SUPPLEMENTARY NOTES FOR TEACHING ASSISTANTS FOR THE MUON LAB FOR PHYSICS 134.

This document is meant to aid teaching assistants of physics 134 in the successful execution of the muon lifetime experiment. In this experiment, it is essential that the calibrations and electronics be set up properly beforehand. Errors usually do not manifest themselves until several days after data taking and afterwards take considerable time to track down. Therefore I have provided here detailed descriptions of the timed-amplitude converter, pulse generator, discriminators, and logic so that if a student should end up with meaningless data, the setup can be checked quickly. This guide is a reference with which to check settings and parameters and is also an aid to troubleshooting should a problem arise.

The basic goal of the experiment is to measure the average lifetime of the muon. The decay of any individual muon is random and independent of the decay of any other muon. Therefore, if the lifetime of a muon is a random event, then the lifetimes in a collection of muons should obey Poisson statistics, and a histogram of counts verses lifetime should be of the form of a decaying exponential. The average lifetime of the muon would then be given by the exponential's time constant. The TAC delivers to the computer input data in the form of the voltage pulses that are proportional to the lifetimes of the individual muons. The input data is of the form of voltages, so we will need some way to convert muon lifetimes into voltages. This is the purpose of the time-to-amplitude converter (TAC), to deliver to the computer voltage pulses that are proportional to lifetimes of the individual muons. Once the computer has received a voltage pulse, it adds a count to the bin that that pulse represents. The bins are displayed on the computer screen in units of KeV, and the students must determine how to relate KeV bins to actual muon lifetimes. Discriminators attached to each paddle will reject spurious noise counts. Finally, the logic will help us to discriminate between muons that pass through our apparatus and those that actually decay. See figure 1 for a general block diagram of the experiment.

There are 4 detectors, i.e. paddles A, B, C, and D that are responsible for registering muonic events. The space between the 4 paddles is filled with phone books, a low Z material. The trajectory of the muon is mainly on a path perpendicular to the Earth's surface, so we will assume that the muon impacts paddle "A" first. When the muon impacts paddle A, a voltage is generated in the paddle and the paddle sends a pulse to the discriminator. If the muon does not decay but travels through the apparatus, about a nanosecond later the muon will impact either paddle B, C, or D. Whichever paddle the muon impacts after "A" will also generate a pulse. If, after the muon impacts paddle A, it comes to rest in the low Z material and then decays, an electron will emanate from the decay site, impacting either paddle B, C, or D. The decay will take place on the order of microseconds, so the pulse separation between A and B, C, or D will be on the order of microseconds. The paddles will also generate pulses in response to events that are not muonic. The discriminators will weed these events out. See figures 2 for a graphical representation of the muon decay.

The discriminators have the job of making sure that all and only the pulses generated by muons are processed by the logic. The paddles simply generate a pulse whenever they are impacted. The amplitude of the pulse they generate is proportional to the energy departed to the paddle. So if a noise event emits a low energy particle, the paddle will relay a weak pulse to the discriminator. If decay emits an electron that strikes the paddle with medium energy, the paddle will output a medium sized pulse. Thus we want the discriminators to throw away weak pulses, and relay to the logic pulses that correspond to muon passage or their decay products. We can do this by setting the voltage threshold of each discriminator. We can simulate the decay of muons with an Sr90 source, or if that is not available, Na22.

The discriminator takes input from the appropriate paddle in the lower left, and sends an output to the logic unit from the slot marked "out". At the top left of the discriminator there are the markings "THR" for threshold and "WDTH" for width. These are the thresholds and widths of the output pulses, respectively. They can be adjusted by inserting a screwdriver into the slots next to these markings. Only pulses with an amplitude higher than the threshold will be passed to the logic. All output pulses of the discriminators have the same amplitude. In the top right of the discriminator is a red light that should be constantly blinking when the experiment is running well.

