JPS CONFERENCE • September 2026

CTAO Report 263: Quantifying the Effect of Window Reflections on SiPM Optical Crosstalk in SST Cameras

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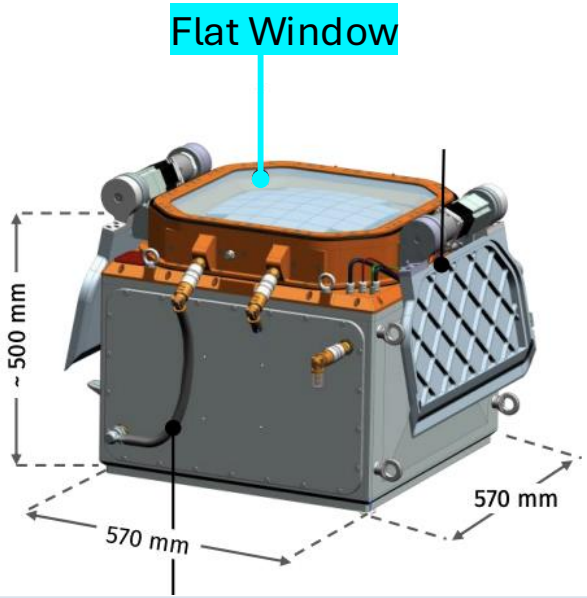
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SST camera

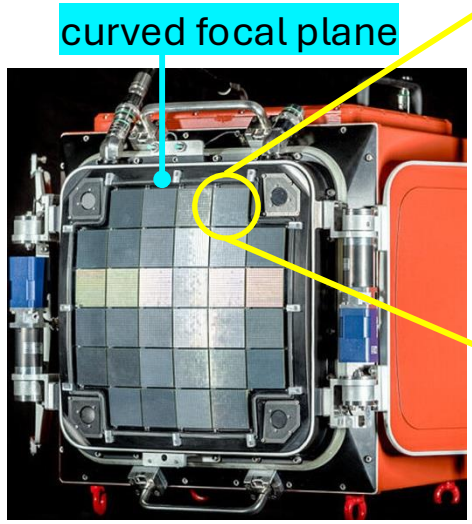
CTAO SST cameras

The **Small-Sized Telescopes (SSTs)** scientific objective is to detect very-high-energy gamma rays $\leq \sim 300\ TeV$. The SST camera uses **SiPMs** as photodetectors for short Cherenkov-light flashes. The SST focal plane is covered with a **flat protective window** to prevent it from **particulate contamination** (dust, etc.) and **temperature** and **humidity** variations. One side of it is multi-layer coated to reflected night sky background.

Annotated model of the SST camera[1]



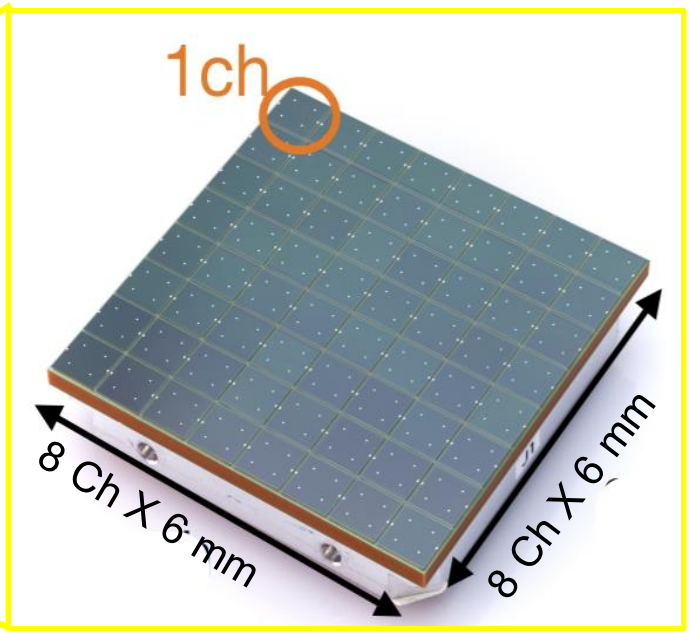
A prototype camera at MPIK



32 SiPM modules per Camera

SiPM

A **silicon photomultiplier (SiPM)** is a highly sensitive photodetector, made of an array of avalanche photodiode (APD) microcells. One detected photon can trigger an avalanche signal.

