Characterisation of the next generation fast-timing photon-detectors:

Current status of testing the new 16 by 96 Channel MCP-PMT

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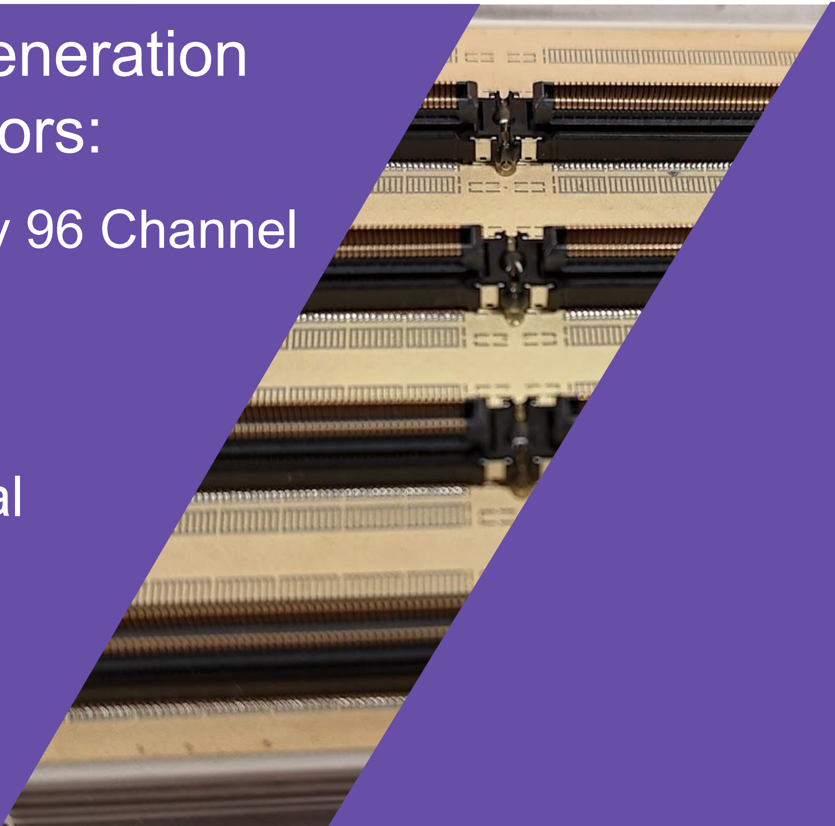
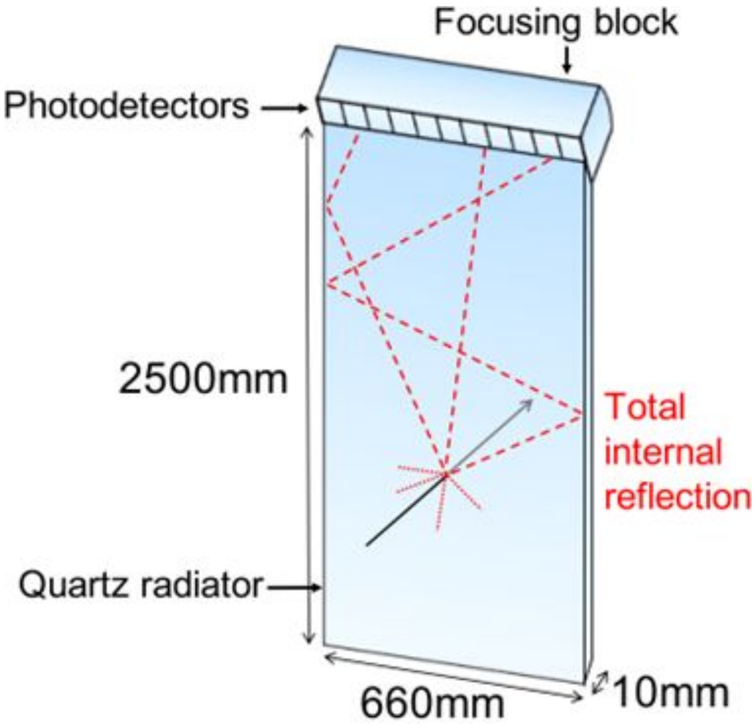


