Simulation of Cherenkov Light Lateral Distribution Function in Extensive Air Showers for Tunka25 EAS Array

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ABSTRACT

The Cherenkov light Lateral distributions function for primary particles in extensive air showers have been simulated with CORSIKA code for conditions and configuration of the Tunka-25 EAS array. In this work the calculation is performed for primary protons, iron nuclei, carbon, helium, lithium and γ-quanta in the energy range \(10^{14}-10^{16}\) eV for three zenith angles 0°, 10° and 30°. The results of this simulation are compared with the measurements of Tunka-25 array for the same particles and energy range.

INTRODUCTION

An air shower is one of the most complex physical processes in the field of particle physics. The only approach to gain access to the information of these processes is with the help of computer simulations of Extensive air showers (EAS) [1]. The program CORSIKA (COrsica Ray SiMulations for KAscade) is a detailed Monte Carlo program to study the evolution and properties of EAS in the atmosphere [2].

In this work the simulation of Cherenkov light Lateral distribution function (LDF) in EAS is performed with the CORSIKA code for configuration of Tunka-25 array [3] using the model QGSJET (Quark Gluon String model with JET’s) [4] for the simulations of hadronic showers for high energies and the model GHEISHA (Gamma Hadron Electron Interaction Shower) [5] for the simulation of hadronic shower at low energies and EGS4 (Electron Gamma Shower) code [6] for the simulation of electromagnetic component and Cherenkov radiation. The calculation was
estimated for Primary protons, iron nuclei, carbons, helium, lithium and γ-quanta in the energy range $10^{14}$-$10^{16}$ eV for three zenith angles (0°, 10° and 30°). The comparison of the simulated Cherenkov light LDF with that measured with Tunka-25 EAS array was gave a good agreement.

The Simulation by Corsika Code

A good procedure to study the cascade development in the atmosphere is a Monte Carlo code to simulate the EAS development in the atmosphere. The CORSIKA program allows to simulate interactions and decays of nuclei, hadrons, muons, electrons, and photons in the atmosphere up to energies of some $10^{20}$ eV [7]. It gives type, energy, location, direction, and arrival times of all secondary particles that are created in an air shower and passed a selected observation level. One of the reasons for the success of CORSIKA as the most used air shower simulation program comes from the combination of the best programs available to describe the interactions of the various particles which appear in the development of EAS. The calculations was performed for different particles like (p, Fe, c, He, Li and γ-quanta) in the energy range $10^{14}$–$10^{16}$ eV for different zenith angles $\theta = (0°, 10°$ and $30°)$. The figure 1a,b shows the results of the simulated Cherenkov light LDF for EAS initiated by primary Carbon, Helium and Lithium for different energies and different angles.

Fig. 1: The lateral distribution function of Cherenkov light simulated by CORSIKA code for; (a) vertical shower at the energy $10^{14}$ eV for carbon, helium and lithium particles and (b) primary lithium for different angles 0°, 10° and 30° at the energy $5 \cdot 10^{14}$ eV.
The characteristics of primary Carbon and Helium particles for different energies and different angles are explained in figures 1a and 1b.

Fig.-2: Lateral distribution of Cherenkov light which simulated with CORSIKA code for (a) primary Carbon at the energies $10^{15}$, $2\cdot10^{15}$ and $5\cdot10^{15}$ eV for vertical showers; (b) primary Helium at the energies $10^{14}$, $10^{15}$ and $10^{16}$ eV for $\theta=30^\circ$.

**Comparison of Corsika Simulation with Experimental Data**

The method of EAS core location reconstruction is based on fitting of the $Q_i$ data by LDF function with light destiny at the core distance $i=190$ m when [8]:

$$Q(R) = Q_{kn}f(R)$$  \hspace{1cm} (1)

$Q_{kn}$ is the light flux at the distance $R_{kn}$, which is given as [8]:

$$Q_{kn} = Q_{190}\left(\frac{R_{kn}}{175}\right)^{-2.2}$$  \hspace{1cm} (2)

Where $Q_{190}$ is density of Cherenkov radiation at the distance 190m from the shower axis.

