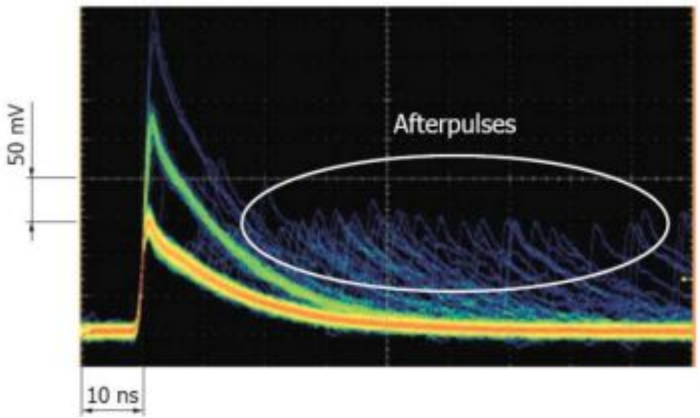
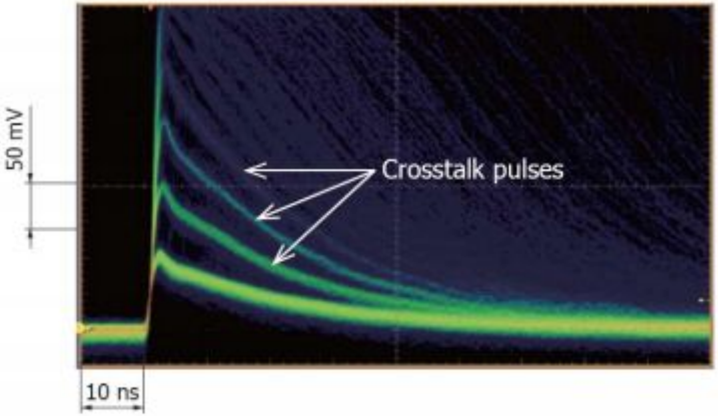
SiPM pulse processing

Maria Jose Ortiz Perez

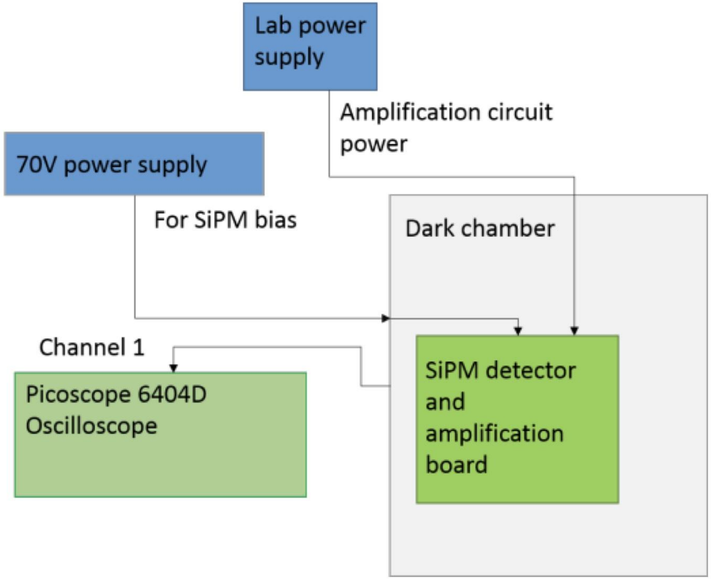
SiPM

- A Silicon photomultiplier is a solid-state device which can detect and potentially quantify small amounts of photons.
- SPAD (Single-Photon Avalanche Diode) connected in parallel
- Types of noise:
    - After pulse
    - Crosstalk
    - Dark pulses

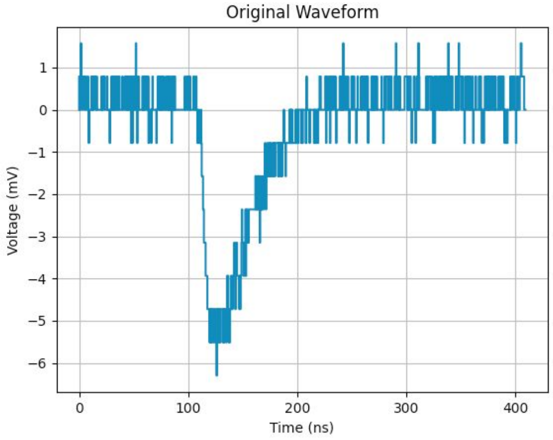




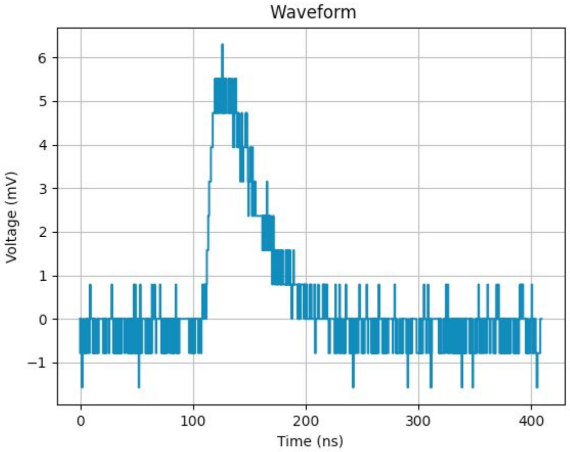
Test set up



Lab power supply
Amplification circuit power
70V power supply
For SiPM bias
Dark chamber
Channel 1
Picoscope 6404D Oscilloscope
SiPM detector and amplification board



Original Waveform
Voltage (mV)
Time (ns)



Waveform
Voltage (mV)
Time (ns)

Fast Fourier Transform

Procedure to analyze an input waveform and obtain its baseline so it can be corrected.

