



Reviewing the Performance of Photek's Single Photon Timing Detectors.

T. M. Conneely¹, A. Markfort¹, A. Davidson², A. Duran¹, J. Milnes¹

1. Photek Ltd, 26 Castleham Rd, TN38 9NS, UK

2. University of Warwick, Warwick,

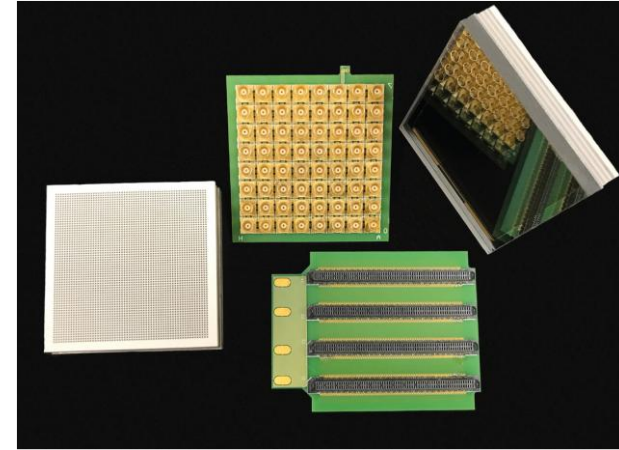
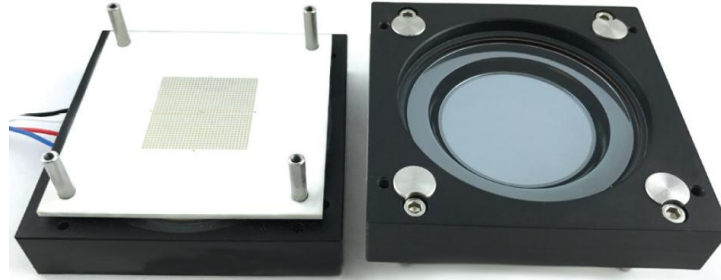
19/05/2024

FAST 2025, Elba, Italy

- Photek Photomultiplier Tubes
- Transit Time Spread Measurements of PMT products
- Multi-anode detectors - TORCH MAPMT and AuraTek Photon Timing System
- Summary

Photek PMTs - History

Microchannel Plate Photomultiplier Tubes



- Photek have manufactured single channel MCP-PMTs since it began in 1991
- 10 mm to 40 mm diameter working areas
- Used in both analogue and counting modes

- Around 2010 developed first AuraTek multichannel PMT using multi-layer anode with pads to achieve high channel density
- Standard unit MAPMT228 has 26.5 × 26.5 mm working area and an anode array of 32 × 32
- Targeted for counting mode

- 2012 to 2017 saw the square PMT development for the TORCH project
- Standard unit MAPMT253 has 53 × 53 mm working area and an anode array of 64 × 64
- Targeted for counting mode

- Photek Photomultiplier Tubes
- Transit Time Spread Measurements of PMT products
- Multi-anode detectors - TORCH MAPMT and AuraTek Photon Timing System
- Summary

> Transit Time Spread (TTS) Measurement

The following data demonstrates the TTS for the following Photek products:

- **PMT210** – 2 MCP's, active area diameter = 10 mm, single channel anode.
- **PMT225** – 2 MCP's, active area diameter = 25 mm, single channel anode.
- **PMT310** – 3 MCP's, active area diameter = 10 mm, single channel anode.
- **TORCH MAPMT253** – 2 MCP's, active area length = 53 mm, 96 x 16 multi-pixel readout anode

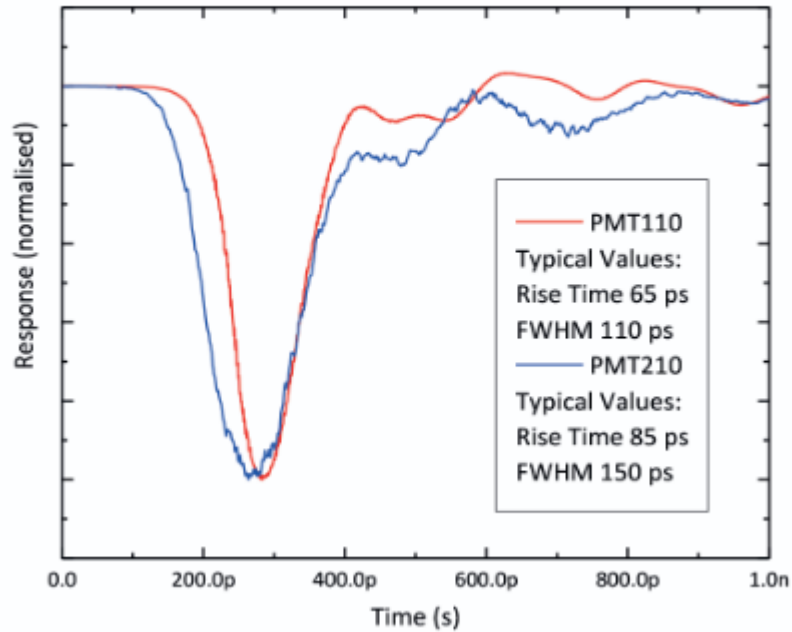
Experimental questions:

1. Does the number of MCP's affect the transit time spread?
2. Does the MCP pore size affect the transit time spread?

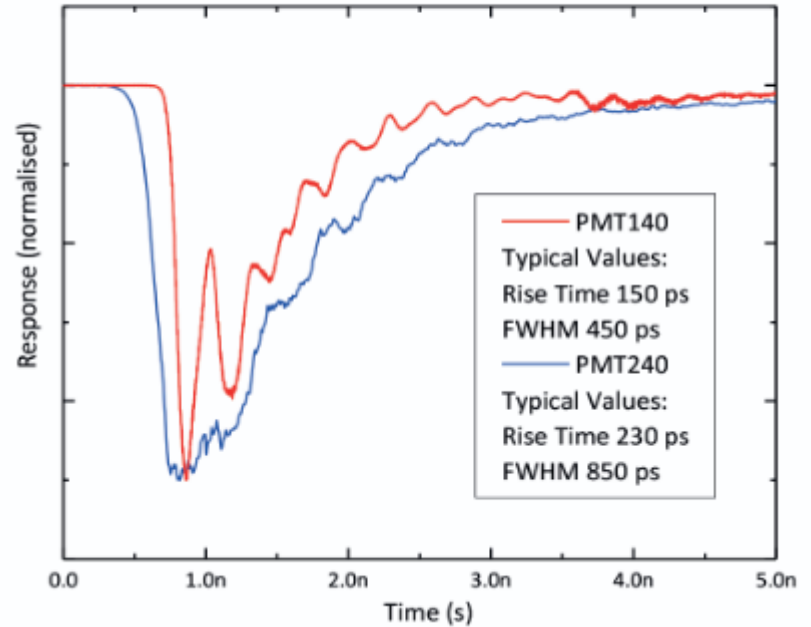


➤ PMT Signal Shape

Results for a 10 mm



Results for a 40 mm



Time Response - Pulse Rise Time (ps)

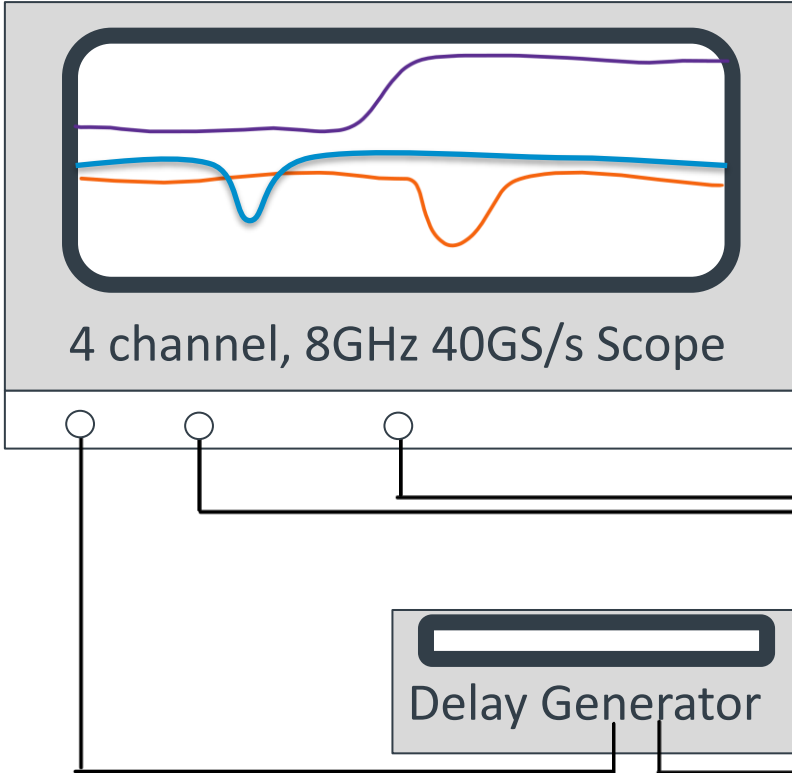
MCPs	Detector Diameter								
	10 mm			25 mm			40 mm		
	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max
1	60	65	70		115		100	150	200
2	75	85	95		190		180	230	280
3		105		300	400	500		320	

Pulse FWHMs (ps)

MCPs	Detector Diameter								
	10 mm			25 mm			40 mm		
	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max
1	100	110	120		700		300	450	600
2	130	150	170		840		600	850	1100
3		170		800	1000	1200		920	

