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Multiple-photon disambiguation on stripline-anode Micro-Channel Plates

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ABSTRACT

Large-Area Picosecond Photo-Detectors (LAPPDs) show great potential for expanding the performance envelope of Micro-Channel Plates (MCPs) to areas of up to 20 × 20 cm and larger. Such scaling introduces new challenges, including how to meet the electronics readout burden of ever larger area MCPs. One solution is to replace the traditional grid anode used for readout with a microwave stripline anode, thus allowing the channel count to scale with MCP width rather than area.

However, stripline anodes introduce new issues not commonly dealt with in grid-anodes, especially as their length increases. One of these issues is the near simultaneous arrival of multiple photons on the detector, creating possible confusion about how to reconstruct their arrival times and positions. We propose a maximum a posteriori solution to the problem and verify its performance in simulated scintillator and water-Cherenkov detectors.

1. Introduction

In an LAPPD device, photoelectrons from a photocathode are amplified in a stack of Micro-Channel Plates (MCP), and the resulting charge cloud is deposited on a stripline-array anode. On each of the affected striplines, the electric charge propagates from the origination point in two opposite directions to the ends of the striplines where the pulse waveforms are acquired with fast analog-to-digital converters (ADCs).

The timing of the original charge-deposition event is found as the average of the two pulse-arrival times, and the position along the striplines is found by their difference, scaled with the signal propagation speed v (typically $0.6c$, where c is the vacuum speed of light, depending on the dielectric properties of the substrate). In the other direction, the position of the detection event is found by interpolating signal strengths between striplines. Stripline anodes and associated readout strategies have been discussed in the past works such as Lampton et al. [1] and Jagutzki et al. [2], with early developments tracing back to work on proportional chambers (e.g., Rindi et al. [3] and Grove et al. [4]). The anode geometry studied in this paper was developed specifically for the LAPPD project [5] and consists of 30 active striplines. In possible modifications to the original design, commercial LAPPD™ detectors might make use of the outermost striplines for high voltage control. The following work therefore assumes only 26 active delay lines, albeit with the same pitch and spacing.

The event time t and longitudinal position d of the arrival PE can be determined from the following set of equations:

$$t = \frac{t_L + t_R - D/v}{2} \tag{1}$$

$$d_L = D/2 - v\left(\frac{t_L - t_R}{2}\right) \tag{2}$$

$$d_R = D - d_L \tag{3}$$

where t_L and t_R are the left and right side arrival times of the charge cloud and D is the total strip length (20 cm in our LAPPD example). While this method works well for resolving single PEs,

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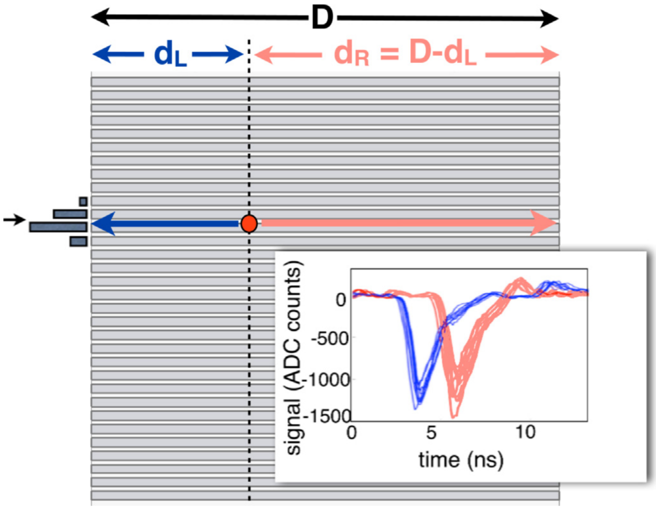

Fig. 1. The stripline-anode pattern on an LAPPD, consisting of 30 4.62 mm-wide striplines separated by 2.29 mm gaps. PE locations are determined by the difference in arrival time between the two ends of the strips. Transverse position is determined by a charge centroid.

multiple pulses due to near-simultaneous PEs lead to multiple pulses arriving at the two sides of a stripline, and ambiguities about time and location may result.

