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High Energy Cosmic Rays Detection by Bulgarian Extensive Air Showers Array (BEASA) Part II. Time and Amplitude Dependencies of the Signals on the Geometry of the Detector Cluster

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Abstract – **The correlation of the output signals of a group of scintillation detectors designed to register extensive air showers is studied as a function of their relative positions.**

Keywords – **Sensor Groups, Signal Correlations, Extensive Air Showers**

I. INTRODUCTION

It is known that the extensive air showers (EAS) [1] induced by the extremely high-energy cosmic particles have several components:

- A "hard" component, consisting of muons and neutrons;
- A "soft" component, consisting of electrons and photons (Bremsstrahlung);
- A component, consisting of light photons (Cherenkov radiation);
- Ultra low radio frequency (RF) electromagnetic bursts (in the range 1 – 10 kHz).

A. Registration of the EAS Components

The principal methods used for registration of cosmic rays are based on their properties when interacting with the matter and include:

- Registration of the charged particles during their transition through specific media (detectors);
- Registration of the Cherenkov radiation emitted by the relativistic charged particles in the atmosphere;
- Registration of low-frequency electromagnetic (EM) waves (in the range 1 – 10 kHz), induced by the interaction of the charged particles with the Earth's EM field.

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Different sensors are used to register different EAS components: muons are usually detected by inexpensive organic (plastic or liquid) scintillators coupled with fast coincidence/non-coincidence circuits, Cherenkov light - by air or water detectors, coupled with PMT, and in the third case ultra-longwave radio-receiver systems combined with spectra analyzers are used [2].

Some of the largest observatories in the world have several hundred scintillation detectors spread over 12 to 100 km^2 area.

B. University Detector Clusters

The accessibility of the Global Positioning System (GPS) allows for the connection of stations with a relatively high number of detectors into a network after a precise time synchronization of the registered events. In addition:

- development of small stations with global time synchronization becomes available to small collaborations (e.g. at university level);
- a new possibility appears for construction of many stations, situated at large distances apart from each other.

Such systems of stations for cosmic radiation study ave been built already, or are under construction in the USA, Canada and in several European countries [4, 5]. The European stations are in process of consolidation in a common network – Eurocosmics.

C. Summary

Usually the small detector systems comprise of several (at least two) scintillation detectors, placed at a certain distance from each other. Fast coincidence circuits are used to follow the simultaneous signal generation in both detectors and register the moment when the event occurs. The data from several systems is synchronized and processed together.

D. Research Goal

The goal of this research is the establishment of a detector system configuration which will allow the extraction of maximum number of parameters for the registered shower.

II. DETECTOR SYSTEM CONFIGURATION

If more than three scintillation detectors, located in different planes in space (Fig. 1), are linked together, that would make possible the reconstruction of more parameters of the air shower (e.g. EAS primary direction, density of the muon flux, etc.). One particular case of organic scintillation detector cluster with dimensions of each part 0.5x0.7 m and 0.01 m thickness has been analyzed. The scintillation pulse is registered by fast XP1912 photomultipliers. They are characterized by rising time of the pulse of only about 2 ns and so, its influence on the form of the signal is insignificant and can be ignored.

A. Definition of the Time Parameters

As it is shown in [6] the muons in an EAS are distributed in a disk with 10 m thickness. If the first detector (S0 on Fig.1) is displaced by 10 m above the rest of the detector group, it is guaranteed that the signal will be induced first into it. This signal will be used as a trigger for the signal processing in the other detectors of the cluster.

