PROCEEDINGS OF SCIENCE

PoS(ICRC2023)427

Observation of Large-Scale Anisotropy of Proton above Tens of TeV with LHAASO-KM2A

Jiayin He,[a,b,*] **Shiping Zhao,**[a,c] **Yingying Guo,**[a] **Yi Zhang**[a,b] **and Qiang Yuan**[a,b] **on behalf of the LHAASO Collaboration**
(a complete list of authors can be found at the end of the proceedings)
[a] *Key Laboratory of Dark Matter and Space Astronomy, Purple Mountain Observatory, Chinese Academy of Sciences,*
210023 Nanjing, 9 Jiangsu, China
[b] *University of Science and Technology of China,*
230026 Hefei, Anhui, China
[c] *Institute of Frontier and Interdisciplinary Science, Shandong University,*
266237 Qingdao, Shandong, China
E-mail: hejy@pmo.ac.cn, zhaosp@mail.sdu.edu.cn, zhangyi@pmo.ac.cn

We present a measurement for large-scale anisotropy of pure protons with the Large High Altitude Air Shower Observatory (LHAASO). We analyze the data collected from the full array of KM2A in one year's operation. To select the proton data set, we employed a technique similar to the gamma/background discrimination method in KM2A, using a cut on the ratio of muonic and electron magnetic components. The purity of the proton sample is up to 90%, and the reconstructed energy is from 10 TeV to 270 TeV. We first perform the energy evolution analysis of the dipole anisotropy of protons at this energy range.

38th International Cosmic Ray Conference (ICRC2023)
26 July - 3 August, 2023
Nagoya, Japan

ICRC2023
38th International Cosmic Ray Conference
The Astroparticle Physics Conference

*Presenter

1. Introduction

The relative intensity of cosmic rays displays non-isotropic behaviour, characterized by large-scale structures with amplitudes ranging from 10^{-4} to 10^{-3}. Several ground-based experiments, such as ASγ[1], ARGO-YBJ[2], Milagro[3], EAS-Top[4], IceCube/IceTop[5, 6], HAWC[7], and Pierre Auger Observatory[8], have successfully measured the energy-dependent amplitude and phase of the dipole components within the energy range of 500 GeV to 32 EeV. The observed anisotropy in the arrival direction of cosmic rays provides valuable insights into cosmic-ray propagation and acceleration.

Protons, helium, and heavy nuclei constitute the majority of cosmic rays, with protons being the dominant contributors at lower energies (TeV) compared to other elements. Previous space experiments have provided detailed measurements of the energy spectra of protons and helium within the corresponding energy range of anisotropy [9–16]. These measurements suggest a common origin for them [17]. Astrophysicists have raised the question of whether the amplitude of anisotropy depends on the mass or rigidity of the particles [18]. Studying anisotropy in combination with energy spectra is essential in unraveling the origin of cosmic rays. However, despite extensive research, there has been no experiment that has reported a significant measurement of anisotropy specifically for cosmic protons. In this study, we utilize data from LHAASO-KM2A to carefully select a data set of high-purity cosmic-ray protons, enabling us to precisely measure the pure proton anisotropy.

2. LHAASO Experiment

The LHAASO experiment, located at Haizi Mountain in Daocheng, Sichuan province, China (100.01°E, 29.35°N), is a hybrid ground-based experiment designed to take advantage of its wide field of view, large detected area, and high duty cycles[19]. The LHAASO experiment consists of three sub-arrays: the KM2A, which covers an area of 1.3 square kilometers; the WCDA (water Cherenkov detector array) spanning 78000 m^2; and the WFCTA (wide field of view Cherenkov/fluorescence telescopes array). Construction of the entire KM2A array was completed on July 20, 2021, and it currently comprises 5195 electromagnetic detectors (EDs) measuring 1 m^2 each on the ground, as well as 1188 muon detectors (MDs) measuring 36 m^2 each underground. The KM2A array's extensive coverage and long observation time have facilitated the accumulation of massive data on cosmic ray events, enabling in-depth studies of cosmic ray physics.

