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An investigation of arrival time of cosmic ray showers and the effects of atmospheric pressure and density on shower rate using a test set-up

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Abstract

The paper describes a short duration investigation of arrival time spacing of omni-directional cosmic ray air showers near ground level using a test set-up of 4 of the total planned 16 detectors in a $14m \times 14m$ square array constructed at the roof of the Department of Physics, Gauhati University. The array has 4 huts at the corners of the square. Each hut can accommodate 4 scintillation detectors. The data acquisition system for the investigation has been locally designed and fabricated with easily available components. The nature of the dependence of shower rate on atmospheric pressure and density at the detector site is also investigated. The outcome of the investigation is presented in the paper.

Keywords: Cosmic rays; EAS; Atmospheric effects; PMT; Scintillation detector; Trigger condition

1. INTRODUCTION

Cosmic ray particles from various sources continually and randomly bombard the upper atmosphere from all directions. Depending on their origin, the primary particles reach the top of the atmosphere with various energies ranging from $E \sim 10^6$ eV to 10^{20} eV. The primaries with high energy undergo nuclear interaction with the nuclei of air molecules and initiate a cascade of secondary particles, called extensive air shower (EAS). Majority of the showers are initiated by primary particles with energy $E > 10$ TeV [1]. The primary particle flux of such high energies is very small. Moreover, the atmosphere almost completely absorbs the primaries; and none of them are able to reach the surface of the earth [2]. Therefore, direct detection of these particles is not possible. A sizeable section of the secondary particles, on the other hand, manages to

reach the ground level and facilitates studies on various characteristics such as composition, mass, frequency of arrival, and above all, the energy of the primary particles [3]. However, atmospheric conditions such as pressure, temperature and density are seen to modulate the counting rate recorded by detectors [1]. Recording the sequential hits of the secondary particles by detectors arranged in arrays of various shapes is the most popular method of detection of cosmic ray showers reaching the ground.

The arrays operational in various locations of the world have sizes ranging from a few metres to several kilometers [4]. We are working on setting up a $14m \times 14m$ square array with 16 scintillation detectors on the roof of the Department of Physics, Gauhati University, Guwahati, India. In order to ascertain the prospect of the array as a useful tool for undertaking various studies on cosmic rays in future, presently only 4 detectors have been installed as a test set-up. Three short duration investigations on the (i) arrival time distribution of cosmic ray air showers, (ii) effect of atmospheric pressure on shower rate and (iii) effect of air density on shower rate have been carried out with the test set-up. In this work 1170 showers have been recorded in staggered manner over 17 days during June-July, 2017.

Atmospheric pressure and temperature are recorded close to the base of detector#1, with the help of a locally designed sensor module (not shown in the block diagrams). All data are stored in the personal computer (PC) in the control room for off-line analysis.

2. EXPERIMENTAL SETUP

2.1. The array

The $14m \times 14m$ square array (fig. 1) is constructed on the roof of the Department of Physics, Gauhati University (26.1537° N, 91.6634° E, 55.5 m a.s.l.≅ 1023 g cm^{-2}). The array consists of 4 detector huts (size: 1.5m × 1.5m × 1.5m) made of MS iron sheet walls and galvanized iron sheet roofs. Each hut can accommodate 4 detectors. Each detector has a plastic scintillation block (Bicron BC-416) of dimensions 50 cm × 50 cm × 5 cm.

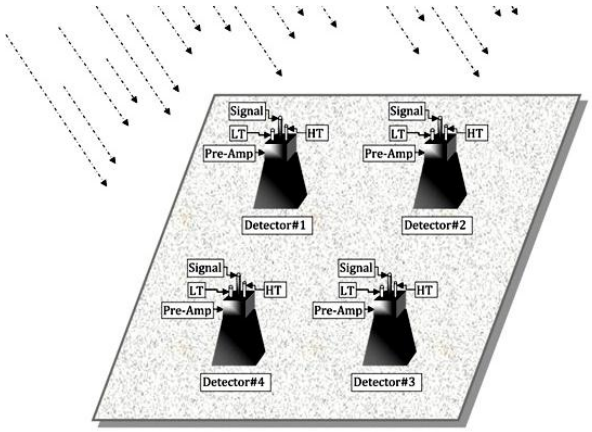

Fig. 1: The array with 4 detectors

CORSIKA simulation results show that the array with 16 detectors can detect EAS with threshold energy > 100 TeV [5]. In the present investigation only 4 detectors are used (Fig. 1) for which the threshold energy comes out to be ~ 500 TeV.