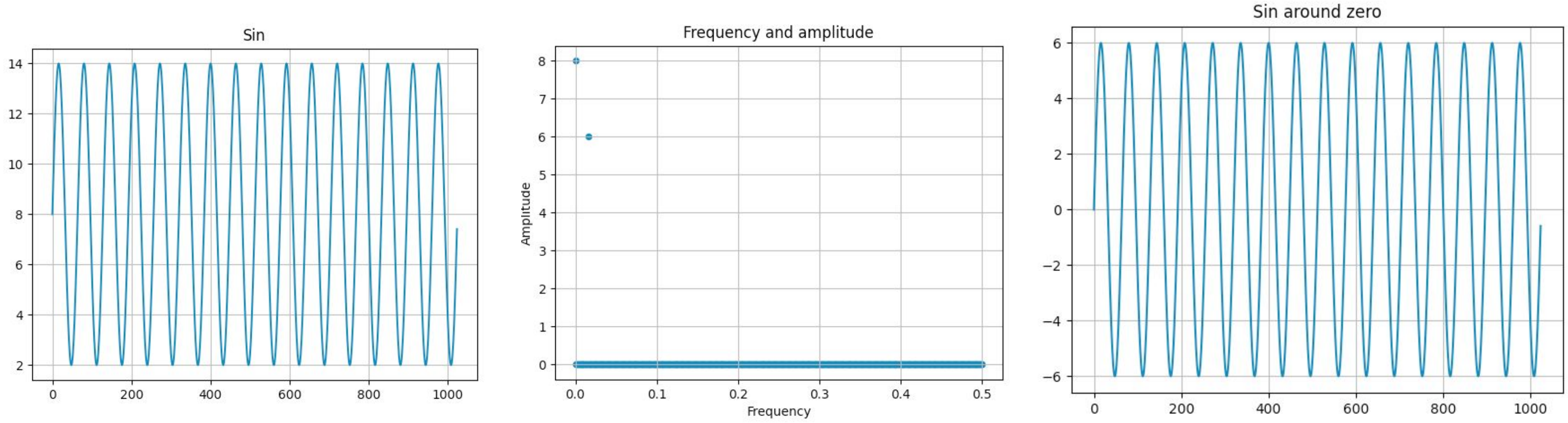
The first step is to take the fast fourier transform to go to the frequency domain.

Python libraries used:

- scipy.fft.rfft
- scipy.fft.irfft

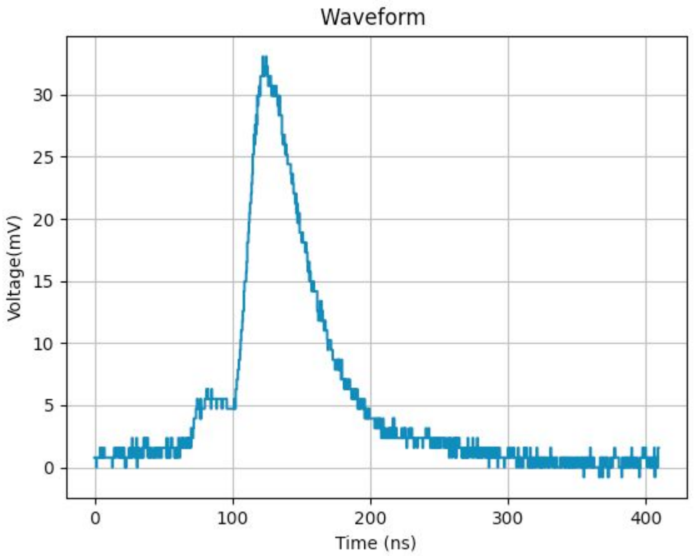
Zero frequency

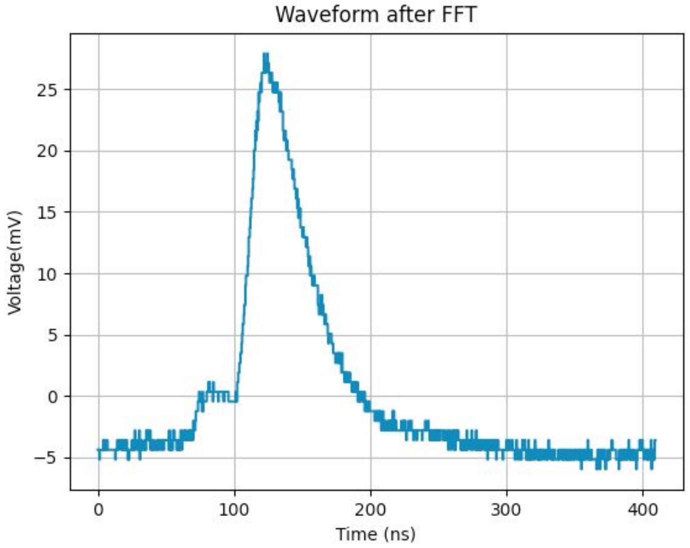
The amplitude of the zero frequency is the average of the samples in the window data. It is the shift from zero.



