Search for Supra-TeV Gamma-Ray Emission from Nearby AGNs with the Tibet Air Shower Array

The Tibet ASγ Collaboration

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Abstract

The Tibet high density air shower array, located at Yangbajing (4300 m above sea level) in Tibet, has been successfully operating from 1996. The mode energy of detected events with this array is estimated to be about 3 TeV. Using the data set obtained during the period since February 1997 through August 1997, we searched for 3 TeV and 7 TeV γ-ray emissions from 14 nearby active galactic nuclei (AGNs) with red-shifts of $z < 0.06$. No excess for continuous emission was detected from any AGNs except Mrk 501 which was in a remarkably flaring state of activity in 1997. Upper limits of the flux at the 90% confidence level were obtained for each object.

1. Introduction

Observations by EGRET on board Compton GRO revealed that blazar type active galactic nuclei (AGNs) are powerful gamma-ray emitters in the universe [1]. Out of about 50 blazers identified by EGRET, three nearby blazes, Mrk 421 (z=0.031), Mrk 501 (z=0.034) and 1ES2344+514 (z=0.044) were also identified as TeV gamma-ray emitters [2]. The absence of TeV gamma-ray emission from other AGNs suggests a strong reduction of TeV γ-rays through photon-photon interactions with the intergalactic infrared photon field before reaching Earth.

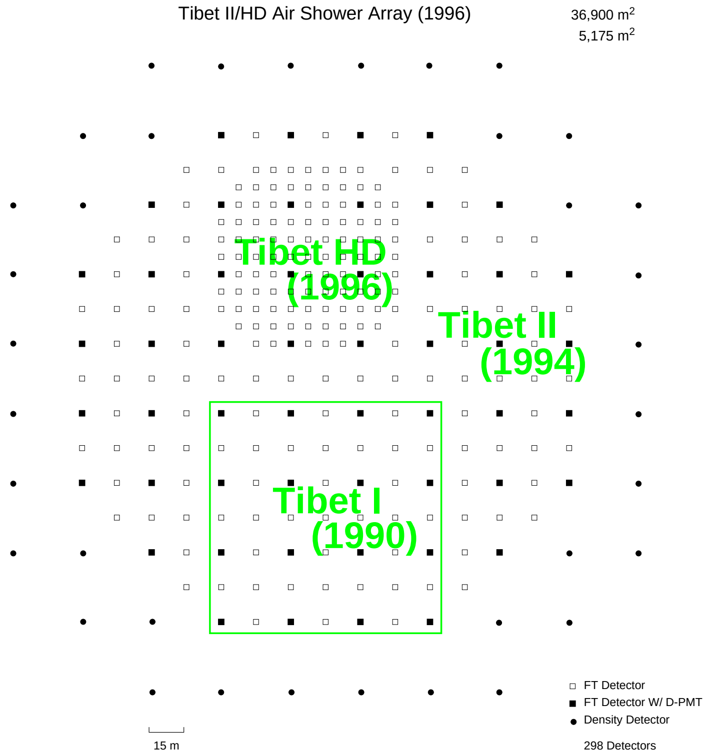

Fig. 1. Schematic view of the Tibet air shower array (Tibet I, II and HD array). Open and Closed squares are equipped with fast response phototubes (FT-detectors, HPK H1161). Closed squares and circles are equipped with wide range phototubes (HPK H3178).

In other words, combined GeV and TeV observations of a set of AGNs can provide an estimate of the intergalactic infrared photon density which is much better than those obtained by direct measurements, as suggested by Stecker From this point of view, it is of great significance to search for TeV γ-rays from nearby AGNs even if results are null. Stringent upper bounds on the flux give constrains on the extra-galactic infrared background in the universe.

The Tibet air shower array can detect air showers in excess of about 3 TeV with a good accuracy [4]. In this paper, we present the results given by this array on the search for 3 TeV and 7 TeV gamma-ray emission from 14 relatively nearby AGNs with red-shifts of $z < 0.06$.

2. Experiment

The Tibet air shower array is located at Yangbajing (4300 m a.s.l., 606 g/cm^2, 90.52°E, 30.11°N) in Tibet, China. The array consists of two overlapping arrays (Tibet-II and HD) as shown in Fig. 1. The Tibet II array consists of 185 scintillation counters (FT-detector) of 0.5 m^2 each, which are placed on a 15 m square grid with a covering area of 36,900 m^2. These FT-detectors inside are surrounded by 36 density detectors of 0.5 m^2 each. In this array, 109 FT-detectors of the HD array are placed on a 7.5 m square grid, while 32 detectors are commonly used for both arrays. This HD array covers an area of 5,175 m^2 and can detect cosmic ray events in excess of about 3 TeV with a good accuracy. Observation of the Moon's shadow with both arrays gives a direct estimate for the angular resolution of the array. Using the data set of the events coming from the direction of the Moon, the angular resolution was estimated to be better than 1.0° for the Tibet-II and HD arrays.

Air shower data are taken at a triggering rate of about 250Hz summing up the events from

Table 1.

