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PROGRESS REPORT ON ČERENKOV RING IMAGING DETECTOR DEVELOPMENT*

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ABSTRACT

We present recent progress on the construction and testing of the first drift boxes and single electron detectors as they come from the production line. These detectors will be used for particle identification using the Ring Imaging technique in the SLD experiment at SLAC. Various experimental results are presented, including single electron pulse height measurements as a function of gas gain, detector gating capability, uniformity of response across the wire plane, charge division performance of a single electron signal, average pulse shape and its comparison with predicted shape, and cross-talk.

INTRODUCTION

The CRID detector is presently being constructed. By January 1989 we plan to build about 15 percent of the barrel part of the device. The remaining part will be finished by summer, 1989. The results being presented were obtained from our first production detectors.

The CRID concept was described in a number of previous publications [1-4]. It is a large scale attempt to implement single electron detection in order to reconstruct Čerenkov rings created by the photoionization process in TMAE laden gas. To do this successfully, one has to solve a number of R&D issues. To illustrate the problems, we mention some examples:

1. Gas purity has to be exceptional; for example the oxygen level must be below 1 ppm before TMAE is allowed to enter the system [5].
2. Only certain glues and materials can be used in the construction [5-6]; for example plain G-10 surfaces are coated with either DP-190 (3M Co.) or Epon 826 (Shell Co.) + Versamid 140 glues (Henkel Co.).
3. Quartz used to construct the drift boxes and liquid radiators has to have UV transmission of 85% or better at 180 nm.
4. The single electron detector must have uniform detection efficiency, good charge division resolution and must survive various TMAE related effects; for example, wire aging [7].
5. Gas and liquid radiators must have good UV transparency above 170 nm.
6. The gas system must deliver high quality gas; for example, the CRID is using electropolished stainless steel components throughout.
7. To be able to use charge division on a single electron signal we need high gain low noise amplifiers; for example the CRID amplifier [11] has rms noise of about 1100-1300 electrons.
8. A system of this complexity needs an extensive monitoring capability [3].

The CRID competes with a similar device being built for DELPHI experiment at LEP accelerator at CERN [8].

CRID CONSTRUCTION STATUS

At present we are involved in construction of all major components for the barrel CRID. Three single electron detectors have been completely finished and seven more are in progress. For instance, the stringing of 7 μm diameter carbon fibers did not prove to be a major obstacle. The results presented in this paper are derived from the testing of the first two detectors. Similarly, we have finished the construction of two drift boxes and the production of six more is well advanced. Two liquid radiator trays have been completed and mirror production is well underway. The final barrel gas system has been completed and the production of the final version of the amplifiers is going ahead. The CRID vessel is in the final stages of completion and will be delivered soon to the SLD experiment.

EXPERIMENTAL TEST SETUPS

Two testing procedures will be described out of the many used in the CRID development; namely, the tests of the single electron detector in non-TMAE gases, and the tests of the drift box together with the detector in the TMAE laden gases.

SINGLE ELECTRON DETECTOR TESTING

Figure 1 shows the coupling of the drift box and the single electron detector in the final CRID system. To test the single electron detectors we have constructed a test setup shown in Fig. 2. The setup has only a short drift of about 1.5 cm in front of the detector. UV light enters through a quartz window, or a possible Fe^{55} source enters through a 12.5 μm thick stainless steel window. Until now this set up has been used only in non-TMAE gases to allow quick access to the detector. To create a photocathode a dense stainless steel cloth has been placed under the quartz window. Figure 3 describes the idea. The UV light strikes the mesh and creates an electron which is then used to study the detector. We use a triggerable UV light source (Hamamatsu Xenon lamp L2435 with our home made trigger circuit) to discriminate against scattered photons. This system operates at $\sim$ 1 kHz with a time jitter of less than 20 ns. The time start signal is provided by a photodiode (EG&G UV-100B). The light is focused by a system of three variable apertures and a quartz lens with a 10 cm focal length. The UV gun can be moved in two directions, one along the wire address plane and the second along the wire length. The efficiency to produce an electron is about 1-5% depending on the aperture opening. This system has proved to be quite useful for a number of studies of our production detectors, some of which will be mentioned in the following.

