The TORCH Detector

Time **O**f internally **R**eflected **CH**erenkov light

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IoP
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On behalf of the TORCH collaboration

Outline

- What is TORCH?
- MCP-PMT development and testing
- Photon yield

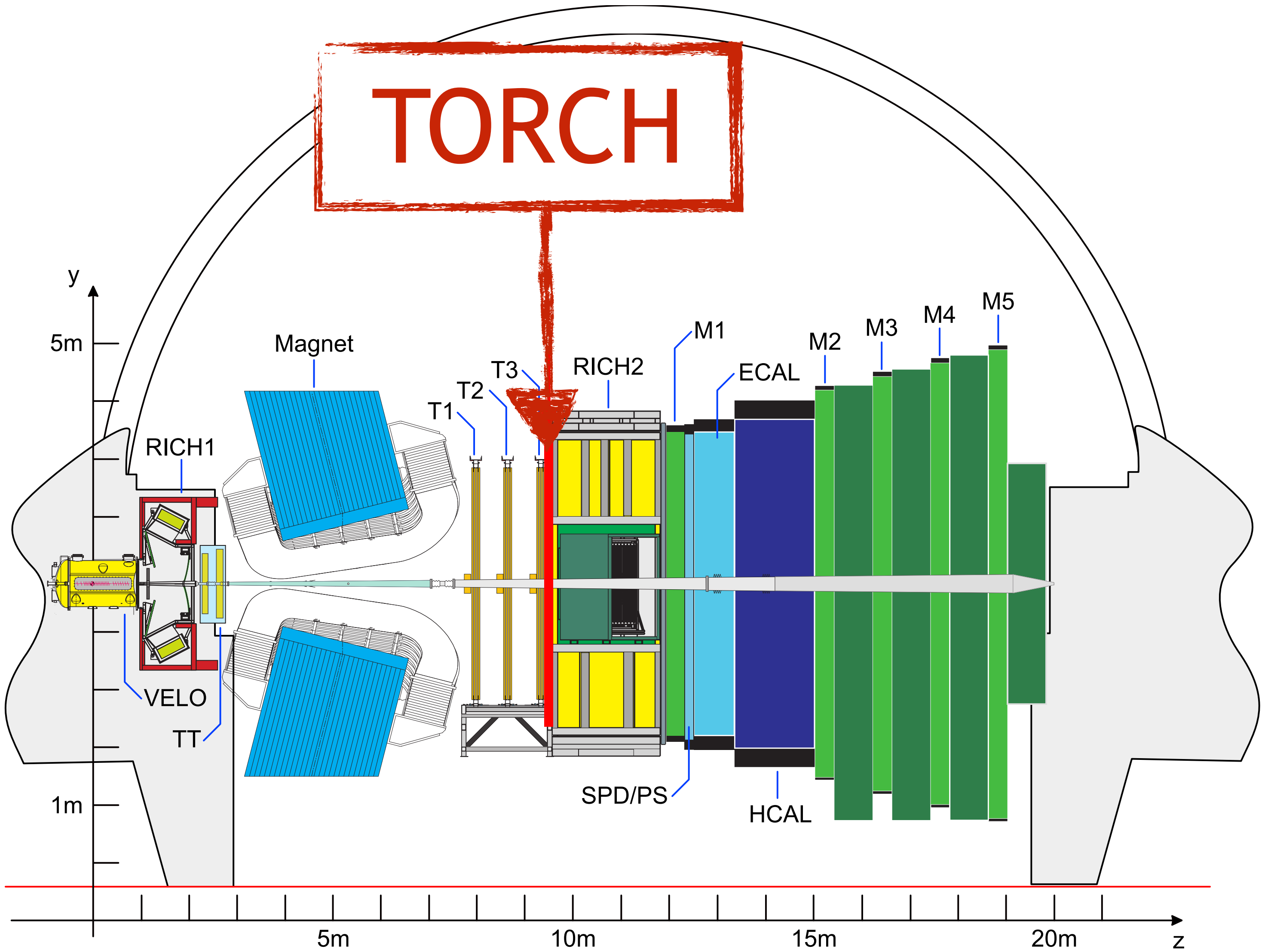
Covered in this talk

- Testbeam campaigns
- Photon time resolution
- PID performance

See talk by Thomas H. Hancock

TORCH in the LHCb detector

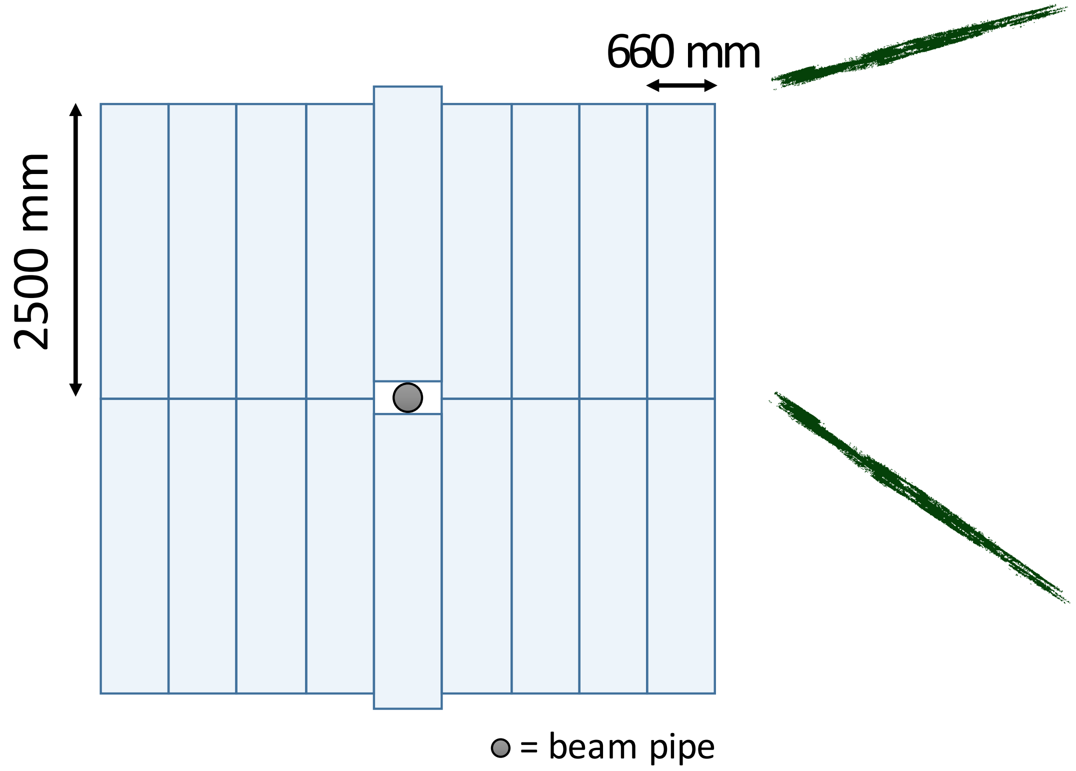
- Aim to improve PID of low momentum particles (2-10 GeV/c)
- The detector exploits the time-of-flight difference between p/K/ π
- Possible installation during the CERN Long Shutdown 3 (~2024)

