The TORCH PMT:

A close packing, multi-anode, long life MCP-PMT for Cherenkov applications

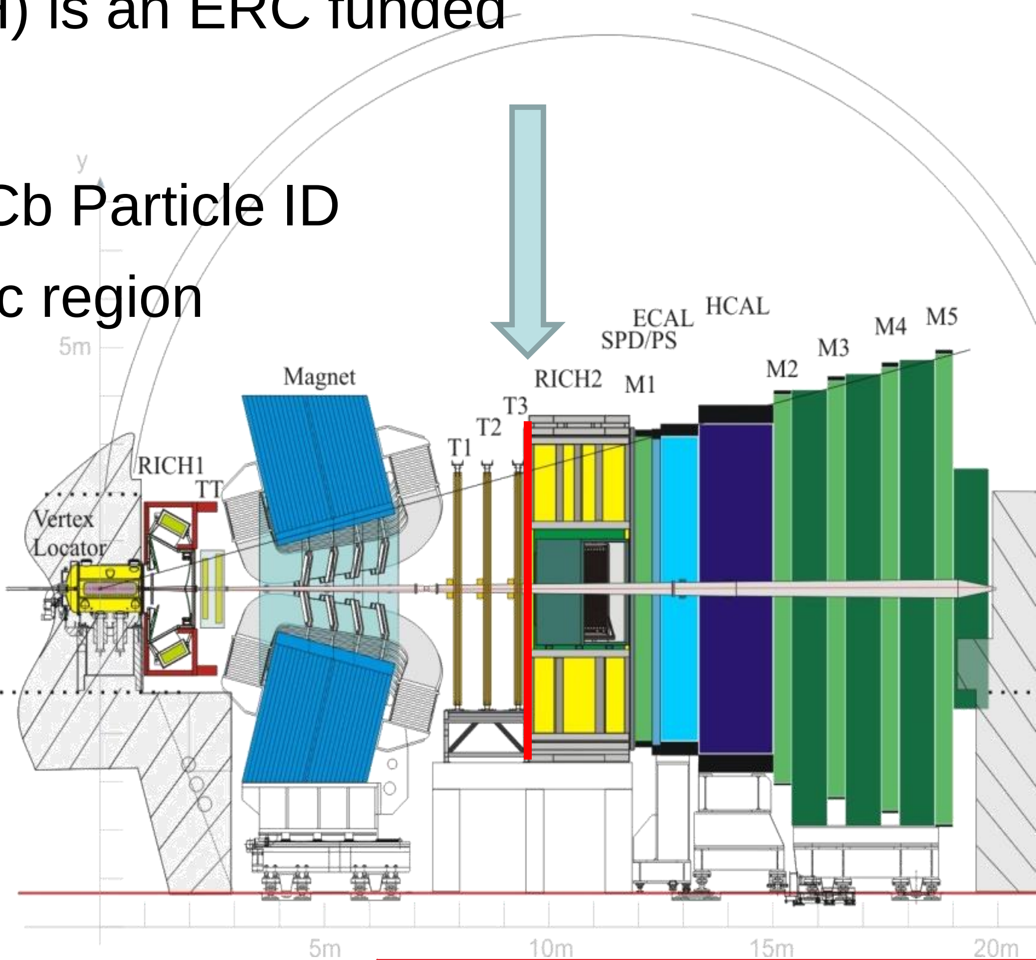
Contents

- TORCH project reqiurements
  - Position sensitivity
  - Timing
  - Lifetime
- Prototype detector
  - Design
  - Characterisation
- ACF Bonding - High density detector/electronics interconnect

THE TORCH PROJECT
PHOTON DETECTOR REQUIREMENTS

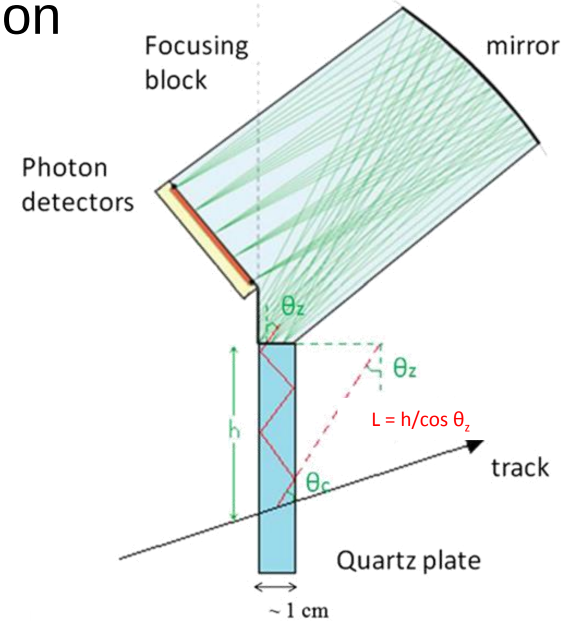
TORCH - Motivation

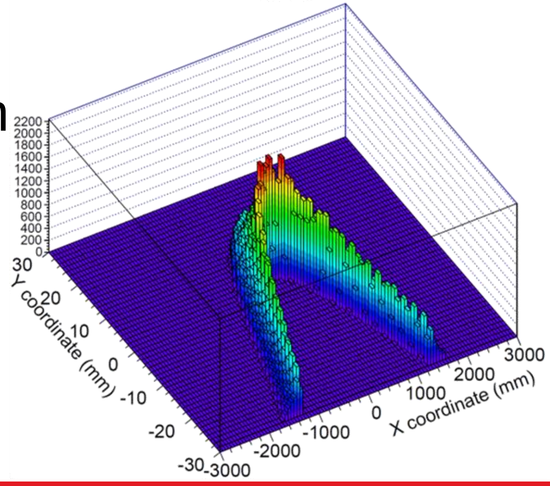
- The Timing Of internally Reflected Cherenkov light (TORCH) is an ERC funded R&D project
- Proposal to upgrade LHCb Particle ID capabilities in 2-10 GeV/c region



Photon Detector - Spatial

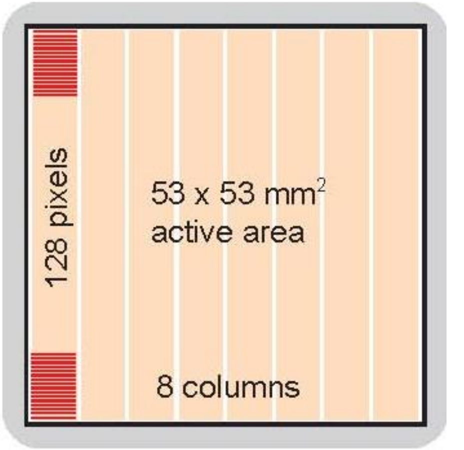
- Photon propagation angle converted into position on focal plane
- Produces “smile” corresponding to the Cherenkov ring
  - One axis has long arm → coarse spatial resolution
  - One axis has short arm → fine spatial resolution
- For 2” square tube, and 1 mrad angle resolution
  - 128 pixels for fine axis, 0.41 mm pitch
  - 8 pixels for coarse axis, 6.63 mm pitch





