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STUDY OF DIMETHYL ETHER FOR LIMITED STREAMER TUBES*

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Abstract

Position resolution and lifetime have been studied for one-atmosphere DME in half-inch diameter aluminum tube chambers operated in the limited streamer mode. The radial resolution was measured by timing to be $\sigma_r = 73\ \mu$m. The longitudinal resolution was measured by charge division to be $< 0.3\%$ of the wire length. No significant gain changes were seen after 12 C/cm.

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1. Introduction

Drift chambers made of aluminum tubes, compared to other designs, offer the advantages of simplicity, lightness in construction, and reliability in performance. A good longitudinal position resolution can be achieved by the charge division method operating in the limited streamer mode. The limited streamer mode is an amplification mode that is intermediate between the proportional and Geiger-Müller modes. The limited streamer conditions are reached with thick wires ($> 35\mu$m) and a good quencher gas. Dimethyl ether (DME) is a quencher gas with an absorption edge of about 195 nm [1]. It is an even better photon quencher than isobutane.

DME is a well-known "cool" gas, with a very low electron diffusion coefficient [2]. The subsequent low electron drift velocity could cause "pile up" in a high-rate environment. This potential problem can be minimized through the use of thick wires, small internal diameter tubes, and the highest possible voltage between wires and tubes. These conditions produce drift electric fields strong enough to accelerate drifting electrons to a velocity of several centimeters per microsecond (see fig. 1 from ref. [3]).

Pure DME is not expected to polymerize because of its oxygen-carbon molecular bond. However, results of tests with contaminated DME (especially Freons) have shown aging problem [4]. In addition, some construction and tubing materials can also lower the aging limit of the detector [5].

With the above facts in mind, by carefully choosing the construction and tubing materials, we decided to study the accuracy of position and aging for limited streamer tubes filled with pure DME. The intent was to use 1 m^2 arrays of these tubes in the small angle regions of the TPC/2γ experiment at PEP.

Dimethyl ether limited streamer tubes may also be useful as an intermediate tracker/trigger chamber at a future high-luminosity B Factory.

2. Test Chamber and Operation

The test module contains a total of eight aluminum tubes in three layers. The length of the tubes is 80 cm. The tubes have an outer diameter of 12.7 mm (0.5 inch) with 0.4 mm (0.016 inch) thick walls. A stainless steel wire of 45 μm diameter with a resistance of 380 Ω is crimped into two stainless steel pins inserted into Delrin plugs placed at each end of the tubes. The wires are pretensioned at 200 gr to assure electrostatic stability. All tubes were glued together with an epoxy [6] that is chemically resistant to DME. There are holes and groves on the Delrin plugs to allow the gas to pass through all the tubes. Two G-10 sheets with epoxy potting at the ends make the whole chamber gas tight.

DME gas (Matheson Gas Products) was used at a flow rate of about 6 cc/min. Its purity was 99.8%, and Halocarbons were less than 1 ppm. There were no filters placed on the gas lines. The gas pressure in the module was maintained at a level slightly over 1 atm by 0.5 cm of hydrocarbon mineral oil (Sargent-Welch Scientific Co.) in the output bubbler. Tygon tubes, copper tubes, and brass connectors were used for gas line. The regulator, valves, and flowmeter were chosen to be resistant to DME.

The chamber had a usable gain over an exceptionally wide range of high voltage. Figure 2 shows the gain of the chamber versus the high voltage. The gain curve was measured using an ^{55}Fe source (5.89 keV x-ray) and a single electron source. The 5.89-keV x-ray makes about 220 ion pairs initially. The single electron was obtained via the photoelectric effect by shining a flashlight on a small hole in the aluminum tube. The limited streamer mode in which the output pulse becomes independent of initial ionization can be clearly seen. For the following measurements, the tubes were operated in the limited streamer mode at 5.2 kV. In this mode, the first electron to multiply at the anode wire makes the entire pulse height. Thus a single electron and ^{55}Fe both cause the same output despite the difference in their initial ionization deposits. The output pulse was about 25 pC. Therefore, the gas gain was about 1.5×10^8.

