New Approach for Experimental Investigation of the Nature of the Knee with the GAMMA Experiment

(preliminary results)

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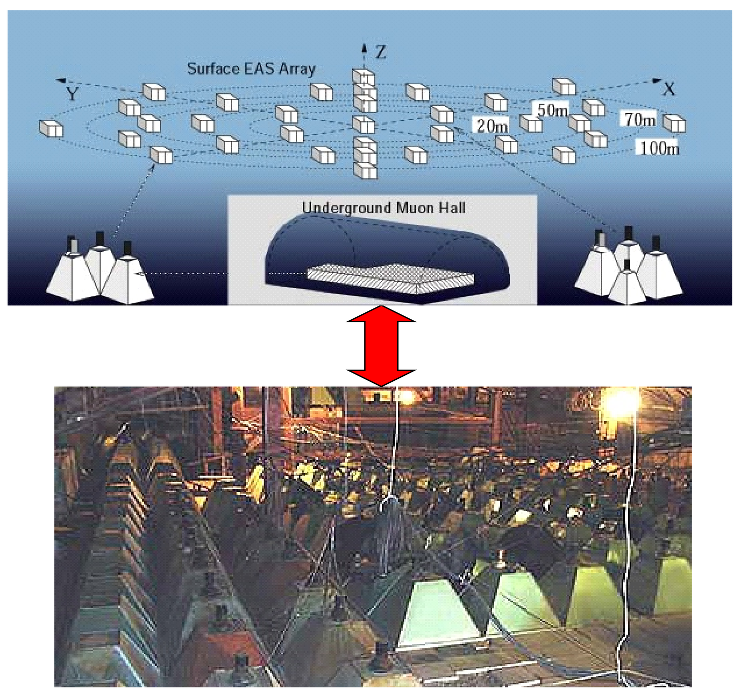
GAMMA experiment at Mt. Aragats (3200m a.s.l., Armenia)

Geographical coordinates: l = 40 28' 12'' N, λ = 44 10' 56'' E



Surface stations for scintillation detectors for study of the EAS electromagnetic component. 116 (107 - 1 sq.m., 9 - 0.09 sq.m.) scintillation detectors in 41 surface stations. Total area - ~ 10^4 sq.m.

25 chanels of fast timing system for measurement of EAS angle characteristics. EAS energy - 10^{14} – 10^{17} eV.

210 muon scintillation detectors (each of 1 sq.m.) for study the EAS muons. Muon energy threshold - 5 GeV.

EAS with the number of charged particles $N_e > 10^5$, zenith angles of θ < 40 in the laboratory coordinate system and the axes with radius of R < 60 m from the center of the GAMMA array are selected for the current analysis. The total number of EAS is 3.382.892 taken over an effective life time of 11544 hours. Laboratory system coordinates were recalculated to the Galactic coordinates (l – longitude, b – latitude). The correctness of the recalculation was checked by the astronomical utilities. The total error of the recalculation from the laboratory system to the Galactic system was no more than 10 angular minutes for the period between 1960 and 2060.

Diffusion-difference method for the analysis of the experimental data (short discription)

(V.P. Pavlyuchenko, 2014, Bull. Lebedev Phys. Inst., 3, 3)

This method was suggested for the test of the models of the knee in the PCR at 3 x10^{15} eV and is based on two natural assumptions:

1. Incoming EAS with primary energies of 10^{14} – 10^{17} eV are isotropic to a level better than 1%. This is due to the presence of numerous sources and to the large-scale diffusion transport of charged particles from the sources to the Earth. It is assumed that under these conditions for a rather big number of registered EAS and not too a large distance between source and the Earth, the contribution of a particular source to the EAS from the source direction will smoothly decrease with the rising angle between the source direction and the direction of the incoming EAS. This is the consequence of the diffusive character of the transport. The maximum contribution is expected from the direction to the source, the minimum contribution - from the opposite direction.
2. It is also assumed that the GAMMA installation operates with the same aperture independently of time of the day and season. This provides the same observational conditions for different directions as the Earth rotates. It is the common requirement for the stable operation of the experimental installation.

