The TORCH time-of-flight detector

T. Blake on behalf of the TORCH collaboration

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The TORCH concept

- Large area time of flight detector designed to provide PID in the 2-10 GeV/c momentum range.
  - ➡ Considered for upgrade II of the LHCb detector.
- Exploit prompt production of Cherenkov light to determine time of flight.
- For K - π separation over 10m, need to aim for a resolution of $\sigma_{\text{track}} \sim 10\text{–}15\,\text{ps}$ ($\sigma_{\text{photon}} \sim 70\,\text{ps}$).

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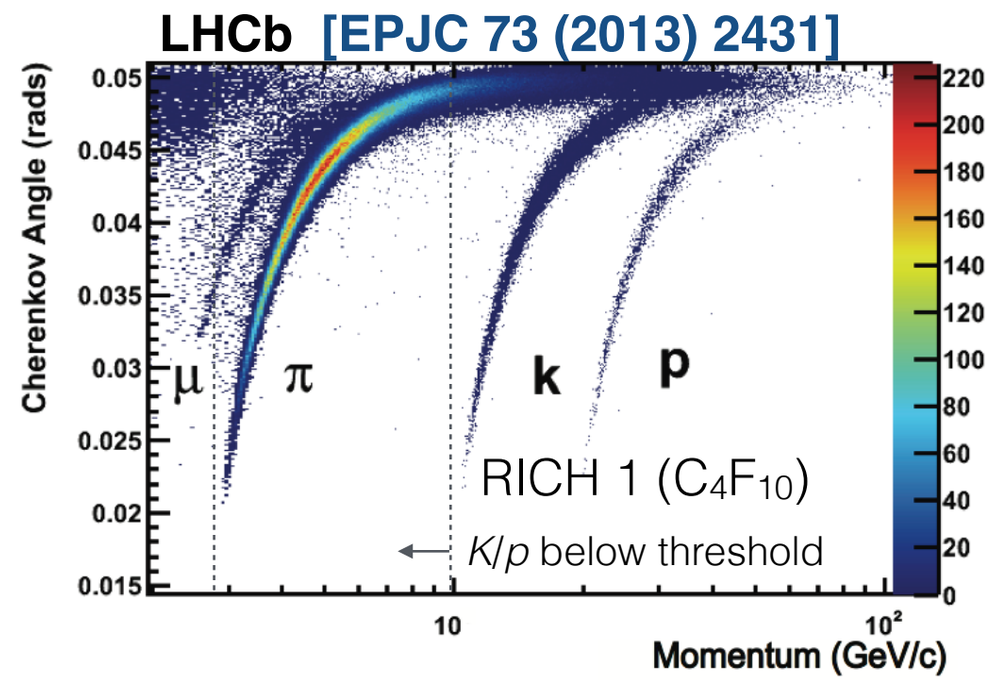
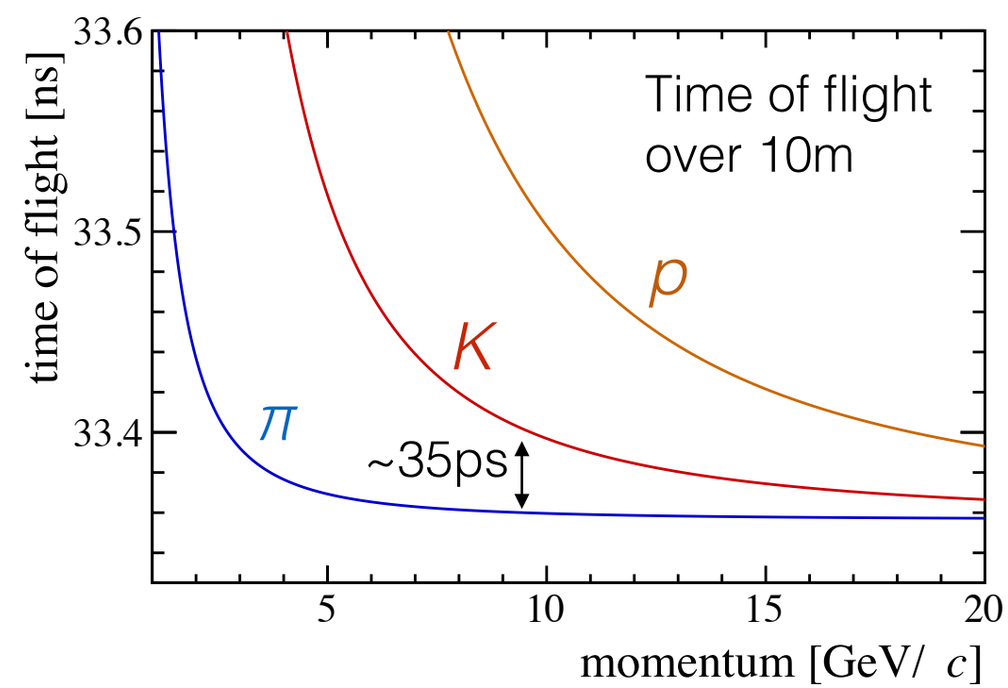
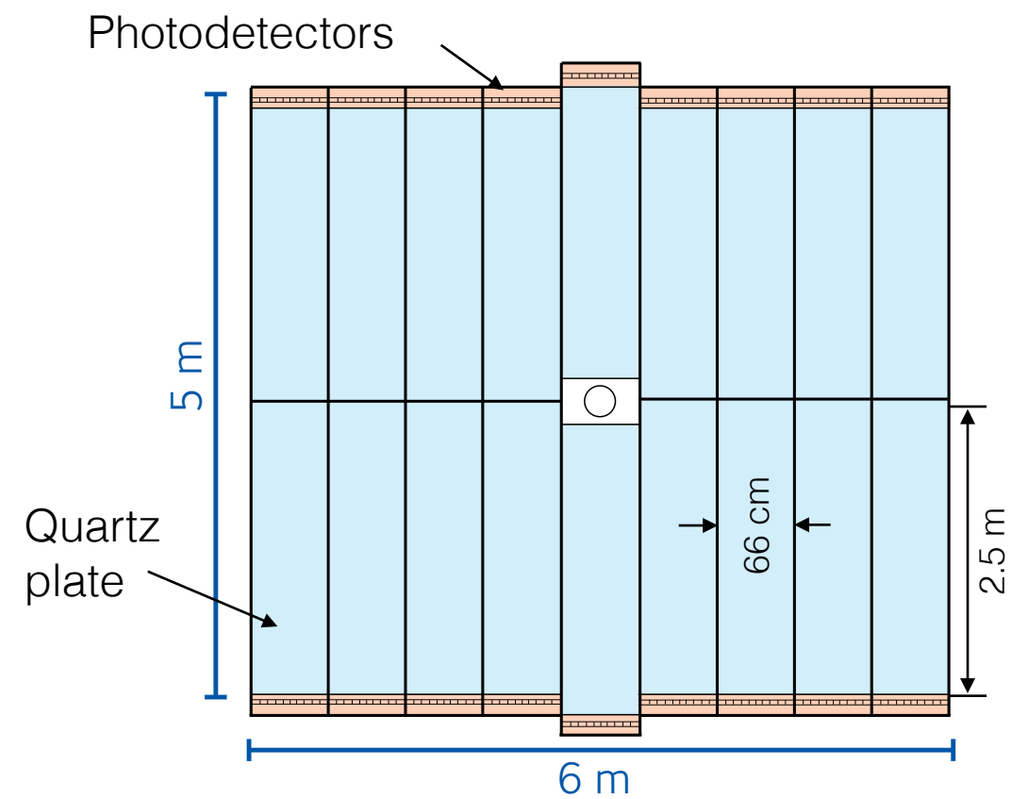
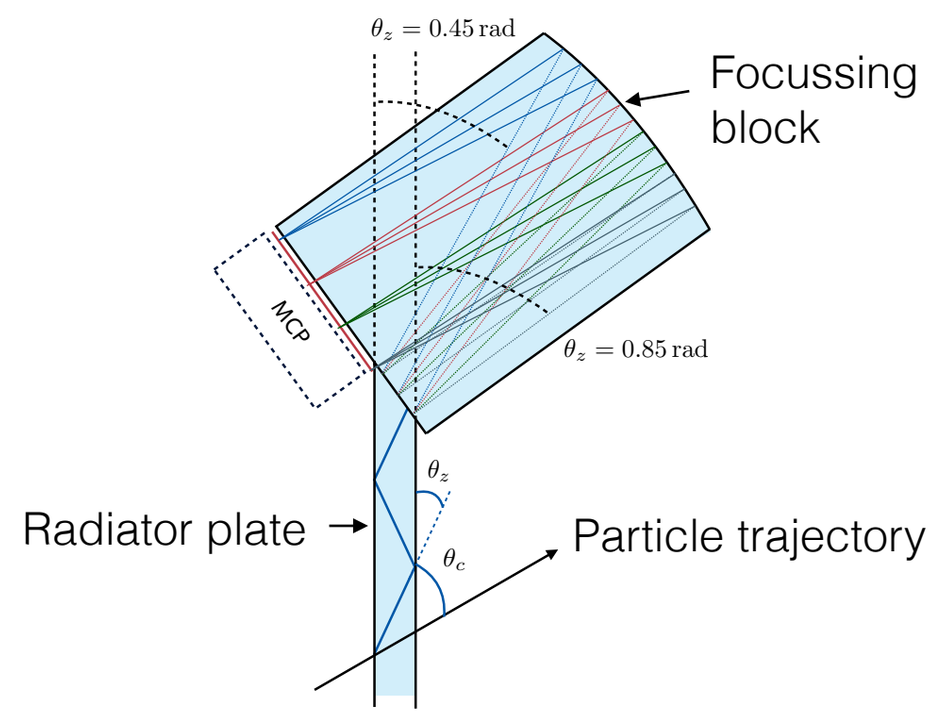




