SiPM Single Photon Time Resolution Measurement

TP4b – Spring 2025

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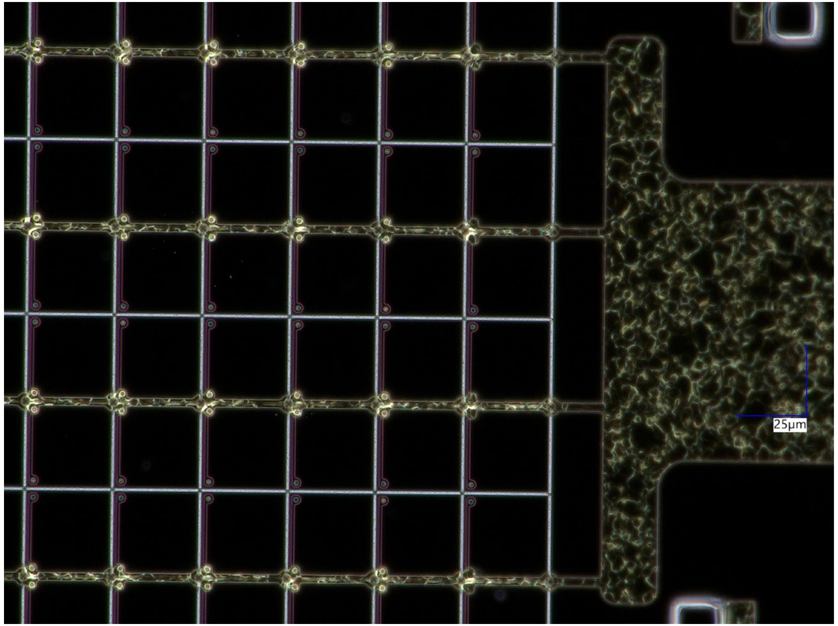
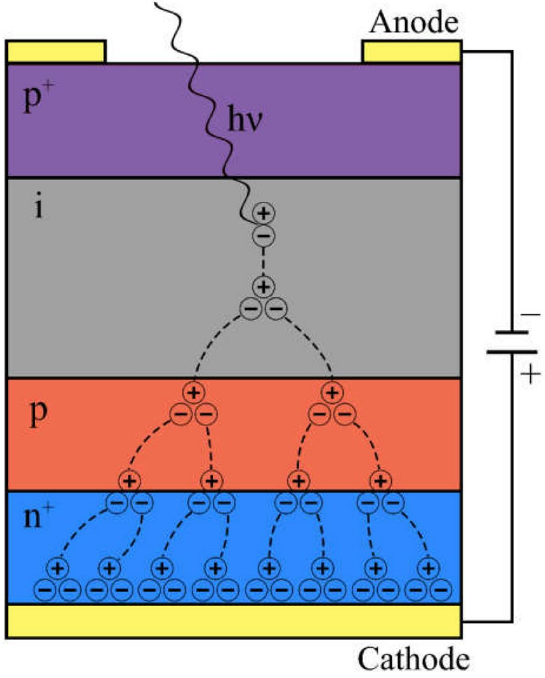
Overview

- Silicon Photomultiplier (SiPM)
- Experimental Setup
- Single Photon Time Resolution (SPTR)
- Analysis Method
- Results
- Future Objectives

SiPM

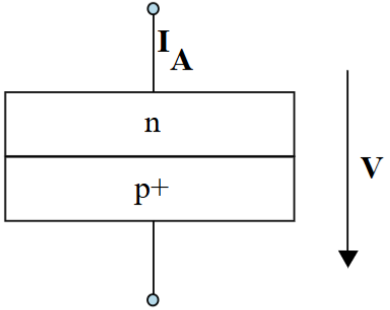
- Composed of Single-Photon Avalanche Diode (SPAD)

