Prelab 2: Cosmics

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1.

This lab main physics concepts are cosmic radiation, and cosmic rays. Specifically cosmic muon-rays are the subject of interest. Cosmic rays are basically are electromagnetic radiation and high energy that can come from astrophysical processes within our solar system and external. They can also bombard earths atmosphere. Cosmic rays, have two types of classifications primaries and secondaries. Primaries are cosmic rays made up of electrons, protons, helium and other nuclei synthesised in star processes, supernova, suns, and pulsars. Secondaries are basically the cosmic rays that are formed based on interactions of primaries and intergalactic gases. They can be made up of muons, also electrons, positrons, nuclei like beryllium and lithium. Now at cosmic muon-rays as addressed earlier they are secondaries and what we are studying today in lab. Muon's themselves are produced by pion and kaon decay. Also they can enter the earth at different zenith angles which has effects from special relativity, other particle interactions in the atmosphere that mainly affect lifetime of existence and how far they take to reach the earth. In this lab we are measuring mainly angular distributions and their lifetimes. We accomplish this by using a scintillating telescope, PMT tubes, TAC. So basically a trial run of data will look like muon and their decays go through scintillation process and through PMT tubes if they pass a specific threshold voltage and by different delay processes we then get coincidence and random measurements (King). (Word Count: 238)

2.

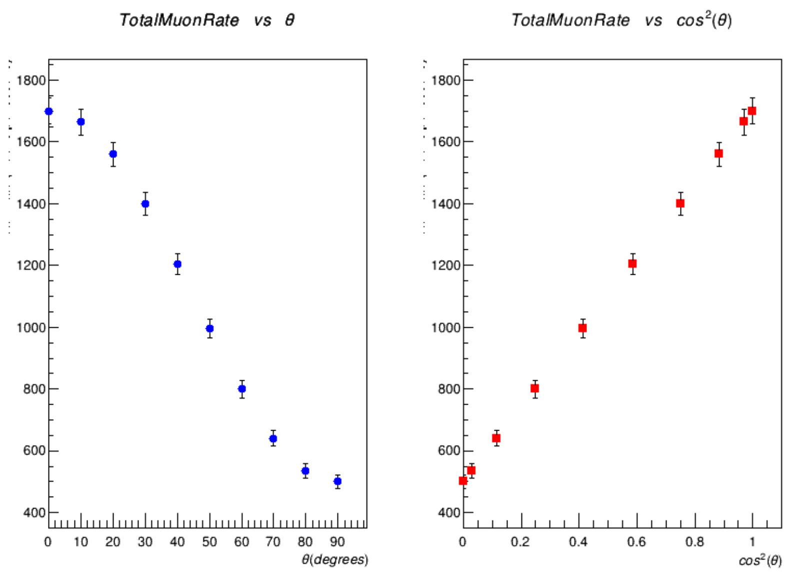

Figure 1: Plots showing the total muon rate vs θ (left) and total muon rate vs $\cos^2(\theta)$ (right).

Equations for Muon Rate Calculation

The **true muon rate** as a function of the angle θ (in degrees) is given by:

$$R_{\text{true}}(\theta) = R_{\text{vertical}} \cdot \cos^2(\theta) \tag{1}$$

where $R_{\text{vertical}} = 1200$ muons per second is the true muon rate when the telescope is vertical.

The **total rate** you will measure is the sum of the true muon rate and the random coincidence rate:

$$R_{\text{total}}(\theta) = R_{\text{true}}(\theta) + R_{\text{random}} \tag{2}$$

where $R_{\text{random}} = 500$ muons per second is the random coincidence rate, which does not depend on the angle.

The **error** in the total rate, assuming Poisson statistics, is:

$$\sigma_{R_{\text{total}}} = \sqrt{R_{\text{total}}(\theta)} \tag{3}$$

```cpp
double total_rates[num_points]; // Total rates (true rate + random coincidences)
double errors[num_points]; // Error in total rates (sqrt of rate)
const double random_rate = 500.0; // Random coincidence rate (constant)
const double true_rate_vertical = 1200.0; // True muon rate when telescope is vertical

// Compute rates at each angle (in steps of 10 degrees)
for (int i = 0; i < num_points; i++) {
    double theta_deg = i * 10.0; // Angle in degrees
    double theta_rad = TMath::DegToRad() * theta_deg; // Convert to radians for calculation

    // Using degrees for cos²(theta)
    double cos_theta = TMath::Cos(theta_rad); // cos(theta)
    double cos2_theta = cos_theta * cos_theta; // cos^2(theta)

    // True rate at this angle
    double true_rate = true_rate_vertical * cos2_theta;

    // Total rate (true + random)
    double total_rate = true_rate + random_rate;

    // Set values
    angles[i] = theta_deg;
    cos2_angles[i] = cos2_theta;
    total_rates[i] = total_rate;
    errors[i] = TMath::Sqrt(total_rate); // Poisson error: sqrt of total rate
}

// Create canvas
TCanvas *c1 = new TCanvas("c1", "Muon Rate Distribution", 800, 600);
c1->Divide(2,1); // Divide canvas into 2 parts for two plots

// Graph for muon rate vs angle (in degrees)
c1->cd(1);
TGraphErrors *gr1 = new TGraphErrors(num_points, angles, total_rates, 0, errors);
gr1->SetTitle("Total Muon Rate\t vs\t \\theta;\\theta (degrees);\tTotal Rate (muons per second)");
gr1->SetMarkerStyle(20);
gr1->SetMarkerColor(kBlue);
gr1->GetYaxis()->SetTitle("Total Rate (muons per second)");  // Set Y-axis label with units
gr1->GetXaxis()->SetTitle("\\theta (degrees)");  // Theta for X-axis (in degrees)
gr1->Draw("AP");

// Graph for muon rate vs cos^2(theta)
c1->cd(2);
TGraphErrors *gr2 = new TGraphErrors(num_points, cos2_angles, total_rates, 0, errors);
gr2->SetTitle("Total Muon Rate\t vs\t cos^{2}(\\theta);cos^{2}(\\theta);Total Rate (muons per second)");
gr2->SetMarkerStyle(21);
```

