

Tibet Air Shower Array: Results and Future Plan

The Tibet AS γ Collaboration

M. Amenomori¹, X. J. Bi², D. Chen³, S. W. Cui⁴, Danzengluobu⁵,
L. K. Ding², X. H. Ding⁵, C. Fan⁶, C. F. Feng⁶, Zhaoyang Feng²,
Z. Y. Feng⁷, X. Y. Gao⁸, Q. X. Geng⁸, H. W. Guo⁵, H. H. He²,
M. He⁶, K. Hibino⁹, N. Hotta¹⁰, Haibing Hu⁵, H. B. Hu², J. Huang¹¹,
Q. Huang⁷, H. Y. Jia⁷, F. Kajino¹², K. Kasahara¹³, Y. Katayose³,
C. Kato¹⁴, K. Kawata^{11,*}, Labaciren⁵, G. M. Le¹⁵, A. F. Li⁶, J. Y. Li⁶,
Y.-Q. Lou¹⁶, H. Lu², S. L. Lu², X. R. Meng⁵, K. Mizutani^{13,17}, J. Mu⁸,
K. Munakata¹⁴, A. Nagai¹⁸, H. Nanjo¹, M. Nishizawa¹⁹, M. Ohnishi¹¹,
I. Ohta²⁰, H. Onuma¹⁷, T. Ouchi⁹, S. Ozawa¹¹, J. R. Ren², T. Saito²¹,
T. Y. Saito²², M. Sakata¹², T. K. Sako¹¹, M. Shibata³, A. Shiomi^{9,11},
T. Shirai⁹, H. Sugimoto²³, M. Takita¹¹, Y. H. Tan², N. Tateyama⁹,
S. Torii¹³, H. Tsuchiya²⁴, S. Udo¹¹, B. Wang⁸, H. Wang², X. Wang¹¹,
Y. Wang², Y. G. Wang⁶, H. R. Wu², L. Xue⁶, Y. Yamamoto¹²,
C. T. Yan¹¹, X. C. Yang⁸, S. Yasue²⁵, Z. H. Ye¹⁵, G. C. Yu⁷,
A. F. Yuan⁵, T. Yuda⁹, H. M. Zhang², J. L. Zhang², N. J. Zhang⁶,
X. Y. Zhang⁶, Y. Zhang², Yi Zhang², Zhaxisangzhu⁵ and X. X. Zhou⁷

¹Department of Physics, Hirosaki University, Hirosaki 036-8561, Japan.

²Key Laboratory of Particle Astrophysics, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China.

³Faculty of Engineering, Yokohama National University, Yokohama 240-8501, Japan.

⁴Department of Physics, Hebei Normal University, Shijiazhuang 050016, China.

⁵Department of Mathematics and Physics, Tibet University, Lhasa 850000, China.

⁶Department of Physics, Shandong University, Jinan 250100, China.

⁷Institute of Modern Physics, SouthWest Jiaotong University, Chengdu 610031, China.

⁸Department of Physics, Yunnan University, Kunming 650091, China.

⁹Faculty of Engineering, Kanagawa University, Yokohama 221-8686, Japan.

¹⁰Faculty of Education, Utsunomiya University, Utsunomiya 321-8505, Japan.

¹¹Institute for Cosmic Ray Research, University of Tokyo, Kashiwa 277-8582, Japan.

¹²Department of Physics, Konan University, Kobe 658-8501, Japan.

¹³Research Institute for Science and Engineering, Waseda University, Tokyo 169-8555, Japan.

¹⁴Department of Physics, Shinshu University, Matsumoto 390-8621, Japan.

¹⁵Center of Space Science and Application Research, Chinese Academy of Sciences, Beijing 100080, China.

¹⁶Physics Department and Tsinghua Center for Astrophysics, Tsinghua University, Beijing 100084, China.

¹⁷Department of Physics, Saitama University, Saitama 338-8570, Japan.

¹⁸Advanced Media Network Center, Utsunomiya University, Utsunomiya 321-8585, Japan.

¹⁹National Institute of Informatics, Tokyo 101-8430, Japan.

