

Time Resolution and Dark Count Rate Measurements of SiPMs

TSM – Autumn 2025

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I: Time Resolution Measurement

- Introduction
- Experimental Setup
- Analysis
- Results
- Conclusion

II: Dark Count Rate Measurement

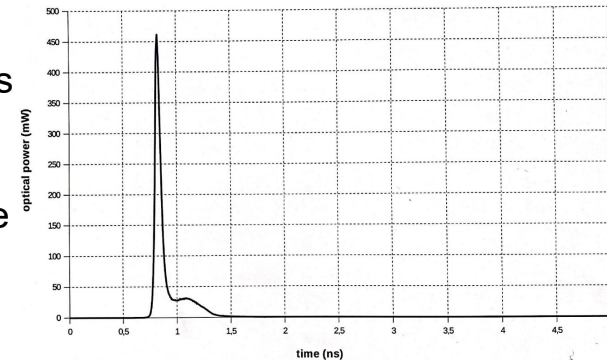
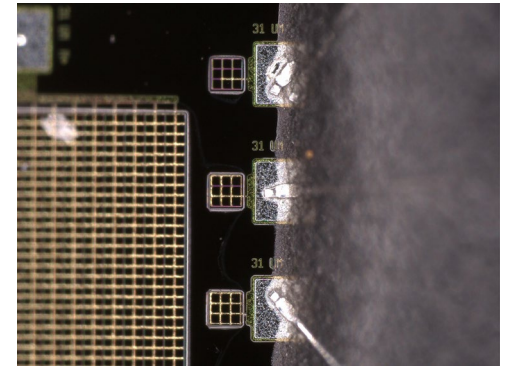
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Part I

Time Resolution Measurement Under Varying Laser Intensity Conditions

Introduction

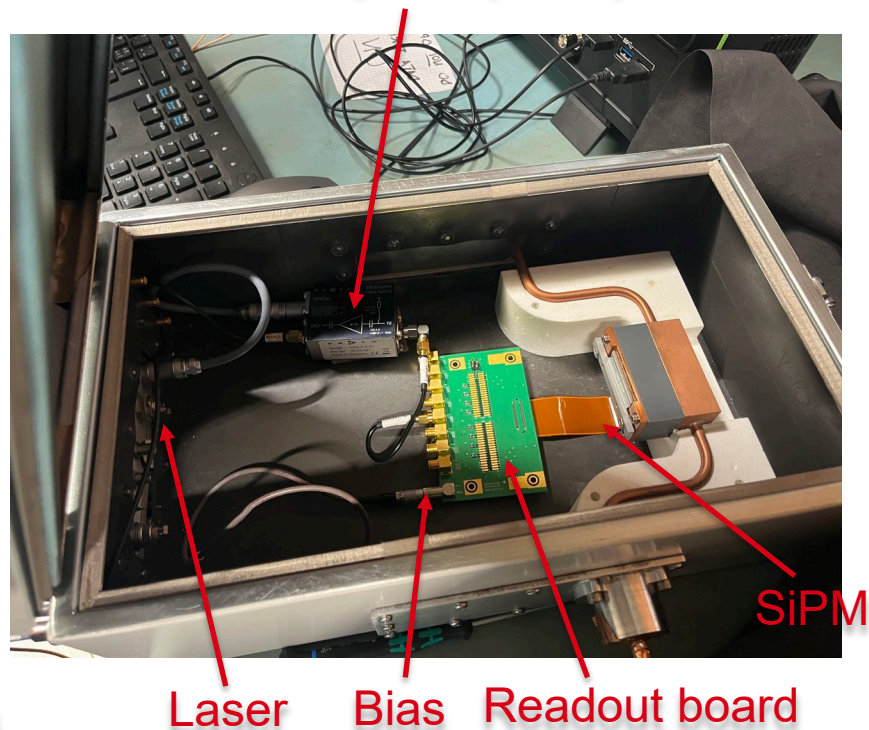
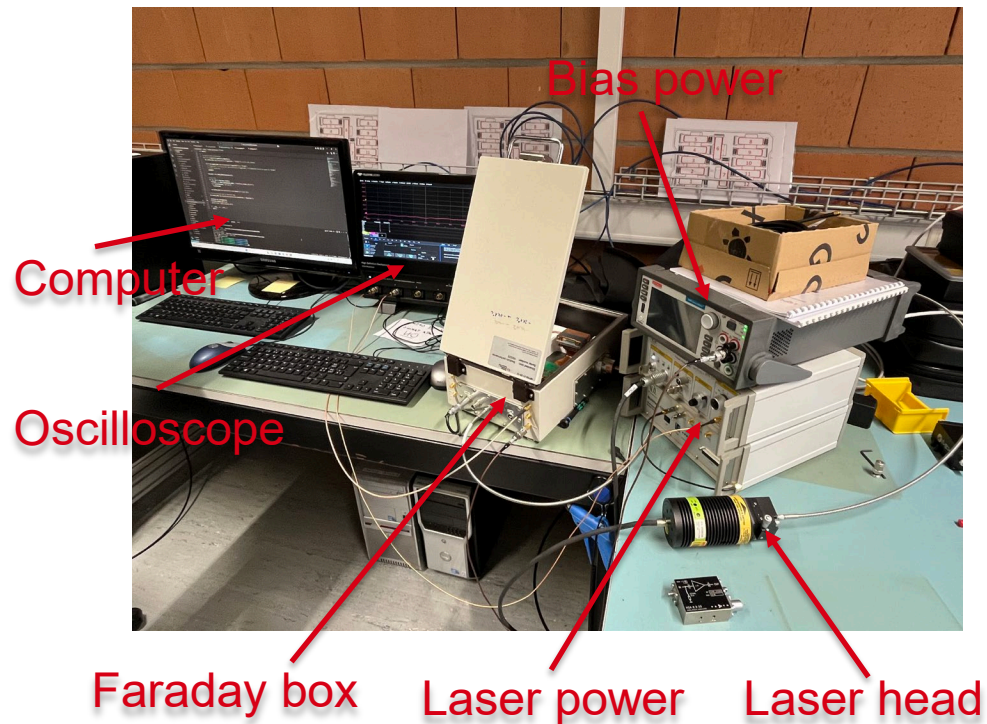
- **Single Photon Time Resolution (SPTR):** Measurement of time distribution for SiPM to react to single photon events
- Contributions from:
 - **Intrinsic error:** electric field in APD is not uniform, some photons take longer time to trigger avalanche current
 - **Transit time skew:** some SiPM cells are further away from the readout
 - **Jitter error:** caused by the random fluctuation of the whole electronics setup
 - **Trigger time error:** the laser trigger has a spread of $<20\text{ps}$ at the time of photon emission
 - **Laser uncertainty:** the laser mechanics makes it follow an optical power distribution when emitting a certain number of photons at a time



