UTK-4: A simple SiPM board design and test with FemtoDAQ

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Abstract:
A simple board with four 6 mm silicon photomultipliers (SiPM) has been designed. Two such boards were attached to a piece of plastic scintillator and tested with a low-cost, two channel digital data acquisition FemtoDAQ system. The FemtoDAQ was used to bias the SiPMs, digitize the SiPM signals, and record the waveforms, histograms, and event files to disk. The test was performed in less than a day thanks to the utmost flexibility of the FemtoDAQ system.

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1 The FemtoDAQ System.

The FemtoDAQ system consists of two boards stacked on top of a commercial, low cost single board Linux computer. The HV+logic board powers the remote detector front end, provides the SiPM bias, and reads the temperature sensor. The ADC board digitizes two inputs with 14 bits at 100 MSPS. The field programmable gate array (FPGA) performs pulse detection and extracts pulse characteristics using digital signal processing. The FemtoDAQ is completely self contained. It does not rely on any external controller other than itself.

Figure 1: The FemtoDAQ provides two ADC channels (coaxial connectors in the middle) and a logic bus with detector bias supply (rectangular connector below analog inputs).

2 The design of the SiPM board UTK-4.

The UTK-4 is a printed circuit board holding four surface mount, 6x6 mm series C silicon photo multipliers from SensL. Both the anodes and the cathodes are connected in parallel. The “fast” SiPM outputs are left unconnected. The cathodes are biased with positive voltage filtered on board with an RC filter. The bias is delivered with either a coaxial MMCX connector or a two pin connector. The signal is routed to another coaxial MMCX connector. All the passive RC components are on the side of the board opposite to the SiPM chips.

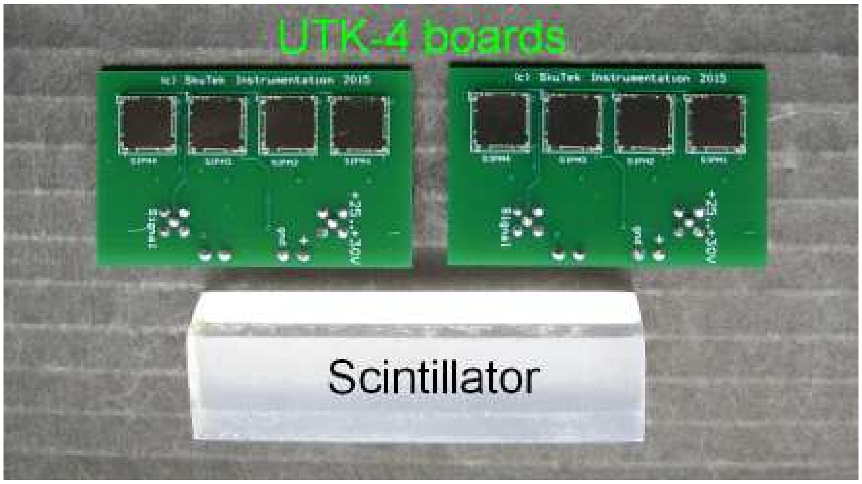

Figure 2: Two UTK-4 boards and the piece of plastic scintillator.

Each of the SiPM devices is composed of 18,980 pixels. There are 75,920 pixels per board, all of them connected in parallel.

3 Connecting the UTK-4 with FemtoDAQ.

Two UTK-4 boards were connected to a piece of fast plastic scintillator. The coupling grease was not used to avoid contaminating the boards. The boards were rather pressed against plastic from two opposite sides using teflon tape. Due to lack of couplant the SiPMs did not make good contact with the scintillator and the light collection was not efficient. This arrangement was sufficient for testing the boards.

