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Note: Position dependence of time signals picked off a microchannel plate detector

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Using an ultrafast laser and a precision mask, we demonstrate that time signals picked off directly from a microchannel plate detector depend on the position of the hit. This causes a time spread of about 280 ps, which can affect the quality of imaging measurements using large detectors. © *2015 AIP Publishing LLC.* [http://dx.doi.org/10.1063/1.4906327]

The use of multi-hit detectors that provide time and position information for each of a few particles created in a single event is widespread across many disciplines, ranging from atomic, molecular, and optical (AMO) physics[1–3] to nuclear physics,[4] particle physics, and space instrumentation,[5] as well as other fields.[6] In many of these detectors, a stack of microchannel plates (MCPs) is used to convert the single particle hit (including photons) into an electron "cloud" producing a large enough signal to be detected.[7] Many decoding schemes have been used to measure the position information of each particle in such detectors, including resistive anodes,[8] backgammon anodes,[9] delay-line anodes,[10] and phosphor screens coupled with a CCD (or CMOS) camera.[11,12] The time signal in most cases is directly measured from the front or back side of the MCP stack.[7,10,13]

Microchannel plate detectors can achieve "ultra-high time resolution (<100 ps)."[7] However, as the diameter of these MCP detectors used in imaging applications increases, one may wonder if this time resolution is affected by the propagation time on the detector surface when the timing signal is picked off directly from the MCP surface. This time can be estimated to be at least 100 ps for a signal originating 30 mm away from the pickup if one assumes that the charge signal propagates at the speed of light. Using a more realistic velocity factor[14] of 0.5 will yield 200 ps for the same signal. Given that 80 and 120 mm diameter MCP detectors are commonly used suggests time spreads of the order of 250 and 400 ps, respectively.

In this work, we are addressing exactly this question, namely, what is the time broadening caused by hits across the MCP surface? In other words, we determine the position dependence of the time signals picked off directly from the MCP back surface. To accomplish this goal, a MCP detector with a delay-line anode was illuminated through a regular mask by about 90 fs laser pulses—effectively instantaneous in comparison to the signal propagation time across the MCP. Employing a similar ultrafast laser beam technique, the time resolution of a MCP has been determined to be 200-300 ps, depending on the voltage applied across the MCP.[15] It is important to note that in that study,[15] only a small spot was illuminated, and the time signal was picked off from an impedance-matched anode.[7,16] Therefore, the issue of propagation of the charge signal on the MCP surface remains to be studied. This question is important when using position-sensitive anodes and picking off the time signal directly from the MCP front or back surface. In the results presented below, it is shown that time-broadening is due in large part to the position dependence of the time signal taken directly from the MCP. Moreover, the measured values are consistent with the pulse-propagation estimates above. The impact of this "time dependence on position" on reducing electronic noise affecting the position signals of such detectors and on lost-signal reconstruction is also briefly discussed.

As mentioned above, we have used an ultrafast laser providing about 2 mJ pulses centered at 787 nm (with a 28 nm bandwidth) at a repetition rate of 2 kHz. To activate the MCP efficiently, a higher energy photon is needed[7,17]—in an earlier study,[15] 267 nm pulses worked well. To that end, we generated 262 nm pulses through third harmonic generation using two type-I beta-barium borate (BBO) crystals, as described in detail by Zohrabi[18] and others.[19,20] This 262 nm laser beam is directed toward the detector through a diverging lens and a flat mirror such that it illuminates the whole detector, as shown in Fig. 1(a). A mask with regular circular holes (0.78 mm in diameter) spaced by 5 mm (center to center) and placed a few mm in front of the detector defined the x,y position on the detector surface, as shown in Fig. 1(b).

The detector used in this study consists of a pair of 80 mm diameter MCPs (chevron assembly[7]) coupled with a RoentDek[13] hex delay-line anode. The position information is determined from the time difference between signals arriving at both ends of each wire.[10,13] The time information is evaluated from a charge signal picked off directly from either the front or back surface of the MCP stack.[7,10,13] Since they are similar, we show only back surface results here.

