PARTICLE AND UV-IMAGING WITH POSITION SENSITIVE MCP-DETECTORS - THREE-DIMENSIONAL MOMENTUM SPACE IMAGING

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ABSTRACT

Various position sensitive microchannel-plate (MCP) detector systems for ion, electron and photon detection are presented. We have also developed a complete set of electronics to operate the detectors and software to analyze the incoming data. The detectors provide two-dimensional position as well as excellent timing information, e.g. for time-of-flight measurements. All data can be stored in single event mode. These MCP-detectors were used for electron and ion analyzers, which provide a three-dimensional imaging of the momentum space of all detected particles.

1. INTRODUCTION

Nearly every physical experiment needs some kind of detector as an interface between the mind of a scientist and nature[1]. The feasibility of an experiment depends strongly on the quality of the detector equipment. Today detectors which are able to detect single microscopic particles like ions, electrons and photons become more and more important for chemical and physical applications. Common detectors used for many experiments are CCD-cameras. They provide a good position resolution at a reasonable price, but they also have (depending on the application) two main disadvantages:

1. Particle impact has to be converted into visible light to be detectable with the CCD-chip. This is usually performed with one or more MCPs in combination with a fluorescence screen. The light is transmitted through a vacuum window into the camera. To improve the sensitivity some cameras have an additional amplifier stage in the camera itself, which includes another photo cathode, MCP and screen. This set-up is expensive as well as complicated (a particle is converted with the MCP into an electron cloud, the electrons are converted into light, the light is converted into electrons, these electrons again produce light and finally this light is detected with the CCD and converted into an electronic signal).
2. CCD-cameras do not provide sub microsecond timing information. With a pulsed gate device some fast timing information can be obtained, but this is again expensive and complicated.

Position sensitive anodes in combination with MCP electron multipliers provide a powerful alternative with single event detection at reasonable cost.

2. THE EXPERIMENTAL PRINCIPLE OF SINGLE EVENT MCP-DETECTORS

The readout of MCPs with such „single event“ anodes provide both good position resolution (down to 50μm) as well as excellent timing resolution (down to 500ps)[2]. For coincident detection of multi-fragmentation events in scattering experiments such fast single event systems are especially useful.

A MCP is an array of many small glass tubes, which act as very localized secondary electron-multipliers. The diameter of these tubes is usually between 10μm and 25μm[3]. When a single

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photon[4] or a particle hits the MCP a secondary electron cloud of 10^6 to 10^7 electrons is created by 2 or more MCPs. The outcoming electron cloud is directly collected by a position sensitive anode to be processed electronically. After digitalization of all electronic signals the images can be monitored and stored with a computer. The complete detector system is mounted in the vacuum. Only a standard electric feedthrough flange is necessary to transmit the electronic signals to the electronic modules.

We have developed two different kinds of two-dimensional position sensitive readout techniques: one is based on a fast passive delay-line anode, and the other one on a compact charge dividing wedge-and-strip anode. Also two different types of one-dimensional anodes were developed (delay-line and resistive anode). One standard MCP-holder can be combined with all anode types. In figure 1 two different detector assemblies are shown.

Another application of position sensitive detectors is the readout of spectrometers where the time consuming scanning method with fixed aperture can be replaced by a simultaneous and continuous data collection with a position sensitive detector mounted in the spectrometer's focal plane. This may increase the collection efficiency by orders of magnitude.

We have also developed front-end electronics optimized for the use with these detectors. These include amplifiers, constant-fraction-discriminators, time-to-digital-converters (TDC). We have designed the complete acquisition software ourselves. This package provides a good detector performance at reasonable costs.

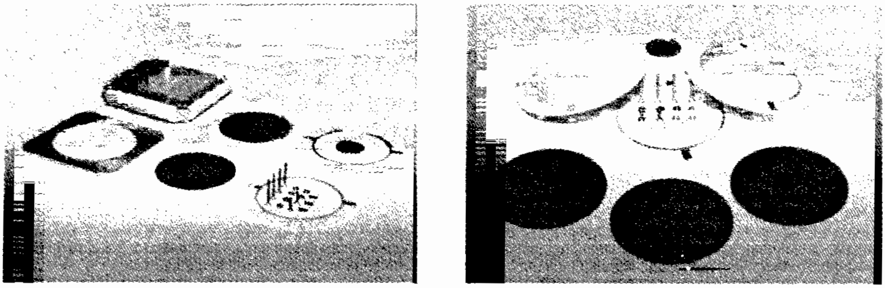

***Figure 1:** MCP-holder with MCPs of 50mm diameter, delay-line (left fig.) or wedge-and-strip anode (right fig.). The white holder rings and the plate on which the wedge-and-strip is printed are made of aluminum oxide.*

