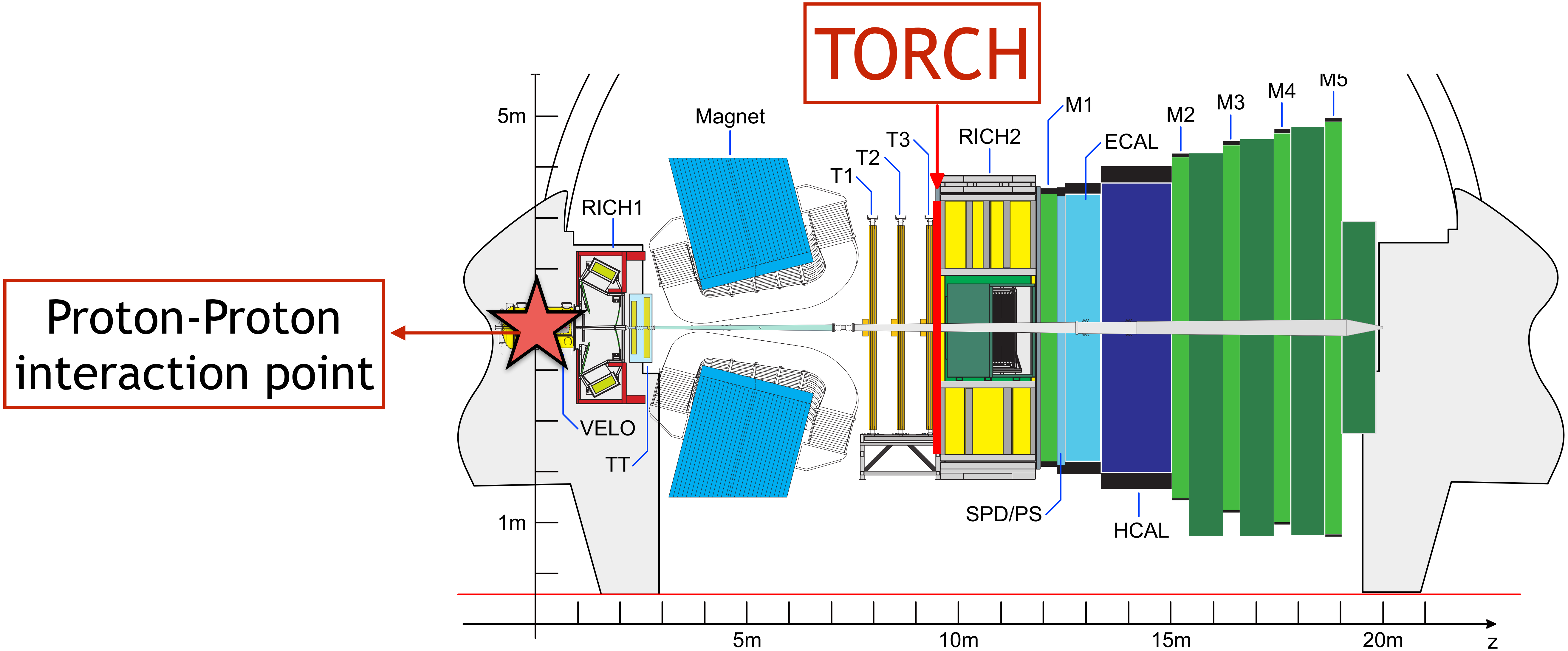
The TORCH Detector

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

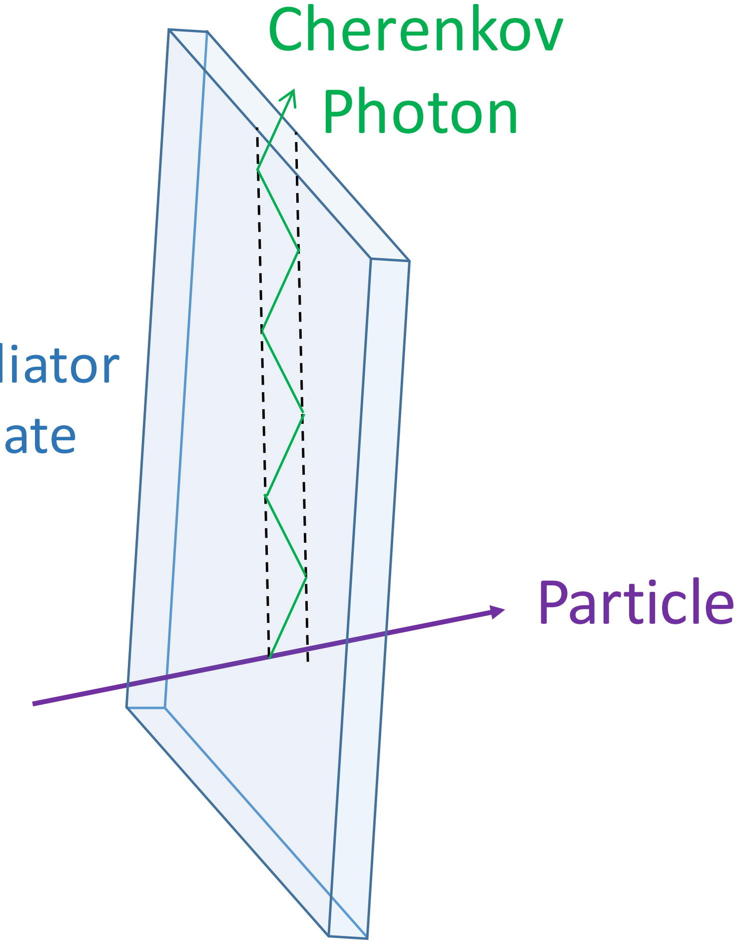
Emmy Gabriel
Edinburgh PPE Christmas meeting
December 14th 2018

TORCH in the LHCb detector

- Aims at identifying particles of low momentum (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)

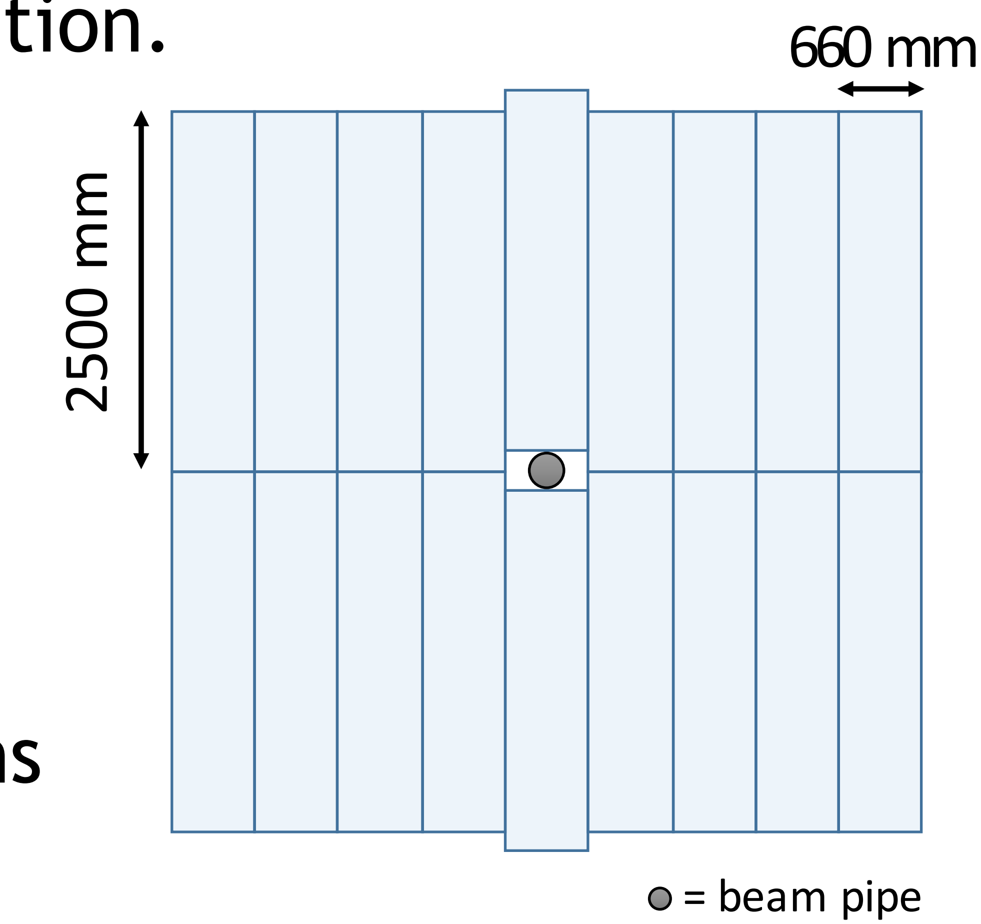


How does TORCH work?



- A particle passing through the quartz plate emits Cherenkov light.

- The Cherenkov photons are trapped in the plate and travel up through total internal reflection.

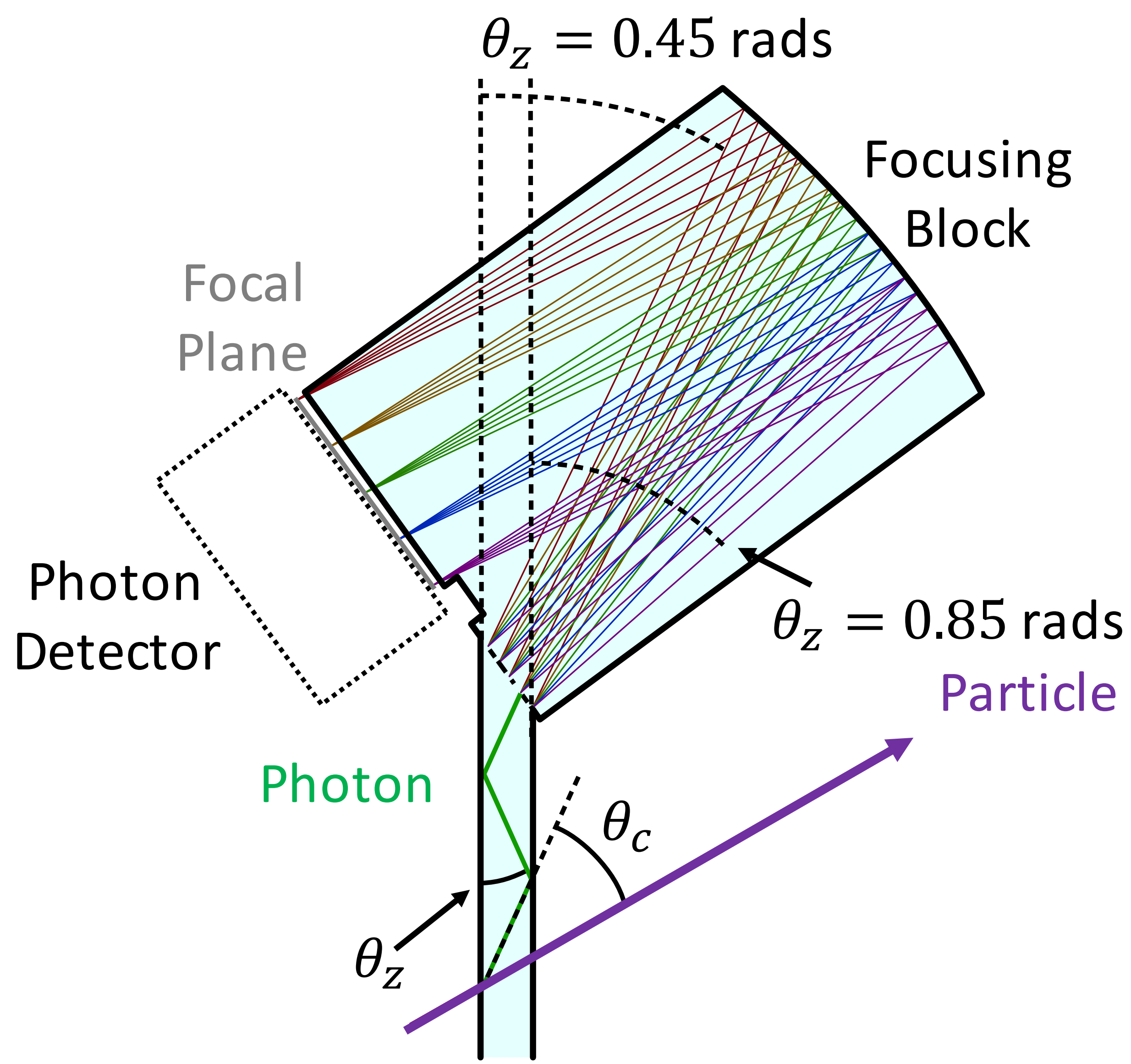


- The full TORCH detector will consist of 18 quartz modules (~30 m^2 total).

