# EKA Laboratory – Muon Lifetime Experiment Instructions

## *October 2006*

**0       Lab setup and singles rate.**

When high-energy cosmic rays encounter the earth's atmosphere, they decay into a shower of elementary particles.  Muons from these showers slow down as they pass through the scintillator panel, losing energy in the form of radiating photons.  Some of these photons enter the photomultiplier tube on the side of the panel and smash into its high-voltage cathode plate, ejecting a few of the plate's electrons.  These initial electrons accelerate toward the first of a series of dynodes, smash into it, and knock off more electrons.  As the process continues, more and more electrons are ejected from each successive dynode, until $10^5$ to $10^7$ electrons smash into the anode, sending a pulse into the outgoing wire.  The photomultiplication process is shown in Figure 1.
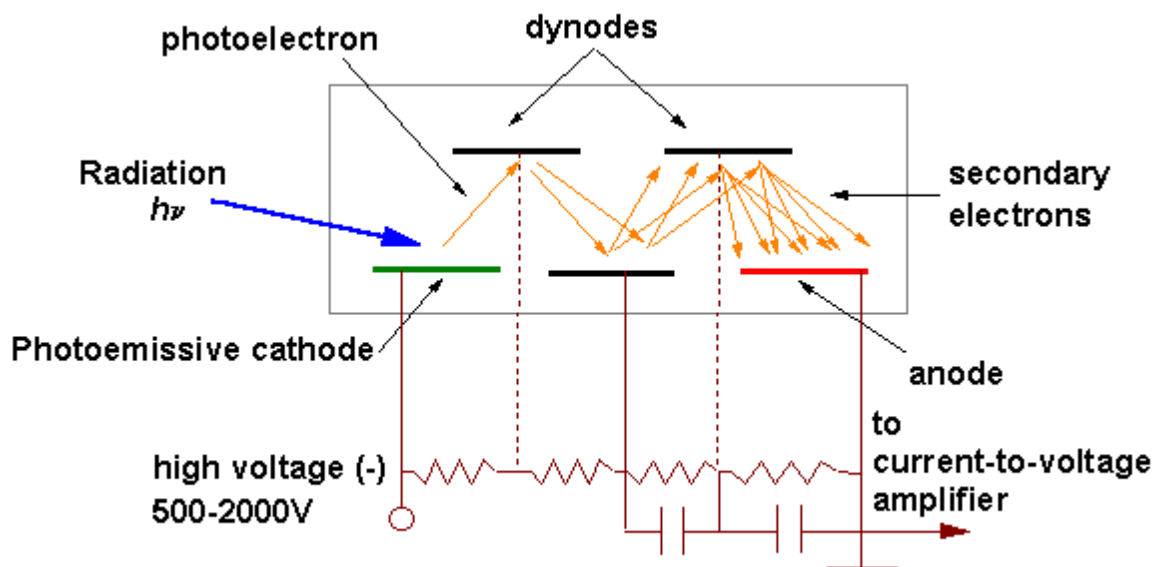


Source: http://elchem.kaist.ac.kr/vt/chem-ed/optics/detector/pmt.htm
*Figure 1: A diagram of a photomultiplier tube.*

The equipment should be set up so the high voltage power supply is powering the tube, and so that the produced pulses are sent first to the discriminator, which will render them all the same size and shape, and then to the event counter (or, later, the oscilloscope).  Turn on the event counter and determine the number of muons coming through the panel per unit time, the "singles rate", as a function of the voltage applied to the photomultiplier tube in the range 800-1400 volts.

The rest of the lab makes use of the LeCroy digital oscilloscope to observe only those instances where two particles pass through the panel within a short time.  Most of the time this is due to a muon entering the detector, slowing down by radiating (one pulse), getting captured by atoms in the panel and sitting around for a fraction of a second, and then decaying into an electron that radiates on its way out of the panel (a second pulse).  From observations of these pulse pairs, it is possible to determine the lifetime of the muon (how long it takes until 1/e of the original muons are still present).

**I       Setting up the LeCroy digital oscilloscope.**

There used to be a setup file, Muon_Lifetime_Interval_Setup.vi, the execution of which would automatically set up the oscilloscope. If you see this file, do not use it, as it may provide incorrect settings. You should set up the scope manually, as follows, and then open up the data acquisition file directly.

Connect the discriminator to the digital oscilloscope. All of the pulses coming out of the discriminator should be about 10 ns wide and -1 volt. Therefore, the scope's trigger level should be set to around -0.1 volt and the delay to -0.3 microseconds (so that the entire pulse is visible).

