Measurement & Test

Report

LAPPD 124

05/02/2022

Contents

LAPPD 124 Specific Performance

Summary

LAPPD 124 has single photoelectron gain in the low-to-high 10^6 range. Simultaneously, it has dark rates in the ~0.01-10 kHz/cm^2 regime. Gain is sustained at high rates, falling to three-quarters of nominal gain at 100 kHz/mm^2. Quantum efficiency is 29.0% at 365 nm, and is spatially uniform to the 2.5% level. This LAPPD can be used in applications requiring external triggering on single photons though time is needed for LAPPD to equilibrate at most voltage settings. Due to this feature, the LAPPD was under continuous high voltage for over 10 days to obtain the following data points for gain and dark rates.

Seal Date	12/22/2021
Pilot Production / Experimental	Baseline Pilot
Version	Gen II
Important Features	Large region of comparatively low QE (~25% at 365nm). Requires “cooldown” period for most voltage settings.
Quality Grade (Production vs. Development)	Development
Pass / Fail	Pass
Analysis	
Disposition	

LAPPD 124 General Features and Parameters:

Feature	Parameter
Photodetector Material	Gen II, borosilicate glass lower tile assembly; interior ground plane anode
Window Material	Fused silica glass, 5.0 mm thick
Photocathode Material	Multi-Alkali (K_2NaSb)
Spectral Response (nm)	160-650
Wavelength – Maximum Sensitivity (nm)	≤ 365 nm
Photodetector Active Area Dimensions	195mm X 195mm
• Minimum Effective Area	373cm^2
• Active fraction with Edge Frame Rib-Spacers	97%
Anode Configuration	Monolithic ground plane
Voltage Distribution	5 taps for independent control of voltage to the photocathode and entry and exit of MCP

LAPPD 124 Operational Ratings

Parameter	Rating
Supply voltage Photocathode — Anode (Volts)	Typical: 50V between MCP and photocathode • 850 V/MCP • 200 V between MCPs • 200 V between MCP and anode • Photocathode voltage is -2150 V Maximum: Photocathode voltage at -2150 V
Operating ambient temperature °C	TBD (nominal room temperature)
Storage temperature °C	-12 to 50 (Avoid indium seal melt)

LAPPD Package / Housing Characteristics

Parameter	Rating

Photodetector Physical Dimensions (L X W X Thickness, mm)	230 x 220 x 22
Photodetector Mounting Case	ULTEM or equivalent dielectric polymer
Photodetector Mounting Case Dimensions	243 mm X 274 mm X 25.2 mm
Connectivity	Passive PC Interface Board, (300 mm X 264 mm X 1.6mm)
Overall Footprint, with Mounting Case & PC Interface Board	300 mm X 274 mm X 26.8 mm
Shipping Container	Pelican Case + Cardboard Box + G-force indicators

LAPPD 124 Microchannel Plate (MCP) Features & Performance

MCPs	Two Arranged in a Chevron Pair
Dimensions	203 mm x 203 mm X 1.2 mm
MCP Substrate	Incom C5 Glass
Capillary Pore Diameter (µm) Center to Center Pitch (µm)	20 25
Channel Length / diameter Substrate Thickness (mm)	60:1 1.2
Bias Angle	13
Capillary Open Area Ratio	≥65%
Resistive and Emissive Coatings	Chem 1, Applied via Atomic Layer Deposition (ALD)
Secondary Emission (SEE) Layer Material	MgO
Electrode Penetration – Input & Output (Pore Diameter)	0.5-1.0
MCP ID (Entry / Exit)	C00145-224 / C00145-227
MCP resistance, Entry/Exit (@ LAPPD M&T) Please Note High Voltage Stability Section for more detail.	6.8/5.2 MΩ at 900 V
MCP Dark Rate in the tile (Obtained by setting the photocathode more positive than the entry MCP)	18.38 Hz/cm^2 at a threshold of 8x10^5 gain (134 fC), 900 V/MCP, 10 V positive on photocathode [A]
Max Voltage	900/900 V/MCP (entry/exit), with -2,210 volts on the photocathode; dark rate limited.

LAPPD 124 Operating Performance (ROP = Recommended Operating Point)

Parameter	**Performance**
Photocathode Quantum efficiency @ 365 nm	Mean QE (@365 nm) = 29.0%, Maximum: 32.4%
Photocathode QE Spatial Variability (σ)	2.5%
ROP Voltages	200V above anode, 200V between MCPs, 850V/MCP, 50V on photocathode
LAPPD Gain @ ROP	4.01x10^6
LAPPD Gain @ 10V on Photocathode, 900V MCP	9.12x10^6
LAPPD Dark Count rate @ ROP (threshold = 4mV)	9.29 kHz/cm^2 at a threshold of 8x10^5 gain (134 fC), 850 V/MCP, 50 V on photocathode [A]
Dark Rate @ 10 V on PC, 900V MCP	19.42 kHz/cm^2
Optimal Transit Time Variation (single P/E)	77.5 pS
Note: INCOM TTS results are "Provisional". Work recently done at INFN Bologna Italy shows that Incom reported TTS understate the true timing capability of LAPPD. Efforts at Incom are now focused on resolving calibration issues and other factors that can introduce jitter into the TTS result.	
Position Resolution Along/Across Pads (mm) (typical, not measured for this tile)	Not measured for this tile

Gain

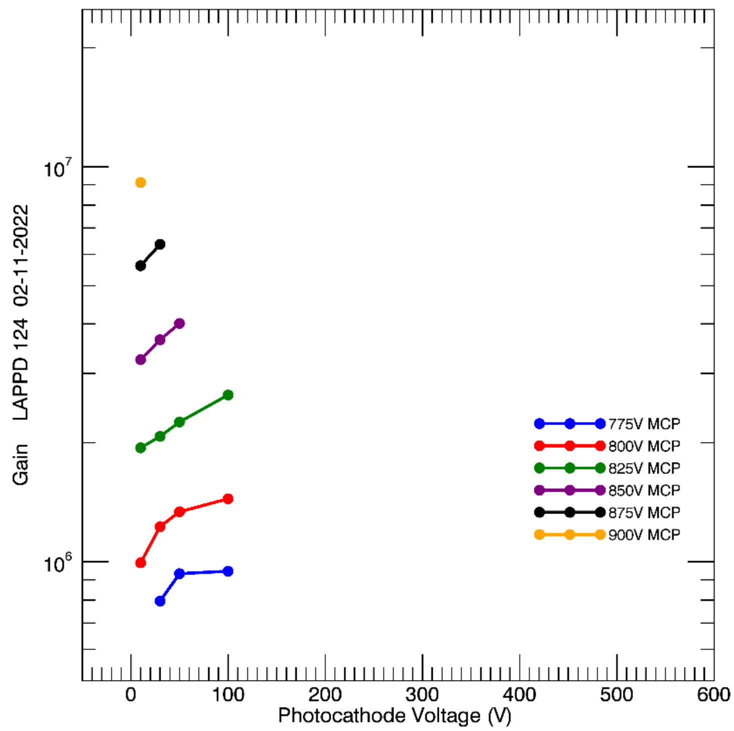
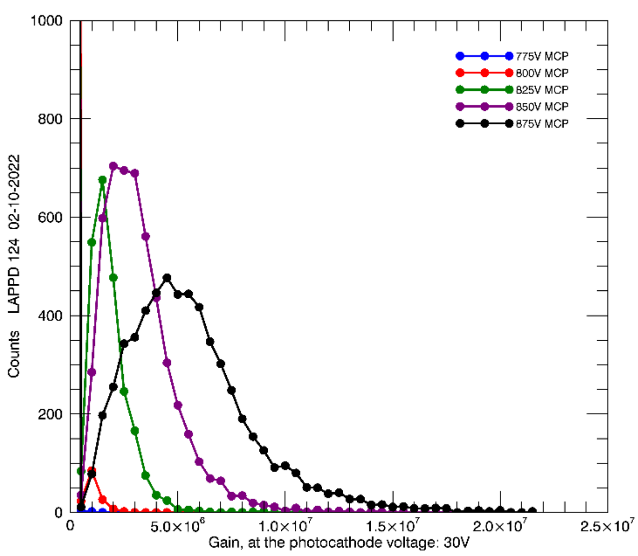