And:

$$f(R) = \begin{cases} 
\exp\left(\frac{(R_{kn} - R)}{R_o}\left(1 + \frac{3}{R + 3}\right)\right), & R < R_{kn} \\
\left(\frac{R_{kn}}{R}\right)^{2.2}, & 200 \geq R \geq R_{kn} \\
\left(\frac{R_{kn}}{200}\right)^{2.2}\left(\frac{R}{200} + 1\right)^{-b}/2, & R > 200
\end{cases} \hspace{1cm} (3)$$
Where $R$ is the core distance (in meter), $R_o$ is a parameter of the first branch of LDF and $R_{kn}$ is the distance of the first change of LDF given by [8]:

$$R_o = \exp(6.79 - 0.56P),$$  \hspace{1cm} (4)

$$R_{kn} = 207 - 24.5P$$  \hspace{1cm} (5)

Where the steepness $P$ is given by [9]:

$$P = 7.3 - (0.008 \times \Delta X).$$  \hspace{1cm} (6)

Where

$$\Delta X = \frac{X_o}{\cos \theta} - X_{max}$$  \hspace{1cm} (7)

where $X_o = 955g.cm^{-2}$ (The total vertical depth of the atmosphere) [10]; and $X_{max}$ is the depth of the shower maximum development which is given by[10]:

$$X_{max} = 560 + 65\log \left( \frac{E_o}{10^{16} eV} \right)$$  \hspace{1cm} (8)

The parameter $b$ in eq. (3) can be defined as [8]:

$$b = \begin{cases} 
4.48 - 12.3 \ln (6.5P), & P < 6 \\
3.43, & P \geq 6 
\end{cases}$$  \hspace{1cm} (9)

In Figure 3a, the comparison between the Cherenkov light LDF which was simulated by using CORSIKA code with that measured with Tunka-25 array for different energies is presented for iron nuclei. Figure 3b displays the difference between the primary proton for vertical showers and the same particle at $\theta=30^\circ$ in comparison with the Tunka-25 at the energy $2 \cdot 10^{15}$ eV.
Fig.-3: Comparison of the simulated Cherenkov light LDF (solid lines) with the data obtained with Tunka-25 EAS array (symbol lines) for (a) Iron nuclei at the energies $10^{15}$, $2 \cdot 10^{15}$ and $5 \cdot 10^{15}$ eV for $\theta=10^\circ$; (b) primary proton at the energy $2 \cdot 10^{15}$ eV for different angles $\theta=0^\circ$ and $30^\circ$.

In Figure 4a one can see the comparison between the simulated Cherenkov light LDF and that measured with Tunka-25 EAS array for primary $\gamma$-quanta at the energy $10^{14}$, $2 \cdot 10^{14}$ at vertical shower. Figure 4b demonstrates the possibility for reconstruction the type of the EAS primary particles, where in these figure one can see the differences between the simulated Cherenkov light LDF and that measured with Tunka-25 EAS array for different particles.

Fig.-4: Lateral distribution of Cherenkov light which is simulated with CORSIKA code (solid lines) and one measured with Tunka-25 (symbols) for (a) $\gamma$-quanta for vertical showers at energies $10^{14}$ and $2 \cdot 10^{14}$ eV; (b) primary proton and iron nuclei for vertical showers at energy $2 \cdot 10^{15}$ eV.
In the present work the Monte Carlo code CORSIKA has been used to simulate the development of cascades in the atmosphere initiated by p, Fe, c, He, Li and \( \gamma \)-quanta) in the energy range \( 10^{14}-10^{16} \) eV for three zenith angles (0°, 10° and 30°). The CORSIKA simulation of the Cherenkov light lateral distribution function in Extensive Air Shower is performed for configuration of the Tunka-25 EAS array. The comparison of the simulated Cherenkov light lateral distribution function with that measured with the Tunka-25 array demonstrates the possibility to identify the primary particles and to determine their energies in the energy range \( 10^{14}-10^{16} \) eV. The main advantage of the given approach consists in the possibility to make a library of lateral distribution function samples which could be utilized for the analysis of real events which are detected with the Extensive Air Shower array and reconstructed of the primary cosmic rays energy spectrum and mass composition.

REFERENCES