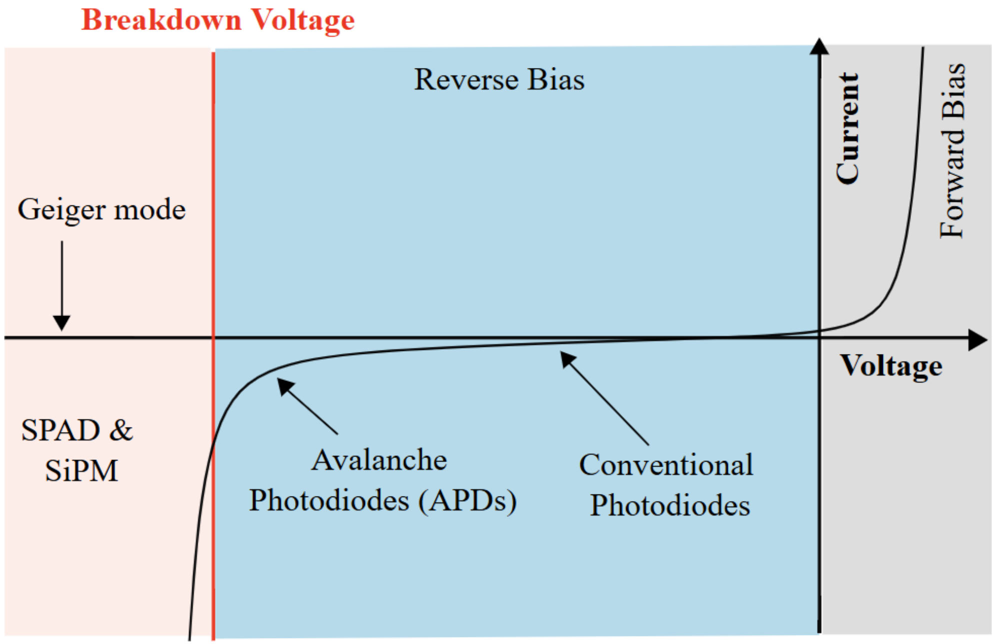




SiPM

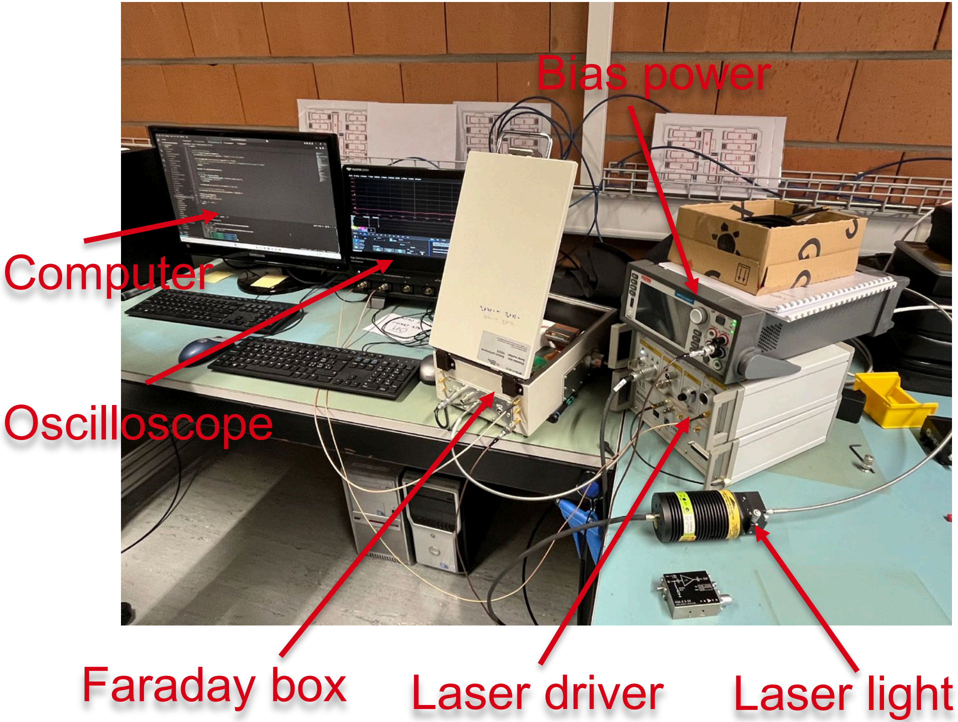
- SiPM cells operate at Geiger mode

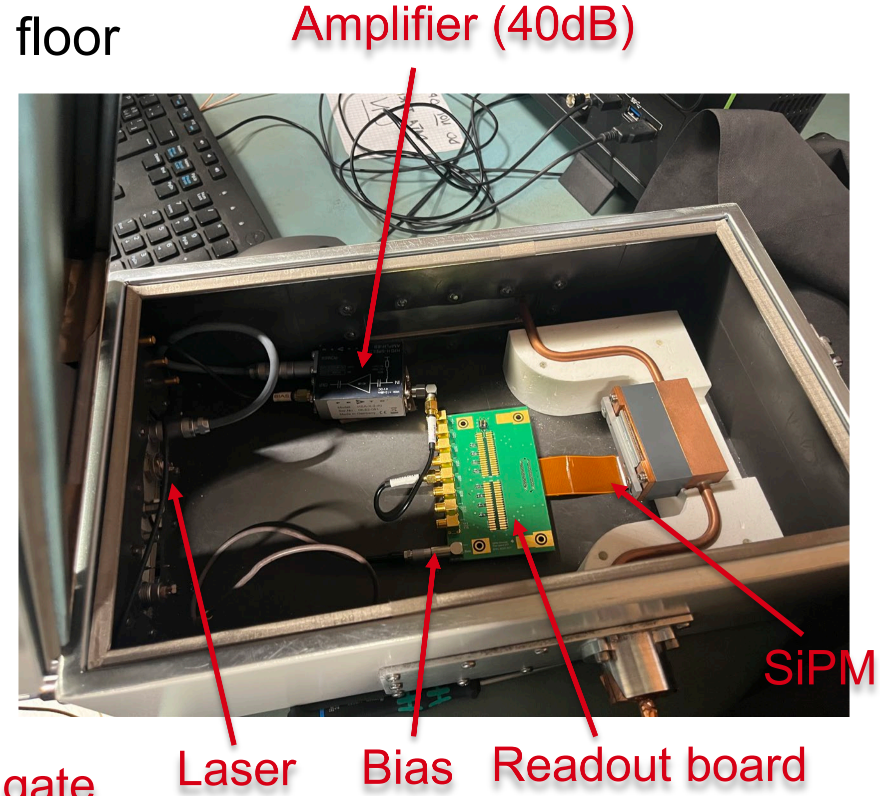




Experimental Setup

- Setup in the SiPM room on the 2nd floor

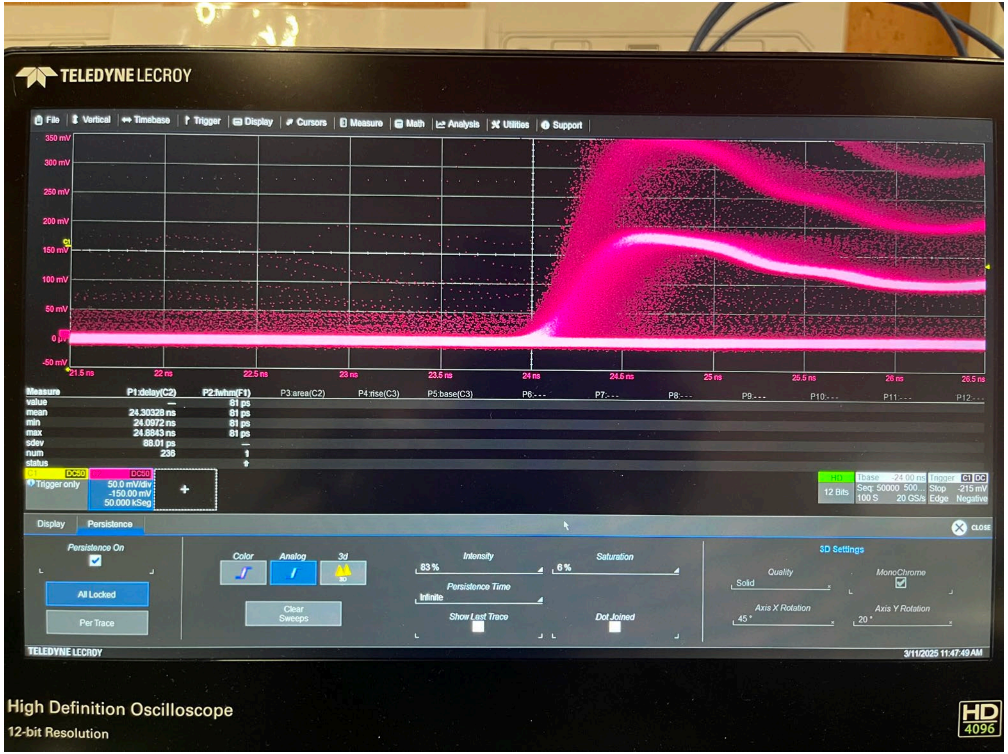




Experimental Setup

- Using the oscilloscope to acquire waveforms

- Task: analyse the time distribution at which the voltage of single photon events reach a certain threshold



Measure	P1:delay(C2)	P2:fwhm(F1)	P3:area(C2)	P4:rise(C3)	P5:base(C3)	P6:- - -	P7:- - -	P8:- - -	P9:- - -	P10:- - -	P11:- - -	P12:- - -
value	—	81 ps										
mean	24.30328 ns	81 ps										
min	24.0972 ns	81 ps										
max	24.8843 ns	81 ps										
sdev	88.01 ps	—										
num	236	1										
status		⬆										

C1 Trigger only

C2 50.0 mV/div -150.00 mV 50.000 kSeg

12 Bits

Tbase -24.00 ns Seq: 50000 500... 100 S 20 GS/s

Trigger C1 DC Stop -215 mV Edge Negative

Persistence On ☑

Intensity 83 %

Saturation 6 %

Persistence Time Infinite

Show Last Trace ☐

Dot Joined ☐

Quality Solid

MonoChrome ☑

Axis X Rotation 45 °

Axis Y Rotation 20 °

3/11/2025 11:47:49 AM

Single Photon Time Resolution

- Measurement of time distribution for SiPM to react to single photon events

- Caused by:

  - Intrinsic error: electric field in APD is not uniform, some photons take longer time to trigger avalanche current

  - Transit time skew: some SiPM cells are further away from the readout

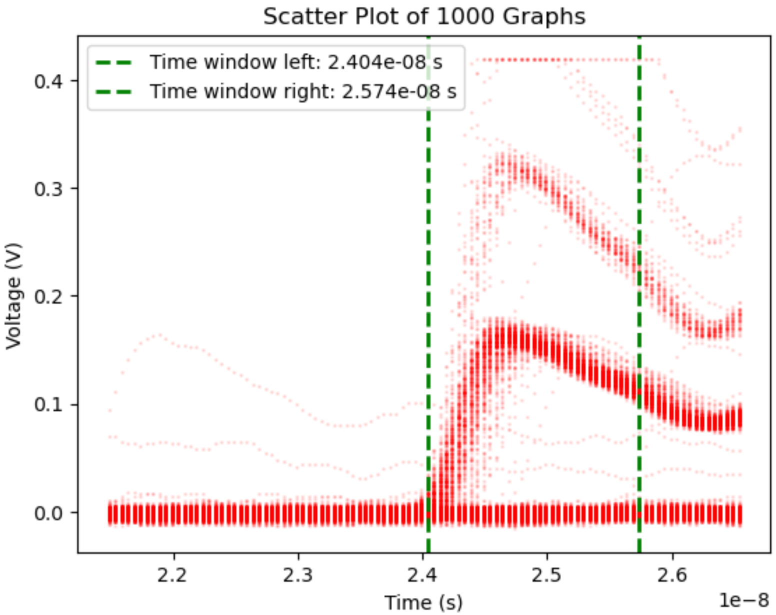
  - Trigger time error: the laser trigger has a spread of <20ps at the time of photon emission

