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Small shower array for education purposes – the CREDO-Maze Project

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We have noticed in many places around the world in recent years an increasing interest in small-scale extensive air shower experiments designed to satisfy young people's scientific curiosity and develop their interest in science and in physics in particular. It is difficult to think of ways and opportunities to introduce practical classes in modern high-energy physics, astrophysics, or particle physics into school curricula and after-school activities. Small EAS array experiments are just such a proposal. As part of the CREDO-Maze project, we plan to equip local high schools with sets of four small detectors, with a simple system for triggering, recording, and online communication with the world. Networked experiments from several schools add significant new educational value to the process of developing good behavior appropriate to scientific communities. Cooperation and competition at the stage of own research and information exchange are essential new and valuable values in educating young generation. Small local arrays connected to the global CREDO network will provide additional data and opportunities for important cosmic ray studies, what is an additional benefit of the CREDO-Maze Project. In this paper we will present the characteristics of our prototype detector.

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1. Introduction

There is a belief that conducting research and experiments in particle and high-energy physics is reserved only for scientists from scientific centres with powerful research facilities. However, anyone can use the constant and uniform bombardment of the Earth's surface with cosmic rays to study the properties of high-energy particles (especially muons), test relativity (e.g. the twin paradox) or monitor the impact of space weather id. Such experiments can be offered to children as part of a range of school lessons as well as extracurricular activities. Similar activities are regularly undertaken and described in the literature:

- *An educational study of the barometric effect of cosmic rays with a Geiger counter* by Famoso, La Rocca and Riggi (2005) [1],
- *Educational cosmic ray experiments with Geiger counters* by F. Blanco *et al.*. (2006) [2],
- *Geiger counters offer powerful way to teach detection methods* by F. Blanco *et al.*. (2006) [3],
- *Educational studies of cosmic rays with telescope of Geiger-Muller counters* by T. Wibig *et al.*. (2006) [4],
- *Cosmic ray measurements by scintillators with metal resistor semiconductor avalanche photo diodes* by F. Blanco *et al.*. (2008) [5],
- *Cosmic rays with portable Geiger counters: From sea level to airplane cruise altitudes* by F. Blanco, P. La Rocca, and F. Riggi (2009) [6],
- *An Inexpensive Cosmic Ray Detector for the Classroom* by Goldader and Choi (2010)[7],
- *The EEE Project: cosmic rays, multigap resistive plate chambers and high school students* by Abbrescia *et al.*. (2012) [8],
- *High energy astroparticle physics for high school students* by Krause *et al.*. (2015) [9],
- *μCosmics: A Low-Cost Educational Cosmic Ray Telescope* by Tsirigotis and Leisos (2019) [10].

Some of these works are experiments performed with single cosmic ray muons, which are very numerous and highly penetrable However, it would be most attractive to study a phenomenon called Extension Air Shower (EAS) - a cascade of elementary particles travelling at the speed of light (almost) from the upper layers of the Earth's atmosphere to the surface, where we can see them. They arrive in a very short instant as a disk of particles (a millions or even a billions). The source of such very high-energy particles that initiated such a showers is in general unknown, as is the mechanism of their acceleration in astrophysical sources.

One of those seeking answers is the Cosmic Ray Extremely Distributed Observatory (CREDO) Project[11]. By design, it is a large international enterprise, now consisting of 19 countries, involving many scientific and educational institutions. The main scientific objective of CREDO is the detection of so-called cosmic ray ensembles. These are beams of cosmic rays of very high energy, producing simultaneous extensive air shower across the exposed surface of the Earth. Such a phenomenon has never been seen, but there are several models in which such an event is possible. A system operating on a global scale is needed to observe such events.

In the paper *The first CREDO registration of extensive air shower*[12] we tested the principle of a small local array for EAS detection build with the commercially available small CosmicWatch Muon Detector.

The Cosmic Watch detectors had an area of 5 cm × 5 cm and the chance of them observing some EAS was very small.

