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INVESTIGATION OF EXTENSIVE AIR SHOWERS BY MEANS OF THE NETWORK OF THE COSMIC RAYS STATIONS IN GEORGIA

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Abstract:
*The experimental measurements results of the first cycle of operation in the framework of cosmic ray project **GELATICA (GE**orgian **L**arge-area **A**ngle and **TI**me **C**oincidence **A**rray) are presented. The purpose of the project is the investigation of the Extensive Air Showers (EAS) by means of spatially separated EAS detector systems synchronized by the Global Positioning System (GPS). The background conditions of the scintillation detectors systems have been investigated for two currently working stations. Some data on the achieved EAS arrival direction accuracy are shown. The facility meant for the EAS location with the use of radio reflection from the shower's ionization trace in the atmosphere is described.*

Keywords*: cosmic rays stations' network, EAS direction estimation, passive radar.*

1 Introduction

Studies in the field of Cosmic Ray (CR) physics are currently gaining increasing importance all over the world. Good evidence is the multiplicity of experiments in this direction, which are characterized with a large verity of deployed experimental methods and scales [1 – 16].

Cosmic ray investigations are traditional in Georgia. CR stations had been operating as well in Tbilisi and in Bakuriani and Tskhra-Tskaro [17, 18]. Since 2006 the Cosmic Ray experiments have been renewed in Georgia with use of modern complex apparatus. Project named GELATICA (**GE**orgian **L**arge-area **A**ngle and **TI**me **C**oincidence **A**rray) is devoted to creation and development of the network of the **C**osmic **R**ay (CR) stations over the area of Georgia. The purpose of the project is the investigation of the **E**xtensive **A**ir **S**howers (EAS) by means of spatially separated EAS detector systems timed by the **G**lobal **P**ositioning **S**ystem (GPS).

The GELATICA experiment is devoted to the two-aim cosmic ray investigation. First, it has to join to the world-wide investigations of CR energy spectrum at high and very high energies [1, 2]. Next objective is to find correlations in the arrival times and directions of separate air showers over large distances. The last type of problems is widely researchable during last period. Similar projects are running in North America (NALTA [3], ALTA [4], SALTA [5], WALTA [6], CHICOS [7], CROP [8], etc.), in Europe (EEE [9], SEASA [10], CZELTA [11], HiSPARC [12], ALTA/CZELTA [13], etc), and in Japan (LAAS [14]). Since the project has an educational aspect, the cosmic ray stations will be allocated in sites of high schools and universities.

The goal of the GELATICA project is to overlap the area of Georgia (**Fig.1**) with Cosmic Rays detector complexes [19].

The experimental equipment contains two types of apparatus being connected into the GELATICA network. The first is the well approved shower detectors system – scintillation detectors working in the coincidence logics – for the shower charged component detection.

The second one is bi-static radar system [15, 16] – geographically separated transmitter and receiver antenna system – to register radio signals reflected from the EAS ionized tracks.

Such detector complex will permit to perform both tasks mentioned. The radar system will identify the reflected signals from the showers with energy $>10^{18}$eV in the coincidence mode with

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the shower scintillation detectors. The last system of detectors will register the UTC (**U**niversal **T**ime **C**oordinated) moment and direction of EAS arrival, allowing to investigate space-time correlations of EAS with energies $>10^{15}$eV. Indeed, some interactions of primary CR of high and very high energies (HE, VHE) in near or deep space could produce several particles or even a jet of particles propagating towards the Earth. For instance, there could be interactions of primary protons with interstellar and interplanetary matter, or disintegration of CR nuclei by solar photons [20, 21]. These particles could produce within a short time a set of detectable EAS separated by large distances. All these effects are very rare, but during recent years have appeared some observed evidence of their existence [13, 14, 21].

Fig.1. The network region for Cosmic Rays Array. The expected locations of stations are marked in red. The pair of presently operating stations Tbilisi - Telavi is connected by the yellow line; distance is ~ 63.7km

At this stage the two stations with four scintillation detectors are working in monitoring regime. The first station is situated in Telavi State University, the second one at Andronikashvili Institute of Physics. The ‘radar’ station with the passive antennas system is under testing now. Each station is provided with Global Positioning System (GPS) to register events with time precision ~1 μs for their synchronization.

2 The experimental setup for the shower detectors system

A Installations

Each of two stations of the shower detectors system are provided with the same set of equipment: four pieces of scintillators, four photo-multiplier tubes, two high voltage supplies and a data acquisition (DAQ) card with a GPS unit. Each piece of 5 cm thick scintillators has an area of (50×50) cm^2. The PMT pulses are read out by DAQ card [22], shown in **Fig.2.** It is designed and developed at Fermilab and the University of Nebraska with support of QuarkNet [23].

