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A 256-channel photon counting module using a square microchannel plate PMT in a tight packing envelop achieving < 100 ps single photon timing

James Milnes

15th September 2022

RICH Conference, Edinburgh

- Photek Photomultiplier Tubes
- AuraTek Photon Counting System (PCS)
- PCS Readout with a Square PMT
- Summary

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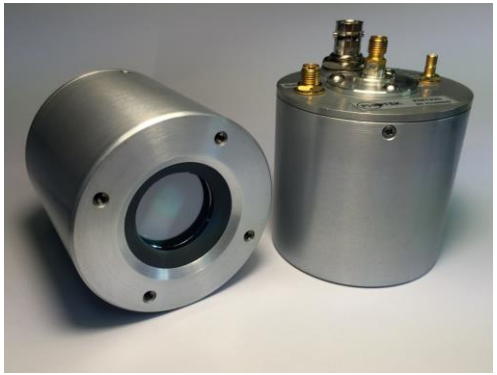
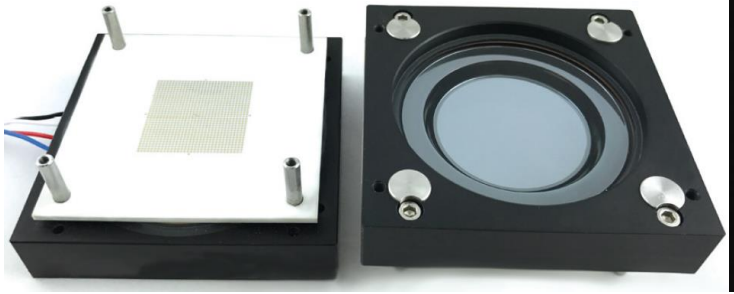
Photek PMTs – History

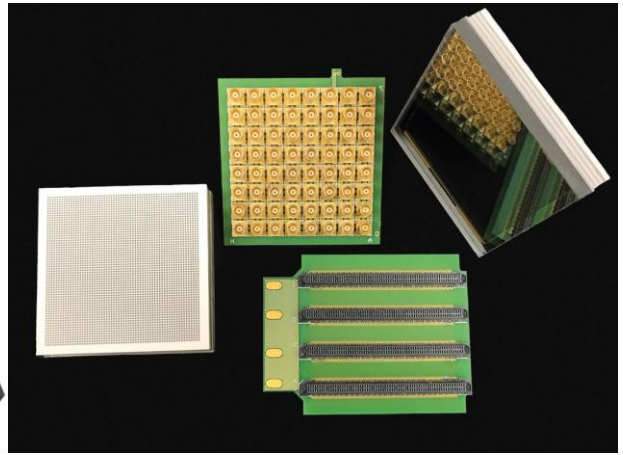
Microchannel Plate Photomultiplier Tubes



- 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

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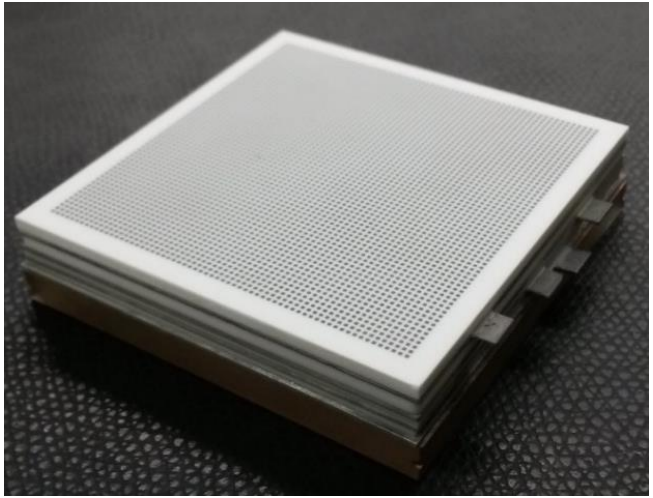
AuraTek Square: MAPMT253

Features

- A 64×64 anode square MCP-PMT
- Derived from novel PMT development with the TORCH group
- Unique build provides short front (1.5 – 2 mm) and rear (3 mm) gaps
- Results from the 15 µm pore MCP version previously published*
- This study looks at MAPMT253 with 6 µm pore MCPs



*See Milnes et al, JINST 15 C02036 (2020)

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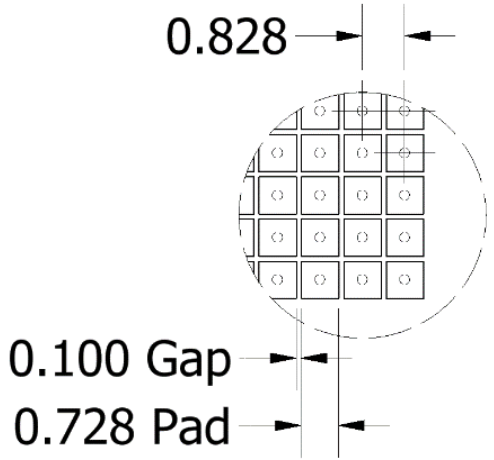
MAPMT253 Geometrical / Mechanical

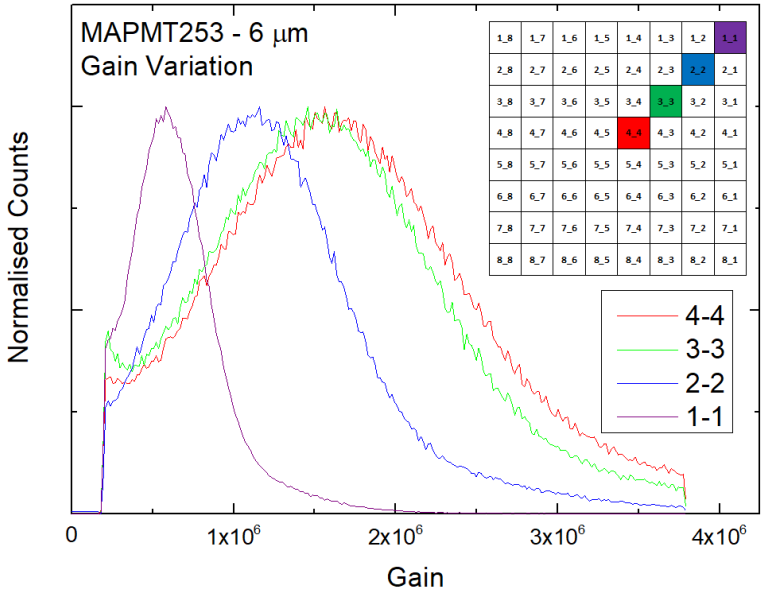
Mechanical Properties	MAPMT253
Input Window Material	Fused Silica or Sapphire
Input Window Thickness (mm)	5.0
Active area (mm)	53×53
Photocathode – MCP Gap (mm)	1.6
MCP – Anode Gap (mm)	3.0
MCP Pore Diameter (µm)	6 or 15
Bare Tube Dimensions (mm)	59×59×13
Housed Tube Dimensions (mm)	62×60×13
Native Anode Pattern	64×64
Native Anode Pitch (mm)	0.828



MAPMT253 – 6 µm

Electron Gain Uniformity

- Test device configured with 8×8 readout pattern
- These results show Peak / Valley ~ 3 and max/min ratio of 2.8
- More than seen in 15 µm pore version (~1.5), possibly due to more flexible MCPs