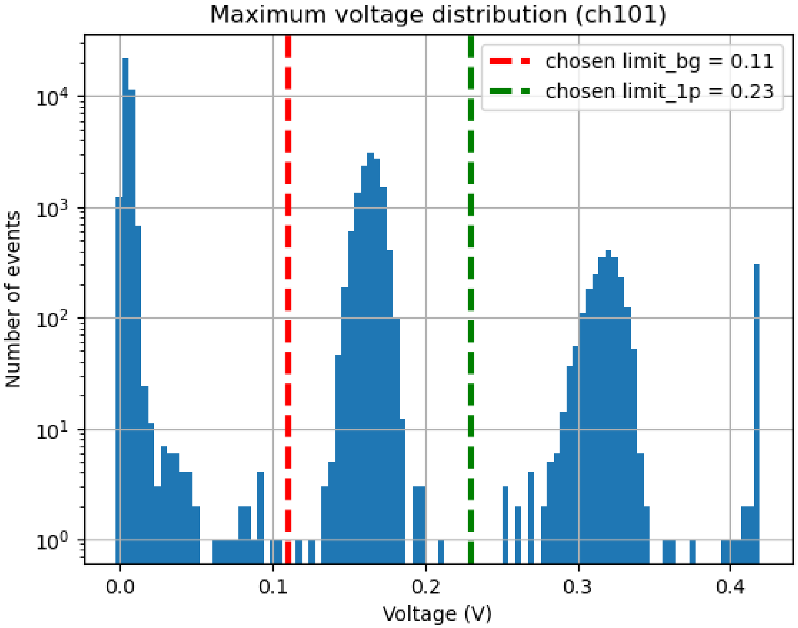
  - Laser statistics: photons are emitted at slightly different times for each pulse with respect to the trigger

  - Jitter error: caused by the random fluctuation of the whole electronics setup

Analysis Method

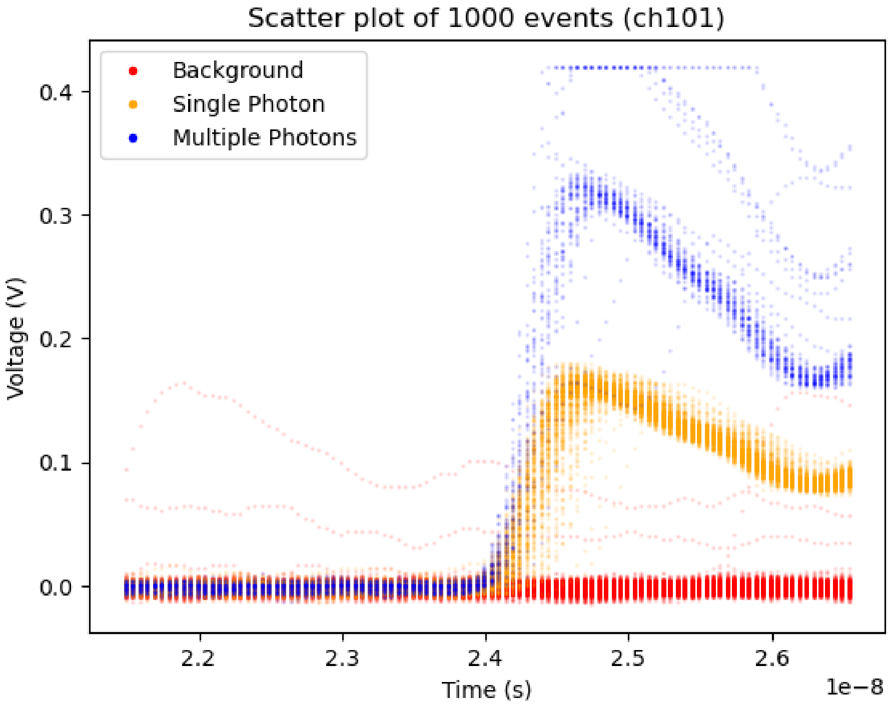
- Separate events based on maximum amplitudes





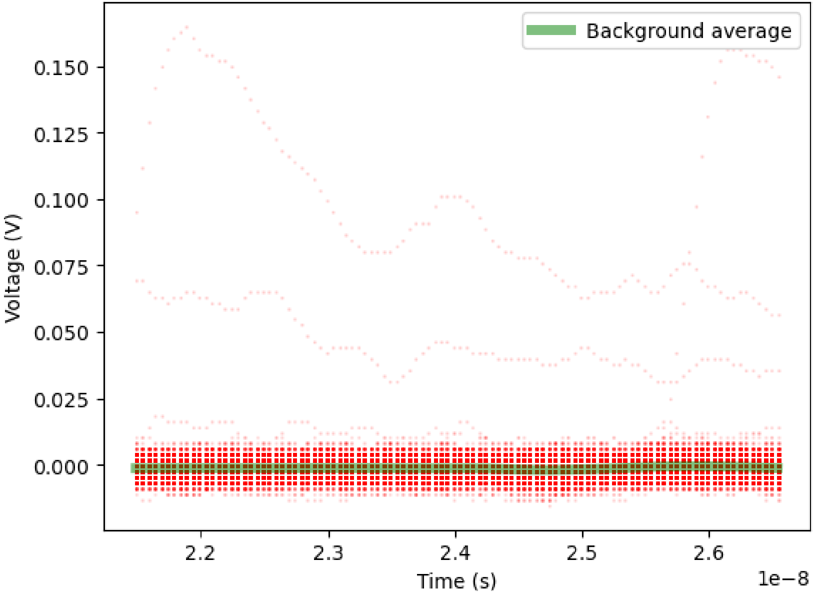
Analysis Method

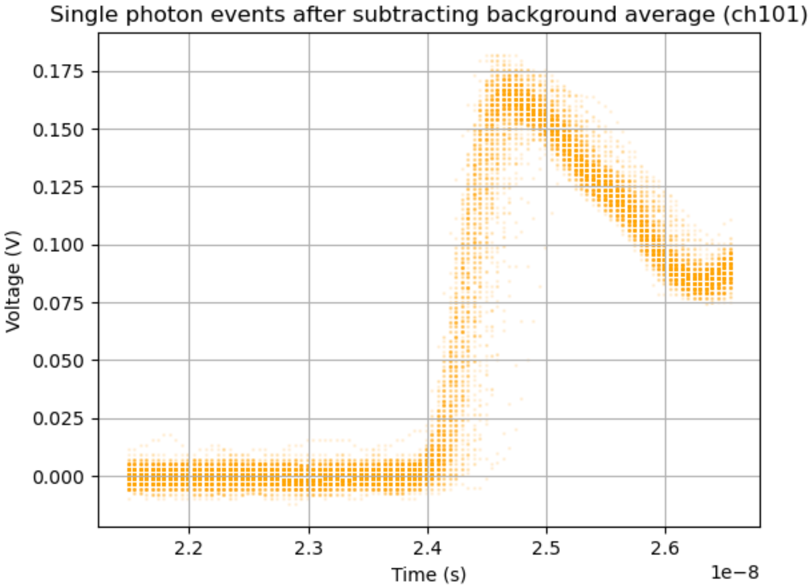
- Separate events based on maximum voltages



