Systems-Level Characterization of Microchannel Plate Detector Assemblies,
Using a Pulsed sub-Picosecond Laser

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Abstract
Micro-channel plates (MCPs) are widely used as electron amplifiers in applications ranging from charged-particle detection to photon counting, imaging, and night vision. To date, obstacles in wider use of MCPs are the complicated and costly manufacturing process, fragility, and limited lifetime. Recently, the method of atomic-layer deposition (ALD) has been applied to the production of relatively inexpensive, robust, and high-performance MCPs. Furthermore, ALD opens a large parameter space for optimization. In order to fully make use of it, detailed characterization tools are required to measure gain, and timing characteristics, not only of the plates themselves but in configurations approximating complete detectors. Here, we report on such a characterization effort based on a short-pulse laser.

Keywords: microchannel, MCP, time-of-flight, ...

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1. Introduction
Microchannel plate photomultiplier tubes (MCP-PMTs) are compact photodetectors [1], known for their excellent spatial and time resolutions [2, 3, 4], and capable of being operated as both imaging and photon counting devices. These properties make these photodetectors ideal successors to conventional photomultiplier tubes (PMTs) for a wide variety of applications such as in high energy particle physics, medical imaging, and X-ray detection. The Large Area Picosecond Photodetector (LAPPD) collaboration has developed techniques for making large-format MCP-PMT detector systems using scalable methods and low cost materials, attacking all aspects of the problem: from the photocathode and the gain stage to the readout electronics and vacuum packaging. A central aspect of the project is a technique known as atomic layer deposition (ALD) [5], which enables the fabrication of large-area MCP gain structures by conformally coating inactive, porous glass substrates [6, 7]. This approach allows for the independent optimization of the geometric, resistive, and secondary electron emission properties [6] of the channel plates. It also enables bulk activation of larger microchannel plates than could be made using conventional techniques.

Essential to the development of new photodetector technology is the ability to characterize the components of these devices, individually and in configurations approximating complete systems. The LAPPD collaboration has developed a wide variety of detector characterization facilities. In this paper we will describe a system developed for testing MCP detector systems in vacuum chambers, using a pulsed (O(100) femtoseconds) Ti:Sapph laser. Located at the Advanced Photon Source (APS) at Argonne National Laboratory (ANL), this laser-test stand exploits the unique properties of a pulsed laser to make precision measurements of the timing, position, and gain characteristics of microchannel plate detectors. The lab is capable of testing a wide variety of microchannel plate and anode configurations along with a simple metallic photocathode used to provide a well-defined photoelectron source.

Use of a pulsed laser provides many advantages in characterizing photodetectors. By triggering to the short, sub-picosecond pulses, we can make very precise measurements of the MCP time resolution -the so-called transit-time spread (TTS). The low duty-cyle of the laser can be used to gate out dark noise and identify any after-pulsing, if present. Using statistical arguments, we can identify single photo-electron operation without detailed calibrations, attenuating the laser pulses to the point where few pulses produce any signal and the likelihood of exciting two photoelectrons is highly unlikely.
2. Outline

In this paper we describe the complete pulsed-laser testing facility, and the analysis techniques used to characterize MCP detectors. Section 3 describes our experimental setup in several stages. The vacuum chambers and detector assemblies are described in Sec 3.1. The optical setup and laser diagnostics are discussed in Sections 3.2 and 3.3, respectively. Section 3.4 outlines the method for ensuring single photoelectron operation. The high voltage system is described in Sec 3.5 and readout in 3.6. Section 3.7 introduced the concept of systematic scans. Section 4 describes our methods for reconstructing and analyzing MCP signals. Our criteria for identifying MCP pulses is described in Sec 4.1. Charge integration and calibration are described in Sec 4.2 and 4.3, respectively. Time resolved characterization is discuss in 4.4. We provide concluding remarks in Sec 5.

