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Cosmic Ray Showers: Angular Perspective

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Abstract

Angular Flux Distribution of Cosmic rays is measured using two identical plastic scintillators of dimensions 100 x 10 x 1.0 cm^3 each coupled optically to a photomultiplier tubes. The two scintillation counters are mounted on an auxiliary wooden structure that is bilaterally constrained to rotate through angles 0^0, -31^0, -45^0, -60^0, -75^0, -85^0, 29^0, 43^0, 55^0, 77^0, 85^0, and 90^0. One of the counters forms the exterior layer and extends parallel to the other detector that forms the interior layer at a separation distance of 1.5 m. Signals detected from both detectors at a particular angular position are channeled to the Nuclear Instrumentation Modules (NIMs) for discrimination and counting of coincidences.

Standard statistical methods of data analysis are used to calculate the mean and corresponding uncertainties of cosmic – ray flux measurements in every angular displacement of the detector assembly. Results show that the angular flux distribution as measured at the MSU-IIT HEP Laboratory is very nearly proportional to the square of the cosine of the zenith angle.

1. Introduction

Cosmic rays are high-energy subatomic particles that originate from outer space that initiate ionization on the upper atmosphere of the Earth. This ionization produces extensive air showers of secondary particles that, in turn, decay in flight to form the atmospheric muons that traverse the atmosphere in all directions and interact with surface materials

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and even caused tertiary productions of photons, electrons, and hadrons underground. These facts made it possible for such interactions to be detected and measured using proper absorbing materials, detection and measurement system, and techniques of observation.

In this study angular flux distribution of cosmic rays is measured using two identical plastic scintillators of dimensions 100 x 10 x 1.0 cm^3 each coupled optically to photomultiplier tubes. The two scintillation counters are mounted on an auxiliary wooden structure that is bilaterally constrained to rotate through angles 0^0, -31^0, -45^0, -60^0, -75^0, -85^0, 29^0, 43^0, 55^0, 77^0, 85^0, and 90^0. One of the counters forms the exterior layer and extends parallel to the other detector that forms the interior layer at a separation distance of 1.5 m.

2. Research Design and Methodology

Two plastic scintillators are used in the initial stage of detecting and measuring secondary cosmic radiations. Each scintillation detector is coupled to a photomultiplier tube. Figure 1 shows one of the installed scintillation counters.

Figure 1. A pictorial view of one of the installed scintillation counters

2.1 Data Acquisition Technique

The two scintillation counters are mounted horizontally on a supporting wooden stand, such that one sensitive part will face in parallel to the other. A separation distance of 1.5 m is maintained between the detectors. The output terminals of the scintillation counter assembly are attached to the nuclear instrument module (NIM) consisting of the delay, discriminator, coincidence and scaler modules, via small co-axial cables, each of 3 meters length. The scintillation counter wooden support is allowed to rotate from the horizontal through angles -31°, -45°, -60°, 29°, 43°, 55°, 77°, -75°, 85°, -85° and 90° after each count is recorded for every inclination angle. Figure 2 shows one of the experimental set-up.

The logic circuit diagram of the particle detection and measurement system (PDMS) used in the study is shown in figure 3. Data acquisitions are done for at least four days on each rotation. Counts registered in the scaler were recorded on an hourly basis.

2.2 Signal Processing

Scintillators are useless without amplification from the photomultiplier tube (PM-tube). However, photomultipliers used in this study can be operated over a wide range of working voltages extending over 1000 volts up to the maximum rating of 2500 volts. In order for the PM tube to operate precisely an appropriate working voltage must be supplied and this can be determined only through the process called *plateau measurement*. The analog signals from the scintillation detectors are channeled to the Nuclear Instrument Module (NIM), figure 4 shows the NIM used. These distinct electric pulses actually represent the amplified photoemissions coming from cosmic ray particles hitting the detector. Low-level pulses collectively called electronic noise, however, usually accompany these signals and tend to distort them. Hence, a standard logic circuit unit called discriminator is used to select the desired input pulses and eliminate electronic noise by setting the unit to a certain threshold voltage. These discriminators act as the interface between the analog world of the detector and the digital world of logic system. Input pulses whose corresponding energies are lower than the indicated threshold are rejected while pulses whose corresponding energies exceeded or at least equaled the threshold are allowed for subsequent counting.

