Cosmic Ray Muon Detection

Measurements of Cosmic Ray Muon Flux and Muon Lifetime Using Scintillation Detectors

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Muons are created in the upper atmosphere of the Earth by **cosmic rays**, which are mostly protons that come from outer space. When a high-energy proton hits one of the nuclei of the atmospheric gas molecules, it creates an "**air shower**." In an air shower, different subatomic particles are created, including pions, which then decay into muons. These highly energetic muons interact only weakly with the air and have a mean lifetime long enough for some to arrive at the Earth's surface, where they can be detected.

Figure 1: Development of Cosmic Ray Air Shower

Figure 2: Cosmic Ray Air Shower

Project Summary

Using a setup of two scintillation detectors:

- **Flux**
- **Count rate**
- **Energy variation** of muons originating from cosmic ray air showers are investigated.

The factors considered are:

- **Amount of material muons travel through**
- **Zenith angle**
- **North-South (NS) vs. East-West (EW) orientation**
- **Setup configuration of the detection system (overlap area and separation distance)**

Additionally, the method of detection allowed for verification of the theoretical value for the **muon lifetime**.

Setup Specifications

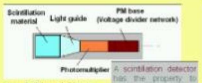


Figure 3: Schematic Diagram for the Scintillators

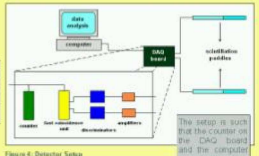


Figure 4: Detector Setup

The technique of recording "coincidences"

- **Results in elimination of background noise**
- **Offers a great number of possible experiments**

Background Concepts

Flux

Muons reach the surface of the Earth with typically constant flux F_μ:

$$F_\mu = \frac{\text{(count rate)}\, d^2}{\text{(area of top panel)(area of bottom panel)}}$$

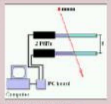


Figure 5: Detector Setup

[Horizontal detectors]
$F_\mu = 0.48\ cm^{-2} min^{-1} sterad^{-1}$ (PDG theoretical value)
Count rate: $0.585 cm^{-2} min^{-1}$ (for horizontal detectors)
Our experimental value: 36min^{-1} (8% efficiency)

The flux varies with zenith angle θ as:

$F_\mu \sim \cos^2\theta$

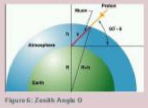


Figure 6: Zenith Angle θ

Results

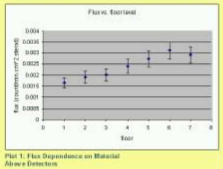
Investigation of Flux Variation

- With material above detectors

Data were collected on the 7 different floors* of Crawford Building, on the Florida Tech Campus

* All measurements were taken along the same vertical axis, except for the one on the 7th floor

Figure 7: 7th floor, Crawford Building, Florida Tech Campus



Plot 1: Flux Dependence on Material Above Detectors

- With zenith angle

A rotational mount was constructed that allowed variation of the zenith angle of the setup keeping all other parameters constant.

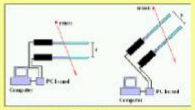
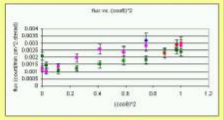
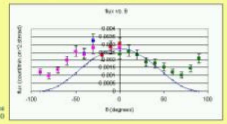


Figure 8: Rotation Configuration



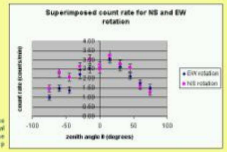
Plot 2: Flux Dependence on Zenith Angle θ



Plot 3: Flux Dependence on Cosine Squared of Zenith Angle θ

- With NS vs. EW orientation

Data were collected for a 180-degree rotation, first in an EW, and then in a NS orientation.



Plot 3: Flux Dependence on Cosine Squared of Zenith Angle θ

- With overlap area

The measurement was conducted to confirm the independence of flux with detection area, as well as to define any possible non-uniformities in the active area of the scintillation paddles.

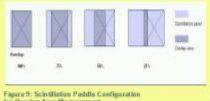
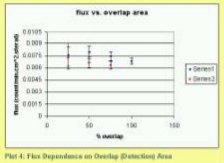


Figure 9: Scintillation Paddle Configuration for Overlap Area Measurement

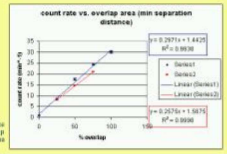


Plot 4: Flux Dependence on Overlap (Detection) Area

Investigation of Count Rate Variation

- With overlap area

The measurement was conducted to confirm the linear dependence of count rate with detection area.



Plot 5: Count Rate Dependence on Overlap (Detection) Area

- With separation distance d between the two paddles

The paddles were placed in a rectangular arrangement. The active area (horizontal) was kept constant (l x l), and the separation distance d was altered in multiples of l.

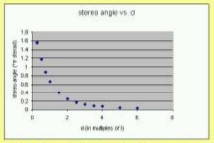
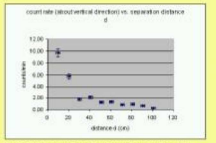


Figure 10: Theoretical Dependence of Stereo Angle,* Calculated Using Mathematica Integral Output



Plot 6: Experimental Count Rate Dependence on Separation Distance d

* Count rate is proportional to the stereo angle viewed along a specific direction

Investigation of Energy Variation

Using a **QuarkNet DAQ v.1 board**, low energy (decaying) muon events on the computer. These events are called "**doubles**."

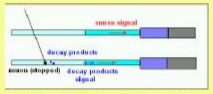
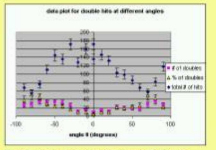


Figure 11: Coincidence Event from a Decaying Muon, Recorded as a Double Event



Plot 7: Double Event Flux Dependence on Zenith Angle θ

Muon Lifetime Measurement

The muon lifetime was calculated using the QuarkNet DAQ v.1 board data for double events. The decay time $t_{N/e}$ of an initial sample N_0 of **decaying** muons was recorded. N(t) was plotted and the data were fitted to an exponential curve of the form:

$N(t) = N_0 e^{-t/T}$

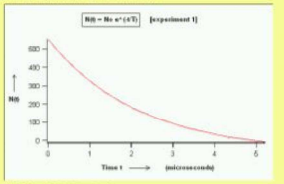
where T = muon lifetime

Results:

Fit line:
y = -63.056 + 616.791e^(-0.4550x)

Lifetime T:
T = 2.1906μs

Theoretical lifetime T_0:
T = 2.1970μs



Plot 8: Muon Lifetime Experiment Curve

Photos

Looking for Coincidences

Rotation Mount and Setup for Flux Measurement

Rotation Mount

Recording Data Using QuarkNet DAQ v.1 board

Flux Measurements, Ground Floor of Crawford Building

References
- http://pdglbl.gov/2002comp.pdf
- http://www2.slac.stanford.edu/vvc/cosmicrayintro.html
- http://cosmus.physics.adelaide.edu.au/astrophysics/muon/

Presenter will be available for discussion from 6:30pm to 7:30pm