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Fast position and time resolved read-out of micro-channelplates with the delay-line technique for single particle and photon detection

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ABSTRACT

Based on delay-line read-out methods of micro-channelplate (MCP) stacks we develop imaging systems for single particle and photon spectroscopy. A complete system consists of an open MCP-detector with helical wire anode, specially designed front-end electronics ("black box" containing signal de-coupling circuits, amplifiers and discriminators) and a standalone PC-based TDC-system. We achieve a position resolution better than 0.1 mm and excellent linearity for open dimensions up to 100 mm, multi-hit operation (up to 4 particles with dead-time of 10-15 nanosec each hit), and detection rates up to 20 kiloEvents/sec in an event-listing mode or over 1 MegaCount/sec in a histogram mode (single hit). Both modes allow two-dimensional position *and* time-of-flight (TOF) spectroscopy with approximately 1 nanosec TOF resolution ("3D-imaging"). Furthermore, we currently test a delay-line anode on printed circuit that operates with image charge pick-up from a high-resistive collecting anode. With an image charge detection method this 3D-imaging technique can be applied to commercial sealed MCP single-photon detectors. While a simple high-resistive collection anode is placed inside the tube, a position sensitive pick-up electrode can be mounted next to it outside the vacuum wall.

Keywords: position sensitive MCP-detector, delay-line, fast single particle read-out, multi-hit detection, single photon imaging, simultaneous position and time-of-flight spectroscopy, image charge detection, sealed MCP-detector

1. INTRODUCTION

Micro-channelplate (MCP) assemblies are widely used to detect single particles as electrons, ions and photons[1] and to do spectroscopy of their impact position (“imaging”) and/or time-of-flight (“timing”) with respect to an outer trigger. There are different approaches to retrieve the two-dimensional (2D) position and time information from the MCP.[2] The incoming particle induces an electron cloud exiting the MCP-stack back side which is very localized in position and time. The obtainable position and time resolution is limited by the single channel dimensions to a few 10 microns and by the charge output sequence to fractions of a nanosec, respectively.

However, the actual position or time resolution of a MCP-detector depends on the ability to presume this inherent information when the charge cloud is collected on an anode. As there is no read-out principle giving simultaneously optimal position *and* timing information for all applications there is a variety of solutions, each optimized for the respective main goal, to achieve either good position *or* good timing information. Other important parameters to consider for the choice of the anode are detector size, required detection rate, the need to detect more than one particle at a time (multi-hit capability), and - of course - cost efficiency, to name only the most important points.

If *both* timing and imaging of a detected particle or a particle shower (e.g. for imaging fragment patterns of a particle break-up) is important with a certain precision one first of all has to introduce a more complex data acquisition and storage scheme. It is not sufficient anymore to just sum up a two-dimensional (2D) position profile or a time spectrum over a certain period. Instead, one has to introduce an event-by-event handling that stores the relevant information in a list (list-mode) or in a multi-dimensional histogram (e.g. 2D-position and TOF require a three-dimensional histogram).

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One can classify the different approaches of MCP read-out for their suitability to give optimized imaging or timing precision.

- The "classical" phosphor screen as optical collecting anode, eventually combined with video and/or CCD read-out, is optimized for imaging of single particles or particle showers at maximum particle flow. Due to the "slow" electronic read-out of the optical image this method is not very useful to obtain a timing information that is significant compared to what a MCP-detector is inherently capable of.

- Commercially available specially shaped anodes optimized for *electronic* timing read-out can provide optimal timing information for single and multiple particle impact on a MCP but usually do not presume any position information.

- Segmented anodes, each segment equipped with independent parallel electronic read-out chains or, similar, crossed-wire arrays give a fair (though not optimal) timing information for single and multiple hits and rough position information, limited by the pixel size or the wire distances.[3] There is a practical limitation of the achievable position resolution as only a given number of electronic "digital" timing read-out channels can be handled.

- If special anode segmentations or wire arrays are combined with advanced electronic read-out circuits that are able to measure and evaluate charge portions collected on the distinct electrodes of the anode[4-6] one can obtain an excellent *continuous* position information as with optical methods *and* presume a fair timing resolution that is sufficient for most applications. However, as charge integrating electronics is inherently slow the achievable count rate is quite limited as compared to the rate acceptance of the MCP itself, and multi-hit events can not be analyzed. Other concepts that use micro-structured electrode[7] or wire array[8] as an anode provide a very good position resolution but again the hereby required coincidence electronics is rather slow.

We consider the application of another method of quasi-continuous electronic read-out, the *delay-line technique*, as briefly described in the next section, combined with modern timing electronics and digitization methods to be the most promising approach to design a detector system that takes most advantage of the superior imaging and timing performance of MCP-detectors as compared to other particle detection methods. We designed a system that shall challenge other concepts in the optimal combination of performance, cost, and wide application range for various fields of science.

2. MCP-DETECTOR WITH HELICAL WIRE DELAY-LINE ANODE

The delay-line method is an alternative approach to charge evaluating methods in order to achieve a *continuous* position information with a *discrete* anode pattern and *electronic* read-out. The method was first applied to multi-wire proportional counters (gas detectors)[9] but is also widely applied for MCP read-out.[10-14]

The idea is to take advantage of the delay that a signal experiences traveling on a transmission line which is either meander-shaped or helical to reduce the effective propagation speed in a given direction (see figure 1). Sometimes discrete electronic delay-circuits are implemented in the transmission line. A signal induced somewhere on this *delay-line* will propagate in both directions towards the ends where impedance adjusted circuits pick it up for further processing. With a given correspondence between the position of signal pickup (i.e. from the electron avalanche) and the propagation delay one can perform a position determination by measuring the time period between the signal arrivals on both ends of the transmission line for a respective propagation direction (dimension). For 2D-imaging an additional delay-line has to be implemented with perpendicular orientation. By proper biasing one has to ensure that both delay-lines receive their share from the charge cloud.