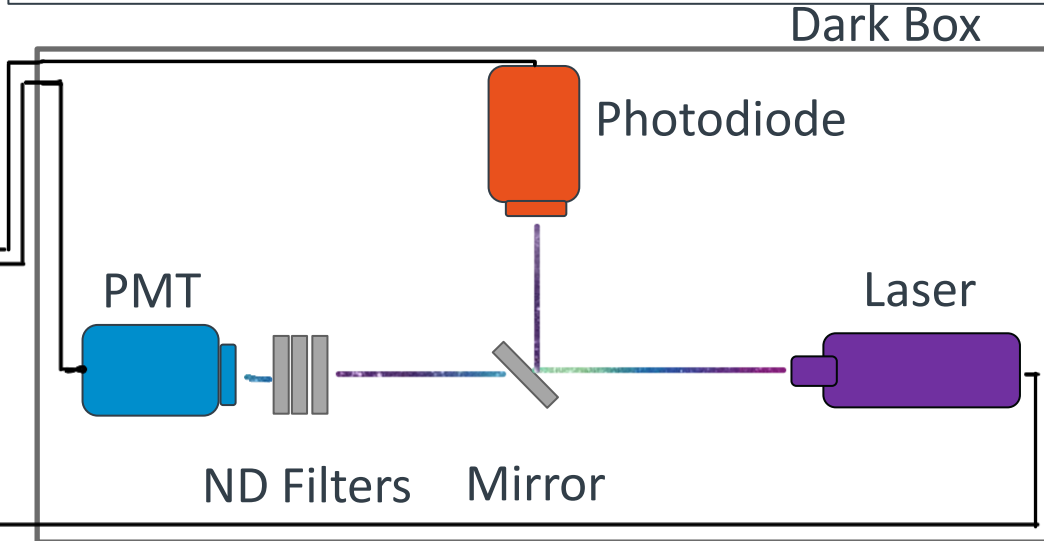
Transit Time Spread (TTS) Measurement

Setup:



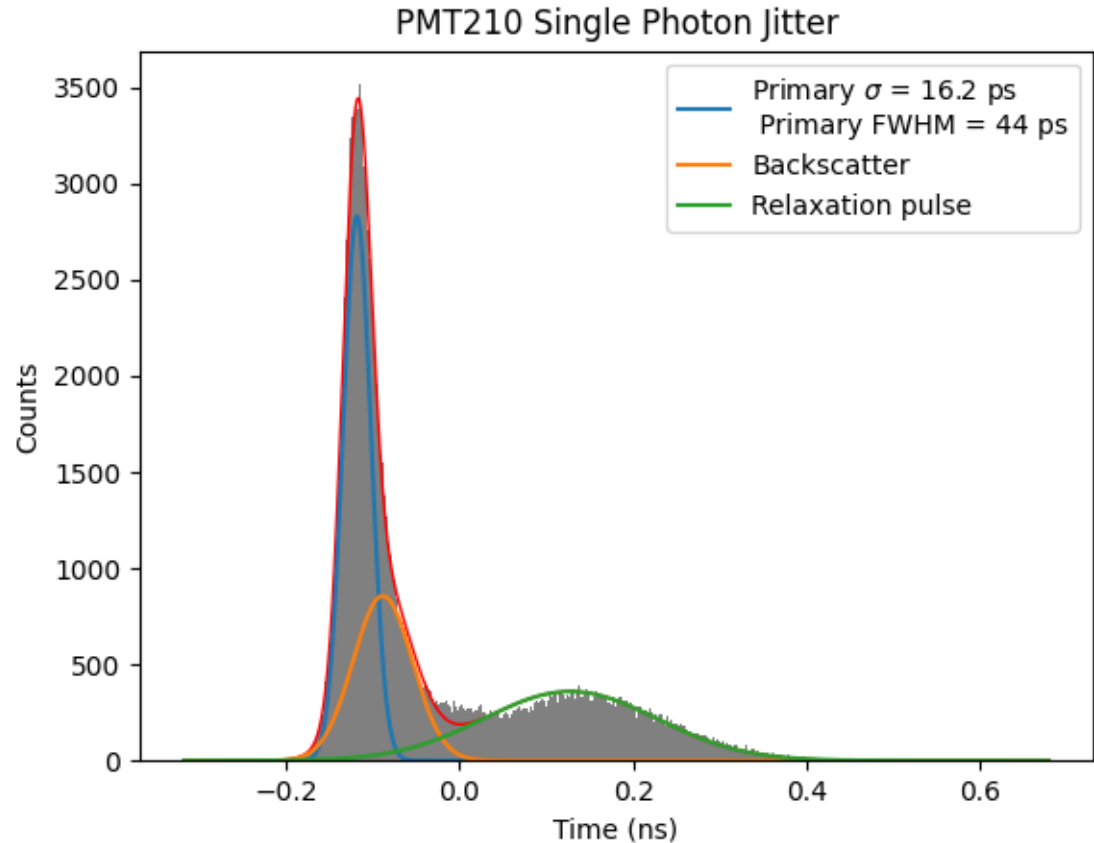
Ensure experimentally you are at single photon rate!

Using Poisson's statistics if the $P(\gamma) = 5\%$, $P(2\gamma) \sim 0.1\%$.
Using count rate electronics, if the laser trigger rate = 100kHz, the signal count rate of the PMT should be dark count rate + 5k counts.

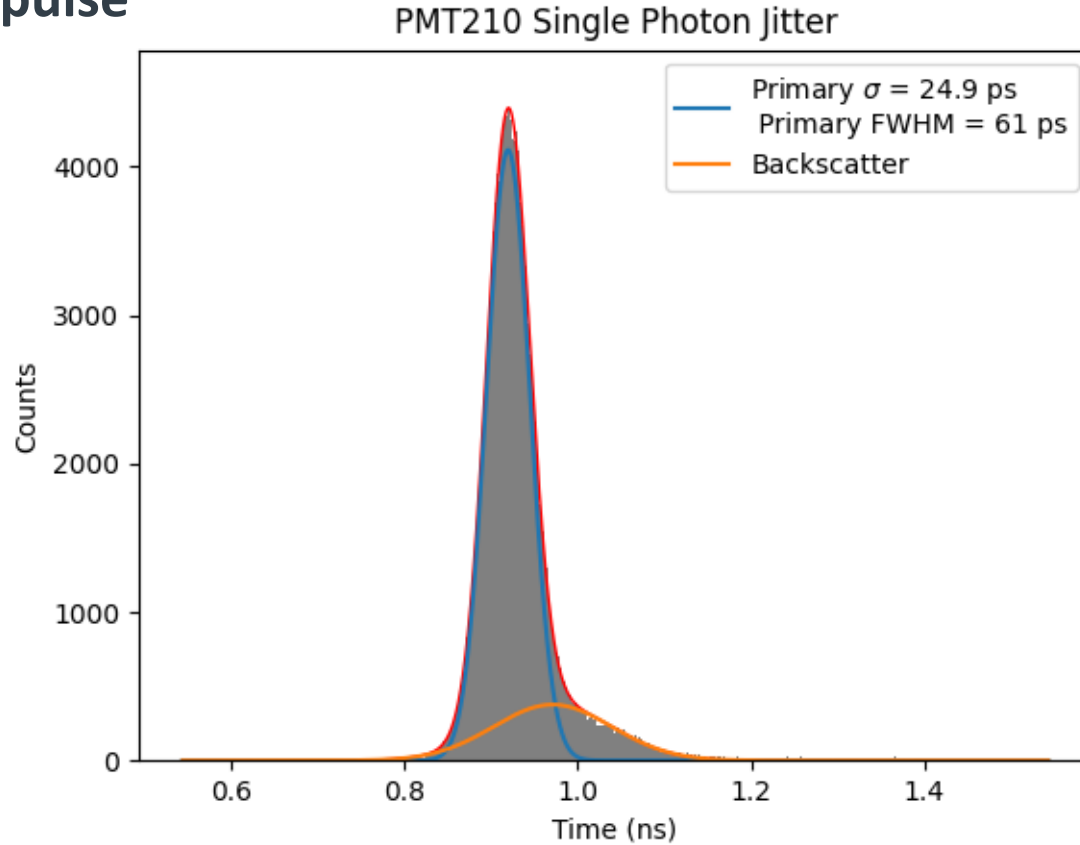


➤ PMT210 TTS with Photek's LPG650 laser

- 200 V from photocathode to MCP input
- Gain $\sim 1.6 \times 10^6$
- 1 photon per ~ 20 laser pulses
- LeCroy Wavemaster 808Zi-A (8 GHz, 40 GS/s)
- Photek's LPG-650 laser source ~ 40 ps FWHM
- Time stamped at 50% of peak amplitude to correct for amplitude variation
- $3\mu\text{m}$ MCP pore size



