Measurement of Weak Coupling Constant blahblah

1 Introduction

The muon, a fundamental particle produced in the upper atmosphere as a secondary product of cosmic ray collisions, was originally discovered in 1936 []. It decays via the weak interaction with a mean decay lifetime of $2.2\mu s$, longer than every known particle other than the neutron []. With muons comprising 80% of cosmic ray flux at sea level, the muon is a good candidate for the study of the weak force [].

Our experiment consists of two main components: the muon lifetime measurement and the muon mass measurement. In section 2, *Background*, we introduce the theoretical basis for these measurement as well as that of muon creation and decay. We describe the experimental setup which consists of a system of three scintillators and photomultiplier tubes (PMTs) in *Setup*. Using this system, the cosmic ray muons passing through the scintillators and their decay products can be detected along with their enegy (*Procedure*). The muon lifetime and mass results are presented in *Results* and *Discussion* with the relevant statistical analysis of data, and compared to previous experimentally established values. Finally, we use the muon mass and lifetime values to calculate the weak force coupling constant, g_w.

2 Background

Muons (μ^-) and antimuons(μ^+) are the most numerous charged particles at sea level [**?**]. Most of them are produced at a height of about 15 km in decays of charged kaons and pions which are formed via the interaction of cosmic ray particles with the Earth's upper atmosphere [**?**]. The muon is produced in a weak decays as shown for example in Figure and at sea level forms 80% of cosmic ray flux.

2.1 Muon Decay

In free space, negatively charged muons decay weakly into an electron, muon neutrino, and electron antineutrino [**?**] (Figure):

$$\mu^- \rightarrow e^- \nu_\mu \overline{\nu_e} \tag{1}$$

with a corresponding antimatter process of

$$\mu^+ \rightarrow e^+ \overline{\nu_\mu} \nu_e \tag{2}$$

The muon lifetime is approximately 2.2μs [?], second only to the lifetime of the neutron. In matter, another decay is possible for μ^- via nucleus capture:

$$\mu^- p^+ \rightarrow n \nu_\mu \tag{3}$$

(**insert stuff about the muon capture lifetime here**)

The decay of the muon is desribed by an exponential function

$$N(t) = N_0 e^{-\Gamma_\mu t} \tag{4}$$

here Γ_μ is the decay rate, which gives the decay lifetime $\tau_\mu = 1/\Gamma_\mu$.

In this experiment, we measure the time between the start event, when a $\mu^-(\mu^+)$ comes to rest in a scintillator in the lab and the stop event, which signals the emission of $e^-(e^+)$ in the muon decay. The histogram of the recorded times is then fit to (**??**) to give the lifetime of the muon.

2.2 Effects of Relativistic Time Dilation

Even with velocities within a percent of the speed of light, the travel time of the muon from the point of creation in the atmosphere takes approximately 50μs - over 20 decay lifetimes - to reach the ground. According to Newtonian physics, the flux would be reduced by a factor of over 10^{10}. However, the flux of muons at sea level, where the lab is located, remains large at 10^{-2} cm$^-$2s$^-$1sr$^-$1, only reduced by a factor of 5 from the peak flux at 15km [**?**].

This effect is due to the relativistic time dilation predicted by Special Relativity. While in the frame of the laboratory, the time of flight of the muons is 50μs, the muon itself experiences a proper time reduced by a factor of γ: $t_\mu = t_{lab}\gamma$, where $\gamma = 1/sqrt1 - \frac{v^2}{c^2}$. Since the particles are travelling close to the speed of light, the relativistic correction becomes non-negligible. With muon speeds ranging from $.994c$ to $.998c$, the proper time experienced by the muon is between 3.2 and 5.5μs, less than 2 lifetimes on average.

The time in flight is still on the same order, and even greater than, the lifetime of muon decay which our experiment seeks to measure. Nevertheless, this fact has no effect on the experiment, because while we do sample fewer short decay times and slow moving muons, the travels simply decreases the amount of data without affecting the parameters of the exponential.

2.3 Weak Force Coupling Constant

The decay rate Γ_μ is proportional to the square of the amplitude of the decay diagram (Figure **??**, which depends on the product of the couplings at each vertex. In this case, the coupling at each of the two vertices is proportional to $\sqrt{G_F}$, the Fermi constant, so we have

$$\Gamma_\mu \propto G_F^2 \tag{5}$$

A more involved calculation gives that the lifetime of the muon is

$$\tau_\mu = \frac{192\pi^3\hbar^7}{G_F^2 m_\mu^5 c^4} \tag{6}$$

where c is the speed of light, $\hbar$ is Planck's constant, and m_μ is the rest mass of the muon.

Once we establish the value of m_μ, we can find the Fermi constant G_F and the

The weak decay of the muon is the clearest of all weak interaction phenomena in both its experimental and theoretical aspects. Thus, the muon decay is an effective means of studying the weak force, and specifically finding the weak coupling constant g_w.

(7)