TELESCOPE ARRAY AS AN EXTREMELY HIGH ENERGY COSMIC RAY DETECTOR

Telescope Array Collaboration[1]

ABSTRACT

The Telescope Array (TA) Extremely High Energy (EHE) detector is designed to provide precise measurements of EHE cosmic rays (EHECRs) around 10^{20}eV with excellent acceptance using the air-fluorescence technique[2]. It consists of 8 experimental stations separated by 25-30km. Each station consists of 42 telescopes with 3m-diameter mirror systems covering a solid angle of more than π. 50 events/year at 10^{20}eV will be reconstructed well. The existence of the GZK-cutoff[3] can be concluded by 4σ with only statistics for one year observation.

INTRODUCTION

Recent results on primary cosmic rays of energies above 10^{19} eV have provided us the consequences of the existence of EHECRs with energy in excess of GZK-cutoff and some hints for the origin[4]. The scientific motivations concerned with EHECRs are discussed elsewhere[5]. The basic concept guiding the design of TA EHECR detector has been to detect air-fluorescence yielded in air-showers with accurate reconstruction of the shower development, which is important to classify the mass and measure the energy of primary cosmic rays, keeping a huge acceptance enough to explore the EHE frontier in a statistically significant way. The main features of the detector are:

- Good S/N using the large mirror system and fine PMT size.
- Good aperture for stereo events using uniformly distributed multiple stations.
- Centered telescopes into a station house to minimize construction and maintenance works.
- Active on-line monitoring to reduce measurement systematics.

DETECTOR

The TA EHECR detector consists of 8 experimental stations separated by 25-30km from each other. Each station consists of 42 telescopes with 3m-diameter mirror system.

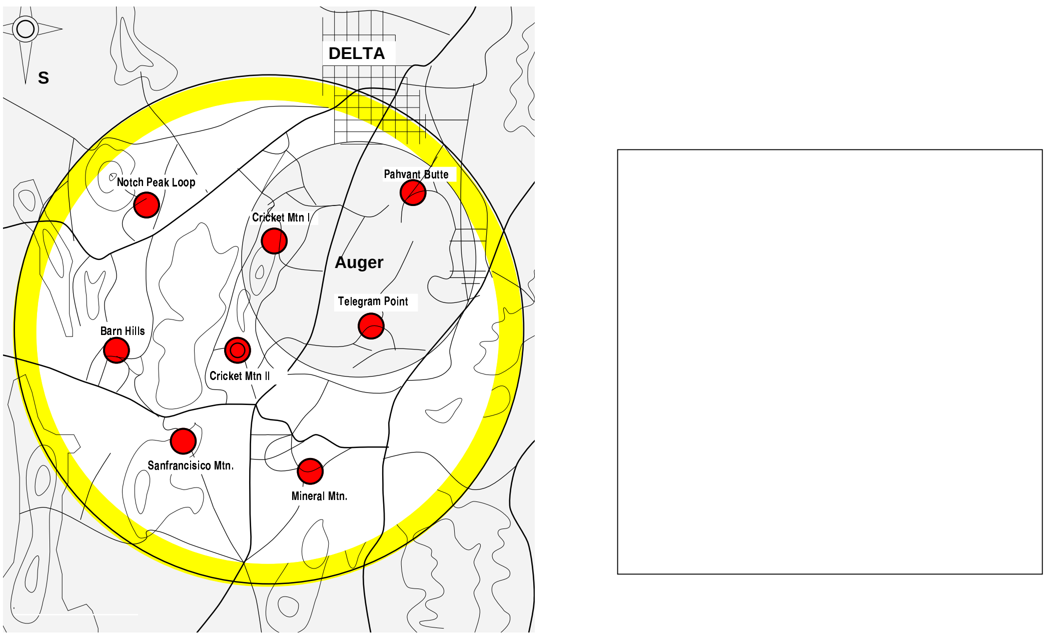

Figure 1: (a) TA EHECR Stations in Millard County and (b) the general layout of the station.

Figure 2: The TA telescopes and supports in the station.