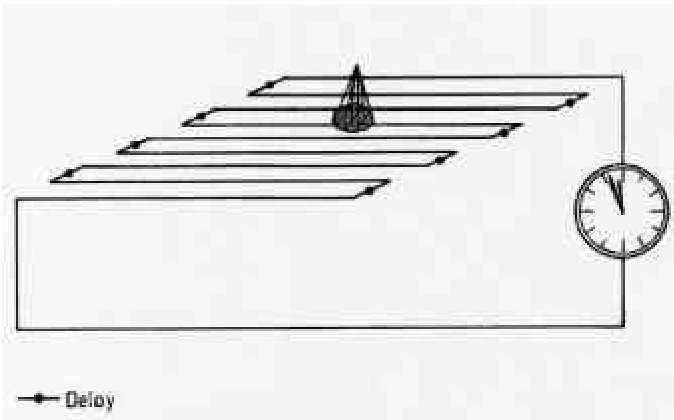

Figure 1: Sketch of the delay-line method (see text).

If the charge cloud is spread out over several discrete pick-up structures it is possible to achieve a position resolution which is not limited by the pitch distance or width, as it is the case for discrete read-out of crossed-wire arrays for example. One can interpolate the center-of-mass of the collected charge cloud that corresponds accurately to the impact position of the particle on the MCP. Thus, a *continuous* imaging can be achieved with a *discrete* anode pattern that is *electronically* read out presuming also the timing information.

For one dimension and constant position/delay equivalent the respective position is directly proportional to the time difference $t_1 - t_2$, denominating the arrival instants ("time" t_1 and t_2) at the two ends of the line with respect to an arbitrary time-zero. The time-zero can be given by the signal on the MCP-stack front or back plane that arises from the charge avalanche in the MCP with the particle/photon impact. This signal can be picked up by a proper de-coupling and amplification/timing circuit and marks the arrival time. The *time-sum* $t_1 + t_2$ is a constant (well known for a given delay-line anode) for *all* positions and can be used as a *time-of-flight* mark if the time-zero corresponds to an *outer* trigger, e.g. a laser or Synchrotron pulse. The simultaneous position determination in the other dimension can be performed likewise. Having two time-sum values for each event allows consistency checks for the validity of the acquired position information for each particle, also for several particles in a shower.

Whenever good timing *and* imaging are of equal interest it is clear that the delay-line method has a principal advantage as only an electronic time measurement circuit is required to achieve both goals simultaneously. Moreover, as the electronic circuits to process a time information are fast as compared to any precise charge measuring technique, they can handle high rates on the detector and analyze even multi-hits. These advantages can only recently be fully exploited with the advent of fast time-to-digital converters (TDC) because the time digitalization devices were so far the bottle-neck as long as internally a (slow) charge evaluation was involved here.

In this section we will describe the currently used detector hardware which is part of the detector *system* presented in the following chapters.

The MCP-stack

As described earlier, the principal position resolution limit for MCP is the pore size, or better, the inter-pore distance. It is clear that if one wants to achieve a certain position resolution this pore size/distance should not exceed about half of the aimed position resolution. If a phosphor screen is used for the position determination the demand for tiny pore dimensions gets even more important as there is some spatial spread of the charge cloud before it hits the screen, leading to some blur. Therefore very small pore sizes are always desirable for phosphor screen systems which are more difficult to produce and costly. Furthermore, a uniform electron yield over the whole active region is vital to achieve sufficient imaging quality. Center-of-mass evaluation methods for the electron cloud as the delay-line technique are not so dependent on such MCP quality features (the charge cloud is even further spread on purpose). Therefore we can use MCP with larger pore dimensions and even a non-perfect gain uniformity is not a problem as long as there is only a sufficient signal-to-noise ratio maintained for discriminating the true events. We found that even "engineering quality" MCP with a total pore length-to-diameter ratio (L/D) of 120 (e.g. Z-stack with L/D=40 each) are suitable to achieve sufficient results in resolution and efficiency uniformity.

In our standard set-up a Z-stack (3 MCP) is clamped between two ceramic rings (Al_2O_3), the single MCP positioned face to face without intermediate contact. No special care to ensure an optimal gain in size and uniformity needs to be taken according to the above consideration, but the single MCP need to be selected for their electrical resistance (+/- 10%). Metal coatings on the ceramic rings supply the MCP-stack bias (front and back face) and are shaped to allow a convenient contacting. The stack is held together by spring clamps. In combination with sufficiently rigid MCP (1 mm thick, outer length/diameter up to 100 mm) this setup has proven to be both convenient and reliable also for UHV-applications and it is suitable for the use of different mountings and anode types.

The helical wire delay-line

Although we feel inspired be recent reports on other delay-line lay-outs for our future developments we currently follow a delay-line geometry proposed by Sobottka *et al*.[12] A metal body supports ceramic rods placed on the edges where a wire *pair* is wound helical with 1 mm spacing around the support. The wire pair forms a delay-line with a linear position-delay correspondence for the dimension perpendicular to the wire orientation. For the other position dimension another helical wire pair is wound around the support perpendicular to the first one with small lateral distance (see figure 2). Thus, each dimension's helical double-wire forms a transmission line for high frequency signals that features low damping and low dispersion when operated in the differential mode. If a (differential) signal is induced on such a line it will propagate with speed c towards the ends of the line where it can be picked up and processed by a differential amplifier as the first stage of the timing circuit, followed by a constant fraction discriminator.

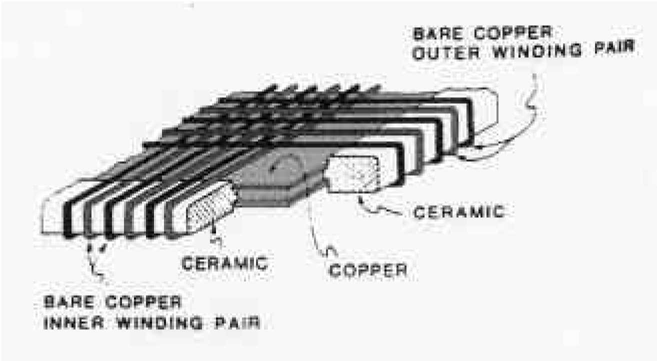

Figure 2: Corner detail of a helical wire delay-line anode[12]

For inducing a *differential* signal on the wire by the incoming charge cloud from the MCP it is sufficient to care for a small potential difference between the two wires of the pair superposed on the larger potential difference between MCP exit and the wires. This large extraction voltage provides a collection of the charge cloud on the anode with specific broadening over several wire distances. The small inter-wire potential difference then ensures that *locally* almost all electrons will be collected on only one wire of the pair. As the extended charge cloud is collected on several pitches there are several simultaneous differential signal sources on each dimension's delay-line that superpose. Each portion is distinct in space/time by one revolution of the line around the support and accounts in height for the amount of charge collected at the respective position, thus mapping the spatial charge cloud distribution. Since the signal rise time (MCP charge output sequence) is in the same order as the signal propagation time needed for one revolution around the support, the shape of the aggregated signal on the line is continuous. Small position variations of the charge cloud's center-of-mass will give rise to slight variations in the relative portions of the local signal contributions and thus change the shape of the composed signal. Such shape deviations can be interpreted as a signal with always similar shape but with slight timely shift following the center-of-mass position shift.