Figure 1: Average gain is shown vs. MCP and photocathode voltage, as measured with PSI DRS4 waveform samplers. [A]



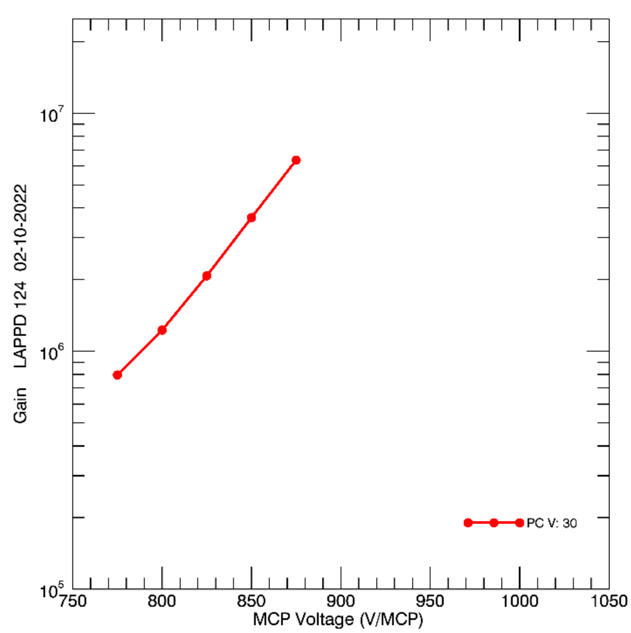
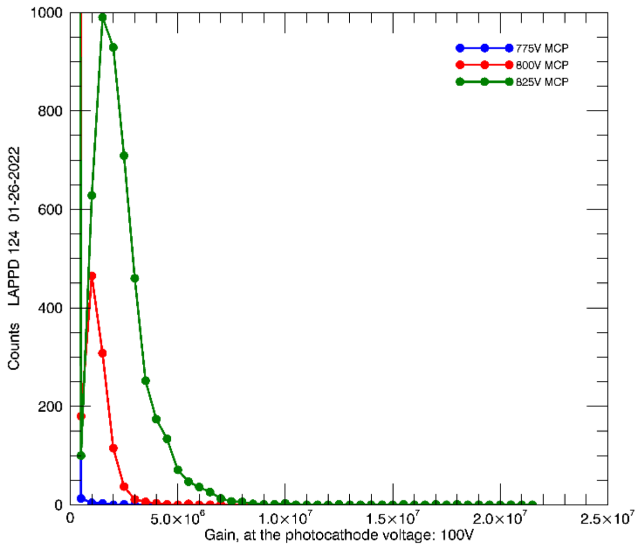


Figure 2: Gain is shown as a function of MCP voltage, with 30 V on the photocathode.[A] **Left**: pulse height distributions. **Right**: Average gain vs. MCP voltage.



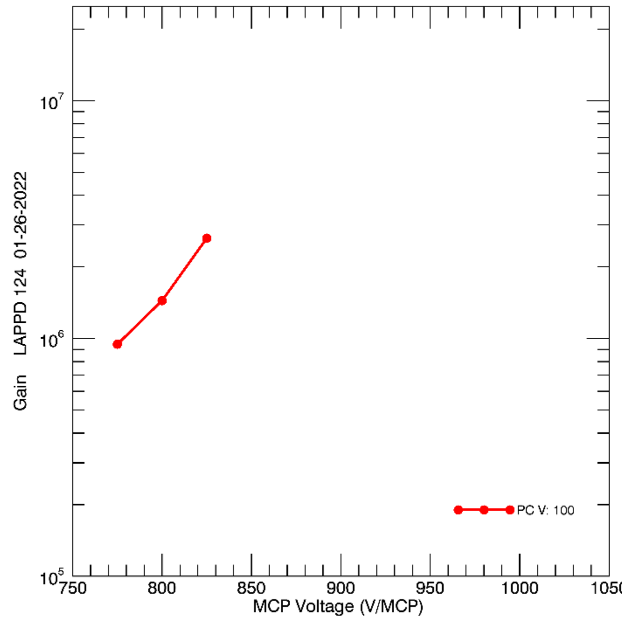
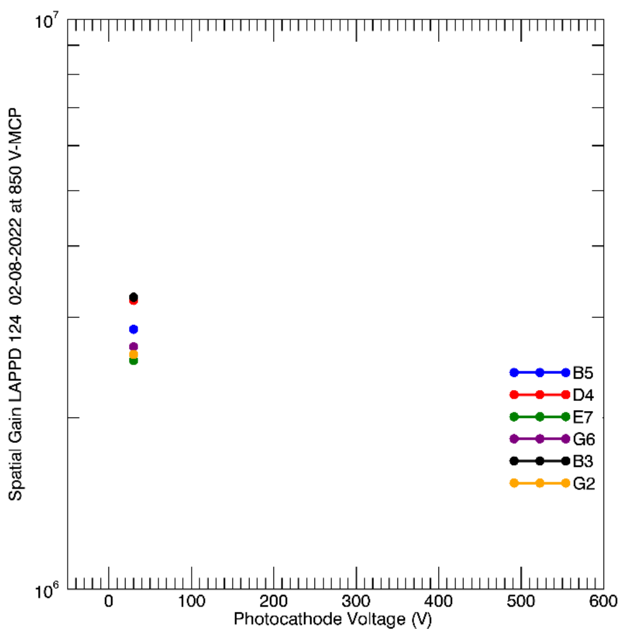


Figure 3. Gain is shown as a function of MCP voltage, with 100 V on the photocathode.[A] **Left**: pulse height distributions. **Right**: Average gain vs. MCP voltage.