An important question is whether or not DME can offer a short enough drift time for electrons in a high-rate environment. At 5.2 kV high voltage, the drift electric field was 1.6 kV/cm at the wall of the tubes. The drift time distribution of the tubes was measured using cosmic rays with the setup illustrated in fig. 3. The measured maximum drift time from the wall of the tubes to the wires was about 500 ns, in agreement with a 530 ns calculation based on the tube radius and the drift velocity versus electric field of fig. 1. Figure 4 shows the measured drift time distribution for a tube uniformly illuminated by cosmic rays.

3. Accuracy of Drift Time

Tests of the position accuracy from drift timing were done using three parallel tubes in the chamber, operated as described above (see fig. 3). The cosmic ray data were used to calculate the resolution by fitting a Gaussian to the distribution

$$\frac{d(t_1) + d(t_3)}{2} - d(t_2) \quad ,$$

where t_i is the drift time for tube i, and $d(t_i)$ is the drift distance corresponding to the time t_i. The drift velocity varied from 5 μm/ns to more than 50 μm/ns with the electric field. Since the drift velocity varied with the drift distance, we have determined $d(t)$ using a function derived from a formula of Bari et al. [7].

Figure 5 shows a typical three-tube resolution distribution. Assuming the three tubes in a triplet contribute equally to the resolution σ, the single-tube resolution $\sigma_r = \sqrt{2/3}\,\sigma$. This resolution is nearly constant for different longitudinal positions of the track, and for a fairly broad range of operation voltages. The radial position resolution of a single tube is determined to be $\sigma_r = 73 \pm 1 \pm 7$ μm averaged over all drift distances, where the second error is systematic.

4. Charge Division

Charge division was used to determine the longitudinal positions of incident tracks. This technique relates the charge detected at the two ends of an anode wire to the position of the avalanche along the wire. The charge was measured by integrating the current signal with the circuit show in fig. 6. The preamplifiers, located at each end of the anode wire, had an input impedance of about 10 Ω. Tracks from a collimated ^{106}Ru source that passed through three tubes and a scintillator were used. A LeCroy 2249w ADC, gated with a trigger obtained from the scintillator below the drift tubes, was used to measure the charge..

The charge asymmetry ratio f_Q is given by

$$f_Q = \frac{Q_A - Q_B}{Q} \quad ,$$

where $Q = Q_A + Q_B$ and Q_A and Q_B are the charges collected at the two ends of the wire, after pedestal subtraction and correction for different preamplifier gains. The position was calculated from [8]

$$Z = \frac{L}{2}\left[f_Q\left(1 + \frac{R_A + R_B}{R_W}\right) + \frac{R_A - R_B}{R_W}\right] \quad ,$$

where R_A, R_B are the input impedances of preamplifiers connecting the ends of the wire and R_W (380 Ω) is the resistance of the wire. If the resistance of the wire is large compared with the preamplifier input impedances, then the position is just

$$Z = \frac{L}{2} f_Q \quad ,$$

where Z is the distance along the wire of the length L, with respect to the center of the wire.

Figure 7 shows the distribution of the quantity

$$\Delta Z = \frac{Z_1 + Z_3}{2} - Z_2 \quad ,$$

when the source was positioned at $Z = 20$ cm. The shape of the distribution is quite Gaussian, and the σ of the distribution is $\sqrt{3/2}$ times the single tube resolution. Figure 8 shows the measured single tube resolution as a function of the source position. This resolution ranges from 1.5 mm at the center to 2.3 mm at the ends of the tube. Thus charge division produces a position resolution of $\sigma/L = .19\%$ to .29% for a collected signal charge of about 25 pC. A slight dependence of the charge division resolution was found on the angle between the particle trajectory and anode wire. If the angle changed from 90° to 45° or 135°, the resolution was degraded by 7%. An ADC gate width of 800 ns was used, since the preamp output signal decreased exponentially with a time constant of 200 ns, and the maximum electron's drift time from wire to tube was 500 ns. We did not find any significant change in the charge division resolution when varying the gate width from 600 ns to 1 μs.

