Journal of Instrumentation

Precision electronics for a system of custom MCPs in the TORCH Time of Flight detector

To cite this article: R. Gao *et al* 2017 *JINST* **12** C03008

Published by IOP Publishing for Sissa Medialab

Received: *November 8, 2016*
Accepted: *February 12, 2017*
Published: *March 2, 2017*

Topical Workshop on Electronics for Particle Physics,
26–30 September 2016,
Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

Precision electronics for a system of custom MCPs in the TORCH Time of Flight detector

R.Gao,[a,1] N. Brook,[b] L. Castillo García,[a,c] T. Conneely,[d] D. Cussans,[e] K. Föhl,[c] R. Forty,[c] C. Frei,[c] T. Gys,[c] N. Harnew,[a] D. Piedigrossi,[c] J. Rademacker,[e] A. Ros García[e] and M. Van Dijk[a,c]

[a] *Department of Physics, University of Oxford, Keble Road, Oxford, OX1 3RH, U.K.*
[b] *Wessex House, Faculty of Science, University of Bath, Claverton Down, Bath, BA2 7AY, U.K.*
[c] *Physics Department, CERN, CH-1211 Geneva 23, Switzerland*
[d] *Photek Ltd., 2 Castleham Road, St Leonards on Sea, TN38 9NR, U.K.*
[e] *H.H. Wills Physics Laboratory, University of Bristol, Bristol, BS8 1TL, U.K.*

E-mail: r.gao@physics.ox.ac.uk

Abstract: The TORCH detector will provide charged particle pi/K/p identification up to 10 GeV/c, combining Time-of-Flight and Cherenkov techniques to achieve a timing resolution of 70 ps for single photons. Based on a scalable design, a Time-of-Flight electronics readout system has been developed to instrument a novel customized 512-channel Micro Channel Plate (MCP) device. A Gigabit Ethernet-based readout scheme that operates the TORCH demonstration unit consisting of ten such MCPs will be reported. The trigger and clock distribution will also be discussed.

Keywords: Cherenkov detectors; Electronic detector readout concepts (solid-state); Front-end electronics for detector readout; Photon detectors for UV, visible and IR photons (vacuum) (photo-multipliers, HPDs, others)

[1] Corresponding author.

doi:10.1088/1748-0221/12/03/C03008

Contents

1 Introduction **1**

2 The TORCH photon detectors and electronics developments **1**
- 2.1 Photon detectors 1
- 2.2 Electronics development 2

3 Test-beam and instrumentation of MCPs **4**
- 3.1 Coupling to MCPs 4
- 3.2 Test-beam setup 4
- 3.3 Hit-map from the MCP 5

4 Future work and plans **6**

1 Introduction

The Time Of internally Reflected CHerenkov light (TORCH) detector [1] is proposed for the low-momentum particle identification upgrade of the LHCb experiment [2] and an R&D project is currently underway [3]. The TORCH detector measures Time-Of-Flight (TOF) using the Cherenkov technique to achieve positive π/K/p separation up to 10 GeV/c over a flight path of approximately 10 m from the interaction region. Cherenkov photons are generated when a charged particle traverses a 10 mm-thick quartz plate of overall dimension $5 \times 6\,\text{m}^2$, as shown in figure 1, segmented into 11 individual modules. The photons propagate by total internal reflection to the periphery of the plate, where they are focused onto an array of Micro Channel Plate (MCP) photomultiplier detectors, which measure their position and time of arrival. In order to achieve the required π/K separation, a TOF resolution of 15 ps per track is required which, given ~30 detected photoelectrons, necessitates a 70 ps time resolution per single photon.

Based on the developments of the TORCH TOF readout system previously reported [4], this paper highlights the subsequent test-beam activities, as well as the preparation of the final TORCH system.

2 The TORCH photon detectors and electronics developments

2.1 Photon detectors

The TORCH detector will use an array of novel MCP photomultipliers to detect the Cherenkov photons. The MCP device needs to provide a stable gain with no loss of photocathode efficiency after at least $5\,\text{C/cm}^2$ of integrated charge. To achieve the necessary spatial resolution for the TOF measurement, it must have a physical granularity equivalent to 8×128 pixels over a $53 \times 53\,\text{mm}^2$