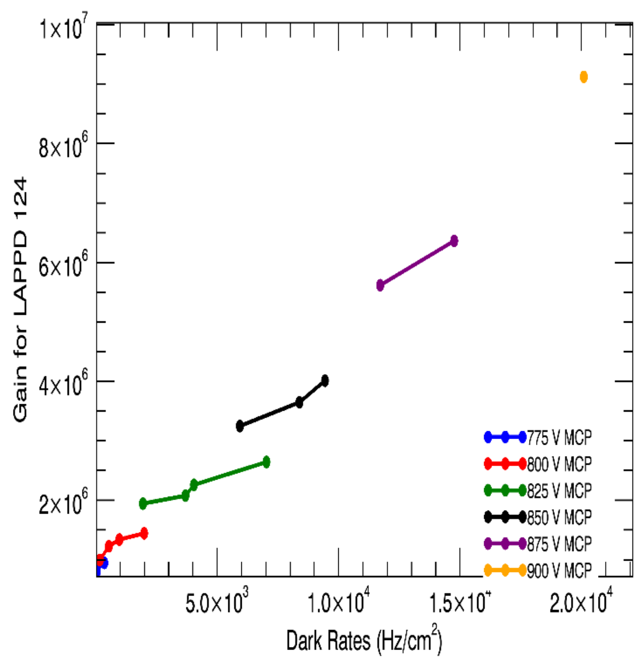


Figure 4. Left: Gain comparison at 850 V/MCP and 30V on the photocathode at 6 different pixels. **Right:** Gain for LAPPD 124 at Pixel D4 is compared to Dark Rates Noted at Pixel D3.[A]

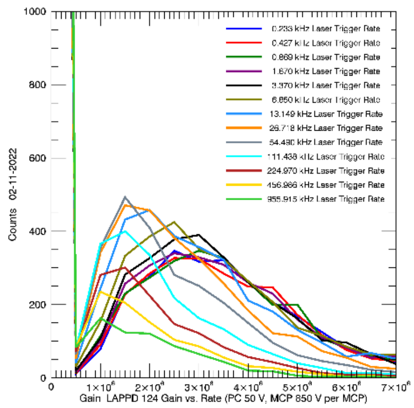


Figure 5: Gain is shown vs. laser repetition rate for single photoelectrons. [A]

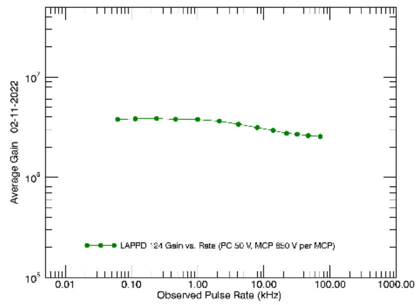


Figure 6: Gain is shown vs. observed pulse rate for single photoelectrons.

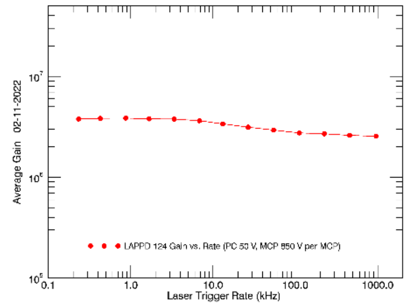


Figure 7: The pulse distributions are shown as a function of laser trigger rate.

Dark Rates

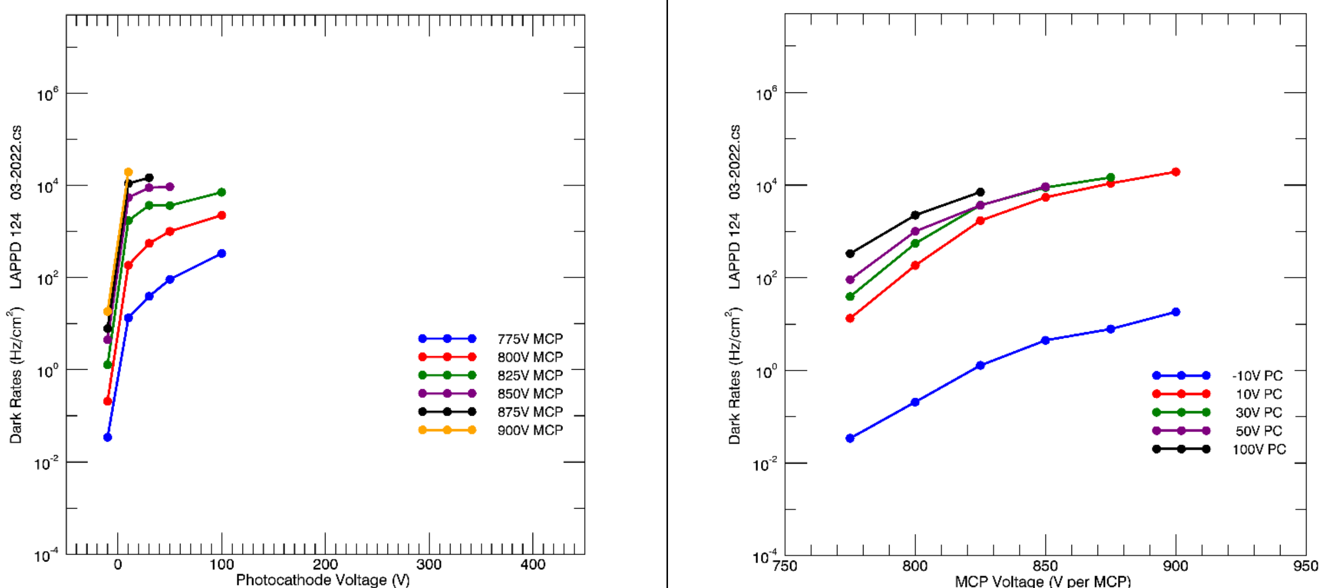


Figure 8: Dark rates as a function of photocathode and MCP voltage.[A]

Photocathode QE Spectrum

Date	Mean QE	Max QE
1/26/2022 2/14/2022 3/18/2022	30.2 ± 2.5% 30.3 ± 2.3% 29.0 ± 2.5%	33.2% 32.6% 32.4%

Table 1: Quantum efficiency measurements at 365 nm on LAPPD 124 are listed.