A photodiode exposed to a small fraction of the laser beam provides the start signal for a multi-hit, multi-channel time-to-digital converter (TDC, CAEN V1290N) while the time signals from the MCP back surface are used as the stop. The MCP signals were amplified by a pre-amplifier (ORTEC VT-120B), and a constant-fraction discriminator (CFD, ORTEC 935) was used to generate the standard Nuclear Instrumentation Module (NIM) signal needed by the TDC. The TDC resolution is about 25 ps, i.e., better than that of

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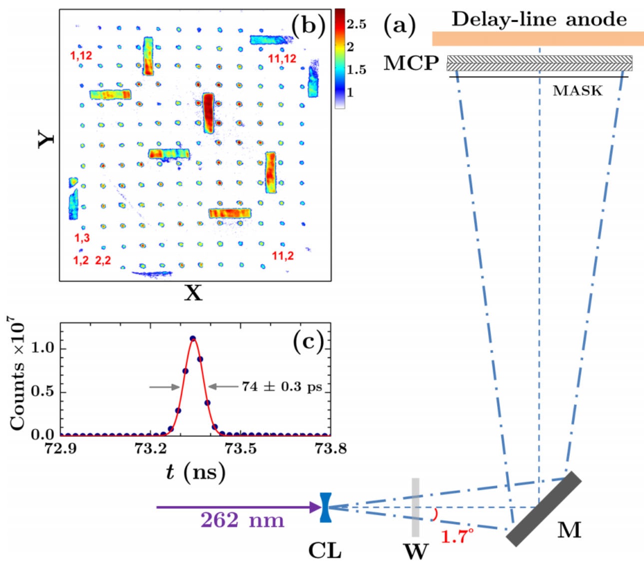

FIG. 1. Experimental schematic: (a) schematic of the setup used for testing an 80 mm MCP with about 90 fs pulses at 262 nm, where CL—concave lens, W—window, and M—mirror. (b) The mask used to define the position, having a regular array of small holes 5 mm center-to-center. (c) The time-difference spectrum of a photodiode start—photodiode stop measurement used to determine the electronic broadening to be about $74/\sqrt{2} \sim 50$ ps.

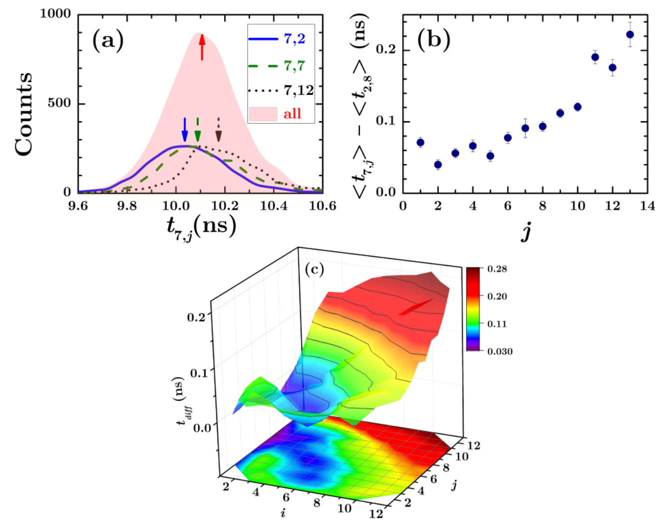

FIG. 2. Position dependence of time signals: (a) time distributions (with scaled peak value) for a few holes along a column near the detector center (the centroid of each, $\langle t_{i,j}\rangle$, evaluated by a Gaussian fit is marked by an arrow). Also shown is the distribution for all holes—scaled to fit. The deviation of $\langle t_{i,j}\rangle$ from $\langle t_{2,8}\rangle$, the shortest time, is shown in (b) along the same column shown in (a), and (c) the whole detector—a smoothed surface plot.

the MCP. Moreover, the 262 nm chirped laser pulses are estimated to be about 90 fs long, practically instantaneous on the response time scale of the MCP. In principle, any sub 25 ps pulsed laser can be used to reproduce the present detector test if it provides energetic enough photons. The time-broadening caused by the photo-diode and timing electronics was measured to be about 50 ps by using an identical photodiode to generate the stop signal instead of the MCP [see Fig. 1(c)].

The photon flux (i.e., laser intensity) was kept low enough to keep the counting rate at about 200 Hz on average, a photon-hit probability smaller than 0.1 per pulse, to reduce multiple-photon hits on the detector and their effect on the time-position correlation. The data were recorded event-by-event, enabling offline analysis, which includes the elimination of the small fraction of multi-hit events. Moreover, this allows the analysis of the time signals of events originating from specific holes or a row or column of holes, therefore mapping the position dependence of the MCP time signal.

The main finding of our study is that the time signal picked off a MCP back surface depends on the position of the particle's (photon in this case) hit on the detector. This effect causes a time spread of about 280 ps over the whole detector, defined as the maximum difference between the centroids of the time distributions for all holes. In Fig. 2(a), we present the time distributions associated with a few well-defined 0.78-mm circular holes along the detector center, which clearly show that the time shift from one position to another is a significant contribution to the time broadening. This time dependence on position is further illustrated in Figs. 2(b) and 2(c), which show the centroid of the time distribution $\langle t_{i,j}\rangle$ relative to the shortest measured time $\langle t_{2,8}\rangle$ at specific positions on the MCP detector defined by the mask holes (i,j). This effect is expected to become the limiting factor as other sources of time broadening, like electronics, are improved further.