Figure 2. The Experimental Set-up at the Horizontal Position

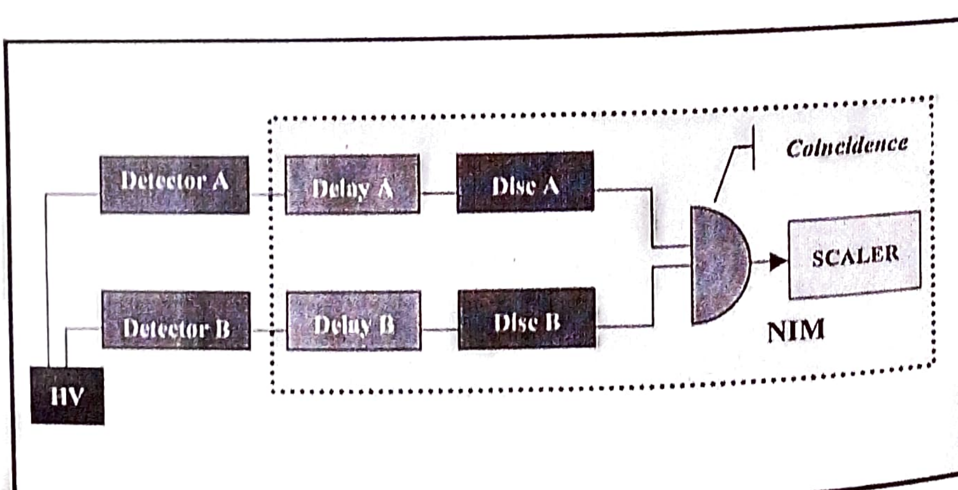

Figure 3. The Logic Diagram for Measuring Cosmic Ray Flux

In this particular study at least two detectors are used to ensure that cosmic rays are the ones detected. This is properly substantiated if the particle of interest is allowed to pass through the primary and secondary detectors and thus generates weak yet amplifiable signals coincidentally. In order to ensure that signals are emanating from both detectors, another standard circuit known as the coincidence module is used. This coincidence unit is responsible for accepting two or more input pulses and conducts signals at its output only if the input pulses arrive at a specified time interval known as the resolving time. In order to register the desired coincidence, detector signals are first allowed to pass through delay lines prior to discrimination process and coincidence counting. Once Proper delays are implemented, signals are then guided to the discriminator, and then to the coincidence unit. Finally, pulses that are observed to be coincident are gated to the output for subsequent recording by the scaler.

Delaying process is typically implemented using coaxial cables and delay module.

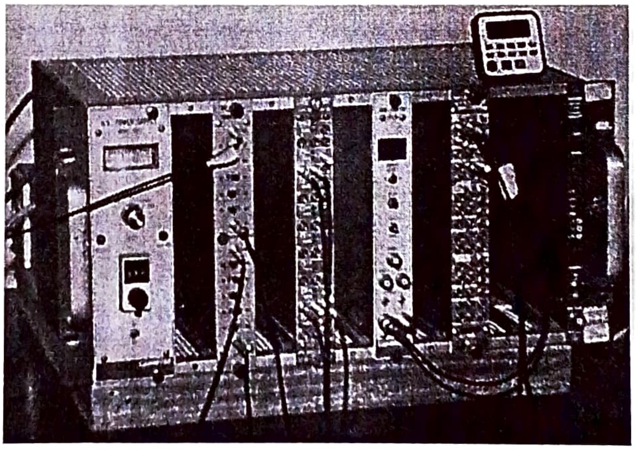

Figure 4. The Nuclear Instrumentation Modules and Power Supply

2.3 Measurement of Cosmic Ray Flux

Measurements of cosmic ray flux proceed right after proper settings for the discriminator threshold and delay modules are established and that stability of the detector assembly is achieved. Plots shown in figure 5 shows the results of the preliminary measurements to have the proper settings.

Counts registered on the scaler on per hour basis are then recorded. To minimize the effects of some power interruptions, the assembly is rotated right after a 23-hour counting is done on a particular angle.