QE Scans

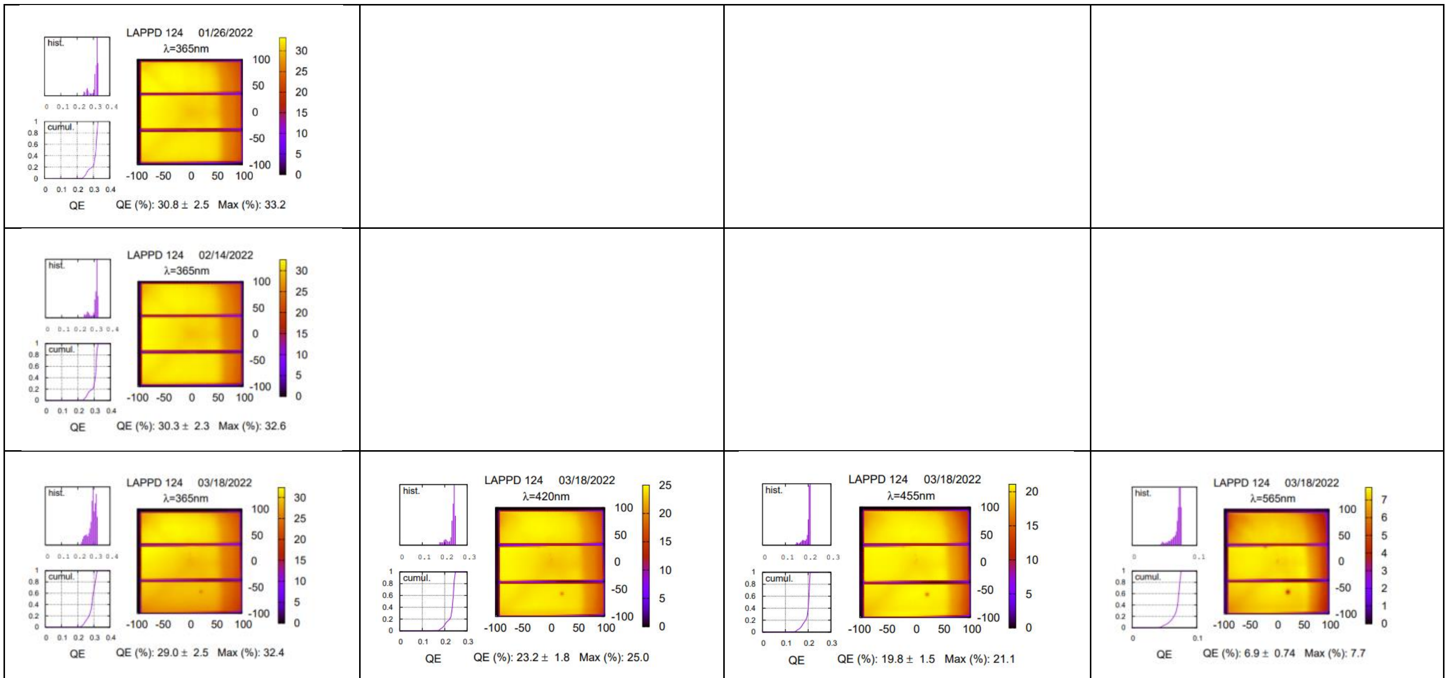


Figure 9. QE Scan data. The columns are scans done at different wavelengths. The rows are different test dates.

Transit Time Variation

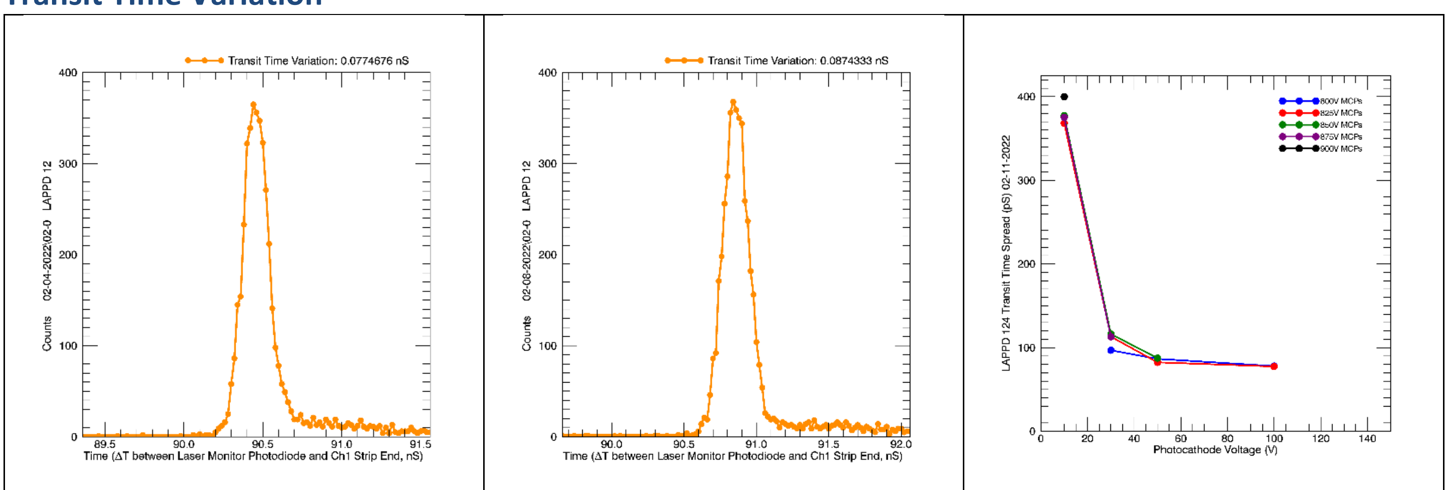


Figure 10. Left: The transit time variation is shown for 825 V/MCP and 100 V on the photocathode. This is the time difference between the observed laser firing and the arrival of the MCP pulse at the resistive anode above the corresponding pixel. **Center:** The transit time variation is shown for 850 V/MCP and 50 V on the

photocathode. This is the time difference between the observed laser firing and the arrival of the MCP pulse at the resistive anode above the corresponding pixel. **Right**: The transit time variation is shown as a function of photocathode voltage for different MCP voltages.

High Voltage Stability vs. Voltage and MCP Resistance vs. Voltage

The high voltages and currents are shown in Figure 11 for operation of LAPPD 124 over the nominal voltage range. The channel numbers in the figure correspond to labels in the high voltage wiring diagram of Figure 13. The photocathode and MCP voltage combinations shown in Figure 1 may be used without driving the LAPPD into a state of high voltage current instabilities.

In Figure 11, Channel 0 is applied to the photocathode. Channel 1 is applied to the exit of the entry MCP, and Channels 2 and 3 are applied respectively to the top and bottom of the exit MCP. The left panel of Figure 11 shows the voltages applied. The right panel shows the corresponding currents. The green trace is the strip current in the exit MCP. It is routed to ground through a resistor between the exit MCP and ground. The yellow trace is additional current provided to the resistor, to maintain 200 or 300 volts. The yellow current trace is complementary to the green trace – when the exit MCP strip current is low, the yellow current trace goes high enough to maintain 200 volts across the resistor (Figure 11, right).

The sum of the Ch 2 and Ch 3 currents should be 400 microamps when 200 volts are applied to the gap between the MCP and anode, because they are the currents in the 0.5 MΩ resistor between the exit MCP and ground (see Figure 16 "2M" resistor, middle panel). An increase in the green Ch 2 trace into the exit MCP will be matched by a corresponding decrease in the yellow Ch 3 current. If the sum of Ch 2 and Ch 3 currents exceeds 400 microamps, then current supplied to the entry side of the exit MCP is partly going through the MCP as expected, but partly going around the MCP to ground via another path, including directly to the anode. These increases can be caused by increases in both MCP and photocathode voltage.