The TORCH detector

- Exploit prompt production of Cherenkov light in an array of quartz bars to determine the time of flight.
- Large area detector covering ~ 5 x 6 m^2.
- Cherenkov photons travel to detector plane via total internal reflection from the quartz surfaces.
- Cylindrical focussing block, focusses the image onto a detector plane.

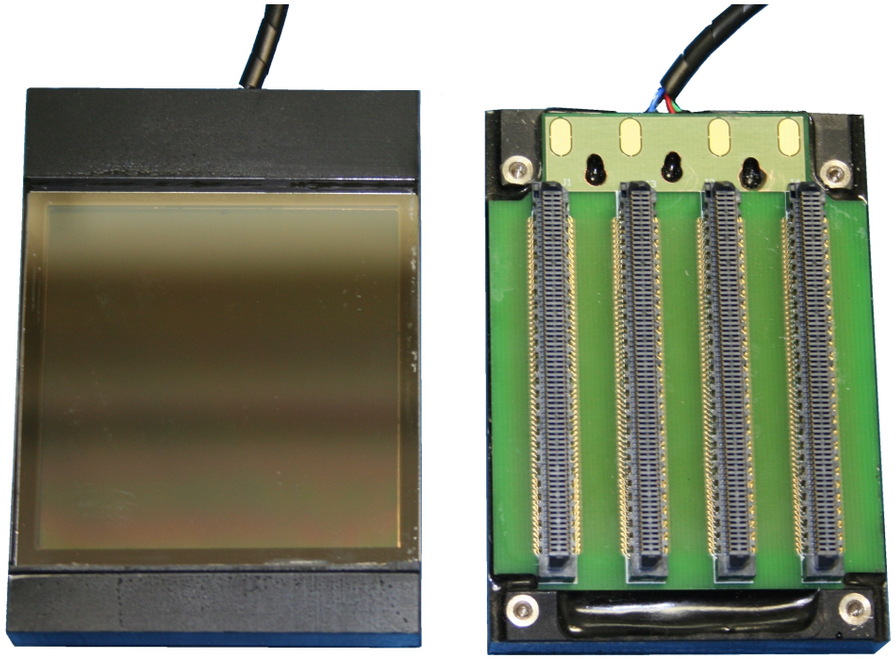




For more details on the TORCH concept see **[NIM A 639 (1) (2011) 173]** and **[arXiv:1805.04849]**

