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

Al-Rubaiee Ahmed
Muhammed Ali Abid Kadhum
Omer Ahmed M.
Al-Mustansiriyah University
College of Science, Department of Physics

ABSTRACT

The simulation of Cherenkov light Lateral distribution function (LDF) for primary particles like primary protons, Iron nuclei, Oxygen, Nitrogen, Calcium, Neutron and Argon have been performed with CORSIKA code for conditions and configuration of Yakutsk array in the energy range 10^{14}-10^{16} eV for four zenith angles 0^o, 5^o, 10^o and 15^o. The results of this simulation are compared with the measurements of Yakutsk array for the same particles and energy range.

INTRODUCTION

The study of the composition of ultra high energy cosmic rays in extensive air showers (EAS) is very interesting in order to obtain information about their origin and the processes involved in their acceleration, since they are generated until entering in the atmosphere [1, 2]. Energy characteristics of a shower such as the energy lose by particles on ionization of medium and total energy transferred to electron–photon EAS component are always considered as important for choice of the interaction mechanism of a cosmic ray primary particle with nuclei of atoms of the air [3]. These characteristics can be used for estimation of primary particle energy without a definite model. The energy can be estimated only in two cases: when the total flux of Cherenkov radiation at the sea level has been measured; the longitudinal EAS development, more exactly, the total number of particles in the maximum of shower development has been measured. At present time, only at two EAS arrays such measurements are carried out: at the Yakutsk array (Russia) [4-6], where the Cherenkov EAS radiation is measured and at the HiRes array (USA) [7], where measurements of the ionization nitrogen luminosity are provided.

In this work the simulation of Cherenkov light LDF for the Yakutsk EAS array is performed with the CORSIKA (COsmic Ray SImulation for KAscad) code [8, 9] using QGSJET [10] and GHEISHA [11] packages for the simulation of hadronic processes and EGS4 code for the simulation of the EAS electromagnetic component and Cherenkov light radiation. The calculation has been performed for primary protons, Iron nuclei, Oxygen, Nitrogen, Calcium, Neutron and Argon in the energy range 10^{14}-10^{16} eV for different zenith angles. The comparison of the simulated Cherenkov light LDF with that measured with Yakutsk array gave a good agreement within the energy range mentioned above.

Description of the Yakutsk Array

From the end of 1970s, the Yakutsk array is detecting muonic, electronic and Cherenkov light components of EAS. The actual detector arrangement of the array is shown in Fig. 1. Open circles are charged particle detectors given as the background here [4, 5].

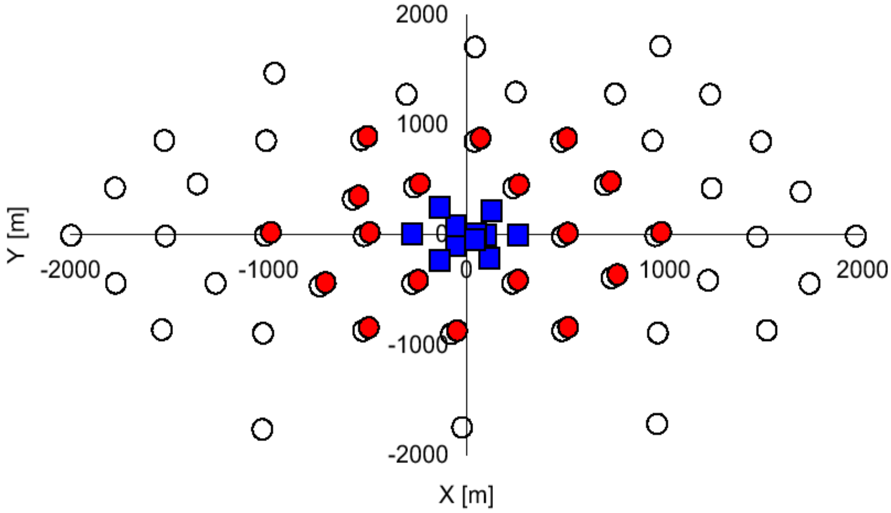

Figure 1. The detector arrangement of the Yakutsk Array [3].