2.1. WEDGE-AND-STRIP ANODE

The wedge-and-strip anode contains three different structures, where position information is obtained by charge division (see figure 2). These structures are wedges and rectangular arrays ("strips", with increasing width from the left to the right). The space between these two structures (so called "meander") covers the rest of the surface. All three structures are contacted separately. The three signals are amplified by a set of charge sensitive pre- and main amplifiers to a 10Volt maximum pulse. These voltage signals are processed by an analog-to-digital-converter (ADC) and given to the computer for monitoring and storage of the information. The width of these structures is 1.2 mm. To reach a better position resolution the charge cloud must cover several structures to determine a mean value. Thus these anodes usually need a drift path between the MCPs and the anode to widen the cloud.

In contrast to this method, our anodes detect the image charge. The side of the anode which is faced to the back side of the MCP is covered with a semi-conducting germanium layer. The segments are printed on the other side of the anode. This method of image charge coupling (patented[5]) allows us to bring the anode close to the MCP-stack to build a very compact detector and with this technique the anode can be used in strong magnetic fields. The total diameter of a detector with 48mm active diameter is 65mm and the total thickness is 7mm (see figure 2).

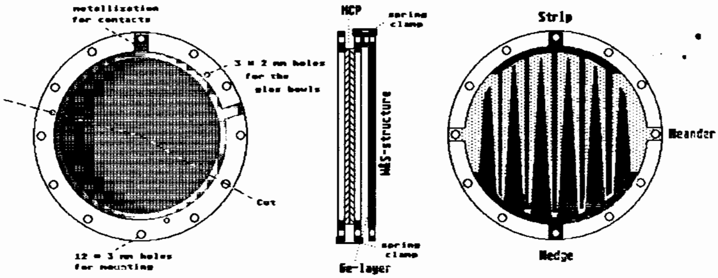

Figure 2: MCP-detector with wedge-and-strip anode. The charge dividing segments, shown in the right figure, are enlarged. The original distance between the segments is 1.2mm. The outer diameter of the detector is 65mm, the thickness is 7mm.

2.2. DELAY-LINE ANODE

The delay-line anode contains two pairs of low resistive wires. Each pair is wound around a supporting plate insulated with ceramic rods (see figure 3), one pair in x- and the other one in y-direction. The signal wire of each pair runs a little higher positive voltage than the reference wire, so that most electrons are collected by the signal wire (Lecher cables). A fast floating amplifier amplifies the difference between these two signals. With this Lecher cable set-up the loss of signal and noise is well suppressed[6]. With constant fraction discriminators precise timing information is produced and fed into a time-to-digital-converter (TDC). The two-dimensional position can be calculated by the signal arrival time at the ends of the two perpendicular wire pairs. The total signal transport time from one end to the other is in the range of 20ns to 100ns. The internal timing resolution is about 50ps which corresponds to a position resolution of about 50µm (see figure 4). To improve the position resolution the position is calculated from the difference time between the two ends. The sum of both arrival times is a constant and can be used as a check. The reachable resolution depends on the properties of the TDC. We use two different TDCs, one with 70ps resolution single hit and another one with 220/110ps. The latter is 4-fold multi-hit capable. The rate capability of the delay-line detector is in the order of 10MHz. The event acquisition rate is presently restricted to 20kHz by the single event transfer to the computer. A new TDC with internal histogram buffer is now under construction. This enables an increase in acquisition rate to about 1MHz.

With the delay-line technique it is even possible to detect multi-hit events (if a multi-hit capable TDC is used) yielding the position and timing resolution for each particle hit (e.g. for imaging the fragmentation of atoms, molecules[7] or clusters, or for the detection of several electrons emitted by a solid from an intense synchrotron or laser pulse). In a test measurement we were able to detect 16 electrons (time and position) emitted from a carbon foil induced by the impact of a highly charged heavy ion[8].

Another more sophisticated design (Eland anode[9]) which is able to work with the mirror charge coupling (like the wedge-and-strip anode) is under construction now. It allows one to print the delay-line structures on some insulating layers like ceramic, glass or capton foil to build cheap, compact and possibly flexible anodes.