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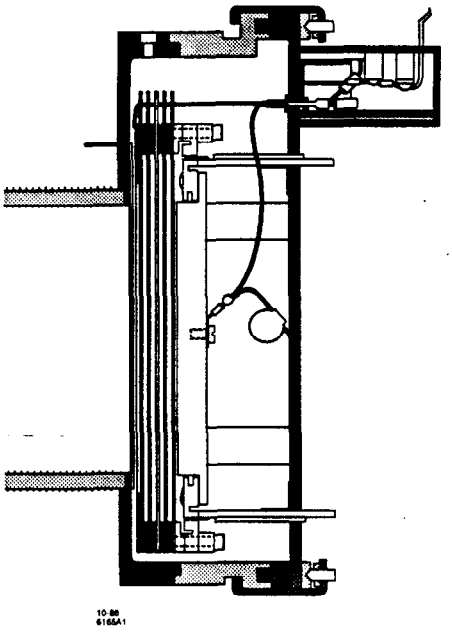

Fig. 1. Single electron detector coupling to the drift box of the final CRID device.

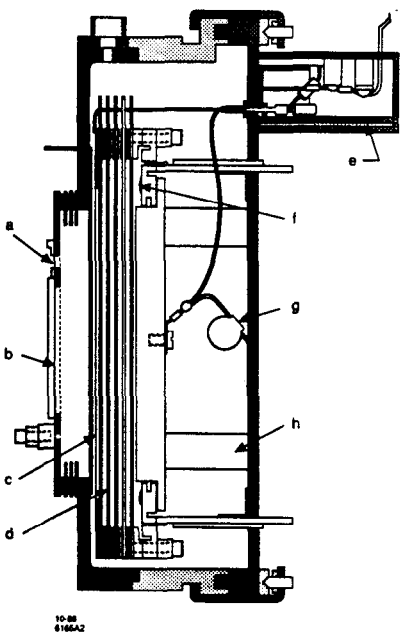

Fig. 2. Test detector enclosure where most of the presented results were made; (a) 12.7 μm stainless steel window, (b) quartz window with a mesh to create photosensitivity, (c) gate wire plane, (d) 254 μm thick Cu-Be etched arrays, (e) high voltage filter box, (f) carbon fiber contact and support, (g) 0.1 nF decoupling capacitor, (h) standoffs supporting cathode.

DRIFT BOX TESTING

In this case the intent is to use the TMAE laden gases to test a complete system including the drift boxes together with the previously tested single electron detectors The device to be tested is placed in a plastic vessel having freon gas surrounding the high voltage structure. The drift box can be tested with either a laser or a system of optical fibers which allow light to enter the quartz window. In this test the photocathode is TMAE itself. Because of the use of TMAE the tests tend to be of longer duration and access to the single electron detector is more difficult.

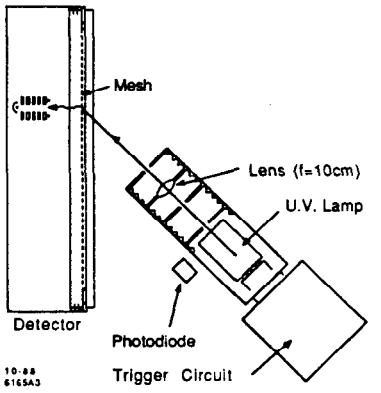

Fig. 3. Setup with the test detector enclosure for checking the single electron detectors.

