LATERAL DISTRIBUTION FUNCTION OF EAS CHERENKOV LIGHT: EXPERIMENT QUEST AND CORSIKA SIMULATION

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Abstract

A new fitting function for the Cherenkov light lateral distribution (LDF)in Extensive Air Showers is obtained from the analysis of the data of QUEST experiment at the EAS-TOP array and the CORSIKA simulation code, in the range of distances 0 to 250 m from the shower axis. The proposed LDF consists of two branches and contains a single shape parameter (P), which is given by the ratio of the light fluxes at 100 m and 200 m from the axis. Parameter P depends only upon the relative position of the shower maximum for any primary nucleus, arrival direction and primary energy.

1. Introduction

The fitting function is very essential for the reconstruction of the extensive air shower (EAS) parameters. Concerning atmospheric Cherenkov light, smooth functions can describe the observed lateral distribution in the limited range of distances only. The most popular approximations are exponential function $\sim exp(-R/R_0)$,suitable inside the distances from 20 to 150 m only [4], and modification of power law function $\sim (1+R/R_L)^{-b}$, suitable in some more wide region from 20 to 200 m [1]. But no one of them can fit the pole of type $\sim 1/R$ close to the axis and change of LDF at distance of about 90 - 100 m. We suggest here a new approach to the fitting function of Cherenkov light LDF.

2. CORSIKA simulation

The CORSIKA [5] code has been used with QGSJET model [6] and the Cherenkov light block [7]. Simulations have been performed both for primary protons and iron nuclei with total energy 1, 2, 4 and 8 PeV, and zenith angles θ from $0°$ to $39°$. Simulation has been made for the EAS-TOP level 2000 m a.s.l. (813 g/cm^2 for the standard atmosphere).

The simulated lateral distribution in general is not smooth and shows a rather sharp break down at some distance from the shower axis R_{kn}, which varies

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from 70 m to 150 m. At the first step we divided each simulated LDF to 3 parts ($5m < R < 50m$, $50m < R < R_{kn}$ and $R_{kn} < R < 250m$), fitting of each part with it's own function: $1/R$ in the first range, exponent in the second one and power function in the third range. Second step was to find out an analytic connections between the parameters of LDF in the different ranges. The third step was to minimize the number of independent parameters. Finally we came to the expression with a single parameter P, introduced at the beginning as the ratio of Cherenkov light flux at 100 m from the axis, derived from the region $R < R_{kn}$, and flux at 200 m from the axis, derived from the region $R \geq R_{kn}$:

$$Q(R) = \begin{cases} Q_{kn} \cdot exp((R_{kn} - R) \cdot (1 + 3/R)/R_0), & for R < R_{kn} \\ Q_{kn} \cdot (R_{kn}/R)^{2.2}, & for R \geq R_{kn} \end{cases} \tag{1}$$

$$R_0 = 10^{2.83 - 0.2 \cdot P}, m$$

$$R_{kn} = 199 - 21.5 \cdot P, m$$

Similar expression may fit LDF at larger distances, but with a variable power exponent instead of the fixed value 2.2, used here.

3. Fitting of simulated EAS Cherenkov light LDF

Fig. 1 shows 5 different examples of simulated LDF fitting. The expression (1) fits every LDF well enough from 5 to 245 m. No one of smooth functions described in the introduction, can fit them in this range of distances.

The primary energy E_0 is almost proportional to the light flux at distances $R > R_{kn}$ with slight correction for low and high values of parameter P only:

$$log_{10}(E_0/TeV) = log_{10}Q_{kn} + 2.2 \cdot log_{10}R_{kn} - 2.4 + o(P) \tag{2}$$

$$o(P) = \begin{cases} 0.14 \cdot (P - 5), & for P > 5 \\ 0, & for 4.3 < P < 5 \\ 0.04 \cdot (4.3 - P), & for P < 4.3 \end{cases}$$

Such method of E_0 measurement provides the teoretical accuracy of about 10%, and difference between energy estimates for proton and iron less than 15%.

Fig. 2 represents the correlation of parameter P with the atmospheric distance between the array and the shower maximum $\Delta X = X_0/cos\theta - X_{max}$, where X_0 is the total depth of the atmosphere, and X_{max} is the depth of shower maximum. The picture represents both protons and iron events, zenith angles from 0° to 39° and primary energies from 1 to 8 PeV. It is well seen that parameter P depends only on the relative position of the shower maximum and is independent of the other details of EAS longitudinal development. The connection of P with ΔX can be approximated with the simple linear expression: $P = 7.3 - 0.008 \cdot \Delta X$. The standard deviation of ΔX from this line is about 20 g/cm^2. This value characterizes the theoretical accuracy of the method of deriving X_{max} from the individual lateral distributions.