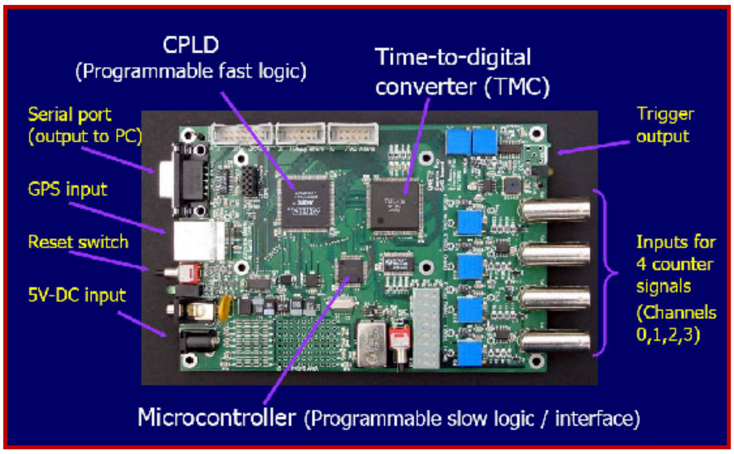

Fig.2 Layout of DAQ Board (Qnet II) with major components labeled.

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For this setup, the DAQ board takes the signals from the counters and provides signal processing and logic basics for a grate variety of nuclear and particle physics experiments. The DAQ board can analyze signals from up to four PMTs. The user can select none, 2, 3, or 4-fold coincidence and also select the effective gate width from 48 ns to 50 μs, based on the fundamental clock cycle of 40 ns. The board produces a record of output data whenever the PMT signal meets a predefined trigger criterion (for example, when two or more PMTs have signals above some predetermined threshold voltage, within a certain time window). The output data record, which can be sent via a standard RS-232 serial interface to any PC, contains information about the PMT signals, including a number of channels with signals exceeding the threshold, their relative arrival times (with the step equal to 1.25 ns), and the starting and stopping times for each detected pulse. In addition, a remote GPS receiver module provides the absolute UTC time of each trigger, accurate within 1 μs. This allows counter arrays using separate DAQ cards (for example different stations in a wide-area array, or two sets of counters at the same site) to correlate their timing data.

The GPS receiver sends two types of data streams to the board. The first is RS-232 ASCII data telling what time it is, at what latitude, longitude and altitude the receiver is, and information about the satellites the receiver is used. The other data is a 5V & 100ms pulse telling exactly when the data is true. Each stream of 5V & 100ms pulses arrives every second, thus the 5V pulse is named 1 pulse per second (1PPS). The microcontroller on the board records the counter value during which the pulse is received. The UTC is taking according to a counter running at ~ 25 MHz.

Commands can be sent to the board to allow users to define trigger criteria, select various options, and retrieve additional data, such as counting rates, auxiliary GPS data, and environmental – temperature and barometric pressure – sensors data, in addition to the trigger and PMT pulse information.

The card can be operated with a variety of software: a basic serial port terminal, a Lab View interface for Windows, and a command-line interface on Linux.

B The performance of the scintillation counters

We have calibrated the scintillation counters by looking at the singles rate as a function of PMT high voltage and threshold settings and selection of the appropriate values. We have selected some pairs of four PMTs with similar parameters for operating at each station. All the channels of the shower detectors are characterized by the distribution of the pulse width (**Fig.3**). The worse channel (ch 0) of Tbilisi station has the pick in the signals noise region. Each of the four channels (separately) has had a singles rate between 100 Hz and 500 Hz. The coincidence rate we have observed was approximately 1 Hz, though it had varied according to the spatial configuration of detectors.

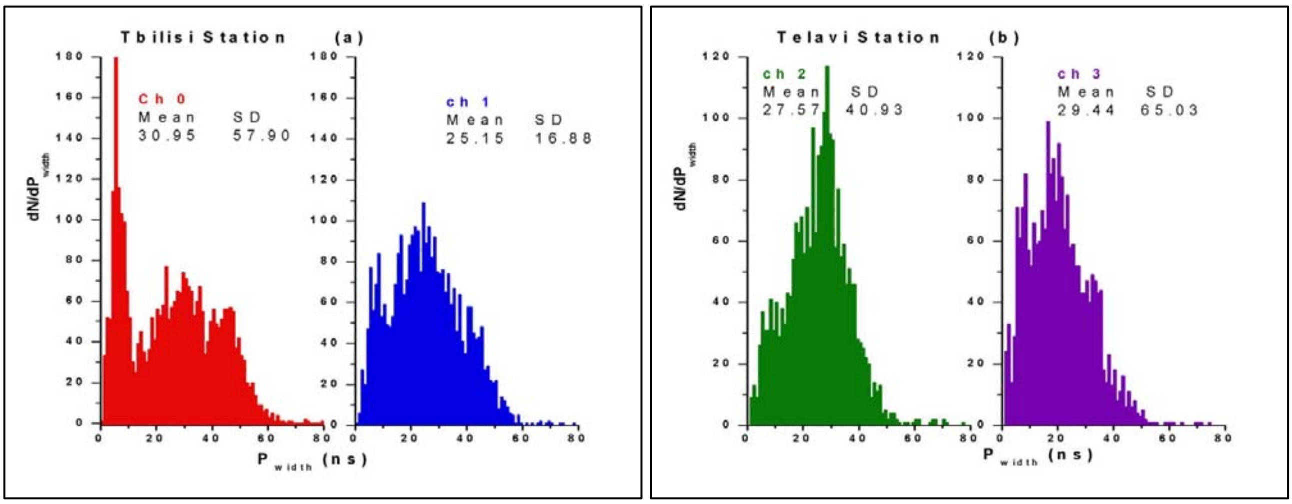

Fig.3 The distributions of the pulse width for the channels of some shower detectors in Tbilisi (a) and Telavi (b).

