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

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Introduction

One of the main goals of the Cosmic Rays Extremely Distributed Observatory (CREDO) is the search for Cosmic-Ray Ensembles (CRE) – occurrences of correlated Extensive Air Showers (EAS) [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 over the Earth and connected in a global network. A good candidate for such device is an array of a few small scintillator detectors connected in a coincidence circuit. This work presents a prototype of such station. Conclusions from the first measurements conducted with it is that it indeed measures cosmic ray flux and is able to observe EAS with temporal resolution that should be sufficient for searching for large scale correlations between individual events. As an example a 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.

Detector array

Detection of EAS with small array of scintillator detectors has been already attempted [2, 3]. This project aims to provide the most optimal design. Signals registered in several devices in a very narrow time window should indicate an occurrence of an EAS. It is however necessary to account for possible signals from other sources as illustrated in Fig. 1:

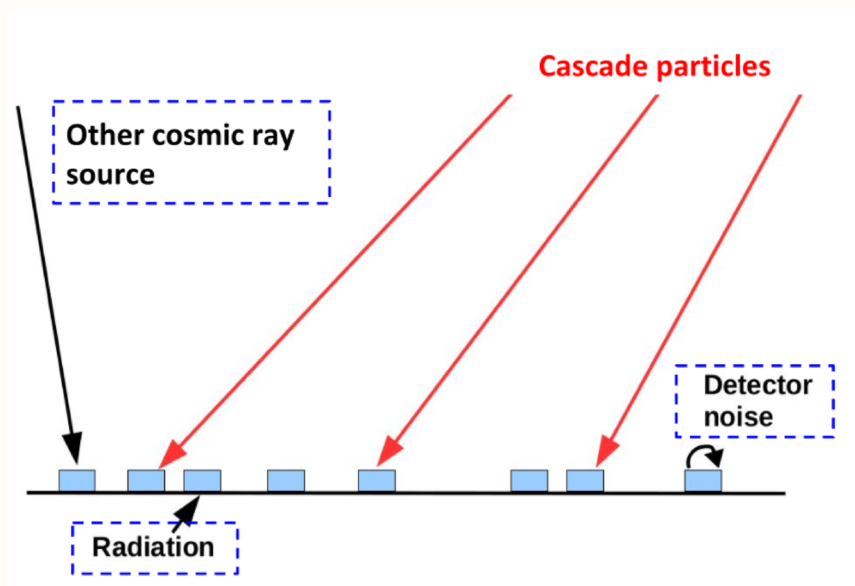

Figure 1: Sources of signals registered by an array of flat detectors.

Scintillator detectors

The active element of the considered array is a small detector based on Cosmic Watch design [4]. It consists of a 6 mm×6 mm SiPM converting photons into electric signal attached to the centre of 5 cm×5 cm×1 cm plastic scintillator as presented in Fig. 2.

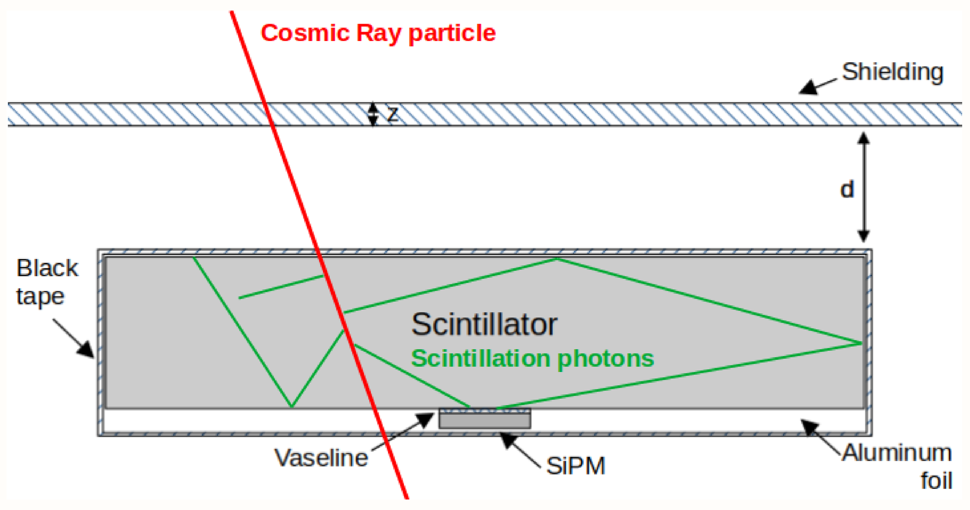

Figure 2: Principle of scintillator operation.

