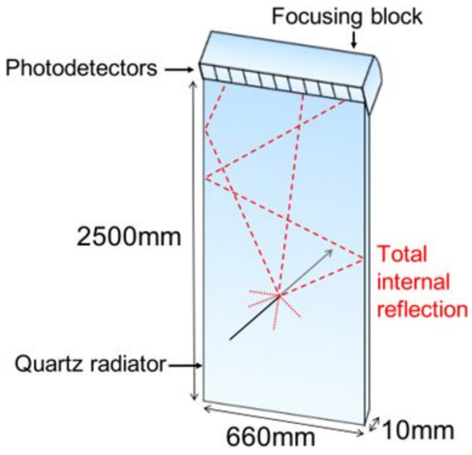
TORCH status of MCP-PMT and test results

LHCb UK Upgrade 2 meeting, 9–10 July 2024

Alexander Davidson and Marion Lehuraux
on behalf of the TORCH collaboration

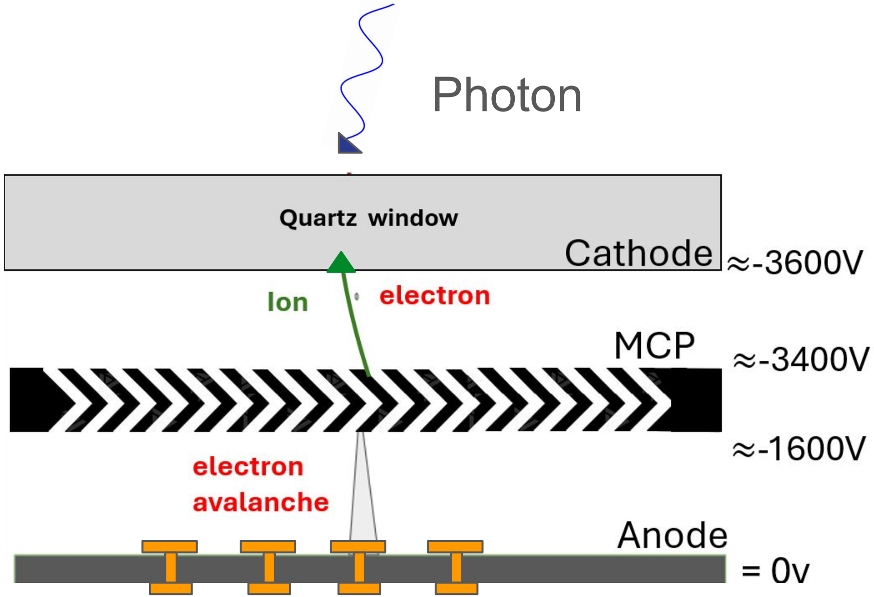
Quick introduction to TORCH

- Aim to provide low momentum (2–15 GeV/*c*) particle identification using time-of-flight.
- Use Cherenkov radiation from 1 cm thick quartz radiator as a timing signal.
- Photons are propagated to the periphery of the detector by total internal reflection.
- Micro-Channel-Plate Photo-Multiplier Tubes (MCP-PMTs) are used as a fast photon detector.
- A single photon timing resolution of around 70 ps is needed to reach 15 ps per track.