3. Experimental Setup

Our characterization facility is designed to accomodate two different testing programs. Development of new MCP chemistries and geometries is studied on small disk-shaped channel plates, 33mm in diameter - a size chosen because it conforms to a common standard used in the night vision industry. Our 33mm program is focused on the fundamental properties of the channel plates themselves, and allows for rapid turnaround. A parallel program for testing full-sized 8" x 8" square MCPs was developed to test detector systems closer to our final LAPPD design. This effort focuses more on systems integration issues, such as the interface between our gain stage and anode design. Both the 8" and 33mm programs share a common optical setup for directing focused, well-characterized, pulsed UV on the detectors, and a common readout system for recording the MCP response. In the following sections we will describe these systems.

3.1. Vacuum Chambers and MCP Mounting Fixtures

Two vacuum systems were designed to accomodate testing of 33 mm microchannel plates and the larger, 8”x8” format, both using standard high vacuum components. These systems are capable of operating at vacua better than $10^{-7}$ torr. They consist of large steel chambers evacuated using turbo pumps in series with scroll pumps. The chambers are sealed with CF flanges, using copper gaskets and viton O-rings. These systems allow testing of large detector systems, free from the constraints of making permanently sealed tubes.

3.1.1. The 33mm MCP Characterization Chambers

For 33 mm testing, the MCP stack is attached a CF-8” flange (shown in Fig 2), with 4 ports available for various feedthroughs. This flange can be attached to a UV-transmissive, fused-silica vacuum window to form a compact, self-contained detector system, or it can be attached to a larger chamber. We typically side-mount the MCP-flange on a small vacuum cross, the surface of the MCPs facing perpendicular to the laser, as shown in Fig 2.

Interchangeable anode boards can be mounted directly onto the CF-8” flange with the MCP-holder sitting above on ceramic posts. The MCP holder, designed at Berkeley Space Sciences Laboratory (SSL), can accomodate stacks of 1, 2, or 3 MCPs with a simple metallic photocathode at various spacings. Figure 1 shows a typical stack of two MCPs. As a naming convention we number the MCPs in order of increasing distance from the light source. Likewise, the top and bottom of the MCPs correspond to the faces pointing toward and away from the light source, respectively.

Both the flange and anode are kept at ground, while the voltages on the electrodes of the MCP stack can be individually controlled. The spacing between the bottom of the MCP assembly and the anode board is approximately 7mm. Spacings of 0.5 mm between the MCPs and between the photocathode are determined by the thickness of our electrodes and thin capton spacers.
Figure 1: Schematic of a typical, two-MCP stack mounted on the 33 mm test-flange. Photons striking the photocathode produce electrons by the photoelectric effect. These electrons are accelerated across a potential gap towards the gain stage, which consists of two porous plates, optimized for secondary electron emission. These plates are typically held at field strengths of 1kV/mm. Electrons accelerate down the pore walls producing an avalanche of secondary electrons. The amplified signal drifts across a final accelerating potential where they form a signal on the anode plane.

Figure 2: A schematic of the 33mm MCP test-chamber (more details to be added to the diagram).
3.1.2. The 8'' MCP Characterization Chamber

In the larger testing chamber, 8'' square MCPs sit in a glass tray at the bottom of the chamber (shown in Fig 3). The laser beam enters through a fused silica vacuum window on the side of the chamber, and is reflected downward onto the stack by an array of 2'' mirrors at 45°. Signals and high voltages are connected to feed-throughs on a flange attached to the top of the chamber.