3. Data Analysis

We utilized the data collected by LHAASO-KM2A from July 20, 2021, to July 19, 2022, encompassing a full year of observations from the entire KM2A array. In order to ensure the reliability of our analysis, we carefully selected events that met the following criteria: the number of triggered electromagnetic detectors (EDs) after applying the noise filter was at least 20, the reconstructed shower core was situated within the array, and the zenith angle was less than 50°.

In order to achieve a highly pure dataset consisting of protons, we make use of the information obtained from the underground muon detectors. The muon number in atmospheric showers is related to the mass number of primary particles. When cosmic ray particles strike the atmosphere, they produce showers that contain secondary electromagnetic particles and muons. In the case of photon/hadron discrimination, a cosmic ray particle shower generates more muons than a photon shower. Therefore, gamma events can be distinguished from the cosmic background based on the ratio of muons and electromagnetic particles. This technique has been utilized in the analysis of gamma-ray astronomy using KM2A data[20].

In this analysis, the ratio is defined as

$$R = log\frac{N_\mu + 0.0001}{N_e}, \tag{1}$$

where N_e represents the number of electromagnetic particles and N_μ corresponds to the number of muons collected by Muon Detectors (MDs) located at a distance greater than 15 m from the shower core, and 0.0001 is used to show the cases with $N_\mu = 0$. The gamma-ray-like events are selected using simple cuts on the parameter R.

Hence, this ratio can be utilized in a similar manner to identify proton events within cosmic ray events. Proton showers exhibit a lower abundance of muons compared to heavier nuclei. Therefore, a new threshold value for the ratio, denoted as R cut, can be established to enhance the purity of the proton sample.

Figure 1 illustrates the relationship between the relative survival fraction of the data sample (represented by the black solid line) and the purity of the proton sample (represented by the blue solid line) for simulated data with varying R values and median energy of 15 TeV. To exclude gamma-like events, we establish a criterion of R > -2. In the energy bin presented in Figure 1, we determine the value of R as -1.08 to achieve a proton purity of 90%. Subsequently, we apply this proton selection criterion to other energy bins, resulting in proton purity of around 90% in each bin, as depicted in Figure 2.

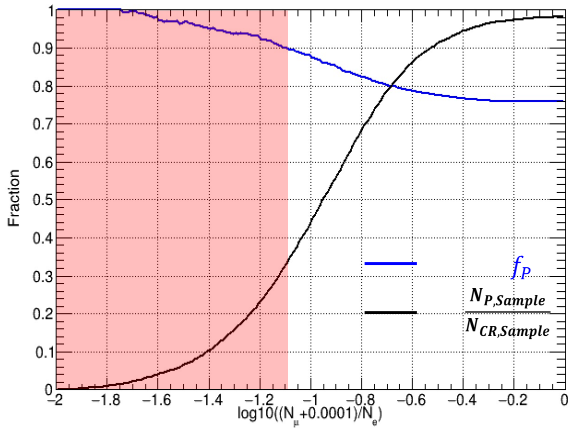

Figure 1: Proton purity and data survival fraction as a function of the discrimination parameter of R. The median energy of the data set is 15 TeV.

To estimate the energy of protons, we utilize the ρ_{50} estimator, which is based on the lateral distribution of the electromagnetic component of the shower. Protons tend to have a lower muon content, making the ρ_{50} estimator robust in this context. This estimator takes advantage of the

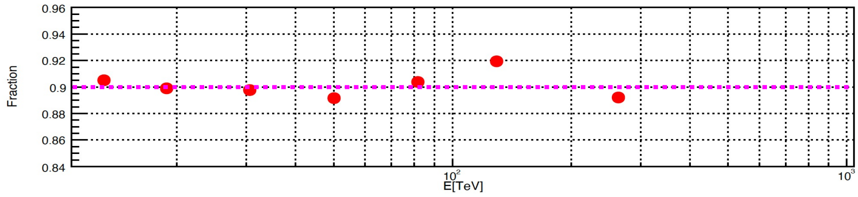

Figure 2: The purity of proton in each energy bin.