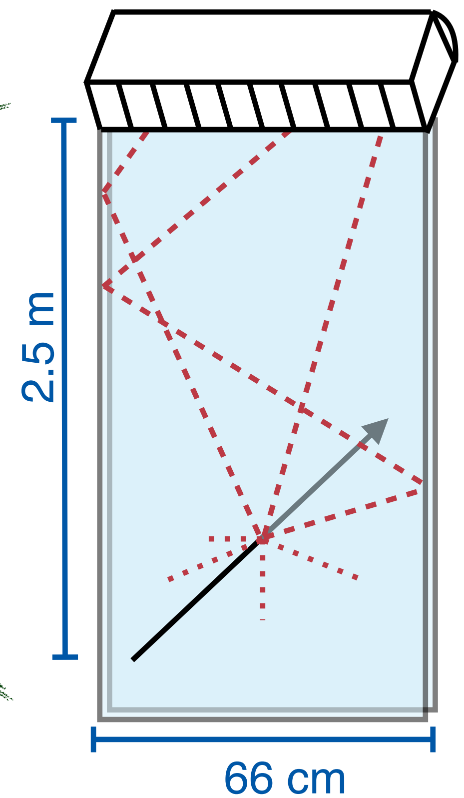


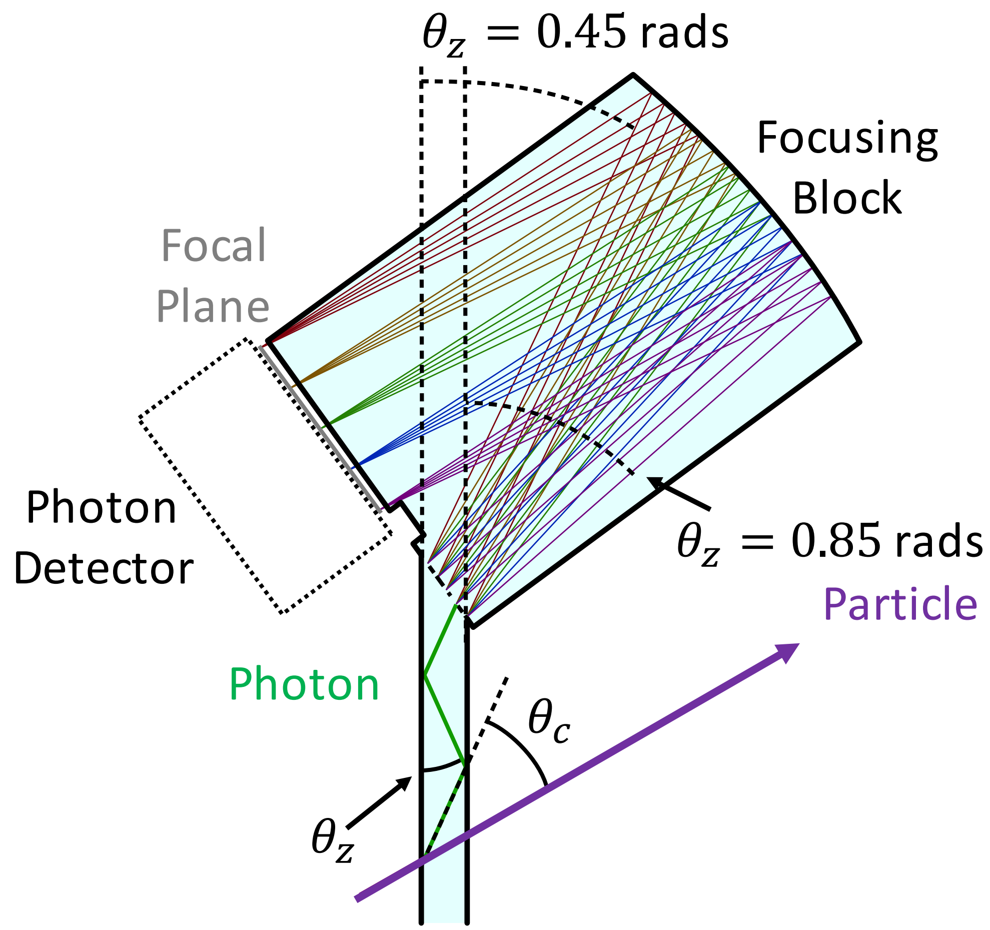
Basic TORCH design

- 18 quartz modules.
- Cherenkov photons travel to focusing block through total internal reflection.
- The angle θ_z determines the position on the focal plane.

Precise determination of the arrival time and position of the Cherenkov photons allows for precision time-of-flight measurements in LHCb.

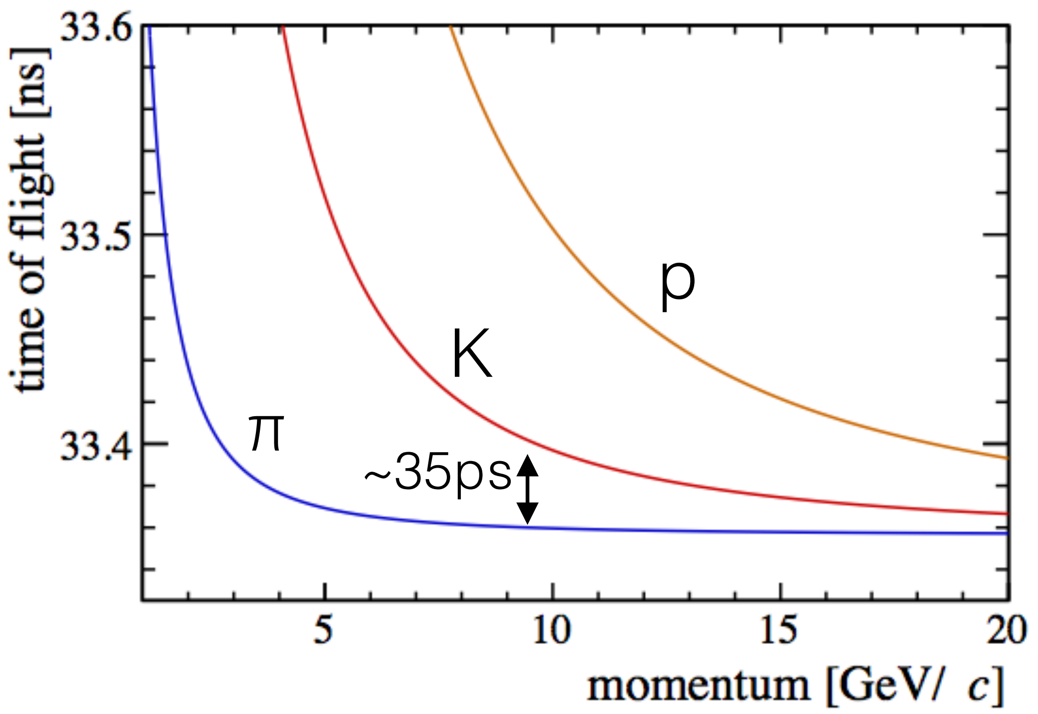






Aim of the TORCH detector

- Time of flight and photon pattern allows for determination of the particle species.

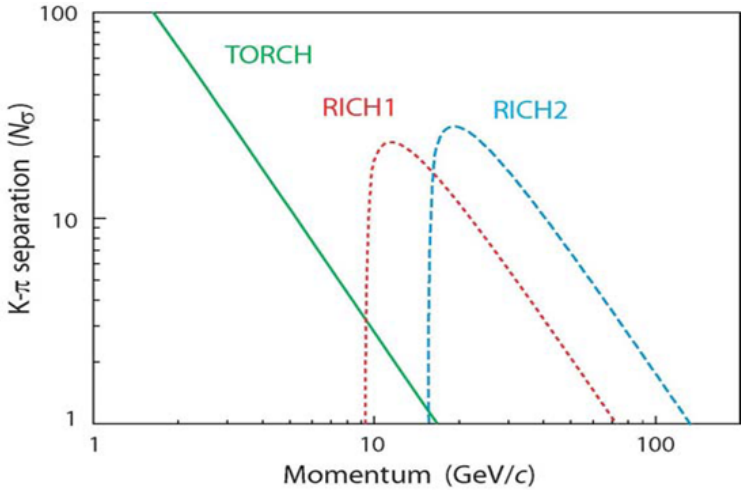


- $\Delta_{TOF}(K-\pi)$ = 35 ps over a ~10m flight path. → aim for a 10-15 ps resolution per track.

- σ_{TOF} requirement for ~30 detected photons per track dictates a single photon timing precision of ~70 ps.

- ~1 mrad precision is required on measurement of the angles to achieve an intrinsic resolution of ~50 ps.