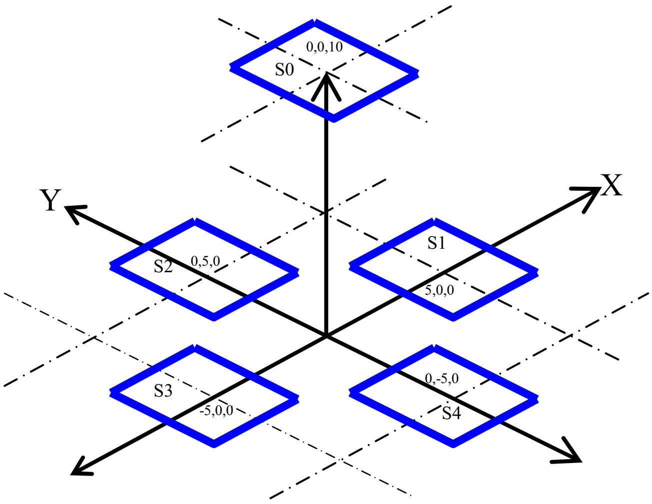

Fig. 1

Unlike other existing systems, in which a signal coincidence is sought among the detector signals in the group within a given timeframe, in the reviewed system is suggested to measure the delay of the pulses, generated in each of the detectors, relative to S0 (and thus to derive the time delay between them). Using a subsequent processing this allows for the reconstruction of the zenith and the azimuthal angle of shower distribution.

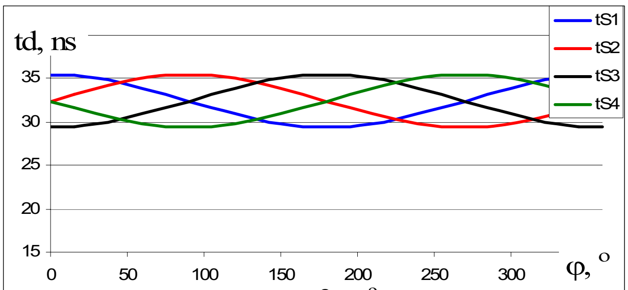

Fig 2a θ=10°

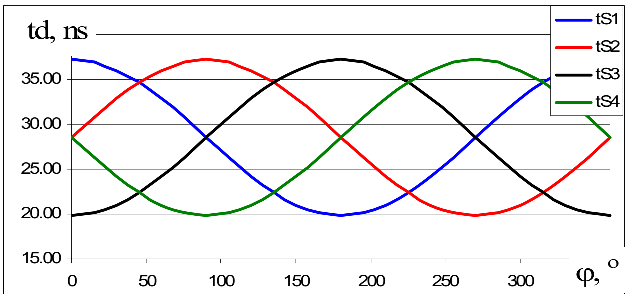

Fig 2b θ=30°

The time diagram in Fig.2a, 2b presents the signal delays of the different detectors relative to the trigger signal at different azimuthal angles. The curve families are given for zenith angles of 10 and 30 degrees. The calculations are made for relativistic particles ($v=c$). It is assumed that the triggering detector (S0) is located at 10 m height above the other detectors (S1 – S4), and they are at 5 m offset from the centre of the reference system. Establishing the delay of the group of signals would make possible the reconstruction of the EAS direction.

B. Definition of the Amplitude Dependencies

It is known that the charge, generated in the anode chain of the PMT, depends on the number of the photons generated in the detector volume and is proportional to the energy deposited by the ionizing particles [3]. In the present case, in which we review the muon registration with flat scintillation detectors, it is necessary to take into consideration three major factors:

1. Muons are characterized by very high energy and, as they are charged particles, in practice their registration efficiency is 100%. The energy given out in the detector volume does not depend on the energy of the given particle but on its linear path – i.e. on the geometrical dimensions of the detector and on the direction of the stream relative to the detector plane.
2. The charge generated in the anode circuit of the PMT depends on the number of particles, passing through the detector during the signal shaping period. This means that the output signal depends on the density of the muon flux in the EAS, which in turn is linearly dependent on the energy of the primary charged particle.
3. Having in mind that the muon flux varies in a very wide range (40 – 40 000 μ/m^2 for energies of the primary particle 10^{17} – 10^{20} eV)[1], the output pulse will have approximately 30 ns length (estimated by the thickness of the EAS) and amplitude, changing by 4 – 5 orders of magnitude.

Considering the aforementioned factors it becomes clear that high accuracy measurement of the amplitude and time characteristics of the signals coming out from the muon component of the EAS is a serious challenge.

