Physics 407

Muon Lifetime Experiment:

1) Goal
Measure the lifetime of a muon. Demonstrate that the time series of event-time differences is consistent and well described as resulting from two Poisson processes: incoming muons, and decaying stopped muons. In addition, prove that the muon-decay events are uncorrelated (i.e. also a Poisson process).

2) Methods:

Our version of the experiment is much simpler than the ones described by Hall, et al, and in the book. Our apparatus consists of a thick solid-material scintillator with two photomultipliers (PMT) to detect the events. Only one PMT is used at a time.

As a muon interacts with the scintillator, a flash of light is emitted. If it stops in the scintillator and decays, it emits a high-energy electron, which causes another flash of light. Each flash of light causes a fast electrical pulse coming from the PMT. This pulse is filtered in a discriminator, amplified to be TTL compatible, and sent to a counter-timer module onboard the data acquisition board in the computer. This module is programmed to measure the time difference $\Delta t_n = t_n - t_{n-1}$ between each pair of consecutive pulses. A computer program collects all the time differences and exports them to an ascii file. It is your job to analyze this series, and extract the results.

Note that you will need to analyze many hundreds of thousands of events. The analysis is reasonably straightforward, but cannot be done in MS Excel.

Note that the counter-timer works as follows: it has onboard a highly reliable oscillator, with an oscillation frequency of 20 MHz. This oscillation signal is sent to a 24-bit counter, which increments each oscillation cycle. Upon receiving an external trigger signal (TTL pulse), the value of the counter is read out and reset to zero. It is this integer value of counts that is written to the file. Therefore, to convert to time difference, one needs to divide by 20 MHz.

3)

Data Modelling
If one considers the events (flashes of light), they can be caused either by muons or electrons, which we'll denote μ or e. The time differences between consecutive events should then take on one of four flavors: between consecutive muons, which we'll denote as $\mu\mu$ events, between muons and electrons, μe, between electrons and muons, $e\mu$, and between consecutive electroncs, ee. If we look at the distribution of observed time differences $P(\Delta t)$, it should approximately be made of the weighted sum of the probability distributions of the four types of event pairs:

$$P(\Delta) = \alpha P_{\mu\mu}(\Delta) + \beta P_{\mu e}(\Delta) + \gamma P_{e\mu}(\Delta) + \delta P_{ee}(\Delta)$$

where the admixture is properly normalized $\alpha + \beta + \gamma + \delta = 1$. Start by understanding this model and then asserting expected functional forms for the distributions. Next argue through what the different parameters mean, and therefore how big each of the parameters should be. This should lead you to a procedure for measuring these parameters, and thereby finding the muon lifetime. In addition, find a way to further demonstrate that the muon event series is modeled by a Poison process, as is the series of muon decay event series.