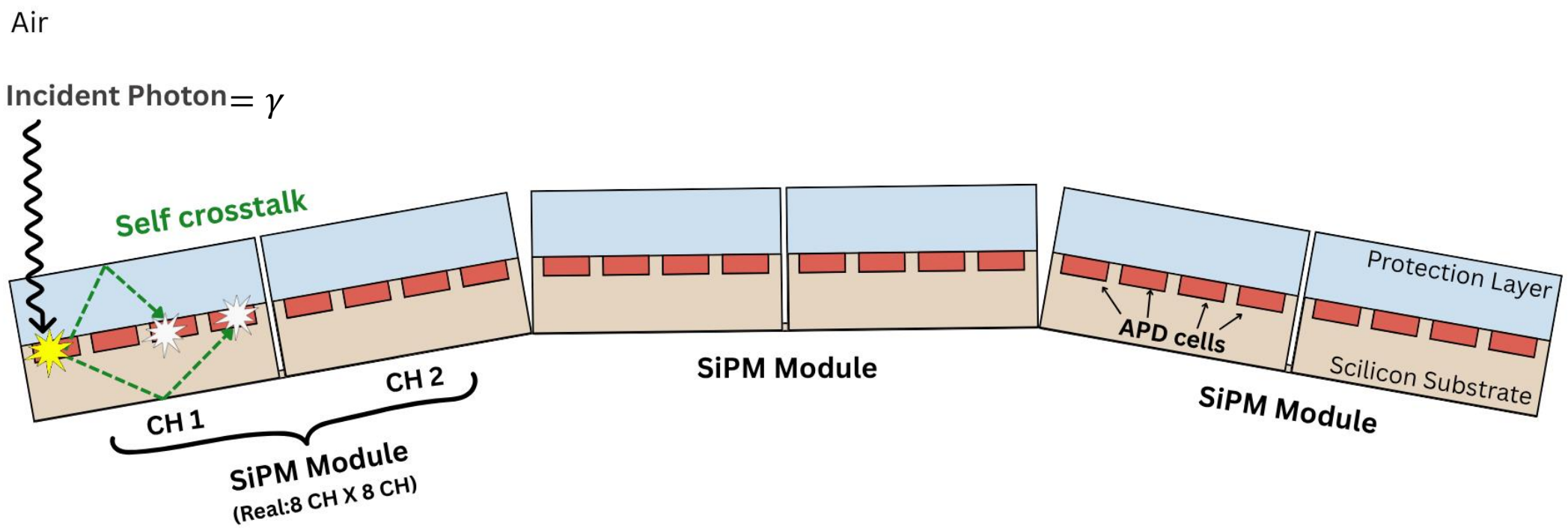


SiPM module: 8 by 8 ch array
Each Ch: ~14,400 APD cells

(1) Source: Depaoli (ICRC2023)

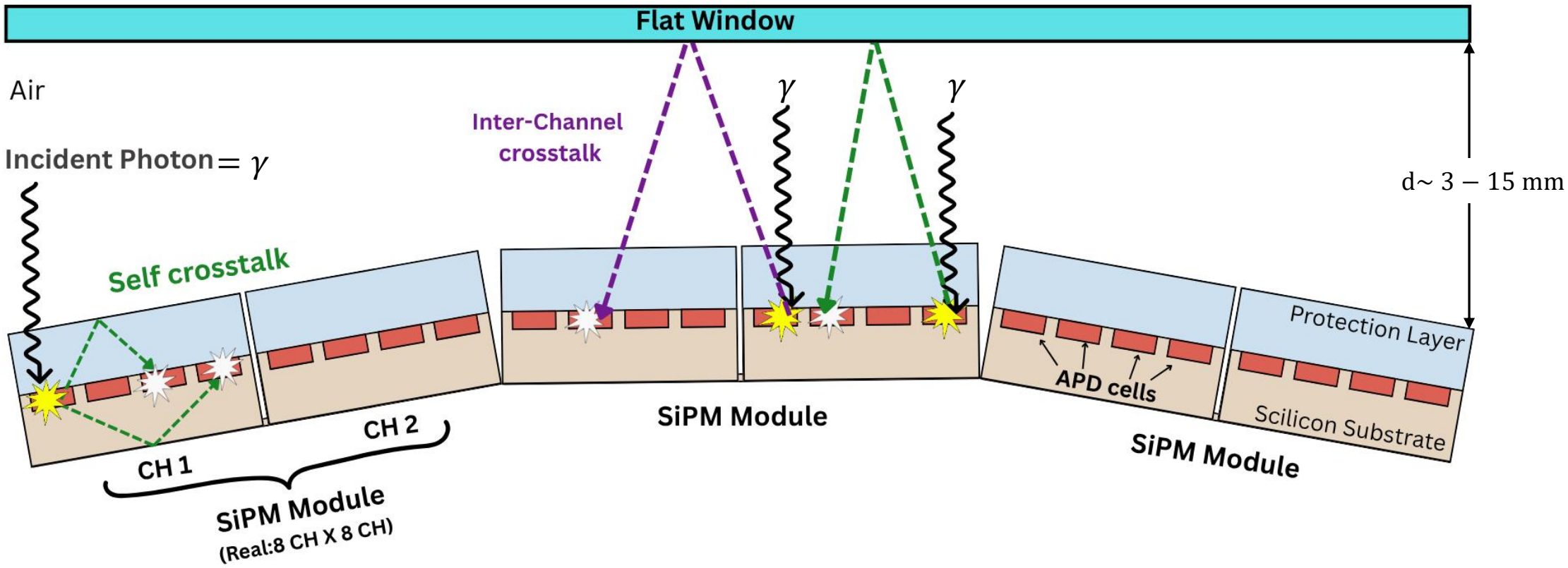
Optical Crosstalk (OCT)

Note: This is only an illustration! Not to scale!
Original SiPM module: 8 X 8 ch array (each 14,440 APD cells)



