Status of the TORCH Project

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On behalf of the TORCH Collaboration

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Outline

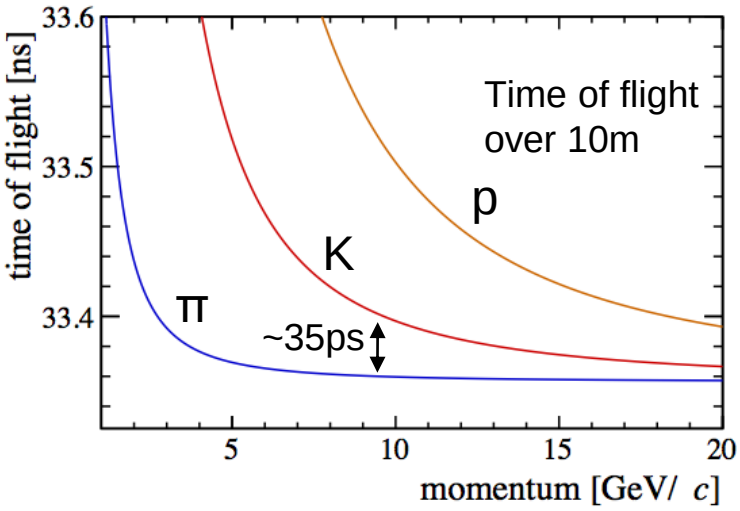
- Introduction to TORCH
  - TORCH principle
- Development of Microchannel Plate PMTs
- Beam test analysis
  - Time resolution and photon yield performance
- TORCH simulation and LHCb physics studies
- Summary

General introduction to TORCH

- TORCH (Time Of internally Reflected CHerenkov light) is an R&D project to develop a large-area time-of-flight system

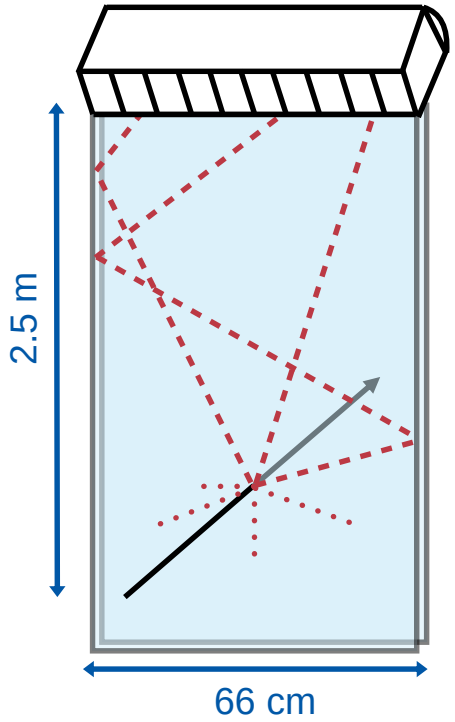
- π-K TOF difference = 35 ps over a ~10 m flight path. To achieve positive identification of kaons up to p ~ 10 GeV/c, need to aim for ~ 10-15 ps resolution per track

- The σ_{TOF} requirement dictates timing single photons to a precision of 70 ps for ~30 detected photons

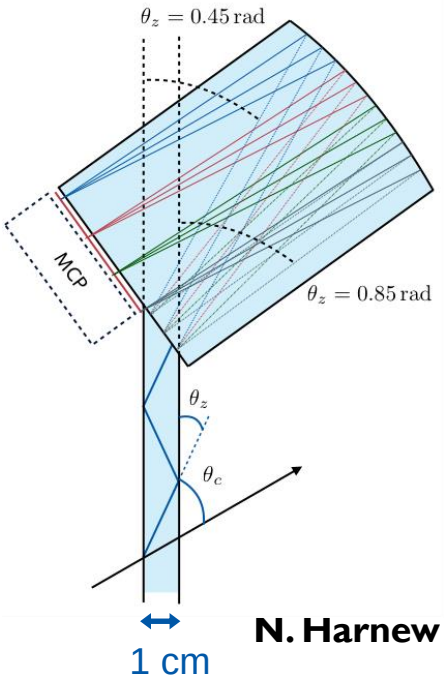


The TORCH detector

- A charged track produces Cherenkov light in a plane of 1 cm thick quartz
- Cherenkov photons travel to the periphery of the detector by total internal reflection and focused → their position and arrival time is measured by Micro-Channel Plate PMTs (MCPs)
- The Cherenkov angle θ_c and path length L in the quartz are measured. The time of arrival is used to correct for the chromatic dispersion in the quartz.
- From simulation, ~1 mrad precision is required on measurement of the angles in both planes to achieve the required intrinsic timing resolution



Non-focussing plane



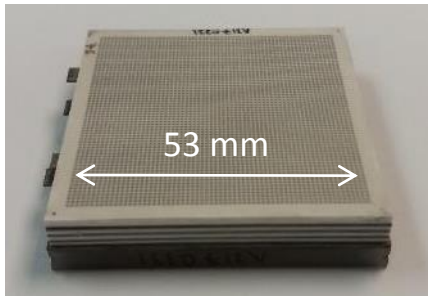
Focussing plane

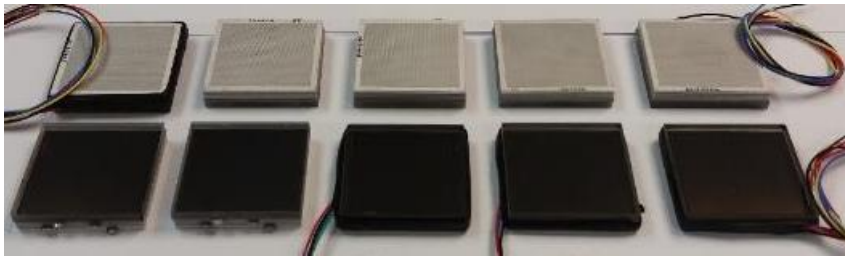
TORCH MCP-PMT development

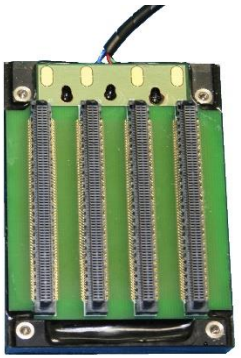
- The Cherenkov photons are focused onto Micro-Channel Plate PMTs
- These have been developed by industrial partner Photek UK in a 3-phase development programme

See talk of J. Milnes

- Each detector has a granularity of 64 x 64 pixels over a 53 x 53 mm^2 active area. A readout PCB is connected via Anisotropic Conductive Film
- Charge sharing and channel grouping is used to achieve an effective granularity of 128 x 8 pixels, which is required for the 1 mrad precision
- The MCPs have ALD coating and are designed to withstand an integrated charge of 5 C/cm^2
- 10 MCP-PMTs delivered from Photek are under test
- Two types of readout PCB for testbeam studies: 64 x 4 pixels and 64 x 8 (nominal).

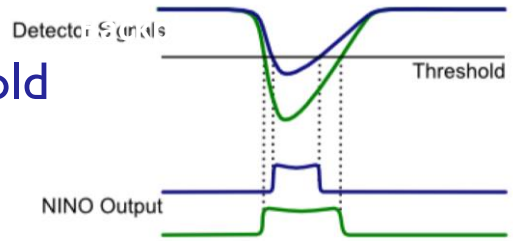






TORCH readout electronics

- Custom readout electronics developed, based on the ALICE TOF system: NINO + HPTDC [F. Anghinolfi *et al*, Nucl. Instr. and Meth. A 533, (2004), 183, M. Despeisse *et al*., IEEE 58 (2011) 202]

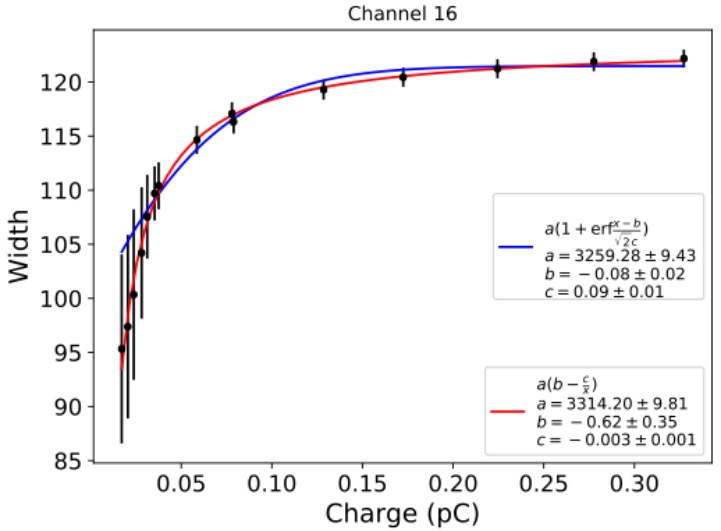


- NINO-32 provides time-over-threshold information which is used to correct time walk & charge to width measurement. Non-linearities of HPTDC time digitization (100 ps bins) are also corrected

