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A LINEAR DRIFT CHAMBER READOUT OF A
GATED MULTISTEP AVALANCHE CHAMBER

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ABSTRACT

A classical drift chamber with linear field cage wires and highly segmented cathode strips is elegantly combined with a gated multistep avalanche chamber. The drift chamber has a linear drift time to drift distance relation over 95% of its length, provides a flexible readout method that can be tailored to the expected event multiplicity of a given experiment, the readout time is considerably faster in comparison to similar devices that can handle large multiplicities, and the readout techniques are well known in High Energy Physics. The gated multistep avalanche chamber with a thin conversion gap amplifies the desired signals, in a given time slice, above the ungated minimum ionizing background making such a device suitable for use in high intensity experiments; while the gas drift delay and gating allows time for the experiment to generate a trigger and to selectively readout only those events of interest. The separation of the gas amplification into three sections permits large gains necessary for UV photon detection in ring imaging Cherenkov techniques thus reducing the gain needed in each parallel plate avalanche gap and completely eliminating electrical discharges.

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1. INTRODUCTION

The future of High Energy Particle Physics requires detectors capable of handling intense particle fluxes of high rates and events with high multiplicities. One type of gaseous detector capable of handling these requirements is the multistep avalanche chamber. Such devices have been shown to perform well under high intensity particle fluxes [1]; however, the readout methods had limitations which could prevent their use in certain experiments. The original multistep detector had a multiwire proportional chamber (MWPC) readout [2] which was limited to low multiplicity events. Camera readout of the secondary light emission from electron impact excitation of the molecules has also been used [3], but is limited by the camera acquisition rate of 25 Hz. Electronic readout by charge collecting pads has also been demonstrated to work [4] limited only by the cost of the readout which is determined by the size and number of pads. Multistep detectors have found limited use in high energy physics experiments because of their small size and frequent electrical discharges.

Preliminary results from a multistep avalanche chamber with a linear drift chamber readout are presented. A previous attempt to readout a parallel-plate avalanche chamber with a drift chamber [5] had a nonlinear drift time to drift distance relation; this problem has been corrected by finding the proper electric field that permits a smooth and efficient transfer of the electrons from the multistep chamber into the drift chamber. The detector has possible application for high multiplicity charged particle tracking and single photoelectron detection such as in ring imaging Cherenkov. The detector has a 100ns charge collection time coupled with a 14

microsecond drift chamber making it considerably faster and less expensive than other readout methods. Measurements indicate that better than 2.4mm FWHM position resolution can be obtained for single photon detection, and the position resolution for charged particles should be better. Because the detector has three steps of amplification the device is well suited for efficient single photon detection, as demonstrated by a peaked pulse height spectrum. The separation of the amplification by sufficiently large distances greatly reduces feedback and permits operation that has completely eliminated electrical discharges in the parallel-plate amplification regions.

2. DETECTOR DESIGN

The detector structure is shown in figure 1. The ultraviolet (UV) photons or beta particles enter the detector gas volume from the left through a quartz or mylar window where they are either absorbed by the photosensitive gas or pass through the conversion gap. Tetrakis(dimethylamine)ethylene (TMAE) was planned as the photosensitive gas. The thickness of the conversion gap and the concentration of the TMAE both determine the efficiency of photon detection. The original aim of this development was to test the detector idea as a prototype for Ring-Imaging of Cherenkov light (RICH) in a high intensity flux of particles. The requirements for the fast-RICH was to have a 100ns collection time which subsequently requires a 6mm conversion gap such that the electrons could all be collected within the 100ns window. Any RICH detector requires a high single photon detection efficiency and the aim was to have a conversion gap of one interaction length (66% detection efficiency), this requires a high TMAE concentration that can only be achieved by

heating the TMAE to 42 degrees Celsius. To prevent condensation of the TMAE onto the walls of the detector it was planned to heat the chamber to 50 degrees. In determining the thickness of the conversion gap it was necessary to take into account the planned gas mixture's drift velocity as a function of the electric field, and the interaction length of the photosensitive gas.