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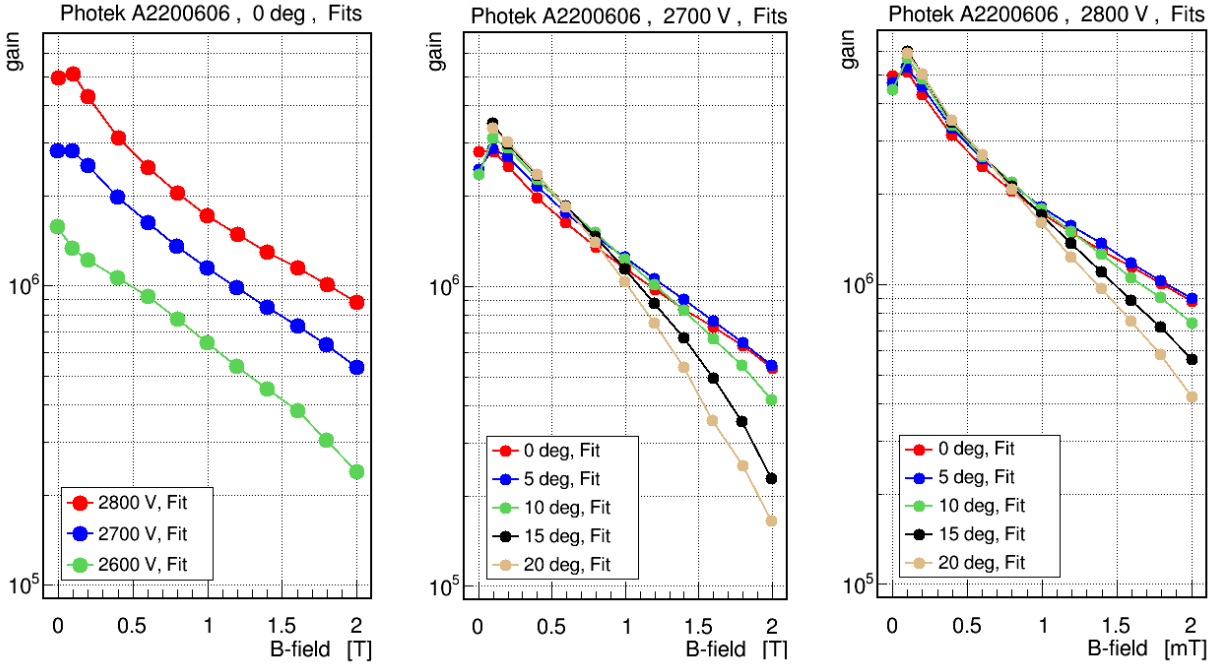
MAPMT253 – 6 µm

Magnetic Field Effects

- The magnetic field impact on electron gain in the region 0 to 1 T appears similar to that observed in 10 and 15 µm pore ALD coated MCP devices, a factor of ~ 3 drop*
- However, in the region 0 to 2 T the 6 µm pore devices show a considerable advantage, a factor of ~ 6 loss compared to > 15 for 10 µm



*See Lehmann et al, NIM A 952 (2020) 161821 & Milnes et al, JINST 15 C02036 (2020)

Magnetic field experiments by Erlangen team at the dipole magnet at FZ Jülich: Albert Lehmann, Merlin Böhm, Steffen Krauss and Daniel Miehling

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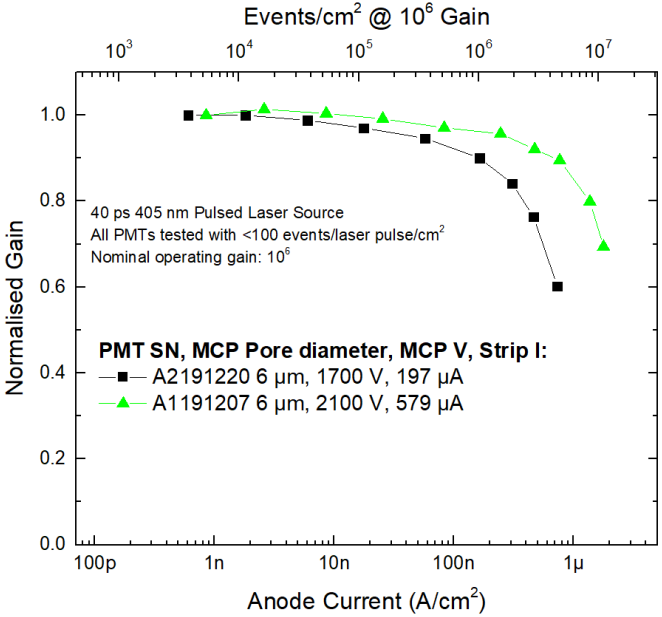
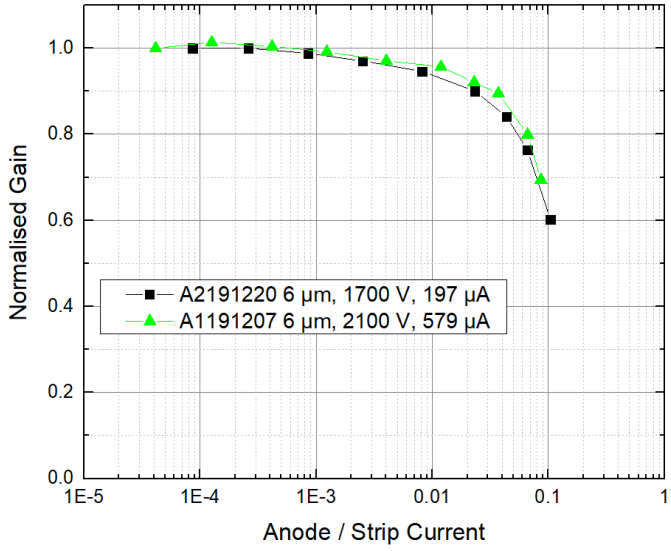
MAPMT253 – 6 µm

Rate Capability

- Flood fill illumination with 405 nm 40 ps laser
- Both PMTs operated at ~ 10^6 gain
- Full area illuminated
- All anodes connected and total d.c. anode current measured
- Ratio of total anode current to strip current is critical





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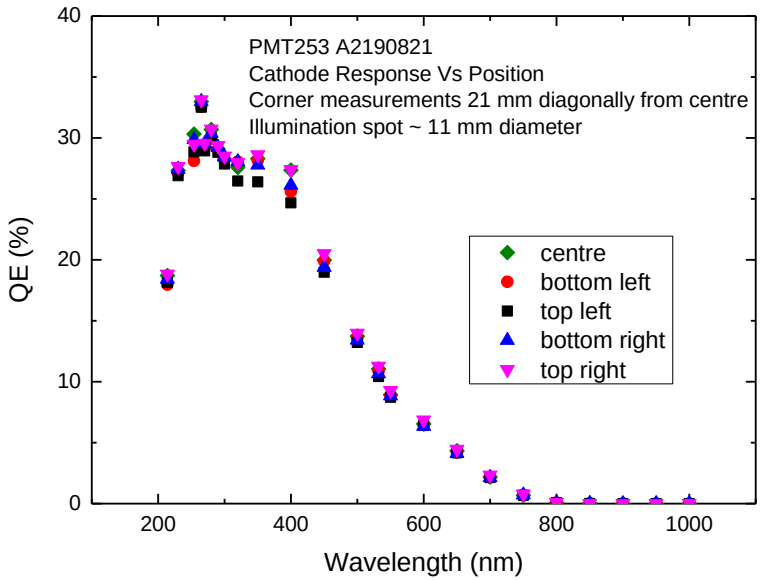
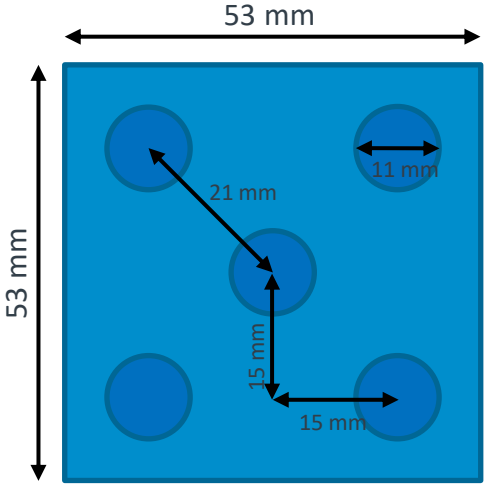
MAPMT253