EXPERIMENTAL RESULTS

Figure 4 shows single electron pulse height spectra measured in the test detector enclosure in C_2H_6, CH_4 and 80% CH_4 + 20% C_2H_6 gases. Spectra are presented as a function of total wire gain and cathode voltage. This was the only measurement where a continuous UV lamp (Hamamatsu Deuterium lamp L1626) was used. The spectra were obtained in the LeCroy QVT (#3001) operating in the charge integrating Q-mode on internal trigger with a 1 mV threshold and with a 420 ns gate. The electronics gain was calibrated by injecting a known charge into the amplifier while the detector was connected. To obtain the total gain the usual correction was made for the total drift of positive ions, which is about 30 microseconds in our geometry at the nominal operating point in C_2H_6 gas. This correction was about 1.6. [10] Figure 4 shows that the spectra involving CH_4 gas are much broader than those for the C_2H_6 gas. The present nominal cathode voltage is -1.55 kV for C_2H_6 gas, and -1.7 kV for CH_4 gas (without TMAE), with all other detector voltages being nominal [9].

Figure 5(a) shows the principle of electron gating in our structure. Notice that the electrons end up on the first blind electrode if we bias the even and odd gate wires by about ± 350 Volts. Figure 5(b) shows the gating for the positive ions. They end up on the gate wires in this geometry. Figure 6 shows the actual measured data as obtained in the test detector enclosure. Notice that the data are in good agreement with a computer simulation of this particular geometry. We used the triggerable UV lamp in this case as it was essential to choose the right electrons originating in the mesh and to reject electrons from general photon scatter.

The single electron pulse shapes were measured in the LeCroy digitizer ICA # 2261. Figure 7(a) shows an average pulse shape, where all pulses were normalized to the peak. It is interesting to compare the measured and expected pulse shape. In this one proceeds as follows. The amplifier response is measured by injecting charge via a 1 pF capacitor. Figure 7(b) shows the resulting pulse average. It has been fitted with $te^{-t/\tau}$, $\tau = 65.0$ ns, and as one can see the agreement is good in the region up to about 600 ns. The amplifier response was then convoluted with the response of positive ions [10]. The avalanche characteristic time t_0 was calculated to be 0.2 ns in our detector. The integration can be done analytically in this case:

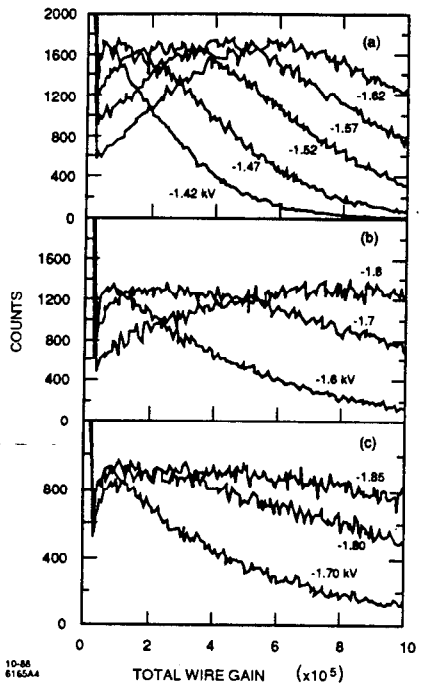

Fig. 4. Single electron pulse height spectra measured with 7 μm carbon fibers in C_2H_6(a), 80% CH_4 + 20% C_2H_6(b) and CH_4(c) gases as a function of total wire gain [10].

$$
\begin{aligned}
C(t) &= \int_0^t \frac{t' e^{-t'/\tau}}{t - t' + t_0} dt' \\
&= e^{-(t+t_0)/\tau}(t + t_0)\,[\ell n(1 + t/t_0) \\
&+ \sum_{n=1}^{\infty} \left(\frac{t_0}{\tau}\right)^n \frac{1}{n \cdot n!}\,[(1 + t/t_0)^n - 1]\,] \\
&- \tau(1 - e^{-t/\tau})
\end{aligned}
$$

All pulse shapes in Fig. 7(b) were normalized to the peak and also the respective leading edges were adjusted to agree. One can see that our measured detector pulse shape agrees well with the theoretical pulse, considering the number of uncertainties involved in this problem.

