Performance of High Pixel Density Multi-anode Microchannel Plate Photomultiplier tubes

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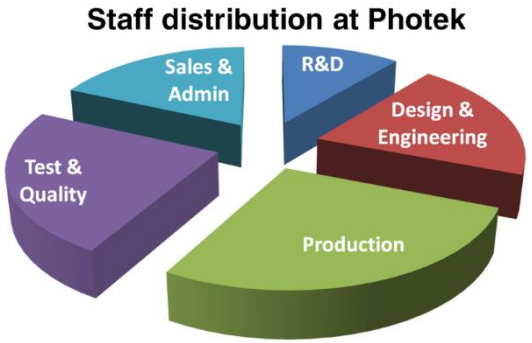
Company overview

Specialist manufacturers of photon detectors and camera systems. Photek manufacture Image Intensifiers, PMTs, Streak Tubes, open faced detectors and a range of associated electronics and camera systems

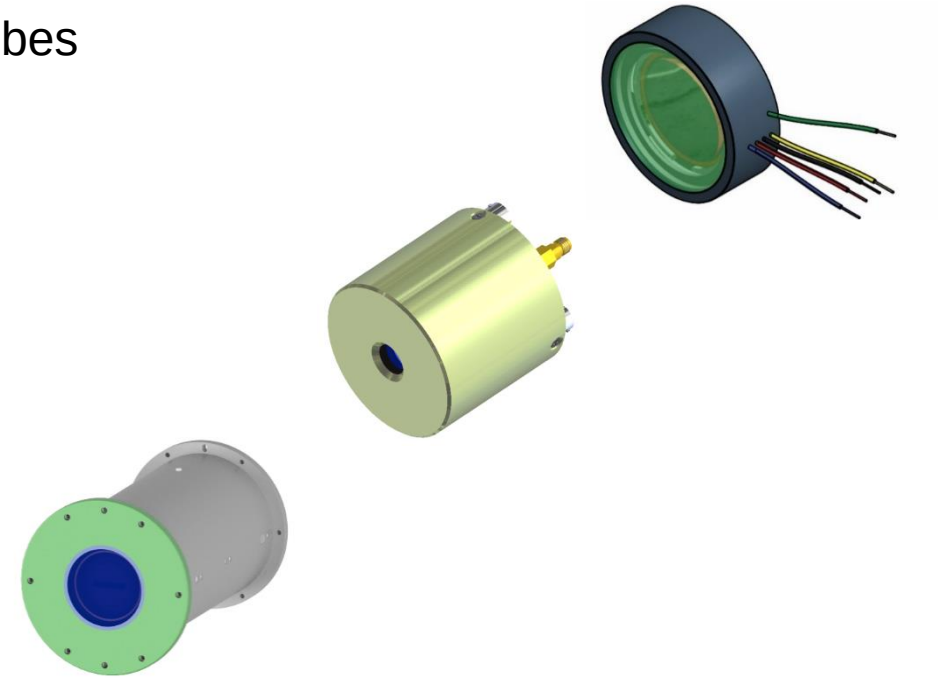
- Founded in 1991
- St Leonards-on-sea, East Sussex
- 60 employees
- Approximately ¼ of employees educated to PHD or degree level
  - → Research & Development
  - → Design & Engineering
  - → Production
  - → Test & Quality Control
  - → Sales & Administration



Company Overview: What we make

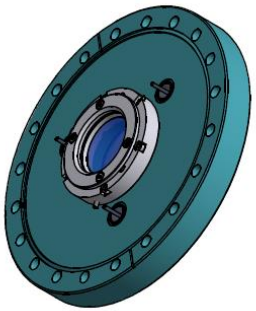
Photek design and manufacture vacuum based sensors and camera systems for photon and particle detection such as:

- Gen II MCP image intensifiers
- Ultra fast MCP photomultiplier tubes
- UV detectors
- Streak Tubes



Company Overview: What we make

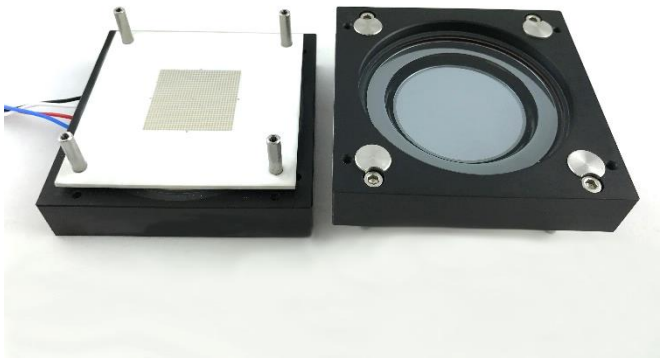
- Advanced photon counting/imaging camera systems
- Ultra high vacuum imaging detectors (VIDS)
- Electronic products

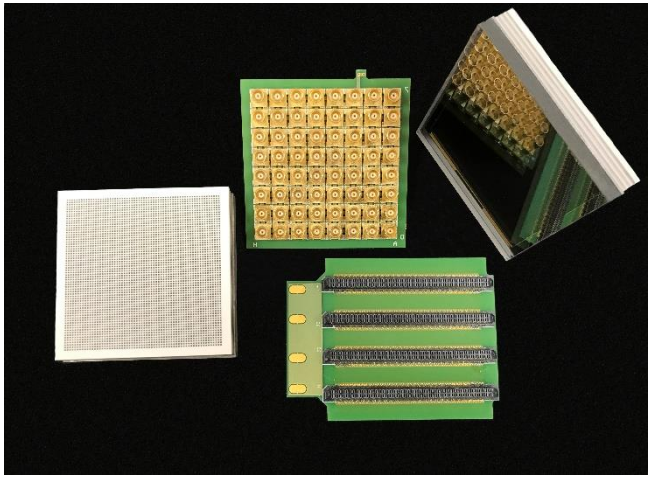


All our products are *bespoke*

Covered detectors

- New range of Multi-anode MCP PMTs
  - Auratek MAPMT-253
  - Auratek MAPMT-228
- Plus integrated readout solutions
  - Auratek PCS-256 multi-channel photon counting system



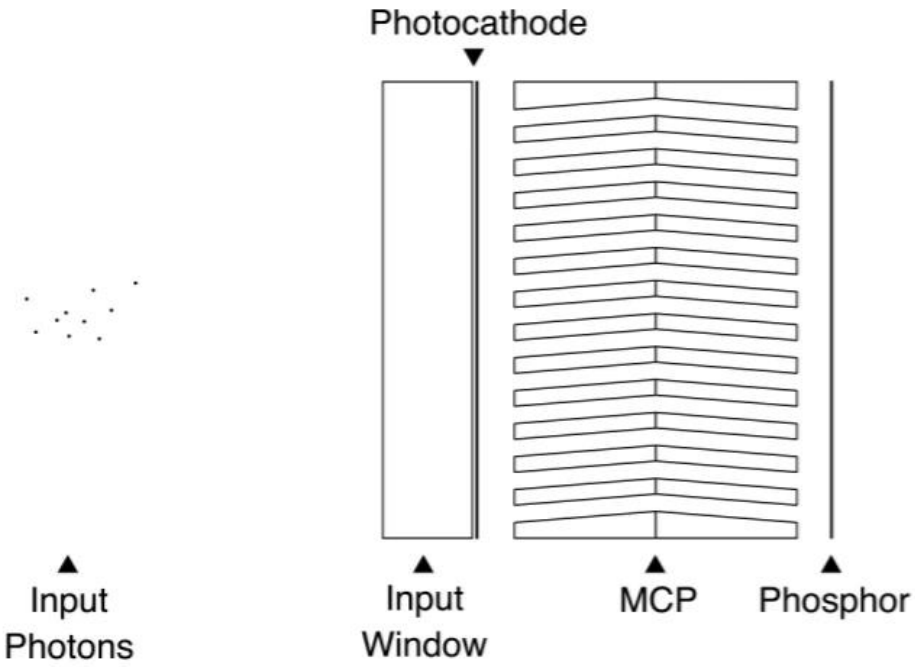


MAPMT Applications

- Cerenkov radiation detection (e.g. DIRC/RICH detectors)
- Time resolved spectroscopy
- Fluorescent Lifetime Imaging
- LIDAR
- Scintillating fibre readout
- Beam monitoring
- Sampling Calorimeter Readout