MCP-PMTs

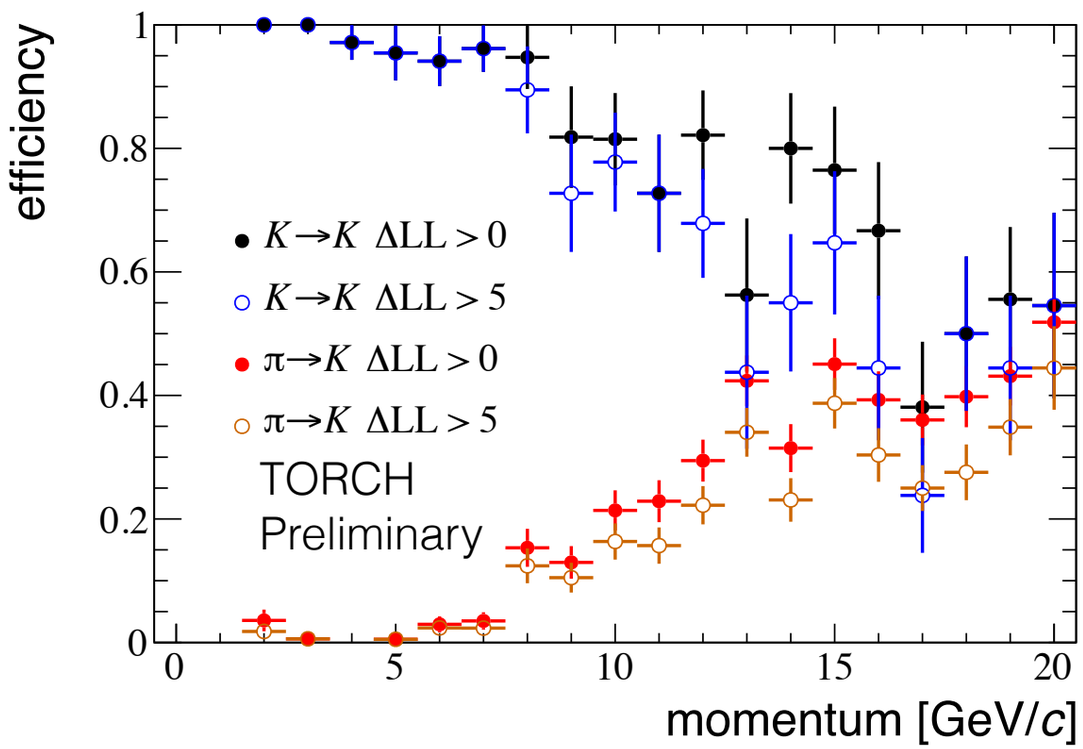
- Fast timing of photons is provided by Microchannel plate PMTs.
- Three phase programme of R&D with a commercial partner (PHOTEK, UK) to develop tubes with a long lifetime (>5 C cm^{-2}) **[JINST 10 (2015) C05003]**.
- Phase-III tube is a square tube:
  - 53 x 53 mm^2 active area.
  - 64 x 8 pixels per tube, effective resolution improved to 128 x 8 pixels by exploiting charge sharing.
- Readout connectors mounted on a PCB and connected via ACF (anisotropic conductive film).

