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FIRST RESULTS OBTAINED BY THE GELATICA NETWORK OF THE COSMIC RAYS STATIONS IN GEORGIA

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Abstract
First results obtained by the Network's Cosmic Rays stations recording Extensive Air Showers events are described. The data specifying properties of the EAS goniometers operating in Tbilisi and Telavi are presented. The influence of detectors' disposition and of surroundings of the installations onto the form of the measured histograms of the arrival directions of registered EAS events is shown.

Keywords*: extensive air shower, cosmic rays stations' network, EAS arrival direction estimation.*

1 Introduction

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 [1]. 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).

There are two obvious sets of measuring tasks to be realized by the network of this type. First, it has to estimate the energies of observed showers for the purpose of investigation of the primary CR spectrum [2, 3]. Next objective is the investigation of possible space-time correlations of showers observed by remote installations [4, 5]. Evidently, the simultaneous measurement of EAS arrival time and direction is required in this case. The last type of problems is widely researching along last time. Similar projects are running in North America (NALTA [6], ALTA [7], SALTA [8], WALTA [9], CHICOS [10], CROP [11], etc.), in Europe (EEE [12], SEASA [13], CZELTA [14], HiSPARC [15], ALTA/CZELTA [5], etc), and in Japan (LAAS [4]).

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, they could be some interactions of primary protons with interstellar and interplanetary matter, or disintegration of CR nuclei by solar photons [16]. These particles could produce a set of detectable EAS within a short time interval, separated by large distances. All these effects are very rare, but during last years of the past century there has appeared some observational evidence of their existence [17].

Since GELATICA project has an educational component, all cosmic ray stations have to be allocated in sites of high schools and universities in Tbilisi, Batumi, Kutaisi, Gori, as well as in Bakuriani and Mtzkheta [1]. It is during last four years that first two CR stations of the GELATICA network have been constructed by the joint team from Andronikashvili Institute of Physics in Tbilisi State University and Gogebashvili University in Telavi [18].

Three EAS goniometers have been constructed already: two installations in Tbilisi (TBSa & TBSb) and one installation in Telavi (TELa). *EAS goniometer* is an installation consisting of a scintillation detector system, registering the times of EAS particles passages through detectors [19, 20, 21]. This information allows estimation of the EAS arrival direction by means of the relative delays of the signals mentioned. The UTC (**U**niversal **T**ime **C**oordinated) moment of EAS

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arrival is registered simultaneously by the GPS unit, allowing to investigate space-time correlations of EAS with energies $>10^{15}$eV.

First steps of the current approach to desired solution of the EAS space-time correlations problem, got by Tbilisi and Telavi stations, are presented here. Short survey of some properties of the installations has been published earlier [18]. Temporal resolution (digitization step) of detectors' signals provided by the equipment used proves to be 1.25ns

As every installation in our case consists of only 4 detectors [22] due to the standard equipment used [23], all direction estimations are forcibly constrained by the flat EAS front approximation. Apart from the constructional complications of spatial disposition of detectors, the flat goniometers (i.e. with all detectors in common plane) are used by the same reason.

Any flat goniometer possesses some essential fault [24], unfortunately. It can measure inherently only those components of unit ort $\mathbf{n}$ of EAS arrival direction, which are parallel to the plane of detectors location. This algebraic restriction allows estimation of azimuth of required direction only, while the constrained zenith angle has to be determined through the unity condition $|\mathbf{n}| = 1$ for the length of the ort. This approach is reasonable and sufficient if both components of $\mathbf{n}$ in the detectors' plane are measured exactly. However, as a matter of fact, they are determined with some ambiguity. That is why forced use of the unity condition for the length of the 3-ort implies underestimation of zenith angle value if the length of ort projection onto the detectors' plane appears to be stochastically underestimated, and vice versa. Moreover, under big overestimation of the projection length, in the case when it is estimated by the value greater then unity (due to measurement errors), the estimation of zenith angle proves to be impossible. This last situation especially spoils measurement of the near-horizon directions.

2. Results obtained by the first goniometer in Tbilisi

In the beginning of the project development TBSa goniometer has been constructed and has started registration of the EAS arrival times and direction. This installation has been disposed within the main building of Andronikashvili Institute of Physics. Total number of 1635 "true" EAS events have been recorded during the installation operation period. Respective rate of events registration has proved to be (4.07 ± 0.08) EAS/h. The scheme of detectors' disposition in the station room is shown on the **Fig. 1**.

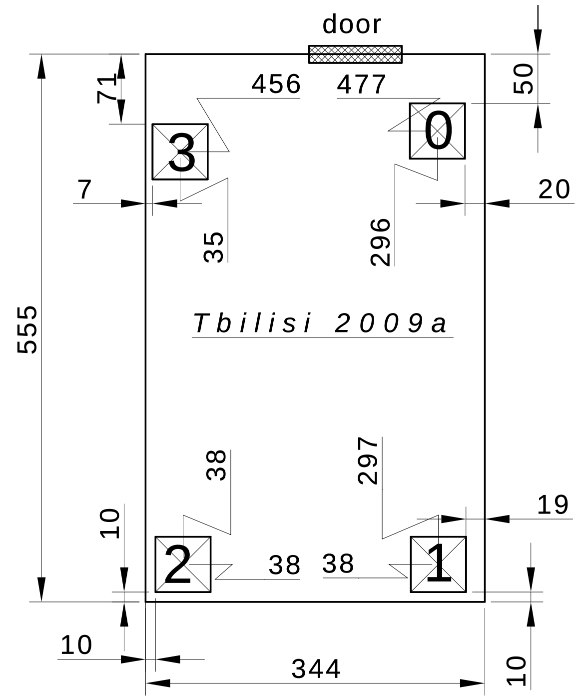

Fig. 1 Detectors' disposition for the first case of EAS goniometer (TBSa) arranged in Andronikashvili Institute of Physics (Tbilisi). All dimensions are specified in centimeters.

