PHSX815_Project1:
Simulating Cosmic Muon Decay

Suyash Sakhare

February 2023

1 Introduction

Although cosmic muons may sound like a tool aliens use to frame dogs for eating cookies, they are quite real - or at least simulated in this project. Cosmic rays react with air molecules and produce a cascade of atomic and subatomic particles. One of these particles are pions, which decay into muons. Muons have an average lifetime between 2.0μs 3.0μs.

$$\pi^+ \to \mu^+ \nu_\mu$$

$$\pi^- \to \mu^- \nu_\mu$$

Muons lifetimes can be measure using a scintillator, which traps the incoming muon and electron from the muon decay. The muon and the decay electron each produce two short light pulses. The time between these light pulses are measured to calculate the Muon decay time.

A simulation for this scenario can helpful for students who have to collect data for four weeks before they can even attempt to distinguish between the positive and negative muon lifetime.But before we can create a working simulation there are few steps that we need to follow. The first steps involve finding our limits in simulating two distinguishable particles.

2 Hypotheses

Average muon lifetime is between 2.0μs 3.0μs. Hence, out final simulation must be able to distinguish between the positive muon lifetime τ_p and negative muon lifetime τ_n. From literature we know that τ_p is around 2.196 μs. What is a value for τ_n such that it is distinguishable? Picking an arbitrary value of 2.7μs.

$$H_0 : \tau_n = 2.7\mu s$$

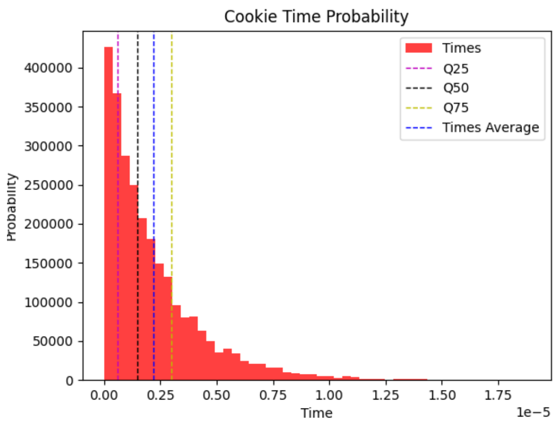
$$H_1 : \tau_n < 2.7\mu s$$

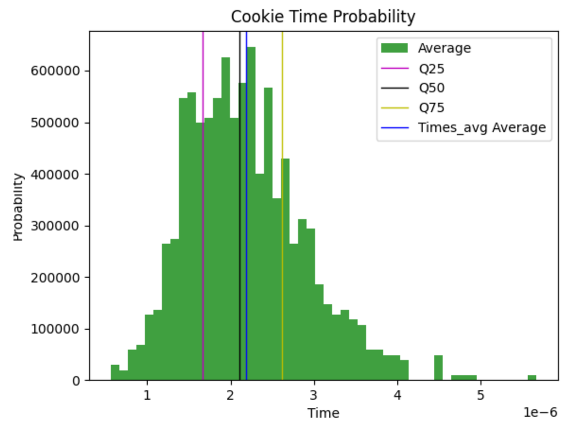
3 Code and Experimental Simulation

The decay of the muon can be simulated using the exponential probability sampling. Exponential sampling is controlled using the rate parameter, λ. The rate parameter is related to any decay lifetime τ by the following relation:

$$\lambda = \frac{1}{\tau}$$

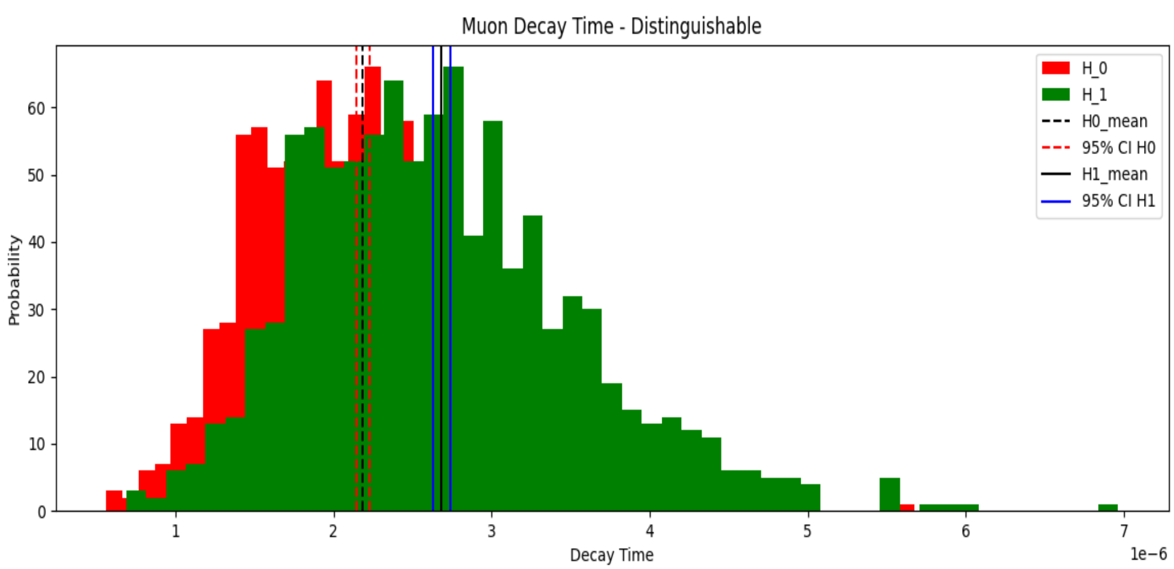
The exponential distribution leads us into issue of visually indistinguishable plots, considering that we might be simulating scenarios where the difference between positive and negative muon lifetime is 0.01 μs. Hence, we must move into the Erlang distribution by taking multiple measurements for each experiment.





4 Analysis

To test the hypothesis, the code was used to plot the normal normal distribution for τ_p = 2.2 μs and null hypothesis of τ_n = 2.7 μs. To further help the analysis the 95 % confidence interval was plotted for each of the histogram.



Visually, it seems that the two lifetimes can be much closer and still be distinguishable. Hence, the negative muon lifetime is smaller than $2.7\mu s$.

5 Conclusion

We conclude that the simulation has viable enough to simulate positive and negative muons. It seems that the ability to simulate a large number of events can make it helpful tool for the students. In the next step for the project would moving the τ_n closer to τ_p to find out the limit of the simulation.