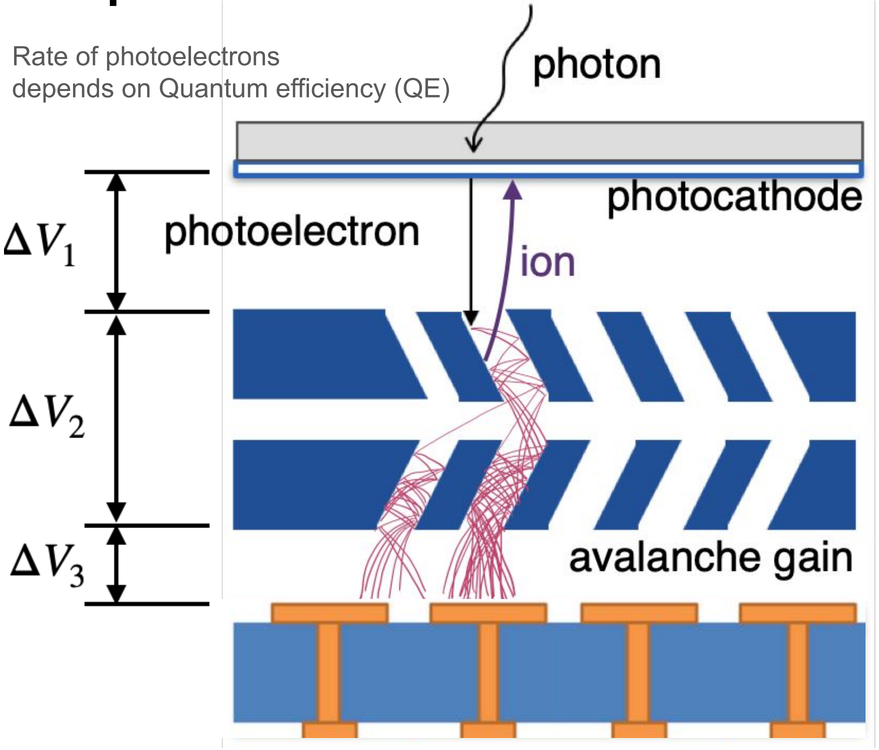
Quick introduction to TORCH

- Aim to provide low momentum (2–15 GeV/*c*) particle identification using time-of-flight.
- Charge particles produced Cherenkov photons which migrate to the edge of detector.
- 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, assuming 30 reconstructed photons per-particle.



Micro-channel-plate photomultipliers

- Cherenkov photons get converted to electrons by the cathode.
- Chevron structure leads to multiple electron wall impacts, causing avalanche gain.
- There is ongoing work into simulating these effects CST studio suite.

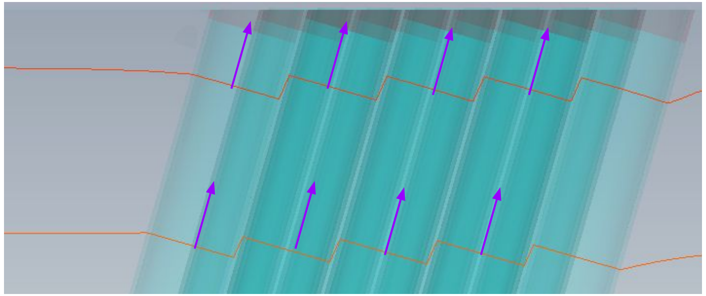


Cut through of a multi-anode MCP-PMT

Micro-channel-plate

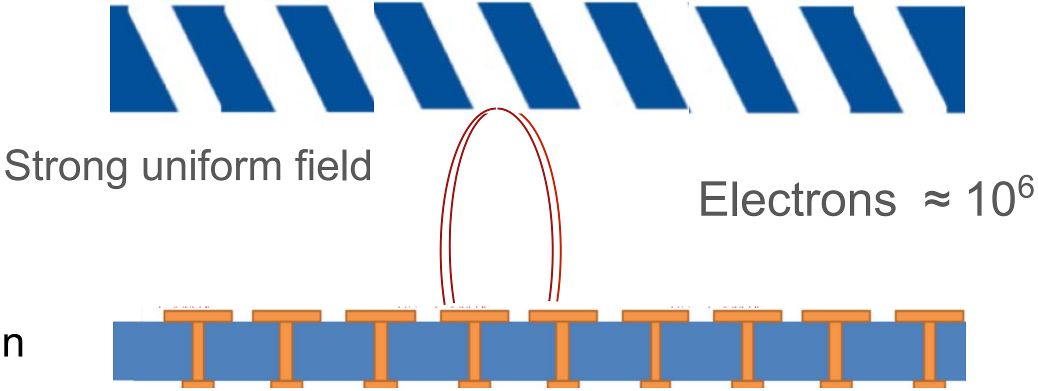
- Made up of a hexagonal array of pores with order 10 μm
- High axial fields accelerate the electrons
- Secondary electrons are produced by a emissive layer coated on the MCP’s surface and pore walls. Leading to avalanche gain effect
- Number of secondaries one electron produces is angle and energy dependent, following a probability distribution. Hence the gain has a charicastic distribution

bird's-eye view of a MCP

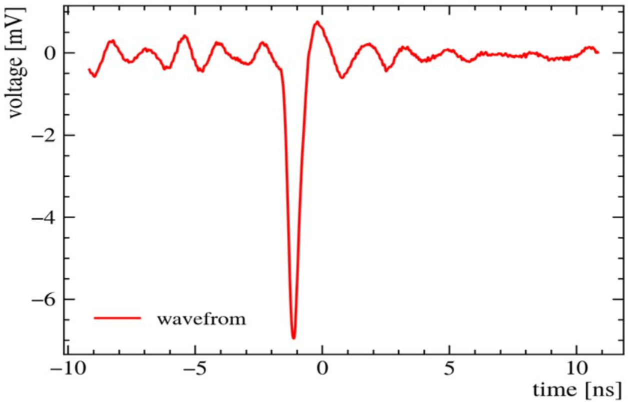


Equipotential lines inside the pore, with arrows (for demonstration)showing the direction of the E-field