The scintillation blocks are laid horizontally, and are housed in tetrahedral shaped aluminum boxes [4] of height 68 cm. Each scintillation block is viewed by a 5 in. photomultiplier tube (PMT) (Du Mont 6364) with grounded cathode dynode chain. A preamplifier is attached near the base of the PMT. The preamplifier pulse is brought to the control room, located in the first floor of the Department of Physics, Gauhati University, through RG-58 coaxial cables. Each of the 4 signal cables is 40 m long. The extra high tension is taken from the control room to the huts through coaxial audio cables. The insulation strength of the audio cable has been tested in the laboratory and is found to withstand voltages up to almost 2 kV.

2.2. Experimental procedure

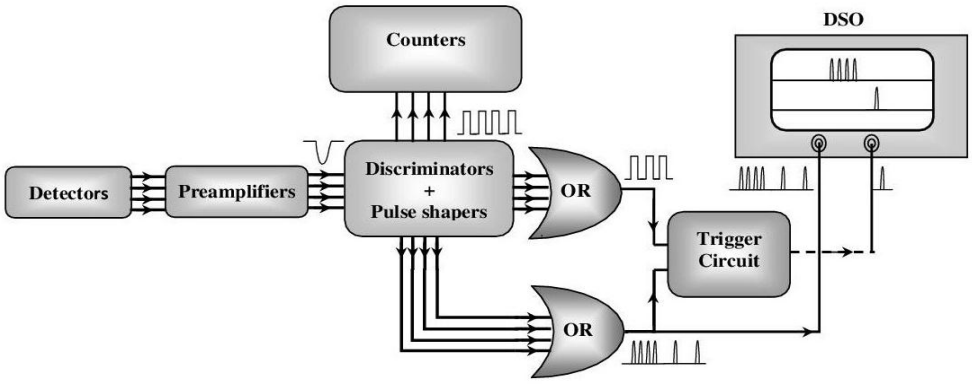

Fig. 2: Block diagram of experimental procedure

The block diagram shown in fig.2 represents the main components of the set-up. Each detector is individually calibrated to give an output pulse for a minimum number of one cosmic ray charged particle passing through it. The negative analog pulse from the detector is brought to the control room through the signal cable. It is then fed to the discriminator. The logic output of the discriminator is divided into two branches, and is fed to the pulse shaper circuit to get two different width logic pulses, one having a width of ~ 600 ns and the other ~20 ns derived from the same output of the discriminator. The broader pulse is transmitted to the counter-timer to record the number of particles passing through a particular detector within an interval of 10 second. The narrow pulses from the 4 channels are ORed to get a single pulse train. One branch of the train from the OR circuit is fed to the trigger circuit and the other branch is fed to channel#1 of the digital storage oscilloscope (DSO) (Tektronix TDS 2022, Two Channel DSO, 200 MHz, 2 GS/s). The wider pulses from the discriminators are similarly ORed and then fed to the trigger circuit to fire a monoshot

(DM 74121), which generates a gate pulse of ~100 ns.

When a minimum of 3 narrow width pulses enter the trigger circuit within the gate of ~100 ns, the trigger circuit gives an output. The trigger output is fed to channel#2 of the DSO, which is set in the real time single acquisition mode. Whenever a trigger pulse arrives at channel#2 of the DSO, it completes the acquisition and displays the waveforms of the pulses coming from both channel #1 and channel #2 on the screen. A program is written in C-language to transfer the BMP files of the captured waveforms bearing time-stamps to the PC through GPIB interface. The real time counts displayed by the counters (~ 40 pulses per second per detector) are used to ensure that the detectors are working at their optimum level. Whenever counts go very high or fall off drastically the system is shut down; the fault is identified and the necessary maintenance is carried out.

2.3. Data acquisition system

Most parts of the data acquisition system needed for operation of the array are locally designed and fabricated with easily available components in the market. The system consists of a preamplifier, discriminator, pulse shaper, counter-timer and a trigger circuit. The trigger circuit is an adaptation of the circuit described in reference [6], while the other parts of the data acquisition system are discussed in details in reference [7].