The whole celestial sphere in the Galactic coordinates is divided into two (typically unequal) parts: one in the given direction (l_0,b_0), the other – in the opposite direction $(l_0 - 180, -b_0)$. The division is made in a way that the number of events for both samples is the same. The characteristics of the EAS from these two parts of the sky are compared with one another. For both sets of events the experimental distributions of the EAS parameter selected for the analysis (or of the combination of several parameters) are calculated. Since both sets have been reduced to equal conditions, these distributions can be subtracted from one another to study possible differences.

The reduction to equal conditions means taking the same limits of intervals for both distributions and the choice of such an angle ψ_0 (or H_0=cos ψ_0) of the spherical cone around the direction (l_0, b_0), that the number of events n and n^{anti} for both sets are equal and at $H \geq H_0$ the EAS are coming from a part of the sky centered around the given direction, and at $H < H_0$ – from the opposite sky part. For EAS with angles *(l, b)*

$$H = \cos\psi = \sin b_0 \cdot \sin b + \cos b_0 \cdot \cos b \cdot \cos (l - l_0)$$

Taking into account assumptions 1 and 2 it can be said that for $n = n \;\; n^{anti}$ the observation periods for the two parts of the celestial sphere are equal, and any additional validation of the conditions for the EAS registration efficiency is not required. In the difference method the common background and the possible methodical errors are subtracted automatically, because they are the same for both sets. The error in the assignment of EAS to the incorrect sample at the boundary region due to the errors in the angle estimations does not matter much. The EAS characteristics are practically similar to each other for close arrival angles and they are subtracted as a common background. The numerical parameter for the difference of two distributions is χ^2/J, where $\chi^2 = \Sigma(\Delta_i/\sigma_i)^2$ and J is the number of degrees of freedom. The sum runs over all intervals i of the parameter chosen for this analysis. The difference between the distributions in the interval i is equal to $\Delta_i = m_i - m_i^{anti}$ (m_i and m_i^{anti} being the number of events in the two parts of the sky for the given Interval i of the parameter under study). $\sigma = (m_i + m_i^{ant} + 1)^{1/2}$.

Experimental results (available at 0993272_astro-ph.HE)

The EAS age parameter S has been chosen because of its weak dependence on the primary energy and on the EAS incoming angles in the laboratory coordinate system.

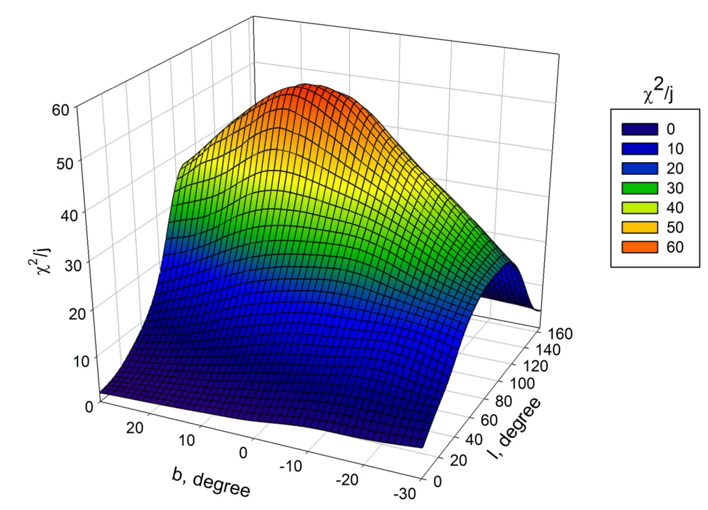


Fig. 1. We have scanned the (l_0, b_0) plane in order to find the maximum value of χ^2/J (Figure 1). The range of studied directions is l_0 = 0° - 180° and b_0 = -30° - +30°. The local maximum of the χ^2/J distribution was found in the direction l_0 = 97 ± 3, b_0 = 5 ± 3 (or l_0 = 277 ± 3, b_0 = -5 ± 3 since we get the maximum by comparing opposite directions)