Figure 8 shows the detector response across the wire plane as obtained by moving the UV gun from wire to wire in small steps. Again, it was essential to use the triggerable lamp to eliminate noise electrons from scattered photons. Figure 8(a) shows the raw data. The variations in peak heights may be due to a number of possibilities. For example, the mesh may not be uniform, the wire diameter may vary, or one may have a variation in the electronics threshold. One normalizes the peaks to unity, assuming that in the center of each wire, we are fully efficient – see Fig. 8(b). To check that the overall response is uniform, one integrates the peaks of Fig. 8b, to obtain Fig. 8(c).

Finally, the most important measurement is the verification of the charge division resolution in our production detectors. It was shown earlier, on a small single wire test detector, that it is possible, in principle, to obtain good charge division performance on single electron pulses [12], if one uses 7 μm diameter carbon wires having a resistance of approximately 40 kΩ/10 cm length of wire. Such a large value of resistance was considered necessary to minimize the Johnson noise contribution to the final noise. At that time, the measured charge division resolution was $\frac{\sigma_x}{x} = 1.7\%$. This measurement uses the

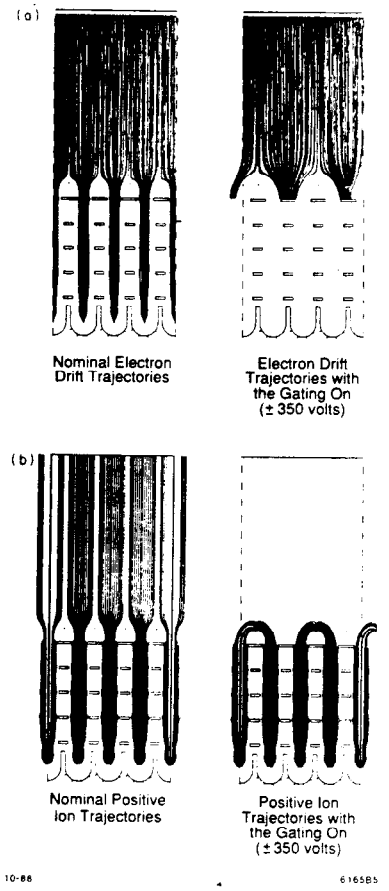

Fig. 5. a) Nominal electron drift in the CRID single electron detector and fully gated electron trajectories obtained by biasing even and odd gate wires by ± 350 V. b) The same for the positive ions.

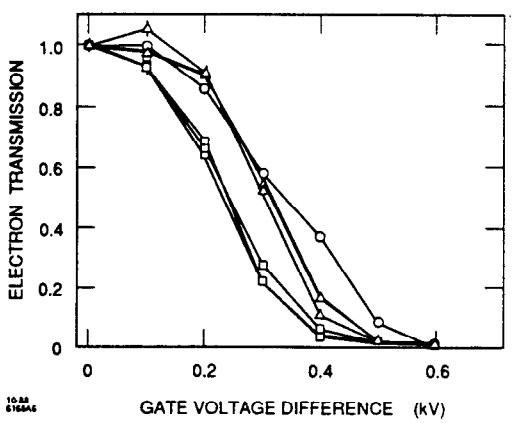

Fig. 6. Experimental results of the detector gating response to drifting electrons (△ – ($V_{even} - V_{odd}$)) (□ – ($V_{odd} - V_{even}$)) and a computer simulation (o) as obtained in the test detector enclosure in the setup of Fig. 3 and CH_4 gas. Notice that in this geometry it takes about ± 300 V to gate the electrons off.

