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**A PARALLEL-PLATE AVALANCHE CHAMBER
WITH A GATED DRIFT-CHAMBER READOUT**

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ABSTRACT

We describe a new high-rate detector suitable for X-ray imaging, ring imaging of Cherenkov light, and charged-particle tracking. The device is a parallel-plate avalanche chamber coupled to a gated drift-chamber readout. This design incorporates the advantages of parallel-plate avalanche chambers and drift-chamber readout methods, and avoids some of the disadvantages of both. The two-dimensional readout of the detection plane is obtained by time slicing in one dimension and cathode pads in the other.

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1. INTRODUCTION

New instrumentation is needed to be able to handle the high rates and intense particle fluxes of present fixed-target experiments and planned colliders. Although the device described here was originally conceived for possible use as a fast Ring-Imaging Cherenkov counter (RICH), it has wider applications in all aspects of future high-rate experiments where charged-particle tracking is desired. During the operation of the device it has been noticed that this is a conveniently inexpensive method of determining simultaneously the energy and position of X-rays.

Ring-imaging detectors are now widely used or being considered for use in high-energy physics. A strong demand has arisen for instruments capable of dealing with large multiplicities of events within a short collection time enabling high-rate operation. Detection of single photoelectrons from the conversion of ultraviolet (UV) light in photosensitive gases such as tetrakis(dimethylamine)ethylene (TMAE) or triethylamine (TEA) requires high gains that are difficult to obtain in normal gaseous chambers. We present here an approach where we try to meet these requirements by a novel arrangement of multistep chambers and drift chambers.

2. CHAMBER DESCRIPTION

The device is shown schematically in fig. 1; it consists of a thin input window made of Aclar^{*)}, which is transparent to UV light of wavelength $\lambda > 200$ nm and forms part of the gas enclosure, and a series of wire mesh planes. These meshes are constructed from 50 μ m diameter stainless-steel wires, spaced at half-millimetre intervals and interwoven in orthogonal directions^{**)} . The first gap is a 17 mm thick low electric field region, which is a conversion gap for X-rays or UV light or an ionization collection gap for charged particles. The electrons produced in this conversion gap are moved by the electric field perpendicular to the mesh planes into a region of higher electric field, called the preamplification gap, 4 mm thick, where the field is sufficiently high for the entering electrons to ionize the gas. Essentially the electrons are amplified continuously along this preamplification region, and gains of 1,000 to 10,000 can easily be reached. As the electrons drift to the end of the preamplification gap they can either be collected on the wire grid or transferred out. The percentage of electrons transferred out of the preamplification region, with good approximation, depends upon the percentage of field lines leaving this region and entering the transfer gap; this is just the ratio of the electric field in the transfer gap to that in the preamplification gap [1]. Transfer efficiencies of 10% to 20% are reasonable. Figure 2 shows an enlarged view of the electric-field lines and equipotential lines of the preamplification region as well as the adjacent transfer region.

The electrons that are transferred out of the preamplification region enter the transfer gap, which is 9 mm thick in our detector. This gap acts as a charge transfer region, delaying the signal and isolating the two parts of the detector from each other. During this delay, created by the slow drift-time in gases, an experiment should have enough time to generate a trigger to determine if that event should be read out. At the end of the transfer gap is a plane of thick wires, 100 μ m in diameter and spaced 1 mm apart, where every other wire is either at ground or a higher voltage than the previous mesh plane. This wire plane is referred to as the gate because in its normal operation it acts like a charge collector without amplification, stopping any charged particles from penetrating into the drift chamber; but when the experiment's trigger has decided to read out an event the voltages can be pulsed to transfer the charge through this grid [2]. In this way the gate can then be used to transfer electrons from any time slice, coming from the conversion or collection gap, into the drift-chamber

^{*)} Aclar: polychlorotrifluoroethylene (PCTFE).

^{**)} Manufactured by Gantois, Saint-Dié, France.

part of the detector. This type of gating does not require that all of the conversion space be gated; it is possible to gate only a small slice of the conversion gap. It is because of this gating that our detector is capable of being used in high-rate environments; however, one limiting factor is given by the preamplification region. The gain achievable in this region is dependent upon the rate there. To obtain higher amplification of the signal it is possible to add a second parallel-plate amplification region before entering the drift chamber; the rate of events passing into this second parallel-plate amplification region can be limited by a similar gating process. Reasonable gating times for this type of operation are greater than 50 ns.