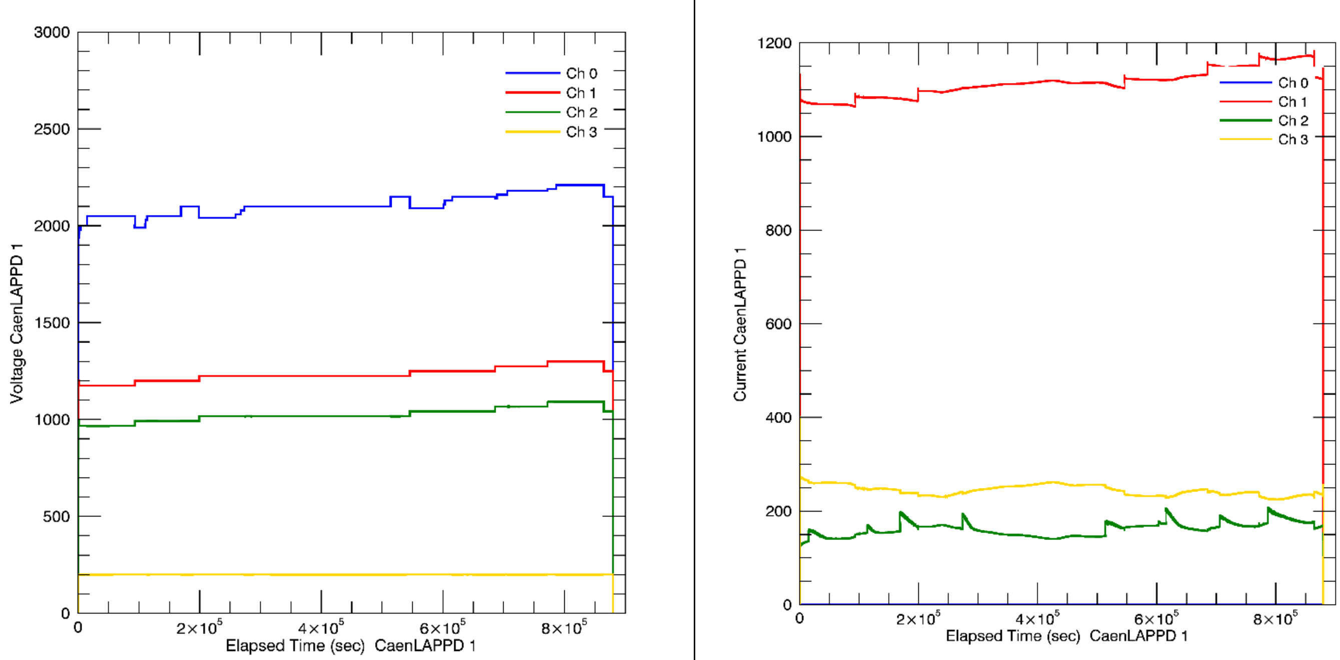


Figure 11: The high voltages (left) and currents (right) are shown for LAPPD 124 operation. Stability is demonstrated up to 900 V/MCP.

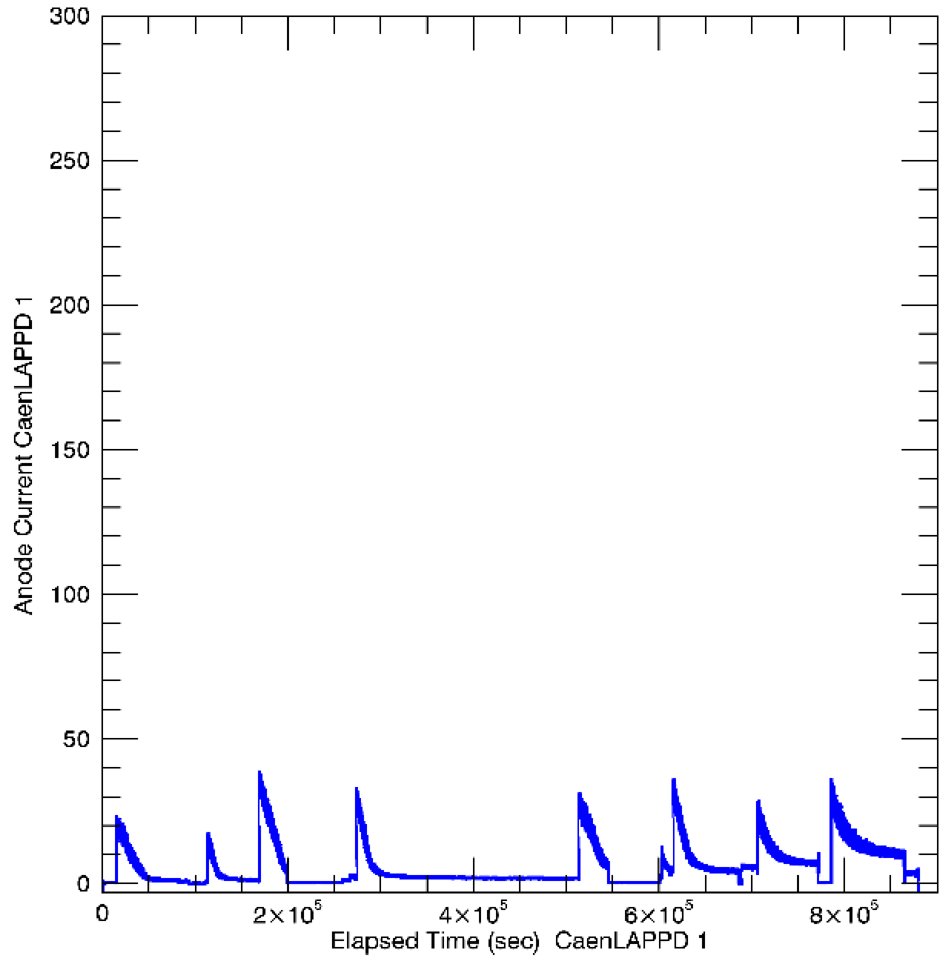


Figure 12: Calculated Anode Current from analysis of CAEN High Voltage Data file during LAPPD standard testing. The calculated extracted charge taken from LAPPD 124 during testing is approximately 5.16 Coulombs.

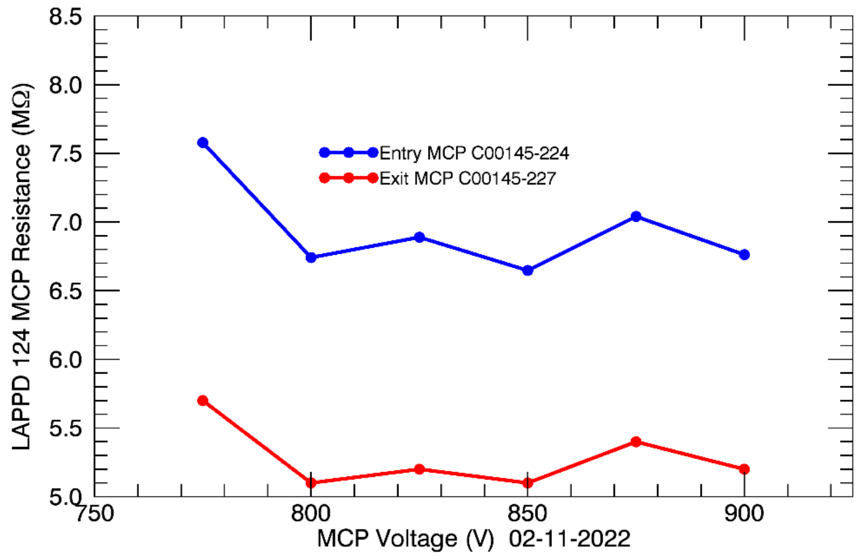


Figure 13: MCP resistances are shown for LAPPD 124.[A]

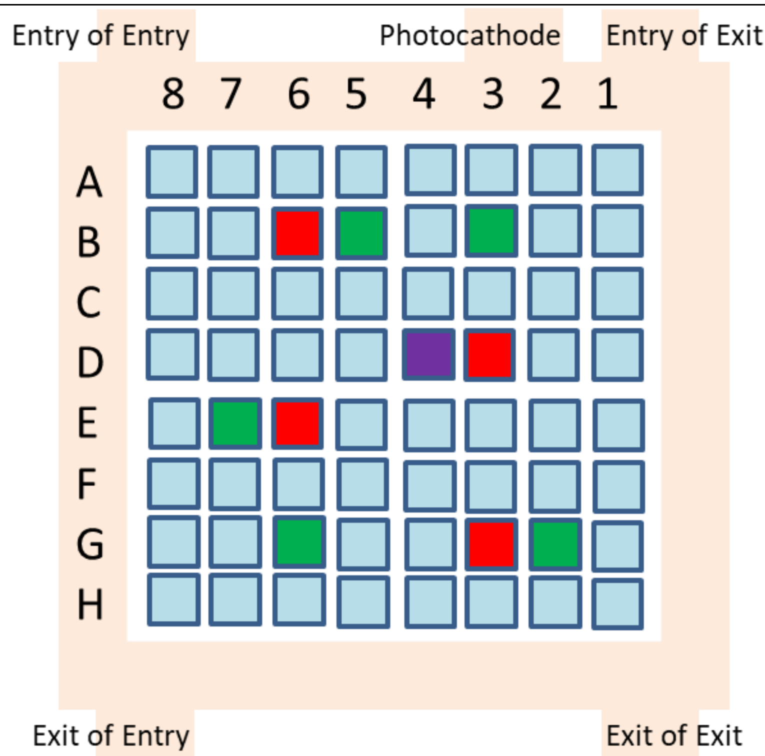


Figure 14: Layout for pads used to test LAPPD 124 (as seen looking directly at the front of the detector). The pad highlighted in purple was used to collect waveforms for gain, gain vs rate, and transit time spread. The pads highlighted in green were used to collect data for spatial gain calculations. The pads highlighted in red were used to collect dark rates. Light blue pads were not used. [A]