Here is the procedure for the calibration of the discriminators. Figures 3 and 4 may help to visualize the setup. First, when you calibrate a discriminator, put either the Sr90 or the Na22 source such that its normal vector is perpendicular to the paddle (figure 4). The Kiethley multimeter will measure the voltage of the threshold of the discriminator and the counter (5315A Universal Counter) the number of counts per second passed to the next stage. In the Kiethley, the "Lo" is connected to the chassis, i.e. ground. The "Hi" of the Kiethley should be (held by hand) connected to a small metal hole encircled by a white ring in the top left of the discriminator. The display on the Kiethley should be exhibiting a stable, negative value. This voltage is 10 times the true threshold value. The output of the discriminator should be connected to channel "A" of the counter and 50-Ohm terminated. The terminator prevents reflections that can cause spurious counts. On the counter, the buttons below "freq A", under "Level/Sens", "AC", and "Trig Level" should all be pushed in. The "Gate/Time Delay" should be set to half of its maximum value. The level/sens should be turned to its maximum value. The "Hz" (counts per second) light in the display should be active and bright red.

From the plot of counting rate VS threshold, students are to determine where to set the threshold. At each threshold value, students are to compare the counting rate between putting the source on the paddle and leaving it off. At maximally negative values there should be no difference in the counting rate between either case because the threshold is too high to pass sodium counts. As the threshold is increased to zero, a discrepancy between the source on the paddle being on or off will arise. Half this value corresponds to the energy of a muon decay, and this is where the discriminator should be set.

Some discriminator thresholds that were recorded for a successful experiment were as follows: A was -3.5 V, B was -9.2 V, C was -3.3 V, and D was -0.6 V. The counting rates with a Na22 source on (off) the paddle were: A was 3.18 kHz (40 Hz), B was 450 Hz (25 Hz), C was 1500 kHz (87 Hz), and D was 7 kHz (80 Hz). All the power supply settings for the discriminators were set at maximum value. The counting rates fluctuate about these values and are stable to within an order of magnitude.

Students should not adjust the widths of the "out" pulses. If the widths have been changed, here are the values (oscilloscope 50-Ohm terminated): A is 70 ns wide with an amplitude of -.8 Volts. B, C, and D are each 50 ns wide with amplitudes of -.8 Volts each.

If, in a logic unit, a particular input (A, B, C, D) is not being used, then a red pin should be placed in its corresponding disable state. For this experiment, there should be a red pin in B, C, and D in the top logic unit and a pin in A for the bottom logic unit. This is to ensure that disabled channels do not contribute spurious signals to the logic process. The white oval under the disable switches has slots for unused pins. The coincidence level for both logic units should be set to 1. For the bottom logic unit, a coincidence level of 1 establishes the OR condition between B, C, and D as B OR C OR D.

If the count is legitimate, the logic will output a pulse to the TAC START input and a pulse to the TAC STOP input. If the TAC receives a START and a STOP command, it will tell the computer that a count has occurred and which bin it is to be placed in. If the count is not legitimate, the TAC STOP will still receive a pulse, but the TAC START will not, and the TAC will not send anything to the computer.

We can tell the logic to not issue a pulse to the TAC START by means of the VETO mechanism. The VETO has two inputs, one from A, the other from B OR C OR D. If there is a pulse on one input but not the other, no VETO will be issued, and a TAC START will be activated. If there is a pulse on both inputs, the VETO will be activated, preventing a TAC START from being activated. The former case corresponds to genuine decay, the later to when a muon travels straight through the apparatus. In the first situation, the input on A precedes the input on B by microseconds, and the pulses don't overlap. In the later situation, the two pulses do overlap, the input from A arriving just behind the leading edge of B OR C OR D. Since the electronics require 30 ns to process a VETO, we delay the pulse on A by means of a coiled wire. This can be seen visually in figure 5.