It has been shown that this delay-line concept gives indeed very good results for two-dimensional imaging. The position resolution is not limited by the wire distance but only by the achievable time resolution of the electronic circuit, assuming a sufficient signal-to-noise ratio from the MCP.

We have built such delay-line anodes/detectors for several active detection areas (see figure 3). To achieve a maximum position resolution when the time-resolution is limited it is best to build the anode rather large to increase the propagation time per pitch (note that: the bigger the detector, the better the resolution, unlike with charge division methods!). For practical reasons one often scales down the anode with the MCP dimension. We use outer delay-line sizes between 70 and 130 mm and found equal performance and reasonable scaling of the achieved position resolution. This variability has certainly its limit when the size gets too small or too big and the delay per pitch is not matching the charge cloud rise time anymore.

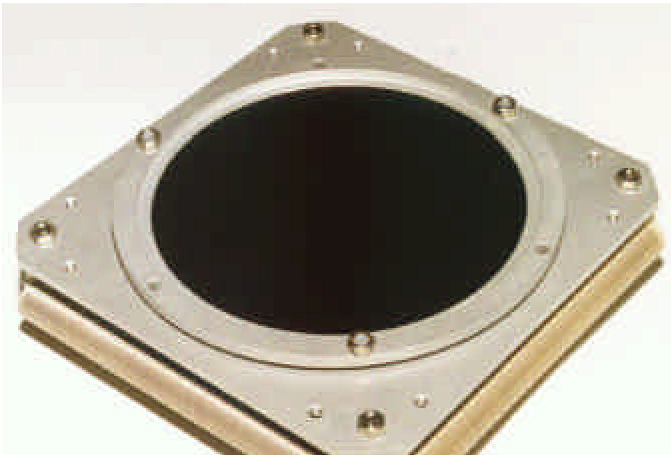

Figure 3: Delay-line detector with 80 mm active diameter in aluminum housing

We use pure copper wire or copper alloy with 2% beryllium, between 125 and 250 micron thick for the transmission line and aluminum or stainless steel for the anode support body. The MCP-stack enclosed in the ceramic (sometimes metal) holder rings is mounted to the anode via an intermediate metal plate. The detector construction and materials have proven to be UHV-compatible and withstand the respective preparation procedures.

3. ELECTRONIC READ-OUT CIRCUIT FOR THE DELAY-LINE DETECTOR

The determination of the timing of a signal is a well-known technique and commercial modules are available (e.g. in NIM or CAMAC standard). The signals have to be de-coupled from the DC-voltages on the wires/contacts and are amplified and transmitted to constant fraction discriminators which produce “digital” norm signals. The time order of these output signal reflects the - position bearing - time sequence of the raw signals on the detector outputs as induced by a single particle registered from the MCP. With TDCs or similar time measuring devices and an interface to a computer one thus can create digital images of particles impinging on the MCP.

However, if one tries to apply this technique for reading out a delay-line detector straightforward one encounters often electronic problems that lead to an image distortion. Even if the specifications of the commercial modules are sufficient concerning amplification, signal-to-noise ratio, impedance, rise time, time resolution, etc., the combination of signals to be processed simultaneously, although in different channels, and the sensitivity on timing deviations in the picosec regime will likely lead to time cross talk between the parallel operating electronic channels that can affect the imaging. Great care has also to be taken in the design of the cables transmitting the signals on their journey from the anode to the TDC.

For that reason we designed a special **“front-end” electronic circuit (“DLATR6”)** that contains up to 6 independent channels of electronic timing determination circuits including proper signal de-coupling from the DC-potentials, differential amplifiers and constant fraction stages in a single “black box”. It is optimized to be the “interface” between the detector and the TDC. This DLATR6 unit (along with standardized UHV-feed-throughs and cable connections to the anode) delivers ECL, NIM or (after adaptation) TTL norm outputs with adjustable signal length reflecting the proper time sequence from the detector. It features an analog control output for the pre-amplified signals, adjustable thresholds to discriminate the electronic noise on the line, an automated walk adjust, and the option to de-multiplex a pair of pulses (double hit) on the circuit giving separate single outputs. Four electronic channels are occupied by the delay-line anode signals. The spare channels are suitable for pick-up of the signals at the MCP-stack front and back side, the differential amplifier stage then operated as an ordinary timing amplifier. Thus, all signals to operate a delay-line detector for imaging and TOF are processed via just one electronic module. Only 4-5 bias potentials to operate the detector have to be supplied from adequate high-voltage power supplies (see figure 4).

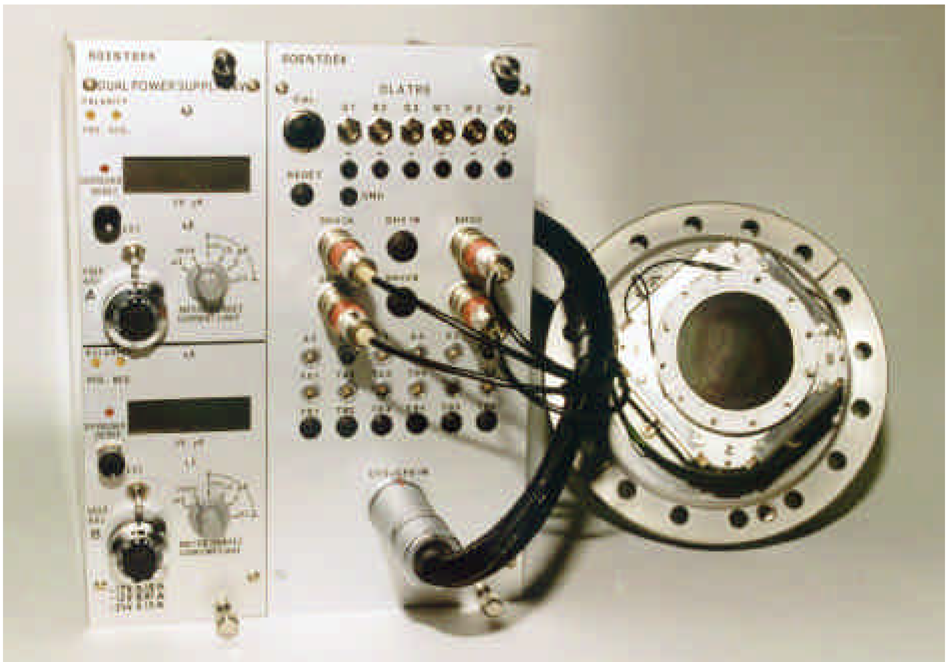

Figure 4: Components of the delay-line detector system. Right to left: MCP-detector with delay-line anode (active diameter 45 mm) mounted on CF100-flange with feed-through, front-end electronics box and specially developed power supply unit with two independent channels, +/- 4 kV, trip protected.