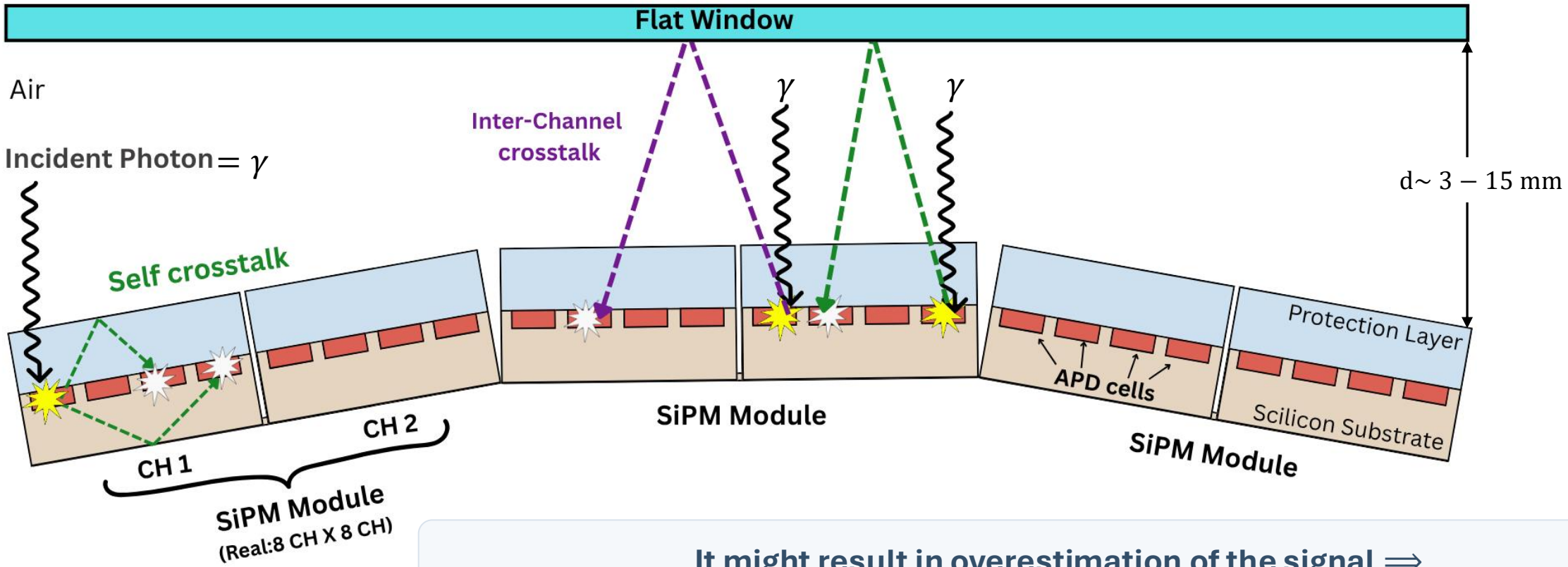
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Original SiPM module: 8 X 8 ch array (each 14,440 APD cells)

Optical Crosstalk (OCT)



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Optical Crosstalk (OCT)



It might result in overestimation of the signal ⟹

Can affect the reconstruction of gamma-ray energy. Therefore, the motivation is to characterize the window-induced OCT by evaluating the probability of self and inter OCT

The Experiment

Dark Current measurements with 3 distance configurations:

WO (Without window) – OCT baseline check

- to understand the OCT probability without a window

1 mm – Closest distance available (in our setup)

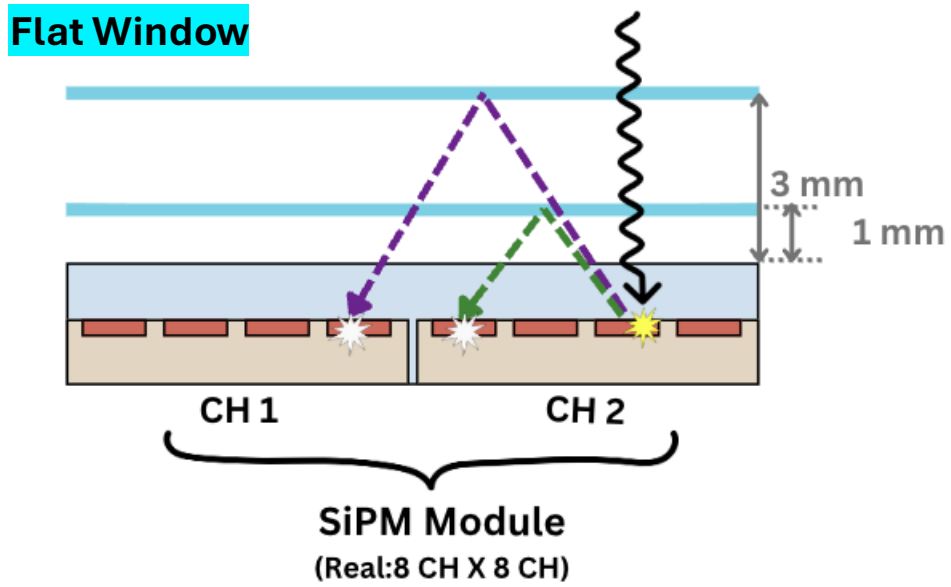
- Expect that most of the secondary reflected photons will reach the same channel (self-OCT)
- Upper limit of self-OCT fraction for a channel

3 mm – Most SST realistic configuration

- Tentative distance for first validation of the distance dependence of the P_{OCT} (and to detect inter-OCT)

Objective:

Measure the effect of the protective window on the OCT probability and its distance dependence



SST window-camera distance: $d = 3 - 15$ mm

Self P_{OCT} Estimation

$DCR \cong 4 - 5\ MHz$
(Dark Count Rate)