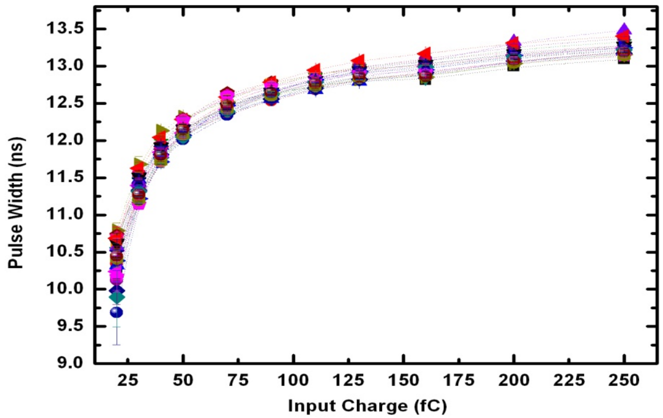
Photon Detector - Spatial

- We plan to use a hybrid charge sharing/multi-anode design
  - Artificially enlarge charge footprint to spread over multiple readout pads
  - Reduces number of required channels
  - Allows operation of detector with anode at high voltage (AC coupling)
- Reconstruct photon position using charge sharing algorithm
- Requires charge sensitive electronics to reconstruct position



Electronics

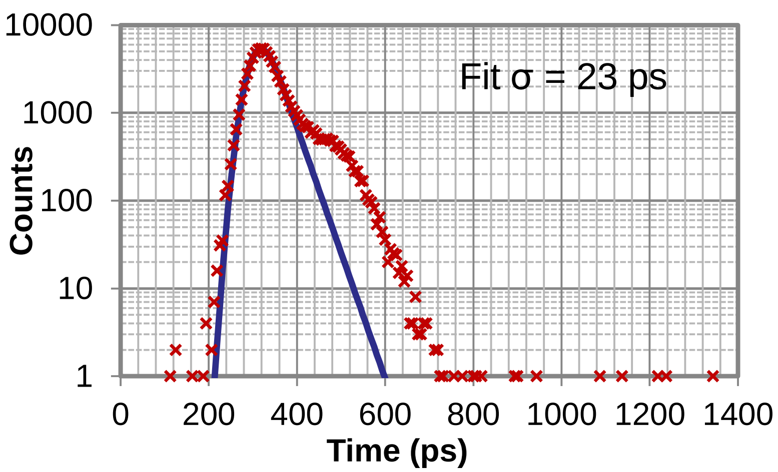
- TORCH group have developed NINO & HPTDC based readout electronics
- Time-over-threshold information used to measure charge for position algorithm



- Performance of charge sharing anode intimately linked to NINO
  - Integration time
  - Threshold
- Important in determining mean number of pads usable in position algorithm and detector occupancy

Photon Detector - Timing

- Pion-Kaon time-of-flight difference ~35ps over 9.5m
  - 3σ separation requires 10-15 ps timing per particle
  - Each particle produces ~30 detected photons
- Hence need 50ps timing from detector/electronics combined
- Charge sharing - improvement in single photoelectron timing



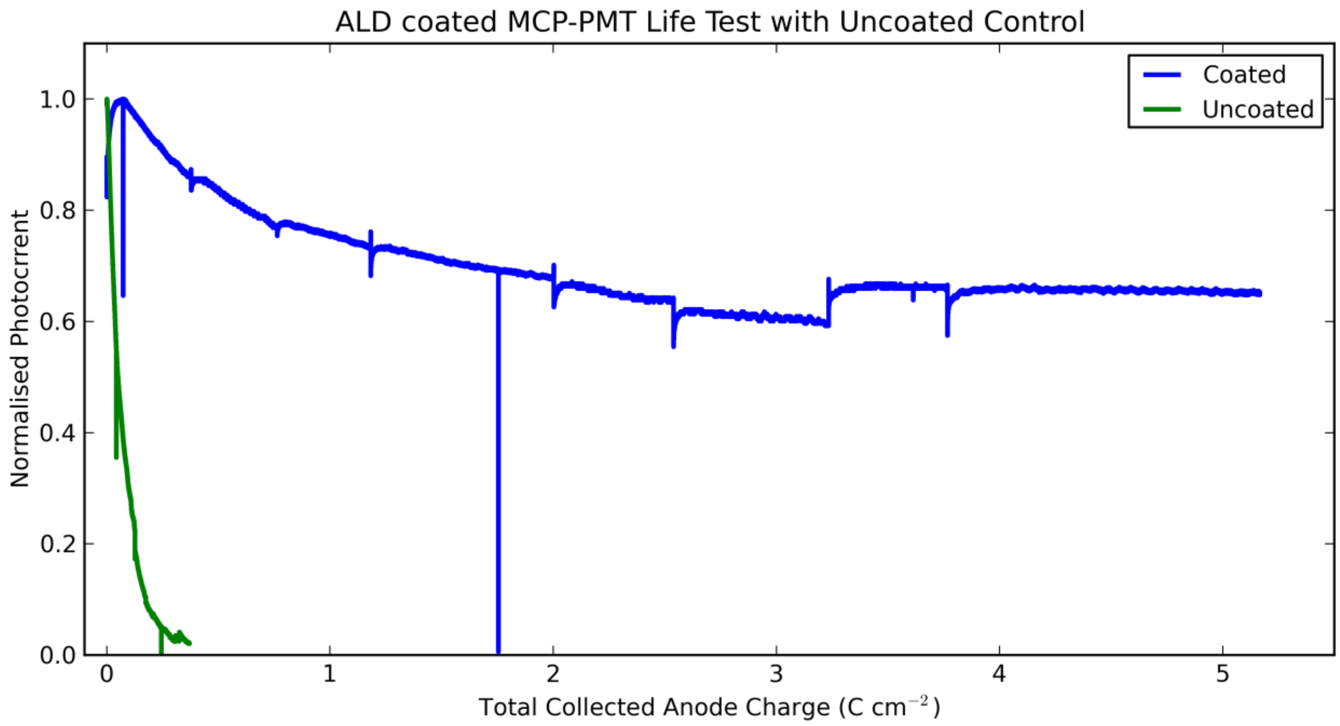
L. Castillo García, *“Timing performance of a MCP photon detector read out with multi-channel electronics for the TORCH system”,* 14th ICATPP Conference, 25 September 2013, Villa Olmo, Italy.

Photon Detector - Lifetime

- Over 5 years of operation expected cumulative charge extracted from MCP expected to be 5 C/cm^2
- Required new technology to extend lifetime of MCP detector from <0.1 C/cm^2 (due to photocathode damage)