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The overall disposition of detectors is oblong, consequent to the room form, and rather asymmetrical, especially for detector **3.** As one would can see further, this asymmetry has some consequences in properties of ensemble of observations.

Some properties of the 1635-directions ensemble of the EAS arrivals, measured by means of TBSa goniometer, are described below. Every direction is specified by the projection of the EAS front unit ort onto the special plane parallel to the detectors' plane. Just these values are estimated immediately from the registered data of the times of the shower particles passage through detectors. Positions of the ends of these projections of orts' estimations (with common beginning in the coordinates' origin, which corresponds to the zenith direction) are shown on the **Fig. 2 a)** by the crosses. The same picture in the zenith vicinity is shown on **Fig. 2 b)** with large scale.

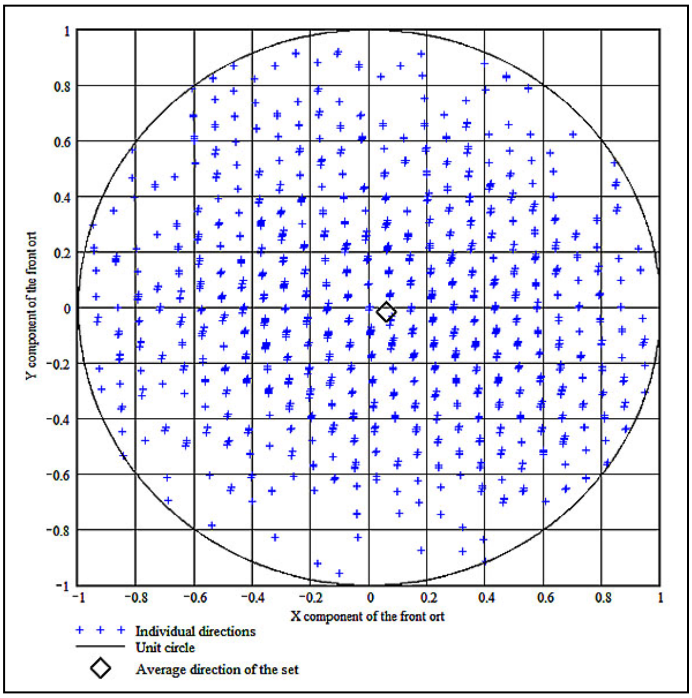

Fig. 2. a) TBSa goniometer Projections of EAS front orts onto the special plane parallel to the detectors' plane.

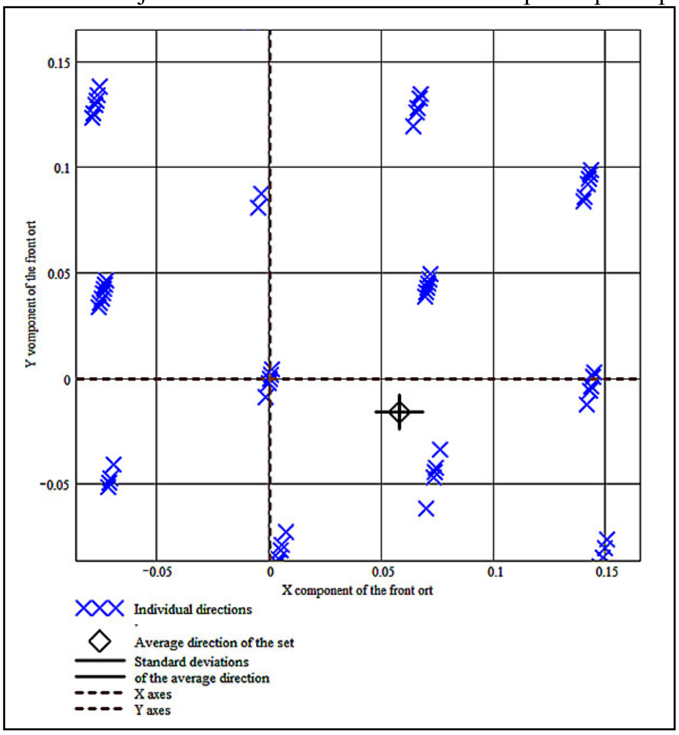

Fig. 2. b) Circle with unit radius represents the horizon. Events number = 1635

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Some peculiarities of the picture have to be mentioned.

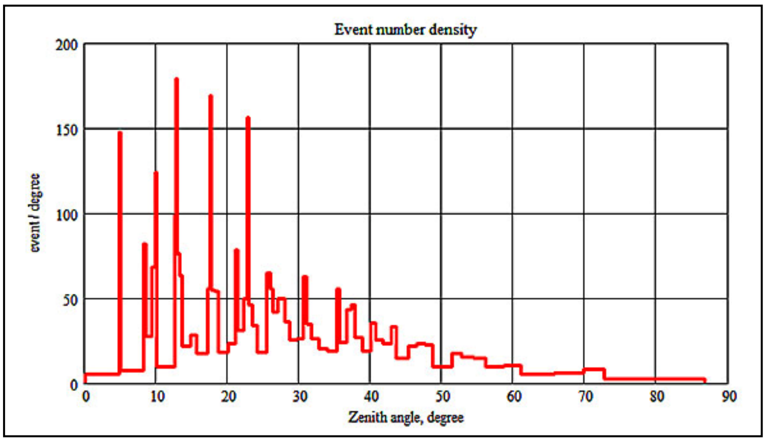
First, the average position of all directions recorded is reliably distinguishable with the zenith direction: $\theta_z = 3.4°\pm0.5°$. This shift can be explained by the asymmetric location of installation within the building – absorbing material depth is strongly dependent on direction.

