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Customisation of the Large Area Picosecond Photodetector for the Upgrade II of the LHCb RICH

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ABSTRACT

The LHCb is one of the four large experiments at CERN's Large Hadron Collider (LHC). LHCb physics program includes studies of CP violation and decays of heavy-flavour hadrons. The RICH (Ring Imaging Cherenkov) detectors play a key role in particle identification. There is currently an intense detector R&D programme towards the LHCb Upgrade II, planned for 2032. One of the main photon detectors candidate for the Upgrade II of the RICH, the Large Area Picosecond Photodetector (LAPPD), will be presented, together with first tests and latest developments.

1. LHCb Upgrade II

The High-Lumi LHC era with a five-fold increase in luminosity represents a significant challenge for the LHCb RICH subdetector [1]. One part of the foreseen enhancements for the RICH Upgrade II is the use of timing information to associate Cherenkov photons with particles from separate primary interactions and reduce the event complexity. The requirements for the new photon detectors include high granularity, low dark noise and imaging single photons with outstanding time resolution. One of the possible candidates under investigation is the Large Area Picosecond Photon Detector (LAPPD), fabricated by industrial partner INCOM (US) [2].

2. LAPPD technology and first tests

The LAPPD consists of two planes of Micro Channel Plate (MCP), with a total area of 20×20 cm^2. The available prototype for the tests performed by the RICH group is a Gen II 20 μm pore size LAPPD with a spectral response in the wavelength range of 160–650 nm and 5 taps for independent voltage control of the photocathode and entry and exit of each MCP plane. The detector is capacitively coupled to a backplane supplied directly by the company, which features 64 pixels, each measuring 24×24 mm^2 with a 1 mm gap between them, resulting in a total active area that matches the size of the LAPPD. The performance of this prototype was studied in the laboratory of Edinburgh using a picosecond laser, in particular the gain and dark counts were extracted using a DRS4 chip based CAEN digitiser (as detailed in [3]). For these tests, a bias voltage of 850 V was applied to each MCP connected in series and a voltage difference of 100 V was applied to the photocathode with respect to the closest MCP. Photocathode and MCP voltages were varied to perform the studies. In addition to the studies outlined in the cited paper, an oscilloscope was employed to extract the preliminary time resolution, using the same backplane, with measurements indicating values below 100 ps.

3. LAPPD custom backplane

A custom readout backplane (version V0) with in total 512 pixels with 3 mm pitch (2.9×2.9 mm^2 active area and 0.1 mm dead gap) was designed in Edinburgh. The overall dimensions of the backplane are consistent with those of the INCOM version, while the active area of this initial customised version has been intentionally reduced for testing purposes. The latter has been designed to match the area where the Cherenkov ring is expected on the surface during beam tests. The ultimate goal is to have a fully equipped backplane. The backplane was realised by Beta Layout [4], and the assembly to the detector was performed in Edinburgh.

Only the backplane was replaced, without any other design changes. This allowed the complete integration of the new backplane while maintaining the original MCP housing provided by INCOM, exploiting the same HV taps. The backplane equipped with Samtec connectors on the back, as showed in Fig. 1, allows the connection of a multi-channel electronics developed mainly in collaboration with CERN and Barcelona University, to provide a fast readout with a resolution down to 3 ps and high granularity. First validation tests of the custom backplane were conducted in the laboratory. An interface PCB was used, allowing the direct connection of the backplane to a fast oscilloscope

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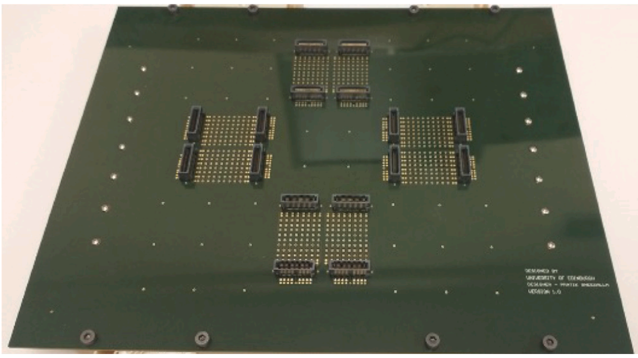

Fig. 1. Back side of the LAPPD Gen II prototype, after the assembly to the custom board designed in Edinburgh.