Footnotes

A LAPPD 124 01/28/2022 Data.xlsx

LAPPD Testing Protocols

Introduction

Functional tests were performed on the LAPPD in a dark box that was fitted with a UV light source and signal acquisition hardware. A summary of the results is shown below. The measurements include:

1. **Gain**
   - Gain vs. MCP and Photocathode voltage
   - Gain vs. repetition rate
2. **Dark rates** vs. MCP and photocathode voltage
3. **Transit Time Variation**
4. **Photocathode QE spectrum and map**
5. **MCP resistance vs. voltage**
6. **High voltages and currents vs. time**
7. **High voltage connection diagram**

Gain

Gain vs. MCP voltage

Gain was measured as a function of MCP voltage, using PSI DRS4 waveform samplers. MCP pulses were produced by directing a 405 nm Pilas 19-63 pS UV pulsed laser to a selected point on the LAPPD window. The laser was triggered externally at 3.0 kHz.

A neutral density filter (NE540B from Thorlabs) and a polarization filter were used on the laser to reduce the intensity to the single photon level. At this level, the LAPPD responded 15-30% of the laser pulses.

The gain results are a function of both MCP and photocathode voltage. The average LAPPD gain for single photoelectrons is as high at 9.12×10^6 at 900 V/MCP and 10 V on the photocathode. The gain tends to increase with increasing photocathode voltages. This is consistent with the expected increase in the number of secondary electrons from the MgO film as incident electron energy rises (Jokela et al., 2012).

Typically, pulse height distributions are well-separated from threshold at 900 V/MCP and above.

Gain vs. repetition rate

When a microchannel produces a charge pulse, it needs time to recharge. Otherwise, subsequent pulses will be smaller than the first. The microchannel plates are suitable for high rate conditions because the channels are nearly independent of each other, and unless the same one is struck twice, they will have time to recover.

The reduction of gain as a function of rate was tested by applying the 405 nm laser to a spot on the LAPPD window, of about 1 mm in diameter. The repetition rate was changed, and the corresponding gain was measured. Based on Photocathode QE, the LAPPD typically respond to 3-6 out of 20 laser pulses. The gain is therefore also analyzed as a function of observed pulse rate, rather than the laser trigger rate. The gain typically declines by a factor of approximately two as the observed rate is increased from ~0.2 kHz/mm^2 to ~50 kHz/mm^2), a gain decrease typically from 1×10^7 to 5×10^6.

This rate is somewhat threshold-dependent, so at higher rates, some pulses fall below threshold and therefore the pulse height distributions shift to the left, corresponding to reduced gain.

Dark rates vs. MCP and photocathode voltage

Dark rates are a function of MCP voltage and photocathode voltage. The higher photocathode voltages tend to increase the gain, but they also increase the dark rates. Rates were acquired from an average of four 6.25

cm^2 pads. Some combinations of MCP and photocathode voltages can sharply increase the dark rates, simultaneously create high voltage current instabilities, and produce excess currents to ground within the LAPPD.

The Recommended Operating Point (ROP) voltages are selected by examination of the gain and dark rates as a function of MCP and photocathode voltage. The voltages are high enough to provide a gain in the mid-10^6 range, good transit time spread, and yet avoid high dark rates and high voltage current instabilities.

Transit Time Variation

The time variation between the initiation of a photoelectron and the arrival of the MCP pulse at the resistive anode above the corresponding pixel is of interest for timing applications. This variation represents the timing uncertainty of the LAPPD. The time variation was measured by using a fast photodiode to directly monitor the 405 nm laser pulse. The time difference between the monitor pulse and the corresponding pulse from a single pad was measured using the DRS4 waveform samplers. The variation in this time is the transit time variation of the LAPPD. Variations may come from phenomena such as the depth to which the photoelectron advances into the microchannel before striking the walls of the channel. Additional variations arise from electronic noise superimposed on the pad measurement, and on the photodiode waveform. There is also a ~±25 pS jitter in the width of the DRS4 timesteps, which is not corrected here. Hence, the quality of the measurement is somewhat environment-dependent, and the result here may not be the best achievable with the LAPPD. Typically, the best transit time variation is found at an MCP voltage setting with a high gain before excess dark rates are observed, and with at least 100V on the photocathode.

The transit time variation was also measured as a function of photocathode voltage, at a fixed MCP voltage. Typically, the transit time variation improves rapidly with increasing photocathode voltage, up to about 50 volts. Above that, the variation continues to improve, but at a slower pace.

The 405 nm laser that is used for the LAPPD tests has a 19 pS FWHM firing window at the laser intensity used for the measurement. The intensity is further reduced by a neutral density filter to produce single photoelectrons. Therefore, the laser photon that produces the single electron may arrive at any time within the 19 pS window. The standard deviation of the distribution is measured. The variation of the laser photon is believed to have a standard deviation of (19/2.35) pS. Therefore, the LAPPD transit time variation may be extracted as a sum of squared variations using the following formula, where σ_{LAPPD} is the desired quantity:

$$\sigma_{Meas}^2 = \sigma_{LAPPD}^2 + \sigma_{LaserWidth}^2.$$

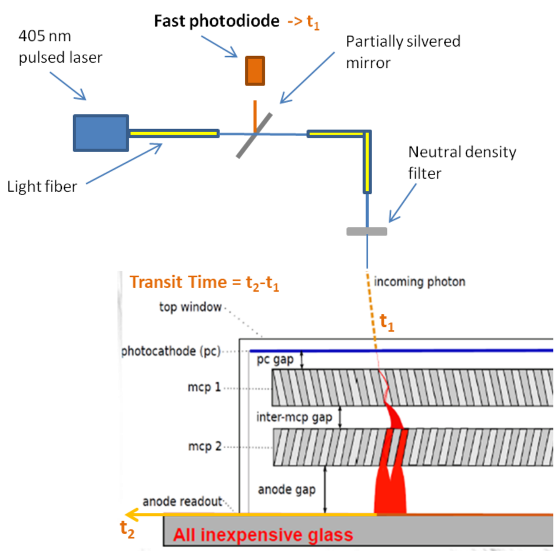


Figure 15: The measurement of the Transit Time Variation is shown.

Photocathode QE spectrum and map

The quantum efficiency of the photocathode was measured across the LAPPD window by scanning a 365 nm UV LED in an XY pattern of 3 mm steps. The illumination on the window had a circular pattern with a ~2.5 mm diameter. The intensity of the input light was measured with a Thorlabs SM1PD2A photodiode, and a Keithley 6485 picoammeter. The photocurrent was collected and measured by connecting both sides of the entry MCP to a Keithley 2400 picoammeter, with a 42 V bias voltage between the MCP and the photocathode. The quantum efficiency is calculated from the ratio of these two quantities, less the dark current in each.