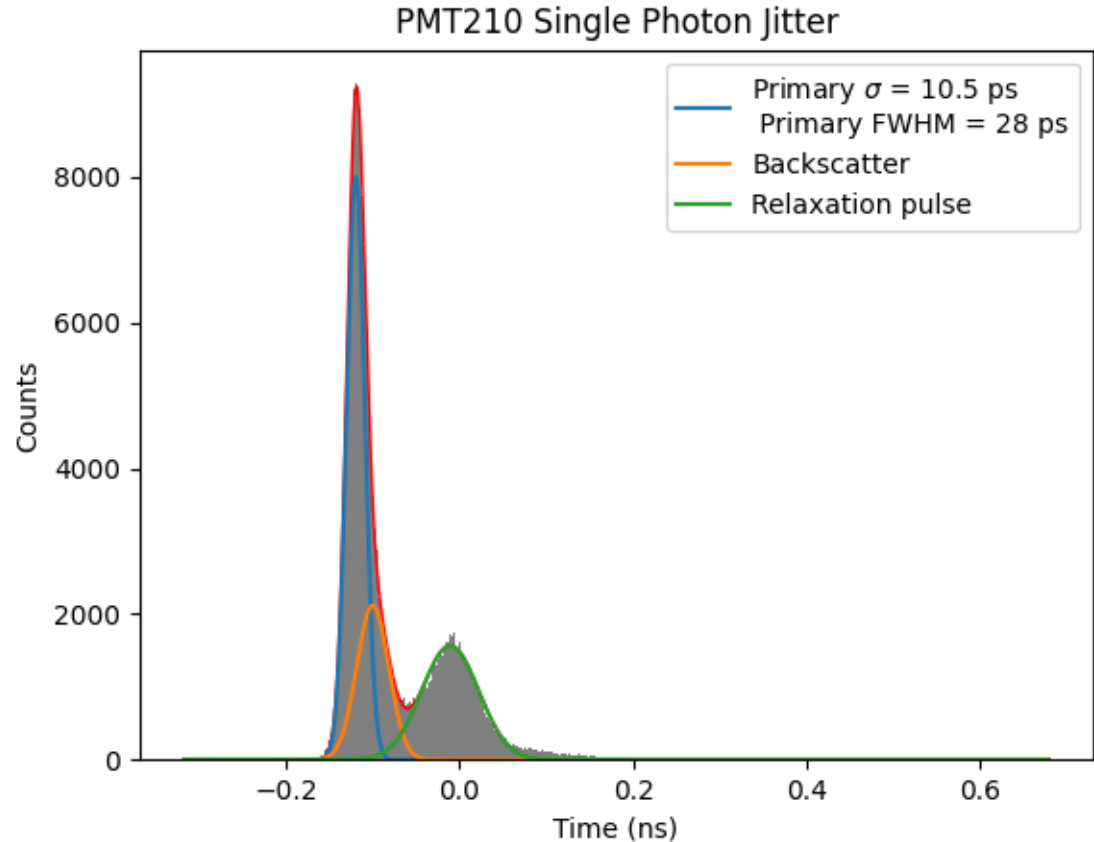
➤ PMT210 TTS with PiLAS laser PiL063X – tune 50% → removes relaxation pulse



➤ PMT210 TTS with Photek's LPG405 laser

Improved Laser Results – improved tuning of LPG405

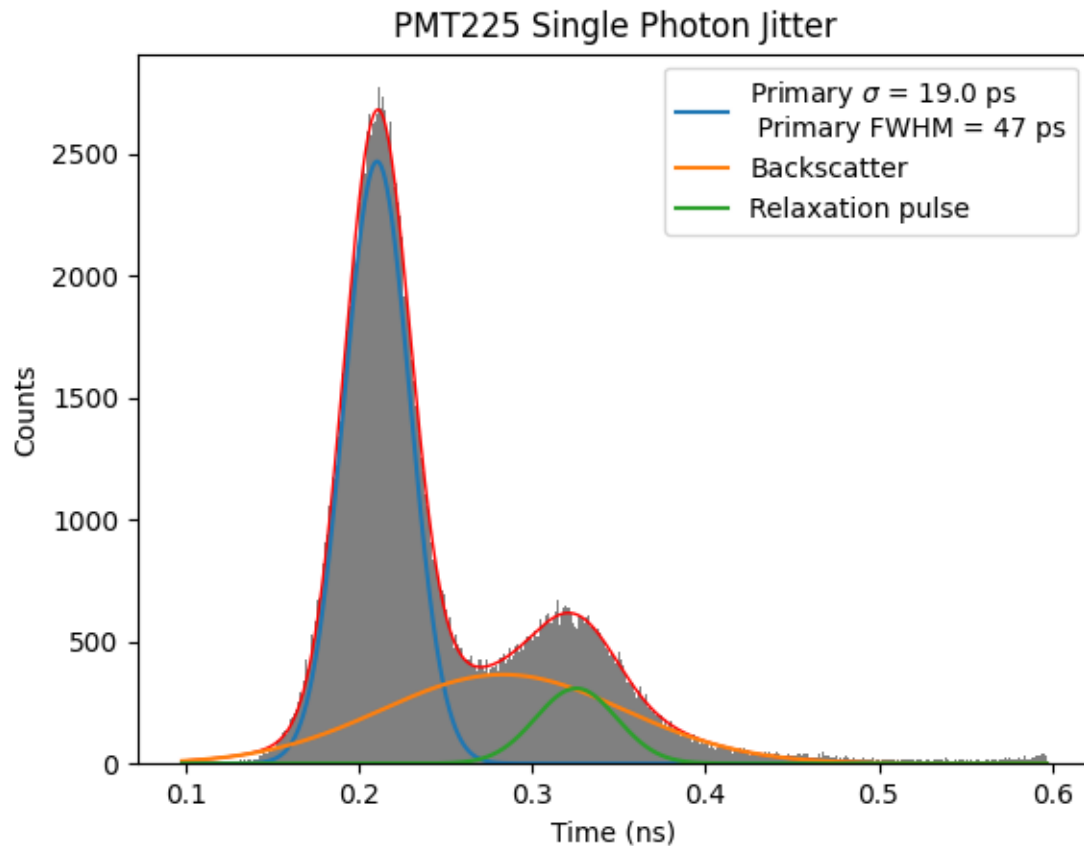
- 200 V from photocathode to MCP input
- Gain $\sim 1.6 \times 10^6$
- 1 photon per ~ 20 laser pulses
- LeCroy Wavemaster 808Zi-A (8 GHz, 40 GS/s)
- Photek's LPG-405 laser source \sim tuned for performance FWHM unknown
- Time stamped at 50% of peak amplitude to correct for amplitude variation
- $3\mu\text{m}$ MCP pore size



➤ PMT225 TTS with Photek's LPG405 laser

Does the MCP pore size affect the transit time spread?

- 200 V from photocathode to MCP input
- Gain $\sim 1.6 \times 10^6$
- 1 photon per ~ 20 laser pulses
- Photek's LPG-405
- LeCroy Wavemaster 808Zi-A (8 GHz, 40 GS/s)
- Time stamped at 50% of peak amplitude to correct for amplitude variation
- $10\mu\text{m}$ MCP pore size

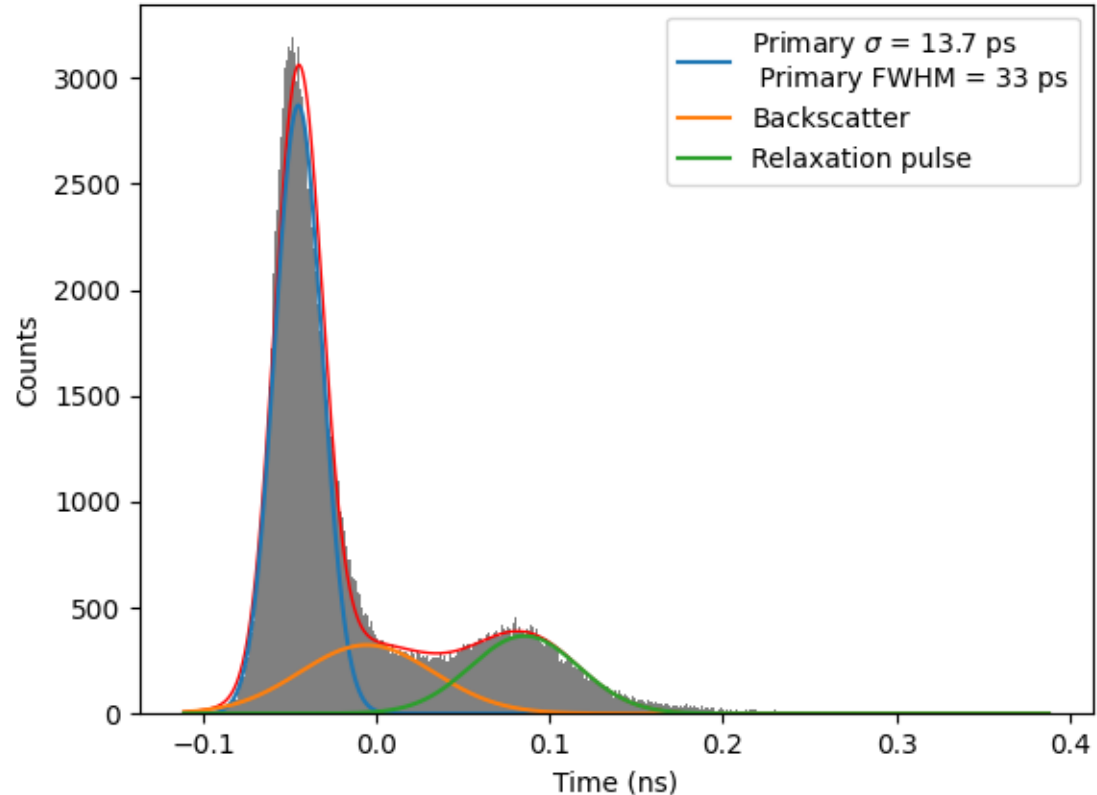


➤ PMT310 TTS with Photek's LPG405 laser

Does the number of MCP's affect the transit time spread?