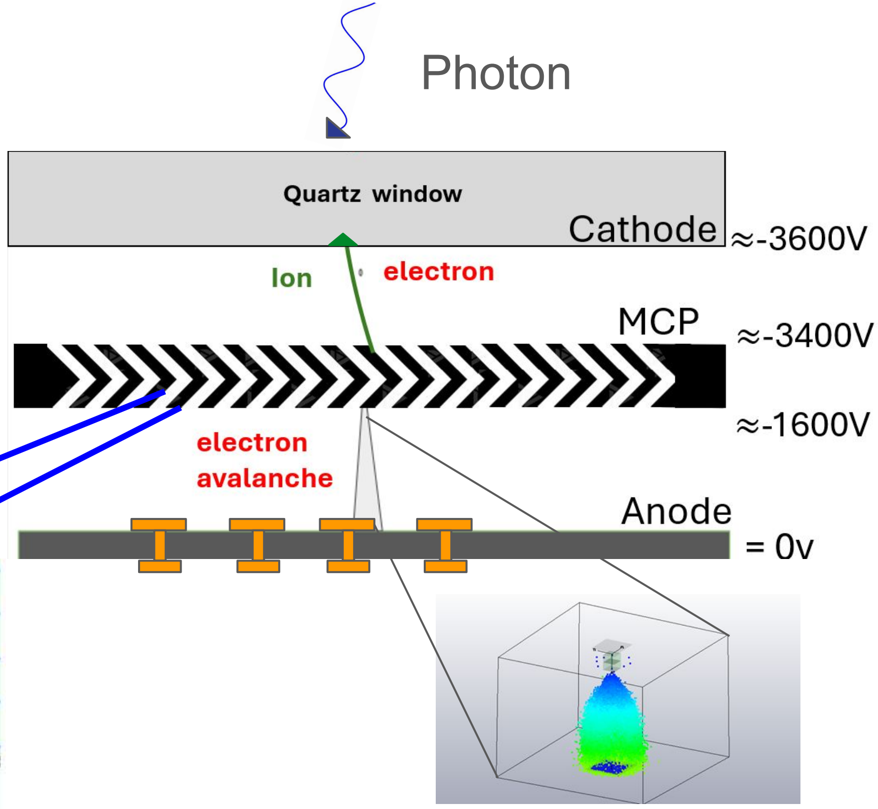
Micro-channel-plate photomultipliers

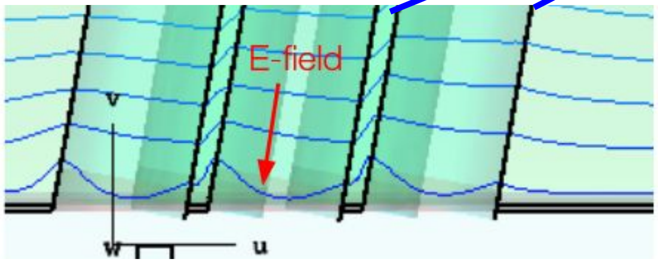
- Cherenkov photons get converted to electrons by the cathode.
- Secondary electrons are produced by a emissive layer coated on the MCP's surface and pore walls.
- Chevron structure is used to reduce ion feedback.
- Due to high electric field strength this device has a intrinsically fast time response.



Micro-channel-plate photomultipliers

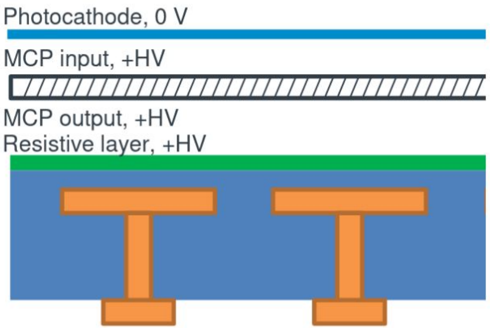
- Ongoing effort to simulate the MCP-PMT in CST studio:
  - Electric field structure / mapping.
  - Propagating electrons through said field with secondary production from wall collisions. Achieving the MCP gain effect.
  - Charge-sharing between readout pads.





TORCH MCP-PMTs

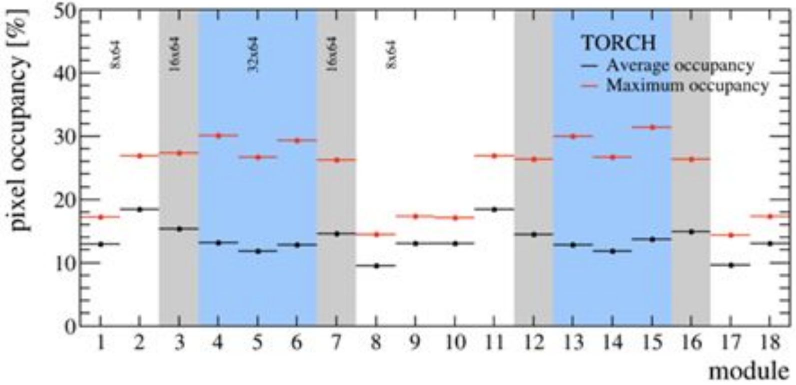
- Current TORCH prototype use custom 53-by-53mm MCP-PMTs with 64-by-64 pads [JINST 10 (2015) C05003] that are ganged to form 8-by-64 pixels.
- Readout connectors are mounted on an external PCB and connected via anisotropic conductive film.
- Anode is capacitively coupled with charge sharing between pixels.
    - Exploit charge sharing to achieve an effective 128-by-8 granularity.
- MCP coated with ALD for extended lifetime.



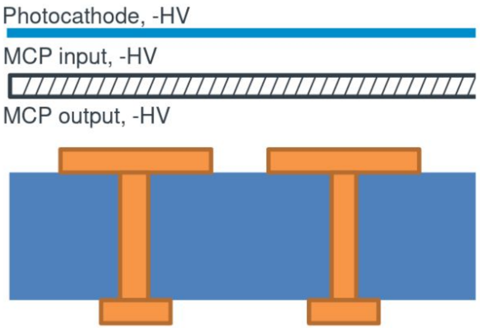
Capacitively coupled readout

Motivation for layout for new MCP-PMT

Pixel occupancy from FTDR (at $1.4 \times 10^{34}\ cm^{-2}s^{-1}$)



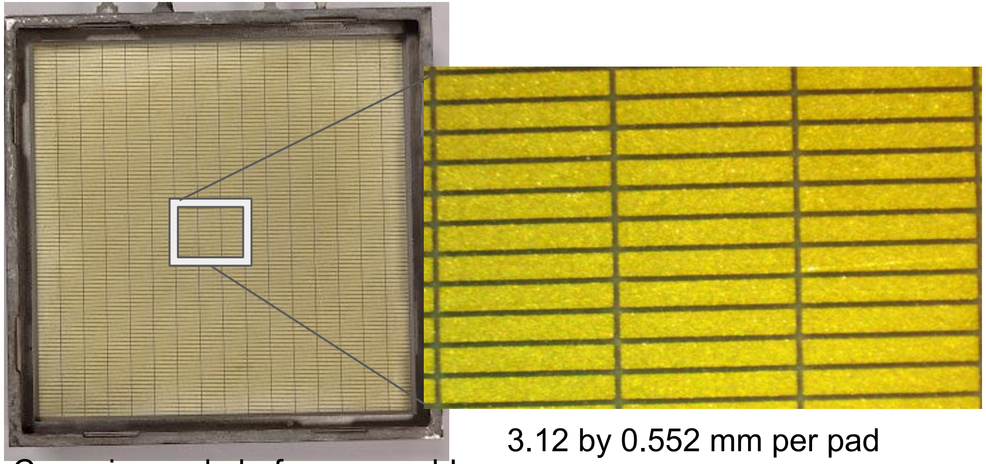
- At Upgrade 2 luminosities per-pixel occupancy becomes large.
- In FTDR granularity is increased to compensate (up-to 32-by-64).
- Aim to reduce occupancy with directly coupled PMT output:
  - Reduces charge-sharing and detector occupancy.
  - Requires increased granularity in fine-pixel direction to compensate for loss of centroiding.