It could be verified in first tests that this unit (and a specially developed external 8-fold ECL-TTL signal level adapter) is indeed avoiding any cross talk problems, presumes an electronic timing precision below 50 picosec and has a low dead-time for multiple hits, only limited by the analog signal rise time of a few nanosec. The remaining task is to complete this "plug-and-play" detector system with a TDC unit or other time measuring device that has sufficient time resolution *and* supports the ability of the detector to handle high rates and multi-hit events (see figure 5).

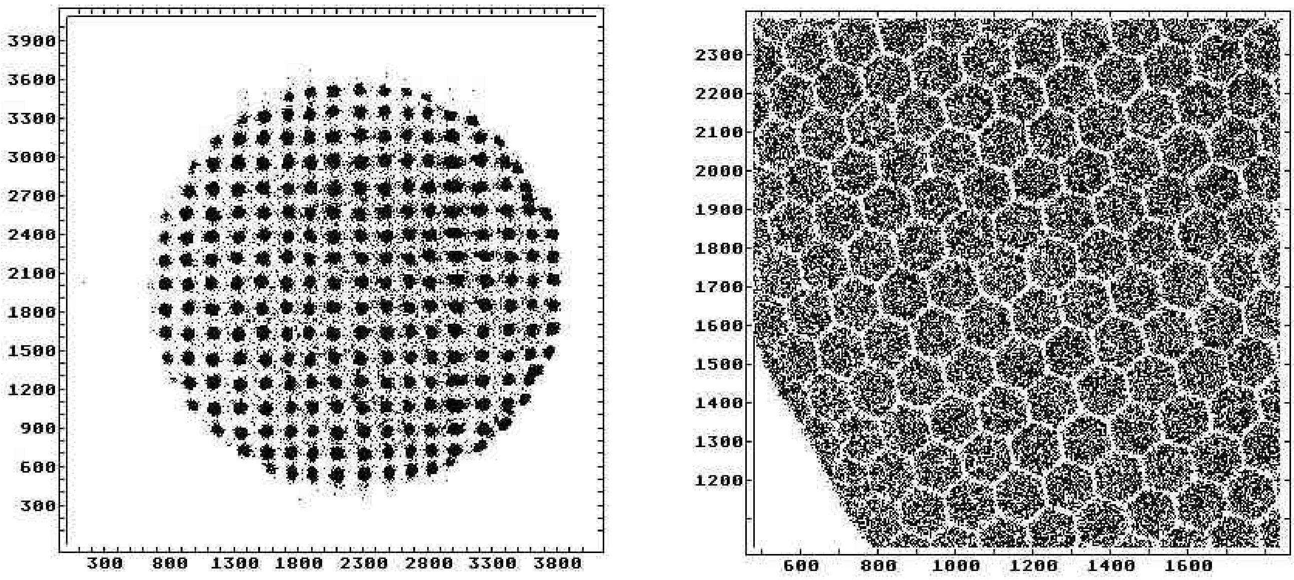

Figure 5: Imaging performance of the delay-line detector/front-end box investigated by irradiating a MCP-stack with an a-source. A TDC with 50 picosec resolution has been used here. The MCP have a pore size of 25 mm (center-to-center 32 µm), an L/D of 40, "detection quality".
Left: MCP-chevron with 45 mm active diameter, shaded with a mask of 1 mm holes, and 2.5 mm spacing. The background count rate is about 10/sec. The overall linearity can be estimated to be < 0.2 mm.
Right: MCP-chevron with 80 mm active diameter (enlarged picture), shaded with an etched hexagonal wire (0.2 mm) mask. The hexagons have 3 mm lateral dimension. A position resolution of 0.05 mm can be estimated.

The TDC-system

The commercially available multi-parameter TDC-systems generally require a large "overhead" of control hardware. Although being very costly they seldom offer a sufficiently fast data handling to support the potential of the delay-line-detector systems. Most operate with a conversion principle that involves an analog-to-digital conversion step which allows a very precise time-measurement but principally limits the data acquisition speed and is therefore not optimal for our peculiar application.

Another time-to-digital conversion method, the simple counting of pulses from a digital clock over the respective time period recently became commercially available for time measurements with sub-nanosec precision using the Vernier principle.[16] With the advent of stable high frequency clocks and modern electronic concepts one is now able to build rather cheap TDC circuits which combine fair resolution and very low conversion dead-time for multiple time-measurements (multi-stop) and high rate demands. It is clear that this TDC concept is superior for the application envisioned.

The most advanced commercial TDC-system known to us that operates without "overhead" and can be directly addressed and controlled by a modern PC was chosen for our system.[17] The standard "GP1"-chip in its optimal operation mode features a time-resolution (LSB) of about 120 picosec, stores up to 4 stops per channels and has a multi-stop dead-time of 15 nanosec. None of these basic features is yet sufficient to optimally exploit the detector potential. Especially the still "coarse" LSB (even blurred furthermore by a certain inherent differential non-linearity) are limiting the imaging performance of the complete detector system. However, a fair performance has already been obtained and as technology advances we hope for next-generation TDC-chips to overcome the current limitations.

On the base of this current technology we designed a PC-controlled 4 channel TDC board "HM1" that is optimized to complete our MCP-detector with front-end electronics to a reasonably priced MCP-detector system that combines good imaging performance with good timing ability at high data acquisition speed. This HM1 module has two operation modes.

