Recent status of the Tibet ASγ experiment

(The Tibet ASγ Collaboration)

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Abstract

A high-sensitivity air shower array has been operating successfully at Yangbajing (4300 a.s.l.) in Tibet since 1990. Using this air shower array, we have already detected multi-TeV γ-rays from the Crab Nebula (unpulsed) and also from BL Lac objects such as Mrk501(1997) and Mrk421(2001) in flaring states. The high-density detector part of the Tibet-III array will be further enlarged in this fall and its effective area becomes about 37000 m^2 in which 733 plastic scintillation detectors are deployed on a 7.5 m square grid. We summarize the recent results obtained with the Tibet air shower array and discuss the performance of new array.

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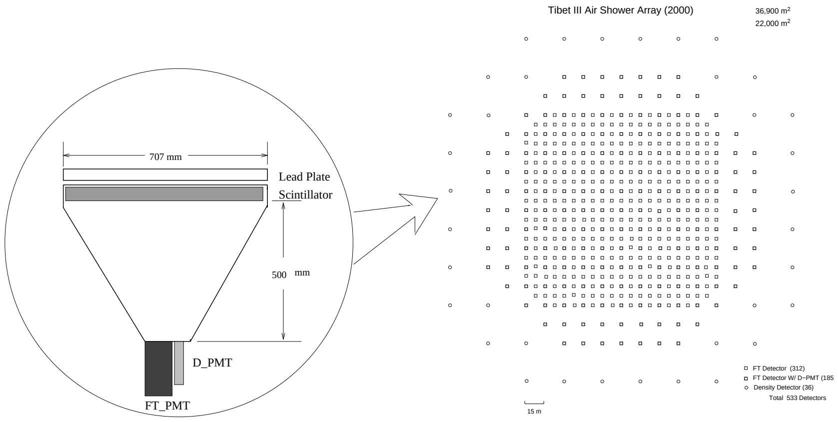

Fig. 1. Schematic views of the Tibet-III array (before Nov. 2002) and the scintillation detector used in Tibet ASγ experiment. A lead plate of 5mm thickness is placed on the top of each detector to improve the fast timing and density data.

1. Introduction

The Tibet ASγ experiment started in 1990 as a collaboration experiment between China and Japan to study the origin of primary cosmic rays (Amenomori M. et al. 1992). The air shower experiment has three main objectives, that is, 1) to search for high-energy γ-ray sources, 2) to observe the energy spectra and chemical composition of primary cosmic rays around the knee energy region, and 3) to study a global structure of the solar and interplanetary magnetic fields by observing the shadowing of cosmic rays by the Sun. In this paper, however, our discussions are focused on the search for high-energy γ-ray point sources. It is worthwhile to note that the air shower array has a wide field of view and can search for the sky continuously for 24 hours every day. This is very effective for searching for gamma-ray bursts and transient objects such as BL Lac objects.

2. Experiment

The Tibet air-shower array has been successively operated at Yangbajing (4300m a.s.l., 30°N, 90°E) in Tibet. Figure 1 shows a schematic view of the Tibet-III array constructed in the late fall of 1999. The inner part of the array has an area of about 22000 m^2 and the plastic scintillation detectors of 0.5 m^2 each are placed on a 7.5m square grid, while the outskirts are covered by the detectors placed on a 15 m square grid. The total number of detectors used in this array is 533. A lead plate of 5mm thickness is placed on the top of each detector to improve the fast timing data by converting gamma-rays in the air showers into electron pairs. The lead converters can increase the size of each air shower by a factor of about 2 and also improve the angular resolution by about 30%. Also,

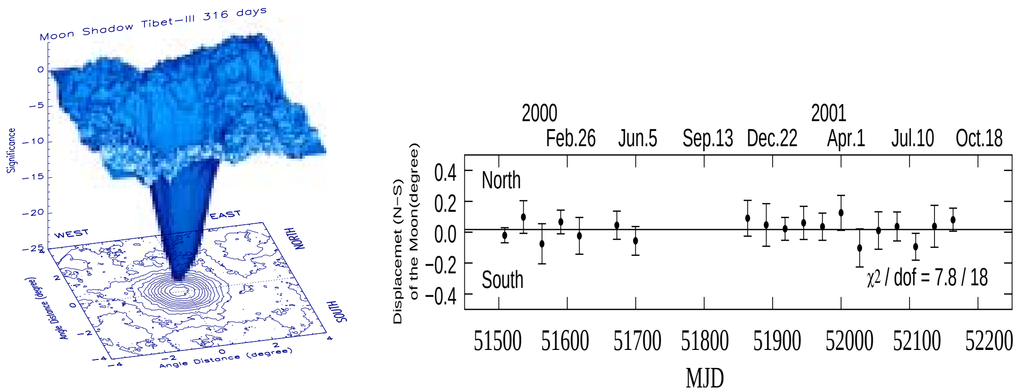

Fig. 2. Left : counter map of the weights of deficit event density of cosmic rays around the Moon (observation of 316 days with the Tibet-III array). Right : time variation of north-south displacement of the center of the Moon shadow. It gives the pointing accuracy of the Tibet array.

this somewhat flattens the conical shape of the shower front (Amenomori M. et al. 1990). The array is recording the events at a rate of about 680Hz with any fourfold coincidence appearing in the fast-timing (FT) detectors, and the dead time is estimated to be 7.0%.