Assuming that the error in our measurement is due only to the error in measuring the charge, then

$$\sigma_Z = \frac{L}{2} \left\{ \frac{1}{Q^2} \left[(1-f)^2 \sigma_A^2 + (1+f)^2 \sigma_B^2 - 2c(1-f^2)\sigma_A \sigma_B \right] + \sigma_0^2 \right\}^{1/2} ,$$

where σ_A, σ_B are the errors on Q_A, Q_B; σ_0 is the total of the other errors, and c is the correlation coefficient. This expression agrees with our observation that better resolutions are obtained for larger measured charges. Using a relative error of 0.3% for measured charges, which was estimated based on the uncertainty of pedestals and preamplifier gains in the test, the expression was compared with our data in fig. 8. The fitted curve in fig. 8 gives $c = 0.3$ and σ_0=0.7 mm.

5. Aging

In addition to the eight-tube test chamber described above, a large chamber was constructed as a prototype for chambers built to go around the beam pipe in the forward and backward direction of the TPC/2γ detector at PEP. The prototype module contained a total of 84 aluminum tubes in two layers, with the same tube diameter as the eight-tube test chamber, but with 45 μm diameter gold-plated tungsten wire instead of stainless steel. The lengths of tubes range from 15 to 37 inches. An aging test was performed on the prototype chamber by monitoring the variation in gain at a spot on the chamber exposed to a ^{90}Sr source. The ^{90}Sr beta source was located at a fixed spot on the test tube in the chamber. The gain was set to about 1.5×10^8 with a high voltage of 5.2 kV, yielding a current of 3.0 ± 0.3 μA. A longitudinal coordinate, measured by charge division, showed that the current was distributed along the wire with a FWHM of 1.2 cm. The gains of various tubes were occasionally monitored by exposing the chamber to a ^{241}Am γ source. The γ source illuminated about 0.8 cm (FWHM) of anode wire, a region that is smaller than the beta source.

The test was nearly continuous over a period of more than two months; the exposure to the beta source was interrupted only once by a four-day power outage. There were also many short interruptions in order to measure various gains from the chamber. In addition to measuring the gain at the place where the beta source was located, we also measured the chamber gain at several other positions. One of them was located on the same test tube, but about 15 cm from the source. The others were on other tubes. In the region not exposed to the beta source, the relative gains measured during the test were nearly constant, though all gains together fluctuated by as much as $\pm 10\%$ during the two-month test.

At the end of the test, the integrated dose was more than 15 C. No significant change was detected in the current being drawn by the tube under test relative to other tubes or relative to the same tube with the beta source placed at an unexposed location. However, under an electron microscope a 5 μm thick deposit was observed on the anode wire where it was irradiated (but not elsewhere). The characteristic fluorescent x-rays from the deposit showed it to be predominately Si. We therefore conclude that there was no change in the gain with an error less than $\pm 5\%$ for an accumulated charge of 12 C/cm. Since the chamber is operated in the limited streamer mode, we estimate that the chamber could operate at a gain of 1.5×10^8 for an integrated particle flux at least 4×10^{11} hits/cm^2. This is a gain loss of $< 0.5\%$ (C/cm)$^{-1}$ in the units of ref. [9].

6. Conclusions

We have found DME to be a well-behaved and stable gas for drift tubes with stainless steel or gold-plated wires, operated in the limited streamer mode.

The resolution on the drift time for unsaturated DME gas is 73 μm, averaged over all radii. A longitudinal position resolution better than 0.3% of chamber length was obtained by the charge division method, using the limited streamer pulses. An aging test showed that by using pure DME and our chosen construction and tubing materials, the limited streamer drift tubes can reach at least 12 C/cm charge deposition, without significant gain changes but with noticeable Si deposits on the anode wires.

Acknowledgements

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References

[1] M. Jibaly et al., Nucl. Instr. and Meth. A273 (1988) 161.

[2] F. Villa, Nucl. Instr. and Meth. A217 (1983) 273.

[3] T. Cottrell et al., Trans. Faraday Soc. 61 (1965) 1585;
M. Basile et al., Nucl. Instr. and Meth. A239 (1985) 497.

[4] J. Va'Vra, Nucl. Instr. and Meth. A252 (1986) 547.

[5] M. Jibaly et al., Nucl. Instr. and Meth. A283 (1989) 692.

[6] The epoxy glue is made by 828 EPON resin manufactured by SHELL CHEMICAL and 140 VERSAMID curing agent manufactured by HENKEL Corp.