Here are the connections for the logic. Input A on the top logic unit is connected to the output from the A discriminator, via the coiled wire. On the bottom logic unit, B, C, and D inputs receive from B, C, and D discriminator outputs, respectively. One output from the bottom logic unit connects to the VETO on the top logic unit. One output from the bottom logic unit goes to TAC STOP. One output from the top logic unit goes to TAC START. I have included a schematic of all of this in figure 6.

The TAC is the brown box on the right side of the crate. The range and the multiplier control the range of lifetimes the TAC will convert into a pulse. For example, if the range * multiplier equals 10 us, lifetimes between 0 and 10 us will be converted to a voltage, but a 20 us pulse separation will be ignored. For this experiment, a 200ns range and a multiplier of 100 are typical. The control STB is set to INT. The connection EXT is left unconnected. The TAC OUTPUT goes straight to the computer.

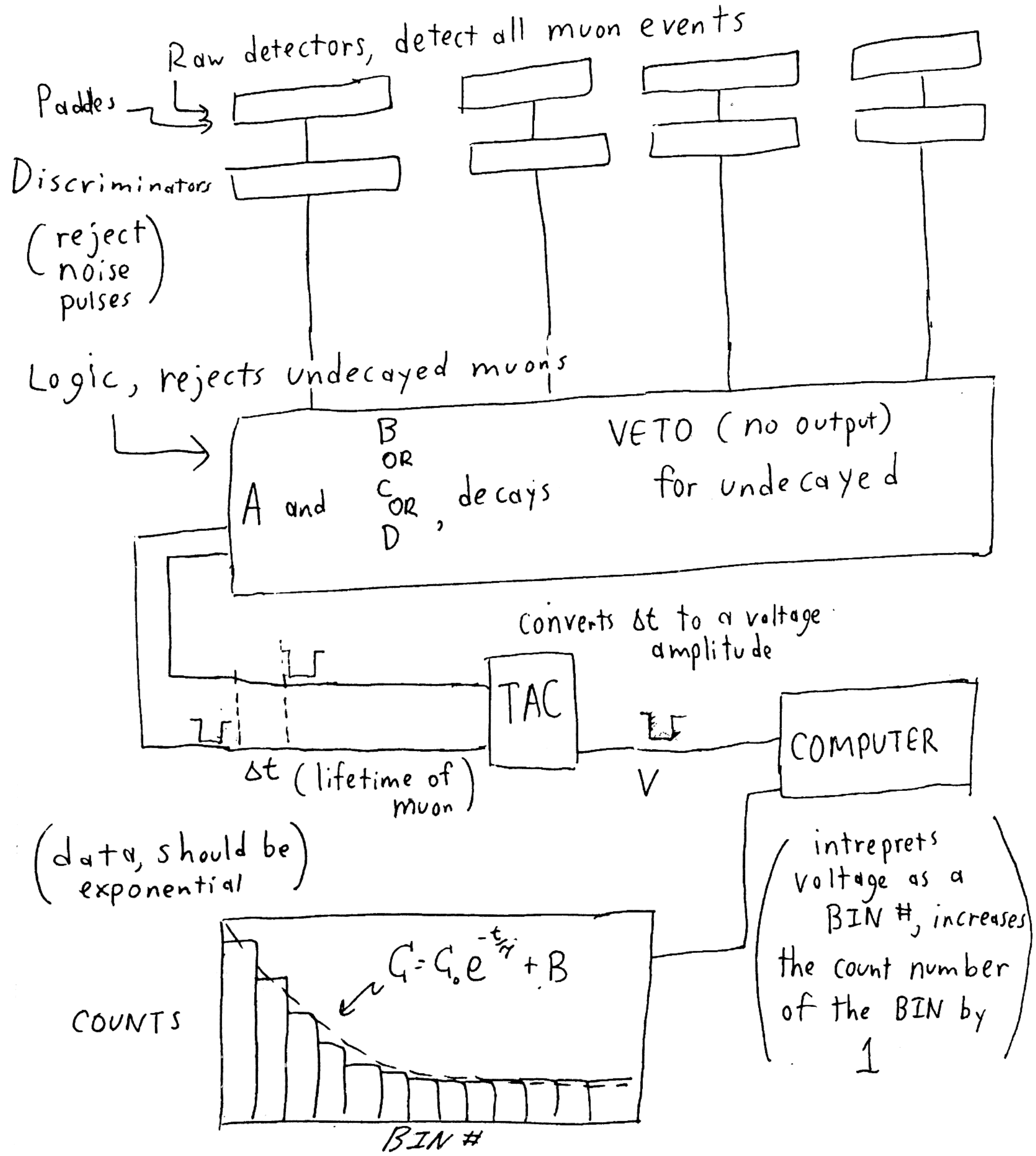
The students are required to calibrate the TAC, that is, determine the linear relationship between the KeV bin number and lifetime. They can do this using the "BNC Model BH-1 Tail Pulse Generator". During calibration, the TRIG OUT is connected to TAC START and PULSE OUT is connected to TAC STOP. Each of these connections should be displayed on the oscilloscope and 50-Ohm terminated. The TAC does not receive any inputs from the logic units during calibration. During the actual experiment, the Pulse Generator is not connected in any way to the logic or TAC. The frequency of the pulse generator should be set at 10 kHz or higher. The "delay" represents the time separation between the two pulses the generator will output and hence is the simulation of the lifetimes of events. The "delay" will occupy several values between 0.5 us and 20 us. The generator should be set to "single pulse", negative polarity, internal reference, both attenuators should be off, and the rise and fall times of the pulses should be minimal. EXT REF and EXT TRIG are left unconnected. The TAC OUTPUT goes to the computer. The computer should be acquiring data during the collection. The connections are shown in figure 7.