Experimental Setup

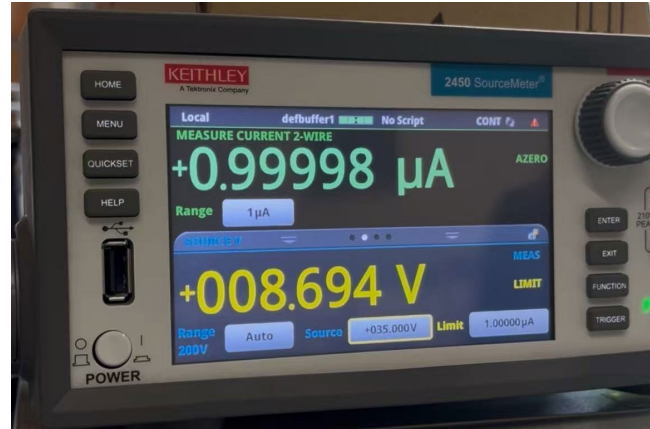
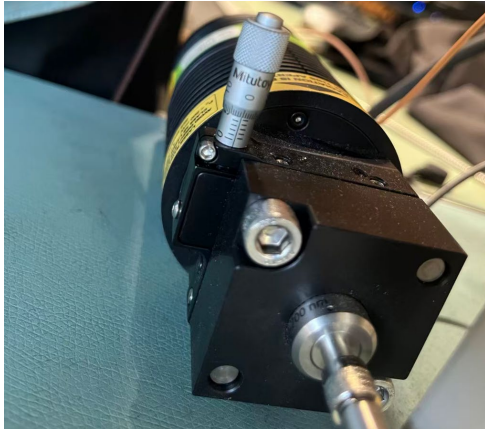
- Setup in the SiPM room on the 2nd floor

Amplifier (40dB)

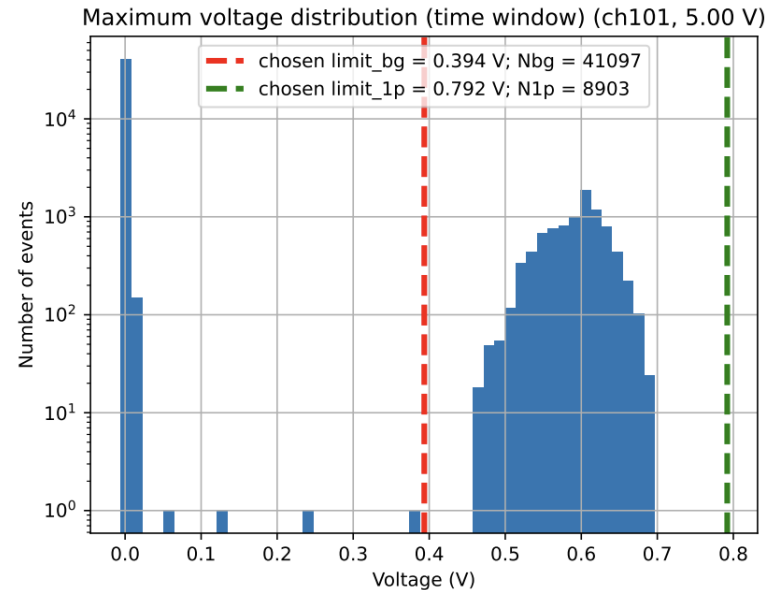
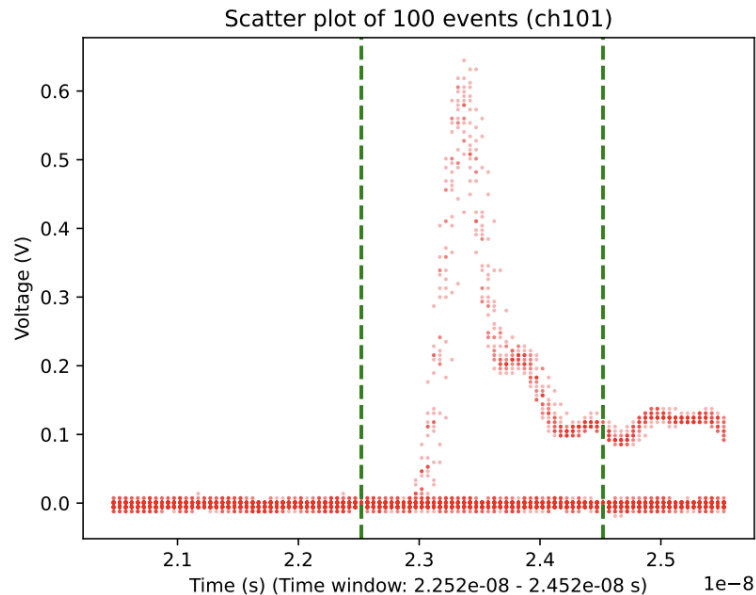


Experimental Setup

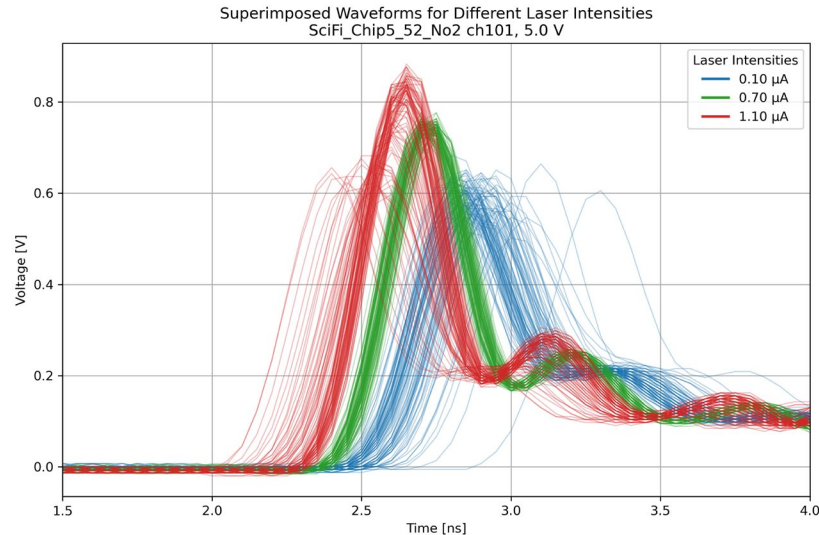
- Put SiPM as close to the laser as possible
- Tune aperture size on the laser head and use current when bias is 35V as a reference of the laser intensity
- Collect waveforms using oscilloscope



