# Method of Cosmic Ray Flux

**TURO, B**[*,1]

[1] *Physics Department, Florida International University*
[*] *Corresponding author: bturo001@fiu.edu*

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**Cosmic rays are high energy elementary particles and nuclei which travel through space at high velocities. By using two photo-multiplier tubes (PMTs) it was possible to determine the cosmic ray flux by plotting a flux vs angle measurement. An approximate rate of** $0.92\ cos^2(\theta)\ cm^{-2}min^{-1}$**, where** $\theta$ **is the azimuthal angle with respect to the vertical direction, was determined through a fit.**

## 1. INTRODUCTION

### A. Cosmic rays

Cosmic rays can be split into several categories, primary cosmic rays are composed of protons and alpha particles (99%) and a small amount of heavier nuclei such as carbon and iron ($\approx$ 1%). Primary cosmic rays are generally extra-solar but, are also produced in the solar system especially during solar eruptions [1]. Occasionally primary cosmic rays interact with the atmosphere and cause a cascade of reactions leading to secondary "cosmic rays" which includes x-rays, protons, alpha particles, neutrons and charged mesons. Of particular abundance are electrons, muons, and neutrinos which decay from charged mesons [2] as shown in fig. 1 :

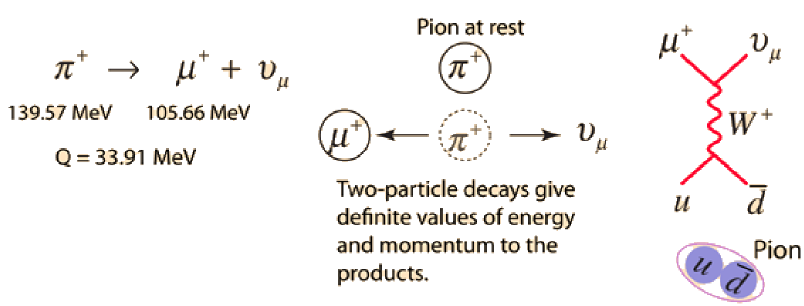


**Fig. 1.** Pion decay producing a muon and muon neutrino

This is supported by the fact most of the cosmic rays observed at sea level are muons.

### B. Cosmic ray detection

These particles are detected in various ways including cloud chambers, bubble chambers, water-Cherenkov or scintillator detectors. Scintillator detectors function based on materials that elicit a photo-luminescence. Organic scintillators are based on molecular orbitals whereas inorganic scintillators are based on the electronic band structure found in crystals. A Bicron BC 400 series plastic scintillator was used to conduct this experiment. [3]

Since the scintillator releases weak optical signals it is important to exclude external sources by covering it. To register detection a photo-multiplier tube is used as an optical amplifier. As demonstrated in fig. 1 the weak optical source from the scintillator strikes the photocathode and, due to the photoelectric effect, electrons are ejected from the photocathode. These electrons are lead through a electron multiplier which uses secondary emission to multiply the number of electrons in the path. PMTs require high voltage supplies to provide the necessary voltage distribution across each dynode and for secondary emission to occur.

### C. Signal processing

Signals from the PMT are not directly used, instead they are passed through a Nuclear Instrumentation Module (NIM) bin which is a standard for electronic modules. The NIM bin used includes a fan out, discriminator, coincidence, and counting module. Fan out modules are used to duplicate signals. A discriminator is used to apply a threshold on a signal source only allowing voltages above said threshold, this is used to remove noise. A coincidence module outputs the result of an AND operation on two signals. The coincidence module is used to confirm that a particle passed through both PMTs. Lastly, a counting module counts how many coincidences we have.

## 2. SET-UP AND CALIBRATION

To capture all photo-luminescence from our scintillator, the photomultiplier tube must be calibrated to an optimal voltage. Using a known source such as Sr-90 capable of providing large quantities of detections a plot of counts vs voltage was measured for both PMTs which will be labeled A and B.

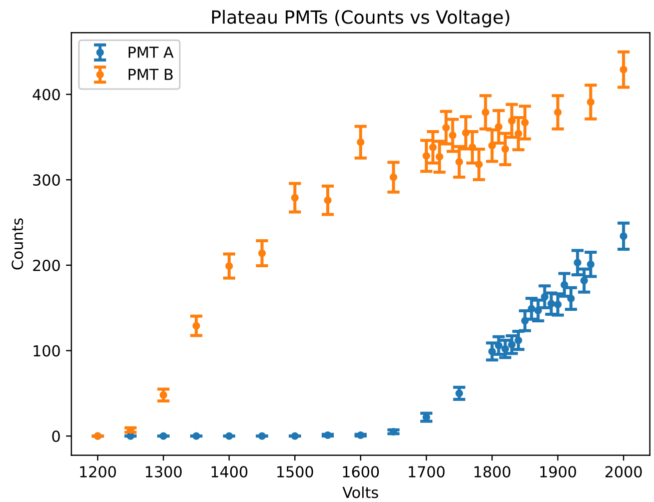


**Fig. 2.** PMT calibration using a Sr-90 source, plateaus can be noticed around 1800 V

At some point, voltage no longer increases the number of counts and that is the optimal voltage. A bias towards PMT A was noticed which affected future measurements.