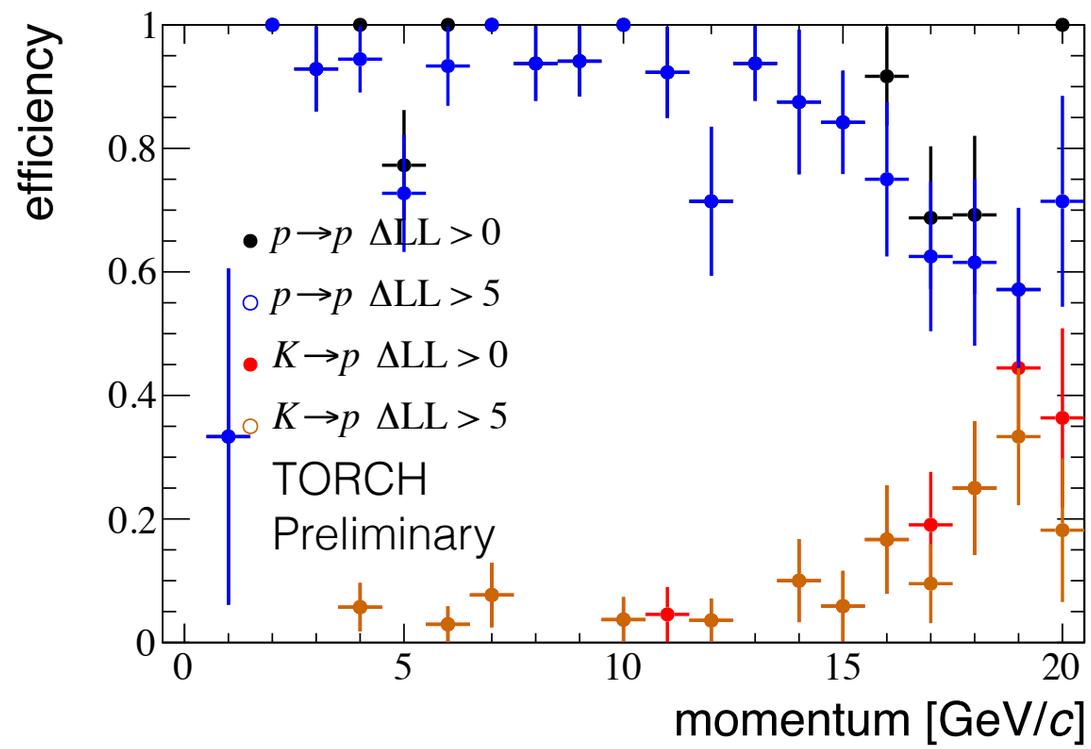


Phase-III prototype

PID performance

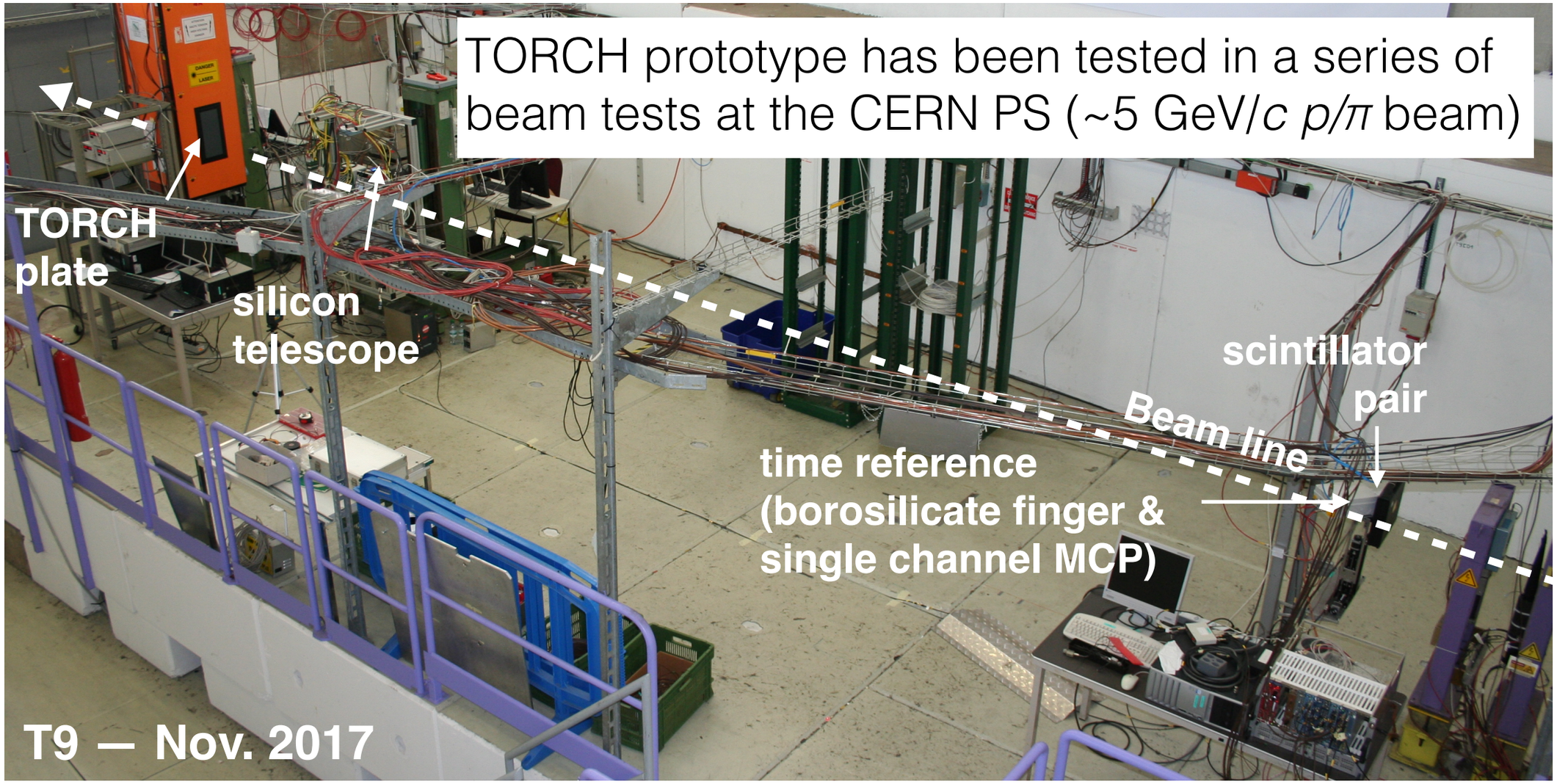
- Simulated PID performance for charged particles produced in *pp* collisions and in heavy flavour decays at (at $\mathscr{L}$ = 2x10^{33} cm^{-2}s^{-1}).





- Good separation between *π*/*K*/*p* in the 2 -10 GeV/*c* range

Beam tests at the CERN PS



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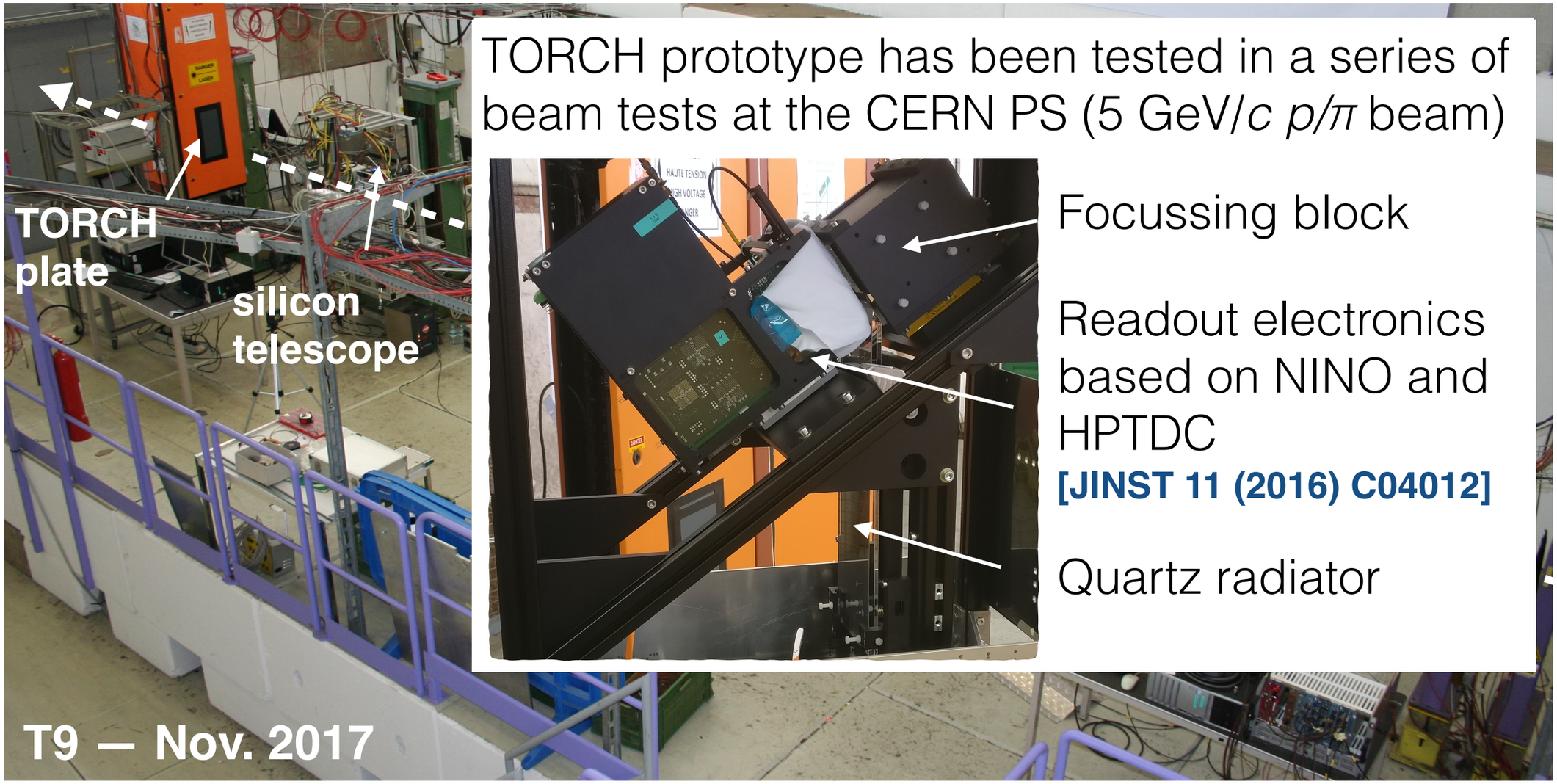