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The shower detectors with four scintillators are working in different configurations and operation conditions in Tbilisi and Telavi. In Tbilisi shower detectors are arranged on the attic floor of the Physics Institute building. Detectors are situated in the corners of (10m × 10m) area. In Telavi the equipment disposed on the ground floor of the four-storied building at the corners of the room of (5.2m × 2.6m) area. These conditions predetermine the frequencies of the EAS' events for four-fold coincidence. The rates of these shower detectors are ~12 EAS/h and ~2 EAS/h for Tbilisi and Telavi stations correspondingly.

The picture of two separate detector complexes performance in Tbilisi and Telavi under the condition of four-fold coincidence within the 800ns temporal gate is shown on the **Fig.4.** The delay times of all detectors are shown for one day (twenty-four hours = 86400s) operation. Current detectors' disposition on both stations with existing maximal distances (Tbilisi – ~14 m, Telavi – ~5.8 m) allows following identifications of signals issued from the single EAS event in the 50ns-restricted delay time interval.

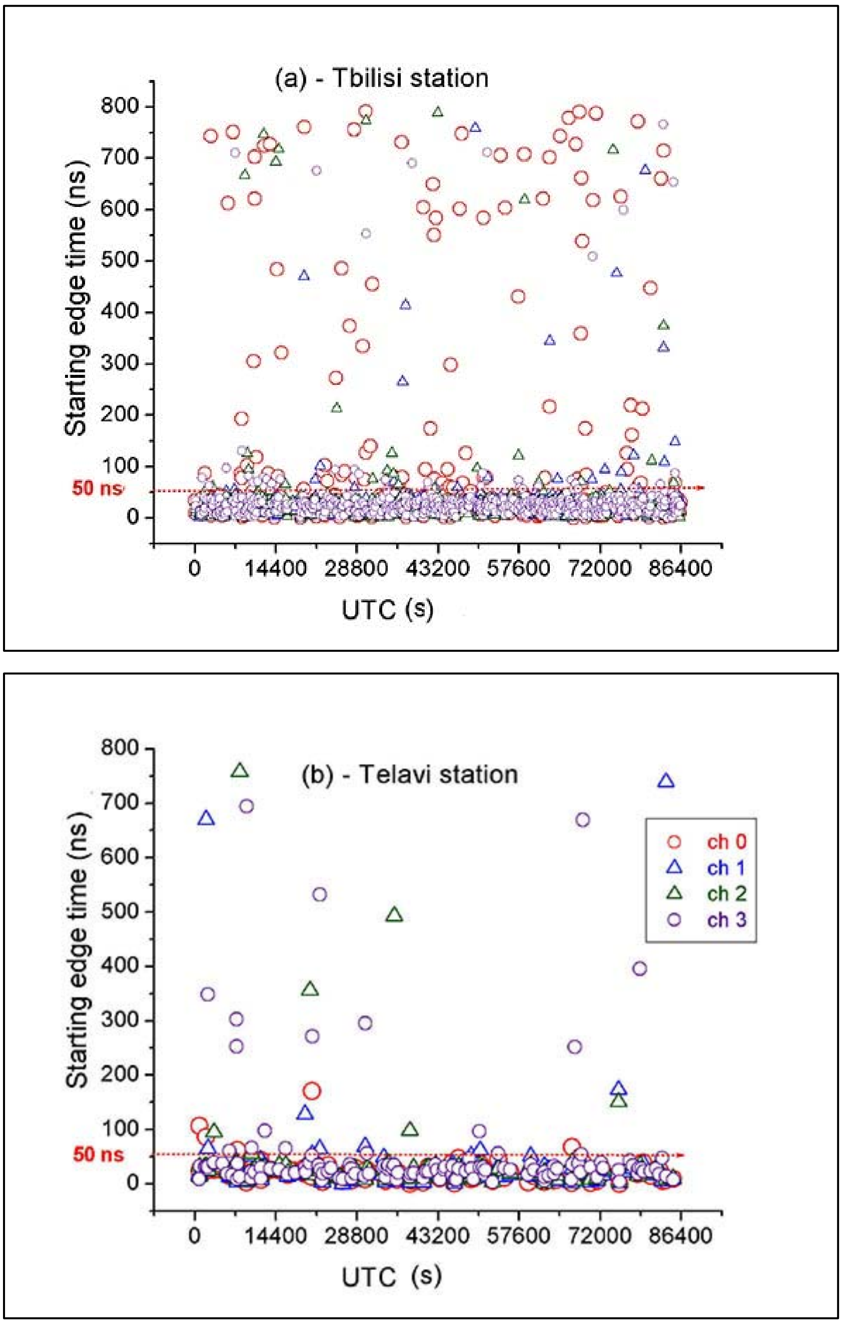

Fig.4 Starting times of all 4 detectors of installation for all detected events – vs. the UTC time of each trigger during twenty-four hours' period:
(a) – for Tbilisi shower detector;
(b) – for Telavi one.

