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Comprehensive characterization of LAPPD and HRPPD photodetectors

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Abstract: In this proceeding we present a comprehensive characterization of LAPPDs and HRPPD. This included an evaluation of time resolution for single photoelectron signals, the behavior in magnetic fields up to 1.5 T and accelerated ageing. The detectors demonstrated the time resolution of about 80 ps. The magnetic field applied at not very large angles cause an exponential loss of gain and significant loss of efficiency, but both these quantities can be partially or completely recovered by higher bias voltages, extending beyond zero field limits. The accelerated ageing tests at a relatively low gain showed no significant QE degradation, while the gain was affected.

Keywords: Photon detectors for UV, visible and IR photons (vacuum), Timing detectors

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1 Introduction

Large Area and High Rate Picosecond PhotoDetectors (LAPPDs and HRPPDs, respectively) are novel photosensors based on MicroChannel Plates (MCPs) [1] developed by Incom. These photosensors combine the large sensitive area, fast response time with a high spacial granularity. Here we present several characterization tests of these sensors aimed to qualify them for use in ePIC detector.

Particle identification (PID) is one of key requirements to achieve many physics objectives at the EIC [2]. The pfRICH, located at the backward endcap of the ePIC detector, will provide a π/K/p separation up to 7 GeV/c, along with electron identification at momenta below 5 GeV/c, where the PID performance of the ECAL deteriorates. It was decided to select HRPPDs as photosensors of pfRICH. This application requires a single-photon detection with time resolution <100 ps with spacial resolution of a few mm in a magnetic field of <1.4 T having an inclination angle with respect to the normal to sensor plane <13°.

The present tests concerned the following parameters of the sensors:

1. absolute time resolution in the single photon detections;
2. gain and efficiency variations in magnetic field;
3. photocathode and MCP damage due to sensor long time operations.

All these tests are briefly described below, while other details can be found in Refs. [3, 4].

Previous studies of MCP-based photodetectors are described in Refs. [5–9]

2 Time resolution measurements

The experiment was performed at CERN PS using mixed hadron (mostly protons and pions) beams at few different energies from 4 to 12 GeV/c. The LAPPD (unit #124) capacitively coupled to the Incom's readout PCB with 8×8 one inch pads was installed on the beamline inside a darkbox. The Cherenkov light cone was produced in the plano-convex fused silica lens installed downstream the LAPPD and reflected backwards on the LAPPD photocathode by the total internal reflection. An acrylic filter installed between the lens and LAPPD allowed to reduce the mean number of photo-electrons per pad (in the cone) to about 0.5 suppressing also chromatic dispersion of the UV part of the spectrum. The LAPPD time was measured with respect to the reference Hamamatsu MCP-PMT R3809U-50, featuring <10 ps time resolution. The clear Cherenkov cone was observed, as it is shown in Figure 1, on the LAPPD, especially in the runs without acrylic filter for which the mean number of photoelectrons per pad was six times larger.

The measured time resolution was about 80 ps for the single photoelectron, rapidly falling with signal amplitude, as it is shown in Figure 1. The observed dependence of the time resolution on the amplitude roughly can be described by $1/\sqrt{N}$ behavior, where N is the number of photoelectrons. The best time resolution achieved in these measurements was about 20 ps, mostly attributed to the large readout pad size.

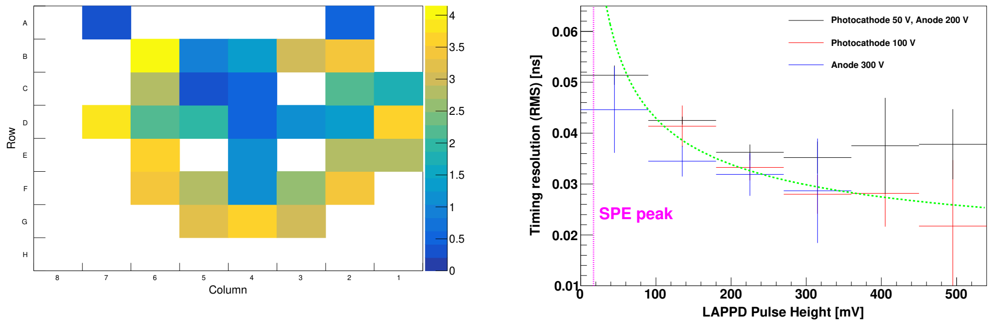

Figure 1. Cherenkov cone measured at the LAPPD (left) and the obtained time resolution as a function of LAPPD pulse height (right). Figures adopted from Ref.[3].