production model of the single electron detector, and a prototype of the final amplifier [10, 11]. For the pulse digitization, a LeCroy digitizer ICA# 2261 (with 20 ns binning) was used. The measured rms noise was about 1150 electrons in this setup. This value is consistent with the calculated value due to the Johnson noise, the amplifier and the detector capacitance [11]. The trigger required to have a sum of left and right pulses to be greater than a 30 mV threshold. The volt-

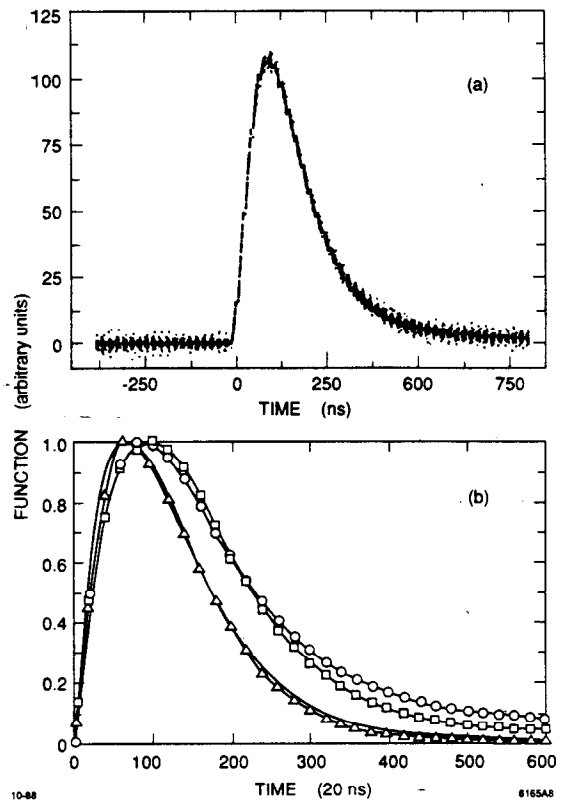

Fig. 7. a) Average single electron measured pulse shapes obtained in CH4 gas and the prototype amplifier [10, 11]. b) Comparison of an average measured test pulse shape (△) and calculated amplifier response $t \cdot e^{(-t/\tau)}$, $\tau = 65$ ns(solid line); and the average single electron measured pulse shape (□) and its theoretical calculated shape (○).

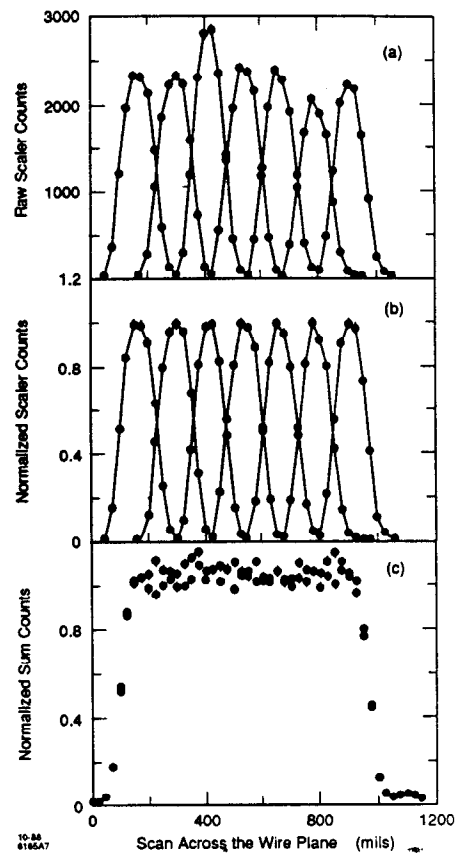

Fig. 8. a) Raw data of the single electron response across the wire plane. b) The same data, normalized to the peak, assuming that each wire is fully efficient in the middle of its acceptance. c) Integrated detector response (peaks of Fig. 8(b) summed).

