The TORCH Time-Of-Flight Detector

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Introduction
TORCH — Time Of internally Reflected CHERenkov light

- TORCH is a time of flight detector which gives positive PID for low momentum $\pi/K$ (K/p) between 2-10 (20) GeV/c over a 10 m flight path.
- 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 53mm² active area.
- They are read out by customized electronics. JINST 11 (2016) C04012

TORCH prototyping in the CERN T9 Test-Beam

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

- The prototype has a 660 x 1250 x 10 mm³ (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.
- 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 $N_{photon}=0$ are excluded.

Performance of the prototype

- 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.

- 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.

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