Directly coupled readout

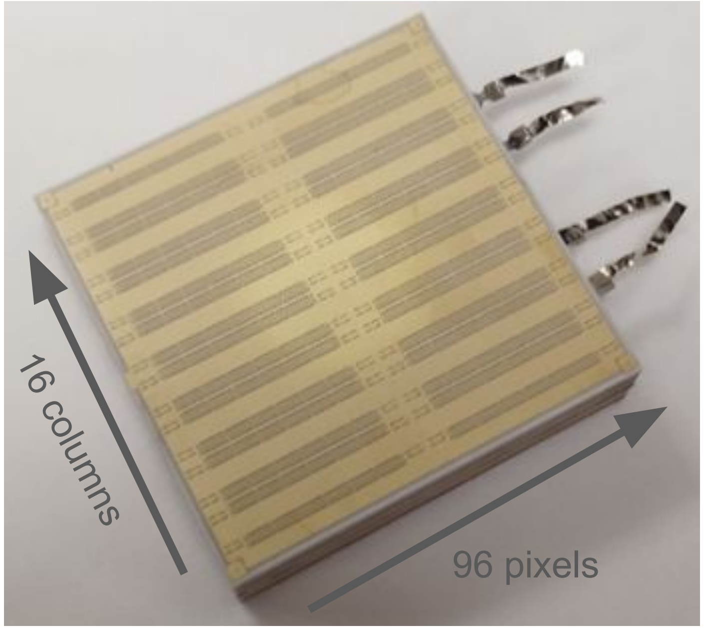
NEW anode layout

- New MCP-PMT has a 53 × 53 mm^2 active area with an anode with 96-by-96 pads.
- Pads are ganged into a 16-by-96 arrangement.



3.12 by 0.552 mm per pad

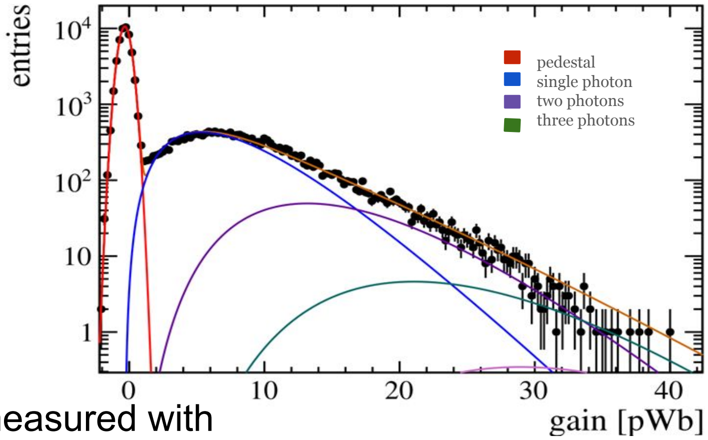
Ceramic anode before assembly



Backside of the anode after assembly but before soldering.

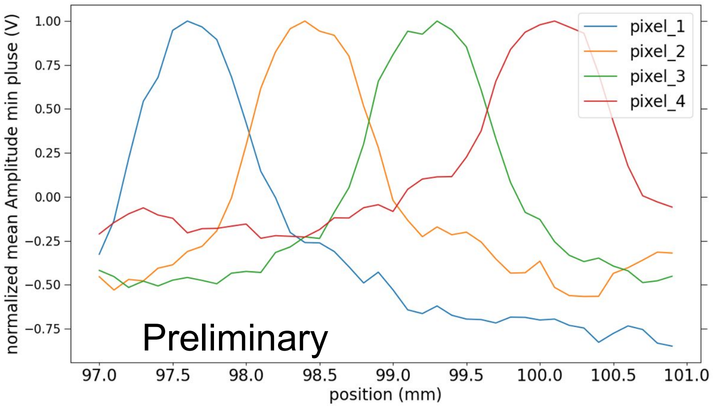
Charge sharing studies with an 8-by-64 MCP-PMT

- Sweeping laser over 4 pixels reading out to a oscilloscope via a breakout board.
- Pulse height distribution fitted with Polya model to estimate gain.
- Will complete similar studies on 16-by-96.