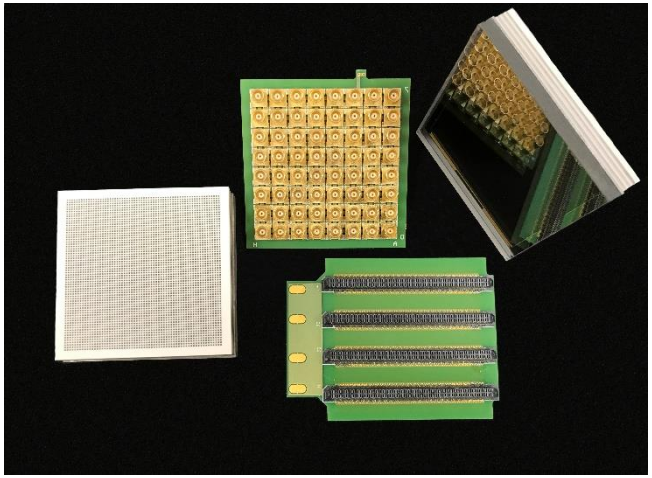
MCP OPERATING PRINCIPLE

MCP Photon Detection



Vacuum MCP detector advantages

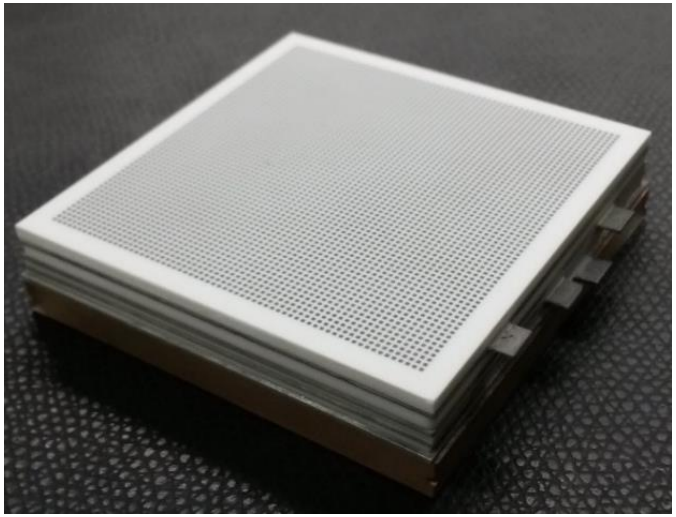
- Low-noise gain from 10^3 up to 10^7
- Single photon imaging devices, i.e. preserves photon's position
- High bandwidth signal (~6GHz for single channel)
- High time resolution
  - <50ps single photon jitter
  - <10ps multi-photon jitter



A tileable, high density, multi-anode MCP-PMT

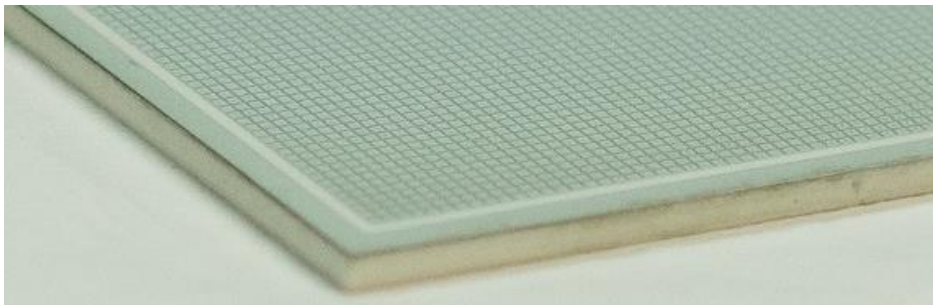
PMT253

PMT253 Readout Format

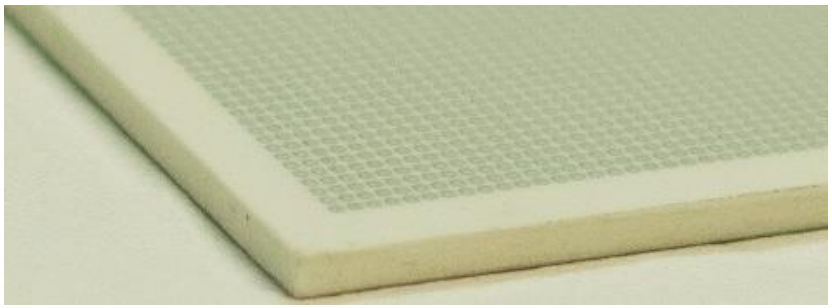


- Direct couple anodes
- 64 x 64 array
- 0.73 mm pad width on a 0.83 mm pitch
- Outer dimensions of 60×60 mm^2, with 53×53mm^2 active area

Vacuum side

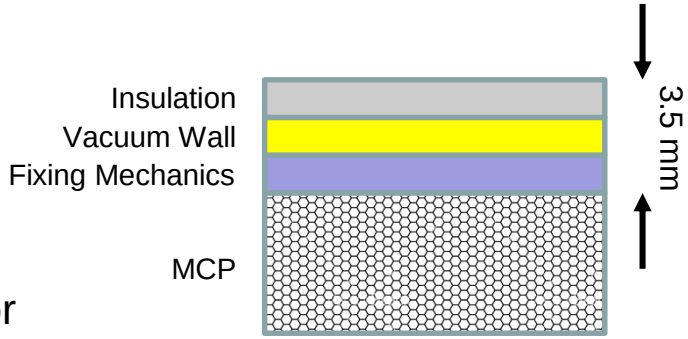


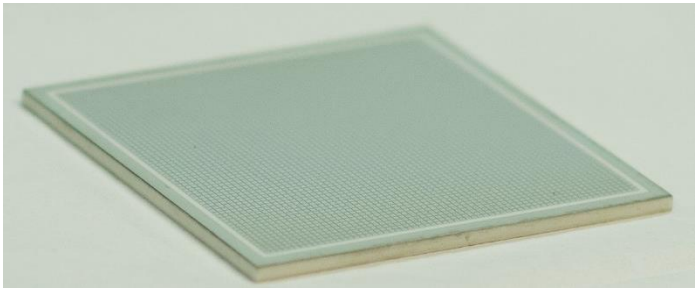
Air side



Challenges and Solutions

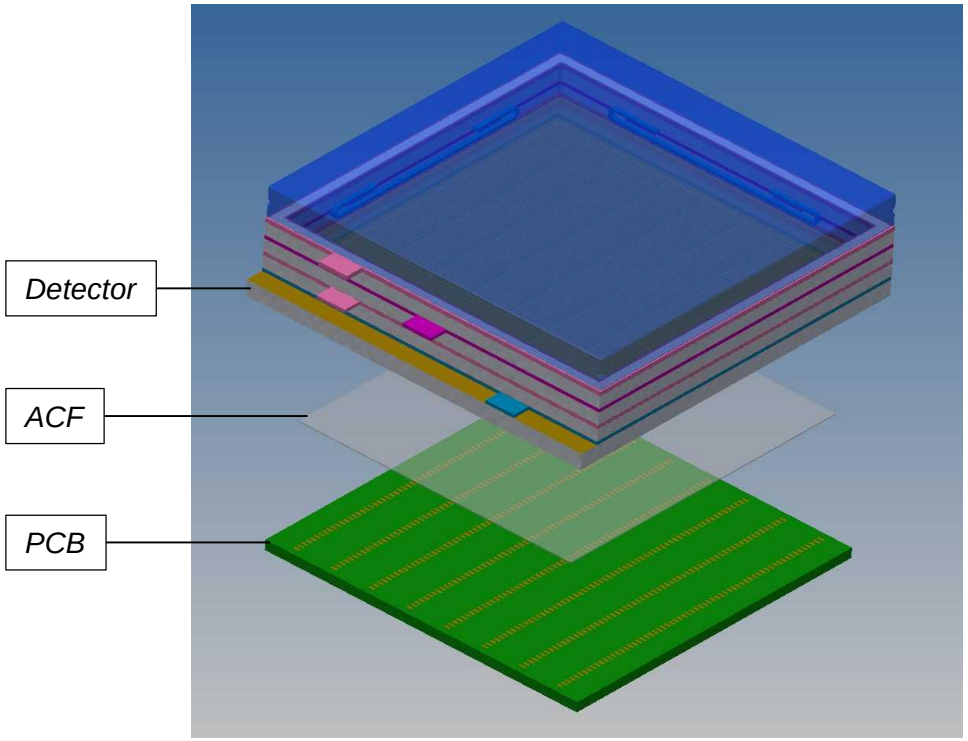
- Only 3.5 mm available for HV insulation, vacuum wall and MCP fixing around outside
  - 40 mm circular image intensifier has 16.5 mm for the same task!
- Our novel MCP fixing method allows tight gap between photocathode, and MCP input
  - In the range 1.5 – 2 mm
  - Leads to improved timing performance
- Predicted MCP – anode gap is 2.5 – 3 mm
- 15 µm MCP pore size

