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The Telescope Array Project

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Abstract. The Telescope Array project aims at understanding the origin of super-GZK cosmic rays, which is the most intriguing and urgent problem of the cosmic ray physics today. Addressing the problem may entail to understand the high energy astrophysical objects and the violent transient phenomena of the present universe, or the elementary particle reactions in the very early universe. The identification of the primary particle species, the search for the point source and the global anisotropy are important experimental features charged to the new generation cosmic ray detectors. The Telescope Array plans to deploy 10 large air fluorescence stations in the West desert of Utah covering the acceptance of 65,000 km^{2}sr with 10 % duty factor. It will be co-sited with the northern hemisphere Pierre Auger ground arrays of the similar exposure. The gamma ray primary will be identified with the modulation of the shower maximum; an elongation of the shower by the LPM effect and the north–south asymmetry by the geomagnetic cascade. A uniform detection of the air showers in the entire atmosphere will be most suited for the identification of the horizontal showers produced by the neutrinos. With a stereo reconstruction, an angular resolution of 0.6° is expected for the 10^{20}eV shower.

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1 Introduction

The Telescope Array(TA) detector(Sasaki et al., 1997; Design Report, 2000) has been planned in order to draw a decisive conclusion on the mysterious origin of extremely high energy cosmic rays. For this purpose, the detector is required to have much larger aperture for super-GZK events than the present detectors. Also it should provide a particle identification as well as an accurate determination of energy and arrival direction for primary cosmic rays. This paper describes an overall introduction to the TA and its expected performance.

2 TA Detector

2.1 Site, Stations and Telescopes

The Telescope Array consists of 10 measurement stations, each separated by 30–40km, installed in the West Desert of USA, near Salt Lake City, Utah. A plan of TA station deployment is shown in Fig.1. At each station, 40 fixed telescopes covering a certain region of the sky are arranged in two concentric rings with a diameter of $\sim 30\mathrm{m}$ looking outward from the telescope housing as shown in Fig.2.

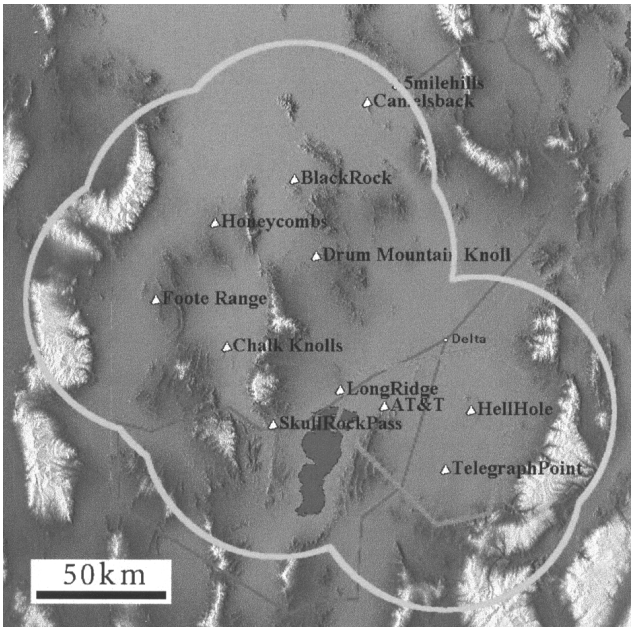

Fig. 1. Station deployment of Telescope Array.

The field of view of the telescope unit is $18.0°$ in azimuth and $15.5°$ in elevation. The upper ring composed 20 telescope units covers the entire azimuthal angle and the elevation angle of $3° - 18.5°$. The lower ring covers $18.5° - 34°$.

The telescope has a main dish with a diameter of 3.3m which is composed of 18 hexagonal shape segment mirrors (see Fig. 3). The total mirror area is $6.8\mathrm{m}^2$ and the focal length is $2960\mathrm{mm}$ with spherical mirror optics. The spot size on the focal plane for parallel light beam is better than 30mm in FWHM according to a ray tracing calculation. This spot size is sufficiently small compared with one readout pixel and does not affect much for the determination of the resolutions of the telescope.