Gain measured with

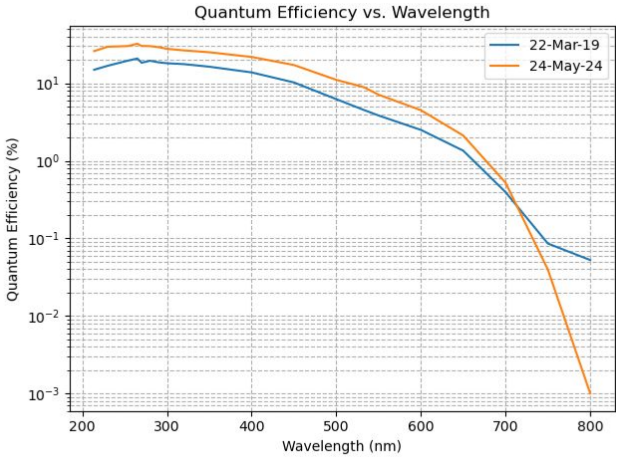
LeCroy Wavemaster 808Zi-A (8 GHz, 40 GS/s)

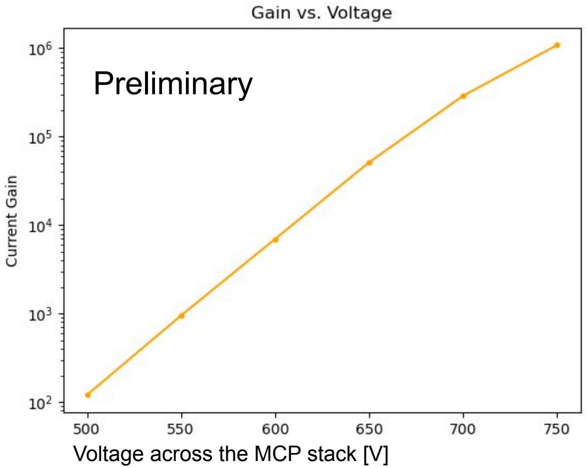


8-by-64 directly coupled MCP-PMT

First measurements from the new MCP-PMT

- First measurements performed at Photek on the bare MCP-PMT (before soldering/potting).
- Response looks good:
  - QE is significantly improved from earlier TORCH MCP-PMTs.
  - Gain from calibrated light-source varies as expected.





Laser soldering

- Due to density of connections on anode and the need to limit extended periods of heating, connectors are soldered using laser jet soldering.
- Solder balls are heated by a laser, and fired under pressure to hit target.
- 2 MCP-PMT with the Laser soldering company, waiting on confirmation of completion and shipment back to Photek.

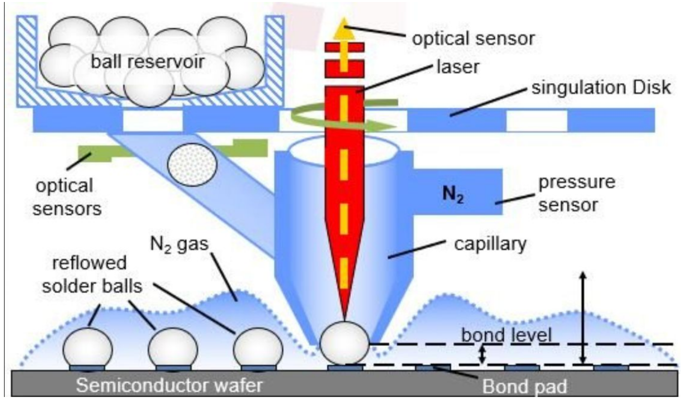
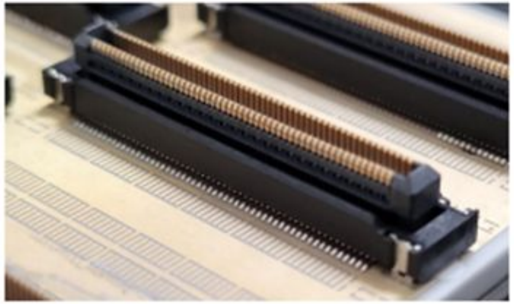
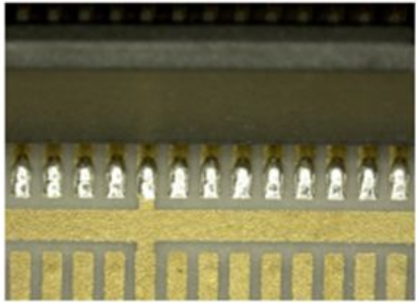
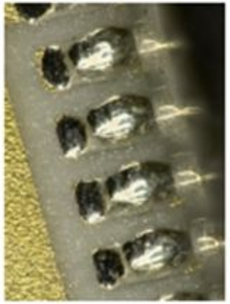


Image [accessed on 04/07/24]



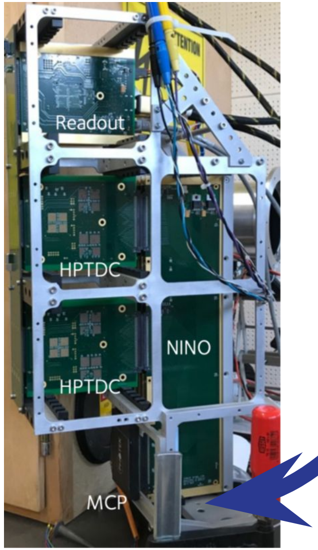




Images show a successful run of one of 16 connectors added on a test anode.