For n left-side pulses and m right-side pulses, we create a likelihood matrix Λ to evaluate all possible left–right pair combinations Λ_{ij}, where $i = 1 \ldots n$ and $j = 1 \ldots m$:

$$\Lambda = \begin{bmatrix} \Lambda_{11} & \cdots & \Lambda_{1m} \\ \vdots & \ddots & \vdots \\ \Lambda_{n1} & \cdots & \Lambda_{nm} \end{bmatrix} \tag{4}$$

Individual pair likelihoods Λ_{ij} are the product of 3 component likelihoods: amplitude likelihood Λ_a, time probability P_t, and location likelihood Λ_y:

$$\Lambda_{ij} = \Lambda_a\left(a_L^i | a_R^j\right) P_t\left(t_L^i | t_R^j\right) \Lambda_y\left(y_L^i | y_R^j\right) \tag{5}$$

The highest likelihood elements in each row (if there are less rows than columns) or column (if there are less columns than rows) are used to match up each left-side pulse with the most similar right side pulse. Pair likelihoods must exceed a certain threshold to reduce false positives. This threshold is determined a priori by Monte Carlo modeling of the LAPPD in its intended target environment (Fig. 1).

2. Our test setup

We assembled a laser test [9] at the Argonne National Lab (ANL) Advanced Photon Source (APS) to gather empirical data on LAPPD performance. The setup, pictured in Fig. 2, consists of a prototype LAPPD with a high gain photo-cathode attached to continuously operating vacuum pumps. The prototype LAPPD had two MCP layers with 20 μm pores at an 8° bias angle, with 60 L/D ratio (1.2 mm MCP thickness) and a 2.29 mm gap between the second MCP and the anode [9]. The LAPPD voltages are set by the relative resistances in each stack:

- 5 MΩ across the photocathode gap,
- 5 MΩ across the gap between the MCPs,
- 10 MΩ across the anode gap,
- 40 MΩ across each MCP.

At 2700 V High Voltage (HV), that means there would be 135 V across the photocathode gap and inter-MCP gap and 270 V across the anode gap.

A pulsed laser delivered photons to a targeted location on the LAPPD surface, and an external trigger fed 10 PSEC4 [10] chips, 5 on each side, which each recorded 256 samples along 6 channels of 12 bit digitized (10.5 Effective Number of Bits, (ENOB) [10]) data covering all 26 anode-strips (both sides) on the LAPPD. The sampling rate was 10 Gs/s, or 100 ps between samples, for a total listening time of 25.6 ns. The noise level observed on the PSEC4 was about 1 mV with saturation occurring at ± 1.1 V, equivalent to 3 PEs. Each laser pulse produced 2 × 26 waveforms, each with 256 samples digitized at 10 bits.

We used multiple laser pulses to characterize the LAPPD Single Photon Response (SPR), including the distribution of the charge cloud signals (both along and across the anodes), amplitude distribution, propagation speed v down the strips ($v \approx 0.6c$), and 20 μm MCP Transit Time Spread (TTS) of ~60 ps [13] 1σ. We then modeled Monte Carlo (MC) SPRs from these distributions, and assumed analog linearity when extrapolating to a multiple photon response (single-PE charge clouds with average amplitudes of about 400 mV were linearly added if they overlapped, though our PSEC4 digitizer model ensured the total signal was clipped at ± 1.1 V, or about 3 PEs). Our validated SPR is employed throughout this paper to model both single and multiple photons on an LAPPD.

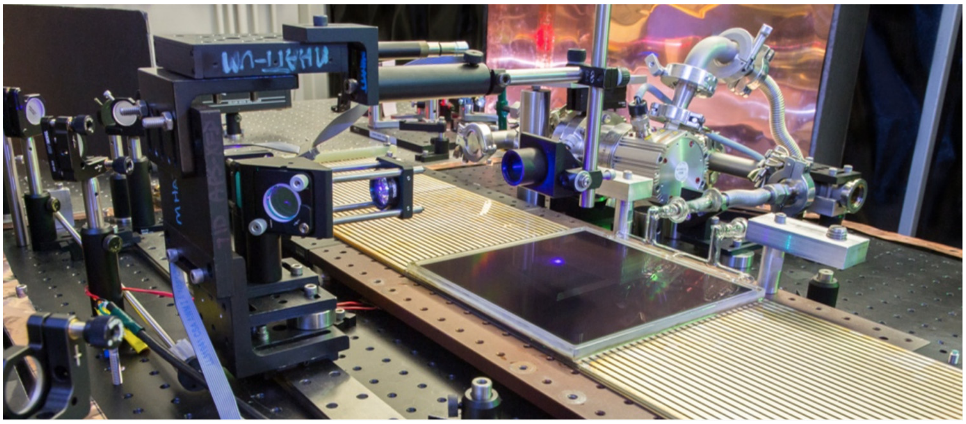

Fig. 2. LAPPD + PSEC4 [10] test setup at Argonne National Lab [9].