Time of flight and position measurement using a micro-channel plate with resistive position readout

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Introduction

Thanks to their excellent timing properties, micro-channel plates (MCPs) are often used to measure time of flight (TOF) of charged particles. If connected to proper anodes, they can also measure the position of incident particles at their surface. The example below illustrates the use of such a device connected to a resistive anode readout system. This kind of anode is easy to use. It performs so called "charge division" and presents good spatial resolution as we will see later.

What will you find in this educational document?

- An example of resistive anode coupled to a micro-channel plate
- The principles of resistive anodes readout (i.e. charge division methods)
- How to calibrate the resistive anode image in terms of position referred to MCP front face
- How to integrate this device in the FASTER data acquisition and processing system

1. The device and its electronic

The device used for this example is a double stage MCP (Fig. 1).

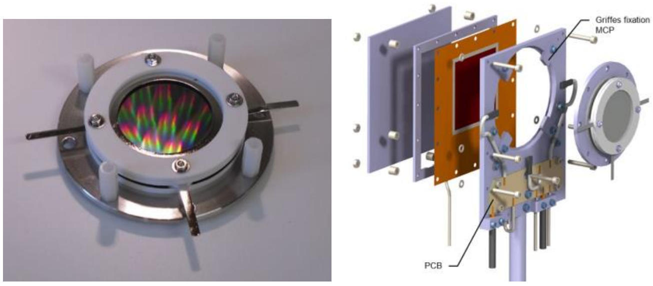

Fig. 1: the MCP (left) and its assembly (right)

The resistive anode consists of horizontal strips (pitch 1.3mm) connected to their neighbors by the mean of 10Ω resistors. In and between the strips, one can see pads (pitch 0.9mm) which are vertically connected on back side of the kapton PCB. Each vertical band of pads is connected to its neighbors by the mean of 10Ω resistors (see Fig. 2).

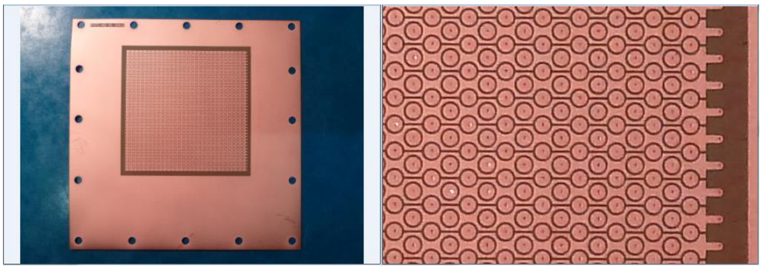

Fig. 2: resistive anode made of kapton Printed Circuit Board facing the back side of the MCP

When a particle hits the front side of the MCP, the signal is amplified (about 10^6 times, depending on the polarization voltage). The total charge *Qtot* is spread on the surface of the resistive anode, illuminating both horizontal strips and vertical pads, producing four signals (*Qleft*, *Qright*, *Qtop*, *Qbottom*). The value of these four charges depends on the total charge and on the position of the incident particle.

The rear side of the MCP is connected thru a 1nF capacitance to a 50Ω matched impedance wideband voltage preamplifier of gain 50 (called *Qtrig* line), as the four localization signals (except you don't need the capacitance).

The *Qtrig* signal is positive, with a few hundred mV height, a rise time of about 2ns and a fall time of 4 ns. The (*Qleft*, *Qright*, *Qtop*, *Qbottom*) signals are negative and their shape depends on the position of the incident particle.

2. Data acquisition

Qleft, *Qright*, *Qtop*, *Qbottom* and *Qtrig* signals are simply connected to the inputs of five 50Ω channels of three CARAS (12bits, 500MHz) daughter boards, as shown on Fig. 3.