2.3.1. Trigger conditions

The narrow output pulses from the 4 channels are assumed to represent a cosmic ray shower when the following conditions are satisfied:

(i) At least three pulses reach the trigger circuit from the detectors [8]

(ii) The pulses are within a time window ≤ 100 ns.

2.3.2. Sensor module

Atmospheric pressure and the temperature are measured at detector site with the high precision digital sensor BMP180 (Bosch Sensortec) [9]. A real time clock DS3231 [10] records the time. The data from both BMP180 and DS3231 are transferred serially to a personal computer by RS232 protocol. The data are logged and stored in the PC in a plain text file using a terminal program written in C-language for off-line analysis.

3. RESULTS

3.1. Arrival time spacing of showers

Primary cosmic ray particles fall randomly on the upper atmosphere and initiate showers, which are also randomly incident on the surface of the earth with respect to

time. The event rate is expected to follow an exponential distribution law of the form

$$P(t) = A \exp\left(-\frac{t}{\tau}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where $\left(1/\tau\right)$ is the mean event rate [11]. The time distribution of the 1170 showers recorded with the help of the test set-up is shown in Fig. 3. The adjusted R-square value of the fitted curve is found to be = 0.96. From the fit the mean event rate is found to be ~ 16 per hour. The raw data also gives an average event rate of ~ 16 per hour.

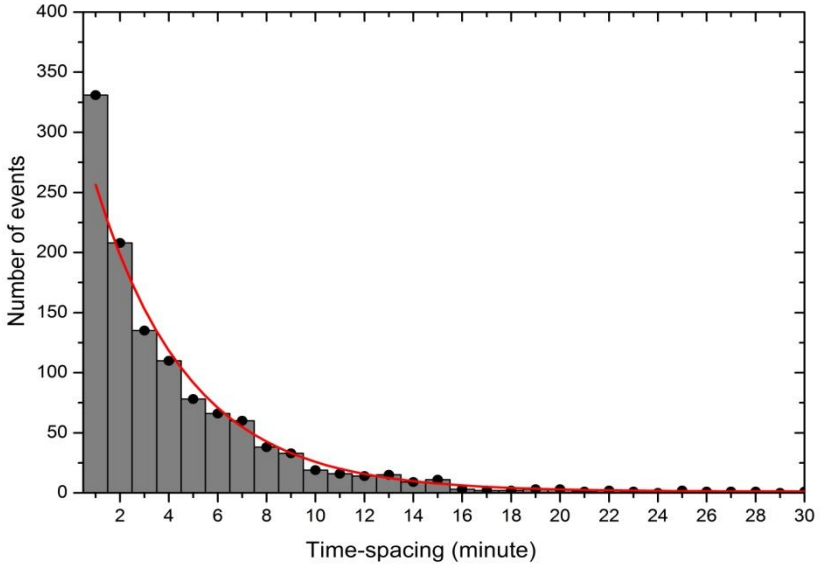

Fig. 3: Arrival time spacing of showers

3.2. Effect of atmospheric pressure on shower rate

Cosmic ray shower detection rate has a negative correlation with the atmospheric pressure at the ground level. Greater air pressure implies greater absorption of lower energy shower particles, and hence, a reduced rate of showers reaching an array. Shower rate may be taken to be dependent on atmospheric pressure according to the relation

$$R = R_o \exp\left(\frac{P_o - P_i}{P_I}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where R is the event rate at a pressure P_i while P_o is the mean atmospheric pressure and P_I is a constant [11].

The graph between the pressure P_i and event rate R is shown in fig. 4, which is similar to the one found by authors of reference [11]. The adjusted R-square value of the fitted curve is found to be = 0.36. The curve shows that the event rate decreases with pressure. The slope of the straight line fit is found to be =

(-0.36 ± 0.14) per hour per hPa.

