

Analyzing Muon Lifetime Data

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INTRODUCTION:

Muons are not stable. They decay into electrons following an exponential decay law, i.e. If we start with N_0 muons then the number of muons left at time t , is given by the formula

$$N = N_0 e^{t/\tau}$$

where τ is the typical lifetime of the muon. Cosmic ray muons, traveling at close to the speed of light, will experience relativistic time dilation which causes the lifetime, as seen by us, to be much longer than a few μs . However, if a muon comes to rest (or is traveling much slower than the speed of light) then the rate of decay will be unaffected by relativity.

We will use two paddles of scintillator material to detect the decay of cosmic ray muons. We will attempt to isolate data which arises from a muon entering a paddle, (producing a signal) then, after coming to rest within the paddle, decaying into an electron (producing a second signal). By looking at the time between observing the muon and observing the electron we can calculate τ .

APPARATUS:

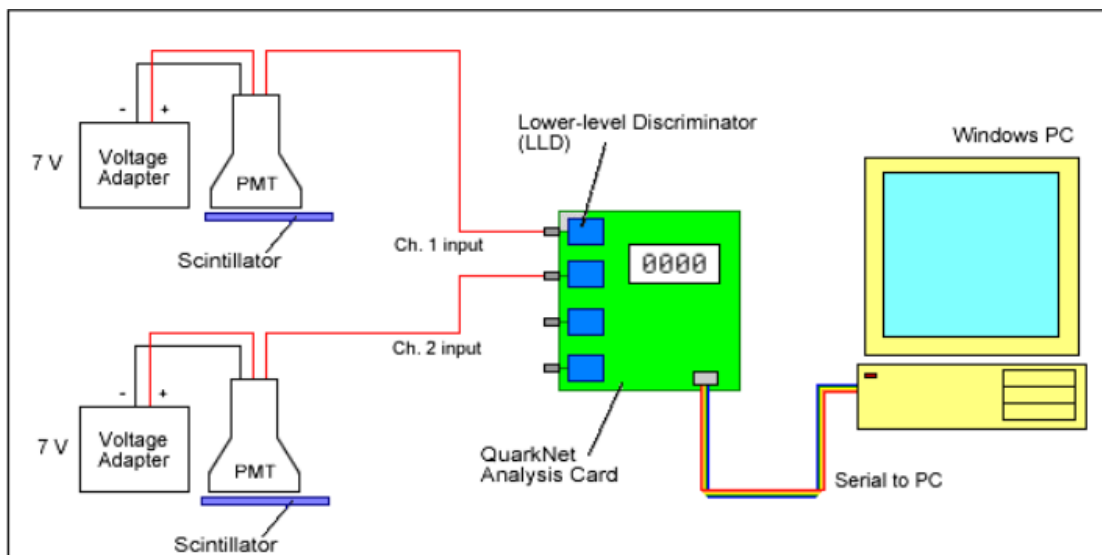


Figure 1: Two-paddle muon lifetime experiment

There are two paddles made out of **scintillator** material, which converts the energy of charged particles traveling through it into light. The paddles are wrapped in an inner layer of reflective foil material which keeps the scintillation light inside the paddle. There is an outer layer of black tape which prevents outside light from entering the paddle.

The light (even a single photon, but usually several photons) is detected by a **photomultiplier tube** (PMT) in contact with each scintillation paddle. The tube uses high voltage to create a pulse of electrons when any photons are detected.

The PMTs are connected to a **Quarknet card**, which is a logic device capable of counting (and combining) the pulses of electrons. The card is set such that a sufficiently strong electron pulse is registered as an **event**.

The count rates, time between counts and other information can be read from the Quarknet card by a **computer**. The computer is also used to control the Quarknet card (e.g. setting trigger conditions as explained below).

PROCEDURE:

Radioactivity is ubiquitous. Our scintillators detect charged particles and radioactive decay products from a number of sources (e.g. ground radioactivity, radioactivity originating within the scintillation materials). Also, there is the possibility that some outside light may enter the paddle and thus produce a signal inside the photomultiplier tube.

