Digital oscilloscope-based acquisition for fast and dynamic sampling of photo detector signals

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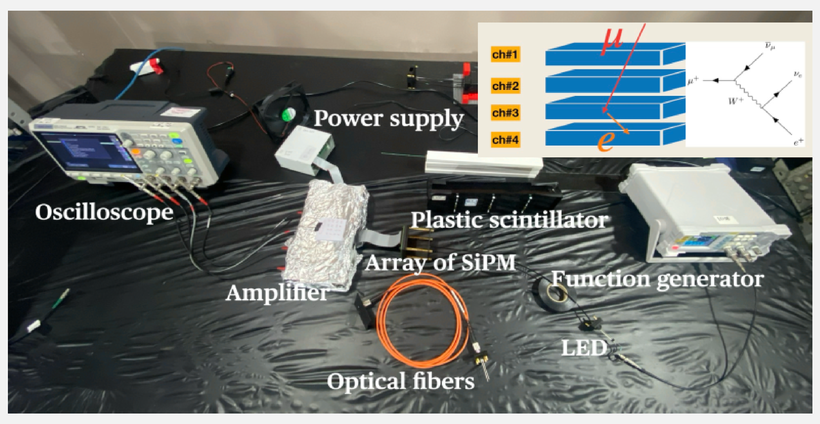
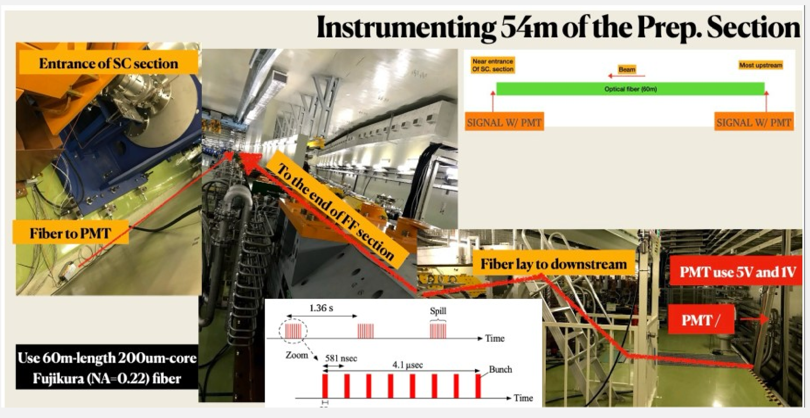
Abstract:A digital oscilloscope can trigger with a mV threshold, digitalize analog signals with 500Mhz sampling in a dynamic timing window, and acquire several channels in a fraction of a second. These characteristics provide oscillscope a distinct advantage when working with small or medium-sized setups that require photosensor signals to be acquired lightning fast. We created a system to study cosmic muon decays using SiPM and plastic scintillators, as well as another using optical fibers and PMT to monitor proton beam loss at the J-PARC neutrino beamline. We will discuss our experiences with these developments

Two main physical objectives



(a) Table-top muon detector and the like (TOF, fluoresence...)



(b) Fiber-based beam loss monitors at J-PARC neutrio beamline

- Use plastic scintillator, wavelength shifting fiber, and SiPM (*4 channels*).
- No use of amplifier, shaper or coincidence unit, faint signal with few 10mV pulse height, single photoelectron (p.e) < 1mV.
- Prompt signal: ∼ ns - few ns; delay signal (*for $\mu \rightarrow e$ decay signal*): few us to few 10s of us.
- Unknown timing trigger.
- Rate (*depending on detector size*), but mostly designed for ∼ 1 Hz operation.

- Optical-fiber -based + Metal-package PMT (*also SiPM*) in highly radioactive environment; 3 channels + 1 for external trigger.
- Basically known timing trigger; sometimes use self-triggering for unknown loss source
- Proton bunch structure: (*60ns/bunch width + 600ns bunch gap*)x 8 bunches with 1.36s cycling.
- Wide dynamic range in both pulse height and sampling interval.