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The distribution of the time differences in rising edges for all channels in four-fold coincidences is shown in **Fig.5**. The coincidences caused by air showers (i.e. within the peak area) are clearly distinguishable, on the top of the random background.

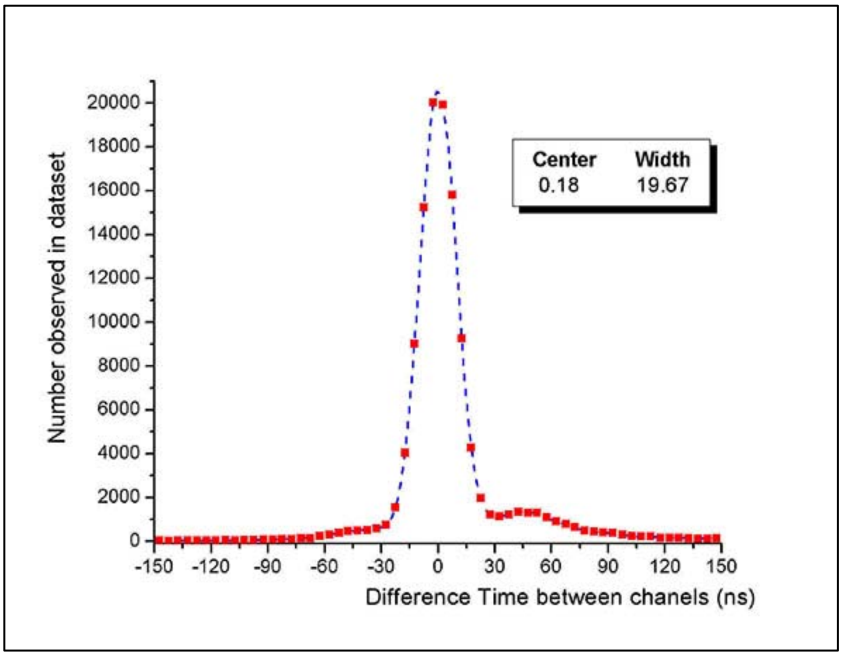

Fig.5 The distribution of the time differences in rising edges for the pairs of channels in each trigger for the Tbilisi installation.

The correlation plot of the event rate is made as function of barometric pressure, to demonstrate that these events originate in the atmosphere **(Fig.6)**. The position of the maximum of the shower changes with the thickness of the atmosphere and consequently more (less) counts will be detected as the barometric pressure decreases (increases).

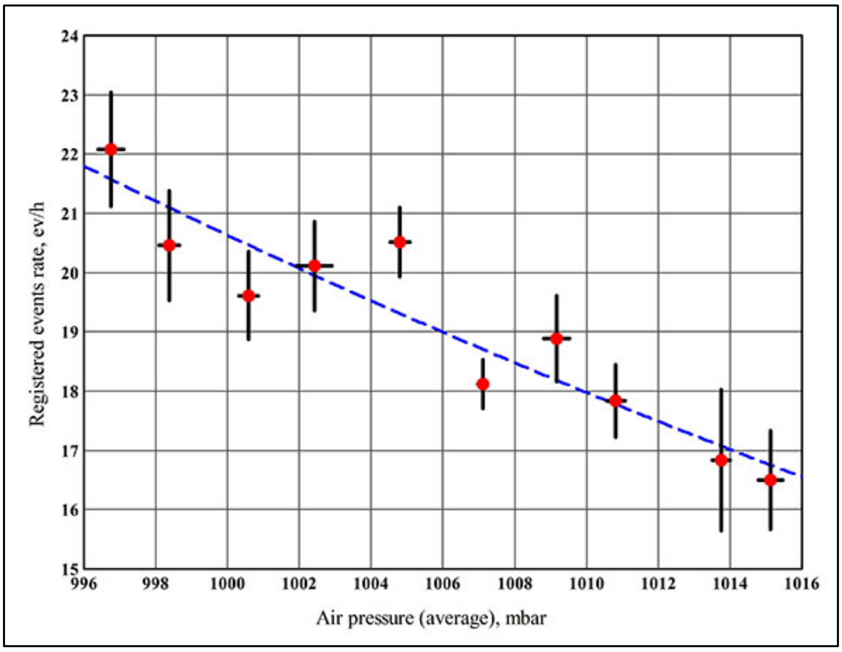

Fig.6. The dependence of the rate of events detected by the scintillation counters on the atmospheric pressure.