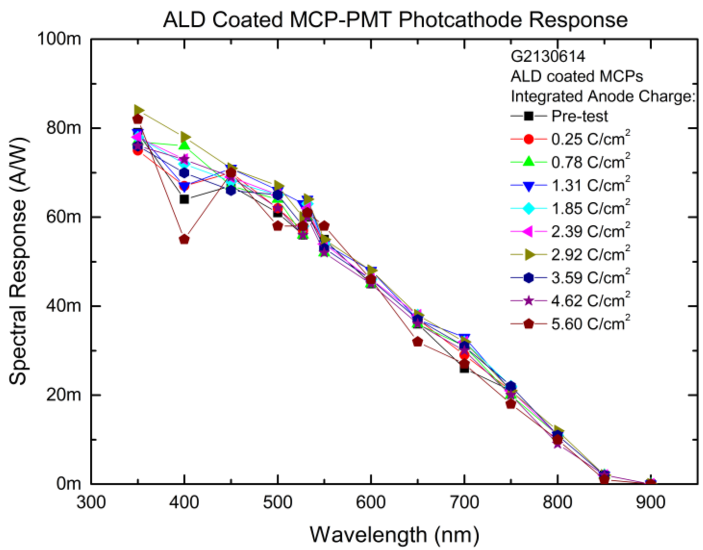
Photon Detector - Lifetime

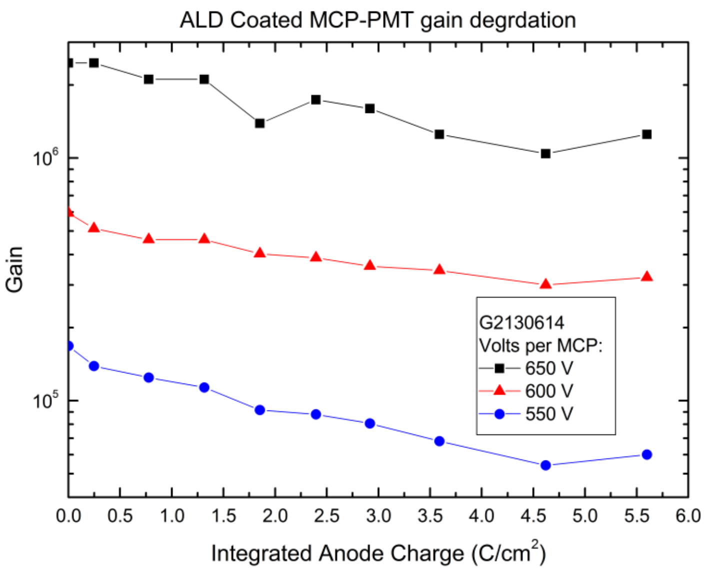
- Using Atomic Layer Deposition to deposit Al_2O_3
  - prevents ion feedback (seals MCP surface)
  - improves MCP gain (higher Secondary Electron Yield)



ALD – Photocathode Ageing

- Three tubes single channel MCP-PMT tested at Photek so far





- The TORCH group are currently performing their own lifetime tests

ALD – Future developments

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

- Begun 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/gain

Photon Detector - Shape

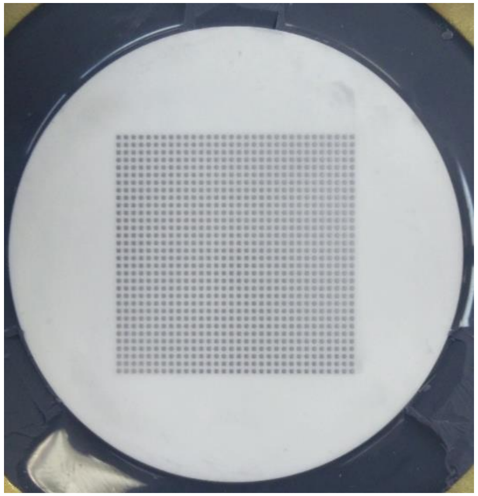
PHOTEK
ENVISAGE THE FUTURE

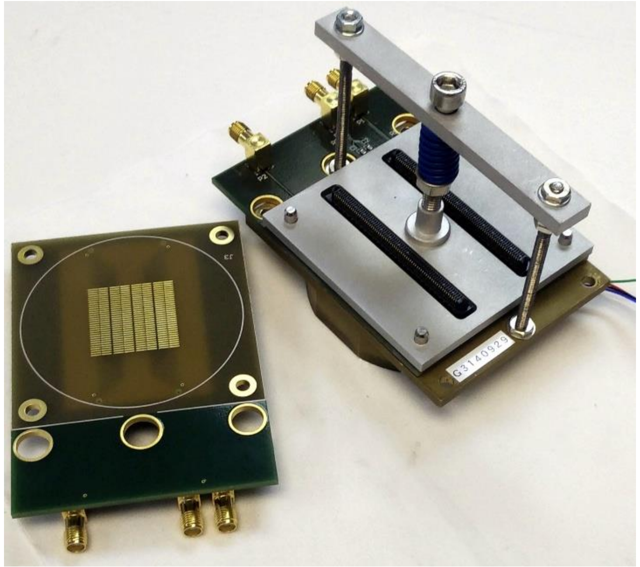
- 2” Square format required development program
  - Sealing ceramic anode
  - Sealing photocathode
  - Channel plate mounting
- Currently regularly producing 2” square test cells
  - Photocathode, with solid readout anode (no MCP)
  - Long term monitoring photocathode response, to detect leaks
- Production of full 2" square tubes with MCP expected soon

CHARGE SHARING ANODE
CHARACTERISATION

Prototype Detectors

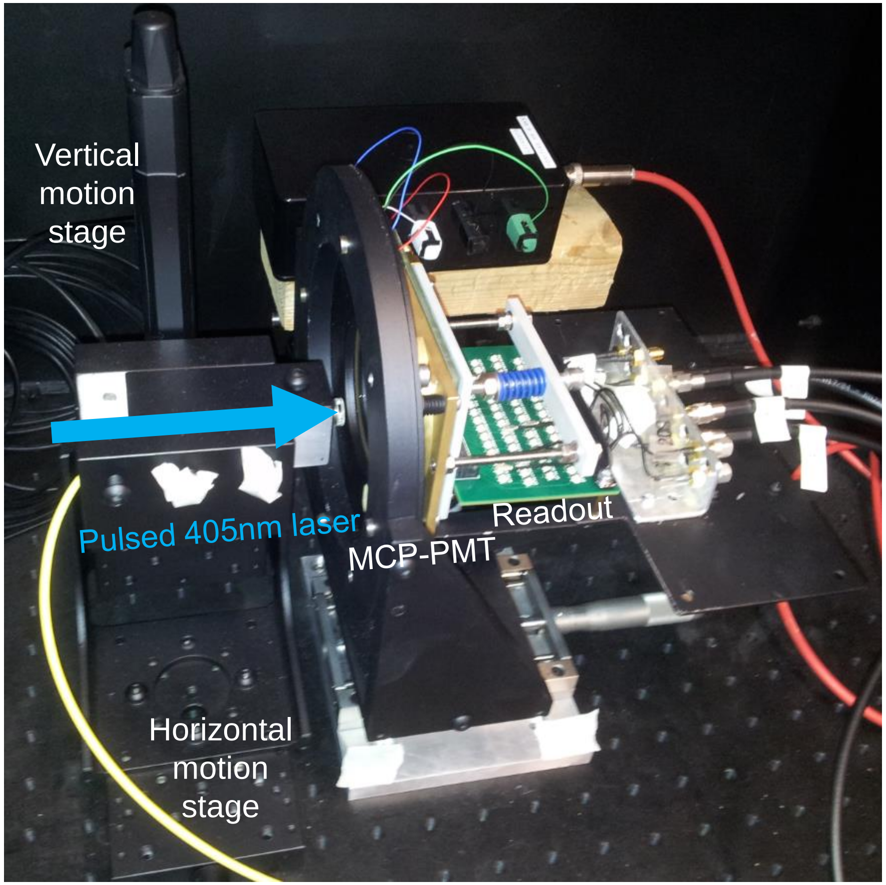
- Seven 32×32 multi-anode prototypes built with charge sharing anode
  - 0.828 mm anode pitch in both directions, 26.5x26.5 mm active area
  - In one direction 8 pads ganged together to create 32×8 layout (1/4 of square tube's active area)
  - With charge sharing improve resolution to 64×8 pixel equivalent (or better)
  - Use Anisotropic Conductive film to connector detector output to readout PCB