New readout adaptor board

TORCH electronics



Adaptor board

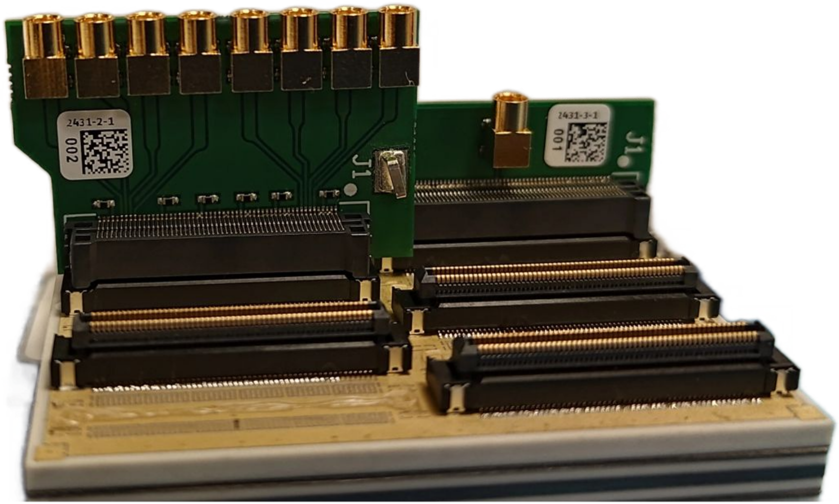
- Adaptor board has been developed to instrument 64 of the 96 outputs on a single column.
    - Unconnected channels are terminated.
- Original plan to develop new electronics using FastIC and picoTDC shelved due to availability of ASICs.
- No plans to test the new MCP-PMT in test beam next year at present.

New analog breakout board

- We are also developing analog breakout boards for use with an oscilloscope.

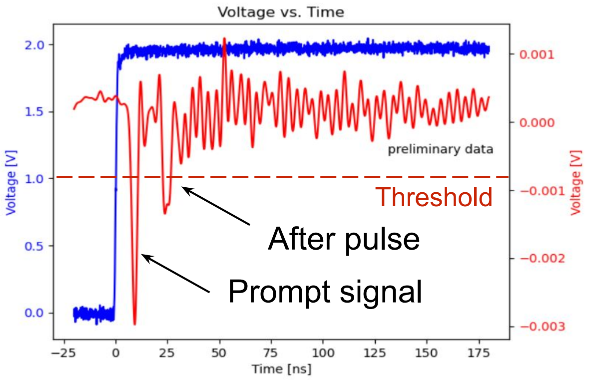
  e.g. boards in use at Photek:

8 central pixels   48 into 1

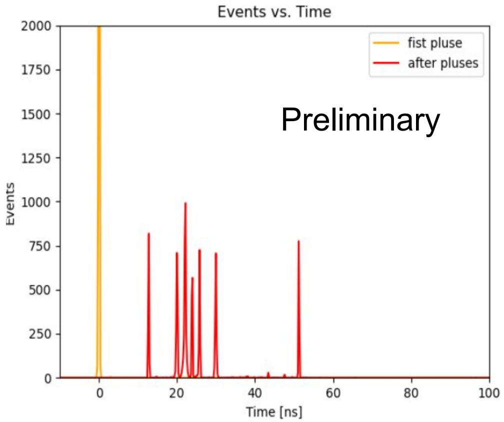


Towards understanding Ion feedback

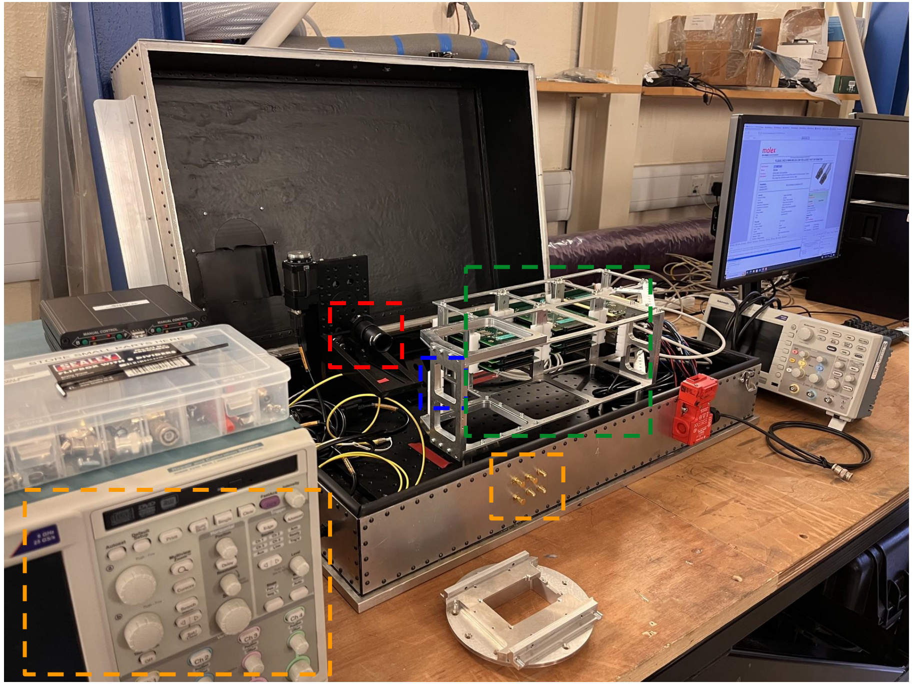
- MCP-PMT lifetime is limited by ion-feedback.
  - Current devices do not meet needs of TORCH in upgrade 2.
- Work started to understand contribution from different ions using a MCP-PMT (mcp 240) with poor vacuum quality.
- Premliminary, the first after pluse loooks to be He with the group after being 0 and H_20