Anode



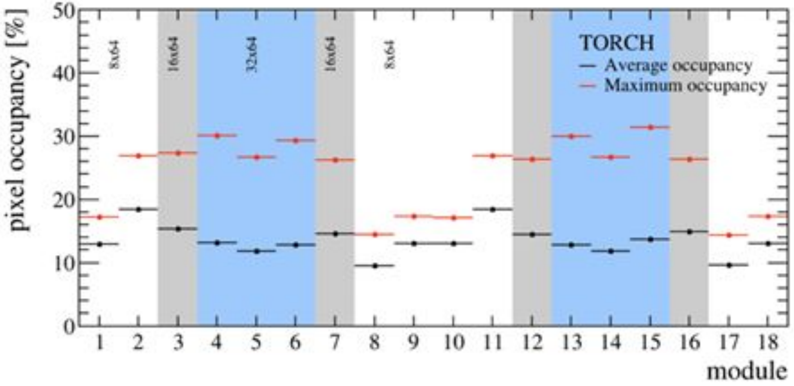
- After the MCP the electrons our accelerated towards the anode
- This charge cloud induces a charge on the anode’s electrodes.
- Charge of the signal around 100 fC.
- Due to the Small distances and high fields a the MCP-PMT have an intrinsically fast time response. As seen by the fast waveform of the analog signal.



Example waveform taken from reading one of the anodes pixel on an oscilloscope

Motivation for layout for new MCP-PMT

- At Upgrade 2 luminosities per-pixel occupancy become 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.

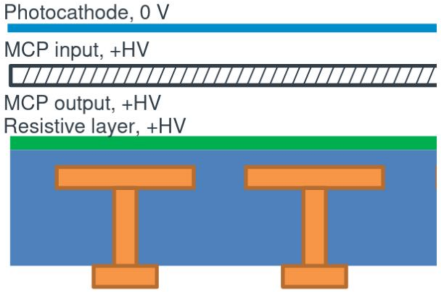


Pixel occupancy from FTDR (at $1.4\text{x}10^{34}$ $\text{cm}^{-2}\text{s}^{-1}$)

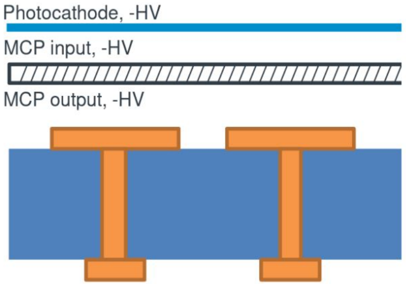
Motivation for layout for new MCP-PMT

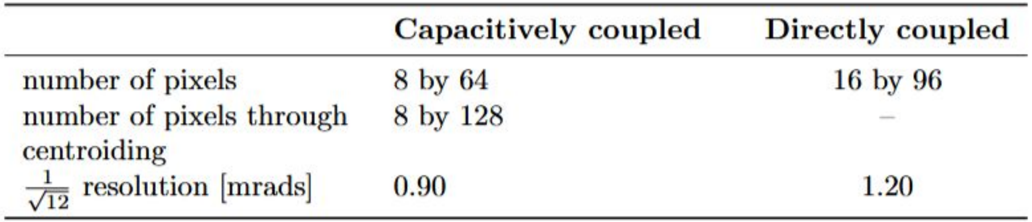
- The resistive layer spreads charge over multiple pixels.
- Where as the new device has a directly coupled anode (via vias). Instrumented to reduce charge sharing.