The time dependence on position, $t(x,y)$, follows the expected trend of longer times for particles (i.e., photons) hitting the MCP further from the connection of the pick-off wire, which is near $i,j = 7,1$, as shown for the mask column with $i = 7$ in Fig. 2(b). However, the complete distribution on the detector suggests that charge signal propagation along the MCP surface cannot be the whole story, as that would suggest a similar time for $i,j = 2,6$ and 12,6, which is clearly not the case according to Fig. 2(c). The most likely reason is signal propagation along the conducting surface of the ceramic ring holding the MCP stack, which can provide a faster route for charge signals from these specific points to the pick-off wire. The fact that this route reduces the time for $i,j = 2,6$ but not for $i,j = 12,6$ is most likely due to the better contact of the ceramic ring on one side of the stack than the other. Moreover, this may also explain why the lowest time is near $i,j = 2,8$, where one of the stacking clips is attached, and not next to the pick-off wire as expected. Further work is needed to understand the complex time dependence on position, to model $t(x,y)$, and to try to reduce its impact by improving the contact and conductivity of the rings holding the MCP stack together. However, this goes beyond the scope of this work.

This time dependence on position might have significant consequences on imaging MCP detectors as they get larger and their resolution improves. For example, if a three-dimensional velocity image is desired, then the time dependence on position may distort the image by affecting the velocity component perpendicular to the detector plane. This is particularly important when imaging electrons, for which short time-of-flights are typical.[3] At present, the use of meshes in front of imaging detectors typically causes larger distortions than $t(x,y)$.

Another example where $t(x,y)$ may have an impact is on the MCP detector using a delay-line anode, like the detector used here. In a delay line, the position is determined from the

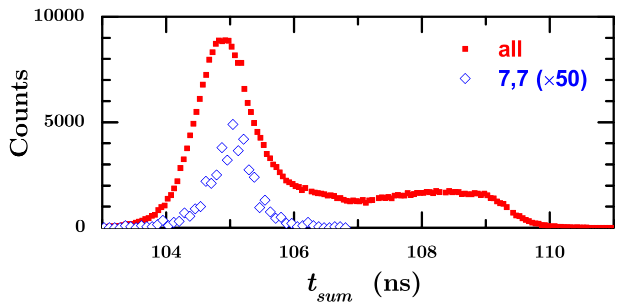

FIG. 3. Time-sum distribution for one of the wires of the delay-line anode, which is aligned 15° relative to the x-axis. Note that the distribution at a specific location (i, j = 7, 7) is significantly narrower than the one including the contributions from all holes—a broadening that limits electronic noise suppression on the delay-line decoder (see text).

time difference between the signals arriving at the two ends, t_1 and t_2. It is convenient to also define the time sum, as it is expected to be constant

$$t_{sum} = (t_1 - t_i) + (t_2 - t_i) = L/v_s\ , \qquad (1)$$

where t_i is the time the charge cloud of the MCP hits the delay-line wire of length L, and v_s is the signal speed on that wire.

According to Eq. (1), the time-sum spectrum, like the one shown in Fig. 3, should exhibit a single narrow peak. In practice, this spectrum is typically noisy, but the noise can be greatly suppressed by accepting only t_1 and t_2 signal pairs for which the time sum falls in a narrow "gate" centered around the expected value. Figure 3 clearly indicates that the time-sum peak associated with a specific position on the detector is much narrower than for the whole detector. The position dependence of t_i in Eq. (1) contributes about 0.5 ns to the width of the measured t_{sum} distribution, shown in Fig. 3, and clearly other sources contribute too. Reducing the width of the t_{sum} peak will ultimately improve the signal to noise of delay line detectors.

More importantly, Eq. (1) is commonly used to "reconstruct lost signals,"[21] for example, one can compute $t_2 = t_{sum} - t_1 + 2\,t_i$ (using $\langle t_{sum} \rangle$ of the distribution) in cases where a t_2 signal is missing. Clearly, the computed t_2 accuracy will be reduced, by about 0.5 ns in our case, because of the position dependence of t_i. Modeling of $t(x, y)$ may, therefore, improve the reconstructed events in imaging measurements using delay-line detectors.

In summary, a method for measuring the position dependence of time signals picked off a MCP surface is presented. A time spread of about 280 ps was measured for an 80 mm MCP detector—large enough to affect imaging measurements and expected to increase with MCP size.

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