In order to reduce the amount of data we observe that is from non-muon sources (i.e. **noise**) we will set up the Quarknet card to **trigger** on certain conditions:

1. **Coincidence:** Two scintillators must observe an event within a small time window. This will exclude many scintillation events caused by some sort of radioactivity inside the scintillator (since the other scintillator will not detect that event, yet muons traveling through both scintillators will still be recorded. It also reduces noise from light leaking into the paddle, since this is unlikely to happen in both paddles simultaneously.
2. There must be a **double event** in one of the scintillators: i.e. inside one of the scintillators there will be two events detected in quick succession. This will isolate those events in which a muon decays within the scintillator, producing an electron. Both the muon and the electron will produce signals from the photomultiplier tubes.

We will also apply this cut to the triggered events

- The **double event must be in the lower scintillator**: We are looking for cosmic ray muons which will be traveling downwards, thus passing through the upper paddle and decaying inside the lower paddle. Double events inside the top paddle coincident with an event in the lower paddle would indicate an upward-traveling particle (perhaps ground radiation) which would contaminate our data set. The Quarknet card records which channel (paddle) the double event occurred in, so we can select the lower-double events only.

A possible improvement to cut non-muon events from our sample

- We could set up a third scintillator paddle below the 'double event' paddle, and require that there be NO event in third paddle. This is called a **veto** trigger condition. The idea is that if the muon decayed in the second paddle, there should not be a simultaneous event in the lower paddle. This will cut any muons which travel through all three paddles, coincident with a noise event occurring in the second paddle.

Even after applying multiple trigger requirements, there will still be some fraction of the recorded data which is not due to muon decay. One improvement we can make is a **data cut** based on plausibility. If we assume that the muon lifetime is approximately $2\mu\text{s}$, then it would be reasonable to exclude data which has a

large time difference between the double events.

After setting up the triggers (see the Quarknet manual), take data with the Quarknet card (again, see the manual) and save the data as a text file.

Analysis Method:

1. Put the data into a useful format (import from text file into Mathematica)
2. Apply the cuts discussed above
3. Using Mathematica, fit an exponential function to the data.

Parsing the Quarknet Output:

This method applies to v1 of the Quarknet card. More recent versions use a different output format.

We will use Mathematica to parse the text file produced by the Quarknet card. The format of that file is as follows

```
000DACE3 53 01 0004
001562FD 53 02 0004
00252DDF 53 02 004E
000F6901 53 02 0004
00039B1C 53 01 0004
001D054E 53 02 0005
002FC4C0 53 02 0004
00022253 53 02 0105
```

Column 1 is the time, in hexadecimal multiples of 160ns, since the last event. For example, the value '000DACE3' corresponds to 896227 multiples of 160ns, i.e. 143396 μ s.

Column 2 is two hexadecimal characters (one byte) representing the nature of the event. The byte is laid out like this

7	6	5	4	3	2	1	0
Not Used	Set if a double occurs on any channel	Not used	Set if the trigger is satisfied	Set if channel 4 registered an event	Set if channel 3 registered an event	Set if channel 2 registered an event	Set if channel 1 registered an event

In this way we can interpret the second column. Our left-hand four bits read 0x5. The corresponding bits are 0101, which means that there was a double, and that this satisfied the trigger (which we programmed into the card when we started the experiment).

The second four bits read 0x3, i.e. 0011 in binary. This means that channel 1 and channel two registered pulses in this event.

Column 3 in our data tells us which channel registered the 'double'. In this case it is a mixture between channels 1 and 2... but we need to select only channel 2, the bottom scintillator.

Column 4 is the time in multiples of 20ns between the two pulses in a 'double'. Note that there are a total of three pulses in the events that we are looking for: One in the top scintillator, one caused by a muon in the lower scintillator, shortly followed by a pulse caused by an electron in the lower scintillator. These last two make up the

'double'.

Mathematica:

First we read in the data from a file, typically saved as something like "CAPTURE_081702_1837.TXT". We have provided a Mathematica program to read in the data from the text file. It is in the notebook "muon_data_analysis.nb", found at

<http://www.nevis.columbia.edu/~oneill/NYSCPT/>

The three functions are called ReadMuonFile, FromHexString and PlotDecayTime. A brief description of each is included in the notebook. Only the function PlotDecayTime will be called by you, the others are 'subfunctions' used by PlotDecayTime.