normalization of the lateral distribution function (LDF) of the shower. The implementation involves determining the particle density at the optimal radius where the uncertainty is minimized. It is important to consider the zenith angle effect in the energy reconstruction, as the atmospheric depth over which the shower develops is proportional to $sec(\theta)$. In this work, the ρ_{50}, obtained at a radius of 50 m[20], is used to estimate the energy of gamma rays.

For the analysis, the proton-like experimental data is divided into seven bins. These distributions are obtained using MC data, with median energies for each bin: 13.1 TeV, 18.8 TeV, 30.1 TeV, 50.1 TeV, 81.7 TeV, 129.4 TeV, and 263.6 TeV. The number of events per bin is as follows: 1.09×10^9, 1.68×10^9, 1.05×10^9, 3.80×10^8, 1.70×10^8, 6.46×10^7, 3.71×10^7. The resulting response function between the reconstructed energy and the primary energy is presented in Figure 3.

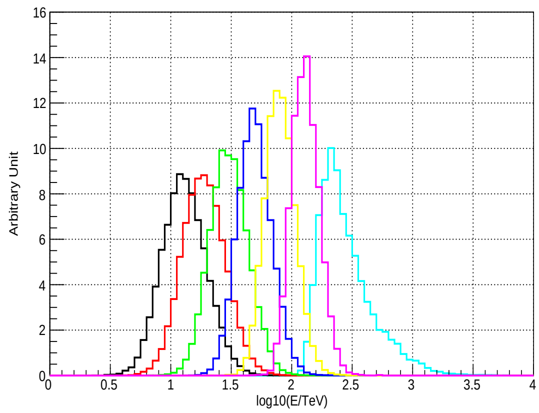

Figure 3: Distribution of the primary energy in each reconstrued energy bin.

4. Results

We analyze the data using the all-distance equi-zenith method [21, 22], which has been proven effective in detecting large-scale anisotropy. More details about this method can be found in [21]. First, we obtain two-dimensional maps for each energy and then smooth these maps in the equatorial coordinate system using a window with a radius of 30°. Figure 4 displays the 2D maps of the relative intensity and significance of the proton-like sample.

In order to obtain a one-dimensional (1D) profile of the anisotropy, we project the two-dimensional (2D) anisotropy map onto the right ascension (R.A.) axis and calculate the average relative intensities across all declinations. To quantify the amplitude and phase, we project the unsmoothed 2D maps onto the R.A. axis and fit them with the function $f(\alpha) = 1 + A_1 \cos(\alpha - \phi_1) + A_2 \cos(2(\alpha - \phi_2))$ for the sidereal time anisotropy. Here, A_1 and A_2 represent the amplitudes, α denotes the time, and ϕ_1 and ϕ_2 represent the phases. The anti-sidereal time projection is fitted using $f(\alpha) = 1 + A\cos(\alpha - \phi)$. The anisotropy in the anti-sidereal time is generally used to estimate the systematic error of the local sidereal time anisotropy. In this study, no significant anisotropy is observed in the anti-sidereal time, indicating that the systematic error is well controlled. The energy evolution of the anisotropy is presented in Figure 4, showcasing both a 2D map and 1D projections.