The electrodes are made of stainless-steel meshes that have 50 micrometer diameter wires with half-millimetre pitch. The voltages on the electrodes are such as to move the electrons produced in the conversion gap to the right where they enter a 3mm amplification gap. In the amplification gap the higher electric field accelerates the electrons to sufficient energy to further ionize the gas, such as in a parallel-plate avalanche chamber. The electrodes here are made of meshes which are transparent to allow some of the electrons produced to be transferred out to another amplification gap. The percentage of electrons transferred out of the amplification 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 amplification gap [1]. Transfer efficiencies of 10% to 20% are reasonable. Located in the center of the transfer gap is a wire grid that allows gating of the events of interest. The transfer distance to this gate grid is large (15mm) which allows, by means of a gas drift delay, time for an experiment to generate a trigger and open the gate only for those events of interest. The transfer distance after the gate is 15mm but could be much smaller. The background signal originates in this second transfer gap from the ionization deposited by the charged particles that cross this gap but are not associated with the event of interest.

Making this second transfer gap smaller would reduce the background signal. Both the unwanted ionization from those particles out of time with the event and the gated signal from the conversion gap then enter a second amplification gap of 3mm, identical to the first. Each of these amplification gaps can easily reach a gain of 1000 to 10000, with 10% transfer efficiency making an effective gain of 100 to 1000 in each gap. The purpose of the multistep chamber is not to amplify single photoelectrons sufficiently to detect them, but is only to amplify them above the background ionization. The background ionization can also be reduced by the proper selection of the gas mixture. For charged particle tracking a gas mixture of 90% Argon and 10% Methane was used and any further reduction of background not possible. However, because the photosensitive gas, TMAE, provides the single photoelectron the carrier gas could be a low ionization gas such as Helium with a small amount of quencher added. Drift chambers have been made to work with mixtures containing mostly Helium [6] as well as parallel-plate avalanche chambers [7] and so does not present a problem.

After the signal was amplified in the second amplification gap it enters the transition region that transfers the electrons from the multistep chamber into the drift chamber (see figure 2) in such a manner so that the timing information can be used to determine the coordinate perpendicular to the anode wire. It was also important that the timing information be linear to make data collection and analysis easier. The drift chamber was constructed in a standard method: field wire electrodes every 2mm, 10mm thick drift chamber of 100mm drift distance in both directions to 50 micrometer anode wires. The anode wires were surrounded by ground electrodes on three sides and open to

the drift chamber on the fourth. In back of the anode wire was an array of cathode strips 2.5mm pitch that are used to determine the coordinate of the signal along the anode wire. In this prototype the anode wires were 200mm long. For simplicity it was necessary to have the cathode strips at ground potential, this required that all of the multistep electrodes be at negative high voltage. With the correct selection of the electric field in the transition region and in the drift chamber it was possible to uniformly transfer from the multistep chamber to the drift chamber; electric field calculations were used to determine these fields. Also through electric field calculations it was determined that the drift chamber electrodes had to have an electric field across the drift chamber gap to help turn the lines of force, otherwise many force lines from long drift distances would not terminate on the anode wire. There are also additional losses of electrons in the transition region from the multistep chamber to the drift chamber because not all of the electric field lines enter into the drift chamber. A simple calculation of the number of field lines entering the drift chamber to the total number of field lines gave 8% transparency. Others have done more detailed calculations than ours [8], by calculating the field density on both sides of the drift chamber electrodes giving 2% transparency.