Location

Careful site-survey is still continued. However, the most attractive candidate is now Millard County in U.S.A. which the Auger project has selected as an observation site in the northern hemisphere. If we select it as the final site, the TA EHECR detector will be installed as shown in Figure 1 a. The fluorescence detector is preferable to be built on top of hill or mountain to avoid hard attenuation effect by atmospheric Mie scattering. The mountain peaks in Millard County are located rather uniformly with the distance of 25-30km. Such a geometrical advantage allow us a good detection aperture for stereo reconstructed events.

3 of 8 stations will be installed in the commonly sensitive area where the Auger detector spread out. The detection aperture for stereo events with the 3 stations is so good that almost all coincidenced events can be reconstructed with a stereo technique, which enhances the contribution to hybridized analysis using both air-fluorescence and ground-array techniques.

Station

The general layout of the TA EHECR station is shown in Figure 1 b. The station consists of 42 telescopes covering 2π in azimuth and elevation angles ranging of $34°$. The telescopes are mounted on 2 layers of tetrahedron structure made of steel pipes, which also partially supports the station house. The house protects the telescopes and readout apparatuses against rain, wind, dust, and so on. During observation at night, all shutters on the side of the house are opened to keep enough field of views. At the center of the house there is an operating room, which contains all frontend electronics without preamplifiers nearby PMT and on-line trigger, filter, and monitor systems. Also, YAG-laser system will be installed in the operating room in each station house, which is utilized to monitor and calibrate the atmospheric attenuation with a real time method.

Telescope

Each telescope has the 3m-diameter mirror system which consists of 7 hexagon front aluminized spherical segment mirrors with 1.1m distance between opposite sides. The mirror system has good advantages of a large field of view, a high reflection rate of more than 90%, and a large light collection area of $7m^2$ without sacrificing an accurate focal spot size within a few mm. The segment mirrors are supported by radial square steel pipes. The radial mirror support is statically mounted on the two sides of steel pipes with tetrahedron structure. The TA telescopes mounted on the support structure are shown in Figure 2.

256 2-in photomultiplier tubes mounted in the focal plane of the mirror system are served as pixels of a fluorescence sensing camera. A BG3 optical filter plate is put on the camera surface. Each pixel covers a view of approximately 0.4 msr, which correcponds to the total field of view per telescope, 0.1 sr.

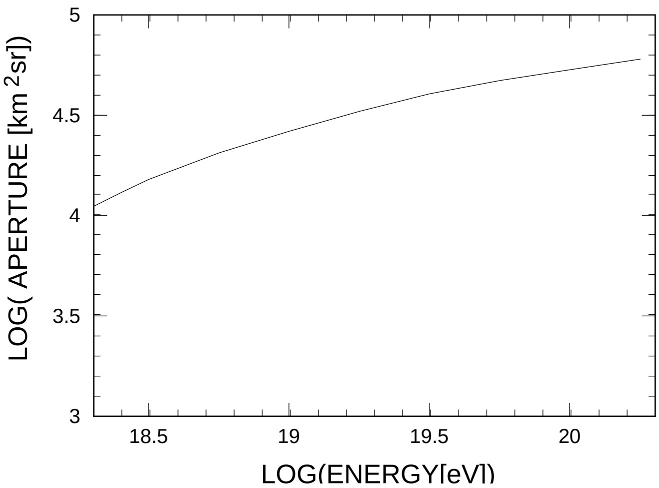

Figure 3: The triggered aperture as a function of primary energy.

Frontend
Low noise preamplifiers are mounted on the end plates close to the PMT assembly where the signal output is attached. The waveforms of the amplified signals from each end of every PMT are cabled into the operating room at the center of the station house and recorded with 10 MHz flash analogue-to-digital converters (FADCs) after feedbacked pedestal subtraction associated with digital-analogue-converters (DACs) controled by the on-line monitoring system. All frontend electronics except for the preamplifiers are installed in the operating room where temperature and humidity are controled well.

The trigger system is based on 3 levels: PMT trigger, cluster trigger, and telescope trigger fully applying digital signal processors (DSPs). Detailed trigger scheme is now under development. The quantitative arguments on it will be presented at the conference.

Calibration and Monitoring
When we explore the EHE region with good statistics, systematic calibration and monitoring procedures will make an important role according to our desired measurement precision. We will use an on-line real-time monitoring method as much as possible because only real-time feedback can significantly reduce unknown systematics in our measurements taking account the variation of the detector elements and environment.

