Photek MCP Development

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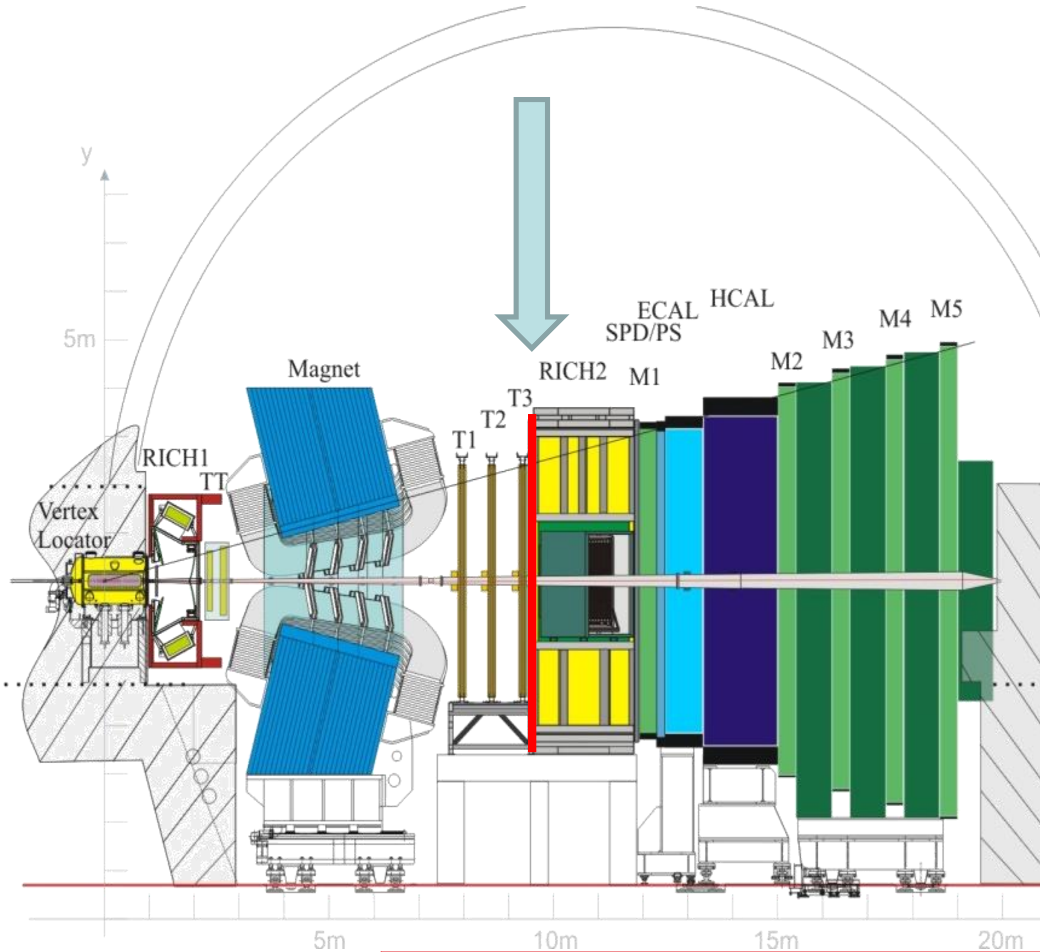
DIRC 2017

The TORCH PMT

- In November 2012 Photek began development of an MCP detector for the TORCH collaboration
- Technical aims:
  - A lifetime of 5 C/cm^2 of accumulated anode charge or better
  - A multi-anode readout equivalent to 8x128 pixels, in 60x60mm package
    - Fine pitch resolution target σ = 0.12 mm
  - Close packing on two apposing sides with a fill factor of 88% or better
    - 53 mm working width within a 60 mm envelope
- Photek contribution to the R&D project is no finishing
  - Shipped 10 detectors to CERN

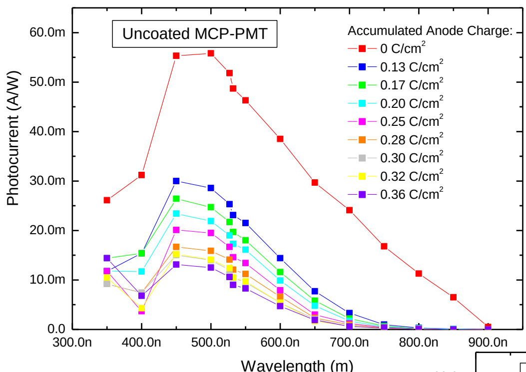
TORCH - Motivation

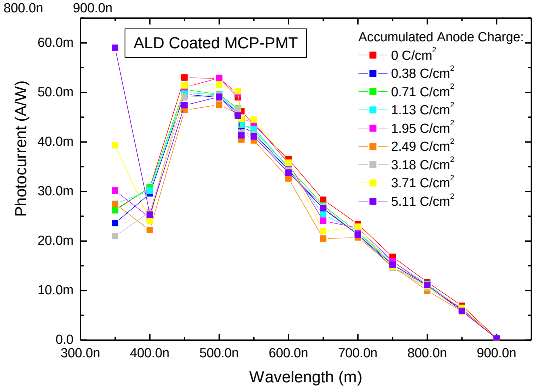
- TORCH is an ERC funded R&D project
- Proposal to upgrade LHCb Particle ID capabilities in 2-10 GeV/c region
- See talk by Neville Harnew (11.00 am, Tue)

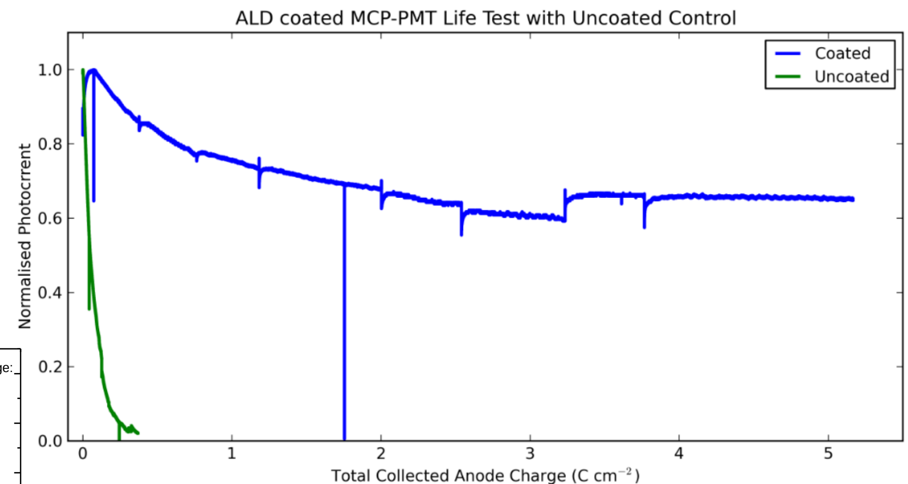


MCP-PMT Lifetime

- Photek had already achieved the life time aim in previous work
- Two PMT samples produced in 2011: 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