TORCH prototype has been tested in a series of beam tests at the CERN PS (5 GeV/*c* *p*/*π* beam)

Focussing block

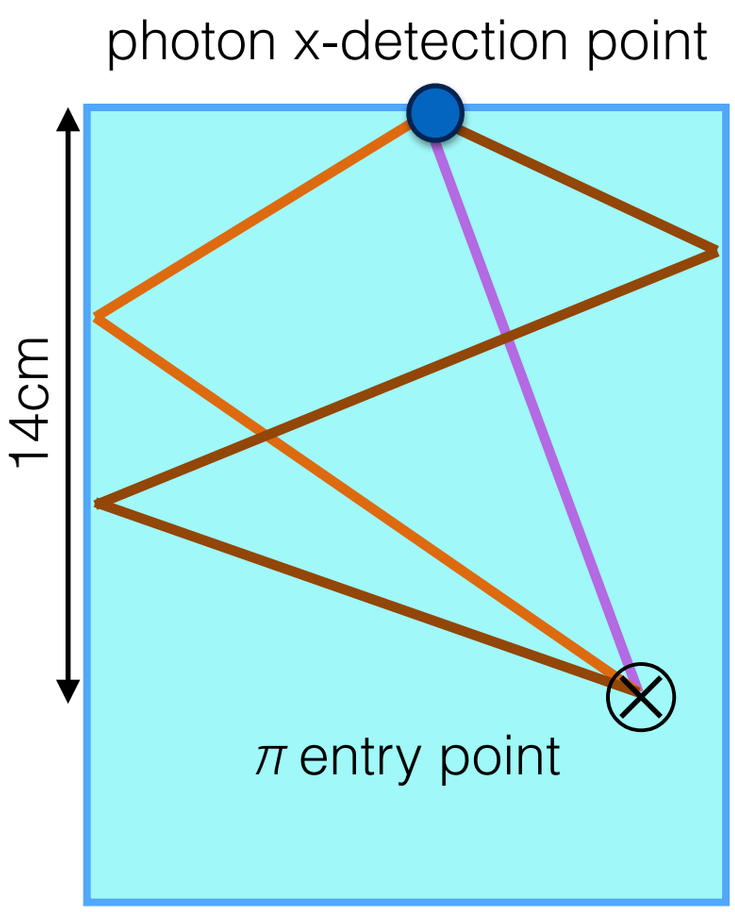
Readout electronics based on NINO and HPTDC

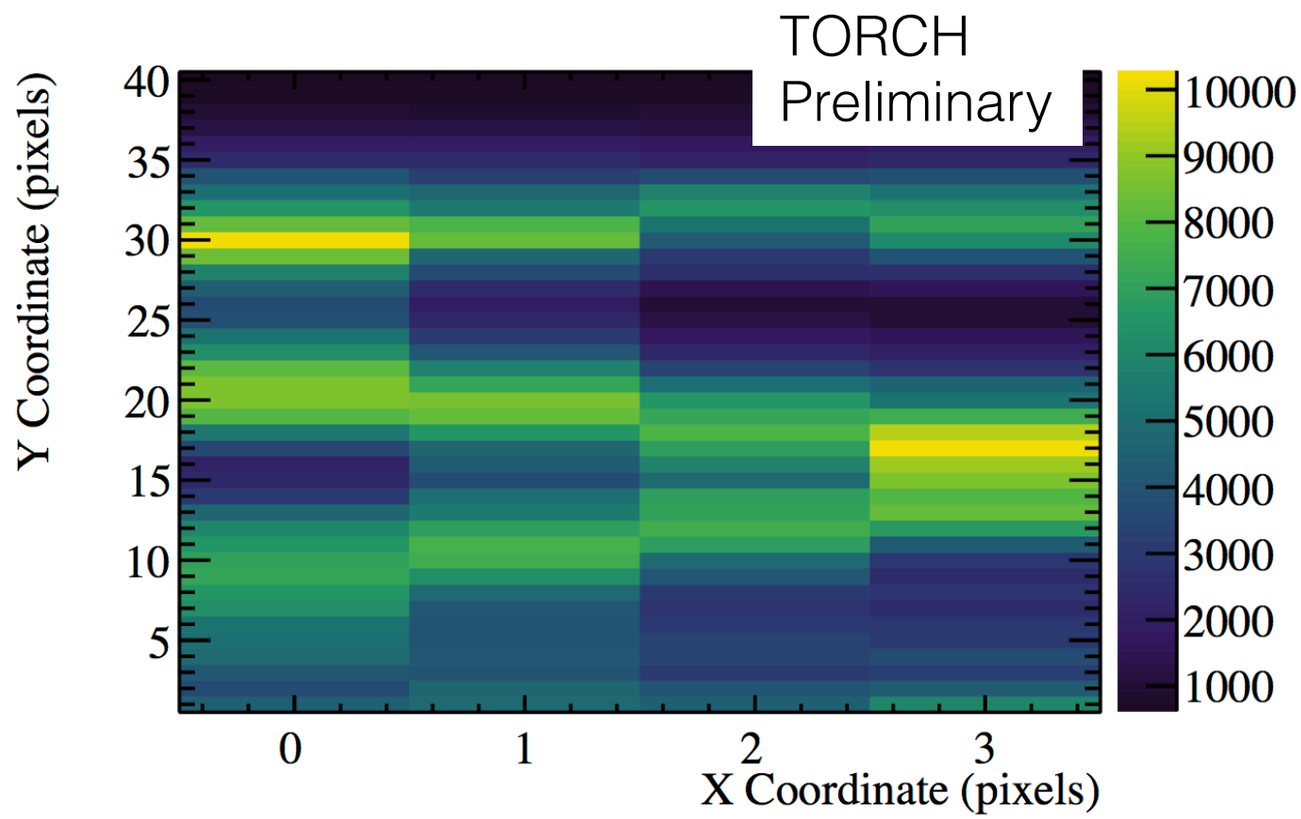
[JINST 11 (2016) C04012]

