Experiments to Do with Your Counters

Sept. 27, 2007

Introduction

We'll do three sets of experiments during the afternoon session.

1. First we'll do a series of measurements with two counters in coincidence. We'll look at the angular dependence of the rate and see how the rate changes as the separation of the two counter is changed.
2. Next, we'll see what is the rate at which two muons are detected in coincidence. This is a very interesting experiment that is easy to do and opens up some interesting questions. We'll try to figure why there are two muons coming through our counters at the same time.
3. Finally, we'll do the penultimate experiment of measuring the lifetime of the muon. By knowing where the muons are coming from this will allow us to say something about relativistic time dilation.

There are many other interesting experiments that can be done but this is about all we'll have time for Saturday afternoon. If you want to find out about other experiments that you can do or want more information about the experiments described here, please see the document "Cosmic Ray Detector Experiments" written by Kimberly Li, Matt Cordiero and Ben Sheng under the direction of Brendan Field. This is an excellent document with lots of useful information. It's a 11 MB file which is a bit much to send as an email attachment. You can view and download it from the following URL www.physics.rutgers.edu/~steves/cosmic_ray_workshop/Cosmic_Ray_Experiments.pdf.

Two Counters in Coincidence

1. Choose any two of your four counters.
2. Stack them on top of each other completely overlapping.
3. On the GUI panel, enable these two counters and set for two-fold coincidence.
4. Determine the rate by counting for a few minutes.
5. Change the amount by which the counters overlap each other and measure the rate. Does the rate change the way that you expect it to.
6. Now, completely overlap the two counters again and turn them 90^o's so that they are standing on end. What happens to the rate? Does it go to zero? If not, do you really think there are that many horizontal muons?
7. Put the counters back flat on the table completely overlapped. Now, increase the vertical separation of the two counters. What happens to the rate? Can you explain it?
8. Rotate the counters so that there measuring horizontal muons again but now separate them by about 30 cm or so. Now do you get any horizontal muons?
9. In order to make your cosmic ray telescope sensitive to direction you have to separate the counters. The further you separate them the more they are directional but the rate goes down with separation. Choose a separation of about 30 cm. Point your telescope in different directions and measure the rates. If we had a protractor you could plot the angular dependence of cosmic ray muons. You can do that in your classroom but for now just get a qualitative result.

There's a lot more you can do, see Kimbely et al.'s write up. But for now let's move on.

Two Muons in Coincidence

Here's a really neat experiment to see how often we get two muons at once. These may be muons coming a primary cosmic ray shower in the upper atmosphere or maybe not. Let's see.

1. Use all four of your counters.
2. On the GUI panel, enable all four counters and set for four-fold coincidence.
3. We're going to want to make the coincidence timing fairly loose since we want to be sensitive to muons coming from different points in the cosmic ray shower that may be separated by a kilometer or so. At the speed of light, 3×10^8 m/s, this distance corresponds to about 3 μs so this is the coincidence time we want. The timing gate, the time within which pulses have to arrive in order to be considered in coincidence, is determined by setting the timing gate slider on the GUI. Set this to a value of 3 μs.
4. Arrange the counters on the table such that they don't overlap at all.
5. Determine the rate. This is going to be very low so you should probably count for 10 minutes or so. The likelihood that there are four muons coming down at once is very small so the rate that you're measuring is just the accidental four-fold coincidence rate.
6. Now arrange the counters in two stacks of two counters with the counter in each stack completely overlapped.
7. Determine the rate by running for 10 minutes or more. Is it greater than when the four counters were separate. If so, then the difference is the rate of two particles coming down in coincidence.
8. Are these two coincident particles muons originating in the upper atmosphere or something else. Another possibility is that they could be due to electrons (some of the particles reaching the Earth's surface are electrons) that interact in the ceiling producing other electrons. Can you think how you might go about telling the difference?

Muon Lifetime Measurement

Muons are heavy electrons. They have a mass of 106 MeV/c^2 which is about 210 times the mass of the electron. They behave exactly as an electron would if it were 210 times more massive. Because of its mass, muons are not stable but decay with an average lifetime of 2.2 μs into an electron, a muon neutrino and an electron neutrino, $\mu \rightarrow e\,\nu_\mu\,\bar{\nu}_e$. The average muon lifetime is 2.2 μs but even though all muons are identical they don't all decay after the same time. Their decay time probability follows an exponential distribution, $e^{-t/\tau}$, with an average lifetime, $\tau = 2.2$ μs. This manifests one of the basic strange aspects of quantum mechanics. Nature does play dice.

Using the cosmic ray counters, we'll be able to stop a few cosmic ray muons, measure their decay time distribution and determine their average lifetime.

1. Select three of your your counters.
2. Stack the three counters on top of each other so that they completely overlap. Label the counters 1 to 3 top to bottom.
3. Connect count 1 and 3 to the DAQ board with long cables connect counter 2 to the DAQ with the short cable from the PMT. I'll try to explain the reason for this during the workshop.
4. On the GUI panel, enable counters 1, 2 and 3 and set for two-fold coincidence.
5. We're going to run a program called muon lifetime. Here is what the program will do.
   a) It will receive an event when ever there is a two-fold coincidence of counters 1 and 2.
   b) It will veto the event if there is also a prompt coincidence in counter 3. This will give a good indication that a comic ray muon entered the counter stack but stopped in counter two.

c) If a muon stopped in counter 2, after some time it will decay as noted above. The electron from the decay will produce a signal in counter 2. The program waits for a time set by the timing gate. If there is a delayed signal in counter 2 during this time the program records the time that it occurred relative to the time when the muon entered the stack.

d) It will write out the data in a Comma Separated Value (CVS) format then can then be simply imported into EXCEL. You can then use EXCEL to fit an exponential curve to the data and determine the exponential decay time. There'll be several EXCEL experts on hand (I'm not one of them) to help you with this.

6. In order to set up the program and start taking data do the following.

   a) Set the delay time slider to 50 ns (0.05 μs) .

   b) Set the timing gate slider to its maximum of 10 μs. This is the time that the program will wait to see if there is a delayed muon decay signal. We want this time to be long compared to the muon lifetime of 2.2 μs..

7. This experiment requires patience. Not very many of the incident muons stop. You should get a muon decay about once every six or seven minutes. Since we'll only have about an hour to run this each of you will get about ten decays. If we have time, we'll transfer all of the data files onto one computer and merge them into an EXCEL file. That will give about 60 events still not much but maybe enough to see the exponential shape. Back at your school, you should run this experiment over night or longer. Then you'll get a few hundred events and should be able to quite precisely determine the lifetime.

The really neat thing about this experiment is that it demonstrates relativistic time dilation. The muons are produced in the primary cosmic ray shower about 10 km up in the atmosphere. Moving at near the speed of light, it takes them about 30 μs to reach us at the Earth's surface. If there were no relativistic time dilation, only $e^{(-30\ \mu\text{s}/2.2\ \mu\text{s})} \approx 10^{-6}$ of them would reach us at the surface. In fact, most of them do. The reason is that when they're moving at the velocity, v, in our frame of reference, there time is dilated by the factor of $\left(1/\sqrt{1 - v^2/c^2}\right)$.