MUO

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May 2023

Abstract

This lab report presents the results of an experiment conducted to determine the lifetime of muons. The experiment utilizes a scintillation tank to record muon decays and applies LabView programs to analyze signals and noises. The goal of the lab is to gain practical experience in conducting experiments while also developing an understanding of the limitations of electronics and their impact on the experimental process.

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1 Introduction

Muons are elementary particles that are created when cosmic rays interact with the Earth's atmosphere. The mass of muon is about 200 times the mass of electron. If we initially have N_o muons, then the number of muons present at a time t later is $N(t) = N_o e^{-t\lambda}$, where λ is the radioactive decay constant[1]. Muons with postive charge or negative charge decay into two nutrinos and one electron or one positron, as described below:

$$\mu^+ \rightarrow e^+ + \nu_e + \overline{\nu}_\mu \tag{1}$$

$$\mu^- \rightarrow e^- + \overline{\nu}_e + \nu_\mu \tag{2}$$

Using the zenith angle dependence of muon intensity, the muon flux is given by [2]:

$$\int I_o \; cos^2\theta \; A_{eff} \; sin(\theta) \; d\theta d\phi \tag{3}$$

Imagine cosmic rays shooting down to an upper hemisphere. When considering a horizontal surface, the effective area A_{eff} is A $cos\theta$, equation 3 becomes:

$$\int_0^{2\pi} \int_0^{\pi/2} I_o cos^2\theta \; Acos\theta \; sin(\theta) \; d\theta d\phi \tag{4}$$

When considering a vertical surface, the effective area A_{eff} is A $sin\theta sin\phi$, equation 3 becomes:

$$\int_0^{\pi/2} \int_0^{2\pi} I_o cos^2\theta \; Asin\theta \; sin\phi \; sin(\theta) \; d\theta d\phi \tag{5}$$

Integrating equations above, the muon flux is approximately one particle per square centimeter per minute on any horizontal surface. The flux passing in both directions through a vertical surface is one-half as much.

The geometry of the detector used in this experiment is 60 cm x 30 cm x 240 cm high. Based on the above approximation, the number of cosmic rays that enter the detector is 25200 particles per minute or 420 particles per second.

The number of muons which stop in a shallow detector depends only on the mass of the detector, not the shape of the detector or the directions of incidence of the muons. Assume the density of the mineral oil is 0.8 g/cm^3 and solid angle is $2\pi/3$ steradians. The number of muons that will stop in the detector is calculated [3]:

$$(\frac{5 \cdot 10^{-6}}{g \cdot sec \cdot ster})(\frac{2\pi}{3} ster)(0.8 \frac{g}{cm^3})(60 \cdot 30 \cdot 240 cm^3) = \frac{3.619}{sec} \tag{6}$$