²⁰Tochigi Study Center, University of the Air, Utsunomiya 321-0943, Japan.

²¹Tokyo Metropolitan College of Industrial Technology, Tokyo 116-8523, Japan.

²²Max-Planck-Institut für Physik, München D-80805, Deutschland.

²³Shonan Institute of Technology, Fujisawa 251-8511, Japan.

²⁴RIKEN, Wako 351-0198, Japan.

²⁵School of General Education, Shinshu University, Matsumoto 390-8621, Japan.

* Paper presented at the conference by K. Kawata

E-mail: kawata@icrr.u-tokyo.ac.jp

Abstract. The Tibet air shower array, which has an effective area of 36,900 m², has been in operation at Yangbajing in Tibet, China at an altitude of 4,300 m above sea level. In this paper, we will briefly introduce the recent gamma-ray observation with the present Tibet air shower array and our future plan which is called the Tibet muon detector (MD) project.

1. Introduction

The Tibet air shower (AS) experiment has been successfully operated at Yangbajing (90.522° E, 30.102° N, 4,300 m above sea level) in Tibet, China since 1990. The array was constructed first in 1990 and gradually upgraded by increasing the number of counters, then the Tibet AS array was consists of 533 plastic scintillation counters of 0.5 m² placed on a 7.5 m square grid to detect high-energy ($>$ a few TeV) cosmic-ray showers. In the late fall of 2003, the area of the Tibet AS array was further enlarged up to 36,900 m² by adding 256 counters. This final array configuration has been successfully in operation, triggering AS events at a rate of 1,700 Hz. Using these arrays, we already successfully detected gamma rays from Crab, Mrk 501 and Mrk 421 [1, 2, 3]. Also, we set stringent upper limits to gamma rays from Galactic plane at 3 TeV and 10 TeV [4, 5].

2. Recent results

Recently, we updated the gamma-ray energy spectrum of the Crab Nebula [6]. We found no evidence for time variability of flux intensity from the Crab Nebula at multi-TeV energies. Also the gamma-ray energy spectrum of the Crab Nebula is consistent with our previous results and other observations by the atmospheric imaging Cherenkov telescopes. We also have successfully observed gamma-ray sources and precise large-scale cosmic-ray anisotropy in the northern sky [8, 9, 10]. In these results, we first pointed out new small anisotropies in Cygnus region at multi-TeV energies [10]. One of them is coincident with MGRO J2019+37 which the Milagro experiment recently established to gamma-ray source [11]. After that, we first present the energy spectrum of MGRO J2019+37 in multi TeV region [12].

The absolute gamma-ray energies in multi-TeV region observed by the Tibet AS array are verified by the Moon's shadow observation [7]. As primary cosmic rays are shielded by the Moon, we observed a deficit in cosmic rays called the Moon's shadow, and the center of the Moon's shadow shifts westward depending on primary cosmic-ray energies due to the geomagnetic field. Using this effect, the systematic error of absolute energy scale is estimated to be less than approximately $\pm 10\%$ level.

3. Future plan

We are planning to build a water-Cherenkov-type muon detector array (Tibet MD array) around the Tibet AS array [13, 14, 15]. Each muon detector is a waterproof concrete pool, 7.2 m wide \times 7.2 m long \times 1.5 m deep in size, equipped with two 20 inch-in-diameter PMT (HAMAMATSU R3600). The Tibet MD array consists of 192 muon detectors set up 2.5 m underground as shown by gray areas in Figure 1. Its total effective area amounts to be 10,000 m² approximately for muon detection with an energy threshold of 1 GeV.

The Monte Carlo simulation including the AS generation and responses of the Tibet AS array and MD array was done to estimate the discrimination between gamma rays and hadrons based on counting the number of muons accompanying an air shower [14]. As a result, hadron-induced

air showers are suppressed by 99.99% around 100 TeV, while gamma-ray-induced air showers remain by more than 95%. Finally, we calculate the integral flux sensitivity of the Tibet AS+MD array to point-like gamma rays as shown by the thick solid curve in Figure 2. Note that our sensitivity above 200 TeV is defined as a flux corresponding to 10 gamma-ray events, since the background events are fully suppressed to less than one event.