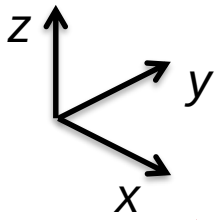




Signal Interface

- We have adopted Anisotropic Conductive Film (ACF) as an interconnect solution
- Uses temperature/pressure to permanently bond PCB to detector output
- Allows connectors etc… to be mounted on PCB
  - significant per application customisation



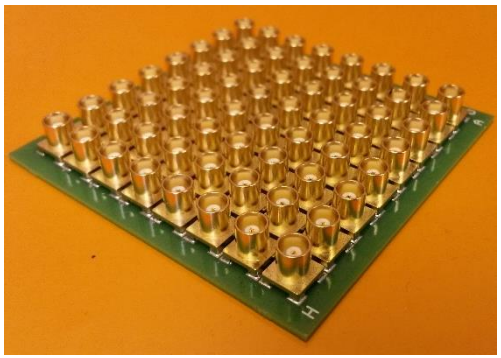


ACF is insulating in *x* and *y* but conducting in *z*

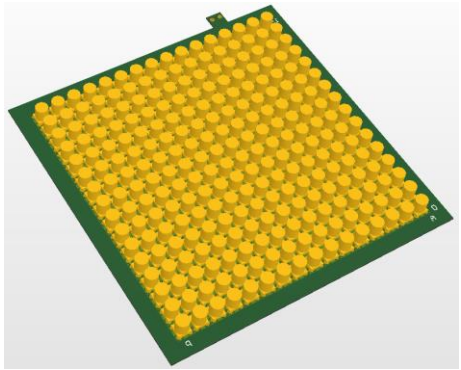
Interface Options

- Currently a challenge to connect all 4096 connections in 64 x 64 array to front-end electronics
- However, this format gives flexibility to gang pads together:

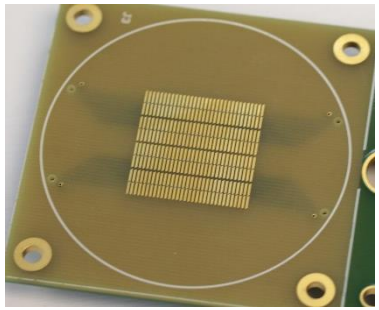
- Gang 8 x 8 pads together
- 8 x 8 array
- e.g. MCX co-ax

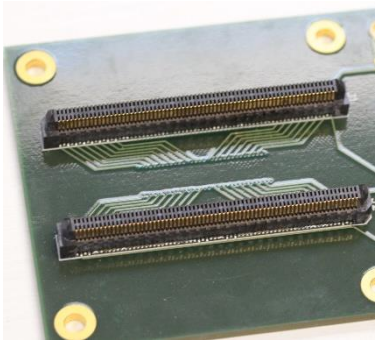


- Gang 4 x 4 pads together
- 16 x 16 array
- e.g. SSMCX co-ax

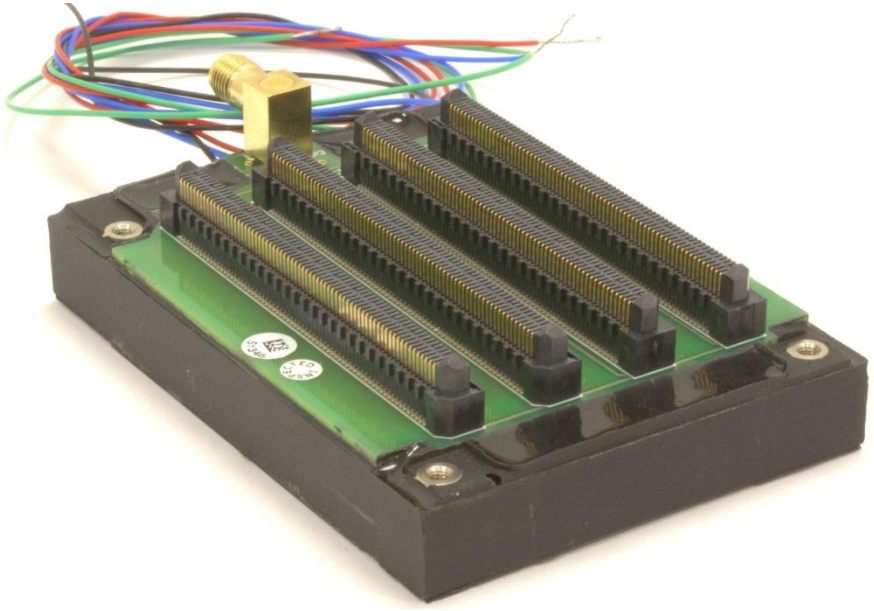


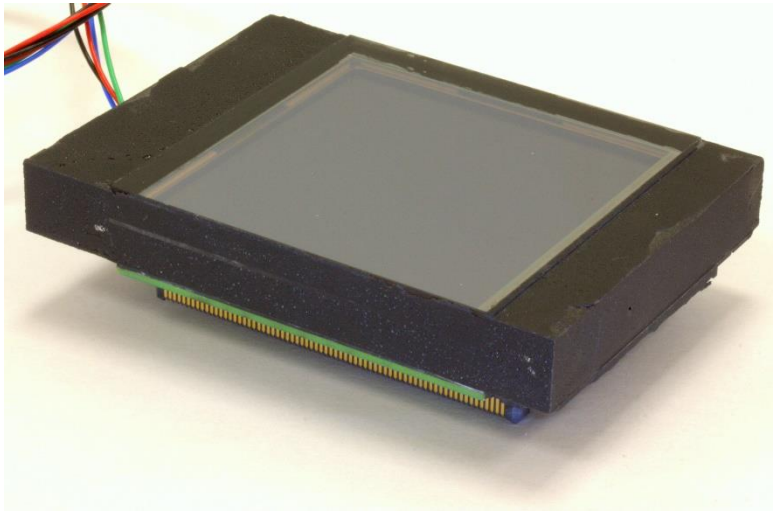
- Gang 8 x 1 pads together
- 8 x 64 array
- e.g. Samtec 140-pin multi-way





The TORCH detector format – Cerenkov PID

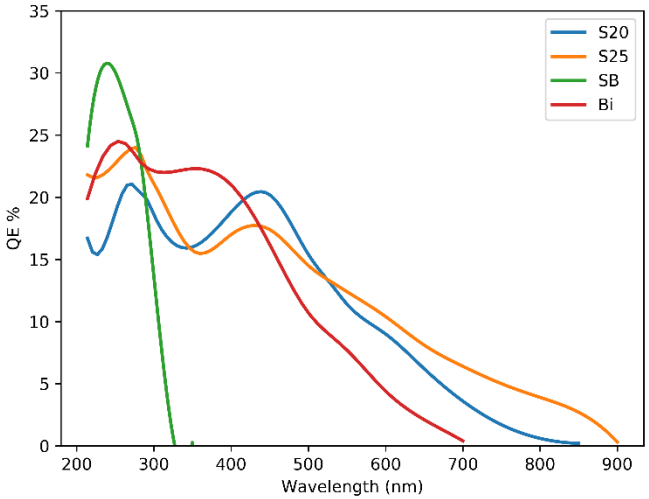


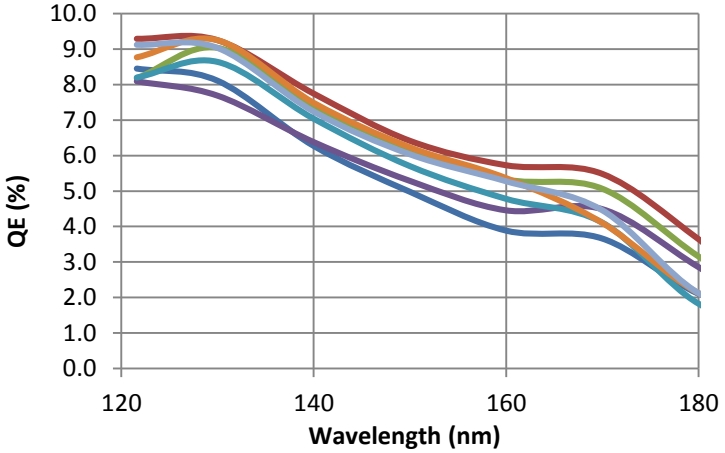


The TORCH project is funded by an ERC Advanced Grant ur Seventh Framework Programme (FP7), code ERC-2011-ADG 299175.