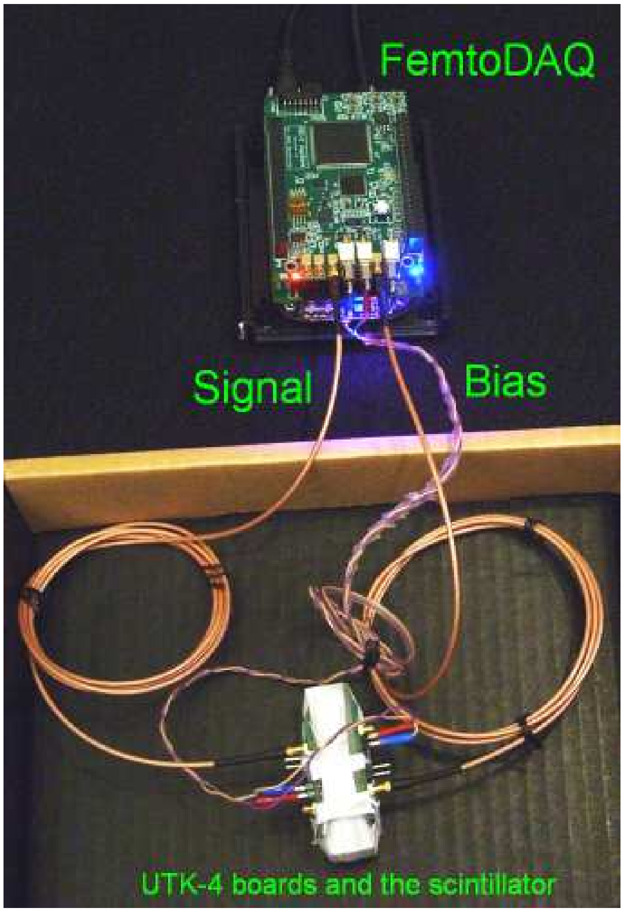

Figure 3: The scintillator assembly connected to FemtoDAQ.

The scintillator assembly was connected to the FemtoDAQ with two coaxial MMCX cables type Pomona 73077-UU-48. The bias was delivered from the FemtoDAQ to both UTK-4's with a custom made twisted pair cable connected to the UTK-4 pin headers. The bias cable was branched off from one board to the other, as shown in Figure 3. The assembly was enclosed in a cardboard board painted black inside. The box was covered with several layers of black cloth. The FemtoDAQ was not covered with cloth to avoid overheating. The FemtoDAQ was operated without the enclosure which has not been finished yet.

4 Testing the UTK-4's with FemtoDAQ.

The FemtoDAQ delivered V_{bias}=29.7 volts to the SiPMs, which is about 5 volts above the nominal breakdown voltage of this SiPM type. We have chosen the largest recommended bias in order to maximize the signal.

The FemtoDAQ was operated with Ethernet-over-USB connection using the RNDIS device driver under Windows. The alternative to RNDIS is regular RJ-45 Ethernet which was not used because the FemtoDAQ was in close proximity to the Windows host. All the data acquisition was performed with the help of Python scripts executed by the FemtoDAQ Linux system from the command line window. We used PuTTY for the command line terminal. The FemtoDAQ graphical user interface was not used because the measurements were simple enough to be conveniently performed with Python. We recorded the waveforms and online histograms accumulated by the FemtoDAQ. We also recorded the list-mode event file containing the waveforms for offline timing analysis. In each case the data was recorded on the FemtoDAQ internal solid state disk, and then transferred to the host Windows machine using the TCP/IP Secure Copy. The list-mode event file containing 20,000 waveforms occupied 57 megabytes.

All the files were recorded in ASCII using IGOR format. FemtoDAQ can also record the same files in the gnuplot format for those users who prefer plotting with gnuplot directly on board without copying the files to the host computer. In this work we opted for analyzing the data with IGOR.

5 The UTK-4 waveforms collected with FemtoDAQ.

We started the test with recording several coincident waveforms using the FemtoDAQ Python command *capture_both.py*. We adjusted the DC offset to be close to zero using the Python command *offset.py*. (Initially the waveforms were offset from zero due to the previous offset settings that remained in the permanent offset memory of the FemtoDAQ system.)