3 Measurements in magnetic field

A more recent version of LAPPD (unit #153): featuring much shorter stack with reduced gaps and 10 μm MCP capillaries was tested in the vertical dipole magnets MNP-17 and M113 at CERN. The LAPPD in a small darkbox was installed inside the bore of the dipole magnet on its mechanical supports allowing rotations up to 40°. The pulsed laser source was connected to the darkbox by a long 65 μm diameter optical fiber. The intensity of the laser was selected to provide <5% fraction of useful pulses, ensuring dominance of the single photoelectron signal. Integrating LAPPD voltage signals acquired by digitizer, normalizing them to the load resistance and scaling for the amplifier gain we obtained the charge collected on the anode (assuming no loss in couplings). The collected charge spectra exhibited evident SPE peaks, allowing a threshold independent estimate of LAPPD gain. The observed collected charge spectra shrink with magnetic field magnitude. This allowed to evaluate LAPPD gain variation in magnetic field and as a function of the field inclination angle, as it is shown in Figure 2. The LAPPD gain fall is almost exponential in magnetic field magnitude with width of exponential of about 0.4 T. Instead, the angular dependence is small w.r.t. **B**-dependence, however it has a particular dip at -13°, when the magnetic field is parallel to the exit MCP capillaries.

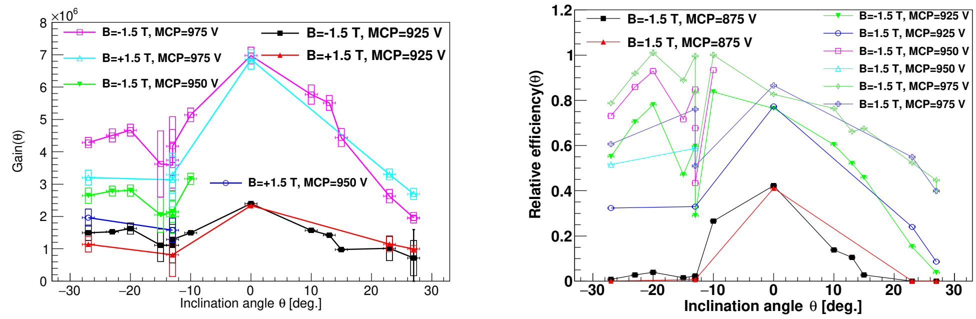

Figure 2. Gain (left) and relative efficiency (right) of LAPPD in 1.5 T magnetic field as a function of the field inclination angle. Figures adopted from Ref.[4].

The charge collection efficiency of LAPPD is also affected by the magnetic field, as it is shown in Figure 2. However, the increase of MCP bias voltage, which can go beyond the limits determined in zero field conditions, partially or completely compensates the efficiency loss.

4 Accelerated ageing measurements

MCPs are known to deteriorate their performances over operation time [10]. This deterioration, called ageing, is one of the main obstacles limiting applications of MCPs in experiments. In order to evaluate the ageing of HRPPDs irradiations were performed at INFN of Trieste. The irradiations performed on a scale of time of order of a month were aimed to simulate dozens of years of ePIC detector operations. Thus, to accelerate the ageing a proportionally higher photon flux of about 10^8 ph/cm^2/s was used. The irradiation for accelerated ageing was performed using a continuous LED connected to darkbox through light transportation and monitoring system, with the final spot radius on HRPPD window of 5.3 mm. The MCPs were biased at 650 V, corresponding to the HRPPD gain of 2×10^6. In the first ageing period only the entry MCP of HRPPD was biased to avoid saturation in the exit MCP. The second part of ageing was performed with both MCPs biased to study the difference.

The results of these ageing tests demonstrated a negligible variation of the photocathode Quantum Efficiency (QE), along with a significant gain suppression. The evolution of QE and gain comparison are shown in the Figure 3.

The previous studies attribute QE damage to the ion feedback mechanism, where an atom is ionized by the secondary electron avalanche and after acceleration in MCP electric field hits the photocathode. If exists a location where the ions which can reach the photocathode are most likely ionized the feedback signals will form a series of peaks. The observed time delay distribution from the laser pulse to the observed signal shown in Figure 4 in fact demonstrate such peaks. In order to attribute the observed peak delays we had to assume that most of feedback ions were ionized at the bottom of the entry MCP. With this assumption the peaks could be identified by the observed