You should be able to observe the background "singles" rate by setting the scope to **edge trigger mode**. In other words, the scope should trigger on every event, and all the pulses should look the same. You can turn on and off statistics measurements, which can calculate averages in real time, with the CURSORS button. This is another way to verify the singles rate.

To single out potential events, set the scope to **smart mode** using the TRIGGER button. You should set the scope to trigger when it receives two negative edges in the interval 200 nanoseconds to 10 microseconds. (Setting the interval shorter than 200 ns may cause the scope to trigger on some part of the first pulse; setting it longer than 10 us is unnecessary because it is much longer than the expected muon lifetime, and inconvenient in that so few events occur in this region that a good measurement would require many days of data collection.)

**A note on the pulse generator:**
Although it is not strictly necessary for collecting data, you may wish to observe some more predictable pulses on the scope/computer before you look at the erratically-timed muon decays themselves. For this, you can use the pulse generator. When the pulse generator is putting out pulses that resemble the discriminator (except with positive voltage, not negative), the triggering should be set to about 0.15 volts for good results. Adjusting the duration and period of the pulses is accomplished with the dials on the front.

When you connect the pulse generator to the scope, you might need to operate the Delay control. The delay sets a time interval between successive recordings of data from the scope, otherwise the data recording and the writing of the files might get crammed.

## II      Preliminaries

Before using the computer to collect a large dataset, you will want to find an operating voltage (in the range 800-1400 volts) that maximizes the number of actual events (muon decays) and minimizes the number of "accidentals" (two muons passing through in a short time). Using the scope, record the time between pulse pairs by hand for 10 or 20 events. Repeat for several different voltage settings. Then, using your previous observations of the singles rate (from the event counter), calculate the number of accidentals occurring in the 200 ns to 10 us range, as a function of voltage. Comparing these rates for different voltages should help you choose a good operating voltage.

You should also attempt to calculate the muon lifetime by hand with a small amount of data. At this step, you can approximate the lifetime by simply taking the mean value of the event times. Then correct for the accidentals rate and for the fact that you only examined a finite time interval (see the notes, and section IV below, as necessary).

## III      Data acquisition

The step-by-step guidelines here should help you set up the computer for acquiring a large

dataset.

   1) Enter the **C:\Student Directories** directory. The program doesn't function properly if you try recording the data in the "My Documents" directory.  Create a new folder using your name and your partner's name.  This is where your data will be saved.
   2) Open the Muon_Lifetime_Data_Acquisition.vi file on the Desktop. An image of the front panel of the Muon_Lifetime_Data_Acquisition.vi program is shown in Figure 2.