3 The estimation of the EAS arrival direction

Four detectors arranged in the corners of the installation are used as the EAS goniometer [24]. The delay time of the EAS frontal passage registered by the DAQ Board (Qnet II) is used for estimation of distances from the detectors to the EAS front:

$$d_i = q_i \cdot \tau \cdot c; \qquad i = 0,1,2,3 - \text{indexes of detectors.} \qquad (*)$$

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Here q_i – digital delay measures from the DAQ Board (integers);
$\tau = 1.25$ ns – delay time duration equivalent to unit delay digital measure;
$c = 29.9792\ldots$ cm/ns – speed of light.

The EAS direction is defined as a unit vector orthogonal to the plane (EAS front plane), which minimizes the sum of squares of differences of estimated distances mentioned and calculated distances between the detectors and the estimating plane. An illustrative example of the direction estimation by the installation in Tbilisi is shown on **Fig.7a**, while the **Fig.7b** demonstrates the spatial disposition of the corresponding EAS front estimated. All detectors are placed in the corners of (10m × 10m) area. The fours of red line segments represent the estimated distances from the detectors to the EAS front **(*)**. The root-mean-square deviation of the tips of these segments from the estimated EAS front plane (i.e. residual discrepancy) is the basis of errors estimation of the direction angles.

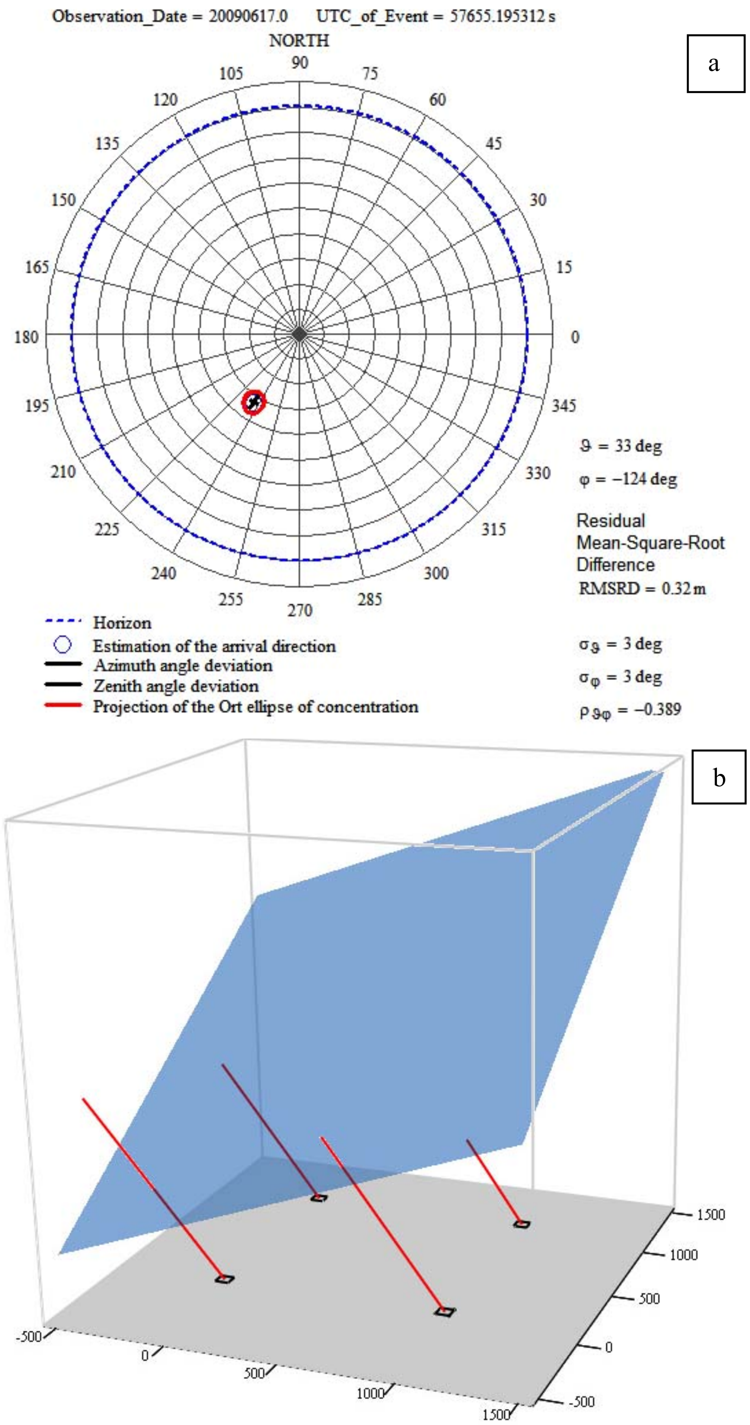

Fig.7. Example of the estimation of the EAS arrival direction shown as:

(a) the special local map of sky with the ellipse of concentration of the EAS ort estimation projected on the last map;

(b) spatial image of estimation of the front plane position for the same EAS event.
All distances are measured in centimeters

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The estimated distribution of these discrepancies is shown on **Fig.8a.** The distribution appears to be of discontinuous type. This feature is connected with a discreteness of digital delay measures q_i **(*)** (i.e. with the digitized data from the DAQ Board). This peculiarity is typical for planar EAS goniometers with symmetrical arrangement of detectors. Indeed, in the case of flat installation with the symmetry violated, all possible discrete values of residual discrepancies prove to be replaced by some discrepancies bands. This effect is clearly expressed in **Fig.8b,** showing the same distribution for Telavi installation. In this case four detectors are arranged asymmetrically, approximately in corners of (5.2m × 2.6m) area.

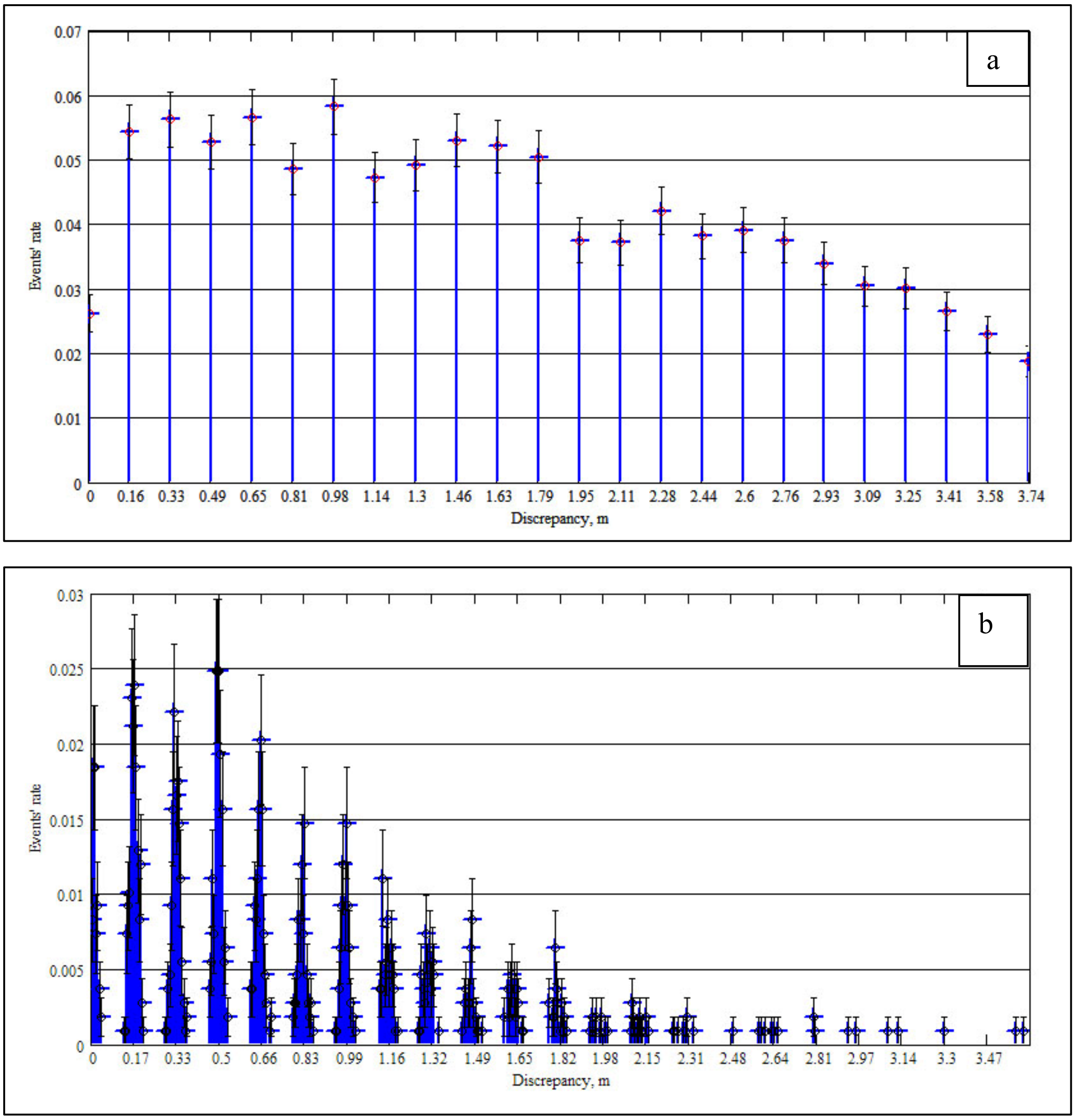

Fig.8. The estimated EAS front planes' residual discrepancies distributions:
a) – for installation in Tbilisi; b) – for installation in Telavi.

In the case of spatially separated detectors (3D goniometers) some mathematical digital imitations of the properties of residual discrepancies distribution have shown that it becomes, *ex facte,* continuous.