- What happens when the Cherenkov photons reach the periphery of the radiator plate?

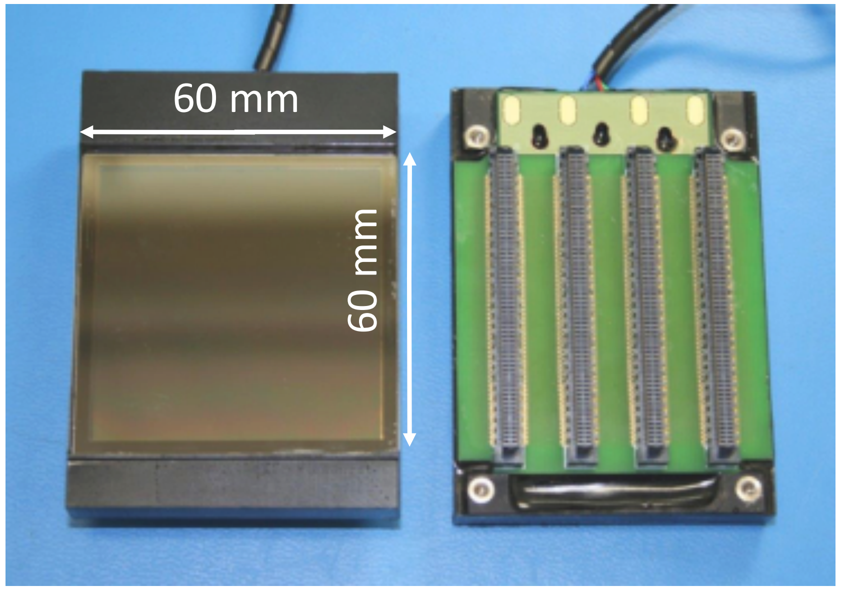
How does TORCH work?

- Focusing block maps the photons onto the focal plane.
- The angle θ_z determines the position on the focal plane.
- A precise determination of the arrival time and position of the Cherenkov photons allows for precision time-of-flight measurements in LHCb.

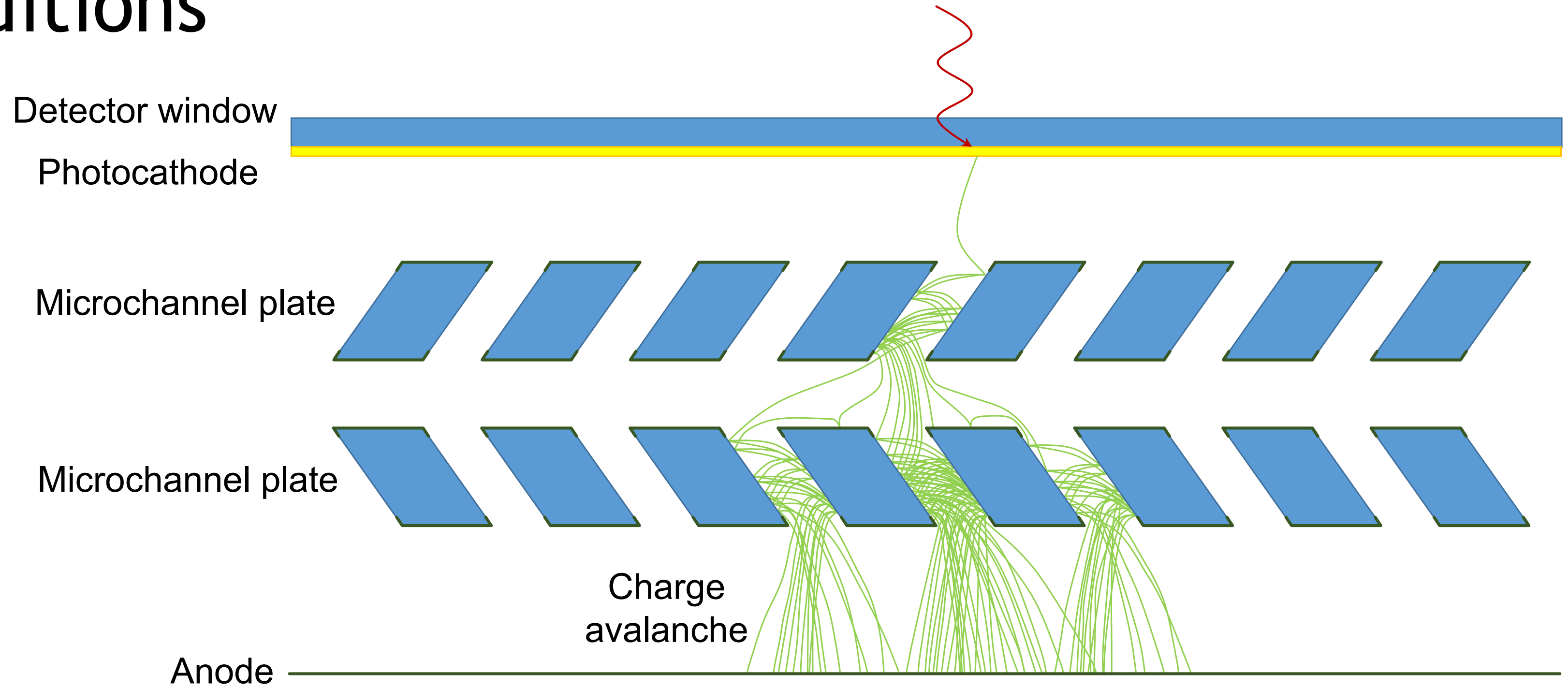


How does TORCH work?

- Photons are detected on Micro-Channel Plate Photon Multiplier Tubes (MCP PMTs).
- The MCP PMTs have been developed specifically for the TORCH detector to have:
  - high granularity (8x64 pixels)
  - extended lifetime
  - resistance to LHC conditions

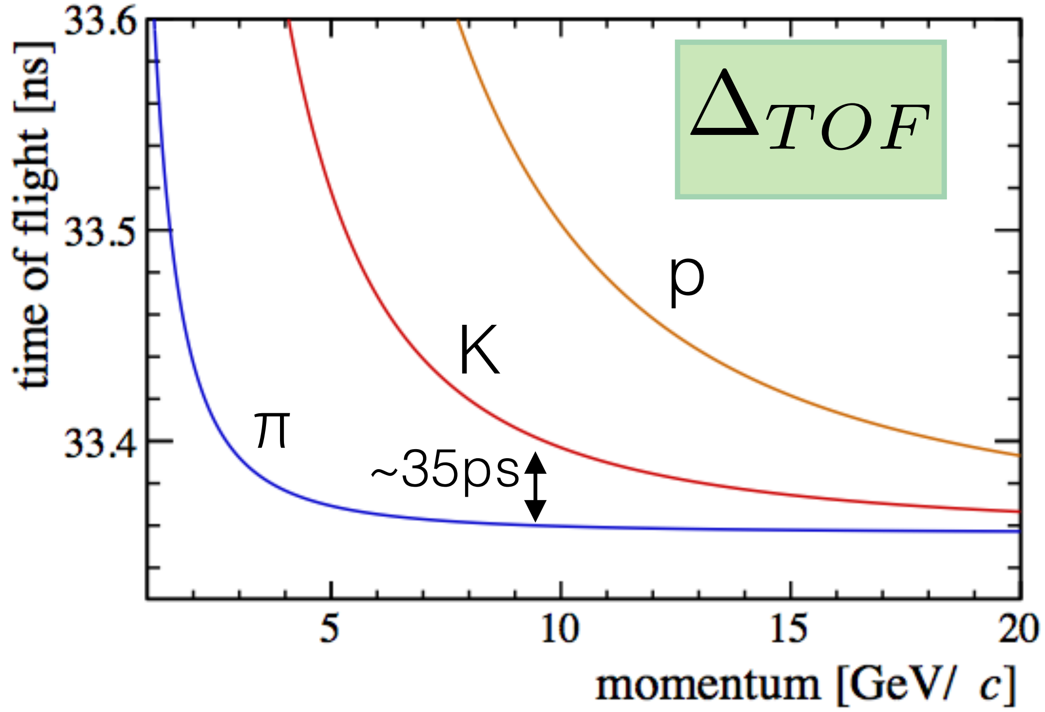


Schematic view of a MCP PMT

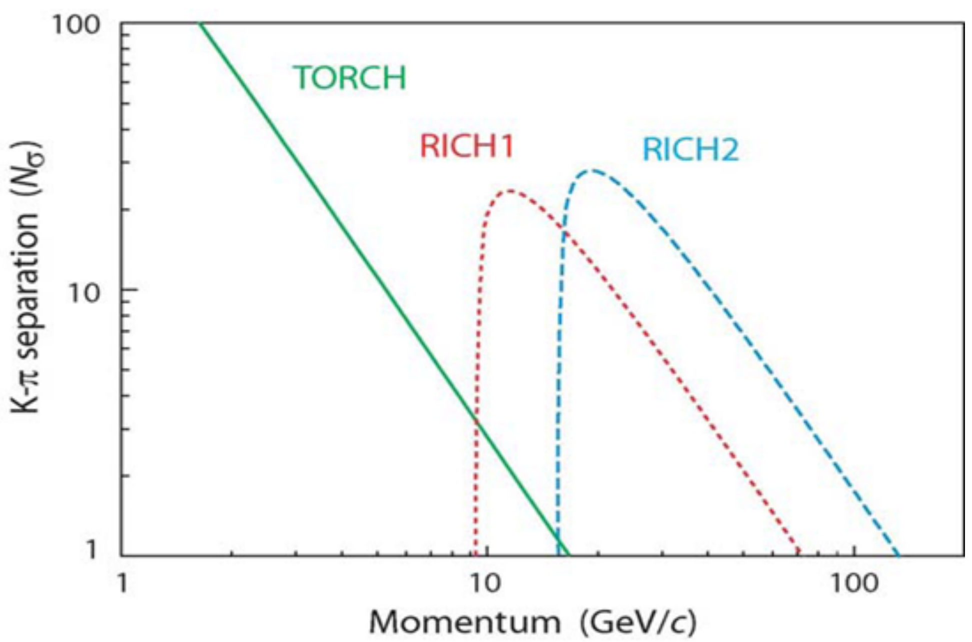


How does TORCH work?