An example of an event

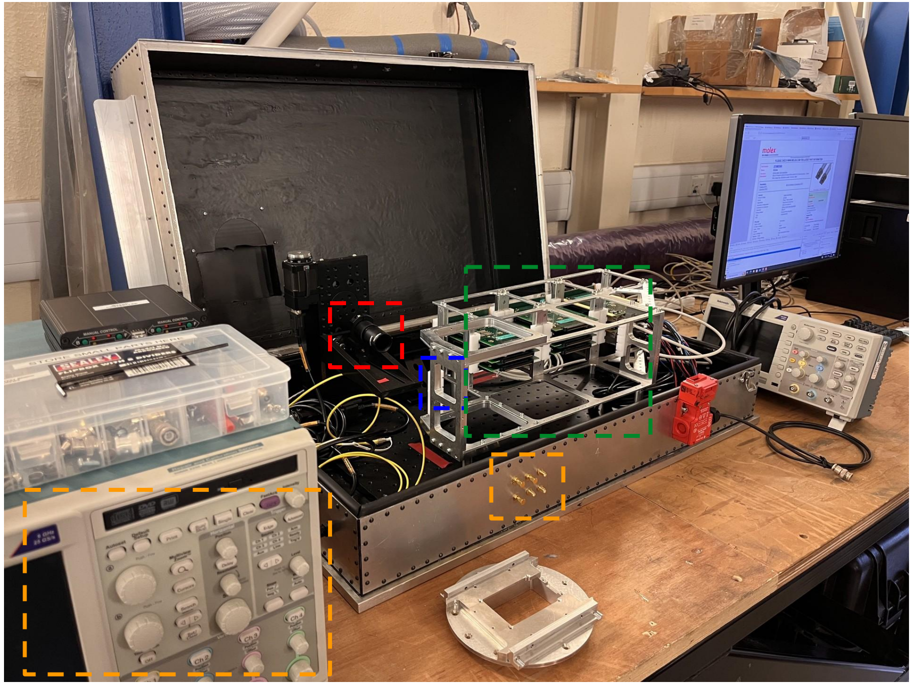


Warwick lab setup

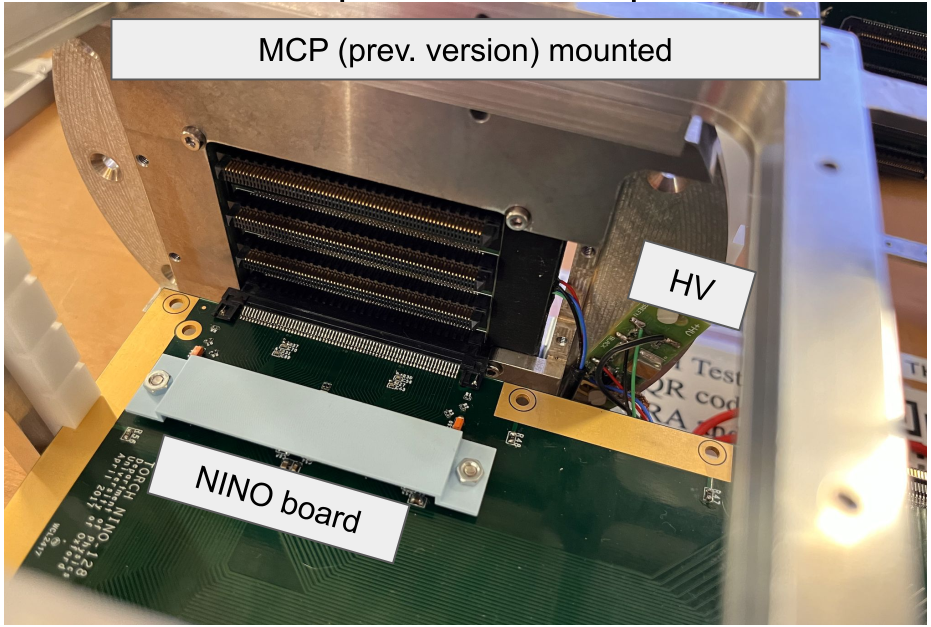


- Aim to characterize MCP-PMTs for TORCH (old and new version).
- Uses a fast pulsed 405 nm picosecond **LASER** to shoot photons at **MCP-PMT.**
- Synch. output used for trigger and time reference.
- **Analog readout** of few pixels using fast oscilloscope with breakout board.
- OR **Digital readout** of the entire detector using the existing TORCH electronics (NINO + HPTDCs).