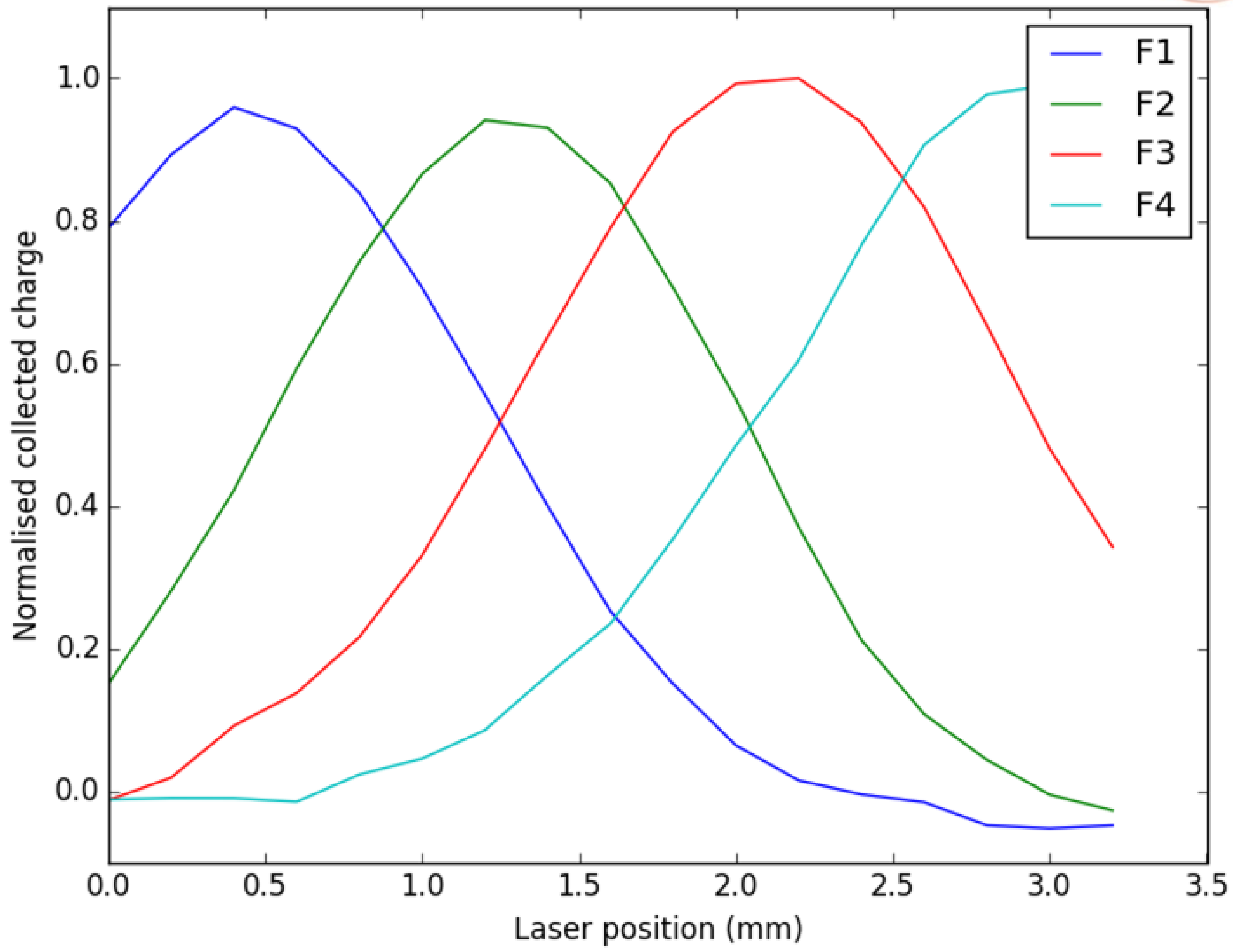


Detector testing setup

- Test performed on University of Bristol laser scanning setup
- >0.1µm laser spot size
- Use a 5GHz, 40 GS/sec scope to sample output for four channels
- Digitised pulse integrated to measure charge per pad
- 20-30 ps FWHM



Charge Footprint Measurement

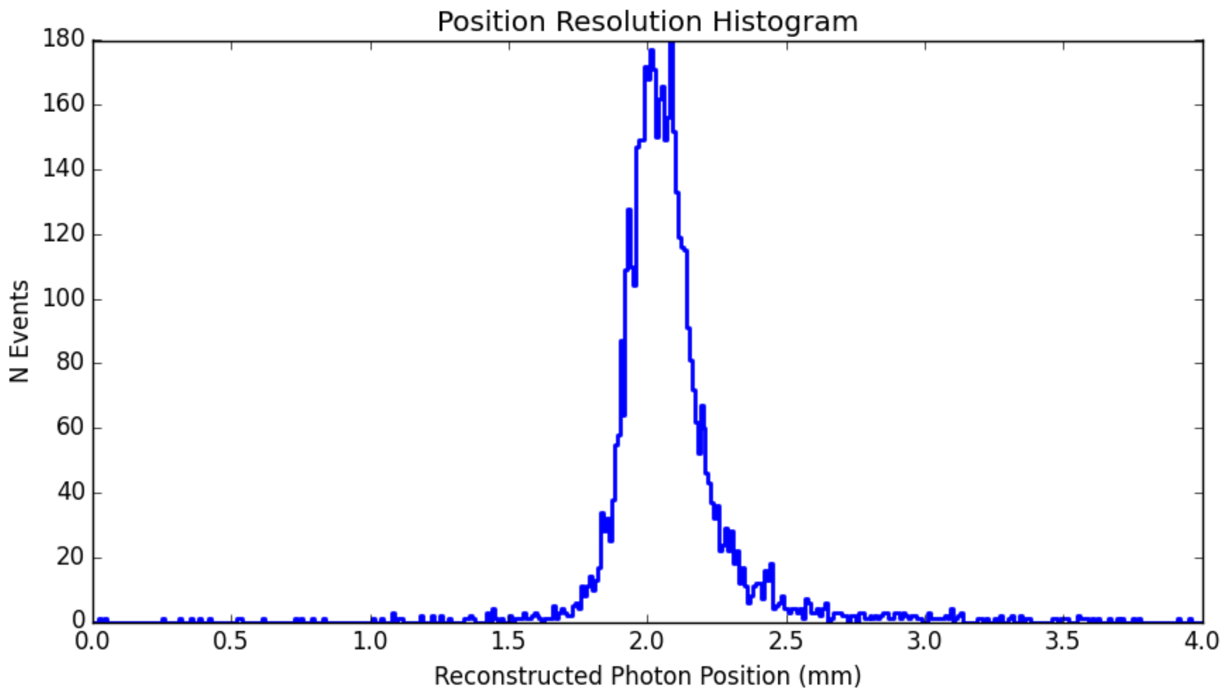


F2 FWHM = 1.62 mm

F3 FWHM = 1.75 mm

These do not account for baseline offsets/pedestal!!

