Cosmic Rays

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Abstract

In this paper, cosmic rays are detected at varying zenith angles in order to measure the zenith angular-distribution of cosmic rays. The detector setup consists of two long scintillator paddles with photo-multiplier tubes (PMT). Counts for cosmic rays require double coincidence in the scintillators. In performing this experiment, we show agreement with literature that the flux of cosmic rays is proportional to $I_{vert}cos^2(\theta)$.

1 Introduction

Cosmic rays are sub-atomic particles traveling at near light speed through space. They originate from celestial bodies within and outside our galaxy. Cosmic rays have been a resource of energetic particles for high energy physics experiments because they can exceed energies from particle accelerators [2]. Examples of cosmic rays include electrons, protons, photons, and atomic nuclei such as helium.

When cosmic rays interact with the Earth's atmosphere they produce showers of secondary particles. Majority of these secondary particles are deflected back into space; the ones that make it to earths surface consist mostly of muons. Muons are highly energetic and penetrative particles that can be used for imaging large dense objects.

The intensity of cosmic rays depends on the zenith angle (θ) and is known to follow $I(\theta) = I_{vert} \times cos^2(\theta)$ with $I_{vert} = 0.01 \, \frac{\text{particles}}{\text{sec}\times\text{cm}^2\times\text{steradians}}$ at sea level [5]. In many experimental results, this relation doesn't exactly hold with over counting at low zenith angles and under counting at high zenith angles. To improve on this, one can consider an effective solid state angle based on the configuration of the detector [1]. The aim of this experiment is to show the zenith angle-dependence for the flux of cosmic rays and to give a value of I_{vert} in Fort Collins.

2 Experimental Techniques

2.1 Setup

Figure 1: Front view of cosmic ray detector setup

Figure 2: Side view of cosmic ray detector setup

2.2 Parts and Equipment [5]

- Scintillator paddles with photomultipliers (PMT) with positive HV and signal output connectors.
- Stanford Research Systems (SRS) power supply
- LeCroy 825 discriminators octal module
- Phillips 752 Logic quad module
- Ortec 974 scaler counters
- Textronix digital scope

2.3 Power Supply [5]

The SRS power supply allows us to adjust the voltage going into the PMT. The applied voltage may be positive or negative depending on the switch on the power supplies rear. Check that the power is off, then make sure this switch is set to positive. Connect the PMT's with red high-voltage (HV) cables by plugging them into the connectors located at the back of the SRS power supply.

2.4 Operating PMT's [5]

Now that we have connected the PMTs to the power supply, continue by connecting the oscilloscope input to the PMTs. Proceed using the following steps.

1. Turn on the scope, choose channel 1 to display to and trigger. For channel 1 set: $gain = 20\,\frac{\text{mV}}{\text{cm}}$ and $Probe = 1X$, for the horizontal menu set $timebase = 100\,\frac{\text{ns}}{\text{cm}}$ and Trig menu to $trigger = normal$, $triggerlevel = -25\,\text{mV}$, $triggerslope = negative$, $coupling = DC$, $Type = edge$.
2. Set the SRS voltage to $1200\,\text{V}$, the current should be $\approx 0.25\,\text{mA}$. Cosmic rays will appear on the scope as negative signals.
3. A signal on the scope should be $\approx 50\,\text{mV}$ so setup the scope with channel 1 at $50\,\frac{\text{mV}}{\text{Div}}$, time base $100\,\frac{\text{ns}}{\text{Div}}$ and the trigger at $-20\,\text{mV}$.
4. Check for light leakage into the scintillator by covering the paddles. If there is a noticeable difference in signal when covered then you are leaking light and must better wrap the paddles to fix this.

2.5 Digital Electronics Module [5]

In the crate directly below the oscilloscope there are three modules. Ortec scaler, Phillips Logic module, and the LeCroy discriminator.

The LeCroy discriminator takes input pulses from the PMT and checks if that pulse exceeds the set threshold. If the input pulse exceeds the threshold, a true signal is returned by the discriminator. Otherwise a false signal is returned. This threshold can be adjusted with the THR screw and the ouput pulse width can be adjusted with the WIDTH screw. Set these accordingly so you are sure that you are reading cosmic rays.

The Philips logic compares the two pulses from the PMT's to verify that both paddles were triggered before making a count.

The ORTEC scaler counts pulses and time in different channels. You can switch the display to each channel and reset the counts. Each count measures the coincidence between two scintillator paddles.

2.6 Data Taking

At this point we are ready to begin taking data. When taking data we considered time intervals of 30 seconds to allow for sufficient detection at high zenith angles. Using geometry arguments, we can find the angular resolution of our setup and increment our zenith angles accordingly. For each angle, take twenty 30 second runs and record the measured counts. Cleaned the data by removing the two highest counts and the lowest two counts in attempt to remove outliers without bias since they might skew our data.

3 Data Analysis and Results

Table 1 below shows the dimensions of the scintillator paddle setup.

Length	$(30.48 \pm 0.01)\,\mathrm{cm}$
Width	$(7.50 \pm 0.01)\,\mathrm{cm}$
Seperation	$(19.05 \pm 0.01)\,\mathrm{cm}$

Table 1: Dimensions of detector setup

Table 2 below shows the averaged data of twenty runs for each angle measurement after removing the outlying 20% of points. The raw data can be found in [3].