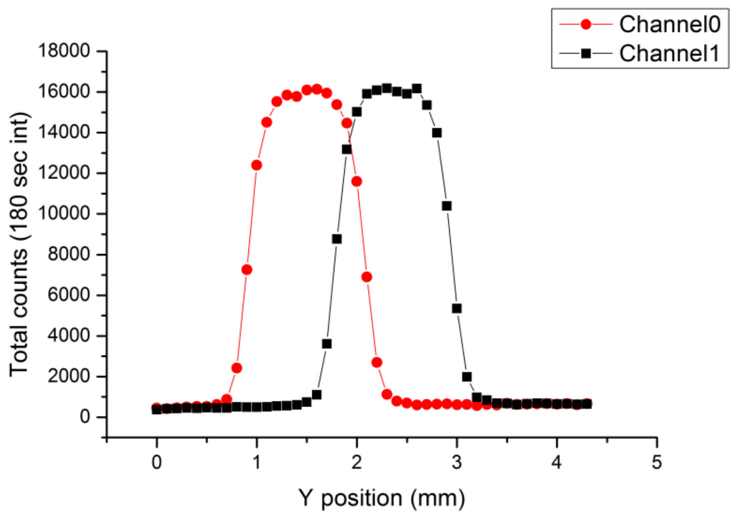


- Photek have licensed Arradiance ALD technology for in-house coating of MCP substrates

- Work presented by Conneely et al at VCI 2013

High Granularity Multi-anode

- TORCH required equivalent of 0.414 mm pixels (in one dimension)
- At this anode pitch cross talk must be considered



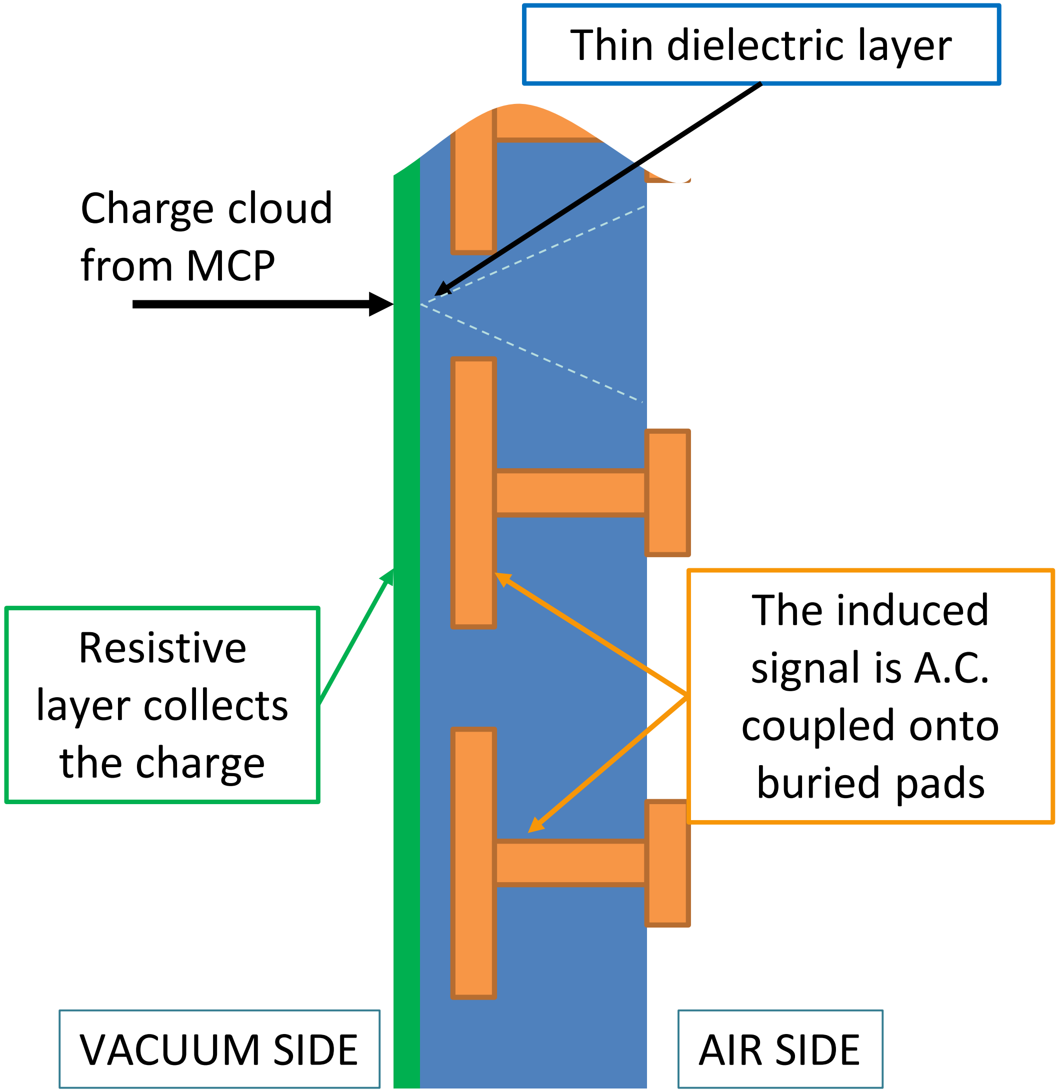
Crosstalk for 0.88 mm anodes
covers ~0.2 mm region

- Plus manufacturing constraints limit minimum pitch to ~0.5 mm
- For the TORCH project, how do we obtain position resolution beyond the pitch of the pads?

High Granularity Multi-anode

PHOTEK
ENVISAGE THE FUTURE

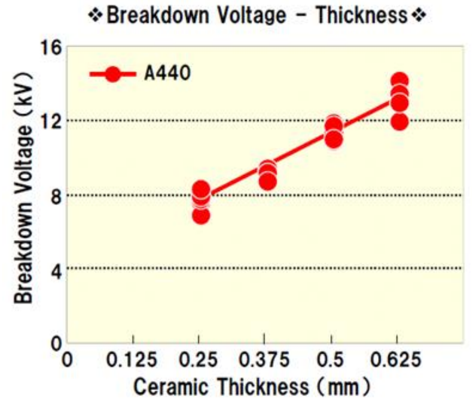
- Introduce a thin dielectric between charge collection and readout (AC coupling)
- Spreads the MCP charge footprint
  - Controlled and tunable size
- Use charge sharing algorithm to reconstruct photon position



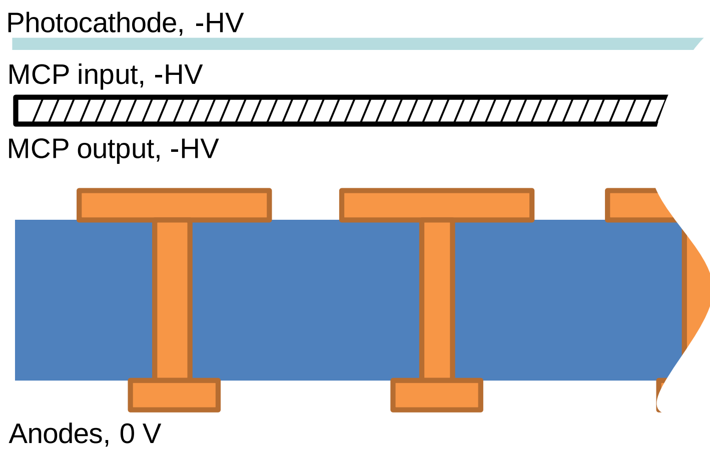
Patent applications EP3107115 A1 & US20160370476 A1