Single Photon Imaging



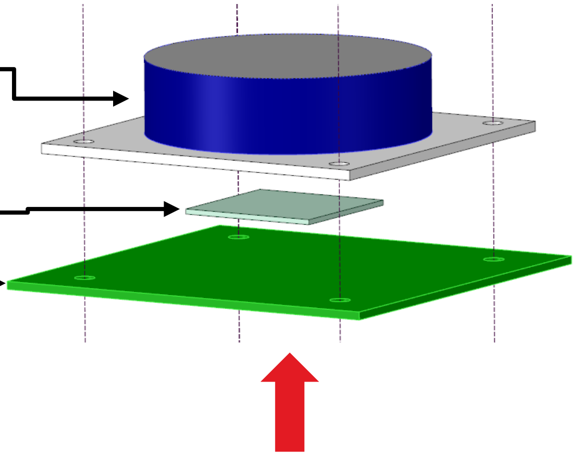
Applying imaging algorithm on event by event basis, with laser aligned in centre of 4 pixels

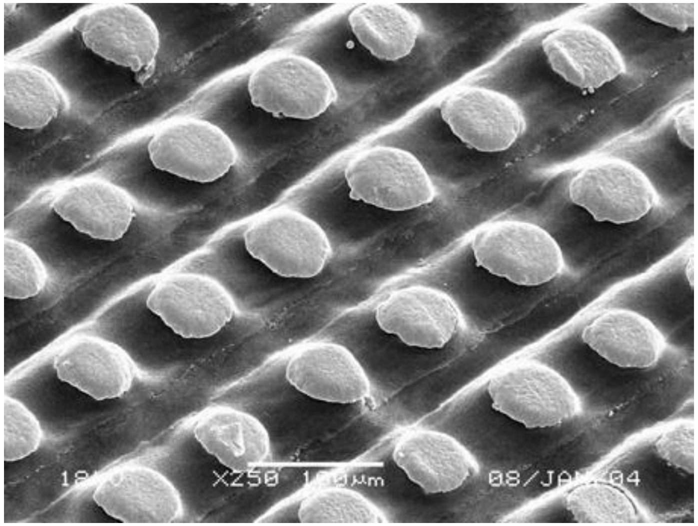
0.095 mm resolution (with 0.828mm pixel pitch)
NINO calibration in progress, measurements pending

ACF BONDING

Electronics Interface

- High density multi-anode output requires space efficient connection to readout electronics
- Anisotropic Conductive Film (ACF) is the current chosen solution
- Thin Si polymer film, with embedded wires
- 100 µm wire pitch

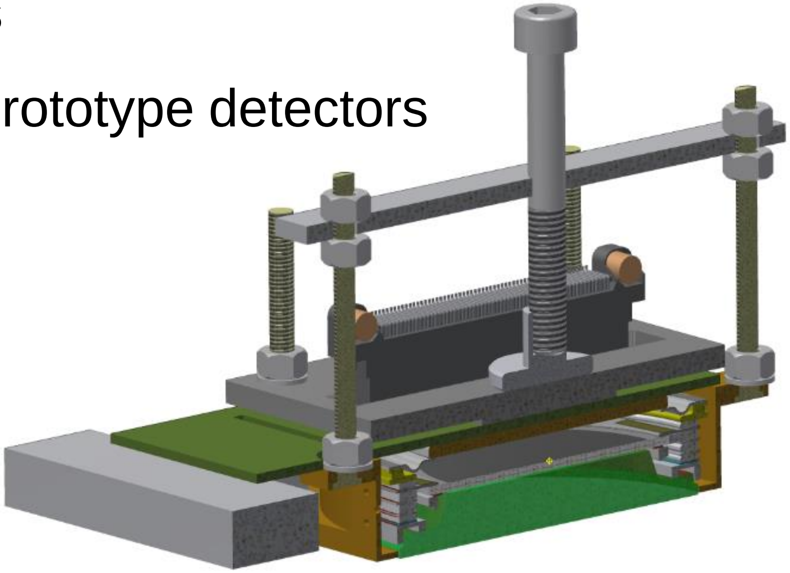




Shin-Etsu Polymer MT-P Datasheet

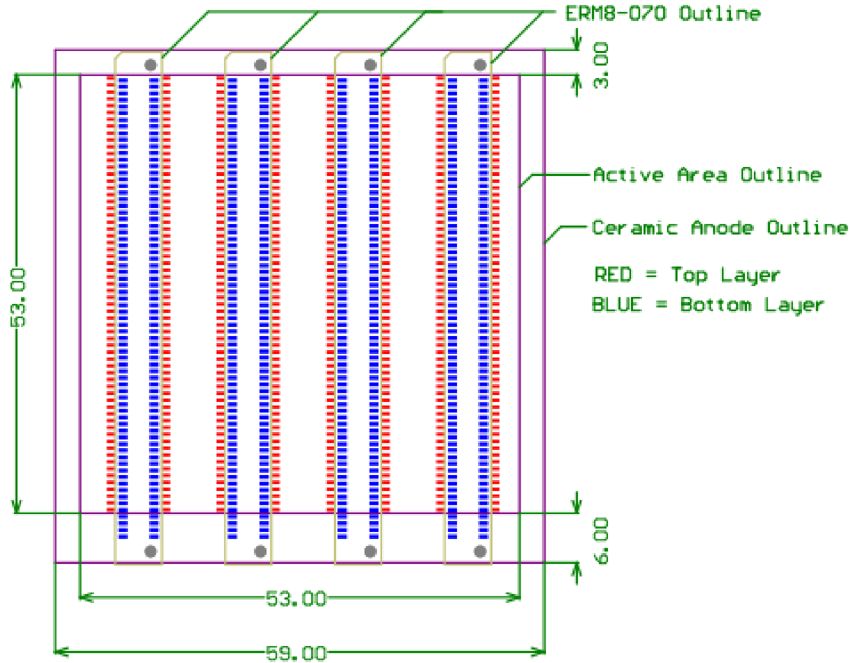
TORCH Prototypes - ACF

- Uses "cold" ACF (ShinEtsu MT-P)
  - All pads <0.1Ω resistance in trials
  - Provides reliable contact for the prototype detectors
  - Simple assembly
  - Reusable



- Requires high pressure during operation
- Bulky mechanical system to maintain pressure