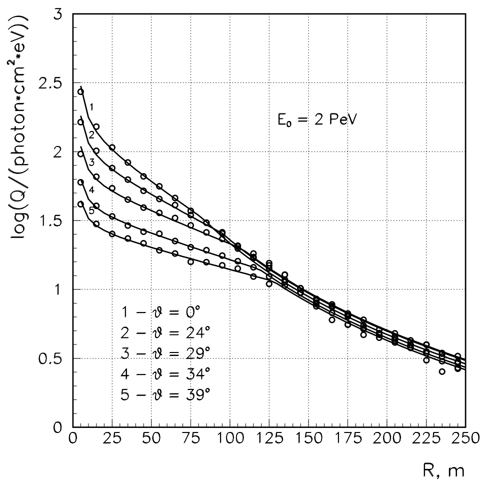

Fig. 1. Fitting of CORSIKA simulated LDF with function (1)

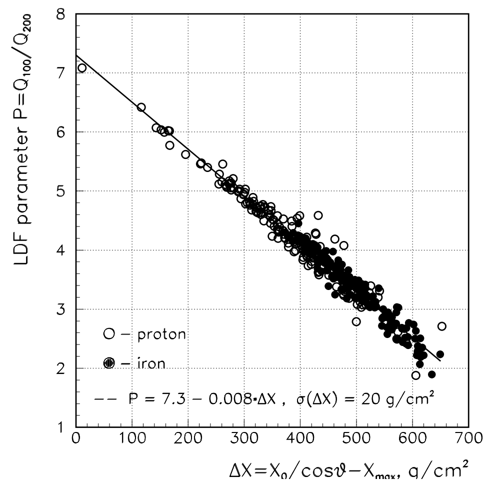

Fig. 2. Plot of parameter P of simulated LDF on ΔX

4. Mean experimental LDF

The QUEST experiment consisted of 5 wide angle ($\theta = 40°$) and large area ($1000\ cm^2$) Cherenkov light detectors positioned inside the EAS-TOP array [2]. The Cherenkov array had it's own trigger, could provide the range of distances to the axis in individual events till about 180 m at energy threshold similar to that of the electromagnetic EAS-TOP array.

To obtain the experimental Cerenkov light LDF we used the EAS parameters (position of the axis and the arrival direction) from independent data of electromagnetic detectors of EAS-TOP. To reduce the fluctuations we used for classification the size $N_{e,34}$, recalculated from the original zenith angle to one the same zenith angle $\theta = 34°$, using the attenuation length of size $\lambda = 220 g/cm^2$ from the original EAS-TOP measurements [3]. We've selected events within $5 \cdot 10^5 < N_{e,34} < 10^6$ and separated them to three groups by $sec\theta$: $1 < sec\theta < 1.1$ (234 events), $1.1 < sec\theta < 1.2$ (162 events), $1.2 < sec\theta < 1.3$ (112 events). Fit was made by the individual points: the 1st by 932 points, the 2nd by 656 points, and the third by 424 points. Then the points have been averaged in the 20 m bins of distances. Fig. 3 shows the so obtained mean LDF. Even the mean experimental curves are not smooth and function (1) reflects the fluctuations of their shape. LDF becomes flatter with increasing zenith angles.

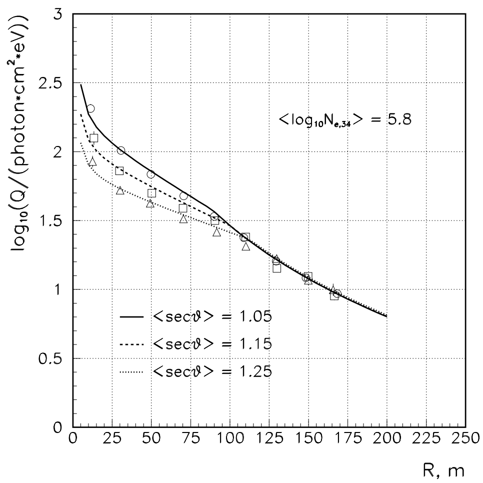

Fig. 3. Fitting of the average experimental LDF with function (1)

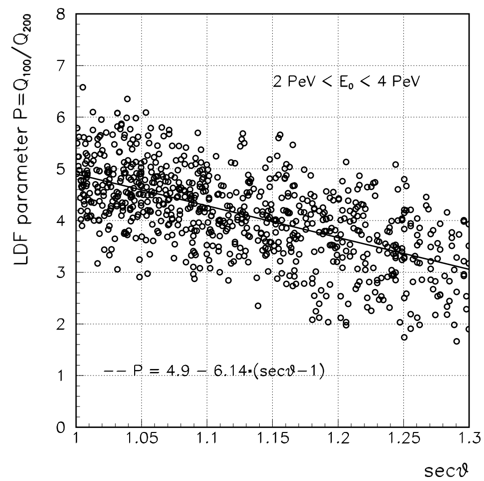

Fig. 4. Plot of the individual experimental parameters P on $sec\theta$

5. Fitting of individual experimental LDF

Having from 3 to 5 points for every individual event, we can estimate the parameter of LDF shape P as well as the flux at distance more than R_{kn}. Fig. 4 represents the plot of individual parameters P on the $sec\theta$ for about 800 events in the experimental energy range from 2 to 4 PeV. The inclination of fit line ($b_{exper} = 6.14 \pm 0.43$) is in good agreement with the theoretical value, which can be easily derived from Fig. 2: $b_{theor} = 6.5 \pm 0.1$. Fig 4. confirms therefore the sensitivity of P to the relative position of EAS maximum.

6. Acknowledgments

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7. References

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