The holder for 8'' MCPs is a glass-tile assembly of the same specifications as the glass-body, sealed-tube design developed by University of Chicago and ANL [8]. Free from the constraint of sealing the tube, this setup can also accommodate variable stacks of one or more MCPs and various spacings. Glass grid spacers, similar to those in the design for the vacuum tubes, are used to separate the various components of the stack. High voltage connections between the MCPs are made using thin sheet-metal electrodes, framing the outer few millimeters of the MCPs and aluminum photocathode and allow for independent voltage control at each stage of the detector. The glass anode plate is patterned with 32 silver striplines, 4.62 mm wide and spaced with a 2.29 mm gap between them [9]. The anode pattern is soldered on to a custom fanout board with SMA connectors [9]. Unused channels are 50 ohm terminated while the signal channels are brought out from the chamber through vacuum feedthroughs with SMA cables. Both the anode and fanout cards share a groundplane made of copper-clad FR4 circuit board material. The assembly consisting of the stack in the glass tile and the copper-clad FR4 ground plate sits on a 10'' x 12'' breadboard. The entire MCP stack in the glass tray is compressed to make electrical contact, using steel crossbars with bowed ribbons of thin stainless-steel. These cross bars are screwed down onto the hole pattern of the breadboard. The complete assembly is shown in Fig ??.

3.2. Laser and Optics

Our choice of laser system is an infrared (800nm) pulsed, Ti::Saph laser operating at an average power of approximately 800 mWatts. The repetition rate is 1000 Hz, providing short (O(100) femtoseconds) 800 \( \mu \)J pulses. The laser light is sent through a pair of nonlinear-optical beta-barium borate (BBO) crystals to produce the third harmonic at 266 nm. Our current beam-spot is roughly 0.5 mm in diameter, but it is possible to achieve spots sizes below 20 microns to address individual. The oscilloscope trigger signal is derived from laser light incident on a fast photodiode with time jitter well below a picosecond.

Our optics are implemented in two stages. The first optical path is used to produce UV light and to remove residual IR and blue components. The UV production optics are diagrammed in Fig 4. A fast,
InGaAs photo-diode (www.judsontechnologies.com/InGaAs.html) is used to detect the occurrence of the laser pulses from reflected blue light, and provide an external trigger signal from which we can measure the arrival of the MCP signal. The photodiode is optimized for 1500 nm light, but the blue light is sufficiently intense to produce a strong signal, nonetheless. Given the precision of the trigger, it is possible to measure relative changes in arrival time to within less than a picosecond. It is also possible, by accounting for time delays from cabling and the optical path after the photodiode, to measure the absolute transit time of the avalanche to an accuracy in the tens of picoseconds.

The second stage of our optics is used to align, focus, characterize, and finally point the UV light at our MCP detector stacks. This optical setup is illustrated in Fig 5. A small colimation optic configured as a Galilean telescope is used to image the beam spot to a diameter smaller than a millimeter. This telescope is followed by a series of alignment mirrors and irises to parallelize the beam. Located between the alignment optics is a 50/50 beam splitter, directing half the light to a fast, UV optimized gallium phosphide photodiode used to characterize pulse-by-pulse variations. A flip mirror can be engaged to send the remaining light to a calibrated UV power sensor to provide absolute calibration for the output of the fast UV photodiode. When the flip mirror is disengaged the UV beam can continue on to the MCP detectors. Two translational stages control pointing of the laser on the MCP with micron-level precision, while keeping the beam at normal incidence to the MCP surface.

3.3. Characterization of Laser Pulse Energy

Energy of a pulsed laser can fluctuate from pulse to pulse due to instabilities in the amplifier operation. Any variability in the infrared intensity is further confounded by the non-linear process of frequency doubling and tripling in the BBO optics. In order to compare detector responses to laser pulses of equal energy, it is necessary to characterize the ultraviolet energy of each laser pulse. We choose to separate between the timing measurement and pulse characterization, retaining our sub-picosecond InGaAs trigger photodiode and adding a separate UV photodiode (UVPD) for measuring relative pulse energy of the weak UV light. For this purpose, we choose a Thorlabs FDS010 silicon photodiode with 0.82 mm² active area and 1 nanosecond rise time (www.thorlabs.com/Thorcat/0600/FDS010-SpecSheet.pdf). Given the limited channel count of our oscilloscope (4 channels) we combine the signal from both photodiodes into a single trace (shown in Fig 6), separated by an optical and cabling delay. The sharp rising edge of the first photodiode is used to trigger the oscilloscope, while the UVPD signal is integrated to determine the energy of each laser pulse. The integrated UVPD signal allows us to characterize pulse-to-pulse intensity in variations, and even select MCP data taken at constant laser intensities. Figure 7 shows the integrated UVPD signal over time, and a
Figure 5: Schematic of the imaging and beam steering optics for the pulsed UV light.