Photocathode Uniformity

- The cathode uniformity was analysed by spot measurements using the Photek photometer
- Photometer spot size ø ~ 11 mm

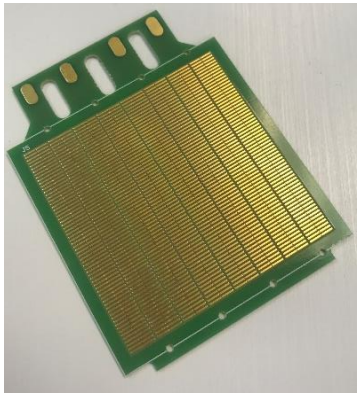


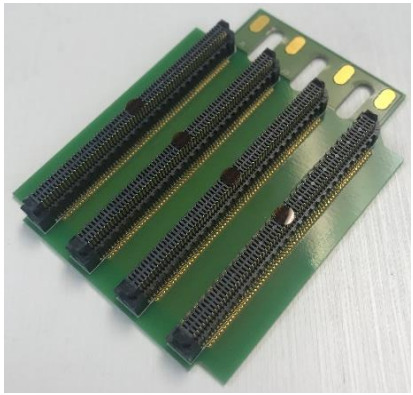


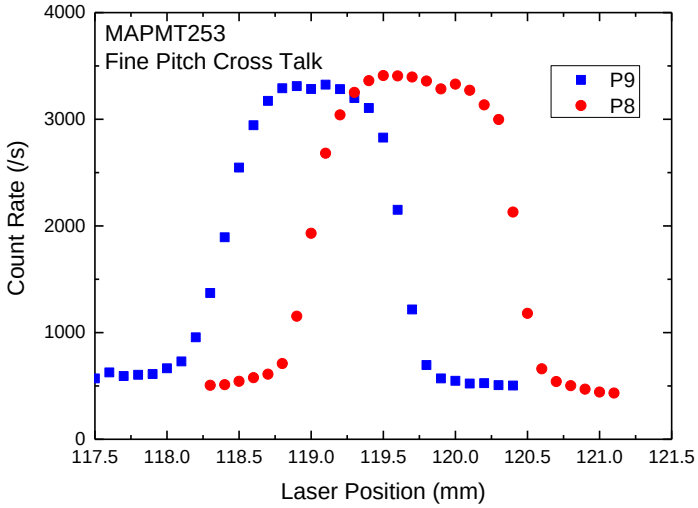
MAPMT253 – 15 µm

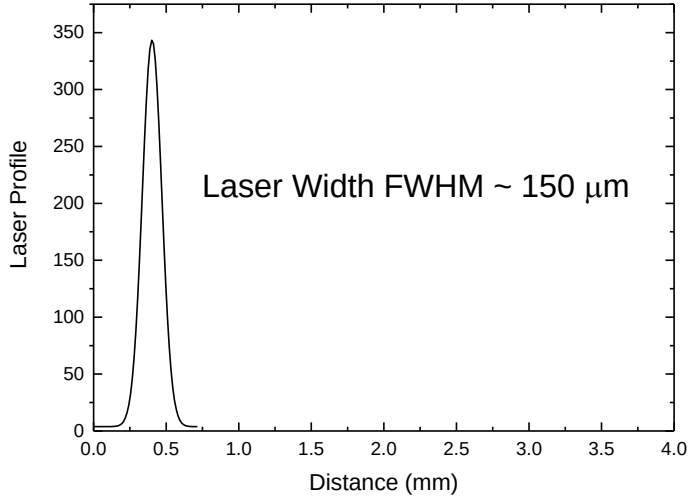
Fine Pitch Cross Talk

- Test device configured with 8×64 readout pattern (TORCH design)
- 0.828 mm pitch between channels
- Single photon gain peak ~ 1.2×10^6
- Threshold 50% of gain peak
- Photek LPG-650 focussed to ~ 150 µm spot









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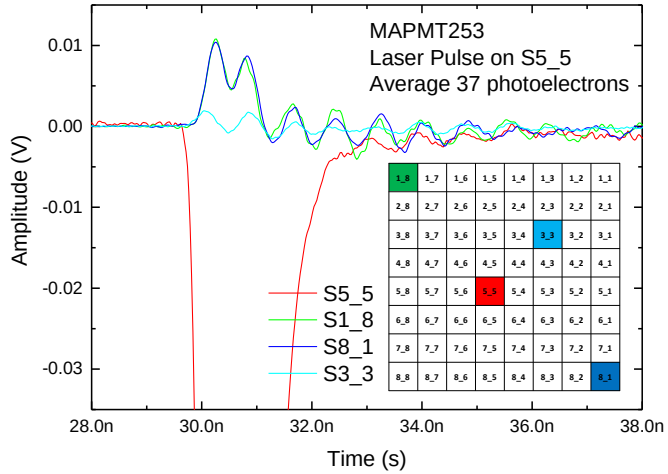
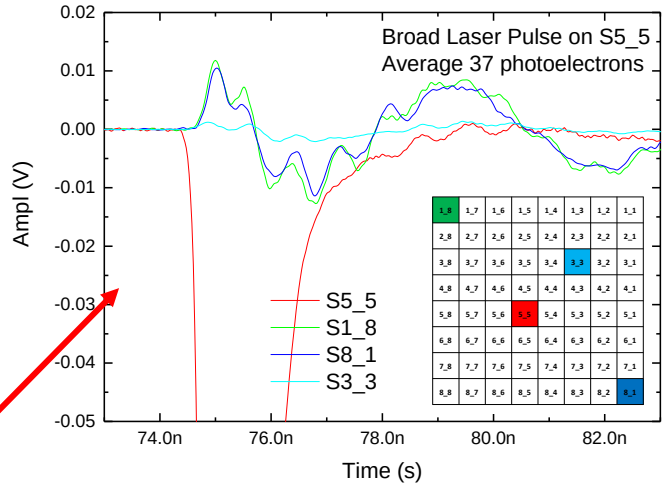
MAPMT253 – 15 µm

Edge Effects

- Perimeter anodes exhibit an inverted signal at a level of 2.5 – 3.0% of the peak pulse amplitude
- The amplitude of this edge effect remains 2.5 – 3.0% of the peak signal independent of pulse amplitude
- Since the amplitude of the edge effect is inverted it should not create false triggers
- For reference, the average signal for a single photon in these measurements had amplitude of 12 mV
- Adding a decoupling capacitor to the MCP Output electrode actually made the effect worse!



