Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008
Vol. 2 (OG part 1), pages 575–578

30TH INTERNATIONAL COSMIC RAY CONFERENCE

ICRC'07 Mérida, México

A search for 100 TeV celestial gamma rays with the Tibet air shower array and a future prospect

THE TIBET ASγ COLLABORATION

Abstract: Search for steady 100 TeV gamma-ray point sources is done from -10° to $+70^\circ$ in declination based on six-year data obtained from Nov. 1999 to Nov. 2005 by the Tibet air shower array. We found no new source and no significant excess of events was detected from known TeV gamma-ray sources. Flux upper limits are set above 100 TeV on several nearby objects located inside our Galaxy. All of them are slightly higher than the extrapolation from lower energies by a factor of 1 to 20. Our upgrade plan with a large underground water Cherenkov muon detector array will improve our sensitivity by a factor of $\sim$10 or more in the 100 TeV region (10TeV - 1000 TeV). Approximately 10 new sources are expected to be discovered and we will be able to measure cutoff energy of known and unknown sources which are potential origin of galactic cosmic rays.

Introduction

Based on observation by 4 large imaging air Cherenkov telescopes in Namibia, the HESS group recently reported on discovery of new 14 gamma-ray sources [1]. Most of them are UNIDentified (UNID) sources and faint in X-rays or other wavelengths. It was surprising that the conventional method to search for a new TeV gamma-ray source by an air Cherenkov telescope had assumed strong X-ray emission accompanied with it. Upon the HESS discovery, the importance of a wide field-of-view unbiased survey is recognized. Furthemore, many of the 14 sources have a harder energy spectrum (indices;-1.8 to -2.8) at TeV energies than the standard candle Crab (index;-2.6). The energy spectra turnd out to extend up to 10 TeV approximately. Cosmic rays are supposed to be accelerated up to the knee energy region at supernova remnants (SNRs) in our galaxy. Therefore, we naturally expect gamma rays in the 100 TeV region (10-1000TeV) which originate in π^0 decays produced by the accelerated cosmic rays interacting with matter surrounding the SNRs.

The Tibet air shower array is one of the best apparatuses for observing gamma rays in the 100 TeV region, because it is in operation in daytime(duty cycle $\sim$ 90%) and its angular resolution(0.2° at 100 TeV) and its effective area (22,000m^2 in this paper) are comparable to imaging air Cherenkov telescopes (IACTs) ($\sim$ $0.1^\circ, \sim$ $50,000$m^2). Besides, the large field of view of our experiment (2 sr) is is suitable for non-biased wide sky survey.

We report on search for point sources in the 100 TeV region, in this paper, in order to demonstrate the current sensitivity without hadron/gamma-ray discrimination. And then, we introduce our planned upgrade with a large underground water Cherenkov muon detector array (Tibet-MD), which will improve our sensitivity by a factor of 10 or more.

Experiment

The Tibet air shower experiment has been in operation at Yangbajing (90°31$'$ E, 30°06$'$ N; 4,300 m a. s. l.) in Tibet, China since 1990. The Tibet I array was constructed in 1990 [2] and it was gradually expanded to the Tibet II by 1994 which consisted of 185 fast-timing (FT) scintillation counters covering 36,900 m^2, and 36 density (D) scintillation counters around the FT-counter array. From 1996 the array was upgraded again and the Tibet III was set up in 1999 composed of 497 FT counters covering 36,900 m^2 and 36 D counters around them. In the inner 22,000 m^2, we deployed 429 FT counters with 7.5 m lattice interval, the rest of 68 FT counters with 15m lattice interval, and 36 D counters with 30 m lattice interval around FT counter array. The array continued to be upgraded until 2003, and it consists of 761 FT counters, at present, covering 50,400m^2 and 28 D counters around them. With the Tibet air shower array, we have successfully observed a new cosmic-ray anisotropy in the Cygnus region at multi-TeV energies [3] as well as multi-TeV gamma-rays from Crab [4], Mrk501 [5] and Mrk421 [6] together with searches for multi-TeV new point sources in the northern sky [7], for multi-TeV diffuse gamma rays from the galactic plane [8], and for PeV gamma rays from point sources [9].

In the present paper, we only use data from 497 FT counters and 36 D counters set up by 1999 in order to keep the data consistency.