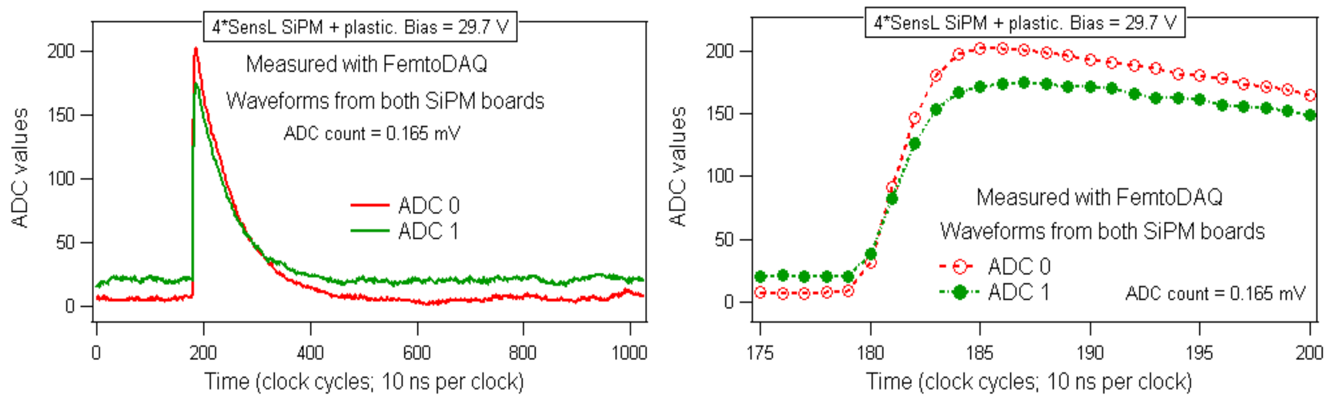

Figure 4: The coincident signals from two UTK-4 boards coupled to a plastic scintillator. The expanded leading edges are shown in the right panel.

The waveforms shown in Figure **4** demonstrate that the anode signal from the board is about ~2 μs wide, consistent with the SiPM data sheet. The leading edge rise time is about 50 ns, probably due to the capacitance of four chips connected in parallel. We note that the chips are passively driving the cable. A faster rise time would be achieved if a fast opamp was placed on the UTK-4 board to provide drive current to the cable.

The late portions of both waveforms are shown in Figure **5** on the next page. There are numerous small amplitude pulses in both waveforms which comprise the "shot noise" due to dark current which is characteristic of this kind of SiPM. The pulses would be less frequent if lower bias voltage was used. (The dark current rate strongly depends on the applied voltage.) In this measurement we intentionally used high bias to increase the pulse amplitude of the passively driven signal. An alternative solution is to lower the bias and to amplify the pulses in order to increase the amplitude while decreasing the dark current. The best result will be achieved with an opamp placed directly on the board, but it will require powering the board. An intermediate solution will consist of using a fast pickoff amplifier (such as Ortec VT120 or similar), or a Timing Filter Amplifier (TFA) in the NIM bin next to the setup. We draw the attention to the fact that the length of the cable between the UTK-4 and the timing amplifier should be minimized in order to improve the rise time of the leading edge (see Figure **4**).

The amplitude of dark pulses was about five to ten ADC counts, which is 0.5 mV to 1 mV. The dark pulses, which are effectively noise, determine the trigger threshold that can be used in this measurement. The threshold of about 3 mV should be adequate at this bias voltage and temperature. One should pay attention to the fact that the dark count rate and the single-pixel amplitude both depend on the bias. The rate also depends on the temperature. A careful optimization may be needed if low threshold is desired.

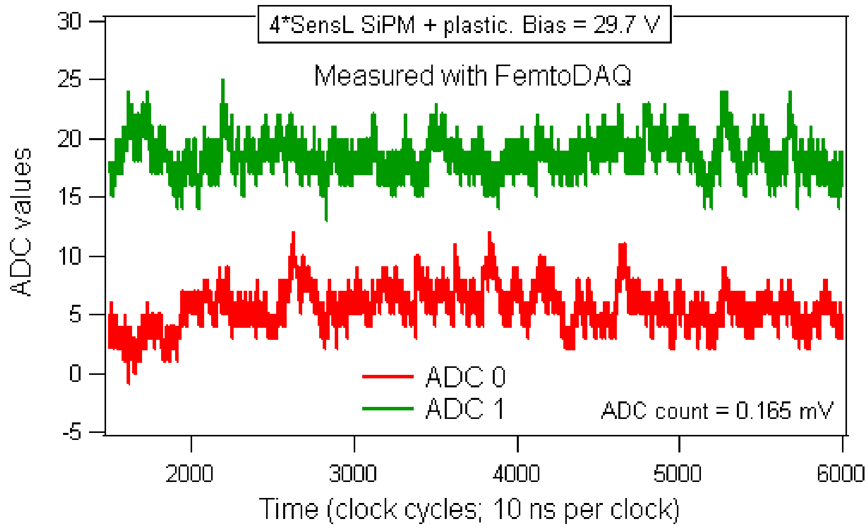

Figure 5: The late portions of the event waveforms.

6 The pulse height histograms collected in real time with FemtoDAQ.

The FemtoDAQ features built-in pulse height histogramming with the FemtoDAQ Python command *get_histogram.py* which collects the histograms and also reads the temperature. In this measurement we used a variant *get_histogram_no_temp.py* because the UTK-4 was not equipped with a temperature sensor. We collected background histograms from both boards over the period of 125 minutes. The histograms consisted of 3,257 counts, corresponding to one event every 2 seconds. This rate is clearly higher than the cosmic rate of about one cosmic event per minute per cm^2. Low energy events may have been triggered by the radon contamination of the dark box that has been previously used with natural Thorium sources. The events around PH>50 may be due to cosmic rays.

