Physics 210 Lab 1B: Muon Lifetime

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The goal of this lab was to measure the average lifetime of the muon, the heavier unstable cousin of the electron. Using the fitted model, we found $\tau = 2.20\ \mu s \pm 0.12\ \mu s$. This matches the expected value of τ, which was $2.20\ \mu s$.

I. INTRODUCTION

The muons we're observing are primarily created by collisions of cosmic rays with particles in the upper atmosphere. They then shower downward, with roughly 1 muon per cm^2 per minute at sea level with energies of order 4 GeV. Like all unstable particles, the probability that an individual muon remains undecayed after a time t decays exponentially with time.

II. THEORETICAL MODEL

If we start off with N_0 muons at $t = 0$, then the number which have not decayed away at time t is

$$N(t) = N_0 e^{-t/\tau} \tag{1}$$

where $N(t)$ is the number of undecayed muons remaining in the sample, N_0 is the initial number of muons, and τ is the average muon lifetime. The problem with this equation however is that it not relevant to this situation. We don't have a collection of muons that we are observing to decay. Rather, for this setup, we are measuring the lifetimes of muons that stop in the scintillating plastic. When the muon is first detected in our setup, we assume it is undecayed. This restarts the clock for the decay probability. To relate our data to Eq. (1), we find the rate at which the muons are decaying, which is the derivative of Eq. (1) with respect to time:

$$\frac{d}{dt}N(t) = -\frac{N_0}{\tau}e^{-t/\tau} \tag{2}$$

The number of muons that decay during some small time interval t to $t + \Delta t$ is:

$$N_{\text{decayed}}(t) \simeq |\dot{N}(t)|\Delta t = \frac{N_0 \Delta t}{\tau}e^{-t/\tau} = N_{\text{Decayed}}(0)e^{-t/\tau} \tag{3}$$

Where $N_{\text{Decayed}}(0)$ is the number of muons that decay during the initial time interval from $t = 0$ to $t = \Delta t$. We will then use this equation to fit the experimental data, which will yield the experimental value for τ.

III. EXPERIMENT

To measure their lifetime, we have set up a cylinder of scintillating plastic on which is mounted a photomultiplier tube. When a muon strikes a nucleus, a photon is emitted and detected by the photomultiplier. Most of the time the muons will just collide and pass through the plastic. However, every so often, the muon strikes a nucleus dead on and stops. It now is the laboratory reference frame and decays. This decay is also picked up by the photomultiplier tube. The LabView software in the detection system then looks for double peaks of photomultiplier voltage separated by times on the order of microseconds. For these double peaks, the times and voltages of the peaks are recorded and saved to an Excel file. By taking the difference in times, the lifetimes of the muons can be determined.

A. Procedure

- Set up the cylinder of scintillating plastic and the a photomultiplier tube, and connect the sensors to the LabView Software.
- Set up the LabView Software to detect double peaks of the muon decay, begin data collection.
- Let the apparatus run for at least a week or more to collect data on as many muons as possible. In this experiment, our setup ran for over a week, and collected approximately 3757 data points.

B. Data

The data was provided by Dr. Brown, and analyzed using Mathematica. The data had approximately 3757 data points to analyze. The data was binned with a bin length of $0.1\ \mu s$. The first point was dropped, as the triggering software may exclude detecting muons which decay extremely quickly or live unusually long, or by the apparatus detecting a collision as it was being turned on, causing an outlier point. From this, the data was binned, then fitted with a Non Linear Weighted Fit for ae^{-bt}, for which the weights were determined by: $\sqrt{N_{\text{decayed}}}$, since we model the muons as a Poisson process, and weight them accordingly. N_{Decayed} is the number of decay events within that time interval.

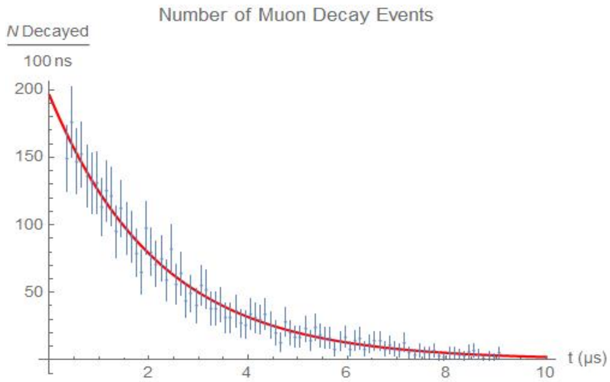

FIG. 1. A graph of the binned data with the fitted curve of the form of Eq. (1)

Using the weighted fit, we found the fit equation to be:

$$195.91e^{-0.46t} \tag{4}$$

IV. ANALYSIS

From this fitted curve, we took the uncertainty of the model (which gave us a 68% CI) and then we multiplied it by 2 to get a 95% CI. We found our average muon lifetime to be:

$$\tau = 2.20\ \mu s \pm 0.12\ \mu s\ (95\%\ \text{CI}) \tag{5}$$

V. CONCLUSION

Using the fitted model, we found $\tau = 2.20\ \mu s \pm 0.12\ \mu s$. This matches the expected value of τ closely, which was $2.1969811\ \mu s$. Possibly putting the apparatus in a vacuum apparatus would improve the data further, since the expected value is the average lifetime for muons (and anti-muons) in free space, but in a nuclear environment, μ^{-}s can stimulate inverse beta decay which provides an addition mode of decay, which could lower τ. Running the apparatus for longer could also improve the experiment, as well as using more than one scintillation bar to minimize the impact of material defects.

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