Capacitively coupled readout



Directly coupled readout

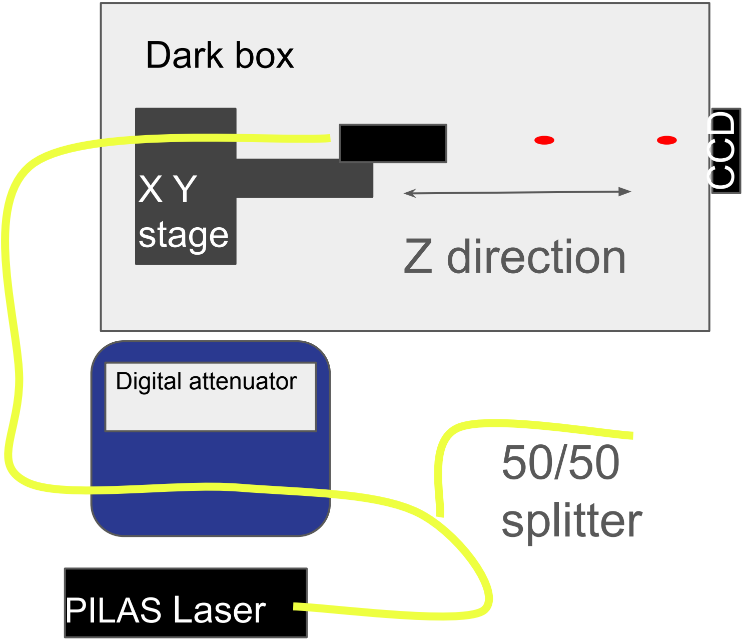




	Capacitively coupled	Directly coupled
number of pixels	8 by 64	16 by 96
number of pixels through centroiding	8 by 128	–
$\frac{1}{\sqrt{12}}$ resolution [mrads]	0.90	1.20

Timing performance is linked to reconstruction of the Cherenkov photons. The spatial resolution of the PMTs is key for this. Here we are aiming for ≈ 1 mrad.

Lab setup for MCP-PMT Characterisation



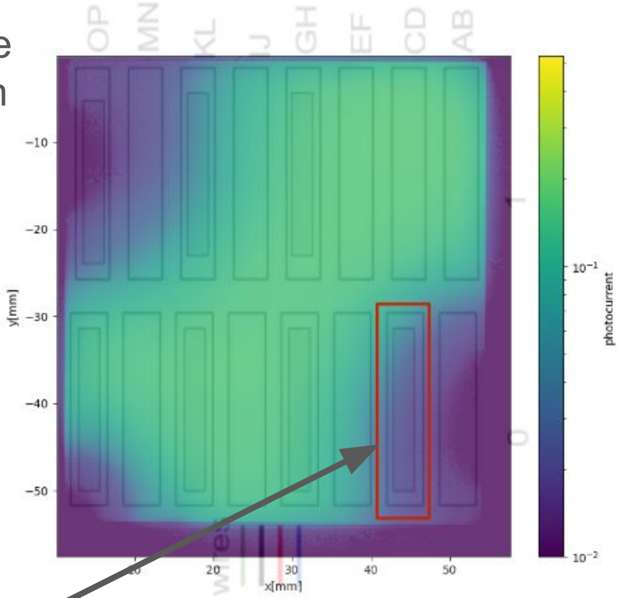
fiber optic cables, passing light into the box.

- Optically coupled a 45ps pulsed Pilas laser with a wavelength of 407nm and jitter < 3 ps.
- Attenuating signal with a digital attenuator to get to single photons.
- Laser position in the dark box is controlled by a motorised X/Y translation stage.
- Repetition rate of the laser pulse is controlled by a DG645 delay generator

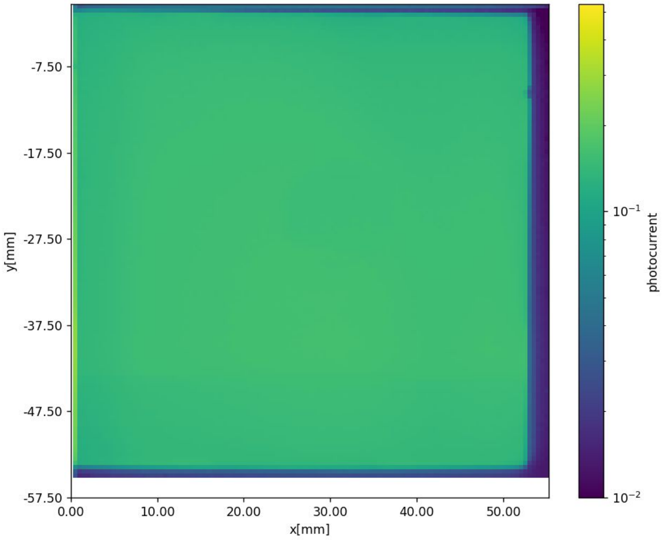
Quantum Efficiency

This is a relative, light source not calibrated

- Able to measure the full active area of the cathode in 0.25mm steps.
- See that one MCP-PMT has non-uniform efficiency. Speculation is that this is caused by a poor vacuum seal.
- Dead area appears to not grow with time.
- A second device (without connectors) shows a much better uniformity.