Analysis Method

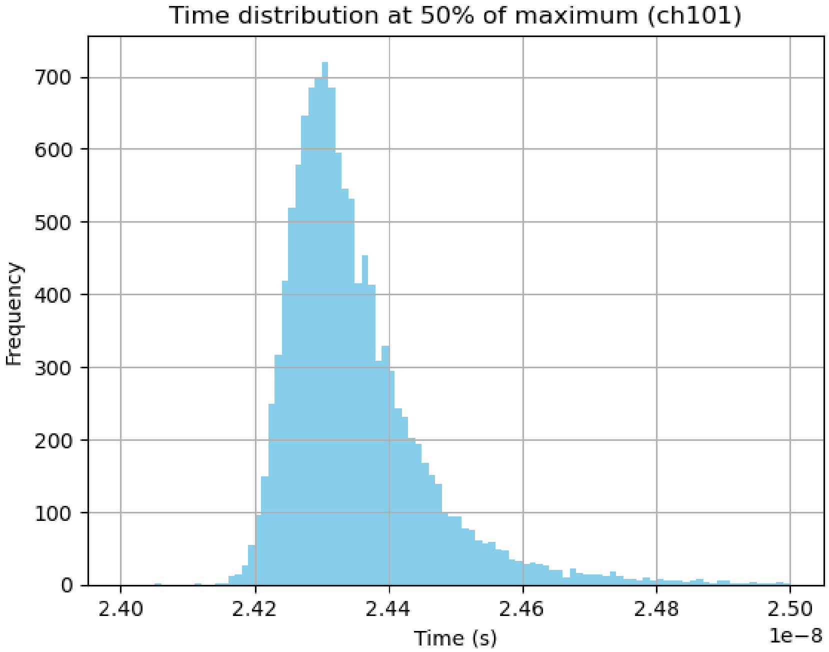
- Calculate mean bg and deduct from 1p events





Analysis Method

- Construct histogram of time distribution at different thresholds

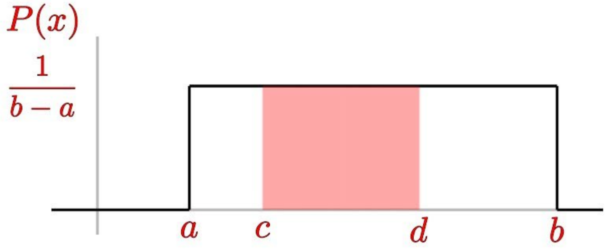


Analysis Method

- Bin width should not be lower than uniform distribution standard deviation

- In our case of sampling time interval 50 ps, bin sizes should be > 14.43 ps

Uniform Distribution



$$Mean: \quad \mu = \frac{a+b}{2}$$

$$S.D.: \quad \sigma = \sqrt{\frac{(b-a)^2}{12}}$$

Probability

$$P(c \leq X \leq d) = \frac{d-c}{b-a}$$

Analysis Method

- Fitting model – Exponentially Modified Gaussian (EMG)

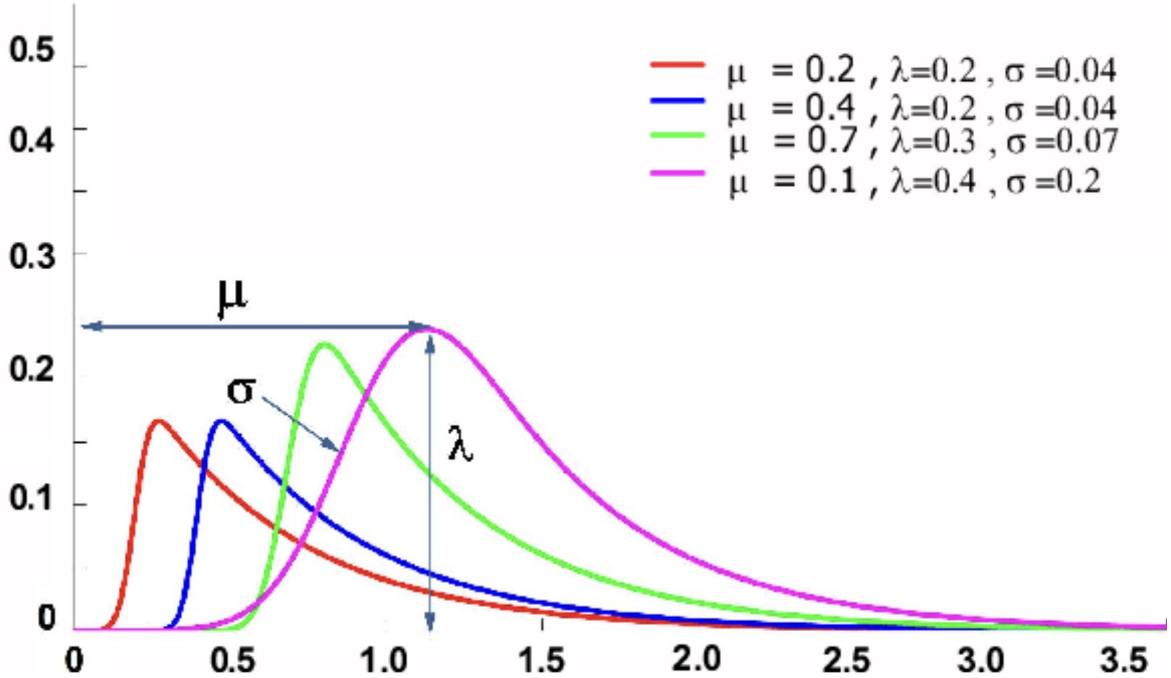
$$f(x;\mu,\sigma,\lambda)=\frac{\lambda}{2}\exp\left[\frac{\lambda}{2}(2\mu+\lambda\sigma^2-2x)\right]\operatorname{erfc}\left(\frac{\mu+\lambda\sigma^2-x}{\sqrt{2}\sigma}\right)$$

where complementary error function:

$$\begin{aligned}\operatorname{erfc}(x)&=1-\operatorname{erf}(x)\\&=\frac{2}{\sqrt{\pi}}\int_x^\infty e^{-t^2}\,dt\end{aligned}$$