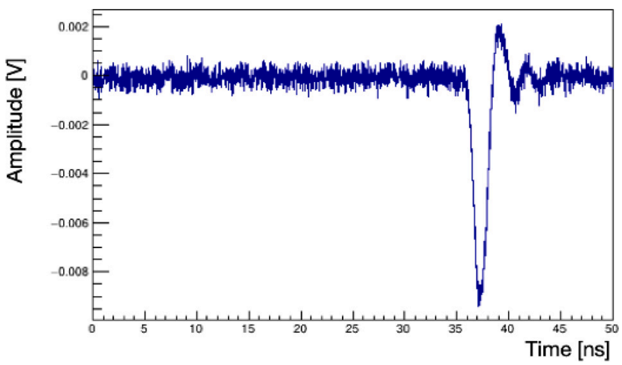

Fig. 2. Waveform acquired with a fast oscilloscope. Digitisation rate 128 GS/s, bandwidth 20 GHz, 50 Ω termination. Bias supplied to the detector is 850 V for the MCP voltage and a relative +100 V applied to the photocathode.

for debugging. An example of the single photo-electron analogue signal, as acquired by the fast oscilloscope, is shown in Fig. 2. The rise time, determined by fitting the waveform to a Gaussian function and calculating the time difference between the 90% and 10% amplitude levels from the fit, is of the order of 800 ps.

3.1. Beam tests in Autumn 2023 and Spring 2024

The RICH group tested the LAPPD in September 2023 and April/May 2024 at CERN SPS. The sensor was connected to a multi-channel electronics chain, equipped with two fastIC plug-INs, a picoTDC module and an optical link for connection to the back-end. For the beam test the back-end was consisting of a custom FPGA based board called the MuDAQ.

Each custom carrier board allowed to read up to 64 channels at a time. Up to 8 boards could have been connected to the LAPPD, however, only two boards were available, limiting the number of readout channels to 128. A picture of the beam test setup is represented in Fig. 3. The SPS pion beam crosses the aerogel, producing Cherenkov photons which are redirected to the surface of the detector thanks to a mirror and a lens. The detector is placed off beam to avoid aging of the photocathode and micro-channel plates. The reference for timing

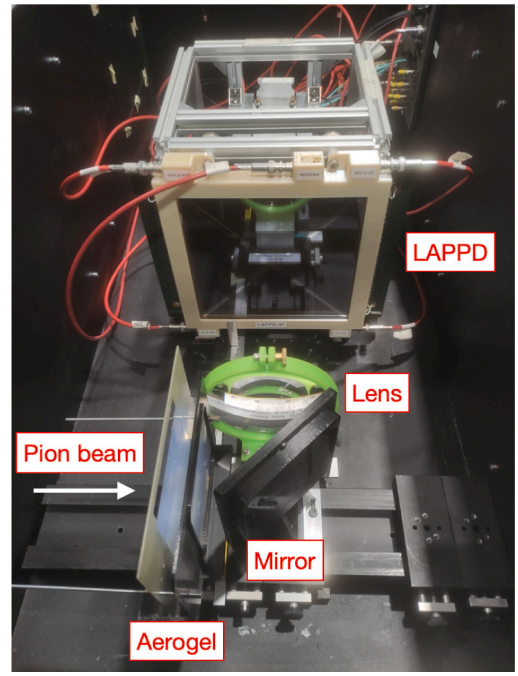

Fig. 3. Picture of the setup at the CERN SPS beam test. The sensor is off beam; the optics help to focus the Cherenkov photon ring on the surface of the LAPPD.

studies is provided by two separate MCP detectors placed downstream to the LAPPD box. The first Cherenkov rings were observed and analysis of the data is in progress, aiming at extracting the ultimate time resolution of the detector connected to the multi-channel electronics in the beam environment, to compare with laboratory measurements.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Federica Oliva reports financial support was provided by Leverhulme Trust. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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