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Reconstruction of the Direction of True Anisotropy of Cosmic Rays at Energy of about 100 TeV

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Abstract: Based on experimental data of the Baksan Air Shower Array (BASA) for the period 1994 – 2006 we have derived the true declination of cosmic ray anisotropy with effective energy about 100 TeV. The method used for this is a modification of the method suggested by us in 2005 and based on the analysis of zero harmonic of intensity in the sidereal time. The CR anisotropy declination turned out to be about 60 degrees. Thus, our previously published data, according to which the anisotropy vector lies in the galactic plane, is confirmed. In this case the correction of the amplitude of the first harmonic in sidereal time reduced to the equator by the cosine of the true declination gives for the total amplitude of the anisotropy vector a value of 0.16%.

Keywords: Anisotropy, Cosmic rays

1 Introduction

Large scale anisotropy of cosmic rays is a subject of permanent interest of researchers for decades. Recently, many new pieces of experimental data have appeared, mainly provided by giant modern collaborations like Superkamiokande [1], Tibet AS-γ [2], and Milagro [3]. However, the experimental situation remains not very clear. For example, a steady increase of anisotropy for seven years was found by Milagro at 6 TeV. This strange experimental fact was disproved by Tibet [4]. We have criticized [5, 6] both SuperK and Tibet collaborations for their erroneous identification of equatorial maxima on two-dimensional RA-declination maps with real maximum of cosmic ray intensity. In papers [5, 6] we argued that only right ascension of the anisotropy is directly derived from experimental data on the first harmonic of intensity in sidereal time. Due to unknown declination of the true anisotropy its amplitude is unknown too, since the first harmonics includes the unknown factor $cos\delta_0$. In [7] we proposed a method of determining δ_0 based on the analysis of zero harmonic, and this method was applied to experimental data of Baksan air shower array in paper [8]. The result is that the sought-for declination is about 60°, which automatically means that the anisotropy vector lies in the galactic plane and that its magnitude after correcting the first harmonic amplitude by cos60° increases twice.

In this paper we use a certain modification of the method applied in [8].

2 Method

Figure 1 presents the plan view of the Baksan air shower array. The huts 1-6 with 9 m^2 of scintillation detectors are arranged around the Carpet with 200 m^2 of scintillators in the center. In [8] we analyzed the distribution of delays at points 2 and 3 constructing cross telescopes that divide the hemisphere of air shower arrival directions along the line of detectors 1-4.

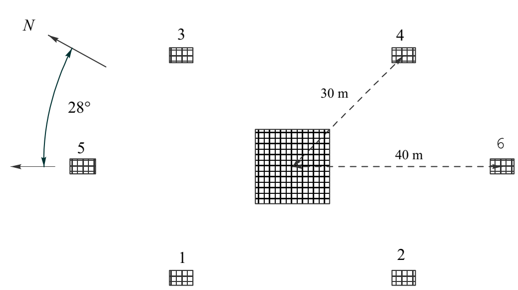

Figure 1. Plan view of the Baksan air shower array.

These distributions of delays were used to determine the ratio of counting rates of these two telescopes, $K_{1/2}$.

Then, using the ratio $K_{1/2}$ and calculated effective sinuses $Sin\ \delta_{T1}$ and $Sin\ \delta_{T2}$ of the telescopes the declination of the anisotropy direction was calculated by the following formula [7]

$$tg\delta_0 = \frac{K_{1/2} - 1}{P(Sin\delta_{T1} - K_{1/2}\, Sin\delta_{T2})}, \quad (1)$$

where P is the normalized (reduced to the equator) amplitude of the first harmonic in sidereal time. The analysis made in this paper differs from that of [8] in the following.

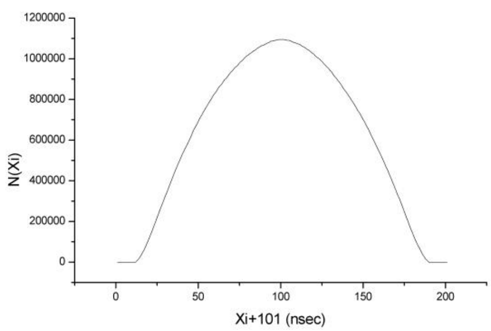

Figure 2. Distribution of quantity X_i shifted by 101 ns.

Choosing the coordinate system where pairs of detectors 1 and 4 and 2 and 3 lie on the axes X and Y, respectively, for every shower the following time delays are determined: $X_i = \tau_1 - \tau_4$ and $Y_i = \tau_2 - \tau_3$, where τ_1 , τ_2 , τ_3 , and τ_4 are the times when signals appear in corresponding detectors. Quantities X_i and Y_i can be used for determination of the arrival angles of showers, azimuth and zenith:

$$tgA = Y_i / X_i \text{ and } tg\theta = \sqrt{X_i^2 + Y_i^2} \Big/ \sqrt{T^2 - X_i^2 - Y_i^2} ,$$

where T is the difference between diagonal huts in nanoseconds. Figure 2 presents the distribution of X_i truncated to exclude events with zenith angles exceeding 40° and shifted by 101 ns to go away from zero and negative values. For completely isotropic flux X_i and Y_i would be symmetric about zero and after addition of constant shift about 101 ns. In reality, due to small errors in positions of detectors 1, 2, 3, and 4, the maxima of distributions are symmetric about 100.49 ns (for pair 1-4) and 101.33 ns (for 2-3 pair). Approximating these curves by β–functions we have determined the areas under each half of the curve of Fig. 2 and similar to it with respect to precisely determined maxima. These densities of events were taken as counting rates of four telescopes representing each a half of the upper hemisphere observing directions of detectors 1, 2, 3, and 4. Effective declinations for these four telescopes were calculated numerically from the experimental angular distributions using the following formula

$$Sin\delta_T = \frac{1}{N}\sum_i n_i Sin\delta_i .$$

The values of $Sin\delta_{eff}$ for all four telescopes are presented in Table 1 together with their counting rates determined as described above. Then, we consider our wide-angle telescopes as four equivalent narrow-angle telescopes with corresponding counting rates and effective declinations, applying to them formula (1) which now takes on the following form

$$tg\delta_0 = \frac{K_{(i/j)} - 1}{P(Sin\delta_i - K_{(i/j)} Sin\delta_j)} . \quad (2)$$

As in [8], P was assumed to be known and its value was taken from another experiment made at the same place with approximately equal effective energy.

