PROCEEDINGS OF SCIENCE

Small Extensive Air Shower detector array – a tool for global cosmic-ray research

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The CREDO collaboration studies cosmic-ray related phenomena on a large scale, searching for so called Cosmic-Ray Ensembles (CRE) and other unusual correlations and anomalies of non local nature. Such studies require data on Extensive Air Showers (EAS) and flux of secondary cosmic-ray particles that covers large areas. To perform such measurements, a large network of inexpensive detectors working continuously is necessary, and this work presents a design of such device. It comprises several small (5 cm × 5 cm × 1 cm) scintillator detectors connected in a flat coincidence circuit, which makes it a desktop-size device. Such station is designed to work for months or even years without human intervention, as it can send collected data directly to the database through internet. Cost of construction of a complete device ranges from 1000 \$ to 2000 \$ depending on the number of detectors used. Results of measurements performed with the use of constructed prototype are compared with estimations based on the analysis of CORSIKA simulations of EAS with Geant4 simulation of scintillator detectors response. They indicate that the proposed device is capable to measure flux of cosmic rays with high statistics and can reliably distinguish EAS events from signals originating from various backgrounds. It is a good candidate for an element of a large-scale network that should be able to not only monitor cosmic-ray flux on large area in real time, but also provide data for studies of CRE and any other phenomena related to cosmic rays.

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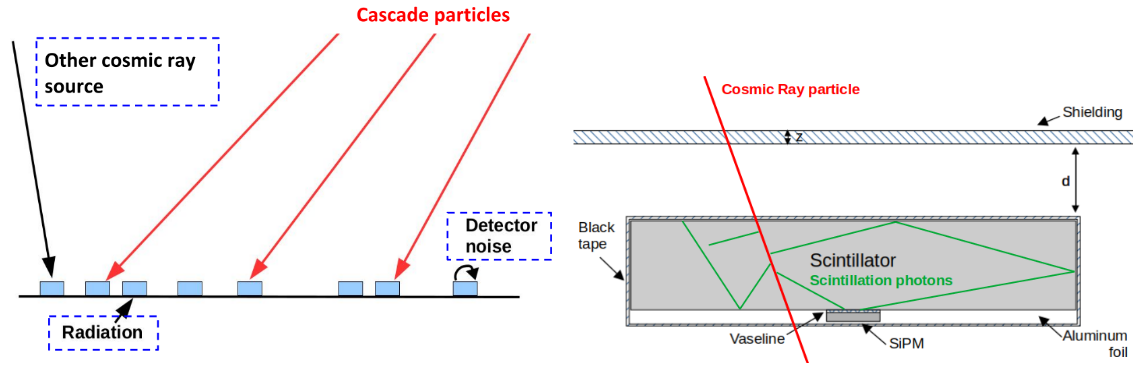

Figure 1: Sources of signals registered by an array of flat detectors (left). Principle of scintillator operation (right).

1. Introduction

One of the main goals of the Cosmic Rays Extremely Distributed Observatory (CREDO) is the search for Cosmic Ray Ensembles (CRE) – a groups of correlated Extensive Air Showers (EAS) of common origin in outer space [1]. To confirm the existence of such phenomena large scale observations of EAS signals and analysis of their correlations in time are necessary. For this purpose, infrastructure of low-cost detector stations should be developed, distributed across the Earth, and connected in a global network. Currently, the main source of data for CREDO are smartphones in which cameras are used as particle detectors with the use of a dedicated application [2]. However, each smartphone behaves differently and provides only information about individual particles with a very poor temporal resolution ($\sim$ 1/30 s). This makes such data insufficient for analysis of correlations between single events. A candidate for a device with properties better suited for such purposes is an array of a few small scintillator detectors connected in a coincidence circuit. This work presents a prototype of such station and an exemplary method of searching for CRE that produce line-like patterns using a network of such devices placed on the surface of the Earth is presented.

2. Detector array

Detection of EAS with a small array of scintillator detectors has already been attempted [3, 4]. This project aims to provide the most optimal design. Signals registered in several devices in a very narrow time window should indicate the occurrence of an EAS. However, it is necessary to account for possible signals from other sources, as illustrated in Fig. 1 (left).