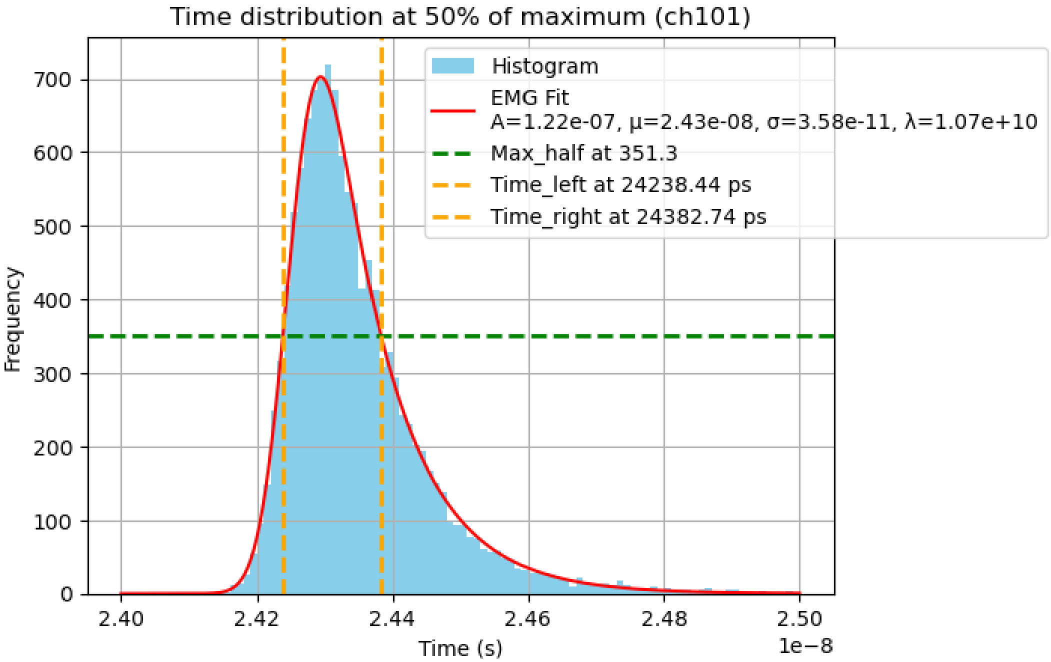
Analysis Method

- Fitting model – Exponentially Modified Gaussian (EMG)



Analysis Method

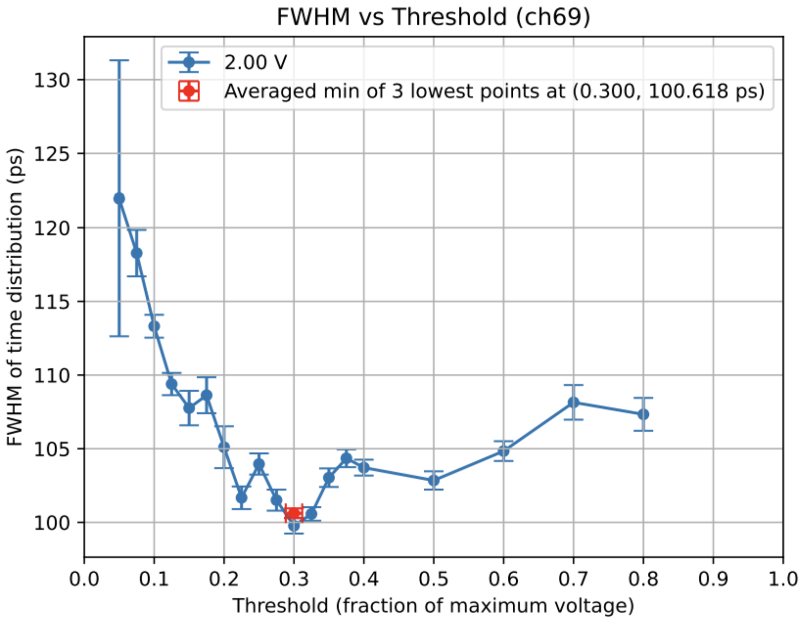
- Perform fitting



- Result of FWHM: 145.16 ps

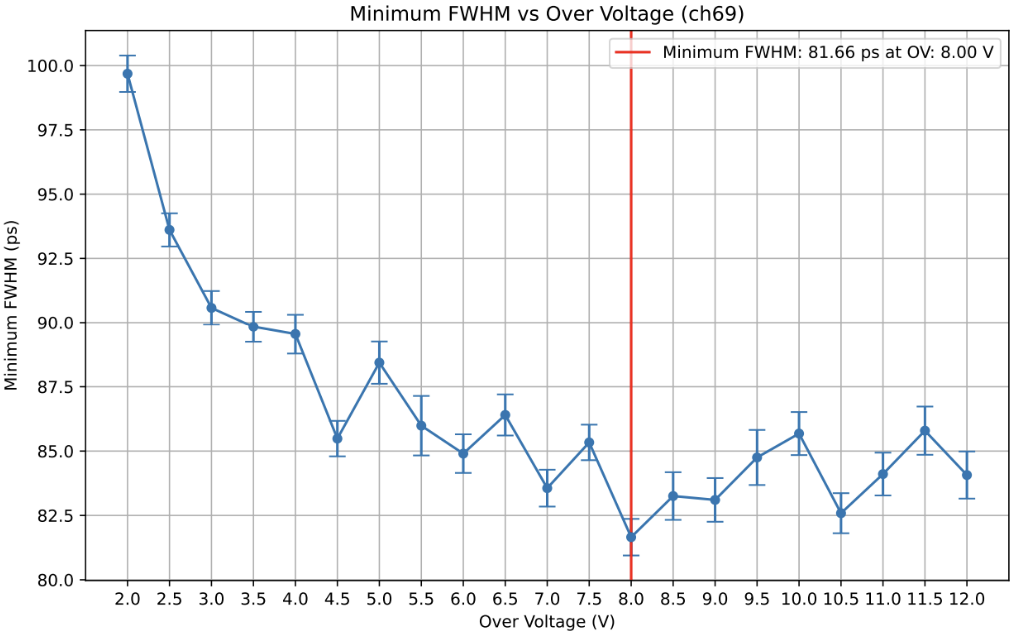
Analysis Method

- Plot over thresholds and find average of 3 points of lowest FWHM



Analysis Method

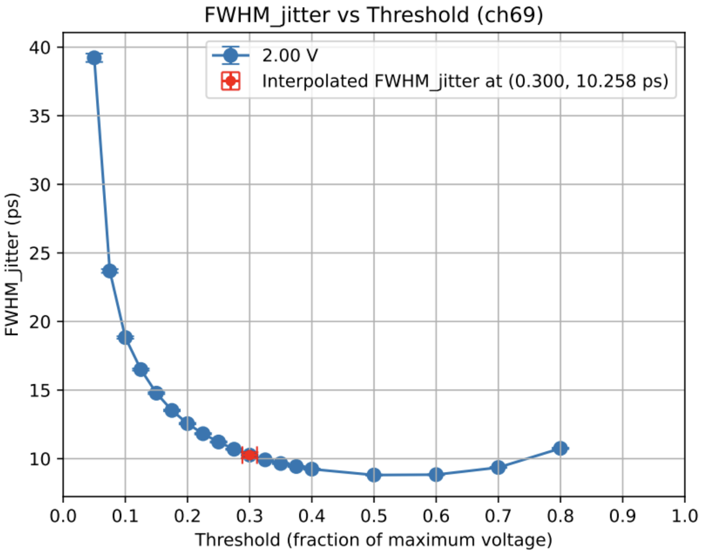
- Plot over different over voltages



Analysis Method

- Jitter error analysis

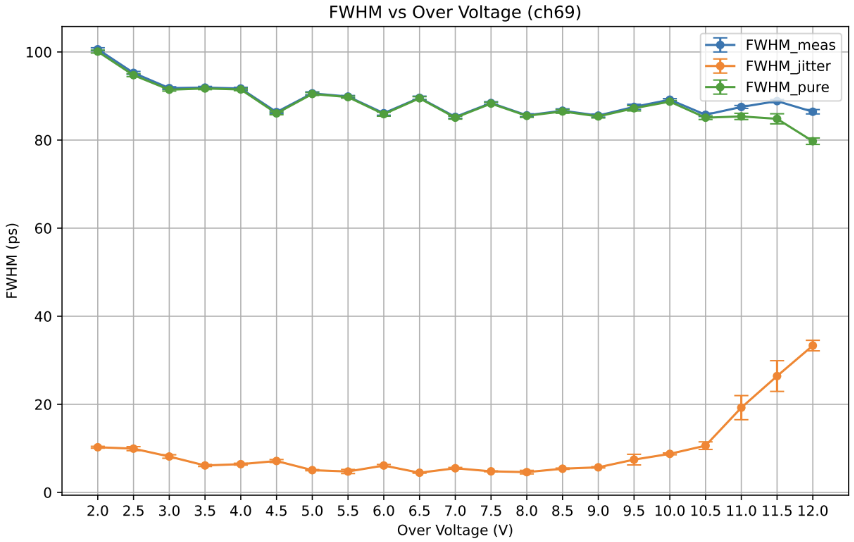
$$FWHM_{jitter} = 2.3458\,\frac{Background\ std}{Average\ gradient}$$