In the *transparent* mode, the read-out and event handling is controlled by a PC-software that reads the content of the 4 TDC-channels event-by-event and computes the position and TOF for each of the up to 4 detected particles per event for storage and on-line control. The "COBOLD"-software[18] is an advanced and wide application data acquisition and analysis software for Windows 95 or NT4.0 environment[19] developed by us for general purposes. It has a potential compatibility to all data formats and I/O-hardware and features all standard data treatment and display options. With a modern PC-processor (type 586 and higher) an event acquisition speed of at least 20 kiloEvents/sec is obtained. This acquisition speed will increase further as processor and board technology advances, the current performance proved to be sufficient for most applications where the computing with multi-hit events and/or TOF-information is required. This operation mode maintains full control over the data handling by adjustable software inserts for any such application. An example for such experiments is the detailed fragment detection of a molecule break-up[20] or the complete determination of particle momenta in an atomic interaction with several particles involved (see figure 6), eventually detected on more than one detector in coincidence.[21]

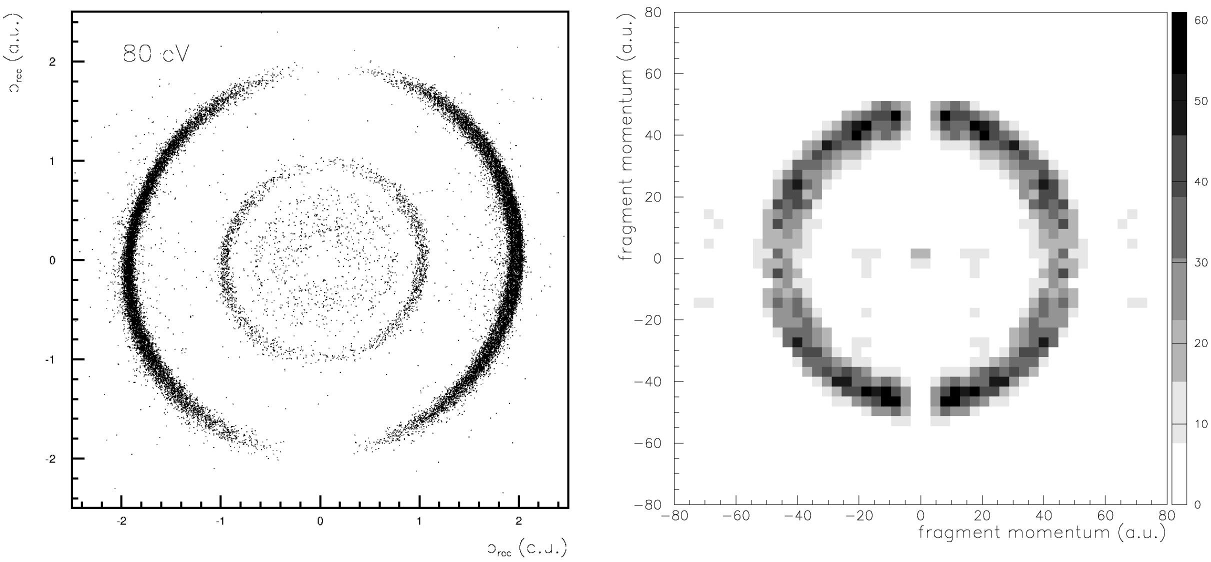

Figure 6: „ momentum images" as acquired with our delay-line detector system in an advanced 3D-imaging technique. Atoms (molecules) are prepared in a macroscopic state that allows a detailed momentum measurement on a single atom (molecule) following an ionization process (COLTRIMS)[21]. Analyzing the trajectory in a spectrometer by a position sensitive detector with TOF measurement, the 3D-momentum vector for each ion can be deduced. The figures show momentum distributions in two dimensions only for those events located in momentum space within a "slice" around zero in the third dimension.

Left: break-up pattern in momentum space of a Helium atom after photo-ionization from an 80 eV photon (1eV excess energy). The dipol emission pattern for the "photo-ions" reflecting the photo-electron momenta are visible for the pure ionization and ionization-plus-excitation final states of the He^{+}-atom.[22]

Right: Emission pattern of photo-dissoziated Deuterium molecules. Analyzed are only events where both fragments are ionized (Coulomb explosion) and both are detected on the delay-line detector (multi-hit operation). The momentum distribution is dominated by the spherical back-to-back emission characteristics as expected for Coulomb explosion of a diatomar molecule. The gap in the distribution is due to the dead-time of the electronics for multi-hit events.[23]

However, for applications where a maximum acquisition speed but no multi-hit event handling is desirable, another *histogram* operation mode can be addressed. After initialization by the PC an FPGA-unit on-board is controlling the event handling independently, computes the 2D-position and the time-sum (TOF-information) and stores it to an on-board histogram memory. The position and/or TOF information content is accumulated over a certain period or event number in the two- or three-dimensionally organized histogram buffer. The maximum acquisition speed exceeds 1 MegaCount/sec in this mode. After the collection period, the histogram buffer is transferred to the PC-memory and the data content can be further treated by the COBOLD program package (see figure 7). An analog XY-DAC-output provides the option to visualize each particle position in real time on an oscilloscope for on-line control. This option allows a visual verification as is for example provided by the phosphor screen systems. So our system can even compete with these optical read-out systems in acquisition speed and ease of control. Only in case of multiple hits one has to use the “slow” transparent mode. However, as our system features digital data handling it does not suffer from image artefacts and blur as the optical read-out methods with phosphor screens have to deal with.

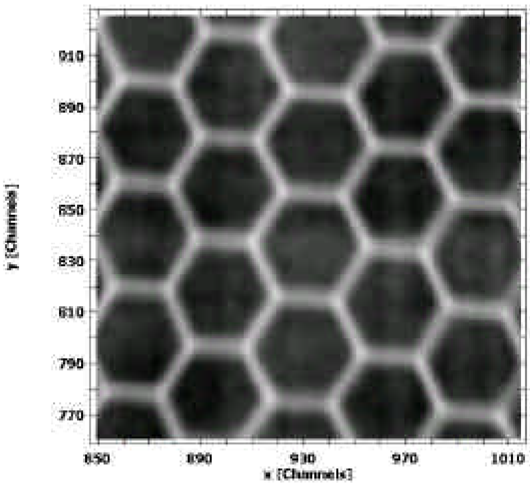

Figure 7: Detail of an image acquired with our delay-line detector system *; as figure 5 (right), but with the* HM1-*TDC unit*

The major superiority of the method, the ability for 3D-imaging, is revealed when the imaging *and* timing features of MCP (or other detectors with delay-line read-out) must be exploited and a high acquisition speed is desirable. Such demand is especially found in several fields of spectroscopy. Examples of such applications will be presented in the following section.