According to Geant4 [5] simulations with the use of proper shielding it should have very high sensitivity (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). One of currently tested prototypes is presented in Fig. 3.

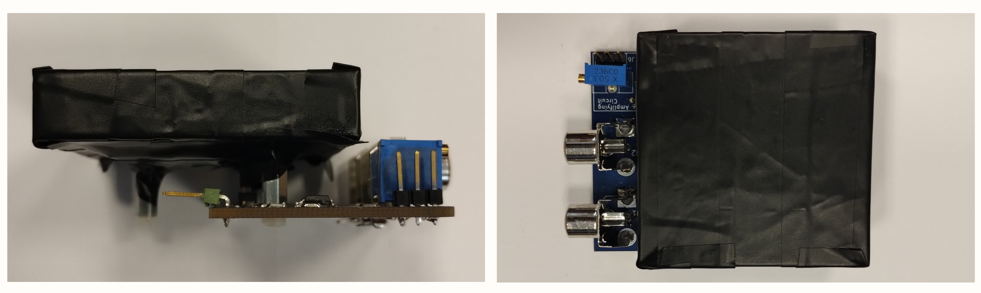

Figure 3: Prototype of simplified Cosmic Watch (without enclosure).

Coincidence system and data collection

All detectors are connected to a master device which provides power, contains coincidence circuit and a microcontroller which saves the data locally and sends it to the database through internet. Recorded data include time of each event, detector location, number of signals in coincidence, temperature, pressure and humidity inside and outside the detector enclosure. Diagram of such station is presented in Fig. 4.

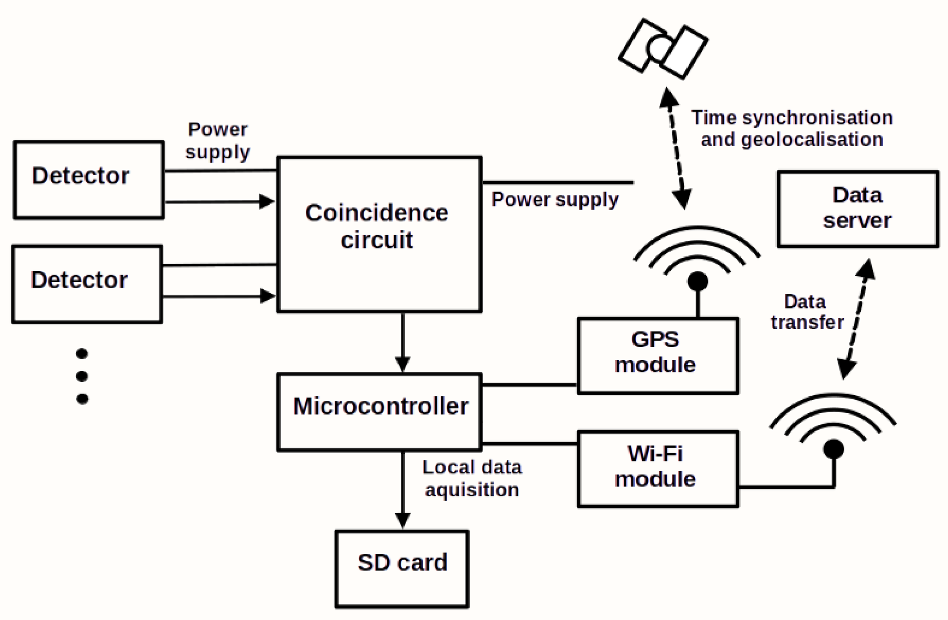

Figure 4: Diagram of proposed detector array.

Measurements

In the first detector performance test relationship between cosmic-ray flux and zenith angle, θ, was measured (Fig. 5). It agrees with the expected $\cos^2\theta$ dependence, but the value of $I\mu(0) \approx 70\ \mathrm{m^{-2}s^{-1}sr^{-1}}$ for muons with momentum above 1 GeV/c [6] suggests, that the real efficiency of detector is between 20% to 30%.