Similar but separate setup as before but measures the current across the photocathode MCP gap



Second MCP-PMT without anode connectors but better QE

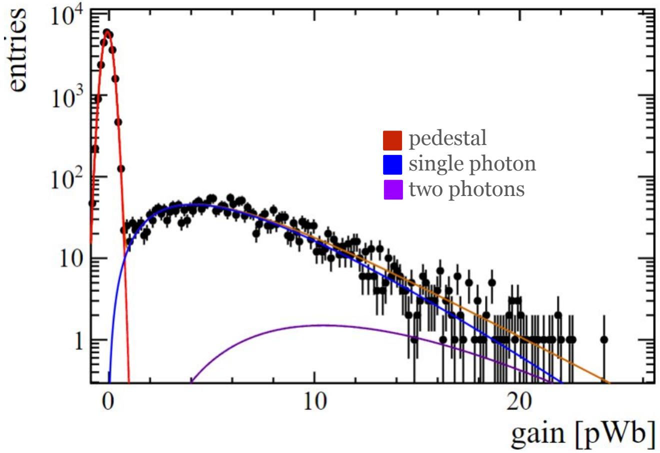
Note: background shows location of anode layout with dark rectangles indicating instrumented connectors

Charge sharing

- Data was read out to a lecroy waveMaster 808zi-A (8 GHz, 40 GS/s) oscilloscope where the raw waveform could be processed.
- Oscilloscope was triggered on the laser pulse and the area of the pulse (proportional to charge) recorded.

- The gain distribution was then fitted with a Polya model*. This fitter takes into account the contributions of no photons, single photons, two photons, three photons etc.

*[Prescott, 39 (1966) 173-179]



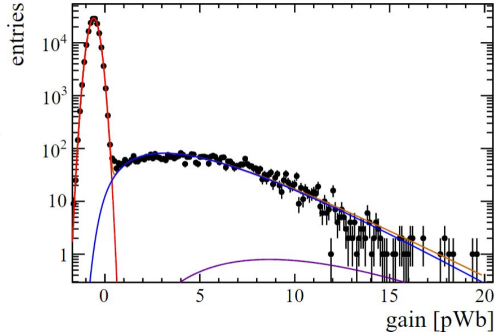
Example with mean gain around 10^6

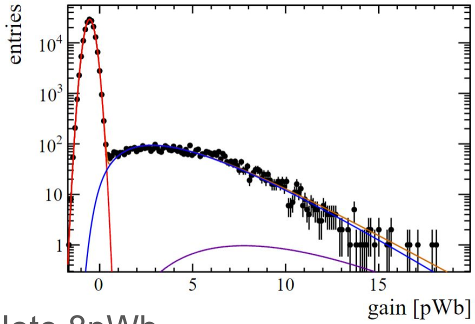
Image spread in the fine direction

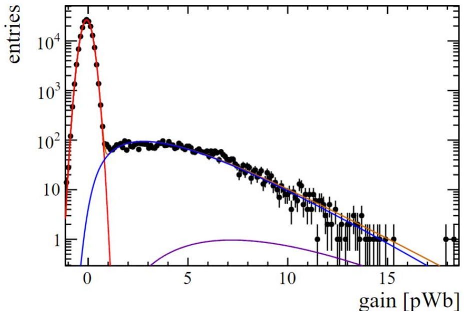
Laser is sweeped 4mm along the y direction in 0.1 steps (50 hours long total)

Voltage applied

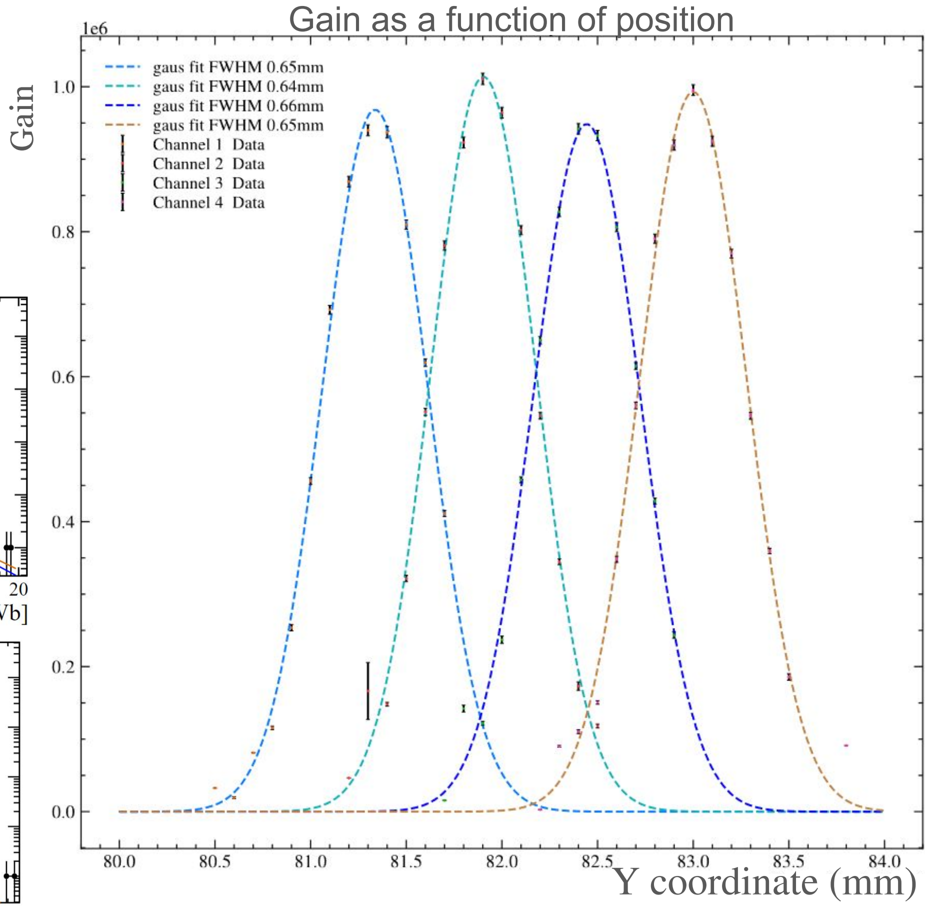
600V cathode to MCP
1400V across MCP
1500V MCP to anode
(with anode at 0V)