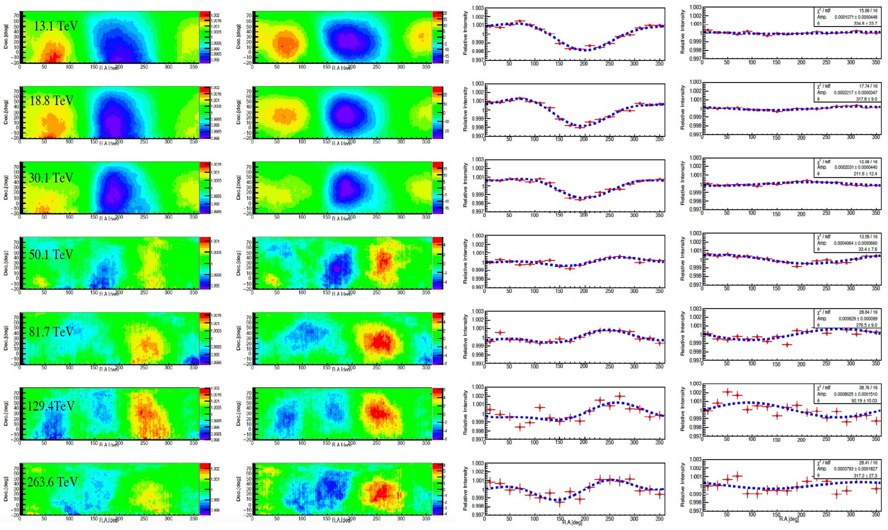

Figure 4: Anisotropy evolution of Proton Sample: 2D Maps and 1D Projections. The first column represents the relative intensity, while the second column displays the significance. The third column showcases the sidereal time relative intensity projection, and the fourth column presents the anti-sidereal time relative intensity projection.

5. Conclusion

The study presents a search for pure proton anisotropy with a purity of 90% for energies above 10 TeV. The analysis utilizes one year of data from the KM2A full array. A notable observation is a noticeable shift in the anisotropy of protons around 50 TeV, specifically in the phase. This change in the proton sample's anisotropy occurs earlier compared to the energy evolution of the large-scale anisotropy of all-particle cosmic rays. However, due to statistical limitations, additional data is required to accurately measure the energy point at which the phase changes.

6. Acknowledgement

We would like to thank all staff members who work at the LHAASO site above 4400 meters above sea level year-round to maintain the detector and keep the water recycling system, electricity power supply, and other components of the experiment operating smoothly. We are grateful to the Chengdu Management Committee of Tianfu New Area for the constant financial support for research with LHAASO data. This research work is also supported by the following grants: The National Key R&D program of China under grants 2018YFA0404201, 2018YFA0404202, 2018YFA0404203, and 2018YFA0404204, by the National Natural Science Foundation of China No.12273114,No.12022502, No.12205314, No. 12105301, No. 12261160362, No.12105294, No.U1931201, Project for Young Scientists in Basic Research of Chinese Academy of Sciences No. YSBR-061, the Program for Innovative Talents and Entrepreneur in Jiangsu.

References

[1] M. Amenomori, X. J. Bi, D. Chen, T. L. Chen, W. Y. Chen, S. W. Cui, Danzengluobu, L. K. Ding, C. F. Feng, Z. Feng, et al., The Astrophysical Journal **836**, 153 (2017).

[2] B. Bartoli, P. Bernardini, X. J. Bi, Z. Cao, S. Catalanotti, S. Z. Chen, T. L. Chen, S. W. Cui, B. Z. Dai, A. D'Amone, et al., The Astrophysical Journal **861**, 93 (2018).

[3] A. A. Abdo, B. T. Allen, T. Aune, D. Berley, S. Casanova, C. Chen, B. L. Dingus, R. W. Ellsworth, L. Fleysher, R. Fleysher, et al., The Astrophysical Journal **698**, 2121 (2009).

[4] M. Aglietta, V. V. Alekseenko, B. Alessandro, P. Antonioli, F. Arneodo, L. Bergamasco, M. Bertaina, R. Bonino, A. Castellina, A. Chiavassa, et al., The Astrophysical Journal **692**, L130 (2009).

[5] R. Abbasi, Y. Abdou, T. Abu-Zayyad, M. Ackermann, J. Adams, J. A. Aguilar, M. Ahlers, M. M. Allen, D. Altmann, K. Andeen, et al., The Astrophysical Journal **746**, 33 (2012).