Second, the points of estimated directions are clustered in stripes; this peculiarity is due to the installation's oblongness. All points are located around the vertexes of rhombuses in ort projection plane and their positions are somewhat fuzzy. This blurring is due to asymmetry in the detectors disposition. Indeed, the Monte Carlo computations have shown that for the symmetrical plane goniometers with detectors disposed in the vertexes of square, the points representing measured directions have to be located exactly in the vertexes of square on the ort projection plane. This prediction is proved by the results of TBSb goniometer, see below.

Observable discretization of measured directions is a direct sequence of timing digitization of detected particles passage through detectors, which realizes the hardware used [23].

Obvious consequence of this specific arrangement of measured EAS arrival directions are peculiarities of the angular distributions. The distribution of zenith angles (**Fig. 3.**) is rather smooth under large histogram cells charges (left bottom), while it appears to be composed of a sequence of short spikes under big resolution (right top). The last is an apparent sequence of digitization.

It is considerable that the zenith angles distribution measured by the TBSa goniometer appears to have a noticeable amount of recorded events near the horizon (**Fig. 2**), while it contradicts with the known behavior [20] of the distribution. This distortion of distribution observed is connected with small geometrical dimensions of the installation.



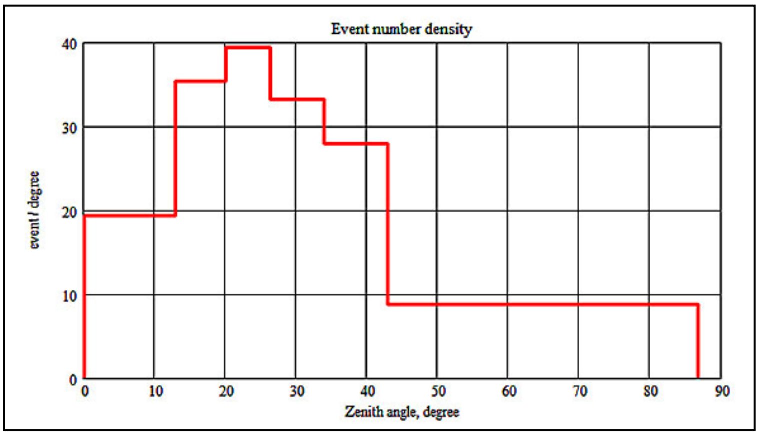


Fig. 3 The histograms of zenith angles distribution acquired by TBSa goniometer. The histogram cell charges are 250 events/cell (left) and 25 events/cell (right)

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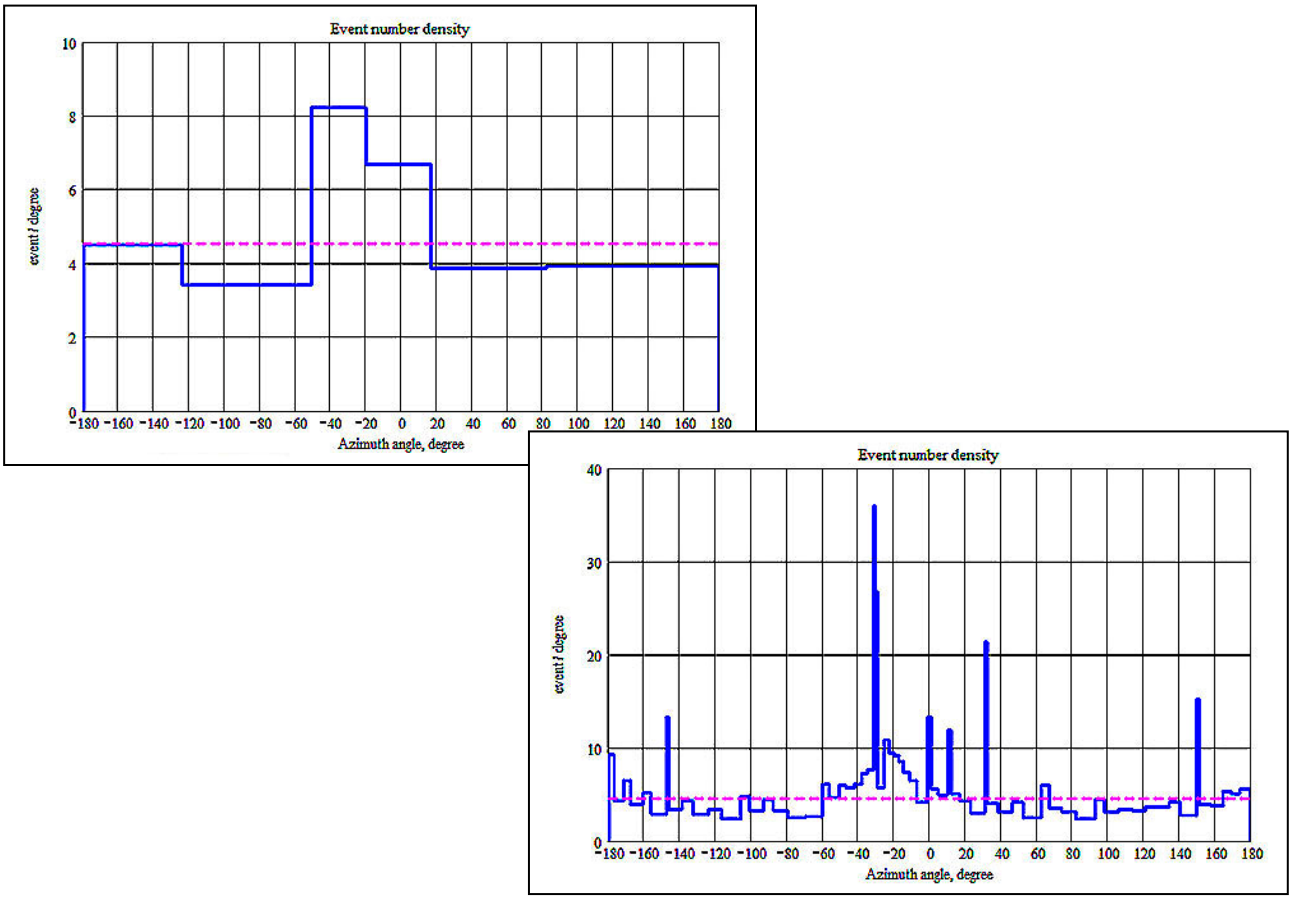