Advantages

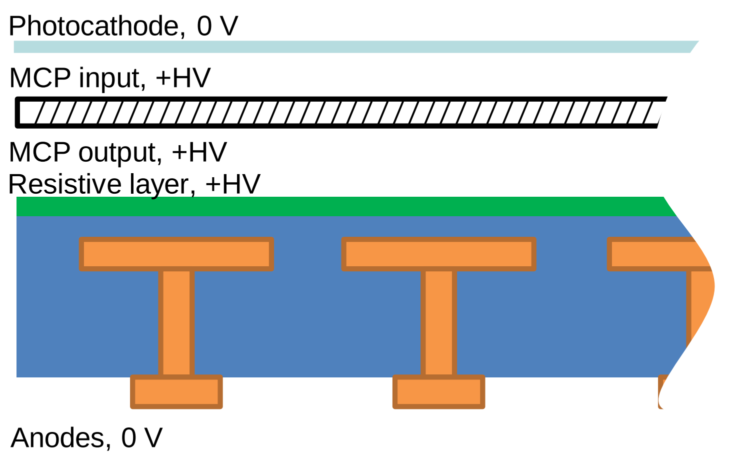
- AC coupled anode allows the photocathode to be operated at 0 V
  - Removes issues with charge-up on the input window
- Reduces required electronic channel count
  - However, requires more complicated readout/analysis



DC Anode

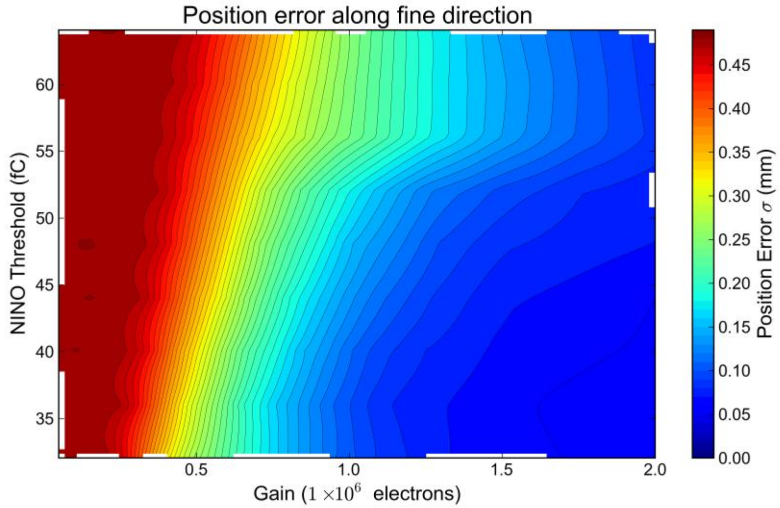


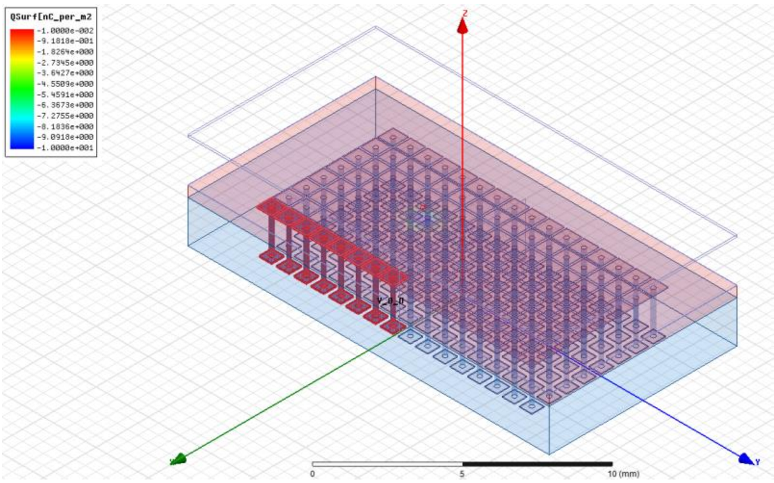
AC Anodes



Simulation

- ANSYS Maxwell modelling software used to optimise anode geometry
- Model had to consider:
  - Dimension of the thin insulator between the resistive layer and the buried pads
  - Pulse Height Distribution (gain variation) and jitter of MCP charge cloud
  - Threshold and other characteristics of the NINO front-end electronics
  - Temporal profile of the MCP cloud profile
  - The effect of the sheet resistance on charge footprint dispersion, and effects of electronics charge integration time
  - These factors are then applied to an imaging algorithm to produce a predicted resolution
- Modelling showed strong dependence on detector gain and NINO threshold

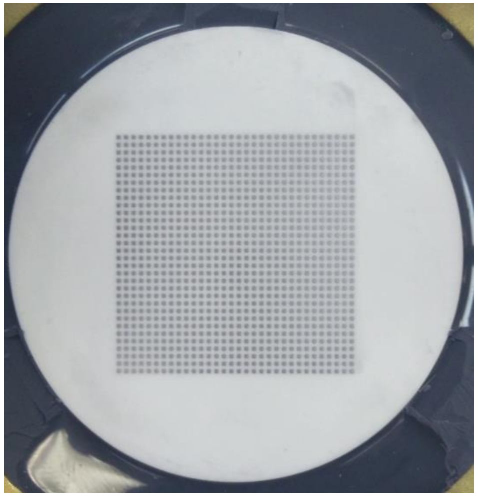


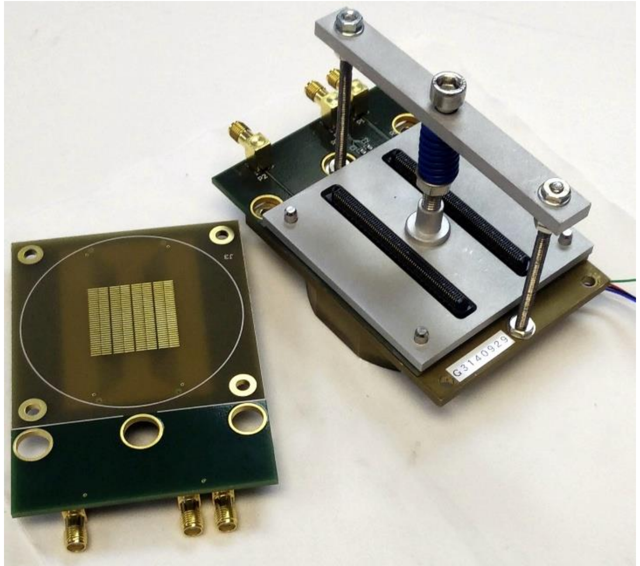


See Conneely *et al* JINST 10 C05003 (2015)