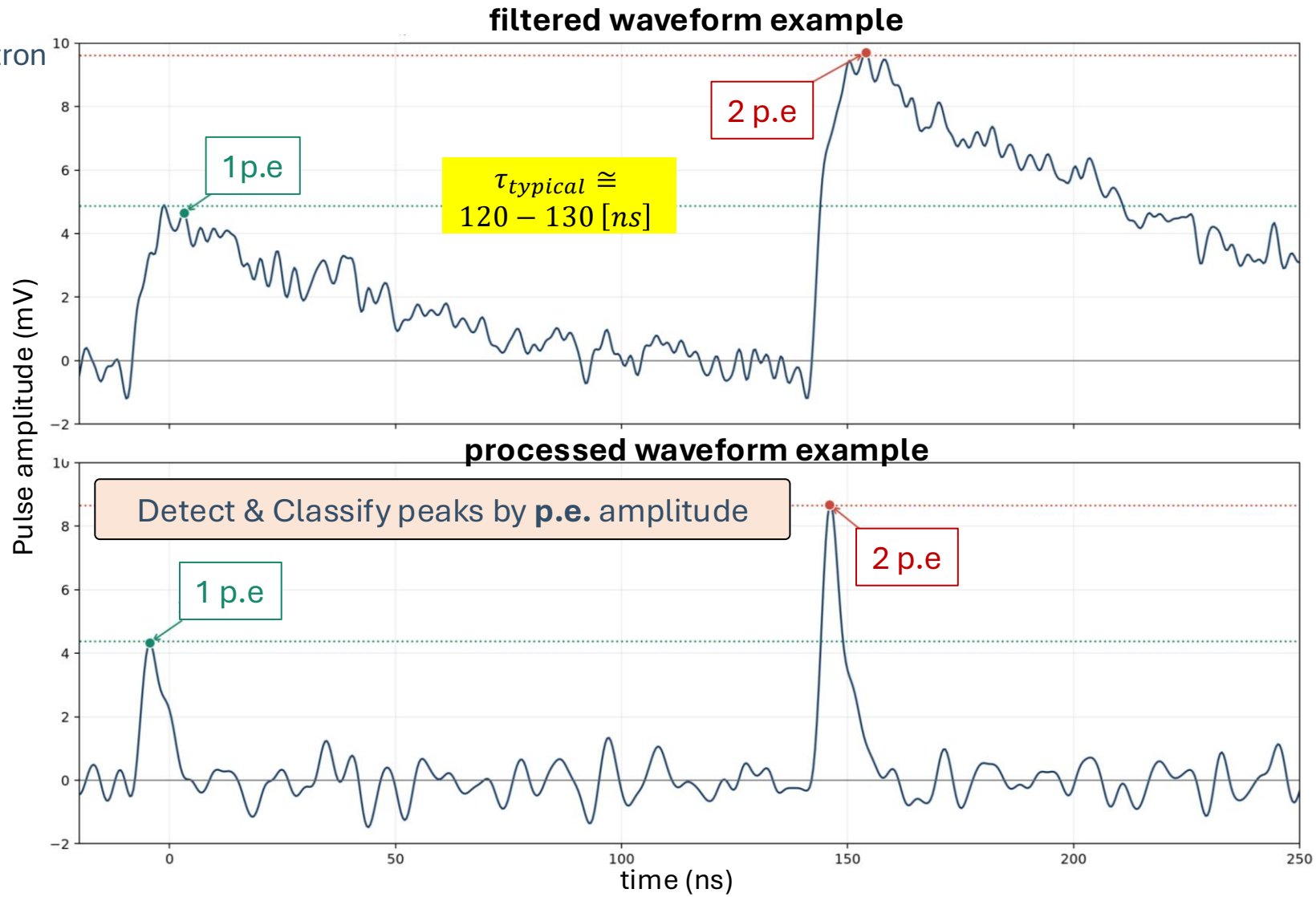
Dark pulses are normally 1 p.e. photoelectron

but can be **≥2 p.e.** due to

Optical Crosstalk (OCT)

$$P_{OCT} = \frac{OCT\ Candidate}{Total\ Pulses} = \frac{N(Amp \geq 2.p.e)}{N(Amp \geq 1.p.e)}$$

(*) Calculated according to the Gaussian fit integral



Self-crosstalk results

	Self P_{OCT} [%] per distance [mm]
WO	4.80 ± 0.10 (stat) ± 0.02 (sys) [%]
3 mm	6.10 ± 0.08 (stat) ± 0.03 (sys) [%]
1 mm	8.30 ± 0.08 (stat) ± 0.02 (sys) [%]
	Excess **~ 3.5%**