Amplitude: 6
Offset: 8

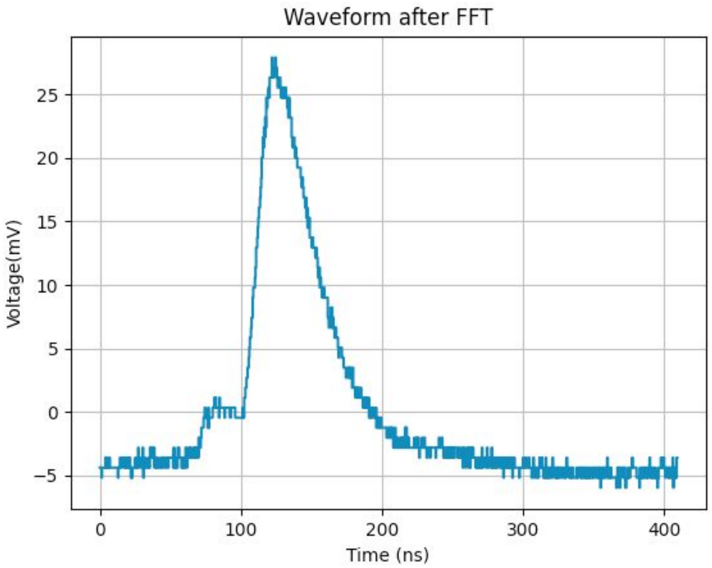
Unipolar signal

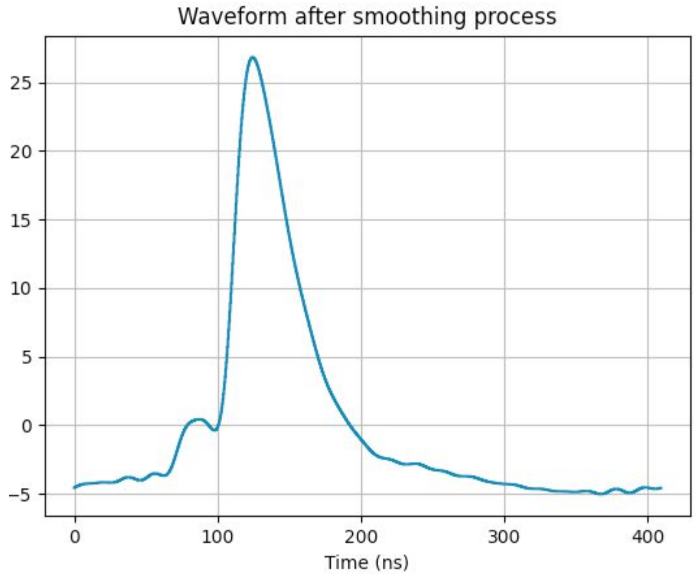




Amplitude of zero frequency= 5.174mV

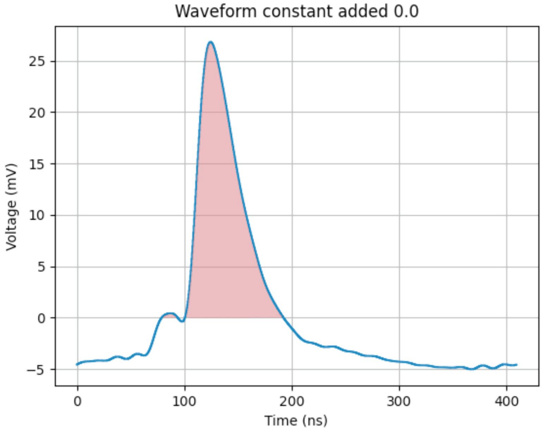
Smoothing process

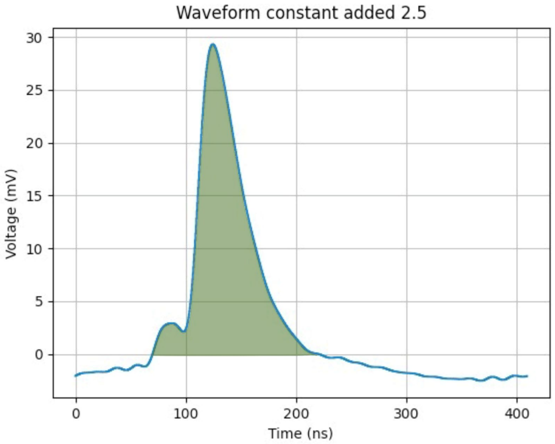


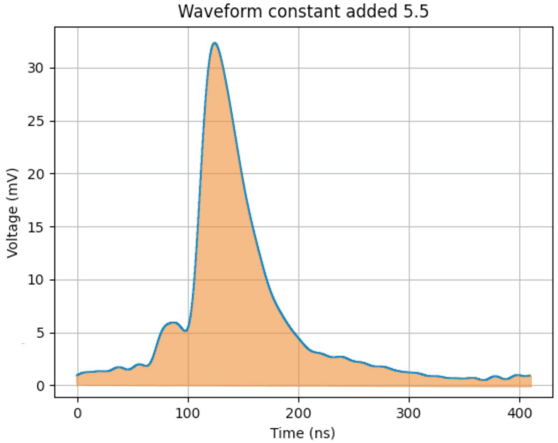


The zero frequency, the Nyquist frequency and 95% of the high frequencies are set to zero.

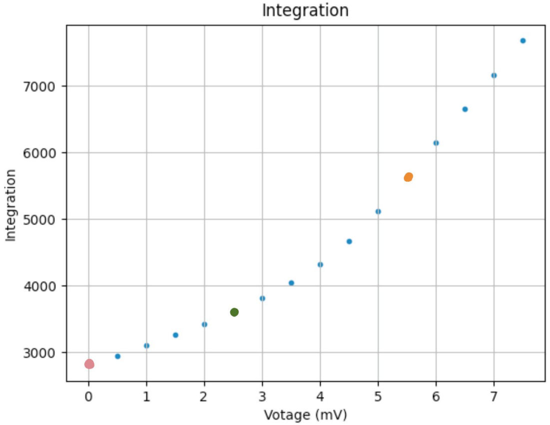
Integration





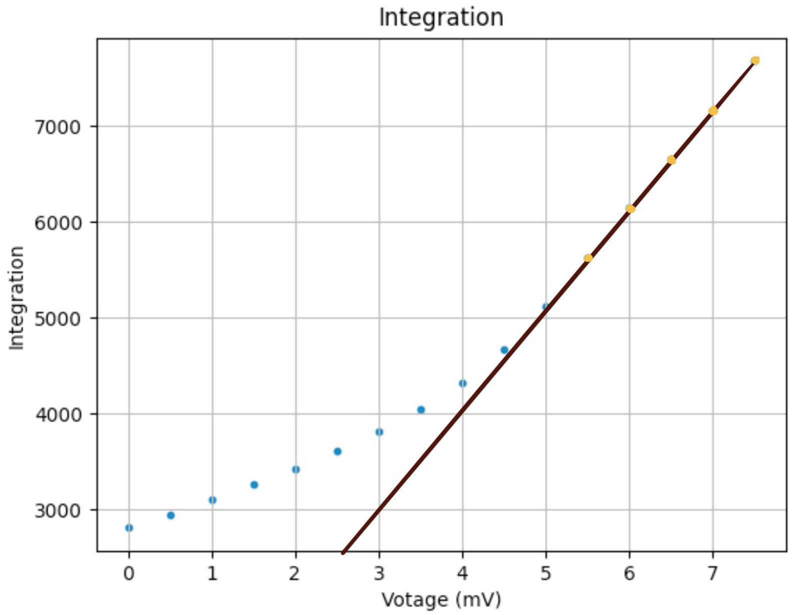


The constant added in this example is 0.5mV



Linear relation

There is a linear relation in the integration points when all the waveform is above zero.



