The TORCH Time-Of-Flight Detector

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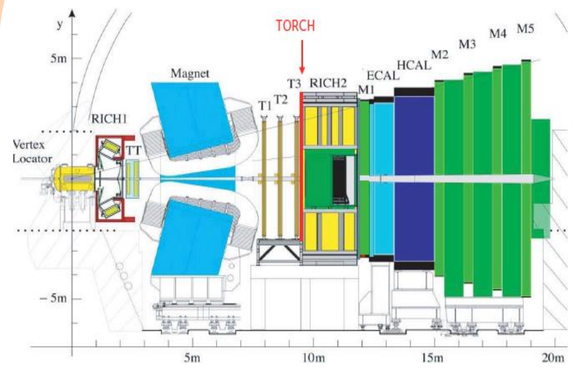
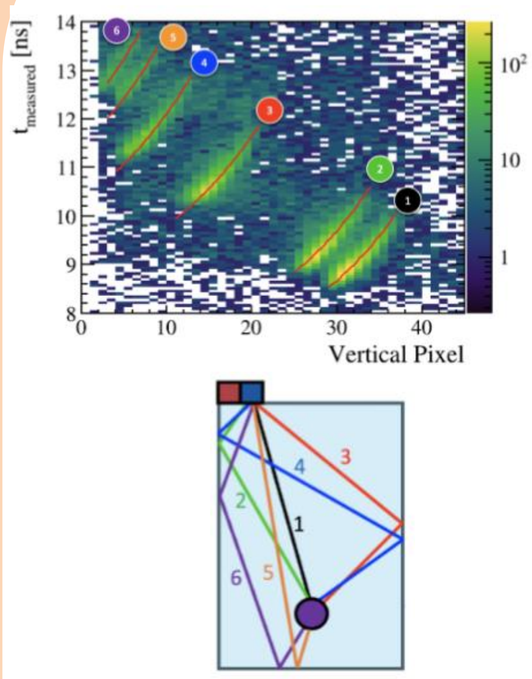
Introduction

*TORCH— **T**ime **O**f internally **R**eflected **CH**erenkov light*



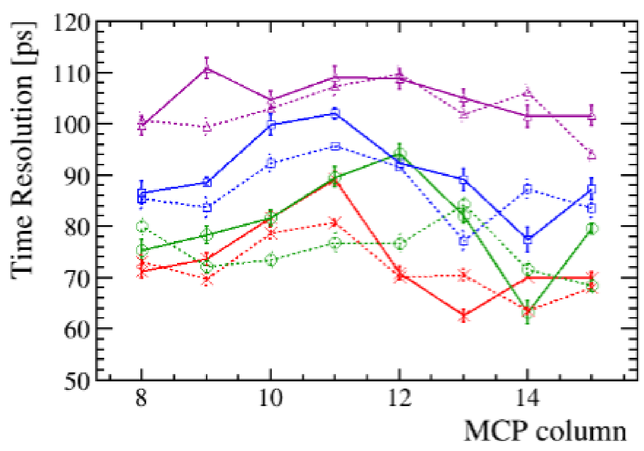
- TORCH is a time of flight detector which gives positive PID for low momentum π/K (K/p) between 2-10 (20) GeV/c over a 10 m flight path. *NIM A908421 (2018) 256*
- TORCH is proposed for the Upgrade-II of LHCb. *CERN-LHCC-2021-012 (2021)*
- The aim is to achieve a timing resolution of 15 ps per incident particle, and with 30 detected photons, this means a resolution of 70 ps per single photon.
- Cherenkov photons are emitted in a 1cm thick fused-silica plate, and transmitted to the periphery of the plate via total internal reflection.
- Here the photons are focused onto an array of customised Micro-Channel Plate (MCP-PMT) photo-detectors, developed with industrial partner Photek UK.
- Each MCP-PMT detector has an effective granularity of 128 x 8 over a 53 x 53mm^2 active area.
- They are read out by customized electronics. *JINST 11 (2016) C04012*