- 128 channel NINO board developed

  R. Gao *et al*., JINST 10 C02028 (2015)

- The calibrations are challenging and work is still ongoing to optimize them

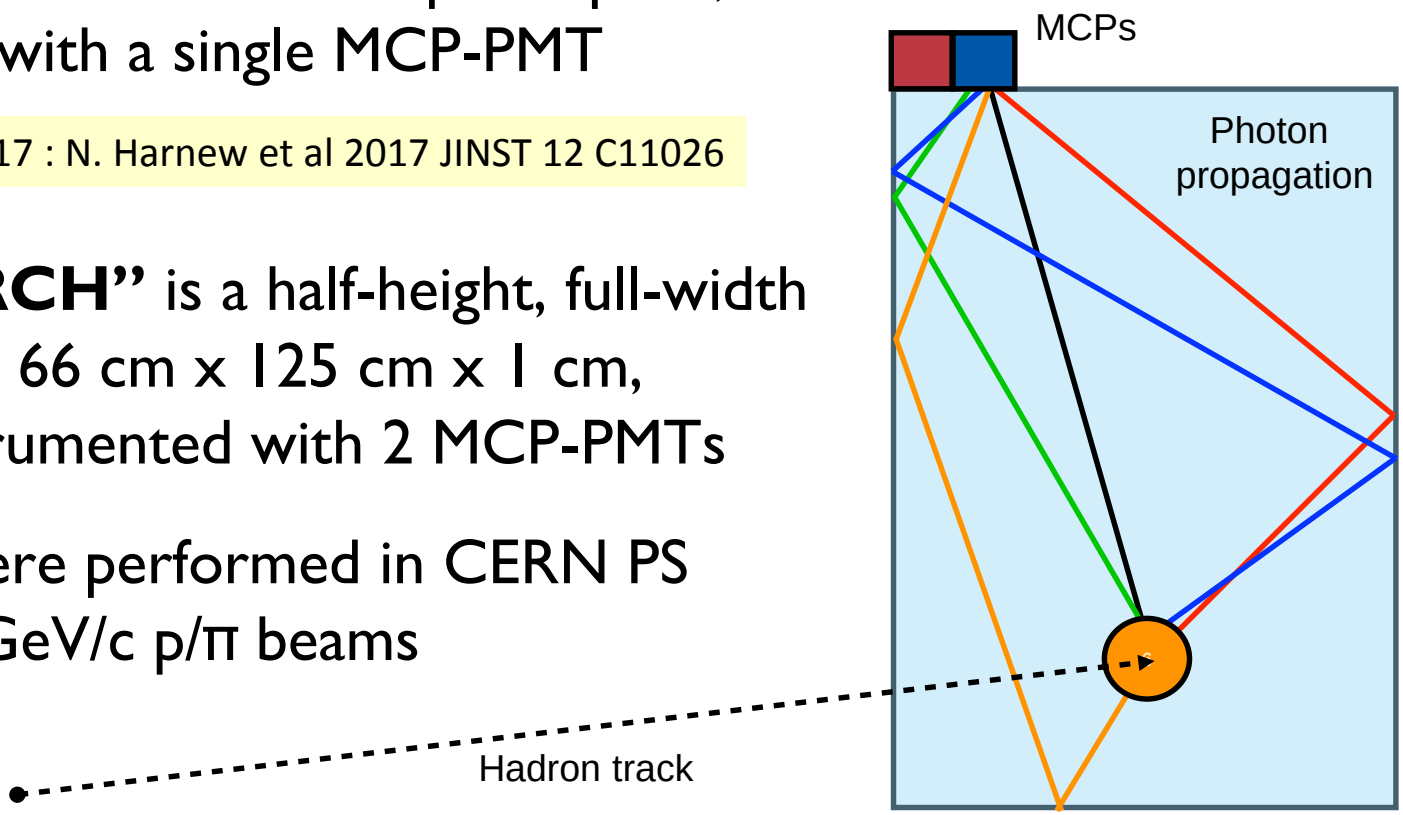


TORCH prototypes

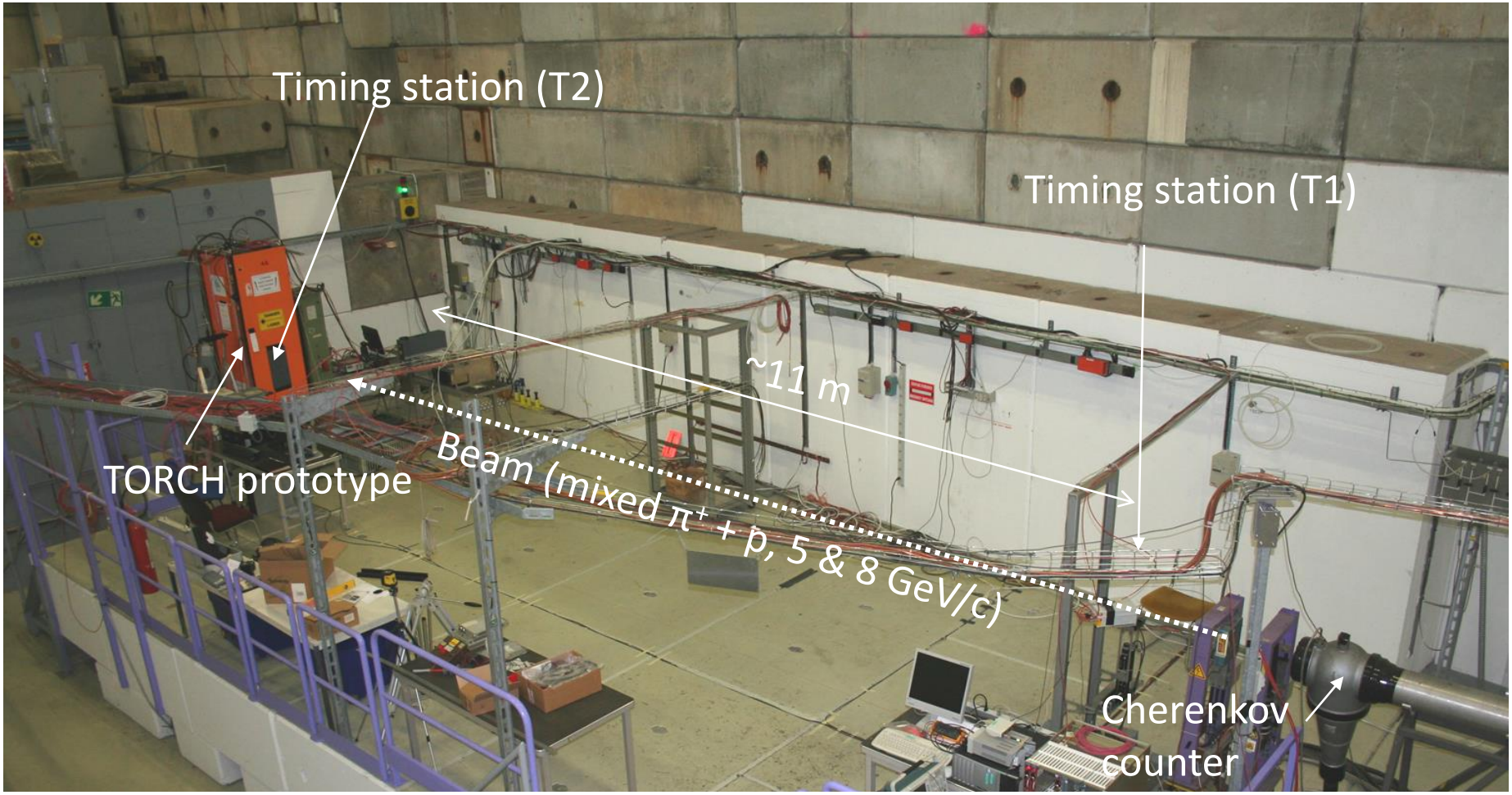
- TORCH prototypes have been tested in several beam tests between 2015 and 2018
- **"Mini-TORCH"** is a small scale module with a 12 cm x 35 cm x 1 cm quartz plate, instrumented with a single MCP-PMT