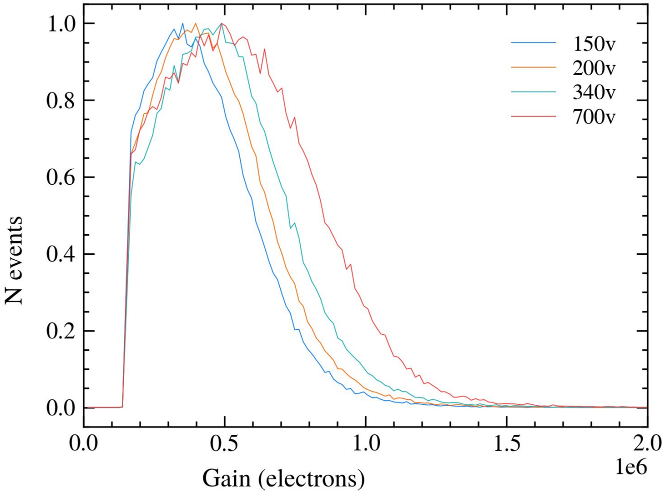
Note 8pWb ~ 10^6 electrons

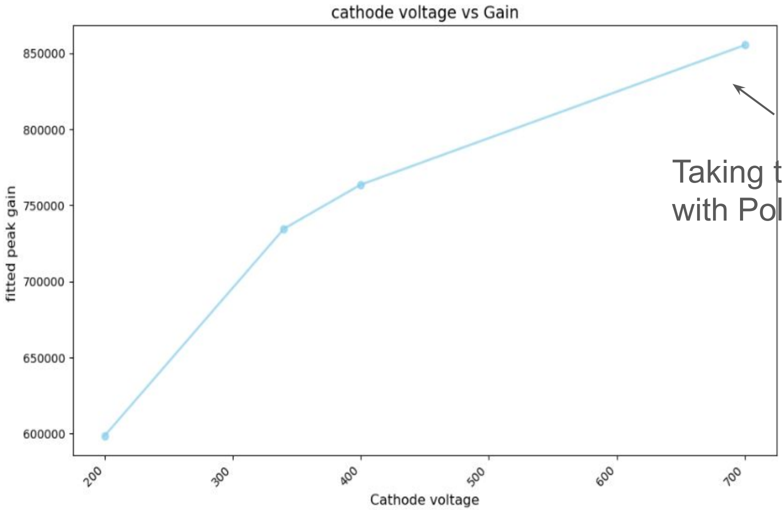

Gain as a function of position

*Fitting a gaussian convolved with a top hat of the pixel size yields a **FWHM of ≈ 0.65 mm***

Cathode-MCP gap voltage gain dependence

- Gain depends on the voltage difference between photocathode and MCP input.
- Expected gain roll of not seen, which would suggests this happens at a higher impact energy.



