Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008
Vol. 4 (HE part 1), pages 291–294

30TH INTERNATIONAL COSMIC RAY CONFERENCE

A shape of charged particle lateral distribution in individual EAS events with energy above 10^{19} eV arriving from different celestial regions

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Abstract: A shape of lateral distribution for charged particles in events with energy above 10^{19} eV is considered. Two methods were used for individual LDF parametrization. In the first approach, the index of power was determined for generalized Greisen-Linsley approximation. In second, mean square radius of the shower was determined for approximation proposed by Lagutin et al. Comparison of resulted parameters is presented for individual events arrived from different celestial regions — Galactic planes and the region with increased flux of particles with $E_0 \geq 10^{19}$ eV (according to Yakutsk array): 1.7h – 3.7h right ascension ; $45^{\circ} - 60^{\circ}$ declination.

Introduction

The knowledge of the lateral distribution function (LDF) of charged particles from extensive air shower (EAS) is vital for experiments in the field of ultra-high energy cosmic ray (UHECR) studying. It is LDF that defines main shower parameters such as ρ_{600} (charged particle density at the distance 600 m from the core) and thus — primary energy.

In this paper we consider parameters of individual LDFs resulted from revision of high energy events registered at the Yakutsk EAS array. The aim of this work is to trace possible correlation between parameters of individual showers and their arrival directions on the sky, especially for Galactic planes and for the region with significantly increased UHECR flux, detected by Yakutsk group [1].

Estimation of lateral distribution parameters for individual showers

For the analysis we selected showers with $E_0 \geq 10^{19}$ eV, with zenith angles $\theta < 60^{\circ}$ and with core lying well within the boundaries of the array, to make sure that shower core is found correctly.

At the Yakutsk EAS array, approximation proposed by Greisen [2] is used for primary data processing:

$$\rho(r) = M \cdot \left(\frac{r}{R_0}\right)^{-1} \cdot \left(1 + \frac{r}{R_0}\right)^{\langle b\rangle+1}, \quad (1)$$

where R_0 is Moiere radius and slope parameter $\langle b\rangle = -1.38 - 2.16 \cdot \cos\theta - 0.15 \cdot \lg\rho_{600}$.

In the work by Glushkov et al [3], an updated approximation was proposed, that demonstrated better description of experimental points at large distances from the core ($r > 1000$ m):

$$\rho(r) = M \cdot \left(\frac{r}{R_0}\right)^{-1.3} \cdot \left(1 + \frac{r}{R_0}\right)^{\langle b\rangle+1.3} \times \times \left(1 + \frac{r}{2000}\right)^{-3.5}, \quad (2)$$

where $\langle b\rangle = 2.6 \cdot (1 - \cos\theta) - 3.242$.

In equations (1) and (2) the slope parameter $\langle b\rangle$ is derived from average LDF. While it describes most of showers quite well, it certainly fails doing so in dozen number of events. During revision we performed χ^2-fitting of functions (1) and (2) normalized to ρ_{600} on experimental data for each selected shower with free parameters ρ_{600} and b.

The value $\Delta b = |\langle b\rangle - b|$ could give a hint of possible astrophysical aspect of the slope parameter in functions (1) and (2). As seen on Fig.1, compari-

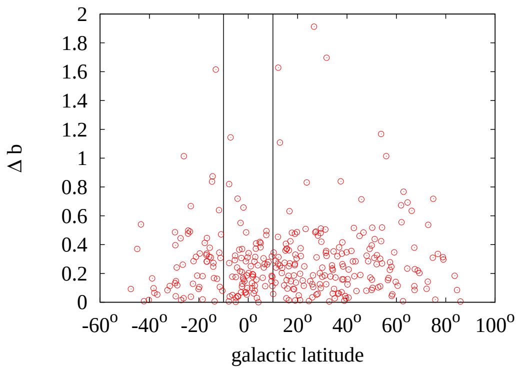

Figure 1: Δb vs Galactic latitude. Marked stripe $\pm 10^o$ is Galaxy plane.

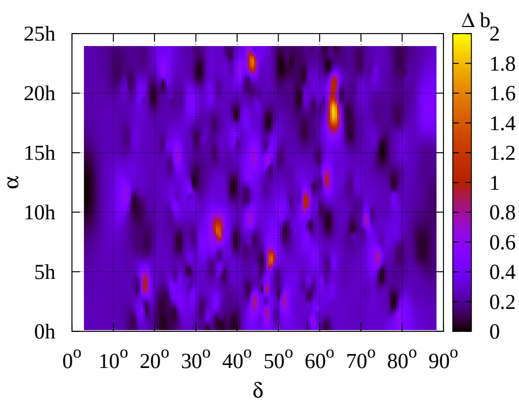

Figure 2: Δb vs astrophysical coordinates.

son to Galactic coordinates showed no correlation between Δb and Galaxy plane.

To trace possible dependency on astrophysical coordinates, we selected a "stripe" of 15^o width along declination and divided it into "chunks" of 2h each along right ascension. Such a stripe was selected to exclude zenith-angular dependency. Averaged Δb values in each chunk are presented in table 1 in comparison to averaged value in the rest chunks of the stripe.