2.4 Background Radiation Determination

The probability of detecting noise coincidence inside the electronics and scintillators and the probability of counting possible hits of different particles on each detectors but not on both that still causes coincidences are determined. This was done by separating the detectors by at least 1.5 m apart horizontally depending on the length of the high voltage cable. Settings that obtained for the operating voltage of the detectors, the threshold voltage for the discriminators, and the delay settings for the delay modules in measuring the flux are still used. Background measurements are done for every angular positions of the detector assembly. This background data acquisition are carried after obtaining cosmic ray flux. Figure 6 shows the experimental set-up during the background count at 90^0 position.

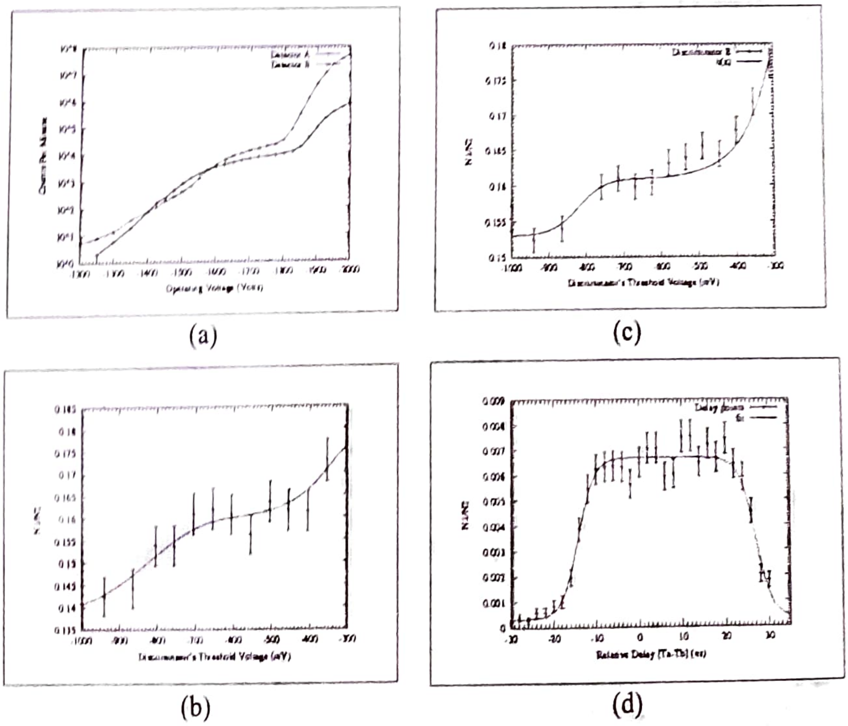

Figure 5. The Preliminary Measurements Results for: (a) Detectors Operating Voltage, (b) Discriminator A's Threshold Voltage, (c) Discriminator B's Threshold Voltage, (d) The Relative Delay.

3. Analysis of Data

The measured fluxes recorded on the scaler on a per hour basis are converted to a per minute basis of measurement, that is, the recorded counts are divided by sixty. They are grouped according to its position. Each group has 23 samples corresponding to the number of per hour measurements taken from 9:00 p.m. to 8:00 p.m. continuously. Using standard statistical tools, the averages and its corresponding errors are taken. The average $\bar{n}$ of each group and the corresponding error s are computed using equation;

$$\bar{n} = \left(\frac{1}{N}\right)\sum_{i=1}^{N} n_i \quad \text{and} \quad \sigma^2 = \left(\frac{1}{N-1}\right)\sum_{i=1}^{N}\left(n_i - \bar{n}\right)^2,$$

where N is the number of samples for the specific hour on both equations and n_i is the data obtained on per minute basis. Table 1 shows the measured values of flux and the background radiation counts in every angle

Flux measured still includes background radiation, background radiation then is measured using same settings used in flux measurements just as the detectors are separated in at least 1.5 m horizontally. The data obtained are then subtracted to the measured flux to come up a corrected flux values, table 2 shows the results for the corrected values of flux.

Direct examination of the fluxes presented in table 1 revealed that cosmic ray flux decreases with increasing angles of detectors with respect to the horizontal.