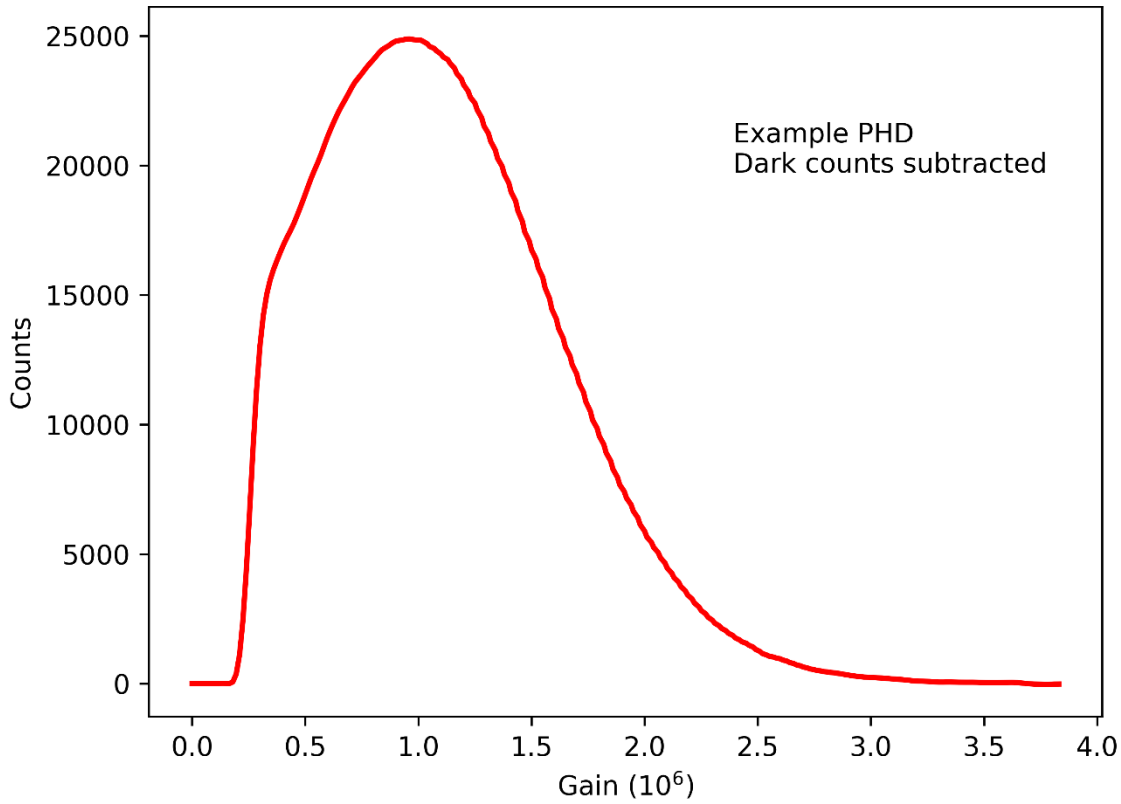
Spectral Response

- Broad range of photocathodes available
  - visible (S20, S25, Bialkali)
  - near-UV (solar blind)
  - deep-UV (CsI)



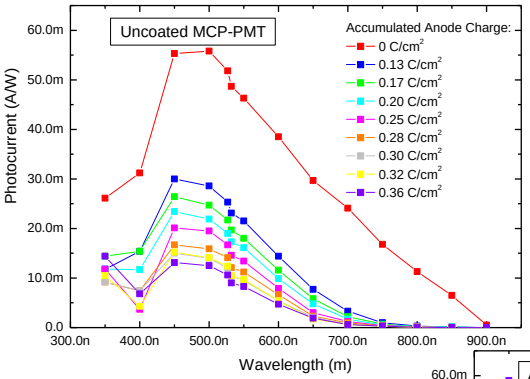


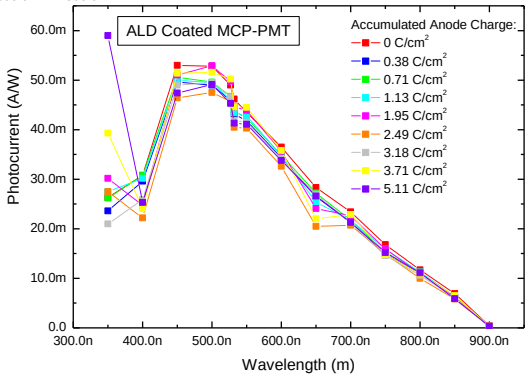
Single Photon Pulse Height Distribution

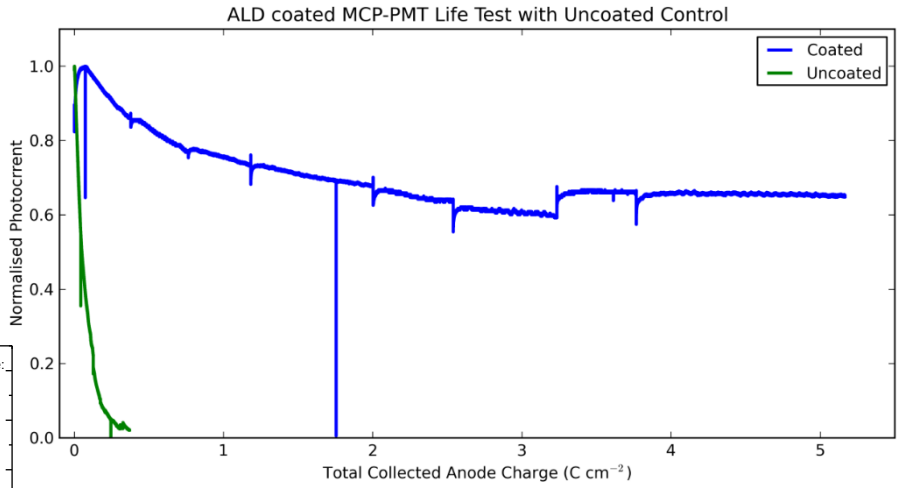


MCP-PMT Lifetime

- ALD has allowed Photek to achieve drastic improvements in detector lifetime
- Two PMTs produced: Double-MCP 10 mm diameter working area
  - One with ALD coated MCPs, One control with standard MCPs
  - Accelerated test: ~ 800 nA / cm^2 for ~ 14 weeks over small area



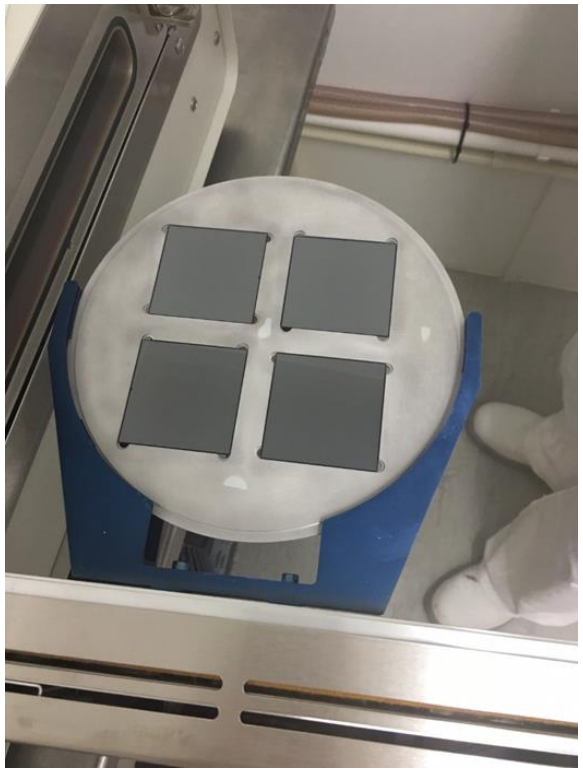


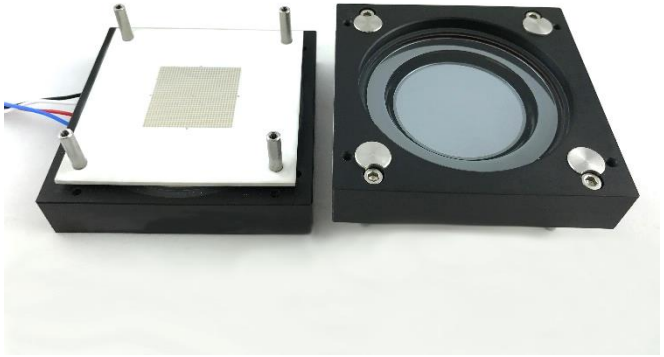


- Work presented by Conneely et al at VCI 2013

MCP-PMT Lifetime

- Photek have licensed Arradiance ALD technology for in-house coating of MCP substrates
- We have started a KTP project in collaboration with the University of Liverpool ALD research group
  - Embed ALD process knowledge in Photek
  - Optimise process to improve MCP collection efficiency
  - Use ALD for improving other aspects of detector performance