Time-of-flight difference between kaons and pions at 10 GeV/c over a 10 m flight path is ~35ps.



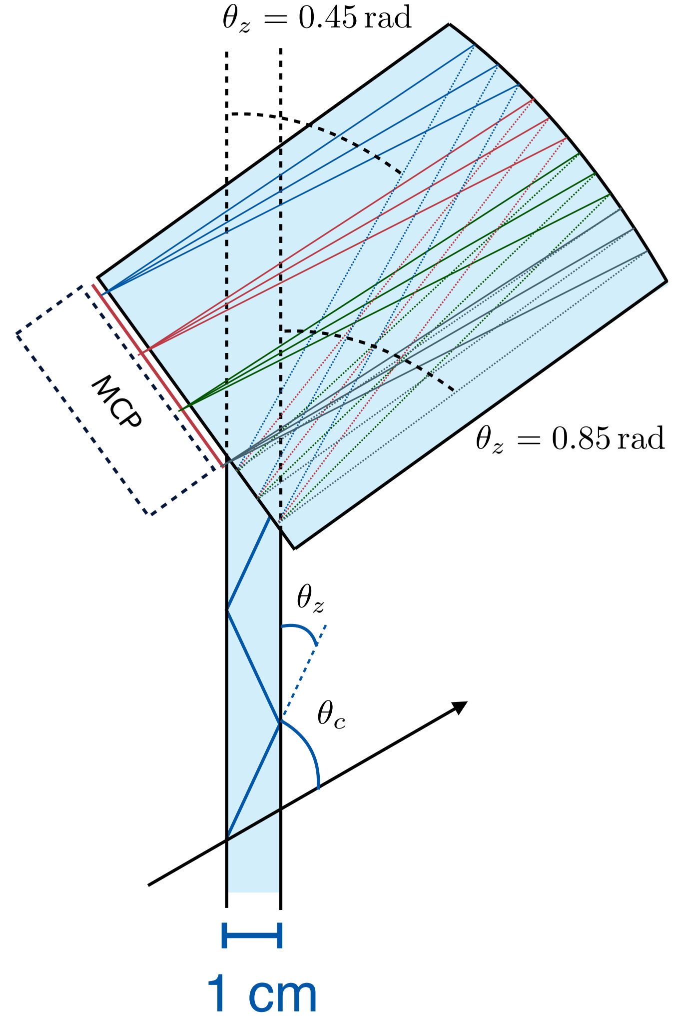
A single photon time resolution of 70 ps with an estimated 30 detected photons per track gives a ~15 ps time resolution per track.

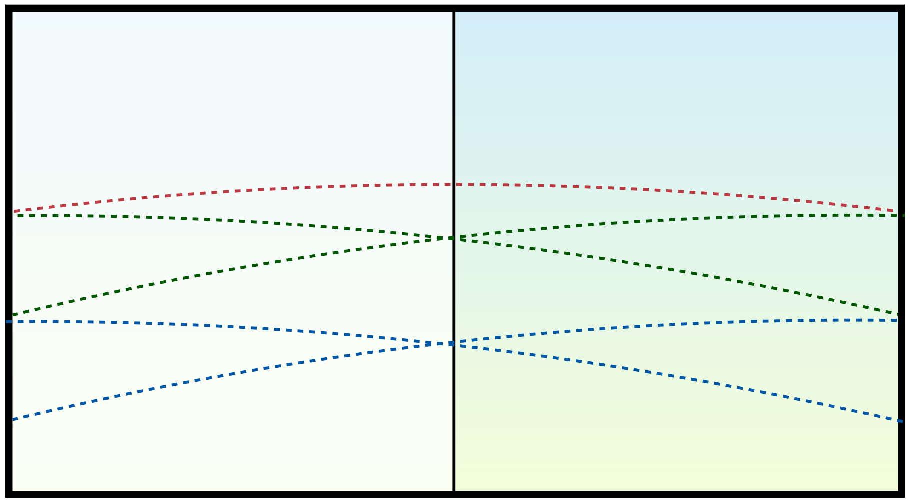


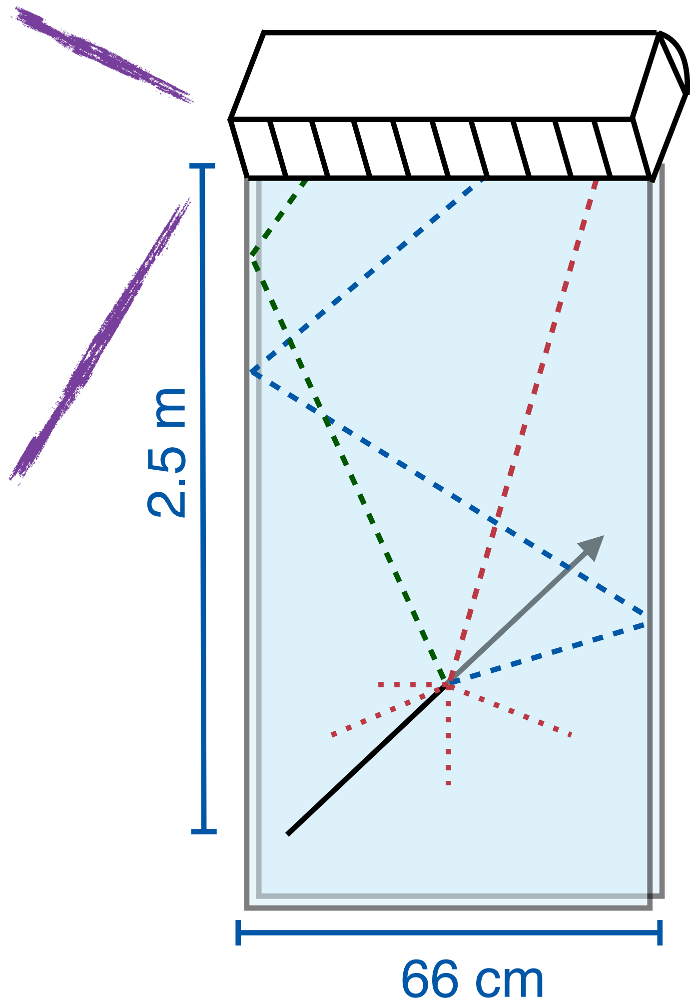
Isolated track particle identification performance

How does TORCH work?

- Angle θ_z is converted into precise position on the MCPs by the focusing block.
- Photons arriving on the MCP create bands.







No side reflections
One side reflection
Two side reflections

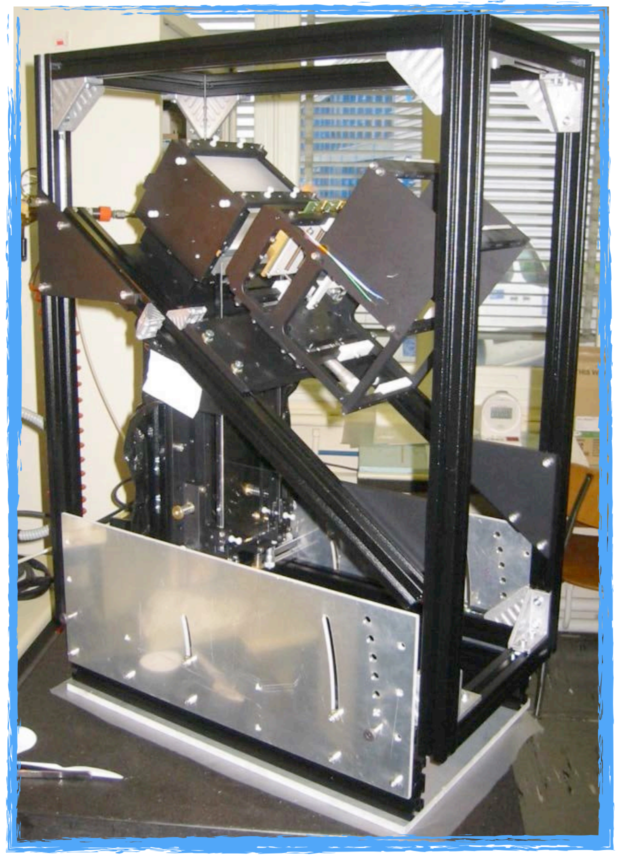
Ongoing R&D

Recent Testbeam campaigns at CERN PS in a 5GeV/c proton and pion beam:

November '17:
MiniTORCH with one 4x64 MCP

June '18:
MiniTORCH with one 8x64 MCP

November '18:
ProtoTORCH with two 8x64 MCPs



MiniTORCH
12 x 35 x 1 cm
quartz plate
Max. 2 MCPs

ProtoTORCH
66 x 125 x 1 cm
quartz plate
Max. 10 MCPs

Ongoing R&D - testbeam setup

Beam

Mini-TORCH

Timing Stations

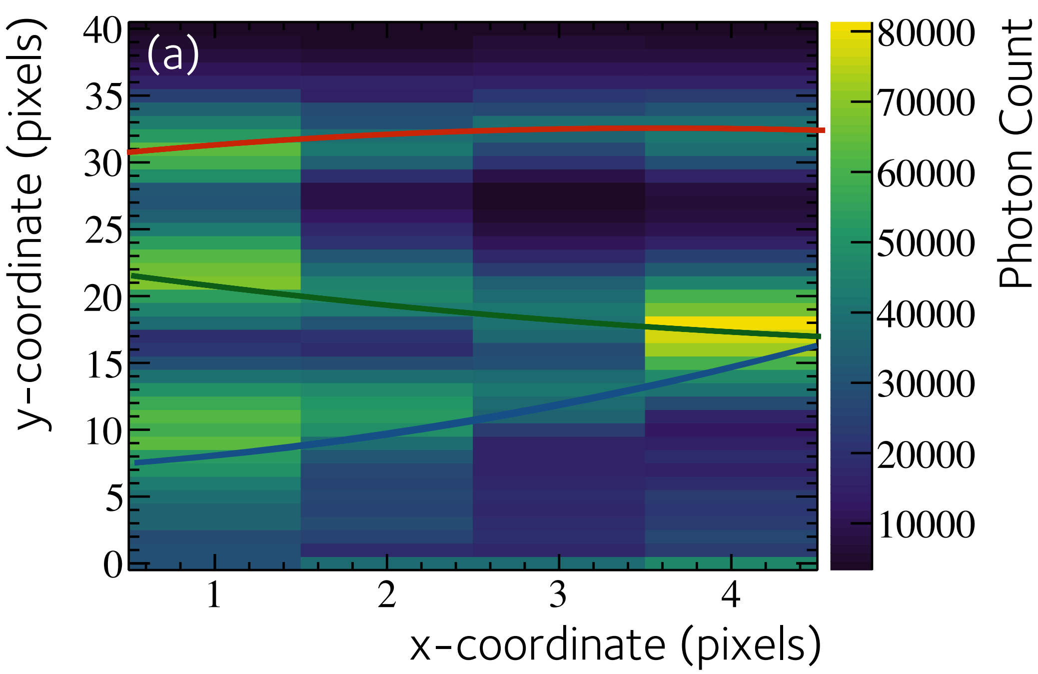
AIDA Telescope

Cherenkov Counter C2

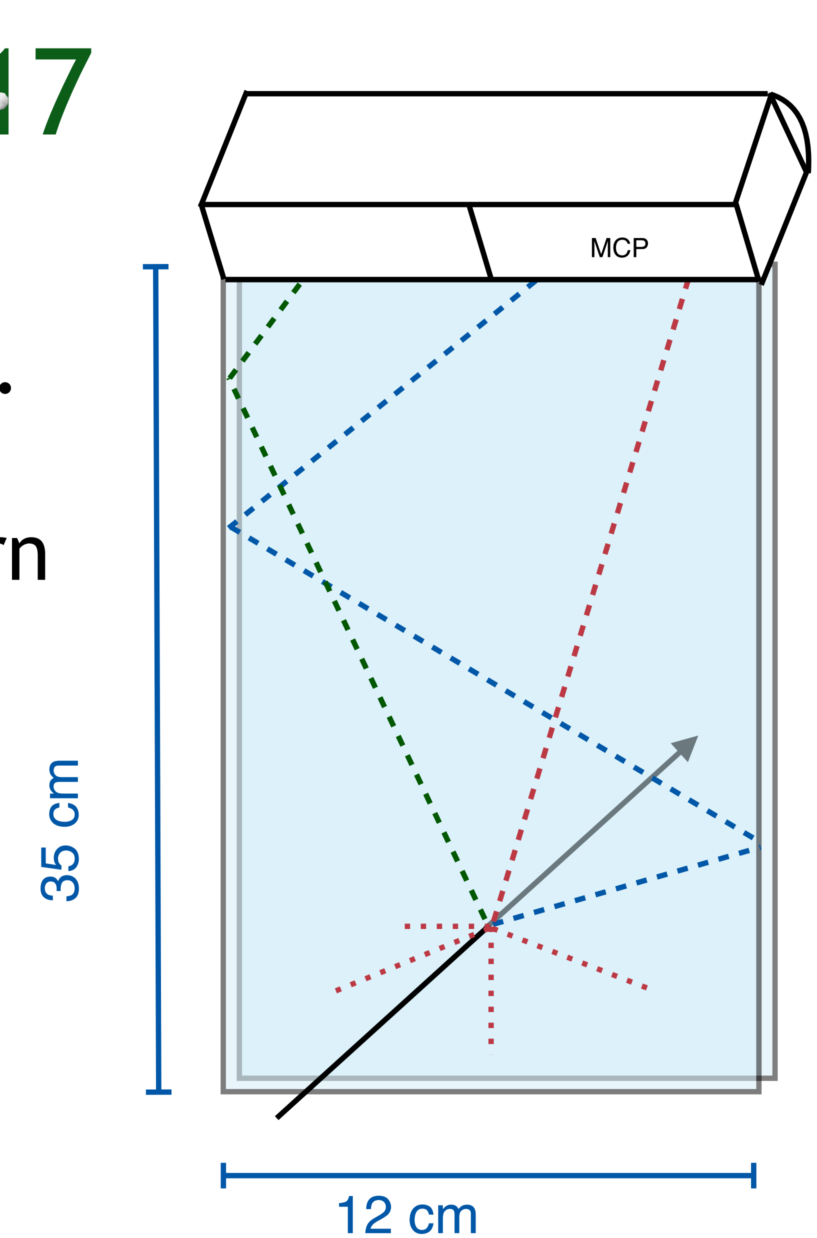
Beamtest results - November 2017

One 4x64 MCP in Mini-TORCH
Analysis of the test beam data almost complete.

- Hitmap of the MCP shows the expected pattern
  - only half the pattern visible since only 1/2 MCPs was read out.



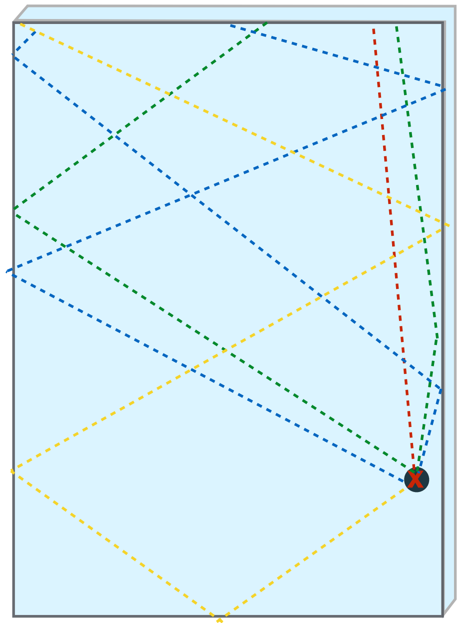
No side reflections
One side reflection
Two side reflections



Beamtest results - November 2017

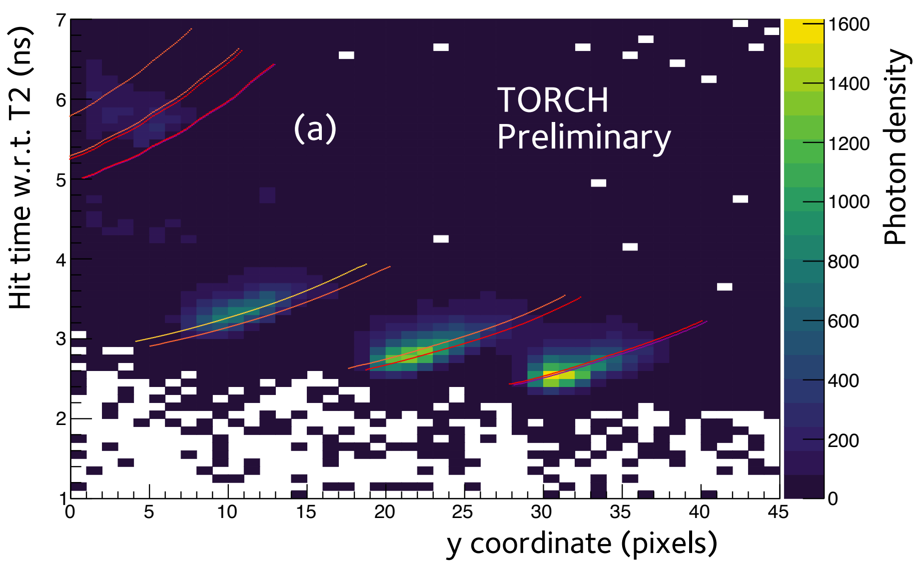
Time resolution is determined per column. Beam focused on the edge of the quartz plate.

No side reflections
One side reflection
Two side reflections
Bottom reflections

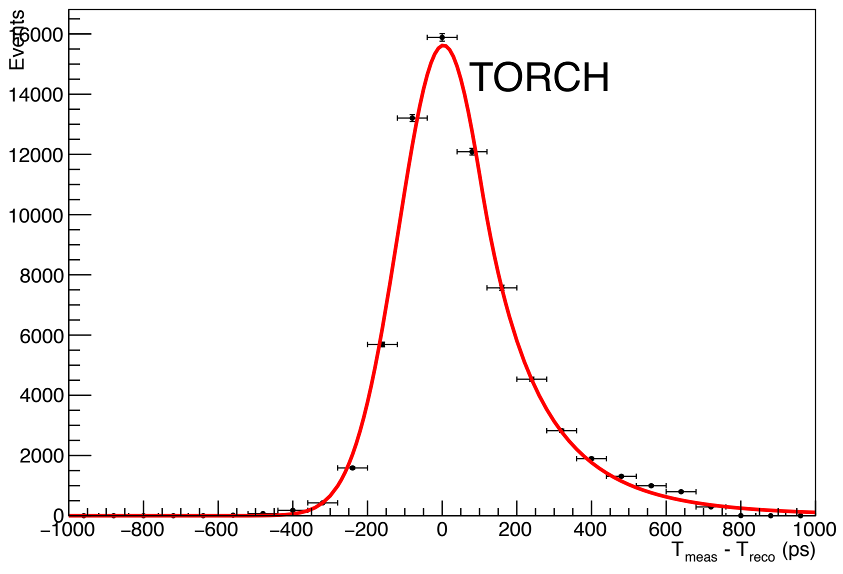


$$\sigma^2_{\mathrm{TORCH}} = \sigma^2_{\mathrm{meas}} - \sigma^2_{\mathrm{beam}} - \sigma^2_{\mathrm{timeref}} \rightarrow 112\pm1 \text{ ps}$$

120.8±0.6 ps   15.6±0.1 ps   42±3 ps



Time projection (for 1 column)

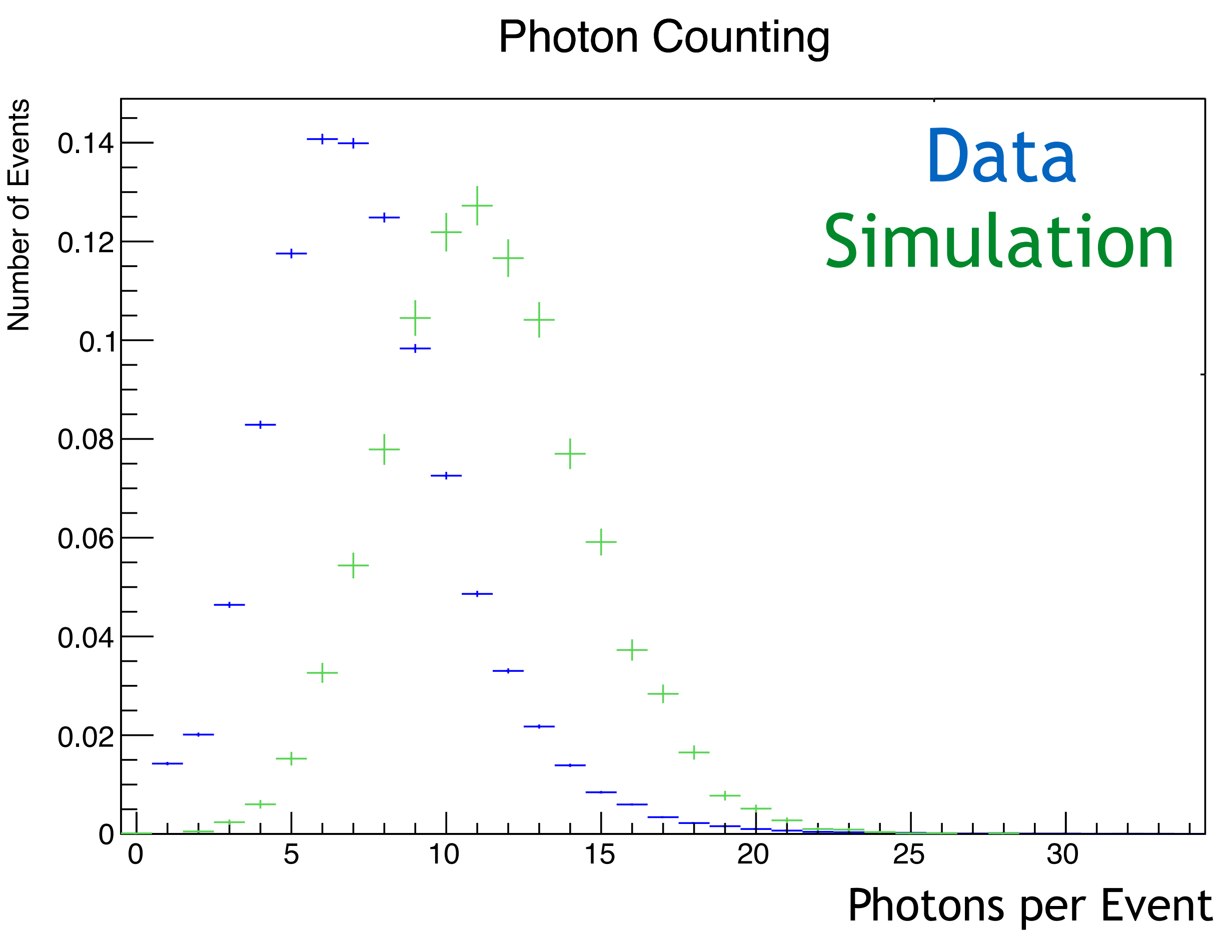


Time resolution (for 1 reflection)