The UV LED source was stepped across the LAPPD window, and at each step, the input light intensity was measured, as well as the resulting photocurrent. The X-spacers are visible in QE maps.

A series of QE maps are made throughout testing, beginning at the fabrication chamber and the initial installation in the darkbox, and then after characterization in the darkbox. Before and after characterization, the average QE is measured at 365nm, 420nm, 455nm, and 565nm. Typically, the QE will not change during testing within the uncertainties of the QE measurement. Changes in QE that occur with operation would normally suggest that the photocathode degraded as a result of ion implantation of feedback ions, while changes that occur with elapsed time would suggest leakage. Variation of the average QE in the plots may be symptomatic of the uncertainty of the QE measurement.

A reduction in QE might occur if ions are ejected from the entry MCP through an ion feedback during operation. The electric field imposed on the MCPs to make the electron cascade move down to the anode will also drive loosely bound ions upward. If the ions implant in the photocathode, the composition of the photocathode, and therefore the ionization energy, could change.

MCP resistance vs. voltage

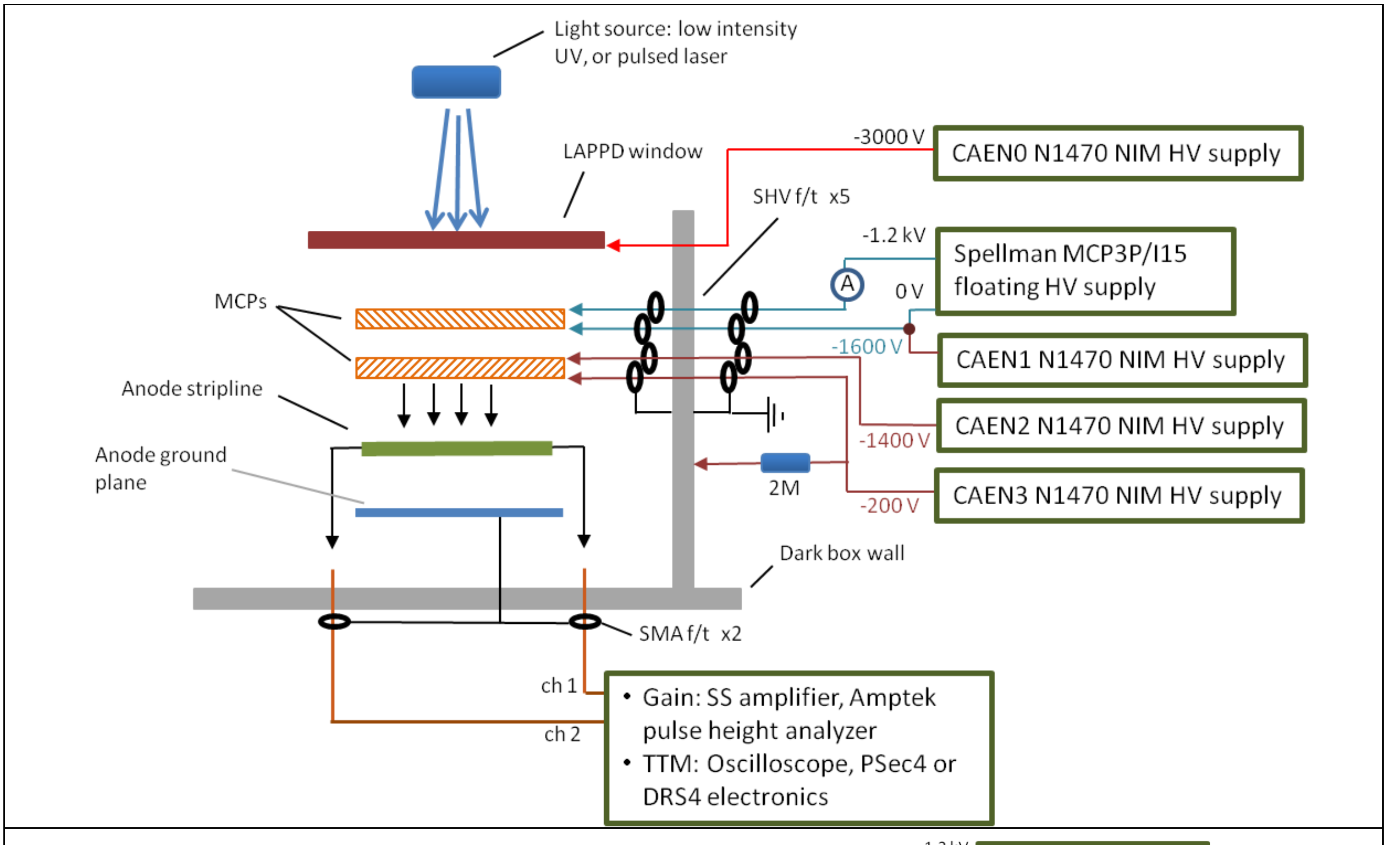
The MCP resistance is measured as a function of voltage. MCPs are non-ohmic, and their resistance decreases somewhat with increasing voltage. Some of this behavior may be attributed to warming, as the MCP resistance decreases with increasing temperature. The variation of resistance with voltage must be considered if a resistor divider network will be used to distribute high voltages.

High Voltage Stability vs. Voltage

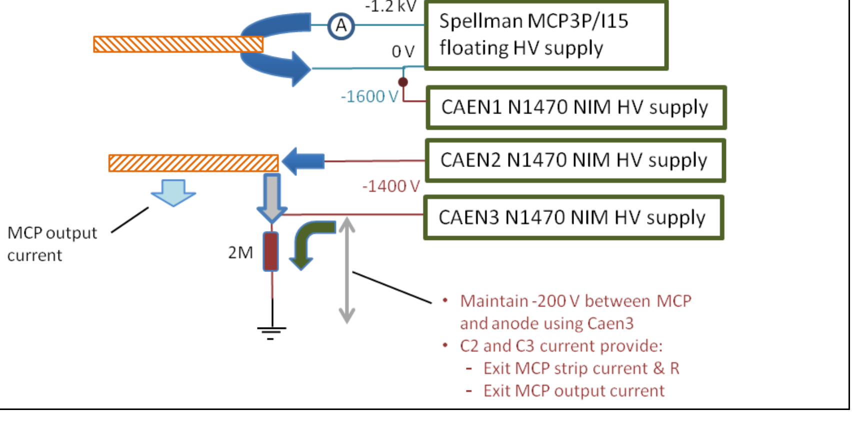
The LAPPD is typically electrically stable up to 1000V per MCP and up to 400V bias between the entry MCP and the photocathode. However, as the voltages across each MCP and the photocathode bias are increased, eventually the LAPPD will be driven into an unstable state where the currents start fluctuating by several to a few dozen µA and the dark rates sharply increase. The voltage settings at which this phenomenon occurs vary from LAPPD to LAPPD, but the ROP for each LAPPD is selected to maximize gain while nullifying the risk of driving the LAPPD into this unstable state. Typically, this unstable state occurs only when increasing voltage, and not when the LAPPD is left running. In fact, sometimes when the LAPPD is driven into this unstable state, the device will stabilize over time if left running.