Quartz radiator

Folded image

- Mini-TORCH instrumented with a single MCP-PMT with 64 x 4 pixels.

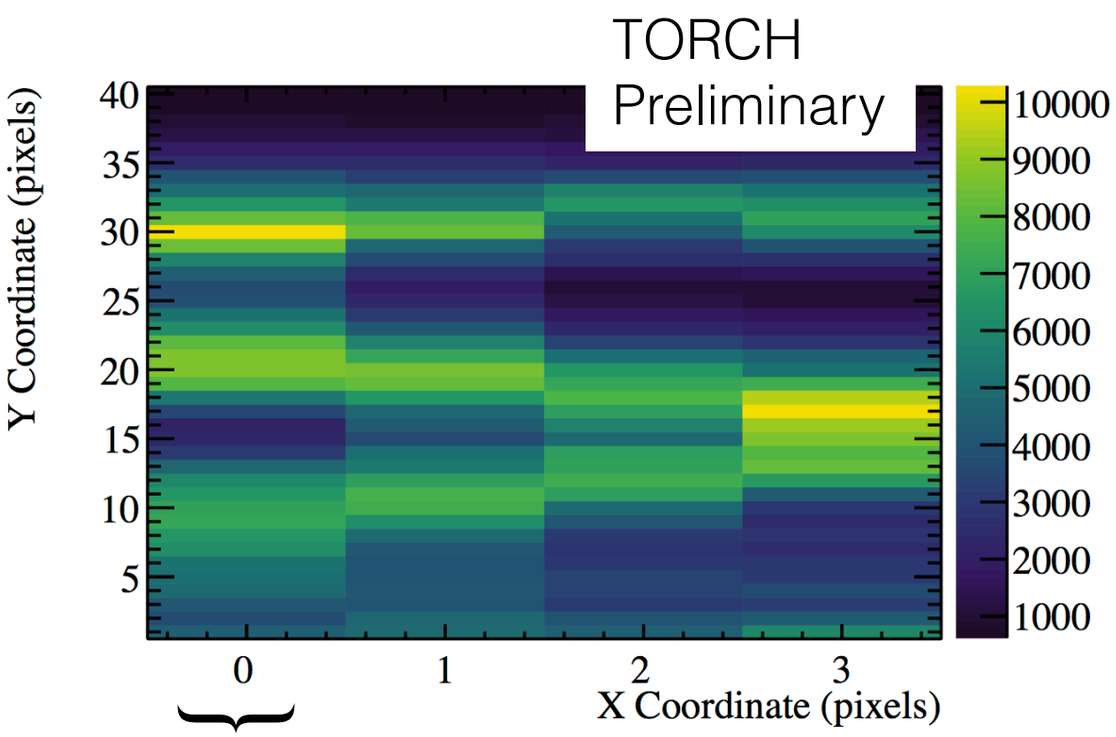




- Cluster data and average spatial/time position.
- Image in the spatial coordinates is folded due to reflections from the side faces of the radiator block.