Figure 2: ROOT code used to calculate and plot the muon rate distribution as a function of θ and $\cos^2(\theta)$.

3.

General Equations

The Time to Analog Converter (TAC) outputs a voltage proportional to the time between start and stop signals. This voltage is then read by the Analog to Digital Converter (ADC). The relevant equations are:

$$V_{\text{TAC}} = V_{\max} \cdot \frac{t_{\text{measured}}}{t_{\text{full}}} \tag{4}$$

$$D_{\text{ADC}} = (2^n - 1) \cdot \frac{V_{\text{TAC}}}{V_{\text{ADC}}} \tag{5}$$

Where:

- t_{measured}: Time measured by the TAC (start-stop duration)
- t_{full}: Full range of TAC (max duration)
- $V_{\max}$: Max TAC output voltage
- V_{TAC}: Voltage output by the TAC
- V_{ADC}: Full voltage range of the ADC
- n: Number of bits of the ADC

1 Part (a)

For this case:

$$t_{\text{measured}} = 4\,\mu\text{s}, \quad t_{\text{full}} = 6\,\mu\text{s}, \quad V_{\text{ADC}} = 12\,\text{V}, \quad V_{\max} = 8\,\text{V}, \quad n = 12$$

1. Calculate the TAC output voltage:

$$V_{\text{TAC}} = 8\,\text{V} \cdot \frac{4\,\mu\text{s}}{6\,\mu\text{s}} \approx 5.33\,\text{V}$$

2. Calculate the ADC output:

$$D_{\text{ADC}} = (2^{12} - 1) \cdot \frac{5.33\,\text{V}}{12\,\text{V}} = 4095 \cdot \frac{5.33}{12} \approx 1820$$

2 Part (b)

For this case:

$$t_{\text{measured}} = 4\,\mu\text{s}, \quad t_{\text{full}} = 12\,\mu\text{s}, \quad V_{\text{ADC}} = 12\,\text{V}, \quad V_{\max} = 8\,\text{V}, \quad n = 12$$

1. Calculate the TAC output voltage:

$$V_{\text{TAC}} = 8\,\text{V} \cdot \frac{4\,\mu\text{s}}{12\,\mu\text{s}} \approx 2.66\,\text{V}$$

2. Calculate the ADC output:

$$D_{\text{ADC}} = (2^{12} - 1) \cdot \frac{2.66\,\text{V}}{12\,\text{V}} = 4095 \cdot \frac{2.66}{12} \approx 908$$

3 Part (c)

For this case:

$$t_{\text{measured}} = 4\,\mu\text{s}, \quad t_{\text{full}} = 16\,\mu\text{s}, \quad V_{\text{ADC}} = 12\,\text{V}, \quad V_{\max} = 4\,\text{V}, \quad n = 12$$

1. Calculate the TAC output voltage:

$$V_{\text{TAC}} = 4\,\text{V} \cdot \frac{4\,\mu\text{s}}{16\,\mu\text{s}} = 1\,\text{V}$$

2. Calculate the ADC output:

$$D_{\text{ADC}} = (2^{12} - 1) \cdot \frac{1\,\text{V}}{12\,\text{V}} = 4095 \cdot \frac{1}{12} \approx 341$$

4 Part (d)

For this case:

$$t_{\text{measured}} = 2\,\mu\text{s}, \quad t_{\text{full}} = 6\,\mu\text{s}, \quad V_{\text{ADC}} = 12\,\text{V}, \quad V_{\max} = 8\,\text{V}, \quad n = 12$$

1. Calculate the TAC output voltage:

$$V_{\text{TAC}} = 8\,\text{V} \cdot \frac{2\,\mu\text{s}}{6\,\mu\text{s}} \approx 2.66\,\text{V}$$

2. Calculate the ADC output:

$$D_{\text{ADC}} = (2^{12} - 1) \cdot \frac{2.66\,\text{V}}{12\,\text{V}} = 4095 \cdot \frac{2.66}{12} \approx 908$$

4.

The difference between figure 10 and 12 diagrams is the time delay in the stop chain. The reason for this difference is to perform correct time calibration on the TAC.

Works Cited

King, Dr. Paul. Physics 6751: Nuclear Lab Manual. Version 24.5, Ohio U, 2024.