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Angular Resolution of the GRAPES-3 Array for UHE Gamma-Ray Astronomy

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Observations on cosmic sources of ultra high energy (UHE) gamma rays provide information on the origin of cosmic rays and their acceleration mechanisms. In order to detect a UHE gamma ray source with its extremely low flux against a large isotropic cosmic ray background, an Extensive Air Shower (EAS) array with very large collection area and high angular resolution is necessary. The GRAPES-3 EAS array operating at Ooty covering an area of $\sim$ 18000 m^2 with $\sim$ 300 fast scintillation detectors is being used for studies on UHE gamma-ray sources. Here we have described the method of reconstruction of the arrival angle of showers and determination of the angular resolution of the GRAPES-3 array.

1. Introduction

GRAPES-3 is a high density air shower array designed to measure both densities and relative arrival times of shower particles to determine the energy and incident direction of primary cosmic ray particle which initiates a shower in the atmosphere. The details of the experiment with shower detectors, shower trigger and data acquisition is described elsewhere [1]. At present the array records 2.2 million showers per day with TDCs for arrival time and ADCs for particle density measurement in the energy range 3×10^{13} - 3×10^{16} eV. Monte-Carlo simulation shows that the GRAPES-3 array has the trigger efficiency $\sim$ 90 % at $E_\gamma \sim 30$ TeV for γ-ray primaries [1]. With it's high trigger efficiency for lower energy γ-ray showers, it has the potentiality to study the γ-ray sources. The other biggest advantage of the array is, it is associated with a large (560 m^2) muon tracking detector which can distinguish primary γ-rays from charged cosmic ray particles through the muon content of the shower [2]. In addition to this, the other important requirement to study γ-ray sources is higher angular resolution the array. Since there is large fluctuation in the arrival times of shower particles and instrumental uncertainty in measuring these times, it limits the angular resolution.

2. Angle Reconstruction

Assuming shower front to be a plane, the shower direction characterized by zenith angle θ and azimuth angle ϕ has been reconstructed by fitting a plane to the observed relative arrival times of shower particles at individual detectors by minimizing χ^2 through least square method. Before doing the fit, these arrival times have been corrected for the time offsets of the individual detectors which arise due to difference in photomultiplier transit time, electronic propagation delay etc. These time offsets have been determined from the shower data itself by a method developed and used by KGF group [3].

The angle is reconstructed for those showers, for which highest recorded density detector is on and within the

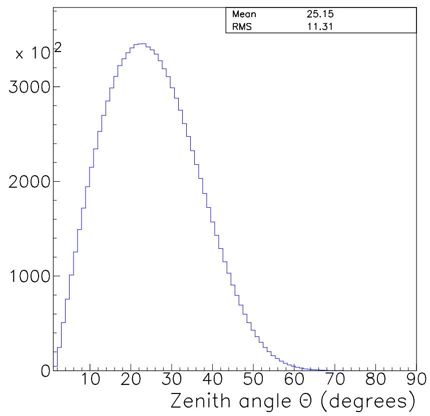

Figure 1. Zenith angle distribution of showers

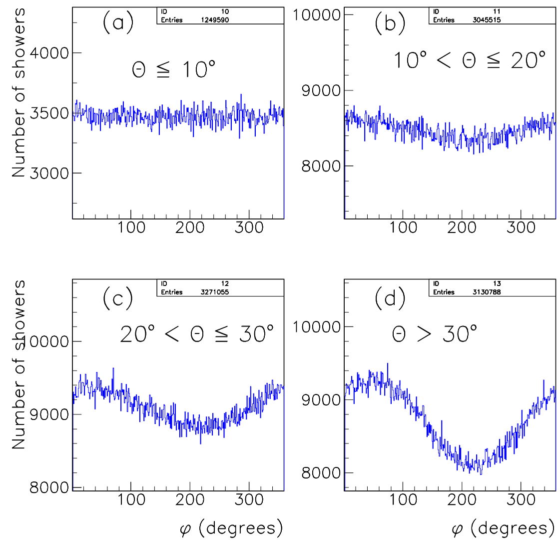

Figure 2. Azimuth angle ϕ distribution for different zenith angle ranges. A large decrease is seen at higher zenith angle from expected flat distribution

second last ring the array. This condition is imposed because the shower which gives highest density in the last ring, its core might be landed out side the array boundary and with partial information available, the angle determination can be highly inaccurate. This selection rejects 21% of showers from angle reconstruction.