Further, the consequent distributions of errors of zenith and azimuth angles for Tbilisi installation are shown on **Fig.9.** Both distributions depend on the mentioned residual discrepancies distribution (**Fig.8a**) and some common geometric factors, depending on the estimated angels values. These distributions are wide enough and even theirs averages are impres-

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sive: $<\sigma_\theta = 32.2°>$, $<\sigma_\varphi = 41.2°>$. This observation reaffirms the necessity of use of spatial goniometers [25] in future.

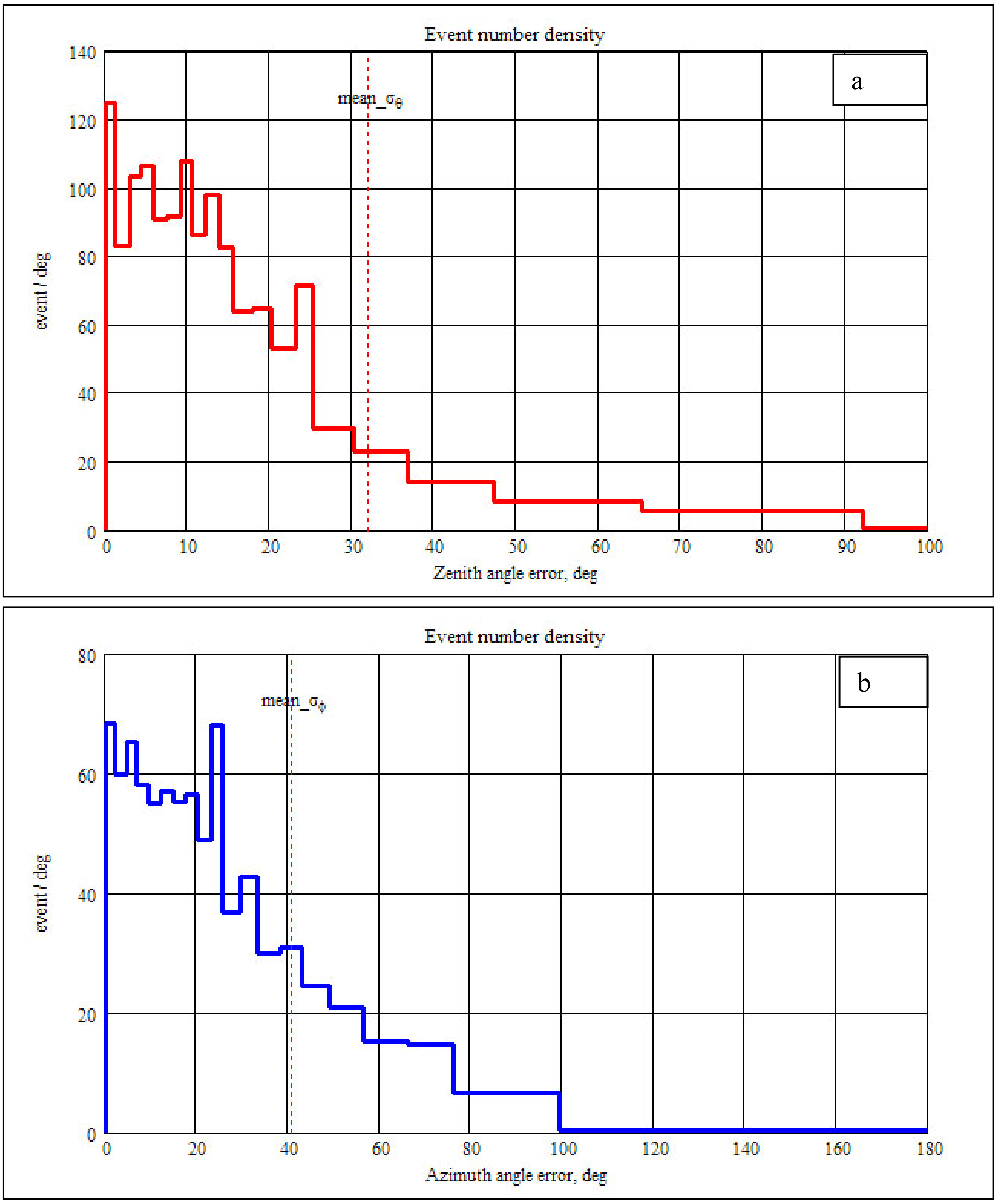

Fig.9. The distributions of angles estimation errors for Tbilisi installation.
a) – errors in zenith angles estimations; b) – errors in azimuth angles estimations.

4 The passive radar technique for ultra high energy cosmic rays detection.

A. Motivation for the radio detection system

The detection and study of ultra high energy cosmic rays (UHECR) require detectors that cover large areas. The largest detector, the Auger Observatory [1, 2] is now in operation and span area of 3000 km^2. Even on such large area, one can detect only a few hundred UHECR events per year with energies larger than 10^{18} eV due to their very low event rates. In acquiring data with more statistics and for detecting rarer events, one would need detectors that extend over much larger areas.