4. APPLICATIONS FOR A FAST 3D-IMAGING TECHNIQUE

It has been shown that it is possible to design a MCP read-out anode that combines a wire array (coarse imaging but good timing) and a phosphor screen with CCD read-out (good imaging but coarse timing) so that simultaneously good imaging and timing can be obtained even for multi-hit events.[24] These systems (some are equipped alternatively with a diode array for the timing read-out task)[25] perform well but they are mechanically and electronically quite complicated, a very advanced software is required and the data acquisition speed is very low as also the back-draws of the respective detection techniques are combined. However, these techniques enabled applications of the 3D-imaging technique in molecular break-up experiments.[20,24]

Our delay-line detector system can compete with these “standard” 3D-imaging techniques (see figure 6) and allows moreover a significantly enhanced speed for multi-hit detection even in the “slow” *transparent mode.*

Whenever only single particle events need to be analyzed one can exceed the acquisition beyond one MegaCount/sec in the *histogram mode*, only this acquisition speed being sufficient for applications in surface science spectroscopy, where not only single molecules or atoms are to be investigated but extended two-dimensional targets.

A very powerful tool for the microscopic investigation of surfaces is the so-called **P**hoto-**E**lectron **E**mission **M**icroscope (PEEM)[26]. An electron optics as known from standard electron microscopy magnifies a certain region of a solid substrate as electrons emitted from the surface are projected onto a MCP detector with phosphor screen. The electron emission is driven by photo-effect from UV-photons impinging on the surface. By tuning the incoming light for its wavelength and polarization very subtle investigations of the surface layer on atomic level can be performed.

For a certain photon energy the emitted electron energy spectrum will show discrete Auger-lines for different element species on the surface and even probe the electronic structure of the respective core levels. If the energy of the emitted electrons could be evaluated simultaneously (e.g. by measuring their TOF in the electron optics) it would be possible to map the surface "in the light" of certain element species, even of certain electronic configurations. The distribution of certain atoms on the surface and details about their respective electronic structure could be visualized.

In first experiments to equip a standard PEEM with a 3D-imaging detector of delay-line type one could indeed resolve Auger-lines by the TOF evaluation and get an image of the surface (see figure 8). In current experiments our newest version of delay-line detector systems was installed. For this detector a standard phosphor screen was additionally embedded in the body of the delay-line anode forming an even more powerful diagnostic tool complementing the standard PEEM to a *TOF-PEEM*. A very good time-resolution is desired here to achieve a good electron energy resolution.

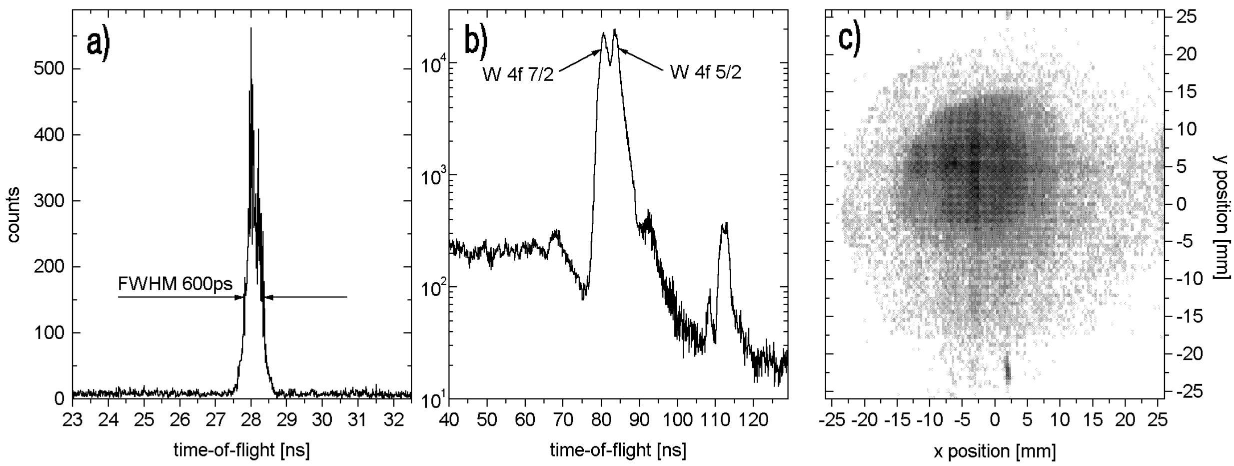

Figure 8: Preliminary results of a first TOF-PEEM *experiment. The timing resolution for the electron-TOF was about 600 picosec as could be verified by a coincidence between the synchrotron machine pulse (time-zero trigger) and stray photons on the detector (a). The 4f 7/2 and 4f 5/2 Auger states of Tungsten atoms on the surface could be separated by measuring the TOF of core electrons, liberated by photons from the Synchrotron light pulses (b). Simultaneously a microscopic picture of the surface could be obtained (c), principally for each TOF-bin. The actual fast detector system was not yet applied here, electronic mismatches have still blurred the imaging in this pilot experiment.*[27]

Another surface science spectroscopy method could also greatly profit from the implementation of a fast 3D-imaging detector. In the standard **S**econdary-**I**on **M**ass **S**pectroscopy (SIMS) technique the element species distribution over a surface is investigated by scanning an energetic photon or particle beam across the surface and detecting the TOF of the sputtered ions in a standard time-of-flight tube. Alternatively, a TOF-PEEM-like instrument could be used, optimized for ion optics and imaging the complete surface element simultaneously. A fast 3D-imaging detector with multi-hit capability should be implemented here.[28]

5. SEALED MCP-DETECTOR SYSTEM FOR SINGLE PHOTON IMAGING

MCP are operable only under high vacuum condition which significantly limits their application range. But it is possible to confine the required vacuum with the MCP-stack in a sealed glass/metal/ceramic housing so that the detector can be operated in almost any environment. Such detectors, equipped with a phosphor screen and eventually with photon/electron converter entrance window are widely used for position sensitive photon detection. In order to exploit the above discussed advantages of electronic read-out one needs to replace the phosphor screen by another anode type for electronic charge weighing or of delay-line type. For practical reasons, a wire array is not easy to incorporate in such a sealed detector housing. [29]Also, it is a major task to even implement any structured anode of delay-line type or other as these are also very delicate to handle. A resistive anode type would be easier manageable but being a charge sensitive method it lacks the desired data acquisition speed.