Analysis Method

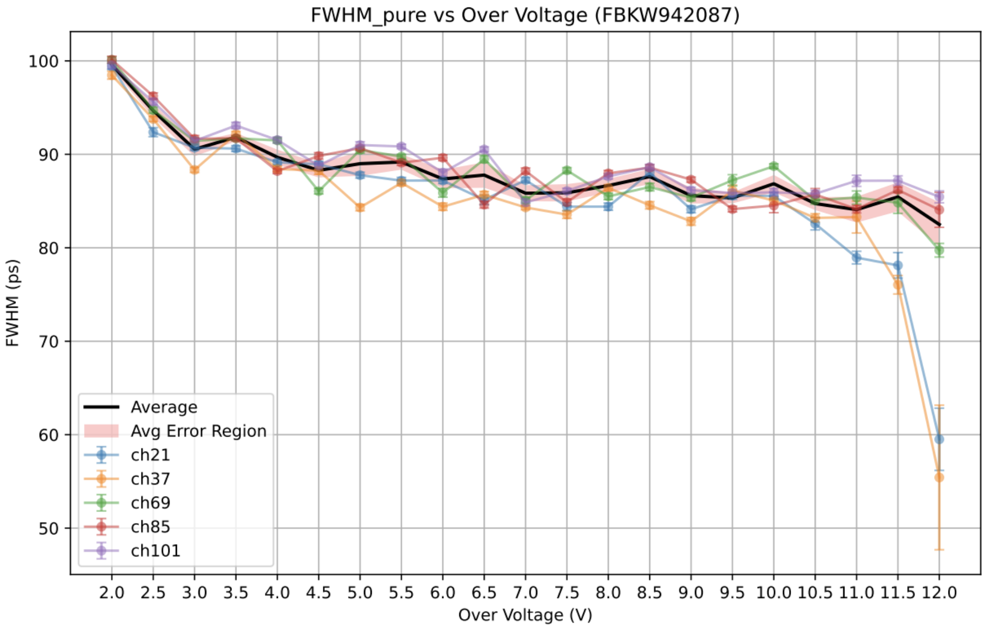
- $FWHM_{pure}$ can hence be obtained by

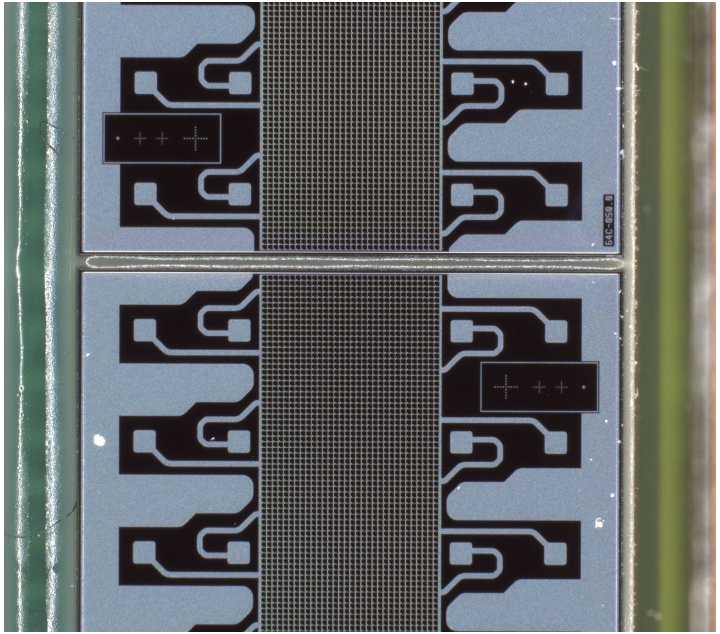
$$FWHM_{meas}^2 = FWHM_{pure}^2 + FWHM_{jitter}^2$$



Analysis Method

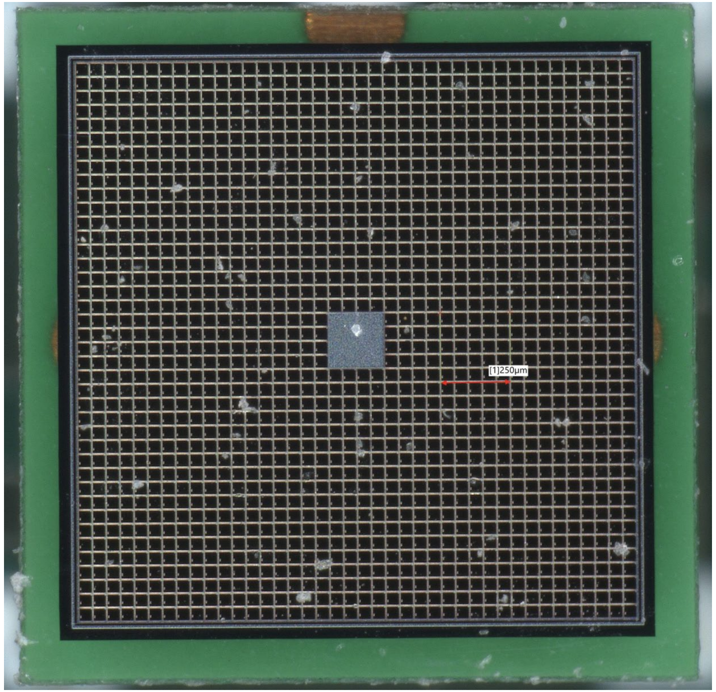
- Repeat for several channels to get average of the SiPM