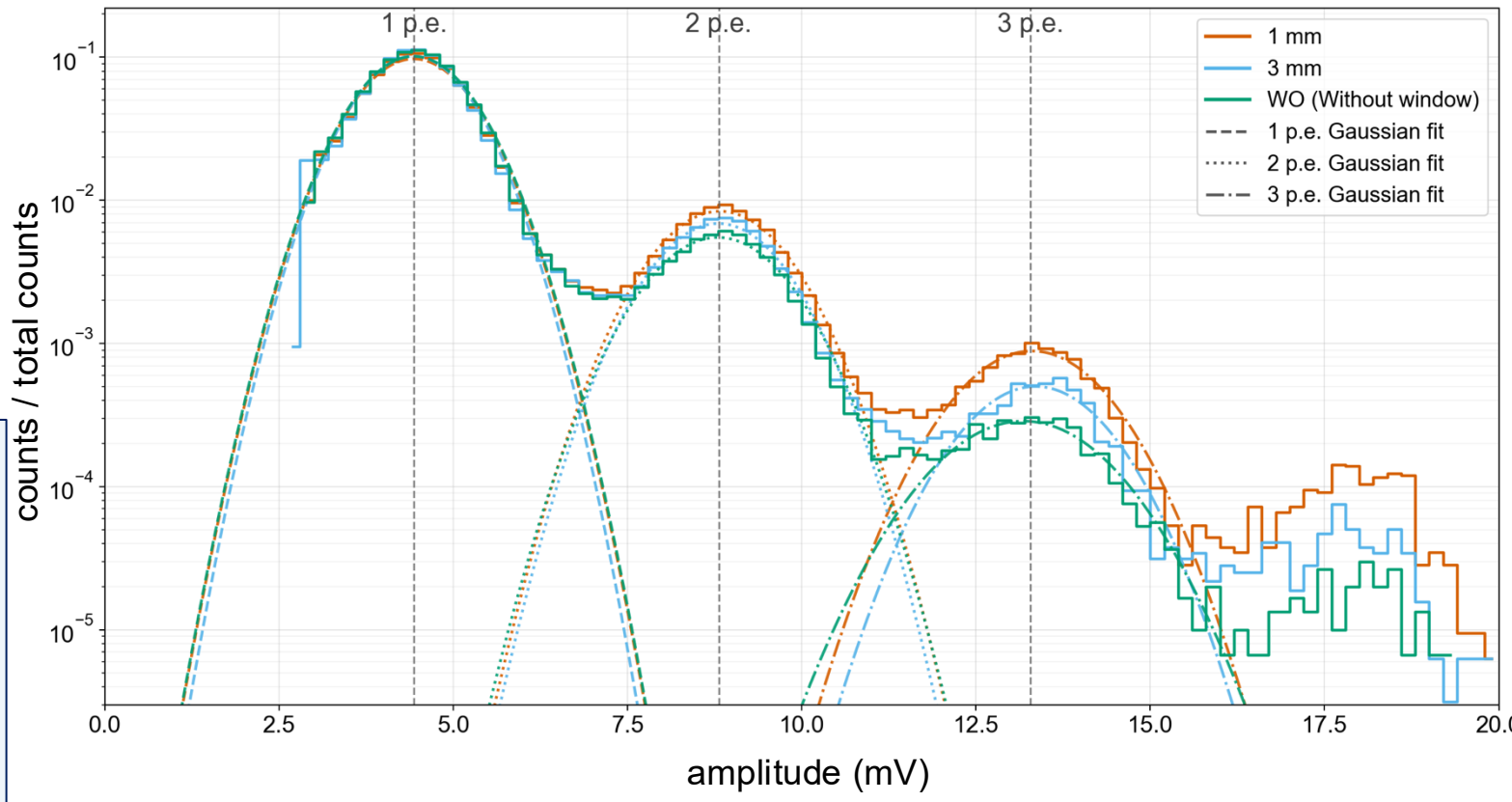
Interpretation of results

WO (baseline) –the smallest result as there is no window.

3 mm – smaller excess of **~1.3%**. Probably the photons are spreading to different channels.

1 mm – Larger OCT increase of **~3.5%**. Due to the close distance secondary photons reflect back.

p.e distribution for One Channel



P_{OCT} decreases with increasing distance

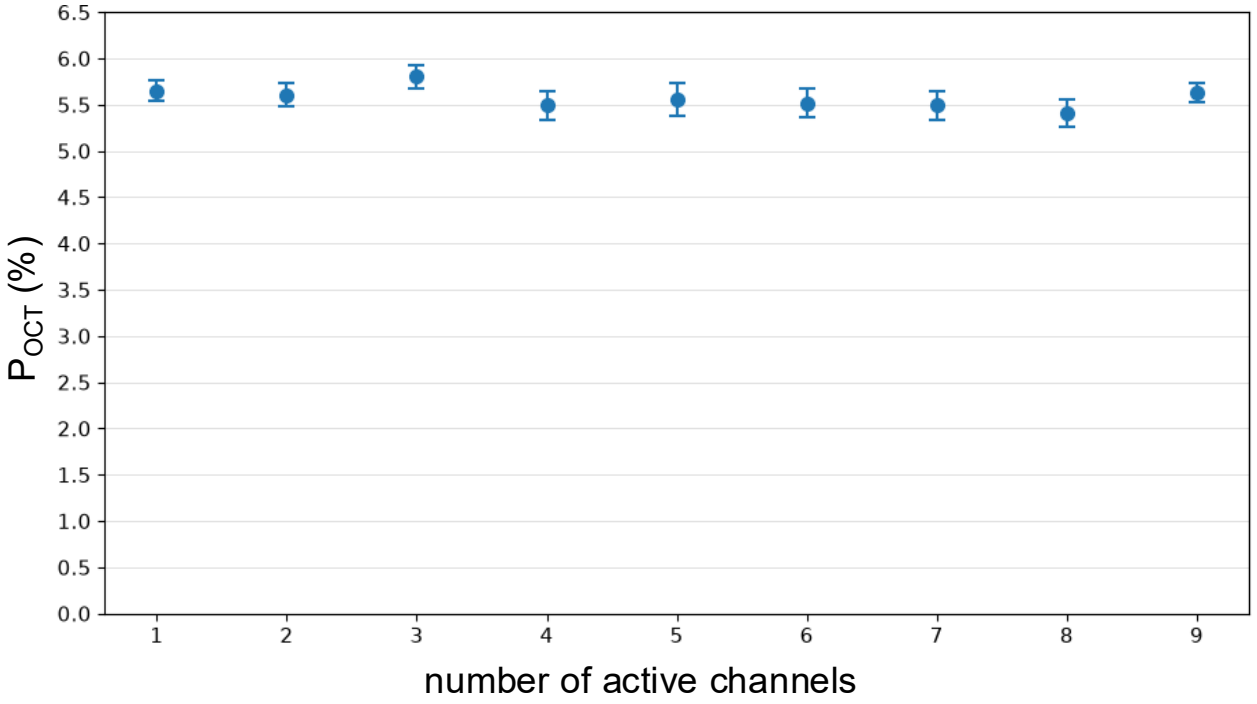
and is smallest when no window is present, as expected.