The drift-chamber part of this detector consists of a grounded box surrounding the drift volume, see fig. 3. The input to the drift chamber is through a grounded mesh plane and the back plane is made of copper-plated printed-circuit board. The 100 μm diameter cathode wire in the centre is also grounded. There are two anode wires of 50 μm diameter, operated at positive high voltage and located 5 mm away from the side walls; these are cathodes grounded through the amplifiers. The localization of the particles can be determined by dividing the cathode into strips in the direction perpendicular to the anode wire; the other dimension is determined by measuring the drift-time between the signal either from the preamplification grid or from an external trigger, and the signals on the cathodes. In our tests the cathodes were not divided into strips, but were one complete cathode. The electric-field lines for the drift-chamber part of this detector are shown in fig. 3; only those field lines entering the drift chamber through the grounded mesh plane are shown.

3. THEORY OF OPERATION

The drift chamber is a common device used in high-energy physics and was first developed at CERN in 1968 [3]. It has the advantage of a small number of channels of electronics because the information for one of the directions comes from measuring the drift-time after a trigger, which can be done simply by a time-to-digital converter (TDC), or for those events that possibly have many hits by using a flashing analog-to-digital converter (FADC). The main disadvantage of a drift chamber is that when a single event occurs it can take a long time to read out the whole length of the drift chamber; however, if a second event were to occur over the first then pattern reconstructions would become complicated because it is impossible to tell which pulse came from which event. This fact makes long drift chambers useful only for low-event-rate experiments with very little background. When using drift chambers for ring-imaging Cherenkov techniques with photosensitive gases such as TMAE or TEA, then the absorption of the UV photon from Cherenkov radiation produces one electron which must be drifted to the anode wire. This one electron, if drifted over large distances, can easily be lost when impurities are above 10 ppm. In order to drift for very long distances, extreme purities of the drift-chamber gas are thus required.

Another problem with drifting one electron over a long distance is the scattering of this electron from its nominal path, caused by random processes of Brownian motion. The longer the drift the worse the accuracy in localizing the initial UV photon or X-ray. In our device, because the drift-chamber part of the detector is gated, there are no ambiguities of overlapping events because only one event is gated into the drift chamber at any time. Also, since preamplification is done in the parallel-plate avalanche chamber (PPAC) part of our detector, the one electron from the UV photon or the many electrons from an ionizing particle drift only a short distance before they are amplified. As in other PPACs, because of this short drift to the preamplification gap, there are less losses and less scattering of the initial electrons. After transfer of the charge out of the preamplification grid there are many electrons, and loss or scattering of these electrons is acceptable.

Single-step PPACs have been used since the dawn of nuclear physics. They permit the easy detection of heavily ionizing particles with low-pressure gas fillings, requiring moderate amplification. There have been many attempts to use them for the detection of minimum-ionizing

particles. Their attractive feature is the time resolution, better than that of wire chambers. Their negative feature is the occurrence of occasional destructive sparking, especially with large surfaces. This feature is aggravated in magnetic fields. The multistep chamber, which is a PPAC coupled to a multiwire proportional chamber or another avalanche chamber, was first developed in 1978 at CERN [4]. This work showed that single-step parallel grids, coupled to a conversion space for X-rays, give good energy resolution for low-energy X-rays. It also showed that it is possible to transfer the amplified swarm of electrons, in a proportional mode, to successive multiplying gaps, with the possibility of having large amplification and gating at intermediate stages. It was also found that it is easy to reach a level of amplification where single electrons can be detected with a high efficiency and the feedback photons eliminated by separating the gaseous amplification process into two parts at a distance from one another in space. Although the multistep chamber has many advantages it is not a widely used detection technique in high-energy physics because of the popularity and simplicity of the multiwire proportional chamber (MWPC). The advantages of this type of PPAC are the parallel transfer and the amplification of the charge. It is a gateable device with high-rate capabilities and has the nice feature of a charge transfer delay line. Its disadvantages are the small amplification signal with a single PPAC gap, the large number of electronics channels needed for parallel readout of the whole surface, the large spot size of the final avalanches, and finally—when two PPAC gaps are used—the spot size of the avalanche can be as much as 1 mm to 2 mm.