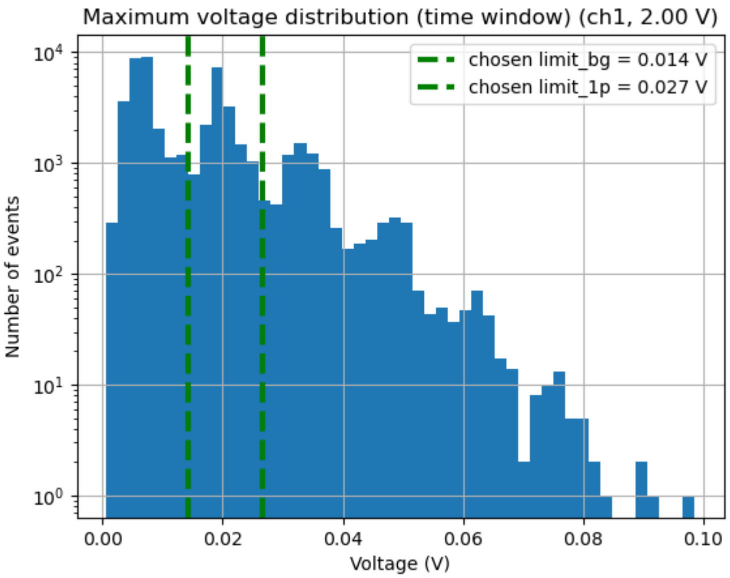
Analysis Method

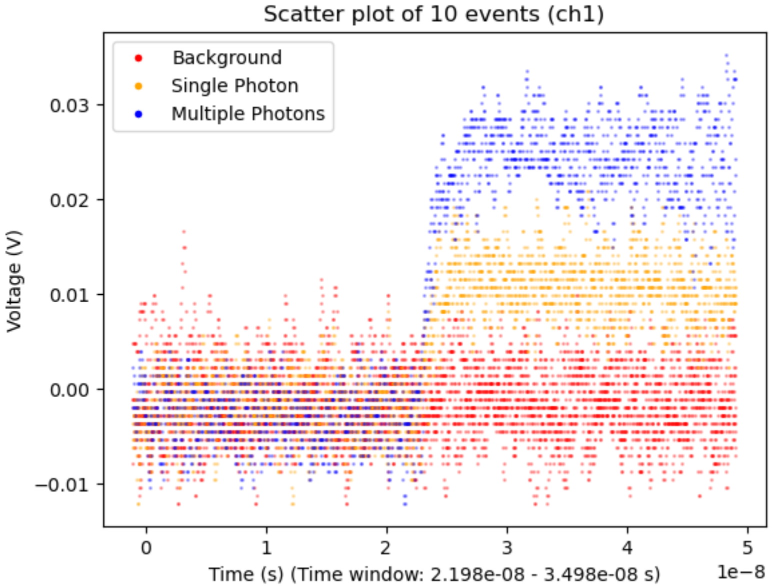
- Single channel SiPM analysis



Analysis Method

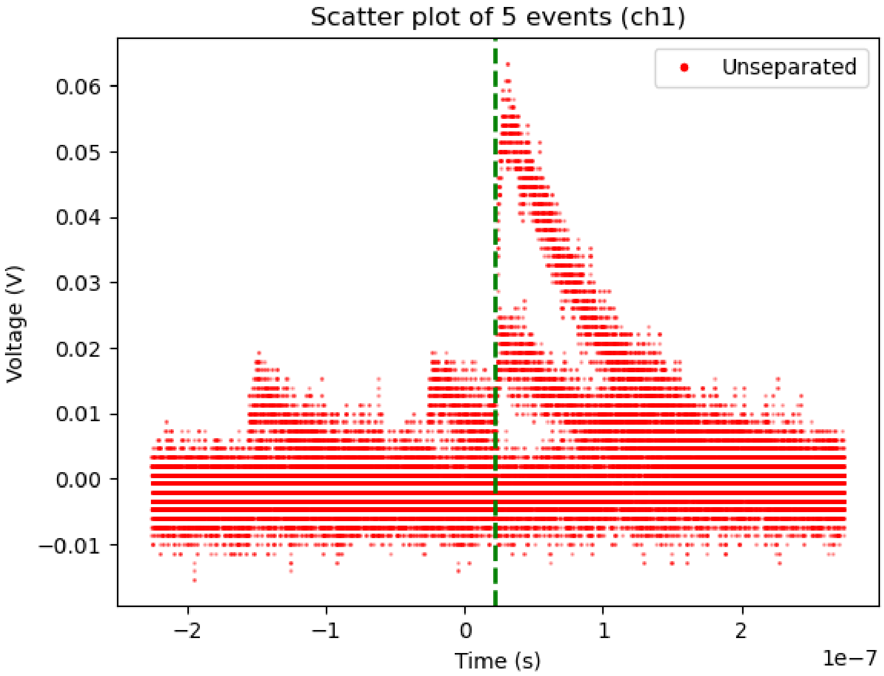
- Single channel SiPM analysis





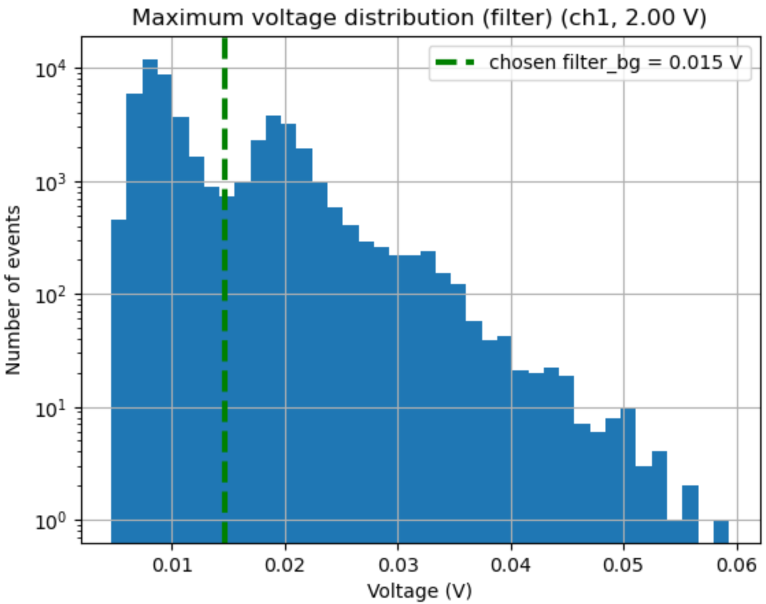
Analysis Method

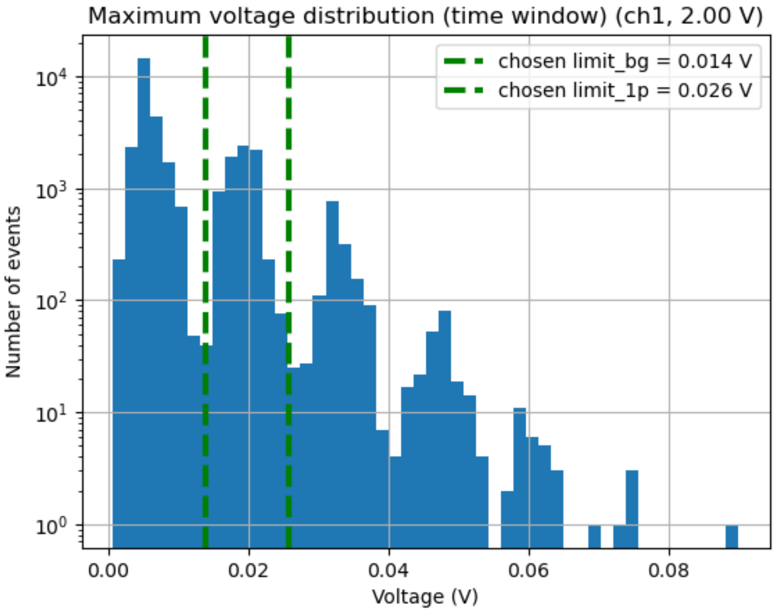
- Range enlarged 10 times



Analysis Method

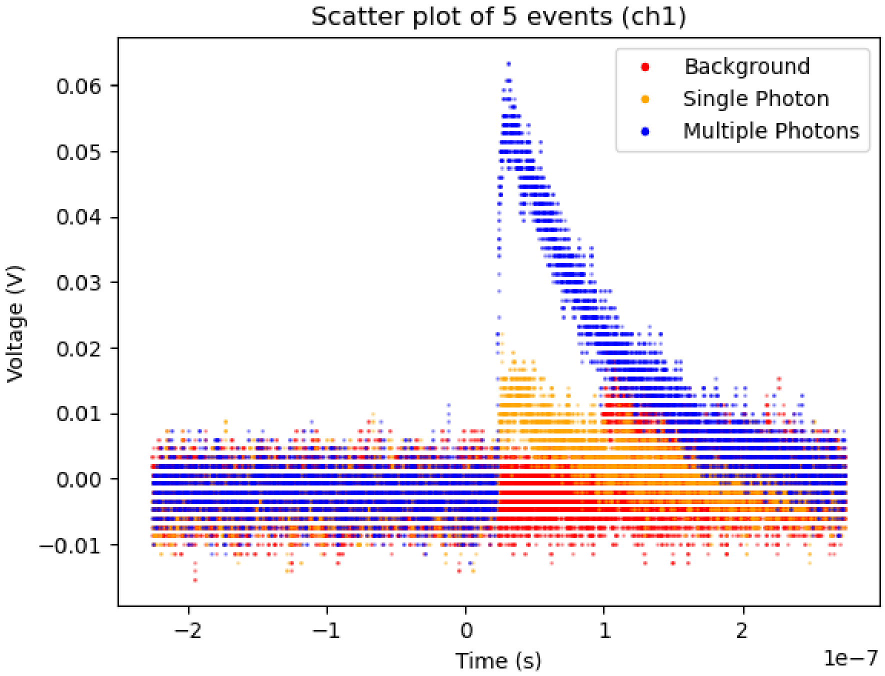
- Voltage filter