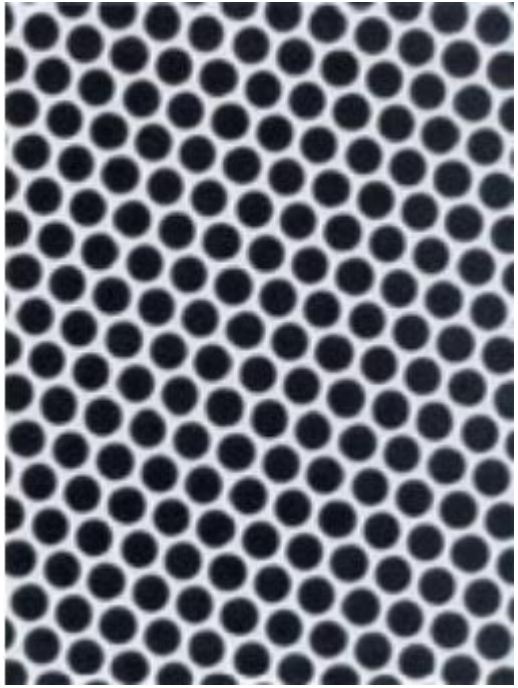


Added decoupling capacitor

MAPMT253

Detective Quantum Efficiency

- Detective Quantum Efficiency: DQE = Photocathode QE × MCP Collection Efficiency (CE)
- Traditional MCPs have ~ 60% CE, limited by pore geometry
- We have a method that:
  - Directly measures the photocathode current
  - Scales the input light to photon counting level
  - Measures single photon detection rate, including electronic threshold effects
- Using the same MCP glass and ALD coating as the MAPMT253, we have measured CE of ~ 90%
- CE measured at Erlangen ~ 83% (±10%) *Thanks to Albert Lehmann*



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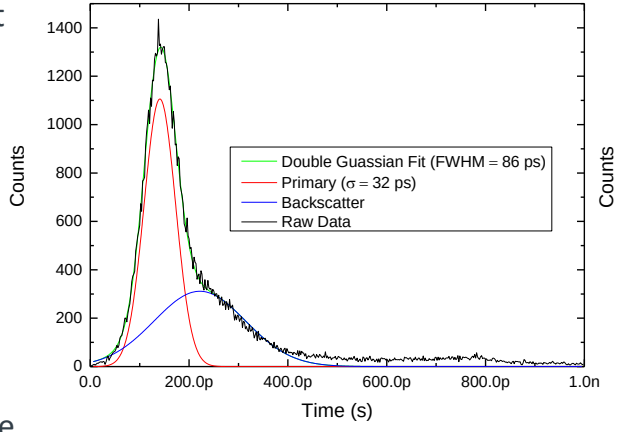
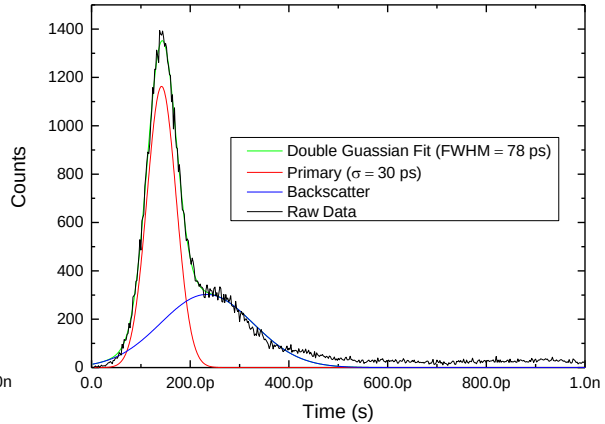
Single Photon Timing Accuracy

MAPMT253 – 6 and 15 µm

- 200 V from photocathode to MCP input
- Gain ~ 2×10^6
- 1 photon per ~ 20 laser pulses
- Photek LPG-405 laser source ~ 40 ps FWHM
- LeCroy Wavemaster 808Zi-A (8 GHz, 40 GS/s)
- Time stamped at 50% of peak amplitude to correct for amplitude variation
- Referenced against laser trigger
- PMTs configured with 8×8 readout pattern, single channel analysed



SN A3180815 – 15 µm pore MCPs



SN A2191220 – 6 µm pore MCPs

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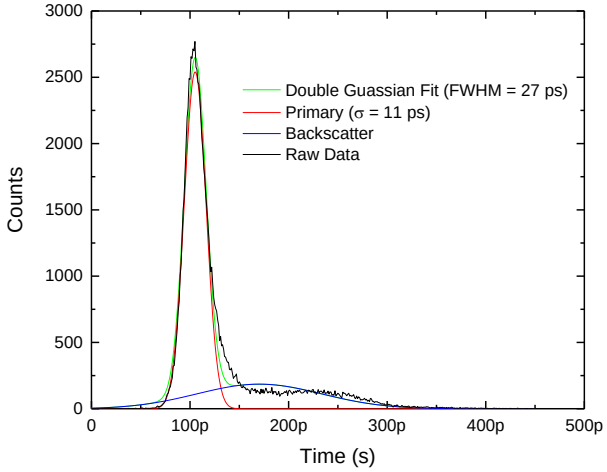
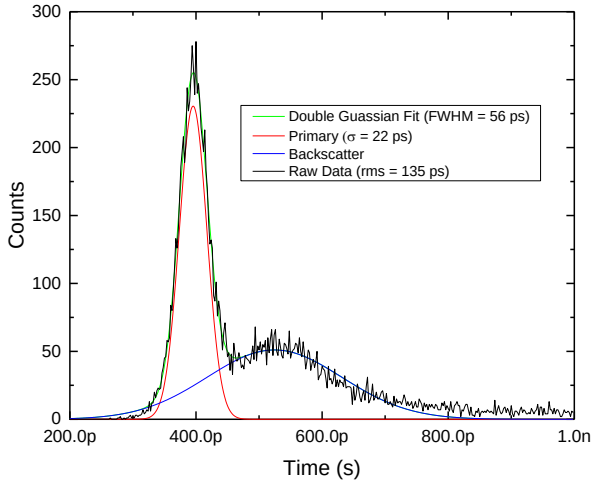
Single Photon Timing Accuracy

Improved Laser Results

- An improved laser measurement on a single channel 10 mm MCP-PMT (PMT210, SN 22171219) showed a significant improvement in timing accuracy
- This improvement is reflected in a follow-up measurement on an MAPMT253 with 6 µm pores