age calibration was 2.4 μV/electron, thus the threshold corresponded to about 12,500 electrons. Two calibrations were performed in this test. One was the usual electronics calibration of pulsing the left and the right amplifier with the same charge. The second resulted from our ability to move the UV gun along the wire by a known distance, thus allowing a direct scale check – see Fig. 9(e). The algorithm used for pulse integration finds the peak of the digitized pulse shape first, and then integrates 60 ns before and 140 ns after the peak, thus integrating for a total of 200 ns. Figure 9(a) is a scatter plot of a sum of the left and the right pulse heights against the measured z coordinate for CH_4 gas at $V_{\text{cathode}} = -1.70$ kV. Figure 9(b) shows its projection onto the z-axis. From Fig. 9(b) one obtains a charge division resolution $\frac{\sigma_z}{z} = 0.9\%$. Figures 9(c) and 9(d) show the same set of plots for the C_2H_6 gas operating at $V_{\text{cathode}} = -1.55$ kV. In this case, one obtains the charge division resolution of about 0.6%. Figure 9(f) shows the measured charge division resolution using either a UV light generated electron signal or a signal injected into the amplifiers with detector connected. In both cases, the noise contribution due to the amplifier noise, the capacitance and the wire resistance are included. However, in the first case we also have a contribution due to the finite beam size (the light beam spot size and electron diffusion). These are compared with a calculated resolution assuming that the theoretical noise limit in this amplifier is 1100 electrons (rms) [11]. Figure 9(g) shows an overall summary of our measured single electron charge division resolution as a function of cathode voltage in CH_4 and C_2H_6 gases. One can clearly see that the C_2H_6 gas performs much better due to its more desirable pulse height spectrum (the CH_4 gas has a larger proportion of smaller pulses).

Cross-talk is very important in this type of detector because single electron signal is frequently obscured by a huge dE/dx signal, especially in the core of jets. We do not have final values yet because the final amplifier motherboard was not available. It is, however, already clear that the amplifiers have to be individually shielded, just like the signal traces, as they propagate from the anode wires to the amplifier. Masurements were made both with an Fe^{55} signal as well as with a single electron signal. We found that distant channel-to-channel cross-talk is at the 0.2-0.3% level, and nearest neighbor cross-talk is at the 1% level.

It is absolutely necessary to check the optical transparency of every quartz piece we buy. We built a UV-transmission testing station which is large enough to accommodate the entire drift box. Figure 10(a) shows the transmission of an acceptable quartz sheet. Typical problems include either bad polishing — Fig. 10(b), or bad bulk material — Fig. 10(c). The combined efficiency due to the quartz transmission and the TMAE photosensitivity peaks around 180 nm, so the defects in that region are very serious.

There are parts in both drift box and single electron detector which are made of G-10 (impregnated with non-brominated epoxies). We have found that uncoated G-10 adversely affects electron lifetime [6]. To remedy this problem, we paint all surfaces with either DP-190 or EPON826+VERSAMID 140 epoxies. However, a problem arose in the drift box where the side surface is made of G-10 with copper traces to define electrostatic field. Painting with epoxy in-between the copper traces is very difficult and painting over the copper surface can distort the field if the positive ion charge is not removed

