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# Performance and lifetime of micro-channel plate tubes for the TORCH detector

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ABSTRACT

Timing Of internally Reflected CHerenkov photons (TORCH) is a time-of-flight detector proposed for particle identification at low momentum. Charged particles passing through a plane of quartz produce Cherenkov light, some of which is trapped within the plane by total internal reflection and then emerges at the edges. There the photons are focused onto micro-channel plate photon detectors that register their position and arrival time. This allows reconstructing the photon trajectories in quartz and determining the particle crossing time. Commercial micro-channel plate tubes can achieve the required timing resolution, but their anode spatial segmentation is too coarse, at least in one dimension. In addition, these devices must survive a number of years in a high occupancy environment. Micro-channel plate tubes specifically dedicated to the TORCH are currently being designed, constructed and prototyped in collaboration with industry. In the present paper, results from commercial and dedicated devices are reported.



## 1. Introduction

Timing Of internally Reflected CHerenkov photons (TORCH) [1,2] is a Time-Of-Flight (TOF) detector proposed for particle identification at low momentum (2–10 GeV/*c*). It involves the use of a 1 cm-thick plane of quartz, possibly segmented in small modules. Charged particles passing through this plane produce Cherenkov light, some of which is trapped within the plane by total internal reflection and then emerges at the edges. There the photons are focused onto micro-channel plate (MCP) photon detectors where their position and arrival time are recorded. The focusing element makes use of a cylindrical mirror that converts the total internal reflection angle in one spatial coordinate that needs to be measured with sub-millimetre resolution. The propagation angle in the quartz plane is converted in the other spatial coordinate to be measured with a resolution of a few millimetres. In this way, the trajectory of the Cherenkov photons in the quartz can be reconstructed and the particle crossing time determined. From simulation, TORCH requires the development of MCPs with a transit time spread (TTS) better than 50 ps (rms) for single photons and an anode segmented in $128 \times 8$ pads each $0.4\ \text{mm} \times 6.4\ \text{mm}$ in size (for a 2″ square tube). This segmentation imposes a matching charge footprint at the anode to optimize charge sharing and readout performance in terms of efficiency, spatial and time resolutions.

Commercial MCP tubes can achieve the required time resolution, but their anode spatial segmentation is too coarse, at least in one dimension. In addition, the photon detectors for TORCH must survive a number of years in a high occupancy environment. For a MCP gain of 100 fC ($6 \times 10^5$), and for 100 tracks per event and 30 detected photons per track every 25 ns, the instantaneous average detected photon rate is in the range 1–10 MHz/cm$^2$, corresponding to an anode current between 0.1 and 1 μA/cm$^2$, and to an integrated anode charge per year between 1 and 10 C/cm$^2$.

## 2. Performance of commercial devices

The performance of commercial devices has been assessed in the laboratory [3] using Planacon tubes model XP85012/A1.[1] These are 2″ square devices with an anode segmented as $8 \times 8$ square pads 5.9 mm/6.5 mm in size/pitch. They are equipped with two MCPs in chevron configuration and 25 μm pore size. A picosecond pulsed laser source was used, together with monomode fibres to preserve the laser time resolution. The laser driver electronics was also providing a very precise START time. The standard single-channel electronics consisted

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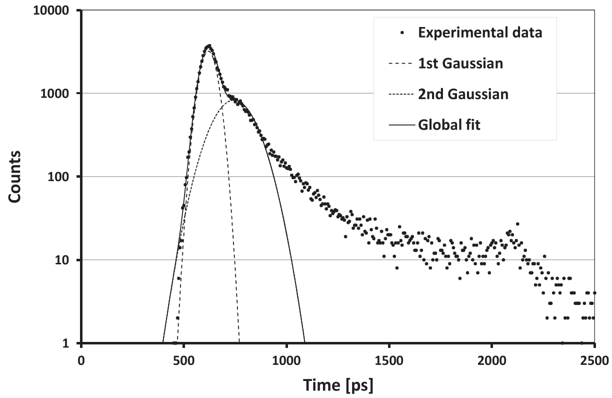