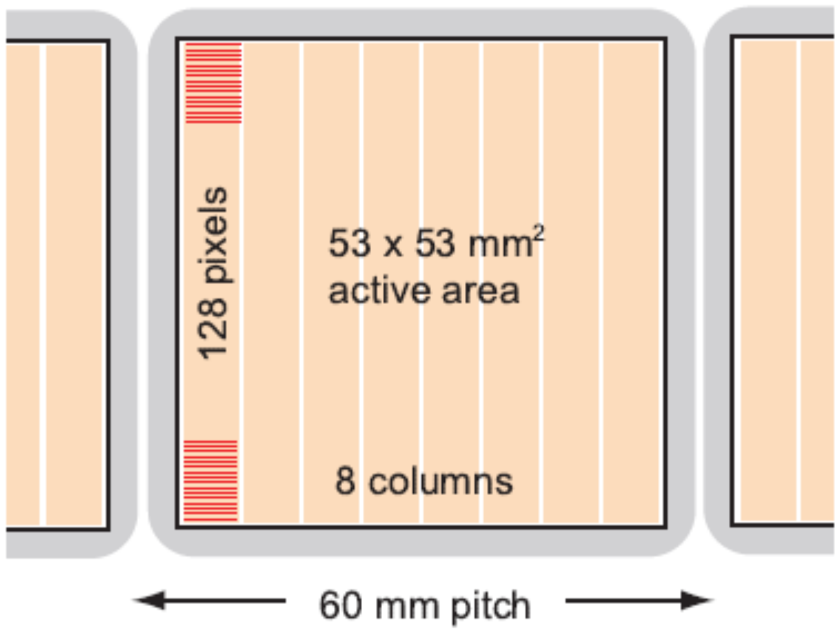
Isolated track PID performance



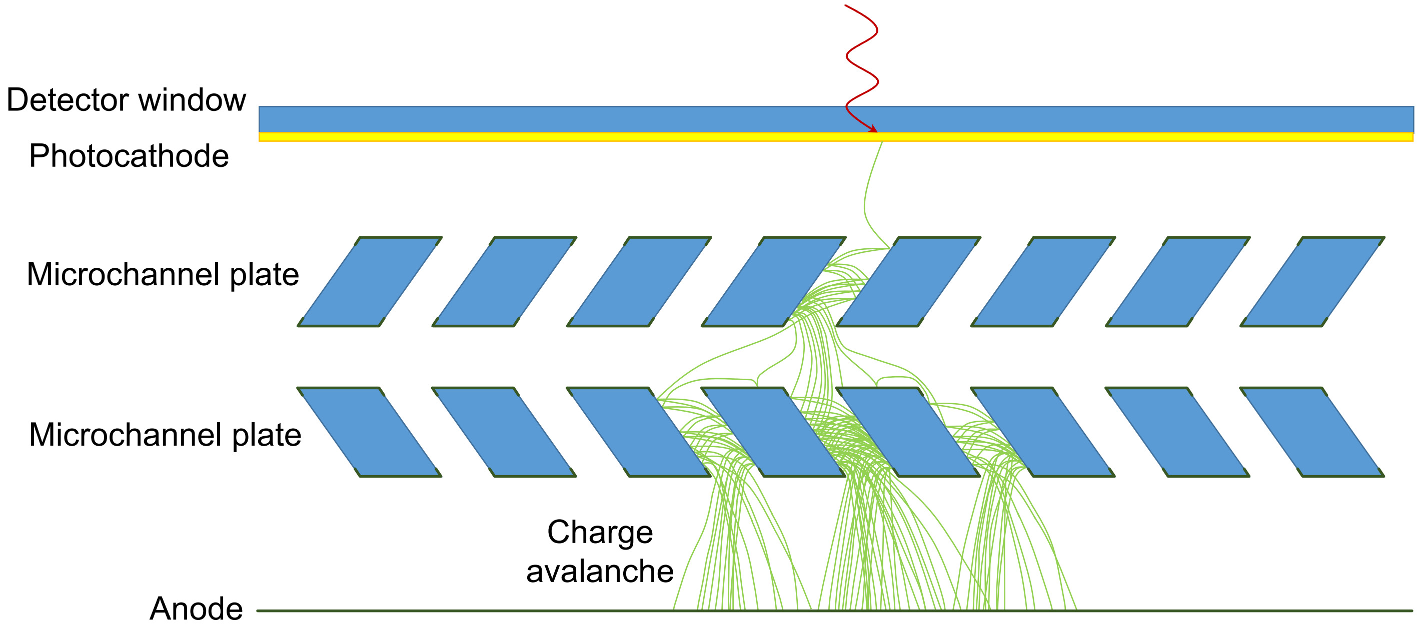
MCP-PMT development

MCP-PMT's (micro-channel plate photomultiplier tubes) are used as photodetectors for TORCH.

- Good intrinsic time resolution
- Low dark noise, radiation resistant and robust to magnetic field
- High active area to packaging ratio
- Lifetime $\geq 5C/cm^2$



Baseline TORCH design segmentation of 128×8 with a 2" sq. tube

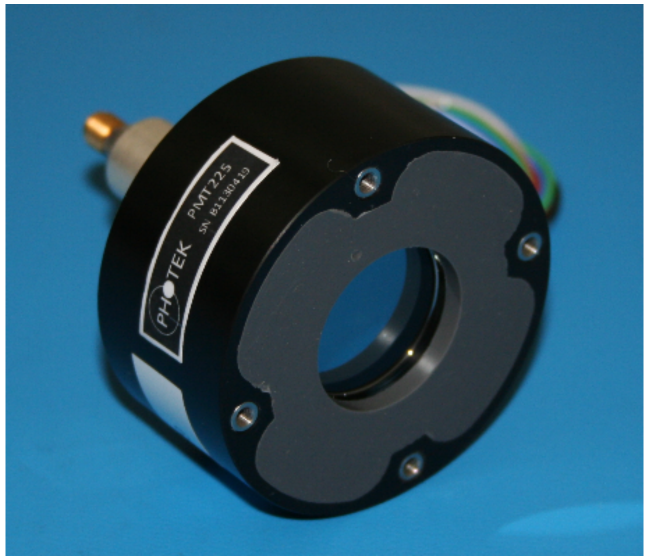


A three stage development program was set up with an industrial partner, Photek Ltd

MCP-PMT development

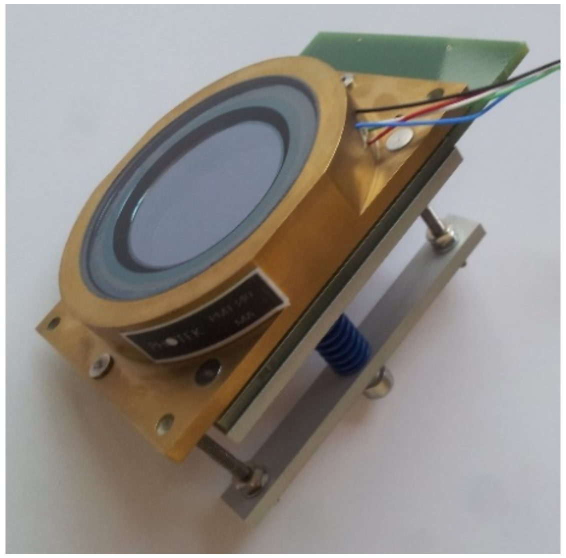
Phase I:

- Single channel MCP
  25 mm active ∅
- Focus on extended lifetime ($\geq 5C/cm^2$)



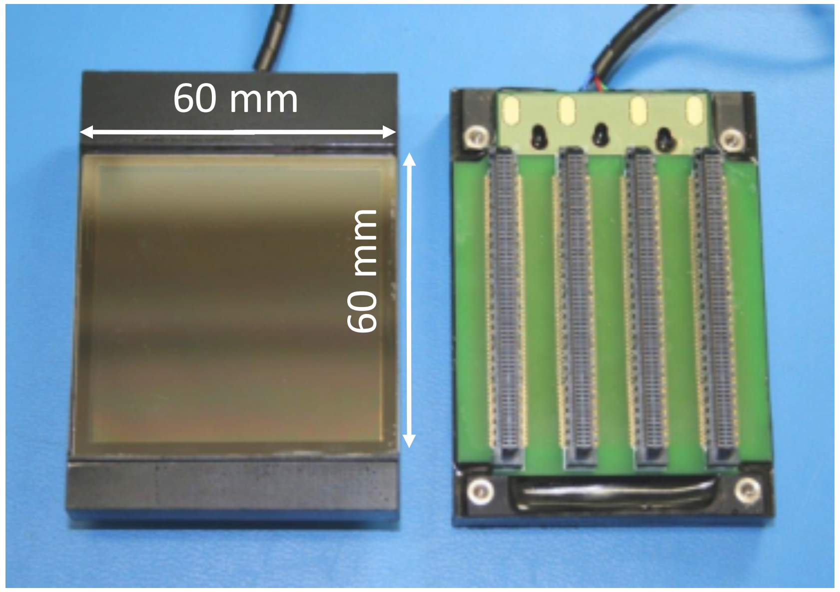
Phase II:

- Circular MCP
  40 mm active ∅
- High granularity (charge sharing)



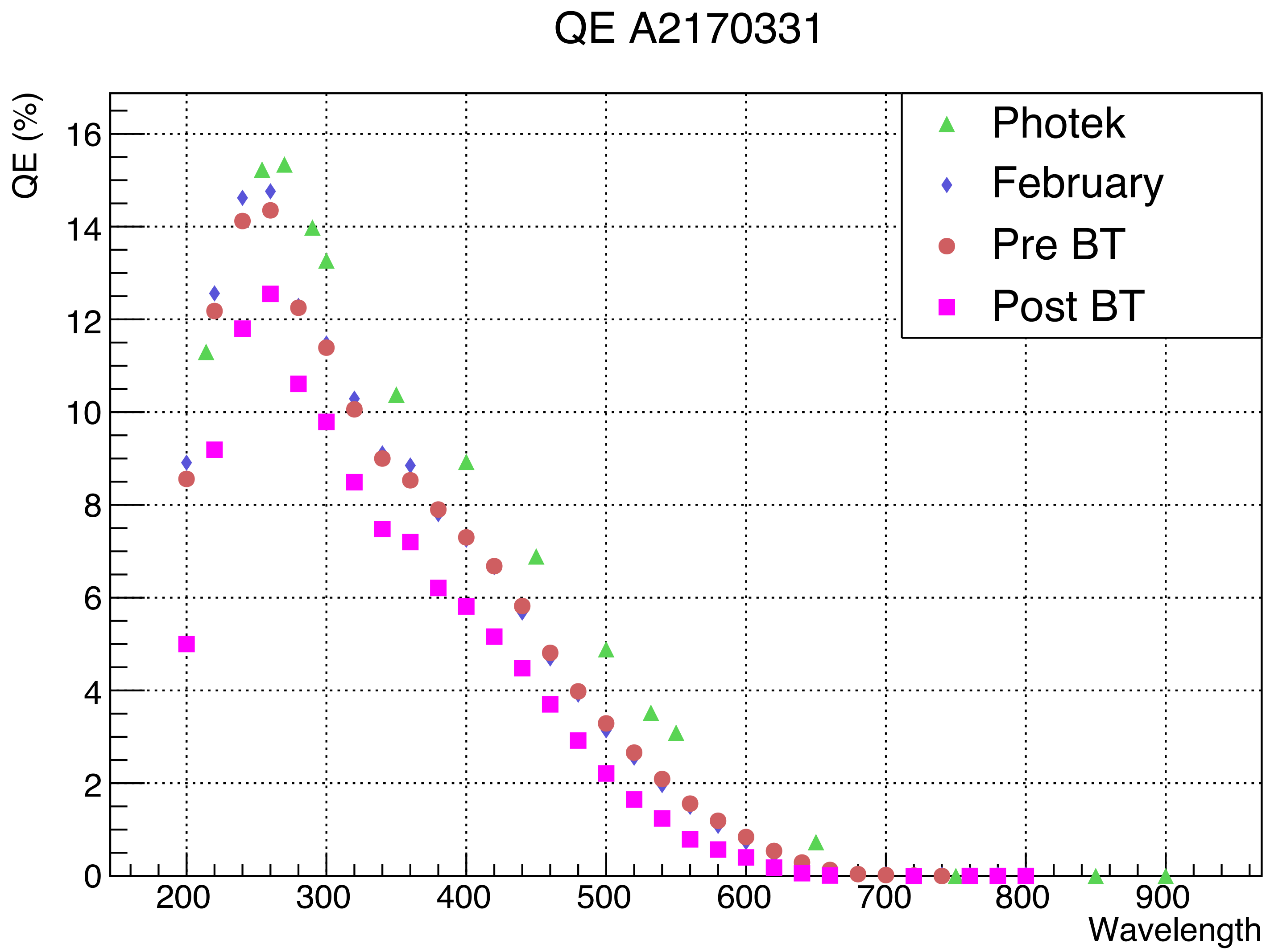
Phase III:

- Square tube with > 80% active area
- Extended lifetime and required granularity



MCP-PMT lab measurements - testing

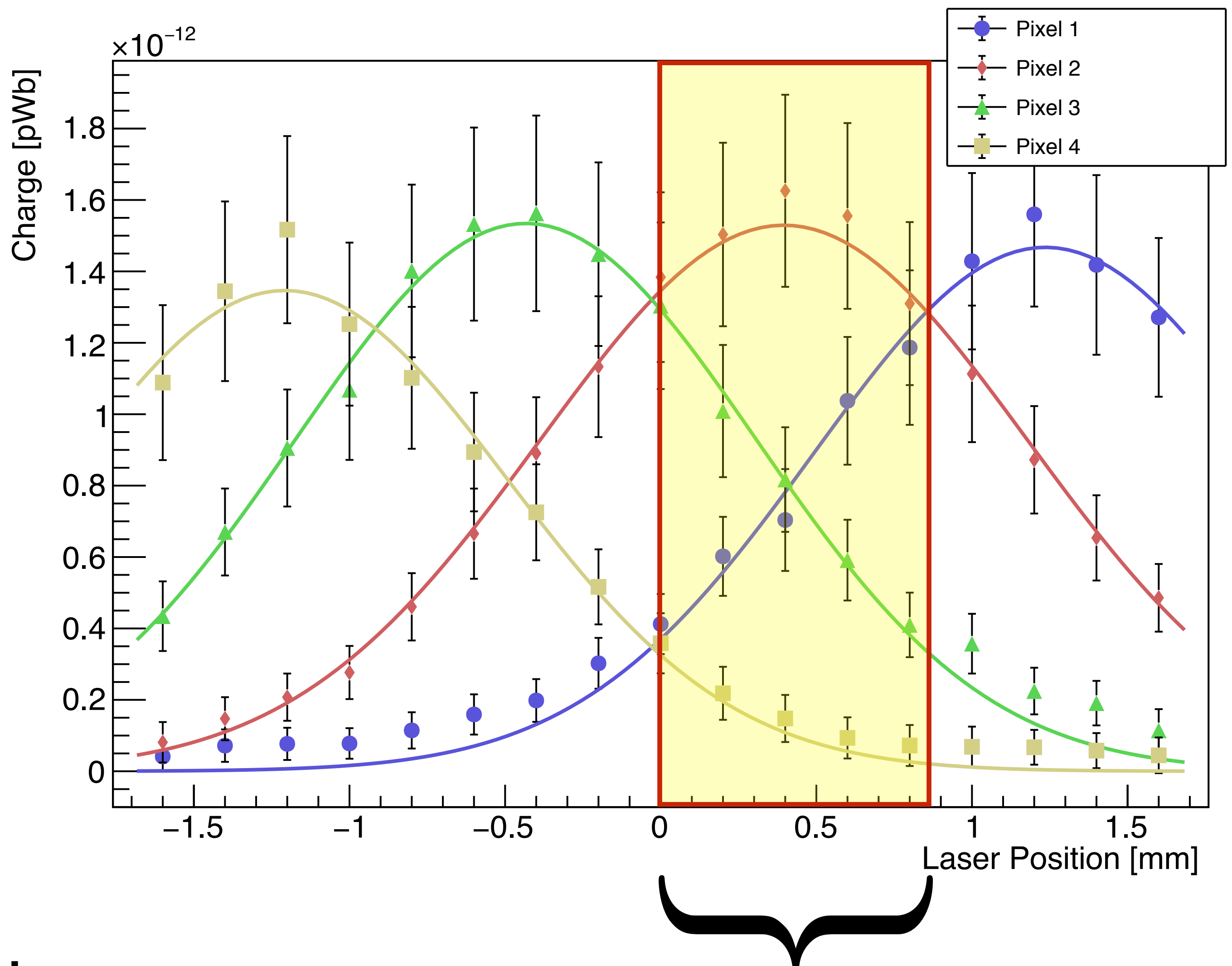
- Lab tests of the prototypes to decide which MCPs to use in beam tests
  - Uniformity
  - Gain
  - Quantum efficiency



- The graph shows Phase III MCP-PMT quantum efficiency measurements of the MCP used in the Nov’17 testbeam.
- Degradation of the performance over time observed - being investi-gated by Photek.