Fig. 4. The histograms of azimuth angles distribution acquired by TBSa goniometer The histogram cell charges are 250 events/cell (left) and 25 events/cell (right). The anticipated uniform distribution is shown too.

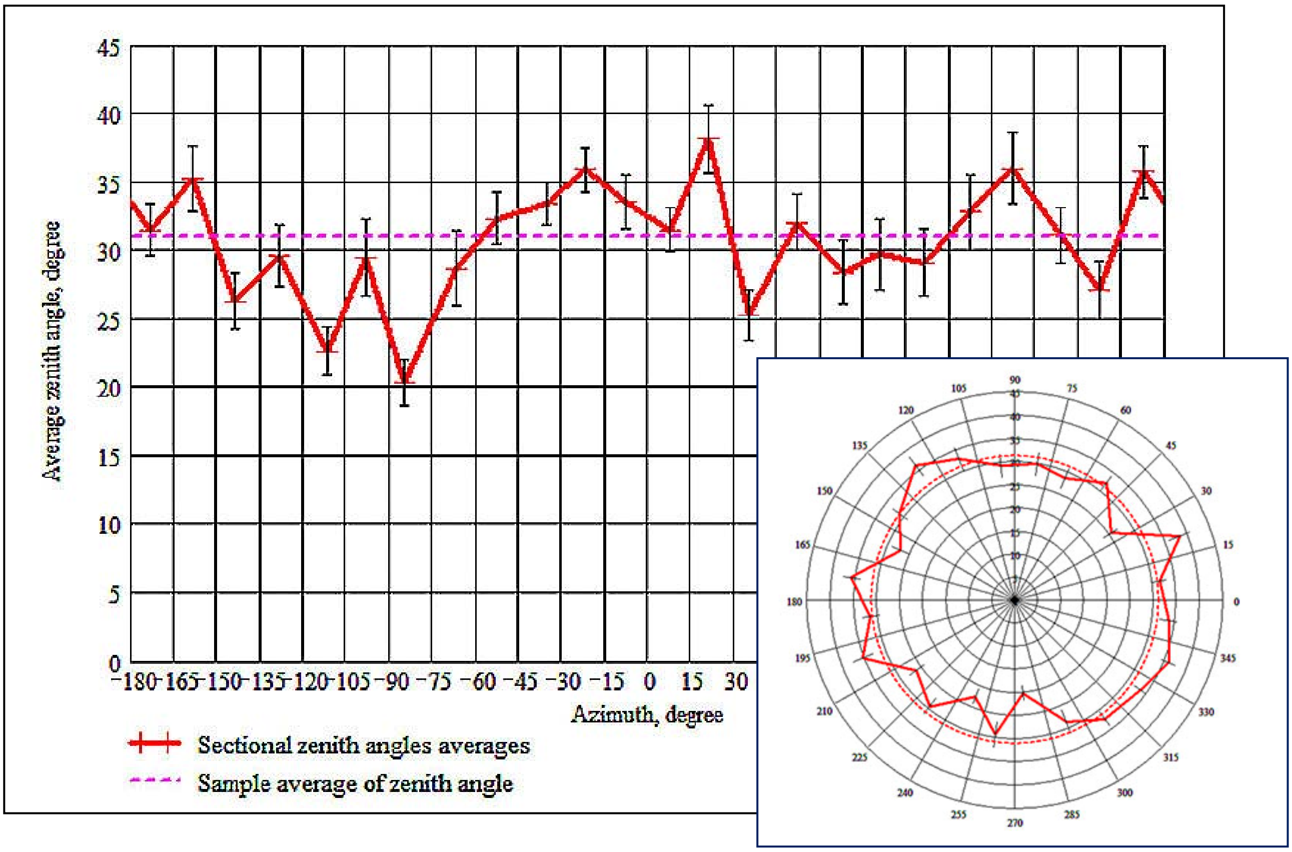

Fig. 5. Mean zenith angle dependence on the azimuthal direction acquired by TBSa goniometer. General average zenith angle $\Theta_{av} = 31.1°\pm0.5°$.

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Naturally, the digitization of registered times affects the distribution of azimuth angles, as well (**Fig. 4.** right bottom). This feature corresponds to the discussed picture (**Fig. 2.**) of projections of EAS front orts onto the special plane with points clustered in groups near the sites of some regular lattice.

In addition, the apparent deviation of measured azimuth distribution from the anticipated uniform distribution is revealed. This difference is a consequence of the anisotropy of the matter surrounding the installation.

