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TORCH: A large area time-of-flight detector for particle identification

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ABSTRACT

TORCH is a time-of-flight detector that is being developed for the Upgrade II of the LHCb experiment, with the aim of providing charged particle identification over the momentum range 2–10 GeV/c. A small-scale TORCH demonstrator with customised readout electronics has been operated successfully in beam tests at the CERN PS. Preliminary results indicate that a single-photon resolution better than 100 ps can be achieved.

Contents

1. Introduction

TORCH is a time-of-flight detector designed to provide Particle IDentification (PID) for low momentum particles between 2–10 GeV/c [1,2]. The detector exploits prompt Cherenkov light produced when charged particles traverse a 10 mm thick quartz plate. The photons propagate via total internal reflection to the edge of the plate where they are focussed onto a detector plane comprising micro-channel plate photomultipliers (MCP-PMTs), shown in Fig. 1(a). The aim is to measure individual photons with an angular precision of 1 mrad and 70 ps time resolution and, with ~30 detected photons, this would result in ~13 ps per incident charged particle.

TORCH is proposed for the upgrade II of the LHCb experiment, where PID of pions, kaons and protons is essential for CP violation measurements, exotic spectroscopy and particle tagging [3]. To provide the necessary PID discrimination up to 10 GeV/c over the full spectrometer acceptance, TORCH forms a time of flight wall of area $5 \times 6\,m^2$, located 10 m from the proton–proton interaction region. The detector is divided into 18 modules, each 66 cm wide and 2.5 m high, illustrated in Fig. 1(b). To meet the challenging LHC environment, TORCH is designed for high occupancy and significant pile-up.

When a charged particle passes through a TORCH module, the track entry point in the quartz radiator is measured from position information provided by the tracking system of the LHCb spectrometer. The characteristic photon patterns are reconstructed from the MCP-PMT photon detectors and corrections made to account for chromatic dispersion. To then distinguish the different particle species, the expected distributions for $\pi/K/p$ hypotheses are compared to the measured MCP-PMT photon spatial hits and arrival times.

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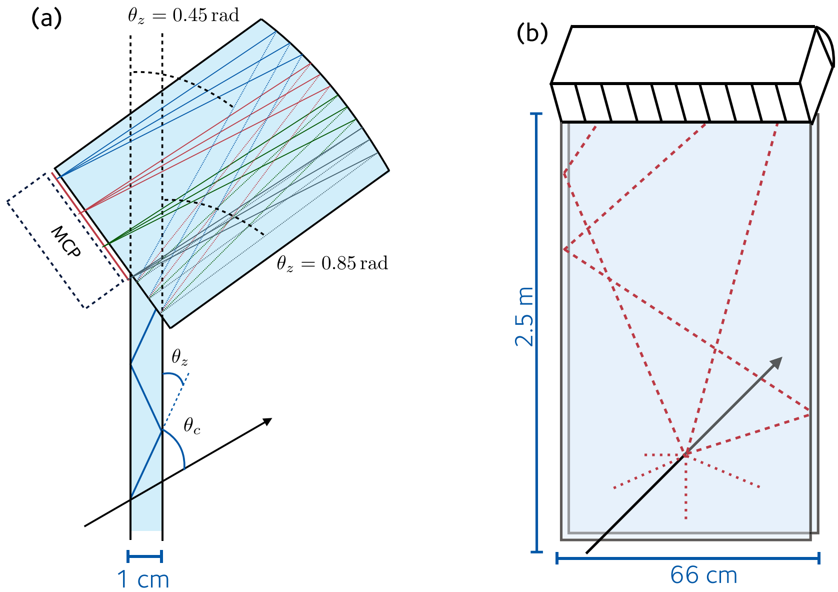

Fig. 1. Schematics of a TORCH module showing possible reflection paths: (a) the focussing block and MCP plane, (b) a single LHCb module.

2. Micro-channel plate PMTs

To achieve the required angular resolution of TORCH, each MCP-PMT detector requires 128 × 8 effective granularity in the transverse and longitudinal projections over a 53 × 53 mm^2 active area, with 11 MCP-PMTs per module. The MCP-PMTs [4] are developed with industrial partners, Photek UK. The pixels are 64 × 64 and grouped to read out with 64 × 8 granularity; charge sharing is then used to give required 128 granularity in the transverse direction. To survive the LHC environment, each MCP-PMT must also be capable of withstanding a large integrated charge on its anode (5 C cm^{-2}), achieved using an atomic-layer deposition (ALD) coating [5,6]. The MCP-PMTs are read out with a customised electronics system [7], and utilise the NINO32 [8] and HPTDC [9] chipsets, developed for fast timing applications of the ALICE experiment.