Before you can use them, the functions need to be evaluated by doing shift-enter in each of the cells (Mathematica might ask you if you want to evaluate all initialization statements, which is the equivalent of going to each cell and typing shift-enter, so say 'yes').

At the bottom of the file is an example usage. PlotDecayTime takes three arguments which are explained here.

The first argument is the name of the text file holding the four column data.

The second is a list with three parts {t_min, t_max, dt}. These tell Mathematica how to plot the data. Data with delta-T less than t_min will be discarded (this is our fourth cut.) Also data with delta-T greater than t_max will be discarded (not a cut, try playing with it, does it make much difference to change this in a certain range?). dt is the bin size for the histogram. Make it too small, and there will be mostly bins with 0 events, make it too large and we lose information. Times are in units of μs .

The third argument should be the channel number of the lower detector... this is the one that should be registering doubles.

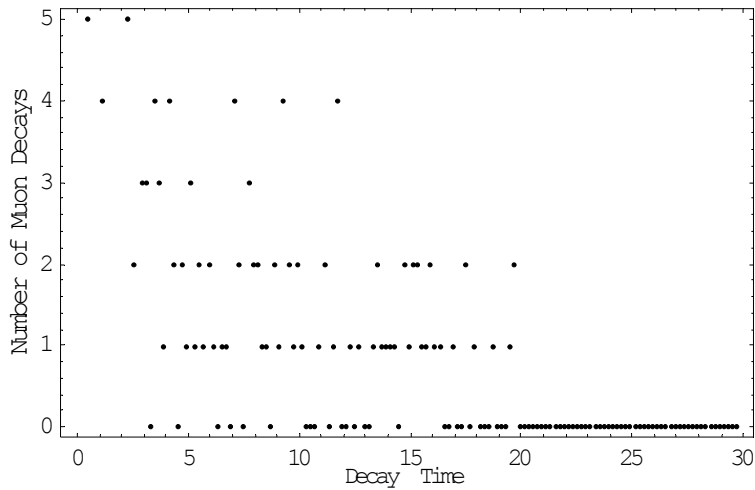
My example command was

```
mydatafile="C:\Documents and Settings\oneill\My
Documents\muondata.dat";
PlotDecayTime[mydatafile, {0.16,30,0.2}, 2]
```

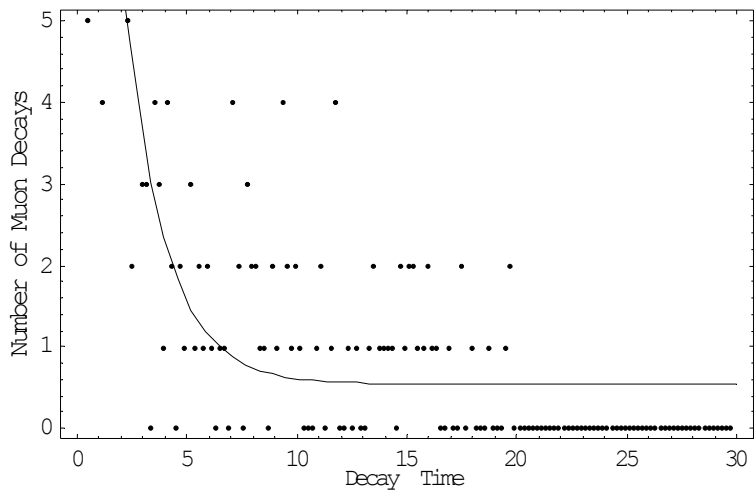
Evaluating this cell gave me

No. of events above t_min: 0

re for file C:\Documents and Settings \oneill \My Documents \muon_data



re for file C:\Documents and Settings \oneill \My Documents \muon_data



Muon lifetime from data = 1.83259 usec

This was using a very small data set. The exponential shape of the data is evident, but could be more well defined. Hopefully your data will be better (with more data points).

Further Reading:

1. New York Schools Cosmic Particle Telescope
<http://www.physics.nyu.edu/NYSCPT/>
2. Presentation on Muon lifetime
<http://www.nevis.columbia.edu/~oneill/NYSCPT/>