3. MEASUREMENTS

The detector was first operated with a gas mixture of 90% Argon and 10% Methane. The operating voltages used are listed in table one and the symbols refer to those in figure one. The drift time to drift distance relation shown in figure 3 was measured using a collimated ^{106}Ru beta source. A scintillator and photomultiplier (PMT) provided

the start signal and the cathode strip signal the stop. The pulse height as a function of drift distance in the drift chamber was also measured and is shown in figure 3. A reduction of pulse height as a function of drift distance was seen because the transfer efficiency out of the second parallel-plate amplification region varies as a function of drift distance which was caused by the electric field variation in the transition region. In the center of the drift chamber the electrodes have their highest voltage and at the edges the electrodes are close to ground potential; it is here near the edges that the electric field in the transition region is the highest and the transfer efficiency out of the multistep chamber the greatest. A pulse height spectrum is shown in figure 4 and was taken at 7cm drift distance. The black curve in the figure is the pulse height spectrum with the gate open and the underlying white curve with the gate closed, the pulse height spectrum in both cases was taken in coincidence with a PMT trigger. It can be seen from a comparison of the two spectrum in figure 4 that a threshold can be set to eliminate the sensitivity to the background particles. Further reduction of pulse height, for the gate closed signal, by a factor of 8 is possible by reducing the transfer gap after the gate plane to 2mm, or by making the gate plane the first grid of the second parallel-plate amplification gap.

As a prelude to testing the detector as a RICH, it was operated in the lab using single photoelectrons with a gas mixture of 95% Helium and 5% Ethane bubbling through liquid TMAE at 42 degrees Celsius. The detector was operated in an insulated hot box kept at 50 degrees, and the necessary voltages for operation are listed in table one. Ultraviolet photons were produced by a deuterium spark lamp that

provided a trigger when the lamp pulsed. The UV light was measured to be emitted over a 25ns time period and was collimated down to single photoelectrons by using a 30cm tube with 200 micrometer diameter holes on both ends. Single photoelectron signals were observed on the cathode strips to be as large as 40mV using a simple current amplifier, with sensitivity of 10-20 mV/pC, and produced a pulse height spectrum that just starts to peak above the threshold of the multichannel analyser, as can be seen in figure 5. An absorber of UV photons, transparent to UV light above 190nm, was placed between the chamber and the UV lamp and the rate of single photon detection was reduced but the pulse height spectrum remained unchanged, indicating that the spectrum measured was that of single photons. The two parallel-plate avalanche chambers were operated more than 400 volts below their sparking threshold, for these measurements, completely eliminating any electrical discharges. The hot TMAE gas or the chamber appears to generate a 1 kHz noise similar to a thermal photocathode noise in a PMT. This noise was not a problem because the events were triggered by the pulse signal from the UV lamp, and this noise would only be noticeable if the gate is left open. The pulse height spectrum of this hot noise is similar to the single photon spectrum but with an extended exponential tail. At present the pulse height ratios in the helium gas mixture between single photoelectrons, minimum ionizing particles gated with the event, and background particles are not known. There are many places to reduce the minimum ionizing background by reducing the size of the transfer gap after the gate and by adding an additional gate plane before entering the drift chamber.

The drift time to drift distance relation, shown in figure 6, was measured with single photoelectrons in the Helium gas mixture by

using the UV lamp's trigger pulse as the start and the cathode strip signal as the stop. The position resolution for single photoelectrons was measured using the deuterium UV lamp and the collimating telescope to make a small spot of UV light on the quartz entrance window of the chamber. Figure 7 shows the time spectrum of the single photoelectrons at 5 cm drift distance. The horizontal scale is 710ns per division and using the drift time to drift distance relation of figure 6 gives 2.4mm FWHM (1mm sigma) position resolution. The actual position resolution is probably better than this because the UV spot used was 200 micrometers and because the UV light was emitted from the lamp over 25ns. The main limiting factor on the position resolution with this type of detector is the timing fluctuation in the arriving signal on the anode wire caused by the different depths of conversion of the UV photons in the gas. The naive approach would be to say that the position resolution should be the thickness of the conversion gap; however, two other factors are important. First the probability for a UV photon interaction is exponential and second the drift velocity in the conversion gap is much faster than in the drift chamber. The voltages were set in the drift chamber to be three times slower than in the conversion gap so that the 6mm conversion gap would map into a 2mm error in the drift chamber's timing measurement. This effect was well demonstrated when the position resolution was measured for different electric fields in the conversion gap and is shown in figure 8. It can be seen that as the drift velocity saturates to its maximum in the conversion gap the position resolution is best.

