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Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
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Future plan for observation of cosmic gamma rays in the 100 TeV energy region with the Tibet air shower array : physics goal and overview

THE TIBET ASγ COLLABORATION

tsako@icrr.u-tokyo.ac.jp

Abstract: The Tibet air shower array, which has an effective area of 37,000 square meters and is located at 4300 m in altitude, has been observing air showers induced by cosmic rays with energies above a few TeV. We are planning to add a large muon detector array to it for the purpose of increasing its sensitivity to cosmic gamma rays in the 100 TeV (10 - 1000 TeV) energy region by discriminating them from cosmic-ray hadrons. We report on the possibility of detection of gamma rays in the 100 TeV energy region in our field of view, based on the improved sensitivity of our air shower array deduced from the full Monte Carlo simulation.

Introduction

Although SNRs are theoretically considered to be the most plausible candidates for acceleration of cosmic-ray hadrons up to PeV energies, no observations have succeeded in identifying them so far. Since accelerated electrons have difficulty producing very high-energy gamma rays with energies above 100 TeV via bremsstrahlung or inverse Compton scattering, it can be an effective way of obtaining clear evidence for hadronic acceleration to detect high-energy gamma rays above 100 TeV generating via the decay of neutral pions produced in interactions of accelerated hadrons with ambient material, e.g. molecular clouds. In other words, study of the energy-dependent morphology of the sources in the 100 TeV region (10 - 1000 TeV) is a clue to disentangle their acceleration mechanism.

The HESS group reported in 2005 on the discovery of 14 new TeV gamma-ray sources in the southern hemisphere and many of them have a harder energy spectrum (indices: -1.8 to -2.8) [1], which implies that hadrons should be accelerated there. No definite claims have been made yet, however, because it is difficult for HESS to measure the sources above $\sim$10 TeV. Also, many of the 14 sources are faint in other wavelengths. This strongly suggests that an unbiased survey irrelevant to observations in other wavelengths using a wide field-of-view apparatus, e.g. an air shower array, is needed.

The Tibet Air Shower Experiment

The Tibet air shower experiment has been successfully operating at Yangbajing (90°31' E, 30°06' N; 4,300 m a.s.l.) in Tibet, China since 1990. Being expanded several times, the Tibet air shower (AS) array now consists of 789 plastic scintillation counters placed on a 7.5 m square grid with an effective area of 37,000 m^2, and is detecting high-energy ($>$ a few TeV) cosmic gamma rays and hadrons.

Using the Tibet AS array, we so far have observed a new cosmic-ray anisotropy in the Cygnus region at multi-TeV energies [2] as well as TeV gamma rays from the Crab [3], Mrk501 [4] and Mrk421 [5]. Because the anisotropy that we observed in the Cygnus region is relatively narrow, it may favor the existence of a gamma-ray component as claimed by the Milagro group [6]. We can not draw any clear conclusion on the region, however, because the AS array at present is unable to discriminate gamma rays from hadrons in the multi-TeV energy region.

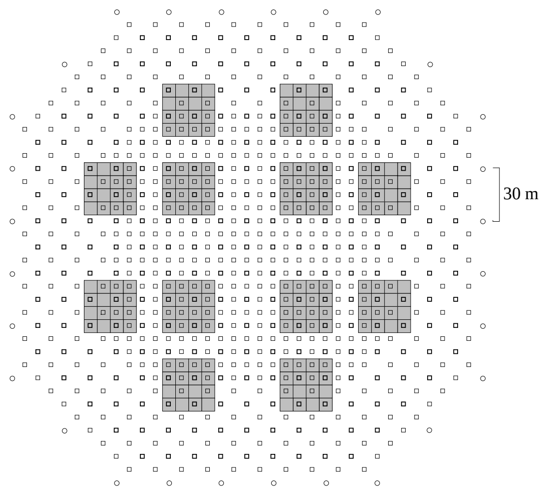

Figure 1: Schematic view of the Tibet AS+MD array. Open squares and open circles represent the surface scintillation detectors that compose the Tibet AS array. Note that the AS array drawn here is upgraded from the current version so that its effective area becomes 50,000 m^2 by modifying the configuration of the scintillation detectors. Filled squares show the proposed Tibet MD array 2.5 m underground.

The Tibet Muon Detector Array

The currently proposed configuration of the Tibet MD array is shown in Figure 1. It is composed of 12 pools, each of which consists of 16 cells. Each cell is a waterproof concrete tank which is 7.2 m wide $\times$ 7.2 m long $\times$ 1.5 m deep in size. Two 20 inch-in-diameter photomultiplier tubes (PMTs, Hamamatsu R3600) are put on its ceiling, facing downwards. Its inside is painted with white epoxy resin to waterproof and to efficiently reflect water Cherenkov light, which is then collected with the PMTs. The MD array is set up 2.5 m underground ($\sim$19 radiation lengths) in order to detect the penetrating muon component of air showers, suppressing the electromagnetic one. Its total effective area amounts to 9,950 m^2 for muon detection with the energy threshold of approximately 1 GeV.