C. Modified Configuration of the Detector System

It seems reasonable to suppose that if the detectors on the measurement plane are tilted at some angles to the zenith then the amplitudes of their signals will be different (due to the different effective thickness of each detector relative to the EAS direction). This gives grounds for the expectation that analyzing the amplitude correlations of the signals from the detectors might allow for the estimation of the EAS primary direction.

However, the change of the detector's effective area occurring when it is tilted has also to be taken into account in the analysis. It is necessary to note that those factors act in opposite directions – when the shower direction is perpendicular to the detector plane, the effective area of the detector is maximal but the effective detector thickness is minimal.

A modified spatial detector system has been analyzed, consisting of five detectors, four of which are situated in one plane and are 30° tilted to the vertical axis and 5 m offset from it (Fig. 3), and the fifth detector S0 is 10 m vertically above the main plane.

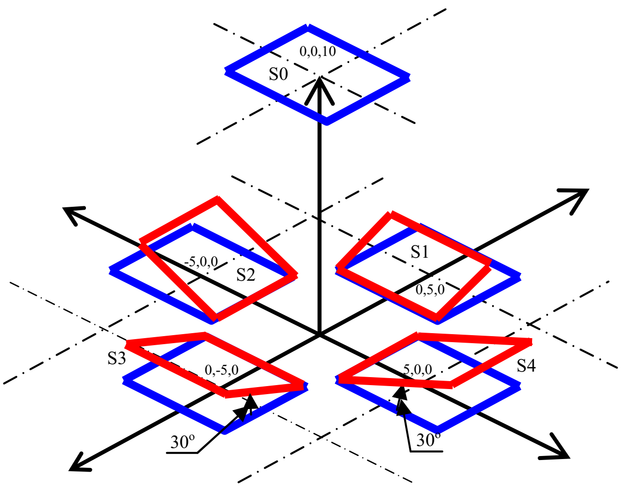

Fig. 3

Fig. 4 presents the effective area and the effective thickness of two opposite-standing detectors (S2 and S4) *vs* the azimuthal angle of EAS distribution for zenith angles of 10 and 30 degrees. It can be seen that there is a clear anticorrelation between these parameters and the EAS direction but a single valid conclusion cannot be made whether the shower direction can be recalculated from the

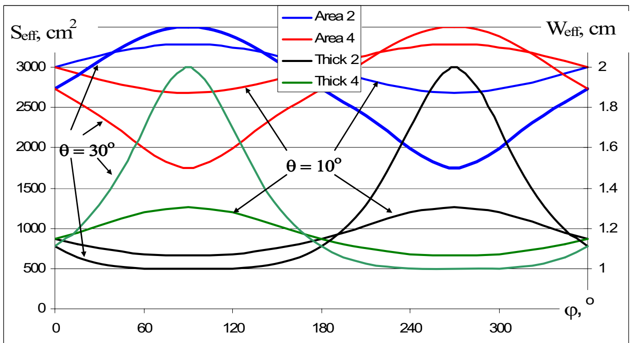

Fig. 4

amplitude characteristics.

The number of photons, generated in the detector as a function of the EAS direction has also been analyzed. The following formula is valid for it:

$$N_{\Phi} = \Phi_{\mu}.S_{eff}.\frac{dE}{dx}.k_D.h_{eff},$$

where: Φ_{μ} is the density of the muon flux, muons/m^{-2};

S_{eff} is the effective detector area, m^2;

dE/dx is the muon energy loss per unit length. For the material of the used detector and the particles' energy its value is constant (about 1,8 MeV/cm);

k_D – scintillator's light yield, photons/MeV;

h_{eff} – effective detector thickness, cm.

The relative distributions of the number of photons generated in the detector for energies of the primary charged particles of 10^{18} eV and different azimuthal and zenith angles are shown on Fig. 5. It can be seen that the variations are less than 6 %. On the other hand, the output pulse amplitude depends linearly on the muon flux density. Therefore, it can be concluded that the density of the EAS (and so, the energy of the primary particle) can be estimated via the amplitude of the PMT's output signal and that the latter signal is almost independent on the shower direction. So, it seems useless to make more complex the detector system structure by tilting the isoplanar detectors at 30° to the vertical axis.