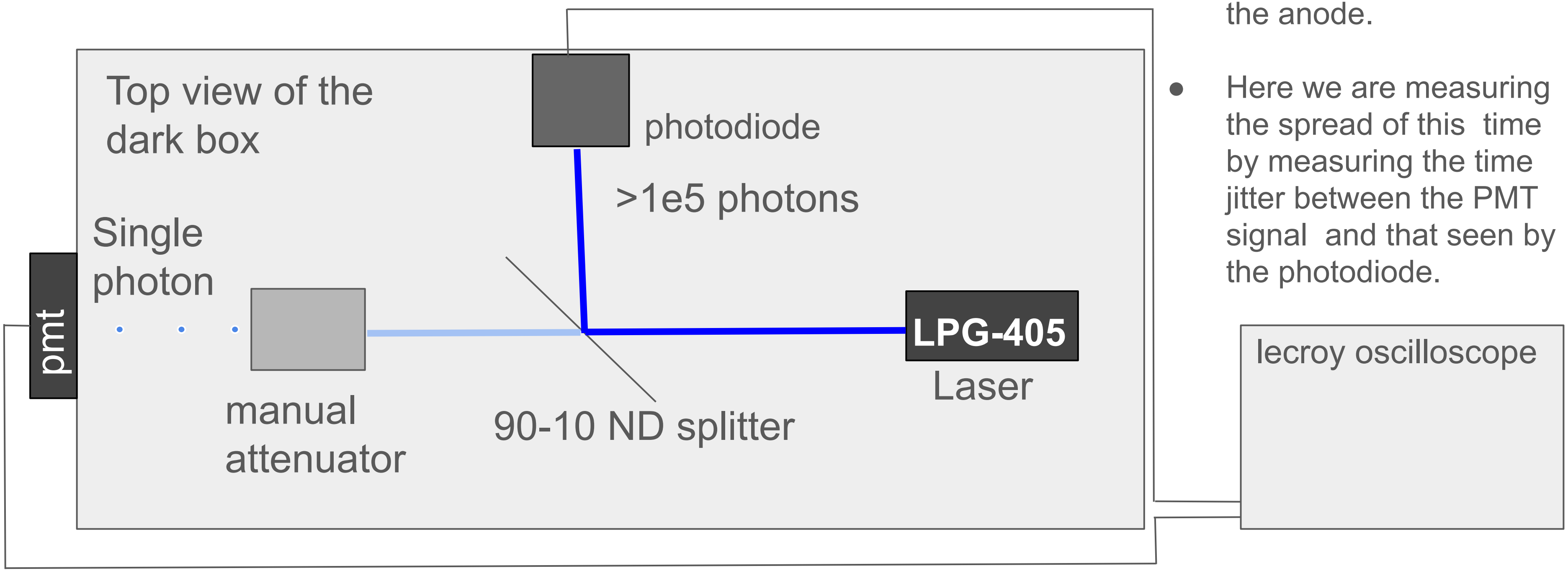


Taking the gain measured with Polya model

For more info see:
paper
presentation
SEY curve

Transit Time Spread (TTS) measurement

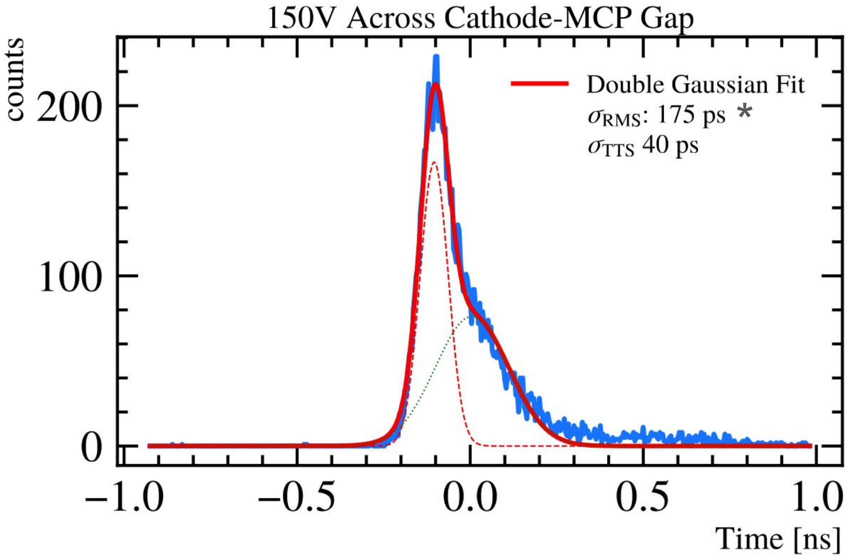
- The transit time is the time taken for electron produced at the cathode to generate a pulse at the anode.
- Here we are measuring the spread of this time by measuring the time jitter between the PMT signal and that seen by the photodiode.