On the scope, one should see two negative, equal amplitude pulses, one on channel 1 and the other on channel 2. The TAC can only accept negative amplitude pulses. An inverter can remedy any output that is generating positive pulses. If the "delay" is set to some value between 0.5 and 20 us, one should notice that on the computer, one particular bin is getting all the counts. Furthermore, on the scope, the two pulses should be separated by the time the delay is set to. We measure the time between the pulses as the time difference between their leading edges. If the delay is changed to a new lifetime, a new bin will begin accepting counts.

Finally, the data should be of an exponential form as displayed on the computer. The binning should be divided between 1024 bins. This control is in the top right of the monitor display. The pull down menu "Acquisition" has the usual "Start", "Stop", and "Clear" options. The data should run for about a week but should be checked periodically, as an exponential like curve will begin to manifest itself after a day or two. No terminators or inverters should be in any of the connections while the experiment is in progress. The lifetime after the fit program is run from Fermi should be about 2.19 us or so.

Figure 1, below, basic diagram of the experiment. The paddles are the raw detectors. After the paddles the next stage is the discriminators, which weed out noise or weak events. The third stage is the logic, which discriminates between valid muon decays and muons that travel straight through the apparatus. The TAC converts the separation between the two pulses of an accepted muon event into a voltage amplitude. The computer interprets this amplitude as a bin number, increasing the total count of that bin by one. Since the decay of a muon is a random process, a histogram of counts versus bin should behave like an exponential. The time constant is the average lifetime of the muon, which we wish to measure.