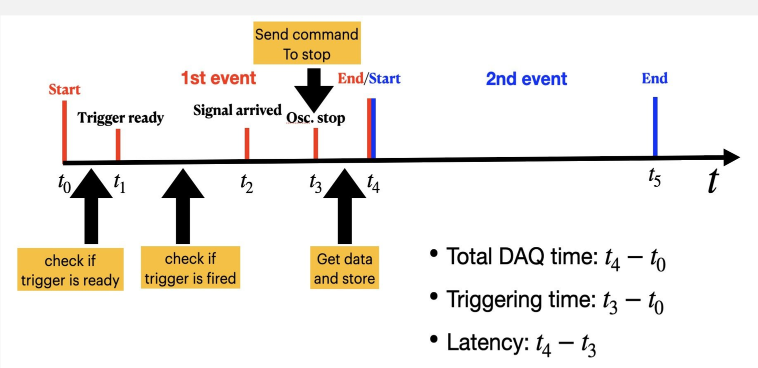
Oscilloscope-based DAQ is found as a cost-effective all-in-one solution with numerous features: intelligent trigger, fast sampling (*500 Mhz or more*); wide-dynamic range in term of the pulse height (*from sub-mV to few V*) and sampling window (*from ∼ ns to few ms*), portable, programmable, and remote-controlled.

Two DAQ modes and capture rate

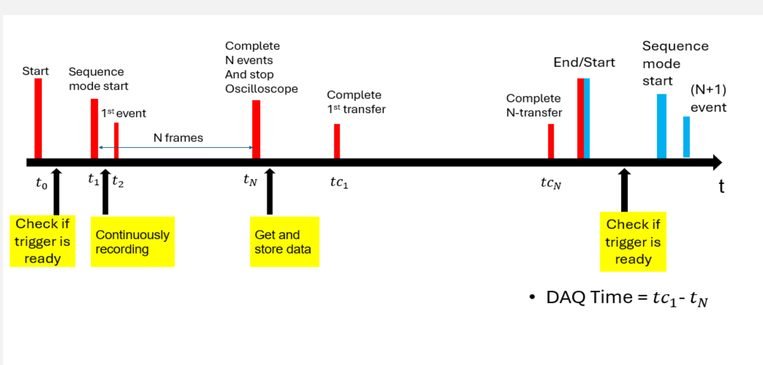
(a) Function generator to generate pulsed signal, mimicking output from photodetectors, with varied frequencies

(b) Siglent oscilloscope SDS1104X-E work at both normal (*real-time*) and sequence modes

Typical oscillation setup: 500 MHz sampling (2ns/point) with waveform length of 28 μs, i.e 14000 data points per waveform. We also examined with shorter and longer waveform length. The DAQ program, based on SCPI and VXI-11, has been developed. The program is also tested on Rohde & Schwarz RTM3004.

