Increasing The Energy Range Of Cherenkov Light LDF Approximation At High Energies (E ≥ 10^{16} eV)

Ahmed Aziz Ahmed
Sana Rasoul Salim
Khaled A. Ahmad
Al-Mustansiriyah university, college of science
department of physics

ABSTRACT

By Using CORSIKA Program, the simulation of Cherenkov light Lateral distribution Function (LDF) of Cherenkov Light in Extensive Air Showers (EAS) of primary protons is performed at the very high energy range ($E \geq 10^{16} eV$). The approximation that constructed on the basis of this simulation have allowed us to reconstruct the events, that is, to reconstruct the type and energy of the particle that generated EAS from signal amplitudes of Cherenkov light registered with the Tunka-25 facility. The extrapolation of the Cherenkov light LDF approximation at the energy range ($10^{16} - 2 \cdot 10^{18} eV$) was taken into account.

INTRODUCTION

The determination of the energy spectrum and mass composition of the ultrahigh energy cosmic rays (E>10^{16} eV) is one of the greatest challenges in cosmic ray measurements. Using the atmosphere as a large target, Detectors are capable of tracing the development of the size of the Extensive Air Shower (EAS) through the atmosphere [1, 2]. Large-scale experiments, like the Yakutsk EAS array [3], AGASA [4] HiRes [5], Pierre Auger Observatory [6] and Tunka-133 [7] focus on the precise determination of the energy spectrum, mass composition and arrival direction distribution of ultrahigh-energy cosmic rays. The analysis of the characteristics of the detected longitudinal profiles is currently the most reliable way for extracting some information about the primary cosmic ray mass composition. One of the main techniques for observing EAS is effectively investigated by the method of Cherenkov light EAS registration [8, 9]. The main tools for calculating of EAS characteristics and experimental data analyzing (Direction of the shower axis, determination of the primary particle energy and type from the characteristics of Cherenkov radiation of secondary charged particles) are codes of numerical simulation by the Monte Carlo method. Reconstruction of the primary particle characteristics initiating the atmospheric cascade from Cherenkov radiation of secondary particles at the energy ranges (10^{16}-10^{18}) eV calls for the creation of a library of shower patterns which requires much computation time.

In the present work, the CORSIKA software package [10] in which hadron interactions are simulated using the QGSJET [11] and GHEISHA codes [12] simulates lateral distributions of Cherenkov light emitted by atmospheric cascades initiated by primary high-energy cosmic ray protons and nuclei. Simulation of Cherenkov radiation using the CORSIKA code requires very long computation time for a single shower with energy of 10^{18} eV for a processor with a frequency of a few GHz. Therefore, the development of fast modeling algorithms and the search for approximations of the results of numerical modeling are important practical problems.

Parameterization of the lateral distribution function (LDF) of Cherenkov radiation versus the distance *R* from the EAS axis and the primary particle energy *E* that can be used to approximate the results of numerical simulation of LDFs of Cherenkov photons emitted by EAS initiated in the Earth's atmosphere by the cosmic ray particle having a very high energy was taken. In the present work, we use this parameterization to describe results of numerical simulation of EAS by the CORSIKA code and of Cherenkov light emitted by EAS measured with the Tunka-25 facility [13].

THE CHERENKOV LIGHT LDF APPROXIMATION

The simulation of the Cherenkov light LDF in EAS was obtained using CORSIKA code for primary protons at the highest energies ($E \geq 10^{16}$) eV. For parameterization of simulated Cherenkov light LDF, we used a proposed function as a function of the distance *R*, from the shower axis and the energy E_o of the initial primary particle, which depends on four parameters *a*, γ, σ and r_o [14, 15]:

$$Q(E,R) = \frac{C\sigma e^{a} e\,xp\left(R/\gamma + (R-r_0)/\gamma + (R/\gamma)^2 + (R-r_0)^2/\gamma^2\right)}{\gamma\left[(R/\gamma)^2 + (R-r_0)^2/\gamma^2 + R\sigma^2/\gamma\right]} m^{-2}, \qquad (1)$$

where C=10^3 m^{-1}; *R* is the distance from the shower axis; *a*, γ, σ and r_o are parameters of Cherenkov light LDF. The energy dependences of the parameters , γ, σ and r_o were shown in Fig.1 for a primary proton.