Warwick lab setup

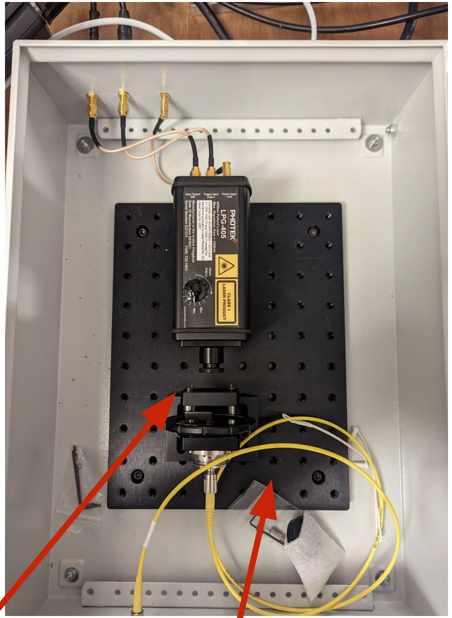


- Aim to characterize MCP-PMTs for TORCH (old and new version).
- Uses a fast pulsed 405 nm picosecond



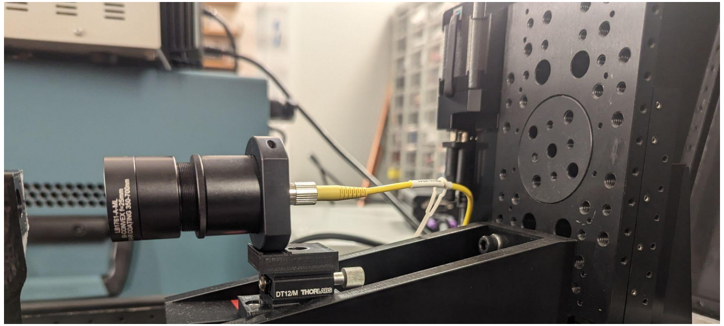
Laser setup and Power calibration

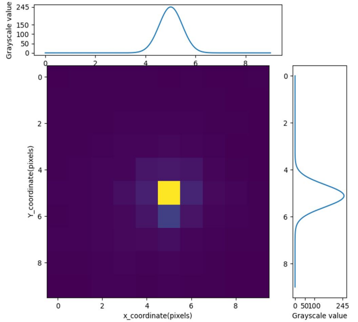
- Using a hamamatsu PMT, plus a counting unit to check for light leaks and laser count rates.
- Setting the Variable neutral density filter to get the region of signal photon, count rate = 10% laser rate.
- Making sure the count rate is stable, overnight.