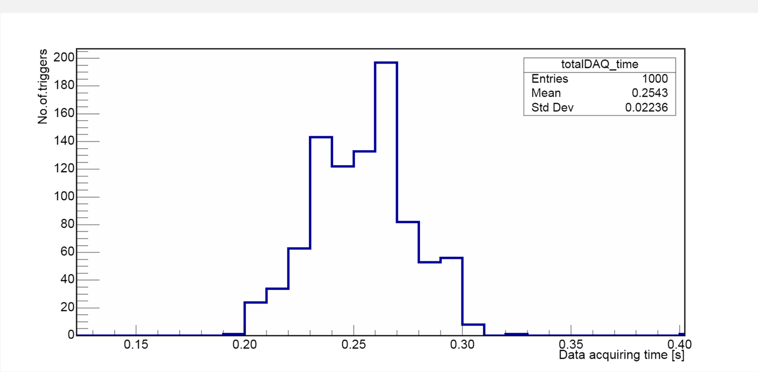


(a) Timing in the real-time mode DAQ

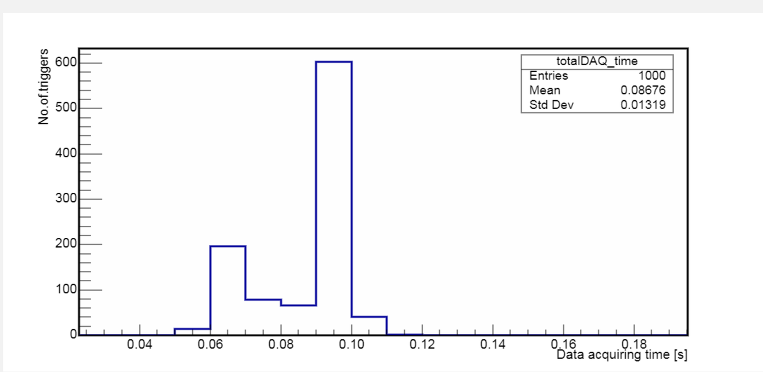


(b) Timing in the sequence mode DAQ

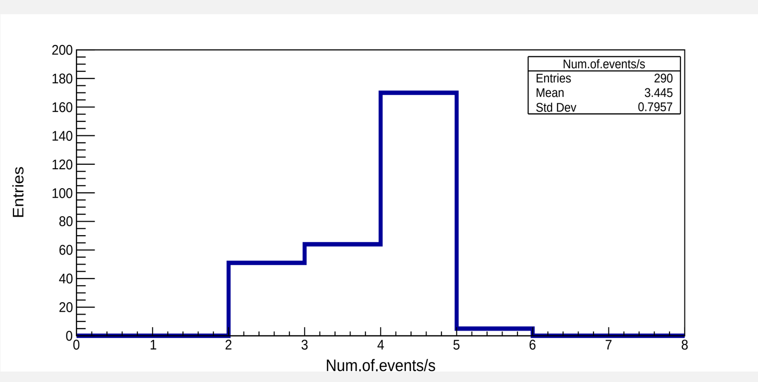
To test capture rate and data acquiring time in both DAQ mode, signal is typically generated at 1 kHz. Slower and faster signals have been tested. In sequence (real-time) mode, capture rate to the local oscilloscope's memory can go up to 400 kHz (100 kHz).



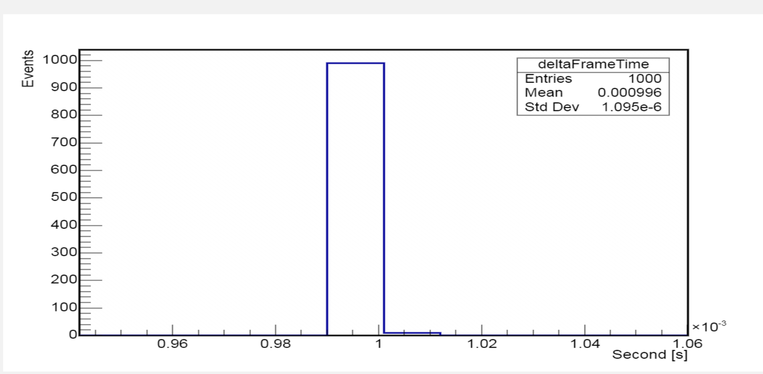
(a) Acquisition time per waveform in real-time mode



(b) Acquisition time per waveform in sequence mode



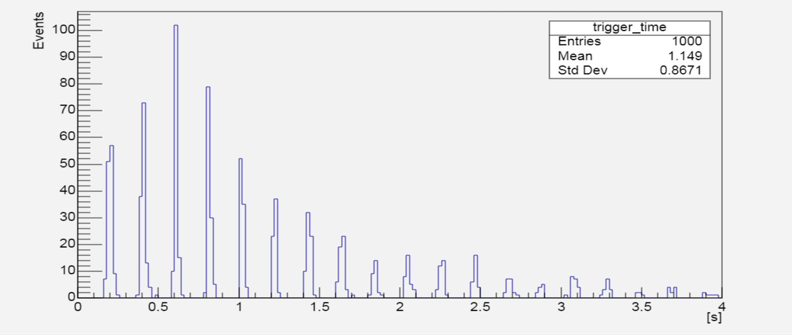
(a) DAQ acquiring rate in real-time mode



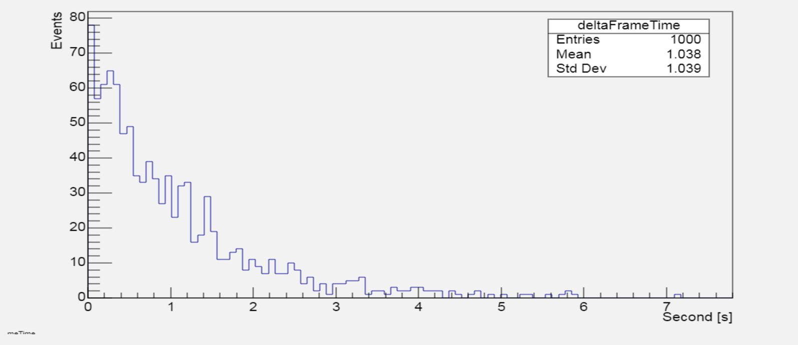
(b) Acquisition time per waveform in sequence mode

- Time for acquiring data per waveform in real-time mode: 0.25 ± 0.02 s.
- Real-time operation can work with repeated signal up to ∼ 3 Hz.
- In sequence mode, data can be transferred and reformatted at speed of 0.087 ± 0.013 s/frame.
- Recording frame rate can go up to 400 khz with frame transferring at ∼ 10 Hz

To examine the DAQ modes with the random signals, we use the cosmic-ray muons at ∼ 1 Hz.