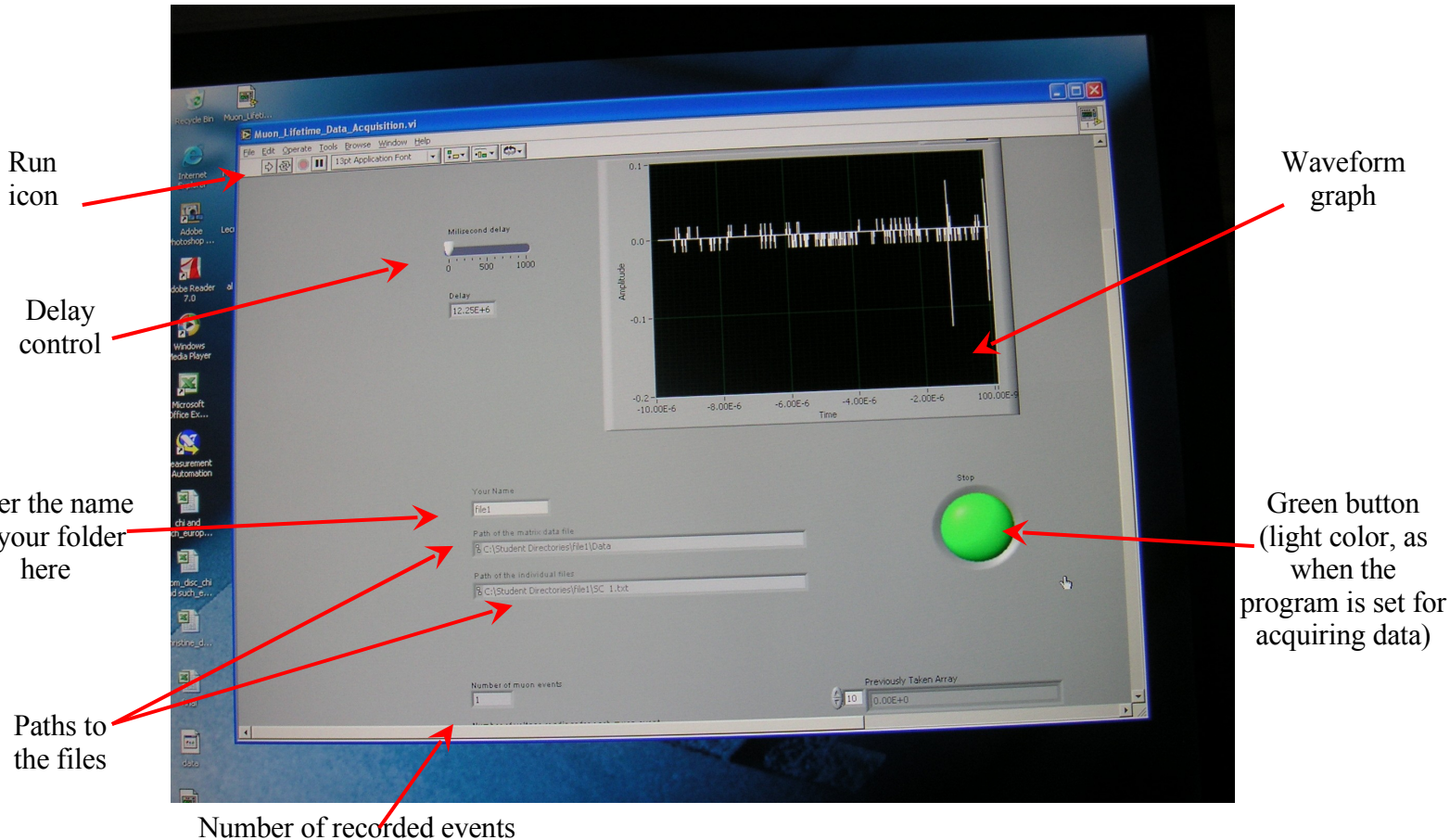**Figure 2:** The Front Panel of the Muon_Lifetime_Data_Acquisition.vi program. The important controls are indicated on the figure. The delay control is used only when connecting to the pulse generator.  You will see in the box "Path of the individual files" the path to the data file most recently acquired.

   3) Type the name of the data folder you created in the box labeled "Your Name".  Note that the program is case-sensitive.  Next, ensure that the box "Time interval between voltage readings" is set to 10 nanoseconds; this frequency ensures that enough data points are recorded from each sweep of the scope so that the time between pulses can be measured accurately and precisely.  Then you can start running the program by clicking the large green button (which should change to a lighter green, indicating the flag is set for data acquisition), and then clicking on the "Run" icon, a left arrow in the menu bar.  You may need to select the Hand tool from Window -> Show Tools Palette.  When you wish to finish the data acquisition, click again on the green button. The color will change back to dark green.
   4) Each muon event is saved in a separate file in the directory you supplied.  The file stores a column of values which are the successive voltage readings, at 10 nanosecond intervals, of the sweep.  You can open these files while the data acquisition program is still running.  Similarly, the location of

a file that contains the voltage readings from all the muon events will be shown in the box "Path of the matrix data file". As in the individual files, the voltage readings from one muon event will be displayed in one column.

5) When you close the Muon_Lifetime_Data_Acquisition.vi program make sure that you do not save any changes to the file.

**NOTE: Do not let the program run indefinitely. You must stop the program when enough data has been acquired.**

Remember that you will need to collect two different datasets, one for the singles rate (background) and one for muon decays (events). The two settings should be adjusted manually on the scope, as described in section I. You will want to make two different folders for acquiring events and background.

When you change the scope parameters between datasets, the acquisition program should not be running. If for any reason the scope is being controlled by the computer, press the button on the scope near the indication "CHANGE TO LOCAL" on the scope screen, and you should regain control of the scope.

**IV     Data analysis**

1)      Checking the files for errors

The first thing to do is to plot the data from each of the individual data files, using (for example) Excel or OpenOffice, to check for errors in the data acquisition. To view the files using Excel, open the Excel program then click on the "File", then the "Open", icons on the menu. After this select the desired file to open. Make sure that the "All Files" option is selected in the box showing the file extension.