Performance of the prototype

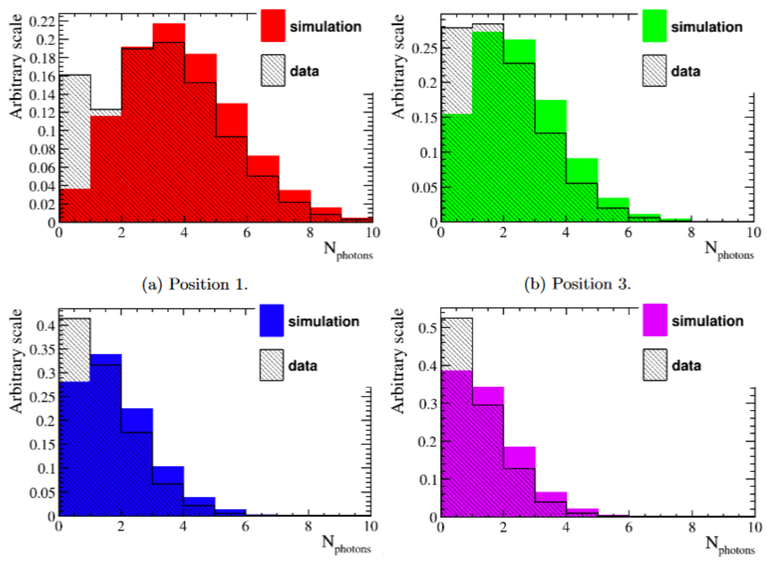


Beam input coordinate x=330 mm, y=1115 mm

- The cones of Cherenkov radiation emitted by the incident hadrons are focused into hyperbole-like patterns.
- The upper plot shows the timing distribution of MCP-B as a function of hit coordinate: pixel number runs from 1 to 64.
- The different orders of reflection (photon paths in the radiator) are well-separated.
- The widths of each order with respect to the mean are measured to determine the single-photon time resolution.



- The single-photon time resolutions are determined in different columns of MCP-B for a range of beam positions in the quartz:
  - Positions shown : 1 (red), 3 (green), 4 (blue), 5 (purple).
  - The full (dotted) lines are the single-photon resolutions measured from the pion (proton) samples.
- 70 ps target resolution is achieved for point closest to the MCPs. As expected, resolution degrades for longer flight paths, although slightly more than suggested from simulation.

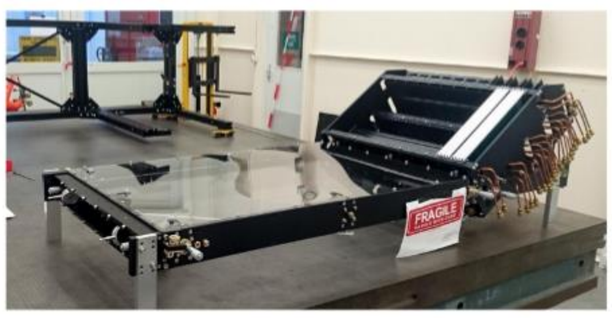


(a) Position 1. (b) Position 3. (c) Position 4. (d) Position 5.

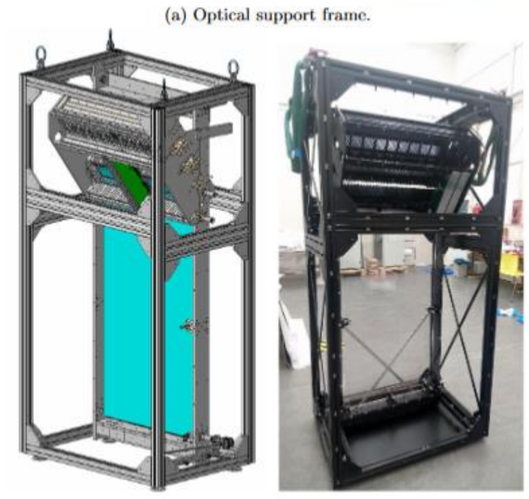
- The photon counting yields are measured for different beam entry positions from data and compared to simulation.
- The yields agree very well with expectations if the small number of events with events with N_photons=0 are excluded.