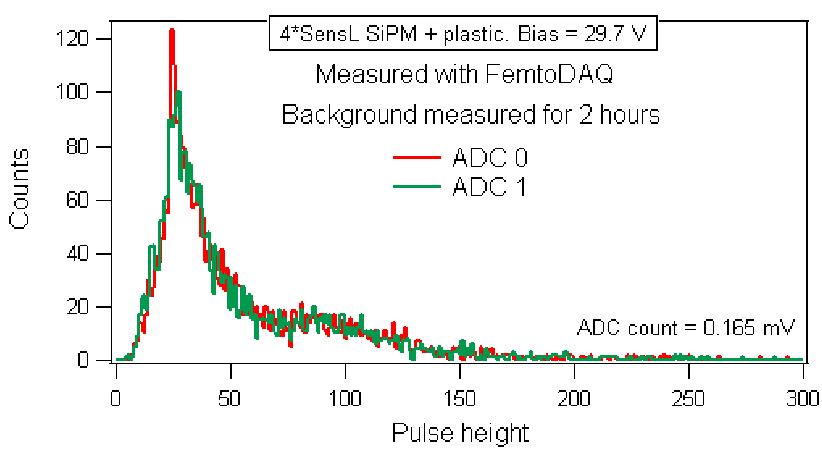

Figure 6: Background measured for 125 minutes.

In order to improve signal-to-noise, the FPGA applied averaging to the calculated pulse height. The average decreased the histogrammed values by a factor three. We will show in the next section that the true pulse height calculated offline was 3x higher than the one shown here.

In the next measurement we compared the pulse height distributions from the ^{60}Co and ^{137}Cs sources placed on top of the detector assembly. The histograms from the same ADC channel are overlaid in the next Figure. There is almost no difference between the histograms. Lack of any indication of the Compton edges can be attributed to a very poor light collection. All the events were of very low amplitude. The count rates were 227 cps and 133 cps for ^{60}Co and ^{137}Cs, respectively, consistent with the the γ-ray multiplicities and nominal source activities of 1 μCi in both cases.

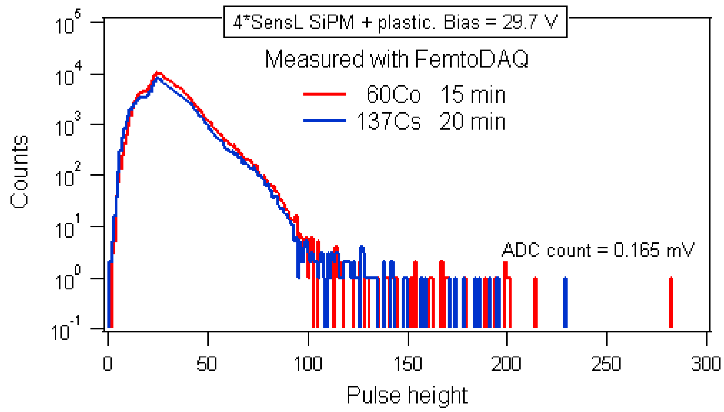

Figure 7: Pulse height distributions measured with trace amounts of rare isotopes placed on top of the detector assembly.

7 Amplitude and timing correlations recorded with FemtoDAQ.

The final measurement consisted of recording 10,000 events in the list-mode event file. Each event consisted of two waveforms with 1024 samples each. The trigger was positioned at sample number 256 to provide ample pre-trigger and post-trigger data. We used the Python script *record_events_UTK.py* which setup the FPGA parameters such as threshold and post-trigger delay, and then recorded the events to the internal FemtoDAQ solid state disk. The file size was 58,574,871 bytes. We copied the event file to the Windows machine and processed with IGOR.

Prior to recording the file we removed the rare isotopes from the detector vicinity in order to take advantage of the cosmic rays visible in Figure **6**. The pulse heights calculated from the recorded waveforms are shown in Figure **8** in both the linear and log scales.