[6] M. G. Aartsen, R. Abbasi, Y. Abdou, M. Ackermann, J. Adams, J. A. Aguilar, M. Ahlers, D. Altmann, K. Andeen, J. Auffenberg, et al., The Astrophysical Journal **765**, 55 (2013).

[7] A. U. Abeysekara, R. Alfaro, C. Alvarez, J. D. Álvarez, R. Arceo, J. C. Arteaga-Velázquez, D. A. Rojas, H. A. A. Solares, A. Becerril, E. Belmont-Moreno, et al., The Astrophysical Journal **865**, 57 (2018).

[8] P. Abreu, M. Aglietta, J. M. Albury, I. Allekotte, K. A. Cheminant, A. Almela, J. Alvarez-Muñiz, R. A. Batista, J. A. Yebra, G. A. Anastasi, et al., The Astrophysical Journal **935**, 170 (2022).

[9] A. Panov, J. H. Adams, H. Ahn, G. Bashinzhagyan, J. Watts, J. Wefel, J. Wu, O. Ganel, T. Guzik, V. Zatsepin, et al., Bulletin of the Russian Academy of Sciences: Physics **73**, 564 (2009).

[10] O. Adriani, G. Barbarino, G. Bazilevskaya, R. Bellotti, M. Boezio, E. Bogomolov, L. Bonechi, M. Bongi, V. Bonvicini, S. Borisov, et al., Science **332**, 69 (2011).

[11] M. Aguilar, D. Aisa, B. Alpat, A. Alvino, G. Ambrosi, K. Andeen, L. Arruda, N. Attig, P. Azzarello, A. Bachlechner, et al., Physical review letters **114**, 171103 (2015).

[12] Y. S. Yoon, T. Anderson, A. Barrau, N. Conklin, S. Coutu, L. Derome, J. Han, J. Jeon, K. Kim, M. Kim, et al., The Astrophysical Journal **839**, 5 (2017).

[13] E. Atkin, V. Bulatov, V. Dorokhov, N. Gorbunov, S. Filippov, V. Grebenyuk, D. Karmanov, I. Kovalev, I. Kudryashov, A. Kurganov, et al., JETP Letters **108**, 5 (2018).

[14] D. collaboration, Q. An, R. Asfandiyarov, P. Azzarello, P. Bernardini, X. Bi, M. Cai, J. Chang, D. Chen, H. Chen, et al., Science advances **5**, eaax3793 (2019).

[15] F. Alemanno, Q. An, P. Azzarello, F. C. T. Barbato, P. Bernardini, X. J. Bi, M. S. Cai, E. Catanzani, J. Chang, D. Y. Chen, et al. (DAMPE Collaboration), Phys. Rev. Lett. **126**, 201102 (2021).

[16] D. Collaboration et al., arXiv preprint arXiv:2304.00137 (2023).

[17] W. Liu, Y.-Q. Guo, and Q. Yuan, Journal of Cosmology and Astroparticle Physics **2019**, 010 (2019).

[18] B.-Q. Qiao, W. Liu, Y.-Q. Guo, and Q. Yuan, Journal of Cosmology and Astroparticle Physics **2019**, 007 (2019).

[19] H. He and F. Collaboration, Radiation Detection Technology and Methods p. 002 (2018).

[20] F. Aharonian, Q. An, Axikegu, L. X. Bai, Y. X. Bai, Y. W. Bao, D. Bastieri, X. J. Bi, Y. J. Bi, H. Cai, et al., Chinese Physics C **45**, 025002 (2021).

[21] M. Amenomori, S. Ayabe, D. Chen, S. W. Cui, Danzengluobu, L. K. Ding, X. H. Ding, C. F. Feng, Z. Y. Feng, X. Y. Gao, et al., ApJ **633**, 1005 (2005), number: 2.