The anisotropy mentioned is clearly demonstrated in the azimuthal dependence of the zenith angle distribution. It is shown on **Fig. 5** as a dependence of the mean zenith angle, averaged in a succession of azimuth intervals, on the mean azimuth value in this interval. Deflections of the measured values of this function from the anticipated constant value exceed the estimations of its standard deviations. Certain oblongness and displacement of the function relative to zenith direction is visible in the polar coordinate system, too.

Thus, both the asymmetry of the detectors' disposition in the TBSa installation and the asymmetry of installation's arrangement with respect to the ambient matter, have observable manifestations in the measured distributions of EAS arrival directions.

3. Installation in Telavi.

A goniometer TELa constructed in Gogebashvili University in Telavi (**Fig. 6.)** is quite similar to the considered above installation in Tbilisi.

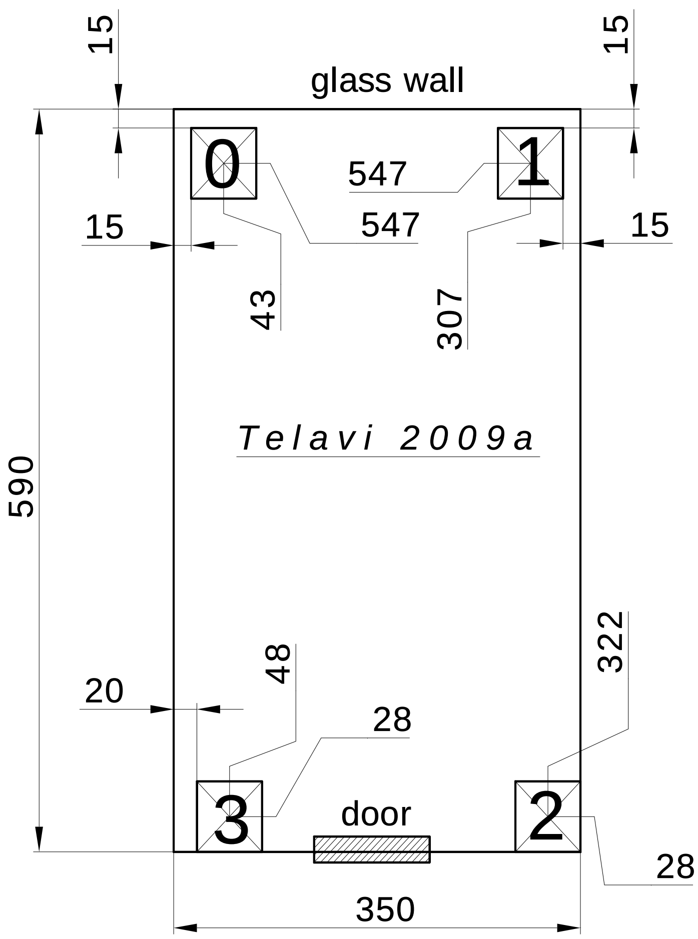

Fig. 6 Disposition of detectors of presently operating EAS goniometer TELa arranged in Gogebashvili University (Telavi). All dimensions are specified in centimeters.

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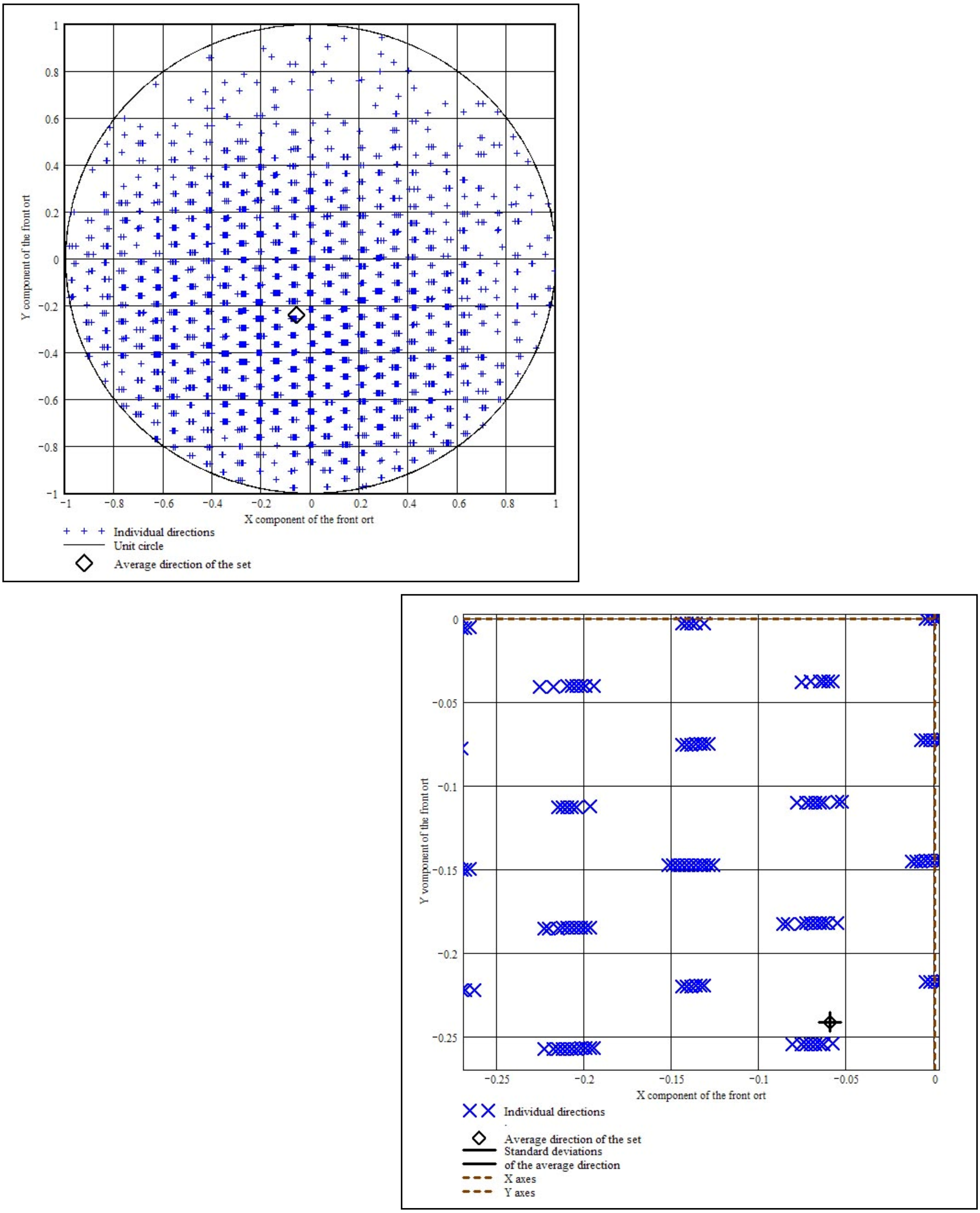