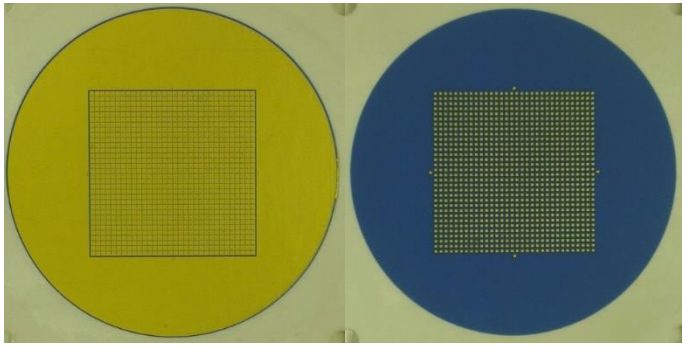


Round format, multi-anode MCP-PMT

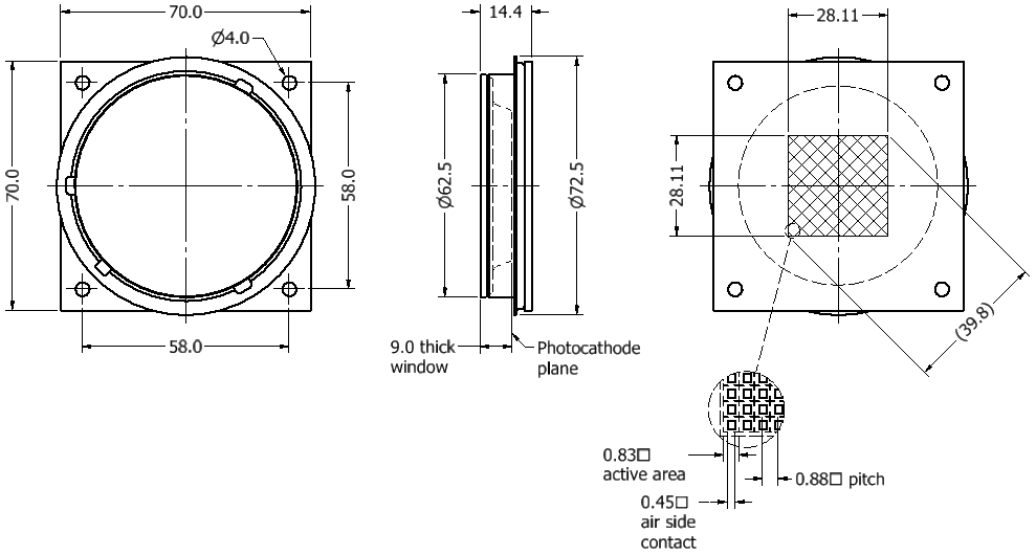
MAPMT228

Multi-Anode

- PMT228 has a 40 mm round format
- Allows a tight photocathode gap for timing performance
  - 0.2mm nominal gap
- Active area
  - 28x28mm area
  - 32x32 pads
  - 0.75 mm width on a 0.88 mm pitch

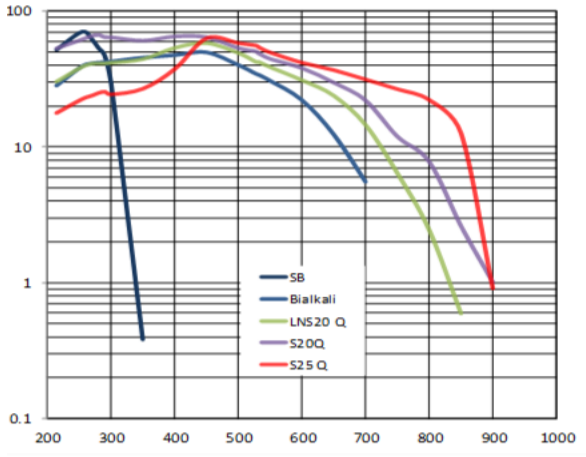


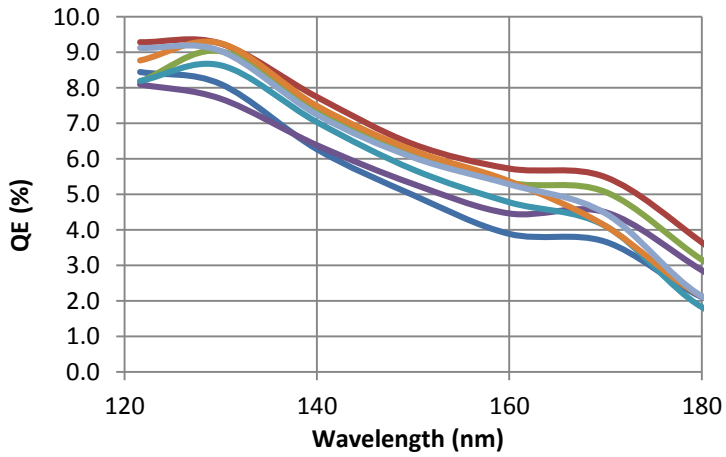
Vacuum side *Air side*



Input Windows

- Broad range of photocathodes available
- Fibre optic and fused silica input windows
- ALD available for enhanced lifetime

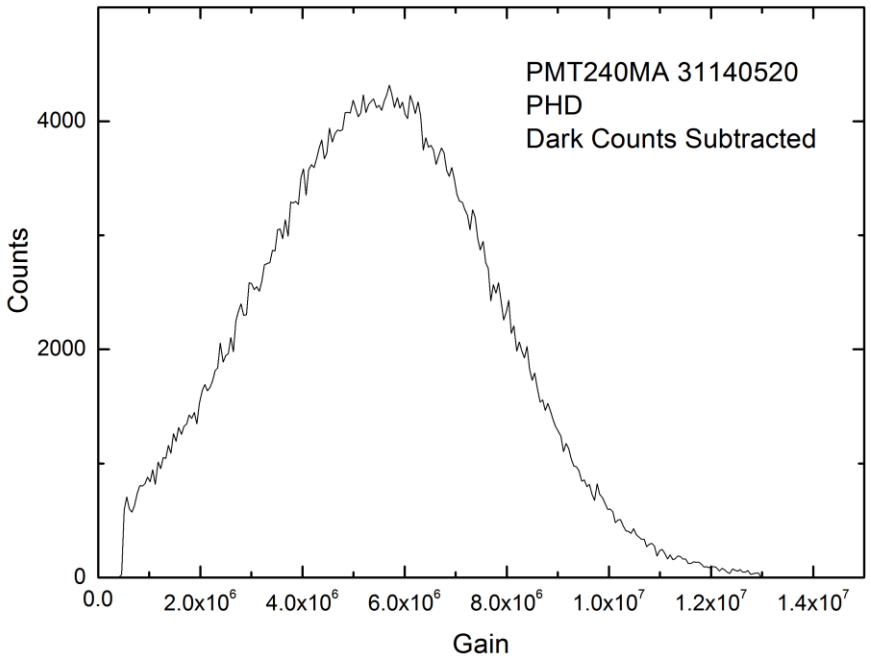




PCB Interface

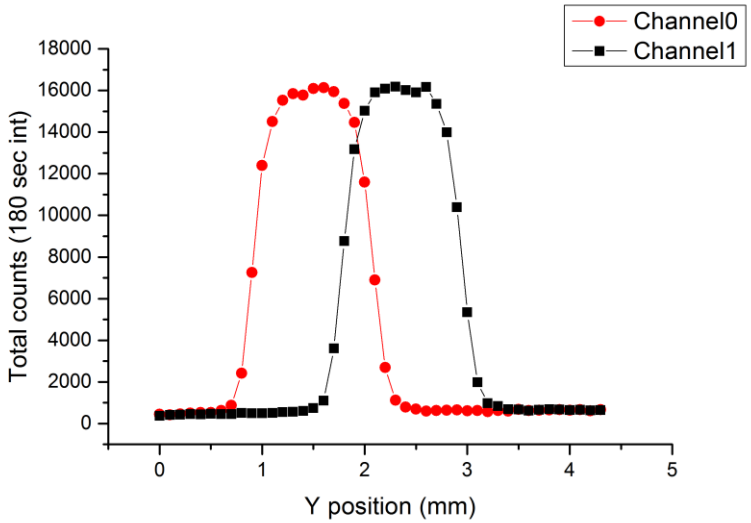
- Currently using “cold” ACF for interface PCBs
  - Does not produce permanent bond
  - Requires constant pressure applied to rear of detector during operation
  - However, PCBs can be changed after purchasing detector
- Possibility of customising anode layout grouping pads together