[7] G. Bari et al., Nucl. Instr. and Meth. A251 (1986) 292.

[8] V. Radeka and P. Rehak, IEEE Trans. Nucl. Sci. NS-26 (1979) 225.

[9] I. Juricic and J. Kadyk, Proceedings of the Workshop on Radiation Damage to Wire Chamber; LBL-21170 (1986) 141.

Figure Captions

1. Electron drift velocity in DME versus the electric field E/p.

2. Average output pulse height as a function of the tube high voltage.

3. Schematic of the setup used for radial accuracy measurements.

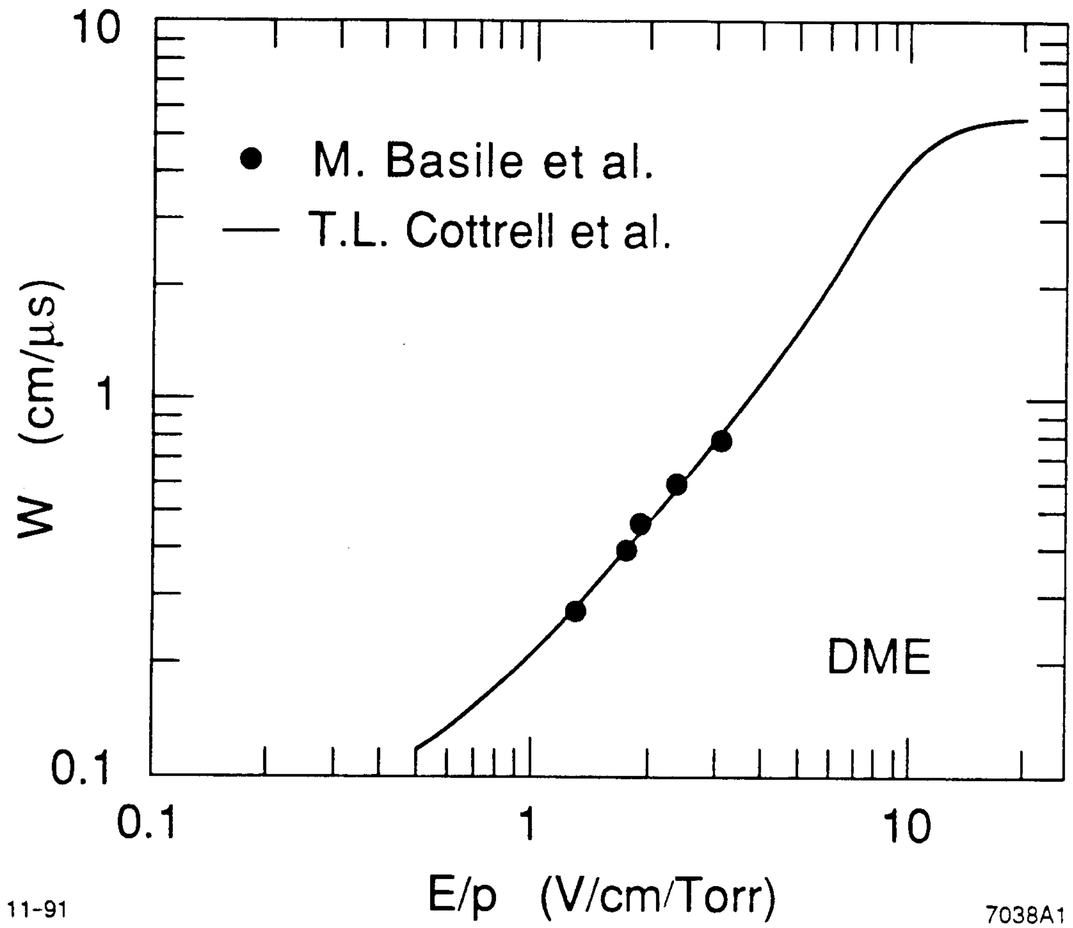
4. Measured drift time distribution for a tube illuminated by cosmic rays.

5. Radial resolution distribution of $[d(t_1) + d(t_3)]/2 - d(t_2)$. The curve is a Gaussian with 90 μm standard deviation.