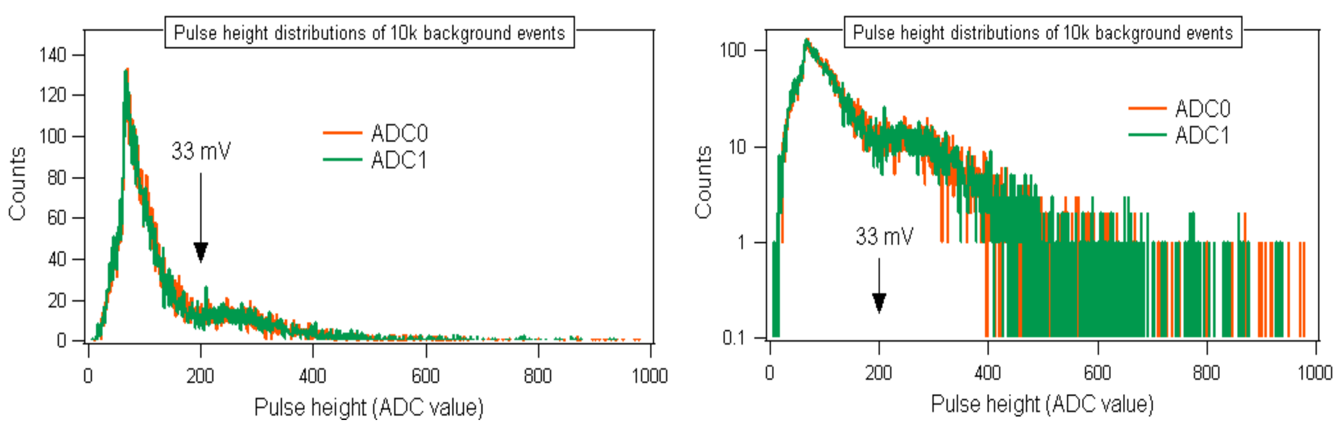

Figure 8: Pulse height distributions projected from the event file plotted in linear and log scales.

The direct comparison of online histogram shown in Figure **6** with the offline histogram shown in Figure **8** demonstrates the factor three scaling mentioned in Section **6**. The FPGA firmware will be modified to remove this discrepancy in the next firmware release.

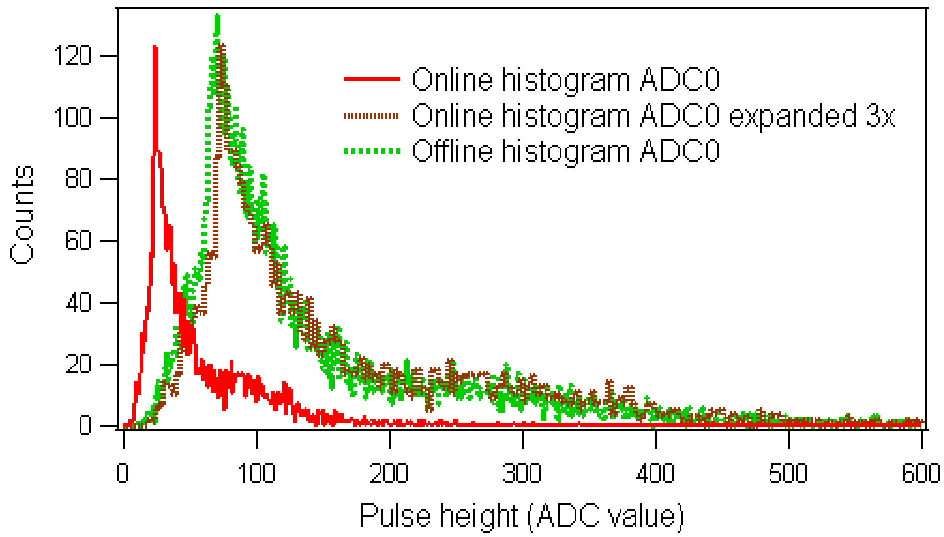

Figure 9: The plot of online and offline histograms shows the 3x compression of the online histogram.

The next plot shows the pulse height correlation between two UTK-4 signals. The correlation is rather broad due to imperfect light collection.