Previously, other investigators have used the PPAC with three readout planes of complex crossing wires providing x, y, u coordinates [5]. Others have managed to successfully read out this type of chamber using small pads (5 mm by 5 mm) [6], but this requires a large number of electronics channels. It is also possible to read out the PPAC by looking at the secondary light emission in the final amplification gap using a charge coupled device (CCD) camera [7]; this was proved to be an efficient method for the detection of Cherenkov photons [8]. This camera has the nice advantage of a compact readout system, but it is difficult to find a CCD camera capable of being read out at preferred high-energy physics data-acquisition rates.

During operation it is important not to run the drift-chamber sense wires at too high a charge gain. The proper operating voltage of the drift-chamber anode wires should be just sufficient to see the number of electrons coming from the preamplification gap; the wires should not be sensitive to single ionizing tracks or single electrons from UV light absorption or X-ray conversion. When this detector is operated for charged-particle tracking, the signal coming from the charged particle's track in the ionization collection gap is still distinguishable from the ionization track in the drift chamber. The signal generated from the ionizing track after it is preamplified can be a charge cloud of 20,000 electrons localized in space, whereas the signal from the background of charged particles passing through the drift chamber or transfer gap is a line of charge spread out over a large distance. Thus there is a clear distinction between the two different types of signals and, if operated properly, the drift chamber's anode wires should be insensitive to the background of charged particles traversing the detector under high-rate environments.

When using wire chambers or PPACs for ring-imaging Cherenkov techniques, a special feedback problem occurs, because these techniques require high gains to see the single electrons converted from the absorption of the UV light. These high gains produce a large number of photons in the avalanche, which are not quenched close to the wire but are absorbed, further away from the wire, either in the gas or on an electrode; these absorbed photons are a source of further electrons, which drift back to the wire, causing another avalanche and becoming a source of noise and background. In a wire chamber sensitive to single photons this problem is difficult to master; however, in a double-step PPAC or in a PPAC with WMPC, methods have been developed that substantially reduce the feedback by dividing the amplification into two parts separated by a large distance. Single photons absorbed on the transfer side of the preamplification gap are not detected

on the anode wire of the drift chamber because the gain is too low to see these single feedback electrons. This is also true for feedback photons which are absorbed in the transfer gap or the drift chamber before reaching the preamplification region. Because of this, it is important to have the transfer gap and the drift chamber large enough to ensure the absorption of the feedback photons in this region, instead of in the conversion or preamplification gap. The amplification of the charge in the preamplification gap is also a source of feedback photons, but those coming from this amplification have a small probability of being detected, mainly because of the lower gains of parallel-plate amplification and because half of them are on the transfer-gap side of the preamplification gap. As discussed earlier, it is necessary to limit the gain in the ungated part of the chamber so as not to have any feedback problems or space-charge effect.

4. OPERATING RESULTS

The detector was operated with a gas mixture of 90% argon and 10% methane (CH_4), at atmospheric pressure. The front input window was made of thin Aclar to allow 5.9 keV X-rays to penetrate and convert to an electron in the conversion gap. The X-ray source was ^{55}Fe , collimated by two thin copper plates, with a 1.0 mm diameter hole in each plate; the copper plates were separated by a distance of 1.0 cm. The exit hole of the collimated source was placed 4.0 cm away from the first mesh plane. The typical operating voltages were (see fig. 1 for this chamber's construction of mesh planes and wires along with a more detailed description of the abbreviations used here):

Drift	$V_D = -6.00 \text{ kV}$,
Preamp. P_1	$V_{P1} = -5.85 \text{ kV}$,
Preamp. P_2	$V_{P2} = -400 \text{ V}$,
Gate grid	$V_G = 0.0 \text{ V}$,
Cathode wire	$V_C = 0.0 \text{ V}$,
Anode wire	$V_A = +1.60 \text{ kV}$,
SC and BP	$V_{SC} = V_{BP} = 0.0 \text{ V}$.