2.2 Cameras, Electronics and Atmospheric monitoring systems

A set of 256 hexagonal PMTs (60mm diagonal) is arranged in 16×16 array and placed on the focal plane of the telescope. A single PMT accepts the fluorescence light from the $1.1° \times 1.0°$. region of the sky

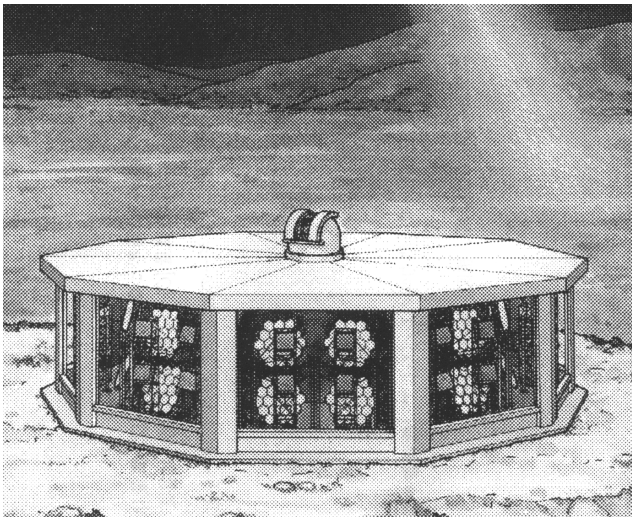

Fig. 2. Telescope Array station.

We developed a new PMT bleeder circuit with Zener diodes to guarantee a good linearity (within 5%) and stability (better than 2%) up to 64,000 photoelectrons in 200 ns time duration under the expected night sky backgrounds. This dynamic range is sufficient for 99% of proton induced air showers with energy 10^{21}eV.

A block diagram of the TA online system(Sasaki et al., 1999; Arai et al., 1999) is shown in Fig. 5. A preamplified signal from the PMT is sent to a Charge Successive Integrators (CSI). The CSI has a rotating set of capacitances to integrate and AD convert a PMT signal continuously for every 200 ns. The digitization is done with a pipelined ADC and the digitized data are stored into the memory of a DSP dedicated for each readout channel. The DSP searches a signal which maximizes the S/N ratio within 25.6μs search window. With the information of recognized signals, a trigger is generated by the track finder module, which searches an event track in a 3-dimensional space; X-Y coordinates on a focal plane and the time coordinate. The information of a trigger is distributed to other stations via an inter–site triggering system.

The atmospheric monitoring system for the TA may consist of a Nd:YAG laser, a light receiver and an infra–red camera for monitoring clouds all mounted on a steerable base. We can shoot laser light at any direction from a station and receive back-scattered light by the same station (a lidar system), or receive the side scattered light by the neighboring stations to estimate the atmospheric transmission in the sensitive air volume.

3 Aperture, Resolutions and Expected Results

In order to estimate the aperture and other performances of TA, we performed a Monte Carlo simulation. We select well reconstructed stereo events with following conditions: (1) at least 6 PMTs of one or two neighboring telescopes are fired

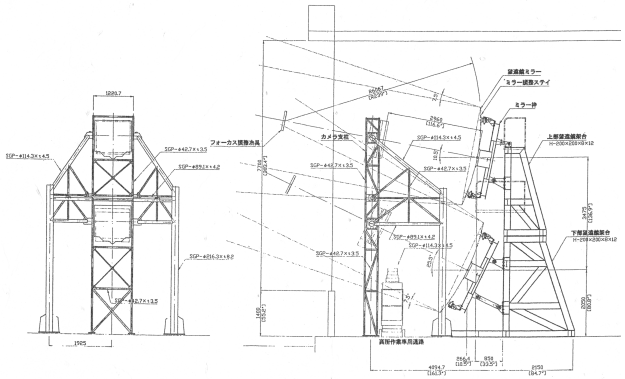

Fig. 3. The design of the telescope.