Analysis

A total of 1.1×10^8 air shower events were collected during 1320 detector live days from November 18, 1999 to November 15, 2005 after the quality cut and the event selection based on the following simple criteria; (1) Air shower core location: Among the nine hottest counters in each event, eight should be contained in the inner 22,000 m^2. (2) Shower Size: $\Sigma\rho_{\rm FT}$ should be more than 1000 where $\Sigma\rho_{\rm FT}$ is the sum of the number of particles per m^2 counted by the 497 FT counters. (3) Zenith angle: The zenith angle of the arrival direction should be less than 50°.

According to the MC simulation including the quality cut and the event selection, the modal energy of primary gamma rays is approximately 100 TeV, the angular resolution is about 0.2°, and the detection efficiency for gamma rays is nearly 100%. The gamma-ray energy is estimated from $\Sigma\rho_{\rm FT}$ by using the MC simulation and the energy resolution is estimated to be around 40% at 100 TeV.

First, northern sky map from $-10°$ to $+70°$ in declination is divided into rectangular cells whose width is 0.5° in declination direction and $\sim 0.5°/\sin(\delta)$ in right ascension direction, where δ is the declination of the center of the cell.

The 92840 cells, any of which non-overlapping, cover the map completely.

The number of background events on each cell is estimated by using eight OFF-windows, which move keeping the zenith angle equal to the cell (ON-window) and azimuthal distance of neighbor windows constant (0.75/sin(θ), where θ is zenith angle). The significance of the excess in each cell is calculated based on the Equation (17) of [10].

Subsequently, we analyze some known galactic TeV gamma-ray sources by using a circular search window with radius of 0.28° in search of 100 TeV gamma rays.

Results and Discussions

The significance distribution of the 92840 cells is shown in Fig. 1 as filled circles. No significant deviation from the normal Gaussian distribution can be seen, which means we couldn't detect any gamma-ray sources. Taking into account the sources located at the edges of the bins, reanalyses were done by employing different binning phases. Filled squares, open circles and open squares in Fig. 1 indicate results by the sliding windows from the original binning by a half bin size in right ascension direction, declination direction, and both directions, respectively. They are all consistent with the normal Gaussian distribution, showing no signal detection. Excesses from some known galactic TeV sources are examined as well. Again, no significant excess was found. Accordingly, we set flux upper limits above 100 TeV on these sources. 99% confidence level flux upper limits above 100 TeV on Crab nebula, TeV2032+413, HESS J1837-069, HESS J1834-087 and Cassiopeia A are 0.8, 1.9, 2.2, 2.3 and 1.6 $\times 10^{-14}$ cm^{-2} sec^{-1}, respectively. Our upper limit on Crab nebula is almost the same level as the extrapolation from the HEGRA result [11] and much higher than extrapolation from the HESS result [12], as shown in Fig 2. Therefore, we cannot provide any meaningful information on the possible inconsistency between HESS and HEGRA. Our upper limits (see also [13]) on the rest of the four objects are slightly higher than the extrapolation from lower energy measurements by a factor of 2, 2, 10 and 20, although the extrapolation is rather ambiguous in the case of Cassiopeia A.

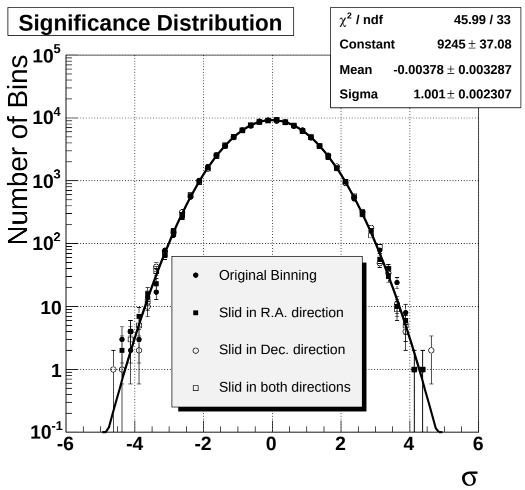

Figure 1: Significance distribution of 92840 cells from –10° to 70° in Dec. above 100 TeV. Filled circles, filled squares, open circles and open squares correspond to the original binning, the binning slid in R.A. direction , the binning slid in Dec. direction and the binning slid in both direction by a half bin from the original one.

