Mean lifetime of cosmic muons

1 Aim

1. To measure the mean lifetime of stopped cosmic muons

2 Required materials

1. Plastic scintillator slab coupled to a Photo-Multiplier Tube (PMT)
2. Data acquisition setup
3. Oscilloscope
4. BNC cables
5. Power supply

3 Introduction

Cosmic rays are predominantly composed of protons (~90 %). The remaining are mainly composed of alpha particles and electrons. Cosmic protons strike the gaseous molecules in the atmosphere creating a shower of hadrons ($K^{\pm,0}, \pi^{\pm,0}$, etc). The charged hadrons having a lifetime of $\sim 10^{-10}$ s (K) and 10^{-8} s (π), decay by weak interaction to produce muons. The decay modes are:

$$K^{\pm} \rightarrow \mu^{\pm} + \overset{(-)}{\nu}_{\mu} \tag{1}$$

$$\pi^{\pm} \rightarrow \mu^{\pm} + \overset{(-)}{\nu}_{\mu} \tag{2}$$

Charged kaons decay into muons and neutrinos around 64% of the time whereas, charged pions always decay into muons and neutrinos. The mean lifetime of muon is ~2 µs. Even though they are produced in the atmosphere at heights of few tens of kilometers above sea level, due to relativistic time dilation, they are able to reach the earth's surface.

Muons are unstable and decay into electrons and neutrinos. The equations are:

$$\mu^{+} \rightarrow e^{+} + \bar{\nu}_{\mu} + \nu_{e} \tag{3}$$

$$\mu^{-} \rightarrow e^{-} + \nu_{\mu} + \bar{\nu}_{e}. \tag{4}$$

In the experiment, we will be measuring the mean lifetime of stopped muons using a plastic scintillator slab - PMT assembly. The lifetime is referred to as the mean lifetime, since the decay of the muon follows an exponential form. A muon does not always decay in 2 μs. When considering a population of muons, the number of muons after a time of ∼2 μs will be $1/e$ of its initial value. The average energy of the muon at sea level is ∼4 GeV/c^2 and the rate is ∼1 cm^2·min^{-1}.

4 Principle and working formula

A cosmic muon enters the scintillator and produces scintillations. This is referred to as the *prompt signal*. It eventually loses energy in the scintillator and decays into electron and neutrino when it stops. The electron produced by the decay again causes scintillations in the scintillator. This is referred to as the *delayed signal*. The time difference between the prompt and delayed signal is measured for a large number of events. The slope of the distribution of these time intervals gives the mean lifetime of muon. Uncorrelated events are also recorded since there may be accidental or chance coincidences with the prompt signal from background radiation, detector noise etc. These events are random in nature and therefore can be considered as a constant background. The distribution of time intervals can be fit using the equation

$$N = N_0 \exp(-t/\tau) + b \tag{5}$$

where, N_0 and b are constants and τ is the mean lifetime of the muon. b parametrizes the events due to random or chance coincidences.

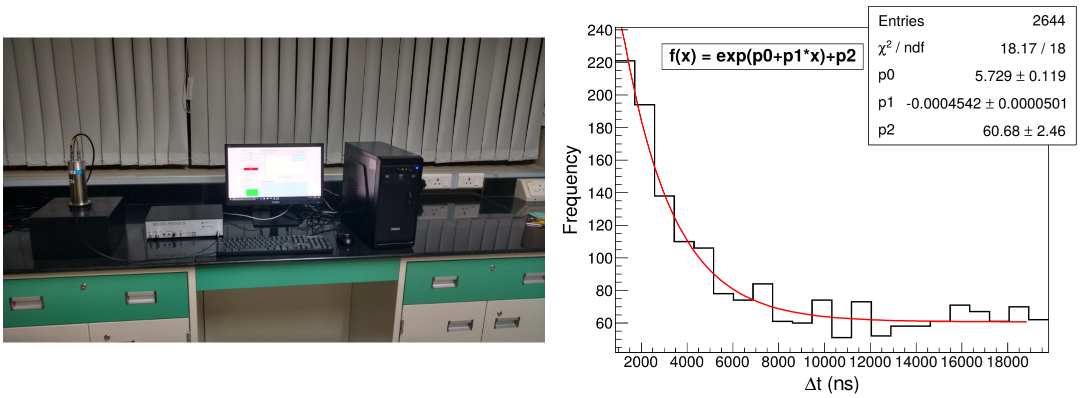

Figure 1: (a) Picture of the setup. (b) Decay spectrum obtained from the setup. The inverse of parameter 'p1' gives the mean lifetime of muon in nanoseconds.

5 Procedure

1. The SHV cable is connected to the scintillator-PMT assembly. Suitable high voltage is applied to the PMT. The anode output of the PMT is fed to the 'Teachspin' data acquisition setup for measuring muon lifetime.

2. The anode output of the PMT is first observed on the oscilloscope. It is then fed to the preamplifier. The preamplifier output is observed on the oscilloscope after which threshold for the discriminator is set.

3. The amplified signal is internally connected to the discriminator in the setup. The amplified signal triggered with the discriminator pulse is observed on the oscilloscope.

4. The time measuring circuit is calibrated with the help of a pulser.

5. The discriminator pulse is fed to the time measuring circuit to measure the time interval between the prompt and the delayed signal. The time intervals are recorded on the computer.

6. From the distribution of the recorded time intervals, the lifetime of the muon is extracted.

Questions

1. A list of modules is given below. Construct a muon lifetime setup from it with proper explanation and block diagram. Commercially available NIM/CAMAC/VME standard modules are to be considered while making the circuit. Where necessary, mention the number of channels/inputs/outputs of the modules that would be needed. (**Remember:** there is only one readout from the detector)

   (a) Scintillator-PMT assembly
   (b) Discriminator
   (c) Coincidence unit
   (d) Gate and delay generator
   (e) Pulser
   (f) HV power supply
   (g) Time to Amplitude Converter (TAC)
   (h) ADC
   (i) Computer

   In a setup constructed using the above modules, what do you think limits the precision? Can you think of other modules that can be used in place of those listed?

2. How can the precision and accuracy of the present setup be improved? What changes or modifications do you think are necessary?