A method to overcome the need to implement a fine-structured anode into the sealing is to detect the image charge[30] outside the vacuum wall. It has been reported that it is possible to achieve comparable imaging performance when the electron cloud is not directly projected onto a read-out anode but is rather collected by a high-resistive layer on an insulating substrate. If both the surface resistance and the effective substrate thickness (taking account of dielectric properties) is chosen properly (transmission and broadening) that one can use this image charge picked up by a structured anode pattern for electronic imaging and timing with either charge weighing (e.g. wedge&strip anode[31]) or delay-line methods.[32]

In figure 9 the imaging performance of a sealed MCP detector tube[33] for detection of single photons is shown. A wedge&strip anode was placed close to the back-side of the detector tube (outside), separated from the resistive layer by the 2 mm thick ceramic wall of the housing. Image distortion due to still not optimally adjusted resistance and size of the layer is found for this prototype, as other image artefacts, however, the method seems to be applicable.[34]

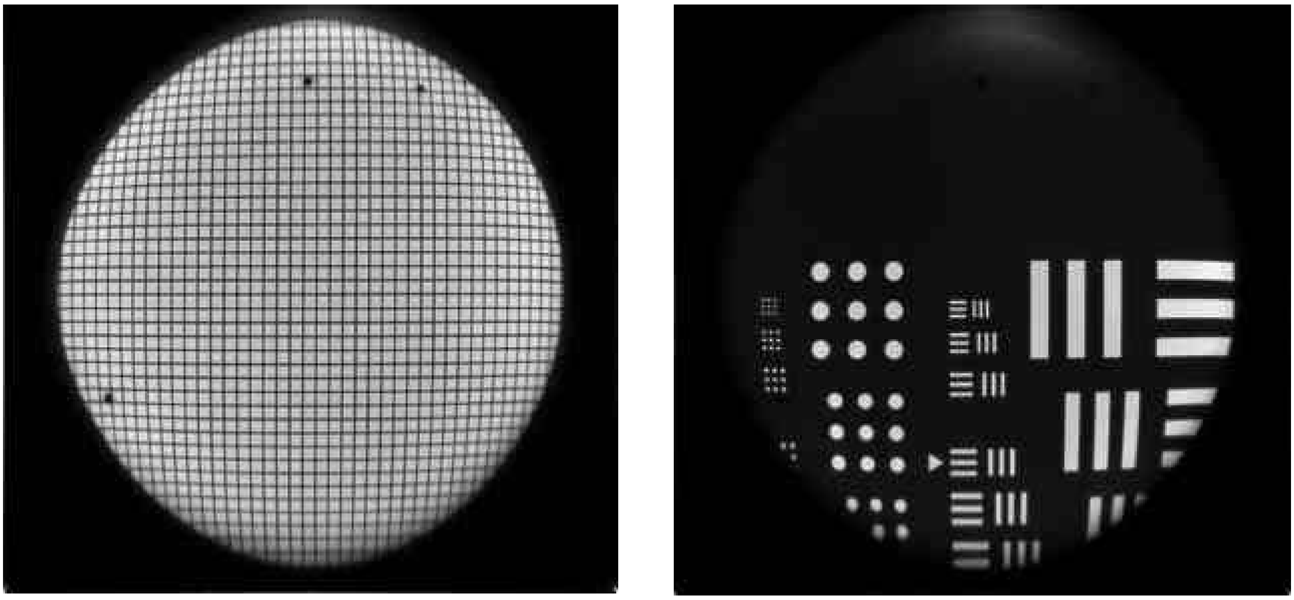

Figure 9: Imaging performance of a sealed single photon MCP-detector with high-resistance anode[33] and image charge pick-up with a wedge&strip anode.[34] The detector is equipped with a bi-alkali photon converter foil to be efficient for visible light. The detector (Z-stack MCP), shaded by a grid mask (70 µm wires, 0.6 mm apart) and a calibration mask (smallest structure dimensions 0.15 mm), respectively, was irradiated by a green diode. The position resolution in the center region was about 30 µm. The spots in the left image are attributed to local defects of the detector hardware (prototype).

As there is great demand for a fast position sensitive single photon detector (e.g. reconnaissance tasks) we try to apply the delay-line technique and the developed electronic read-out scheme also for image charge pick-up. For a one-dimensional position determination a double-meander shaped delay-line as "antenna" for the image charge behind the high resistive layer a very good performance could recently be obtained.[35] Detection rates beyond 1 MegaCount/sec could be handled by the hardware and a superior timing could be obtained as the time-sum width is reported to be as low as 200 picosec (FWHM).

Combining our experience with position sensitive image charge pick-up, delay-line technique in general and the delay-line anode concepts on printed circuits as proposed by Eland[11] and Siegmund *et al.*[13] we currently test several geometries for the optimal performance and hope to report on progress very soon. Such a printed-circuit delay-line anode will soon replace also the wire anodes for the standard applications with open detectors because it promises a cheaper and even more compact and durable hardware design. From the reported time-sum width of 200 picosec obtained for a printed one-dimensional anode we also hope to improve also our current timing limitation when we use the time-sum as a TOF marker in the 3D-imaging scheme and reach the optimal timing a MCP is inherently capable of. So far this precision could only be obtained for non-imaging anodes.

6. CONCLUSION AND OUTLOOK

We have outlined and discussed the advantages of a MCP-detector system with delay-line read-out for fast imaging presuming precise timing information and reported on our first results. We could show that, although cost-efficiency was a major concern, satisfactory performance could be achieved that is challenging other concepts of MCP read-out. Continuous and homogenous detection of single particles (particle showers) with position resolution below 0.1 mm and simultaneous timing analysis with 1 nanosec precision at acquisition rates higher than 1 MegaCount/sec (20 kiloCounts/sec) are, in this combination, benchmarks that have previously not been reported.

These performance parameter make the system a unique tool for many applications and open, as was briefly discussed, in their combination unprecedented opportunities for spectroscopic methods. With our collaboration partners we try to optimize our detector system for applications in surface science spectroscopy instruments.

Sealed MCP-detector systems featuring fast and time-resolved imaging of single photons will soon be operable and will find wide application for spectroscopy and imaging of single photon sources whenever precise timing is of interest.