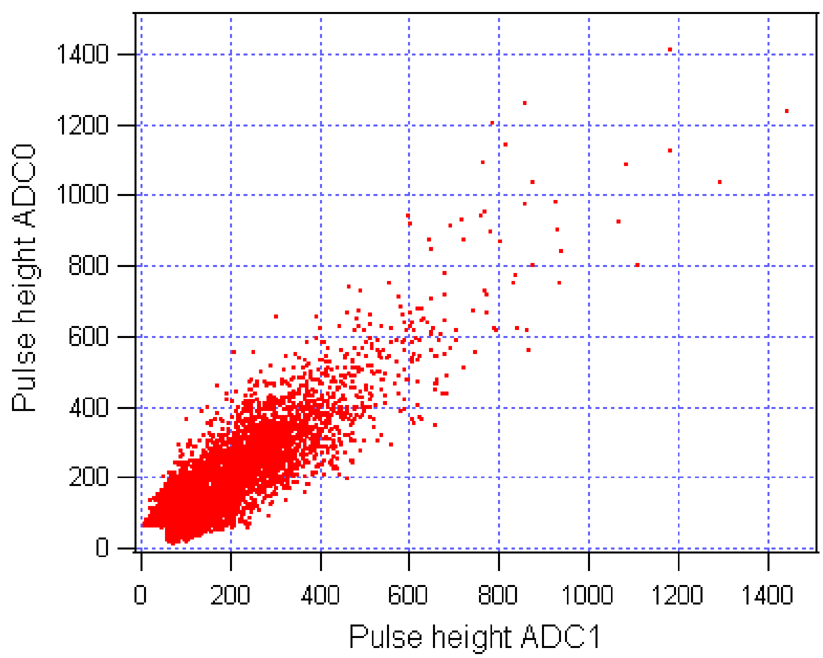

Figure 10: The pulse height correlation between the two UTK-4 boards.

The next plot shows the timing correlation between two UTK-4 signals. The relative timing was calculated by fitting the leading edges of both pulses. The vertical axis in the left panel extends from -5ns to +5ns (i.e., +/- half the ADC clock cycle). The time distribution of the high amplitude events (PH>200) is contained within +/- 2 nanoseconds, with the RMS width of 0.7 ns. One should remember that “high amplitude” is in fact very low due to absence of any amplification of the signals.

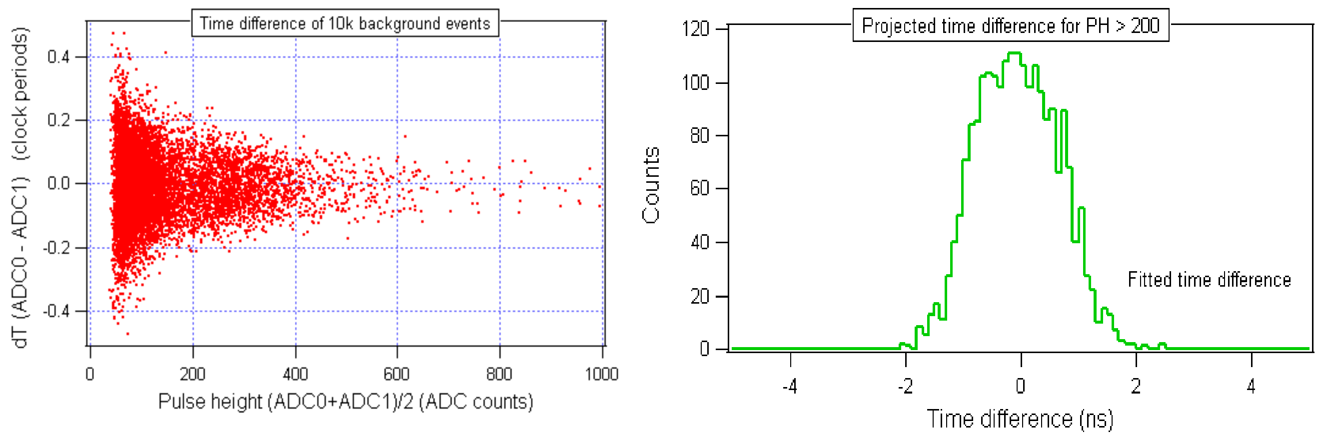

Figure 11: The time difference between the leading edges of the UTK-4 signals.

8 Conclusions.

We developed the silicon photomultiplier carrier board named UTK-4. The board carries four 6x6 mm SiPMs from the SensL C-series. The bias voltage is delivered with the MMCX detectors or the 0.1” pin header (either connector can be used). The bias is filtered on board with a two-stage RC filter. The signal is read with an MMCX coax. Two such boards were coupled to a piece of plastic scintillator without using optical couplant. The signals were digitized and recorded with the low-cost, two channel FemtoDAQ standalone data acquisition system, which also biased the boards with 29.7 volts. The signals were investigated with the background radiation and with rare isotopes. A very rapid progress was achieved in one day of measurements thanks to the utmost flexibility of the FemtoDAQ system.