Scaling approach

A one-parametric scaling representation of charged particle lateral distribution was proposed by Lagutin et al [4]:

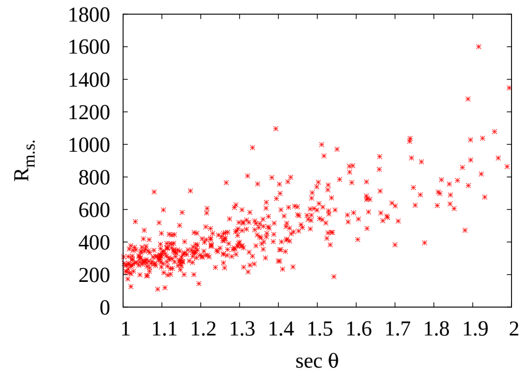

Figure 3: $R_{\text{m.s.}}$ of electrons in individual showers compared to $\sec\theta$.

$$\rho(r) = M \cdot \left(\frac{r}{R_{\text{m.s.}}}\right)^{-1.2} \cdot \left(1 + \frac{r}{R_{\text{m.s.}}}\right)^{-3.33} \times \times \left(1 + \left[\frac{r}{10 \cdot R_{\text{m.s.}}}\right]^2\right)^{-0.6}, \quad (3)$$

here $R_{\text{m.s.}}$ is mean square radius of electrons. This function was obtained with respect to nuclear cascade process in the shower [4]. Since the main classification parameter for the Yakutsk array is ρ_{600}, we used (3) normalized to ρ_{600}. We calculated $R_{\text{m.s.}}$ for each shower in our selection using χ^2-minimization. On Fig. 3 there are shown $R_{\text{m.s.}}$ values obtained for individual events compared to zenith angle. It is clear, that these values significantly exceed predicted in the work [4], though one can note distinct zenith-angular dependence.

We constructed average LDFs for three zenith-angular intervals: $0 - 30^o$, $30 - 45^o$ and $45 - 60^o$. Results can be found in table 2 and Fig.4. It is seen from the table, that resulted $R_{\text{m.s.}}$ values contradict to theoretical predictions from the work [4].

Obtained $R_{\text{m.s.}}$ values did not allow us to make juxtaposition with celestial coordinates as for functions (1) and (2).

Results

Revised parameters of individual lateral distribution functions in Greisen's ((1) and (2)) approxi-

Table 1: Averaged Δb values in the region of interest (see Fig. 2)

	inward			outward		
α, hour	Δb	n	$\delta(\Delta b)$	Δb	n	$\delta(\Delta b)$
$1.7 - 3.7$	0.356961	15	0.080848	0.285764	72	0.031073
$3.7 - 5.7$	0.231064	8	0.041157	0.304822	79	0.031815
$5.7 - 7.7$	0.547938	5	0.283294	0.282802	82	0.025840
$7.7 - 9.7$	0.245541	7	0.081267	0.302633	80	0.030999
$9.7 - 11.7$	0.457900	8	0.109829	0.281851	79	0.029796
$11.7 - 13.7$	0.200063	6	0.045722	0.305297	81	0.031049
$13.7 - 15.7$	0.328212	5	0.134513	0.296200	82	0.030067
$15.7 - 17.7$	0.157237	4	0.085138	0.304825	83	0.030185
$17.7 - 19.7$	0.170663	3	0.102908	0.302589	84	0.029958
$19.7 - 21.7$	0.249221	9	0.037238	0.303672	78	0.032253
$21.7 - 23.7$	0.157450	8	0.043347	0.312276	79	0.031443

Table 2: Parameters for average LDF obtained for approximation (3)

θ	$\langle\rho_{600}\rangle$	ρ_{600}	$R_{\text{m.s.}}$	χ^2
$0 - 30^{\text{o}}$	26.92	31.47	320.42	6.0594
$30 - 45^{\text{o}}$	14.81	17.86	476.45	5.0713
$45 - 60^{\text{o}}$	8.59	10.15	770.07	8.3343

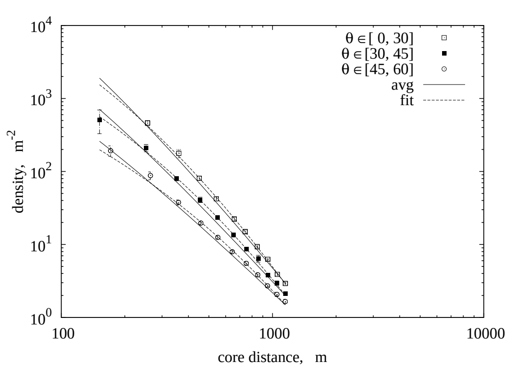

Figure 4: Average scaling LDFs for three different zenith angle intervals.

mation showed no correlation neither with Galactic plane, nor with the region of UHECR region excess. From table 1 it is seen, that increased Δb in the region of interest ($1.7\text{h} < \alpha < 3.7\text{h}$) is not significant and the whole picture is spoiled by poor statistics.

Difficulties in estimation of $R_{\text{m.s.}}$ did now allow us to use scaling approximation (3) in such analysis. In the work by MSU EAS group [5] authors have faced similar obstacles in $R_{\text{m.s.}}$ determination. It is worth mentioning, that KASCADE-Grande group successfully used scaling formalism for estimation of muon density in air showers [6]. Besides, scintillation detectors used at the Yakutsk array may lead to sloping of charged particle distribution caused by registration of atmospheric muons and electrons from muon decay. If we consider this fact together with zenith-angular dependence of $R_{\text{m.s.}}$ more closely, we can obtain more plausible estimation of this parameter.

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