Approximation of lateral distribution function of the Cherenkov light from extensive air showers in primary energy region 1-100 PeV.

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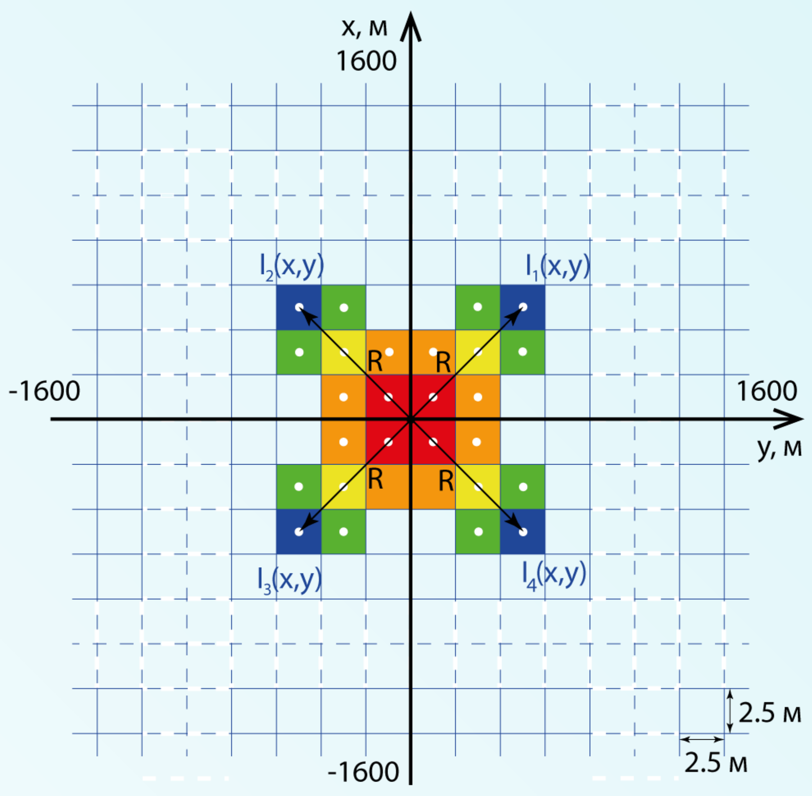
Abstract

We present approximation function that makes it possible to describe the individual extensive air showers (EAS) Cherenkov light lateral distribution function (LDF). It is designed for various primary nuclei with energies of 1-100 PeV and zenith angles up to 20 degrees with an accuracy lower than 10% in the distances range 0-500 meters from the shower axis. Initially approximation was intended for processing the events of the SPHERE-2 experiment [1,2,3], but its capabilities are clearly wider. A comparison was made with a simpler approximating function used in the SPHERE-2 processing and with the function used by the TAIGA experiment.

Generation and processing of EAS events

Events used for approximation were simulated using CORSIKA7.5600. Each event was modelled with following primary parameters:

- E = 1, 10, 30, 100 PeV;
- θ = 10, 15, 20°;
- p, He, N, Fe;
- atmosphere model №1 and №11 in CORSIKA;
- model of the nucleus-nucleus interaction (QGSJET01, QGSJETII-04);
- observation level (455 m above sea level).



LDF can be considered axially symmetric from showers with small zenith angle, therefore, azimuth averaging can be performed. By averaging the number of photons in cells located at the same distance from the shower axis one-dimensional LDF is obtained.

Considered approximations

1. SPHERE-2 previous approximation.

$$F_{old} = \frac{p_0}{1 + p_1 R + p_2 R^2}$$

Relative approximation errors increase with increasing distance from the shower axis and these errors exceed 10%.