MCP-PMT lab measurements

- Measure the size of the spread of the electron avalanche (charge spread function) caused by a photon hitting the MCP-PMT.
- Laser scan, read out with oscilloscope.
- Scan performed over 4 pixels.
- Charge sharing clearly seen: the charge spread scans multiple pixels. This can be used to calculate where the photon hit the MCP-PMT.



Pixel pitch = 0.828 mm
Point spread function:
average σ = 0.7458

Photon counting studies

Aim: Check whether the number of photons observed per particle passing through the detector in data agrees with simulation.

Simulation

- Geant4 simulation of Mini-TORCH
- Mixed proton and pion beam fired through the side of the quartz plate

Data

- Data taken during the Nov. 2017 testbeam campaign using a Phase III MCP-PMT

Photon losses - I

Need to account for many possible losses of photons in the simulation, for example (quoting approximate efficiencies):

• Rayleigh scattering	~99-100%
• Glue between quartz plate and focusing block How does ageing of the glue affect this efficiency? How much does the thickness of the glue change the efficiency?	~99-100%
• Surface roughness of the quartz	~90%
• Reflectivity of the focusing mirror Mirror reflectivity measured in air, not quartz.	~90%
• Active area of the MCP-PMTs (53x53 mm^2 active area in 2” tubes)	88.3%

Photon losses - II

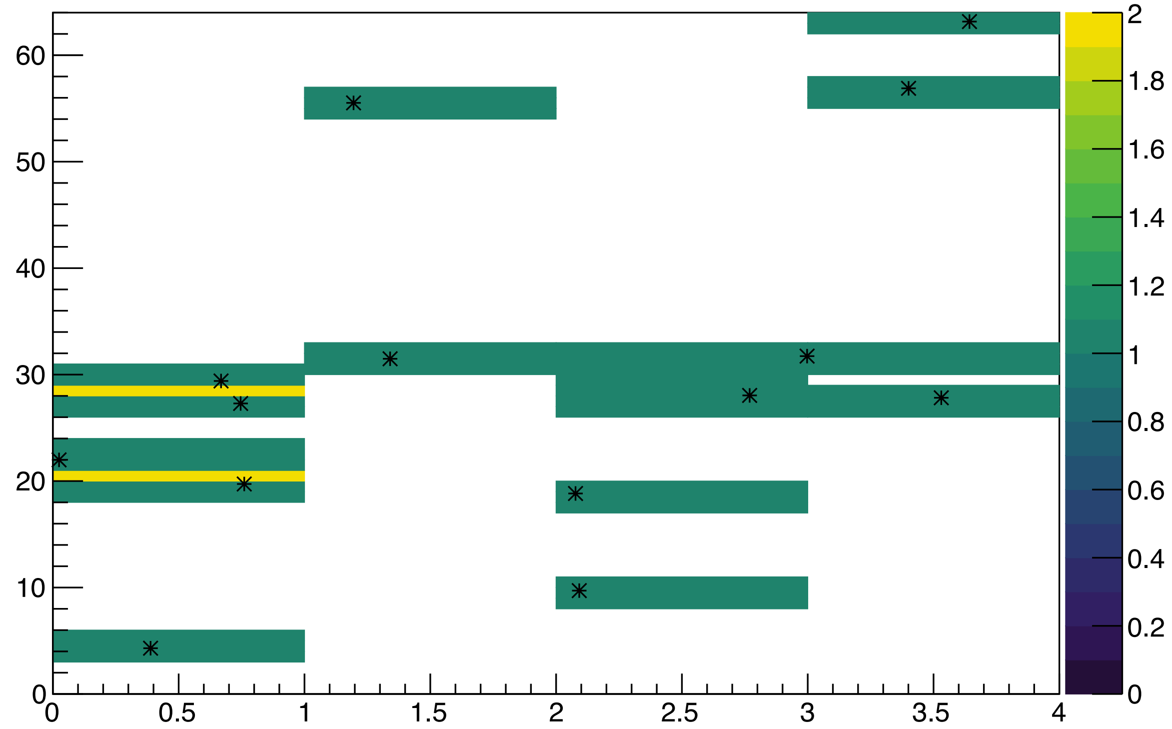
Need to account for many possible losses of photons in the simulation, for example (quoting approximate efficiencies):

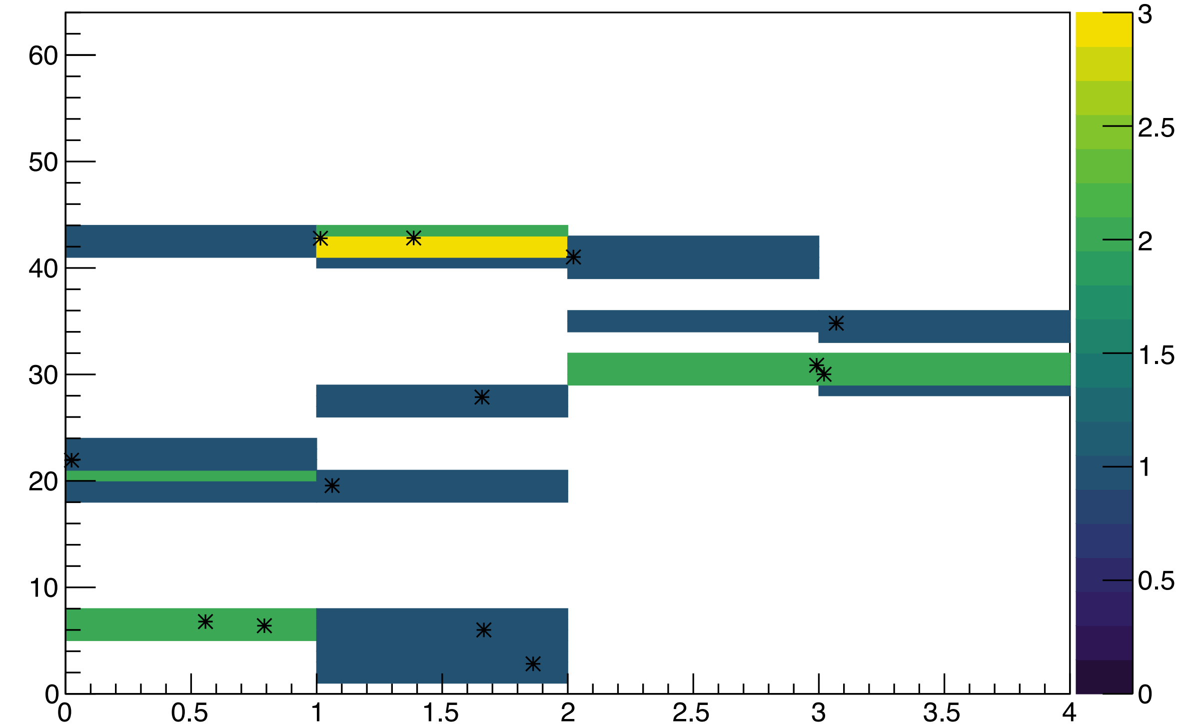
- Collection efficiency (Open Area Ratio) 60-90%
  (= What fraction of electrons are successfully multiplied?)
  Difficult lab measurement - currently waiting on a new measurement from Photek.
- Quantum efficiency (QE) 12-20%
  (= How many photons are converted into electrons?)
  Quantum efficiency varies significantly between MCPs.
  How uniform is the QE across the tube?
- NINO thresholds under investigation
  Would be difficult and very time consuming to measure in the lab.
  At this point in time the most unknown factor in the photon yield analysis.