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Currently, new techniques are being developed to reach this goal. Radar technology, if proven viable, could be such technology.

The phenomenological description [26] of ionization trails produced by EAS suggests that radar techniques would give the new possibility of EAS parameters measurement, like that of meteor ionization trails. It has been shown that ionization densities of the order of 10^{13} m^{-3} can be reached in the shower core of EAS with energy $E = 10^{18}$ eV, initiated by primary proton. At this ionization levels EAS core plasma will efficiently reflect radio waves with frequencies ranging from ~50 MHz to ~100 MHz.

The major problem for UHECR detection is the possible lifetime value of the ionization, produced by the showers, that needs to be understood clearly. Steps towards experimental measurements of EAS core ionization properties are under the way at the Brookhaven National Laboratory by MARIACHI project [15, 16] and under startup at the Andronikashvili Institute of Physics in the framework of our GELATICA project.

B. The equipment for the bi static radar system

In order to search for radio-echo from cosmic ray showers it is employing a system of bi-static Radar. 'Bi-static' means that there exist geographically separated transmitters and receivers, as contrasted with a classic radar system, where the transmitter and receiver are in a single unit. Such radar is tuned to the lower part of VHF band to acquire the signals emitted by TV stations and reflected by the ionization trails in the atmosphere, produced by burning meteors [27] and possible UHECR showers. Due to relatively big lifetimes, the meteor-initiated ionization trails have to be used not only for meteor studies, but also for EAS investigations for the purpose of validation and calibration of the experimental setup.

A schematic representation of the radio-echo reception installation is shown on **Fig.10**.

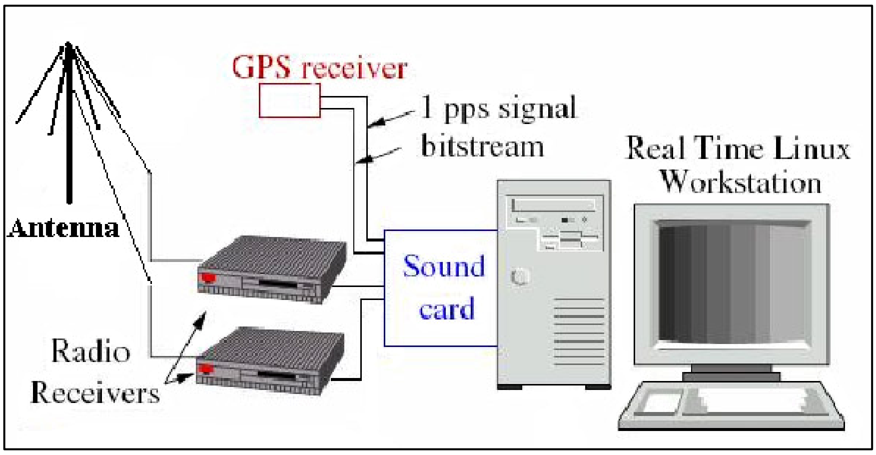

Fig.10 Experimental setup for the Radio Detector System reception station

The antenna is composed of a pair of crossed dipole inverted-V antennas. This antenna has to be installed in the open place, in our instance on the roof of a building. The signal from this antenna is preprocessed by computer-controlled radio receiver (PCR-1500), which demodulates the reflected signal, downshifting their frequency to a limited (2.8 kHz) base band signal. In our experiment both receivers are operating at 83.75 MHz or 77.25 MHz frequencies. The first one is used for the East-West direction dipole; while the second receiver is used for demodulation of the signal registered by the North-South direction dipole. The signals from these receivers are digitized and stored by computer via a high rate acquisition audio card, Delta 1010LT. This card can continuously digitize signals coming from up to 8 different channels at a rate of 96 kHz at 16 bits. The sampling rate used should allow us to identify events occurring in a time scale of ~10 μs. The spectrogram of the signal is displayed while data is being recorded, providing a permanent monitoring of the acquisition system. In order to synchronize future data from different sites, a GPS clock is used. At present the only one passive radar station at Andronikashvili Institute of Physics is

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operating. On the current stage of the method development various configurations of the radio installation parameters are under investigation.

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The prospective further development of the GELATICA network of CR stations will be complied with the educational aspect of the project. New EAS goniometer stations based on the scintillation detector complexes will be arranged among the high schools and universities all over Georgia (**Fig.1**) with the participation of local researchers and students. There will be constructed the spatial (3D) cases of EAS goniometers, as far as it is possible. The last construction will give an opportunity to improve the resources of the network. Indeed, the increased angular resolution of these goniometers with the consequent growth of capabilities in the EAS angular and temporal identification will enable the GELATICA network to join in with the international searches on the ultra-long-range EAS correlations. On the other hand, the development of the passive radar station network will be connected with the ability of their allocation in the areas, sufficiently far from the city-places, according to the necessity of minimization of urban radio noise.

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