## 3. POISSON AND GAUSSIAN DISTRIBUTIONS FROM SR-90

Since decay from Sr-90 is a random process, the central limit theorem explored in Monte Carlo [4] leads to normalized data suggesting a method of validating our detection. One PMT was used to detect a small and a large number of counts from the Sr-90 source, this data was plotted with a histogram and fitted.

The data closely resembled respective Poisson and Gaussian distributions which suggests proper measurement of decay particles.

## 4. SIMULATION OF COSMIC RAY FLUX

In appendex A. of [3] a method of calculating cosmic ray rate is described in the C programming language. Simulating a ray passing through two parallel plates cosmic ray flux can be calculated.

## 5. EXPERIMENTAL RESULTS OF COSMIC RAY FLUX

Using two parallel PMTs mounted on a rotating apparatus, data at various angles was collected for 20 minutes each. In fig. 7 degrees 0 through 90 have higher counts due to the previously

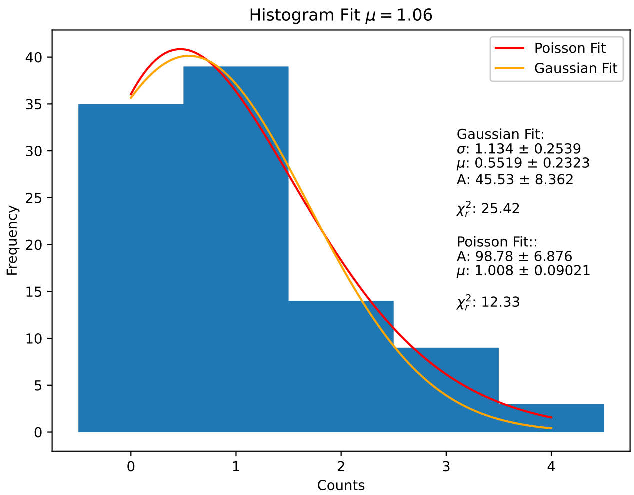


**Fig. 3.** Poisson and Gaussian distribution obtained from Sr-90 source with a $\mu = 1.06$

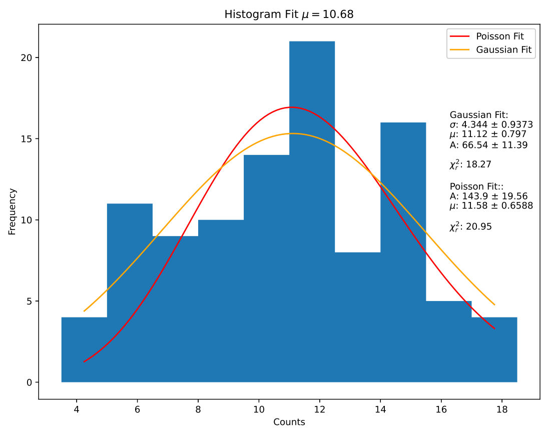


**Fig. 4.** Poisson and Gaussian distribution obtained from Sr-90 source with a $\mu = 10.68$

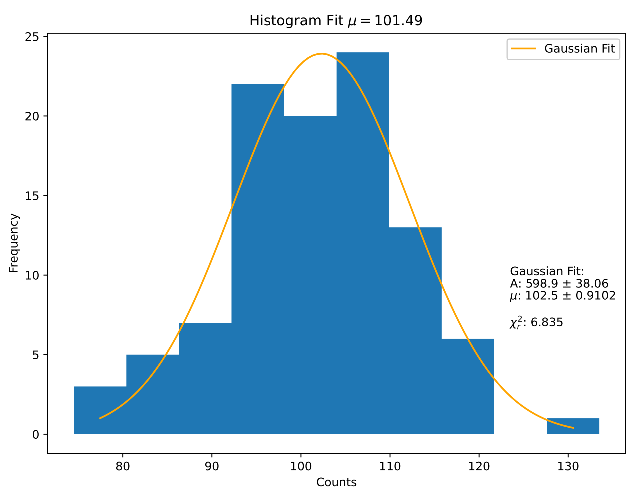


**Fig. 5.** Gaussian distribution obtained from Sr-90 source with a $\mu = 101.49$

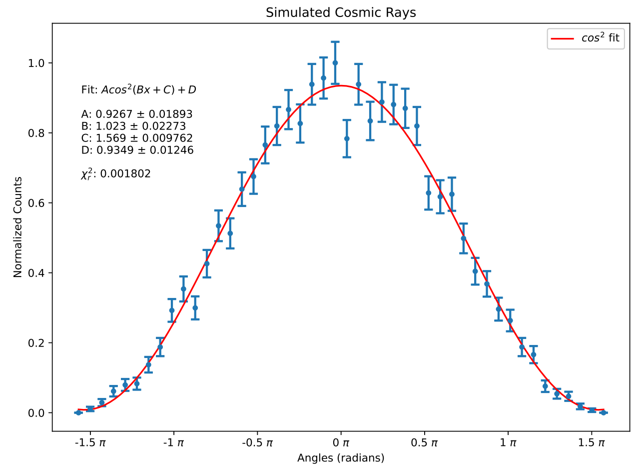