- 200 V from photocathode to MCP input
- Gain $\sim 1.6 \times 10^6$
- 1 photon per ~ 20 laser pulses
- Photek's LPG-405 laser source
- LeCroy Wavemaster 808Zi-A (8 GHz, 40 GS/s)
- Time stamped at 50% of peak amplitude to correct for amplitude variation
- $3\mu\text{m}$ MCP pore size

PMT310 Single Photon Jitter

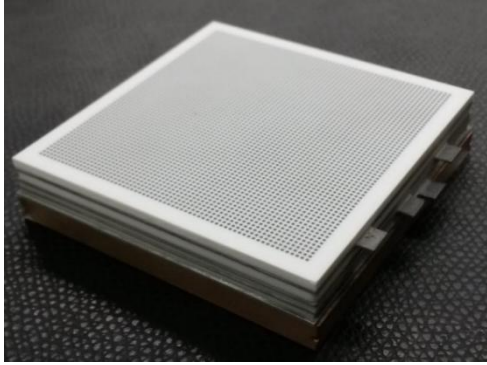


Summary of MCP PMT Timing Performance

Detector	Laser	TTS σ (ps)	TTS FWHM (ps)
PMT210	Pilas 30% Tune	24.3	59
PMT210	LPG650	16.2	44
PMT210	Pilas 50% Tune	24.9	61
PMT210	LPG405	10.5	28
PMT225	LPG405	19	47
PMT310	LPG405	13.7	33
TORCH PID 96 x 16	Pilas 50%	40	

- Photek Photomultiplier Tubes
- Transit Time Spread Measurements of PMT products
- Multi-anode detectors - TORCH MAPMT and AuraTek Photon Timing System
- Summary

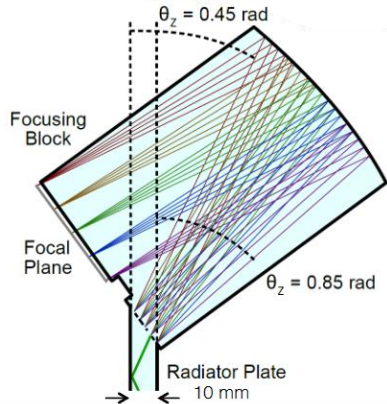
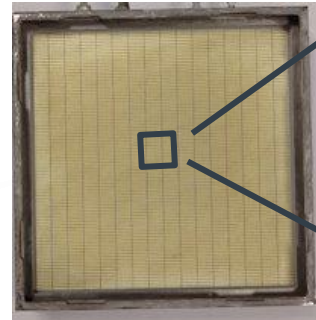
TORCH (Time Of internally Reflected CHerenkov) Detector



A 64x64 anode square MCP-PMT

Features:

- Unique build provides tight Cathode – MCP in gap (1.5 – 2 mm) and MCP out – anode (3 mm) gap
- 16x96 Anode layout, 53x53 mm² active area
- **Fine pitch required in one direction**
 - **0.552 mm pitch**
 - Used to **measure angle** – enables **Cerenkov/chromatic aberration correction**
 - Also helps to **reduce occupancy** under high-rate conditions
- **Coarse direction: 3.312 mm pitch**




> Detailed Characterisation – Talk this afternoon

Characterisation of a 16-by-96 multi-anode MCP-PMT

 May 19, 2025, 3:00 PM

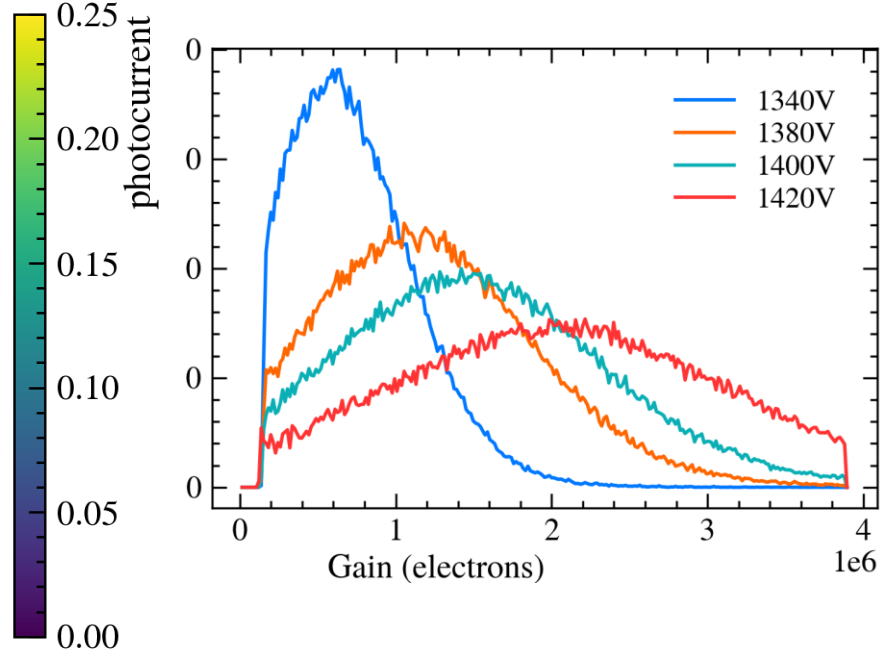
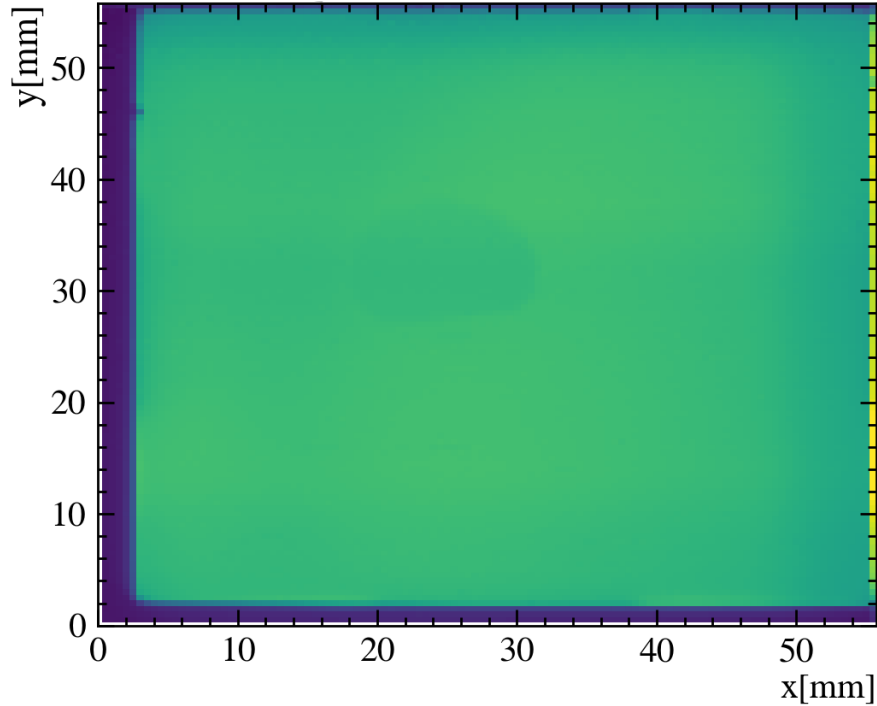
 30m

Speaker

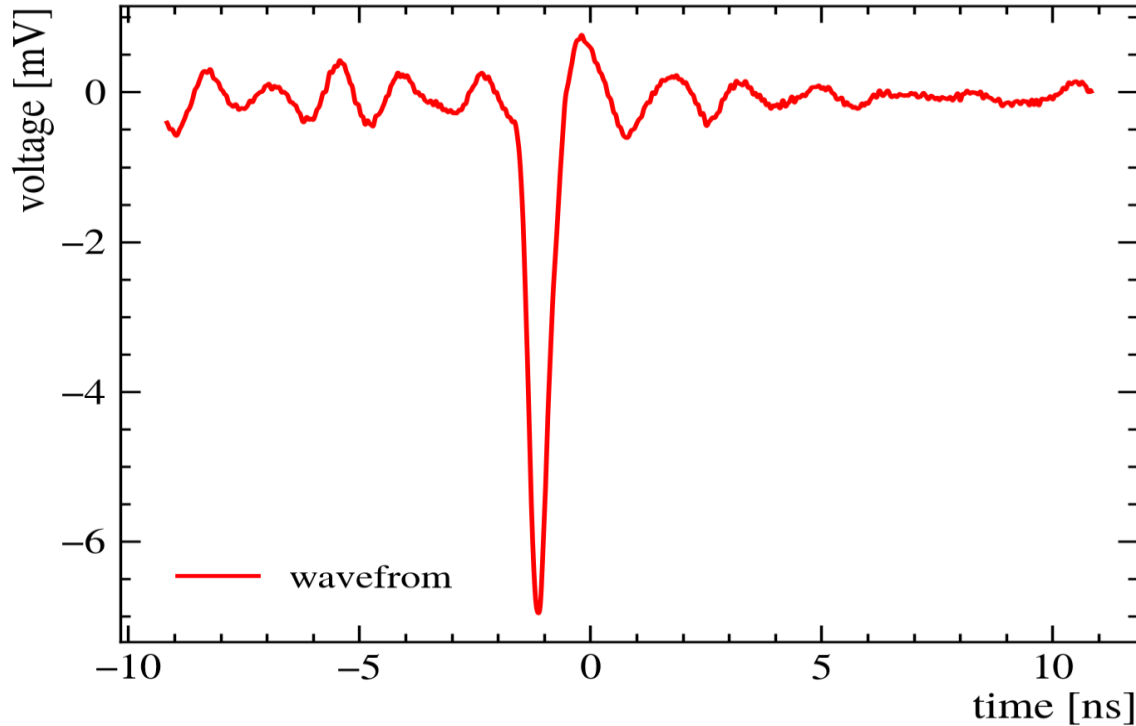
 Alexander Davidson (University of Warwick (GB))