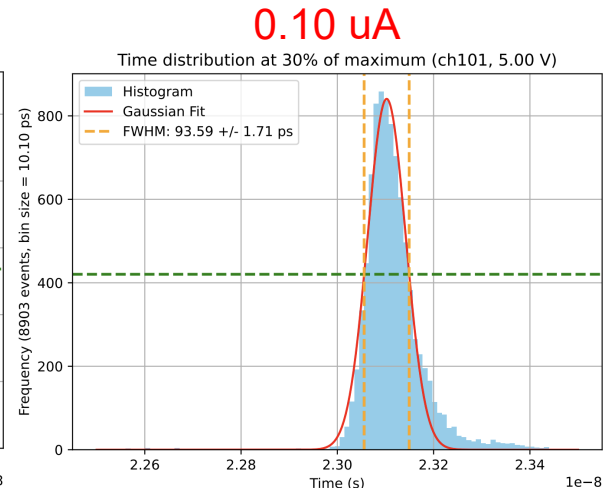
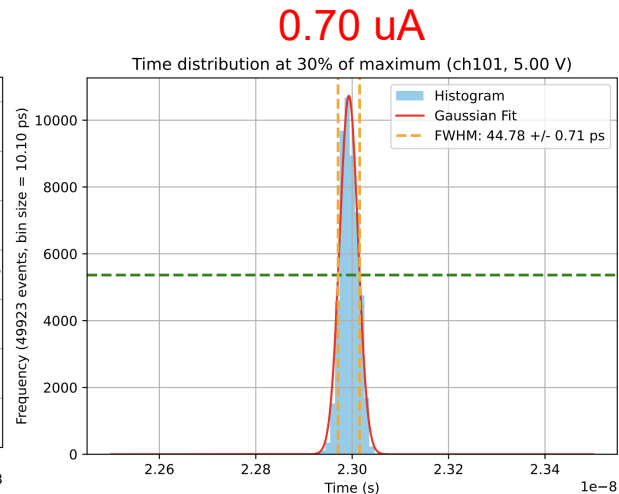
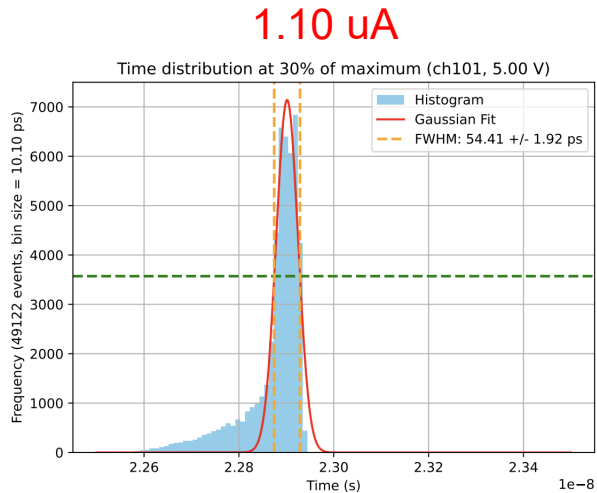
- Use a filter within peak time window to select the single-photon events



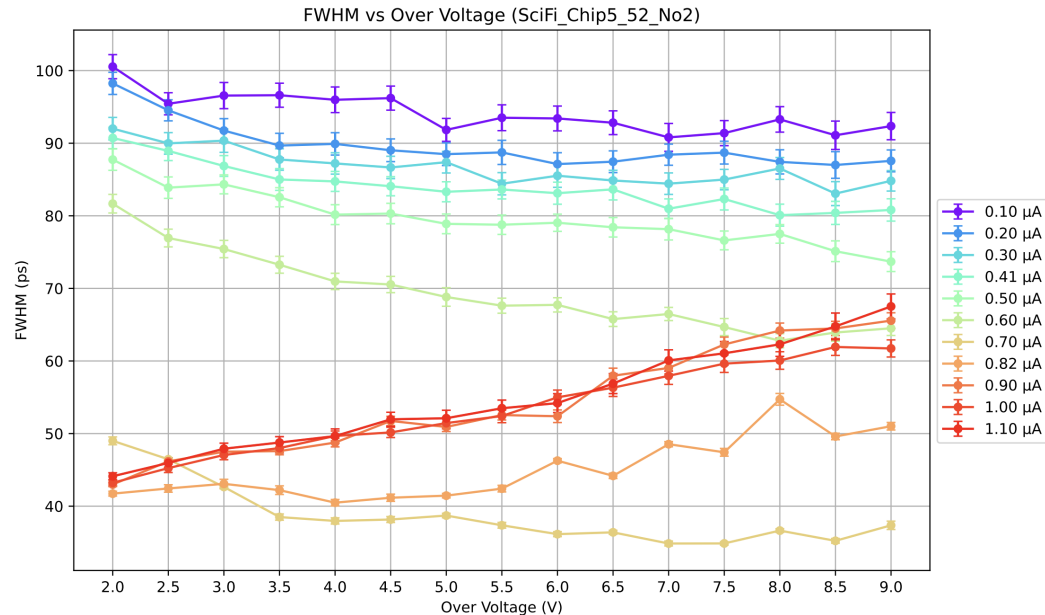
- Plot time distribution at different thresholds
- Different intensity give different time distributions, but they are all fitted with Gaussian to extract FWHM of time resolution



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- Different intensity give different time distributions, but they are all fitted with Gaussian to extract FWHM of time resolution



