ISSN 1062-8738, Bulletin of the Russian Academy of Sciences: Physics, 2023, Vol. 87, No. 7, pp. 1046–1048. © Allerton Press, Inc., 2023.

The Influence of the Strong Atmospheric Electric Fields on the Extensive Air Shower Development

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Received July 29, 2022; revised December 20, 2022; accepted March 29, 2023

Abstract—During thunderstorms, the electric fields above the LHAASO array efficiently modulate Extensive air showers (EASs), initiated by an ultra-high-energy gamma ray. Because of this modulation, the possible bias of the energy estimation for primary gamma rays with energies up to 100 TeV can be up to ten-fold, and for the primary energies of 1 PeV, the bias can range from 2.5 to 3 times. This result can be essential because observation of PEVatrons by LHAASO is based on rather small statistics, and the highest energy events can occasionally coincide with thunderstorms, which are very often on the Tibet plateau.

Keywords: extensive air showers, energy estimator, atmospheric electric field, thunderstorm ground enhancements, thunderstorms

DOI: 10.3103/S1062873823702386

INTRODUCTION

A major challenge of EAS experiments is the energy scale calibration. The shower size (*Ne*) is rather well correlated with the energy of the primary particle. However, the ambiguity in the particle type identification and large fluctuations of first interaction depth (shower age) smear the *E*–*Ne* relation. Due to the large surface of detectors and high location, the LHAASO experiment [1] has a very low energy threshold (≈1 TeV) and excellent rejection of hadron-induced EASs (reaching 10^{-5} at PeV energies). We select the LHAASO array not only because recently they identified 12 PeVatron candidates, which have been previously observed by imaging atmospheric Cherenkov telescopes. LHAASO site locates at Haizi Mountain, Daocheng County, Sichuan Province, which is at the edge of the Tibetan Plateau with an altitude of up to 4410 m. The Tibetan plateau is also known as a place of frequent thunderstorms and very large intracloud electric fields, whose vertical profile can extend to 1–2 km. The strength of the atmospheric electric field depends on the air density (altitude) and can reach 1.5–2 kV/cm at altitudes 3–6 km. Several EAS arrays, including those located in Tibet, already report a 20–30% enhancement of the trigger rate during thunderstorms [2–4]. Correspondingly, the EAS particle number with energies above the detector threshold is significantly enhanced. At Aragats was registered 400% enhancement of MAKET array trigger rate was on 19 September 2019 [6]. Therefore, the relativistic runaway avalanches [6], developed in the thunderous atmosphere, can effectively mimic EASs successfully overgoing all experimental checks and introducing positive bias in the primary particle energy estimation.

DISTORTION OF THE PRIMARY PARTICLE ENERGY ESTIMATE BY ELECTRIC FIELDS IN THE ATMOSPHERE

The CORSIKA code [7], using strong interaction models QGSJETII-04 [8] and UrQMD [9] was used for simulations. Showers were initiated by primary photons entering the terrestrial atmosphere at a zenith angle of 0 deg. The EAS particle transport through the electric field, which was introduced on heights 4460–6460 m, was done by CORSIKA code version 7.7400 [10]. The uniform electric field was introduced at heights of 4460–6460 m. The threshold energies of secondary particles (hadrons, muons, electrons, gamma rays) were 0.3, 0.3, 0.003, and 0.003 GeV respectively. In Table 1 we show the number of electrons (*Ne*) in fair weather ($E_z = 0$), and how the number of EAS electrons abruptly enlarged after crossing the large-scale electric field with strength from 1.9 to 2.1 kV/cm. We didn't show statistical errors because they are very small due to a large number of simulation trials (10000 simulation trials for TeV energies, and 1000 trials for PeV energies). The model used in the simulation was simplified, and systematic errors can be much larger than statistical ones. We don't know the strength and location of atmospheric electric fields, which can be changed each second. Thus, the

Table 1. Enhancement of the number of electrons initiated by a primary gamma ray with energies from 1–1000 TeV in the electric field of different strengths

E_0, TeV	*Ne*			
	E_z = 0 kV/cm	E_z = 1.9 kV/cm	E_z = 2.0 kV/cm	E_z = 2.1 kV/cm
1	316	12103	15904	18044
10	5560	148088	201096	229163
100	69996	1374853	1775837	2169369
1000	827547	10346388	13605357	14066929

Table 2. Genuine and estimated energies of primary gamma rays after transport through the electric field of 2.1 kV/cm strength

E_0, GeV	E_{est}, GeV
10^3	2.23×10^4
10^4	1.34×10^5
10^5	6.50×10^5
10^6	2.42×10^6

uniform electric field introduced in the simulation is a rather coarse approximation.