Filled circles in Figure 1. show the Cherenkov light detectors - open photomultiplier tubes (PMTs) of 176 cm^2 and 530 cm^2 acceptance area, forming a medium sub-array. Filled squares indicate PMTs of autonomous sub-array with independent trigger [6]. The simulation of the Cherenkov radiation LDF is performed for configuration of Yakutsk array that demonstrated in Figure 1.

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. In the present work the extensive air showers are generated by CORSIKA (COsmic Ray SImulation for KAscade) [8] in which hadron interactions are simulated using the QGSJET [10] and GHEISHA codes [11] simulates lateral distributions of Cherenkov light emitted by atmospheric cascades initiated by primary high-energy cosmic ray protons and nuclei. The CORSIKA code is a detailed Monte Carlo program to study the evolution and properties of EAS initiated by primary energies from sub-TeV to $>10^{20}$ eV. 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, such as, the electromagnetic interactions of gammas, electrons, and positrons which are simulated by using the Electron Gamma Shower code EGS4 [8]. The calculation has been performed for for different particles (p, Fe, O_2, N_2, Ca, n and Ar) in the energy range 10^{14}–10^{16} eV for different zenith angles θ = (0°, 5°, 10° and 15°). In figure 2. (a, b) one can see the results of the simulated Cherenkov light LDF for EAS initiated by primary nitrogen and neutron particles for different energies and vertical showers.

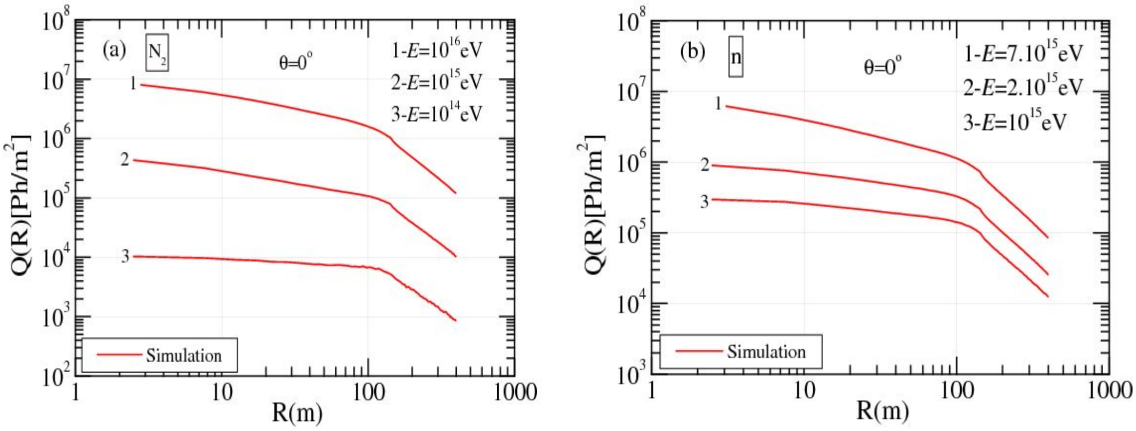

Figure 2. Lateral distribution of Cherenkov light which simulated with CORSIKA code for (a) primary Nitrogen at the energies 10^{14},10^{15} and 10^{16} eV for vertical showers; (b) primary Neutron at the energies 10^{15}, 2.$10^{15}$and 7.10^{15} eV for vertical showers.

The Figure 3. (a, b) shows the results of the simulated Cherenkov light LDF in EAS initiated by primary proton and iron nuclei particles for the energies 7·10^{15} and 10^{16} eV respectively and different angles.