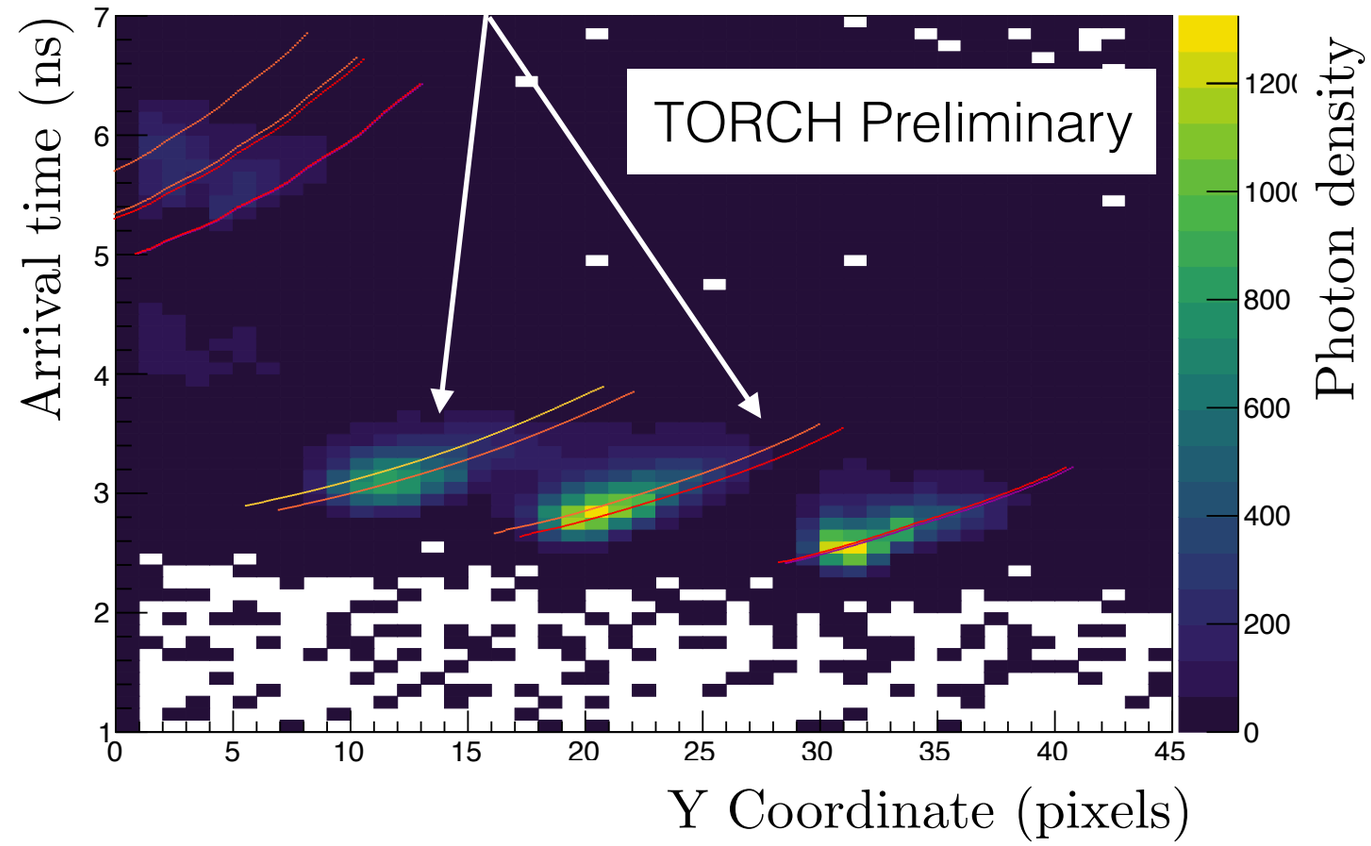
Time structure

- Photons at different angles with same x-position have different vertical position and arrival time.



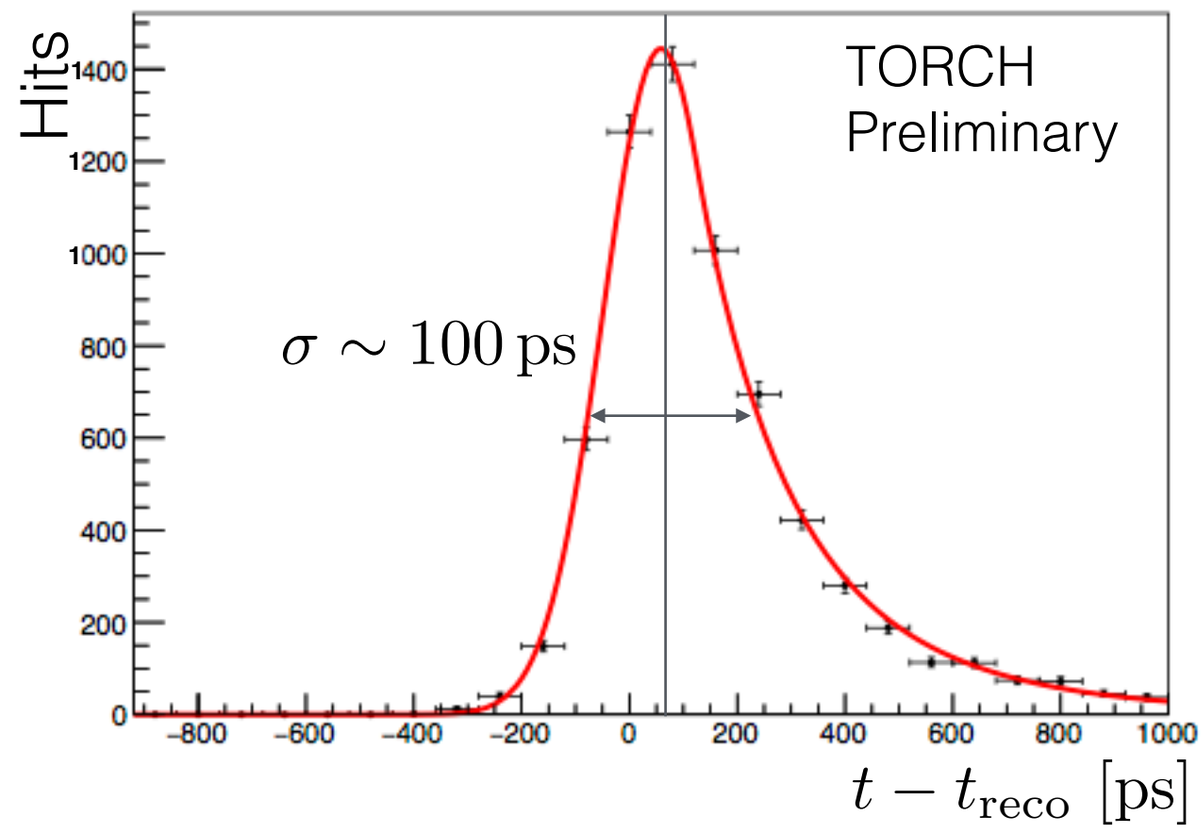
Project Y-coordinate and arrival time for X=0

Simulation of photon position/arrival time at the detector plane based on the extrapolated track entry point.