In fig. 4 the energy resolution of the collimated ^{55}Fe source is shown for the charge signal from the preamplification gap. This signal was taken from the grid plane labelled P_2 through a high-voltage capacitor. The energy resolution is 18% FWHM using an Ortec 142 charge amplifier^{*)}. This detection technique provides only one signal out of the preamplification gap; therefore a large amount of money may be spent on it because it only needs one channel of electronics. However, notice should be taken of fig. 5b where these energy resolutions were obtained with a less expensive charge amplifier^{**) (20 US dollars) obtaining comparable resolutions of 20% FWHM. Because of the high capacitance of a PPAC, care should be taken in choosing the proper charge amplifier that will produce the best energy resolution. Other authors have shown that a parallel-plate amplification structure is best suited to reach very good energy resolution [9]. In fig. 5a the pulse height of the charge signal from the preamplification gap is shown as the source is scanned across the front input window. Figure 5a demonstrates the uniform amplification achievable with a PPAC over large areas. Figure 5b shows the energy resolution obtained for each of the points in fig. 5a; this demonstrates the uniformity of the energy resolution obtainable.}

The source was scanned across the entrance window to the chamber to study: i) the pulse-height reduction in the drift chamber as a function of drift distance, which is shown in fig. 5c; and ii) the

^{*)} Made by EG & G, Oak Ridge, Tenn., USA.

^{**) LH0032CG type, manufactured by National Semiconductor Corp., Santa Clara, Calif., USA.}

sensitivity of the drift-time as a function of drift distance. We observed drastic changes, by a factor of two or three in pulse height, as the flow rate was changed, indicating oxygen contamination. The point on the entrance window directly over the anode wire on the drift chamber is defined as zero on our measuring system, and the furthest drift distance is 45 mm, which is that point on the entrance window directly over the central cathode wire. The drift-time to drift distance relation for the drift chamber is shown in fig. 6a. This shows the non-linear nature of the drift chamber's response. Because in fig. 6a the relation of the drift-time to drift distance is not clear for 30 mm drift and less, it is redrawn in fig. 7 to demonstrate that the drift distances from 10 mm to 30 mm are actually usable to determine the position. However, there is a problem in the region of 10 mm drift and less. It is clear that in this region the drift-time information is not useful to accurately determine the position of the source. As the drift distance is made larger or the thickness of the drift gap is made smaller, the percentage of dead space becomes smaller. Also, because the drift-time to drift distance relation is exponential this will make the determination of the drift distance more difficult to calculate than if the drift-time to drift distance relation were linear. Figure 6b shows the spread in time of the collimated source spot as a function of drift distance; notice should be taken of the similar shape of the curve describing this source spot size as a function of drift distance compared to fig. 6a. Figure 6c is a calculation of the slope of fig. 6a as a function of drift distance; this is used to remove the drift-time to drift distance relation from fig. 6b, and to calculate the actual change in physical spot size of the source as a function of drift distance. It is clearly shown by fig. 6d that the source has a physical spot size of 2 mm FWHM and the measured size is independent of the drift distance. From fig. 6d it is concluded that the resolution does not vary over the drift distance. Although we have not studied the position resolution directly, there is no reason to suspect that this type of drift chamber should have any worse resolution than those of the past.

This chamber was also operated with a beta source of ^{106}Ru and a scintillator-photomultiplier tube (PMT) was used to observe the signals. Figure 8a shows the pulse-height signal of the drift-chamber anode wire in coincidence with the PMT signal with the gating of the drift chamber turned on. Figure 8b shows the same signal with the gating of the drift chamber turned off. Note the change of scale between the two pictures, and further notice that those signals coming from the direct ionization in the drift chamber are hundreds of times smaller than the signal coming from the ionization collection gap, the latter being preamplified by the PPAC front input. This clearly shows the ability of the device to reject the background of charged particles passing through under high-rate environments. Figure 9 shows the relationship between the pulse height on the anode wire and that induced on the cathode pads located on the side wall. This demonstrates that cathode pads can be used to determine the coordinate along the wire.

Using a gas mixture of He, CH_4 , and TEA (80%, 18%, 2%), the device was able to see the single photoelectrons from a UV light source. Helium gas was replacing argon to reduce the pulse height from charged-particle tracks in the drift chamber. Figure 10a shows the frequency histogram for single-photoelectron pulse-height spectra. The anode wire signal from the drift chamber is shown in fig. 10b; it should be compared with the background from charged particles in the drift chamber shown in fig. 10c. This result shows that this device can be used to see single photoelectrons in a high-particle flux experiment. However, it was not possible to operate our PPAC, at these gains, with a ^{106}Ru source, because of too frequent electrical breakdowns. In an actual detector of this type, the gain achieved in our single-gap PPAC would have to be split between two PPACs, the second step being gated. In this way, high gains could be obtained for single photoelectrons, and operation with ionizing particles would be made possible.