2017 JINST 12 C03008

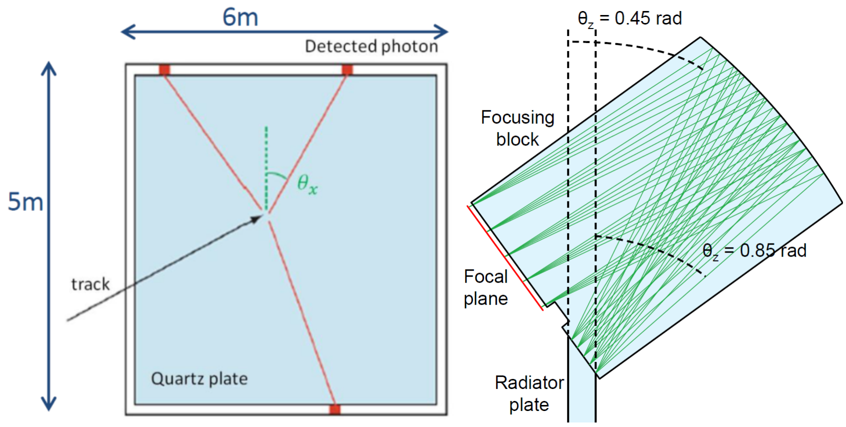

Figure 1. The TORCH quartz plate(Left) and the focusing block (right).

active area within a $60 \times 60\,\mathrm{mm}^2$ physical dimension, as shown in figure 2. Such an MCP is under development by our industrial partner, Photek, U.K. [5]. The final device will use a 64×64-channel physical layout; the channels are externally connected together in groups of eight along the coarse direction. A charge sharing technique between two adjacent channels will be applied along the fine direction in order to achieve the 8×128 granularity requirement. Currently, a quarter-scale prototype with 32×32-channels is being tested, giving a layout equivalent to 4×32 channels. Commercial 32×32-channel Planacon devices [6] from Photonis, U.S.A., are also being investigated, where 4 channels are grouped along the coarse direction to form an 8×32 layout.

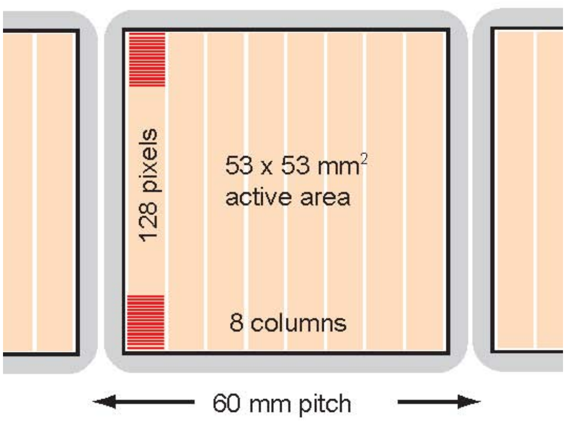

Figure 2. The required MCP layout for the TORCH detector.

2.2 Electronics development

Figure 3 shows the main data flow of the TORCH readout system [4, 7]. The system consists of a NINO board, an HPTDC board, a Readout board and a backplane. A photograph of the electronics components is shown in figure 4. Firstly, 32-channel IRPICS2 (NINO) ASICs [8] amplify the signals from the MCP and measure the Time-Over-Threshold (TOT) according to a user-defined threshold, which is controlled by on-board DACs. The DACs are programmable through the Ethernet interface on the Readout Board. By measuring the TOT, time-walk corrections can be applied off-line. The HPTDC board uses two HPTDC ASICs [9], operated in 32-channel (100 ps) mode. This board digitises the LVDS output from the NINOs. Each NINO and HPTDC board contains two ASICs respectively, providing a total of 64 channels. The HPTDC data are buffered in an on-board FPGA and are subsequently transmitted to the Readout Board which features a Gigabit Ethernet link employing Raw MAC protocol in order to achieve the maximum throughput to a PC. The PC is typical able to process and save data at 700 Mbit/s that is adequate for our system in a test-beam. The Readout board has an FPGA interfaced with the FPGAs on the HPTDC board to format data into Ethernet packets and transfer them to the Ethernet interface to be send to the PC. The Readout board also has a 1 G-bit DDR3 RAM for buffering data and two low-jitter fan-out ASICs to provide quality clocks and triggers for the HPTDCs. The backplane is used to connect HPTDC boards and Readout Board, the latter can accommodate four HPTDC boards. In order to fit the layout of different MCPs, only specific backplanes need to be designed; the other components are not affected.