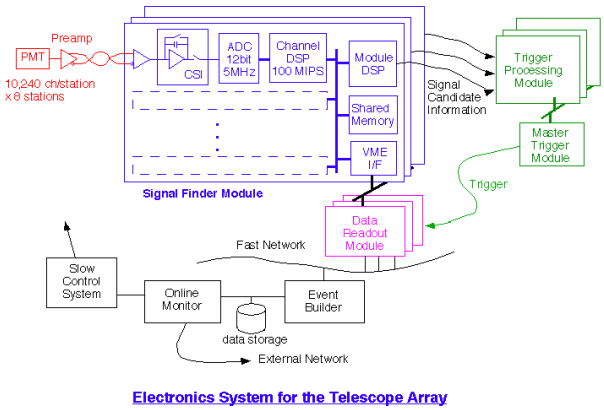

Fig. 4. Block diagram of the TA online system.

4σ above the night sky background, (2) at least two stations detect a well reconstructed track extended more than 5° in the field of view(FOV), (3) a maximum development point of a shower (X_{max}) should be observed by at least one telescope. As a result of the detailed simulations with these selection conditions, the threshold energy for stereo observations is estimated 3×10^{18}eV and the stereo aperture is calculated $\sim 65000\mathrm{km}^2\mathrm{sr}$ for 10^{20}eV protons. Furthermore, the resolutions of the energies, the arrival directions and the X_{max} are estimated 5%, 0.6° and $20\mathrm{g/cm}^2$, respectively. Consequently, the expected event rate with energies above 10^{20}eV detected by TA with these resolutions is 60 events/year assuming a 10 % duty factor and the flux of super GZK events measured by AGASA (Takeda et al., 1998).

Examples of the energy spectrum which would be obtained by 5-year operation of TA are shown in Fig.6 and 7. As shown, it is apparent that the aperture and the resolution of TA are sufficient to distinguish different models proposed for the origins of the extremely high energy cosmic rays.

Some viable models to explain the EHE cosmic rays have predicted that the major primary composition is gamma rays. Thus identification of the gamma ray population is important to resolve the origin of the EHE cosmic rays. If the highest energy cosmic ray has a new population dominating above 10^{20}eV as predicted by the Z–burst (Weiler, 1999; Fagion et al., 1999) or top down models (Bhattacharjee et al., 1992), as shown in Fig.7, we will find a dip structure at 10^{20}eV in our measured energy spectrum. Moreover, it has been suggested that the photon-induced air shower will have different longitudinal development profile than hadron induced showers. The LPM effect leads to a very slow shower development with significant fluctuations for primary energies greater than 5×10^{18}eV. On the other hand, the geomagnetic cascading high above the atmosphere also affects shower curves for energies of greater than 2×10^{19}eV. It causes a much faster development than those of LPM showers and the feature is strongly related to the arrival direction. In Fig. 8 we show the X_{max} distributions for proton and gamma ray showers taking into account TA detector resolutions. From this figure we conclude that TA has a sufficient resolution of X_{max} and capability to measure the longitudinal shower profile and the north–south asymmetry. In other words, the TA has a good sensitivity to identify primary gamma rays if they exist.

Since EHE neutrinos produce deeply penetrating showers, TA also acts as an EHE neutrino detector which has a huge target volume and the excellent angular resolution. Our detailed calculation shows that we can distinguish EHE neutrino induced showers from proton induced showers by searching deeply penetrating showers with $X_{max} \geq 1500g/cm^2$. The target volume of TA for the EHE neutrinos is $\sim 10^{11}$ ton sr and the effective neutrino aperture is $\sim 0.3\mathrm{km}^2$ sr for energies of 10^{20}eV, as shown in Fig. 9. The expected neutrino event rate is $0.4 \sim 20$ event/10yrs for top down models or Z–burst models.

4 Conclusions

An observation of the EHE neutrinos or gamma rays gives rich experimental information of the physics dominating the phase transition in the early Universe and/or the neutrino dark matter. Furthermore, if we find astronomical counterparts in the arrival direction of the EHE cosmic rays, it will be a direct evidence to identify the acceleration site of the highest energy cosmic rays, and it will certainly give abundant information how the Universe produces such energetic particles.