PMT210 SN 22171219 – 3 µm pore MCPs



MAPMT253 SN A3200606 – 6 µm pore MCPs

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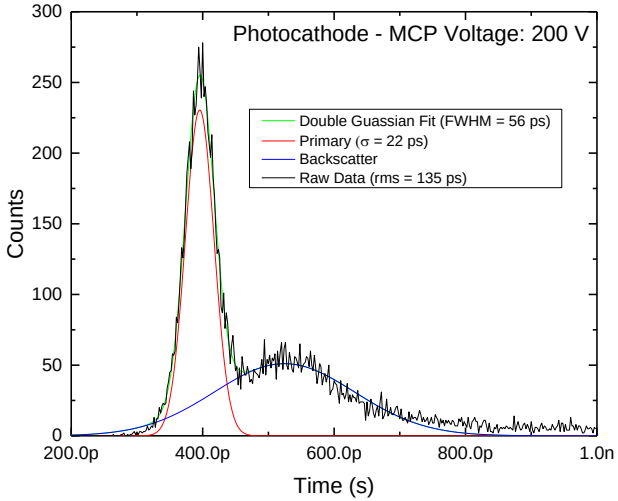
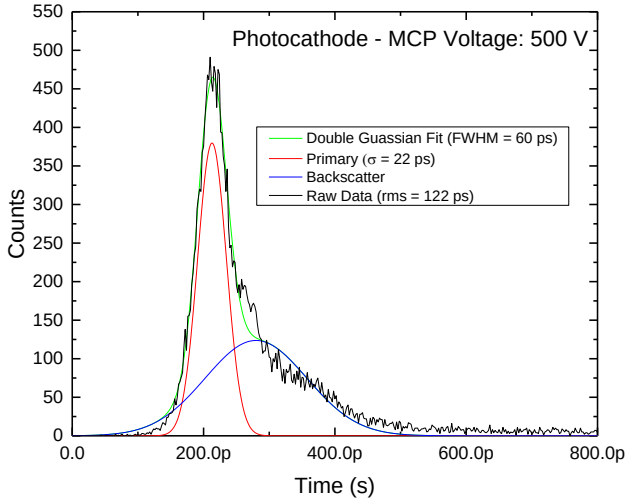
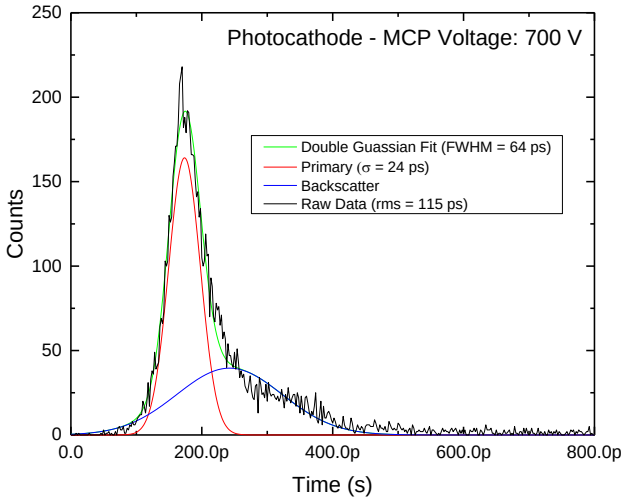
Single Photon Timing Accuracy

Improved Laser Results – Impact of Photocathode to MCP Voltage

MAPMT253 SN A3200606 – 6 µm pore MCPs







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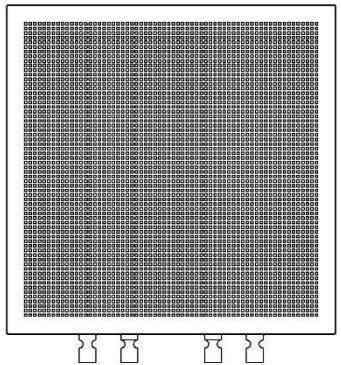
- Photek Photomultiplier Tubes
- AuraTek Photon Counting System (PCS)
- PCS Readout with a Square PMT
- Summary

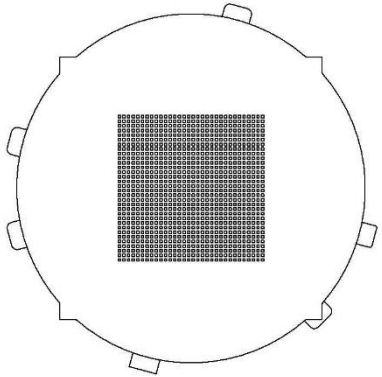
AuraTek PCS

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

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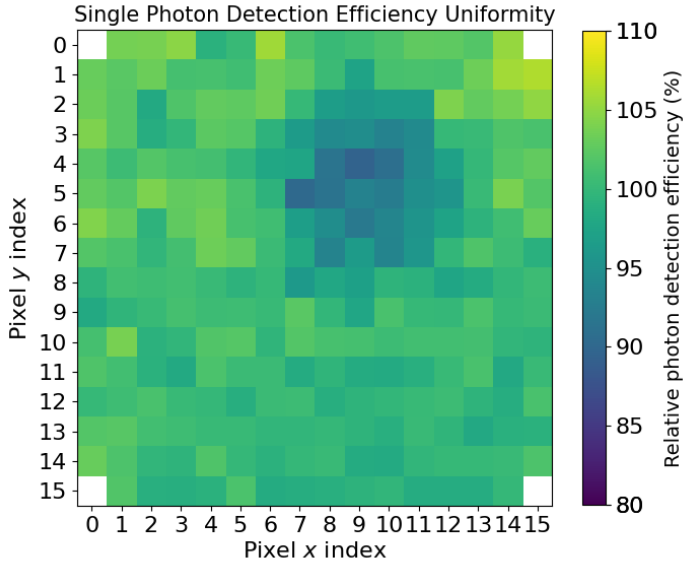
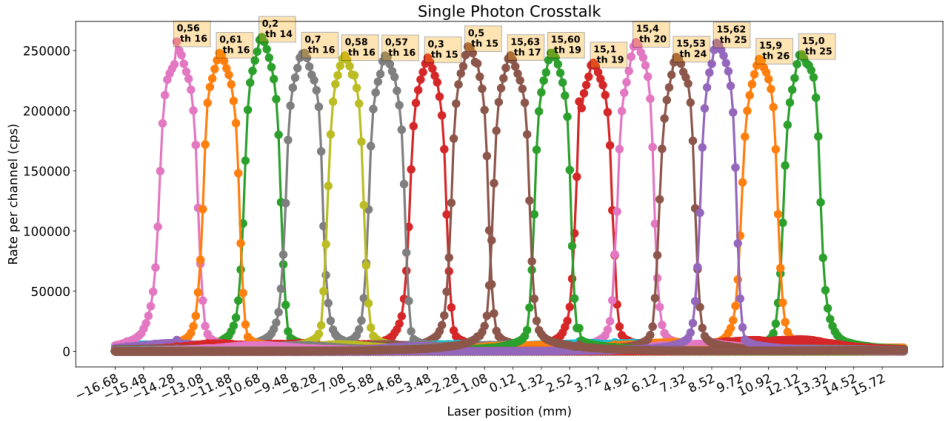
Response Uniformity and Crosstalk

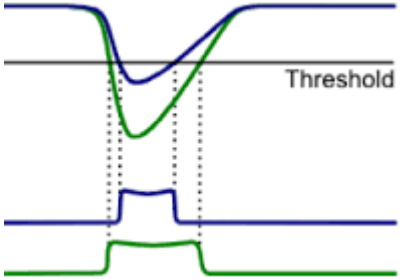
- Each channel has an independent threshold and zero level which is adjusted to normalise the response
- A linear scan of a 0.2 mm laser spot attenuated to single photon level shows the inter-channel crosstalk