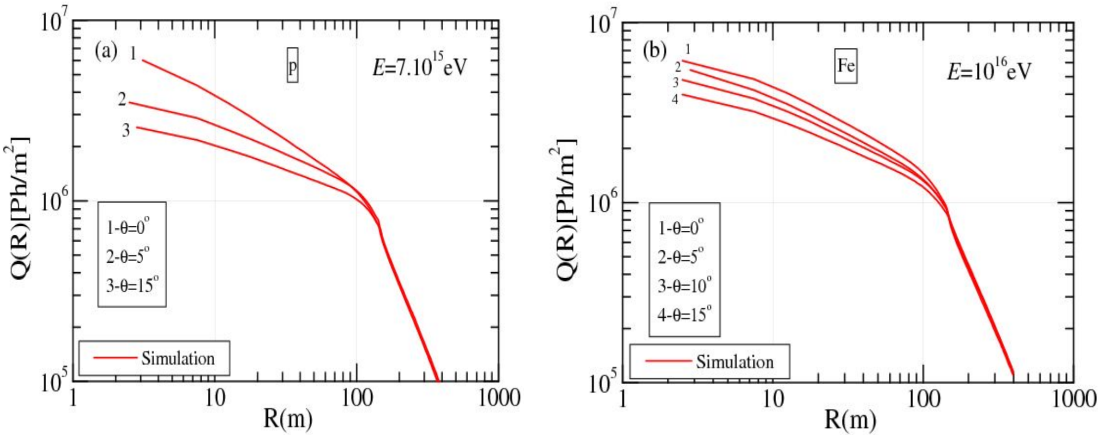

Figure 3. Lateral distribution of Cherenkov light which simulated with CORSIKA code for (a) primary proton at the energy 7.10^{15} eV and different angles θ = 0°, 5° and 15°; (b) iron nuclei at the energy 10^{16} eV and different angles θ = 0°, 5°, 10° and 15° .

Figure 4. (a, b) demonstrates the results of simulated Cherenkov light LDF in EAS initiated by primary Nitrogen, Neutron, proton, iron nuclei and Calcium for the energy 10^{15} eV and different angles.

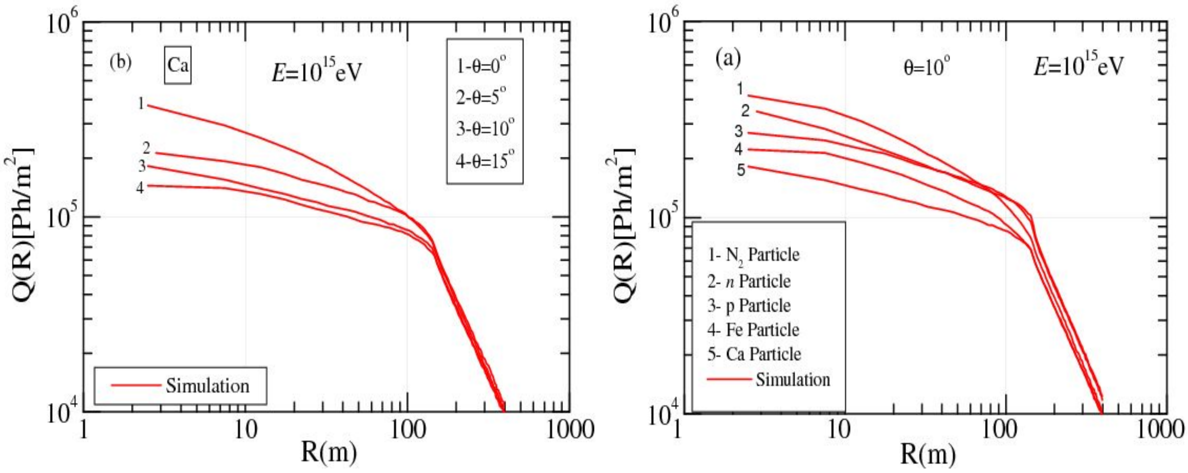

Figure 4. The lateral distribution function of Cherenkov light simulated by CORSIKA code at the energy 10^{15} eV for; (a) Nitrogen, Neutron, proton, iron nuclei and Calcium particles at $\theta=10^o$ and (b) primary Calcium for different angles $\theta=0^o$, 5^o,10^o and 15^o.

Comparison of CORSIKA simulation with experimental data

The wide-angle Yakutsk EAS array [4-6] designed for studying the cosmic ray spectrum and the mass composition near the "knee" and "ankle". The main parameters of EAS measurements are zenith and azimuth angles, shower core location, individual LDF and the density of Cherenkov radiation. The measured Cherenkov light LDF with the Yakutsk EAS array is most sensitive to EAS at the distances 1-400m from the shower axis depending on the EAS longitudinal development. In Figure 5. shown the comparison between the simulated Cherenkov light LDF with that measured with Yakutsk EAS array for primary proton and Argon at different energies and different angles. In these regions of energy one can see the variation of the energetic cosmic ray spectrum which presents an important factor for limitation the mass composition of cosmic rays.