2.1 Scintillator detectors

The active element of the considered array is a small detector based on the Cosmic Watch design [5]. It consists of a 6 mm $\times$ 6 mm SiPM converting photons into an electric signal attached to the centre of a 5 cm $\times$ 5 cm $\times$ 1 cm plastic scintillator as presented in Fig. 1 (right). According to Geant4 [6, 7] simulations with the use of proper shielding it should have very high sensitivity

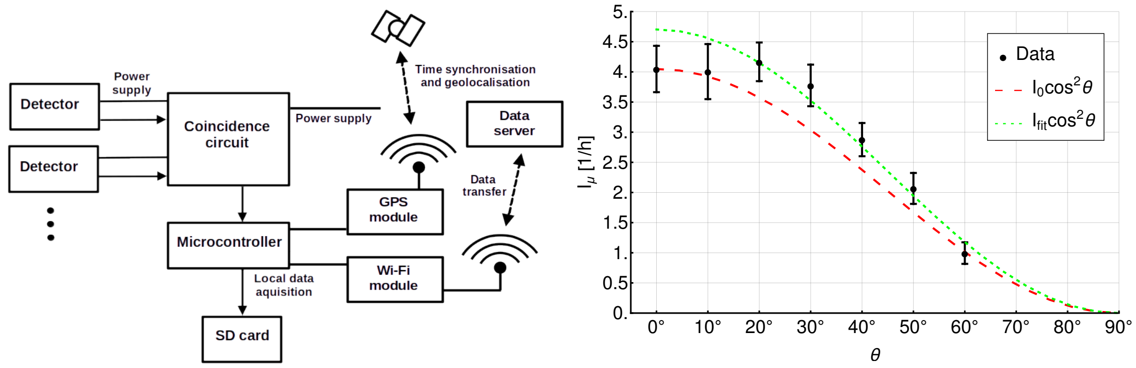

Figure 2: Diagram of proposed detector array (left). Relationship between muon flux I_μ [1/h] and zenith angle θ measured with two detectors in a top-bottom setup (right). $I_0 \approx 4.05$ 1/h which is a value measured in vertical configuration.

(close to 100%) to muons and high energy electrons (momentum > 3 MeV) and low sensitivity for photons (raising from 2% for X-rays to 20% for 1 GeV gammas).

2.2 Coincidence system and data collection

All detectors are connected to a master device which provides power, contains a coincidence circuit, and a microcontroller which saves the data locally and sends it to the database through the internet. The recorded data include the time of each event, the detector location, number of signals in coincidence, temperature, pressure, and humidity inside and outside the detector enclosure. The diagram of such station is presented in Fig. 2 (left).

3. Measurements

In the first detector performance test the relationship between cosmic-ray flux and the zenith angle, θ, was measured. Its results are presented in Fig. 2 (right). It agrees with the expected $\cos^2\theta$ dependence, but the value of $I\mu(0) \approx 70$ m^{-2}s^{-1}sr^{-1} for muons with momentum greater than 1 GeV/c [8] suggests that the real efficiency of the detector is between 20% and 30%. The next measurements in a flat coincidence setup, which lasted together for about a month, were performed on the roof of a university building. Three different thicknesses of steel shielding were used: 0.5 mm, 1 mm and 1.5 mm. Results of these measurements compared to estimations based on CORSIKA simulations are presented in Fig. 3 (left). What seems unusual in those results is the excess of double coincidence signals. They are probably caused by single cosmic-ray particles which interact with the material of the enclosure which produces additional particles like electrons. Those particles then hit the second detector, causing a coincidence event that is not a sign of observation of an EAS.

The analysis of CORSIKA and Geant4 simulations allows to estimate which primary cosmic-ray particles generate the registered signals. Their energy distributions are presented in Fig. 3 (right).