High voltage connection diagram

The high voltages may be connected as shown in Figure 16 for maximum control of the LAPPD. This arrangement is used for all measurements at Incom. This approach separates the current paths of the entry and exit MCPs, so anomalies in either may be detected. Additionally, the photocathode voltage may be controlled independently of the MCPs. Without changing the MCP gain, the photocathode voltage may be increased, which will increase the LAPPD gain somewhat as the photoelectrons acquire more energy before impacting the microchannel. Alternatively, the photocathode voltage may be decreased so it is more positive than the entry side of the entry MCP. In this case, the photoelectrons will remain at the photocathode, and the MCP dark pulses may be observed. This state may also be used if an accidental exposure of the LAPPD to light is anticipated.



- Monitor MCP currents separately.
- Accommodate either orientation: high resistance MCP on the entry or exit side
- Don't close the strip current of the entry MCP through the exit MCP.



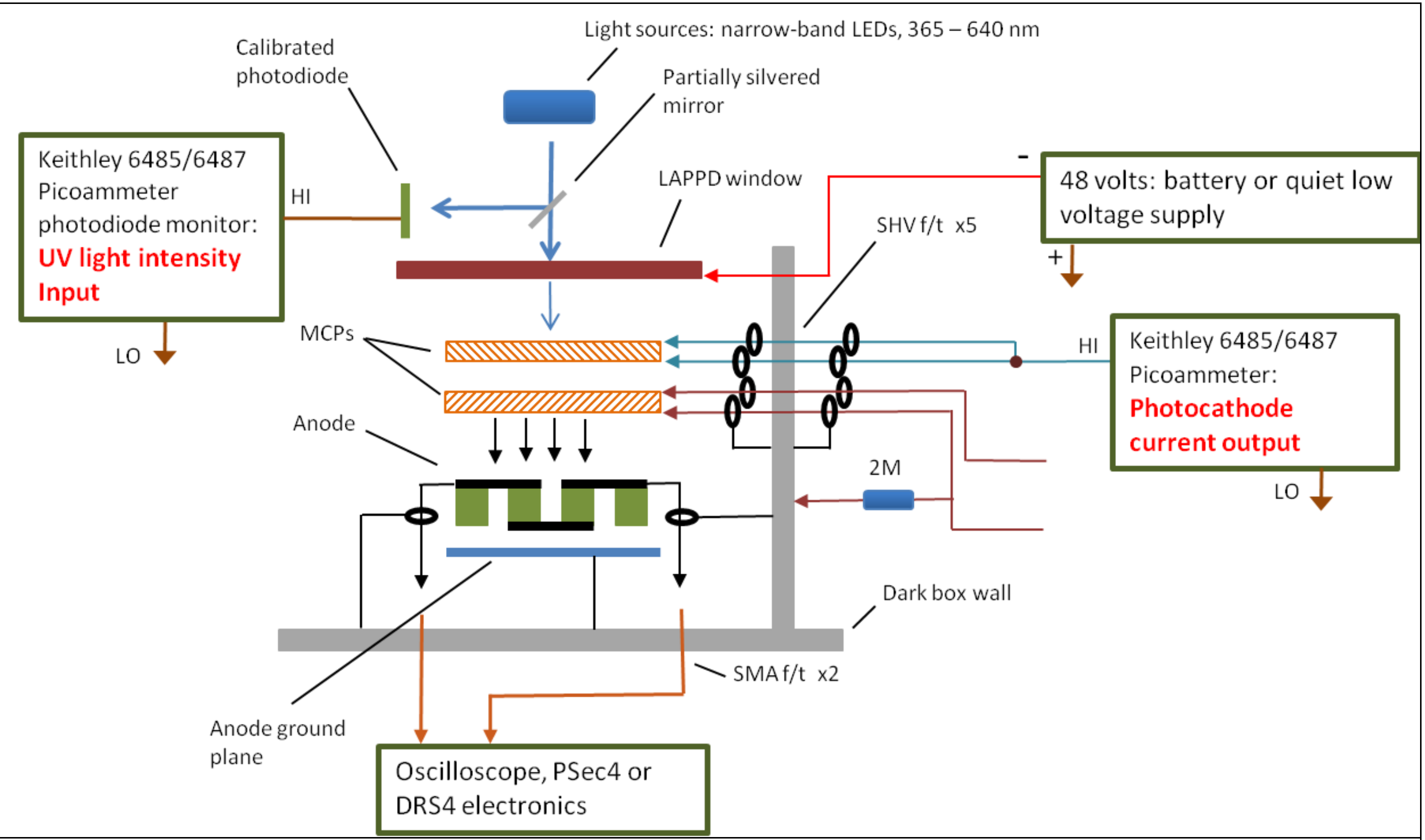


Figure 16: Top - The wiring diagram for high voltage and signals is shown for the LAPPD gain and timing testing at Incom.
Middle - A schematic shows the separation of the two MCP current paths, and the techniques used to separately measure the output current to the anode and the strip current through the exit MCP.
Bottom - The wiring diagram for the QE measurement is shown. The exit MCP and the anode are not involved in this measurement. Instead, the entry MCP serves as the anode for the photocurrent.

Signal and High Voltage Connectivity

An ultem housing and a backplane are provided with each LAPPD (Figure 17). The backplane connects the pixels to SMA connectors with near-50 Ω impedance. The ultem housing provides the high voltage connections. They consist of SHV panel mount connectors on the outside, and Mill-Max spring-loaded ball tip pins on the inside. The pins touch the high voltage pads on the LAPPD envelope. The 5 high voltage connectors are labeled according to their function. The shields on the SHV connectors simply terminate the high voltage cable shield, and minimize unwanted signal pickup in the detector. They do not close any high voltage current paths.

Packing

The LAPPD is wrapped in an antistatic bag and placed in a Pelican case with antistatic foam (Figure 17). The bag helps manage static charging, which could be harmful to charge-sensitive electronics that will be attached to it. It also keeps unnecessary stray light from exciting the photocathode, and charging the entry MCP.

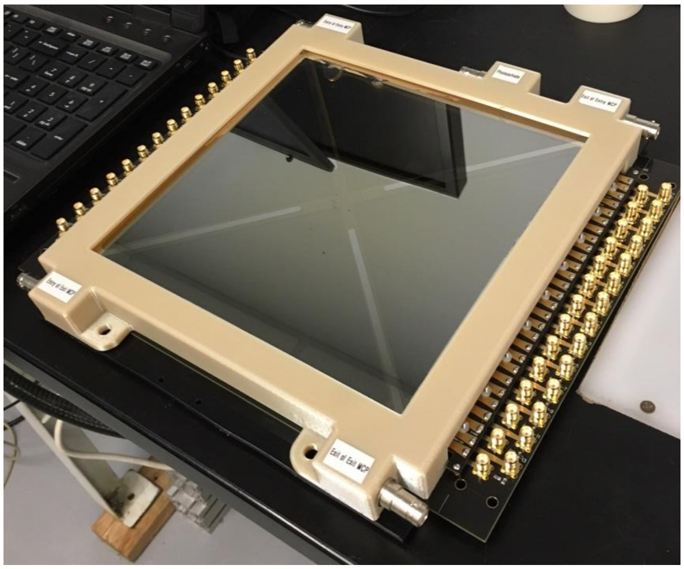


Figure 17: Left - the LAPPD is enclosed in an Ultem housing with high voltage connectors, and mounted on a backplane for signal access. Right - The LAPPD is wrapped in foil to manage static charging, and to keep stray light from the photocathode.