

Muon detection with QuarkNet Card (v1.0)

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The QuarkNet card was designed and built by engineers at Fermilab in Batavia, Illinois to monitor muon signals using photo-multiplier tubes (PMTs) and scintillators. It replaces traditional nuclear instrumentation modules (NIM) that are more expensive, less precise, less reliable, and can be difficult to adjust and calibrate. A single circuit board amplifies PMT signals by 10x and uses voltage comparators for discrimination with adjustable threshold. On-board timing is implemented with CPLD (Complex Programmable Logic Device) via software installed at Fermilab. Photon events are time-resolved with an accuracy of 1.25 ns using a time-digital-converter. A micro-controller interfaces with the control PC using a custom LabVIEW program.

The high voltage PMT power supply is located in the rack with the NIM electronics and is adjustable in the range -1000 to -1500 V. The supply biases both PMTs simultaneously, i.e. the voltage on the PMTs is not individually adjustable. By observing PMT outputs on two channels of a fast oscilloscope, you will notice that they produce different signal magnitudes and photon count rates. The QuarkNet card needs to be configured to handle this.

Connect the PMT outputs to two detector input channels on the QuarkNet card. Each channel preamplifier has 50Ω input impedance, so if the PMT signals are also being monitored on a parallel oscilloscope the channel input impedance should be set to $1 \text{ M}\Omega$. Apply 5V DC power to the QuarkNet card by plugging the AC adapter into a wall socket. A blinking LED associated with each channel indicates the occurrence of a local trigger. The LEDs can give a rough visual guide to assist in configuration (Note: the digital counter is of little value). Open the LabVIEW program Setup.vi.

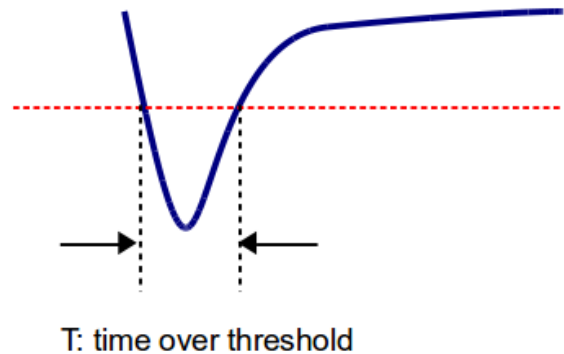
Card Timing: Triggering can be initiated by either: i) one pulse from a single PMT or ii) coincident pulses from 2, 3, or 4 PMTs. Coincident triggering is more reliable because it is less susceptible to false signals produced by random background noise. This experiment has two PMTs available to monitor photons in the scintillator tank.

If coincident triggering is used, the time overlap window (coincidence time) must be set. The default value is 40 ns. At the default setting, two PMTs must produce individual pulses that exceed their specified threshold voltage AND occur within 40 ns of each other to create a trigger. If the coincidence time is too short, relatively few card triggers will occur. If it is too long, there is increased probability of false triggers. The oscilloscope display of the pulses can guide this setting. The coincidence time has no meaning in the single trigger configuration.

Once the card triggers, all the detector input channels will record above-threshold photon signals during a specified time (gate width). The proper gate width will depend on the

type of experiment being performed. If only the triggering pulse or pulses are to be recorded, the gate width can be relatively short. If muon decay events are of interest, the gate width must exceed the expected muon lifetime by 4--5x. Longer than this will introduce noise; a significantly shorter gate will make determination of the decay time difficult.

Threshold: Each channel of the QuarkNet card will locally trigger when the amplified PMT pulse exceeds a specified threshold voltage. This is illustrated by the dotted red line in the adjacent figure. Recall that the threshold voltage must be adjusted by 10x compared to the PMT output to account for amplification on the card. Also note that individual channel triggers do not guarantee the gate will open if coincidence triggering has been selected. Simultaneous PMT events as defined by the coincidence time window are required.



The time-over-threshold of an individual pulse can be recorded with a precision of 1.25 ns. This time gives an approximate measure of the integrated power and hence the relative energy in the PMT pulses.