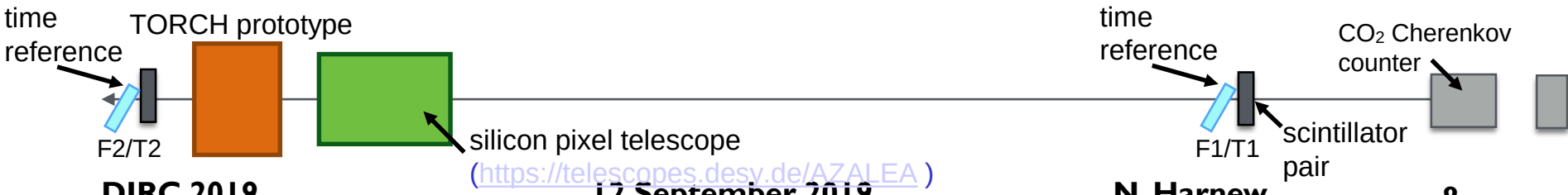
Presented at DIRC 2017 : N. Harnew et al 2017 JINST 12 C11026

- **"Proto-TORCH"** is a half-height, full-width LHCb module 66 cm x 125 cm x 1 cm, currently instrumented with 2 MCP-PMTs
- Beam tests were performed in CERN PS with 5 and 8 GeV/c p/π beams



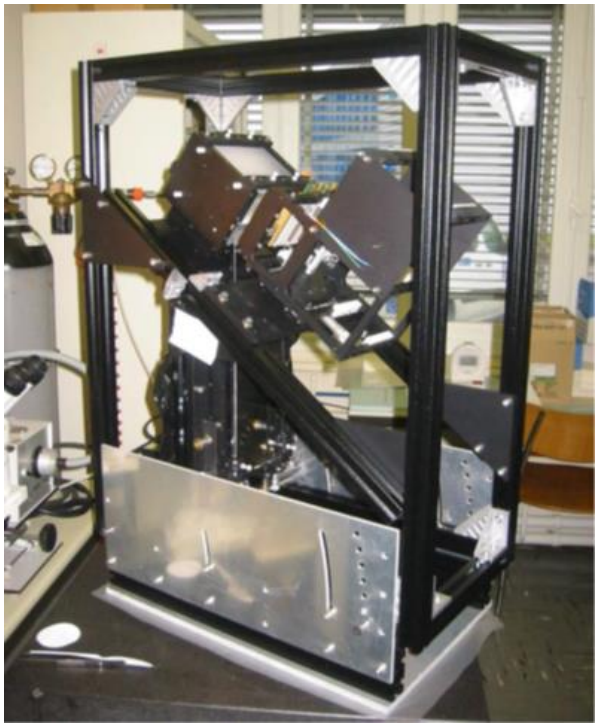
TORCH beam test infrastructure in PS/T9

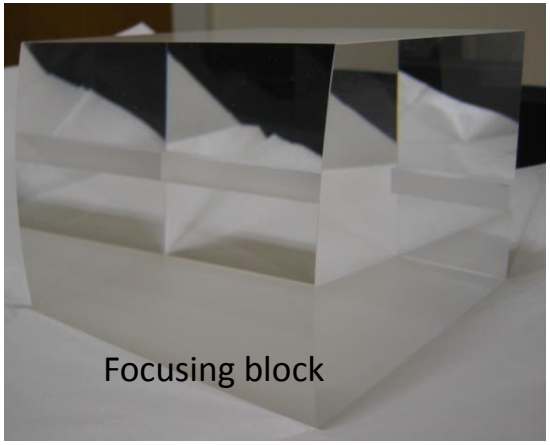




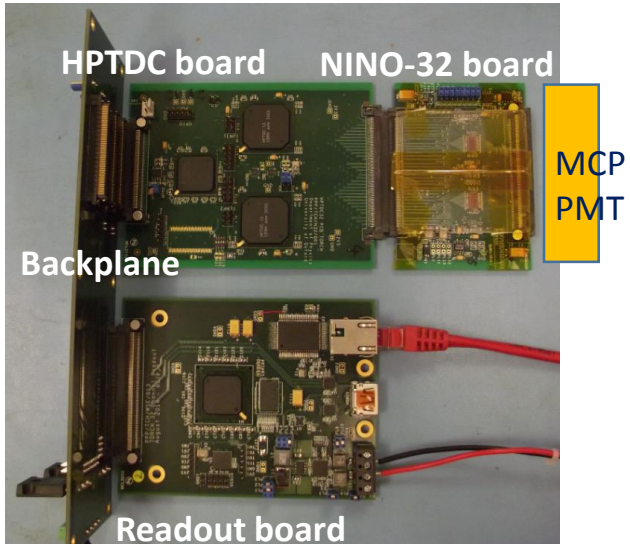
Mini-TORCH demonstrator

- Quartz radiator (12 × 35 × 1cm^3) with matching focusing block (from Schott Germany)
- Early version of NINO board (64-channel)
- Results now finalized – publication in preparation



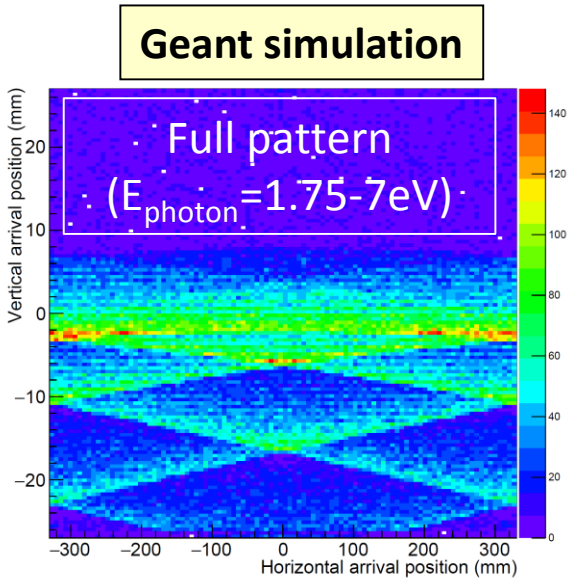


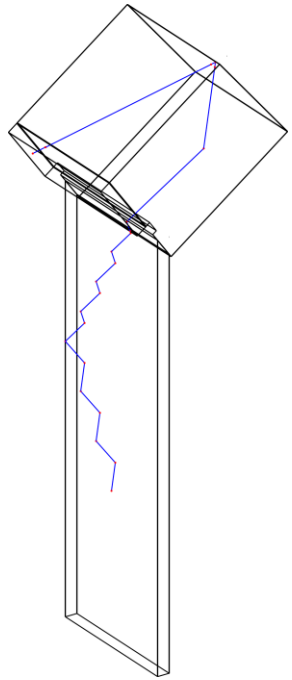
Radiator plate: 35 x 12 x 1 cm^3



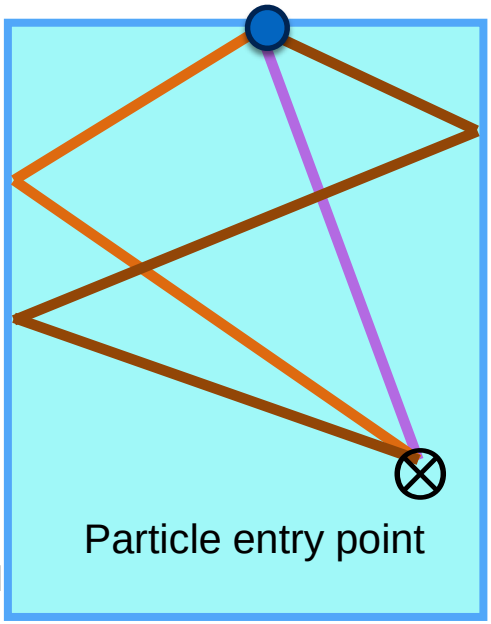
A word on the pattern folding

- Cherenkov cone results in hyperbola-like patterns at the MCP plane
- Reflections off module sides result in folding of this pattern
- Chromatic dispersion spreads line into band





