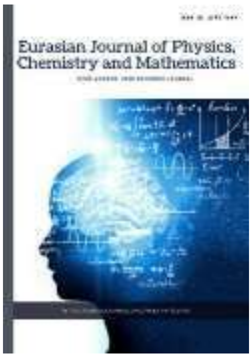

Estimating the Lateral Distribution Function of Cerenkov Light as a Function of the Primary Energy for the Chacaltaya EAS Array

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ABSTRACT

A new method for estimating the energy and the mass composition of primary cosmic radiation based on atmospheric Cerenkov light lateral distribution function (LDF) analyzis is proposed. The Cerenkov light LDF in extensive air showers (EAS) initiated by primary protons and iron nuclei are simulated with CORSIKA code for the Chacaltaya EAS array with the different energies around the knee region with two zenith angles (0^o,15^o). Sets of approximate functions are constructed for two particles as a function of the primary energy based on the findings of the LDF numerical simalution. At the energies (10^{15}–10^{16}) eV, a comparison of the parametrised LDF with that simulated by the Chacaltaya EAS array is confirmed.

Keywords: Cerenkov light, lateral distribution function, Chacaltaya array.

Introduction

High-energy radiation coming from beyond the Earth's atmosphere is known as cosmic rays (CRs). Ultra-high energy CR particles will ultimately with atmospheric nuclei when they reach the atmosphere. This contact starts an atmospheric cascade process known as EAS [1, 2], where the air shower's density is indicated by LDF. The sole technique of CR registration that is effective in the high and ultrahigh energy ranges comes indirectly from the EAS created in the atmosphere, namely by the registration of atmospheric Cerenkov light. Investigating CRs using secondary particles created by EAS cascade processes' Cerenkov light registration [3, 4]. The Monte Carlo approach, utilized for examining EAS characteristics and interpreting experimental data, is one of the essential tools for numerical simulation [5]. For conditions of the Chacaltaya EAS array [6, 7], simulations of the LDF were carried out using the CORSIKA code at high energies (10^{15}, 2.10^{15}, 3.10^{15}, 5.10^{15}, 7.10^{15}, 9.10^{15} and 10^{16}) eV for two primary particles (P and Fe) and two zenith angles (0^o and 15^o). A parameterization of Cerenkov radiation LDF was reconstructed using CORSIKA simulation and the Breit-Wigner function as a function of primary energy.

The Cerenkov light parameterization

A LDF at Chacaltaya observation level 536 g/cm^2 [8] is obtained with CORSIKA code [9,10] using VENUS [11] and GHEISHA [12] as a hadronic model. In Ref. [13] the Cerenkov light LDF in depended on the distance, but in this work, the LDF depends on the primary energy for the primary proton and iron nuclei. The obtained function

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

where E is the primary energy, R is the distance for shower axis and the value of the parameters *a, γ, σ* and r_o were estimeted by fitting Eq. 1 to the values of the Cerenkov radiation LDF that simaluted by the CORSIKA code package with energy around the knee regoin for two particles with the two zenith angles (0^o,15^o). The parameters of LDF in Eq. (1) were parameterised as a function of primary energy using the third polynomial fit, which the relationship gives:

$$K(E) = c_0 + c_1 \log_{10}(E) + c_2 (\log_{10}(E))^2 + c_3 (\log_{10}(E))^3 \qquad (2)$$

where c_0, c_1, c_2 and c_3 are coefficients depending on the primary energy their values in Tables 1 and 2.

Table 1: Coefficients c_i that determine primary energy dependence (Eq. 2) of the parameters *a, γ , σ* and r_o for P and Fe for θ=0^o of Chacaltaya Cerenkov EAS array.

