ANGULAR RESOLUTION OF AN EAS ARRAY FOR GAMMA RAY ASTRONOMY AT ENERGIES $> 5 \times 10^{13}$ eV

Apte, A.R., Gopalakrishnan, N.V., Tonwar, S.C., and Uma, V.

Tata Institute of Fundamental Research
Homi Bhabha Marg, Colaba, Bombay-400 005
India

ABSTRACT

A 24 detector extensive air shower array is being operated at Ootacamund (2300 m altitude, 11.4°N latitude) in southern India for a study of arrival directions of showers of energies greater than 5×10^{13} eV. Various configurations of the array of detectors have been used to estimate the accuracy in determination of arrival angle of showers with such an array. These studies show that it is possible to achieve an angular resolution of better than 2° with the Ooty array for search for point sources of Cosmic gamma rays at energies above 5×10^{13} eV.

1. INTRODUCTION

Interstellar magnetic field causes charged particle trajectories to be tortuous and uncertain for all but the most energetic particles. Therefore information on the highest energy processes occurring in astrophysics can be obtained only from studies of high energy gamma ray photons which travel unscattered and practically unabso-rbed through great lengths of galactic and intergalactic space. Observa-tions at energies less than about 10^{10} eV have been carried out with satellite borne instruments which can discriminate efficiently between photons from a source and the isotropic charged particle background. However, studies of photons of energies above 10^{11} eV require very large effective collection areas which are possible with only ground based techniques. Atmospheric Cerenkov radiation technique has been successful for energies above 10^{11} eV and studies of extensive air showers have been carried out to detect sources of very high energy photons of energi-es above 10^{14} eV. Since most of the Cerenkov photons are produced in the atmosphere near the cascade maximum and suffer negligible scattering before arriving at the detectors placed at sea level or mountain altitude relative timing techniques using detectors spaced few tens of meters apart enable the determination of arrival direction of individual showers to an accuracy[1] of better than about 0.5°. Such good angular resolution of an atmospheric Cerenkov radiation (ACR) telescope allows observation of a small angular region around the suspected source of high energy photons enabling achievement of a large value for the signal to backgrou-nd (S/B) ratio. Studies of extensive air showers (EAS), on the other hand, involve detection of electrons which suffer considerable scattering in the atmosphere. It is therefore expected that angular resolution of an EAS telescope would be much poorer compared to an ACR telescope. However no detailed and systematic studies exist on the possible angular resolution that can be achieved with an air shower array at various energies above 10^{14} eV. In fact, various angular size bins have been used in different experiments[2,3,4] based on approximate estimates of angular resolution of respective arrays, which leads to widely varying values of the S/B ratio causing uncertainities in the estimates of flux of high energy photons from a suspected source.

Since June '84, we have operated an EAS array at Ootacamund (Ooty for short, 2200 m altitude, 11.4° N latitude) in southern India for study of sources of high energy Cosmic ray photons. With data from this experiment we have studied in various ways the time resolution of air shower detectors and the angular resolution achievable with this array. In the next section are presented the details of the array, shower selection and recording system. The observed time resolution of EAS detectors is discussed in section 3 and in section 4 are presented the results on angular resolution achieved with Ooty array for showers of energies $>5 \times 10^{13}$ eV. The conclusions drawn from this study are given in the last section.

2. EXPERIMENTAL SYSTEM

The EAS array at Ooty consists of 24 scintillation detect-ors of various sizes spread over an area of radius of about 40 meters. 20 detectors are plastic scintillators, each 5 cm thick and the other four called N,E,W, and S,are liquid scintillators using 10 cm thick column of mineral oil. These four scintillation detectors are only used for selection of showers through a 4-fold coincidence called NEWS. These four detectors are located at the corners of an approximate square around the centre of side length of about 10 m (see figure 1 of paper OG 2.6-8). All the scintillators are viewed by 5 cm diameter fast photomultipliers (RCA 8575) placed some distance above the scintillator giving about 10% uniformity in signal over the area of the scintillator. Showers are first selected with a four fold coincidence of 100 ns wide pulses obtained from discriminators (LRS 623B) for N,E,W, andS. The thresholds for the discriminators have been set at 30 mV while the mean pulse amplitude for near vertical muons is about 100 mV for these detectors. However, this selection with an observed shower rate of about 30 per minute selects many very small size showers which do not trigger many of the other 20 detectors. Since the angular resolution is expected to depend on the number of detectors available for determinat-ion of shower arrival direction, showers which trigger only few detectors are not considered to be useful for studies of Cosmic gamma ray sources. In an attempt to optimise the selection of showers which trigger a large number of detectors but at the same time keeping the shower size threshold lower, an additional requirement of at least 3 particles in one of the four selection detectors is included in the final shower trigger. Observed shower rate with this final trigger is about 7 per minute. Each such trigger causes the digitization of the charge collected at the anode for each photomultiplier using fast ADC's (LRS 2248A) and the digitization of the relative delay between the trigger and the output from discriminators for each detector with an accuracy of 0.25 ns by using fast TDC's (LRS 2228A). Pulses from the photomultipliers going to the discriminators are amplified with gain 10 (LRS 612A) to keep the effective threshold low while obtaining a good charge measurement for single particles with the ADC's. For each shower information from all the ADC and TDC channels is transferred to a memory buffer preceding a magnetic tape recording system such that the system can record all the details of showers coming as close as 1.5 ms relative to each other. Real time information is read for each shower from a clock running on a crystal with stability of about 1 part in 10^9 per day which is corrected periodically with ATA time signals broadcast from New Delhi. Data collected on magtape at Ooty are then analysed at Bombay using the CYBER 170/730 computer system at the Tata Institute.