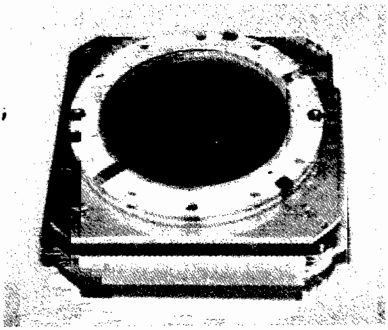

***Figure 3**: MCP-detector with delay-line anode. The total size is 80mm, the active diameter is 47mm.*

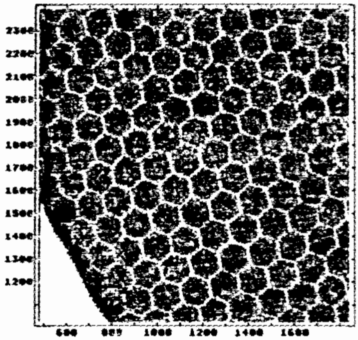

***Figure 4:** Image of a shadow mask by illumination with an α-source. The obstacle width is 0.2mm. The achieved position resolution is 50μm.*

3. COLD TARGET RECOIL ION MOMENTUM SPECTROSCOPY (COLTRIMS) -A 4π ION-ELECTRON-MOMENTUM MICROSCOPE

The position sensitive MCP-detectors were used for three-dimensional electron and ion-analyzers which obtain detection solid angles up to 4π with good angular and energy resolution. These analyzers use combinations of electric and magnetic fields to extract all electrons or ions from a target (gas targets were used so far) onto such imaging position- and time sensitive detectors (note that this technique detects particles emitted into all angles and of all energies up to a maximum value, including zero energy). With the position and timing information the trajectory of the particle can be determined.

This method was successfully used as Cold Target Recoil Ion Momentum Spectroscopy (COLTRIMS)[10] in various gas target experiments for atomic physics, where the whole momentum vectors of at least two particles were measured in coincidence. The electric fields accelerate and focus ions and electrons onto two different MCP-detectors. The fields are adjusted to achieve a detection solid angle of 4π for the target ions. Due to the smaller mass of the electrons the electron velocity is usually much higher than the velocity of the ions. Thus we apply a homogenous magnetic field to bend all electrons on spiral trajectories. In combination with the electric extraction field a solid angle of 4π can be reached for electrons up to a maximum energy. This maximum energy can at present be adjusted up to 1keV, depending on the experimental conditions. Note that the calculated emission energy and angles of the ions and electrons by using the time-of-flight and the two position components is unique.

3.1. MOMENTUM IMAGING OF FRAGMENTATION OF D_2-MOLECULES USING MULTI-HIT CAPABABLE DELAY-LINE-DETECTORS

Using the COLTRIMS-technique with our multi-hit capable delay-line detector and electronics we investigated the Coulomb explosion of molecular deuterium (D_2) after photo double ionization. The experiment was done at the advanced light source (ALS). We used linearly polarized photons with an energy of 85eV. The deuterons were extracted by a homogeneous electric field of 10V/cm yielding to a detection solid angle of 4π for all created deuterons. The electrons were accelerated by the same electric field to opposite direction where another position-sensitive detector was located. The difference of the arrival time of the two deuterons on the detector ranges from zero to 300ns. We detected both deuterons from the same fragmentation event with our MCP-detector with a dead time of 20ns (so called multi-hit detection). Charge integrating anodes like the wedge-and-strip or the resistive anode are not able to image multi-hit events with a time distance less than several hundred nanoseconds. We recorded the arrival time and the two-dimensional position information for both deuterons separately. From the time and position information we can calculate the trajectories of both deuterons and the electron uniquely. At present the dead time of 20ns does not allow also to detect both emitted electrons due to their shorter time-of-flights compared to the deuterons. But it is possible to image two particles, even if they arrive at the detector at the same time, without any dead-time using the timing signal of both ends of the delay-line separately.

