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The TORCH time-of-flight detector

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ABSTRACT

The TORCH time-of-flight detector is being developed to provide particle identification between 2 and 10 GeV/c momentum over a flight distance of 10 m. TORCH is designed for large-area coverage, up to 30 m^2, and has a DIRC-like construction. The goal is to achieve a 15 ps time-of-flight resolution per incident particle by combining arrival times from multiple Cherenkov photons produced within quartz radiator plates of 10 mm thickness. A four-year R&D programme is underway with an industrial partner (Photek, UK) to produce 53×53 mm^2 Micro-Channel Plate (MCP) detectors for the TORCH application. The MCP-PMT will provide a timing accuracy of 40 ps per photon and it will have a lifetime of up to at least 5 Ccm^{-2} of integrated anode charge by utilizing an Atomic Layer Deposition (ALD) coating. The MCP will be read out using charge division with customised electronics incorporating the NINO chipset. Laboratory results on prototype MCPs are presented. The construction of a prototype TORCH module and its simulated performance are also described.

1. Introduction

The (TORCH Time Of internally Reflected CHerenkov light) detector [1] is an R&D project to develop a large-area time-of-flight (ToF) system, up to around 30 m^2. TORCH combines timing information with Detection of Internally Reflected Cherenkov light (DIRC)-type reconstruction, aiming to achieve a ToF resolution of approximately 10–15 ps per track.

A schematic of the TORCH module is shown in Fig. 1. Cherenkov light production is prompt, hence a plane of 10 mm thick quartz is used as the source of a fast signal. Cherenkov photons travel to the periphery of the detector by total internal reflection and their angles (positions) and arrival times are measured with Micro-Channel Plate PMTs (MCPs). Simulation has shown that a 1 mrad angular resolution is required [2] and, to achieve this, 128×8 granularity MCPs of 53×53 mm^2 active area are being developed.

One of the applications of TORCH is for the upgraded LHCb experiment [3]. The aim is to achieve positive identification of kaons up to $\sim$10 GeV/c following removal of the aerogel in the current RICH-1 detector [4]. At this momentum the time of flight difference between a π and K is 35 ps over a $\sim$10 m flight path, hence a $\sim$15 ps time resolution per track is required for a 3σ separation. Assuming $\sim$30 detected photoelectrons over an active area of 30 m^2, the timing of single photons to a precision of 70 ps is required.

2. Principles of operation

In the TORCH detector, precise timing is achieved by correcting for the chromatic dispersion of the radiator material, a concept previously developed by the Belle TOP [5] and the PANDA DIRC [6] collaborations. The technique relies on the measurement of the Cherenkov angle θ_c and the arrival time of the photon at the periphery of a quartz radiator bar (for wavelengths in the range $E_\gamma = 3-5\ eV$, the spread in Cherenkov angles is $\Delta\theta_c \sim 24$ mrad, considerably larger than the 1 mrad angular requirement). From the θ_c measurement, the path length L of the photon after multiple internal reflections can be reconstructed. The time of propagation of the photon can then be determined from L and the group velocity in the quartz, inferred via the dispersion relation.

The $\sim$1 mrad angular precision is required in both planes, namely in θ_z (the angle with respect to the vertical direction) and

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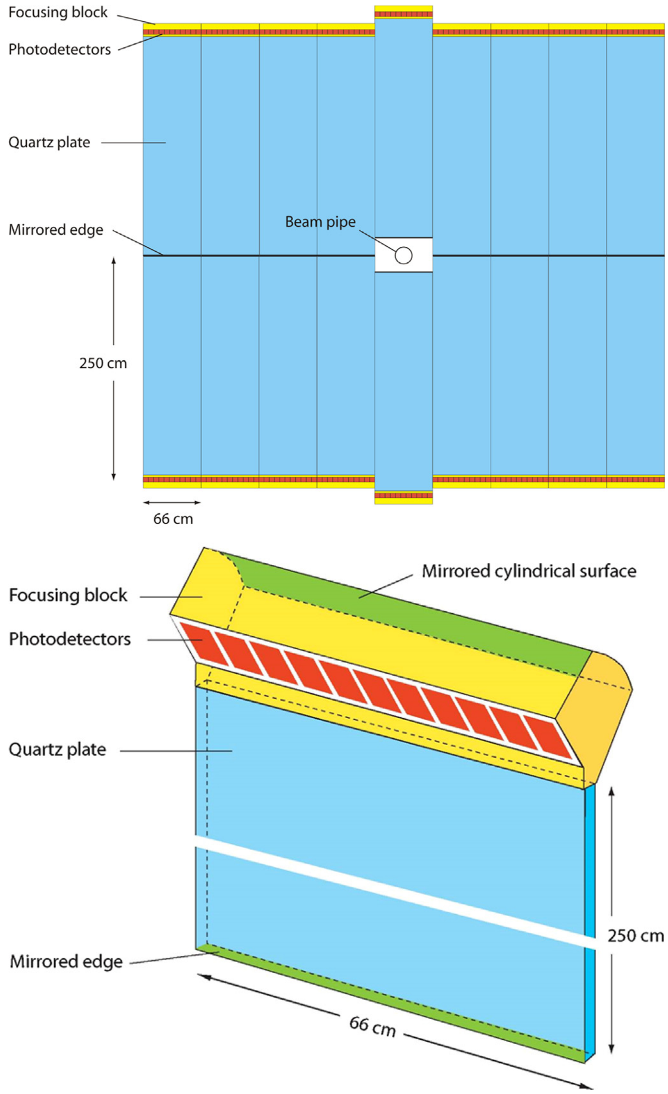

Fig. 1. Schematics of (upper) the TORCH detector, and (lower) a TORCH module.

