

Measurement of muon lifetime

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**Abstract**

Muons are captured in a series of three scintillators where they eventually decay into an electron or positron and two neutrinos. The muon produces a short burst of light within the scintillators which is detected and amplified by a photo multiplier tube. A second burst of light is emitted when the muon decays into an electron or positron and is also amplified by a photo multiplier tube. The two signals from the photo multiplier tubes are then fed into an electronic circuit to determine the time delay between the two pulses. The electronics are then connected to a computer which autonomously gathers data to be analyzed later.

**Introduction**

Muons were discovered in 1937 by C.W. Anderson and S.H. Neddermeyer when they examined the paths created by cosmic rays passing through a cloud chamber1. The muon source for our experiment are cosmic rays. In the upper atmosphere, highly energetic protons (cosmic rays) interact with atmospheric gasses and produce showers of high-energy subatomic particles. These highly energetic subatomic particles then interact with even more atmospheric gasses producing secondary showers, occasionally producing muons.

Muons are elementary particles and a member of the lepton group in the standard model. Muons are very similar to electrons and are often called heavy electrons. The charge of the muon is identical to the electron and the mass of the muon is about 207 times the mass of the electron.

The decay time of the muons follows the exponential decay law

where is the number of muons at time t and is the mean lifetime of the muon in the lab frame.

**Muon Physics**

Muons only interact with matter via electromagnetic interactions and weak interactions with the latter being the cause of their decays. Using Feynman rules, we can calculate the lifetime, , of the muon to be

where is the Fermi coupling constant and is the mass of the muon, and is the mass of the electron. The muon’s high mass makes it unstable and causes it to decay via the weak interaction almost exclusively into an electron or positron and two neutrinos (see figure 1). There is another diagram for an anti-muon decaying into an anti-mu neutrino, a positron, and an electron neutrino. An accepted value for the muon’s lifetime is 2.1969811 0.000022 .

**The Experiment**

To detect these cosmic rays, we have three rectangular plastic slab scintillators oriented on top of each other and shielded from outside light. Each scintillator has a cross sectional area of 0.74 square meters and is then attached to a photo multiplier tube (PMT) and an in-line amplifier to amplify the PMT signal. From top to bottom, the scintillators will be referred to as , , and and the associated voltages will be referred to as , , and , respectively.

After the PMT signals are sent through the amplifier, they are each fed into unique discriminators which convert an otherwise non-uniform pulse into a logical square wave pulse. The discriminators are triggered when the input signal from the amplifier is above a certain threshold. In our experiment, we set each discriminator threshold to 150 mV. This value was determined by finding a voltage that was high enough to avoid random noise fluctuations, but low enough so that any true event would trigger the discriminator (see figure 2). [[Include plot of oscilloscope and signal which illustrates why we chose 150 mV as our discriminator threshold. Also show the square discriminator signal in another color. Figure 2]].

The square wave pulses are then sent to discreet logic units. Since our scintillators are arranged top-to-bottom, we are interested in events where a light pulse is created in the first or second scintillator but not the third. A simultaneous signal in all three scintillators means that the particle either stopped in the third scintillator, or traversed through all three. With no way of knowing which of these scenarios happen, we have no choice but to veto any events where a signal is produced in all three scintillators.



Figure 1. Feynman diagram of a muon decaying into a mu neutrino, an electron, and an anti-electron neutrino. Muon and electron number is conserved in this diagram.

**Bibliography**

1. Neddermeyer, S. H. & Anderson, C. D. Note on the Nature of Cosmic-Ray Particles. *Phys. Rev.* **51,** 884–886 (1937).