3. Beam tests

A small-scale TORCH demonstrator module was tested in the CERN PS 5 GeV/c mixed pion–proton beam in November 2017. The quartz radiator has dimensions 120 × 350 × 10 mm^3 and read out with a single Photek MCP-PMT of 64 × 4 granularity. The radiator plate was mounted in an almost vertical position, tilted backwards by 5° with respect to the horizontal incidence of the beam. Pions and protons were distinguished by an external time-of-flight telescope. A method of data-driven calibration was employed to correct simultaneously for time-walk and integral non-linearities of the electronics [2].

Data analysis from the test-beam run is well advanced. Characteristic photon bands are observed due to reflections from the faces of the radiator plate. With the beam impinging approximately 14 cm below the plate centre and close to its side, the patterns show the expected distribution of reflections, shown in Fig. 2 (a). The residuals between the observed and simulated times of arrival are shown in Fig. 2 (b), resulting in a resolution per photon of ~100 ps. The tail in the distribution is caused by imperfect corrections, and improvements are expected when charge-to-width calibrations are incorporated.

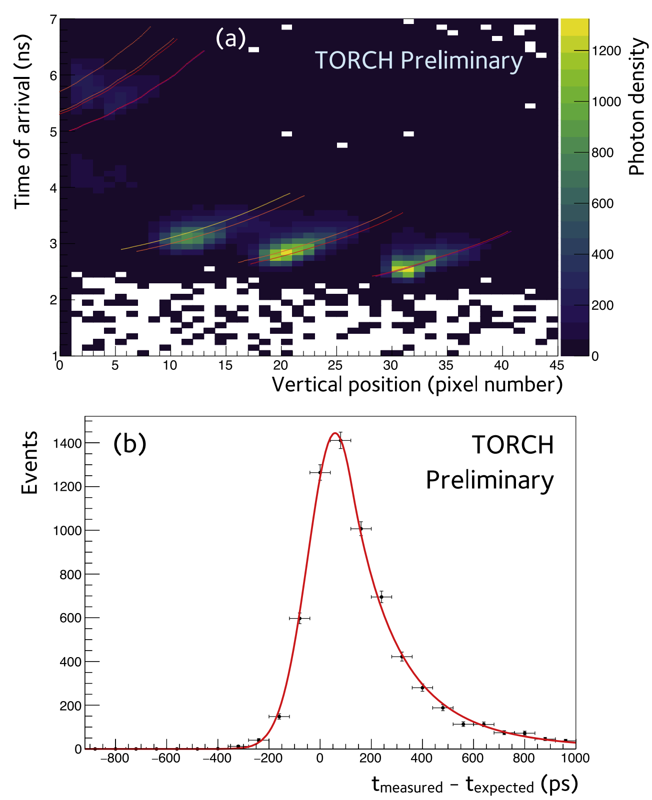

Fig. 2. (a) The time-of-arrival of single Cherenkov photons from a 5 GeV/c pion beam, relative to a beam time-reference station, as a function of detected vertical column pixel number. The overlaid lines represent the simulated patterns for light reflected only off the front and back faces of the radiator plate (lower right distribution), light also undergoing one and two reflections off the side faces (lower central and left distributions, respectively), and multiple reflections from the bottom horizontal face (top left distributions). (b) The distribution of residuals between the measured Cherenkov photon arrival times with respect to the simulated distribution, with a "crystal ball" fit superimposed.

4. Summary and future plans

A single-photon timing resolution of approximately 100 ps has been achieved with a small-scale TORCH demonstrator utilising a customised 64 × 4 pixelated MCP-PMT, and the timing performance is approaching that required for the Upgrade II of the LHCb experiment. This prototype is a precursor to a half-length TORCH module (660 × 1250 × 10 mm^3) which is currently under construction. The half-length module will be equipped with ten 64×8 pixel MCP-PMTs and will be ready for test-beam operation at the end of 2018.

Acknowledgments

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