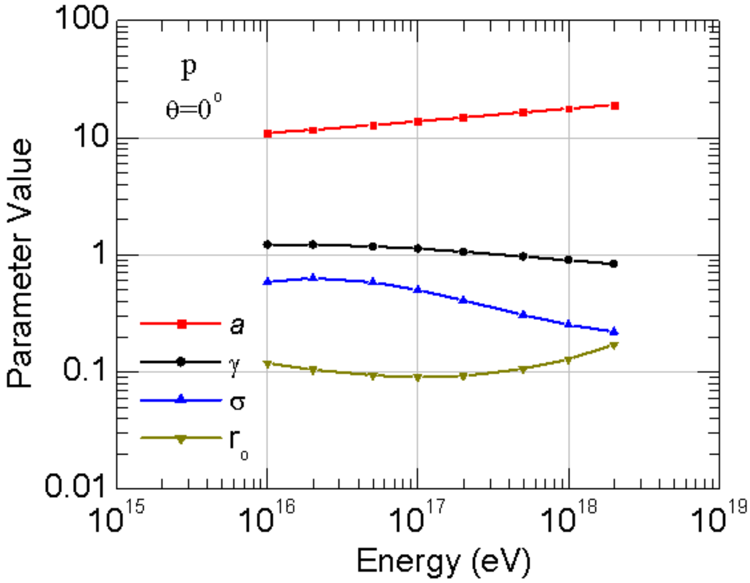

Figure 1. The fit parameters a, γ, σ and r_0 as a function of the primary energy of the initiating primary proton for vertical EAS.

The simulated data and the approximated formula (Eq.(1)) for vertical showers are presented in Fig. 2. for primary protons at the energies 10^{16}, $2{\cdot}10^{16}$ and $5{\cdot}10^{16}$ eV. In Fig. 3. one can see the extrapolation of the Cherenkov light LDF parameterization of the obtained data with CORSIKA program at the energies 10^{17}, $2{\cdot}10^{17}$, $5{\cdot}10^{17}$, 10^{18} and $2{\cdot}10^{18}$ eV. The accuracy of the Cherenkov light LDF approximation for vertical showers for primary protons is better than 15 % at the distances 80-120m from the shower axis, and close to 5 % for the other distances.

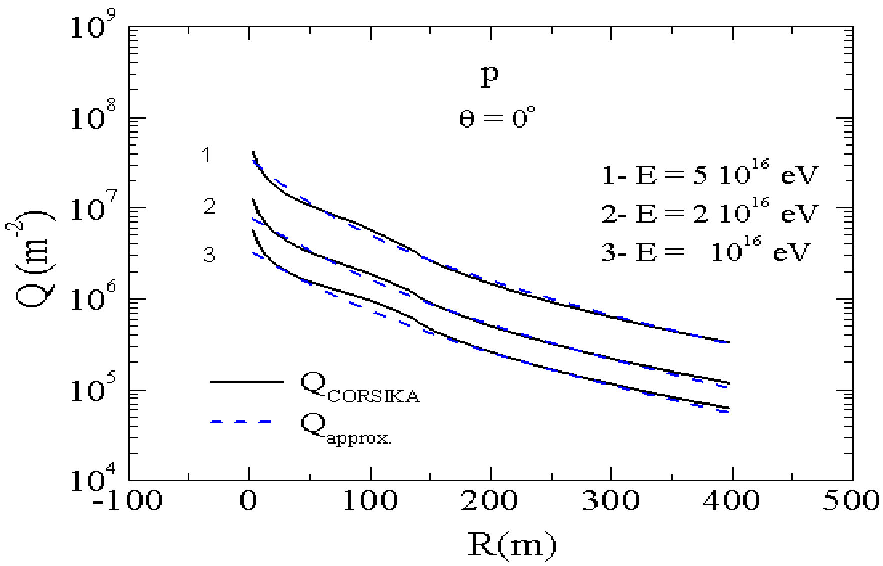

Figure 2. Lateral distribution of Cherenkov light which simulated with CORSIKA code (solid lines) and one calculated (Eq. (1)) (dashed lines) for vertical showers initiated by primary protons at 10^{16}, $2\cdot10^{16}$ and $5\cdot10^{16}$ eV.