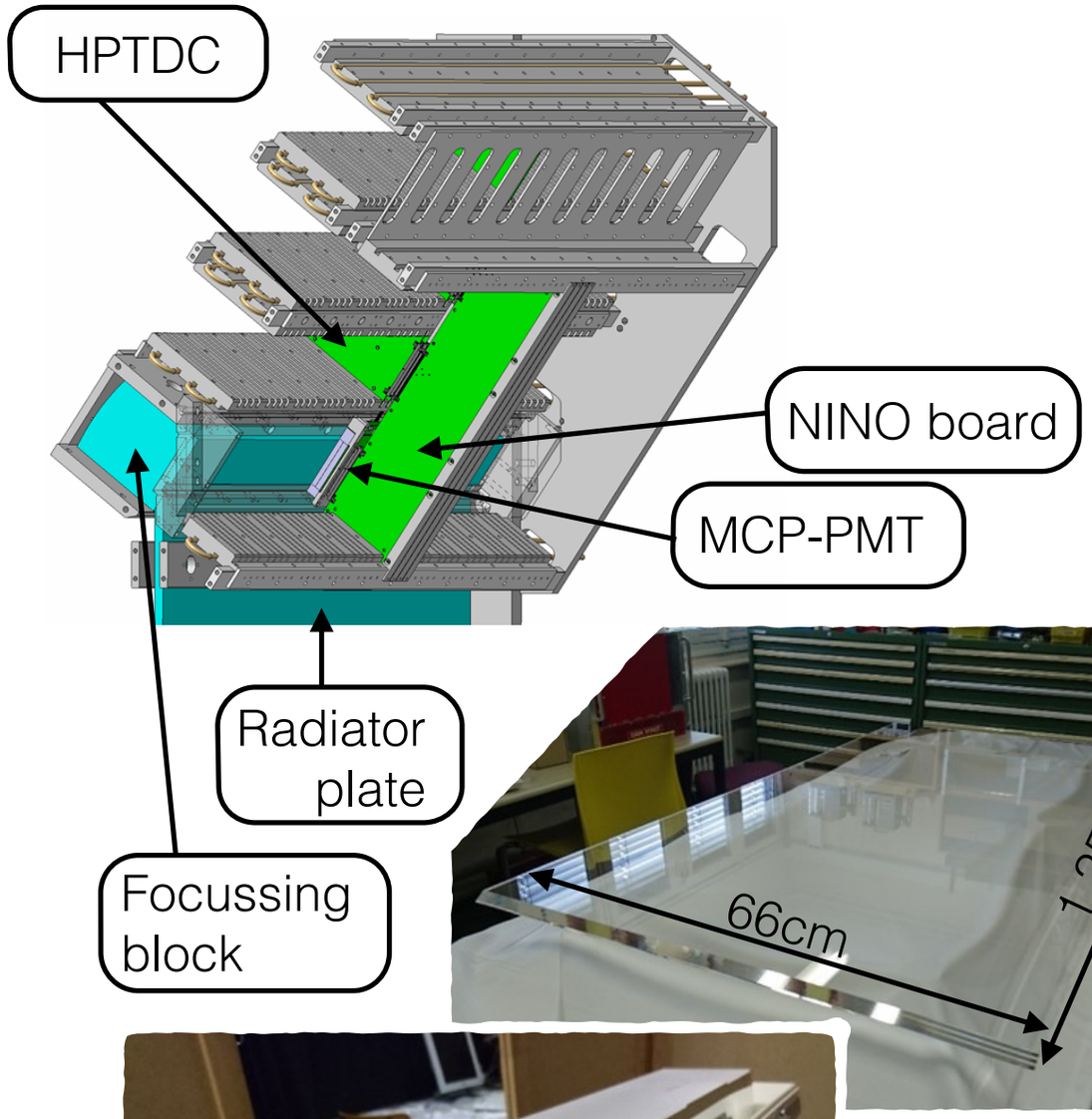
Time resolution

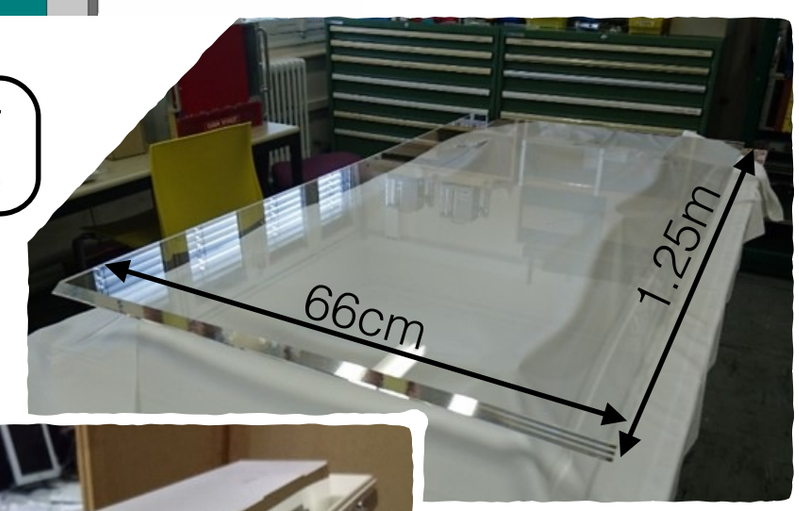
- Compare predicted time from the simulation to measured photon arrival time.
- Correct for non-linearity and time-walk in the TORCH electronics.
- Achieve a single photon resolution of ~100ps (including the resolution on our time reference).
- Further improvements possible with improved calibration/ alignment (e.g. charge-to-width calibration of NINO).



Next steps

- Half-scale demonstrator module under development:
  - ➡ Equipped with 10 MCP-PMTs with 64 x 8 pixels.
  - ➡ Larger scale optical components (from Nikon).
- Aim to test the demonstrator module in a beam test at the CERN PS in October 2018.
- The updated electronics and a single 64 x 8 pixel MCP-PMT have already been tested in a beam test in June this year.





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NINO & HPTDC boards for the demonstrator module

Summary

- TORCH is a large scale time-of-flight detector aiming to provide particle identification (K - π separation) in the range 2-10 GeV/c over a flight-distance of 10 m.
- R&D programme has developed a MCP-PMT detector with a long-lifetime, large active area and fine granularity.
- Performance of a prototype detector in beam tests at the CERN PS is very encouraging, we expect to reach the design sensitivity of $\sigma_{\mathrm{photon}} \sim 70\,\mathrm{ps}$.
- Half-scale demonstrator module under development for a beam test in October.

TORCH in LHCb