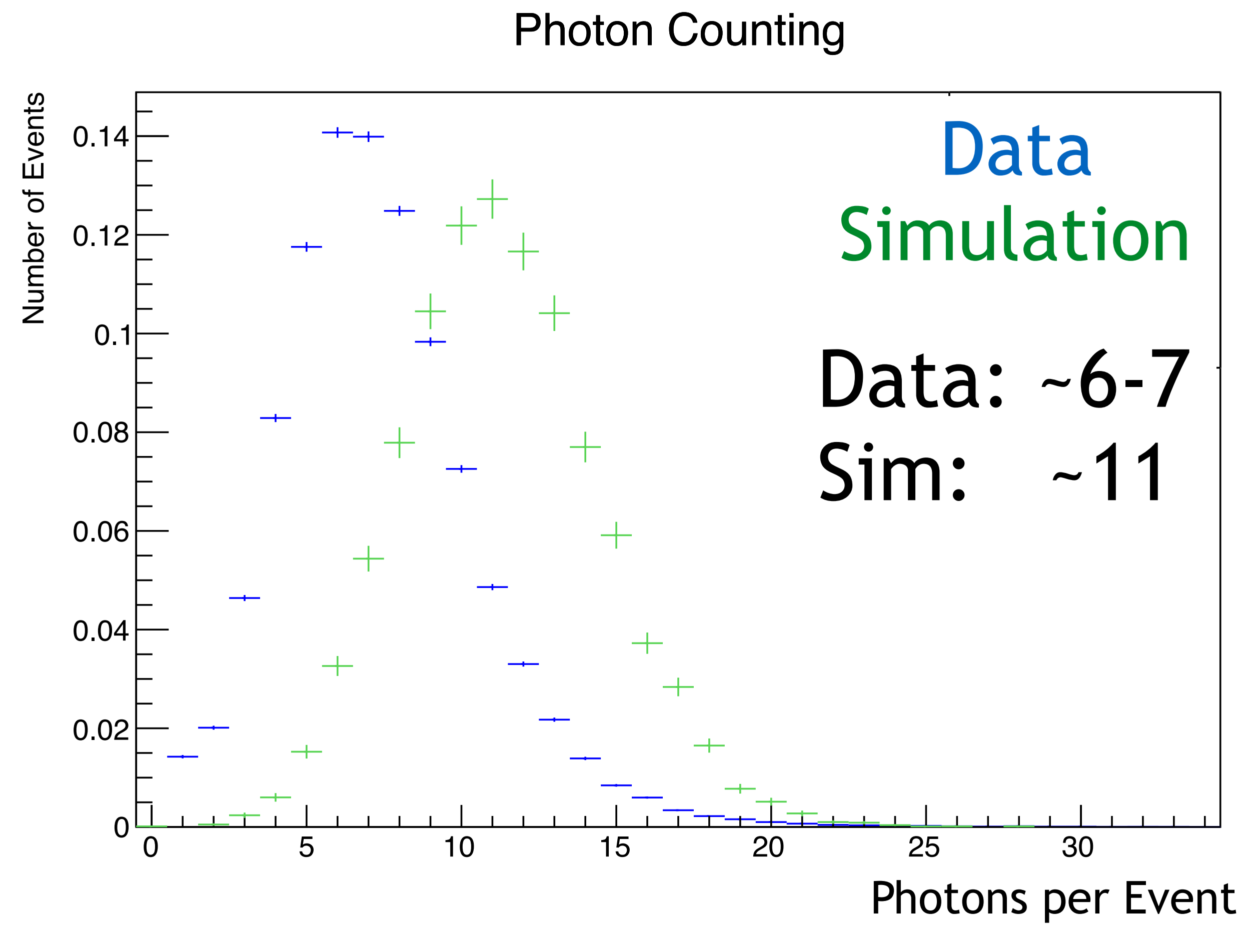
Beamtest results - November 2017

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

- *Geant4 simulation of Mini-TORCH:*
  10000 kaons fired through the side of the quartz plate



Beamtest results - November 2017

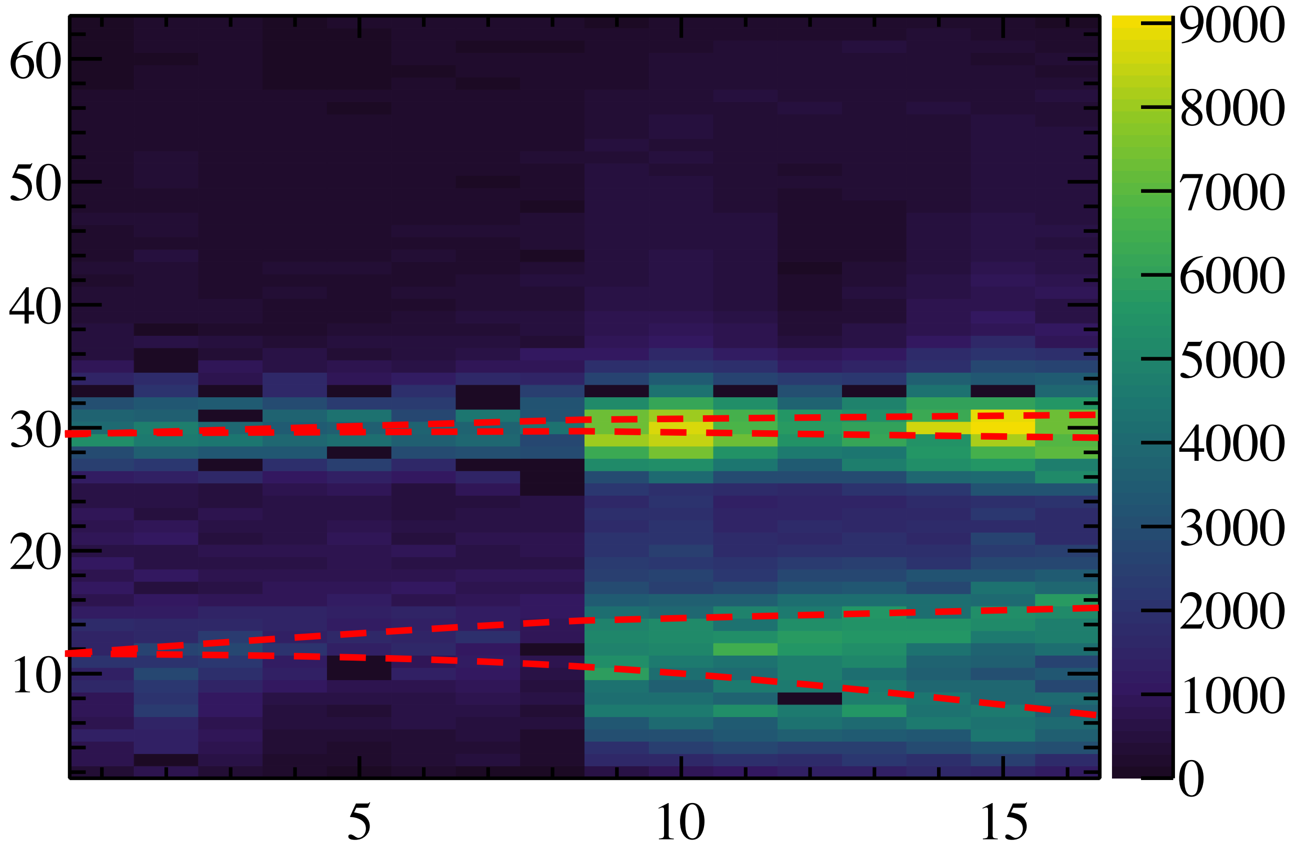


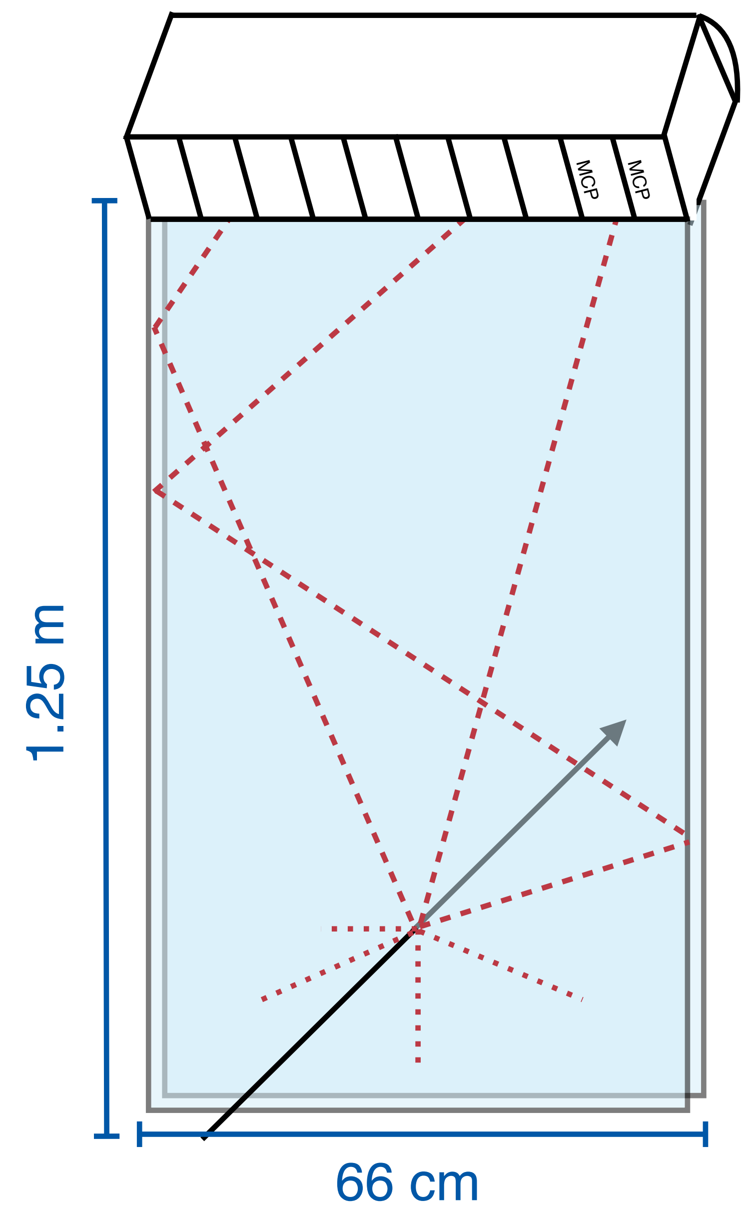
- Simulation accounts for many sources of inefficiency, e.g. MCP efficiencies, mirror reflectivity, quartz surface roughness effects.