1 histogram of the variability in the signal. Currently, the relative pulse energy is determined by integration of the UVPD over a fixed time window with respect to the trigger.

2 The integrated UVPD signal can be used to compare the relative intensity of individual pulses, but the absolute energy of the pulses is unknown. While absolute calibration is unnecessary for our data analysis, it is nonetheless useful for tracking performance of the UVPD over time and for determining the approximate quantum efficiency of our aluminum photocathode. For this purpose we use a silicon UV photodiode with calibrated DC output proportional to the laser power by a known constant. This sensor, a Newport Optics 918DV-UV-OD3 (assets.newport.com/webDocuments-EN/images/918D_Manual_RevD.pdf), is not fast enough to distinguish individual pulses. However, averaged over many laser pulses it can be used to set an absolute energy scale for the integrated signal from fast UVPD averaged over the same period. A single trace from this detector is shown in Fig 8. Ringing from impedance mismatch is averaged out, looking at the mean signal over a long time base. Periodic calibration runs are taken by engaging a flip mirror that directs the out-going half of the UV beam to our calibrated Newport photodetector. The signal from this photosensor is compared with the other half of the UV beam, which is always pointing at the UVPD used for pulse-by-pulse calibrations. In order to ensure that the response of both detectors is being compared over the same time interval, the signals from both photosensors are recorded in separate channels of our oscilloscope for a set of 1,000 laser pulses. The average power measured by our calibrated detector is plotted against the average integral of the fast UVPD pulses. Many such sets are collected, varying the incident laser intensity using a continuous dielectric neutral density filter wheel. Figure 9 shows the relationship between average per-pulse laser energy (in Joules) and average integrated UVPD signal in (Volt-seconds). The plot shows a linear trend with non-zero offset. This offset is due to contributions from a variety of known sources, including the residual signal from the trigger photodiode bleeding into the UVPD trace, RF noise from the Pockels cell drivers of the laser, and small laser after-pulses from instabilities in the regenerative amplifier.

3.4. Identifying Single Photoelectron Operation

The use of a pulsed, sub-ps laser source is crucial for accurate timing measurements. It is also very helpful in gain measurements because we can calibrate the number of photoelectrons per pulse through photon statistics (attenuating to the point where only a fraction of the laser pulses yields a signal), and then dialing in any number of photoelectrons per pulse through simple intensity-ratio determination. This procedure is completely independent of the efficiency of the photocathode used.

The average UV laser power (O(100) nano-Watts) is sufficient to produce many photo-electrons per pulse, even with a low quantum efficiency (QE) aluminum photocathode. Without attenuation, the fraction of laser
pulses with an observed MCP signal is very close to 100%. However, we can attenuate the beam to the point where some fraction of laser pulses produce no discernable signal, as determined from the oscilloscope data using analysis techniques described in Section 4.1. Once we are operating in a regime where the fraction of events with good pulses is sufficiently low, we can assume that the probability of producing more than one PE is statistically suppressed. Figure 10 shows the relationship between average UV intensity and the probability of an MCP signal. The slope of this plot at low laser intensities can be used to extrapolate to higher intensities and allow for good control over the average number of photoelectrons.

3.5. High Voltages

High voltages are controlled by a WIENER power supply capable of 6 kV. Control of these voltages is fully automated, along with oscilloscope control. The power supply is four-quadrant, meaning it can apply both positive and negative voltages, and it can serve as both a current source and a current sink. The voltage is controllable over ethernet, using vx11 protocol. We can control and monitor the voltages using command-line scripts written in python. Similar python scripts control the oscilloscope and can acquire data automatically, for each voltage setting. This allows us to systematically study the parameter dependencies of the MCP performance on the operational voltages.