Future Prospect

We are planning to construct a ∼10,000 m^2 water Cherenkov muon detector array 2.5 m underground around the slightly expanded version of the Tibet air shower array (∼50,000 m^2). We will have ∼200 concrete pools where each pool is ∼50 m^2 in area and is filled with underground water, 1.5 m in depth. Two 20 inch-in-diameter PMTs are mounted on its upper part facing downward.

According to a full Monte Carlo simulation, flux sensitivity of this new project, as shown in Fig. 3, will be an order or more better than the present one in the 100 TeV region (Details are discussed in [14]).

Then, we expect to observe gamma rays in the 100 TeV region from approximately 10 known sources and from rougly 10 new sources. As we will be able to observe gamma-ray acceleration limits on the sources in the 100 TeV region we expect to contribute to identification of origin of galactic cosmic rays. In addition, our wide field of view and high S/N ratio will enable us to search for spacially diffuse gamma rays from the galactic plane or of extragalactic origin in the 100 TeV region at the world-best sensitivity, complementary to IACTs with narrow field of view.

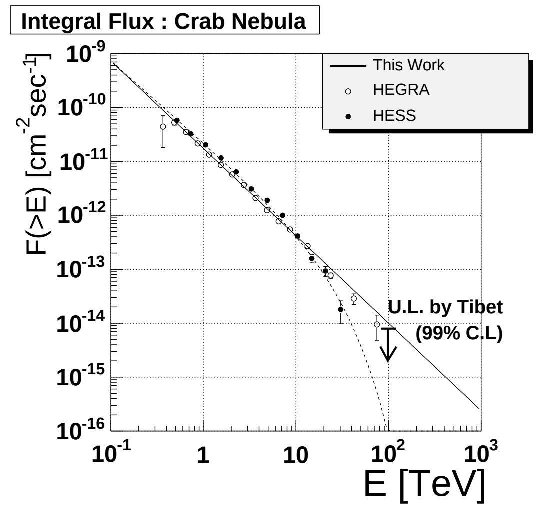

Figure 2: (a)Flux upper limit at 99 % C.L. above 100 TeV(arrows) on Crab nebula with lower energy observations by HESS [12] and HEGRA [11].

Acknowledgements

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 Area (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.

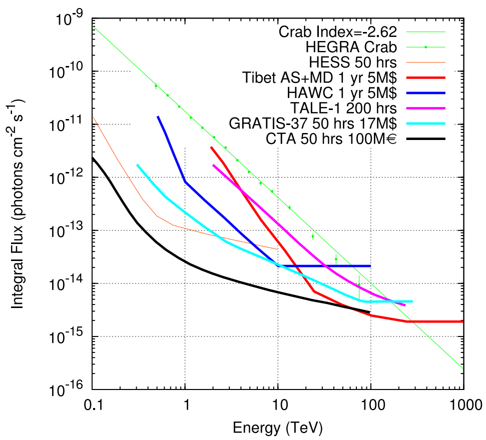

Figure 3: Tibet AS+MD (red curve) integral flux sensitivity (10 events or 5σ) for a point source in comparison with other experiments and proposals

References

[1] F. Aharonian et al., ApJ 636 (2006) 777.
[2] M. Amenomori et al., Physical Review Letters 69 (1992) 2468.
[3] M. Amenomori et al., Science 314 (2006) 439.
[4] M. Amenomori et al., ApJ 525 (1999) L93.
[5] M. Amenomori et al., ApJ 532 (2000) 302.
[6] M. Amenomori et al., ApJ 598 (2003) 242.
[7] M. Amenomori et al., ApJ 633 (2005) 1005.
[8] M. Amenomori et al., ApJ 580 (2002) 887.
[9] M. Amenomori et al., ApJ 635 (2005) L53.
[10] T. P. Li, Y. Q. Ma, ApJ 272 (1983) 317.
[11] F. Aharonian et al., ApJ 614 (2004) 897.
[12] F. Aharonian et al., A & A 457 (2006) 899.
[13] M. Amenomori et al., in: Proc. of "to appear in the proceedings of ISVHECRI2006, Weihai, China, 2005, p. in print.
[14] M. Amenomori et al., in: Proc. of "The Multi-Messenger Approach to High Energy Gamma Ray Sources", Barcelona,, 2006, pp. in print in Astrophyisics and Space Science (astro–ph/0611030).