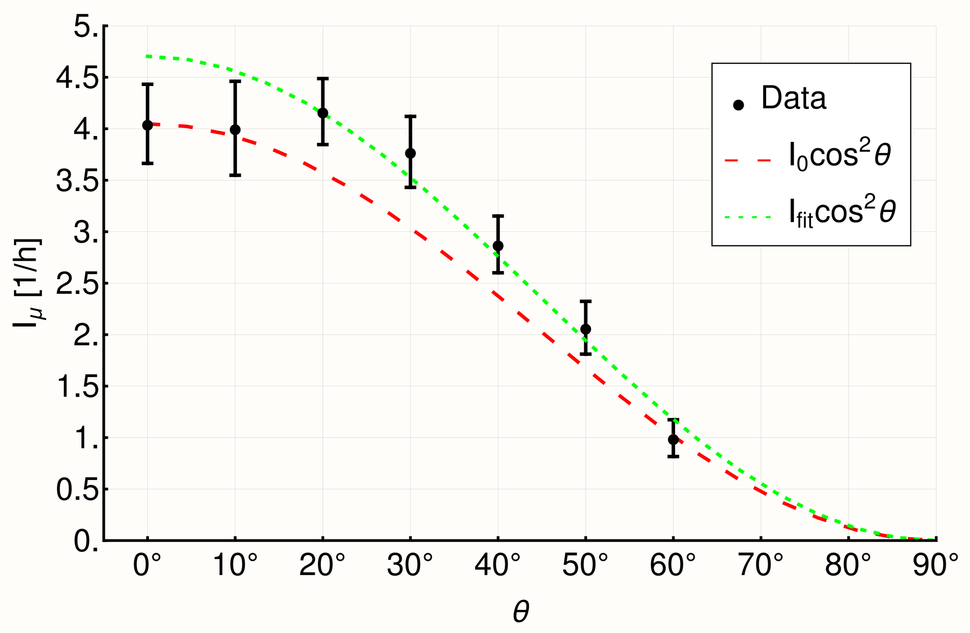

Figure 5: Relationship between muon flux I_μ [1/h] and zenith angle θ measured with two detectors in a top-bottom setup. $I_0 \approx 4.05$ 1/h which is a value measured in vertical configuration.

Next measurements were performed in a flat coincidence setup dedicated to observation of EAS. Array and its placement are presented in Fig. 6 and results are presented in Fig. 7.

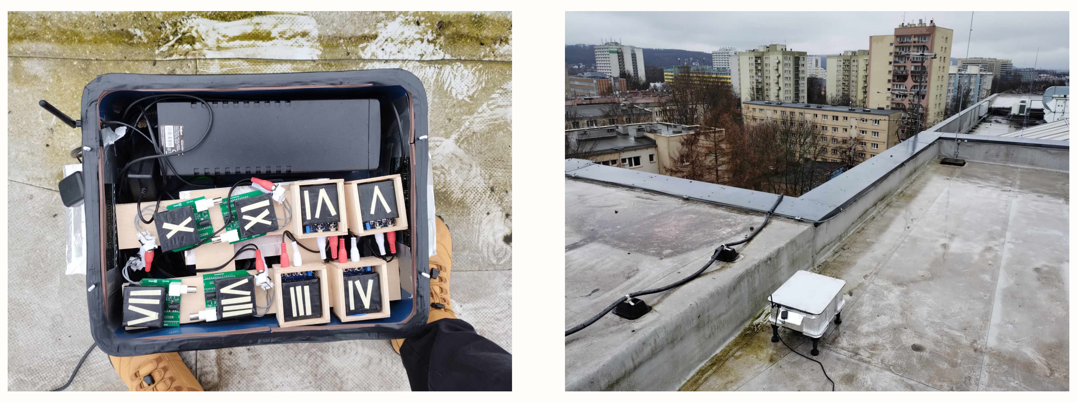

Figure 6: Conditions of measurements in a flat coincidence setup.