Quantum Efficiency Uniformity and Gain

Photocathode Quantum Efficiency



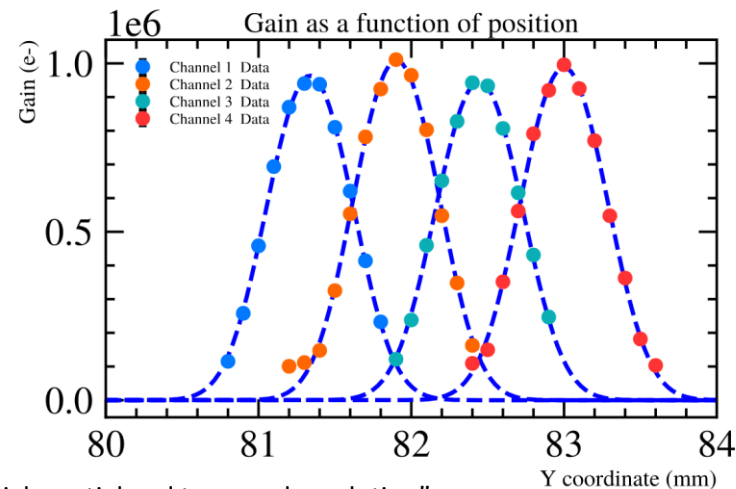
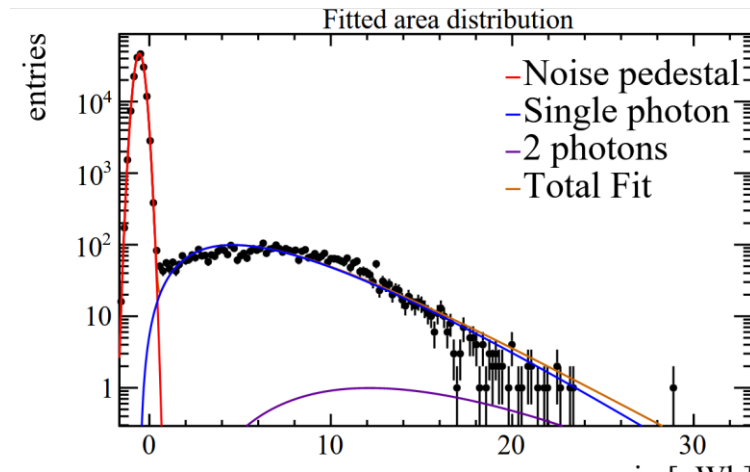
Single Pixel – Average Single Photon Pulse Shape



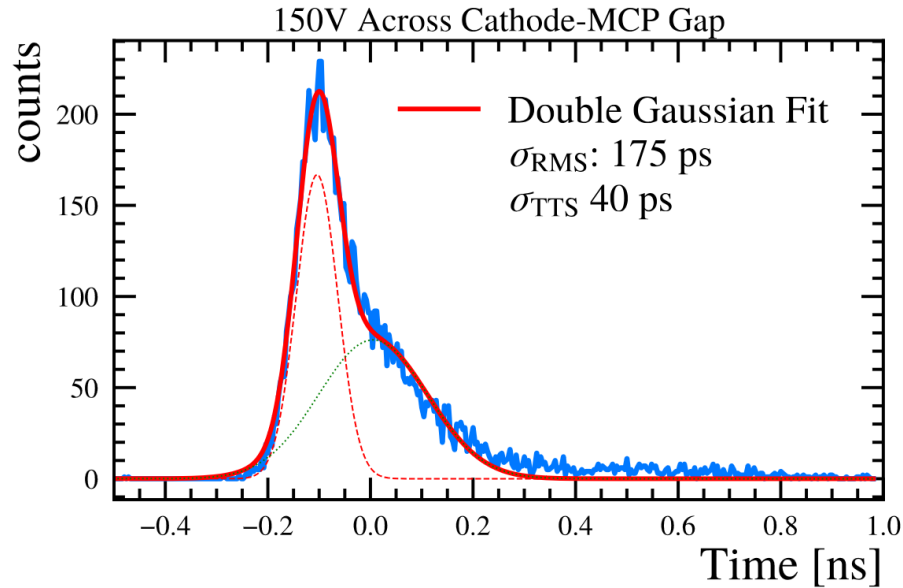
TORCH Detector

Crosstalk Measurements :

- Focussed PiLAS laser to point ($<15\ \mu\text{m}$)
 - Attenuated to single photon level
 - Scanned across instrumented area in 0.2mm steps
- Instrumented 4 channels with 8GHz 40GS/s oscilloscope
 - Single photon pulse area on each channel used to measure charge collected on each channel
 - Histogram charge area for PHD
 - Use peak of Polya fit to determine mean gain



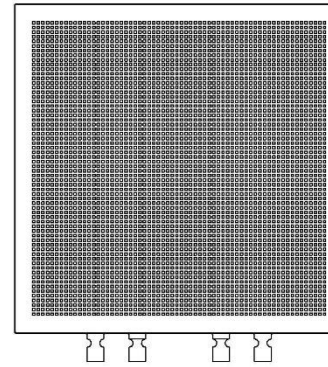
TORCH TTS Measurement with PiLAS laser PiL063X – tune 50%



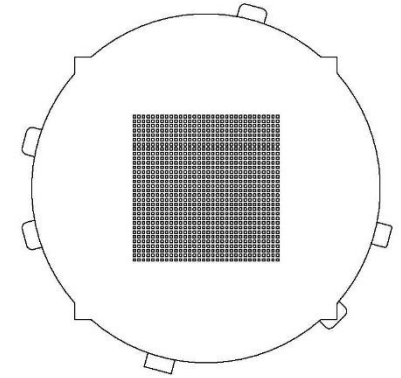
AuraTek PCS

TOFPET2 Integration with multi-anode MCP-PMT

- TOFPET2d is an ASIC with 64 channels of integrated pre-amplifier, discriminator and time to digital convertor from PETsys Electronics
 - Each channel can timestamp signals with a 30 ps TDC bin
 - Maximum rate of 480 kHz per channel
- We have developed the AuraTek PCS; a 256 channel photon counting system incorporating an MAPMT228 and 4x TOFPET2d ASICs
- The MAPMT228 is a sibling device to the MAPMT253; round format, 32x32 anode pattern, tighter photocathode to MCP gap ~ 0.2 mm
- For this device we gang anodes to reduce the 32x32 pattern to 16x16
- AuraTek PCS now commercially available



MAPMT253

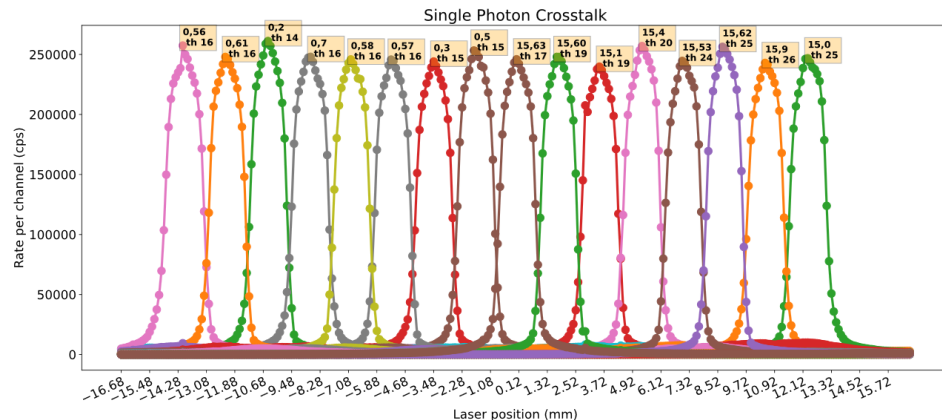
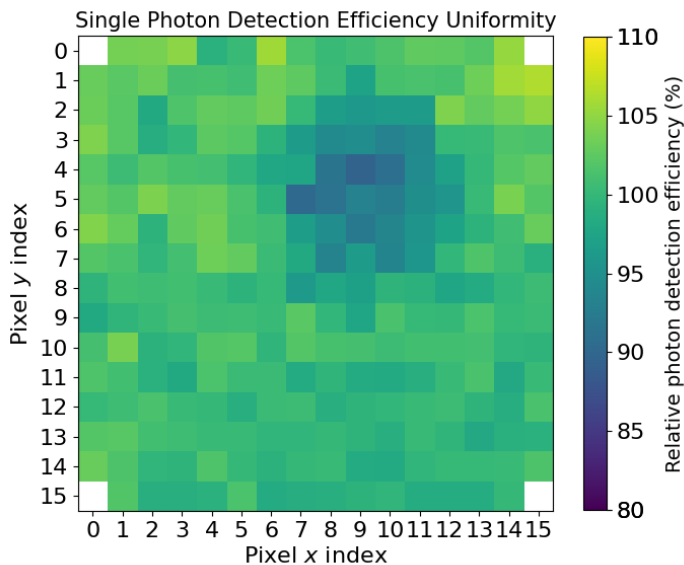