Although the final goal, a simultaneous *optimal* exploitation of the features a MCP-based detector was not yet met with the current system we hope to achieve it in the future as the development in fast timing electronic circuits and CPU is proceeding rapidly. An improvement of the respective features by the (still missing) factors of about five seems to be envisionable.

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8. REFERENCES

1. J.L. Wiza, Nucl. Instrum. Methods **162** (1979) 587
2. G.W. Fraser, Nucl. Instrum. Methods **221** (1984) 115
3. J. Becker, K. Beckord, U. Werner, and H.O. Lutz, Nucl. Instrum. Methods **A337** (1994) 409
4. M. Lampton and F. Paresce, Rev. Sci. Instrum. **45** (1974) 1098
5. C. Martin, P. Jelinsky, M. Lampton, R.F. Malina, and H.O. Anger, Rev. Sci. Instrum. **52** (1981) 1067
6. J.S. Lapington, A.A. Breeveld, M.L. Edgar, and M.W. Trow, Nucl. Instrum. Methods **A310** (1991) 299
7. J.S. Morgan, D.C. Slater, and J.G. Timothy, Appl. Opt. **28** (1989) 1178
8. E. Kellogg, P. Henry, S. Murray, L. Van Speybroeck, and P. Bjorkholm, Rev. Sci. Instrum. **47** (1976) 282
9. G.C. Smith, Nucl. Instrum. Methods **222** (1984) 230
10. H. Keller, G. Klingelhöfer, and Egbert Kankeleit, Nucl. Instrum. Methods **A258** (1987) 221
11. J.H.D. Eland, Meas. Sci. Technol. **5** (1994) 1501
12. S.E. Sobottka and M.B. Williams, IEEE Trans. Nucl. Science **35** (1988) 348
13. O.H.W. Siegmund, J.M. Stock, D.R. Marsh, M.A. Gummin, R. Raffanti, J. Hull, G.A. Gaines, B. Welsh, B. Donakowski, P. Jelinsky, T. Sasseen, J.L. Tom, B. Higgins, T. Magoncelli, J.W. Hamilton, S.J. Battel, A.I. Poland, M. Jhabvala, K. Sizemore, and J. Shannon, Proc. SPIE **2280** (1994) 89
14. P.G. Friedman, R.A. Cuza, J.R. Fleischman, C. Martin, D. Schiminovich, and D.J. Doyle, Rev. Sci. Instrum. **67** (1996) 596
15. http:\\hsbpc1.ikf.physik.uni-frankfurt.de
16. see for example: M.S. Gorbics, J. Kelly, K.M. Roberts, and R.L. Sumner; Lecroy Corp. (working paper)
17. http:\\www.acam.de

18. K. Ullmann-Pfleger, thesis, Universität Frankfurt, to be published (1998)
19. Win95 and WinNT are trademarks of Microsoft Corp.
20. U. Werner, K. Beckord, J. Becker, and H.O. Lutz, Phys. Rev. Lett. **74** (1995) 1962
21. R. Dörner, V. Mergel, O. Jagutzki, L. Spielberger, J. Ullrich, R. Moshammer, and Horst Schmidt-Böcking, *Cold target recoil-ion momentum spectroscopy: A 'momentum microscope' to view atomic collision dynamics*, Phys. Rep., to be published (1998)
22. R. Dörner, J.M. Feagin, C.L. Cocke, H. Bräuning, O. Jagutzki, M. Jung, E.P. Kanter, H. Khemliche, S. Kravis, V. Mergel, M.H. Prior, H. Schmidt-Böcking, L. Spielberger, J. Ullrich, M. Unverzagt, and T. Vogt, Phys. Rev. Lett. **77** (1996) 1024
23. R. Dörner, H.P. Bräuning, O. Jagutzki, V. Mergel, M. Achler, R. Moshammer, J. Feagin, T. Osipov, A. Bräuning-Demian L. Spielberger, J.H. McGuire, M.H. Prior, N. Berrah, J. D. Bozek, C.L.Cocke, and H. Schmidt-Böcking, *Double photo ionization of spatially aligned* D_2, Phys. Rev. Lett. (1998) to be published
24. D. Kella, M. Algranati, H. Feldman, O. Heber, H. Kovner, E. Malkin, E. Miklazky, R. Naaman, D. Zajfman, J. Zajfman, and Z. Vager, Nucl. Instrum. Methods **A329** (1993) 440
25. A. Cerezo, T.J. Godfrey, S.J. Sijbrandij, G.D.W. Smith, and P.J. Warren, Rev. Sci. Instrum. **69** (1998) 49
26. W. Swiech, G.H. Fecher, Ch. Ziethen, O. Schmidt, G. Schönhense, K. Grzelakowski, C.M. Schneider, R. Frömter, and J. Kirschner, J. Elec. Spec. Rel. Phen. **84** (1997) 171-188
27. V. Mergel, O. Jagutzki, L. Spielberger, K. Ullmann-Pfleger, R. Dörner, and H. Schmidt-Böcking, *Partice and UV-imaging with position sensitive MCP-detectors - three dimensional momentum space imaging*, Proceedings of the Material Research Society, 1.12. – 5.12.97 in Boston, Proc.: In Situ Process Diagnostics and Intelligent Materials Processing, in print
28. A. Cerezo, T.J. Godfrey, J.M. Hyde, S.J. Sijbrandij, and G.D.W. Smith, Applied Surface Science **76/77** (1994) 374
29. M.B. Williams, S.E. Sobottka, and J.A. Shepherd, IEEE Trans. Nucl. Sci **38** (1991) 148
30. G. Battistoni, P. Campana, V. Chiarella, U. Denni, E. Iarocci, and G. Nicoletti, Nucl. Instrum. Methods **202** (1982) 459
31. M. Unverzagt, Diploma thesis, Universität Frankfurt (1992), unpublished
32. patented by Roentdek HandelsgmbH DE 4429925 C1
33. http:\\www.proxitronic.de
34. J. Barnstedt, private communication (1997)
35. U. Meyer, P. Forck, T. Hoffmann, O. Jagutzki, A. Peters, P. Strehl, and H. Schmidt-Böcking, *A fast residual-gas ionization monitor for intense stored heavy ions*, Proceedings of the "Sixth European Particle Accelerator Conference" in Stockholm, 22.-26.6.98, to be published (1998)