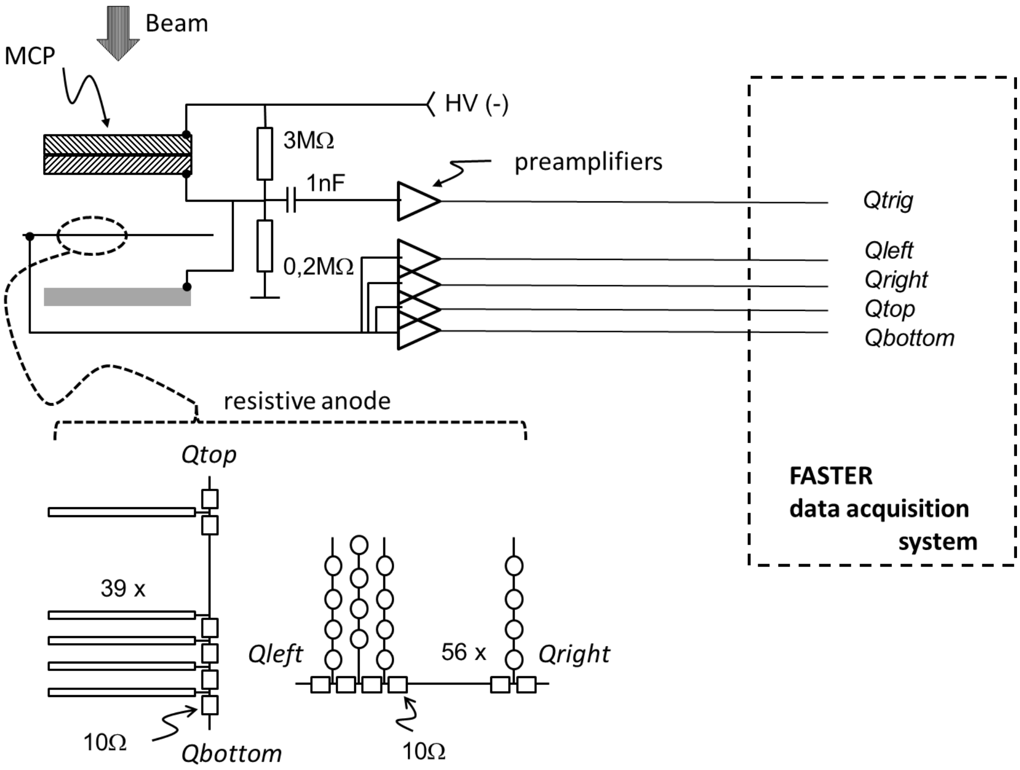

Fig. 3: the complete system for the TOF and localization measurement using a MCP and resistive anode.

The system is triggered by incident particles on the *Qtrig* line. You can use the FASTER internal threshold discriminator, or preferably (if you need precise time of flight measurements) the internal Constant Fraction Discriminator. The *Qtrig* charge is measured by integrating the signal (QDC) on a [-6ns→60ns] gate.

For the localization signal, you can simply use threshold discriminator (as timing is performed on *Qtrig* line) and integrate each signal on the same [-6ns→60ns] gate.

A grouped event is constructed once *Qtrig* line is fired and the localization signals are triggered in a grouping window of 60ns. As a consequence, an event consists of five grouped charges. Fig. 4 shows the *Qtrig* spectrum measured for low energy (10keV) Ar^{1+} ions beam.

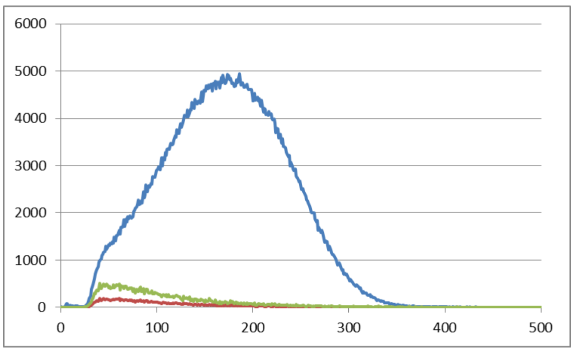

Fig. 4: energy spectra of the MCP under 10keV argon ions beam (blue) and MCP background (red). (x axis arbitrary units, y counts)

3. Data analysis

3.1. TOF measurements

In order to perform TOF measurements, you need a "TOF start" detector, the MCP being the "TOF stop" detector. The time of flight is immediate; this is simply the difference in time of the "TOF stop" minus the "TOF start" of the experiment. The timing resolution depends on both detectors characteristics and signals amplitudes, ranging from say a hundred of picoseconds (for ultra-fast timing detectors as MCP) to a few nanoseconds. These performances are not analyzed furthermore in this use-case. For more information, please refer to the proper use-case datasheet.

3.2. Position measurement

- Raw image reconstruction

An estimator of *x* and *y* position is simply:

$$\tilde{x} = \frac{Qright - Qleft}{Qright + Qlef} \qquad \tilde{y} = \frac{Qtop - Qbottom}{Qtop + Qbottom}$$

These estimations range from -1 to +1 in magnitude and produce the kind of image illustrated on Fig. 5 (a mask was placed in front of the MCP).