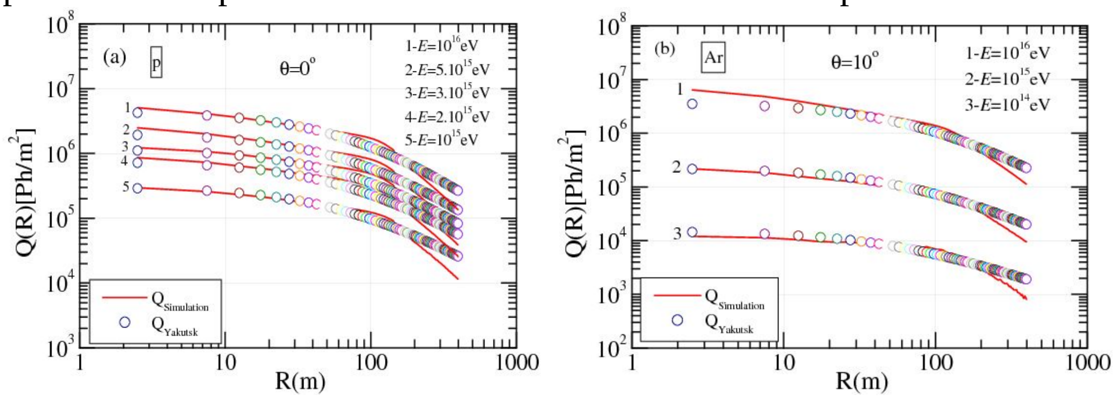

Figure 5. Comparison of the simulated Cherenkov light LDF (solid lines) with the data obtained with Yakutsk EAS array (symbol lines) for (a) proton at the energies 10^{15}, $2{\cdot}10^{15}$,3.10^5, $5{\cdot}10^{15}$ and 10^{16} eV for angle $\theta=0^o$; (b) primary Argon at the energies 10^{14}, 10^{15} and 10^{16} eV for angle $\theta= 10^o$.

In Figure 6. one may see reasonable agreement between the calculated LDF and measurements of LDF at the distances 1-400m from the shower axis. These figures demonstrate the possibility for reconstruction the type of the EAS primary particles.

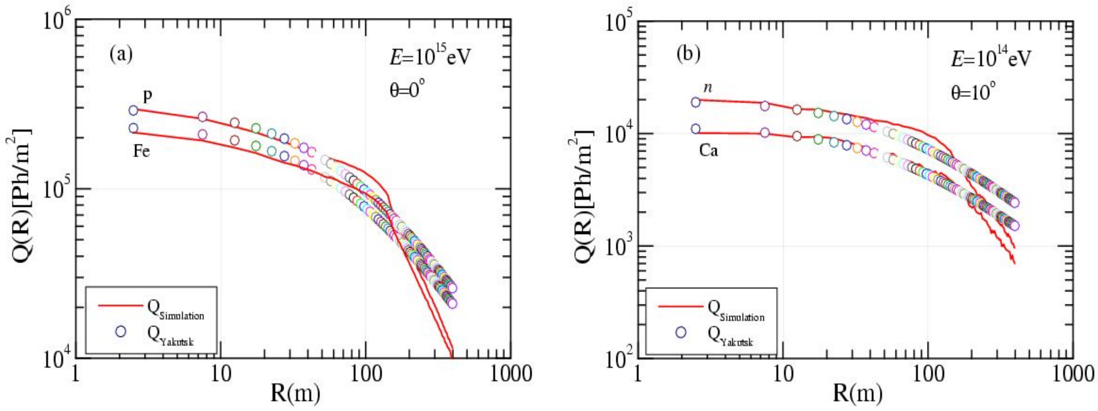

Figure 6. Lateral distribution of Cherenkov light which is simulated with CORSIKA code (solid lines) and one measured with Yakutsk array (symbol lines) for (a) primary proton and iron nuclei for vertical shower at energy 10^{15} eV; (b) primary neutron and calcium for angle θ = 10^{o} at energy 10^{16} eV.