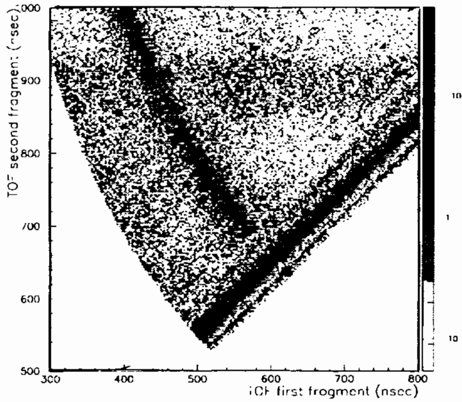

***Figure 5:** Ion time-of-flight of two deuterons from Coulomb explosion. The x-axis shows the TOF of the 1^{st} and the y-axis of the 2^{nd} deuteron, both on the same detector. The counts in the upper slightly curved line are the true coincidences.*

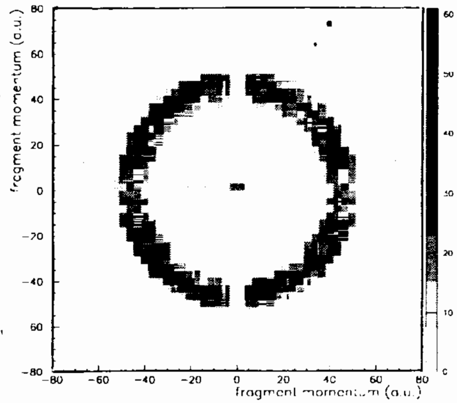

***Figure 6:** Momentum space image of one deuteron after Coulomb explosion. The x-axis shows the momentum in TOF direction and the y-axis a component perpendicular to it. The missing slice at x=0 comes from the dead time of the detector.*

4. A TIME RESOLVING PEEM

As a first test case for an application in solid state physics a MCP-detector with delay-line readout was used in combination with a Photo Electron Emission Microscope (PEEM) at the synchrotron BESSY in Berlin in October 1997. We used an MCP-detector with delay-line readout instead of a phosphor screen and a CCD-camera. The 2-dimensional position and the timing information was obtained simultaneously (a CCD-camera does not supply any timing information useful for electron TOF-measurements). The time-of-flight of the electrons was measured in coincidence between the detector signal and the bunch marker of the storage ring. The experiment was performed during single bunch operation with a bunch distance of 200ns. A position resolution of 100µm over an active diameter of 20mm and a time-of-flight (TOF) resolution of 600ps was achieved (see figure 7a). The 4f lines of Tungsten, which was used as target, could be resolved by the TOF measurement (see figure 7b). We achieved an energy resolution of 2.5eV.

The binding energy of the J=5/2 line is 33eV and for the J=7/2 line 30eV. With this combined position and energy resolving TOF-PEEM we could image the photo electrons from the different Tungsten states separately. Figure 7c) shows the detector image of the electron microscope with a condition on the two Tungsten 4f lines. A new TOF-PEEM which exploits the whole active diameter of our MCP-detector (47mm) will be tested soon.

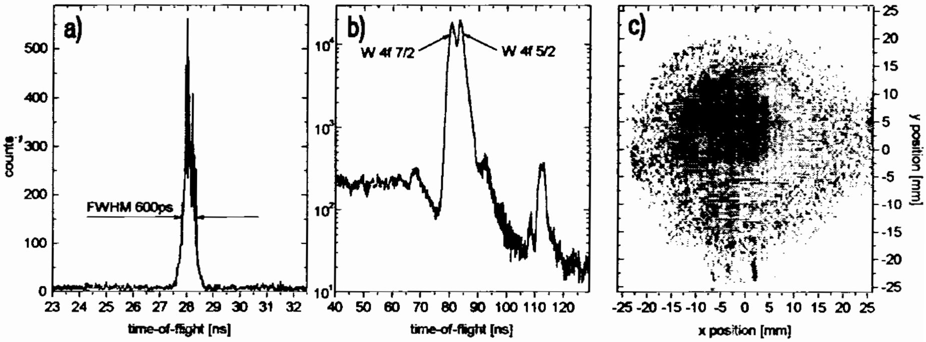

***Figure 7:** Results for photo ionization of Tungsten at E_γ=112eV using a delay-line detector in a PEEM. a) TOF spectrum of secondary photons. b) Electron TOF spectrum. c) Electron image on the MCP-detector with condition on the Tungsten 4f lines.*

5. CONCLUSION

We have shown that single event position sensitive MCP-detectors are a powerful tool for a range of scientific applications. They can be used instead of CCD-cameras to provide position and timing information. We have applied these MCP-detectors for three-dimensional momentum space imaging with a solid angle of up to 4π. Especially the multi-hit capability of the passive delay-line anode is a big progress compared to single hit MCP-detectors.

5. ACKNOWLEDGEMENTS

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