4. CONCLUSION

The principles of operation of this preamplified drift chamber

have been shown to work and warrants further investigation. Many more measurements are necessary before serious consideration can be taken for using such a detector in a high energy physics experiment. A detailed study of the position resolution for both charged particle tracking and single photoelectrons over the entire drift distance is necessary. Uniform detection efficiency over the whole drift distance is necessary and an investigation into the transfer-efficiency variations into the drift chamber must be tackled. Small dead regions in the drift chamber transfer are not a problem because the parallel-plate amplification spreads the electron cloud out over 2mm, depending upon the gas mixture, but large dead regions of poorer transfer-efficiency would mean larger dynamic range of the signal to be detected. At present the detector has been operated with either gate open or gate closed in DC mode, but in the future pulsing is required to make the detector suitable for use in high intensity experiments. Pulsing limitations and induced signals must be studied. High intensity studies are necessary to determine the actual upper limit with such a detector. Use of such a detector in or near a magnetic field is not guaranteed without further calculation of electric and magnetic field effects on the lines of force.

This preamplified drift chamber has many possible uses in experiments that have high intensity particle fluxes and require high readout rates. Possible uses are in charged particle tracking, UV photon detection such as in ring imaging of Cherenkov light or BaF_2 scintillation light. Because an electrical signal can be taken from the second parallel-plate amplification gap this is the first drift chamber that can provide its own start trigger, even for X-ray sources. Since the readout methods of the drift chamber are diverse it is not

clear which electronics is best suited for a given application and could be an interesting topic of further study. At present 100ns charge collection times have been chosen because it is the memory time of the MWPC in the experiment, but in principle faster collection times are possible down to the 10ns rise time of the high voltage gate pulser. For faster UV photon collection higher TMAE temperatures are necessary, or possibly searching for liquid or solid photocathodes capable of being used in gaseous detectors.

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Table 1

Voltages used for operation, symbols refer to those of figure 1. Gate plane voltage was for the condition of gate open, gate closed condition had +/- 100 volts on alternating wires.

Electrode	90% Ar & 10% Methane	95% He, 5% Ethane & 42 C TMAE
D	-12600	-5600
P1	-12500	-5000
P2	-8700	-3700
G	-8050	-3200
P3	-7400	-2700
P4	-4000	-1500
Drift Chain	-3000 to 0	-1000 to 0
Offset across drift chamber added on entrance electrodes to DC	+30	+10
Anode	+1500	+900

Figure Captions

- Fig. 1: Detector design showing the mesh planes as solid lines, the gating grid as a dotted line, and the drift-chamber readout.
- Fig. 2: Electric field calculations for the transition region from the multistep chamber into the drift chamber. The dark lines are the force lines, and the lighter are the lines of equipotentials. The value of the equipotentials are given in the key. The drift chamber has a offset voltage across the drift chamber electrode with either +30 or +10 volts more on the top electrodes.
- Fig. 3: Drift time to drift distance relation using 90% Argon and 10% Methane, and the pulse height as a function of drift distance using a beta source.
- Fig. 4: The black spectrum is the pulse height distribution for ^{106}Ru betas with the gate open, and the lighter with the gate closed.
- Fig. 5: Pulse height spectrum for single photoelectrons in a gas mixture of 95% Helium, and 5% Ethane bubbling through TMAE at 42 degrees Celsius.
- Fig. 6: Drift time to drift distance relation for single photoelectrons using a gas mixture of 95% Helium, and 5% Ethane bubbling through TMAE at 42 degrees Celsius.
- Fig. 7: Timing distribution for a 200 micrometer spot of UV light at 5cm drift distance. Each box is 710ns and using the drift velocity from figure 6 the position resolution is 2.4mm FWHM.
- Fig. 8: Position resolution as a function of the electric field across the conversion gap.

Figure 1

Key	Voltage
1	-2000
2	-1833
3	-1666
4	-1500
5	-1333
6	-1166
7	-1000
8	-833
9	-666
10	-500
11	-333
12	-166
13	0

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8