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Reconstruction of Air Shower by TA Surface Array

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Abstract: Telescope Array (TA) is a EAS detector which is now building in the western desert in Utah, USA. In order to estimate the performance of TA, a detailed detector simulation is being developed in Java. The number of particles produced during the development of the EAS shower with various inclinations is calculated by COSMOS code. The detection effciency of each detector is evaluated by using the various calibration data and the results of GEANT4 simulation. And it is taken into account in estimating the signal. The analysis methods of the EAS data are also being developed using TA simulation. This report describes the structure of our simulation code, the analysis methods and the TA performance estimation based on our simulation.

Introduction

The AGASA observes 11 cosmic rays above 10^{20} eV in 12 years operation and shows the extension of the cosmic ray energy spectrum above the GZK cut-off.[1] Although the arrival direction distribution of EHECRs observed by AGASA is almost isotropic, some events shows an indication of point sources, from which 2 or more EHECRs arrived. High energy astronomical objects such as quasar remnants and BL Lac objects have been searched behind these events, but nothing have been found. There have been several hypothesis to explain these super-GZK events and point sources : super-heavy relics, Z-burst, the violation of Lorentz invariant at extremely high energy, and so on. Hires group have also studied the EHECRs and they reported that their energy spectrum is consistent with the existence of the GZK cut-off.[2][3] From discussions of these two groups, it seems clear that a part of the inconsistency is due to the systematic error of both experiments in the determination of primary cosmic ray energy. In order to dissolve the difference between AGASA and Hires, we are now constructing a hybrid detector which has an AGASA type ground array (SD) and 3 air Fuorescence telescope stations like Hires detector (FD) as the First step of TA experiment.[4] The West Desert in Utah, USA is the experimental site. The Hybrid-TA consists of 512 plastic scintillation counters which cover the ground area of 760 km in 1.2 km mesh and 3 telescope stations (FD stations) which surround the array and look inward. The Field of view (FOV) of each FD station is $3° \sim 34°$ in elevation angle and $120°$ in azimuthal angle. There are 12 telescopes in each FD station. The FOV of each telescope is The FOV of each telescope is $15.5°$ in elevation and $18°$ in azimuthal. Each telescope has spherical mirror of 3.3 m diameter and the shower image is recorded by a camera composed of 2-inch hexagonal PMTs placed on imaging plane.

Each particle detector of the SD is a plastic scintillator of 3 m area and 2 cm thickness. The scintillation photons are fed into PMT via wave length shifter fibers installed in grooves cut on the surface of the scintillator.

Simulation method

The detail of the TA simulation method is reported in the previous ICRC proceeding.[5] The simulation code is develloping now. In this simulation, the Geisser-Hillas function is used for the longitudial development of air shower and the NKG func-

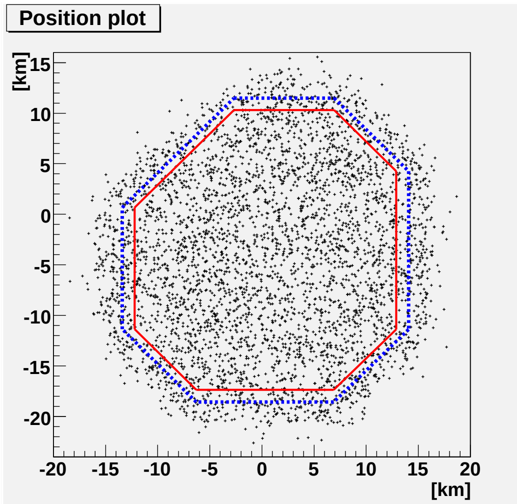

Figure 1: The shower core position triggered by TA surface array. The conditions used to make this figure are as follows: Primary energy is $10^{19.5}$eV. Zenith angle is 0 to 45°. Trigger condition is that the number of SD which hit more than 3 particles is above 3.

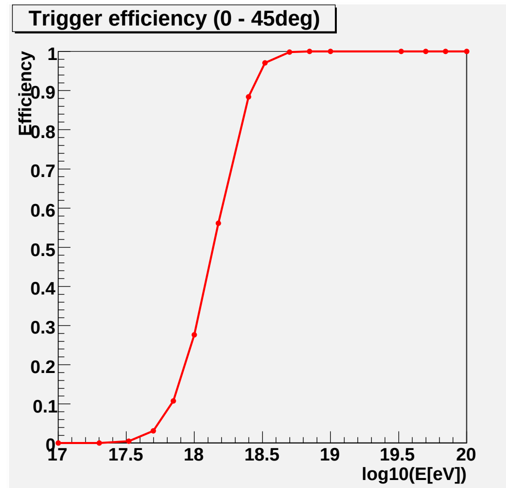

Figure 2: The energy dependence of trigger efficiency. The conditions used to make this figure are as follows: Zenith angle is 0 to 45°. Trigger condition is that the number of SD which hit more than 3 particles is above 3.

tion modified by Linsley is used for the lateral distribution of shower particles. Muon component has not been included yet. The detection effciency of the each SD is estimated using GEANT4.