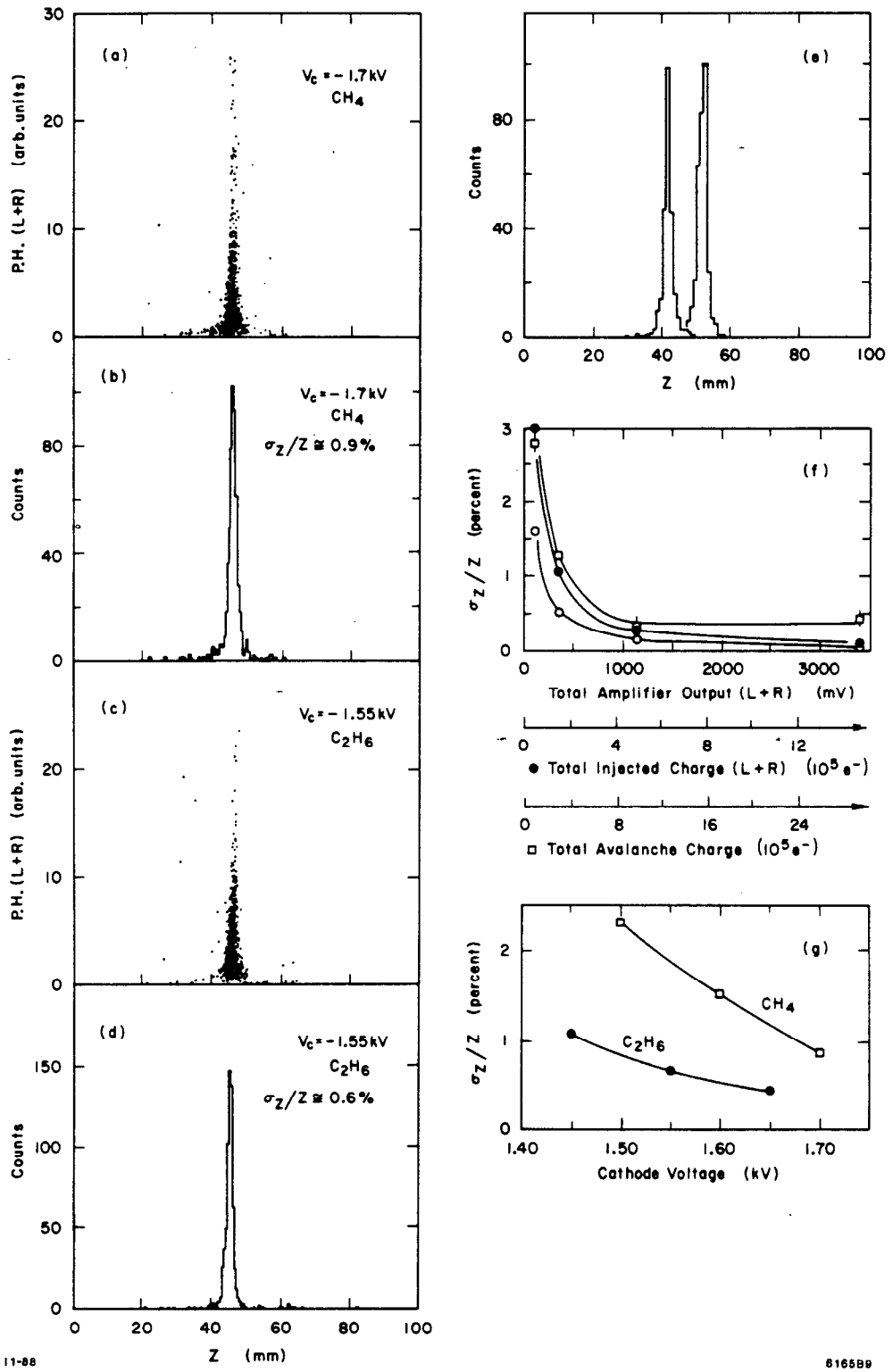

Fig. 9. a) Measured z-resolution plotted against a sum of left and right wire pulse heights in CH_4 gas, 7 μm diameter carbon fibres and nominal voltages ($Vc = -1.7$ kV). b) Projection of (a) on z axis ($\frac{\sigma_z}{z} = 0.9\%$). c) The same as (a) but for C_2H_6 gas, $Vc = -1.55$ kV. d) Projection of (c) on z axis ($\frac{\sigma_z}{z} = 0.6\%$). e) Calibration of the z-position by locating the UV light in two different positions 10 mm apart. f) □ - Charge division resolution measured using the UV lamp; • - charge division resolution measured using injected calibration pulses into the amplifiers while the detector is connected; ○ - Calculation of resolution. g) Overall result of charge division resolution for both gases.