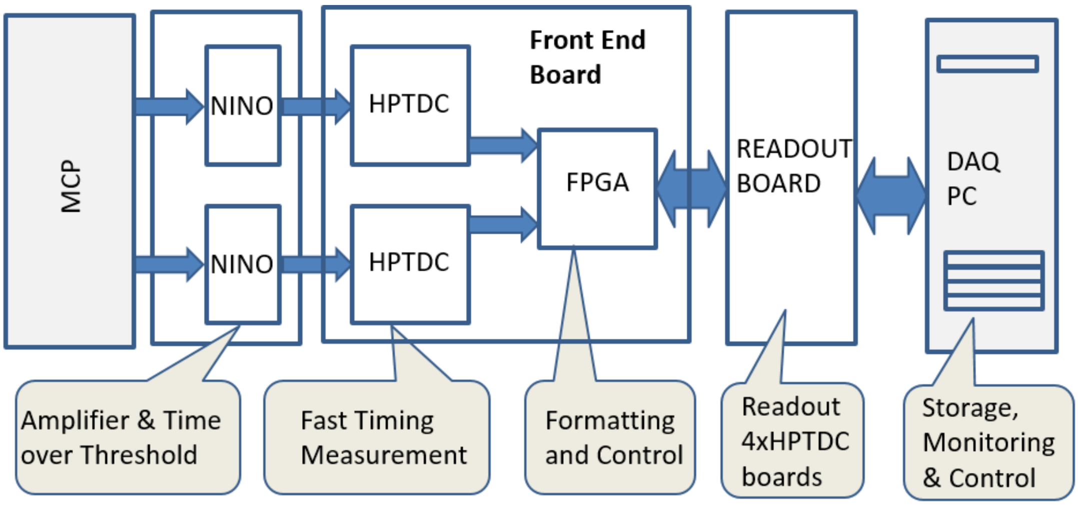

Figure 3. The data flow for the TORCH readout system.

The system has a modular and scalable design, where up to eight NINO/HPTDC boards can be used for a single MCP within its $60 \times 60\,\text{mm}^2$ physical envelope, providing 8×64 channels for the final TORCH requirement. The modular design also allows flexibility to instrument different types of MCP photon detectors during the development phase. Separating the readout board from the NINO/ HPTDC boards allows using an independent readout framework, e.g. the LHCb data acquisition system, at a later stage of the project. This system is also interfaced to an AIDA Trigger Logic Unit (TLU) [10] in order to integrate with external test-beam detectors, e.g. the VELO Timepix Telescope [11] and threshold Cherenkov counters.

2017 JINST 12 C03008

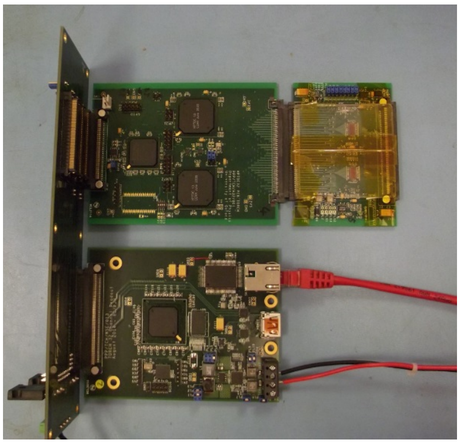

Figure 4. The TORCH electronics readout system. Anticlockwise from top right, the NINO Board, HPTDC Board, Backplane and Readout Board.

3 Test-beam and instrumentation of MCPs

3.1 Coupling to MCPs

The TORCH readout system has been coupled to both commercial and custom MCPs in beam tests. Figure 5 (left) shows a commercial 32×32-channel Planacon MCP instrumented by the developed electronics, incorporating a specific interface board as an interconnect. The MCP is bonded to the interface Printed Circuit Board (PCB) with conductive epoxy; four channels are grouped together on the interface board along the coarse direction to give an 8×32 layout as discussed in section 2.1. Figure 5 (right) shows the system coupled to a customized Phase II Photek MCP featuring a 32×32 channel resolution giving a 4×32 layout. This MCP is coupled to an interface PCB using Anisotropic Conductive Film (ACF), then connected to the TORCH electronics.

3.2 Test-beam setup

A radiator plate of size $120 \times 350 \times 10\,\text{mm}^3$ has been used to generate Cherenkov photons, together with a quartz block to focus the photons onto the MCP. The MCP and the electronics are coupled via a small air gap to the optical system which is installed in a light-tight vessel. Figure 6 shows a typical TORCH test-beam setup at the CERN Proton Synchrotyon (PS). The dashed arrow shows the beam direction and the orange box at the far end of the arrow is the TORCH vessel. T1 and T2 are two timing stations which provide a time reference. C1 and C2 are threshold Cherenkov counters for independent particle identification. The time reference signals are processed and attenuated before being injected into a channel on the NINO board, digitised by a corresponding HPTDC and read out as part of the TORCH data stream. The Cherenkov counters have their own DAQ system and the data are synchronised using trigger numbers and timestamps by the TLU mentioned in section 2.2.