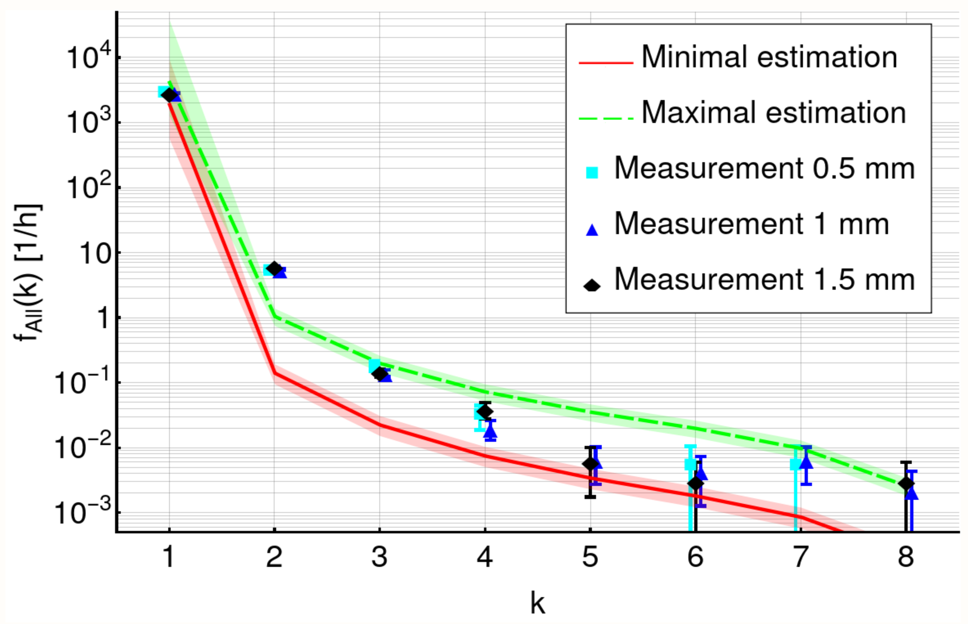

Figure 7: Frequency of coincidence events from measurements with several thicknesses of steel shielding compared to estimations based on CORSIKA [7] and Geant4 simulations.

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. 8.

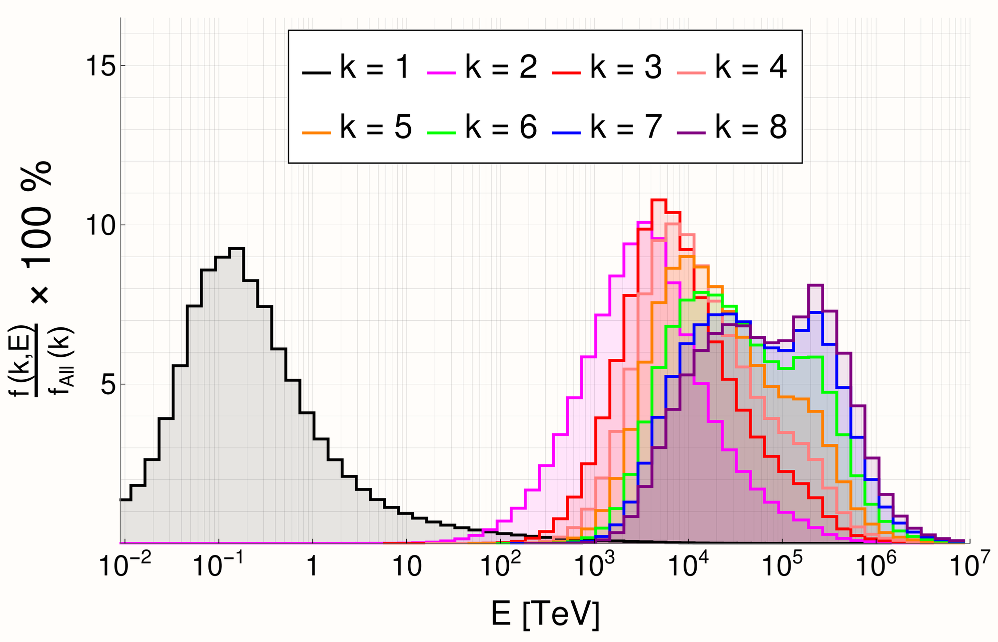

Figure 8: Percentage of signals caused by cascades initiated by primary particles of different energies.