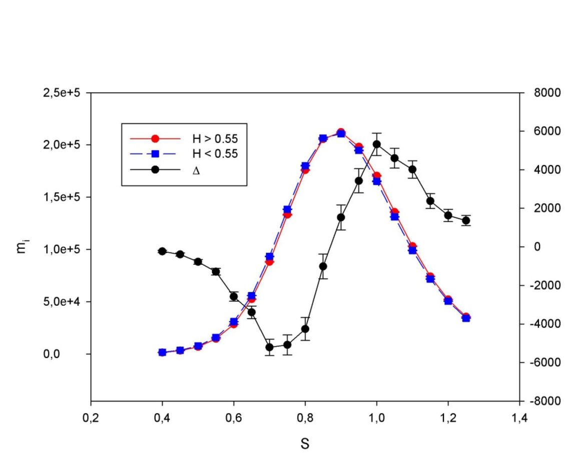


Fig. 2. Number of EAS versus age *S* for the direction l_0 = 97, b_0 = 5 and its opposite (l_0 = 277, b_0 = -5) for θ < 40°. The right scales show the difference between the distributions.

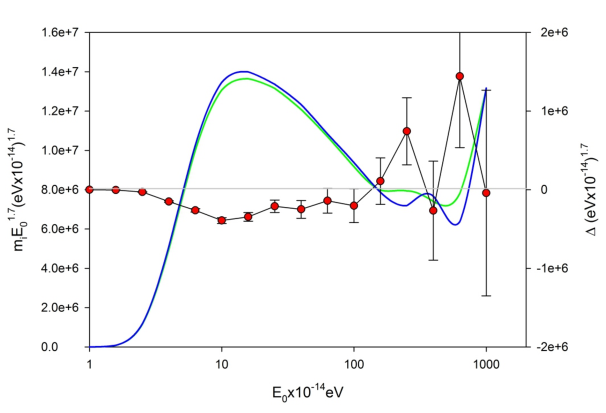


Fig. 3. Dependence of $m_iE_0^{1.7}$ on E_0 for the direction of l_0 = 97, b_0 = 5 and opposite to it (l_0 = 277, b_0 = -5). The right scale shows the difference between the two distributions. This figure demonstrates that there is an excess of EAS in the knee region from the direction l_0 = 277°, b_0 = - 5°. Not far from this point there is a claster in the Vela constellation with two closely appearing supernova remnants Vela X (263.9°, - 3.3°) and Vela Jr (266.2°, - 1.2°) at distances from the Earth 0.3 and 0.2 kpc, respectively.

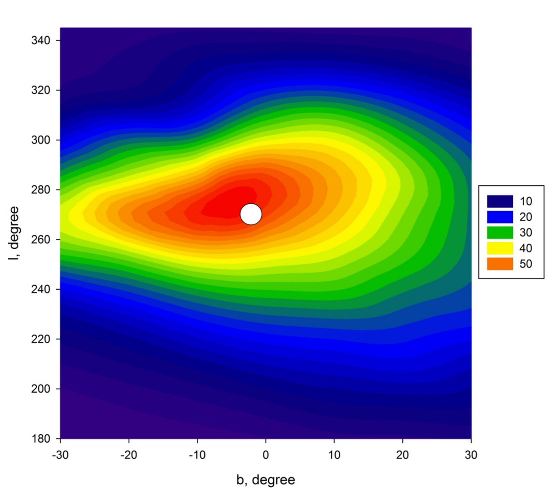


Fig. 4. χ^2/J distribution for the *S* parameter in the Galactic coordinate system (contour diagram). The white circle in the center marks the position of the Vela cluster

Conclusion

We have presented a new method to reveal tiny of primary CR particles provided they consist of protons and heavier nuclei with different galactic diffusion coefficients. **The main feature of the suggested method is a difference study of EAS characteristics but not their intensity in different directions.** We have found the age parameter *S* to be the most suitable and physically motivated parameter. Other parameters may also be useful, and their combination with *S* may be even more powerful than *S* alone. We have used data taken with a comparatively small device, the GAMMA detector in Armenia. We find an anisotropy which is maximal along the direction between the celestial coordinates l_0 = 277, b_0 = -5 and the opposite sky position. The maximum of the excess at these coordinates turns out to be close to the Vela cluster. The effect has a high statistical significance, but yet we cannot exclude that it is caused by hitherto unconsidered systematic biases. Therefore we suggest that other experiments, with different systematics, repeat the analysis with their own data.

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