(a) Triggering time of cosmic-ray muon events in real-time DAQ mode

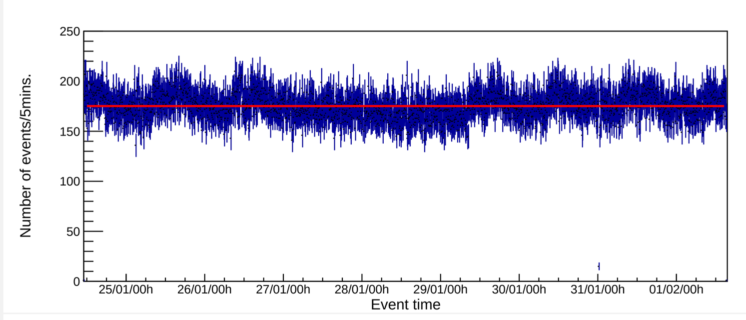


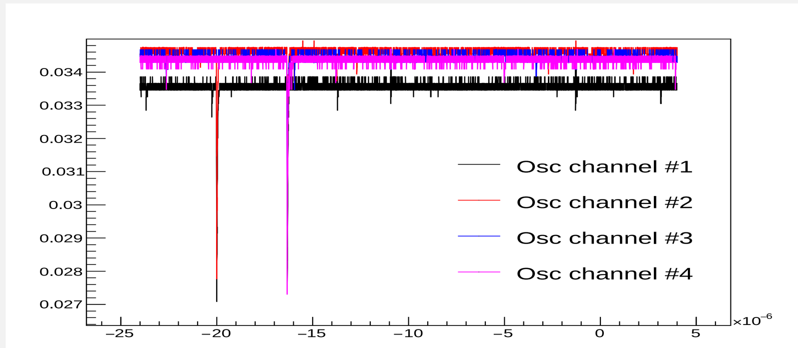
(b) Acquiring time of cosmic-ray muon events in sequence mode

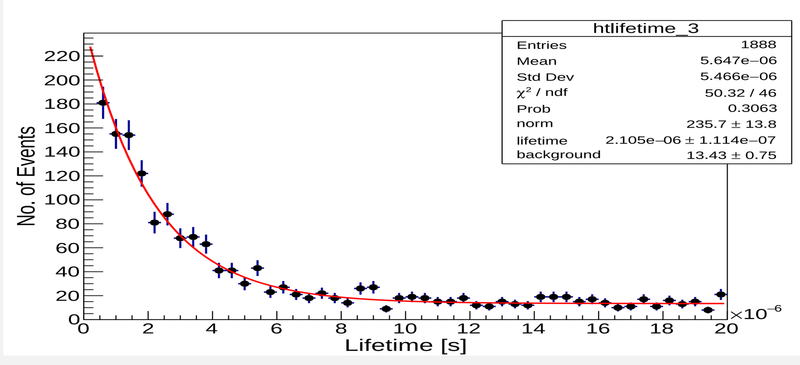
- Real-time DAQ mode suits for recording events happen at relatively slow, ∼3 Hz or less. For unknown timing trigger, data acquiring is affected by the DAQ deadtime.
- The sequence mode DAQ offers capability to work with faster rate of events. Dead time is smaller than the real-time DAQ but oscilloscope also has to be stopped for transferring all recorded frames.

Results with the table-top cosmic-ray muon detector

- Test operation over few months
- Cosmic-ray muon rate (in)-stability (right plot for operation over one week)
- Observed muon decay (oscilloscopes utilized for pattern triggering, ADC, TDC) from the offline analysis. A $\mu \rightarrow e$ decay candidate and the fitted muon lifetime are shown below.
- Operate in both real-time and sequence DAQ modes