**Fig. 1.** TTS of 38 ps measured with a Planacon MCP tube (from Ref. [3]). Note the vertical logarithmic scale.

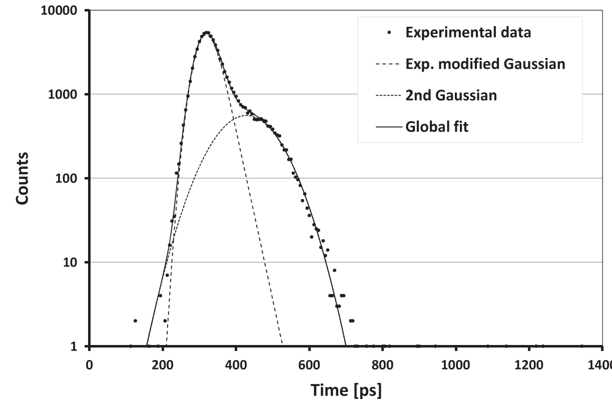


**Fig. 2.** TTS of 23 ps measured with a PMT225 MCP tube. Note the vertical logarithmic scale.

of a fast amplifier and constant fraction discriminator that generated the STOP time signal. The Planacon was operated at a modest gain of 100 fC, a compromise between tube lifetime, timing resolution, performance of the readout electronics and charge sharing effects. In this configuration, a TTS of $\leq 40$ ps for single photons has been measured (Fig. 1).

The time resolution of 38 ps is inferred from a Gaussian fit to the main peak [3]. The shoulder is due to a laser feature that is modelled with a delayed and broader Gaussian curve. The long tail of the TTS distribution is caused by backscattering effects. It extends over 1.5 ns given the 4.5 mm gap distance between the Planacon photocathode and MCP input.

The same Planacon tubes have been read out with dedicated multi-channel electronics [4,5]. The front-end stage [5] consists of a fast amplifier discriminator providing a digital output pulse with time-over-threshold measurement of the input charge. This pulse is input to a time digitization ASIC with 25 ps precision. From raw data, a TTS of 90 ps for single photons has been measured, without correction for time walk and non-linearity effects. The discriminator threshold value was 50 fC, resulting in an efficiency range of 80–90% for single photoelectrons.

## 3. Performance of custom devices

A photon detector R&D programme dedicated to TORCH has been launched in collaboration with an industrial partner.[2] The MCP tube development has been sub-divided in three phases as follows:

- circular devices with extended lifetime;
- circular devices with required segmentation;
- square devices with extended lifetime and required segmentation.

Prototypes with extended lifetime have been manufactured and several such tubes have already been successfully characterized in the company through accelerated ageing tests [6,7]. Their MCPs are coated using an atomic layer deposition (ALD) process. This recent technology has the following two main advantages: a reduced MCP outgassing, the tube lifetime is longer and its noise is reduced; an increased secondary electron emission yield, the efficiency is larger and a given gain is achieved with lower supply voltage.

The current prototype design is based on model PMT225 which has 25 mm active diameter and is equipped with two MCPs in chevron configuration and 10 μm pore size. The intrinsic performance of four such prototypes has been assessed using the procedure already described in Section 2. The typical average gain was set in the range 50–100 fC ($3-6 \times 10^5$). A TTS of $\leq 30$ ps for single photons has been measured (Fig. 2).

The time resolution of 23 ps is inferred from an exponentially-modified Gaussian fit to the main peak [4]. This model more appropriately describes the main peak asymmetry caused by back-scattering effects in PMT225 prototypes, where the gap distance between photocathode and MCP input is 0.2 mm. Consequently, these effects result in a much shorter time range of 100 ps. On the other side, the shoulder due to the laser is seen to be similar to that of Fig. 1.

## 4. Conclusions and perspectives

One PMT225 prototype is currently under accelerated ageing tests at CERN and its main parameters are regularly monitored. The initial illumination level corresponding to a photoelectron rate of 1 MHz/cm$^2$ will be gradually increased to get closer to the expected TORCH operating conditions. In this way, it is expected to reach an accumulated charge of $\sim 5$ C/cm$^2$ after 12 months of testing.

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## References

[1] M.J. Charles, R. Forty, Nuclear Instruments and Methods Physics Research Section A 639 (2011) 173.
[2] M. van Dijk, TORCH—a Cherenkov based time-of-flight detector, Nuclear Instruments and Methods Physics Research Section A 766 (2014) 118.
[3] L. Castillo García, Nuclear Instruments and Methods Physics Research Section A 695 (2012) 398.
[4] L. Castillo García, et al., Timing performance of a MCP photon detector read out with multi-channel electronics for the TORCH system, in: Proceedings of the ICATPP 2013, World Scientific, in preparation.
[5] R. Gao et al., Development of precision time-of-flight electronics for LHCb TORCH, in: Proceedings of the TWEPP 2013 Conference, JINST, in preparation.
[6] T.M. Conneely, et al., Nuclear Instruments and Methods Physics Research Section A 732 (2013) 388.
[7] J. Milnes, et al., The TORCH PMT; a close packing, multi-anode, long life MCP-PMT for Cherenkov applications, Nuclear Instruments and Methods Physics Research Section A 766 (2014) 183.

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