BLOCK DIAGRAM OF GENERAL EXPERIMENTAL SETUP

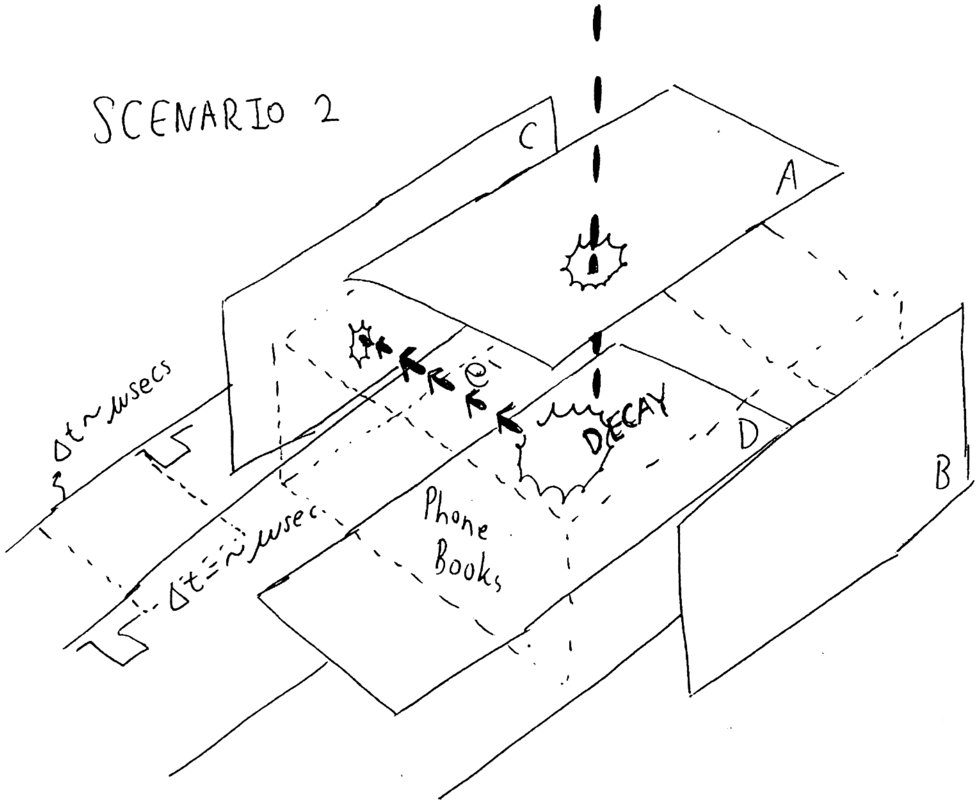


"τ" is average lifetime of muon

Figure 2. After striking paddle A, the muon decays, and its decay electron strikes another paddle. The time between the pulses sent out by paddle A and the other paddle is the same as the time between the impacts on paddle A and the decay event. The time between the pulses, or lifetime, is typically on the order of microseconds. If there had been no decay, the pulses on A and the other impacted paddle would have been separated by about 1 nanosecond at this stage of the experiment.

PADDLES

SCENARIO 2



Muon impacts paddle A,
then decays

Figure 3, below. The normal vector of the source needs to be placed perpendicular to the paddle whose discriminator is being calibrated. Tape helps to hold the source onto the side paddles.