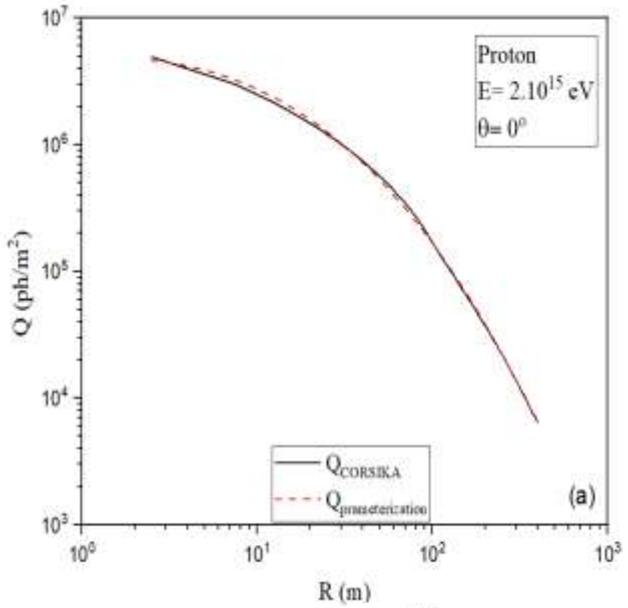
P				
K	c_0	c_1	c_2	c_3
a	0.9138	$3.98445.10^{-7}$	$-4.7243.10^{-33}$	$2.12693.10^{-49}$
γ	2913.89675	-566.49672	36.70576	-0.79265
σ	1488.20697	287.05192	-18.44994	0.39505
r_o	-1287.98717	251.12643	-16.32809	0.35362
Fe				
a	0.98031	$1.30031.10^{-17}$	$-5.27921.10^{-34}$	$-1.88644.10^{-51}$
γ	-4022.65855	770.55128	-49.19794	1.04695
σ	578.1497	-106.90157	6.60145	-0.1362
r_o	232.73668	-42.91956	2.6493	-0.0551

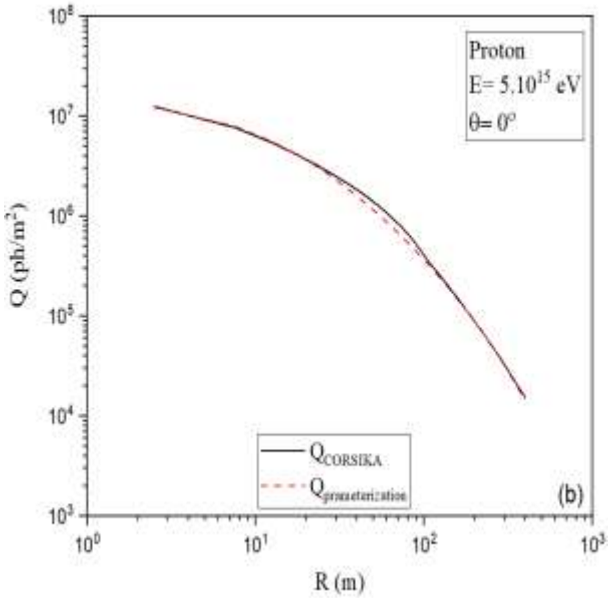
Table 2: Coefficients c_i that determine primary energy dependnce (Eq. 2) of the paramaters *a, γ , σ* and r_o for P and Fe for θ=15^o of Chacaltaya Cerenkov EAS array.

P				
K	c_0	c_1	c_2	c_3
a	0.90037	$4.96575.10^{-17}$	$-6.95656.10^{-33}$	$3.53143.10^{-49}$
γ	1839.55693	-359.2425	23.38274	-0.50726
σ	-2041.14952	397.7522	-25.83157	0.559

r₀	-5922.2762	1144.34147	-73.6989	1.5816
Fe				
a	0.96574	$1.6016.10^{-17}$	$-6.26041.10^{-34}$	$-8.8617.10^{-51}$
γ	-4436.35806	854.93391	54.91136	1.17543
σ	-3704.28072	720.78989	-46.70558	1.007843
r₀	3314.16373	-633.30524	40.33575	-0.8566