Fig. 7. TELa. Projections of EAS front orts onto the special plane parallel to the detectors' plane. Circle with unit radius represents the horizon.Events number = 3817

This installation is oblong, too (but with less symmetry violation in detectors disposition). Moreover, it is arranged on the ground floor of rather heavy building. This is a reason of lower rate of events registration = (2.06 ± 0.03) EAS/h. Total number of 3817 "true" EAS events have been recorded during the TELa installation operation period.

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Anisotropy of the EAS arrival directions is greater then the same value relating to Tbilisi TBSa installation: showers mean direction (**Fig. 7.)** is reliably shifted from zenith: $\theta_z = 14.4°±0.4°$.

Whereas the installation is oblong, it appears that the spread of points representing estimated shower arrival directions is stretched along the short side of installation. However, there is no skew in the detectors disposition in the goniometer under consideration, unlike the TBSa goniometer (**Fig. 1.**), therefore the spread is not skewed, too (cf. **Fig. 2.**).

Special features of angular distributions are qualitatively replicated, too. The azimuthal distribution is anisotropic again, but the shift of overall picture has occurred in different direction in concordance with the different peculiarities of the surroundings and arrangement of the goniometer.

This anisotropy is clearly visible from the azimuthal dependence of the mean zenith angle, averaged in a succession of azimuth intervals. The overall picture is appreciably shifted from the true center in zenith. (**Fig. 8,** cf. **Fig. 5.**)

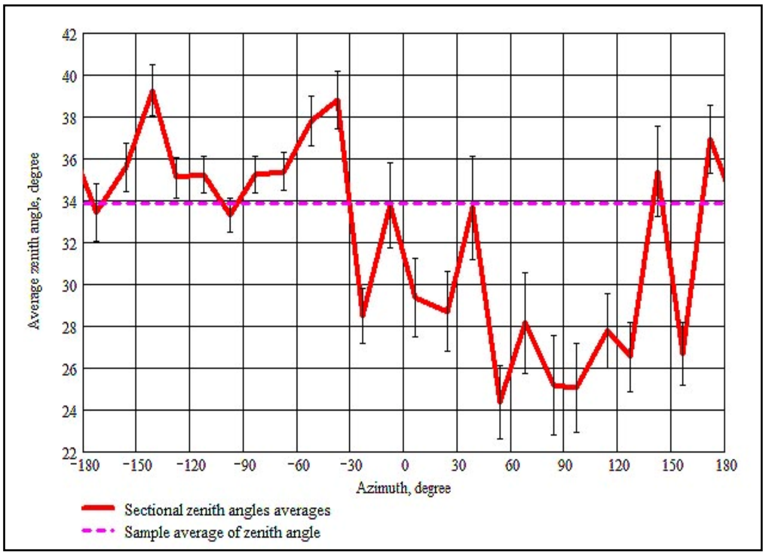

Fig. 8. Mean zenith angle dependence on the azimuthal direction acquired by TELa goniometer. General average zenith angle $\Theta_{av} = 33.8°±0.3°$

Thus, there become apparent the asymmetry of TELa installation arrangement with respect to the matter of building and surroundings in the similar way as for TBSa installation. However, as the installation in Telavi has no skewness in the disposition of detectors, so the picture of points representing estimated shower arrival directions is not skewed. Distribution of zenith angles is widened, too, as the installation concerned is small-scale in much the same way as previous one.

4. Second installation in Tbilisi

The imperfections of the first goniometer TBSa revealed above have stimulated improvements of certain incorrectness for at least of some of them. So, new installation TBSb is disposed now in the roof space of second building of Andronikashvili Institute of Physics. The concrete layer above it is now much thinner and the rate of events' registration has risen

until (12.5 ± 3.2) EAS/h. The distance between detectors is enlarged up to 10m and they are placed *symmetrically* in the corners of square. These changes have result in the observable distributions. Total number of events registered = 52798.