MAPMT228



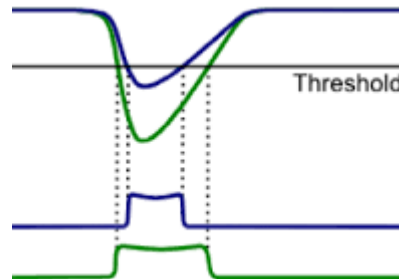
Response Uniformity and Crosstalk

- Each channel has an independent threshold and zero level which is adjusted to normalise the response
- A linear scan of a 0.2 mm laser spot attenuated to single photon level shows the inter-channel crosstalk

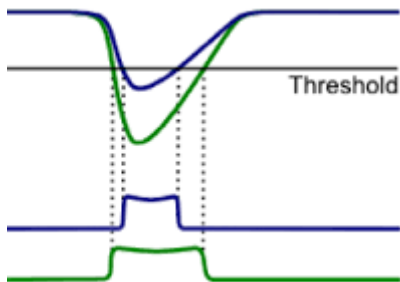


Timing Calibration

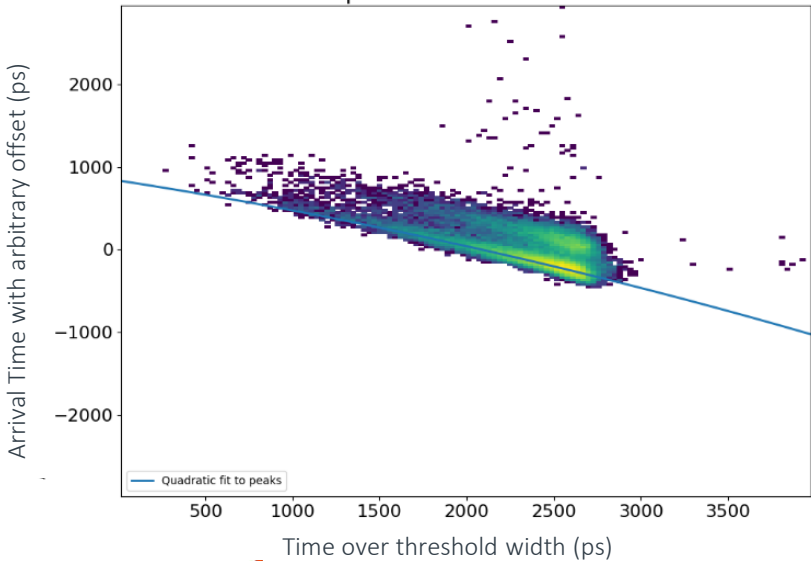
- The timing information for each photon event is logged by the TDC in each channel
- The raw timing data is degraded by the amplitude walk caused by the gain variation in the single photon response of MCPs
- Using the Time-over-Threshold technique restores the timing information
 - The amplitude variation is captured by the pulse width
 - This enables a correction to be implemented
- Accumulated timing data is fitted to a double Gaussian by an automated function
- The shift in the peak of the first fitted pulse is then fitted to a quadratic to apply the correction



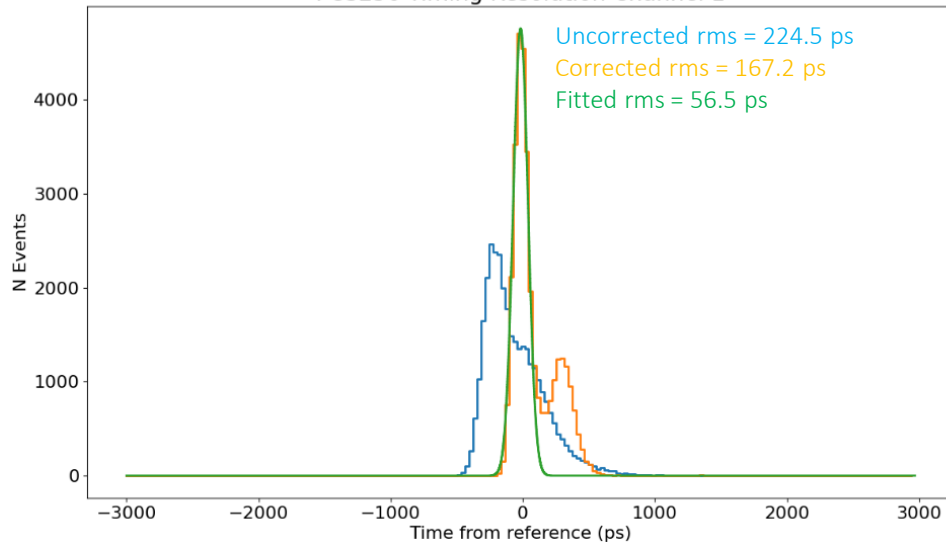
Timing Calibration



TOFPET2 Amplitude Walk Calibration Channel 1

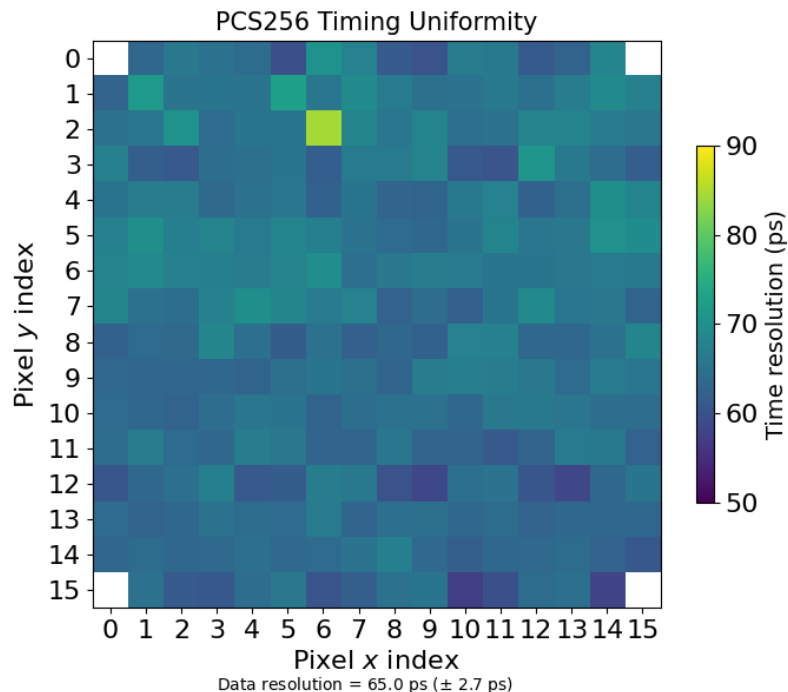


PCS256 Timing Resolution Channel 1



Timing Uniformity

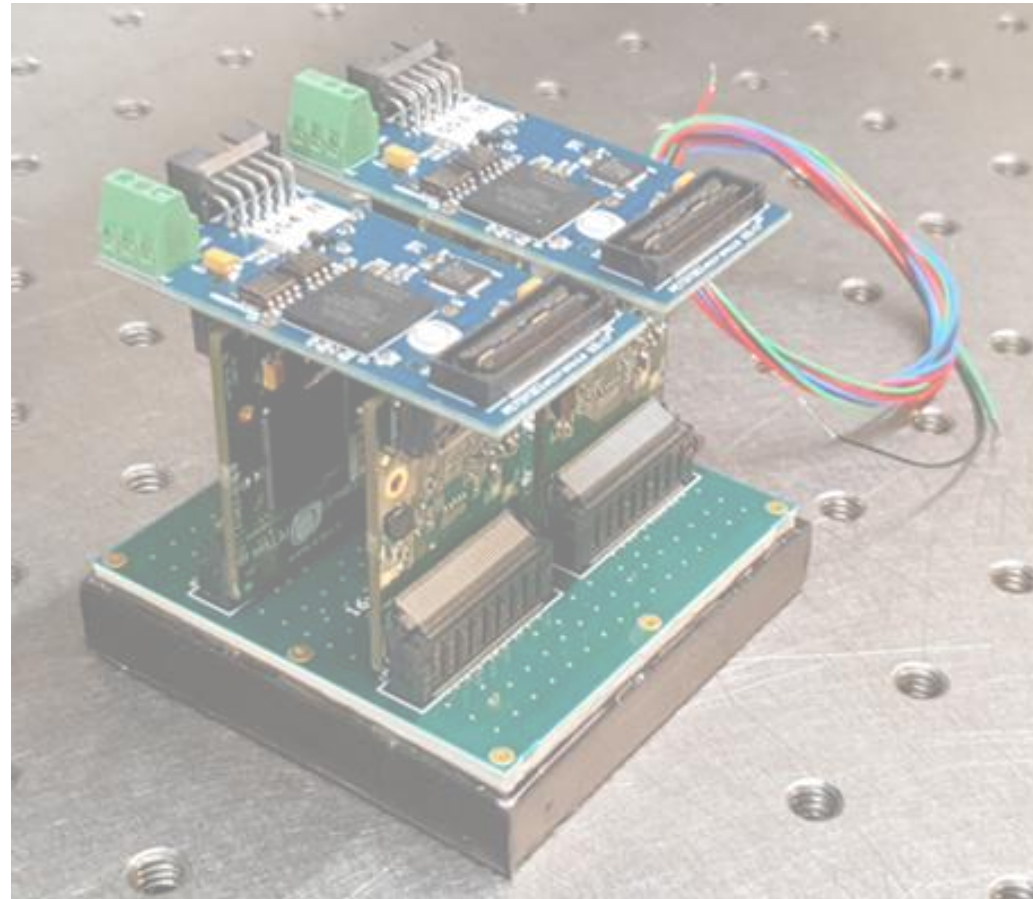
- The uniformity of the timing response was measured by scanning the 40 ps laser pulse across each channel and using Time-over-Threshold to correct for amplitude walk
- This example shows an average σ of 65 ps