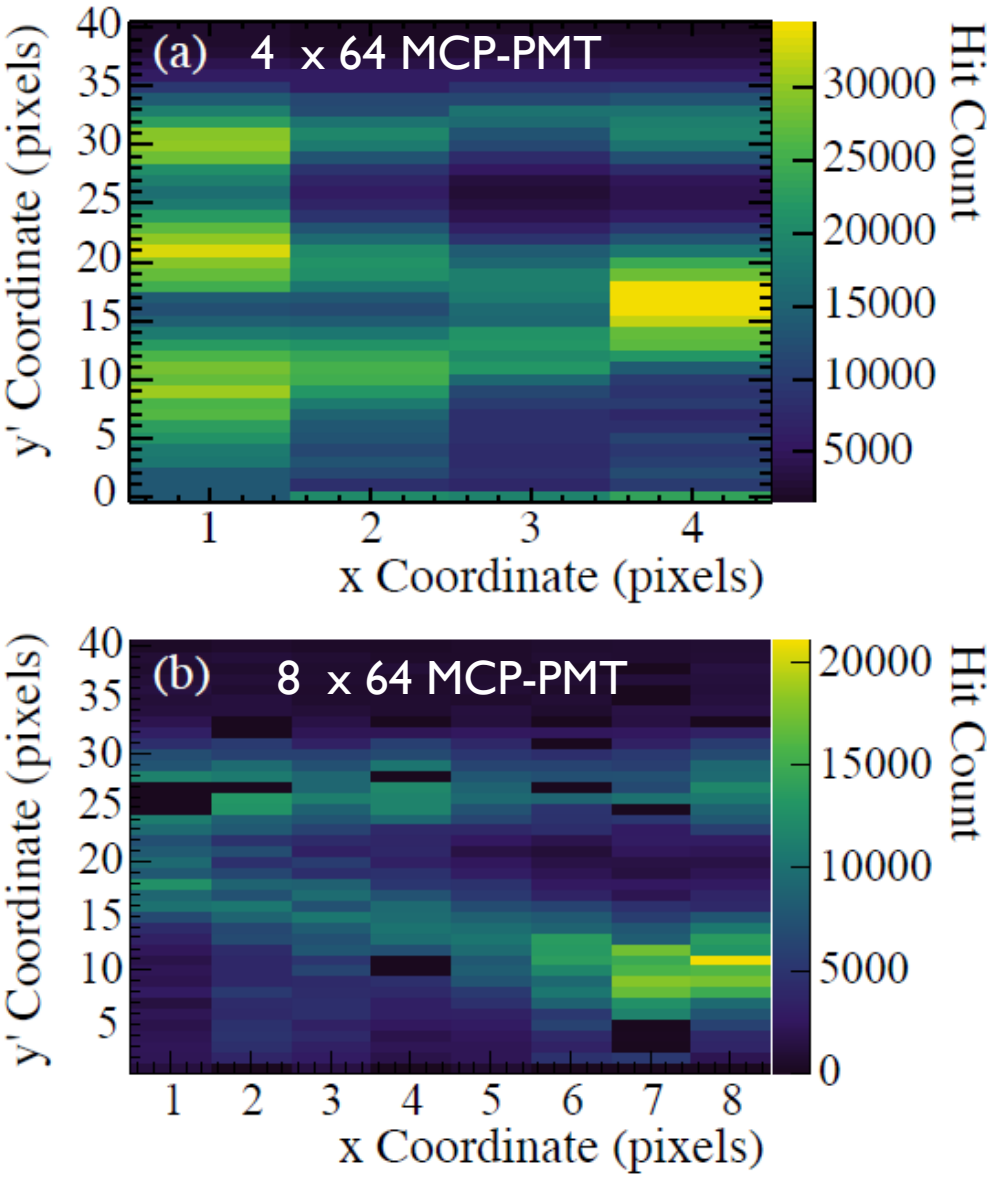
photon x-detection point



- The pattern shown above for a full TORCH module, however this pattern is only *sampled* with partially instrumented MCPs in the testbeam.
- The nominal test-beam configuration is chosen to give cleanly resolved patterns.

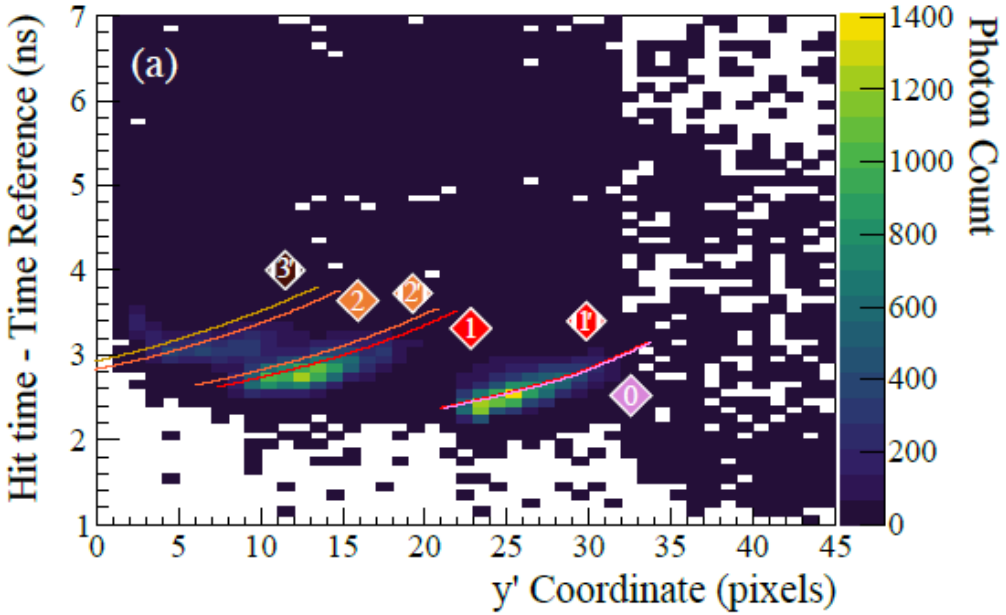
Mini-TORCH hit maps in MCP-PMT

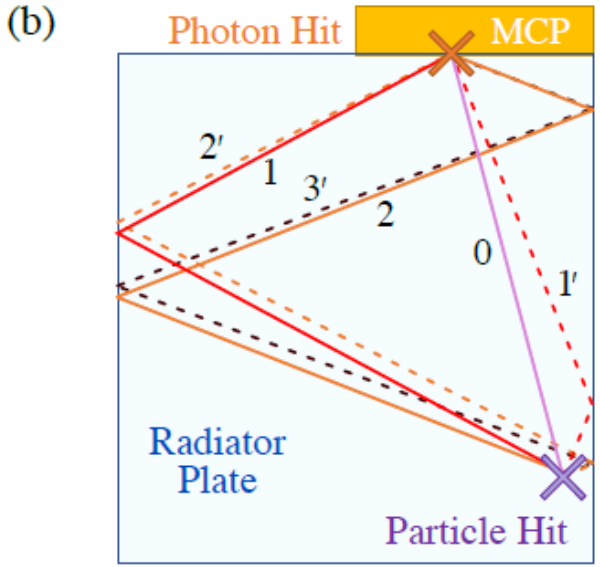
- 4 x 64 and 8 x 64 MCP-PMTs used
- Clustering applied to get MCP centroid hit position
- Correct for non-linearity and time-walk in the TORCH electronics.
- Note: some dead channels in 8 x 64 MCP-PMT due to NINO bonding issues