The θ and ϕ distributions are shown in figure 1 and 2 with the analysis of data from 1-10th April 2005. ϕ is measured with reference to north direction and clockwise. Figure 2a - 2d show ϕ distribution for different zenith angle ranges. The ϕ distribution is flat in figure 2a which is expected due to the isotropic arrival of cosmic rays, whereas deviations seen in figure 2b - 2d from flat distribution. The deviation is quite large in figure 2d for $\theta > 30^o$. This discrepancy can be understood with the ground slope of array which affects the trigger and the effect is more for larger zenith angle showers. So proper care should taken, particularly estimating the back ground while studying astrophysical sources.

3. Angular Resolution by Even-Odd Array Method

To know the accuracy of angle determination i.e. angular resolution, a conventional method has been used by comparing angles determined independently from two sub arrays, one consists even numbered detectors and other with odd numbered detectors using plane fit described in the previous section. The space angle distribution between these two sub-arrays are shown in figure 3. The angular resolution is calculated by dividing a factor of 2 because the error of the two reconstructed directions is larger by a factor of $\sqrt{2}$ compared to the error for the reconstruction with information of the whole array and two errors add quadratically.

From figure 3 it can been seen than the angular resolution is better with more number detectors used in angle fit. The median value of angular resolution is 2^o for NFIT > 10 and it improves to 1^o for NFIT > 40.

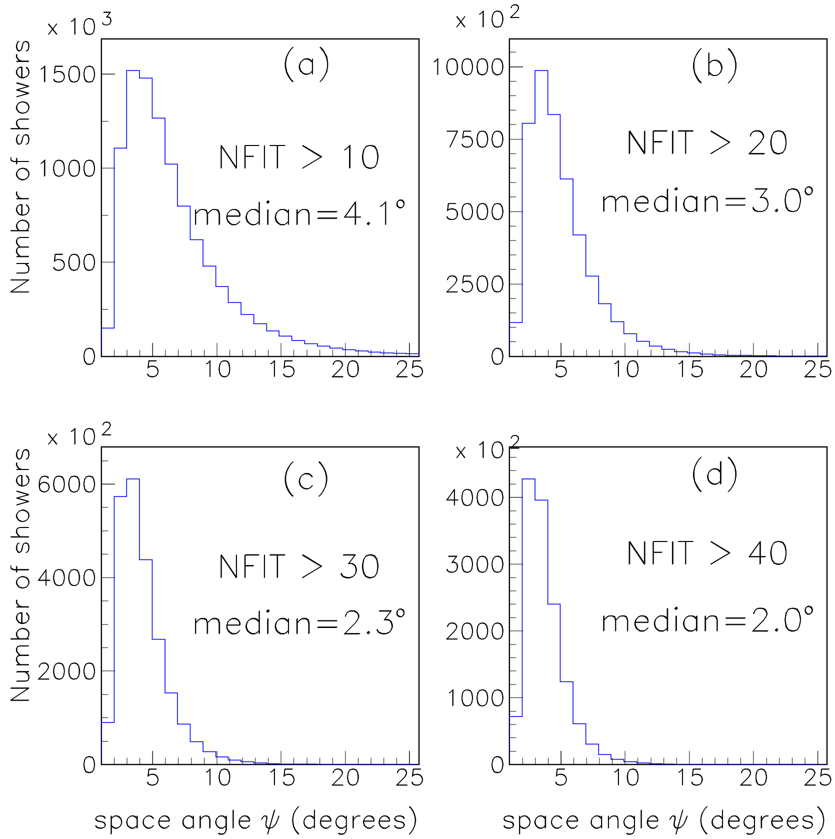

Figure 3. space angle distribution between Even and Odd array as a function of number detectors participated in the angle fit (NFIT). The width of the distributions become narrower from (a) to (d) which tells that the angular resolution is better with more number of detectors.

4. Discussion and Conclusions

The above analysis gives a rough estimate of angular resolution determined by plane fit. A More detail analysis is in progress which may help to improve the angular resolution taking into account the shower curvature correction and electronic slewing effect. We are trying to verify the angular resolution through Moon shadow.

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