Therefore we decided to design our small local array for EAS recording. First of all we increased the size of the individual detectors almost 10 times to 20 cm × 10 cm which will significantly increase the rate of registration.

The design of the small local station for EAS detection is still under development, but to increase the speed of collected statistics we built a new detector 8 times bigger than the mentioned CosmicWatch Muon Detector. When designing the EAS station, we must keep in mind the low budget of local groups who might be interested in this activity, mainly schools and educational institutions. We want the EAS detection station to be accessible to students and enthusiasts.

2. The CREDO-Maze Detector

2.1 Detector design

A plastic scintillator of size 10 cm × 20 cm, which is viewed by two 1 mm × 1 mm silicon photomultipliers (SiPM) were used to build the single detector prototype. To maximise the amount of light, two 1 mm thick optical fibres were mounted in the scintillator and connected to the SiPMs. The arrangement of the optical fibres is shown in Fig.1.

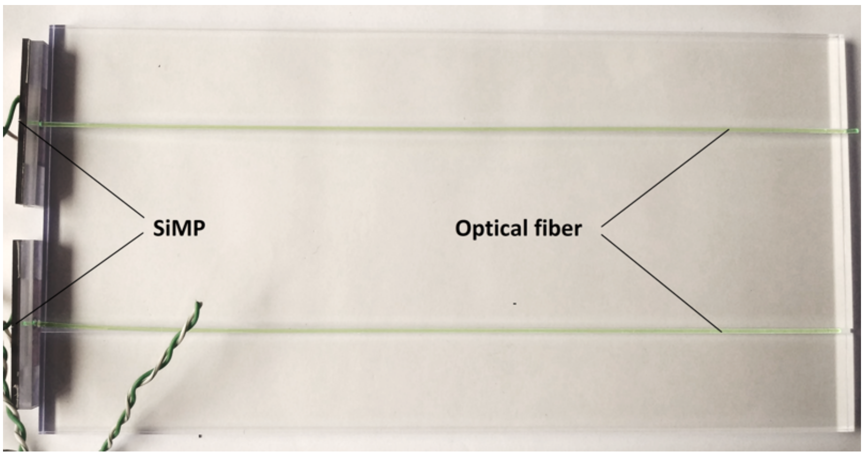

Figure 1: View of (uncovered) scintillator, arranged optical fibres and light-collecting SiPMs.

It is important that the optical fibres point centrally at the active area of the SiPM. We have made them special holders for the ends of the optical fibers.

After mounting the fibers and SiPMs, the scintillator is wrapped with tyvek paper and then it is wrapped in thick aluminium foil, which protects the detector from visible light.

2.2 Electronics

Two electronic circuits have been designed for the CREDO-Maze detector. The first circuit is a SiPM printed circuit board (SiPM PCB) which amplifies and forms the signal from the SiPMs. The PCBs include: SiPM supply voltage filter, the preamplifier build on afast transistor which amplifies of about ten times the SiPM's signals, and comparator with the adjustable threshold providing a rectangular signal (logical +5 V) .

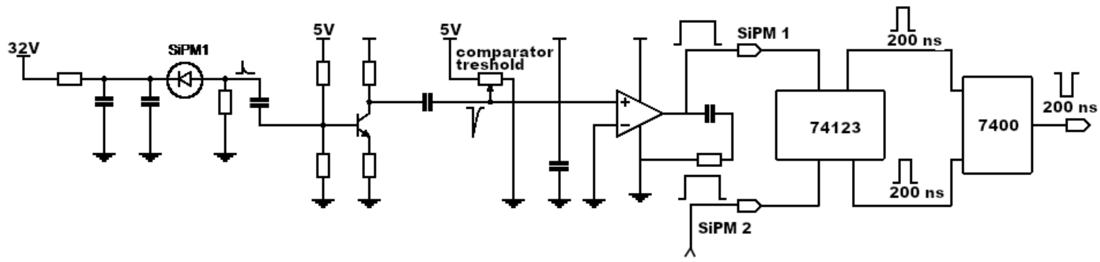

Figure 2: Detector circuit diagram.