The slope of the line is the number of points in a waveform (1024). The only element missing for a liner fit is the intercept.

Intercept

To find the intercept the next equation is used:

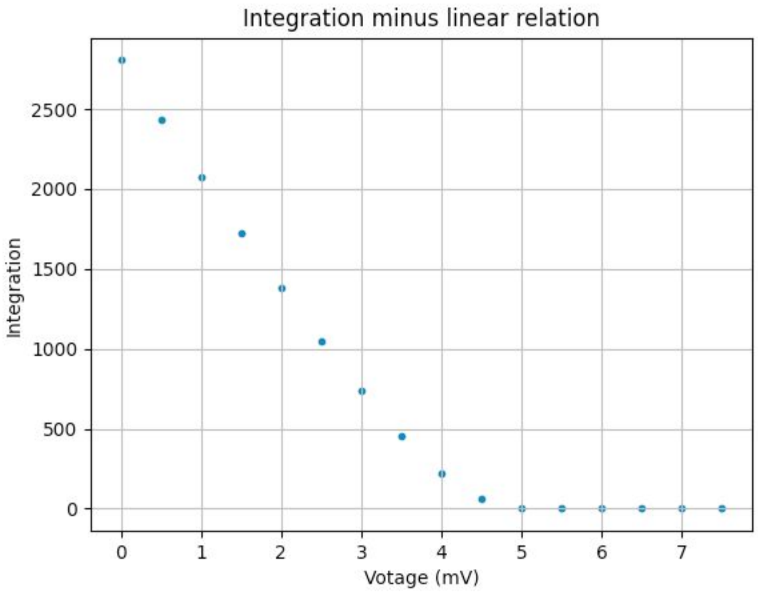
$$b = \frac{(I_{50} + I_{100}) - (m(x_{50} + x_{100}))}{2}$$

Where I_{50} and I_{100} are the integration values when the constants 50 and 100 are added.

m is the slope which is equal to 1024

x_{50} and x_{100} are the x components of the integration which means they are the addition of the zero frequency and the constants

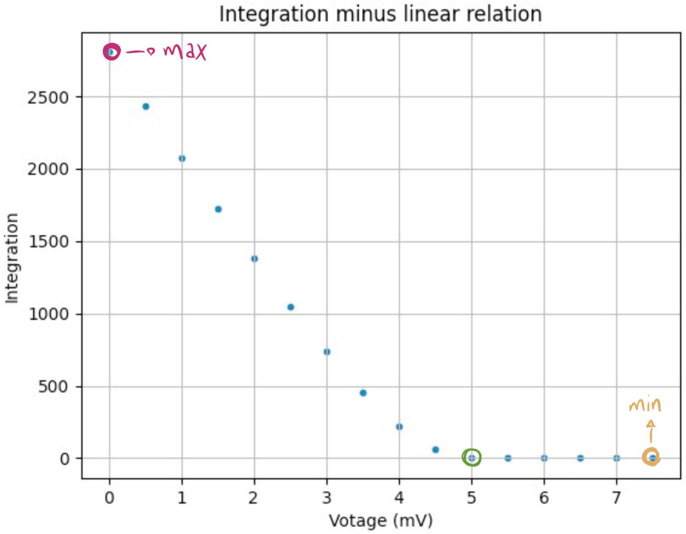
Linear relation subtracted from integration