The calculation of Cerenkov light LDF was estimated by using the function represented by (Eq. (1)) with its parameters (Eq. (2)) for two zenith angles (0^o and 15^o) of CR energy spectrum for two particles (P and Fe). Fig. 1 shows the results of the simulated Cerenkov light LDF (solid line) and that parametrised (dashed line) when $\theta=0^o$ for (a) P at the $E=2.10^{15}$ eV (b) P at the $E=5.10^{15}$ eV and (c) Fe at the $E=2.10^{15}$ eV. While Fig.2 demonstrates the results of the parametrised Cerenkov light LDF (dashed line) in comparison with that simaluted with CORSIKA code at inclined zenith angle $\theta=15^o$ for (a) P at the $E=9.10^{15}$ eV (b) Fe at the $E=10^{15}$ eV and (c) Fe at the $E=10^{16}$ eV.





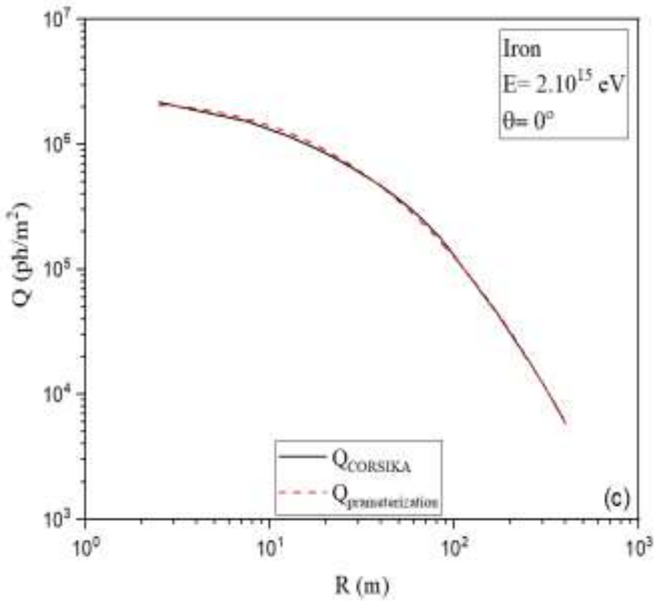


Fig. 1 Com ... h CORSIKA code for Ch ... ameterization (dashed line

The parameterised Cerenkov light LDF compared with Chacaltaya experimental data. The Fig. 3 shows the results of the parameterised Cerenkov light LDF (dashed line) and Chacaltaya experimental data (symbols) when θ=0° and 15° for (a) P at the E=3.10¹⁵ eV (b) P at the E=10¹⁶ eV (c) Fe at the E=3.10¹⁵ eV and (d) Fe at the E=10¹⁶ eV.