Specific firmware has been developed for test-beam use. The firmware allows users to control the module and read out data via a single Ethernet cable, which makes the system significantly more compact and robust. The HPTDC timestamp has 12 bits and it rolls over every 4096 cycles of the 40 MHz clock. That gives a unique timestamp between 0 to 102.4 μs in 25 ns steps. Such a range is much shorter than the time between particle bunches, which is typically around 30 seconds at

2017 JINST 12 C03008

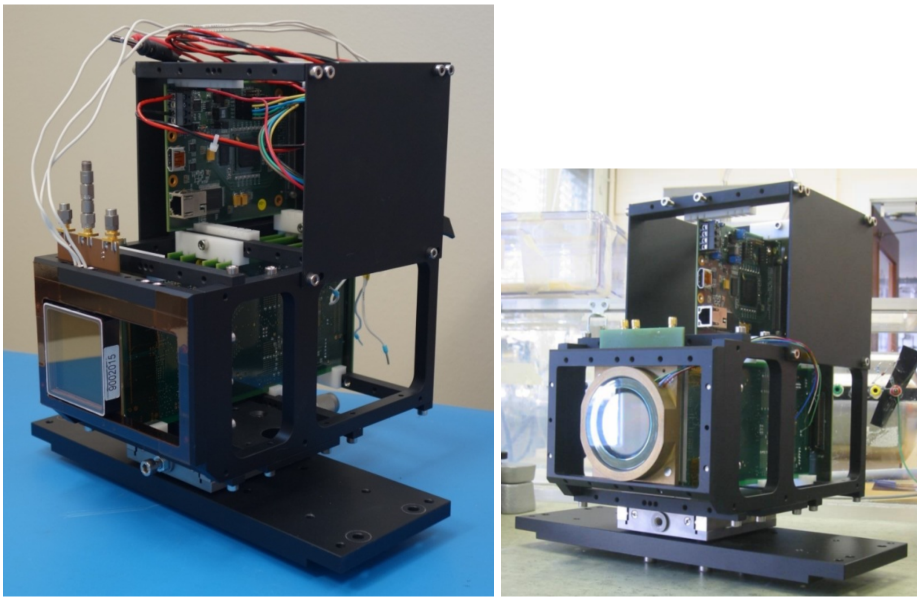

Figure 5. The TORCH electronics coupled to a Planacon MCP (left) and a Photek Phase-II MCP (right).

the CERN PS. This has prevented us from reconstructing hits with an absolute timestamp from the beginning of the run. In order to allow full reconstruction of the hit timestamp, a 28-bit counter has been introduced at the firmware level to count the number of times the HPTDC timestamp has rolled over. Thus, in total we can have a unique timestamp of 40 bits, which covers a range between 0 and approximately 7.5 hours. This also allows working with any external devices, e.g. Cherenkov counters, telescopes, even without synchronised trigger numbers.

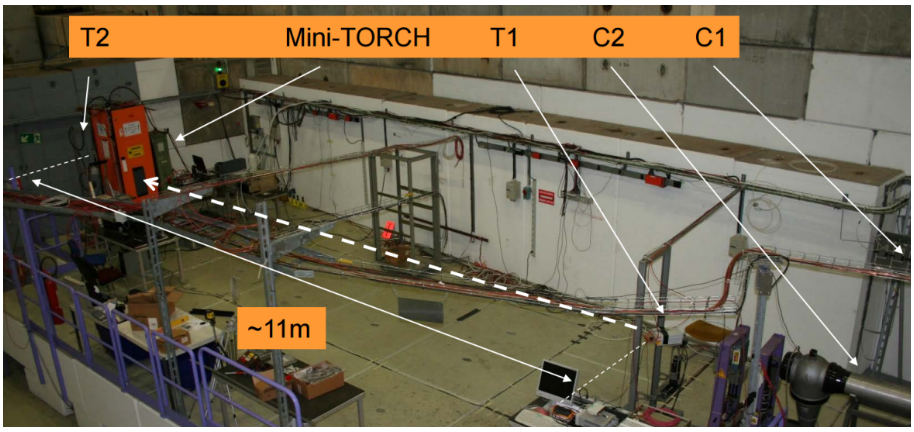

Figure 6. Typical test-beam setup.

3.3 Hit-map from the MCP

A TOF-based selection was made using the T1 and T2 timing stations on the mixed pion/proton beam, retaining only pions. The hit-map of the Cherenkov pattern recorded by the Photek Phase-II MCP is shown in figure 7. Here the x and y axes are the horizontal (coarse) position and vertical (fine) position, respectively. Due to the reflections off the vertical sides of the radiator, the pattern is seen to fold over itself. The lines on the plot show the expected pattern from simulation. Good agreement is observed.