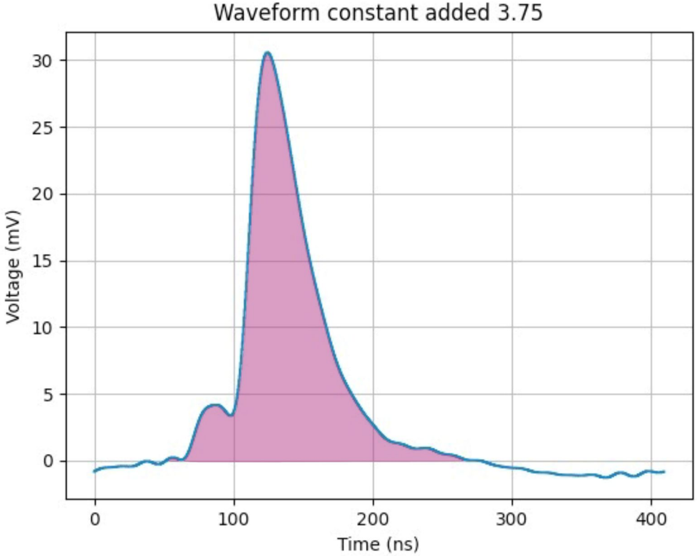


y=1024*x+1.45x10^-11

Binary search

Example:
Min=7.5 and Max=0
Average=3.75



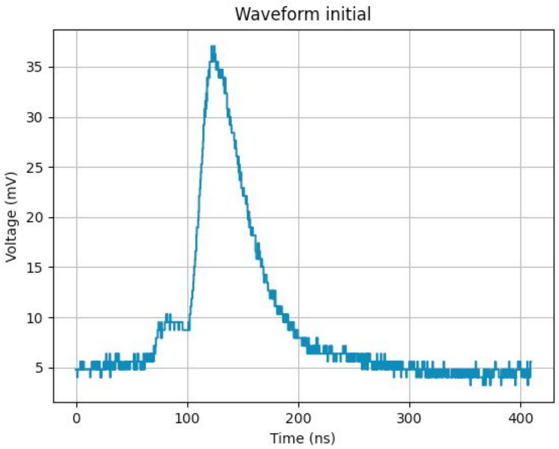


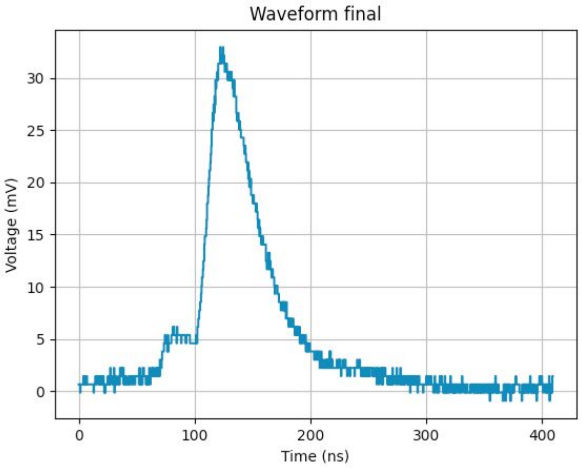
Subtract the linear relation from the integration y=1024(3.75)+1.45x10^-11

Binary search

To find the point where the integration goes to zero a binary search is made within a range. The range established is from 10^-1 to 10^-2.

To obtain the baseline the value found by the binary is subtracted from the zero amplitude.





Example:
Zero frequency amplitude is 9.17mV
Average included in the zero frequency is 5.04mV.
The baseline is 4.13mV

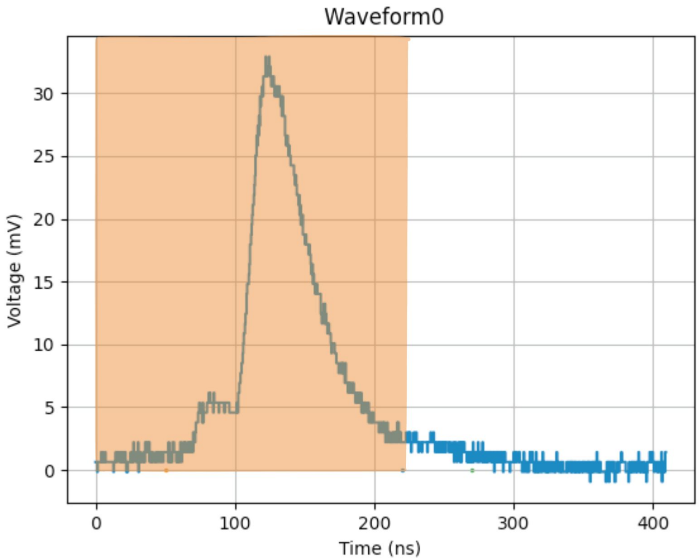
SiPM dark pulse analysis

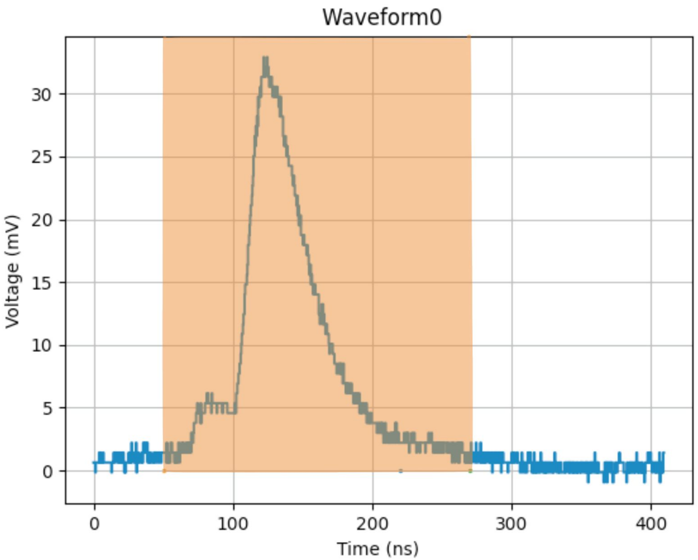
To take only desired data there is a condition imposed so that the data is only taken when the trigger condition is met. Trigger -5mV with 100,000 waveforms

- One wave form has 1,024 points
  - 300 points for pre-trigger and 724 points for post-trigger
- The impedance of the oscilloscope is 50 ohm, to correct for the voltage multiply by two.
- The duration of a waveform is 400 ns, each point spacing is 0.4 ns