[22] M. Amenomori, S. Ayabe, X. J. Bi, D. Chen, S. W. Cui, Danzengluobu, L. K. Ding, X. H. Ding, C. F. Feng, Z. Feng, et al., Science **314**, 439 (2006), number: 5798.

Full Authors List: LHAASO Collaboration

Zhen Cao[1,2,3], F. Aharonian[4,5], Q. An[6,7], Axikegu[8], Y.X. Bai[1,3], Y.W. Bao[9], D. Bastieri[10], X.J. Bi[1,2,3], Y.J. Bi[1,3], J.T. Cai[10], Q. Cao[11], W.Y. Cao[7], Zhe Cao[6,7], J. Chang[12], J.F. Chang[1,3,6], A.M. Chen[13], E.S. Chen[1,2,3], Liang Chen[14], Lin Chen[8], Long Chen[8], M.J. Chen[1,3], M.L. Chen[1,3,6], Q.H. Chen[8], S.H. Chen[1,2,3], S.Z. Chen[1,3], T.L. Chen[15], Y. Chen[9], N. Cheng[1,3], Y.D. Cheng[1,3], M.Y. Cui[12], S.W. Cui[11], X.H. Cui[16], Y.D. Cui[17], B.Z. Dai[18], H.L. Dai[1,3,6], Z.G. Dai[7], Danzengluobu[15], D. della Volpe[19], X.Q. Dong[1,2,3], K.K. Duan[12], J.H. Fan[10], Y.Z. Fan[12], J. Fang[18], K. Fang[1,3], C.F. Feng[20], L. Feng[12], S.H. Feng[1,3], X.T. Feng[20], Y.L. Feng[15], S. Gabici[21], B. Gao[1,3], C.D. Gao[20], L.Q. Gao[1,2,3], Q. Gao[15], W. Gao[1,3], W.K. Gao[1,2,3], M.M. Ge[18], L.S. Geng[1,3], G. Giacinti[13], G.H. Gong[22], Q.B. Gou[1,3], M.H. Gu[1,3,6], F.L. Guo[14], X.L. Guo[8], Y.Q. Guo[1,3], Y.Y. Guo[12], Y.A. Han[23], H.H. He[1,2,3], H.N. He[12], J.Y. He[12], X.B. He[17], Y. He[8], M. Heller[19], Y.K. Hor[17], B.W. Hou[1,2,3], C. Hou[1,3], X. Hou[24], H.B. Hu[1,2,3], Q. Hu[7,12], S.C. Hu[1,2,3], D.H. Huang[8], T.Q. Huang[1,3], W.J. Huang[17], X.T. Huang[20], X.Y. Huang[12], Y. Huang[1,2,3], Z.C. Huang[8], X.L. Ji[1,3,6], H.Y. Jia[8], K. Jia[20], K. Jiang[6,7], X.W. Jiang[1,3], Z.J. Jiang[18], M. Jin[8], M.M. Kang[25], T. Ke[1,3], D. Kuleshov[26], K. Kurinov[26,27], B.B. Li[11], Cheng Li[6,7], Cong Li[1,3], D. Li[1,2,3], F. Li[1,3,6], H.B. Li[1,3], H.C. Li[1,3], H.Y. Li[7,12], J. Li[7,12], Jian Li[7], Jie Li[1,3,6], K. Li[1,3], W.L. Li[20], W.L. Li[13], X.R. Li[1,3], Xin Li[6,7], Y.Z. Li[1,2,3], Zhe Li[1,3], Zhuo