QuarkNet Lifetime Study with Geneva Stack 6674

A QuarkNet cosmic ray detector arranged in a vertical stack recorded muon decays in four different trigger hardware conditions using the parameters trigger gate and coincidence multiplicity. The number of muon decay candidates per hour, the number of decays per muon, and the ratio of signal to random background in the first 10microsecond are presented.

Detector Configuration:

The detector configuration is characterized by the vertical positions in Table 1. This stacked configuration was designed to measure the speed of muons twice per event, to enable a search for upward-going muons. The goal for the special data collected 3Jul-7Aug20 was to investigate the number of muon decays captured using a short or long trigger gate and under 2-fold or 3-fold triggering conditions. Decay candidates are identified by a muon that traverses at least 2 scintillators, triggering the DAQ, followed by another hit in one of the originally hit counters that is identified as the electron candidate.

Channel	Vertical Position (m)
1	0.07
2	0.17
3	1.48
4	1.59

Table 1: Vertical positions of the Geneva Stacked Inverted detector DAQ 6674

Under a long gate (10 s) the electron candidate is captured up to a time near the length of the trigger gate with approximately 100% efficiency. Using a short gate (300ns) the electron candidate must satisfy the trigger that generates a second event to be read out. The efficiency for the electron to fire two scintillators is greatly reduced. The trigger condition of 2-fold or 3-fold also has a dramatic effect on the number of triggers and the efficiency of tagging the electron. The ratio of the rate of triggered muons under 2-fold compared to 3-fold triggering is approximately 18Hz/0.46Hz = 39! Under the condition of 3-fold triggering, almost no electron can traverse 3 counters.

The vertically separated nature of the detectors means that there are two pairs of nearby counters (10cm apart) that have a large muon rate and significant electron acceptance. Under 3-fold triggering the muon rate is reduced due to the geometric acceptance but there are two decay volumes (ch3 and ch4) for the electron to be found for each triggered muon.

Results:

Muon trigger and decay results for each of the four data taking eras, defined by the trigger multiplicity and trigger gate width, are presented in Table 2. Flux plots of each era were checked to ensure that detectors were live during the entire span of each data taking era, and the average trigger rate estimated from the Blessing plots.

The number of muon decay candidates is calculated from the frequency distribution of the time between the muon trigger and the electron candidate hit. Shown in Figure 1 are results from the 2-fold/short gate and 2-fold/long gate data. The total number of decay candidates is defined consistently across all data; obtained by summing the number of events between 0.3 s and 9.5 s after the flat background from random -e candidate coincidences has been subtracted.

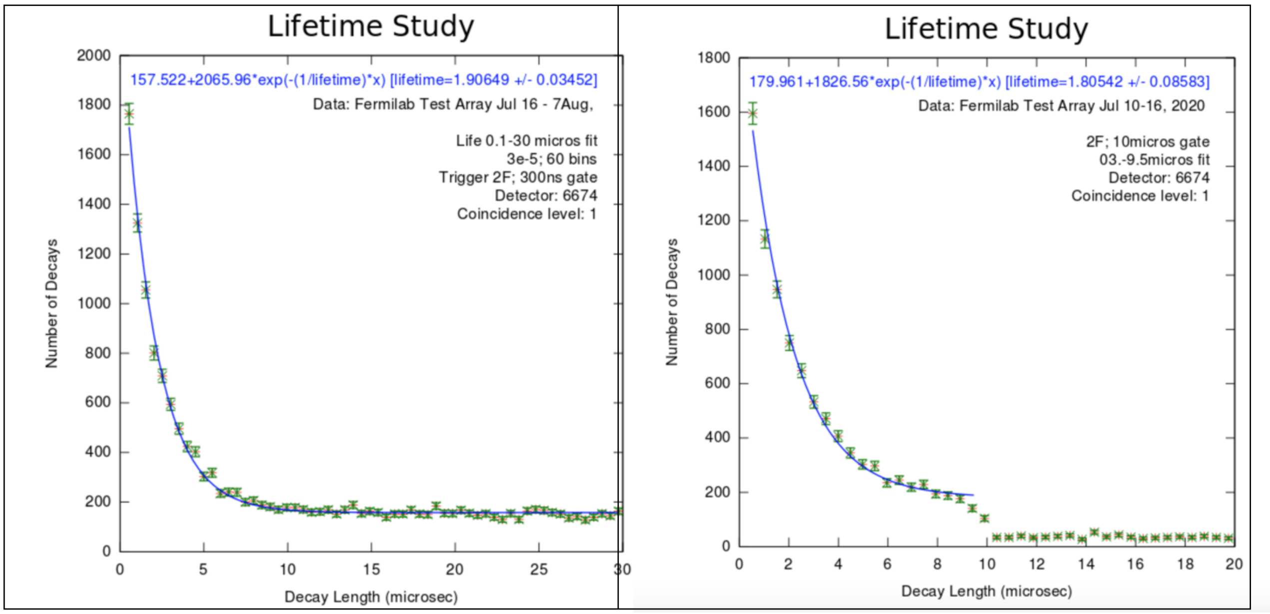

Figure 1. Number of decay candidates versus time in 500ns bins for DAQ 6674 from two eras: left - 2-fold triggering requirement and short trigger gate width; right - 2-fold triggering requirement and long trigger gate width. Fit results for the muon decays and random background are also shown in blue text.