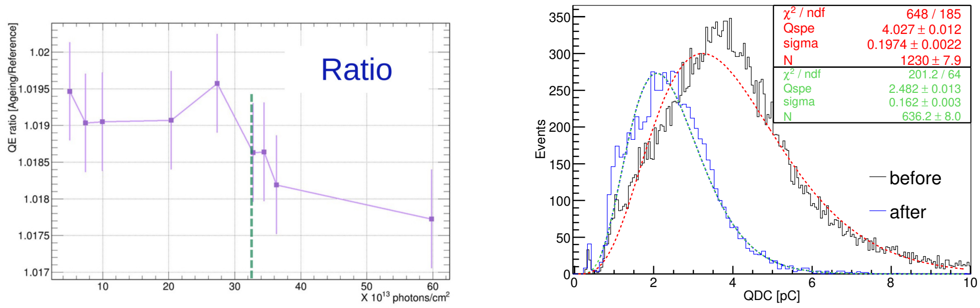

Figure 3. QE evolution as a function of absorbed photon fluence (left) and anode charge distribution before and after ageing irradiation (right).

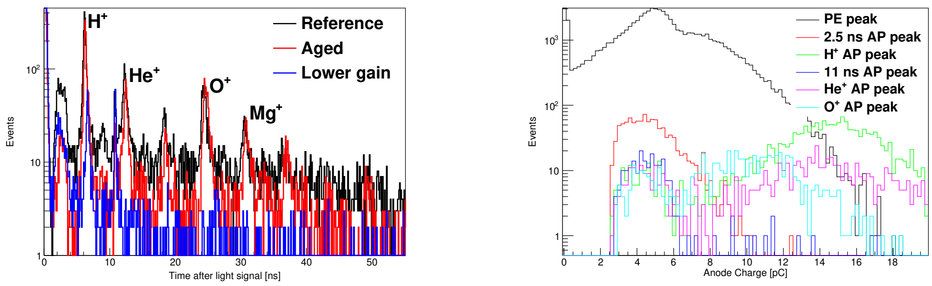

Figure 4. Delayed signal time distribution with indication of expected ion peaks (left) and anode charge distributions for individual afterpulse peaks (right).

delay to be mostly H^+, He^+, O^+ and Mg^+ ions. These peaks moves with MCP bias voltage as expected, with delay proportional to $\frac{1}{\sqrt{V}}$. We found no significant variation of feedback ion yield after HRPPD ageing. Instead, the very clear suppression of feedback ions at lower HRPPD gain suggests longer duration in these conditions. The anode charge distributions of ion feedback signals show in general a large number of photo-electrons, while a few spurious peaks (e.g. that at 2.5 ns) have the same distribution as the main signal.

5 Summary

Summarizing, we performed a comprehensive characterization of LAPPDs and HRPPD. This included evaluation of time resolution for single photoelectron signals, the behavior in magnetic fields up to 1.5 T and accelerated ageing. The detectors demonstrated the time resolution about 80 ps. The magnetic field applied at not very large angles cause an exponential loss of gain and significant loss of efficiency, but both these properties can be partially or completely recovered by higher bias voltages, extending beyond zero field limits. The accelerated ageing tests at a relatively low gain showed no significant QE degradation, while the gain was affected.

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References

[1] T. Gys, *Micro-channel plates and vacuum detectors*, *Nucl. Instr. and Meth. A* **787** (2015) 254.

[2] A. Accardi et al., *Electron ion collider: The next qcd frontier - understanding the glue that binds us all*, *Eur. Phys. J.* **A 52** (2016) 268.

[3] D.S. Bhattacharya et al., *Characterization of lappd timing at cern ps testbeam*, *Nucl. Instr. and Meth. A* **1058** (2024) 168937.

[4] J. Agarwala et al., *Performance of an lappd in magnetic fields*, *Nucl. Instr. and Meth. A* **1072** (2025) 170122.

[5] A. Lehmann et al., *Performance studies of microchannel plate pmts in high magnetic fields*, *Nucl. Instr. and Meth. A* **595** (2008) 173.

[6] E. Morenzoni et al., *Performance of microchannel plates in high magnetic fields*, *Nucl. Instr. and Meth. A* **263** (1988) 397.

[7] M. Hattawy et al., *Characteristics of fast timing mcp-pmts in magnetic fields*, *Nucl. Instr. and Meth. A* **929** (2019) 84.

[8] J. Xie et al., *Rate capability and magnetic field tolerance measurements of fast timing microchannel plate photodetectors*, *Nucl. Instr. and Meth. A* **912** (2018) 85.

[9] Y. Melikyan et al., *Performance of the cost-effective planacon ® mcp-pmts in strong magnetic fields*, *Nucl. Instr. and Meth. A* **983** (2020) 164591.

[10] A. Lehmann et al., *Systematic approach to measure the performance of microchannel-plate photomultipliers*, *Nucl. Instr. and Meth. A* **1065** (2024) 169536.