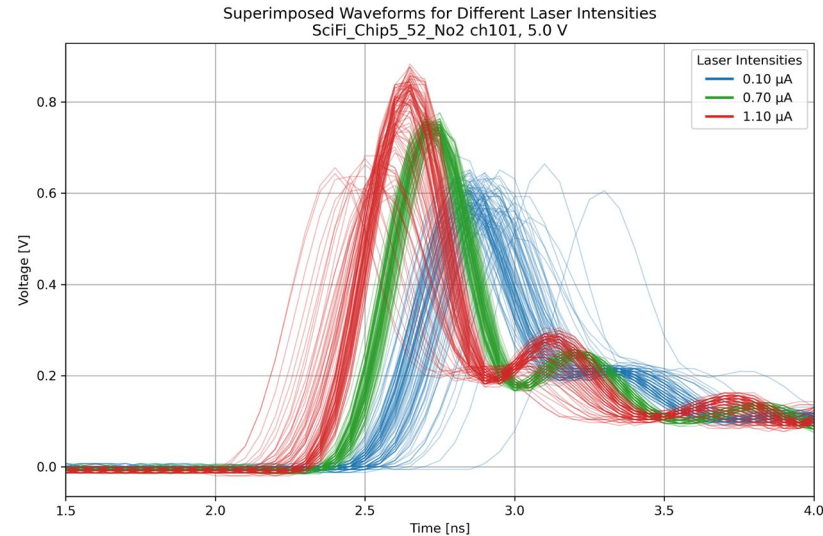
- Repeat for different intensities



- Reaches 35 ps FWHM \rightarrow 15 ps σ \rightarrow 5mm Δx for particles at c

Conclusion

- There is indeed an improvement of FWHM, however this gives the laser uncertainty of $\sim 80\text{ps}$, which is larger than the 56ps as claimed by the manufacturer
- The behaviour of waveforms under different intensities, such as amplitude increase and distribution change still need to be better understood
- Laser intensity can be better measured using spectrometer

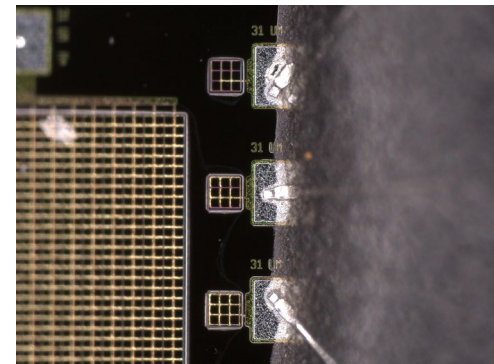
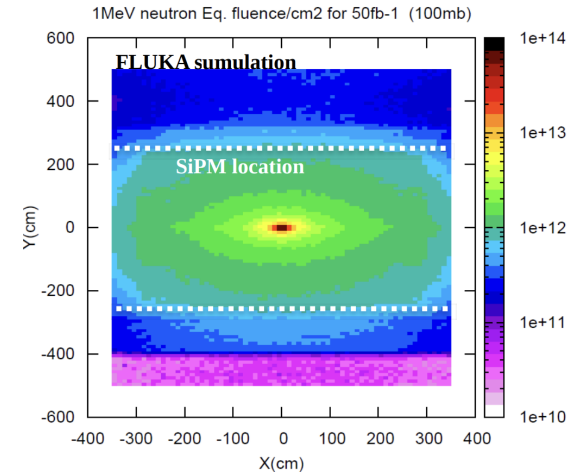


Part II

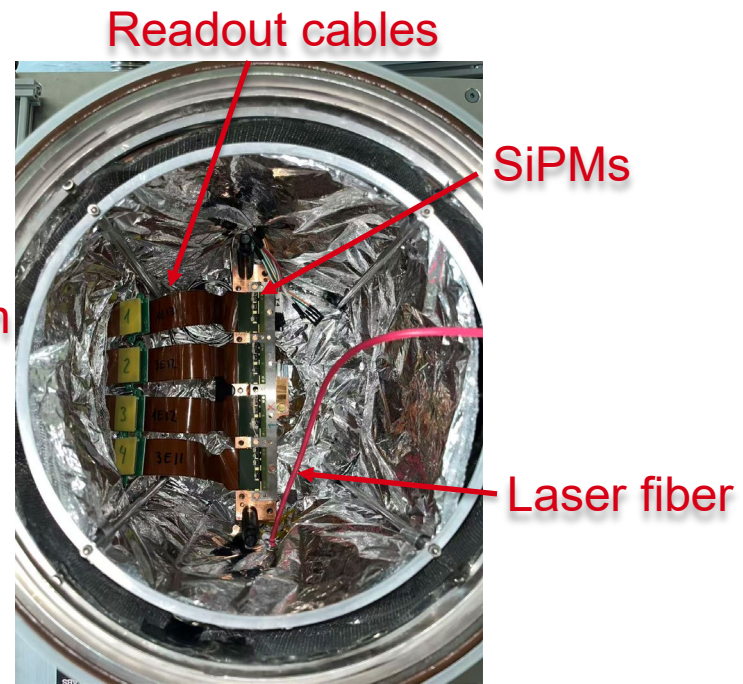
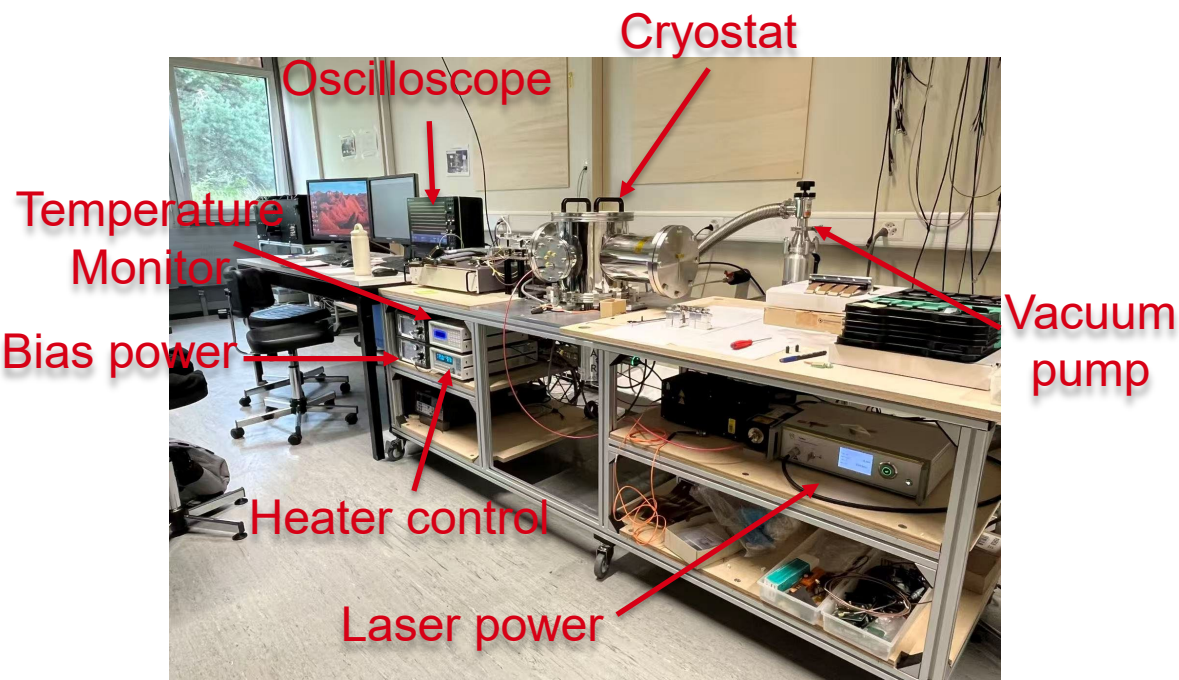
Dark Count Rate Measurement of
Irradiated SiPMs down to 100K