Sliding window integration

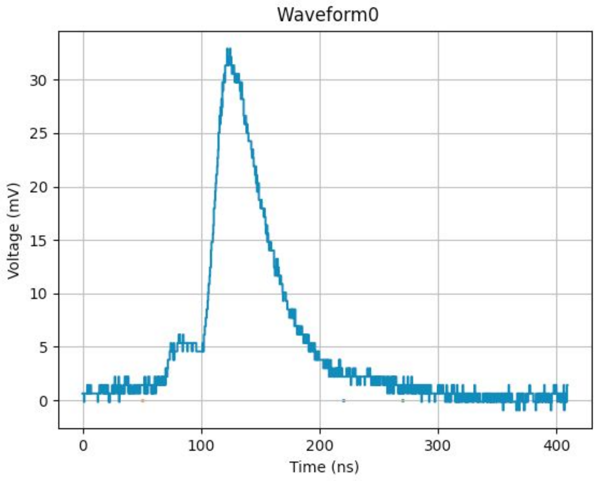
The size of the window is 220 ns

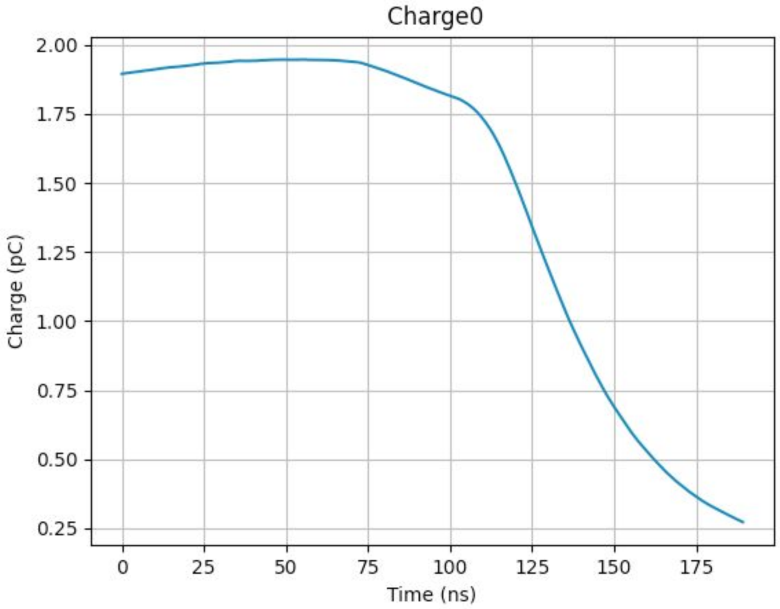




Charge is obtain using the next equation: $$dQ = \frac{V}{R}dt$$ where the resistance is 1k ohm.

Charge


Waveform0
Voltage (mV)
Time (ns)
0
5
10
15
20
25
30
0
100
200
300
400


Charge0
Charge (pC)
Time (ns)
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
0
25
50
75
100
125
150
175

Histogram of total charge

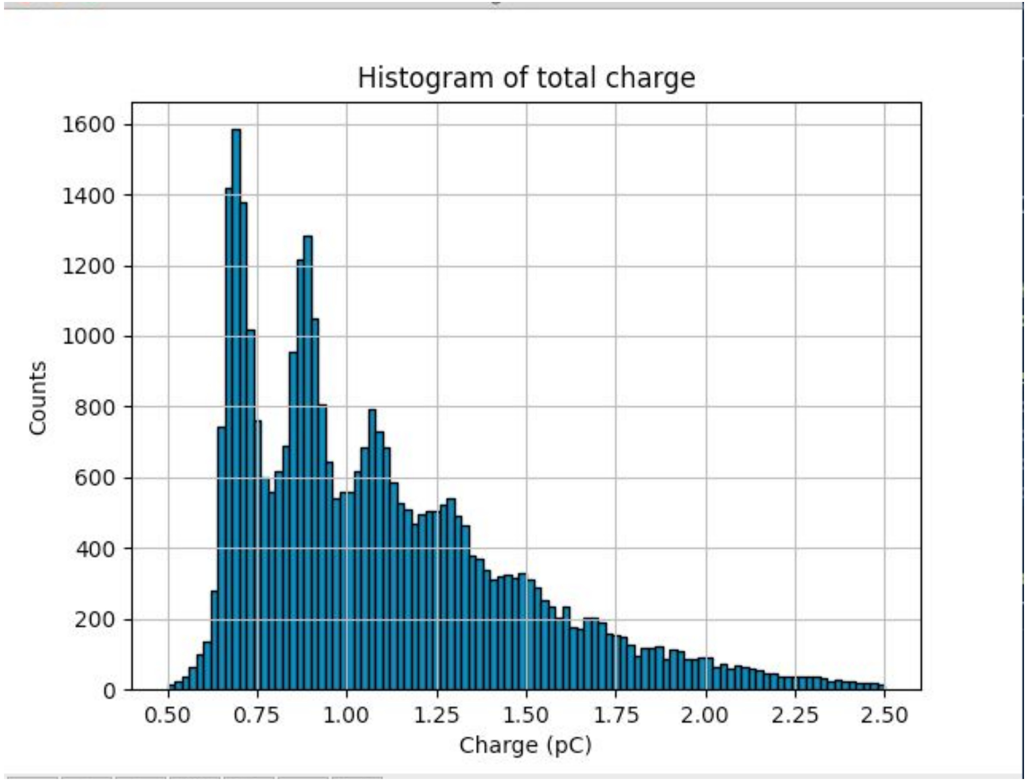
Histogram with the information of 35,000 waveforms.

Fit: Gamma distribution plus four gaussian distribution.

The python library used for this fitting is: curve_fit() from scipy.optimize

The coefficient of determination (R^2) is equal to 0.986

The temperature during the experiment was 25ºC and the biasing was 67V as recommended by the manufacturer Hamamatsu, to obtain a gain of 1.25x10^6



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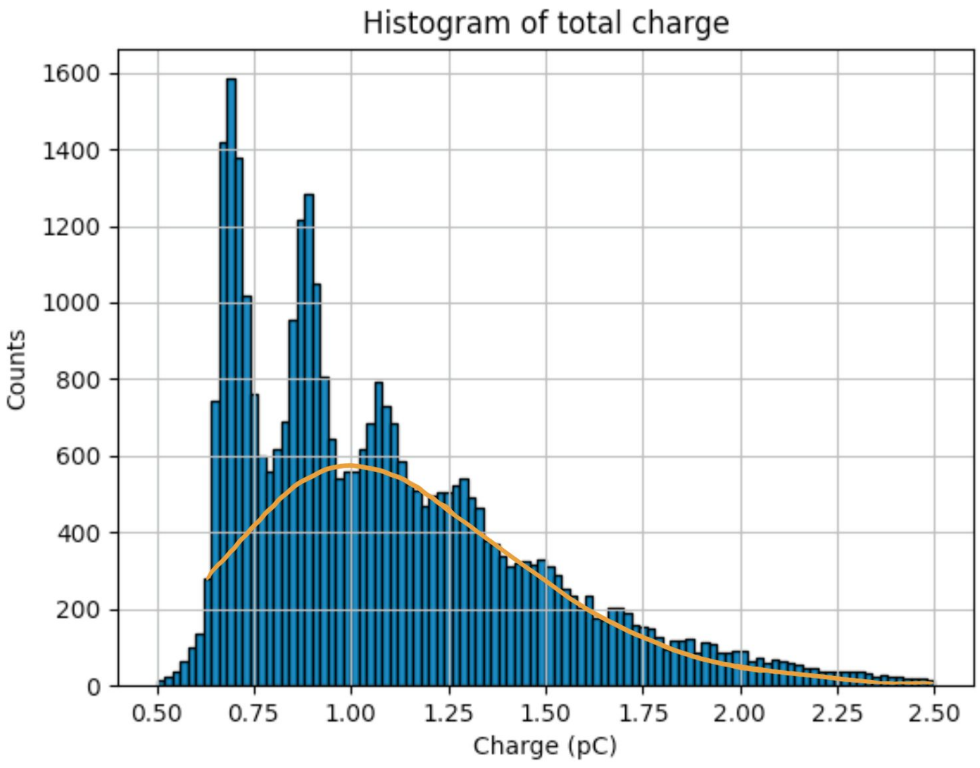