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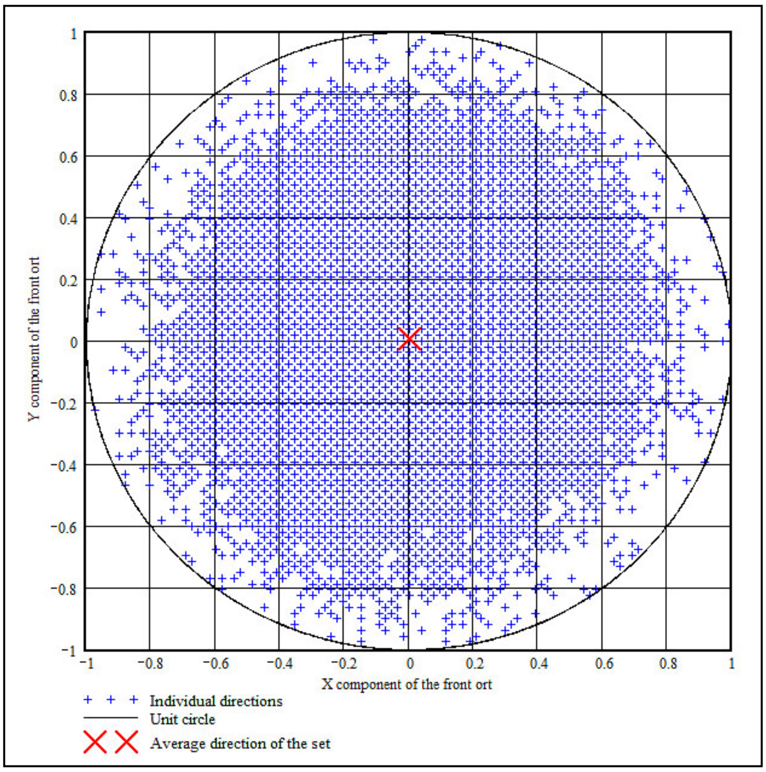

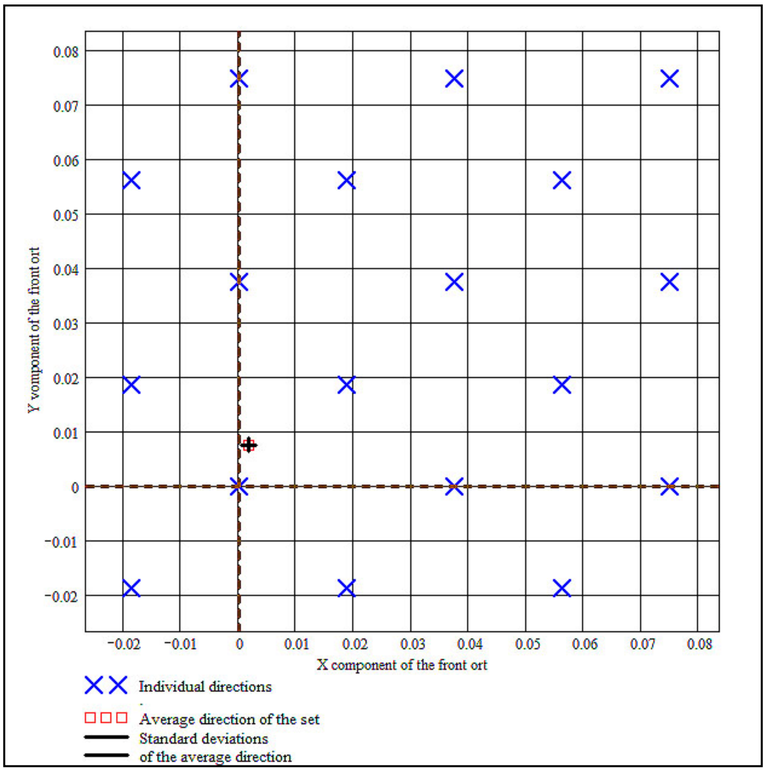

Fig. 9. TBSb goniometer Projections of EAS front orts onto the special plane parallel to the detectors' plane. Circle with unit radius represents the horizon. Events number = 52798 $\theta_z = 0.45°\pm0.07°$

As it can be seen on the **Fig.9**, the average EAS direction now only slightly differ in a sense from zenith direction (i.e. $\theta_z = 0.45°\pm0.07°$), though the deviation is statistically significant. Discrete points of the ends of the registered projections of directional orts' estimations are arranged in the corners of squares, as is perfectly seen in right bottom part of the figure. The increase of inter-detector distances fulfilled has entailed two welcome consequences, at least: the representing points of orts' tips are arranged much closer one to another – i.e. the angular resolution has increased – and

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density of points in the horizon vicinity has decreased (cf. **Fig. 2.**). Therefore, the goniometer in new configuration can represent more accurately the true distribution of EAS arrival zenith angles.

Let us yet stress again that the disposition of detectors is symmetric in this case. That is why the positions of the orts' projections tips are not spread at all and the representing points observed, shown with big resolution on the right bottom part of the current **Fig. 9**, are projected onto the fixed and symmetrically arranged positions of the projections' special plane, parallel to the detectors' plane.

The angular distributions certainly reproduce the statements described just above.

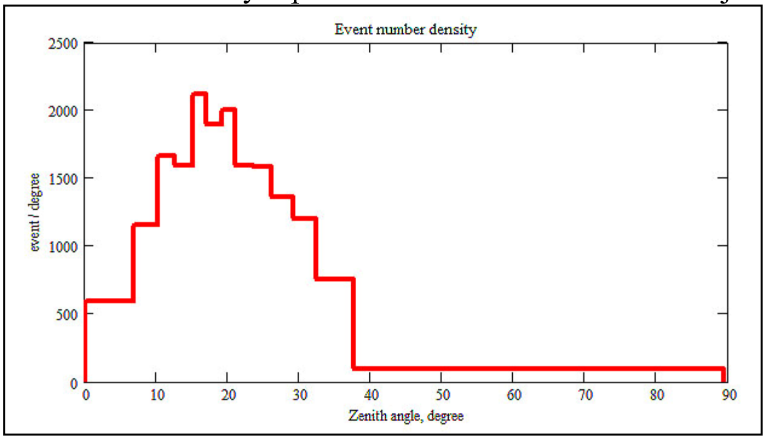

Fig. 10. The histograms of zenith angles distribution acquired by TBSb goniometer. The histogram cell charge is 4000 events/cell.