**Fig. 6.** Simulated data using two parallel plates and Monte-Carlo techniques

mentioned bias towards PMT A. Experimental data closely matched simulated data. This is confirmed through fitted parameters A,B,C,D for the function $Acos^2(Bx + C) + D$. The data is normalized to easily compare between simulated and experimental data.

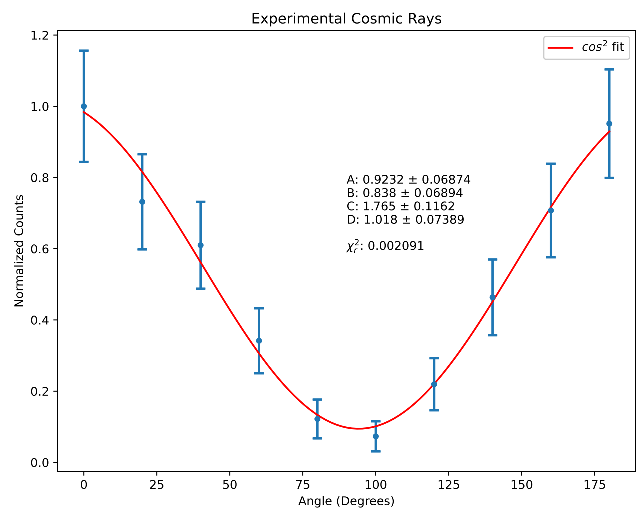


**Fig. 7.** Experimental results obtained from rotating parallel PMTs

## 6. ERROR ANALYSIS

### A. Calculation of uncertainties

For figs. [2,6,7,8] the uncertainty stems from the square root of the counts.

### B. Observed bias from coincidence module

On the coincidence counter, input B must be delayed 5 ns [5] with respect to input A. PMT B had less counts than PMT A, this bias could have led to the discrepancies by the coincidence counter. Due to the pulse shaping and AND logic techniques used by the coincidence module, if input A and B are not correctly utilized there will be false-positives in the coincidence counts and lead to an increase in counts. This bias is demonstrated in fig. 8

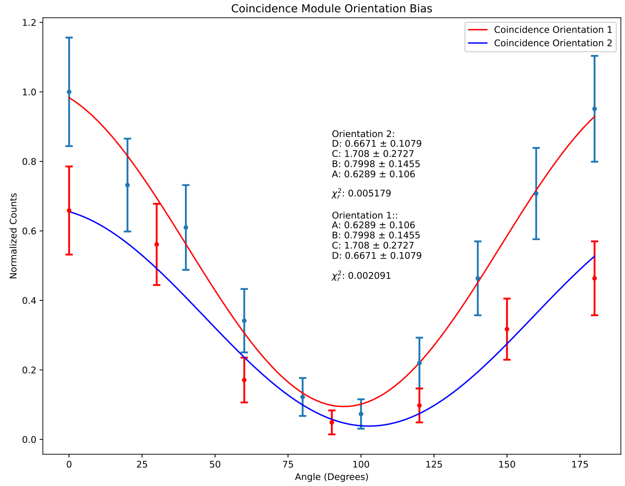


**Fig. 8.** Observed non-negligible bias originating from exchanging input A and input B on the coincidence module

## 7. CONCLUSION

Our analysis of cosmic ray flux coincided with our simulation very closely. A relationship for the flux was determined to be $f(\theta) = A * cos^2(\theta)$. Two primary biases were found to exist: PMT bias and coincidence counter connection preference. The flux found was slightly higher than 0.66, most likely due to environmental factors such as altitude, room radiation and more.

## REFERENCES


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