Prototypes

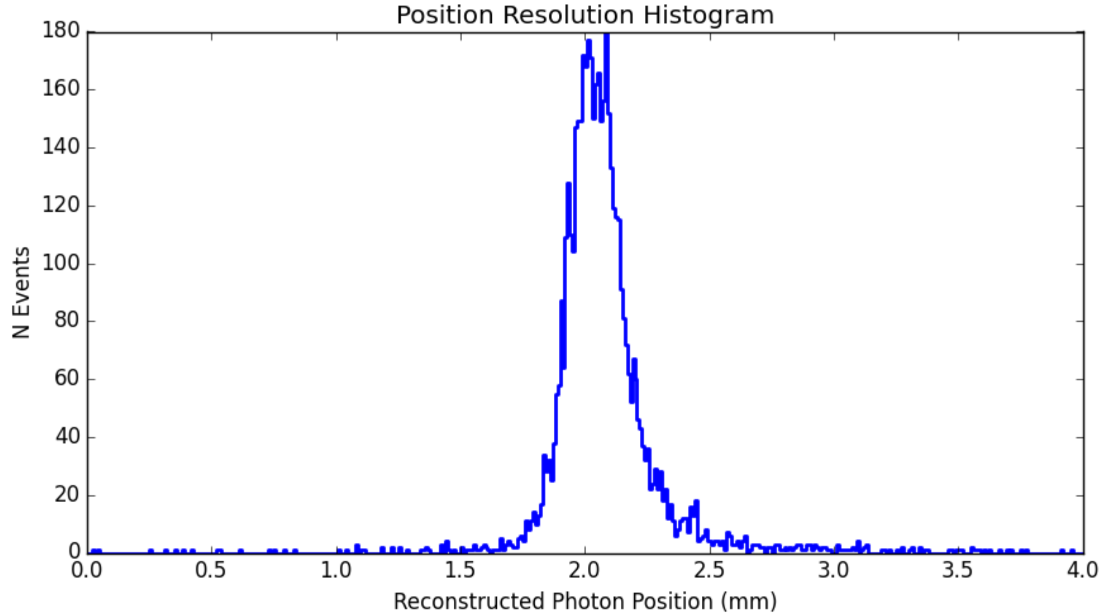
- First prototypes built with 32×32 multi-anode charge sharing anode in round format ~ 26 x 26 mm working area
- In one direction 8 pads ganged together to create 32×4 layout
- These represent ¼ size of final detector (target 128 x 8)
- Use mechanically applied Anisotropic Conductive Film (ACF) to connector detector output to readout PCB





Position Resolution – Early Result

- Measured on 4-channel oscilloscope
- TORCH target σ = 0.12 mm
- σ = 0.096 mm (0.225 mm FWHM) derived from pads on a 0.83 mm pitch



$$x = \frac{\sum_{i=0}^{3} x_i q_i}{Q}$$

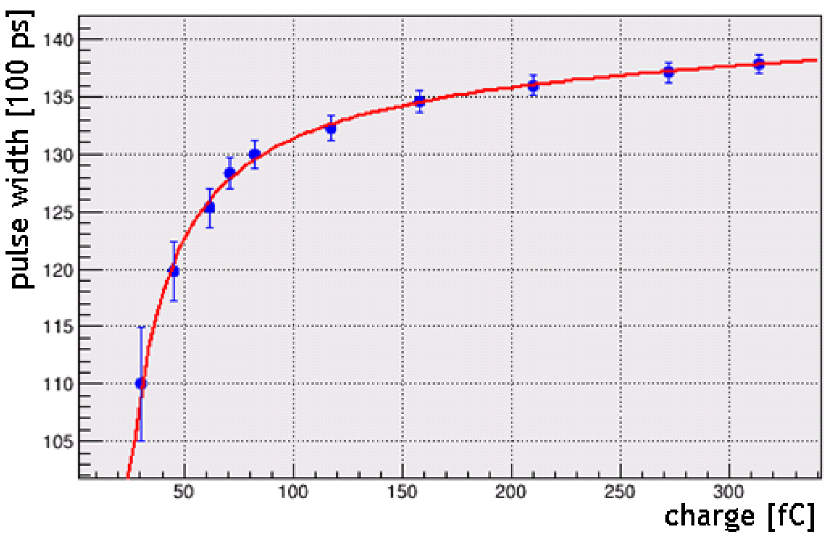
x_i is co-ordinate of pad

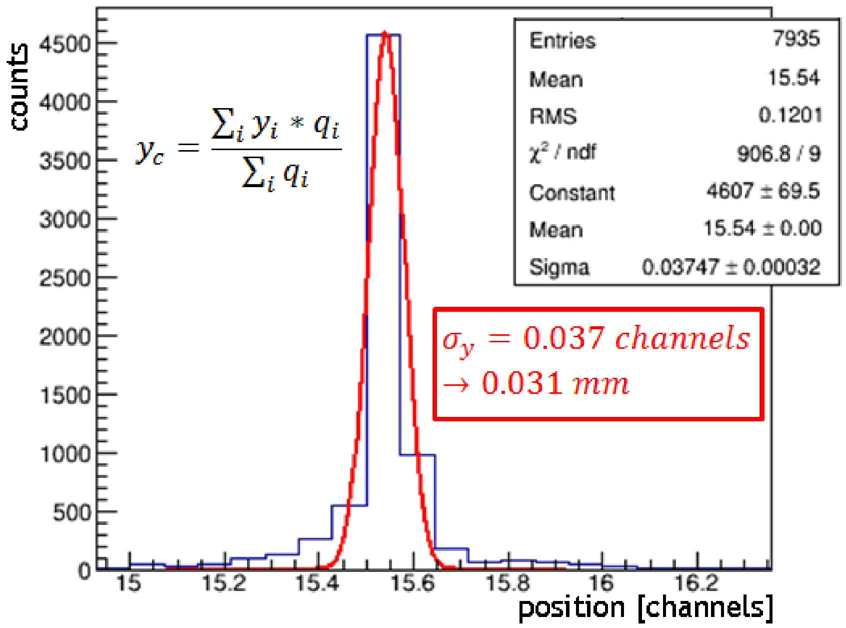
q_i is charge collected by pad i

Q is the sum of all charge collected

Position Resolution – NINO Measurement

- Measurements using the NINO ASIC has it challenges
  - Each channel needs individual charge to width calibration
  - Odd / even channels behave differently for TORCh prototypes (different capacitive loads)
- Despite these issues, an excellent result was achieved:

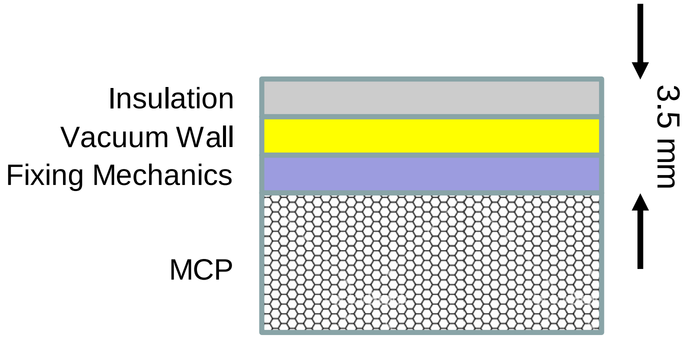


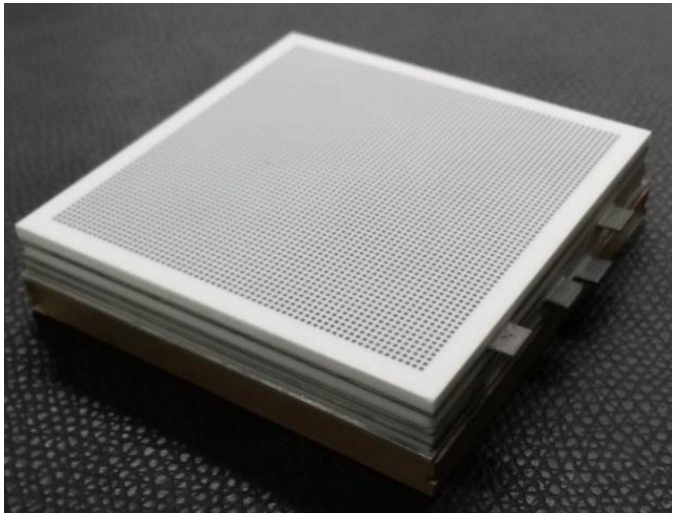


See L. Castillo García et al *JINST 11 C05022 (2016)*

Square Tube Development

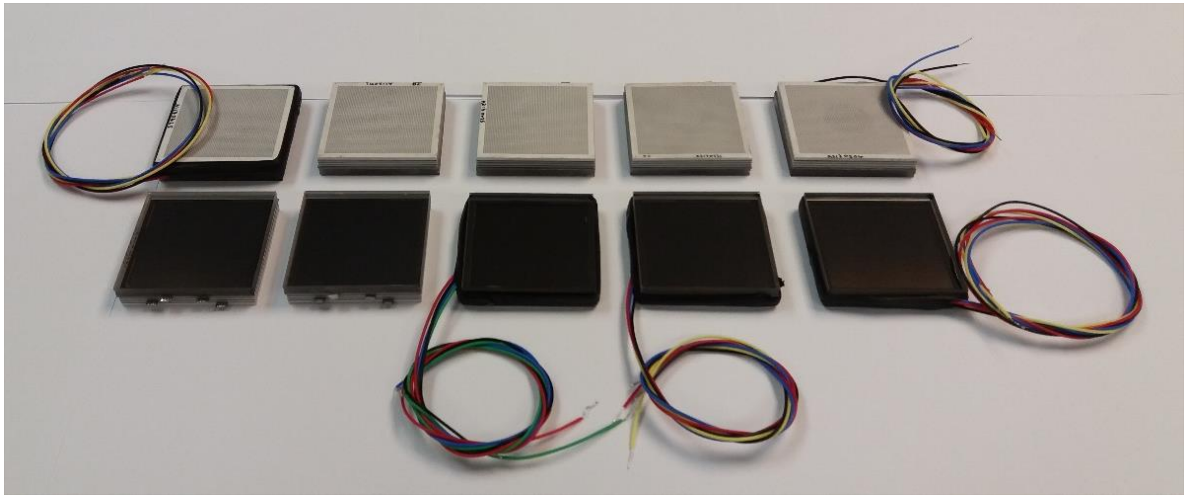
- Increased working area to 53 x 53 mm
- Pad format now 64 x 64
- DC coupled pad anode design developed in parallel
- Our novel MCP fixing method allows short gaps between photocathode, MCPs and anode
- Predicted gap between photocathode and MCP to be 1.5 – 2 mm
- Predicted MCP – anode gap is 2.5 – 3 mm



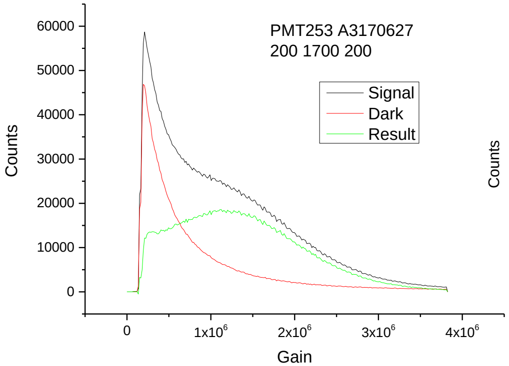


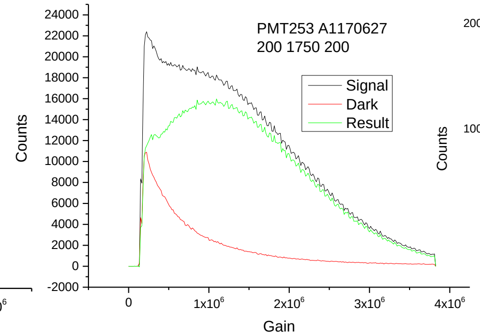
Square Tube Development

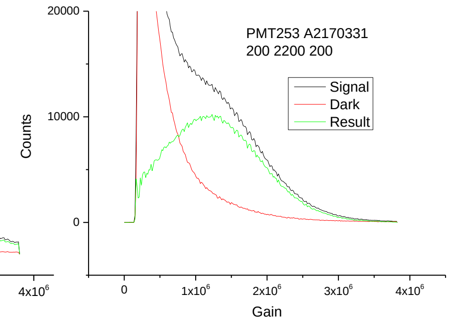
PMT Serial Number	Cathode – MCP gap	PMT Serial Number	Cathode – MCP gap
A1170227	1.95 mm	A1170331	1.58 mm
A2170504	2.00 mm	A2170331	1.51 mm
A3170504	1.42 mm	A3170331	1.99 mm
A1170425	1.47 mm	A2170412	2.00 mm
A3170425	1.47 mm	A3170412	1.83 mm