Introduction

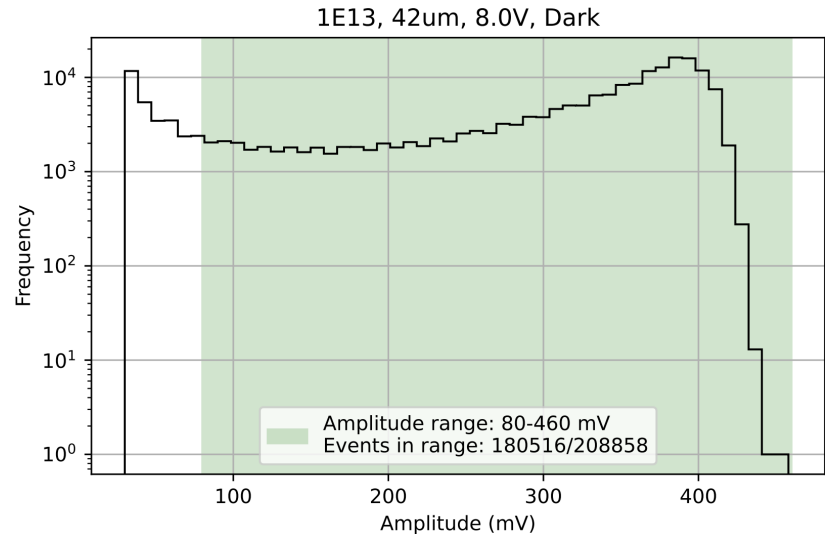
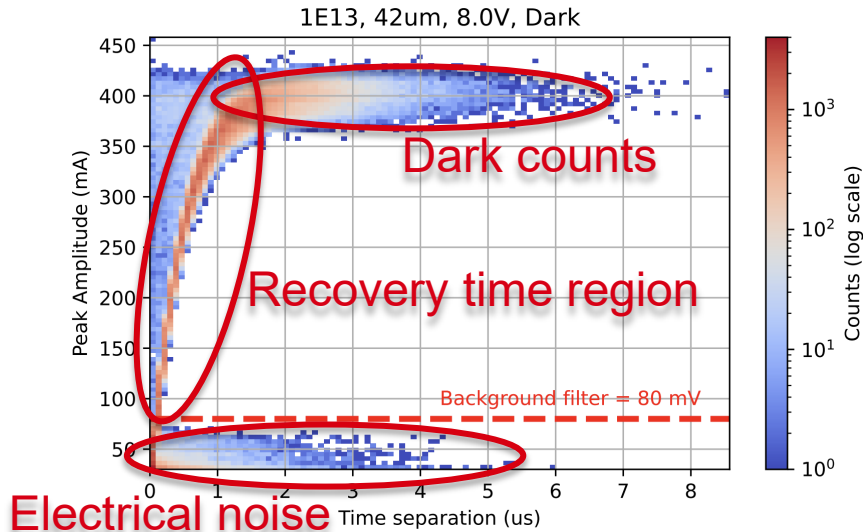
- HL-LHC gives a high neutron fluence on SiPMs ($3E12 n_{eq}/cm^2$ expected). These radiation damages cause SiPMs to produce dark counts
- Using single pixel SiPMs to rule out crosstalk contributions, thus can identify contributions from after pulses and recovery time



Experimental Setup



- Plot 2D histogram to set an amplitude filter threshold



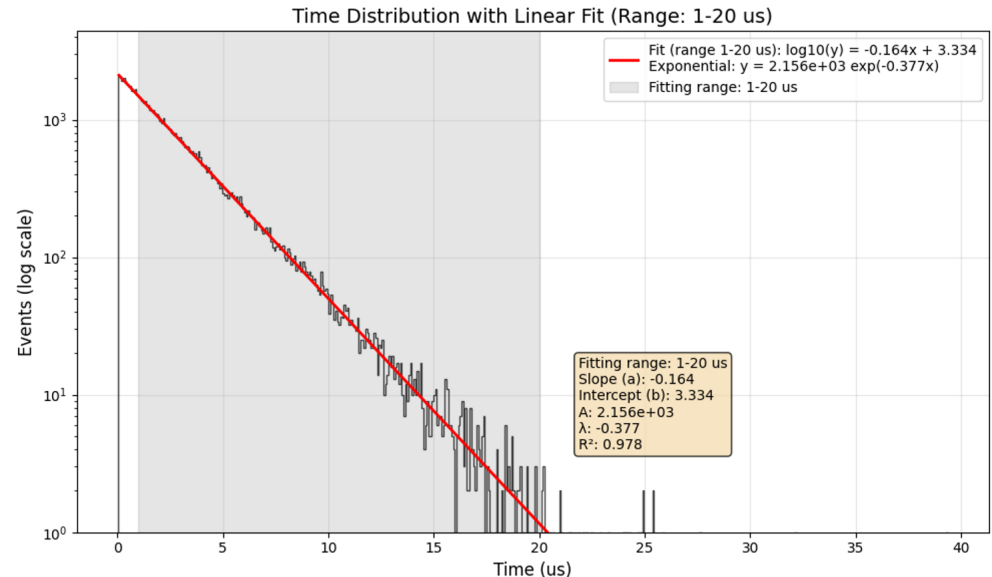
- For non-irradiated SiPM at room temperature, dark count follows Poisson distribution

