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TIBET ASgamma: Dawn of sub-PeV gamma-ray astronomy

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The Tibet air shower (AS) array and underground water-Cherenkov-type muon detector (MD) array have been successfully operating since 2014 at an altitude of 4,300 m in Tibet, China. This hybrid experiment is useful not only for the gamma-ray observation but also for the energy spectrum measurement in the knee energy region of the cosmic-ray energy spectrum. The energy and arrival directions of air showers are determined by the AS array, while the number of muons contained in air showers is counted with the MD array. In terms of gamma-ray observation, the MD array enables us to suppress more than 99.9% of background cosmic rays against gamma-ray signals above 100 TeV. Our gamma-ray and cosmic-ray data from the AS+MD array is well reproduced by our detailed air shower simulations. Here we report on the latest results from the Tibet ASγ experiment, especially focusing on the world's first detection of sub-PeV gamma rays from the Crab Nebula and the world's first detection of sub-PeV diffuse gamma-ray emissions from the Galactic plane.

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1. Introduction, Experiment and Data Analysis

As of the year 2019, the photon energy spectrum of the Crab Nebula had been measured from radio up to nearly 100 TeV. Photons at the TeV energies from the Crab Nebula had been observed with many ground-based gamma-ray experiments including the Tibet ASγ experiment [1, 2]. Photons of energy above 100 TeV, however, had not been detected then from any astrophysical source, and some flux upper limits had been obtained [3, 4].

Gamma-ray telescopes such as EGRET and Fermi-LAT observed diffuse gamma rays from the Galactic plane in the energy range of 0.1 < E < 100 GeV [5, 6]. The Milagro experiment reported TeV diffuse gamma-ray emissions from the Cygnus region in the Galactic disk [7], while ARGO-YBJ reported diffuse gamma rays in the energy range of 0.35 < E < 2 TeV extended over the Galactic longitude between 25° < l < 100° [8]. At sub-PeV energies, the CASA-MIA experiment set upper limits to the Galactic diffuse gamma-ray flux [9].

For the description of the experiment and our data analysis procedures, refer to our published papers [10, 11].

2. Results and Discussions

From the Crab Nebula we detected 24 photon-like events with E > 100 TeV against 5.5 background events, which corresponds to a statistical significance of 5.6σ. This was the first detection of sub-PeV photons from any astrophysical source. For more details see our published paper [10]. After our detection, HAWC and LHAASO also observed photon-like events with E > 100 TeV and confirmed our results [12, 13].

From the Galactic plane we made the world's first detection of sub-PeV diffuse gamma rays. The measured flux of the diffuse gamma rays is compatible with expectations from the hadronic emission scenario in which gamma rays originate from the decay of π^0s produced through the interaction of protons with the interstellar medium in the Galaxy [14]. The arrival directions of all the γ-like events above 398 TeV are apart from the locations of known TeV gamma-ray sources. Our results provide strong evidence that cosmic rays are accelerated beyond PeV energies in our Galaxy and spread over the Galactic disk. For more details see our published paper [11].

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References

[1] M. Amenomori et al., Astrophys. J. 525, L93 (1999).
[2] M. Amenomori et al., Astrophys. J. 692, 61 (2009).
[3] A. Borione et al., Astrophys. J. 481, 313 (1997).
[4] M. Amenomori et al., Astrophys. J. 813, 98 (2015).
[5] S. D. Hunter et al., Astrophys. J. 481, 205 (1997).
[6] M. Ackermann et al., Astrophys. J. 750, 3 (2012).
[7] R. Atkins et al., Phys. Rev. Lett. 95, 251103 (2005).
[8] B. Bartoli et al., Astrophys. J. 806, 20 (2015).
[9] A. Borione et al., Astrophys. J. 493, 175 (1998).
[10] M. Amenomori et al., Phys. Rev. Lett. 123, 051101 (2019).
[11] M. Amenomori et al., Phys. Rev. Lett. 126, 141101 (2021).
[12] A. U. Abeysekara et al., ApJ, 881, 134 (2019).
[13] F. Aharonian et al., Chinese Phys. C 45, 025002 (2021).
[14] P. Lipari and S. Vernetto, Phys. Rev. D 98, 043003 (2018).

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