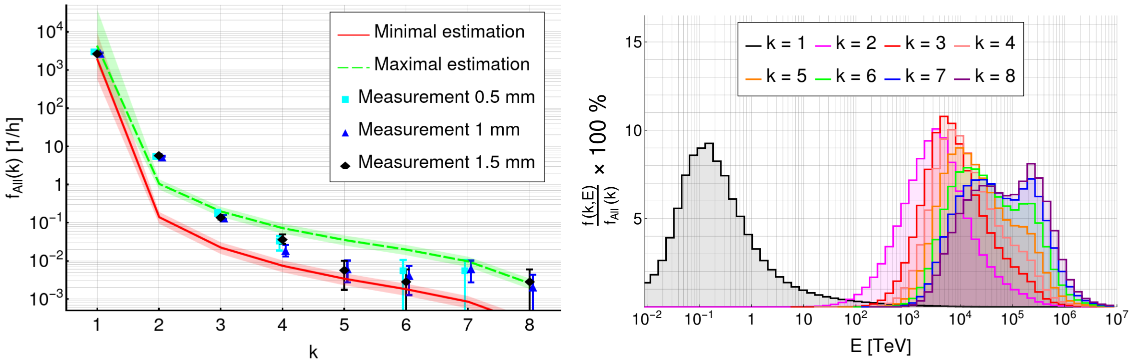

Figure 3: Frequency of coincidence events, $f_{All}(k)$, as a function of number of detectors triggered in a single event, k. The plot presents results from measurements with several thicknesses of steel shielding compared to estimations based on CORSIKA [9] and Geant4 simulations (left). Percentage of signals, $f_(k, E)/f_{All}(k)$, caused by cascades initiated by primary particles of different energies, E, (right).

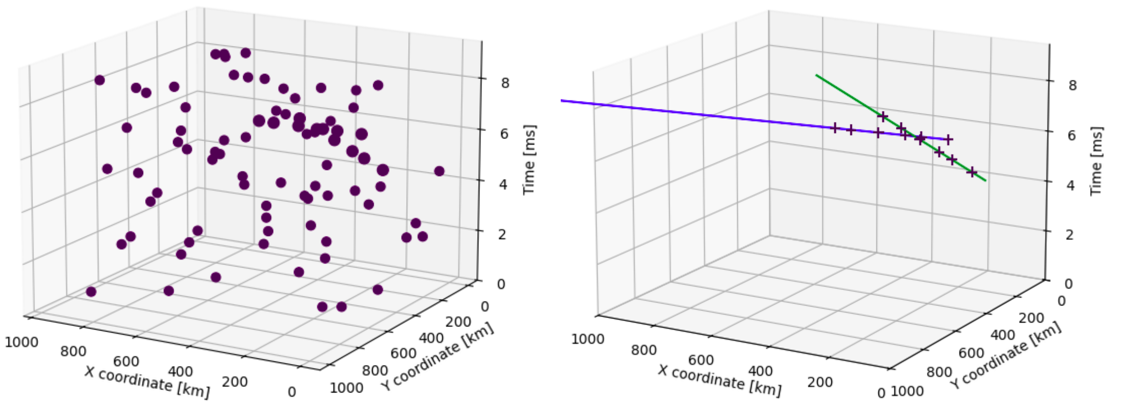

Figure 4: Algorithm input (left panel). Simulation of background and signals from two line-like CREs in a network of 10 000 devices with parameters mimicking constructed prototype. Algorithm output (right panel)

4. Searching for CRE

Using a single station, a single cosmic-ray cascade can be detected. In the global network of stations, it could be possible to find multiple cascades indicating the discovery of CRE. One of the most favourable CRE scenarios predicts groups of photons which can form a very narrow (meter-wide) and long (thousands of kilometres long) line when passing through Earth's atmosphere [10]. Such line-like footprint of secondary cosmic rays reaching the surface of the Earth could be observed with the use of proposed detector arrays. The possibility of detection of such phenomena was studied for a grid-like network of 10 000 stations placed 10 km from each other, for which simulations of CRE overlaid on an uncorrelated background were performed. The registered signals were divided into appropriately narrow slices in time, and then an algorithm was searching for signals placed close to some straight lines. The result of this analysis is a list of potential candidates for line-like CRE ensembles (Fig. 4).

4.1 Conclusions

Small detector arrays that should cost no more than $ 1500 can efficiently monitor cosmic-ray flux and observe EAS of relatively high energy with a frequency of at least few per hour. However, further measurements are necessary to confirm the cause of the excess of double coincidence events. Improvements in the design of detectors to make their efficiency better and more uniform are still possible. Such devices, when used in a sufficiently large and dense network, should be a great tool for global cosmic-ray research that could make observation of CRE possible.

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