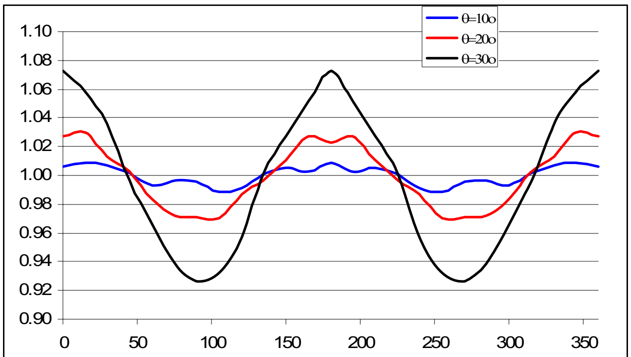

Fig. 5

III. MINIMIZED DETECTOR SYSTEM

If the number of detectors lying on the same plane is reduced to three, the received data will be still sufficient to allow for the estimation of the direction and the density of the muon component of the EAS (Fig. 6). The reduction in the number of detectors minimizes the cost of the detector system and simplifies the requirements to the electronic system for the registration and processing the detector signals.

A study has been conveyed for the calculation of the time-delays of the signals from the three detectors relative to the triggering detector for a system with the geometric parameters shown on the Fig. 6. The results are shown on Fig. 7. The amplitudes of the signals are identical to those reviewed in the previous case with the four isoplanar detectors.

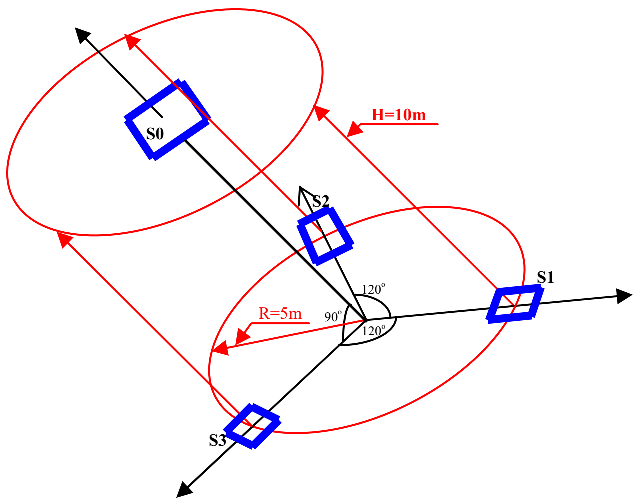

Fig. 6

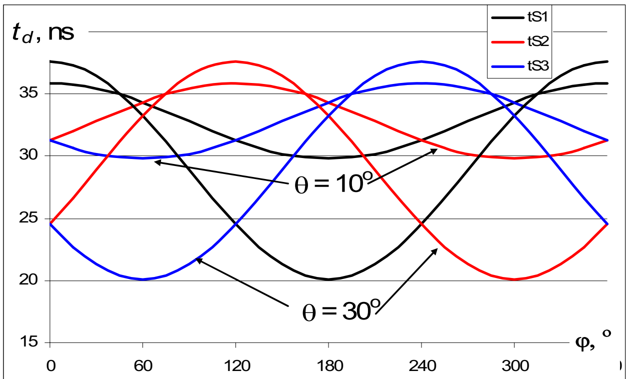

Fig. 7

VI. CONCLUSION

The time delay between the arrivals of the EAS particles into the different elements of a detector group depends on the zenith and azimuthal angles of EAS, while the amplitudes of the output signals depend on the density of the muon component in the EAS. This gives grounds for stating that a precise determination of the amplitude and time parameters of the output signals from a detector group suitably distributed in space can provide reconstruction of the EAS direction and the energy of the primary particle. The requirements to the electronic circuit that will be used for their registration can be defined based on the expected characteristics of the signals, described in the previous sections. These requirements are quite strict as some very small delays need to be measured (up to 30 ns) for short pulses with length up to 40 ns. The requirements for the amplitude channel are even more serious, taking into consideration that the amplitude of the signals changes by 4 – 5 orders of magnitude.

ACKNOWLEDGEMENT

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