6674 era	10-16Jul20	16Jul-7Aug20	3-10Jul20	7-14Aug20
	2F; 10micro	2F; 300ns	3F; 10micro	3F; 300ns
Period (min)	8541	32049	5854	9648
trig rate (Hz)	18	17.5	0.46	0.45
#muons	9224280	33651450	161570.4	260496
#decays <10mics	6877	6847	286.6	1
#decays/hr	48.31	12.82	2.94	0.006
#decays/muon	7.46E-04	2.03E-04	1.77E-03	3.84E-06

Table 2: Data for four data taking conditions: dates; conditions; total time of data collection; average muon trigger rate; number of muon triggers; number of decay candidates after background subtraction; decays/hour; decays/muon trigger.

Two of the most useful measures: the last line in Table 2 presents the number of muon decay candidates per muon trigger and the penultimate line presents the number of muon decay candidates per hour.

Several trends are observed.

1. The trigger rate is approximately 0.46 Hz (18 Hz) for 3-fold (2-fold) trigger multiplicity conditions. This is independent of the trigger gate, however, it depends on the angular acceptance of the detector.
2. Comparing the number of muon decay candidates per muon trigger from the long gate with that from the short gate in the 2-fold samples demonstrates that requiring the electron to hit two counters lowers the efficiency to 27%.
3. The largest rate of decays per muon occurs with the 3-fold; long gate sample. That is occurs because muons can stop in both ch3 or ch4 after satisfying the 3-fold trigger, whereas in the 2-fold case there is only one scintillator available to stop in: ch2 (ch4) for a ch1-ch2 (ch3-ch4) trigger.
4. The 2-fold; long gate sample collects most decays over time.
5. As expected, almost no electron candidates satisfy the 3-fold trigger requirement in the 3-fold; short gate sample.

Two additional metrics not presented in the table are the ratio of signal (number of decays) to the flat, random noise background in the same 0.3-9.5 s region, and the muon's mean lifetime. For data (2F/short: 2F/long; 3F/long) that ratio is (2.56; 1.95; 1.27) and the mean lifetime is (1.91+-0.035 s; 1.81+-0.086 s; 1.46+-0.12 s). The purity of the sample is best with the 2F/short data set, although the number of decays is reduced due to the low efficiency of tagging the electron with two counters. This can be improved by bringing the counters closer together.

Although gates of 10 s and 300ns are used in this study, users can increase their DAQ hardware trigger gate to approximately 50 s. That increases the region where decays can be collected with ~100% efficiency for the electron to 50 s. However, this gate is also used to define the trigger coincidence region for the muon trigger. Users might want to avoid the spurious random muon triggers depending on their detector configuration, since that leads to more random background as well.

Additional investigation of lifetime fit:
The fit of the mean lifetime for the longest data run, obtained from the e-Lab Lifetime module (1.9065+- 0.0345 microseconds), appeared to be systematically lower than the accepted value for a free muon (2.197 microseconds) and below expectations corrections due to negative muon capture in scintillator. A linear fit of ln(number of decays) versus time yielded a lifetime of 2.033 microseconds (see Figure 2). The fitting routine in e-Lab should be evaluated to see if there is a bias due to handling of errors or simply the exponential nature of the distribution. The size of error estimate provided also seems too small when comparing across samples.

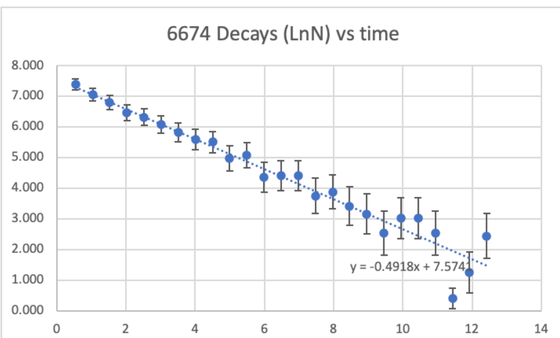

Figure 2: Natural log of the number of decay candidates versus time in 500ns bins for the 2F/short gate data.

Conclusions:
Using a vertical stack of QuarkNet cosmic ray counters, the number of muon decay candidates were studied as a function of DAQ two hardware parameters: trigger gate width and trigger multiplicity requirement. The detector was configured as two pairs of nearby scintillation counters separated by 1.4m. The largest number of decays per muon trigger were found using the 3F/long gate configuration, whereas the largest number of decays per hour was achieved by the 2F/long gate configuration.