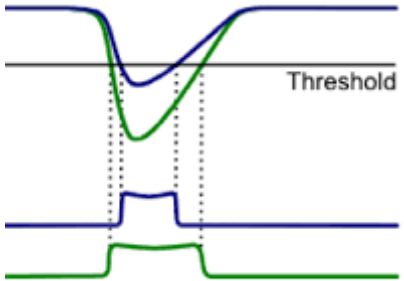
Timing Calibration

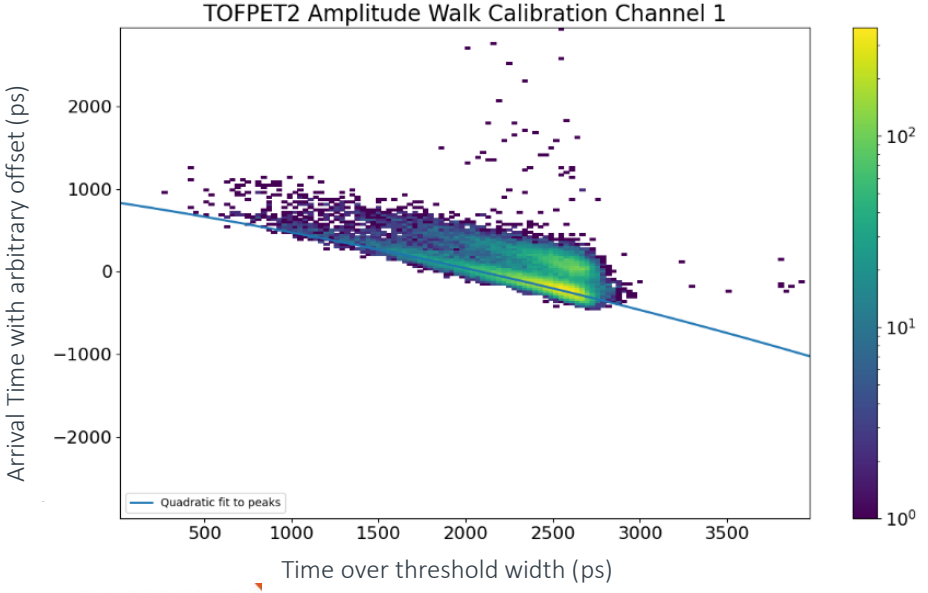
- The timing information for each photon event is logged by the TDC in each channel
- The raw timing data is degraded by the amplitude walk caused by the gain variation in the single photon response of MCPs
- Using the Time-over-Threshold technique restores the timing information
  - The amplitude variation 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

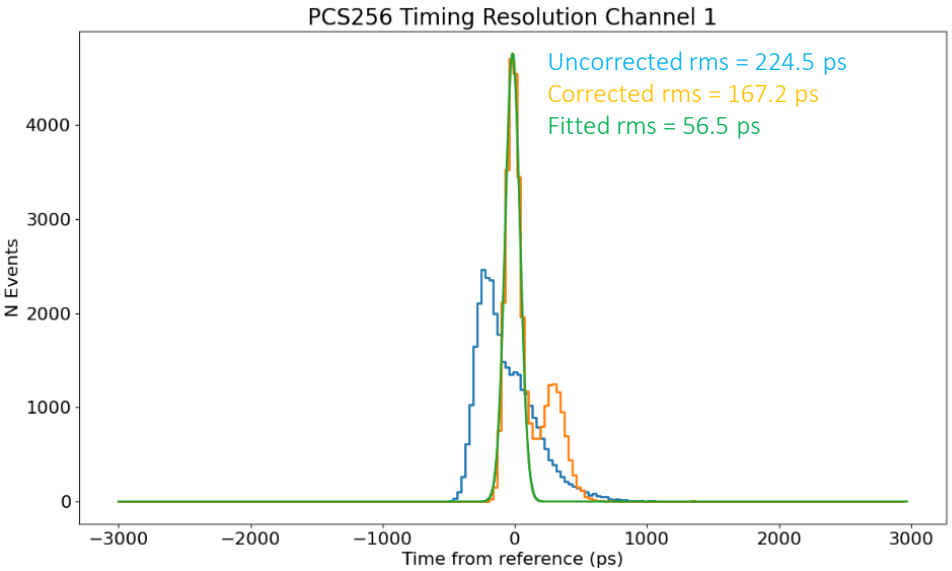


AuraTek PCS

Timing Calibration







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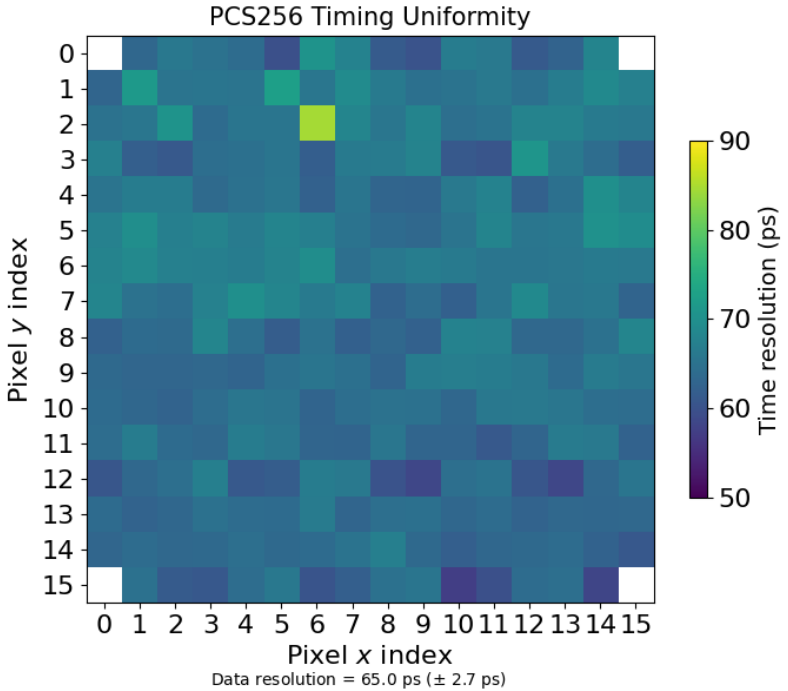
Timing Uniformity

- 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



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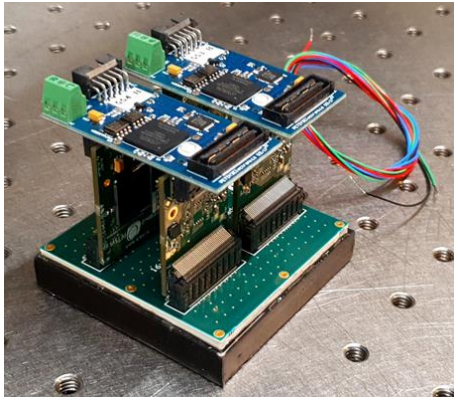
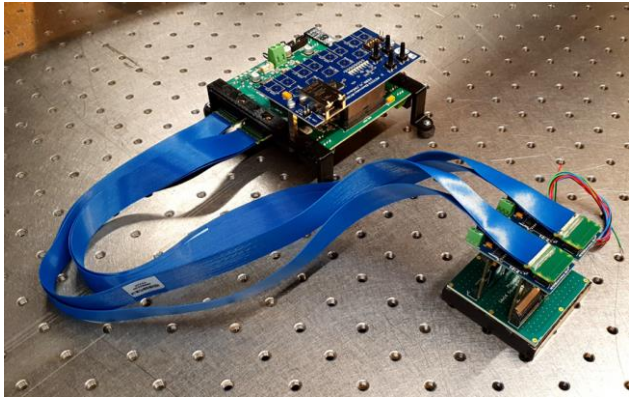
MAPMT253 & PCS

TOFPET2 Integration

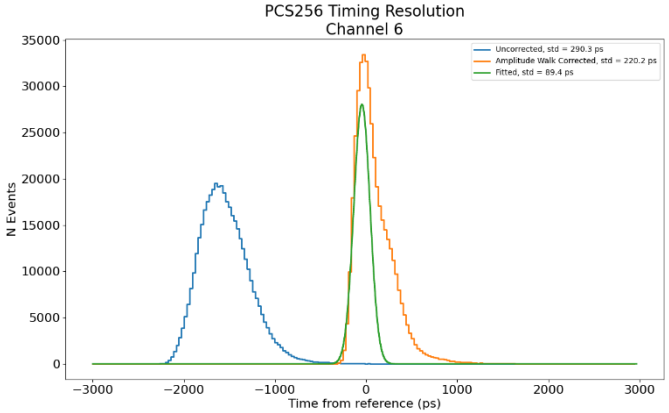
- We have demonstrated hardware compatibility between the square PMT with 16x16 readout PCB and the TOFPET2 front-end
- Mechanical fit into the same envelop
- Back-end electronics can be located remotely