Photon Counting - clustering on simulation

- A clustering algorithm is run over the hits to identify photons as a group of hits on the MCP that are close together in space and time.
- How often would you expect two photons to be clustered together as one?
- Two events shown:

✳ = position of photon hit
Coloured pixels are the pixels that pick up a charge from the photon avalanche.

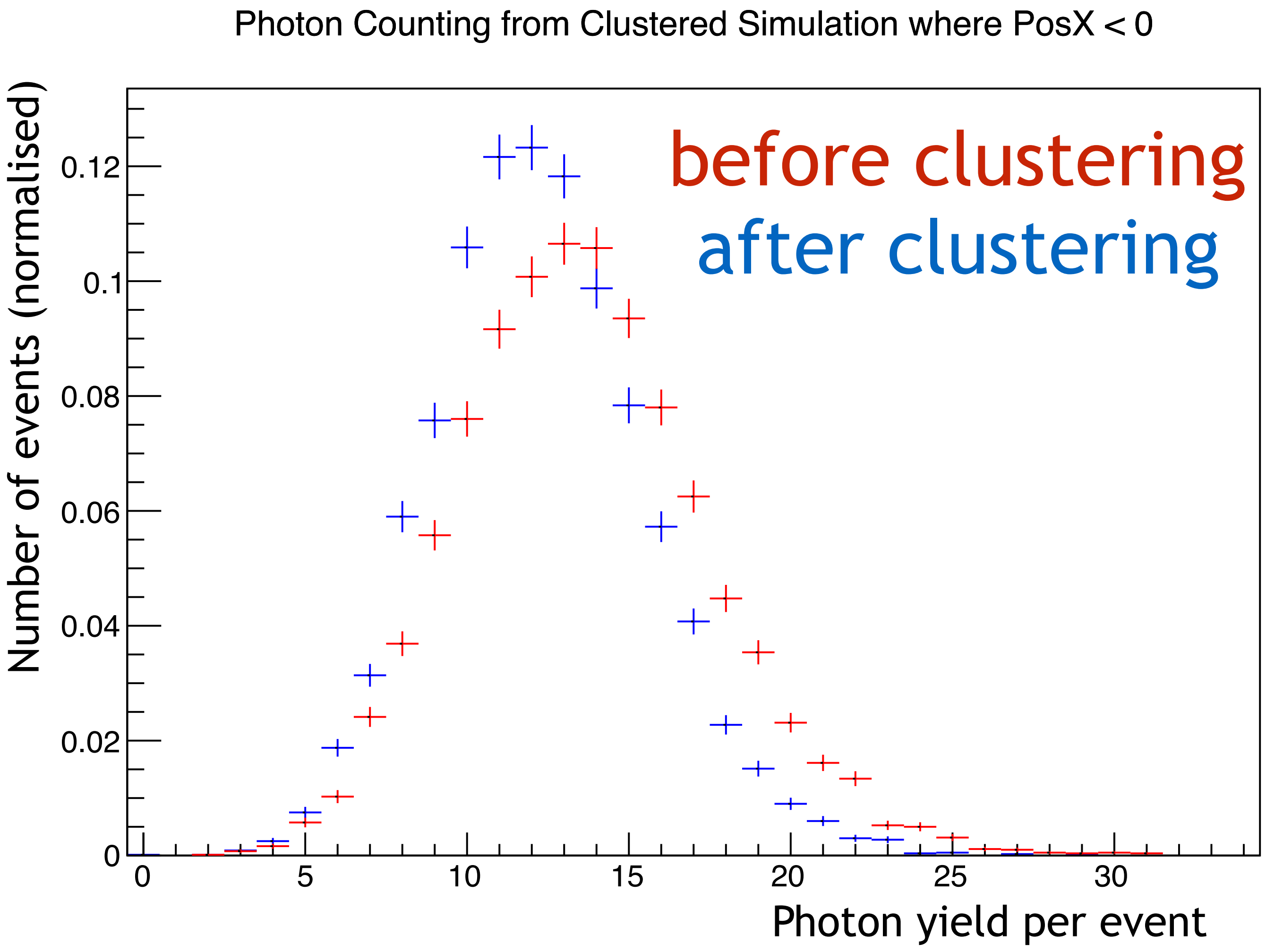




Photon Counting - clustering on simulation

- A clustering algorithm is ran over the hits seen in simulation to identify photons as a group of hits on the MCP that are close together in space and time.

This happens for roughly two photons per event. Not negligible!

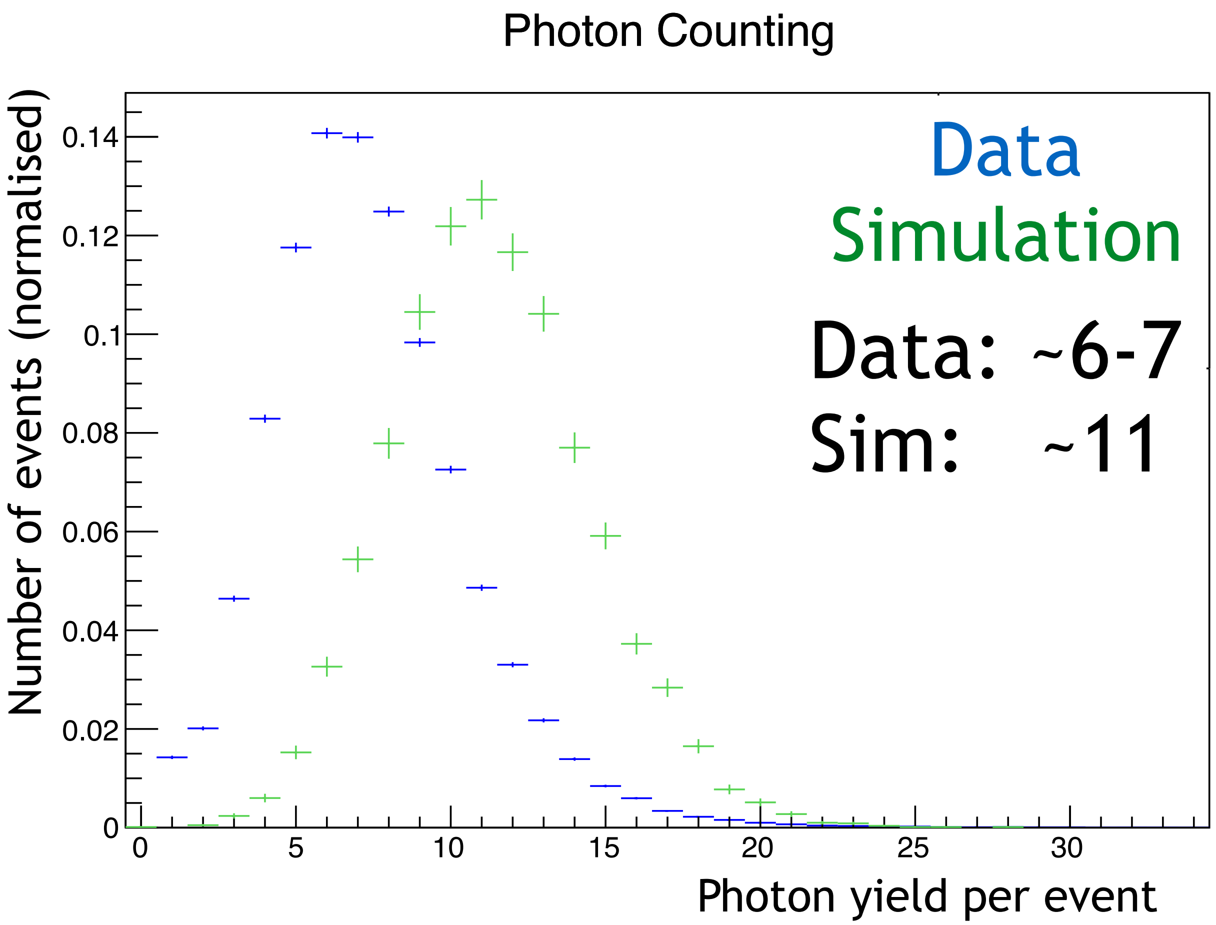


Photon counting

- Clear discrepancy seen - currently under investigation. Most likely culprit: simulation does not yet accurately model the electronics used in data taking.