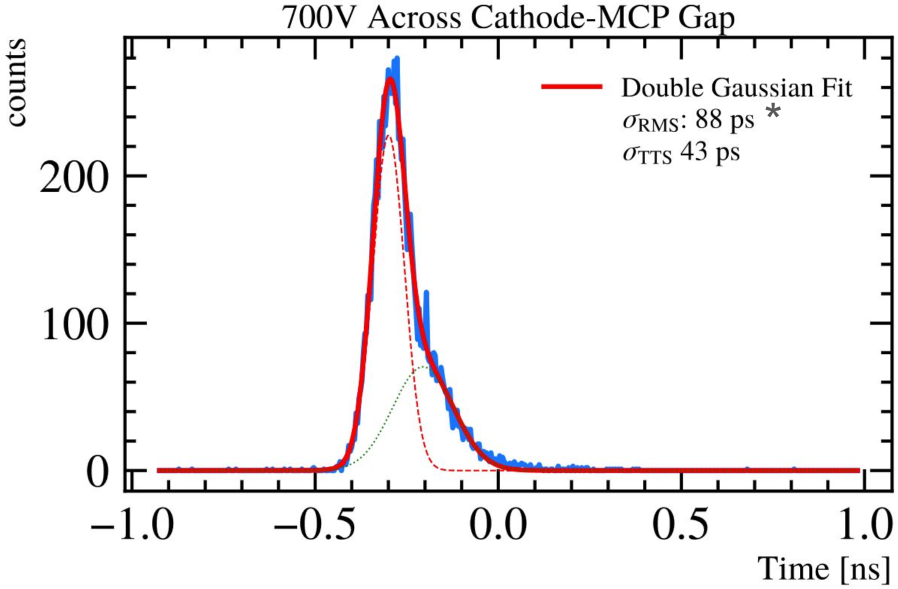


A concerted effort was made to stop reflections getting to the cathode

TTS Results

An improvement in the root mean squared from data is seen when the voltage applied between the cathode and MCP is increased

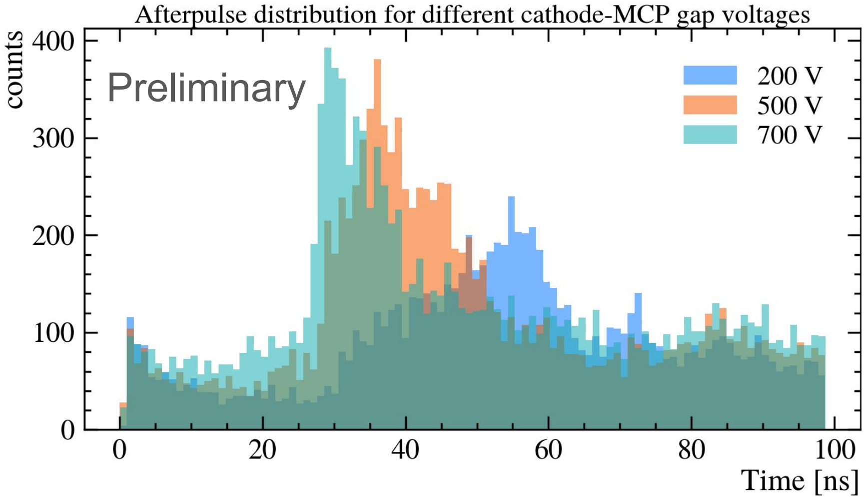


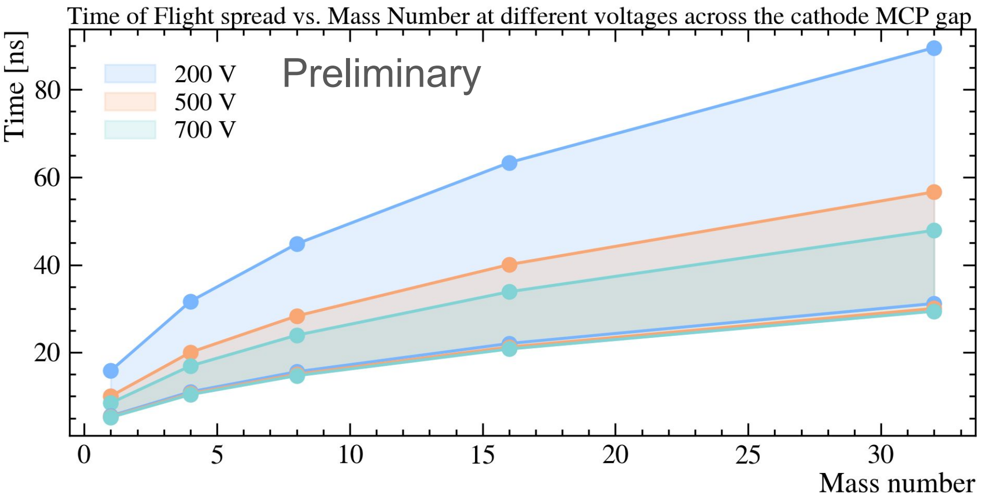


**RMS taken from data not fit*

Ion feedback data from TORCH MCP-PMT (work in progress)

- Ions with positive charge travel back to the cathode can produce afterpluses
- A peak is seen in the time distribution of afterpulses, which is depend on cathode voltage
- Background likely caused by dark counts within the actuation window.





Summary

- Shown characteristic tests and analysis of new 96 x 16 MCP-PMT.
  - Quantum Efficiency
  - Image spread/charge sharing
  - Photocathode/MCP input voltage dependence
    - Gain
    - TTS
    - Ion feedback

- Results so far in charge sharing and TTS show promise.
- Moving forward we want to compare these characteristic tests to CST simulation. To further understand the internal physics of these devices, such as magnetic field effects.