Time resolution : mini-TORCH

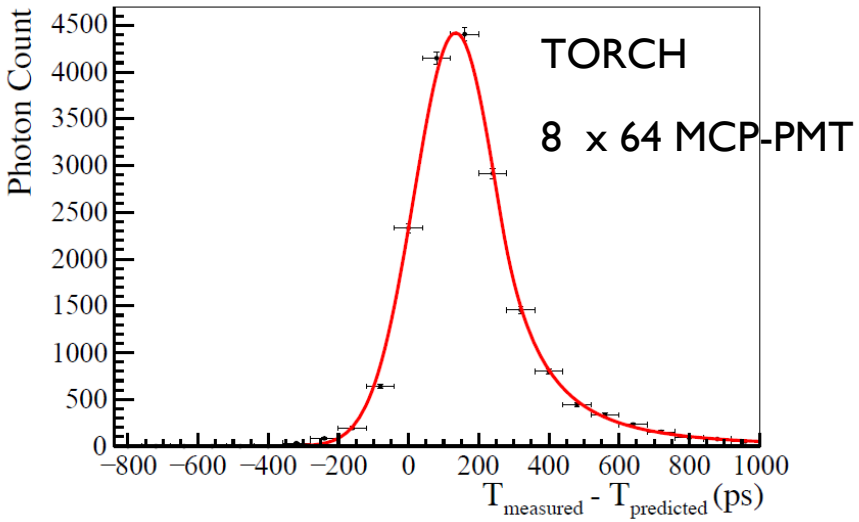
- Shown here is typical data for the 8 x 64 MCP-PMT
- For each column of pixels, plot the time measured for each cluster relative to the timing station T2 *versus* the finely-granulated pixel number (y')
- Reflection bands clearly observed





Time resolution : mini-TORCH

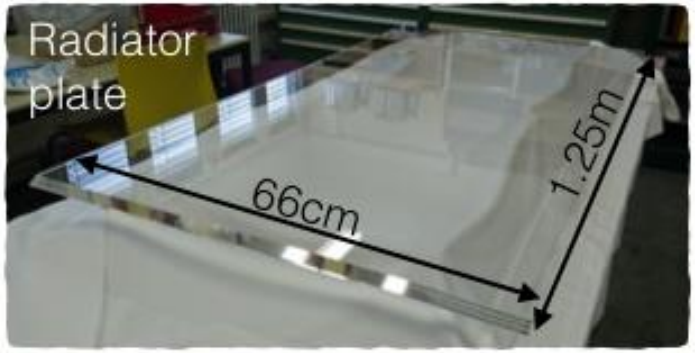
- Plot residuals for reflections 0 and 1'
- Subtract contribution from timing reference (~40 ps)
- We measure resolutions of typically100 ps per photon
- The target resolution is 70 ps per photon: improvements are possible to achieve this :
  - Improved pulse-height to width calibration
  - Limit of 100 ps binning in HPTDC

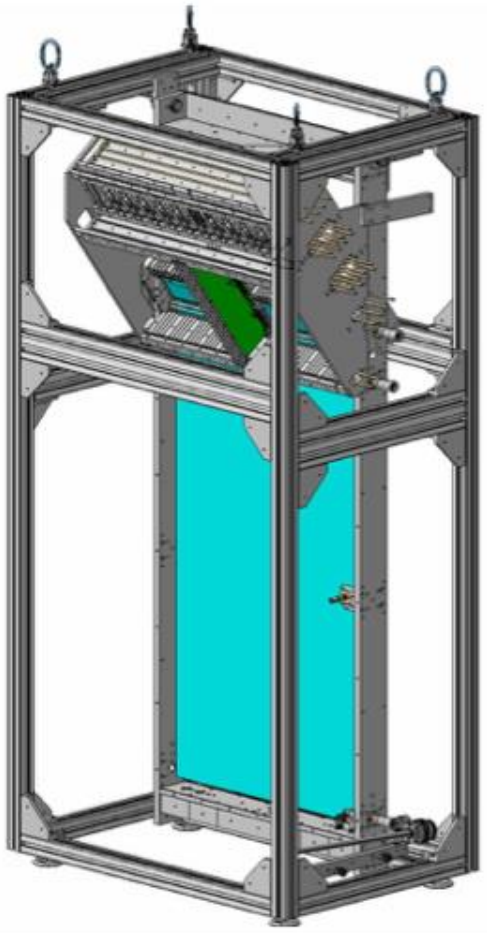


MCP Column	σ_{TORCH} Pions (ps)	σ_{TORCH} Protons (ps)
1	110.6 ± 1.2	112.7 ± 1.4
2	101.7 ± 1.2	110.6 ± 1.4
3	101.5 ± 1.2	110.6 ± 1.4
4	105.5 ± 1.2	106.2 ± 1.4
5	83.8 ± 1.3	91.0 ± 1.4
6	101.3 ± 1.2	103.4 ± 1.2
7	90.3 ± 1.2	87.5 ± 1.4
8	112.4 ± 1.1	102.8 ± 1.4

NEW : "Proto-TORCH" demonstrator

- A half-sized TORCH module : 125 x 66 x 1 cm^3 tested last year
- Optical components from Nikon (radiator plate, focusing block)