- Similar discrepancy between data and simulation is seen in the Jun'18 testbeam data.

- Pinpointing the problem has proven difficult - both the MCPs and TORCH are being developed simultaneously.



Now get ready for the rest of the story…

- What is TORCH?
- MCP-PMT development and testing
- Photon yield

} Discussed in this talk

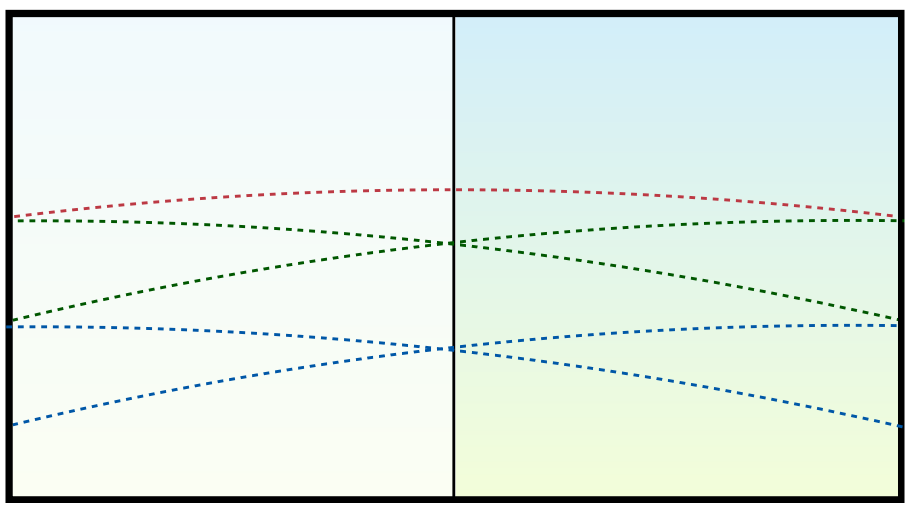
- Testbeam campaigns
- Photon time resolution
- PID performance

} See talk by Thomas H. Hancock

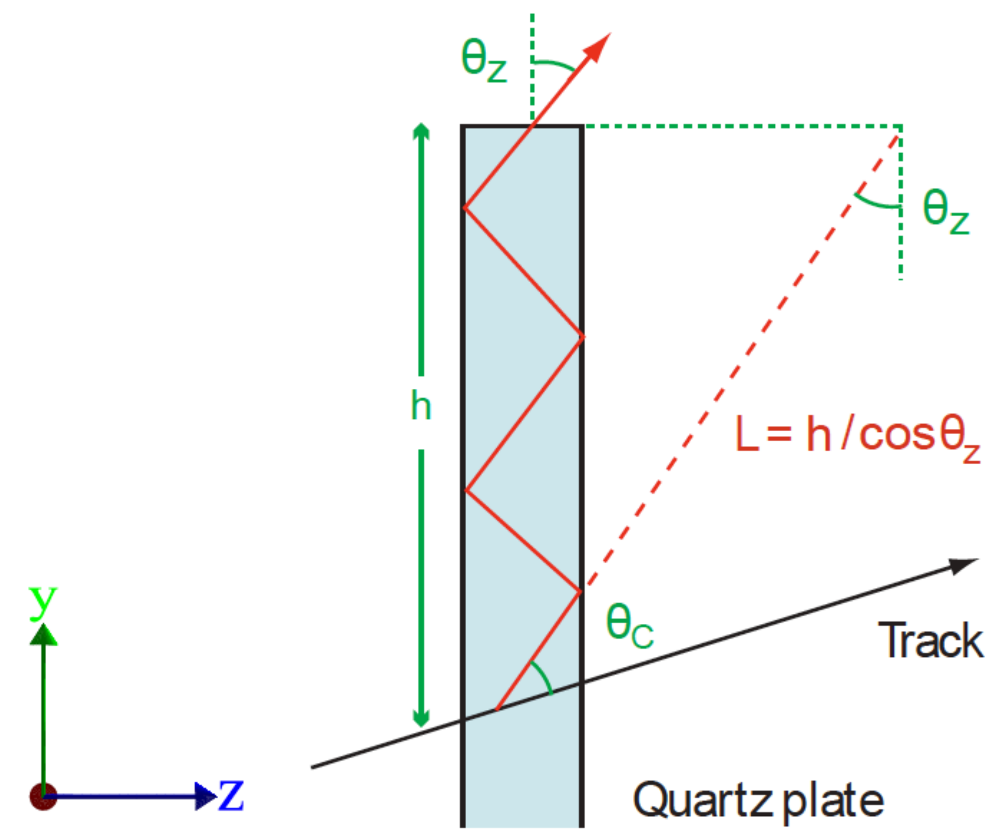
BACKUP

How does TORCH work?

- More side reflections means L increases
- This changes the angle θ_z such that a new band is created on the MCPs through the focusing block

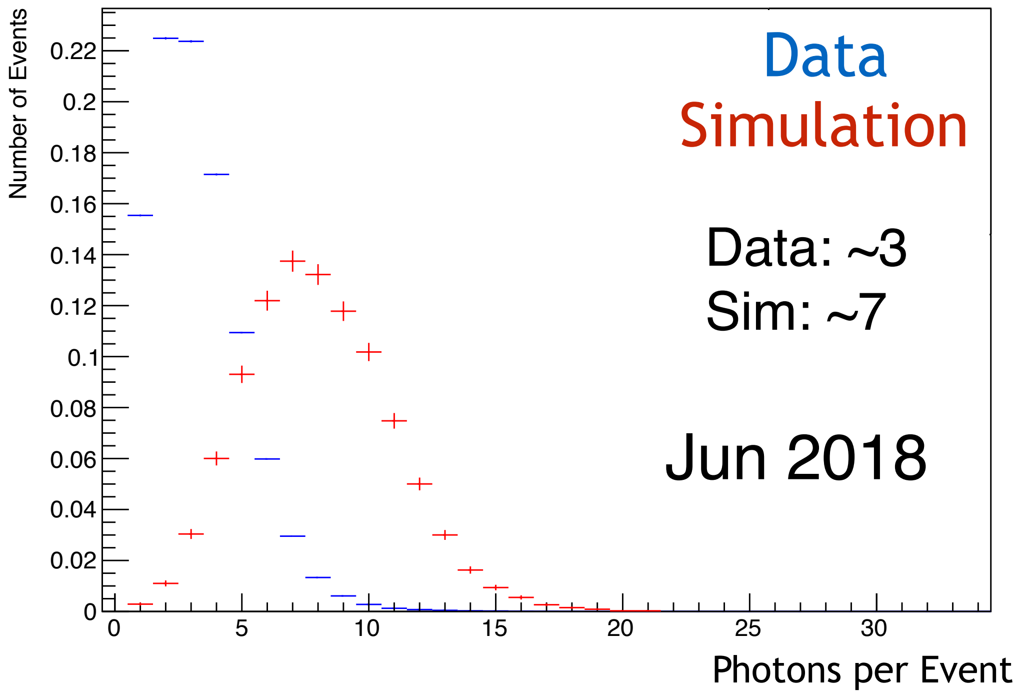


No side reflections
One side reflection
Two side reflections



Photon Counting - Jun’18 Data

- Jun’18 data
- Discrepancy is still higher since the clustering algorithm has not yet been applied to the simulation here.