Self-crosstalk results

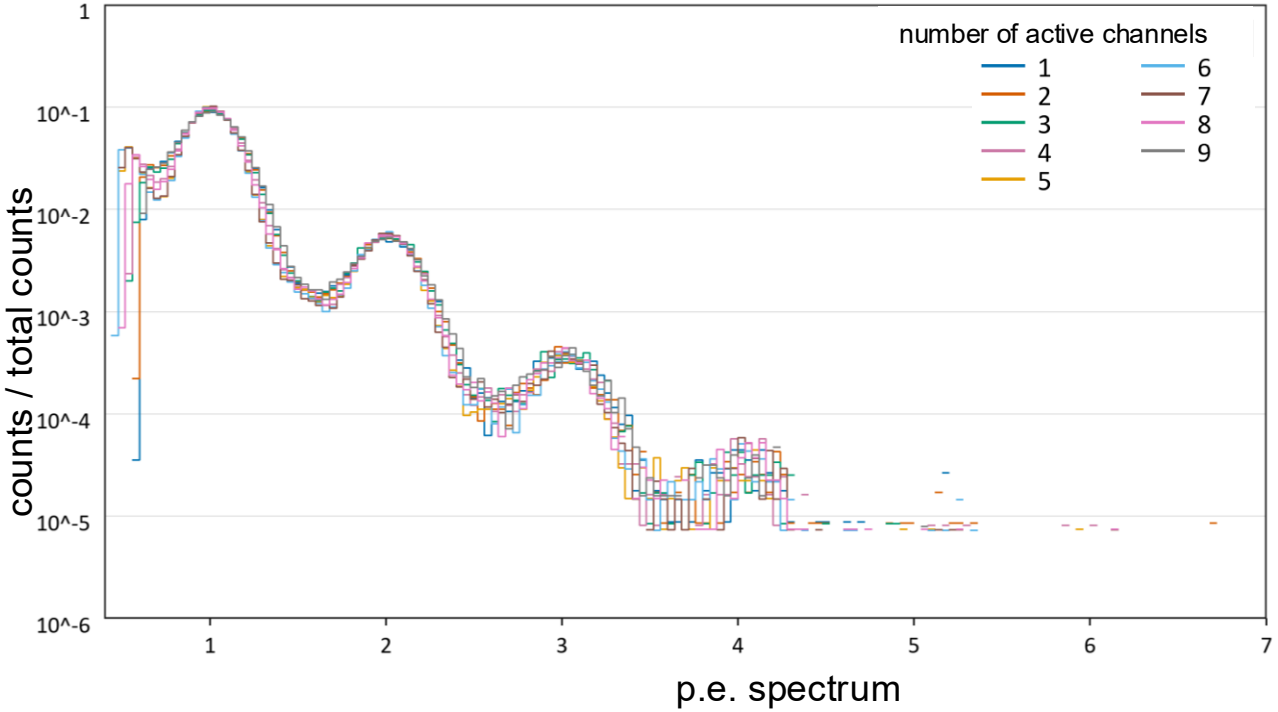
Motivation: To evaluate the inter-OCT first we need to turn-on multiple channels together
First we need to confirm that this won't change the self-P_{OCT} of the reference channel

Reference Channel results (window distance: 3 mm)

Self-OCT per number of active channels



p.e. distribution for reference channel



Self P_{OCT} is almost **flat** + normalized p.e. distribution almost **aligned** ⟹
P_{OCT} % is not affected by the number of active neighboring channels, as expected.
(These results supports the measurement system reliability/stability)

Inter-crosstalk results

What is the excess of photon counts we detected due to neighboring active channels?