Zenith Angle	Average Count
$0°$	(5.5 ± 0.586) counts
$15°$	(4.6 ± 0.534) counts
$30°$	(3.0 ± 0.433) counts
$45°$	(1.875 ± 0.342) counts
$60°$	(1.563 ± 0.313) counts
$75°$	(1.438 ± 0.300) counts
$90°$	(0.813 ± 0.225) counts

Table 2: Average counts at varied zenith angle

This reported uncertainty assumes that the counts follow a Poisson distribution so the uncertainty in counts for a large number of runs is just given as $\frac{\sqrt{N}}{\#runs}$ where N is the sum of counts at a specified angle.

Using the data from table 1, we can estimate the steradians of our setup at $0°$. Then use this to calculate a value of I_{vert} in Fort Collins. An estimate for the solid state angle is given as

$$\Delta\Omega \approx \frac{Length \times Width}{Seperation^2}[4] = \frac{30.48 \times 7.5}{19.05^2} \tag{1}$$

The uncertainty in $\Delta\Omega$ is given as

$$\delta\Delta\Omega = \Omega\sqrt{(\frac{\delta length}{length})^2 + (\frac{\delta width}{width})^2 + (\frac{\delta seperation^2}{seperation^2})^2} \tag{2}$$

Putting this together with $\delta seperation^2 = seperation^2\sqrt{2 \times (\frac{\delta seperation}{seperation})^2} = 0.270$ gives us a $\Delta\Omega = (630 \pm 0.98) \times 10^{-3}$ steradians

Now we can give a measured I_{vert} for Fort Collins.

$$I_{vert} = \frac{5.5\,\text{particles}}{30\,\text{sec} \times 228\,\text{cm}^2 \times 0.630\,\text{steradians}} \tag{3}$$

With uncertainty

$$\delta I_{vert} = I_{vert}\sqrt{(\frac{\delta particles}{particles})^2 + (\frac{\delta sec}{sec})^2 + (\frac{\delta length}{length})^2 + (\frac{\delta wdith}{width})^2 + (\frac{\delta\Omega}{\Omega})^2} \tag{4}$$

This gives us an estimated value of $I_{vert} = (0.00128 \pm 0.000138) \frac{\text{particles}}{\text{sec} \times \text{cm}^2 \times \text{steradians}}$ which is about a factor of 10 from the expected value. This discrepancy comes from the fact that the used solid angle was an estimate for when the separation is much more than the dimensions of the paddles which is not the case here.

Plotting the averaged counts over each angle bin and comparing to cos^2 gives the following plot below.

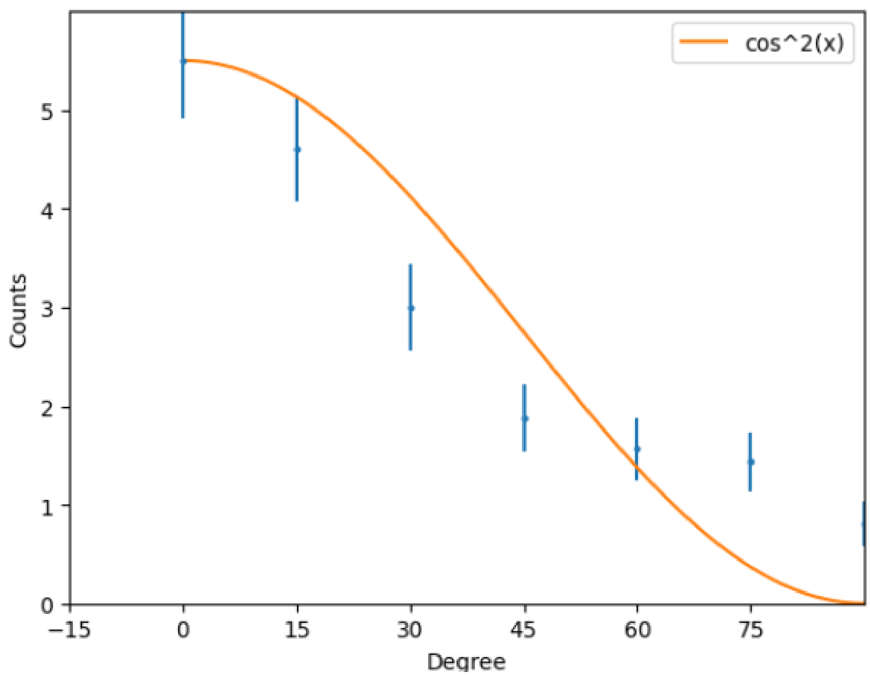

Figure 3: Measured data vs cos^2

It is easy to see that the acquired data fits the expected trend of cos^2.

4 Discussion

In this paper, we count cosmic rays using scintillation detectors. We report data from 0° to 90° in 15 degree increments. Each degree bin consisted of twenty 30 second runs; reduced to 16 runs after data cleaning. We then average the results for each degree bin and graph the zenith angle relation. According to literature, the flux of cosmic rays is proportional to $I_{vert}cos^2(\theta)$ [5]. Figure 3 shows this proportion was also seen in our experiment. The I_{vert} value found in this paper is reported as $I_{vert} = (0.00128 \pm 0.000138)\,\frac{\text{particles}}{\text{sec}\times\text{cm}^2\times\text{steradians}}$. This value is about a factor of 10 less than the expected value and is outside reason. Further analysis of the setup's geometry is required to make a more accurate calculation as the steradians reported was calculated using an approximation which did not hold (as our dimensions were bigger than the separation).

References

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[4] E Harpell, W Langeveld, D McShurley, S Shapiro, and J Venuti. The ccrt: An inexpensive cosmic ray muon detector.

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