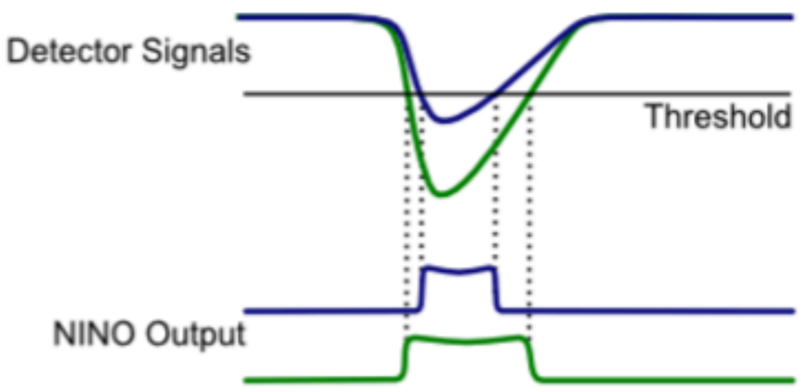


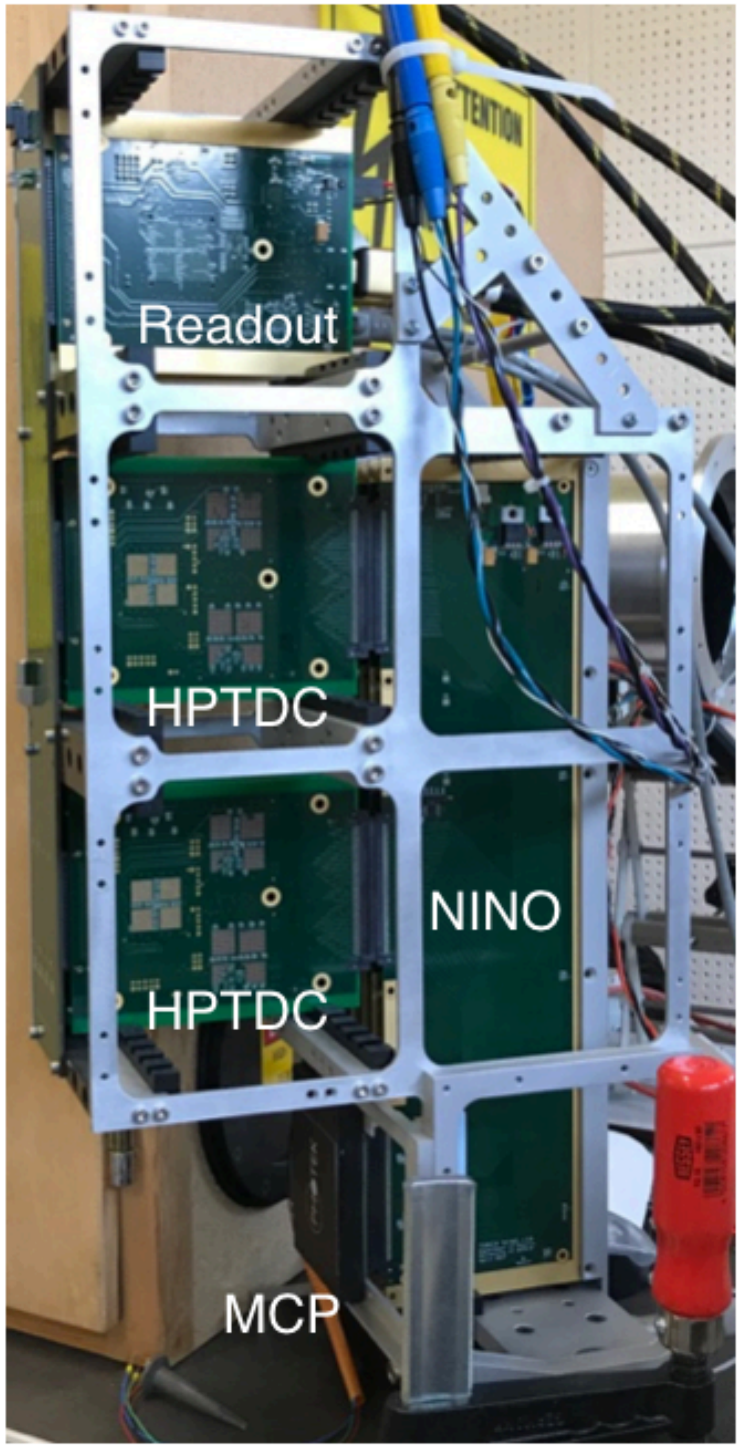
But there are many other factors that are not fully understood…

- Glue transmission & ageing
- Reflection losses
- Reflectivity of mirror
- QE uniformity
- Gain uniformity

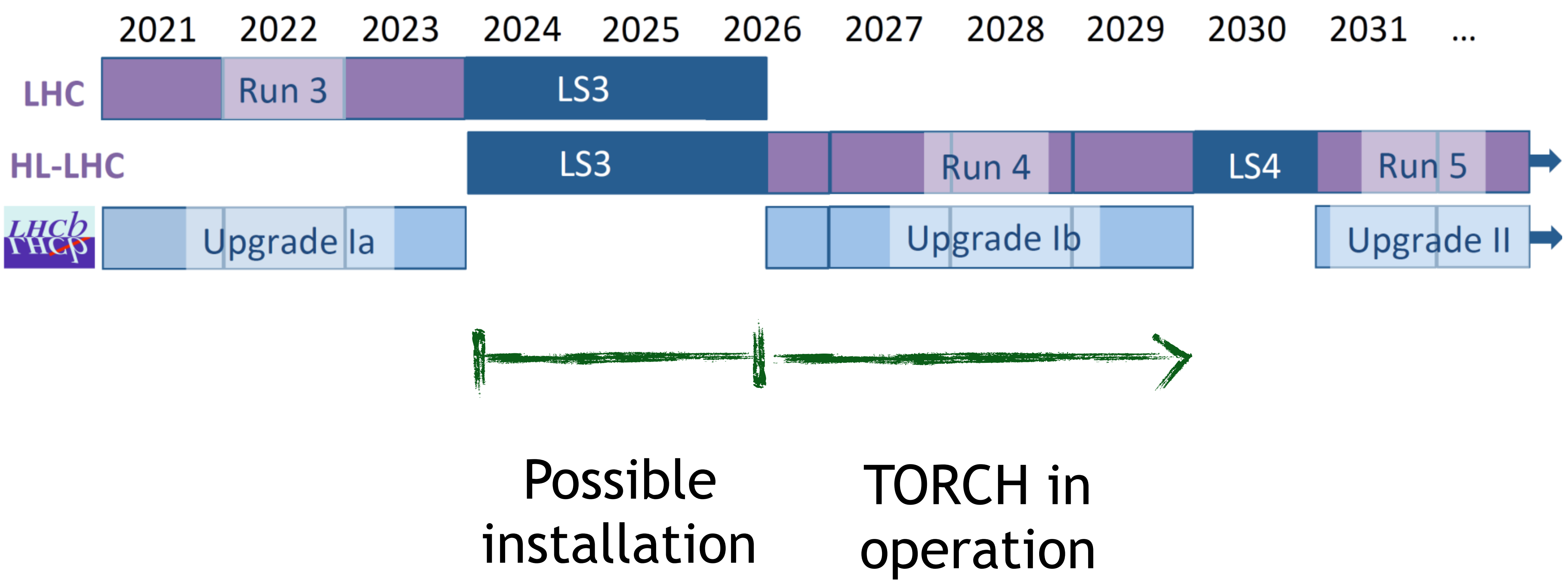
TORCH Readout Electronics

- Readout electronics consist of NINO + HPTDC
- TORCH is using 32 channel NINOs, with 64 channels per board
- NINO-32 provides time-over-threshold information which is used to correct
  - Time walk
  - Charge to width measurement
  - HPTDC time digitisation (100 ps bins) non-linearities





TORCH Timeline



MCP-PMT lab measurements - testing

- Lab measurement where the laser is evenly diffused using a block of Delrin.
- Phase III MCP-PMT used in Nov'17 testbeam.
- Middle two slots seem to have a higher response.