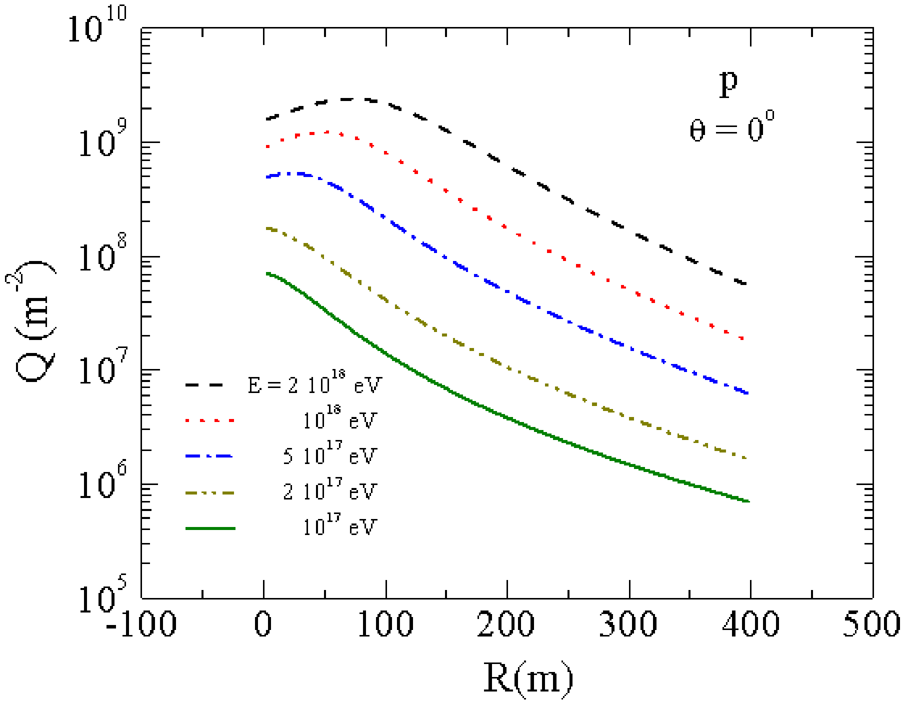

Figure 3. Extrapolation of the Cherenkov light LDF parameterization at energies 10^{17}, $2 \cdot 10^{17}$, $5 \cdot 10^{17}$, 10^{18} and $2 \cdot 10^{18}$ eV with the help of Eq.(1).

CONCLUSION

The simulation of the lateral distribution function of atmospheric Cherenkov light in extensive air showers was performed for primary protons with CORSIKA code for configuration of Tunka-25 EAS array at the highest energies $E \geq 10^{16}$ eV. Using results of this simulation we obtained the parameters of lateral distribution function of the Cherenkov radiation as a functions of the primary energy for primary protons. The extrapolation of the Cherenkov light LDF parameterization of the obtained data with CORSIKA program at the energy range 10^{16}- $2 \cdot 10^{18}$ eV is obtained.

The main advantage of the given approach consists of the possibility to make a library of LDF samples which could be utilized for analysis of real events which detected with the ultrahigh energy EAS arrays and reconstruction of the primary cosmic rays energy spectrum and mass composition.

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زيادة مدى الطاقة لتقريب اشعاع جيرينكوف ضمن مدى الطاقات العالية ($E \geq 10^{16}$ eV)

احمد عزيز احمد ، سناء رسول سالم ، خالد عبد الوهاب احمد
الجامعة المستنصرية، كلية العلوم، قسم الفيزياء.

الخلاصة

لقد تم استخدام برنامج كورسيكا لحساب دالة التوزيع الفراغية لاشعاع جيرينكوف للجسيمات الاولية مثل البروتونات ضمن مدى الطاقات العالية جدا ($E \geq 10^{16} eV$)، وبالاعتماد على النتائج التي تم الحصول عليها تم ايجاد تقريب لدالة التوزيع الفراغية والذي يسمح لنا تحديد نوع وطاقة الجسيم الناشئ نتيجة لتفاعل البروتونات مع نوى ذرات الهواء داخل الغلاف الجوي الأرضي. لقد تم الأخذ بنظر الاعتبار توسيع تقريب دالة التوزيع الفراغية لإشعاع جيرينكوف ضمن مدى الطاقة ($10^{16} - 2\cdot 10^{18} eV$).