Position	Mean $N_{photons}$		$\frac{\text{Data}}{\text{Simulation}}$ (excluding $N_{photons}$=0)
	Data	Simulation	
1	2.605 ± 0.007	2.711 ± 0.017	1.075 ± 0.006
3	1.419 ± 0.005	1.570 ± 0.014	1.002 ± 0.007
4	0.937 ± 0.004	1.072 ± 0.012	0.983 ± 0.007
5	0.677 ± 0.002	0.812 ± 0.010	0.981 ± 0.007

TORCH prototyping in the CERN T9 Test-Beam



(a) Optical support frame.



(b) Full assembly.

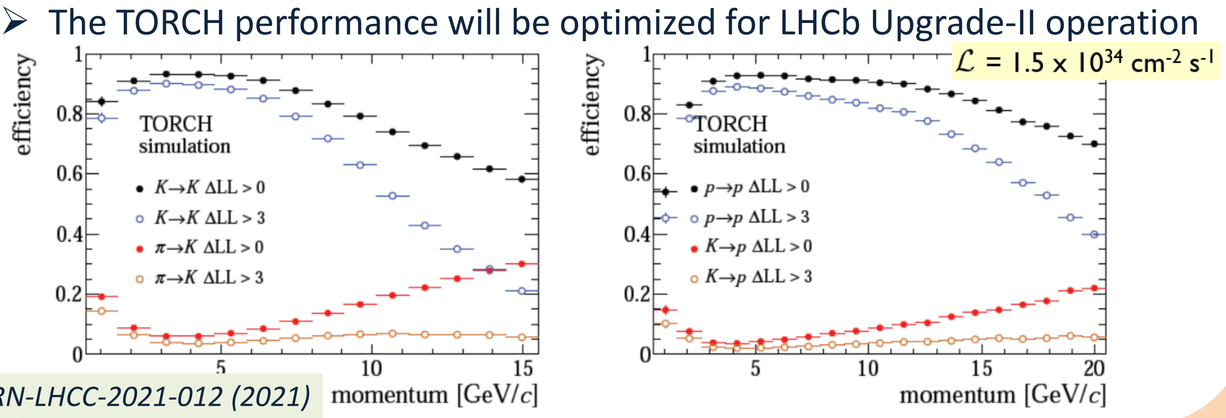
A 1.25m TORCH prototype module "Proto-TORCH" has been constructed:

- The prototype has a 660 x 1250 x 10 mm^3 (width x length x thickness) fused-silica radiator plate.
- The plate has half length and full width of an LHCb TORCH module.
- ProtoTORCH instrumented with two MCP-PMTs (MCP-A and B) , each of 64 x 64 pixels.
- Pixels are grouped electronically into 8 columns horizontally.
- Vertically, charge sharing improves the resolution by a factor ~2 to give 128 pixels effective resolution. *JINST 10 (2015) C05003*
- Beam tests have been carried out in an 8 GeV/c mixed pion/kaon beam in the T9 area at the CERN PS. *arXiv:2111.04627*

a) Photograph showing the frame for the quartz radiator, lying horizontally, the support structure for the MCP-PMTs and electronics on the right.
b) The fully assembled prototype in its casing (left) the CAD model, and (right) after construction.

Future Work

- A future test-beam campaign is planned for the end of 2022, which will employ the fully instrumented TORCH prototype (with up to 11 MCP-PMTs).
- The TORCH performance will be optimized for LHCb Upgrade-II operation



CERN-LHCC-2021-012 (2021) $\mathcal{L}$ = 1.5 x 10^{34} cm^{-2} s^{-1}

TORCH is a collaboration of

with funding from