Square Tube – PCB Layout



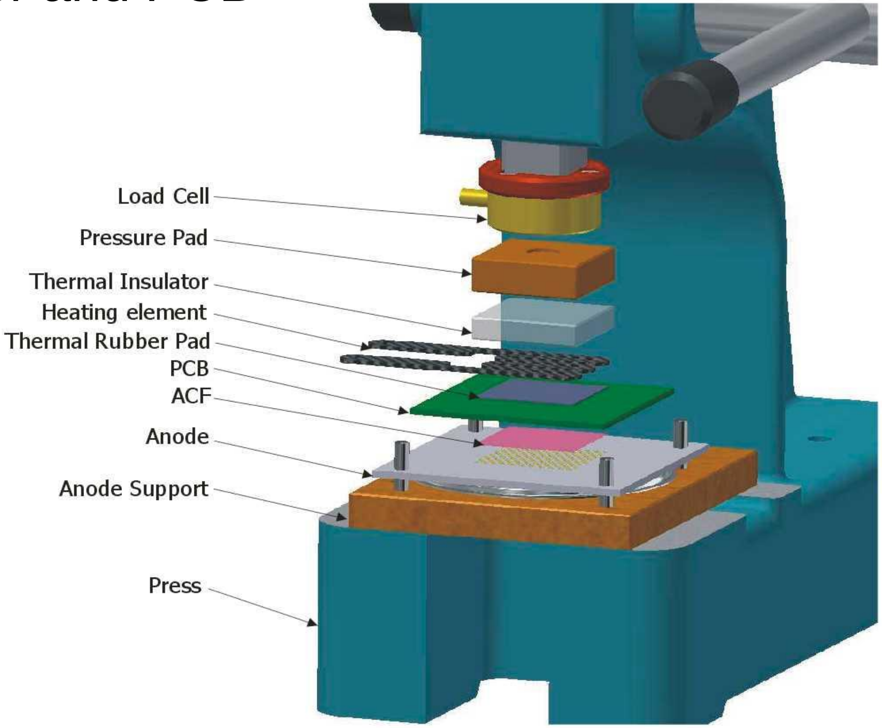
- Connector layout assuming 8x64 readout, and 128 channel NINO board
- Red = detector contacts, Blue = Connector contacts

Layout Issues

- Little to no room for applying pressure between connectors
- Solution – Use “heat applied” ACF
  - 3M 7371
    - Minimum contact pitch 0.2 mm, with minimum 0.1 mm conductor spacing
    - Minimum pad area 0.1 mm^2
  - Bonded by placing between PCB/detector and applying
    - 10-20 kg/cm^2 pressure (~250 kg minimum for 2” square)
    - 180°C for 10 seconds
- Forms permanent bond, requiring no pressure during tube operation
- As pressure/temperature still required, populate connectors with conductive epoxy after ACF bond.

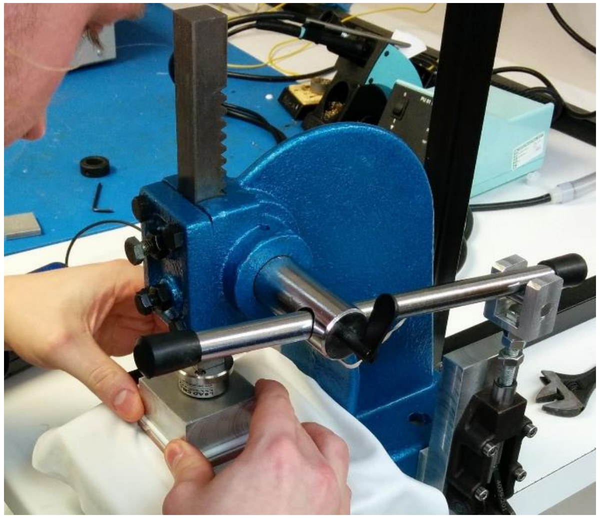
Heat applied ACF Tests

- Designed and built a custom press
- Allows calibrated pressure application
- Integrated heating element with PID control
- Mechanics for aligning detector and PCB



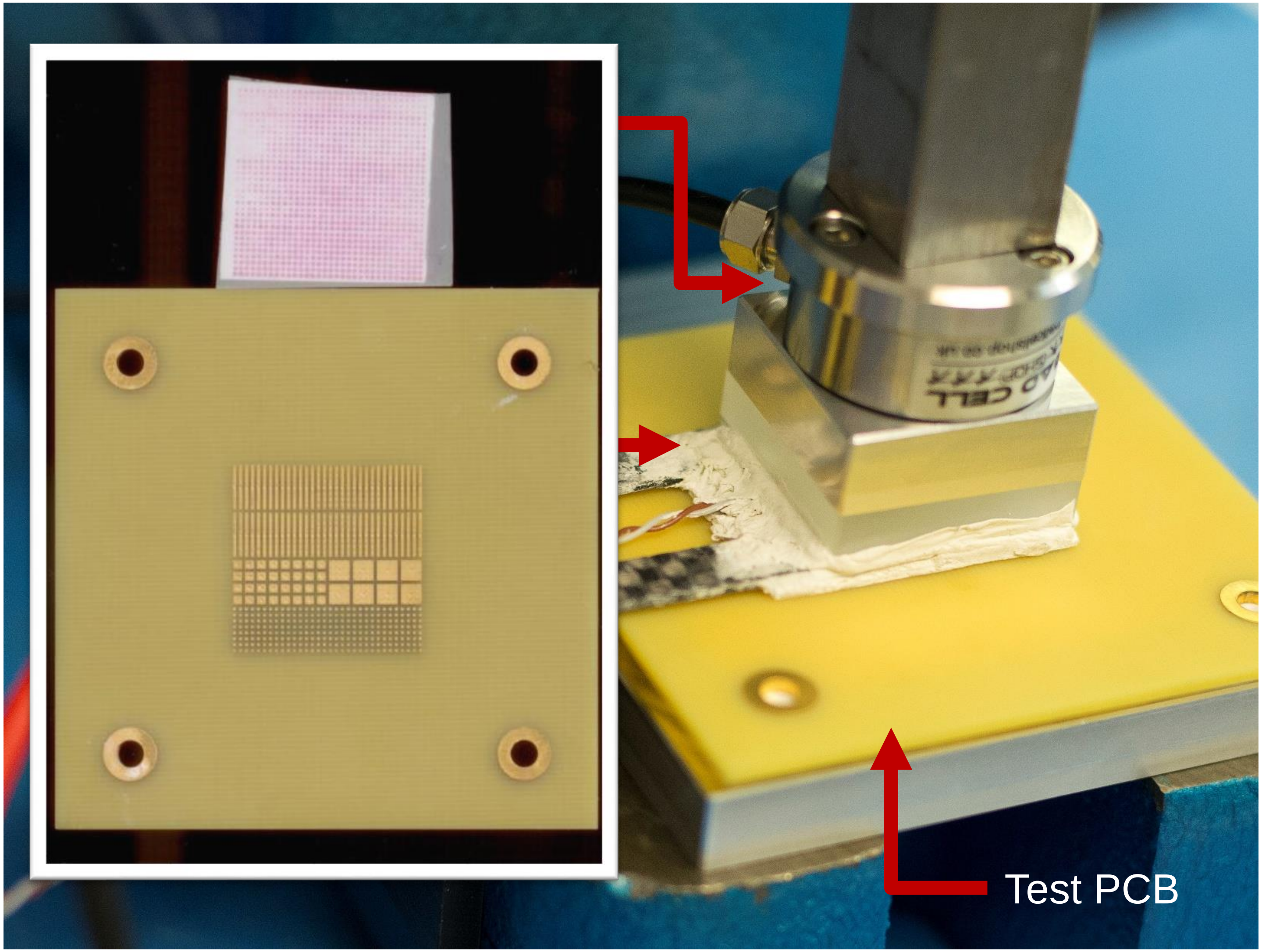
Survivability

- Can a detector survive pressure required?
  - 280kg to 500kg total load required!
- 2” square test cell
  - Solid ceramic anode
- Applied Sealed tube with photocathode



- ~300 kg load on anode ceramic using ceramic (10 kg/cm^2)
- Monitored photocathode responsivity for 2 months (best indication of leak)
  - No change