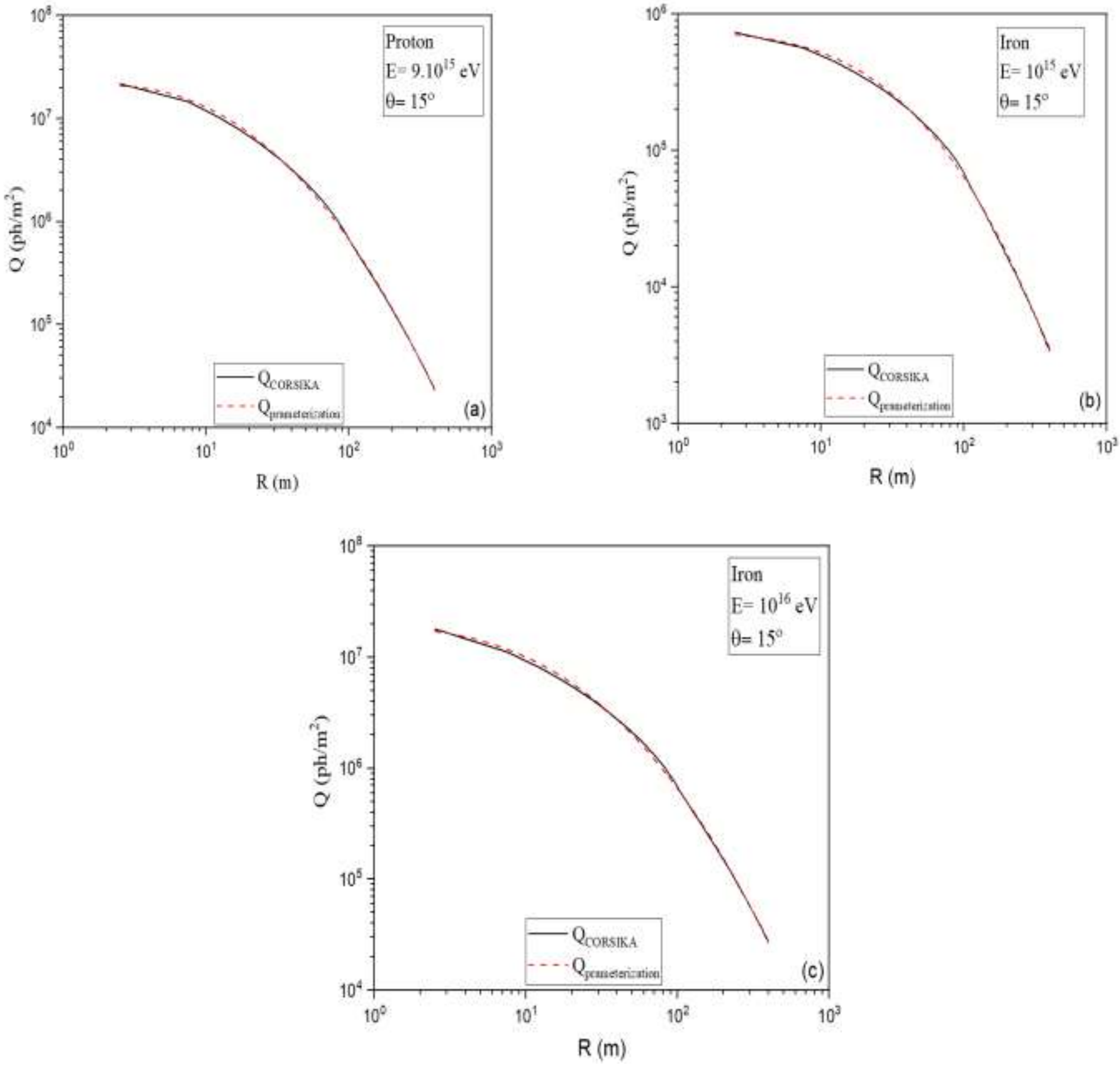


Fig. 2 Comparison of the simulated Cherenkov light LDF with CORSIKA code for Chacaltaya array conditions at θ=15° (solid line) and parameterization (dashed lines)

The accuracy of the Cerenkov light LDF approximation with two zenith angles for P is better than 12 % and close to 18 % for Fe at distances 16-415 m from the shower axis.