- Photek Photomultiplier Tubes
- Transit Time Spread Measurements of PMT products
- Multi-anode detectors - TORCH MAPMT and AuraTek Photon Timing System
- Summary

➤ Summary

- Summary of transit time spread measurements for a range of Photek detectors, best performance PMT210
 - 10.5 ps Std Dev
 - 28 ps FWHM
- Characterisation of TORCH detector
- Auratek Camera Performance
 - 256 channel
 - 16x16 layout
 - ~60 ps timing with amplitude walk



Prototype PCS Electronics with MAPMT253



Photek Limited

26 Castleham Road, St Leonards on Sea,
East Sussex, TN38 9NS, UK

T +44 (0)1424 850 555

F +44 (0)1424 850 051

E sales@photek.co.uk

www.photek.com

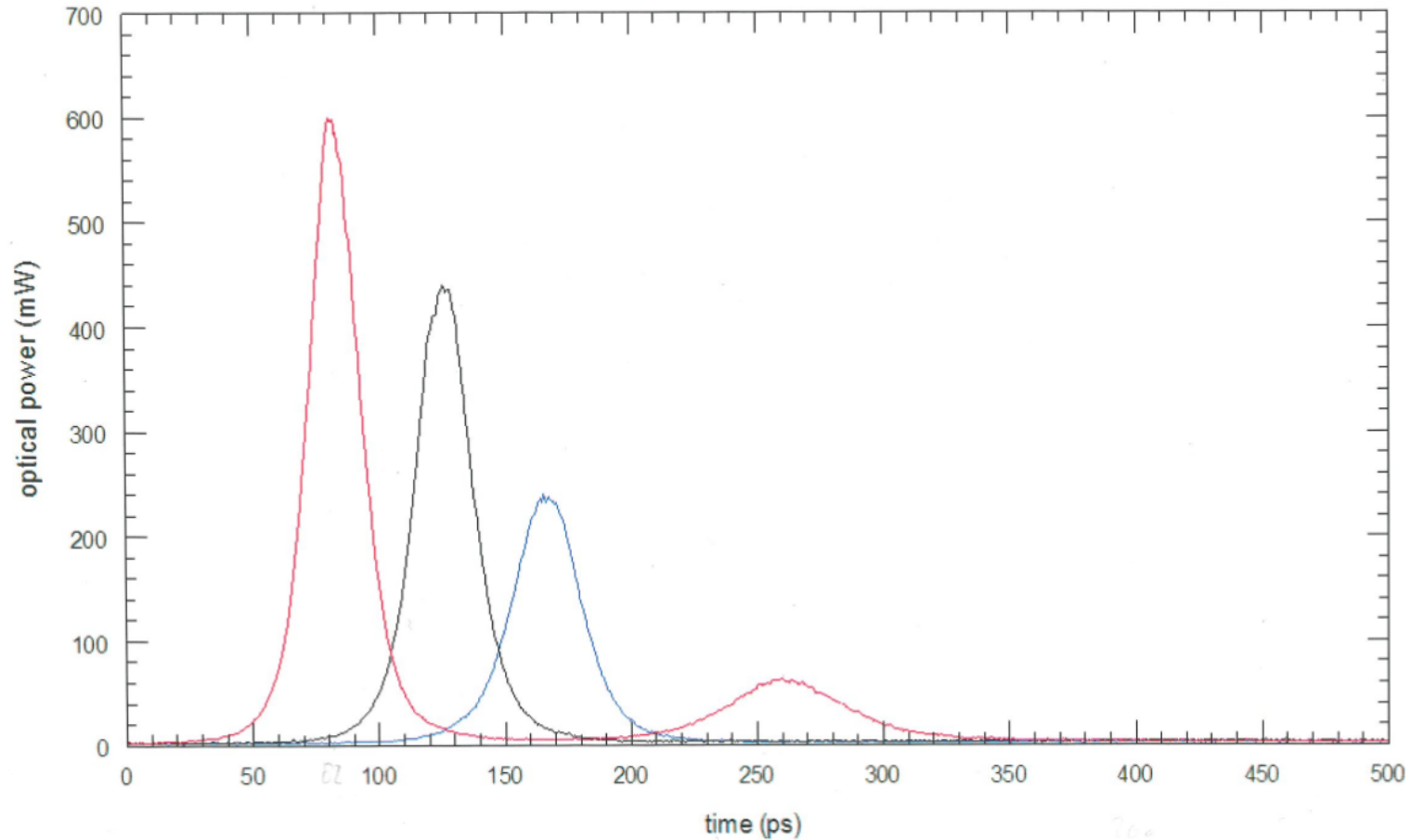
Thank you for listening

And with thanks in particular to
Univ. Warwick for CASE studentship
Univ. Bristol for loan of PiLas Laser
TORCH Collaboration



PiL040X, SN 614, streak camera scan at 100kHz after fiber collimator

tune 70%: 32ps-240mW (blue), 50%: 26ps-440mW (nominal black) and 30%: 22ps-600mW (red)



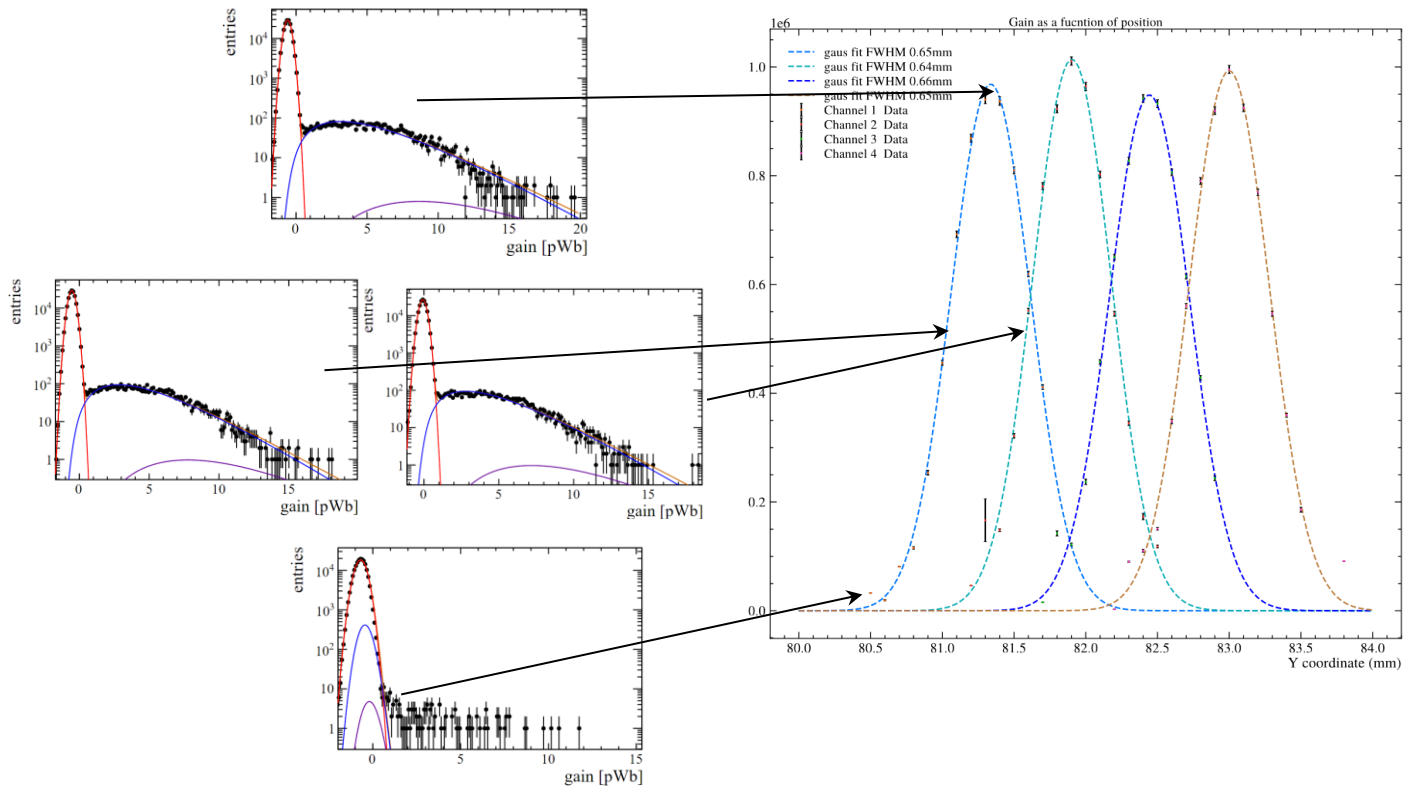
Scope Measured – Gain crosstalk

Alignment

Centre

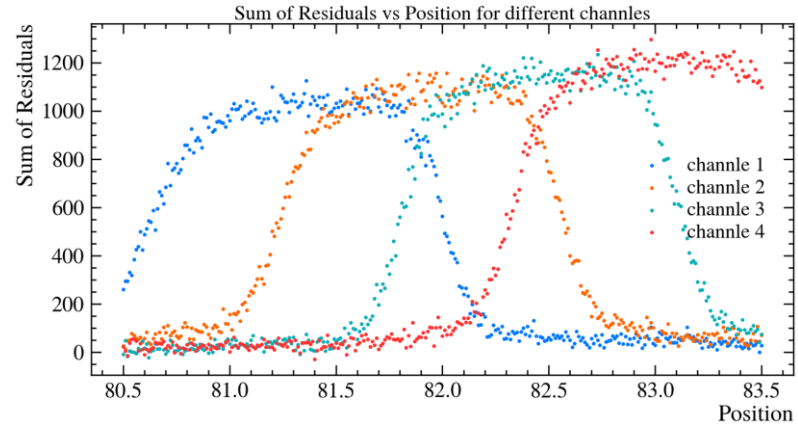
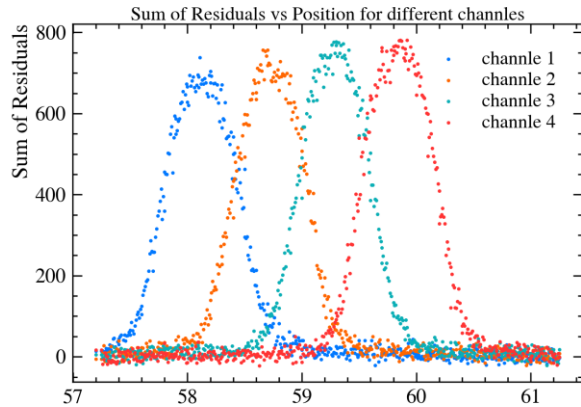
Edge