SOURCE PLACEMENT ON PADDLES FOR DISCRIMINATOR CALIBRATION

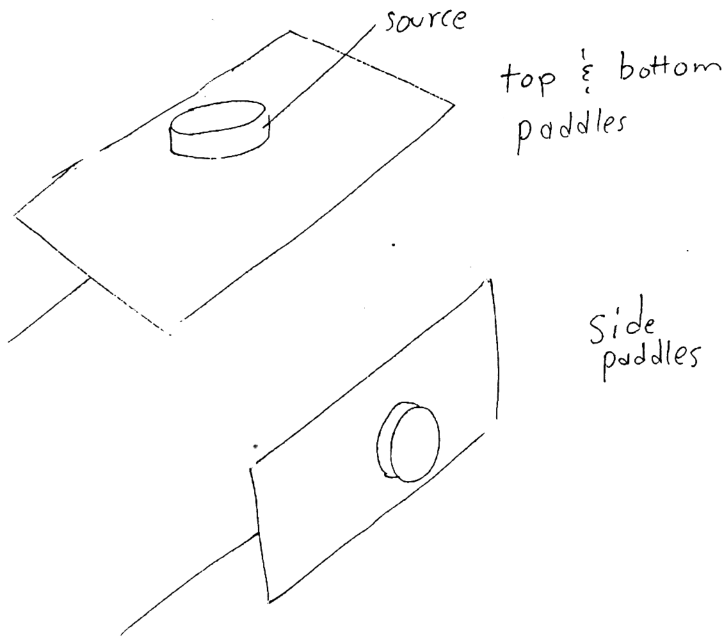


Figure 4, below. Here are the connections for the calibration of each discriminator. The ground (LO, black) of the Kiethley multimeter is connected to the chassis. The HI end is connected to the small metal disk encircled by a white ring at the top of the discriminator (must be held by hand there). On the display of the Kiethley, a negative voltage should appear whose first few digits should not be fluctuating. This is the voltage threshold and it can be adjusted via a screwdriver inserted in the slot marked "THR". One of the "outs" of the discriminator should be connected to an input on the counter. This connection should be 50 Ohm terminated to prevent reflections. There should be a light in the top right of the counter display and it should be red and indicating units of hertz, i.e., a counting rate. These numbers will fluctuate, but the values will be of the same order of magnitude. Another "out" can go to the scope if the width of the output pulse needs to be checked. The width of the pulse can be adjusted via the "WDTH" control. The WDTH needs a screwdriver to be adjusted, same as THR.

CALIBRATION DIAGRAM FOR DISCRIMINATOR

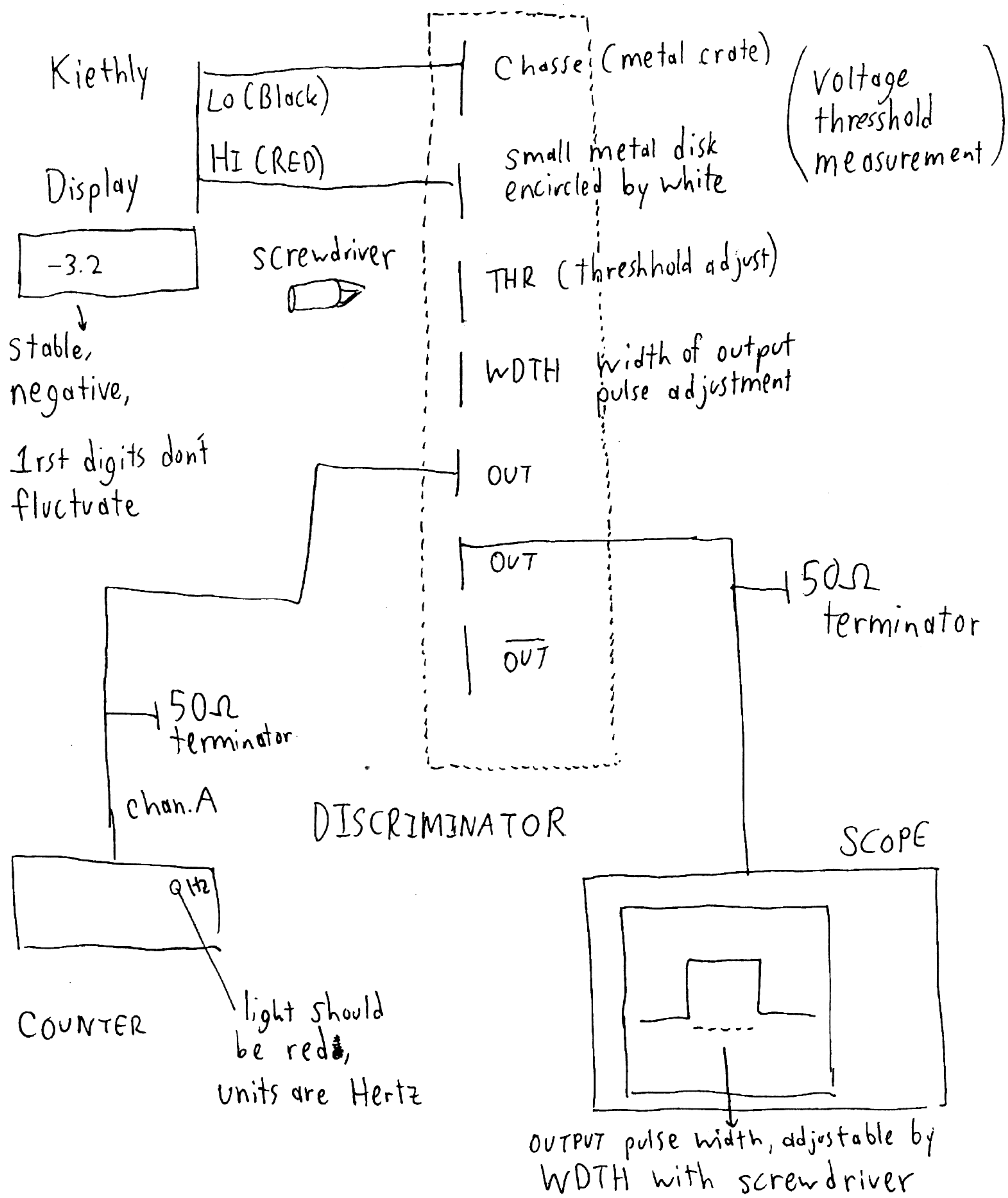
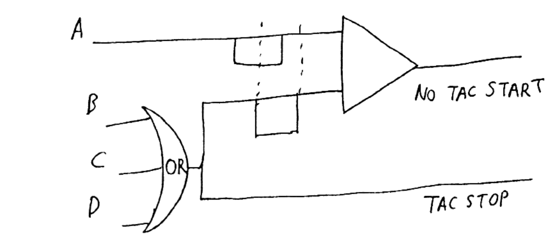