3 Results

The data obtained by the Carpet air shower array in the period 1994–2006 were used for the analysis. The counting rates of four telescopes obtained following the recipe of the previous section are presented in Table 1 along with the values of sinuses of effective declinations of these telescopes.

Telescope	N	Sin δ_{eff}
1	61015190	0.670752
2	60997315	0.467979
3	61025236	0.778062
4	61007360	0.576378

Table 1. Counting rates and effective declinations of four virtual telescopes.

After applying formula (2) to different combinations of the four telescopes, the values of the true declination of cosmic ray anisotropy were determined for these combinations, and the result is shown in Table.2.

(i/j)	1/2	1/3	1/4	2/3	2/4	3/4
δ_0 °	60.1	61.5	58.6	60.6	61.3	60.2

Table 2. Anisotropy declination derived for different pairs of equivalent narrow-angle telescopes.

The values in Table 2 are well consistent with each other, i.e., every combination of the four telescopes gives essentially one and the same result. The averaged value of angles in the second row of Table 2 is (60.4 ± 2)º. However, the full error should include the uncertainty is determination of P in formula (2). Taking this fact into account we finally get for the declination $\delta_0 = 60° \pm 5°$.

4 Discussion and conclusions

In papers [5] it has been shown that so-called two-dimensional measurements of anisotropy of galactic cosmic rays (GCR) carried out by giant international collaborations Super-Kamiokande and Tibet ASγ yielded no new and more precise data on the GCR anisotropy. Moreover, they resulted in a wrong interpretation at which the equatorial maxima of intensity naturally arising in the procedure of constructing two-dimensional (declination – right ascension) maps were identified with the true anisotropy direction. In more detail this subject matter is considered in [6]. However, one possibility still remains for these two-dimensional measurements to be true. The two-dimensional maps give no information on the anisotropy declination, but if it is zero (by chance the maximum of anisotropy coincided with the celestial equator), then these measurements produce the valid result (also by chance). Therefore, it is not sufficient simply to point out to the wrong interpretation of experimental data of two-dimensional measurements. It is also important to get indications to real distinction of the true declination of GCR anisotropy from zero.

Using the method of analysis suggested in [7], we obtained in [8] indications that, indeed, the true large-scale dipole anisotropy of cosmic rays has declination of order of 60°, so that the anisotropy vector lies in the galactic plane. The analysis made in the present paper, based essentially on the same idea of [7], confirms this conclusion.

Figure 3 taken from [8] shows the summary of world data on the degree of CR anisotropy determined by analyzing the first harmonic in sidereal time. The amplitude of the first harmonic reduced to the equator is laid off on the ordinate axis. It can be represented as quantity $\xi Cos\delta_0$, where ξ is the magnitude of the anisotropy vector and δ_0 is its declination. The vertical arrow (placed above the point used in this paper for reconstruction procedure) and horizontal bar show how the value experimentally measured and reduced to the equator should be corrected to reproduce the true amplitude of cosmic ray anisotropy.

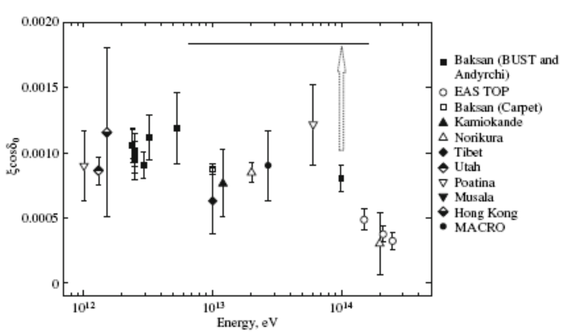

Figure 3. Summary of world data on GCR anisotropy. Presented results are converted to the equator (projection $\xi \cos \delta_0$ of the anisotropy vector onto the equator plane). The horizontal bar shows approximate level of the true anisotropy after correction by the cosine of declination δ_0 determined in the present paper.

Since the value $P = 0.0008$ was used in formula (2), final value for the anisotropy amplitude is $\xi = 1.6 \cdot 10^{-3}$. Upon transformation of declination derived in this paper and right ascension determined earlier into the galactic coordinate system the direction of this vector approximately corresponds to $l = (125 \pm 7)°$ and $b = (0 \pm 5)°$.

In conclusion, it should be noted that, suggesting in [7] the method realized here, we had in mind to create a special array with stabilization of all parameters and high-precision measurement of delays. The present attempt of applying it with an ordinary array turned out, as is seen, to be successful. Nevertheless, we consider it only as a first step and think that the result described here requires confirmation by the data of other arrays. In spite of this remark, one cannot help noting that this result is much more reasonable from the physical point of view than random coincidence of the CR intensity maximum with an imaginary line on the celestial sphere (equator) --- the only possibility at which the result of collaborations Super-Kamiokande and Tibet-ASγ has a chance to be true.

Acknowledgments

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