In Fig. 1 we show the abrupt enhancement of electron number, after an increase of the electric field strength above the critical value. Starting from 1.7 kV/cm the number of electrons exponentially grows for all energies of primary gamma rays.

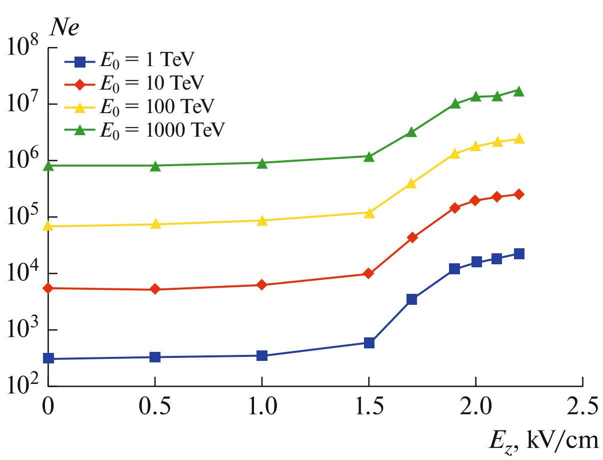

Fig. 1. The number of electrons registered on the earth's surface after crossing the atmospheric electric field of different strengths. The primary gamma ray enters the electric field at a height of 6460 m.

In Table 2 we show the "genuine" gamma ray energies used in the simulation and the estimated ones obtained by the biased by electric field shower size *Ne*. The energy estimation was done by a simple equation $\log E_0 = 0.7 \log \mathrm{Ne} + 1.35$. As we see in Table 2 the number of EAS electrons was significantly enhanced.

CONCLUSIONS

We perform simulations of gamma ray transport in the thunderous atmosphere above the LHAASO array to research possible biases in the energy estimation (we use a very simple estimator based on shower size *Ne* only). For the low primary energies, the bias was tenfold and more, for the higher primary energies (1 PeV) 2.5–3 times. As the highest energy gamma rays observed by LHAASO are rather scarce, it is important to check if they were detected in fair weather and if electrons were not multiplied in the strong electric fields above the detector. We demonstrate as well the threshold effect of intracloud electric field for starting a runaway process, that exponentially multiplied the free electrons entering a strong atmospheric electric field.

ACKNOWLEDGMENTS

We thank Yuri Stenkin and LHAASO collaboration for informing us that two PeV and 1 nearly PeV gamma-ray events occurred in fair weather, and no "thunderstorm multiplication" of secondary electrons took place.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCES

1. Cao, Z., Aharonian, F., An, Q., et al., *Nature*, 2021, vol. 594, p. 33.

2. Aglietta, M. et al. (EAS-TOP Collab.), *Nucl. Instrum. Methods Phys. Res., Sect. A*, 1989, vol. 277, p. 23.
3. Axikegu et al. (ARGO-IBJ Collab.), *Phys. Rev. D*, 2022, vol. 106, p. 022008.
4. Aharonian, F., An, Q., Axikegu, L., et al., *Chin. Phys. C*, 2021, vol. 47, p. 015001.
5. Chilingarian, A., Hovsepyan, G., and Hovhannisyan, A., *Phys. Rev. D*, 2011, vol. 83, p. 062001.
6. Gurevich, A., Milikh, G., and Roussel-Dupre, R., *Phys. Lett. A*, 1992, vol. 165, p. 463.
7. Heck, D. and Knapp, J., FZKA Rep. 6019, 1998.
8. Ostapchenko, S., *Phys. Rev. D*, 2011, vol. 83, p. 014018.
9. Bass, S.A., Belkacem, M., Bleicher, M., et al., *Prog. Part. Nucl. Phys.*, 1998, vol. 41, p. 255.
10. Buitink, S., Huege, T., Falcke, H., et al., *Astropart. Phys.*, 2010, vol. 33, p. 1.