$$\Pr(k; R) = \frac{(Rt)^k e^{-Rt}}{k!}$$



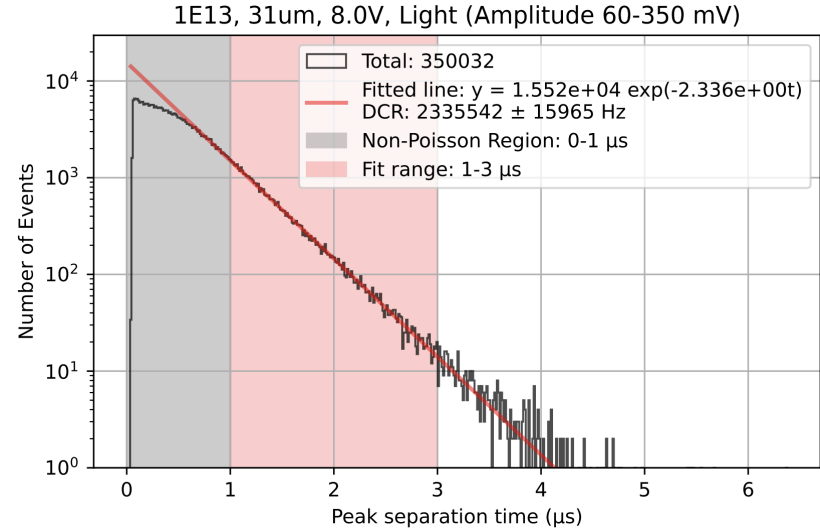
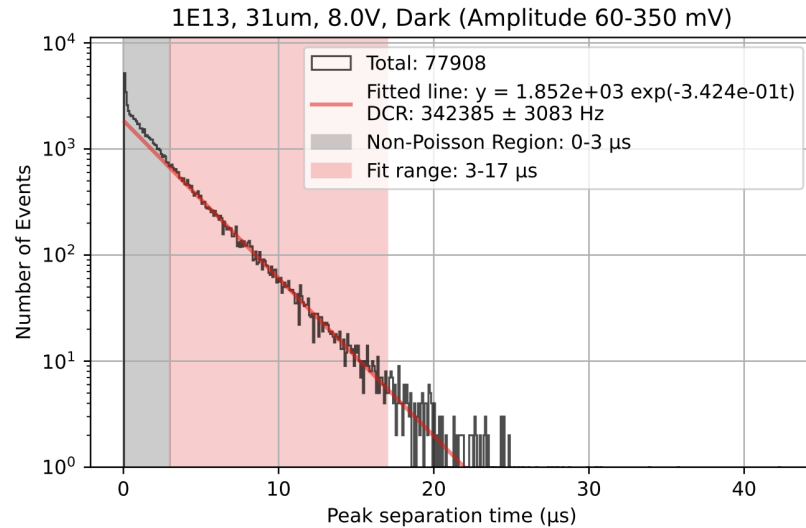
$$\Pr(k = 0; R) = e^{-Rt}$$

where R is the expected dark count rate

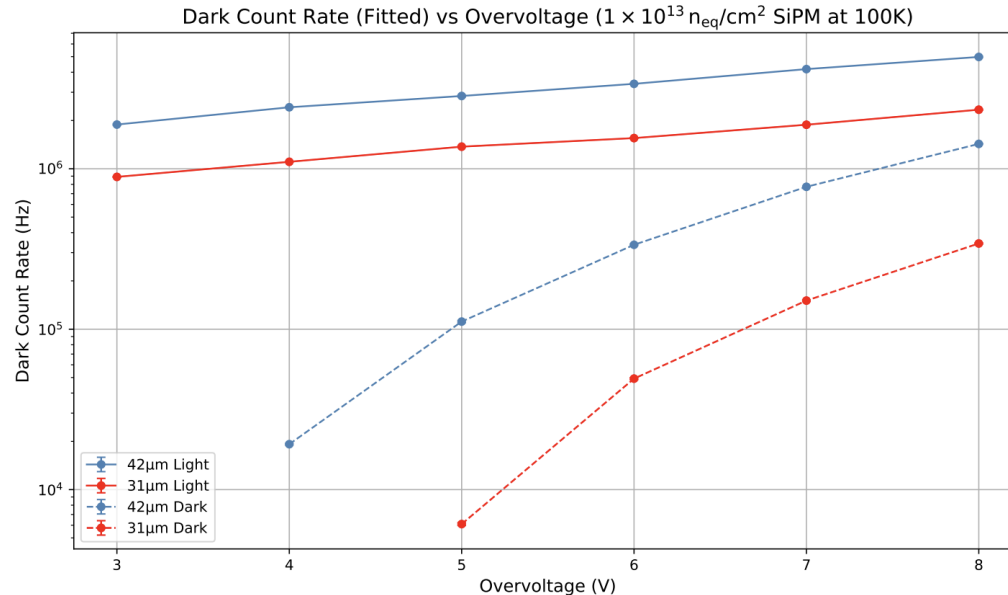


Non-irradiated SiPM at room temperature → Poisson distribution

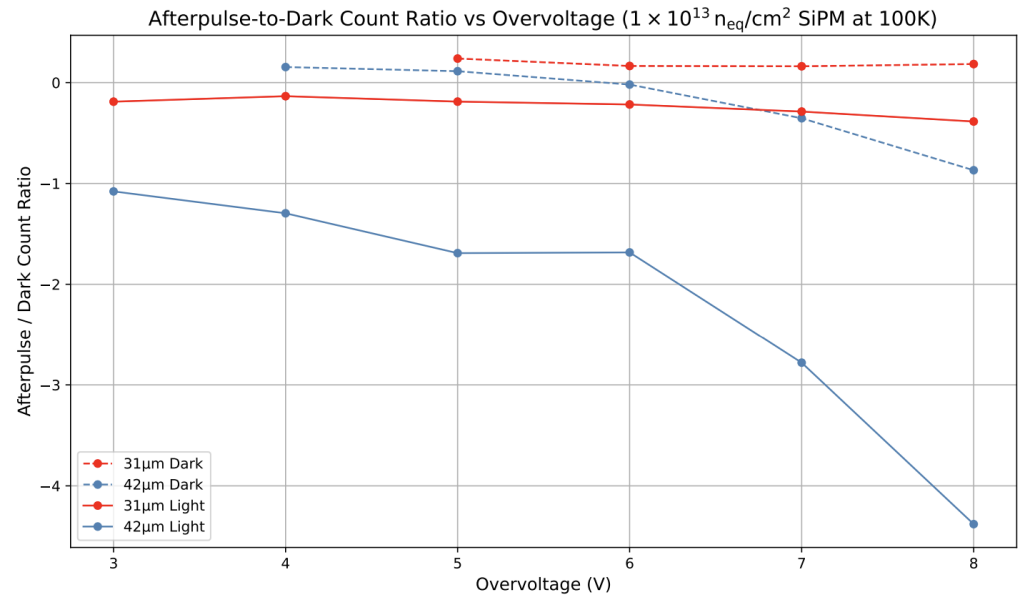
- Plot time separation histogram and fit Poisson distribution