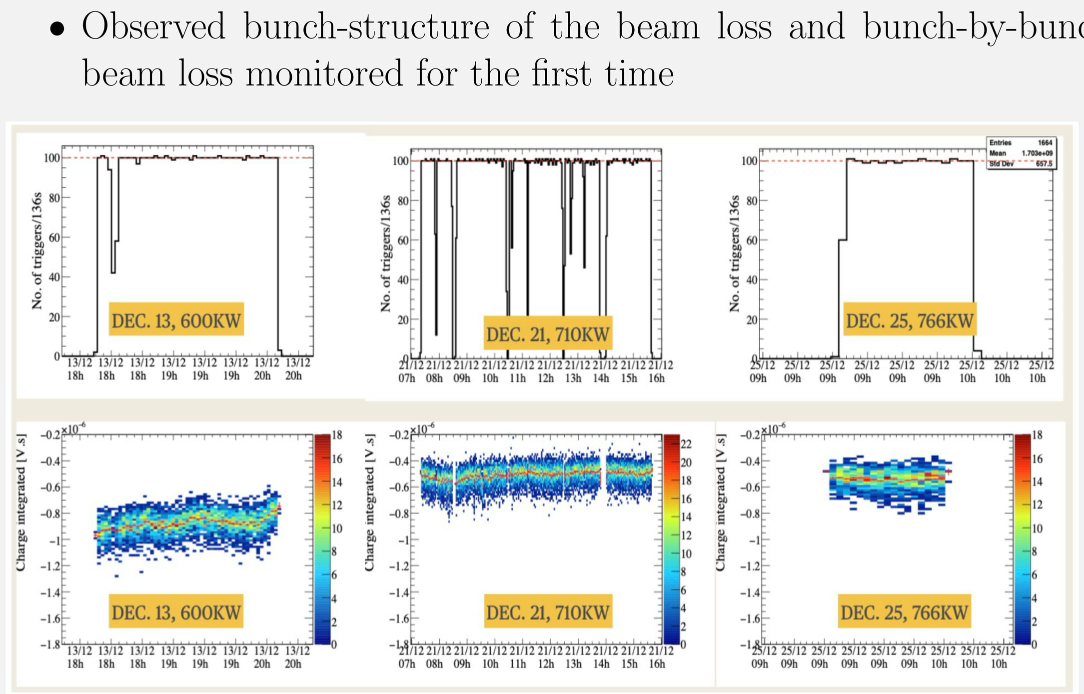


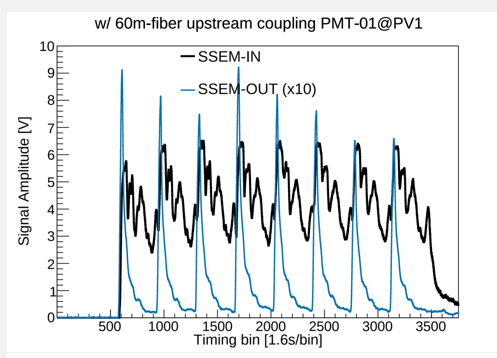


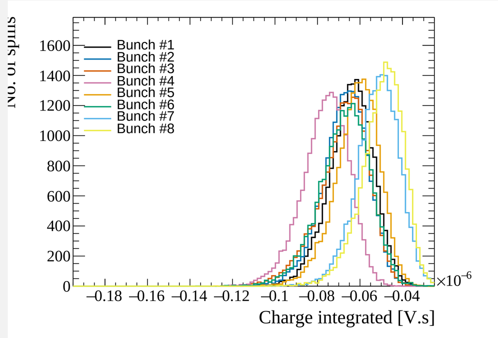


Results with the proton beam-loss monitors

- 650MHz sampling w/ RTM3004 oscilloscope
- (In-)stability operation checked, missed event rate of 1%
- Observed bunch-structure of the beam loss and bunch-by-bunch beam loss monitored for the first time
- Use real-time DAQ mode w/ external trigger or self-triggering







Conclusion

Digital oscilloscopes are investigated to acquire the data from the photodetectors with self-developed VXI-11/SCPI protocol, particularly for applications of a table-top muon four-channel detector and optical fiber-based beam loss monitor.

- DAQ operated in two modes: with real-time mode, the capture time is 0.25 ± 0.02 s; with the sequence mode 400,000 waveform capture can be achieved in the local oscilloscope's memory with a transferring rate of 0.087 ± 0.013 s per frame.
- Applied successfully for muon decay measurement and proton beam loss monitoring.
- In real-time mode, the deadtime is relatively large. Operation in sequence mode can help to reduce the deadtime but still affected by the transferring rate.

Some improvement possibilities and application considerations:

- Streaming data while keep taking data in real-time and sequence DAQ modes.
- Acquiring the binary data as packet may speed up the data transfer.
- Acquiring from multiple oscilloscopes with timing-synchronized capability

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