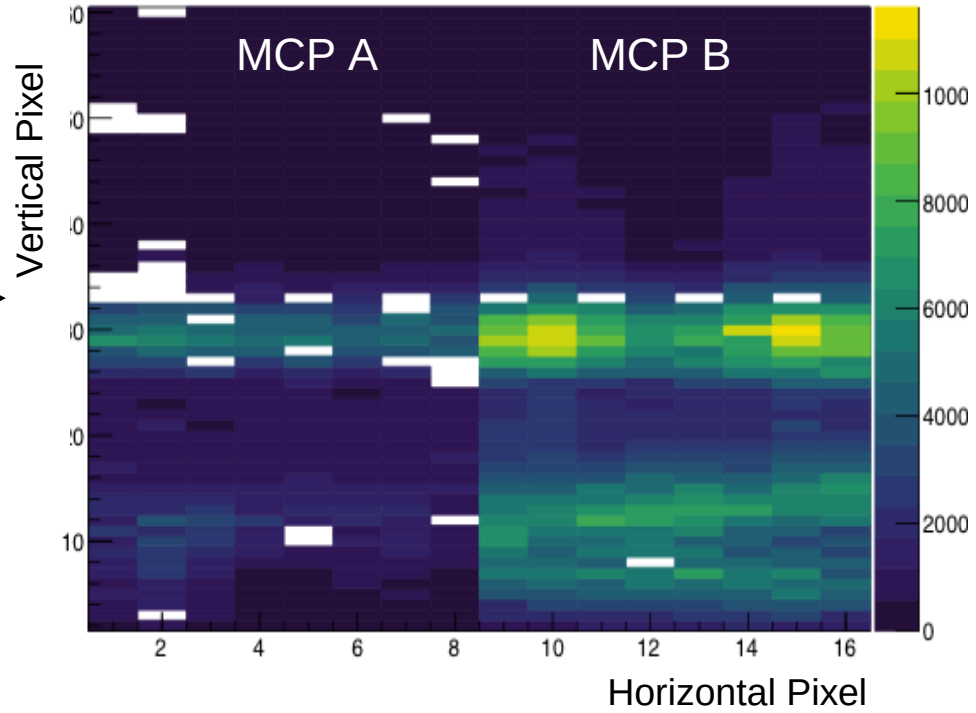


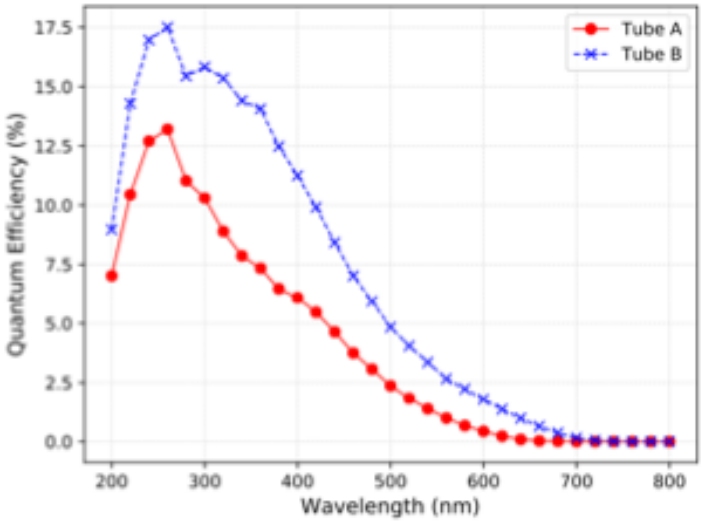


Proto-TORCH preliminary analysis

Hitmap

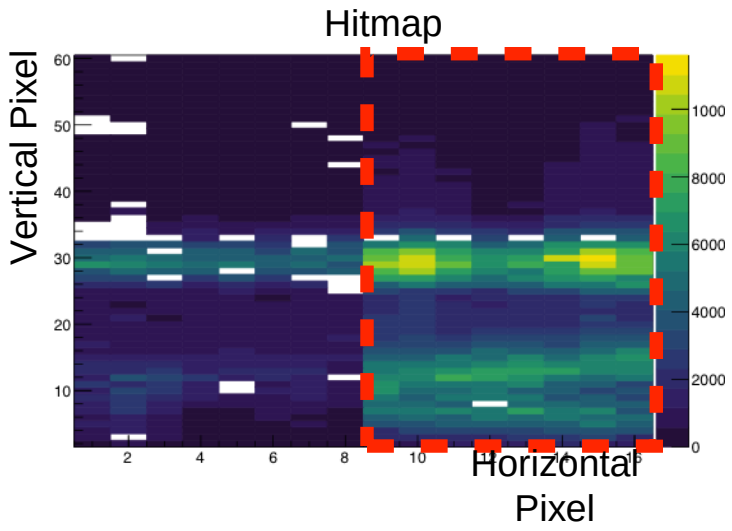
Time reference channels

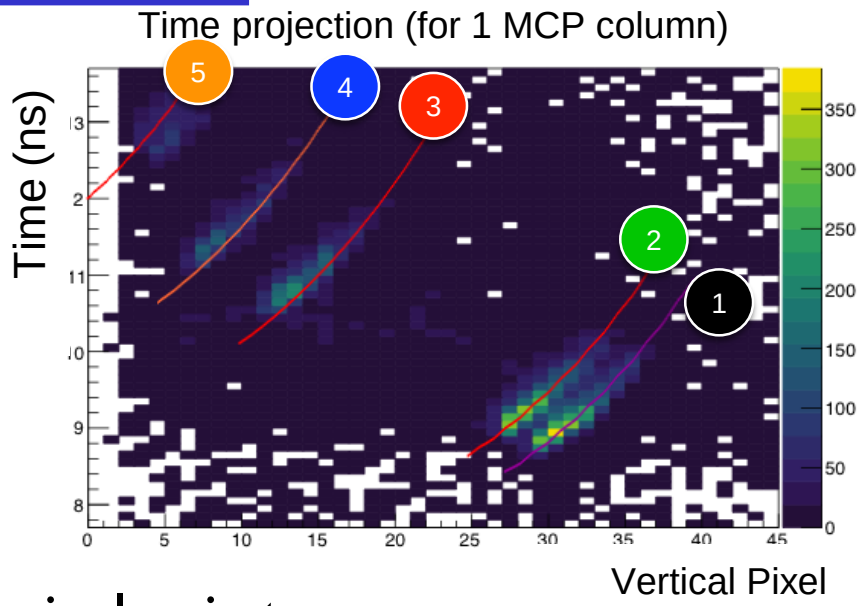




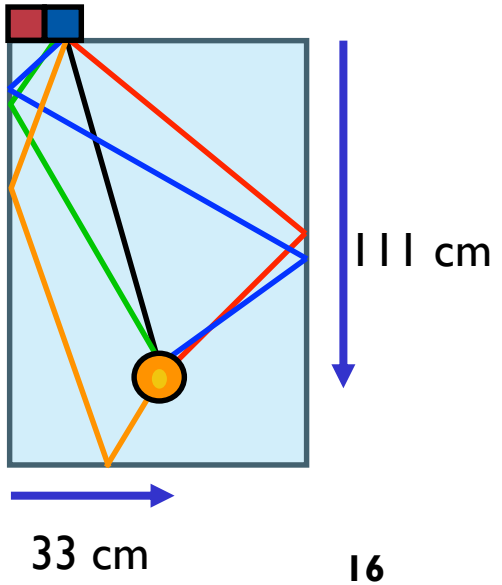
- The analysis focuses on MCP B with the higher quantum efficiency

Preliminary analysis



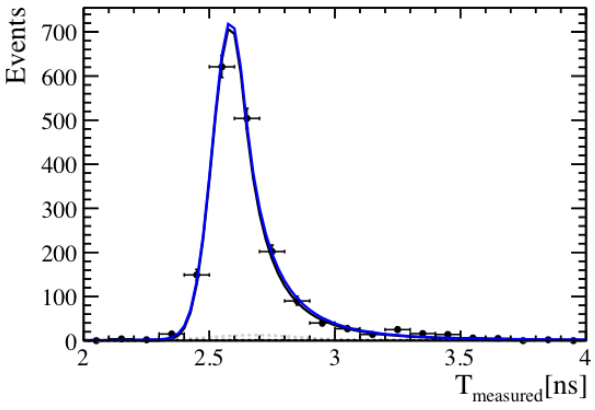


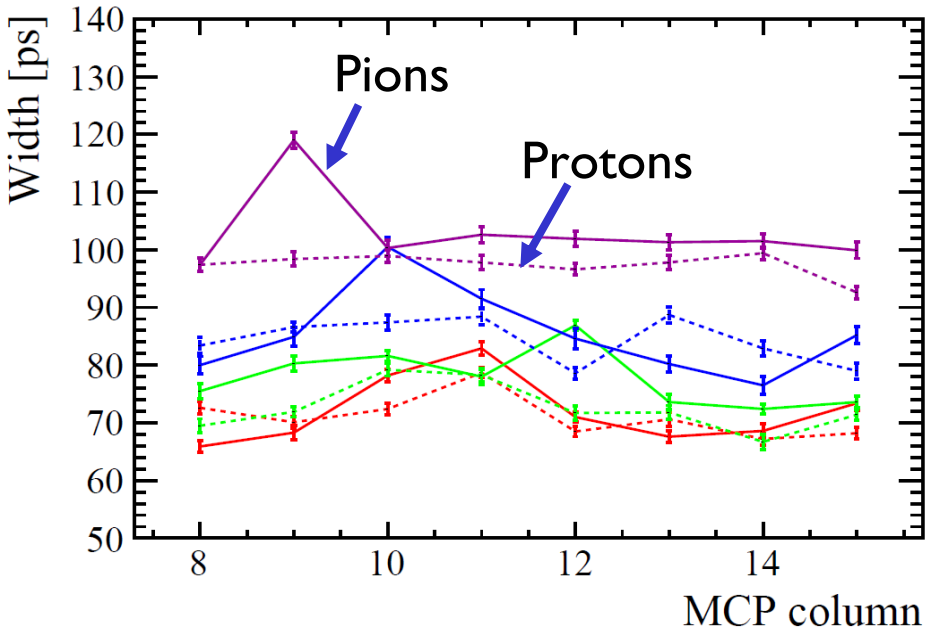
- Project the hits in the time-of-arrival axis to separate the different orders of side reflections
- The overlaid lines represent reconstructed predictions
- The spread in times for each order of reflection is measured to determine the single photon time resolution

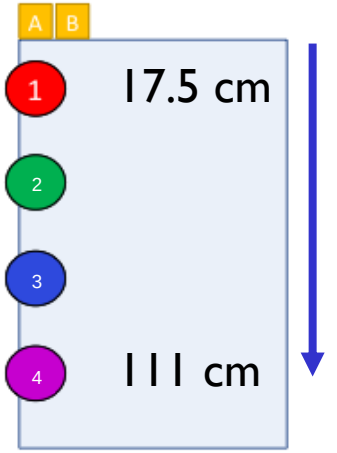


Time resolution studies

- Plot residual distributions of single-photon time resolution for first order reflections versus MCP column number
- A simultaneous fit determines the spread in the time of arrival at each pixel



