Muon Lifetime and Directionality

Benjamin LaRoque, Daniel Bridges

October 2, 2014

You should read this in full before beginning, and use it as you plan your work. This lab should be completed in the form of an original science experiment. In particular, that means your lab notebook must make sense to someone reading it without access to this document or the lab manual.

1 Purpose

The purpose of this lab is to make measurements of the muon lifetime and directionality of the observed muon flux. At the end of this lab you should have a response to the following questions:

1. What is the charge species-averaged muon lifetime inside the scintillator? You will use the boxed system and mostly follow the TeachSpin lab manual for this. Note that the included software is for taking data only; you must do the analysis with a software package of your choice.
2. What is the directional distribution of the local muon flux? There is no magic box for this part. You will be assembling sequences of NIM electronics just as in actual research labs. There are a NIM bin, a collection of modules, and a PMT available to you. You must design, debug, and run the coincidence circuit for yourselves.

2 Theory

You should understand:

1. Where do the muons we measure come from and how are they produced?
2. When a charged particle moves through the scintillator, it produces blue light (exactly what the PMT needs). How does light produced in the scintillator become an electrical signal on the PMT output? Can you predict anything about the size and polarity of the PMT pulses (and/or how they relate to the energy or other properties of whatever causes them)?
3. If the muons take time to get to us, how is it they have not all decayed before they get here? Also, if they are produced elsewhere and at an unknown time, how is it that we are able to measure their lifetime?
4. What are the expected sources of background? What can we do in hardware (*i.e.*, with our settings) to reduce them? What can we do in software (*i.e.*, as part of our analysis)?

3 Muon Lifetime

You should take no more than two lab days to measure the muon lifetime. When you are waiting for data to be acquired, feel free to proceed to start investigating the NIM electronics with the paddle detector in preparation for the muon flux measurement.

Refer to the TeachSpin manual for the measurement of muon lifetime.

4 Muon Flux at Sea Level

When measuring the amplitude and directionality of the muon flux, you will interface two scintillator/PMT apparatus directly with the rack of equipment housing the NIM electronics. Your goal is to quantify the rate and directionality with respect to the zenith, of incoming cosmic-ray muons. You will need to design this experiment yourself by constructing a telescope arrangement with the two detectors. When constructing the apparatus, some questions you should ask yourself are: How does the detector separation affect the rate of coincident muon signals? How does it affect the angular resolution (*i.e.*, how does detector separation change the angle of view)? Do you want the detectors to be very far from each other, very close together, or somewhere in between? In what orientation should the paddle be relative to the zenith angle? *Draw a sketch of your final experiment setup.*

You should provide a figure that plots the muon flux given in $m^{-2}\,sr^{-1}\,s^{-1}$ against the zenith angle. A flux of 100 $m^{-2}\,sr^{-1}\,s^{-1}$ indicates that the number of muons passing through a surface per square meter per steradian per second is 100. A steradian is the unit of solid angle (Ω), analogous to the radian, a unit of plane angle. The solid angle intercepted by a sphere is $4\pi sr$ and for small regions can be approximated by $\Omega = a/r^2$ where a is the area of the region and r is the radius. The solid angle measure is needed to correct for the surface area of the detector and separation between detectors.

4.1 Using the Nuclear Instrumentation Modules (NIM)

- You will use the LeCroy coincidence detector, LeCroy octal discriminator, and Ortec counter/timer.
- Manuals for all of the instruments are available on the Sr. Lab website (http://physics.ucsb.edu/~phys128) or by searching the web.
- Use the negative input to the Ortec counter/timer, located on the rear of the unit.
- Run the signals from both PMTs directly to the NIM electronics. You should not run any output signals to the Muon Physics TeachSpin box. This box is used only to provide power to the PMT.
- Use the oscilloscope to verify correct operation of each stage of the NIM electronics.