EEE researchers with the help of students from the University of Cagliari. They took care also of the planning of the measurements and the test of all the equipment before moving it underground. During the underground measurements, students from three high schools were involved: Liceo "A. Pacinotti", Liceo "Michelangelo" from Cagliari in Sardegna and Liceo "G. Casiraghi" from Cinisello Balsamo (MI) in Lombardia. From two to three students accessed the mine together with their teacher for almost every intervention to the detectors. Inside the experimental area, they put in place the detectors, powered them on, started the data acquisition and recovered the data already acquired from the system. For safety reasons, the movement of the detectors was performed by the local technicians. Both students and researcher presented the status of the activities and the results in several internal meetings.

From an educational point of view, this experiment gave the opportunity to cover several items. Besides the introduction of cosmic rays, which is covered by all EEE students, with this experiment we had the possibility to discuss cosmic ray propagation and absorption in matter. The atmospheric absorption of muons has been already studied by EEE students [6]. With the underground measurements, we can extend the concept and have a direct experience of the implication to the underground laboratories. Since the flux at 500 m underground is of the order of 1 mHz, it is interesting to see which analysis strategy could be used. This requires introducing some knowledge in statistic, such as the exponential law, the Poisson law, how to treat the experimental error and how to calculate the background contribution. Even if it doesn't concern the physics or the research from the scientific point of view, it is worth to be noted that all students had to take part in a safety briefing and learn how to use a self-rescue mask before accessing the mine, exactly how every researcher should do before accessing a laboratory.

4. Preliminary scientific results

For the measurements, a second independent detector called AstrO, made of 8 plastic scintillators read by SiPM [7], was deployed to give more reliability to the results.

The plots in figure 4 show the time difference distribution between two consecutive events for the various depths. Each plot is the sum of the events of the three cosmic boxes. The fit confirms that it follows an exponential distribution as expected, and from the exponential parameter we can obtain the events rate. The graph reported in figure 5 represents the rate as a function of the depth, normalised to the rate at the surface. The statistical error is reported and it is smaller than the dimensions of the dots. By normalising the results for the two different detectors, they were corrected for the efficiency. Due to the fact that the integrated acceptance depends on the angular distribution of the particles, which is different at the various depths, we



(a) (b) (c) (d)

Figure 4: Distribution of the time difference between two consecutive events at different depths. The red line is the exponential fit. Fig. 4a: ground level (rate: 3.83(4) Hz); fig. 4b: 174 m underground (5.4(2) mHz); fig. 4c: 339 m (1.13(4) mHz); fig. 4d: 512 m (0.78(1) mHz).

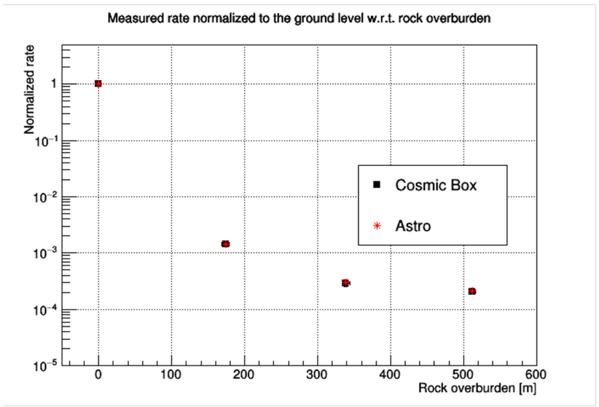


Figure 5: Normalised rate as a function of the depth.

cannot consider the normalised rate as the true ratio of the flux underground and at the surface. Nevertheless, since the detectors were very close to each other, the normalised rate is no more dependent on the surface and shape of the detector. This implies that we can compare the two sets of normalised rate, which, as we can see from the plot, is consistent for all depths.

5. Conclusions

The EEE project has the peculiarity to pursuit both a scientific and dissemination activity. The collaboration started a muon flux measurement campaign underground at Nuraxi Figus and Seruci mine, down to a depth of about 500 m, which roughly corresponds to a depth of 1100 m.w.e. This campaign involved high schools and university students in all the stages of the measurements. In particular, they contributed to the detector building and characterization, the preliminary measurements, the planning, the on-site work and the data analysis. In particular, during on-site activities, they were involved in the installation of the detector, the DAQ startup and the extraction of the acquired data. About 15 high school students with their teachers were involved in the on-site work, giving them the opportunity to work in an unconventional laboratory.

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