Figure 5 below, VETO. In the top figure, for the VETO to work properly, the pulses on both of its input lines must overlap in time, the VETO arriving first. If the comparator sees two pulses that overlap in time at its inputs, it will not send a signal to START TAC, and this count will be rejected. When the muon travels straight through the apparatus, we slow the A pulse down via the coiled wire so that it arrives just behind the leading edge of the possible VETO input from the other impacted paddle. Since these pulses overlap, the VETO rejects the event. If the two pulses do not overlap in time when they arrive at the top logic module, START TAC will be issued, and the event is relayed to the next stage.

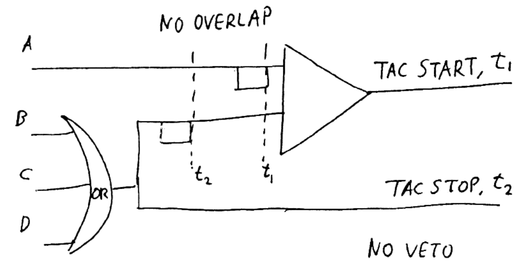
VETO SIGNAL

CONDITION FOR VETO



NO SIGNAL SENT

PULSES SEPARATED BY MORE THAN TENS OF NANOSECONDS



NO VETO

Figure 6, below. Here are the connections between the paddles, discriminators, logic, and TAC during the experiment. The pin assignments on the logic are shown on the left. "R" with a circle means that a red pin should be inserted in that slot, a blank means that no pin should be in that slot.