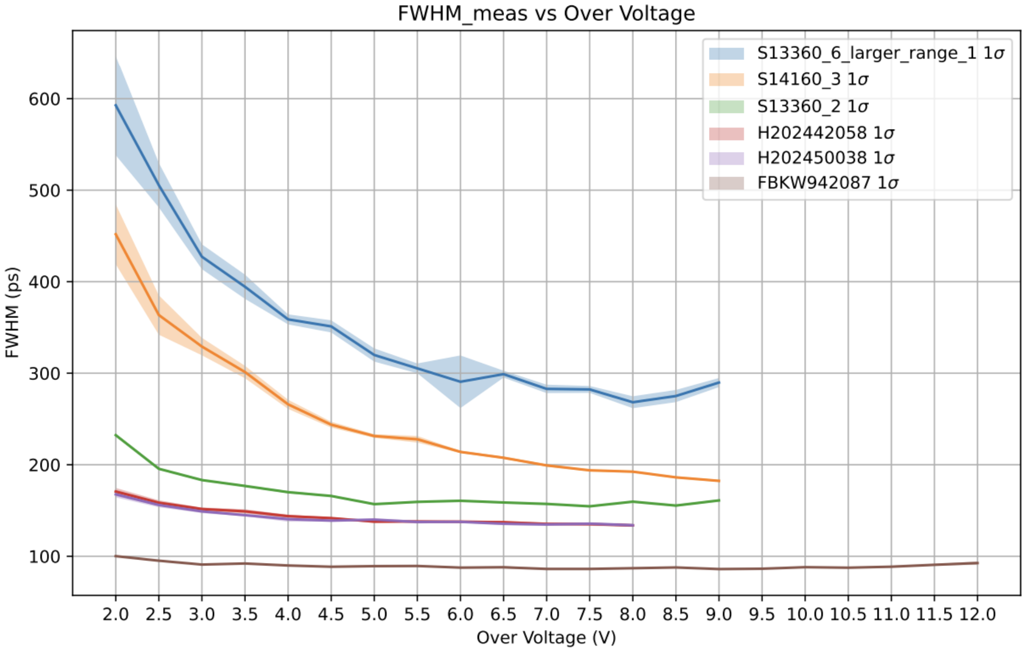
Analysis Method

- Voltage filter



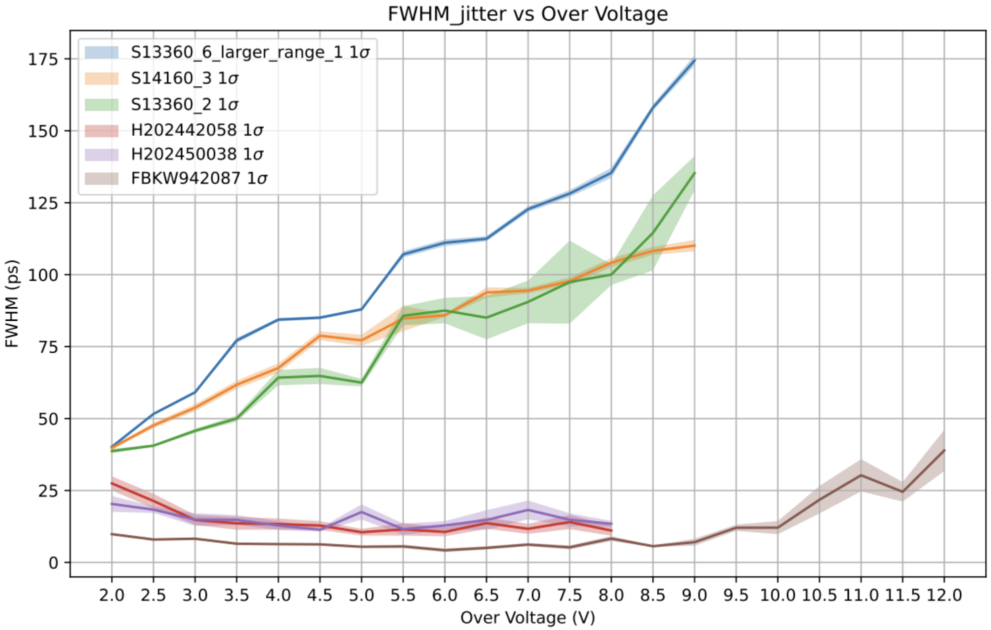
Results

- FWHM$_{meas}$ for all SiPMs



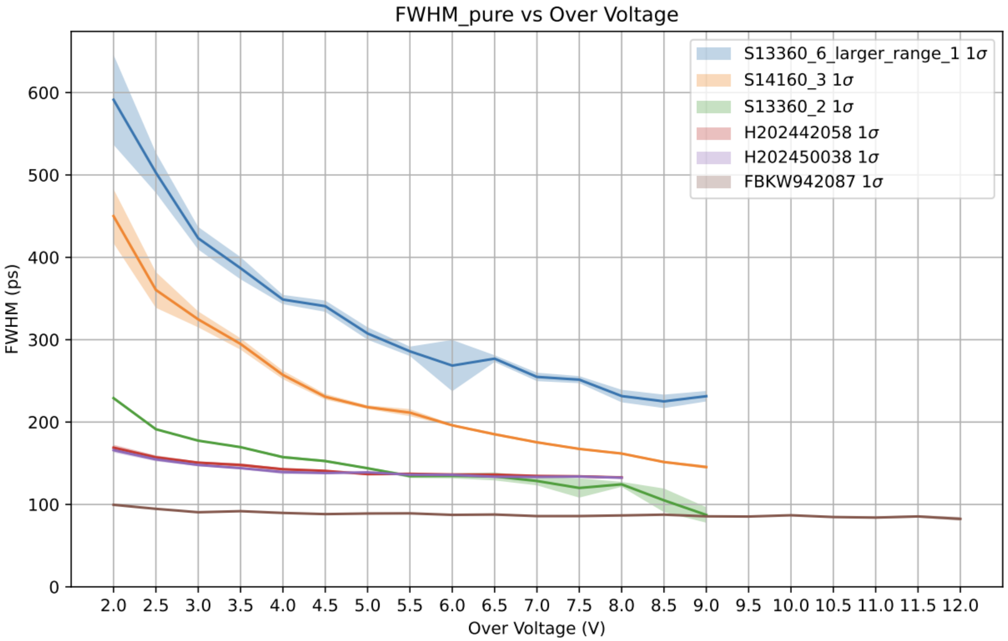
Results

- $\text{FWHM}_{\text{jitter}}$ for all SiPMs



Results

- FWHM$_{pure}$ for all SiPMs



Future Objectives

- Perform SPTR analysis on more SiPMs
- Analyse the reason for this difference in SPTR - cell size? cell number? quenching resistor?
- Compose TP4b report