Cosmic-ray-air Shower Timing Experiment: Performance of a Mini Array Detector

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Abstract

A small-scale, detector utilizing the measurement of finite thickness of air-showers has been developed and operated on the roof of the physics building, Gauhati University (Guwahati, Assam, India), since 1996. The experiment is based on extensive work of Linsley with such detectors. The array consists of eight plastic scintillation detectors (BC416, size: $50 \times 50 \times 5cm^3$) each viewed by fast photomultiplier tubes (PMTs, Type: Thorn EMI 9807B) to look at showers from $10^{17}eV$ to $10^{19}eV$ energy. Performance and end results of the detector array will be discussed.

1. Introduction

The present detector array is based on well known feature of Linsley effect, that is, the increase in spread of arrival time distribution in a particle sample from a given shower with increasing distance from the shower centre [1, 2]. Thus the measured time spread of particles striking localised detector system gives an estimate of the distance (r) to the shower axis. The number of particles give the measure of the local particle density (ρ). The shower size (N) is estimated from the assumed lateral distribution function and primary energy (E) is derived from the estimated shower size.

2. Methods

The array is located at the rooftop of the Physics Building, Gauhati University ($26^0 10'$ N, $91^0 45' E$ and altitude $51.8m$). It consists of eight plastic scintillators (Each of area: $50 \times 50cm^2$, thickness $5cm$) viewed by fast PMT's covering a total area of $2m^2$. The signals from the eight detectors are amplified and then carried to the control room via co-axial cables (Type: RG58U). In the control room, all the eight signals are discriminated to provide corresponding logic signals. The discriminated output is then individually shaped into narrow pulses of $20nS$ width and OR'ed together to give a serial pulse train. The serial pulse train is then branched into three channels , one to the Digital Storage Oscilloscope

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(Tektronix, TDS520A, 500MSample/sec) , one to the 100MHz time digitizer and the other to the trigger unit. The trigger unit senses the incoming pulse train and generates the necessary trigger pulse. Once triggered, the number of detector pulses and their relative time positions are stored in the time digitizer and the scope. The Microprocessor (μP, 8086) stores the data from the time digitizer in RAM and transmits them to the PC (486DX2) via serial port. The pulse waveform is recorded by the scope and transferred to the PC via GPIB interface. The μP also monitors the status of the detectors at a predetermined interval and handles the recording and transfer of data of each event to the PC via RS232 interface.

2.1. Theoretical Calculation

Linsley derived the empirical formula relating the shower disc thickness $\sigma(nS)$ to the core distance r(m), using experimental data from Volcano Ranch Array obtained by averaging over many showers as [3]

$$\sigma = Br^{\beta} \tag{1}$$

Where values of the constants, $B = .0158$ and $\beta = 1.5$ and are derived from the experimental data.

The particle density distribution for large shower and large core distances ($r > 1000m$) is given by [4]

$$\rho = CNr^{-n} \tag{2}$$

Where $C = 853$, N=size of the shower and $n = 3.8$

The integral and differential shower size spectra [5] are:

$$J(N) = DN^{-\gamma}, j(N) = -\gamma DN^{-\gamma-1} \tag{3}$$

where $D = 318$ &, $\gamma = 1.7$

The primary energy corresponding to an event with estimated shower size N is derived from the measurements of giant Array of Yakutsk, in agreement with QGS Model [5]. The best fit relation is derived as,

$$E(ineV) = 1.122 \times 10^{13} \times N^{0.56} \tag{4}$$

2.2. Data collection and analysis

Most of the experimental data were collected during September '96 to March '99. More than 10000 air shower events were recorded and analysed. The results of the earlier analysis of the data were presented elsewhere [6,7,8]. Most of the data collected do not belong to true large shower events. True large shower events with a time spread of shower front 100nS and with local particle densities $\rho \geq 1.5m^{-2}$ are selected and reanalysed. They belong to shower of size $N \geq 7.5 \times 10^{6}$.

3. Results and Discussion

After simulation of the data it is observed that the experimental results agree with the theory upto $N = 2.2 \times 10^8$ that corresponds to a primary energy of $10^{17.2}eV$, above which there is a marked change in the slope of the shower size spectrum. The artificial shower simulation for the fixed shower of sizes 10^7, 10^8 and 10^9 predicts proportional errors of 41.5%, 36.0% and 37.0% respectively in the estimation of the shower size by using the array of area $2m^2$. The simulation gives an average error of 27% in the measurement of energy by the Mini Array. When we consider all the densities and shower front thicknesses above threshold

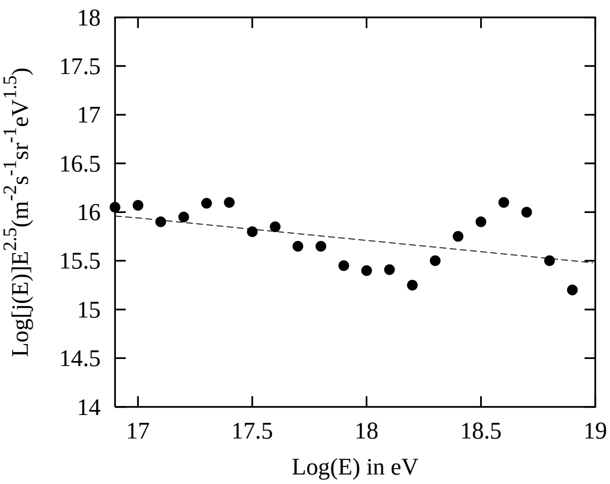

Fig. 1. Energy Spectrum : Best fit upto $10^{18.2}$eV.

then the energy spectrum as shown in fig.1, shows spectral changes similar to those observed by other large groups with overall slope of -2.69. However this slope is much lower than that calculated by others [9] and is due to the abnormally large number of events recorded by the Mini Array in the higher energy range (a significance of 19.15σ excess). This over estimation in the higher energy side may be due to inclusion of some delayed particles, which are not real part of the true shower front and thereby falsely increasing the thickness of the shower front. This gives an over estimation of the core distance, leading to higher energy estimation for a given particle density. Hence we consider the overall spectrum for Mini Array upto $10^{18.2}eV$ with a slope of $-3.14 \pm .05$ which is in reasonable agreement with that calculated by the other groups. The differential energy spectrum corresponding to best fit (Chi-squares fitting) in the energy region $10^{16.7}eV$ to $10^{18.2}eV$ is derived as:

$$j(E) = 10^{25.18} \times E^{-3.14\pm.05} m^{-2} sr^{-1} s^{-1} eV^{-1} \quad (5)$$

The dip observed from the Mini array energy spectrum is prominant as also observed by other groups.

4. Conclusion

The new results of the present mini array data predicts that it may be considered as a better method for detecting UHE cosmic rays among small research group.

References

1. Linsley J. 1983 Research Report UNML - 6/20/83
2. Linsley J. 1986, J. Phys. G: Nucl. Phys., 12, 51
3. Linsley J. 1962, Phys. Rev. Lett., 9, 123
4. Hara T. et al. 1983, Proc. 18th ICRC, Bangalore, 1, 276
5. Afanasiev B. N. et al. 1997, Proc 25th ICRC, Durban, 6, 229
6. Bezboruah T. et al. 1996, Proc. XIV DAE Sym., Gauhati,1,33
7. Bezboruah T. et al.1997, Proc. 25th ICRC, Durban, 6, 218
8. Bezboruah T. et al. 1999, Astropart. Phys.,11,395
9. Bird D. J. et al. 1994, ApJ.,424, 491