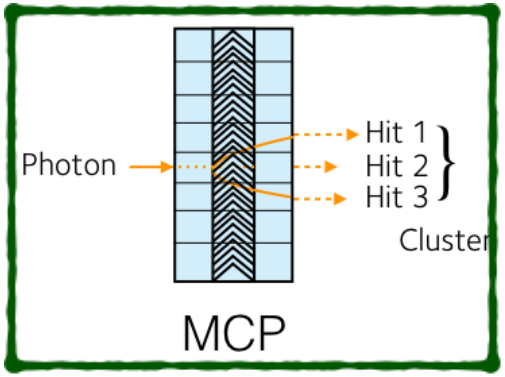


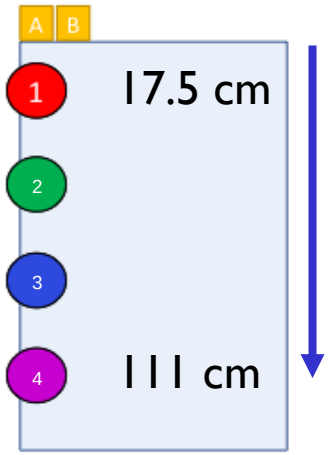


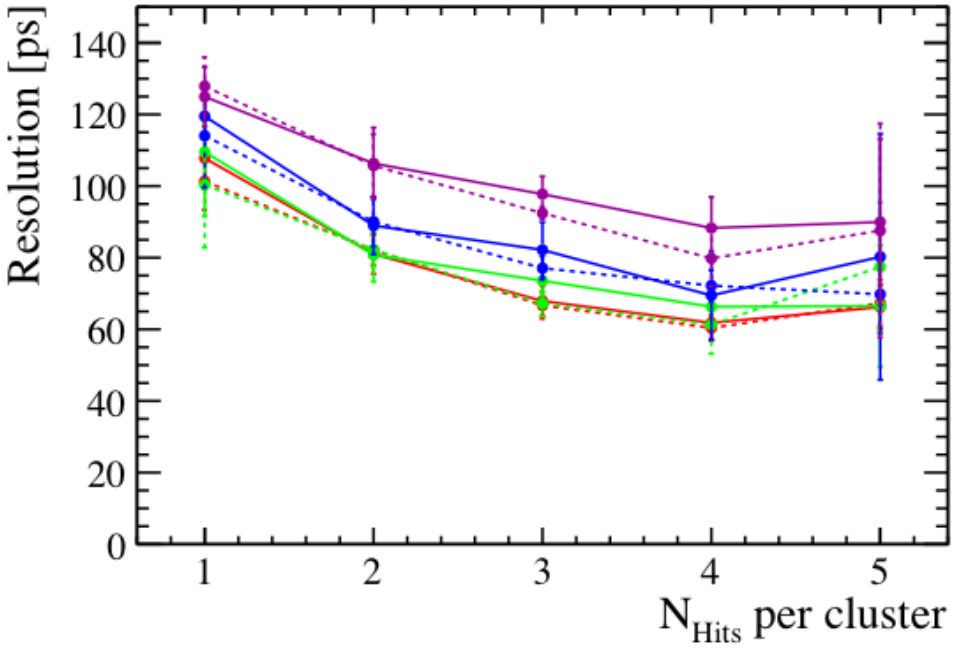
- We see some degradation of time resolution with height in the radiator
- Nevertheless, the time resolution is approaching or matches the design goal of 70 ps

Resolution studies

- Use charge sharing in the MCP to measure the cluster centroid of each photon hit
- Plot the time resolution for different sizes of clusters of hits







Resolution studies continued

- The time resolution can be parameterized into different contributions
- These individual sources are under study in laboratory tests

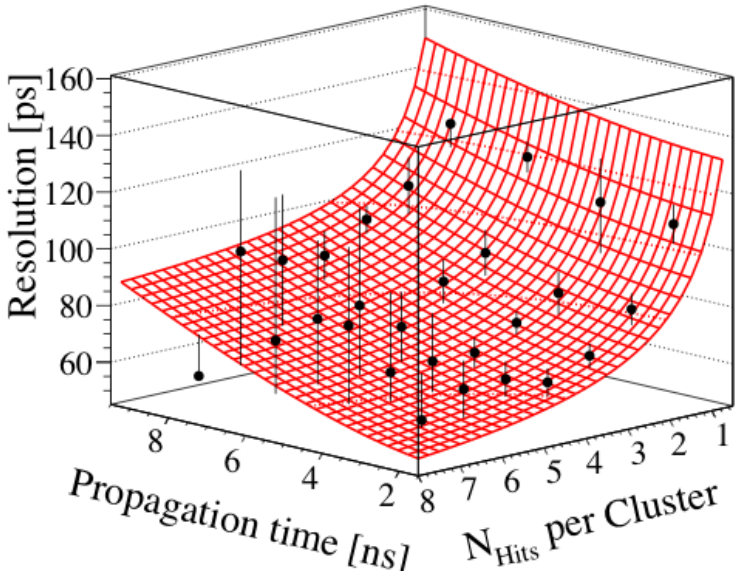
Time resolution parameterisation:

$$\sigma^2_{\mathrm{TORCH}} = \sigma^2_{\mathrm{const}} + \sigma_{\mathrm{prop}}(t_P)^2 + \sigma_{\mathrm{RO}}(N_{\mathrm{Hits}})^2$$

e.g. MCP

Propagation time (t_P) dependent effects

Electronics and readout resolution



$$\sigma_{\mathrm{const}} = 33.0 \pm 7.1\ \mathrm{ps}$$

$$\sigma_{\mathrm{prop}}(t_P) = (7.8 \pm 0.7) \times t_P\ \mathrm{ps}$$

$$\sigma_{\mathrm{RO}}(N_{\mathrm{Hits}}) = \frac{100.5 \pm 5.7}{\sqrt{N_{\mathrm{Hits}}}}\ \mathrm{ps}$$

[with t_P in ns]

Ideal values from simulation

$$\sim 33\ \mathrm{ps}$$

$$\sim (3.75 \pm 0.8) \times t_P\ \mathrm{ps}$$

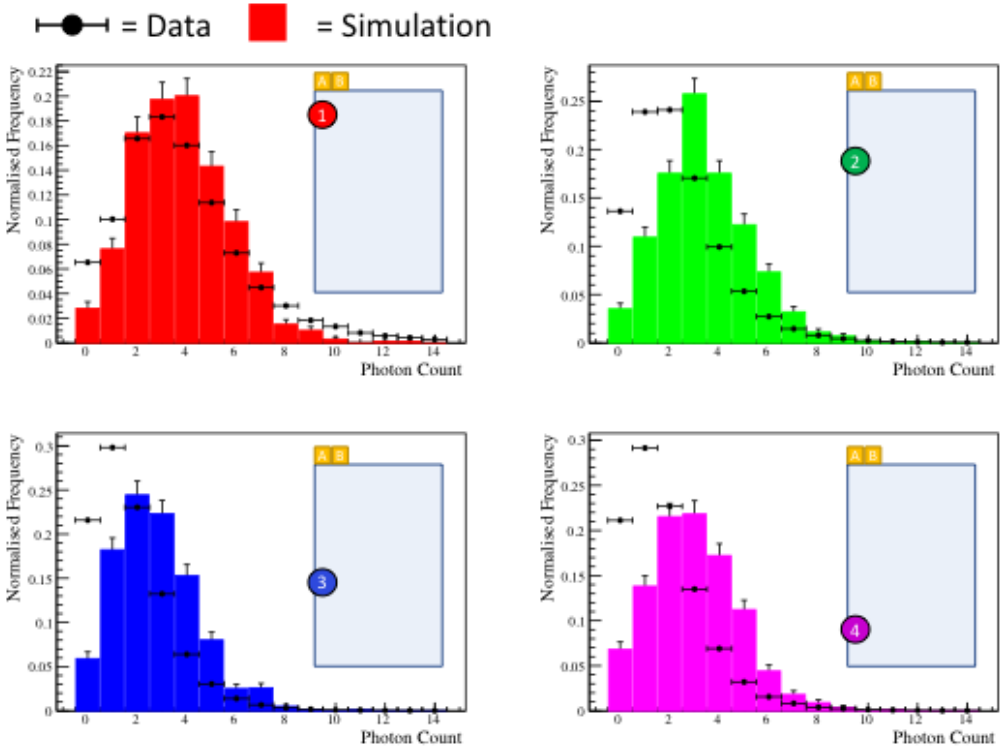
$$\sim \frac{60}{\sqrt{N_{\mathrm{Hits}}}}\ \mathrm{ps}$$

Further improvements from calibrations expected

Photon yields vs vertical height

- Photon yields compared to simulation (which includes MCP quantum efficiency, collection efficiency, surface roughness etc)