3.6. Anode, Readout, and Calibration

LAPPD anode coverage over large areas is achieved using a microstripline design. Position of the impinging photons in the direction parallel to striplines by measuring the differential time between the signal arrival at the two ends of a stripline. In the perpendicular direction, we determine the hit position by taking a weighted centroid of integrated charge on the stripline and its nearest neighbors. This design is ideal for economical MCPs as the number of readout channels scales with length, rather than area. This concept is discussed at length in Ref [9].

We use two different anode designs for our 33mm and 8” testing programs. The 33mm test flange uses a small, custom-designed printed-circuit with striplines 1.1 mm wide and spaced 1.6 mm center-to-center [?]. This board is designed with excellent 50 ohm impedance matching and better than 1 GHz bandwidth for precision characterization of MCP time resolution. Since the goal of the 33mm program is primarily to characterize the intrinsic timing characteristics of the MCPs themselves, we choose a readout capable of time-resolved measurements approaching single picoseconds.
Figure 7: a) Raw, integrated UVPD signal for each of 1000 laser pulses, showing variations in laser power as a function of time.
b) A histogram of integrated UVPD signal for the same 1,000 pulses, with corrections to the true UV pulse energy applied.
Figure 8: An example trace from the UV power detector. Output of the detector is a DC voltage. Ringing of the signal eventually stabilizes several nanoseconds after the initial pulse. We average the later part of the signal to determine the laser power, which is given by 42 nWatts per Volt.

Figure 9: Integrated signal from the UV photodiode provides useful proxy for the energy of each laser pulse. However, it is convenient to translate these integrated signal (in units of Volt-seconds) into physically meaningful units. Each time we acquire 1000 laser pulses in our scope, we use our UV power detector. Comparing the average signal from this UV power detector with the average integral of the UV photodiode, allows us to relate the UV photodiode signal with pulse energy. This figure shows the relationship between the integrated UV photodiode (UVPD) signal and the laser pulse intensity in Joules.
A major goal of the 8” testing program is to benchmark the readout for our “frugal” anode design, designed for large-area coverage. The anodes consist of silver strips silk-screened onto glass, sharing a copper ground plane. The striplines are 4.62 mm wide spaced with a 2.29 mm gap between them. There are 32 strips on the 2.75 mm thick glass plate. This design, when characterized with a vector network analyzer (VNA), reliably provides an analog bandwidth of better than 1 GHz and 50 ohm impedance, which should be sufficient to exceed 100 picosecond single PE time resolutions. Further discussion of the anode design can be found in [9].

Anodes in both the 33mm and 8” test systems follow the same generic circuit diagram, shown in Fig 13. Signal from both sides of each stripline is brought through internal SMA cables to a cluster of SMA feedthrough flanges. External, shielded SMA cables bring the signal to our readout electronics, consisting of either a 3.5 GHz Tektronix DPO7354 oscilloscope (www.tek.com/datasheet/node/796059-digital-phosphor-oscilloscopes) or custom-circuits built around LAPPD-developed chip technology designed specifically for waveform sampling of MCP signals. In either case, we use Mini-Circuits VLM-33+ wideband limiters (www.minicircuits.com/pdfs/VLM-33+.pdf) to protect the electronics from overloads. These fast limiters transmit the fast MCP signals (30 to 3000 MHz) with minimal distortion, but prevent large over-voltages from passing through and damaging our sensitive readout electronics. The limiters do block DC current. Thus, when reading out two sides of a single stripline, it is necessary to prevent the anode from charging. To accomplish this, we connect one side of the delay-line to a Pasternack PE1606 bias-T (www.pasternack.com/images/productpdf/PE1606.pdf) shorted to ground with a 10 kohm resistor, capable of draining the charge without diverting the fast signal. The number of instrumented striplines is limited by the number of available vacuum feedthroughs (currently 8 for both chambers), which is sufficient since the oscilloscope can only read 4 channels at a time. Those striplines not accessible through the vacuum feedthroughs are internally 50 ohm terminated to ground. The external SMA connections not connected to the readout electronics are externally 50 ohm terminated.