ACF Press Trials



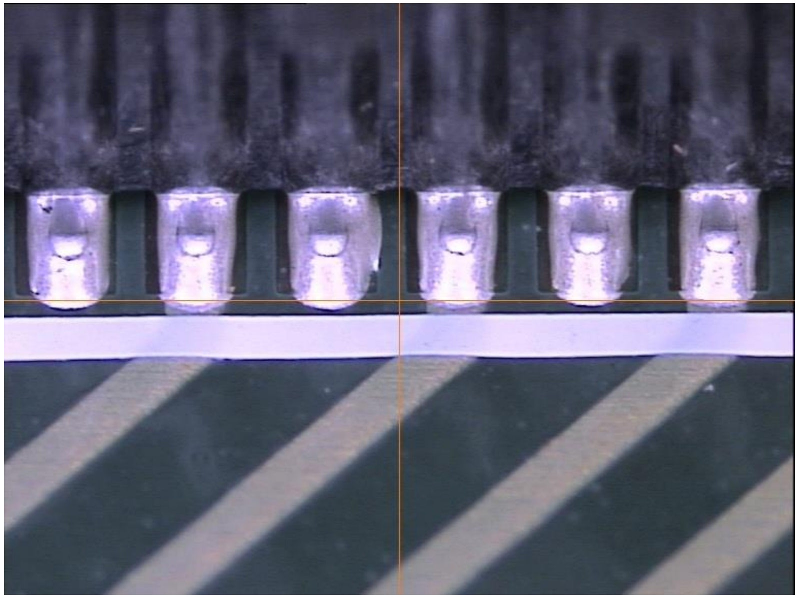
ACF Trials – future plans

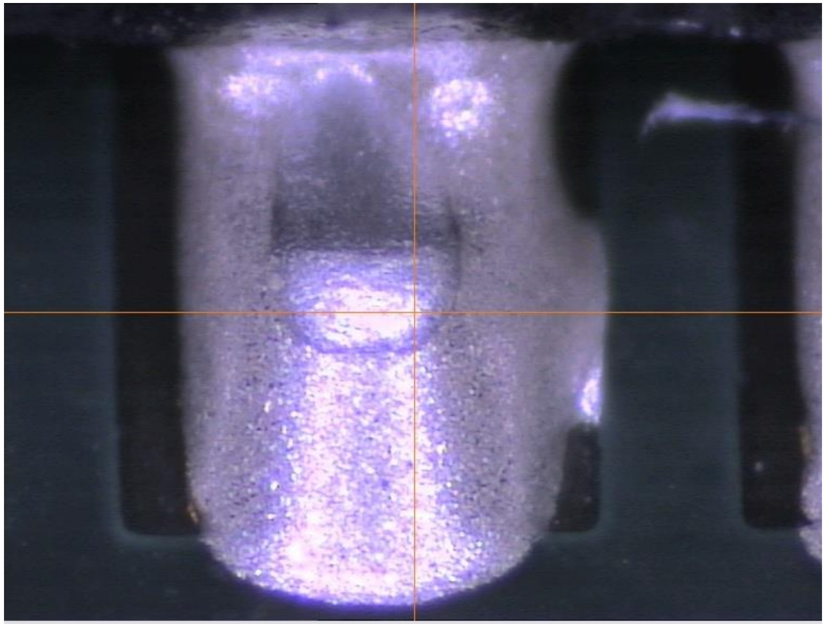
- Confirmed press applies even pressure across test PCB
- Confirmed temperature between PCB and detector reaches 180°C
  - Need to measure temperature uniformity between PCB and detector
- Then trial ACF bonding with test PCB, measuring
  - Resistance
  - Bond strength
  - Removal of film for reworking PCB
- To test with real detector require heat sinking of photocathode seal, to protect indium seal.

Connector Mounting

- Connectors mounted after ACF bonding
- Tube cannot survive reflow soldering process
- Use a silver loaded epoxy in place of solder to mount Samtec ERM8-070 (0.8mm pitch) surface mount connectors
- To trial PCB population interface PCB from TORCH prototypes (no detector present)
- Use stencil process, identical to technique used in reflow soldering
- Then connectors populated and epoxy allowed to cure at controlled 25°C for 24 hours

Epoxy Joints – Visual Inspection





- Visually joints look very good
- Connector tails covered in epoxy
- Small amount of excess epoxy flowing outside of PCB pad area (1 in 10 pads)
- Resistance higher than expected, likely PCB's copper pads contaminated
  - Carry out second trial with revised cleaning procedure

CONCLUSION

Conclusion

- Manufactured prototype detectors using novel charge sharing multi-anode design
- Characterised performance using Bristol test setup
  - Need to analyse position/timing resolution with TORCH electronics
- A single prototype used in test beam (see previous talk, M. van Dijk) with mini-TORCH system
  - Analysis pending
- Square test cells in regular production
- Full assembly with MCP coming soon.
- Developing ACF bonding for high density square tube readout