The signal from the comparator has a rectangular form with the width of 200 μs. This width will prevent the system from being triggered by possible afterpulses The rising edge of the comparator signal activates the 1/2 of UCY74123 monovibrator, which forms logical signal of the width of 200 ns and sends them to the coincidence circuit. The narrow width of the monovibrator outputs (200 ns) eliminates practically any accidental overlapping of signals coming from both detector SiPMs. The resulting outgoing signal from the detector goes to the central unit of the local EAS array.

3. Results

In order to test the detectors and verify their correct performance we set up an arrangement of the two scintillation counters described above in a telescope setup. We know the value of the flux of incoming muons and their angular distribution, so we can compare how our two detector telescope behave when moving one of them horizontally against the other both along the long side (20 cm) and along the short side (10 cm). The first of these measurements tests the homogeneity of the detector, the second additionally checks the efficiency of placing only two optical fibres at a distance of 5 cm one from the other

We recorded the two detector coincidence counting rate as a function of the displacement.

The measurement results are compared with predictions obtained from the integration of the incoherent muon flux at sea level with the condition that the both detector surfaces of a given geometry are crossed. In these calculations it has been assumed that the detectors are ideal, which means that every muon crossing the surfaces of both detectors gives a signal to be counted.

4. Summary and conclusions

The detector under development was designed to find its application in local school small EAS arrays. One of its characteristics should be a low price. This is affected mostly by the cost of

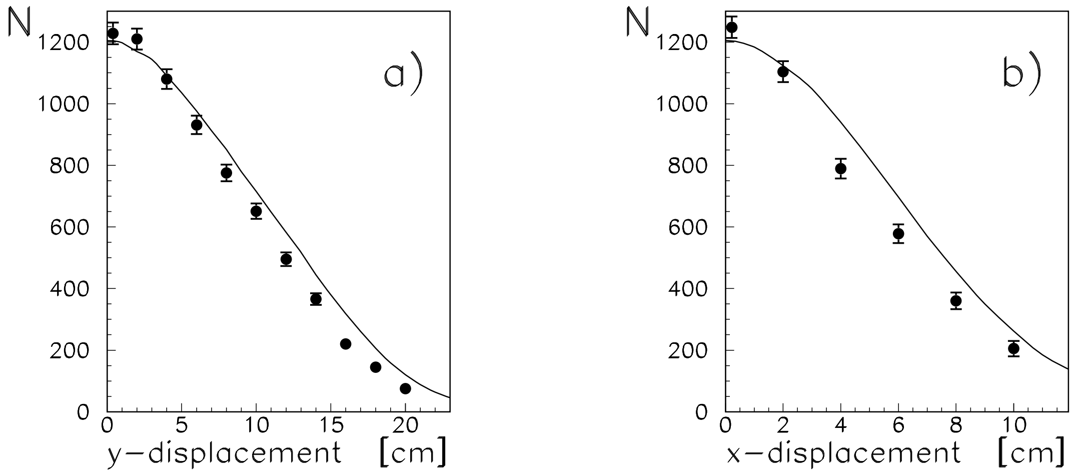

Figure 3: Numbers of coincidence (points) recorded for 30 minutes for a telescope of two detectors with one of them moved along the long side a) and the short side b). The lines show the normalised predictions for well known flux of incoherent muons.

scintillators and SiPMs. We have used the minimum reasonable dimensions of scintillators and diodes with the smallest cathode area, which definitely influences their price. On the other hand, these conditions reduce the magnitude of the recorded signals. This work shows that with the assumed limitations our prototype detectors register single cosmic ray muons and therefore can be used in small, school burst apparatuses.

The four detectors we plan to use in the school arrays will also allow several milestone cosmic ray experiments to be repeated, e.g., the Rossi's transition curve observation, measurements muon attenuation, relativistic time dilation on an example of moun decays in the atmosphere, muon lifetime measurement, or even the reconstruction of famous Auger and Maze's experiment on the roof of the École Normale Supérieure, where they observed for the first time Extensive Air Showers.

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