Li[28], E.W. Liang[29], Y.F. Liang[29], S.J. Lin[17], B. Liu[7], C. Liu[1,3], D. Liu[20], H. Liu[8], H.D. Liu[23], J. Liu[1,3], J.L. Liu[1,3], J.Y. Liu[1,3], M.Y. Liu[15], R.Y. Liu[9], S.M. Liu[8], W. Liu[1,3], Y. Liu[10], Y.N. Liu[22], R. Lu[18], Q. Luo[17], H.K. Lv[1,3], B.Q. Ma[28], L.L. Ma[1,3], X.H. Ma[1,3], J.R. Mao[24], Z. Min[1,3], W. Mitthumsiri[30], H.J. Mu[23], Y.C. Nan[1,3], A. Neronov[21], Z.W. Ou[17], B.Y. Pang[8], P. Pattarakijwanich[30], Z.Y. Pei[10], M.Y. Qi[1,3], Y.Q. Qi[11], B.Q. Qiao[1,3], J.J. Qin[7], D. Ruffolo[30], A. Sáiz[30], D. Semikoz[21], C.Y. Shao[17], L. Shao[11], O. Shchegolev[26,27], X.D. Sheng[1,3], F.W. Shu[31], H.C. Song[28], Yu.V. Stenkin[26,27], V. Stepanov[26], Y. Su[12], Q.N. Sun[8], X.N. Sun[29], Z.B. Sun[32], P.H.T. Tam[17], Q.W. Tang[31], Z.B. Tang[6,7], W.W. Tian[2,16], C. Wang[32], C.B. Wang[8], G.W. Wang[7], H.G. Wang[10], H.H. Wang[17], J.C. Wang[24], K. Wang[9], L.P. Wang[20], L.Y. Wang[1,3], P.H. Wang[8], R. Wang[20], W. Wang[17], X.G. Wang[29], X.Y. Wang[9], Y. Wang[8], Y.D. Wang[1,3], Y.J. Wang[1,3], Z.H. Wang[25], Z.X. Wang[18], Zhen Wang[13], Zheng Wang[1,3,6], D.M. Wei[12], J.J. Wei[12], Y.J. Wei[1,2,3], T. Wen[18], C.Y. Wu[1,3], H.R. Wu[1,3], S. Wu[1,3], X.F. Wu[12], Y.S. Wu[7], S.Q. Xi[1,3], J. Xia[7,12], J.J. Xia[8], G.M. Xiang[2,14], D.X. Xiao[11], G. Xiao[1,3], G.G. Xin[1,3], Y.L. Xin[8], Y. Xing[14], Z. Xiong[1,2,3], D.L. Xu[13], R.F. Xu[1,2,3], R.X. Xu[28], W.L. Xu[25], L. Xue[20], D.H. Yan[18], J.Z. Yan[12], T. Yan[1,3], C.W. Yang[25], F. Yang[11], F.F. Yang[1,3,6], H.W. Yang[17], J.Y. Yang[17], L.L. Yang[17], M.J. Yang[1,3], R.Z. Yang[7], S.B. Yang[18], Y.H. Yao[25], Z.G. Yao[1,3], Y.M. Ye[22], L.Q. Yin[1,3], N. Yin[20], X.H. You[1,3], Z.Y. You[1,2,3], Y.H. Yu[7], Q. Yuan[12], H. Yue[1,2,3], H.D. Zeng[12], T.X. Zeng[1,3,6], W. Zeng[18], M. Zha[1,3], B.B. Zhang[9], F. Zhang[8], H.M. Zhang[9], H.Y. Zhang[1,3], J.L. Zhang[16], L.X. Zhang[10], Li Zhang[18], P.F. Zhang[18], P.P. Zhang[7,12], R. Zhang[7,12], S.B. Zhang[2,16], S.R. Zhang[11], S.S. Zhang[1,3], X. Zhang[9], X.P. Zhang[1,3], Y.F. Zhang[8], Yi Zhang[1,12], Yong Zhang[1,3], B. Zhao[8], J. Zhao[1,3], L. Zhao[6,7], L.Z. Zhao[11], S.P. Zhao[12,20], F. Zheng[32], B. Zhou[1,3], H. Zhou[13], J.N. Zhou[14], M. Zhou[31], P. Zhou[9], R. Zhou[25], X.X. Zhou[8], C.G. Zhu[20], F.R. Zhu[8], H. Zhu[16], K.J. Zhu[1,2,3,6], X. Zuo[1,3], (The LHAASO Collaboration)