With thanks to…

Members of the TORCH collaboration at

University of Bristol, CERN and Oxford University

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

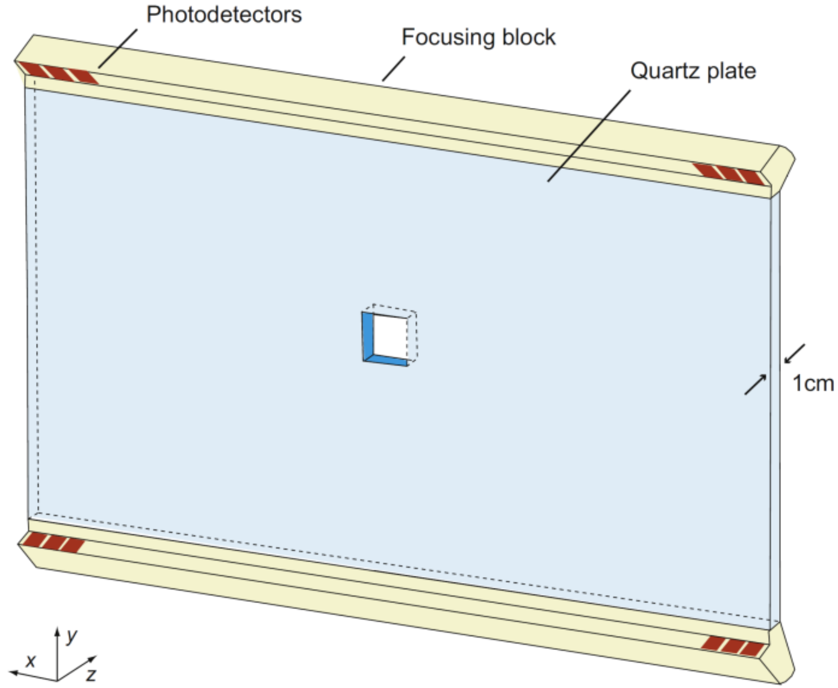
European Research Council

Established by the European Commission

BACKUP

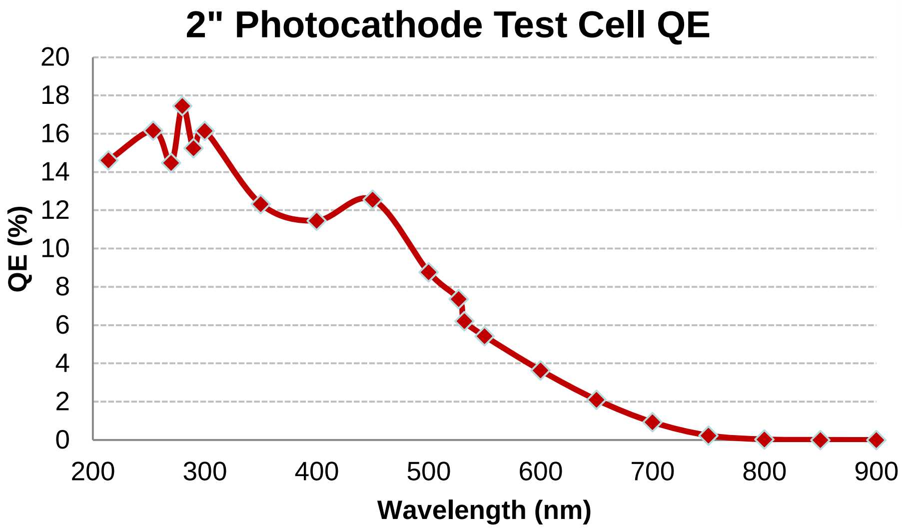
TORCH – TOF Concept

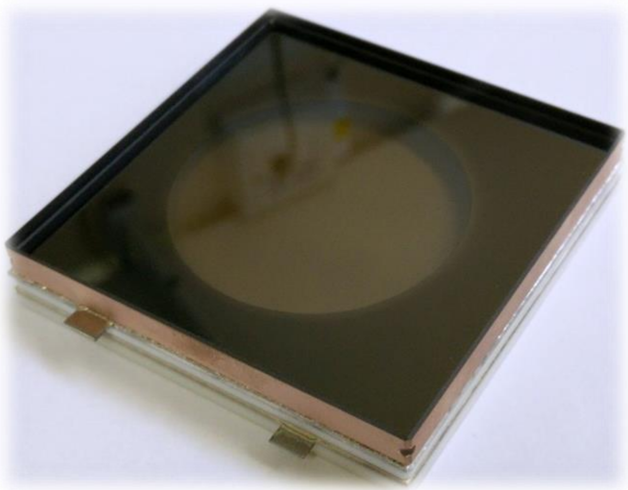
- TORCH aims to achieve 10-15ps timing per particle over a large area
- Utilises Cherenkov light for fast signal production
- Focussing optics along edges couple light to photon detectors



Sealing Square Test Cells

- Successfully produced 2” square test cells with low noise S20 photocathode

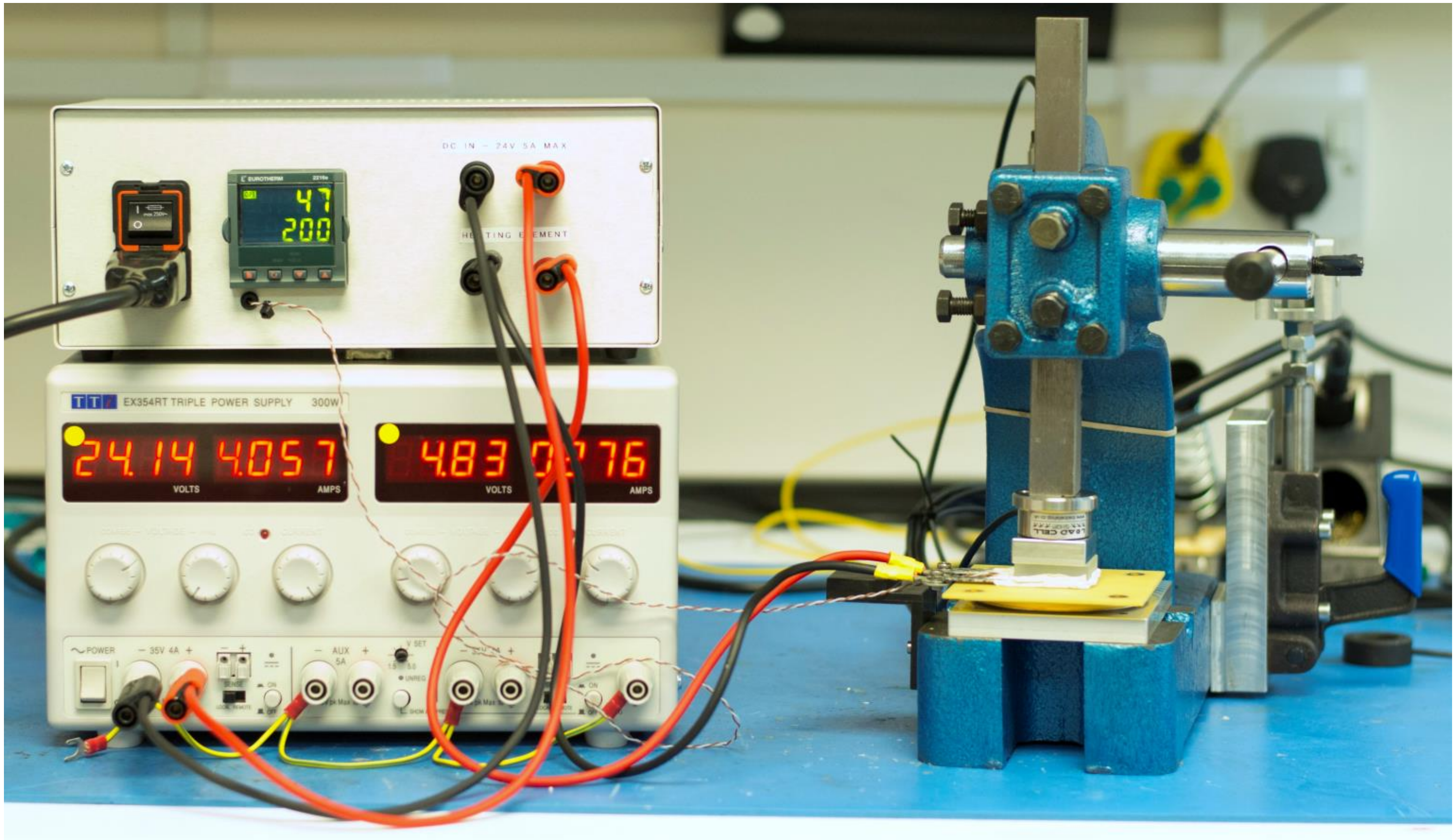




- Oldest cell’s QE stable over 12 month period

Press Construction

- 99% of parts arrived
  - Waiting on alignment pins due to arrive imminently



Poor Conductivity - Causes

- Cured epoxy has 1mΩ cm volume resistivity (in bulk), in ideal cure conditions
- Cured at 25°C for 24 hours, how well maintained were these conditions?
- Connector legs Bronze, coated with 1.25µm Ni then Sn. SnO_n surface layer on legs?
- PCB pads are copper with 3-6µm Ni then 0.030-0.100µm Au. Grease on PCB pad surface?

Changes for TORCH detector

- As ACF bonding is done post tube production need to protect indium photocathode seal from temperatures >100°C
- Add copper heat sink to base with acetone bath covering photocathode seal
- Alignment jig for PCB
- Larger block to spread pressure