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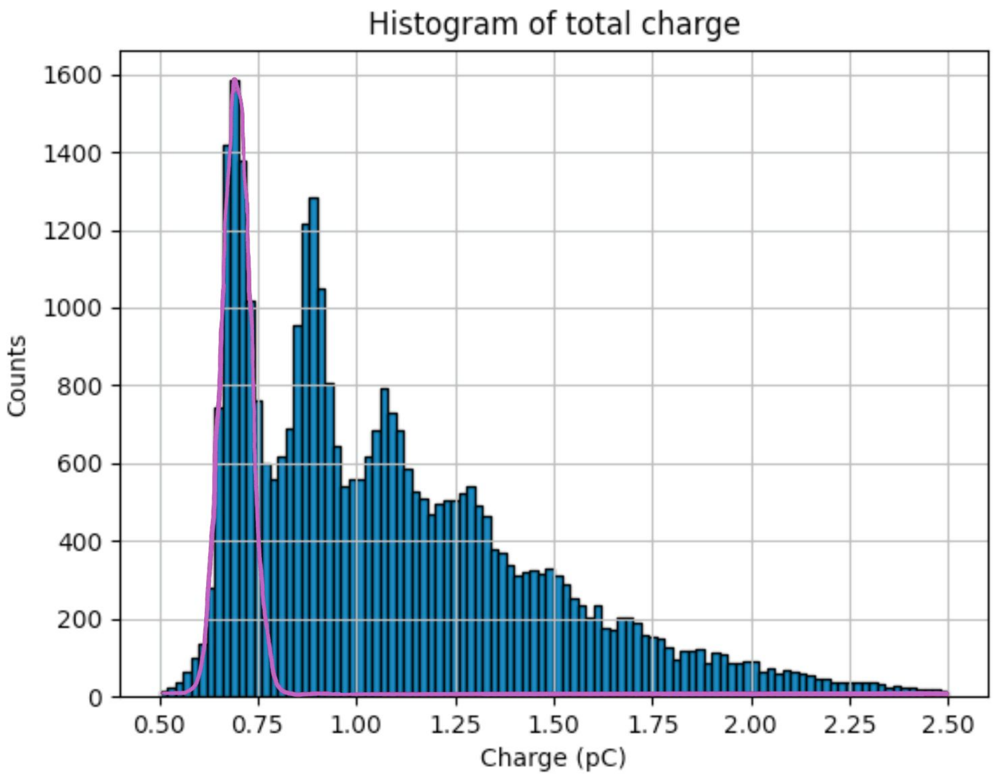

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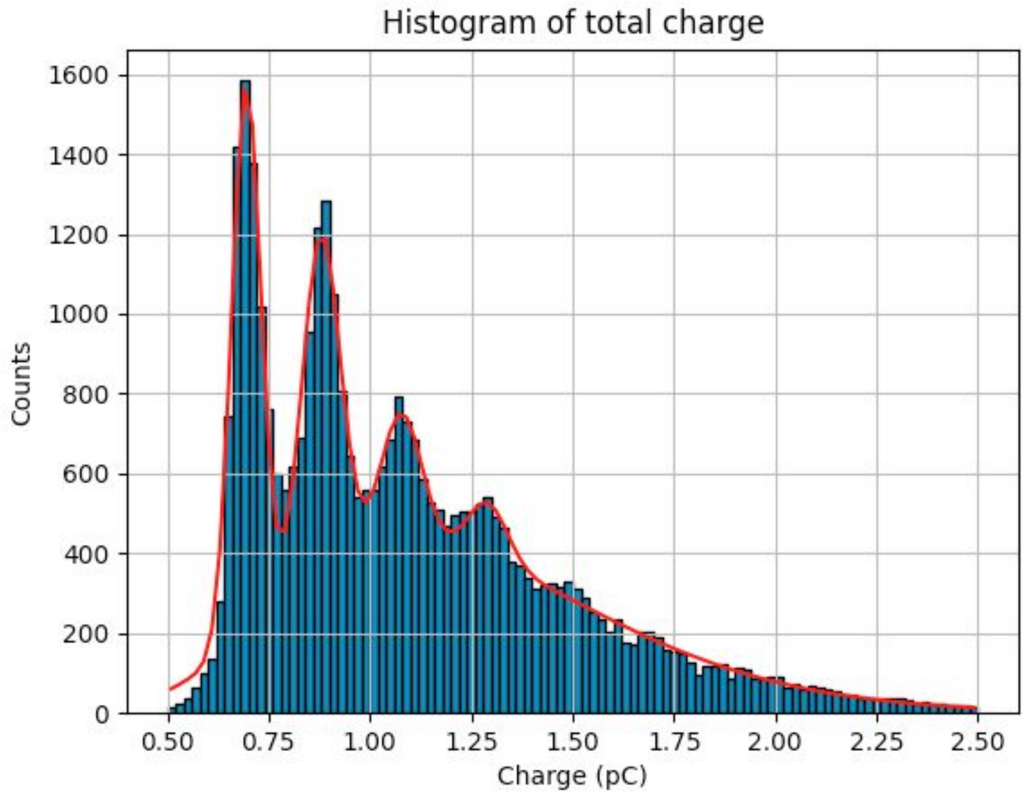