[1] Key Laboratory of Particle Astrophysics & Experimental Physics Division & Computing Center, Institute of High Energy Physics, Chinese Academy of Sciences, 100049 Beijing, China
[2] University of Chinese Academy of Sciences, 100049 Beijing, China
[3] TIANFU Cosmic Ray Research Center, Chengdu, Sichuan, China
[4] Dublin Institute for Advanced Studies, 31 Fitzwilliam Place, 2 Dublin, Ireland
[5] Max-Planck-Institut for Nuclear Physics, P.O. Box 103980, 69029 Heidelberg, Germany
[6] State Key Laboratory of Particle Detection and Electronics, China
[7] University of Science and Technology of China, 230026 Hefei, Anhui, China
[8] School of Physical Science and Technology & School of Information Science and Technology, Southwest Jiaotong University, 610031 Chengdu, Sichuan, China
[9] School of Astronomy and Space Science, Nanjing University, 210023 Nanjing, Jiangsu, China
[10] Center for Astrophysics, Guangzhou University, 510006 Guangzhou, Guangdong, China
[11] Hebei Normal University, 050024 Shijiazhuang, Hebei, China
[12] Key Laboratory of Dark Matter and Space Astronomy & Key Laboratory of Radio Astronomy, Purple Mountain Observatory, Chinese Academy of Sciences, 210023 Nanjing, Jiangsu, China
[13] Tsung-Dao Lee Institute & School of Physics and Astronomy, Shanghai Jiao Tong University, 200240 Shanghai, China
[14] Key Laboratory for Research in Galaxies and Cosmology, Shanghai Astronomical Observatory, Chinese Academy of Sciences, 200030 Shanghai, China
[15] Key Laboratory of Cosmic Rays (Tibet University), Ministry of Education, 850000 Lhasa, Tibet, China
[16] National Astronomical Observatories, Chinese Academy of Sciences, 100101 Beijing, China
[17] School of Physics and Astronomy (Zhuhai) & School of Physics (Guangzhou) & Sino-French Institute of Nuclear Engineering and Technology (Zhuhai), Sun Yat-sen University, 519000 Zhuhai & 510275 Guangzhou, Guangdong, China
[18] School of Physics and Astronomy, Yunnan University, 650091 Kunming, Yunnan, China
[19] Département de Physique Nucléaire et Corpusculaire, Faculté de Sciences, Université de Genève, 24 Quai Ernest Ansermet, 1211 Geneva, Switzerland
[20] Institute of Frontier and Interdisciplinary Science, Shandong University, 266237 Qingdao, Shandong, China
[21] APC, Universit'e Paris Cit'e, CNRS/IN2P3, CEA/IRFU, Observatoire de Paris, 119 75205 Paris, France
[22] Department of Engineering Physics, Tsinghua University, 100084 Beijing, China
[23] School of Physics and Microelectronics, Zhengzhou University, 450001 Zhengzhou, Henan, China
[24] Yunnan Observatories, Chinese Academy of Sciences, 650216 Kunming, Yunnan, China

[25] College of Physics, Sichuan University, 610065 Chengdu, Sichuan, China
[26] Institute for Nuclear Research of Russian Academy of Sciences, 117312 Moscow, Russia
[27] Moscow Institute of Physics and Technology, 141700 Moscow, Russia
[28] School of Physics, Peking University, 100871 Beijing, China
[29] School of Physical Science and Technology, Guangxi University, 530004 Nanning, Guangxi, China
[30] Department of Physics, Faculty of Science, Mahidol University, 10400 Bangkok, Thailand
[31] Center for Relativistic Astrophysics and High Energy Physics, School of Physics and Materials Science & Institute of Space Science and Technology, Nanchang University, 330031 Nanchang, Jiangxi, China
[32] National Space Science Center, Chinese Academy of Sciences, 100190 Beijing, China