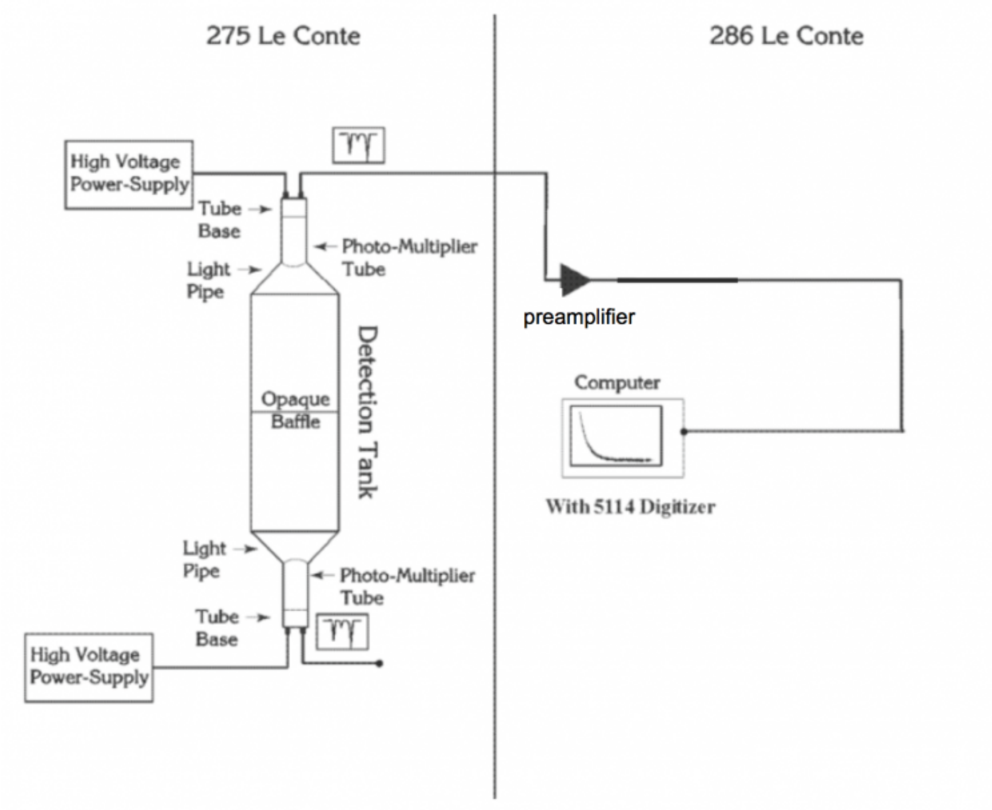


Figure 1: Schematic drawing for the experiment

2 Experimental Procedures

2.1 Equipment setup

A schematic drawing is shown .

The detection tank filled with 125 gallons, 500 kg (1/2 cubic meter) of mineral oil is located in room 275 LeConte (Figure 1). As fast charged particles traverse through the oil, they generate brief bursts of light lasting only a few nanoseconds. These illuminations, referred to as scintillations, are transformed into electrical pulses by photomultiplier tubes (PMT) positioned both at the upper and lower regions of the detector. Each photomultiplier views half of the tank, which is divided by an opaque baffle in the horizontal mid plane [4].

When a muon enter the scintillator, first pulse is given. When a muon decay, second pulse is given. The time between two correlated pulses that come from the same muon is the decay constant or the lifetime of muon.

When the two pulses come down the cable, they are routed to amplifiers and digitizers in room 286 LeConte. We configure triggering and timing properties of the digitizer in the LabView programs. The LabView program Muon Detection Program coupled to the digitizer card detects pulses from two photomultiplier tubes, measures their arrival times, amplitudes, and widths, and, for a subset of pulses that satisfy a preset criteria, writes the data to disk.

2.2 View signals on oscilloscope

We use an oscilloscope(Tektronix TDS 360) to observe the pulses, so that we know what to expect and how to later adjust the setting on the LabView program. Through observation, the width is 1.3320 μs, the amplitude is about 1 V, and polarity is negative.

2.3 Calibration of Electronics

2.3.1 Time resolution of the digitizer

We measure the time recorded by the two PMTs for muons that go through both halves of the scintillator tank. Since we know the height of the tank and the speed of muon, we can calculate the time that muons travel through the tank and compare it to the measurement.

2.3.2 Efficiency of the digitizer

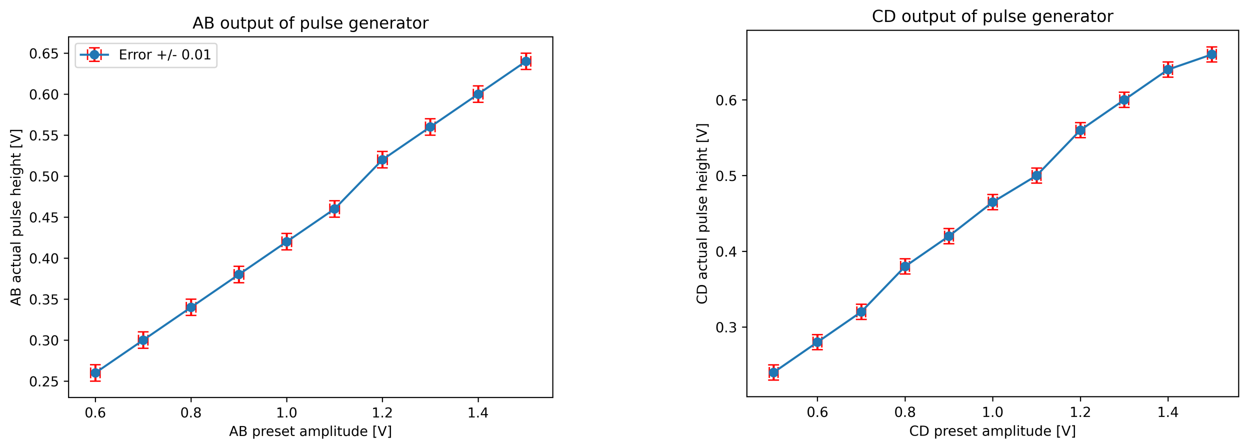
To test the efficiency of the digitizer, we use a ZSCJ-2-1 Power Splitter to combine signals from two uncorrelated sources: a through-going muon, and an external pulse produced by DG645 Digital Delay Generator. We measure these two pulses in one digitizer. For different time intervals, we find the count rate to be nearly constant.