Losses in signal transmission and biases from our charge integration algorithm are characterized by injecting fast signals of known charge on one side of a stripline to be measured on the other side. We use a Tektronix AWG7102 Arbitrary Waveform Generator (www.tek.com/datasheet/arbitrary-waveform-generator-1) to produce 1 nsec pulses range from xx to yy nC. We can also split the signal using a 50/50 resistive splitter, integrating and recombining the measured charge offline, to mimic the effects of MCP

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![Figure 10: At sufficiently high laser intensities, the probability of producing an MCP signal approaches unity. As we attenuate the laser below roughly 10 million UV photons per pulse. The probability of photo-excitation begins to drop.](image-url)
charge spreading over multiple anodes. These pulser tests are conducted in two operational modes. First, we operate the signal generator in self-triggering mode, with the laser turned off. Tests are then repeated with the laser turned on, using the laser clock to trigger the pulse generator. In this mode, the calibration pulses are timed to overlap with any RF noise generated by the Pockels Cell drivers of the laser, so that the effects of RF noise on charge reconstruction can be studied. Results of these pulser tests will be discussed in Sec 4.3. Figure 11 shows a schematic of these configurations. The system is calibrated using a network analyzer and by sending pulses of known signal through a stripline from one end and out the other.

Given a limited number of readout channels, we are restricted in the number of possible simultaneous measurements. Consequently, data acquisition is typically performed in one of several modes, shown in Fig ???. When measuring absolute arrival time and reconstructing MCP pulse heights, we record the signal from one side of each of three consecutive striplines, with the laser pointing at the central of these three striplines (Mode 1). When studying the differential timing between to ends of a stripline as a function of the laser position in the direction parallel to the strips, we record the two ends of one strip and one neighbor, with the laser centered on the two-sided strip (Mode 2). In both of these configurations, those channelss which are not connected to the oscilloscope are 50 ohm terminated, and the remaining free scope channel is used for our trigger and UVPD signal, as was discussed in Sec 3.3. One final operational mode (Mode 3) is to record two sides of a single stripline with one side of its nearest neighbors on either side. Uninstrumented ends are 50 ohm terminated. However, the oscilloscope is triggered directly by the MCP signal on one side of the central strip. This self-triggering mode allows measurement of the differential timing and symmetric charge collection, but at the sacrifice of the precision timing from the trigger photodiode and the pulse characterization from the UVPD.
Figure 12: Three configurations of the four-channel readout. The laser spot (shown as a blue dot) is focused on the central strip of a three stripline cluster. The two sides of all three striplines and the trigger photodiode add up to 7 possible readout channels. Since the oscilloscope can only read four of these channels, we must select a subset of the channels for any given measurement.

3.7. Operational Scans

Once the laser is attenuated to the desired intensity we are ready to collect data. We operate in digital scope in “fast-frames” mode which allows us to write multiple trigger events to disk automatically. We collect many thousands of pulses for a given configuration of operations voltages and a particular beam position. These full traces can then be analyzed offline to extract shape information as well as study variability in MCP performance. Charge integration is used to determine MCP gain, while timing of the signal relative to our trigger photodiode is used to determine the time resolving properties of our MCPs.

4. Analysis

Data analysis is performed in several steps. Selection cuts are applied to identify trigger events that contain MCP pulses and those without a signal. Triggers without a signal are due to low intensity pulses that fail to produce a photoelectron and MCP inefficiencies detecting photoelectrons. Once a significant signal has been identified on at least one stripline, signal integration is performed to determine the charge produced by the microchannel plates. We look for signal not only on the primary stripline, but its nearest neighbors as well. Finally, we want to measure the timing response of the MCP stack, specifically several observables: the rise time of the MCP signal, the full-width at half-maximum (FWHM) of the pulse, the arrival time of the signal relative to the trigger, and the difference in arrival time between the two ends of a stripline.