We have started to test a complete set of the telescope, camera, electronics and the atmospheric monitoring devices among the TA collaborators. All the R & D efforts are targeted for the start of the construction in the spring of 2002. It will take 4 years to build 10 stations.

Further details about TA project can be found at *www-ta.icrr.u–tokyo.ac.jp*.

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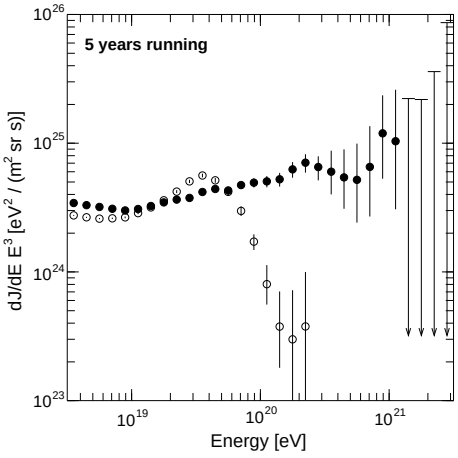

Fig. 5. 5-year observation of the energy spectrum by TA. Closed circles show the case if the spectrum simply extends beyond 10^{20}eV while open circles represent the standard model with the GZK cutoff assuming the sources are distributed homogeneously in the Universe(**?**).

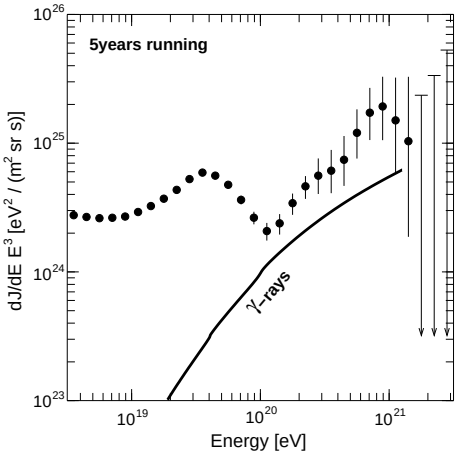

Fig. 6. 5-year observation of the energy spectrum by TA if the highest energy cosmic rays has a new population dominating above 10^{20}eV as predicted by the Z–burst or top down models. The solid curves represents the primary gamma ray component predicted by the Z–burst model(Yoshida et al., 1998).

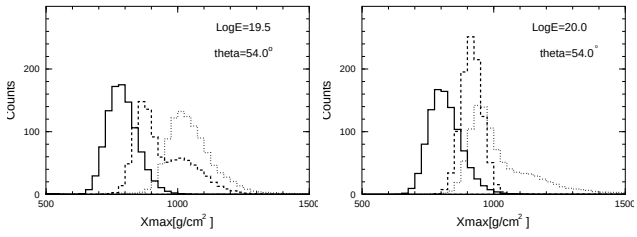

Fig. 7. X_{max} distributions for proton(*solid*) and gamma ray showers with arrival directions from north(*dashed*) and south(*dotted*). The primary energies are $10^{19.5}$eV and 10^{20}eV, and zenith angle of the arrival directions are $54.0°$.

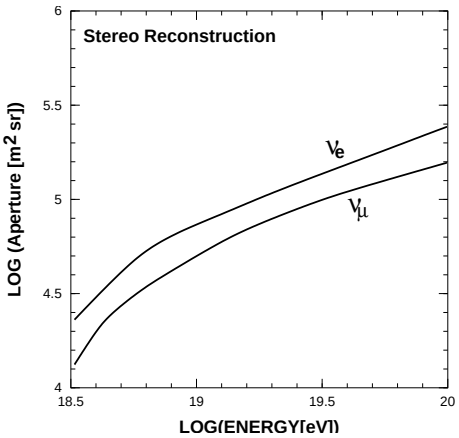

Fig. 8. The effective aperture of TA for the detection of the EHE neutrinos.

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