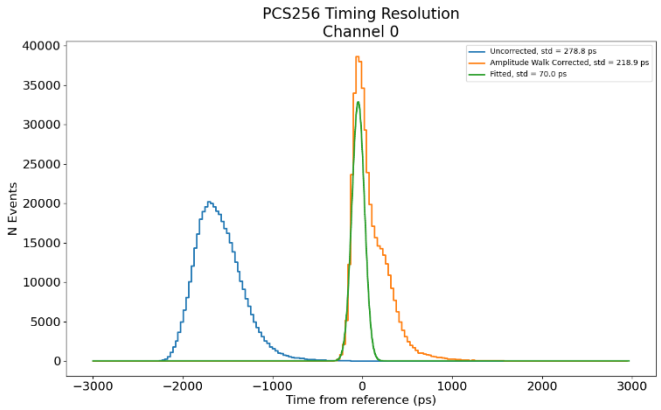


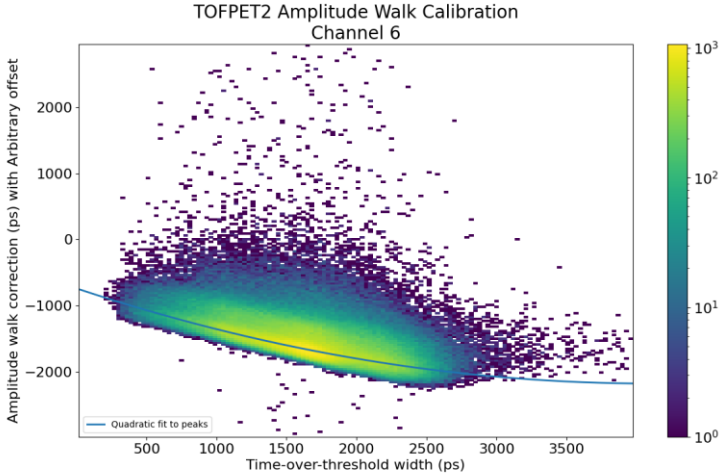


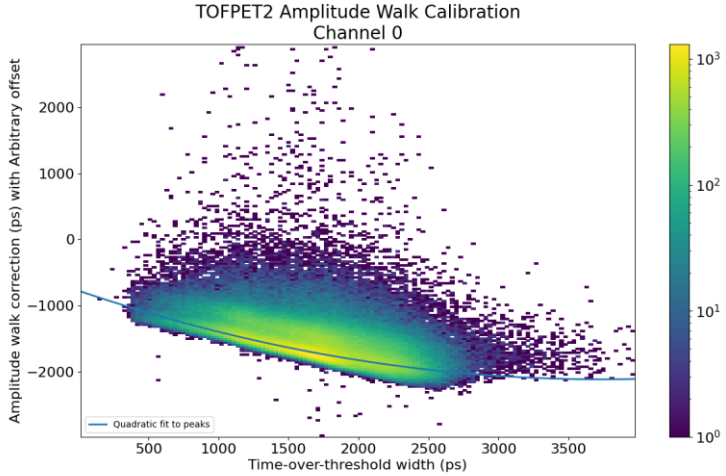
MAPMT253 & PCS

Examples of 256 channel Time-over-Threshold corrections









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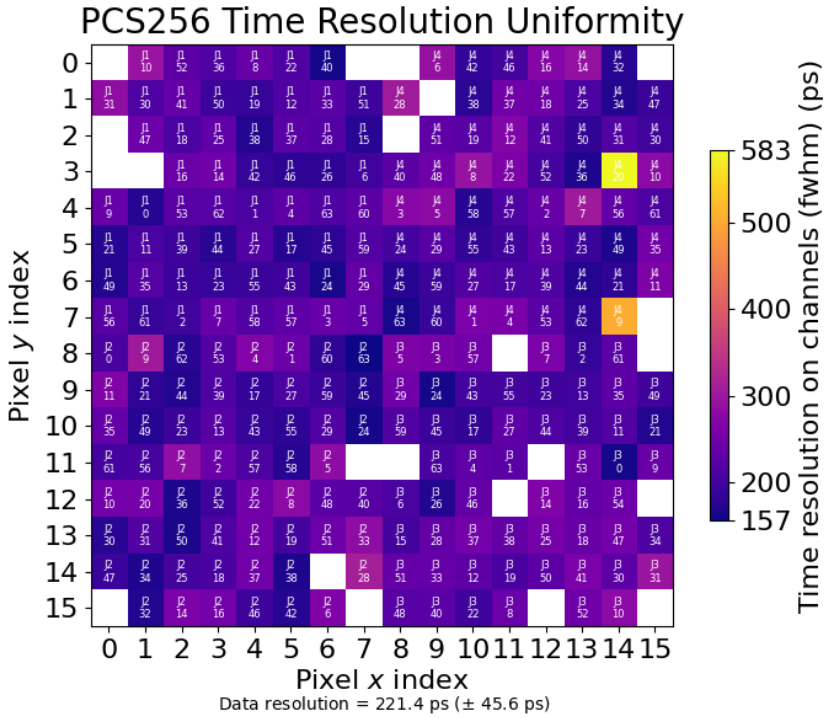
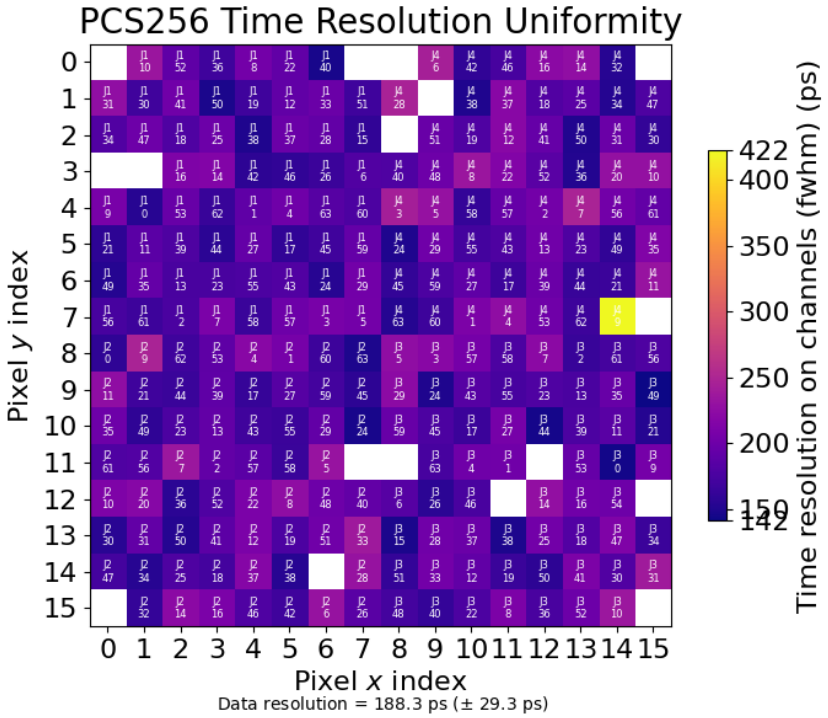
MAPMT253 & PCS