Figure 1 shows the shower core position triggered by TA surface array. Blue line shows the area where our SDs are deployed. Red line shows the area that is 1.2 km smaller than area enclosed in blue line. The area enclosed in a red line is about $600\mathrm{km}^2$.

Figure 2 shows the energy dependence of trigger efficiency. From this figure, we can estimate that trigger efficiency of TA surface array is 100% above 10$^{\{}$18.7eV. Figure 3 and Figure 4 shows the energy dependence of the number of the triggered SDs.

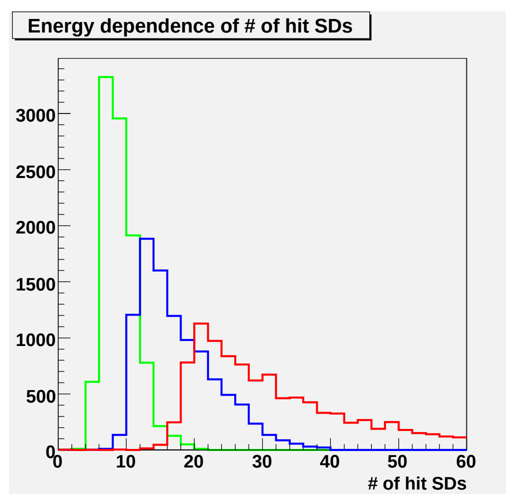

Figure 3: The number of the triggered SDs.
Red line: E=$10^{20.0}$eV
Blue line: E=$10^{19.5}$eV
Green line: E=$10^{19.0}$eV

Event reconstruction

The core location of the event is obtaiend by minimizing the chi square defined by the following function.

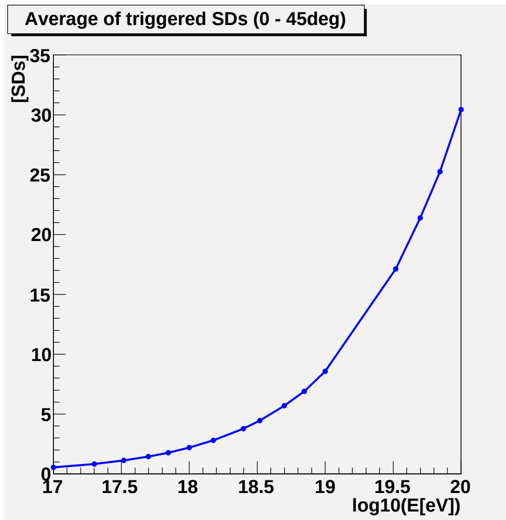

Figure 4: The energy dependence of the number of the triggered SDs.

$$\chi^2 = \frac{1}{n-3}$$
$$\times \sum_{i=1}^{3} \left(\frac{T_i - T_f(\vec{r}_i, \theta, \phi) - T_d(\rho_i, R_i) - T_0}{T_s(\rho_i, R_i)} \right)^2$$

n is the number of hit SDs. T_i is the arrival time of shower particle observed by i-th SD. T_f is the propagation time of tangential plane of the shower front. T_d is the average delay time of the shower particle from the tangentiol shower plane. $\vec{r}_i$ is the vector from the shower core to i-th SD. ρ_i is observed particle density. R_i is the distance from the shower axis. θ, ϕ is the arrival direction of primary particle. T_0 that is time when the shower core hit the ground is obtained as follows.

$$T_0 = T_i - T_f(\vec{r}_i, \theta, \phi) - T_d(\rho_i, R_i) \qquad (1)$$

To optimize the arrival direction of shower, we use the following likelihood function.

$$L = \prod_{i=1}^{n} \left(\frac{1}{\sigma_i \sqrt{2\pi}} \right) exp \left[-\frac{1}{2} \sum_{i=1}^{n} \left(\frac{\rho_i - \rho(R_i)}{\sigma_i} \right)^2 \right] \qquad (2)$$

Here, σ_i is the fluctuation of the electron density observed by i-th SD. I used experimental function which is expressed by Teshima et al.[6].

$$\sigma_i^2 = 2\rho(R_i) + (0.25\rho(R_i))^2 \qquad (3)$$

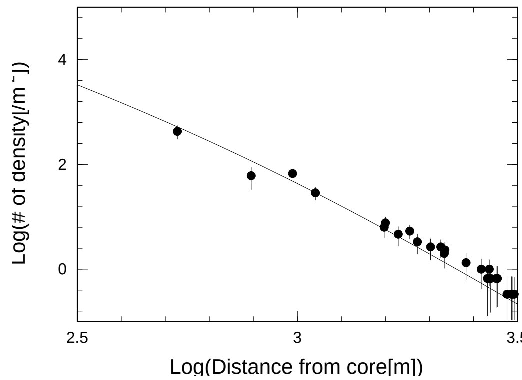

Figure 5: The preliminaly result of the TA SD reconstruction using simulation data.

Figure 4 shows the preliminaly result of the TA SD reconstruction using simulation data. Primary energy is $10^{19.5}$eV. Number of triggered SD is 14.

	Position [km]	Zenith	Azimuth
Input	(-1.889,0.321)	20.0	261.6
Reconst.	(-1.815,0.219)	20.3	260.0

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