variable neutral density filter wheel

single mode optical fiber to dark box

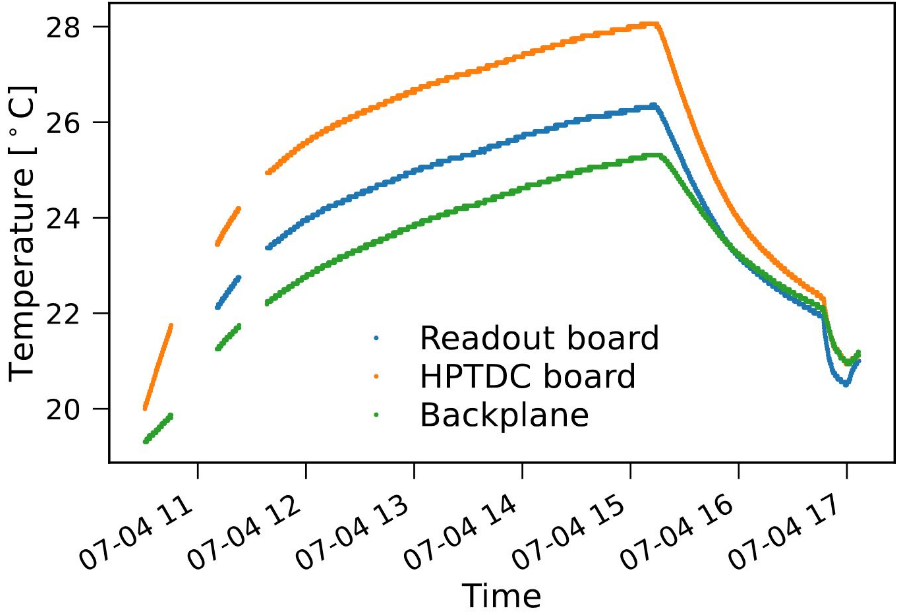




Lens mounted on a x/y stage in dark box

FWHM of 6 µm measured by taking a CCD image

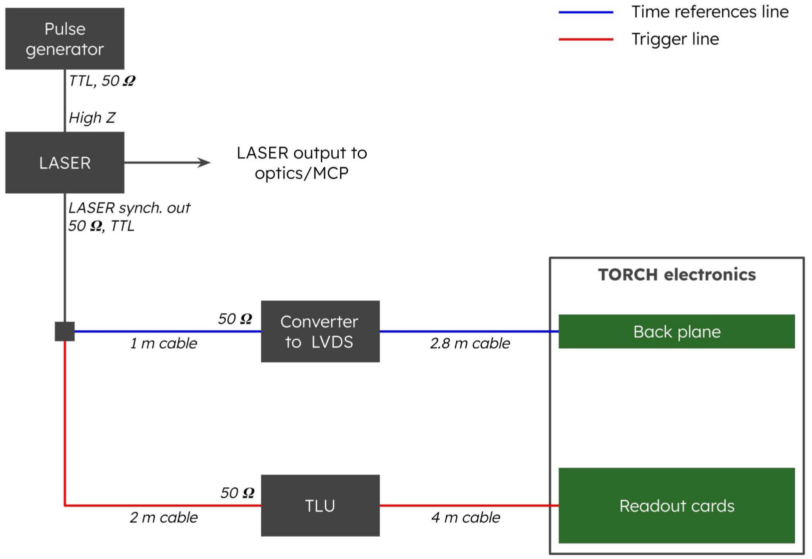
Preliminary temperature results

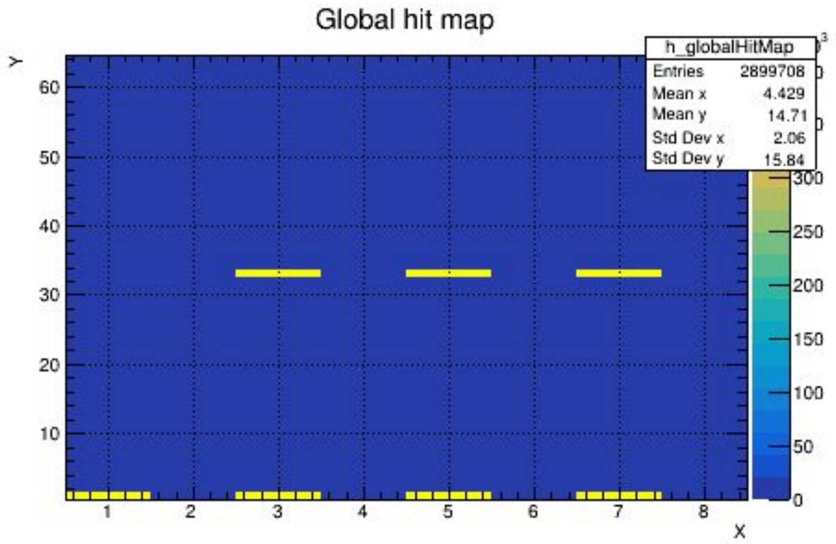


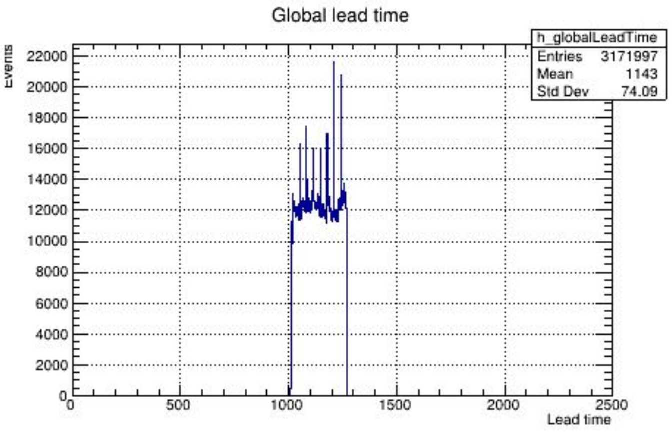
- TORCH electronics prone to heating due to the high power requirements.
- Check temperature to make sure we can run with current setup and lid closed.
- Running under the assumption that if kept lower than 30℃ no cooling measures need to put in place.

Time reference

- Test and validation of test bench trigger line.
- Can see injected signals on time reference channels at the expected rate and delay ✓







Summary & next steps

Photek

- Vacuum sealing of new MCP-PMT complete ✓
- Expect new MCP-PMT to be shipped to CERN within the next few weeks. With also the availability of a second MCP-PMT to be loaned out by Photek for further testing.

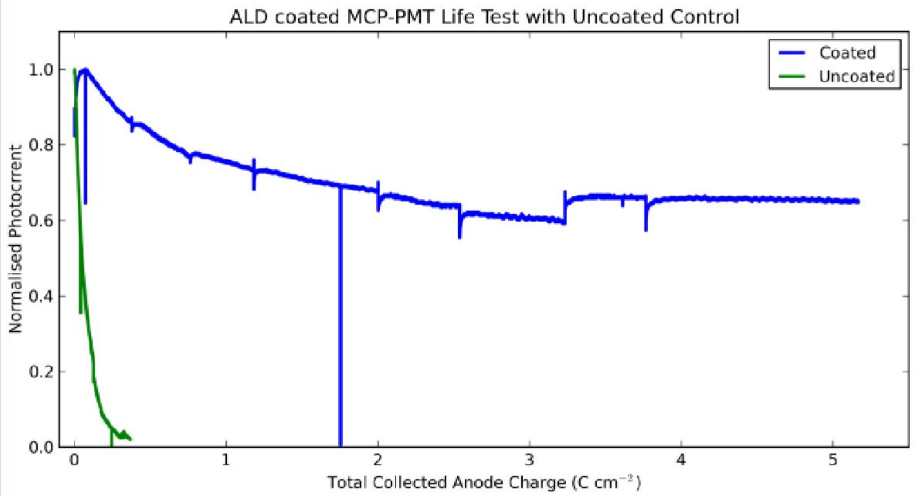
Warwick

- Trigger line tested and validated ✓
- Ongoing temperature checks ✓
- MCP-PMT installed ✓

Thank you for listening

Towards understanding Ion feedback

- ALD coating of MCP-PMT pores significantly enhances lifetime.
- Photonis have demonstrated longer lifetimes using more advanced ALD coatings.



Showing how ALD coating can block ion libration hence increase lifetime

DOI:10.1016/j.nima.2013.07.023

Power calibration

- Using a hamamatsu PMT and counting unit to check for light leaks in the box.
- Secondly setting up the PMT to face the laser.
- Finding the optimum working voltage for this PMT at constant threshold.
- Setting the Variable neutral density filter to get the region of signal photon, count rate = 10% laser rate .
- Making sure the count rate is stable, overnight.