Gain

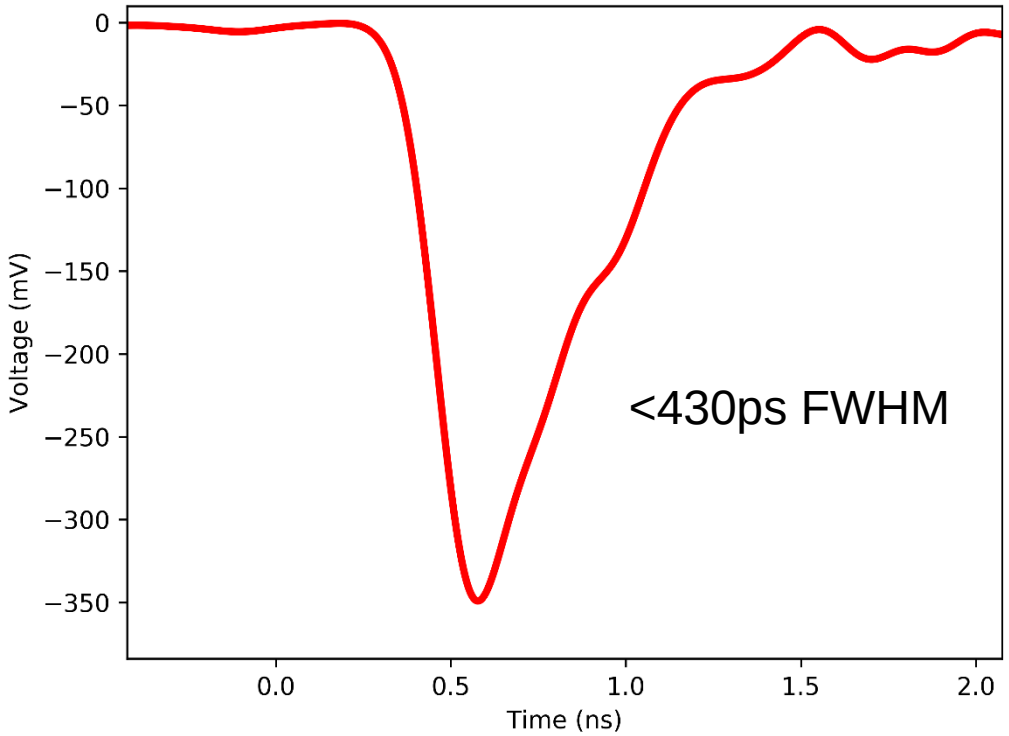

PMT240MA 31140520
PHD
Dark Counts Subtracted
Counts
4000
2000
0
0.0
2.0x10^6
4.0x10^6
6.0x10^6
8.0x10^6
1.0x10^7
1.2x10^7
1.4x10^7
Gain

Detector Crosstalk

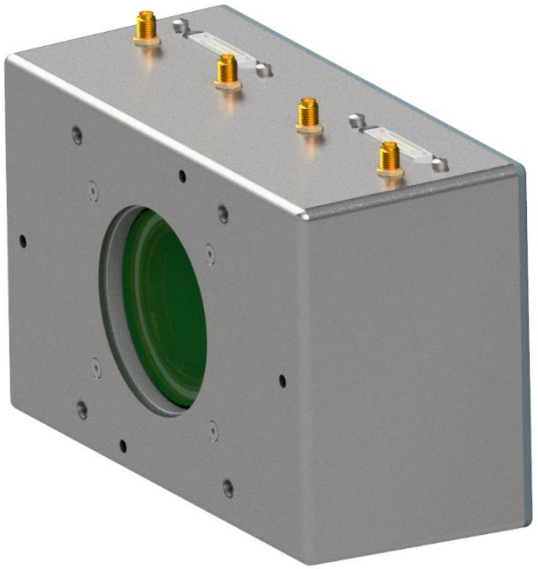
- Measured using single photon illumination at a gain of 5.5×10^6, 0.2 mm FWHM laser spot



Single anode signal



Average of 50 single photon pulses measured on 5 GHz, 20 GS/s scope, using a Photek LPG-405 pulsed laser.



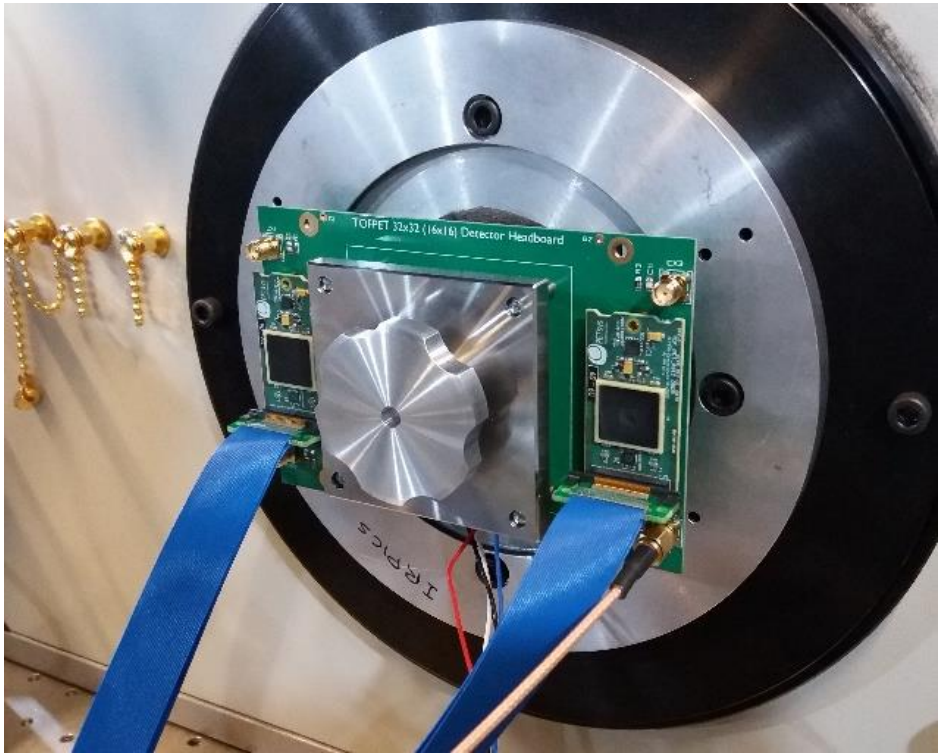
256 Multi-Anode detector with integrated timing electronics

PCS-256

Detector Specification

- Uses the PMT228 MCP detector as a baseline
- Instrumented to provide an 8×8 array of independent pixels
  - 1.5mm pad width, 1.76mm pitch

Multi-Anode / TOFPET Camera System



- Using TOFPET ASIC developed by PETsys Electronics SA (Booth 316)
- Demo available at Photek's Booth no. 318

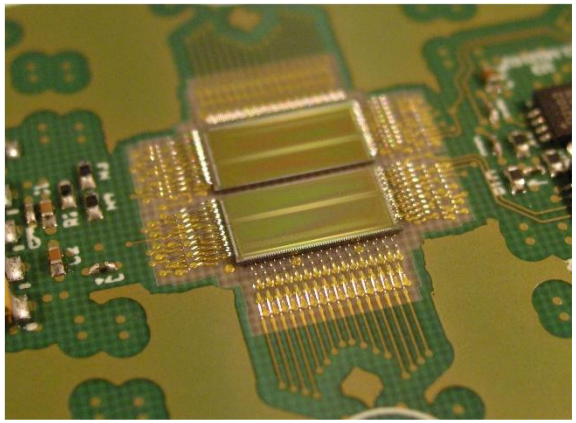
TOFPET ASIC

- Combined analogue frontend and time-to-digital convertor in a single ASIC
- 64 channels per chip (PCS-256 uses 4 ASICs in total)
- Ethernet connection to data acquisition PC
- Time over threshold technique used to correct for amplitude walk
- 160,000 c/s per channel rate limit