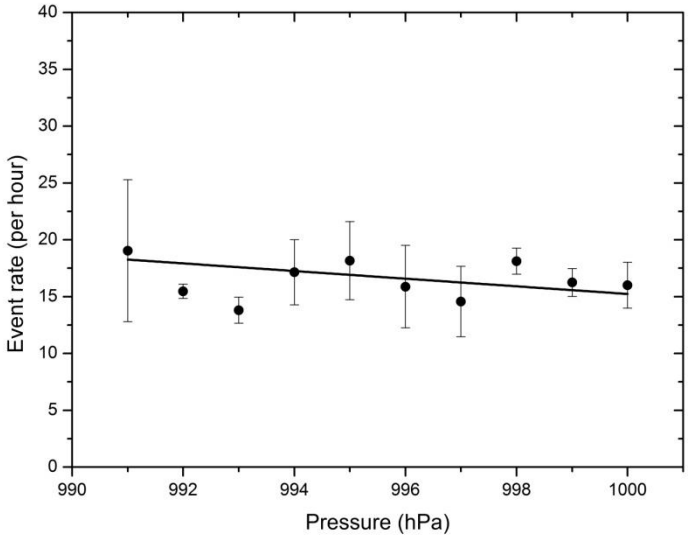

Fig. 4: Variation of event rate with pressure

3.3. Effect of air density

Air density also represents the amount of air overburden on the detector. It has been shown [12] that surface density of air has a negative correlation to Moliere radius, implying a fall in shower rate with increase in density of air. The density of air near the ground is calculated from the relation

$$\rho \approx 348.4 \left(\frac{P}{T}\right) \times 10^{-3} kg\ m^{-3} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

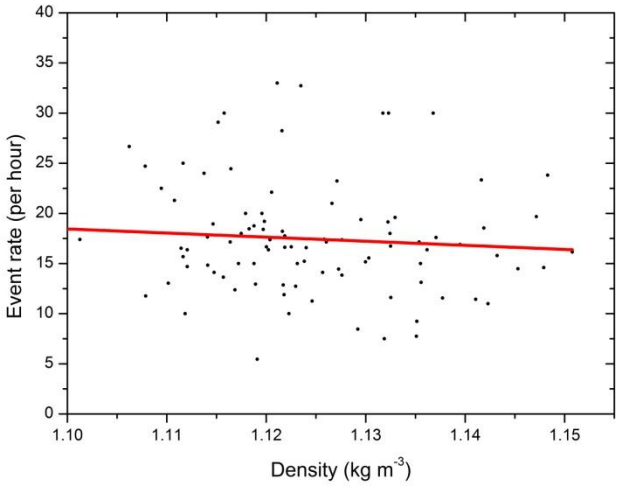

Fig. 5: Variation of event rate with density

The scatter plot of air density versus rate of events is shown in fig. 5. The adjusted R-square value of the fitted curve is found to be = 0.004. The slope of the straight line is found to be $= (-40.7 \pm 53.0)$ per hour per kg per cubic metre. The straight line fit indicates there is a negative correlation between event rate and air density.

3.4. CORSIKA simulation results

Cosmic ray EAS are simulated using a standard code CORSIKA (**CO**smic**R**ay **S**imulations for **KA**scade), which gives the co-ordinates, momenta and the arrival time of secondary particles at the detector level [13]. A FORTRAN code is written to simulate an EAS produced by primary protons with energy greater than the threshold energy, incident vertically on the top of the atmosphere. Threshold primary energy has been estimated by locating core of the shower at the array centre and requiring at least one charged particle (electron, positron or charged muon) to be incident at each detector as predicted by NKG function and Hillas parameters. For the present set-up the threshold energy has been found to be $\sim 500\ TeV$. The EAS core co-ordinates are selected at random within a large area surrounding the square array; and charged particles hitting detector area are counted. If the particle number hitting each detector exceeds the threshold, it is accepted as an event. Knowing the area of random core positions, the effective area is calculated using the fraction of the accepted events. Event rate is estimated by multiplying the primary integral flux by the effective area. For the test setup comprising 4 detectors, each of area $0.25\ m^2$ at the corners of a square of side $14\ m$, the average event rate is found to be ~16 per hour.

4. DISCUSSION

In the present experiment the minimalist version of the array has been used. Only 4 detectors in an array of this size are not expected to give highly accurate data. The PMTs used in the experiment are old. They have been found to get noisy time and again. The control room is not temperature controlled. So the electronic circuitry used in the experiment must have been subject to jitters. So, error levels are high as seen from figs. 4 and 5.

5. CONCLUSION

The test set-up performed on expected lines. It confirms the random nature of cosmic ray showers as is seen from the time-spacing graph. The mean event rate measured by this array is found to be same as that predicted by CORSIKA simulation. The investigation also captures the nature of the variation of count rate with pressure and density. The count variation with air density is also consistent with established theory. It is reasonable to expect that the array will give more reliable data when it is operated at its full potential of 16-detector version, and observations are carried out for a longer period.

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