Setup: The LabVIEW program Setup.vi helps configure the QuarkNet card. The goal is to set the PMT bias voltage along with the channel thresholds to acquire reliable data counts. The negative-going voltage of the PMT output pulses must be sufficiently above the background noise and at a level where they can be readily discriminated.

Initial setup should be performed with single detection, a gate width of 100 ns, and 100 mV threshold. Negative voltage for all PMT signals is assumed, so the threshold is entered as a positive number. These settings are not critical, but should be a good starting point. The sampling period should be long enough that the count does not vary widely between display updates. Start the program, wait three seconds for the card to initialize, and press the RUN button. Detector counts will be displayed. To change an operating parameter, press PAUSE, make the desired change, then press RUN. The PAUSE button allows parameters to be modified without a complete card reset. As the threshold voltage increases, the count rate should drop. When higher thresholds do not noticeably reduce the count rate, a good operating threshold voltage is identified. Keep the PMT voltage constant and configure the second channel using the same criteria. If adequate thresholds can't be established on both channels, the PMT voltage must be changed.

Select the coincidence tab to enable single counting from both PMTs and display their

coincidence counts. Both detectors should be counting at a higher rate than the coincidence events; you can also determine which of the two detectors is limiting the coincidence trigger rate. Proper behavior verifies the threshold settings and the width of the coincidence time window. Record the working parameters and do not adjust the PMT voltage.

Open the LabVIEW program Muon.vi. With appropriate timing settings and threshold parameters determined above, this program records photon events collected by the PMTs. Two measurements can be performed: photon energy distribution and muon decay lifetime.

Energy distribution: Select the measurement 'Energy' and open the Coincidence tab. The experiment can be done with a single PMT, but more reliable data is obtained with simultaneous signals from two PMTs to verify the presence of a valid photon in the scintillator. The goal of this measurement is to determine the approximate energy of each photon event by recording its time above threshold, shown as T in the above figure. The gate width can be set with the aid of the oscilloscope. It should be long enough to capture the photon signal; too long will introduce unnecessary noise. Since the width of the triggering photon is of interest, the gate minimum should be set to zero. Only data from one of the PMTs (decay detector) will be recorded.

Start the program and wait 3 seconds for the card to initialize. When the card is ready, press the RUN button. You will be prompted to specify the name and location of a data file where the collected values of T (in ns) will be written. Since data can be collected for an arbitrarily long time, this file will auto-save at a user-specified interval. Real-time data is displayed on an updating histogram. The distribution should approach an ideal Gaussian depending on the number of data points and histogram bins.

When sufficient data has been collected, stop the program. Repeat the measurement but stop it when the number of data points is about half of the first run. Change the decay detector to the other PMT and do the same pair of measurements (4 total). For the analysis, produce a histogram with a Gaussian fit for all the data sets to determine the mean pulse width and variance; express the latter as a percentage of the mean. How does the analysis depend on the number of histogram bins? Comment on the differences and calculate the experimental uncertainty for each data set.

Muon decay: Select the measurement 'Decay' and open the Coincidence tab. In this experiment, the decay detector waits for a second photon that follows the coincidence trigger, which should correspond to a muon decay. The program must be configured to ignore trigger events, which will radically skew the data toward time zero. The gate minimum setting must be set longer than duration of any possible trigger pulse, accounting for fluctuations introduced by the coincidence time window. (Tip: The gate minimum should be longer than the gate width used in the preceding experiment) To

observe the expected exponential decay, the gate should remain open for several muon decay lifetimes (order of microseconds). If the gate width is set longer than 5 muon lifetimes, data accumulated at long times will represent the noise background. The background data introduces a constant offset on the statistics that can be subtracted. The desired decay events are statistically rare, so an hour or more may be needed to accumulate a useful data set. When sufficient data is collected, stop the program. The time events are all written to the specified data file. For the analysis, setup an appropriate histogram on a semi-log plot. The slope of the linear fit is the measured muon decay lifetime. Calculate the experimental uncertainty and compare the lifetime to the accepted value.