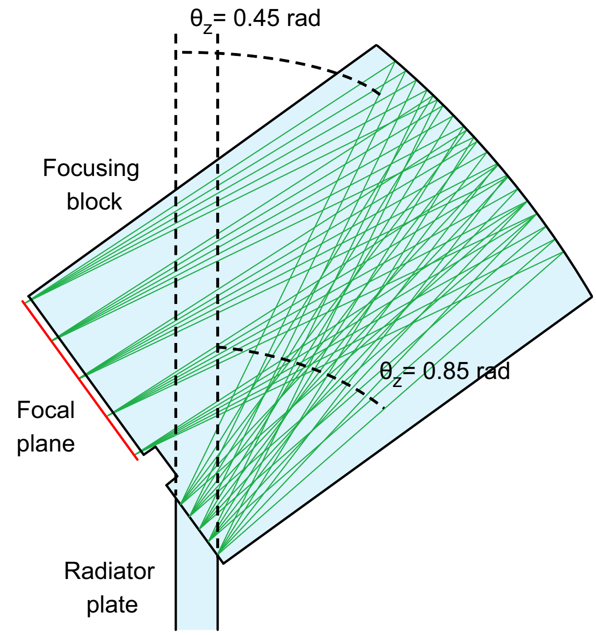

Fig. 2. The TORCH focussing block, showing the range of angles θ_z.

in θ_x (the azimuthal angle in the plane of the quartz front surface). TORCH uses a quartz focusing block, shown in Fig. 2, to convert θ_z into a position on the photon detector plane, and for this good spatial accuracy is required. For the θ_x angular measurement, the longer lever arm requires only coarse precision. Hence we require an MCP-PMT which provides a spatial resolution of 0.4 mm and 6 mm respectively in the two dimensions. For this, 128×8 pixels of an MCP of 53×53 mm^2 (a standard “2 in.”) active dimension is required.

3. MCP development

MCP photon detectors are well known for fast timing of single photon signals ($\sim$20 ps). Additional requirements for TORCH photodetectors also include good lifetime (> 5 C cm^{-2}) and fine granularity. The highest MCP granularity currently commercially available is the 32×32 1.6 mm-pitch Planacon from Photonis.[1] The anode pad structure can in principle be adjusted according to the required resolution (in our case 128×8) provided the charge footprint is small enough.

A major TORCH focus is to develop a customised MCP with an industrial partner, namely Photek (UK).[2] Three phases of R&D have been defined. Phase 1 has been completed and involved the fabrication of a set of single-channel MCPs with extended lifetime and $\sim$30 ps timing resolution. Phase 2 MCPs have customised granularity (128×8 pixels equivalent) and are currently under test. Phase 3 tubes will follow in around 9 months and are 2-in. square with high active area ($> 80\%$), with the required lifetime, granularity and time resolution. These MCPs are in preparation. Photographs of the Photek Phase 1 and Phase 2 tubes are shown in Fig. 3.

Up to quite recently, poor MCP tube lifetime was an issue [7], with severe loss of quantum efficiency with exposures to photon doses significantly below 1 C cm^{-2}. The breakthrough in technology has been the use of Atomic Layer Deposition (ALD) techniques to coat the MCP surface [8]. The normalized photocathode current, shown in Fig. 4 for a Photek tube [9], shows that the uncoated MCPs are significantly out-performed by the ALD-coated MCPs for lifetime (the latter being good to beyond 5 C cm^{-2}). In a parallel activity, TORCH long-term lifetime testing is also underway.

Traditional multi-anode manufacturing of MCPs uses multiple output pins. This is too dense for a 128-column structure, the plan for TORCH is therefore to reduce the size to 64×64 with pixel pads of dimension 0.75 mm wide on a 0.88 mm pitch. Phase 2 tubes have 32×32 pixels of this same geometrical construction (i.e. 1/4 size) in a circular tube, and to achieve 64×8, eight pixels are ganged together in the coarse direction. Charge sharing between pads then recovers the pixel resolution from 64 to 128 pixels equivalent and also halves the total number of readout channels. Also, a novel method is used to couple the MCP-PMT output pads to the readout PCB through an Anisotropic Conductive Film (ACF).

[1] Photonis USA, Lancaster, PA 17601-5688, USA.

[2] Photek Ltd., St. Leonards-on-Sea, TN38 9NS, United Kingdom.