3. TIME RESOLUTION OF EAS DETECTORS

The inherent time resolution of particle detection system used in the present experiment is contributed by the rise time and time jitter in the photomultiplier, amplifier, discriminator and the TDC apart from the scintillator and photon reflections inthe hood on which the photomultiplier is mounted. This resolution has been measured experimentally by mounting two photomultipliers on the same scintillator. The relative time measured between these two channels for showers has a distribution with standard deviation (σ) of about 1 ns which seems to depend only weakly on the particle density over the detector. However the distribution of the relative time between two detectors (N and 6) which are located within 2 m of each other is much broader reflecting the thickness of the shower disk. It is this distribution which is relevant for estimating the accuracy in the determination of arrival angle of showers. The standard deviation for this distribution is 5.2 ns for particle densities of less than 5 particles m^{-2} and 3.8 ns for larger densities. Correcting for the angular distribution of showers and the distance between these two detectors, it is clear that the minimum uncertainity in time measurement by individual detectors, at least for low size showers is about 3 ns. Therefore an EAS array with largest distance span of about 20 m between timing detectors, for example the EAS array at Kiel[4], can hardly achieve an angular resolution better than about 3° for small size showers.

4. ANGULAR RESOLUTION OF OOTY EAS ARRAY

Sine timing information from 24 detectors is available for getting a best fit to a plane shower front passing through all these detectors, it is possible to reduce the effect of timing fluctuations discussed above and achieve a better abgular resolution. In an attempt to estimate the angular resolution of the array, data have been analysed using different sets of detectors and the values of right ascension and declination are compared. In the first instance, the array is split into two arrays, one with odd numbered detectors and the other with even numbered detectors. RA and δ are computed independently with the two arrays. The distribution of the differences between the two RA values as well as the distribution of the differences between the two δ values, show a broad symmetric distribution with σ of about 3°. This suggests a value for σ of about 2° for each sub-array. Another study has been made by comparing the RA and δ values for two arrays, one with all the 20 detectors (excluding the timing selection and reference detectors N,E,W,and S) and the other with only inner 9 detectors. The value of σ for the distribution of the difference in RA values as well as the distribution of the difference in δ values is about 2°. This result suggests that the angular resolution for the array using all the 20 detectors is much better, assuming that the array with only inner 9 detectors has a resolution of about 2^{o}.

These results have been obtained using only those showers which have triggered all the 24 detectors, evidently a sample of some what larger size showers. However similar results have been obtained using showers which have triggered only inner 15 detectors. It should also be noted that showers selected in the manner discussed earlier have on the average 20 out of 24 detectors triggered and nearly 80% of the showers have timing information available from at least 15 out of the 20 detectors, ignoring the selection detectors. The energy threshold for showers triggering at least 15 out of 20 detectors is estimated to be about 5×10^{13} eV.

4. CONCLUSIONS

Ooty air shower array with 24 scintillation detectors, has been used to measure the arrival angles of showers using the relative timing technique. From the computed differences in the values of the right ascension and the declination for showers for various configura -tions of detectors used for calculation of arrival directions, it is estimated that the angular resolution of Ooty array is better than about 2^{o} for showers of energies greater than about 5×10^{13} eV. Results from the search for sources of very high energy gamma rays using data collected with the Ooty array since June '84 is reported elsewhere (OG 2.6-8) in this Conference using the values of angular resolution obtained here.

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