Muon Lifetime and Special Relativity

Introduction

Our aim was to measure muon lifetime because it constitutes evidence of relativistic time dilation.

The Muon

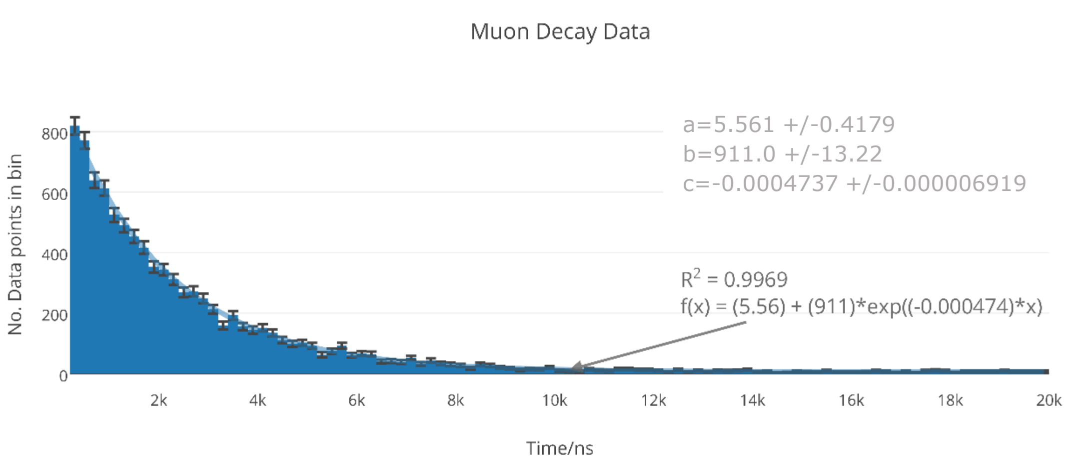
Muons are Fundamental particles (Leptons) which can have a charge of ±1e and have a mass of 1.88 $\times 10^{-28}$kg compared to an electron's respective mass of 9.11 $\times 10^{-31}$kg .

Cosmic Rays

The source of muons we are concerned with is Cosmic Rays. Muons are created in the upper atmosphere.

Method

- To find the lifetime of a muon we used a scintillation tube.
- When a charged particle enters the tube a flash of light is created which can be detected.
- Muons decay as shown in Figure 1, so when a muon decays there are two close flashes of light one from the muon and one from the electron.
- The times it takes for a muon to decay forms an exponential distribution as shown on the graph.



Lifetime: 2.11 ± 0.03μs

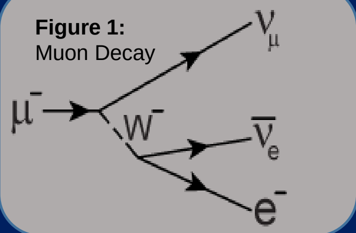


Figure 1: Muon Decay

$$t' = \frac{t}{\sqrt{1-\frac{v^2}{c^2}}}$$

t' = change in time
t = rest time
v = velocity
c = speed of light

Figure 2

$$t' = \frac{2.11 \times 10^{-6}}{\sqrt{1-\frac{0.998^2}{1^2}}} \approx 3.34 \times 10^5$$

$s = 3.34\times10^5 \times 3\times10^8 \approx 10.0km$

Figure 3

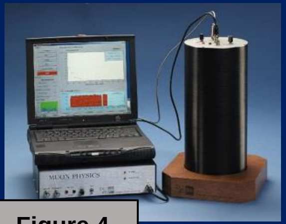


Figure 4

Figure 3 demonstrates how, due to relativistic time dilation muons are able to travel much further than classical physics would suggest. This means we are able to detect cosmic ray muons at sea level.

Results

The graph is in the form ‘a+be^{ʎt}‘ where

- a is the background rate
- b is a coefficient of the exponential function
- ʎ is the decay constant

Our value of ‘a’ was only 5.56, suggesting a low background rate, meaning that our equipment was calibrated well.
Our fit had an R^2 of 99.69% which shows that our trend line is a good fit of the data.

Errors

- To minimise the error of our graph fit and hence the lifetime we adjusted the bin size and range of the data in order to achieve a smooth distribution.
- We set a threshold energy on the equipment so as to exclude noise and lower energy particles.
- We discarded the first bin because it was anomalously large and this was likely an instrumental error.

The established value of muon lifetime (2.20μs) is higher than the value we calculated from our data. With only one set of data we cannot know whether this discrepancy is systematic or random.

Conclusion

Using our value of the lifetime and the fact that muons travel at almost the speed of light we can calculate the distance we would expect muons to travel on average: ~633m
This is considerably less than the height of the atmosphere, so **how do we detect muons at all?** Answer: Special Relativity. As explained to the left.

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