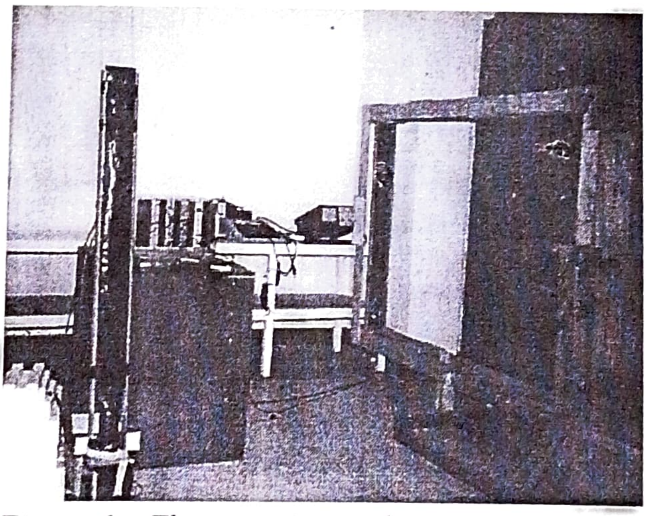

Figure 6. The experimental set-up during the background count at 90⁰ position.

3.1 Estimated Flux

A rough estimate of the solid angle is done to check the measured flux. This estimate proceeds by considering the set-up as contained by spherical enclosure of radius equal to the distance from the center of the top counter to one corner of the bottom counter. The set-up can only subtend a fraction of the 4π-geometry and let us call the fractional solid angle it subtends as

$\Delta\Omega$, where $\Delta\Omega = \frac{10x100}{4\pi R^2} 4\pi = 0.039 sterad$.

The flux per unit solid angle per unit horizontal area per unit time about the vertical direction, I_v is equal to 0.66 $cm^{-2}min^{-1}sterad^{-1}$.

$$Flux_{(estimate)} = \Delta\Omega x I_v x (100x10)$$
$$Flux_{(estimate)} = 26.37\ min^{-1}$$

This estimated flux accounts only for the horizontal detectors. Analytical calculation of the angular flux distribution of cosmic rays is quite mathematically involved. However, Rossi (1947) showed that most muons arriving at the ground with mean energies of ~3Gev have overall angular distribution nearly proportional to $\cos^2\theta$, where θ is the zenith angle. To make matters more convenient we use the intensity relation for I, as $I(\theta) = I_v \cos^2\theta$ to estimate flux at different distributions used in the experiment. Table 2 then shows the results for the estimates.

Table 1. The measured values of flux and the background radiation counts in every angle.

Angle	Measured Flux, $\overline{n}_m$	Background Flux, $\overline{n}_b$
90	3.8490 ± 0.0645 min^{-1}	1.2658 ± 0.3128 min^{-1}
85	3.8520 ± 0.0777 min^{-1}	0.9361 ± 0.1337 min^{-1}
77	4.4844 ± 0.0904 min^{-1}	1.0255 ± 0.1162 min^{-1}
55	8.8831 ± 0.1767 min^{-1}	0.8257 ± 0.5684 min^{-1}
43	14.2361 ± 0.1842 min^{-1}	0.7854 ± 0.6857 min^{-1}
29	19.9591 ± 0.3388 min^{-1}	0.7824 ± 0.8975 min^{-1}
0	26.2322 ± 0.2701 min^{-1}	0.7652 ± 0.8542 min^{-1}
-31	20.0725 ± 0.4347 min^{-1}	1.0216 ± 0.0053 min^{-1}
-45	13.2335 ± 0.1964 min^{-1}	0.9024 ± 0.8977 min^{-1}
-60	7.1413 ± 0.1022 min^{-1}	1.1170 ± 0.9588 min^{-1}
-75	4.7899 ± 0.1486 min^{-1}	1.0185 ± 0.0109 min^{-1}
-85	3.8672 ± 0.0623 min^{-1}	0.9236 ± 0.0119 min^{-1}

Table 2. The Cosmic Rays Corrected and Estimated Flux Values in every angle.