The Tibet AS+MD array will have the sensitivity to gamma rays in the 100 TeV region by an order of magnitude better than any other previous existing detectors in the world. We can expect to discover a dozen new point-like sources and diffuse gamma rays from Galactic plane with extremely low background level in the northern sky. In the near future, the MAGIC and VERITAS experiments, together with the Tibet AS+MD array will contribute to a deeper understanding of the origin and acceleration mechanism of cosmic rays.

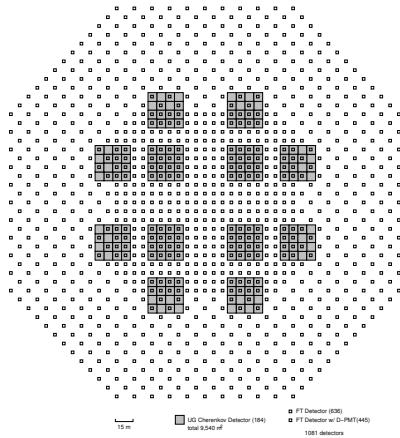


Figure 1. Schematic view of the Tibet AS+MD array.

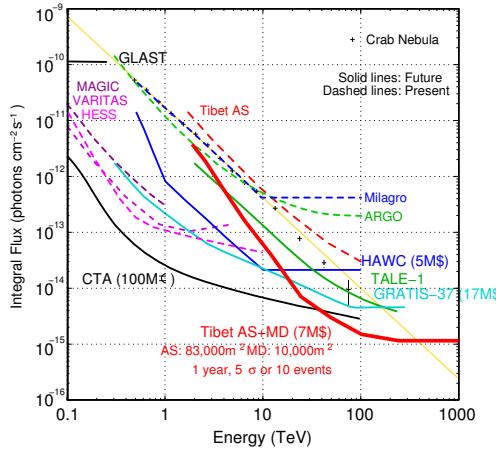


Figure 2. Integral flux sensitivities to point-like gamma-ray sources.

Acknowledgments

The collaborative experiment of the Tibet Air Shower Arrays has been performed under the auspices of the Ministry of Science and Technology of China and the Ministry of Foreign Affairs of Japan. This work was supported in part by Grants-in-Aid for Scientific Research on Priority Areas (712) (MEXT), by the Japan Society for the Promotion of Science, by the National Natural Science Foundation of China, and by the Chinese Academy of Sciences.

References

- [1] Amenomori M et al. 1999 *Astrophys. J.* **525** L93
- [2] Amenomori M et al. 2000 *Astrophys. J.* **532** 302
- [3] Amenomori M et al. 2003 *Astrophys. J.* **598** 242
- [4] Amenomori M et al. 2002 *Astrophys. J.* **580** 887
- [5] Amenomori M et al. 2002 *Advances in Space Research* **37** 1932
- [6] Amenomori M et al. 2007 *Proc. 30th Int. Cosmic Ray Conf.* **OG.2.2**
- [7] Amenomori M et al. 2005 *Proc. 29th Int. Cosmic Ray Conf.* **6**, 53
- [8] Amenomori M et al. 2005 *Astrophys. J.* **626** L29
- [9] Amenomori M et al. 2005 *Astrophys. J.* **633** 1005
- [10] Amenomori M et al. 2006 *Science* **314** 439
- [11] Abdo A A et al. 2007 *Astrophys. J.* **658** L33
- [12] Amenomori M et al. 2007 *Proc. 30th Int. Cosmic Ray Conf.* **OG.2.2**
- [13] Amenomori M et al. 2007 *Astrophys. and Space Science* **309** 435
- [14] Amenomori M et al. 2007 *Proc. 30th Int. Cosmic Ray Conf.* **OG.1.5** (Preprint astro-ph/0710.2757)
- [15] Amenomori M et al. 2007 *Proc. 30th Int. Cosmic Ray Conf.* **OG.1.5** (Preprint astro-ph/0710.2752)