- Fitted DCR increases with OV, and 42 um cell has higher DCR than 31 um cell, as expected

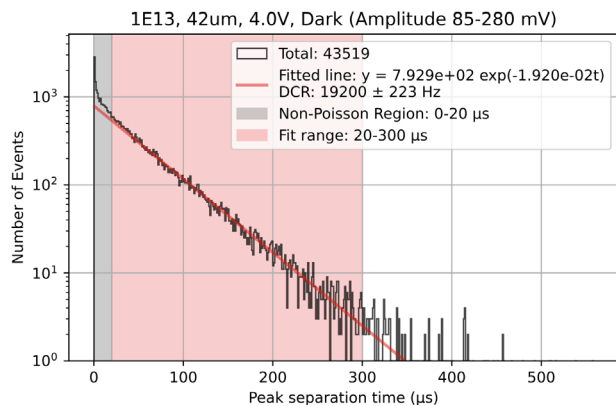


- Illuminated cells always have deficit
- 31 μ m Dark always has excess
- 42 μ m Dark changes from excess to deficit at 6 OV

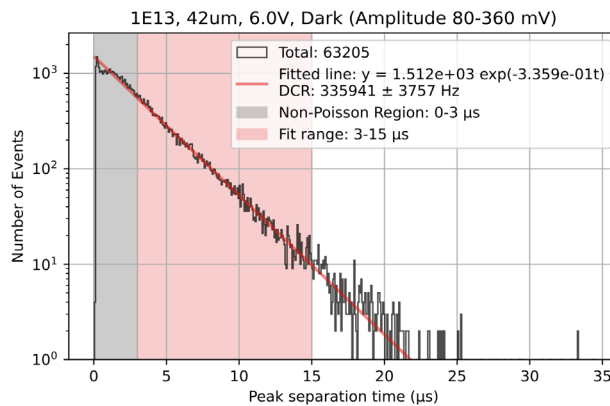


- 42 μm Dark has a shift in extra / deficiency at 6 OV

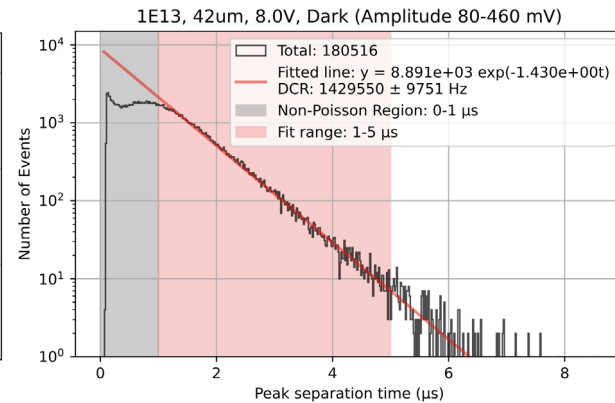
4.0 OV



6.0 OV



8.0 OV



- Dark Count Rate (DCR) increases with OV
- Potential DCR distribution expression:

$$\Pr(k = 0) = C_{DC}e^{-R_{DC}t} + C_{AP}e^{-R_{AP}t} - C_{RT}e^{-R_{RT}t}$$

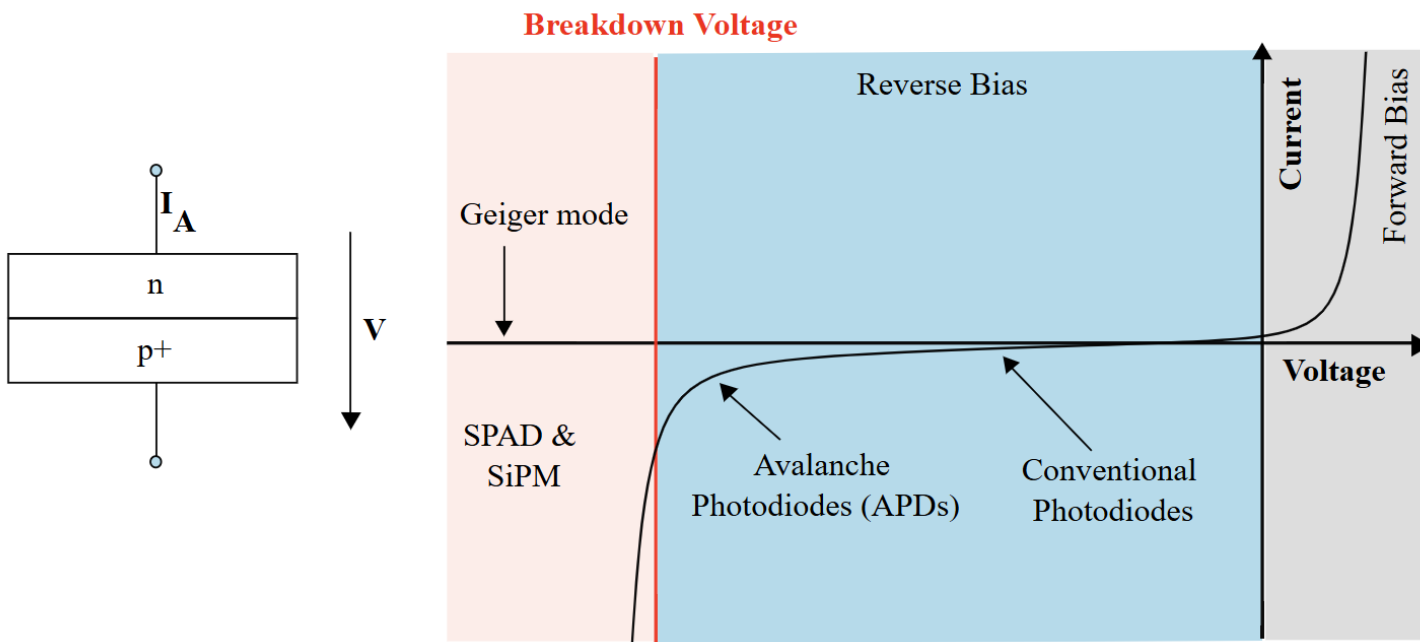
where *DC*: Dark Count; *AP*: Afterpulse; *RT*: Recovery Time