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

Preliminary beamtest results - November 2018

- Proto-TORCH with two 8x64 MCPs
- Completely new prototype
- Patterns observed as expected
- Left MCP runs at lower gain and lower QE





Conclusion

I hope I’ve managed to convince you that TORCH is a very interesting and exciting R&D project!

- *Mini-TORCH era is over!*
  Analysis almost done with a paper being written as we speak.

- Achieved the first results with Proto-TORCH recently - a big step for the collaboration!
- Next stage: aim to instrument Proto-TORCH with 10 MCPs and full readout electronics.

Thank you for your attention!

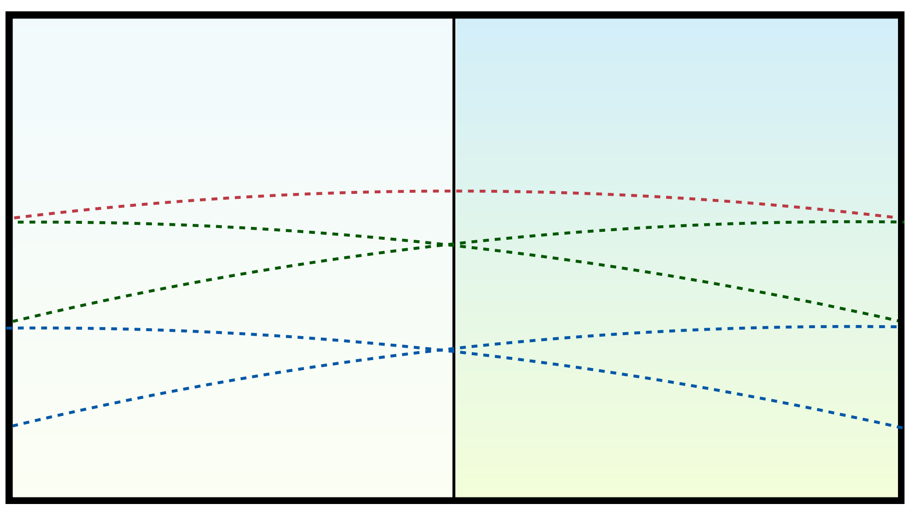
Questions?

happy holidays!

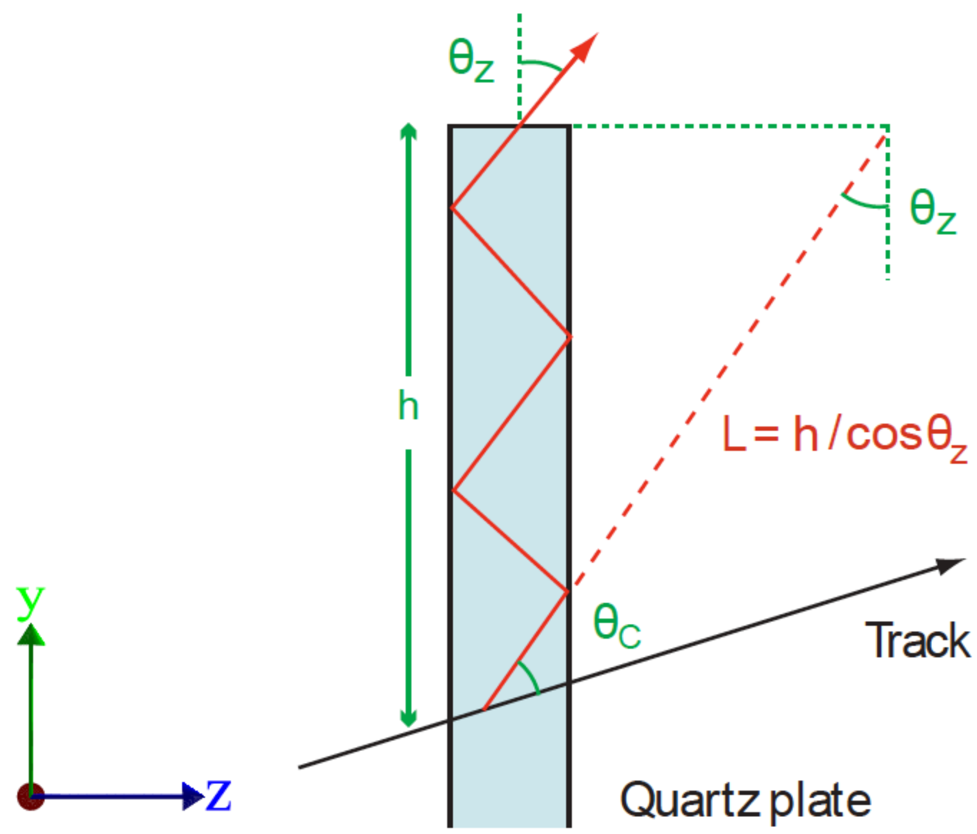
BACKUP

How does TORCH work?

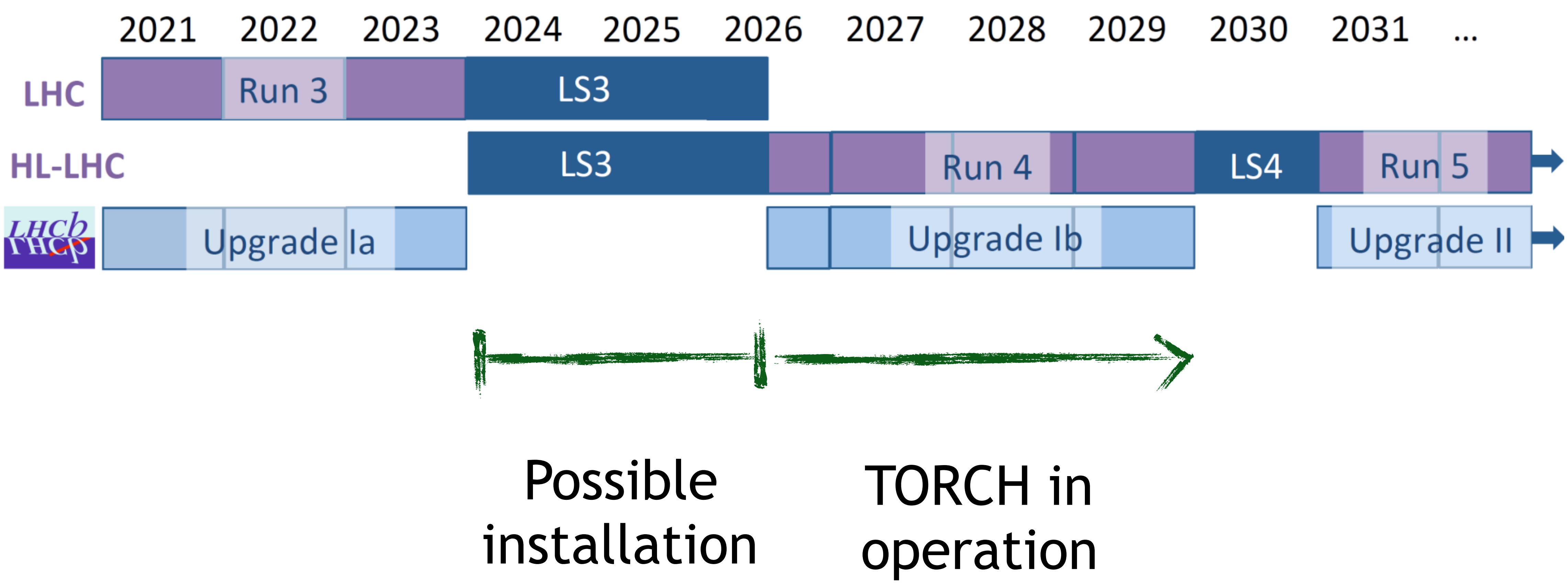
- More side reflections means L increases
- This changes the angle θ_z such that a new band is created on the MCPs through the focusing block



No side reflections
One side reflection
Two side reflections

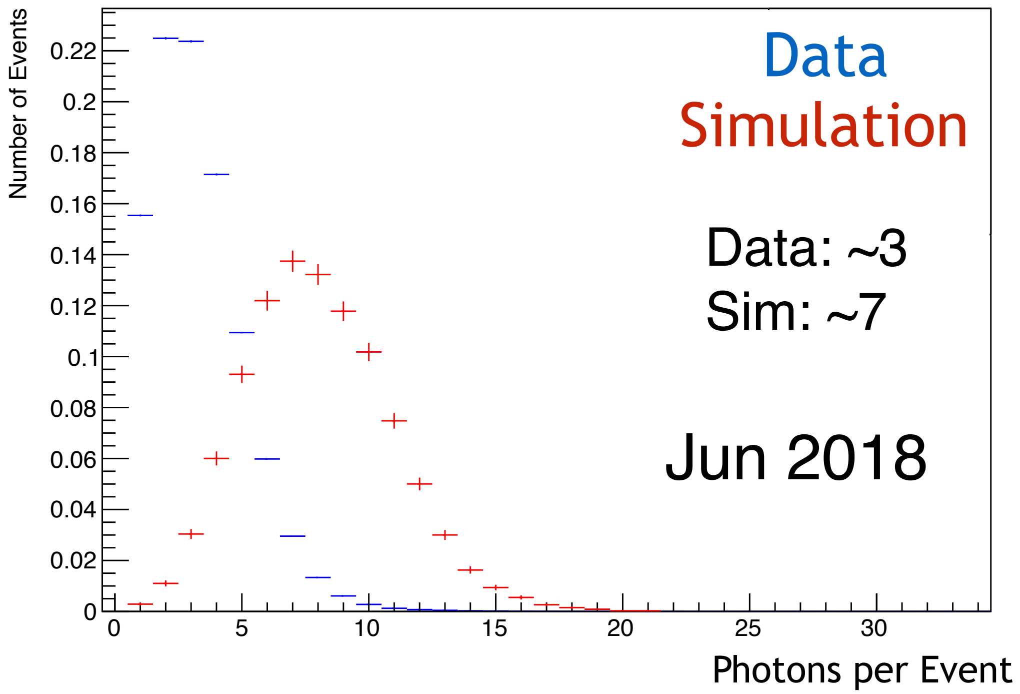


TORCH Timeline



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.