The distribution of zenith angles (**Fig. 10.**) in this case is considerably narrower (cf. **Fig. 3**) as the overall dimension of the installation has become greater. Nevertheless the distribution apprecia-bly spreads until the 90° zenith angle value. This feature is unnatural and indicates certain imperfec-tion of the installation. Undoubtedly, it is a sequence of the flatness of the goniometer used and of the lack of the number of detectors.

The distribution of azimuth angles (**Fig. 11.**) is visually "as if" uniform, but χ^2-test does not confirm this expectation, i.e. the shift of the event's center from zenith position is verified.

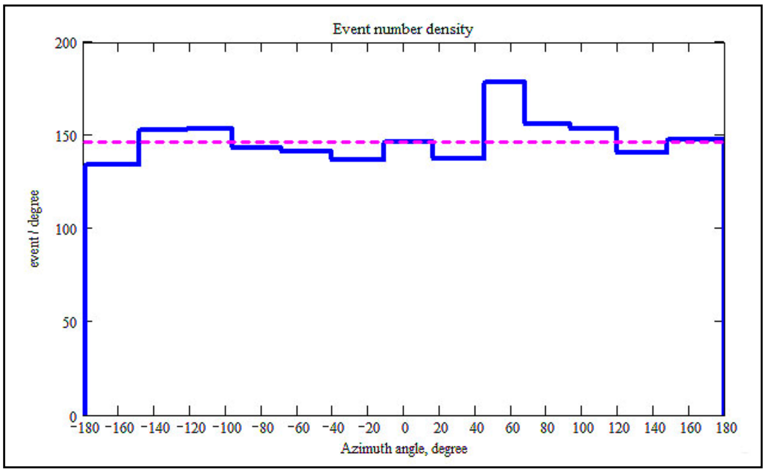

Fig. 11. The histograms of azimuth angles distribution acquired by TBSb goniometer. The histogram cell charge is 4000 events/cell. The anticipated uniform distribution is shown too.

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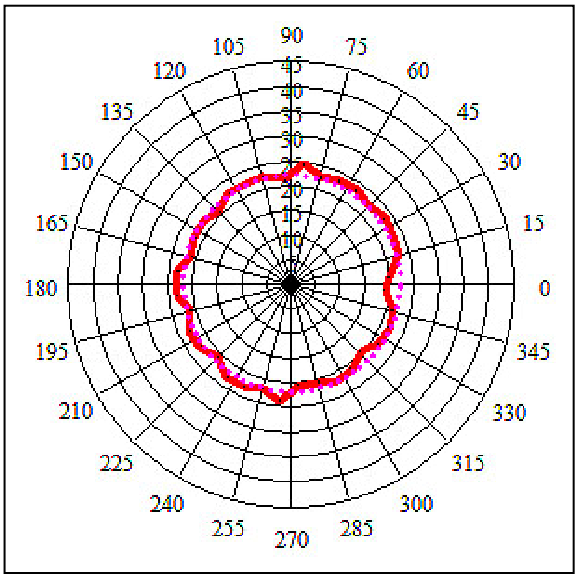

Fig. 12. Mean zenith angle dependence on the azimuthal direction acquired by TBSb goniometer. General average zenith angle $\Theta_{av} = 21.85°\pm0.05°$

Now, in this last case of goniometers considered, the average zenith angles dependence on the azimuth (**Fig. 12.**) does not demonstrate any certain oblongness or visible shift of the center (Zenith), the averages measured angles are distributed evenly on both sides of the line of sample average of zenith angles. But local divergences are big enough and exceed the estimated values of standard deviations. Possibly that is some effect of local deflections of surrounding matter amount or of still the same digitalization. The origin of the phenomenon has to be investigated intently.

5. Conclusion

Executed joint comparison of the first combined results obtained by means of the considered three goniometers makes it possible to assert that the crucial influence onto the possible resolving power of plane goniometers exert at least two factors: the overall dimension of the installation and the finite temporal resolution of signals, i.e. simply that fact that measured delay times undergo the digitalization procedure.

Indeed, due to increasing of the overall dimension of installation, possible resolving power increases too, as expected [21]. But intrinsic digitalization of the measured delays unavoidably manifests in the sets of narrow peaks in the histograms of angular distributions under study, provided the condition of considerably low event amount per every cell of histogram. With optional increasing of the charge of all cells the spikes get wrapped into wider cells and estimated distribution turns into comparatively smooth one.

On the other hand the form of the angular distributions observed proves to be under the influence of factors of form, arrangement and surroundings of the installation. The influence of the surrounding matter is predictable easily. Meanwhile it has appeared that small installations heavily overestimate the relative EAS flow near the horizon. So, the dimension increase of installation reduces this side effect simultaneously with growth of the resolution of goniometer. Unfortunately, this possibility is restricted by properties of the EAS phenomenon itself.

Further development of the quality of goniometers is available by means of the grows of number of detectors, as well as by force of increase of distances between detectors, together with actual turn towards practical application of the axially symmetric 3D structure of EAS goniometers [24].

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