fast enough. Initially, to solve the problem, a low surface and volume resistivity CIBA-GEIGY glue (#508, #6005, #956) was used. Unfortunately, it was found that this epoxy reacts with TMAE over long time periods. DP-190, however, has a larger resistivity than the CIBA-GEIGY epoxy at room temperature. Fortunately, there is a large change in both the surface and the volume resistivity of this epoxy as one goes from 20° to 40°C. Figure 11 shows that the surface resistivity changes by a factor of 100 downward as one goes from 20 to 40°C [13]. The volume resistivity shows a similar drop [14]. We plan to operate the CRID at 40°C, thus DP-190 is an adequate solution.

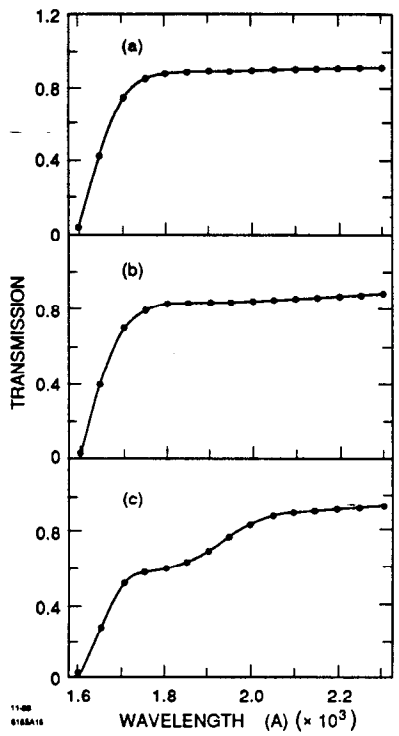

Fig. 10. a) Transmission through a good piece of quartz used for the drift box. b) Transmission through poorly polished quartz. c) Example of a quartz sheet with poor transmission.

The drift box together with its single electron detector has been operated for some time. Presently, the electron lifetime is still measured indirectly, i.e., using an ionization chamber that operates in [6] the gas which has passed through the detector system. We have achieved lifetimes of about 120 microsecond so far, which represents an attenuation length of 10 m in the the CH_4 gas. A more direct measurement using the drift box itself is in progress. In connection with lifetime, we have found in a separate measurement [6] an interesting effect, namely that the Cu-Be etched arrays adversely affect the lifetime. This may be due to the presence of copper and its oxides or the presence of some chemicals left over from the etching process which reacts with TMAE. Plating with tin or gold greatly improves the lifetime. Both of the drift boxes and the detectors have so far used unplated Cu-Be etched arrays.

CONCLUSION

We are in the process of constructing the barrel CRID system. The tests on the production models of detectors and drift boxes indicate very satisfactory results. We are especially pleased with the charge division results on single electron signals.

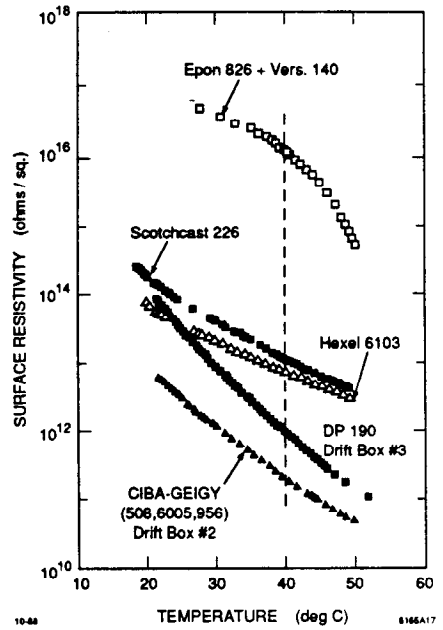

Fig. 11. Measured surface resistivity of various glues as a function of temperature [13].

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