2. Tunka-25 approximation.

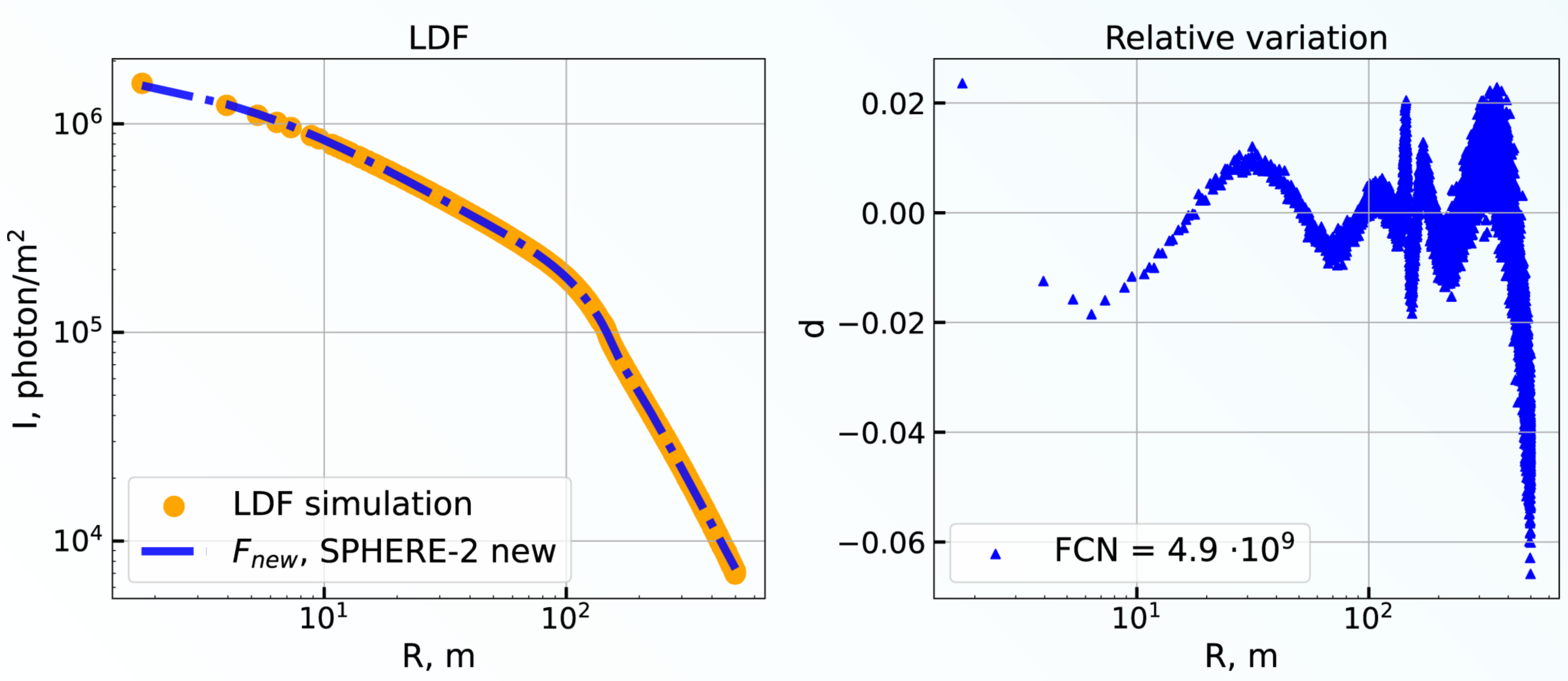
The approximation was taken from [4].

The main approximation error accumulates over the first 100 meters. But it is this region that is significant for further processing of events, since primary mass estimation criterion is essentially based on the LDF steepness in the region near the shower axis.

3. SPHERE-2 approximation.

$$F_{new} = \frac{p_0}{1 + p_1 R + p_2 R^2 + p_3 R^3} \times \omega_1 + \frac{p_4}{1 + p_5 R + p_6 R^2} \times \omega_2,$$

$$\omega_1 = \frac{1}{1 + \exp\left(\frac{R - R_{ch}}{s}\right)}, \quad \omega_2 = \frac{1}{1 + \exp\left(-\frac{R - R_{ch}}{s}\right)}.$$



The approximation function F_{new} of the lateral distribution Cherenkov light EAS deviates from the model I(R) by less than 7% within the 500 m range from the shower axis. In the range up to 400 meters the relative error:

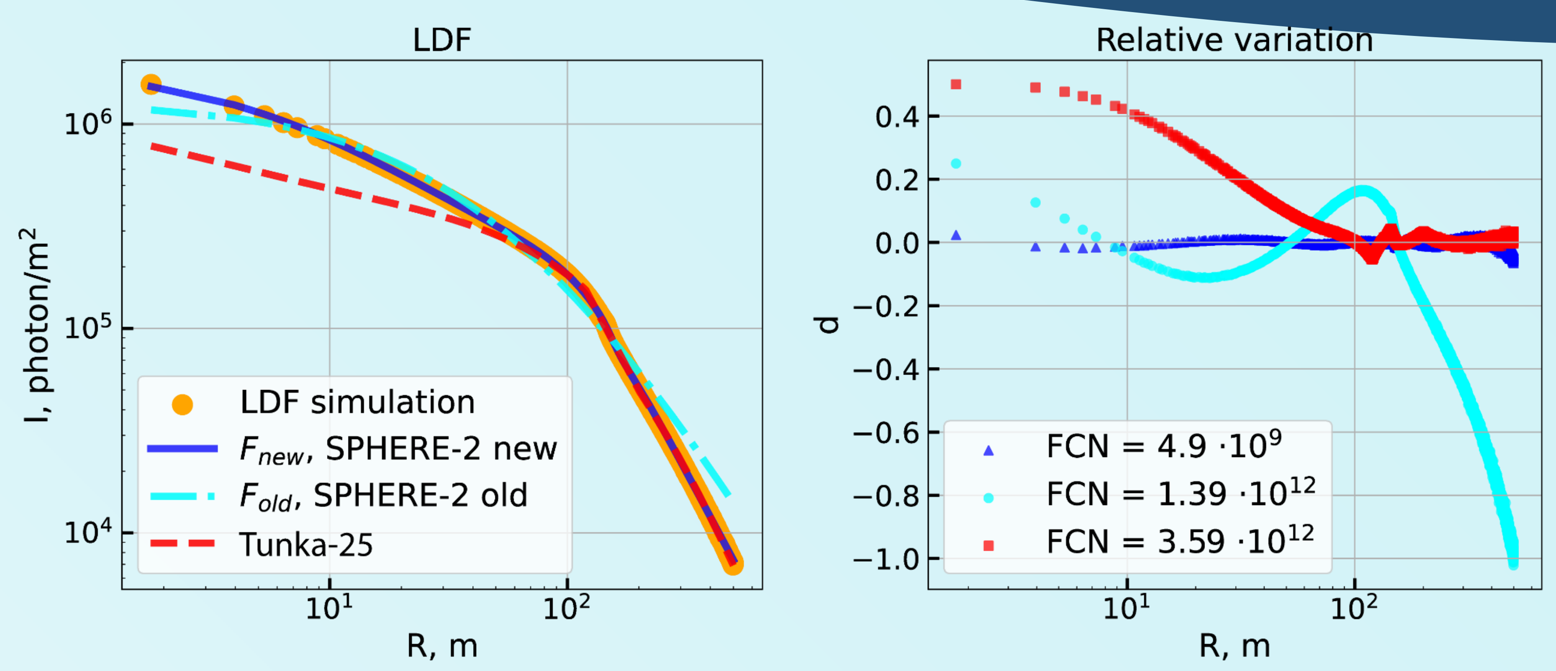
$$d = \frac{I(R) - F(p_i, R)}{I(R)}$$

does not exceed 2% and increases with increasing distance from the axis.

The search for parameters for cases 1 and 3 was carried out using the MINUIT package [5], which minimized the function:

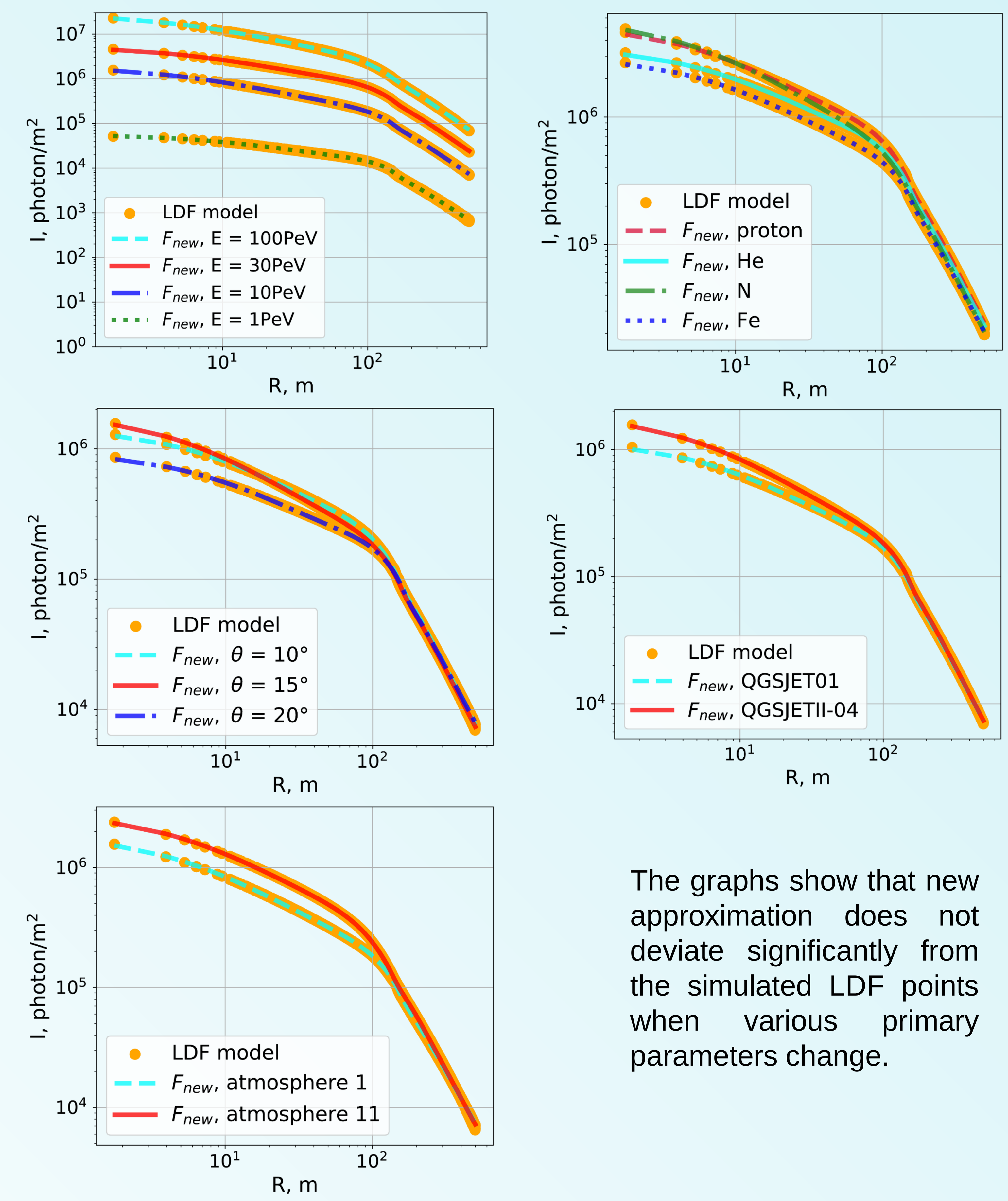
$$FCN = \sum_R (I(R) - F(p_i, R))^2$$

Approximations comparison



Picture above. On the left: an example individual event from primary 10 PeV proton with 15 zenith angle (dots) with best fit approximations (SPHERE new in blue, SPHERE previous in cyan, Tunka-25 in red). On the right: approximations (from the left graph) relative errors - SPHERE new by blue , SPHERE previous by cyan, Tunka-25 by red.

Function F_{new} approximates the EAS Cherenkov light LDF and deviates from the simulated data by less than 10% within 500 m distance from the shower axis.. Changes in the primary particle parameters do not change the quality of the approximation.



The graphs show that new approximation does not deviate significantly from the simulated LDF points when various primary parameters change.

Conclusion

Function F_{new} approximates the EAS Cherenkov light LDF and deviates from the simulated data by less than 10% within 500 m distance from the shower axis. The approximation has been verified for the energy range 1-100 PeV at 455 meters above sea level, for shower axis tilt angles not exceeding 20°. For the majority of events at distances within 2-400 m range, approximation error does not exceed 2% of the simulated data of the EAS Cherenkov light LDF. Such approximation makes it possible to increase the accuracy of subsequent analysis, for example, the estimation of the primary particle energy, as well as its mass number.

References

[1] R.A. Antonov, et al., The SPHERE-2 detector for observation of extensive air showers in 1 PeV – 1 EeV energy range // Astropart. Phys. 2020, No 121.
[2] R.A. Antonov, et al., Spatial and temporal structure of EAS reflected Cherenkov light signal // Astropart. Phys. 2019
[3] R.A. Antonov, et al., Detection of reflected Cherenkov light from extensive air showers in the SPHERE experiment as a method of studying superhigh energy cosmic rays // Physics of Particles and Nuclei, 2015, No 46, p. 60–93
[4] Budnev N., et al., Tunka-25 Air Shower Cherenkov array: The main results // Astropart. Phys. 2013.
[5] James F., MINUIT Function Minimization and Error analysis // CERN Geneva, Switzerland 1994. D.506. V. 94.1.