The set of voltages will appear in column A of the file. To graph the data click on the cell that contains the name of the column, A. This will select all the voltages. After this, click on the graphing icon in the menu, which is a set of colored vertical bars. Select the "XY (Scatter)" option then click on one of the plotting options. Here is best to select one of the options that show only the line connecting the points, otherwise the graph is too crowded. You don't need to label the axes and to give a title in this case.

Open all files and write down the names of all the files that are not good. Not good means that there are more than two peaks, or there is only one peak. Noise from the electric sources in the room could affect the proper functioning of the LeCroy oscilloscope. The next step is to delete these events from the matrix data file.

Open the Data file using Excel. Delimit the data by Tabs and the set of voltages for one data point will appear in one column. To delete the improper events you need to find the corresponding number of the event. This is relatively straightforward to do. In one empty row below the data, enter the numbers 1 and 2 in columns A and B, respectively. Click and select the two cells. Click on the tiny square in the lower right corner of the selection and drag with the mouse to the right. The adjacent cells will be filled with numbers incremented by 1. Finish when each data column has its corresponding number under it. To delete the columns, start from the column having the highest number, click on the header of the column, then on the Edit, then Delete icons in the menu bar.

After this is done, you can delete the column numbers by clicking on the header of the row that contains the numbers, then selecting Edit and Delete from the menu bar.

2)      Extracting the time intervals for each muon event.

Column A now contains the succession of voltages for the first muon event. To find the time between the muon and the electron pulses for the event, you must locate the two places in column A where the voltage exceeds a certain value. Since both pulses have the same shape, you need not find the highest point of each pulse, but any two points that are in the same location in their respective pulse waveforms. You can do this by entering commands similar to the following, under column A:

| Row | Column |
| --- | --- |
| Number | A |
| 1 | =MIN(A1:A982) |
| 2 | =MATCH(A1004,A1:A892,0) |
| 3 | =MIN(A982:A1002) |
| 4 | =MATCH(A1006,A982:A1002,0)+981 |
| 5 | =(A1007-A1005)*10 |

The command in row 1004 outputs the minimum voltage among the voltages in rows 1 to 982, where the muon signal is. To select a set of cells you can click on the topmost cell in the desired range and then drag with the mouse control over the entire range. The command MATCH in row 1005 will show the row number that contains the value found by the MIN command. The MATCH command has three fields: the first field is the value to be located, the second field is the range in which to search, and the third field can be 1,0 or -1. 0 in the third field requires an exact match. To fill the first field, simply click on cell A1004. This way the number in A1004 will be copied in the MATCH command automatically. Do not enter the value by typing the number for two reasons: first, will be explained just a bit later, and second, because you might lose decimal places.

The next two commands locate the position of the electron signal, which appears always at the end of the set of voltages. 981 must be added to the result of the MATCH command in order to show the location of the electron signal within the entire range of voltages. The last command in the set gives the time between the muon and the electron signal in nanoseconds.

The set of commands is easily transferred to adjacent columns by the following procedure: click on cell A1004. Place the cursor on the tiny square in the lower right corner of the cell, click and drag to the right under all columns. The command MIN will be automatically entered under each column, and it will search for the minimum voltage in the range from 1 to 982 in that column. Repeat for all the commands. Now we can explain the reason for which the value in the first field of the MATCH command should not be entered by typing it. If you only type the number, the same number appears under each column. If instead you enter the value by clicking on the cell containing the result of the MIN command, a reference to that number is provided. When you copy the MATCH command under other columns by dragging the mouse, the first field of each MATCH command will contain the reference to the MIN command in that particular column.

The final line will contain the entire set of time intervals.

3) Further analysis and plotting

Now that you have the time between pulses for each muon event in your data, you can analyze these values to extract the muon lifetime. First, you must group together ("bin") events with similar time intervals in order to histogram the decay times. You will want to demonstrate the exponential decay behavior by making a graph of the log of the number in each bin. Then you can easily fit a straight line to the graph to show its behavior. Remember that your graph should include error bars; the error for each bin is the square root of the number of events in each bin, which should be split evenly between + and - error. So, the more data you have, the smaller your error bars will be, and the more convincing your analysis.

A further refinement would involve making another plot where the x-coordinate of each data point in the histogram is positioned not at the center of its time bin, but at the average time of the events in the bin. For this, you need to evaluate the formula for the average time in a bin that was given in the instructions, in the form of an integral (meaning to do the integral on paper). Then evaluate the integral for each bin. Finally, make a new plot with the revised data points, error bars, and straight line fit. As always, you can compare this new result to the original, and/or comment on additional sources of error that you might have introduced.