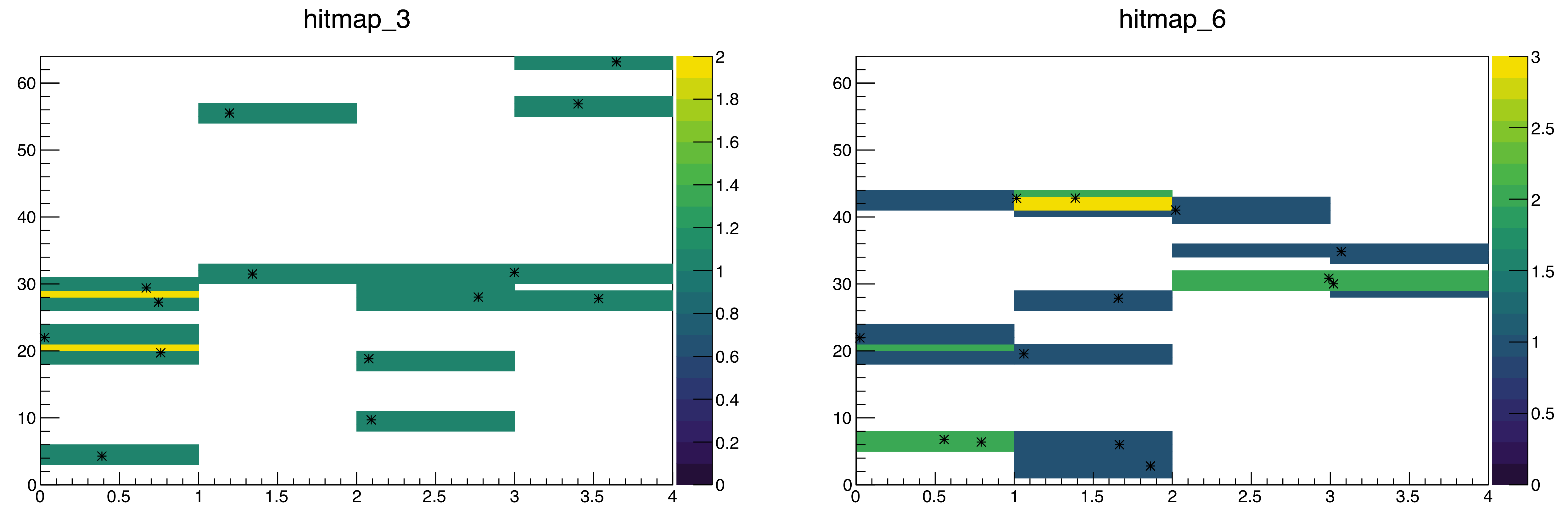


But there are many other factors that are not fully understood…

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

Photon Counting - clustering on simulation

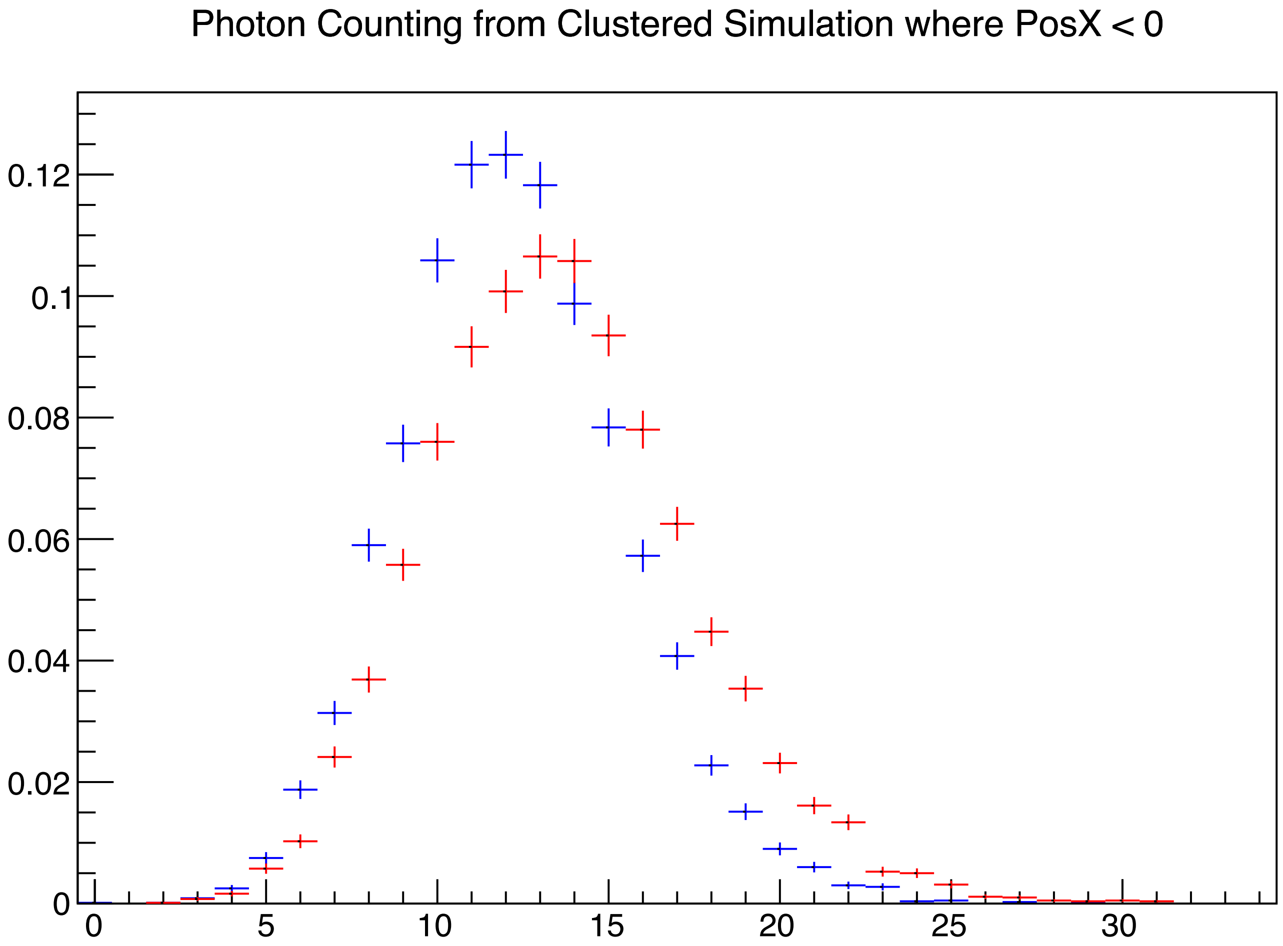
- A clustering algorithm is ran over the hits to identify photons as a group of hits on the MCP that are close together in space and time.
- How often would you expect two photons to be clustered together as one?



Photon Counting - clustering on simulation

- A clustering algorithm is ran 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?

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



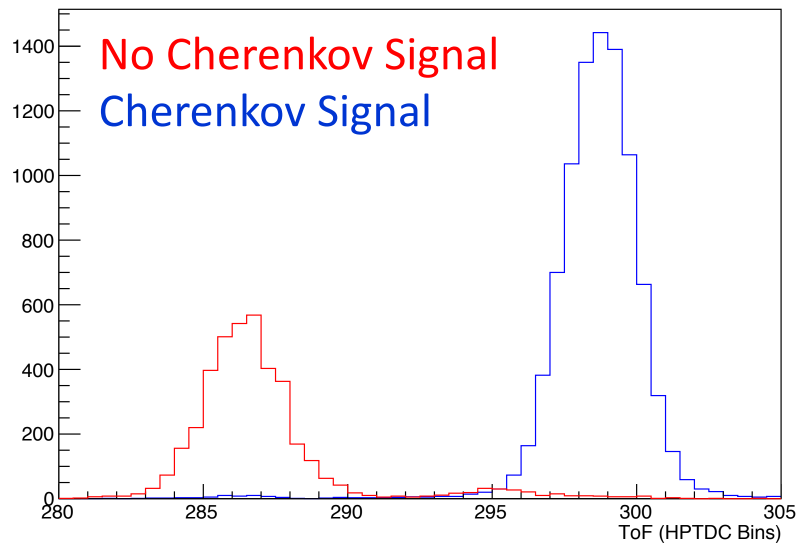
Photon Counting - loss factors

Surface roughness:	~10%
Rayleigh scattering:	small
Glue:	small
Quantum efficiency:	~80%
Mirror reflectivity:	~10%
Collection efficiency: (Open Area Ratio)	35%
NINO thresholds/Gain:	under investigation
Geometric efficiency:	~12%
Active Area:	(53/60)

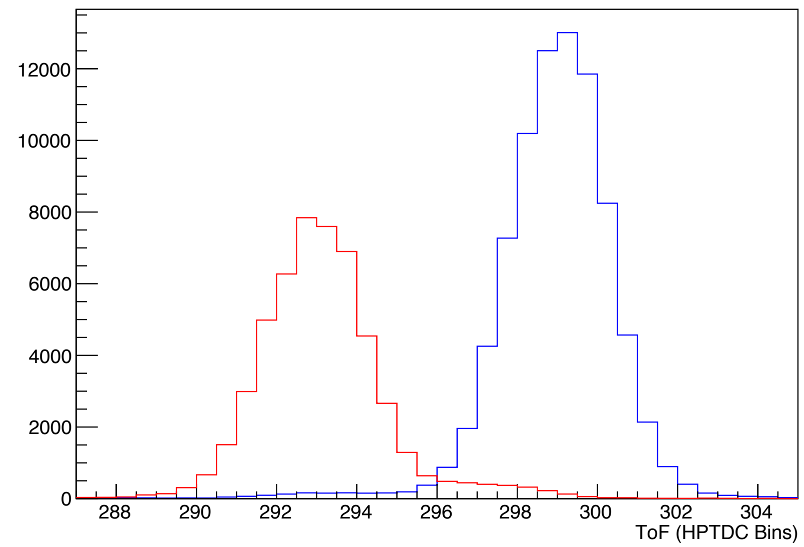
TORCH Testbeam

- Testbeams performed using Pion/proton beam.
- Species determined using two Cherenkov counters.