Time Resolution Map – FWHM of Fitted Peak



PC – MCP: 200 V



PC – MCP: 700 V

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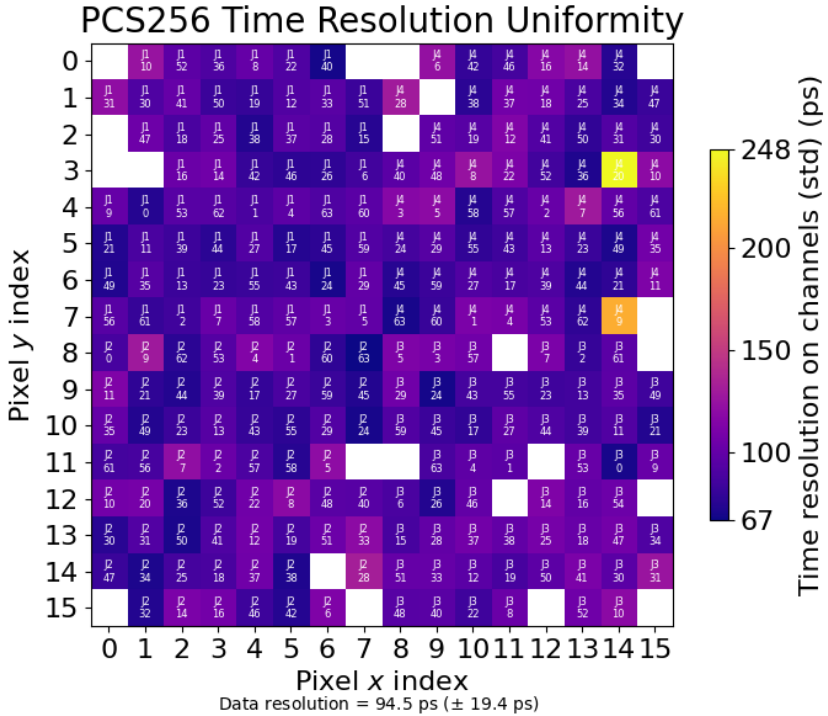
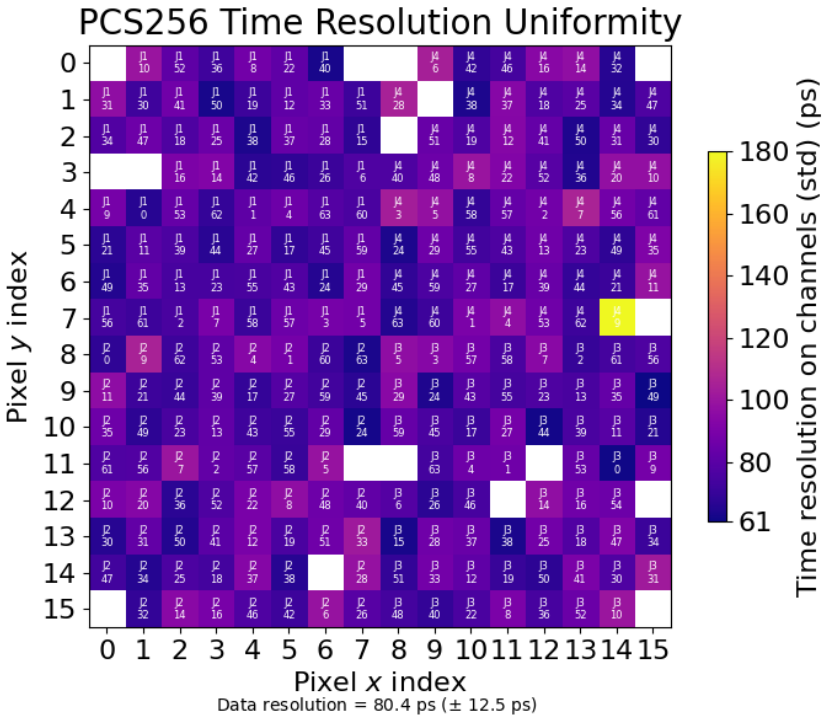
Time Resolution Map – rms of Fitted Peak



PC – MCP: 200 V



PC – MCP: 700 V

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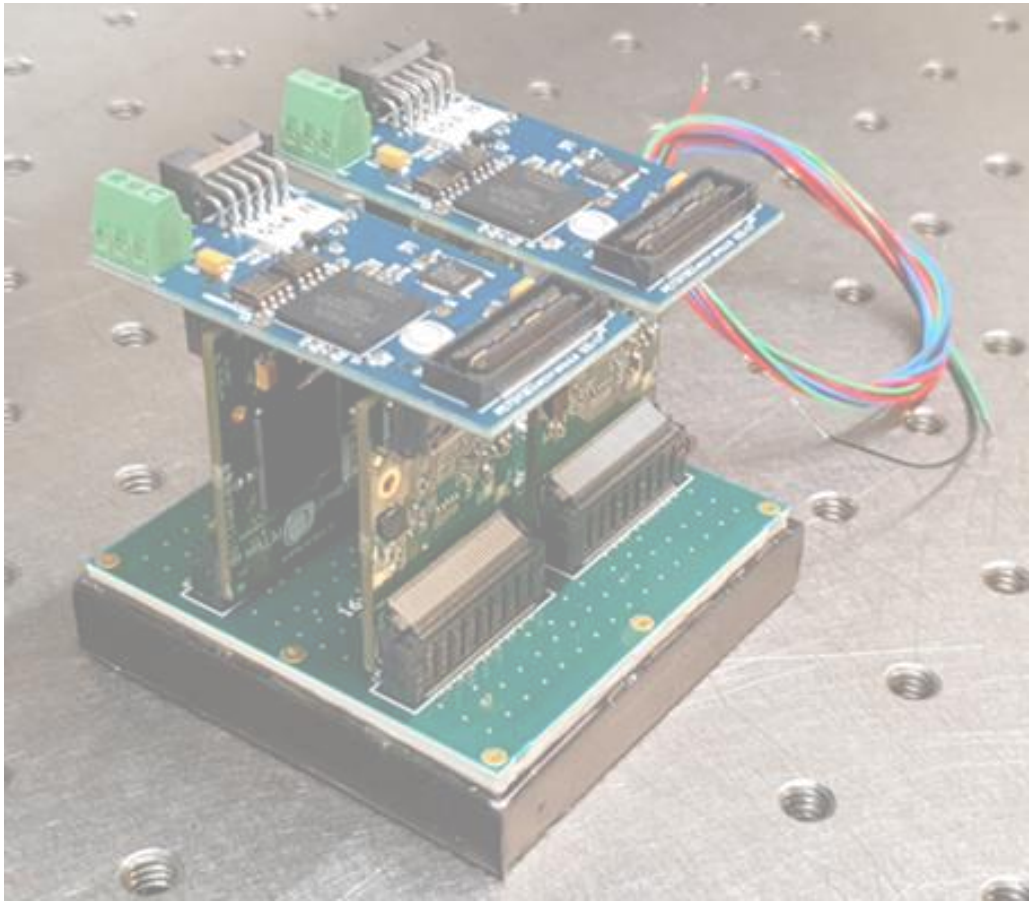
- Photek Photomultiplier Tubes
- AuraTek Photon Counting System (PCS)
- PCS Readout with a Square PMT
- Summary

Summary

- Demonstrated the improved timing and magnetic field performance of a square MCP-PMT with 6 µm pores
- Integrated a multi-anode PMT with TOFPET2 electronics to produce a 256 photon counting system with ~ 65 ps timing resolution
- Demonstrated the same with a square MCP-PMT in a tight packing envelope with ~ 80 ps timing resolution
- Thanks to Thomas Conneely, Ayse Duran and Amelia Markfort from Photek R&D for the measurements



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