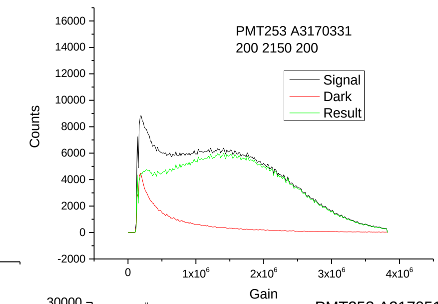


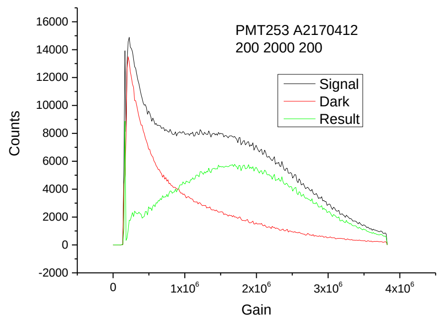
Gain Distribution of Square PMTs

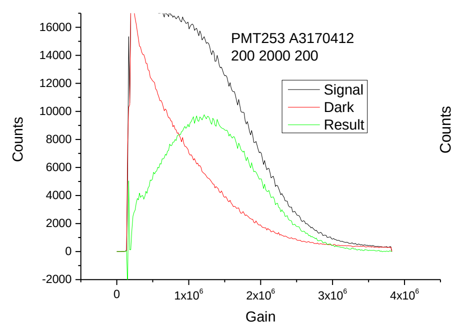


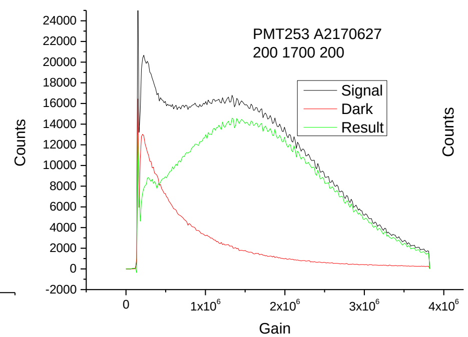


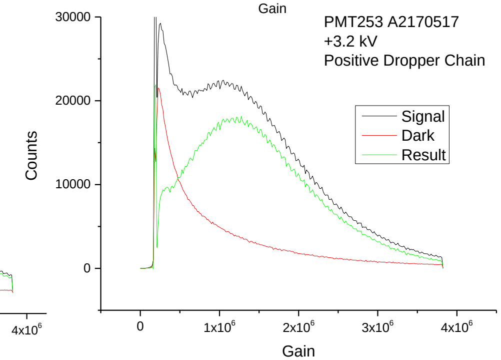


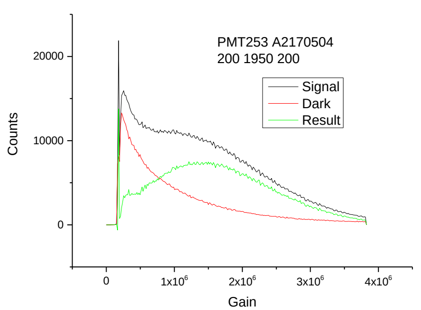


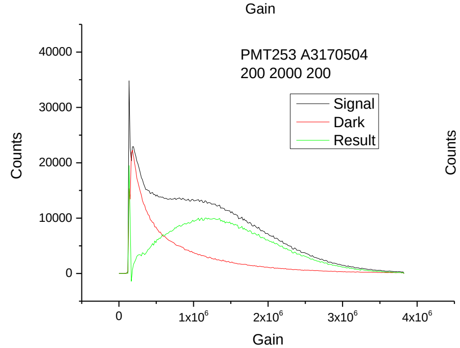


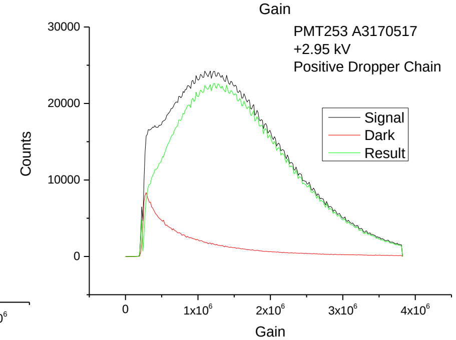








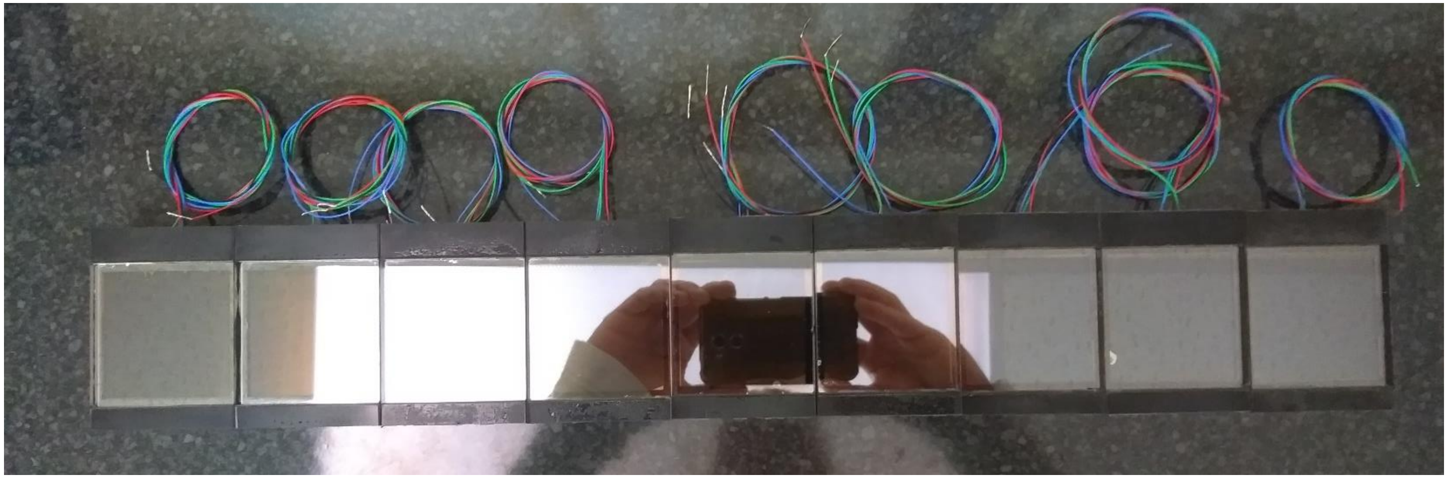


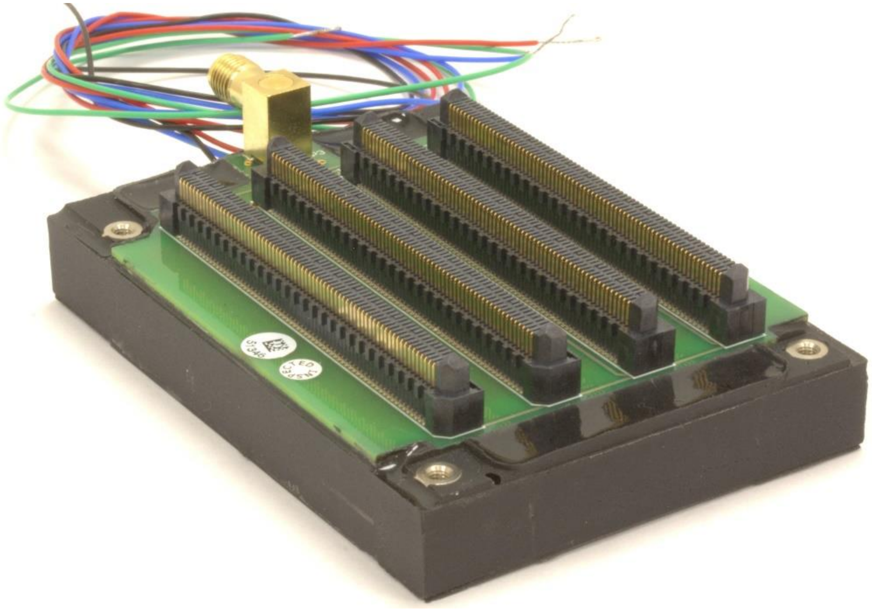


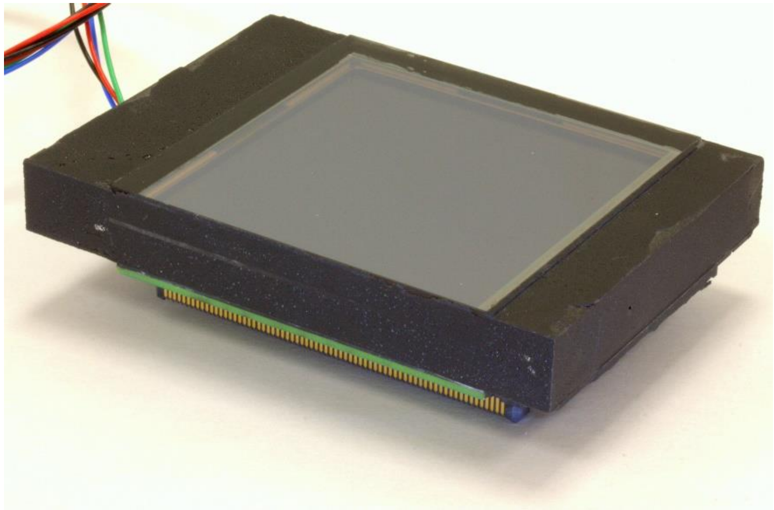
PHDs obtained by:
- Contacting a 25 mm single tapered anode to the central output pads
- Illuminating a central 13 mm diameter region with UV light
- Subtract dark counts from the raw signal to show the true PHD