3. Array Performance

The threshold energy of air showers observed by the array is estimated to be about 3 TeV and the arrival direction of each shower can be estimated with an angular resolution of about 0.9° in this energy region (Amenomori M. et al. 2001a).

As well known, primary cosmic rays fall isotropically on the top of the atmosphere, while γ-rays coming from a source are apparently centered on its source direction. Hence, a reduction of hadronic showers must be attained by the best possible angular resolution of the array. The angular resolution of the array becomes better as air shower size becomes large. For example, it is estimated to become about 0.2° at energies around 100 TeV.

The performance of the Tibet array can be calibrated by observing the Moon shadow in the Galactic cosmic rays (Amenomori M. et al. 1993). In Fig.2, we show the three-dimensional counter map of the weights of deficit event density around the Moon in the area of 8° times 8° centered at the direction of the Moon. Shadowing of cosmic rays by the Moon is clearly seen with a significance of 21σ at the center.

The displacement of the Moon shadow in the north-south direction is almost free from the effect of geomagnetic field. Therefore, it can give the estimate of the systematic pointing error of the array. Figure 2 shows the time variation of

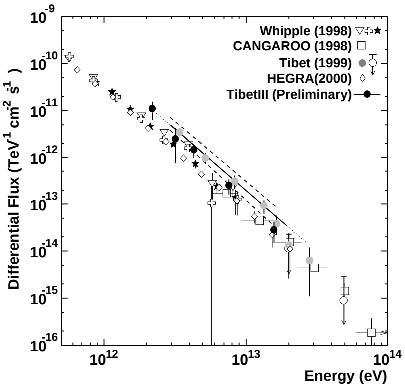

Fig. 3. Energy spectrum of γ-rays from the Carb Nebula(unpulsed).

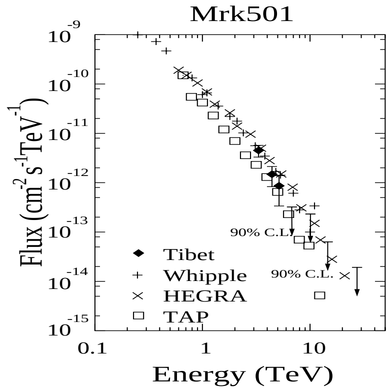

Fig. 4. Energy spectrum of γ-rays from Mrk501(flaring state in 1997).

north-south displacement of the center of the Moon shadow. The data of 30 days moving average are plotted in this figure. It is seen that the systematic pointing error of the Tibet array is smaller than $0.1°$ for a long period of time. Also, a sharpness or width of the Moon shadow gives us an estimate of the angular resolution of the array and a value of about $0.9°$ is obtained from the Moon shadow shown in Fig. 2.

The energy calibration of air showers observed at multi-TeV region can also be done by observing the east-west displacement of the center of the Moon shadow due to the geomagnetic effect. The deflection angle of a proton of energy E (in units of TeV) by the geomagnetic field is easily calculated as $\Delta\theta_{EW}$=$1.6°/E$ (Amenomori M. et al. 1999). The observed displacement of the Moon shadow is almost consistent with that expected from the effect of the geomagnetic field. A detailed Monte Carlo simulation would give us a direct estimate of the primary energy of observed showers in the energy region around 10 TeV.

4. Results and Discussions

We have succeeded to detect a steady emission of multi-TeV γ-rays from the Crab Nebula and obtained the energy spectrum of γ-rays in the energy region above 3 TeV as shown in Fig.3 (Amenomori M. et al. 1999, 2001b). The absolute fluxes observed at a few TeV energies with IACTs (Imaging Air Cerenkov Telescope) seems to be somewhat lower than that of our data. This may be mainly due to a difference of the energy estimation of observed showers, but probably the further consideration will be required. Our data seem to suggest that there is no bend of the spectrum at least up to about 50 TeV, while statistics is still not sufficient. This energy region will be further studied with a new Tibet-III air shower array being under construction.