Results and Discussions

We performed detailed Monte Carlo simulations regarding air showers and the responses of soil, the AS and MD array, which are described in [7]. Based on the number of collected photoelectrons by the PMTs of the MD array, background hadrons can be rejected by selecting muon poor events. Around 100 TeV, the number of hadron-induced events are suppressed down to 0.01% or less, while gamma-induced events are retained by more than 83%.

Table 1 summarizes the comparison of performance between HESS and the Tibet AS+MD array. One can see the advantages of an air shower array, i.e. a wide field-of-view ($\sim$1.5 sr) and high duty cycle ($\sim$90%). Although the angular and energy resolution of the AS+MD array around 100 TeV are two times worse than that of HESS, the difference is not so critical. Taking RX J1713 as an example, a famous source in the southern sky with radius of 0.6° and spectral index of ~ -3, the AS+MD array could extract meaningful physical quantities.

The sensitivity of the Tibet AS+MD array to a gamma-ray point source deduced from the simulation is shown in Figure 2. Its 5σ sensitivity in one calendar year will reach 7% and $\sim$20% Crab above 20 and 100 TeV respectively, and surpass the existing IACTs above 20 TeV. Furthermore, it may surpass the sensitivity of the next generation IACTs above 40 TeV. Since no extensive search has been conducted with an apparatus with sensitivity comparable to HESS in the northern sky, the AS+MD array could discover as many ($\sim$10) unknown TeV gamma-ray sources as HESS did in [1].

As shown in Figure 3, the Tibet AS+MD array will have more advantage in observing spatially diffuse gamma-ray sources, e.g. MGRO J2019+37, discovered by the Milagro experiment [8].

In brief summary, among the known sources in our field-of-view, Crab, TeV J2032+4130, HESS J1837-069, Mrk 501, Mrk 421, MGRO J2019+37, MGRO J2031+41 and MGRO J1908+06 [6] are sufficiently detectable. HESS J1834-087, LS I+61 303, Cas A, and M87 are marginal.

Table 1: Comparison of performance between HESS and the Tibet AS+MD array

	Tibet AS+MD $>\sim$100 TeV	HESS $\sim$TeV
Location	30N - 90E	23S - 16E
FOV	$\sim$1.5 sr	$\sim$0.02 sr
Duty cycle	$\sim$90%	$\sim$10%
Angular res.	$\sim 0.2^\circ$	$\sim 0.1^\circ$
Energy res.	$\sim$40%	$\sim$20%
BG rejection	$\sim 10^{-4}$	$\sim 10^{-2}$
S/N (RX J1713, in	50/0.3 ev. >100 TeV	2500/2000 ev. >1 TeV
0.6° radius, 1yr or 50hrs)	120/3 >40 TeV	20/20 >40 TeV

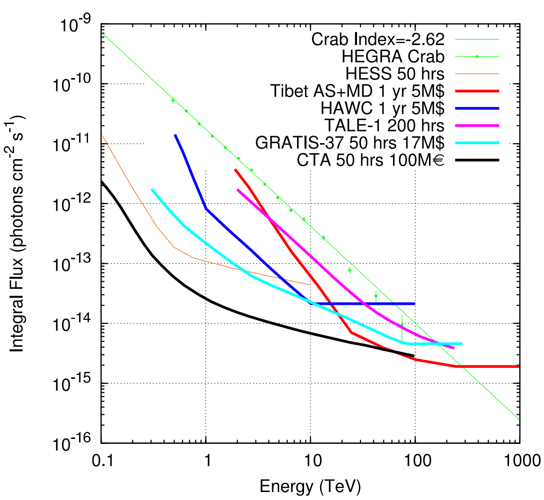

Figure 2: The attainable integral flux sensitivity (5σ in one calendar year) of the Tibet AS+MD array to a point-like gamma-ray source, together with the sensitivity of HESS and some other future experimental plans.

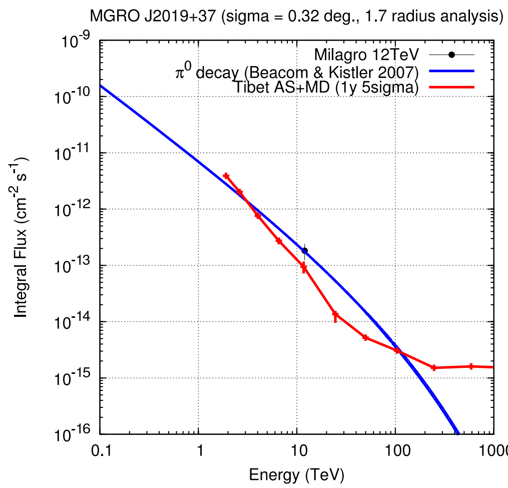

Figure 3: 5σ sensitivity of the Tibet AS+MD array in one calendar year (red) to a diffuse gamma-ray source [8]. The blue line is expected from the Cygnus region in the galactic plane.

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