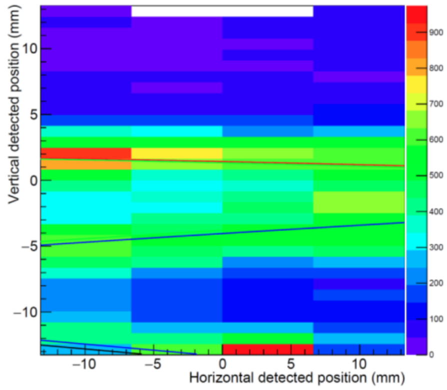

Figure 7. Hit-map of a Cherenkov pattern from the Photek Phase II MCP for 5 GeV/c pions.

4 Future work and plans

A final 8×64-channel square $53 \times 53\,\text{mm}^2$ MCP will be delivered from Photek by the end of 2016. We are preparing the full readout system for 10 final-phase MCPs, reading out a full-scale TORCH module ($660 \times 1250 \times 10\,\text{mm}^3$). Figure 8 shows a diagram of the mechanical arrangement for this system which uses 8 HPTDC boards and 4 adapted NINO boards, each with 4 NINO ASICs, together with a readout module. The MCPs will be mounted along the horizontal direction on the supporting structure in grey. The electronics are mounted perpendicular to the line of MCPs.

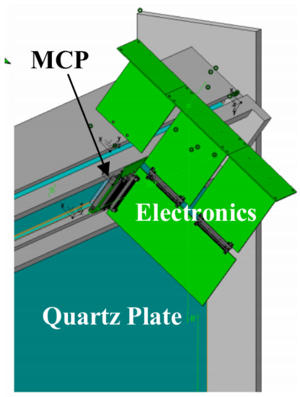

Figure 8. Mechanical arrangement of the future TORCH readout system.

An expanded DAQ system is also being developed. Each MCP module has a Readout Board, which uses an Ethernet cable connected to a PC via a Gigabit Ethernet repeater. The DAQ PC will communicate with the readout modules using a unique MAC address. Once the readout is started, the HPTDC data are temporarily stored on the readout module until requested by the PC. The PC reads a predefined amount of data from one Readout Board then moves to the next one. Priorities can be given to those modules in an area that receive more photons in the detector. A prototype system including two Readout Boards and a basic DAQ has been built to evaluate the optimal buffer size and readout block size.

Acknowledgments

The support of the European Research Council is gratefully acknowledged in the funding of this work (ERC-2011-AdG, 291175-TORCH). We would like to thank the Technology Transfer Department at CERN for providing the NINO-32 chips and Photek Ltd. for sharing their experience and designs. We also acknowledge the Electronics Workshop, Department of Physics, University of Oxford, for assembling the boards.

References

[1] M.J. Charles et al., *TORCH: Time of flight identification with Cherenkov radiation*, *Nucl. Instrum. Meth.* **A 639** (2011) 173 [`arXiv:1009.3793`].

[2] LHCb collaboration, *Letter of Intent for the LHCb Upgrade*, CERN-LHCC-2011-001 (2011).

[3] M.W.U. van Dijk et al., *TORCH: a Cherenkov based time-of-flight detector*, *Nucl. Instrum. Meth.* **A 766** (2014) 118.

[4] R. Gao et al., *Development of TORCH readout electronics for customised MCPs*, 2016 *JINST* **11** C04012.

[5] Photek U.K., http://www.photek.com/.

[6] *Planacon XP85022 Data sheet*, https://www.photonis.com/uploads/datasheet/pd/PLANACON-32x32-datasheet.pdf.

[7] 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 14th ICATPP Conference*, 25 September 2013, Villa Olmo, Italy.

[8] F. Anghinolfi et al.,*NINO: an ultra-fast and low-power front-end amplifier/discriminator ASIC designed for the multigap resistive plate chamber*, *Nucl. Instrum. Meth.* **A 533** (2004) 183.

[9] M. Mota et al., *A flexible multi-channel high-resolution Time-to-Digital Converter ASIC*, *IEEE Nucl. Sci. Symp. Conf. Rec.* **2** (2000) 155.

[10] *AIDA Mini TLU*, http://www.ohwr.org/projects/fmc-mtlu/wiki.

[11] K. Akiba et al., *The Timepix telescope for high performance particle tracking*, *Nucl. Instrum. Meth.* **A 723** (2013) 47.