The calculated Cherenkov light LDF in Figure. 7 for different angles and particles slightly differ from the LDF measured with the Yakutsk EAS array.

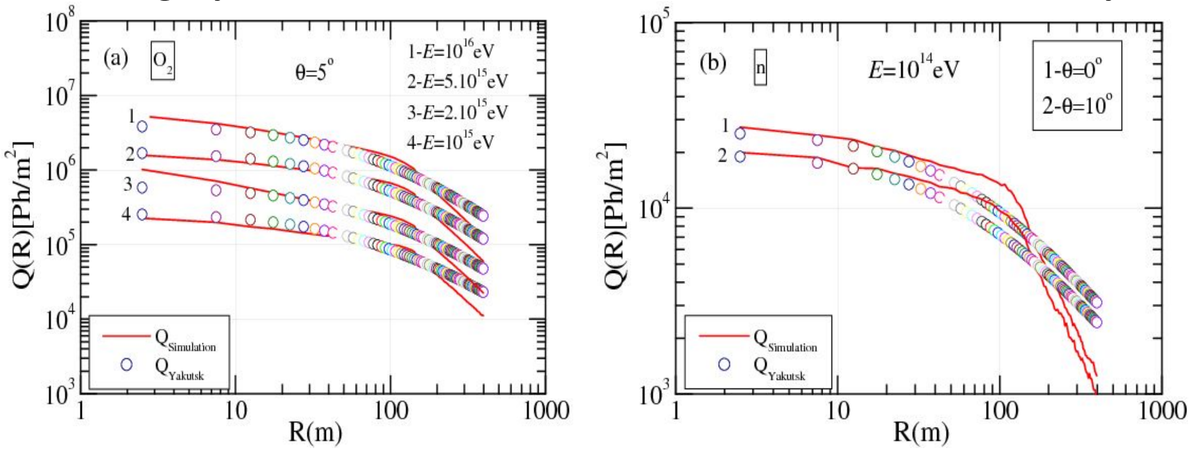

Figure 7. Lateral distribution of Cherenkov light which is simulated with CORSIKA code (solid lines) and one measured with Yakutsk (symbols) for (a) primary oxygen for vertical showers at energies 10^{15} ,2.10^{15},5.10^{15} and 10^{16} eV; (b) primary neutron for different angles θ = 0^{o},10^{o} at energy 10^{16} eV.

Conclusion

In this work the calculations of the lateral distribution function of Cherenkov light in Extensive Air Shower initiated by different primary particles (like - protons, Iron nuclei, Oxygen, Nitrogen, Calcium, Neutron and Argon) have been performed at the energy range (10^{14}-10^{16}) eV. The CORSIKA simulation of the Cherenkov light lateral distribution function is performed for configuration of the Yakutsk EAS array. The comparison between the simulated lateral distribution function of Cherenkov light using the CORSIKA program with the experimental data demonstrates the possibility to identify the primary particles and to determine their energies around the knee. The main advantage of the given approach consists of the possibility to make a library of lateral distribution function samples which could be utilized for analysis of real events which detected with the Extensive Air Shower array and reconstruction of the primary cosmic rays energy spectrum and mass composition.

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محاكاة دالة التوزيع الفراغية لإشعاع جيرينكوف لوابل من الجسيمات المشحونة لمنظومة ياكوتسك

احمد عزيز الربيعي, محمد علي عبد كاظم، عمر احمد موفق

الخلاصة:لقد تم في هذا البحث اجراء محاكاة لدالة التوزيع الفراغية لاشعاع جيرينكوف لبعض الجسيمات الاولية مثل البروتون، نوى ذرات الحديد،الاوكسجين، النتروجين، الكالسيوم، النيوترون والاركون والتي انجزت باستخدام برنامج كورسيكا اعتمادا على شروط منظومة ياكوتسك ضمن مدى الطاقة $١٠^{١٤}$ – $١٠^{١٦}$ الكترون فولت لاربع زوايا مختلفه ٠^{o} , 5^{o}، ١٠^{o} ، ١٥^{o}. لقد تم مقارنة نتائج هذه المحاكاة مع النتائج العملية لمنظومة ياكوتسك وتم الحصول على توافق جيد ضمن مدى الطاقة المذكور.