2.3.3 Calibration of the digitizer clock

To check the accuracy of the digitizer clock, we focus on confirming if the delay recorded by the digitizer is the same as the delay produced by the signal generator. We send two external pulses to one digitizer and vary the delay between the pulses from 1μs to 40μs. The measurements always show counts for only the specific time delay that we preset.

2.3.4 Linearity of the pulse height measurement

The DG645 Digital Delay Generator does not generate a pulse with amplitude exactly as set. We need to check the linearity of this offset. We send two pulses with a fixed delay and vary their amplitude. From Figure2, we confirm that the offset is linearly increasing. The errors are due to reading the height of the pulses.



(a) **(b)**

Figure 2: Output of the pulse generator

2.4 Measure muon lifetime

After calibrating the electronics and knowing their limitations, we proceed to measurement of muon lifetime. Since we have two PMT(top and bottom), we can select different options of PMT to measure the two pulses(enter and decay) of muons. We choose to use only the top PMT for better accuracy. We adjust the settings of the LabView program so that the output count matches with our expectation in Equation 6. Specifically we set the pulse detection threshold to be lower than an obvious pulse height and slightly higher than noise level. We record overnight data to minimize the effect of noise.

3 Results and Analysis

We first applied a cut to remove low-amplitude noise pulses in the data. We also deleted some data points at the beginning and end of the data interval to avoid initial or final transient effects. We studied the linearity of the noise signals located near the end of the lifetime histogram and subtracted the noise count for the entire histogram. The best fit is shown in Figure 3. The fit follows an exponential curve $N(t) = Ae^{t\lambda} + C$. Standard deviation of residuals is 17.1172. Chi-square statistic is 18.8615. The mean muon lifetime is $\tau = \frac{1}{\lambda} = 2.24 \pm 0.0826\mu s$. The errors are due to noises in the electronic equipments.

We calculate the Fermi Coupling constant below:

$$G_F = \sqrt{\frac{192\pi^3\hbar^7}{\tau\ m_\mu^5\ c^4}} \tag{7}$$

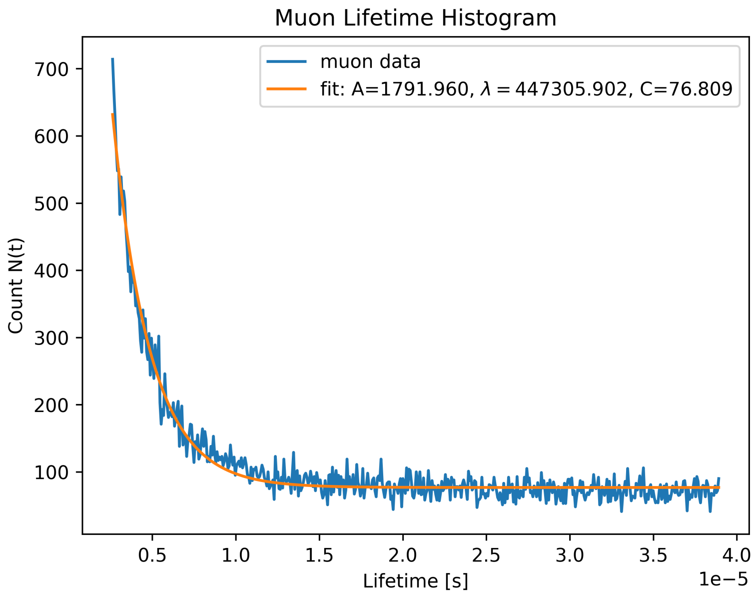


Figure 3: Measurement for muon

m_μ is the mass of muon and τ is the mean muon liftime. G_F is calculated to be $(1.419 \pm 0.026) \cdot 10^{-62} J/m^3$.

4 Conclusion

This experiment provides insight into the fundamental properties of muons and the strength of the weak interaction described by the Fermi coupling constant. Further refinement of electronics would provide better lifetime results.

References

(1) Evans, R. D.; Evans, R., *The atomic nucleus*; McGraw-Hill New York: 1955; Vol. 582.

(2) Lin, J.-W.; Chen, Y.-F.; Sheu, R.-J.; Jiang, S.-H. Measurement of angular distribution of cosmic-ray muon fluence rate. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* **2010**, *619*, 24–27.

(3) Rossi, B. Interpretation of cosmic-ray phenomena. *Reviews of Modern Physics* **1948**, *20*, 537.

(4) Physics, U. MUO Physics 111B: Advanced Experimentation Laboratory `http://experimentationlab.berkeley.edu/%20sites/default/files/writeups/MUO.pdf`.