5. CONCLUDING DISCUSSIONS

Such a device as described here should find immediate applications in soft X-ray imaging, since good energy resolution is obtained from the PPAC front input plane and the position can be determined by the use of two timing units measuring the delay-time of the signal on the anode wires after observing the signal on the preamplification gap. The remaining coordinate can also be obtained by using cheap hit electronics to determine which cathode pad was hit.

This device was originally devised for fast ring-imaging Cherenkov techniques. Further use of it could be made in large-area charged-particle tracking, using a similar layout of electronics for those events which are simple, and more complicated electronics for multiple-hit events. Because of the possibility to gate the drift chamber to read out only those events desired and because of the fast parallel-charge collection of the conversion gap, this type of gated drift-chamber readout scheme should be useful. The main advantages are the cost-saving time-slicing readout for one of the dimensions, which substantially reduces the number of electronics channels.

Further work is required to make such a device feasible for large-area fast-RICH techniques and particle tracking, as, for instance, investigation of the gated drift-chamber readout to make the drift-time to drift distance relation more linear and to reduce the size of the dead zone close to the anode wire of the drift chamber. This could be achieved by making the drift chamber thinner and with longer drift. Another possibility is to add focusing wires between the transfer gap and the drift chamber in order to translate the whole drift space into the active and linear part of the drift chamber. It may be that many of the old techniques used to improve the drift chamber might also be useful here. There are still unanswered questions which we were not able to study with this initial chamber, such as the actual position resolution of the drift chamber readout. Further work should also include readout with FADCs as well as dividing the cathode into strips.

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Figure captions

- Fig. 1: Chamber design showing the mesh planes as dashed lines, the gating grid as a dotted line, and the drift-chamber readout.
- Fig. 2: Three-dimensional calculations of the electric field for a mesh-plane structure. The transition region is shown here, with the parallel-plate amplification on the left and the transfer gap on the right. Only those wires perpendicular to the plane of the page are shown (small circles). The equipotential lines are dashed and the electric-field lines solid. The values of the equipotential lines are shown in the key on the bottom right-hand part of the figure.
- Fig. 3: Two-dimensional calculations of the electric field for the gated drift chamber. Equipotential lines are dashed and only those electric-field lines entering the drift chamber are drawn. The values of the equipotential lines are shown in the key to the right.
- Fig. 4: Frequency histogram for pulse height of the parallel-plate avalanche part of the chamber. The energy resolution is 18% FWHM using an Ortec 142 charge amplifier.
- Fig. 5: a) The pulse height from the parallel-plate avalanche part of the chamber as a function of the drift distance scanned across half of the chamber. b) The energy resolution from the parallel-plate avalanche part of the chamber as a function of the drift distance scanned across half of the chamber. c) The pulse height from the anode wire of the gated drift chamber as a function of the drift distance scanned across the whole drift length of one side of the chamber.
- Fig. 6: a) The drift-time to drift distance relation for the gated drift chamber. b) The FWHM of the source spot size, in time, as a function of drift distance. c) A calculation of the slope of part (a) of this figure as a function of drift distance. d) The FWHM of the source spot size, in millimetres, as a function of drift distance. This was calculated by taking the FWHM of the source spot in time at each point and dividing by the slope of the drift-time to drift distance relation from (c).
- Fig. 7: The drift-time to drift distance relation for the gated drift chamber in the region of drift distance of 0 to 25 mm.
- Fig. 8: Pulse height from the anode wire of the gated drift chamber in coincidence with a PMT signal for ^{106}Ru ; a) when the gating of the drift chamber was turned on in coincidence with the event; b) when the gating of the drift chamber was turned off in coincidence with the event.
- Fig. 9: Frequency histogram of the pulse height; the white histogram shows the pulse height from the anode wire of the drift chamber; the black histogram shows the pulse height from one of the cathode pads of the drift chamber.
- Fig. 10: a) Frequency histogram of single-photoelectron pulse-height spectra; b) Pulse height from the anode wire of the gated drift chamber for a typical single photoelectron using a UV light source; c) Pulse height from the anode wire of the drift chamber, in coincidence with the PMT, with the gating of the drift chamber turned off.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

a)

b)

Fig. 8

Fig. 9

a)

b)

c)

Fig. 10