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A precision Time of Flight measurement system for the TORCH prototype detector

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The TORCH detector provides low-momentum particle identification, combining Time of Flight (TOF) and Cherenkov techniques to achieve charged particle pi/K/p separation between 2-20 GeV/c over a flight distance of 10m. The measurement requires a timing resolution of 70ps for single Cherenkov photons. For precision photon detection, customised Micro-Channel Plate Photomultiplier Tubes (MCP-PMTs) with high precision TOF measurement electronics have been developed. The electronics measures time-over-threshold from the MCP-PMT and features a 10-Gigabit Ethernet readout. A 50ps MCP/electronics time resolution has been demonstrated. This paper reports the design and performance of the system with 5120 channels, instrumenting ten customised MCP-PMT devices.

Summary (500 words)

TORCH is being developed to identify B-meson decay products in the upgrade II of the LHCb experiment, but has wider applications in future particle physics experiments. The TOF measurement requires a timing resolution of 70ps for single Cherenkov photon, which translates to the electronics contributing 50ps time resolution or better.

The TORCH prototype uses ten MCP-PMTs detectors that are installed on the periphery of a 660x1250x10 mm3 quartz plate, in which Cherenkov photons are produced on the passage of a charged track. The photons propagate to the periphery of the plate by total internal reflection where they are focused onto the MCP-PMT detectors. Each MCP-PMT has an 8x64-granularity over a 53x53 mm2 area, and is instrumented with four NINO boards that have in total 16x32-channel NINO ASICs [1] for a Time-Over-Threshold (TOT) measurement. The TOT results are digitised with 8 circuit boards, each equipped with 2x32-channel High Performance Time to Digital Convertor ASICs (HPTDCs) [2]. The data are transferred to a computer by two customised readout boards using a Gigabit Ethernet interface, as shown in Figure 1.

During operations, a DAQ PC first initialises the system by configuring the HPTDCs and NINOs, then sets all HPTDCs to start measurement. The HPTDC measures the photon arrival time and TOT (as the pulse width) when a trigger is received. The data are packed into Ethernet packets and sent to the PC that is connected via an Ethernet switch. The switch can route up 24 Ethernet connections to the PC through a 10 Gbit/s uplink port with buffering and traffic control. The switch also distributes configure data and control instructions from the DAQ PC to designated readout boards using their unique MAC addresses. This scheme has replaced the previous round-robin style readout [3] to allow simultaneous readout of all HPTDC boards with intelligent buffering.

Such a system consisting of 40 NINO boards, 80 HPTDC boards, 20 readout boards and 20 back planes has been produced. The system has been integrated into the TORCH mechanical arrangement and the optical components, as shown in Figure 2. Two previous test-beam campaigns have been carried out utilising a pair of MCP-PMTs [4], and a test beam is planned with the fully instrumented system in 2022.

DC-DC convertor-based power supplies have been added to reduce the complexity of Low-Voltage cabling in the previous system [3], only a small amount of additional power dissipation is expected.

During beam tests at the CERN PS, a Trigger Logic Unit (TLU) is used to distribute triggers and clocks to the 20 readout boards. The TLU also synchronises TORCH with other systems, e.g. beam telescopes, Cherenkov counters. Two timing stations are also used both in front and behind TORCH to generate start and stop signals.

The next generation of electronics system based on the latest technology development such as PicoTDC [5], FastIC [6] and lpGBT [7] from CERN is being developed. This new development will improve the TORCH timing resolution, channel density, as well as integration with DAQ structures in the LHCb experiment.

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