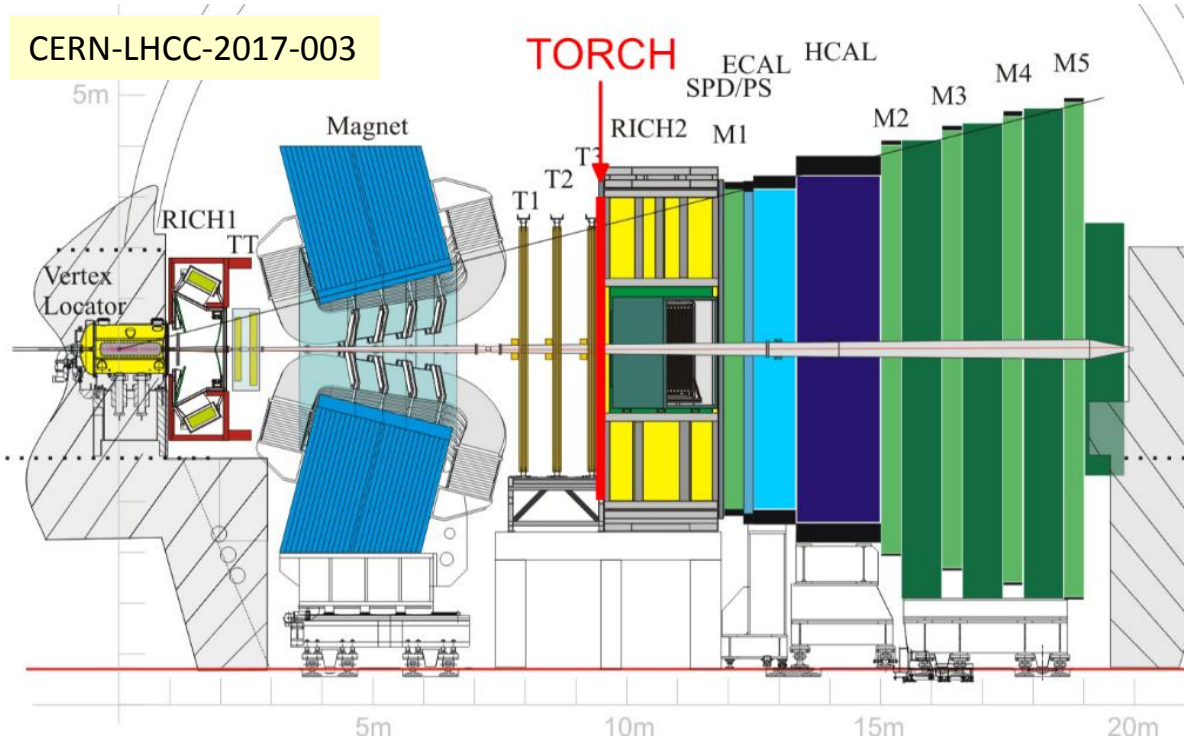
- Discrepancies as a function of vertical position still being studied
- The current prototype only has 2 out of 11 MCPs
  - Photon yields would be ~5.5 times larger than shown here
- Final module expected to have improved quantum efficiency



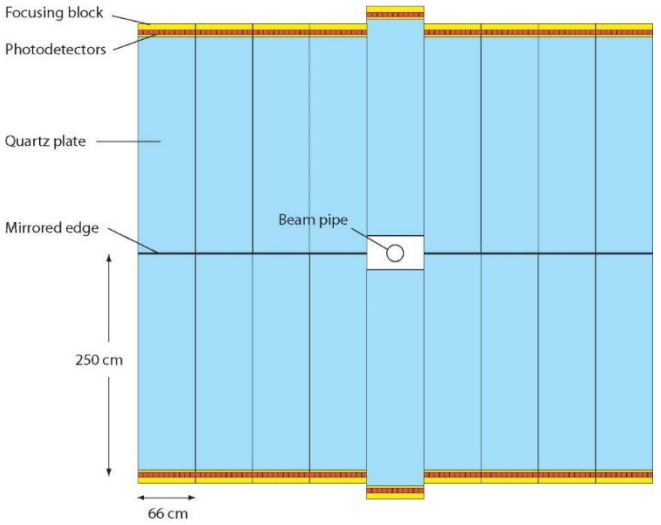
TORCH for LHCb Upgrade IB

- The RICH system provides particle ID in LHCb
- But currently no positive kaon or proton ID below ~10 GeV/c
- Proposal to install TORCH in front of RICH2, possibly already in LS3 (for ~2026)

CERN-LHCC-2017-003



- TORCH area 5 x 6 m^2
- 18 module system
- 11 MCPs per module

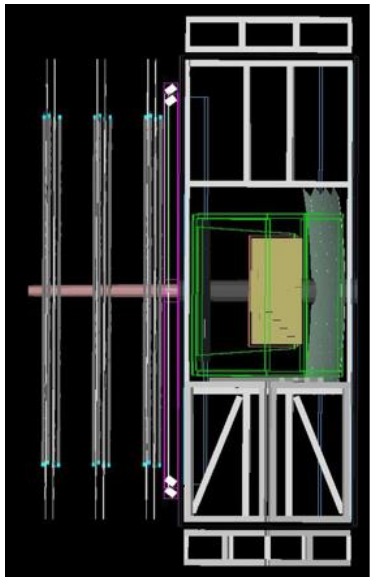


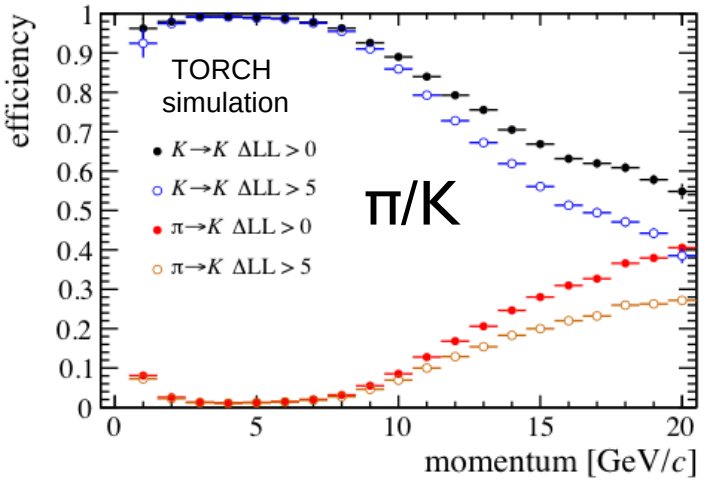
Simulated performance at LHCb

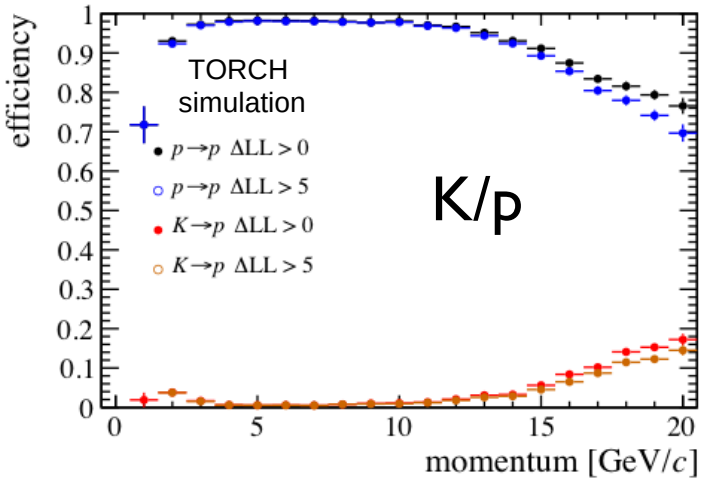
- TORCH has been simulated in the framework of the Upgraded LHCb detector (GEANT4)
- The PID performance is determined for Upgrade IB conditions (Run 4)

$$\mathcal{L} = 2 \times 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$$

- Good separation expected between π/K/p in the 2 -10 GeV/c range and beyond.







Summary and outlook

- The TORCH project is progressing well, with a successful series of beam tests
- The time resolution of the prototype is approaching the design goals : 70 -100 ps timing resolutions per single photon achieved. With improvements in calibration hope to achieve consistently the desired 70 ps. Photon yield still under study.
- Further lab tests and electronics calibrations are ongoing
- TORCH has been simulated in the LHCb experiment. Studies have indicated significant improvements to the LHCb physics potential
- Future tests will involve the fully instrumented (11 MCP) half-height TORCH module

Thanks for your attention

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European Research Council

Established by the European Commission