Angle	Final Measured Flux, $\overline{n_f}$	**Estimated**
90	2.5832 ± 0.3194 min^{-1}	0
85	2.9159 ± 0.1546 min^{-1}	0.2230 min^{-1}
77	3.4589 ± 0.1472 min^{-1}	1.3344 min^{-1}
55	8.0574 ± 0.5952 min^{-1}	8.6755 min^{-1}
43	13.4507 ± 0.7100 min^{-1}	14.1047 min^{-1}
29	19.1767 ± 0.9593 min^{-1}	20.1720 min^{-1}
0	25.4670 ± 0.8959 min^{-1}	26.3700 min^{-1}
-31	19.0509 ± 0.4347 min^{-1}	19.3750 min^{-1}
-45	12.3311 ± 0.9189 min^{-1}	13.1850 min^{-1}
-60	6.0243 ± 0.9642 min^{-1}	6.9950 min^{-1}
-75	3.7714 ± 0.1490 min^{-1}	1.7665 min^{-1}
-85	2.9436 ± 0.0634 min^{-1}	0.2230 min^{-1}

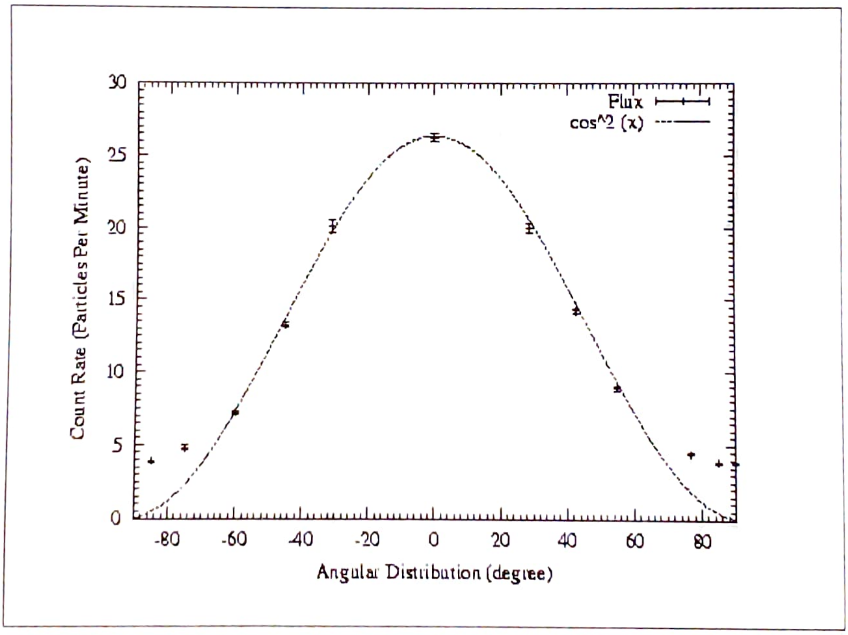

Figure 7. The Angular Distribution of Flux.

Comparison of the fluxes presented in tables 1 and 2 show that at shallow angles of 0^0 to 55^0 measured flux values followed closely the estimated flux values. But as angles grow steeper from 75^0 to 90^0 measured flux values diverged quite significantly from the estimated flux values. The results also proceeded to show that actual measurement of cosmic – ray flux at large zenith angles do not diminish to zero as estimated. It should be noted that the measured flux values indicated by data points with error bars fitted well with the solid $\cos^2\theta$ curve except at tail ends where divergence becomes noticeable.

4. Conclusion

Cosmic ray flux as measured at different angles done in the MSU – IIT HEP Laboratory shows that by direct examination of the fluxes, the data reveals that cosmic ray flux decreases with increasing inclination angles of the detectors with respect to the horizontal.

Measured or corrected flux values agree closely with the estimated flux values at shallow angles but diverge at steeper angles. The results show that particles entering at large zenith angles register themselves consistently throughout the counting period instead of vanishing as estimated. The abrupt change at the tail ends then could be attributed to some unexpected particles coming from unknown secondary sources, fig. 7. T.K. Gaisser and T. Stanev, however, pointed out that muons entering at 90° zenith angle are not uncommon occurrence only that they do not originate from atmospheric muon production but rather from charge-current interactions of muon neutrinos.

5. Acknowledgement

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