- Gamma distribution:

Amplitude= 415.8.18±26.8 Shape parameter (k)=9.0±0.7 Scale parameter(ϴ)=0.139±0.013

- First gaussian distribution (Three pixels):

Amplitude= 19.8±0.9 Mean=(0.6952±0.0009)pC Standard deviation= 0.0358±0.0012

- Second gaussian distribution (Four pixels):

Amplitude= 16.2±1.3 Mean=(0.8810±0.0018)pC Standard deviation=0.0465±0.0025

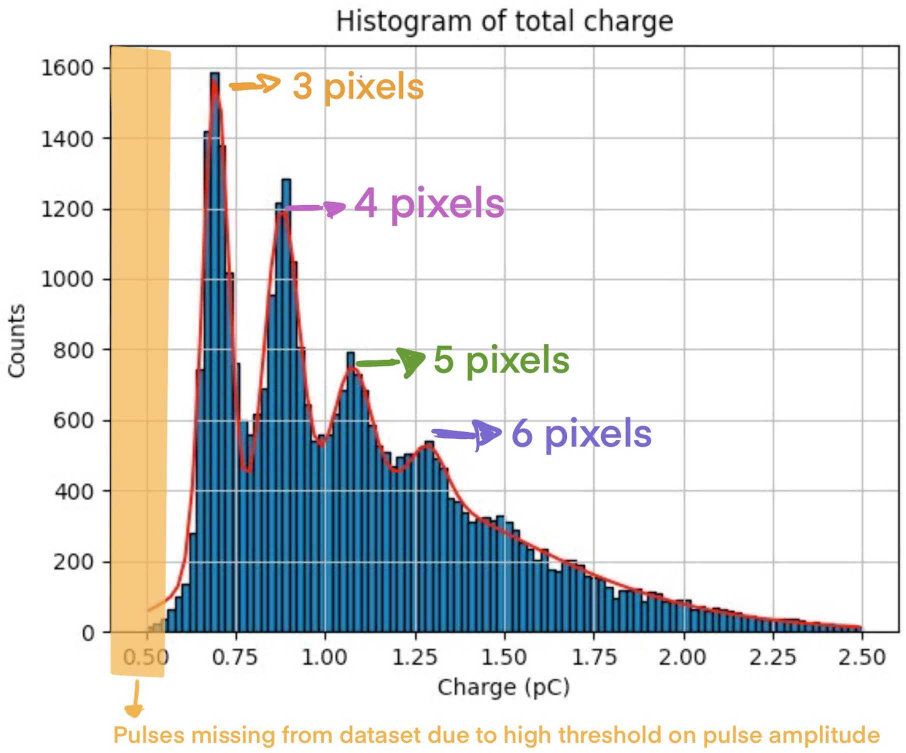
- Third gaussian distribution (Five pixels):

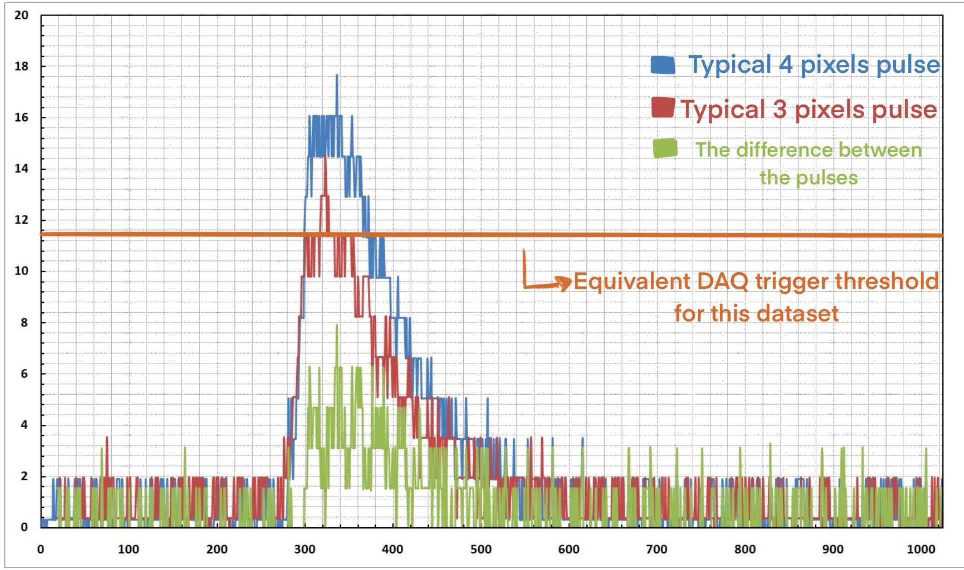
Amplitude=6.8±1.4 Mean=(1.080±0.005)pC Standard deviation=0.052±0.006

- Fourth gaussian distribution (Six pixels):

Amplitude=2.8±1.1 Mean=(1.300±0.011)pC Standard deviation=0.047±0.014

Pixels firing





Gain

The gain is calculated by: $A = \frac{\Delta Q}{e}$

	first peak and second peak	second peak and third peak	third peak and fourth peak
Difference between peaks	(0.1858±0.0020)pC	(0.199±0.005)pC	(0.220±0.012)pC
Gain	(1.159±0.012)x10^6	(1.24±0.03)x10^6	(1.37±0.07)x10^6
Average gain	(1.256±0.026)x10^6		

The gain value given by the manufacturer (Hamamatsu) is 1.25X10^6

Gain

The gain calculated by this method is within 1σ of the manufacturer value.

The previous gain obtain by James Hughes processing was (1.38±0.09)x10^6. This result is within 2σ of the manufacturer value. This shows the analysis has improve.

The improvement planned for the next test is to develop new DAQ system based on the DRS4 evaluation board to handle the threshold limitation and have higher dynamic range.