Estimation for Inter-crosstalk:

- Number of pulse count is **increasing** with adding more active channels.
- The **excess counts** per measurement are:

$$N_{\text{excess}} = N_{\text{total}} - N_{baseline}$$

- Since the $\mathrm{P}_{\mathrm{OCT}_{\mathrm{self}}}$ is Constant:

$$N_{\text{excess}} = N_{\text{inter}}\left(1 + \mathrm{P}_{\mathrm{OCT}_{\mathrm{self}}}\right)$$

- From that, the **inter-channel OCT fraction** can be calculated:

$$\boxed{f_{\mathrm{OCT,inter}}[\%] = \frac{N_{\text{inter}}}{N_{\text{total}}}}$$



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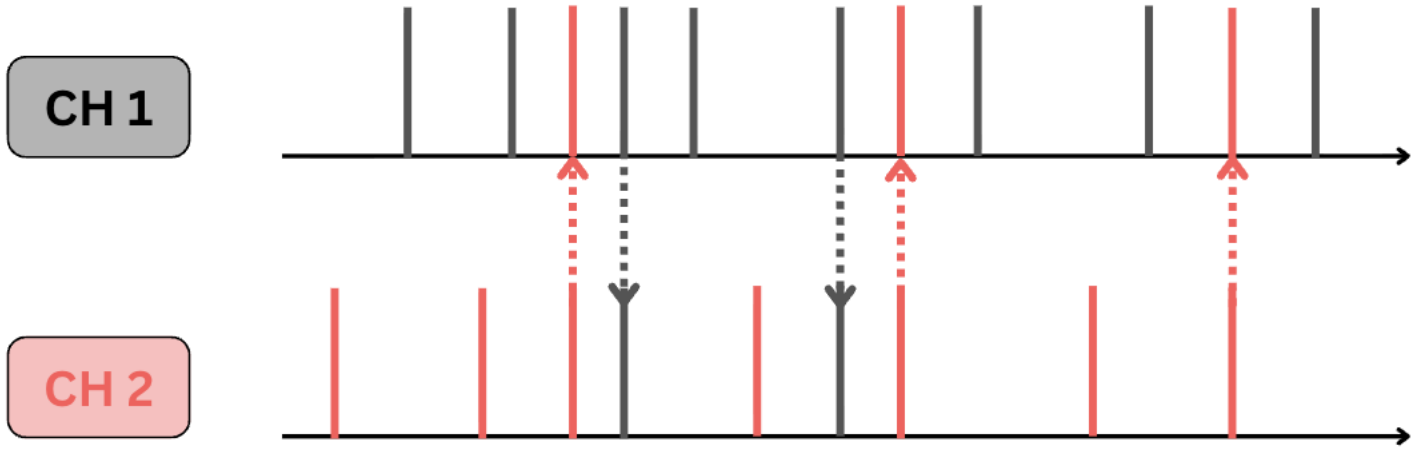
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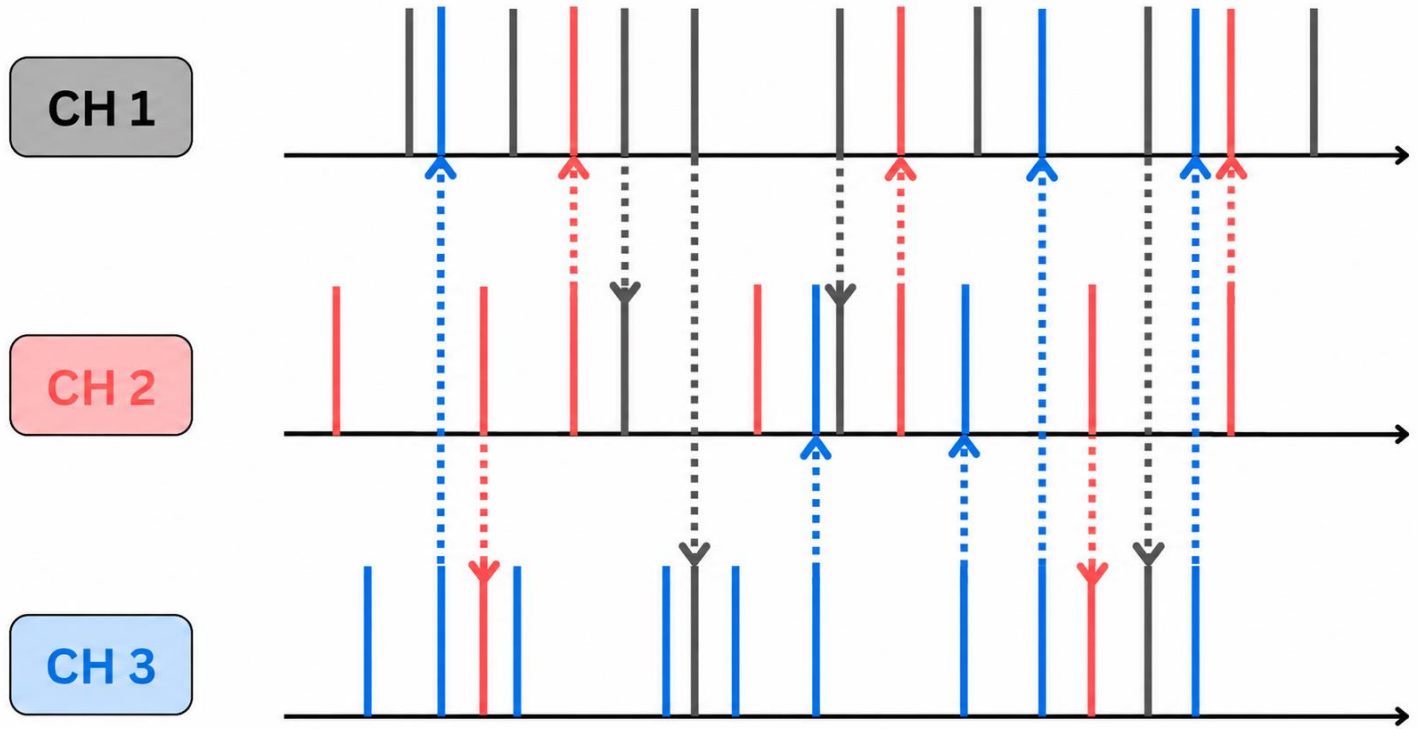
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Inter-crosstalk results