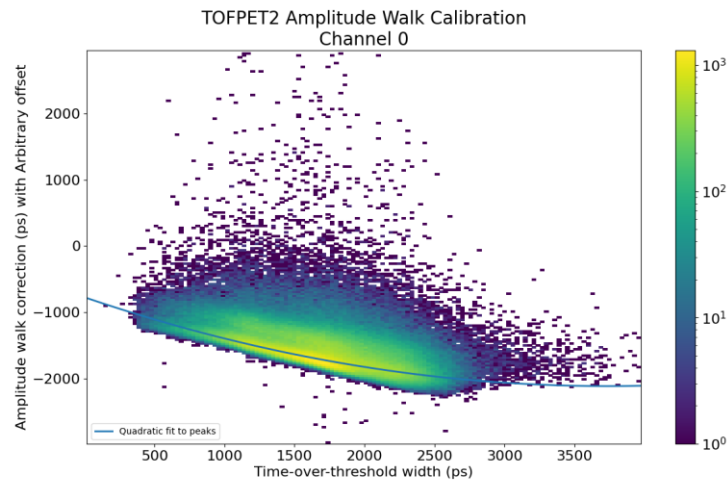
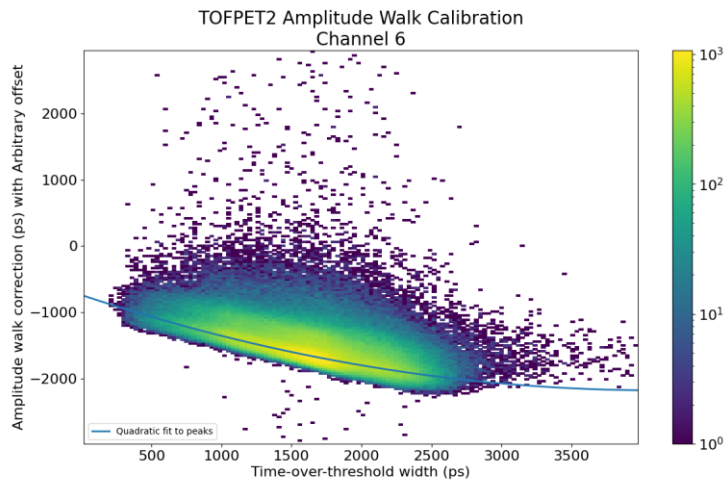
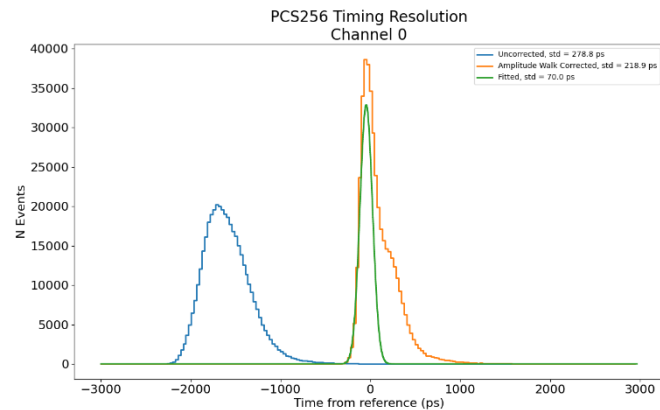
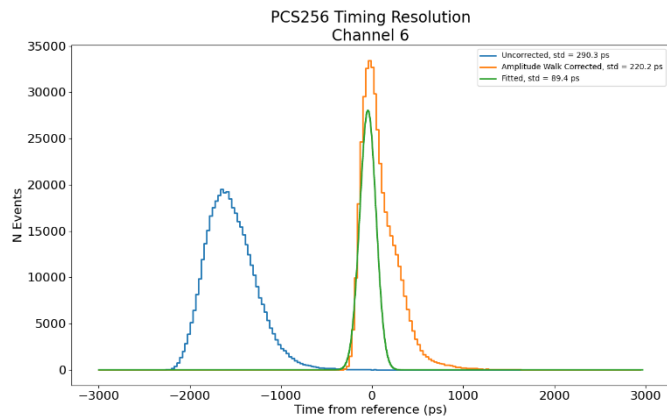
Off pixel



➤ Crosstalk Using residuals

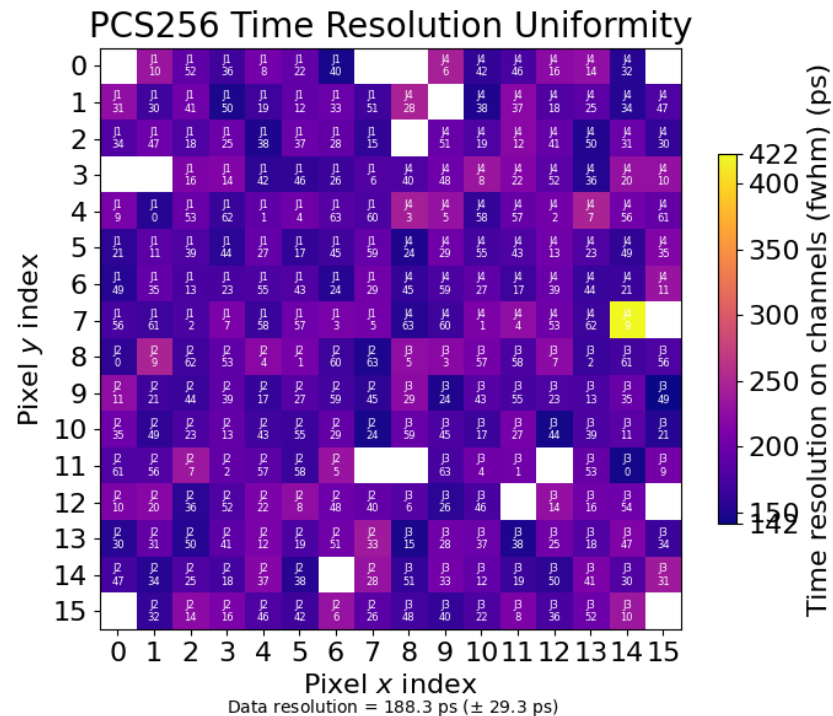
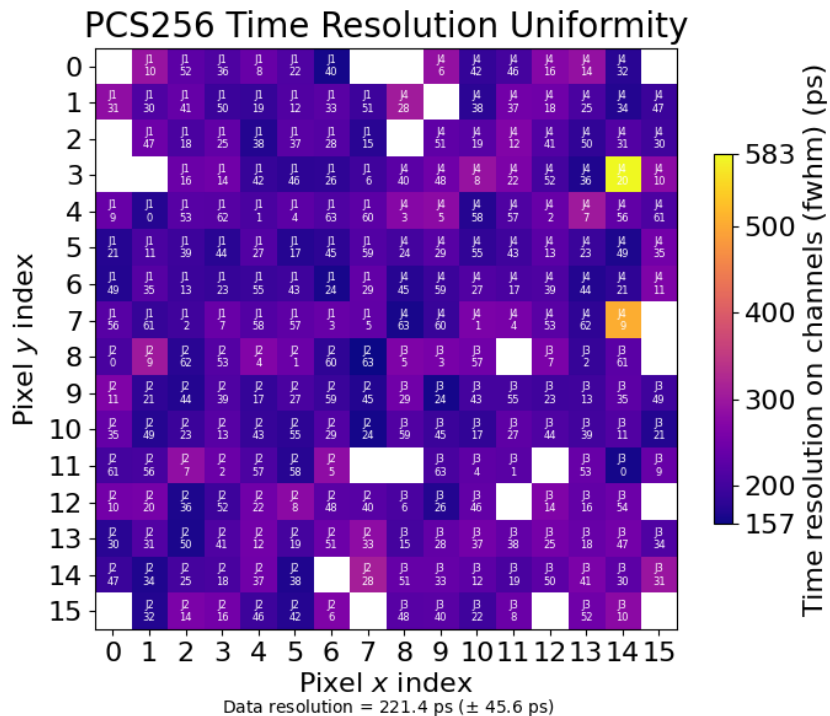
- Measure crosstalk using residuals of PHD fit, i.e. number of events outside noise pedestal (e.g. 5σ and 10σ)





MAPMT253 & PCS

Time Resolution Map – FWHM of Fitted Peak



MAPMT253 & PCS

Time Resolution Map – rms of Fitted Peak