4.1. Discriminating MCP Pulses from Noise

Microchannel plate gains vary over a wide range. Even plates operating with average gains approaching $10^7$ produce a significant number of low gain events. These signals are further reduced when spread over time and over several readout channels. Given the presence of electronics and RF noise, one must discriminate between low gain, single photoelectron events and null events with noise. In order to discriminate between triggers with MCP signal and null events, we construct a measure of “significance” based on deviation of the signal from random noise about the baseline.

Noise in the readout is determined by taking the RMS of the first 100 points of our trace. The DC baseline is determined by taking the median value of the scope trace. Since the signal is spread over many samples in time, we do not want to determine the significance of a trigger event on the basis of the single
Figure 13: a) Both of the MCP test chambers use a microstripline anode structure to collect pulses produced by the microchannel plates. Readout from the striplines is sent through SMA cables to high bandwidth oscilloscopes...protection...bias T-with drain resistors...chamber allows readout of both sides of 4 striplines...scope allows 4 channels at a time... b) Schematic of our pulser calibration setup

sample-point with the highest significance. Rather, we look at the combined signal of several neighboring samples, in a moving window about each point in the trace. We determined a good window-size for the moving sum to be roughly equal to the rise time of our signal. Significance is then defined as the peak value of this moving sum minus the baseline and normalized to the RMS noise. Figures 14 shows the “significance” distribution for a particular set of MCP data.

4.2. Charge Integration, Centroiding, and Gain Characterization

Charge is integrated numerically, summing the pulse signal over a roughly 4 nanosecond window about the signal peak. Position of the window starts off centered on the peak signal, but is then adjusted to maximize the integral, thus accounting for the asymmetry of the pulse shape. Charge from the pulse can spread over several striplines, especially in our 33mm chamber, where strip width is only 1.1 mm. With the limited number of 4 readout channels available on our oscilloscope, we can only readout charge on one side of each of three striplines. Once the integral range is determined for the stripline with the peak signal, we integrate and sum the charges on neighboring strips.

In the 8 inch chamber, one needs to correct for losses over the long transmission length. These losses will be studied in future publications. In this paper we present pulse height distributions measured using our 33mm chamber. The anode is so small in this setup that we can safely assume equal losses on both sides of the stripline. These losses are determined by pulser calibration, using the system described in Sec 3.6 and are presented in Sec 4.3.

Figure 17 shows the pulse height distributions for a pair of 33mm MCPs. We sum over the 3 striplines and multiply by a factor of two to correct for the charge lost in measuring only one side of the anode. We convert from units of Volt-seconds by dividing out the 50 ohm impedance and the elementary charge to express the PHD in terms of number of electrons.

The position of the incident photon in the direction transverse to our microstriplines is determined by calculating the charge centroid of signal collected on multiple strips. Fig 15 shows the centroid distribution, in units of strip-number, for a series of laser pulses focused on the central strip of a three stripline cluster.
Another useful observable is the fraction of the three-strip charge contained on the central strip, shown in Fig. 16. This observable helps us to understand how well the charge from a single photoelectron is concentrated over the target stripline.

4.3. Calibrating the Charge Reconstruction with Pulser Signals

In order to determine the final charge extracted from the MCP stack - and, equivalently, the gain - we must integrate the signal measured on our anode strips. This presents several challenges. First, the MCP signal is typically spread over several striplines. Second, there are some losses due to transmission along the strips and cabling. Miscalibration of our oscilloscope could introduce a bias, as could flaws in our integration algorithm. Finally, some RF noise introduced by the Pockels cells in our laser could contribute to some of the integrate signal from the MCP.