Source	Energy > 3 TeV			Energy > 7 TeV		
	N_b	σ	Flux*	N_b	σ	Flux*
0316+413 (NGC 1275)	86173	−1.06	< 3.96	142061	1.55	< 1.93
0402+379 (4C +37.11)	89954	1.01	< 8.16	146547	0.58	< 1.54
0430+052 (3C 120)	46784	−1.01	< 6.89	77124	0.67	< 2.77
0802+243 (3C 192)	75584	1.37	< 9.29	122609	0.08	< 1.37
1101+384 (Mrk 421)	91013	0.26	< 6.37	149466	−2.39	< 0.61
1514+004 (PKS 1514+00)	34031	0.13	< 14.26	55663	0.63	< 3.43
1652+398 (Mrk 501)	91561	3.05	*****	148964	0.58	< 1.57
1727+502 (1Zw 187)	74002	0.32	< 8.21	121843	−1.51	< 1.00
2201+044 (PKS 2201+04)	45463	−1.26	< 6.63	75204	−0.73	< 1.72
2321+419	86529	−0.23	< 5.38	143254	1.31	< 1.89
2344+514	69083	−0.58	< 6.21	114749	0.00	< 1.77
4C 42.22	86170	0.14	< 6.19	141089	0.25	< 1.47
TEX 0554+534	65190	−1.04	< 5.74	106596	−1.26	< 1.21
Zw 331	86444	−1.18	< 3.80	141730	−1.59	< 0.77

*Flux limits at the 90% confidence level in the unit of 10^{-12} cm^{-2} s^{-1}.

both arrays The dead time of the system is estimated to be about 10% of the total running time.

3. Analysis

We used the data set taken during the period from February 15, 1997 through August 26, 1997. The effective running time was 155.3 days. We first selected the data from the original data set by imposing the following conditions: 1) Each of any 4 detectors out of every FT-detectors should detect signal more than 1.25 particles. 2) At least 2 detectors of highest 3 and 4 signals should be in the inside of the border FT-detectors in the Tibet II and the Tibet HD, respectively. 3) The zenith angle θ of incident direction should be less than 40°. The number of shower events selected is about 9.3×10^8 and 5.0×10^8 for the Tibet II and the HD array, respectively.

The performance of the array was examined by a Monte Carlo simulation using a GENAS code [5], taking into account the observation conditions and the selection criteria mentioned above. The mode values of the energy are estimated to be about 3 TeV and 7 TeV for the shower events observed with the HD and the Tibet II, respectively.

4. Results and Summary

As well known, cosmic ray fluxes observed at ground level depend strongly on the zenith angle. When we estimate the background from regions of the sky that have had the same exposure as the source bin, we must take into account this strong zenith angle dependence. In order to minimize this effect, we adopted an equi-zenithal scan method for searching for a gamma-ray emission from each object as shown in Fig. 2. That is, we counted the number of showers contained in a circle of apparent radius of 1° from the source direction. The background number of events was evaluated from events coming from the 6 windows adjacent to the source window at the same zenith angle.

The target AGNs and the results on the search for continuous emission are listed in Table 1. The results for energy range above 3 TeV and 7 TeV are obtained from the HD and Tibet-II arrays, respectively. No excess was found for steady emission above 3 TeV and 7 TeV γ-rays

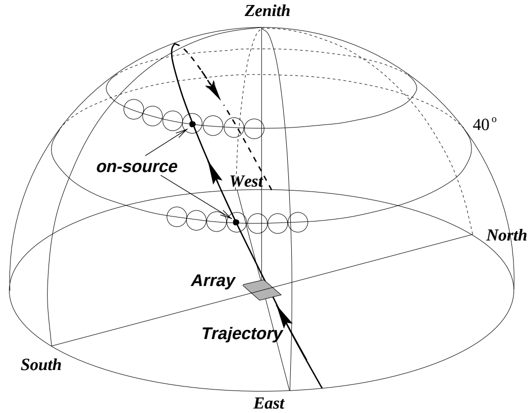

Fig. 2. Schematic view of the equi-zenithal scan method.

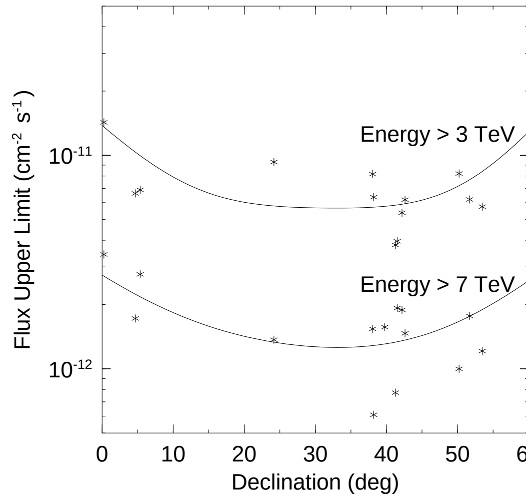

Fig. 3. Flux upper limits above 3 TeV and 7 TeV at the 90% confidence level for each AGN. The solid curves show the cases of no excess events from the source directions.

from any objects except for Mrk 501 at 3 TeV. Flux upper limits at the 90% confidence level were calculated by a Monte Carlo simulation. γ-rays from a source were generated assuming a differential power-law spectrum of the form of $E^{-\beta}$ with $E_{\min} = 0.2$ TeV. The power index β was assumed to be 2.5 for all AGNs. The results are summarized in Table 1 and Fig. 3.

At the Durban conference, very hot discussions were made on the detection of strong TeV γ-ray flares from Mrk 501 [6]. We searched for multi-TeV γ-rays from this source with the HD array, and detected a signal at the 3.7 σ level. Details are presented in the paper of this conference [7].

The number of detectors will be increased by a factor of about three within three years to enlarge the covering area of the present HD array up to the whole Tibet-II array. Then, the statistics will be much improved in the very near future, and steady emission of γ-rays from Mrk 501 and Mrk 421 may be detected with a sufficient significance. The result to be obtained will go far towards probing the extragalactic background photon field as well as determining the model parameters of TeV γ-ray production from AGNs.

Acknowledgments

This work is supported in part by Grants–in–Aid for Scientific Research and also for International Scientific Research from the Ministry of Education, Science and Culture, in Japan and the Committee of National Nature Science Foundation in China.

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