TORCH - Current Status

- 10 detectors shipped to CERN for characterisation by TORCH group with their electronics
- Photek to continue characterisation of just the detector (no NINO)



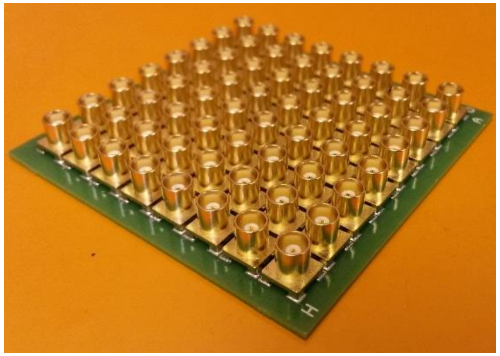




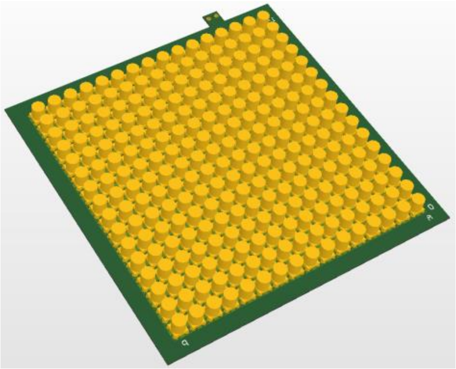
Commercial Square PMT

- Unrealistic to individually connect all 4096 connections in 64 x 64 array to front-end electronics
- However, this format gives flexibility to gang pads together
- We have recently commissioned an ACF (anisotropic conductive film) kit to bond various PCB designs to the output pads of the PMT

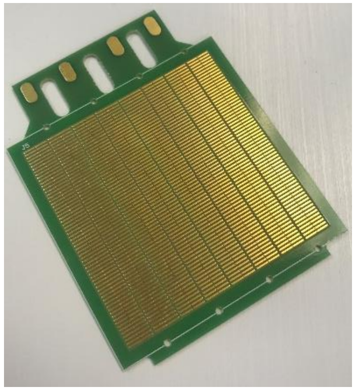
- Gang 8 x 8 pads together
- 8 x 8 array
- e.g. MCX co-ax

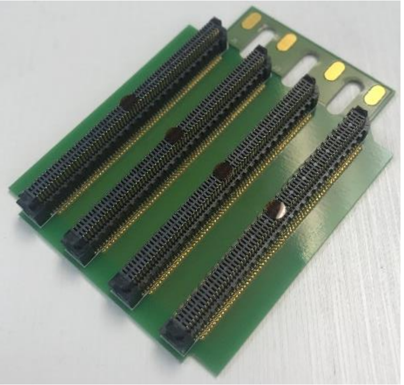


- Gang 4 x 4 pads together
- 16 x 16 array
- e.g. SSMCX co-ax



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

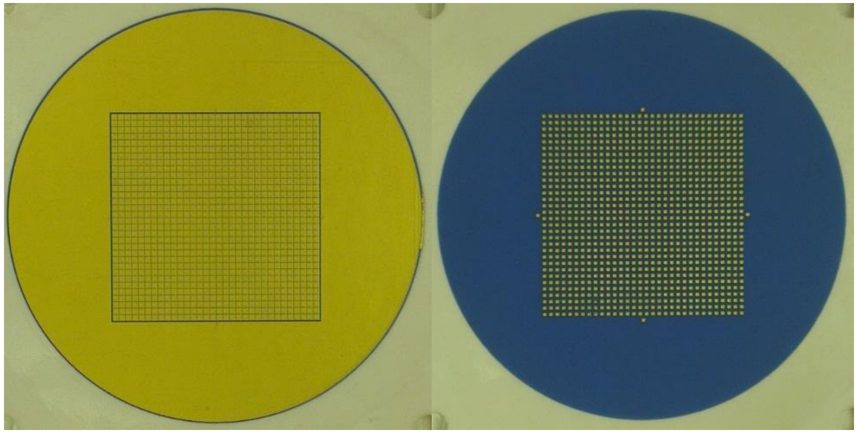




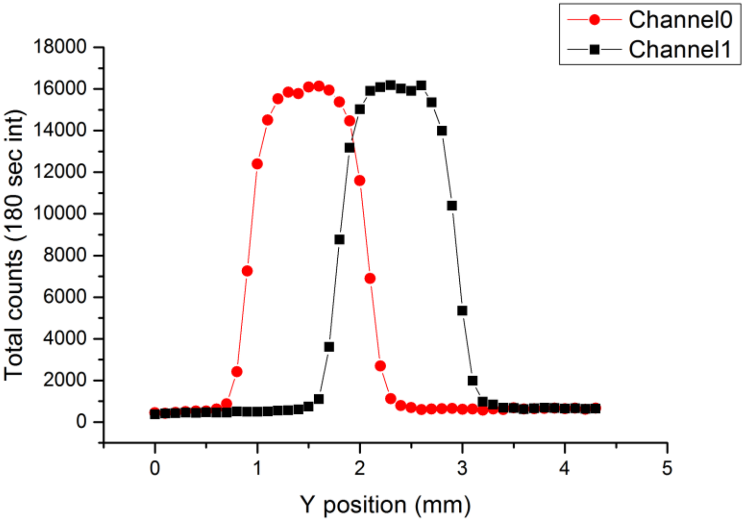
ELECTRONICS DEVELOPMENTS

Multi-Anode / TOFPET Camera System

- Previous project (*IRPics* with University of Leicester) had produced a 40 mm round PMT with 32 x 32 pads, 0.75 mm wide on a 0.88 mm pitch
- Multilayer ceramic with filled vias
- Cross talk measured using single photon illumination at a gain of 5.5×10^6, 0.2 mm FWHM laser spot



Vacuum side *Air side*



TOFPET ASIC:

- Sourced as alternative to NINO
- Combined analogue frontend and TDC in single ASIC
- 64 channels per chip
- < 100 ps rms with time over threshold correction
- 160,000 c/s per channel rate limit
- TOFPET2 now available with 600,000 c/s and full charge integration per channel

Multi-Anode / TOFPET Camera System

Package containing 2 x TOFPET chips – 4 in total

32 x 32 PMT with mechanically compressed ACF

- Anode pads ganged into groups of 4
- Using evaluation kit supplied by PETsys Electronics SA
- 16 x 16 channel system
- Pre-production prototype
- Available for site testing
- Demo to be launched at IEEE NSS/MIC Atlanta