PRIMILINARY plots

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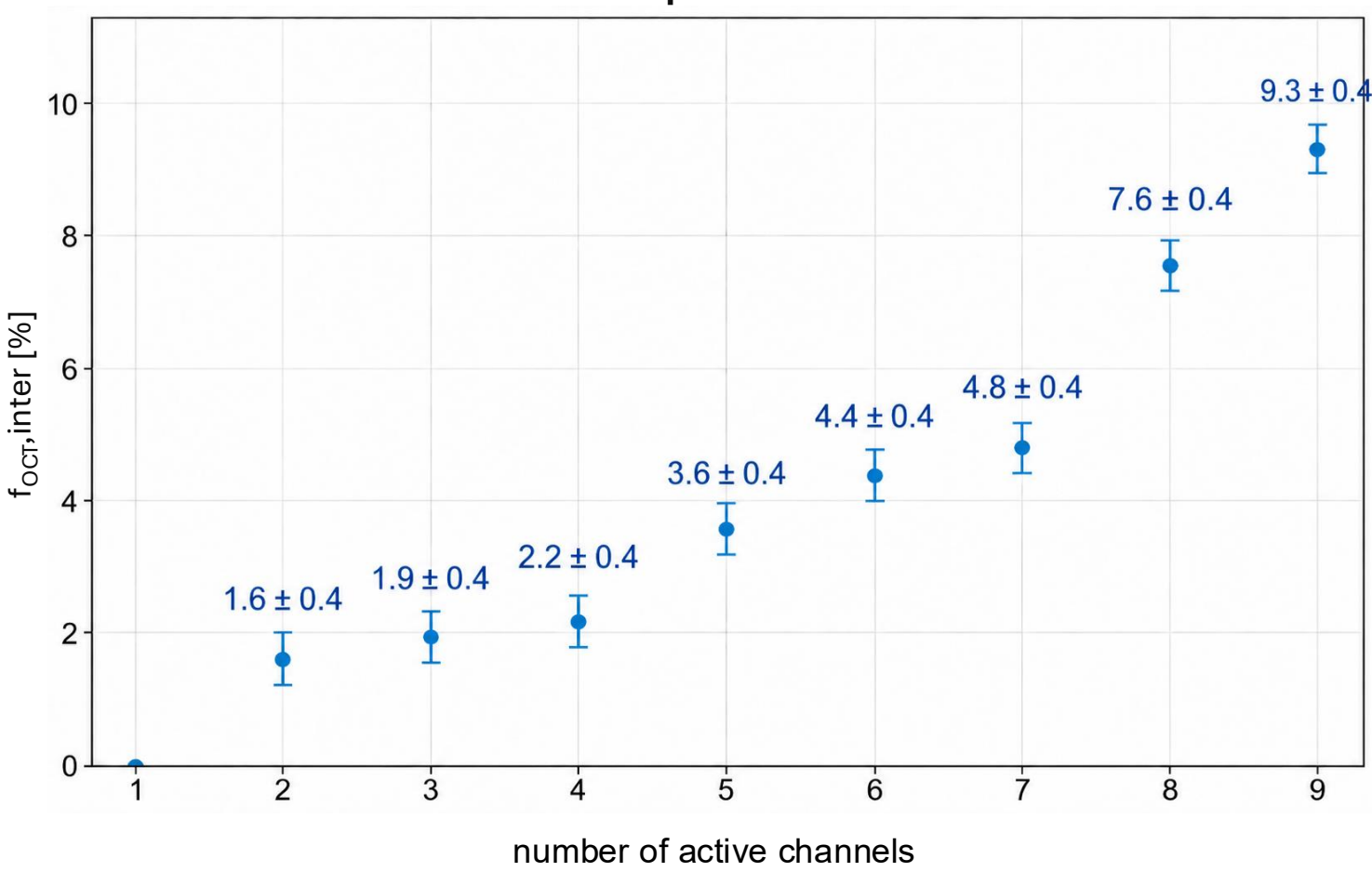
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- From that, the **inter-channel OCT fraction** can be calculated:

$$f_{\text{OCT,inter}}[\%] = \frac{N_{\text{inter}}}{N_{\text{total}}}$$



Increasing with number of active channels, as expected.
We assume that the **slope depends on the extra active channel** - on its relative DCR and position

Summary

The Question

How the protective window effect the **OCT probability** and what is its distance dependence

Assumptions

- **OCT increases with:**
  - decreasing SiPM-window distance
  - More neighboring active channels
- shortest d – the upper limit of self-OCT
- larger d – secondary photons can reflect to other channels → inter-OCT

The current results are consistent with the assumptions

Quantitative Result: ~3.5% self-OCT excess induced by the window

Next Planned Steps

- Using the neighbors' $N_{baseline}$ and to evaluate the $P_{inter\text{-}OCT}$
- Create a 2D distribution of the OCT propagation