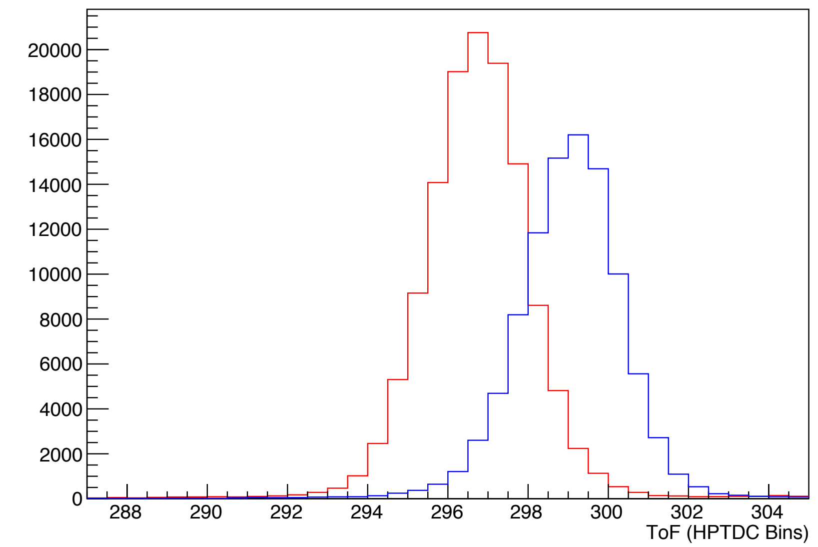
3.5 GeV



5 GeV

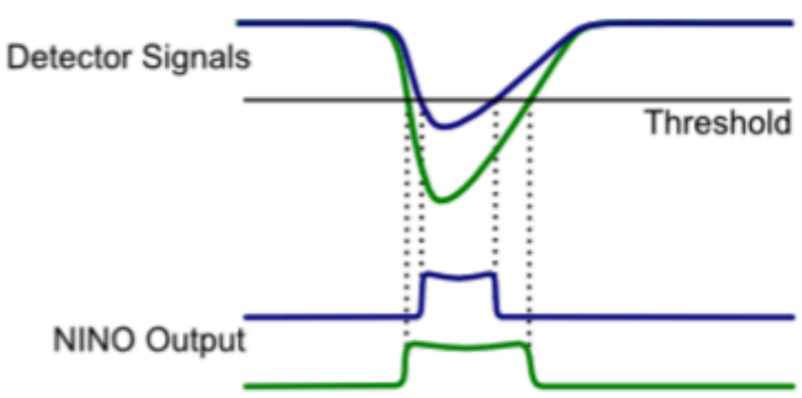


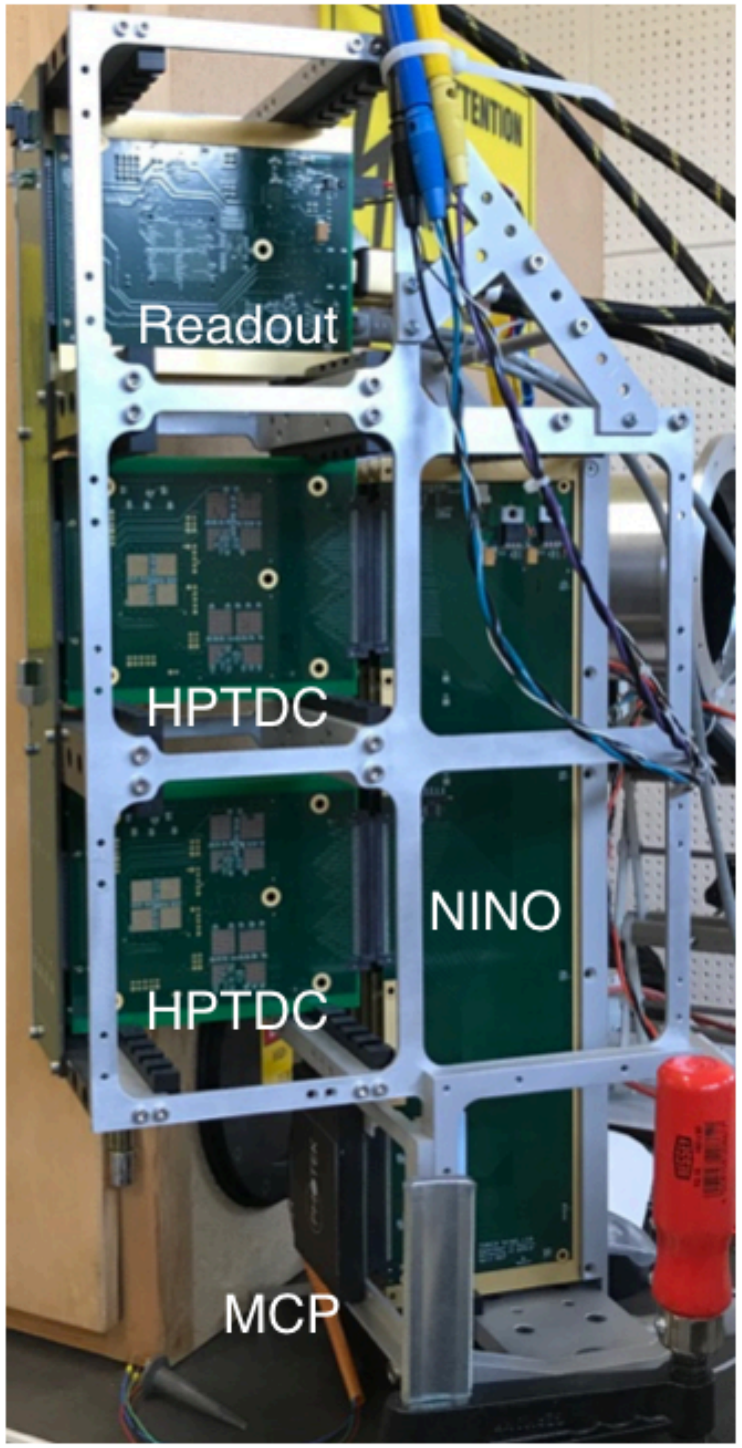
8 GeV



TORCH Readout Electronics

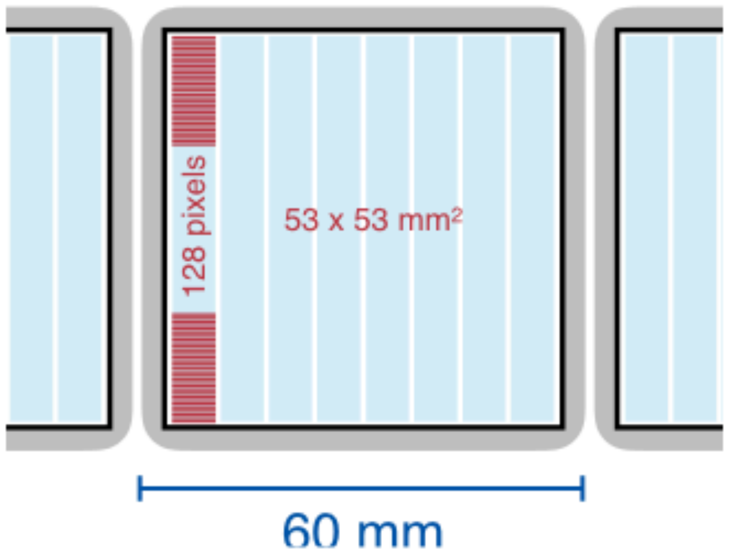
- Readout electronics consist of NINO + HPTDC
- TORCH is using 32 channel NINOs, with 64 channels per board
- NINO-32 provides time-over-threshold information which is used to correct
  - Time walk
  - Charge to width measurement
  - HPTDC time digitisation (100 ps bins) non-linearities

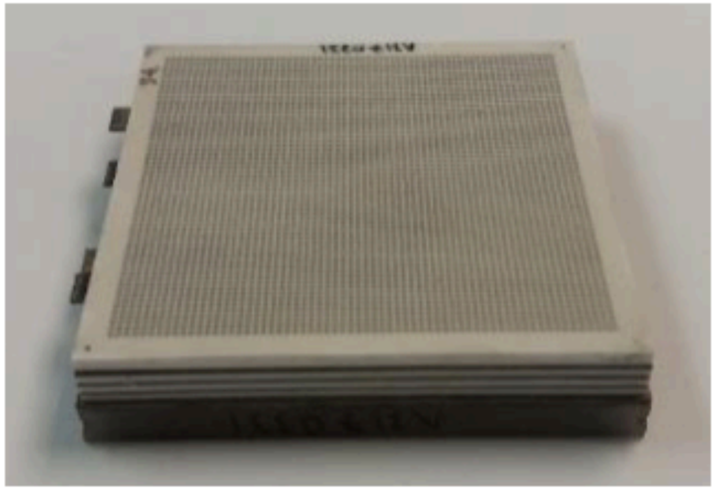




TORCH MCP-PMTs

- To achieve required timing performance, ~1 mrad angular resolution is required for each photon in both longitudinal and transverse projections.
- Hence, each detector needs 128x8 effective granularity over 53x53mm^2 active area, with 11 MCP-PMTs per module.

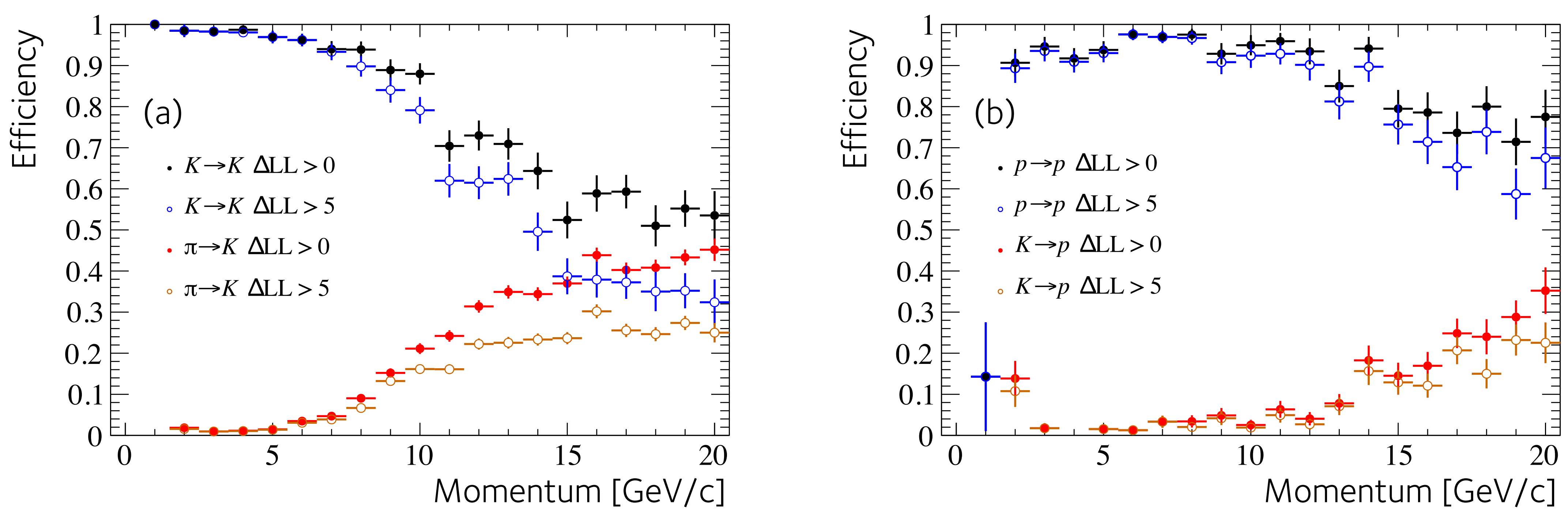




- The MCP-PMTs pixels are 64x64 and grouped to readout with 64x8 granularity. Charge sharing is used to give required granularity in vertical direction.
- To survive the LHC environment, MCPs are required to withstand an integrated charge of 5 C/cm^2 (ALD coating used).

TORCH physics performance

- Expected PID performance studied using a stand-alone TORCH simulation.
- Tracks from inclusive-b LHCb simulations are used to simulate TORCH response



- Integration of TORCH into LHCb framework is being worked on.