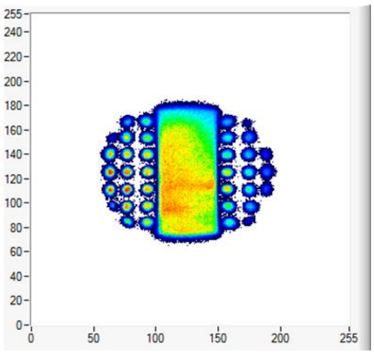

Fig. 5: raw image reconstruction (x & y axis in arbitrary units)

- Localization channels gain equilibration

The first step of the calibration for position measurement consists of equilibrating the gain of the localization channels (*Qloc* = *Qleft*, *Qright*, *Qtop*, *Qbottom*). In fact, there is no reason this gain should be exactly the same (gain variation of fast amplifiers, sensitivity of CARAS channels, …). There exists a strong correlation between these channels and the *Qtrig* channel. In fact, when properly calibrated, the sum of all localization charges should be the same as the charge on *Qtrig* channel. This can be seen when plotting the sum of all four *Qloc* versus *Qtrig* (Fig. 6.left).

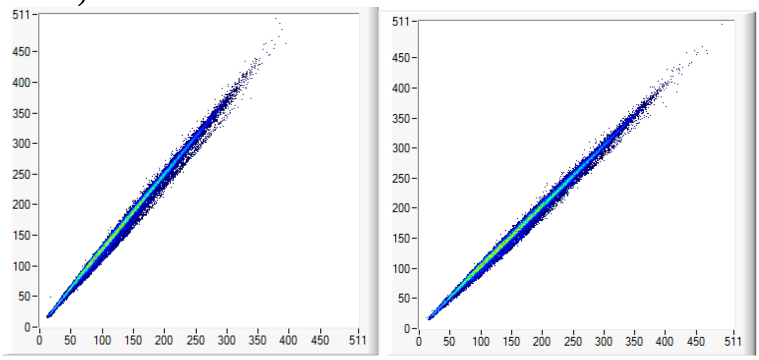

Fig. 6: $\sum$*Qloc* vs *Qtrig* before (left) and after (right) gain equilibration

A way for equilibrating gain mismatch consists in finding the four constants α, β, γ, δ verifying $\alpha \cdot Qleft + \beta \cdot Qright + \gamma \cdot Qtop + \delta \cdot Qbottom = Qtrig$

By selecting a thousand points uniformly distributed at the MCS front face and applying a least squared fit, on obtain the correction values and produce the Fig. 6.right graph. Data are now lying on the first bisectrix of the correlation graph. The equilibrated image writes now:

$$\tilde{x} = \frac{\beta \cdot Qright - \alpha \cdot Qleft}{\beta \cdot Qright + \alpha \cdot Qlef} \qquad \tilde{y} = \frac{\gamma \cdot Qtop - \delta \cdot Qbottom}{\gamma \cdot Qtop + \delta \cdot Qbottom}$$

- Image correction

Knowing the exact position of the holes in the calibration mask (Fig. 5), a spatial calibration can be applied in order to transform the *x* and *y* estimators into the true *x* and *y* position at the MCP front face. A third order polynomial correction is usually sufficient and you need to find 9 coefficients (by the mean of a least squared fit on the holes positions for instance). Eventually, you obtain the corrected image shown on Fig. 7.

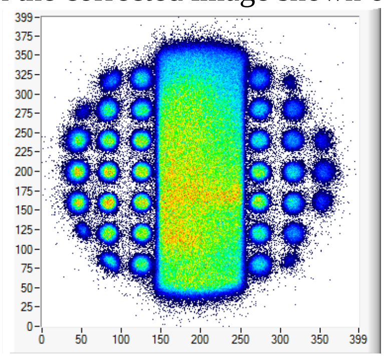

Fig. 7: corrected image (x & y axis in 100µm; center at x=y=200)

4. Conclusions

The spatial resolution of such a process is about 250µm$_{RMS}$, depending on MCP gain and incident particles types and energy. As can be seen, it is far better than the pitch of the resistive anode strips. Provided the electron cloud spreads over several strips, the reconstructed position corresponds to the centroid of the cloud and the spatial resolution is mainly governed by electronics and EMC noise.