We calibrate for all of these affects by sending pulses of known charge - provided by a fast pulse generator - through our readout system. First, we sent the pulse generator directly into a single channel on two oscilloscopes to verify pulse characteristics claimed by the generator. Next we injected the pulses into one end of our readout, recording the signal at the other side of the readout, as described in Sec ?? . These tests were conducted both looking at the pulser signal through one microstripline readout, and with the signal split into smaller signals through several channels (to simulate the effects of charge spreading). We conducted these tests using both the internal clock of the pulse generator and using the laser as an external trigger, so we could study any changes in the integral due to Pockels cell contributions on top of the signal. Figure 18 shows the result of our pulser calibration tests.
Figure 15: Location of signal centroid for several thousand laser pulses. Position of the signal is defined with respect to the stripline number of a three strip cluster, where the laser was directed over strip-2.

Figure 16: Fraction of total three-strip charge collected on central strip, for pulses with centroid location within 0.4 units of stripline number of the central strip.
Figure 17: Pulse height distribution in single PE mode

Figure 18: Pulses of known charge are sent through our readout system, the pulse signal split into three components of varying size. Each of these components is recorded by our oscilloscope. The signals are integrated and summed to reconstruct the charge of the original pulse. This figure shows reconstructed charge versus true charge for known pulses of various sizes. (DUMMY PLOT)
4.4. Timing and Transit Time Spread

The intrinsic time-of-flight resolution of MCP-based detector systems is limited by the capabilities of the readout electronics and the properties of the microchannel plates themselves. With sufficiently fast electronics and an equivalently precise external trigger, it is possible to characterize the intrinsic jitter in the time response of MCPs, known as the Transit Time Spread (TTS). An important feature of our pulsed laser based characterization is the ability to measure this TTS. Given pulse durations of O(100) femtoseconds and similar uncertainties on our trigger photodiode, we can measure the relative time response of an MCP to within a single picosecond. Pulses are recorded on a readout with analog bandwidths better than 500 MHz, noise O(1) mV, and multi-Gsamples per second.

The simplest method to extract the arrival time of the pulse is by using a predefined absolute threshold. In this case, the arrival time is determined by a point on the pulse trace which first crosses the threshold. However, relatively long rise time of the MCP pulses (\(\sim 1\text{ns}\)) leads to so-called time slewing, a dependence of the measured arrival time on the pulse amplitude. This time slewing can be corrected by using constant fraction discrimination (CFD) method where the threshold is defined as a certain fraction of the total pulse amplitude. We chose this fraction to be 50% and the arrival time of the pulse is determined by a point on the trace which first exceeds 50% of the pulse amplitude. Figure 19 shows a schematic of a typical MCP pulse, illustrating our definition of the constant fraction thresholds. The distance between sampling points on our scope is 100ps therefore we are not using the actual measured points on the trace but a spline around the measured points to determine the time when the 50% threshold was crossed.

The transit time spread is determined from the transit time distribution. Figure 20 shows a transit time distribution obtained with our 33 mm setup. We fit the central part of the distribution with Gaussian and we quote sigma parameter of the fit as a transit time spread. We check that transit time spread does not depend on our choice of the fraction threshold. Transit time spreads for the thresholds of 25% and 75% are compatible with \(\sim 17\text{ps}\) measured with 50% threshold.
5. Conclusion

Pulsed laser systems are very useful for characterizing microchannel plates, particularly in the time domain. As the intrinsic time resolution of MCPs continues to improve, fast pulsed lasers could play an important role in characterizing these improvements. The use of varied diagnostic tools and careful calibration can overcome some of the imperfections in a laser system, such as variability in the laser intensity.

We have demonstrated methods for determining gain, position, and time resolution of single photoelectrons on MCP detectors using such a laser system with a microstripline anode and oscilloscope readout. These measurements were limited by the number of available channels provided by the oscilloscope. Low cost CMOS technology under development providing high-bandwidth, fast sampling chips could enable the characterization of detector systems with as many as 64 channels. Further improvements can be made with respect to the reconstruction algorithms. While we present simple numeric techniques in this paper, future analyses could benefit from sophisticated fits to the full shape of the MCP pulses.

References