Our on-line calibration chain consists of 3 steps. One is monitoring a spatial uniformity and gain of the readout system using a small scintillating light pulser with a very weak α source on a 2-axis motorized stage mounted on the camera surface. It will sweep out the surface of the camera every 1 hour or so to monitor the PMT gain at many points on the surface. Second is a monitor of the readout response flushing LED lights nearby the camera toward the mirror system. It is a redundant cross check of the readout and frontend electronics and a calibration of the mirror reflection rate. Third is a laser monitoring of atmospheric transparency between air-shower axis and the station. Laser lights will be shot from the laser shooting tower on the top of the station house in an event-by-event way adjusting the intensity and changing the angle of the lights by an on-line computer control.

PERFORMANCE
We are now intensively evaluating the performance of the design using a detailed Monte Carlo with careful cross checks. The nightsky background rate is assumed to be 75MHz/PMT from the standard nightsky background at Utah Fly's Eye site. Also tentative event trigger requirement

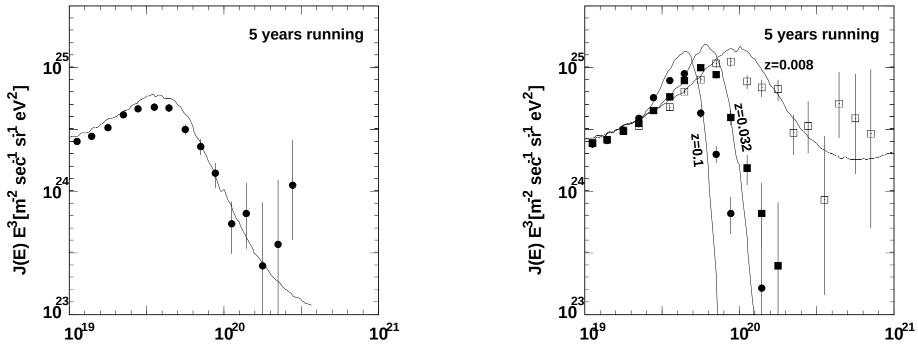

Figure 4: Expected energy spectra measured by the TA EHECR detector for 5 years assuming uniform distribution sources (*left*) and point sources at given red shifts (*right*).

is assumed as: adjacent 4-fold PMT conincidence in a cluster of 4×4 PMTs within 16μs and adjacent 2-fold cluster conincidence in a telescope within 32μs. The preliminary aperture using this trigger requirement is shown as a function of primary energy in Figure 3. The triggered aperture at 10^{20}eV is expected to be more than 50000 km^2 sr.

Requiring further condition that the maximum size of the longitudinal development can be reconstructed from the air-shower well, the preliminary triggered aperture for 10^{20}eV is evaluated to be around 3×10^4km^{2}sr and the energy resolution is 15% from the reconstructed events. Such an aperture and resolution can conclude existence of the GZK-cutoff by 4σ with only statistics for one year observation. 50 events at 10^{20}eV will be reconstructed well from one year observation assuming 10% duty factor due to sun and moon lights.

Figure 4 shows expected energy spectra measured by the TA EHECR detector for 5 years assuming uniform distribution sources and point sources at given red shifts.

CONCLUSIONS

The TA EHECR detector will be the largest fluorescence detector in the world. The excellent acceptance for EHECRs and the accurate reconstruction of air-shower development can provide us unambiguous probes into the EHE frontier physics. Our site selection may allow us to enjoy the hybridized analysis with the Auger northern detector. The complementary cooperation can be attractive.

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References

[1] See the author lists in OG 10.6.15.

[2] R.M.Baltrusaitis, et al, Nucl. Instr. Meth. A240 (1985) 410.

[3] K.Greisen, Phys. Rev. Lett. 16 (1966) 748,
G.T.Zatsepin and V.A.Kuzmin, Pisma Zh. Eksp. Teor. Fiz. 4 (1966) 114.

[4] For example, M.Nagano, Nucl. Phys. B (Proc. Suppl.) 52B (1997) 71.

[5] For example, J.W.Cronin, Proc. International Symposium on *Extremely High Energy Cosmic Rays: Astrophysics and Future Observatories*, ed. by M.Nagano (1996) 2.