- The change in excess / deficit can be a result of afterpulse / recovery time effects competing with each other, and are potentially OV & temperature dependent

*Thank
you!*

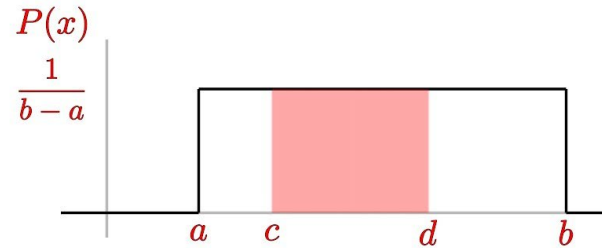
Backup Slides

- SiPM cells operate at Geiger mode



- 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

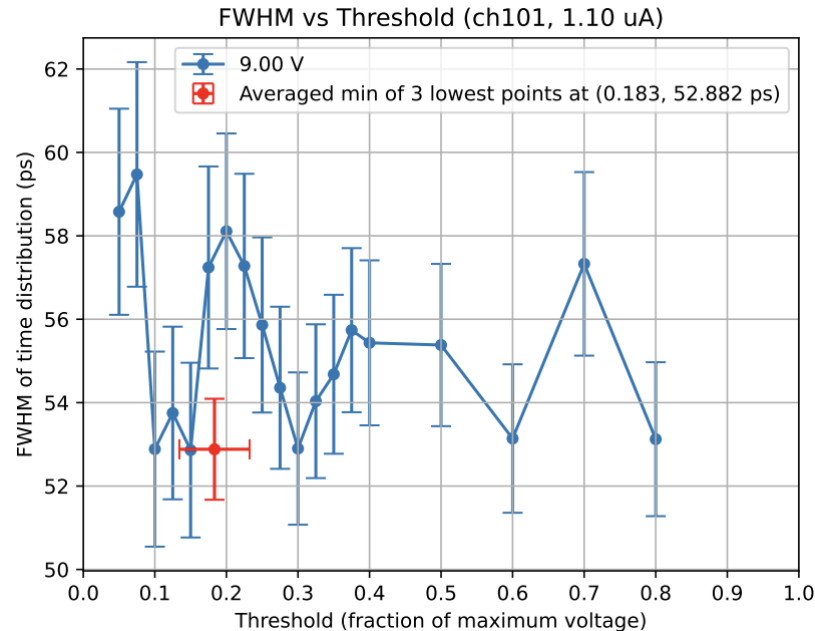


$$\text{Mean: } \mu = \frac{a+b}{2}$$

Probability

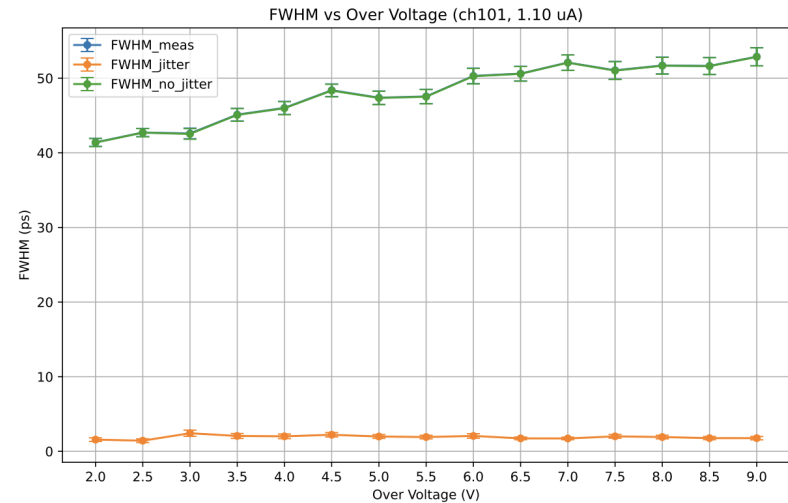
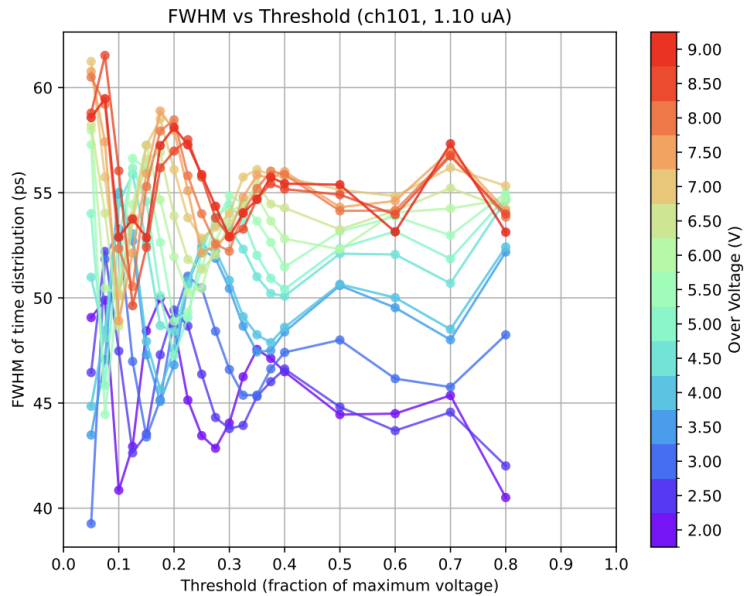
$$\text{S.D.: } \sigma = \sqrt{\frac{(b-a)^2}{12}} \quad P(c \leq X \leq d) = \frac{d-c}{b-a}$$

- Finding the average of three lowest points to be the FWHM of this OV



Analysis method

- Repeat for different OV



- FWHM of different intensities at 5 OV