Shown in Figs. 4 and 5 are the energy spectra of γ-rays from Mrk501

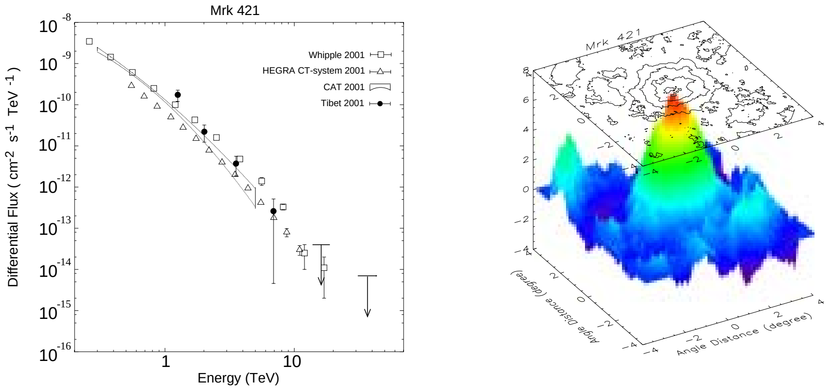

Fig. 5. Left : energy spectrum of γ-rays from Mrk421 (flaring state in 2001). Right : counter map of the weights of excess event density around Mrk421.

(Amenomori M. et al. 2000) and Mrk421 (Amenomori M. et al. 2001c) during their flaring states, respectively. At present, unfortunately, as the observed data are limited in the energy region lower than 10 TeV because of low statistics, it is difficult to examine whether there exists a cut-off of the spectrum due to the intergalactic infrared photon field or not.

Figure 6 shows a time variation of X-ray and γ-ray fluxes from Mrk421. In this figure, the moving averages of 31 days data are plotted. Upper one in the figure shows the data from RXTE/ASM and middle two figures show our data at energies around 2.6 TeV and 4.9 TeV. There is a good correlation between X-rays and TeV γ-rays. Since the Tibet array was continuously operated during this flaring period, this long term correlation of both data may give us a new information about the generation of γ-rays at the source, which may be different with those obtained from a short term correlation by IACTs.

In the poster session of this workshop, we also presented the following results obtained with the Tibet air shower array. These papers are printed in this proceeding.

- A wide sky survey to search for flare type TeV γ-ray sources (Sakata M. S30 in this conference),
- Observation of diffuse γ-rays from the Galactic plane at 10 TeV (Yamamoto Y. S33 in this conference and Amenomori M. et al. 2002),

∗ Search for multi-TeV γ-rays from nearby SNRs (Amenomori M. et al. 2001d),

∗ Search for TeV burst-like events coincident with the BATSE bursts (Amenomori M. et al. 1996 and 2001e).

5. Summary

In this fall, the high-density part of the Tibet-III array will be further enlarged by adding 200 detectors, and its effective area becomes about 37000

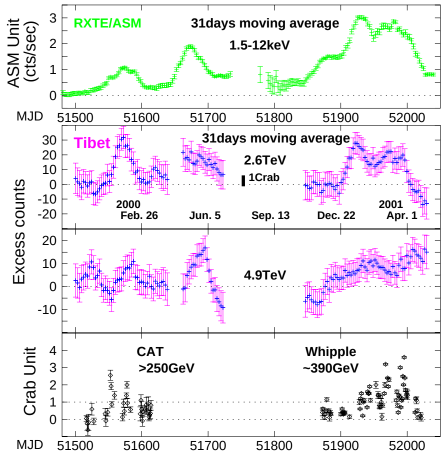

Fig. 6. A time variation of X-ray and γ-ray fluxes from Mrk421.

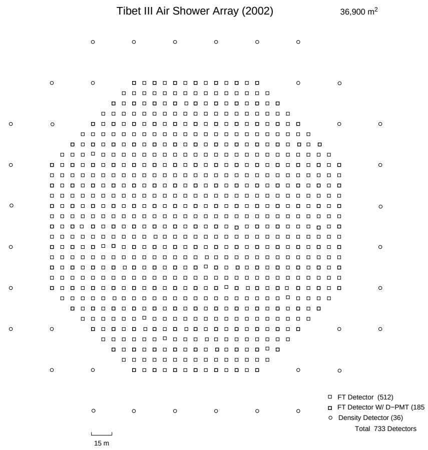

Fig. 7. Tibet-III array which will start to operate from the end of November in 2002.

m^2 as shown in Fig.7. Then, the sensitivity of the array will be increased by about 30% compared with the present one, while the threshold energy of detected showers and angular resolution of the array are the same as those in Fig.1.

The new air shower array will trigger the events at a rate of about 1.5 kHz with a dead time of about 12%, and the total amount of the data per day will be about 30GB.

The sensitivity of the array may be further increased at high energies by using a neural network technique to separate γ-rays from a large number of hadronic showers.

In the near future, the results discussed above will become what have still higher credibility using this new array.

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