Multi-Anode / TOFPET Camera System

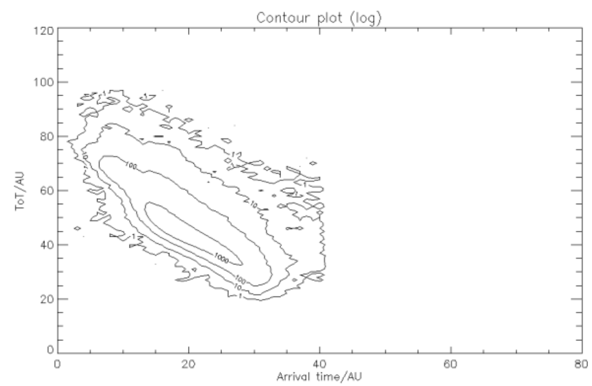
Results of TOFPET chip with MCP-PMT

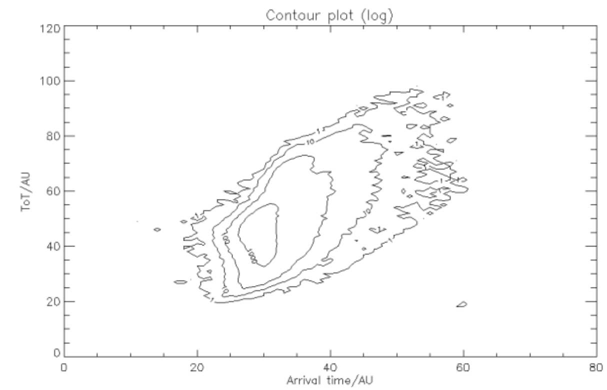
Thanks to Steve Leach & Jon Lapington (University of Leicester) for this data

Raw Data

Simple Linear Correction

Logarithmic plots of time-over-threshold vs arrival time

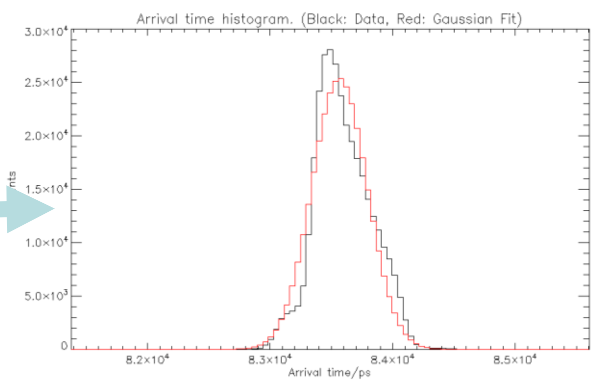


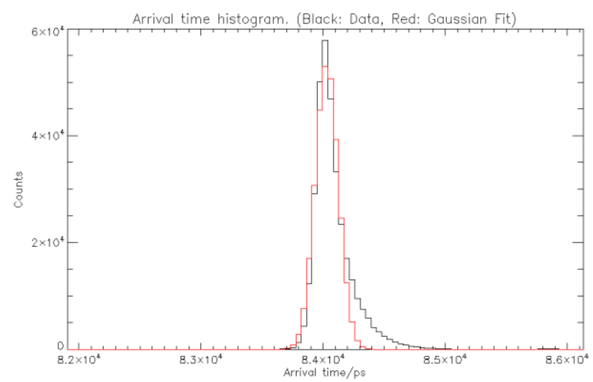


Single photon time resolution (black) with Gaussian fit (red)

Uncorrected σ = 225 ps

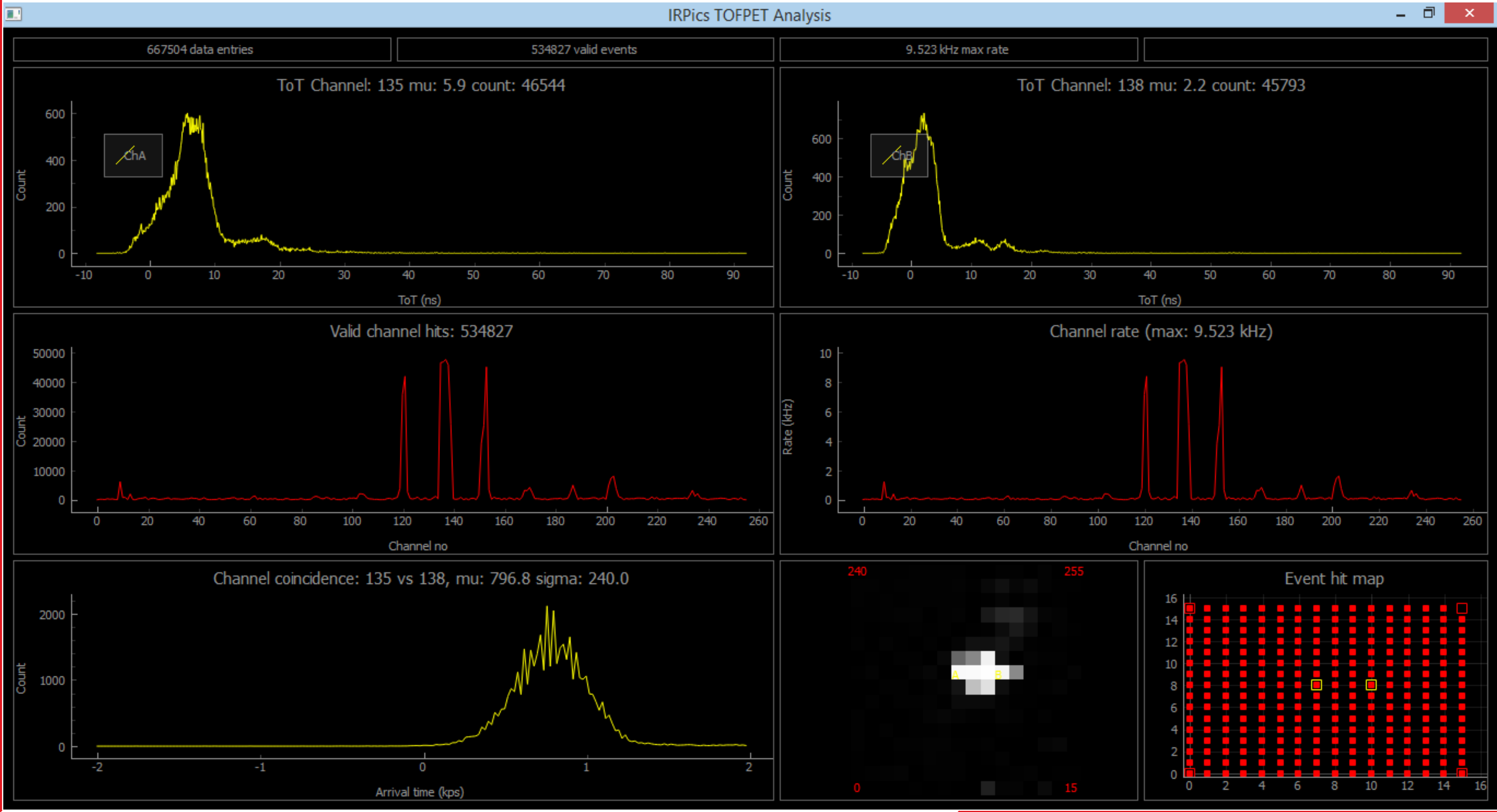
Corrected σ = 96 ps





Multi-Anode / TOFPET Camera System

Screenshot of provisional GUI:



Development time line

- Laboratory demonstrator available Autumn 2017
- Miniaturised system Spring/Summer 2018
- Combine TOFPET electronics with a TORCH like, charge sharing device?

Conclusion

- Ten new square, charge sharing, multi-anode detectors shipped to the TORCH collaboration
  - Prototypes have shown promising timing and spatial resolution
  - Results from characterisation of square format to follow over the coming months
- New electronics development available for lab testing soon

With thanks to…

The members of the TORCH collaboration at the University of Bristol, CERN and the University of Oxford

For IRPICs developments Jon Lapington & Steven Leach at University of Leicester

PETSys Electronics

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Thank you for listening