- TOFPET2 ASIC now available
  - Improved dynamic range
  - Higher per channel rate capability

- Plan to integrate new ASIC with system
- Further work to miniaturise the system

PETsys Electronics



Multi-Anode / TOFPET Camera System

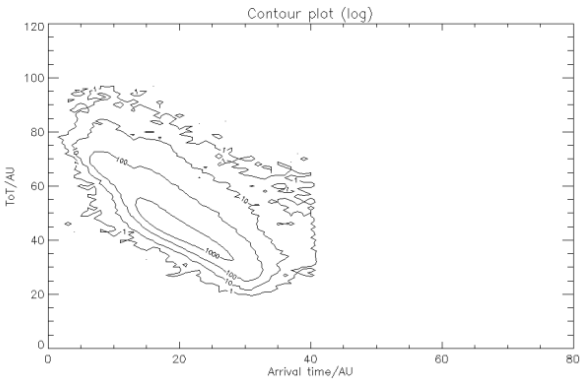
Results of TOFPET chip with MCP-PMT

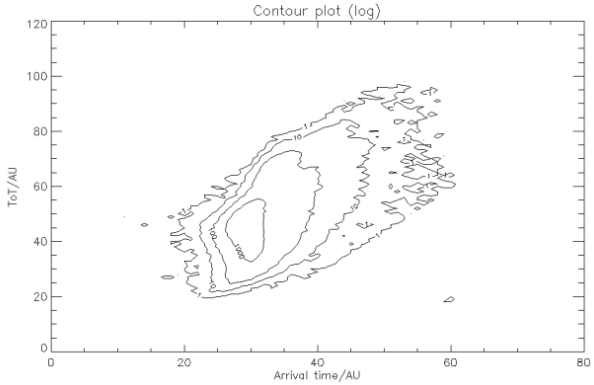
Thanks to Steve Leach & Jon Lapington (University of Leicester) for this data

Raw Data

Simple Linear Correction

Logarithmic plots of time-over-threshold vs arrival time

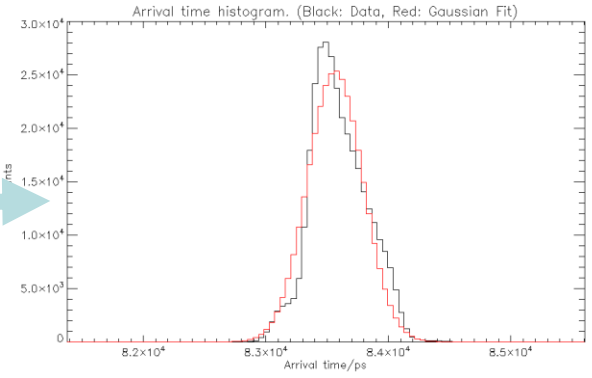


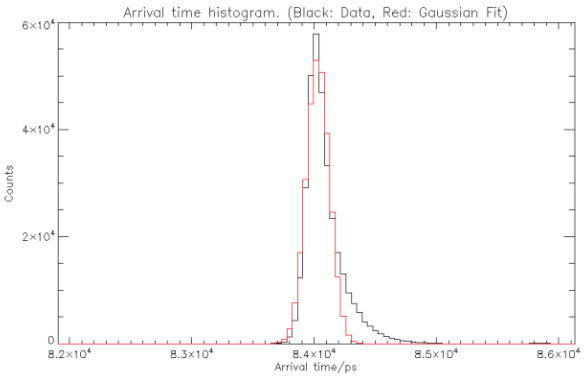


Single photon time resolution (black) with Gaussian fit (red)

Uncorrected σ = 225 ps

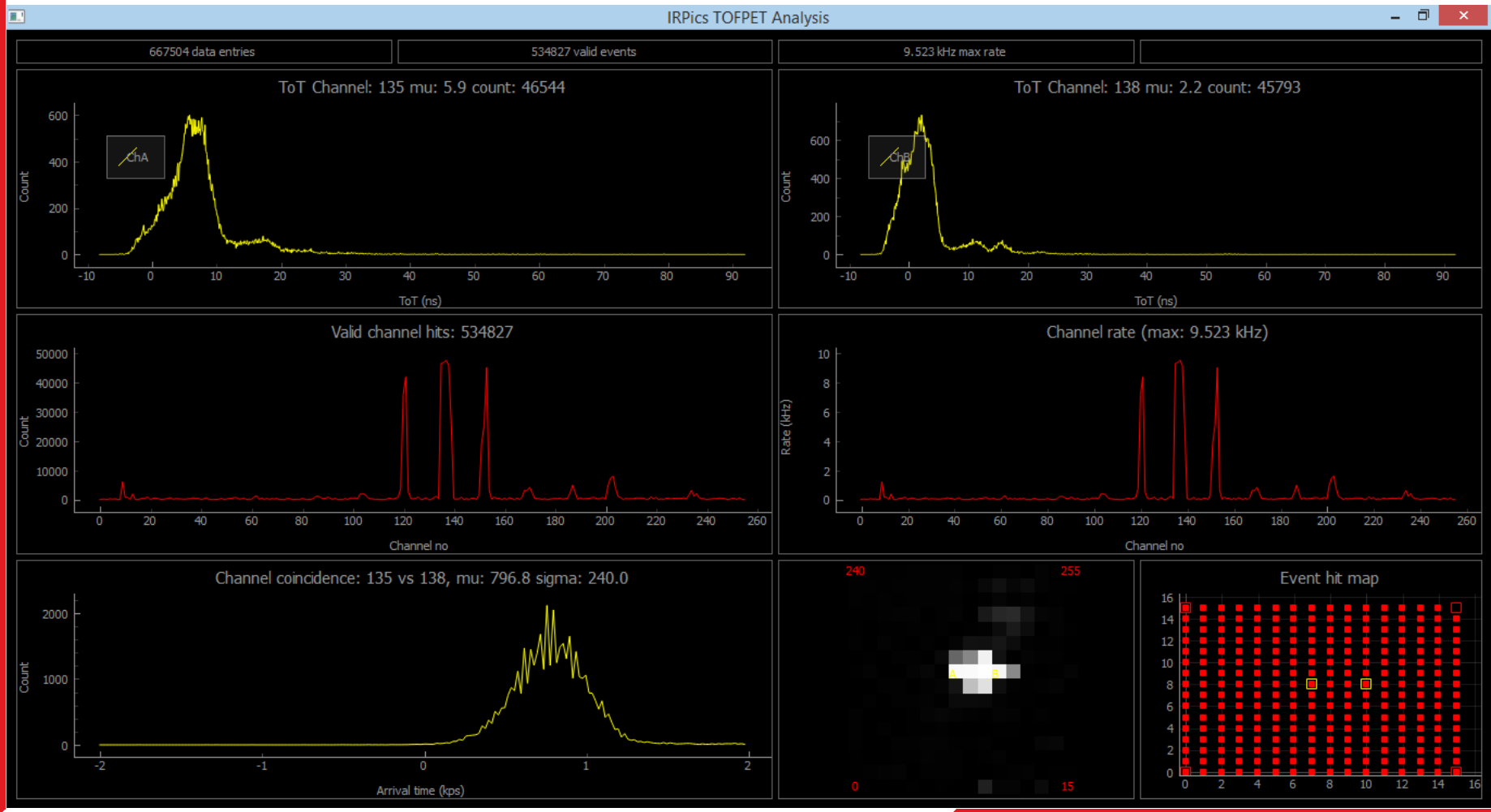
Corrected σ = 96 ps





Multi-Anode / TOFPET Camera System

Screenshot of provisional GUI:

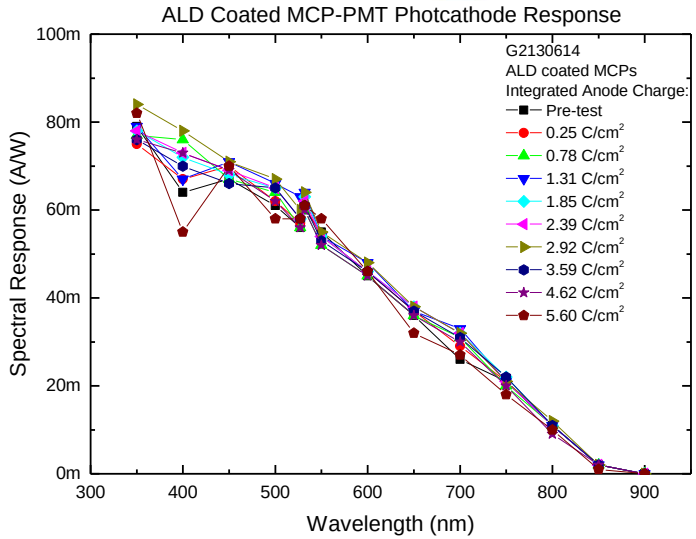


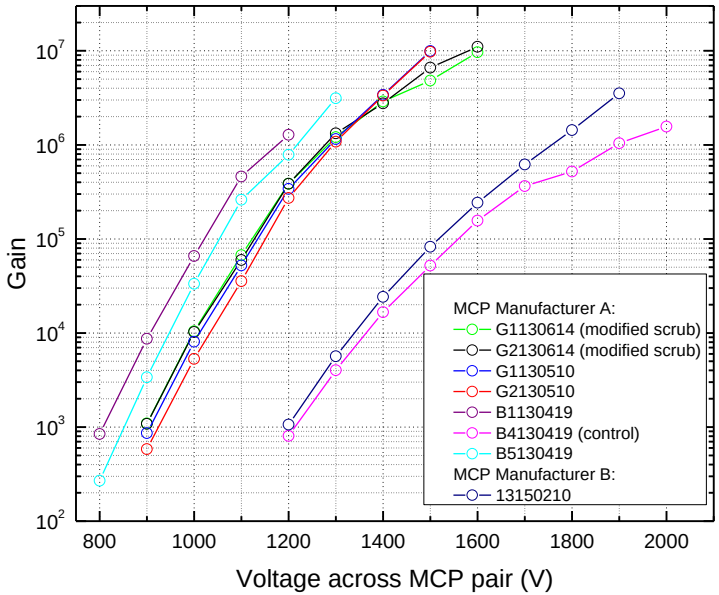
Thank you for listening

BACKUP SLIDES

MCP-PMT Lifetime

- We have also looked at different MCP manufacturers with same ALD coating
  - Differing outcomes for gain enhancement
  - Also some different lifetime results, currently being explored
  - May need different surface preparation or modification of ALD process

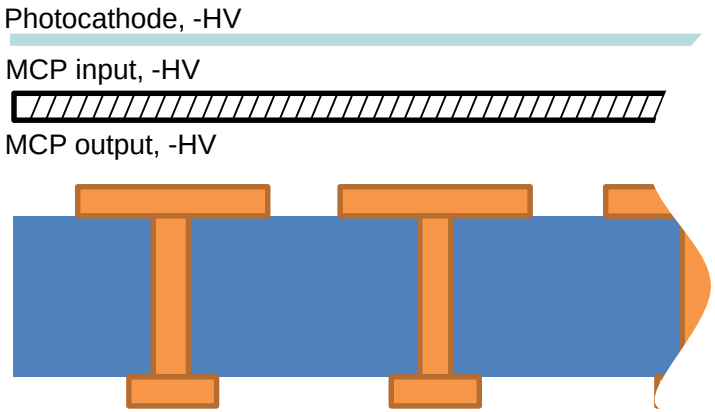




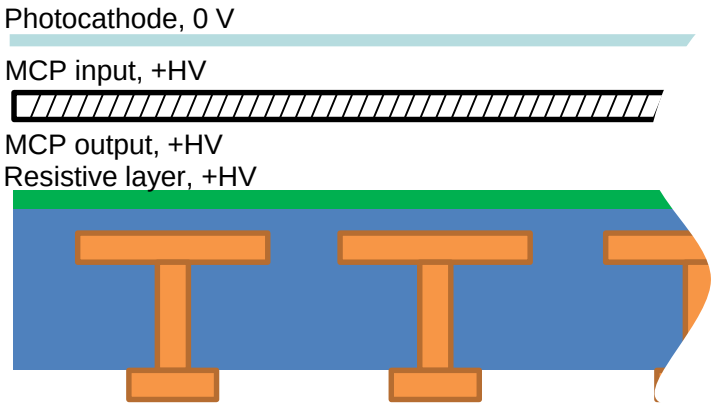
FUTURE DIRECTION

High granularity multi-anode

- Use a AC coupled anode to induce charge spreading
- TOFPET time-over-threshold measures charge collected by each anode
- Multiple pads readout in clusters, then centroiding algorithm used to reconstruct photon position
- Having A.C. coupled anodes allows the photocathode to be operated at 0 V
- Removes issues with charge-up on the input window



D.C. coupled anodes

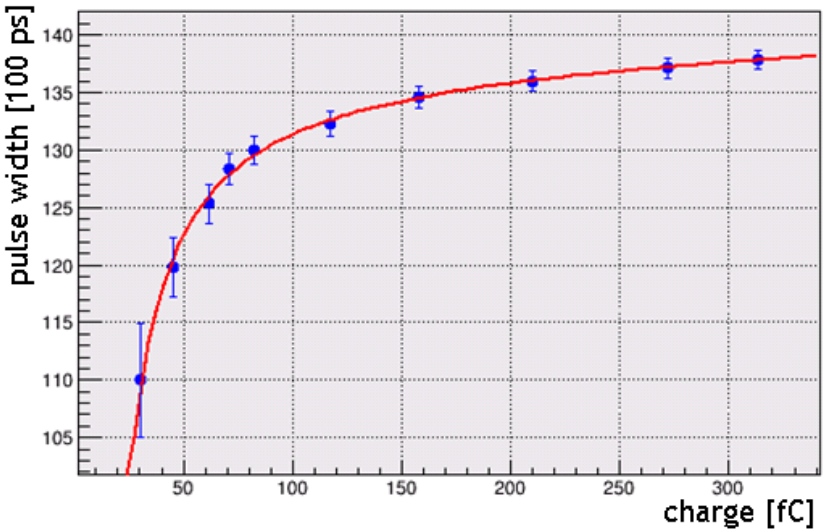


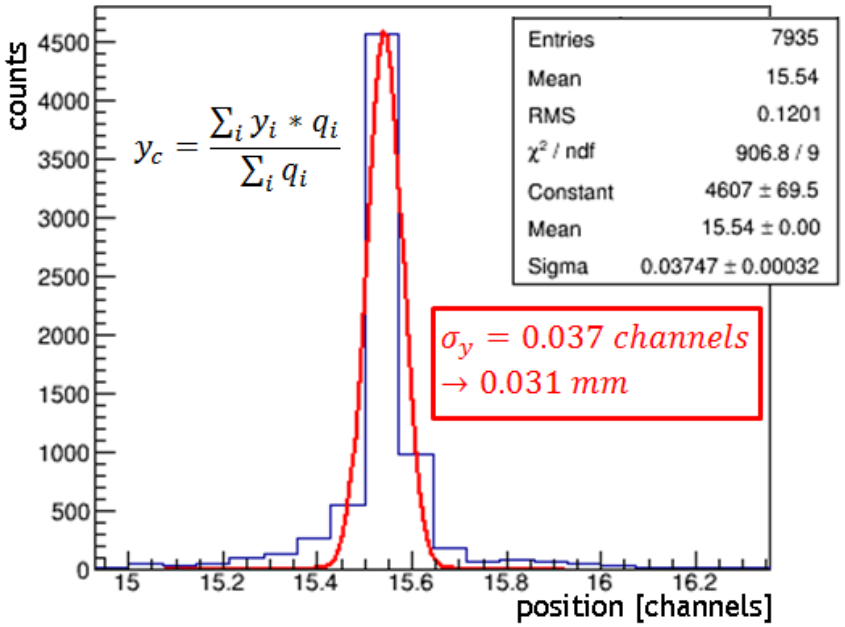
A.C. coupled anodes

Patent applications EP3107115 A1 & US20160370476 A1

High granularity multi-anode

- Concept has been demonstrated by the TORCH project in one dimension using alternative electronics (NINO + HPTDC)





- We plan to extend concept to 2D, using TOFPET ASIC

See L. Castillo García et al *JINST 11 C05022 (2016)*