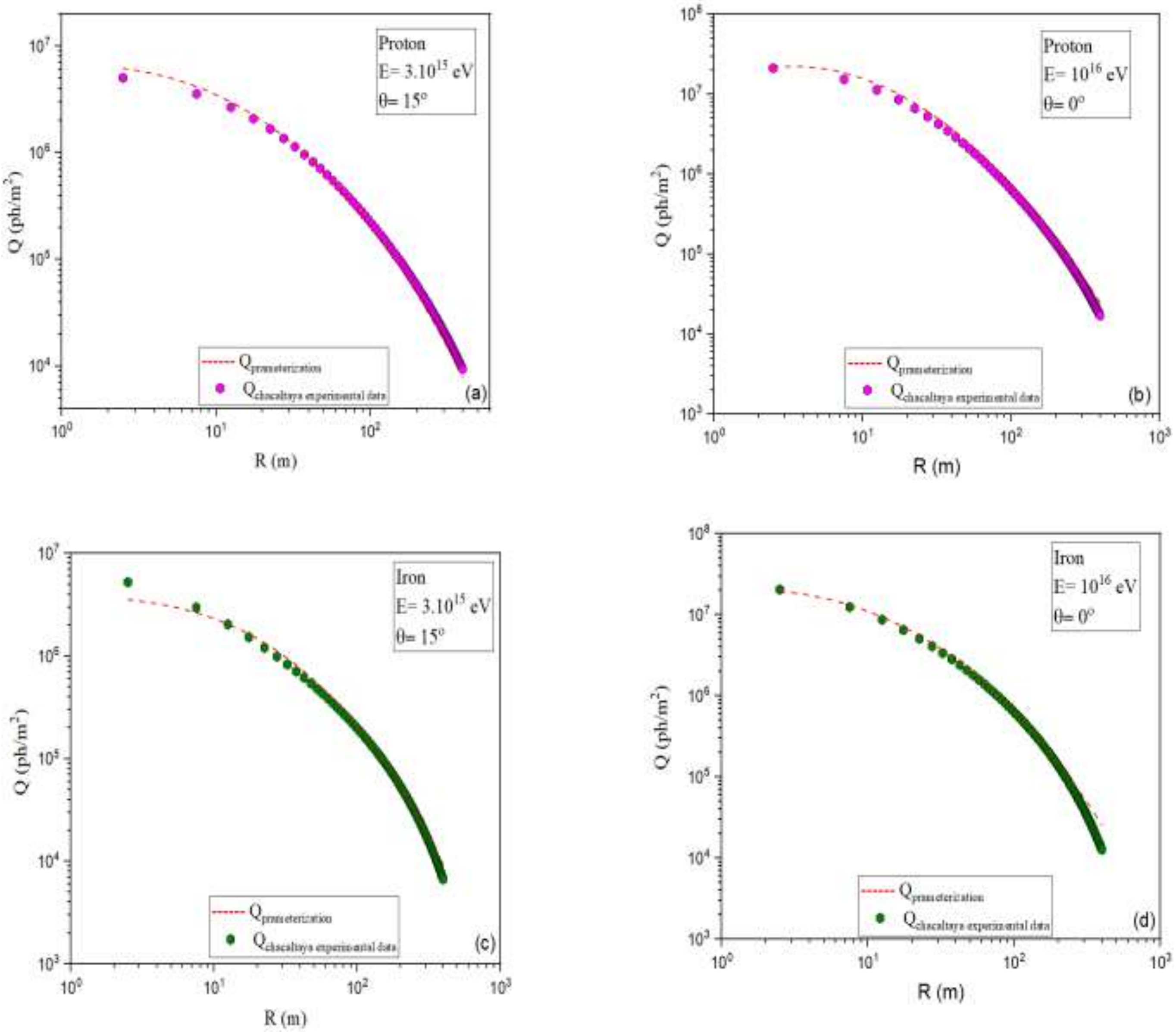


Fig. 3 Comparison of the parameterized LDF (dashed lines) with the experimental data obtained by Chacaltaya EAS array (symbols)

Conclusion

The Monte Carlo Code CORSIKA have been used to simulate Cerenkov light LDF in EAS for configurations and conditions of the Chacaltaya EAS array for two particles (Fe and P) for two zenith angles around the knee region with the seven energies. Based on the Breit-Wigner function a parameterization of Cerenkov light LDF was reconstructed depending on this simulation as a function of primary energy. An estimated Cerenkov light LDF by Eq. (1) for each particles (Fe and P) at zenith angles 0^o and 15^o with primary energies (10^{15}, 2.10^{15}, 3.10^{15}, 5.10^{15}, 7.10^{15}, 9.10^{15} and 10^{16}) eV demonstrated a good agreement with that simulated by CORSIKA code for Chacaltaya EAS array.

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