CONNECTIONS DIAGRAM FOR PADDLES, DISCRIMINATORS, LOGIC, TAC

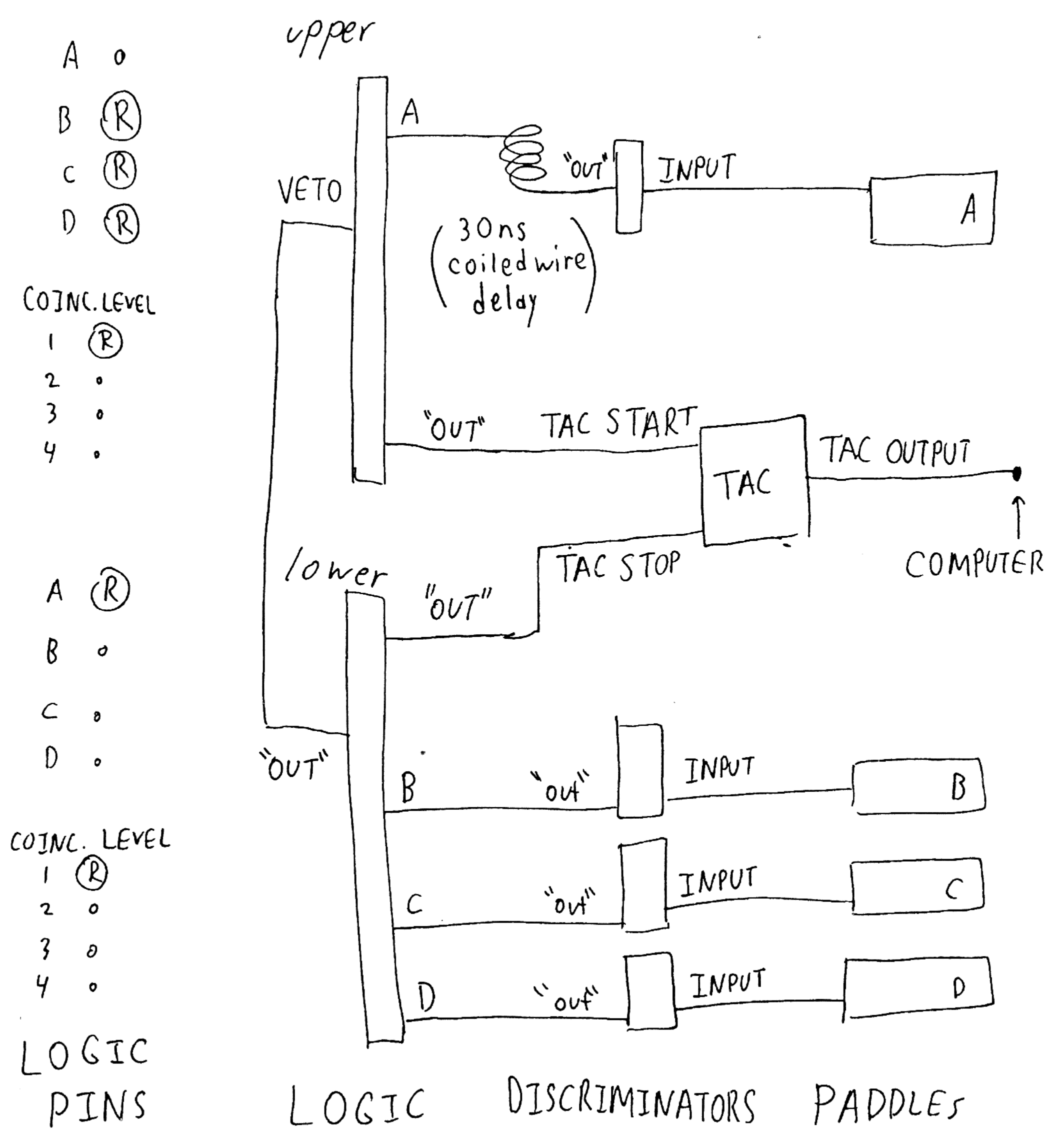


Figure 7, below. Here is the wiring setup to calibrate the TAC. TRIG OUT is connected through an inverter (input pulse to the TAC should be negative) to TAC START and to a connection on the scope. PULSE OUT is connected to TAC STOP and a channel on the scope. On the scope, one should see two negative pulses, the time between them a simulated lifetime of a decay event. This lifetime can be changed via the "delay" on the pulse generator. On the computer, the bin that corresponds to the lifetime the delay is set at should be increasing its total count at the rate set by "freq" on the pulse generator. A different delay time will cause counts to appear in another bin. The relationship between bin number and decay time should be linear, and the students are expected to determine the equation of the line that relates the two.

TAC CALIBRATION DIAGRAM