Searching for CRE

Using a single station a single cosmic-ray cascade can be detected. In the global network of stations we hope to find multiple cascades indicating discovery of CRE. One of most favourable CRE scenario predicts groups of photons which can form a very narrow (meters width) and long (thousands of km long) line when passing through Earth's atmosphere [8]. Such line-like footprint of secondary cosmic rays reaching surface of the Earth that could be observed with the use of proposed detector arrays. 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 uncorrelated background were performed. Registered signals were divided in appropriately narrow slices in time and then an algorithm was searching for signals placed close to some straight lines.

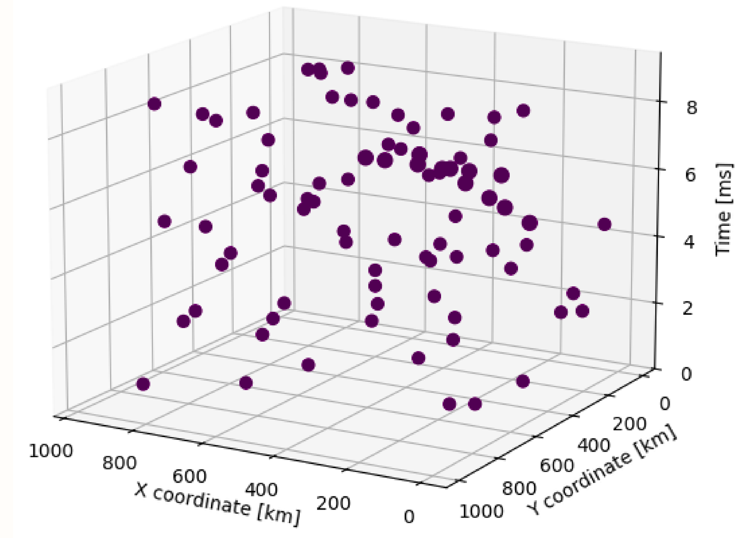

Figure 9: Algorithm input. Simulation of background and signals from two line-like CREs in a network of 10 000 devices with parameters mimicking constructed prototype.

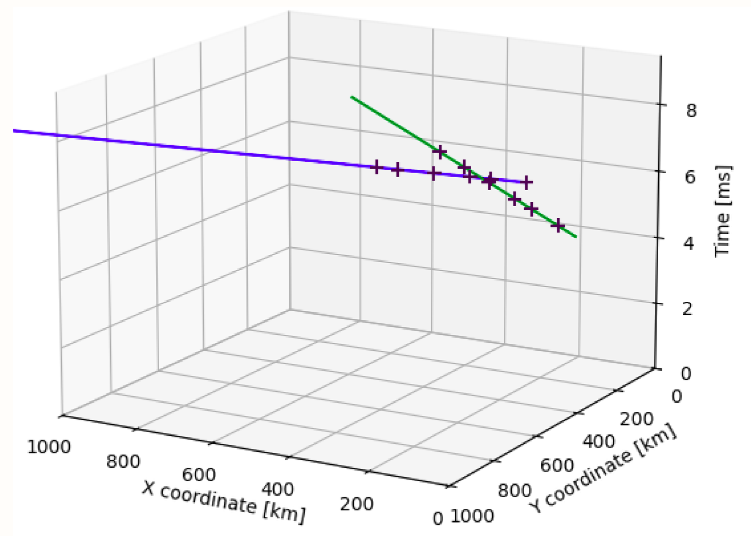

Figure 10: Algorithm output.

In Fig. 9 signals from background and two simulated CRE are depicted, while in Fig. 10 results of the search – two reconstructed lines – are shown. The algorithm correctly identifies the signals from those CRE. By analysis of number and types of signals in the vicinity of those lines a potentially candidates for CRE events can be recognised.

Summary

- Small detector arrays can monitor cosmic-ray flux in real time.
- Proposed small detector arrays should efficiently detect EAS of relatively high energy (at least few/h).
- Cost of each station is around $1500.
- More measurements are necessary to explain the excess of events with double coincidence ($k = 2$). Significant fraction of them may be caused by a single cosmic-ray particle interacting in the enclosure and producing more particles.
- Improvements in the design of detectors to make their efficiency better and more uniform are still possible.
- A sufficiently large and dense network of such stations should be able to reliably observe CRE.

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