6. Experimental layout for the charge division measurements.

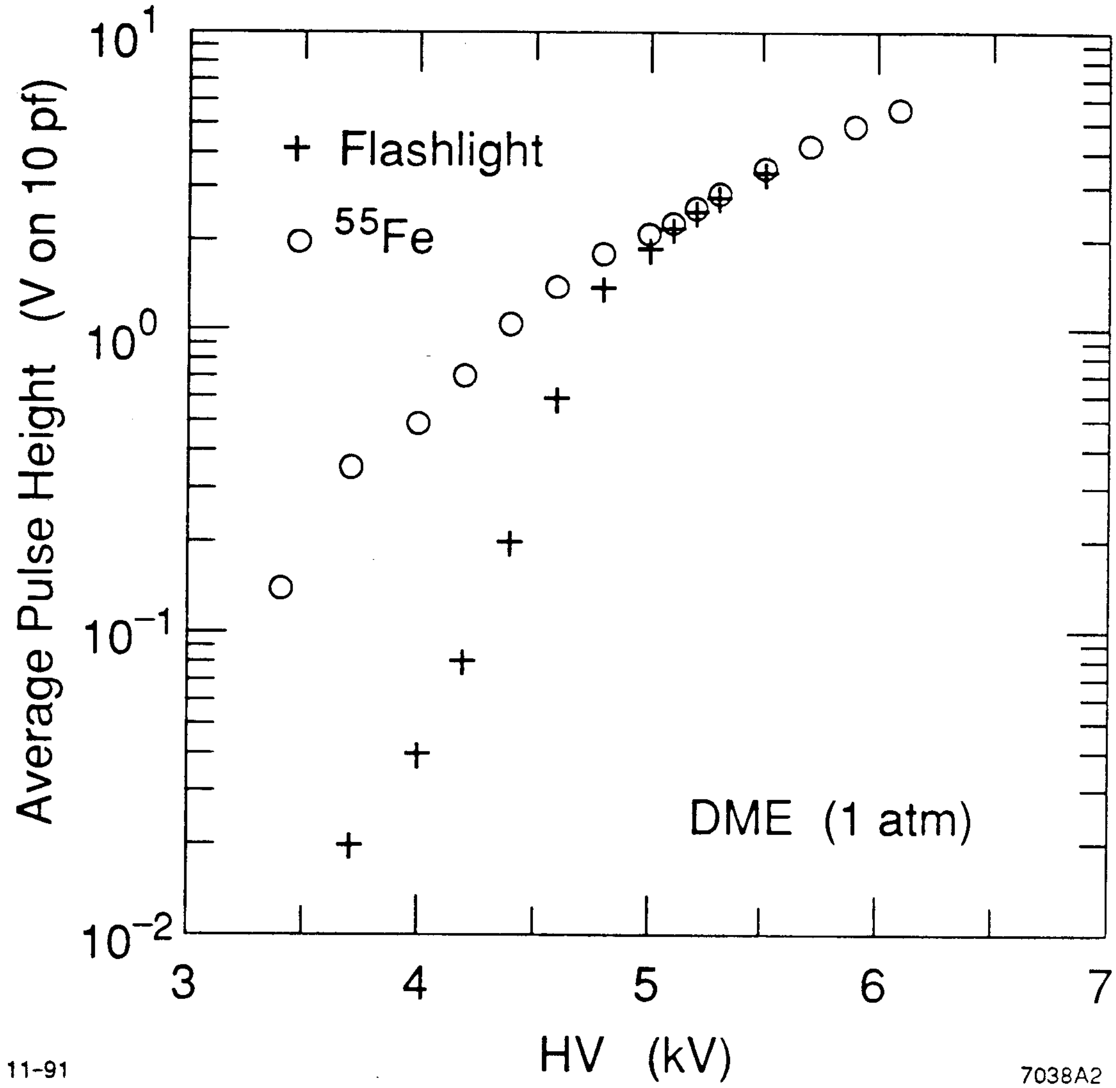
7. A typical charge division spectrum of $(Z_1 + Z_3)/2 - Z_2$. The Gaussian with 2.2 mm standard deviation is a fit to the data.

8. The Z resolution as a function of source position. The curve is fit to the data.



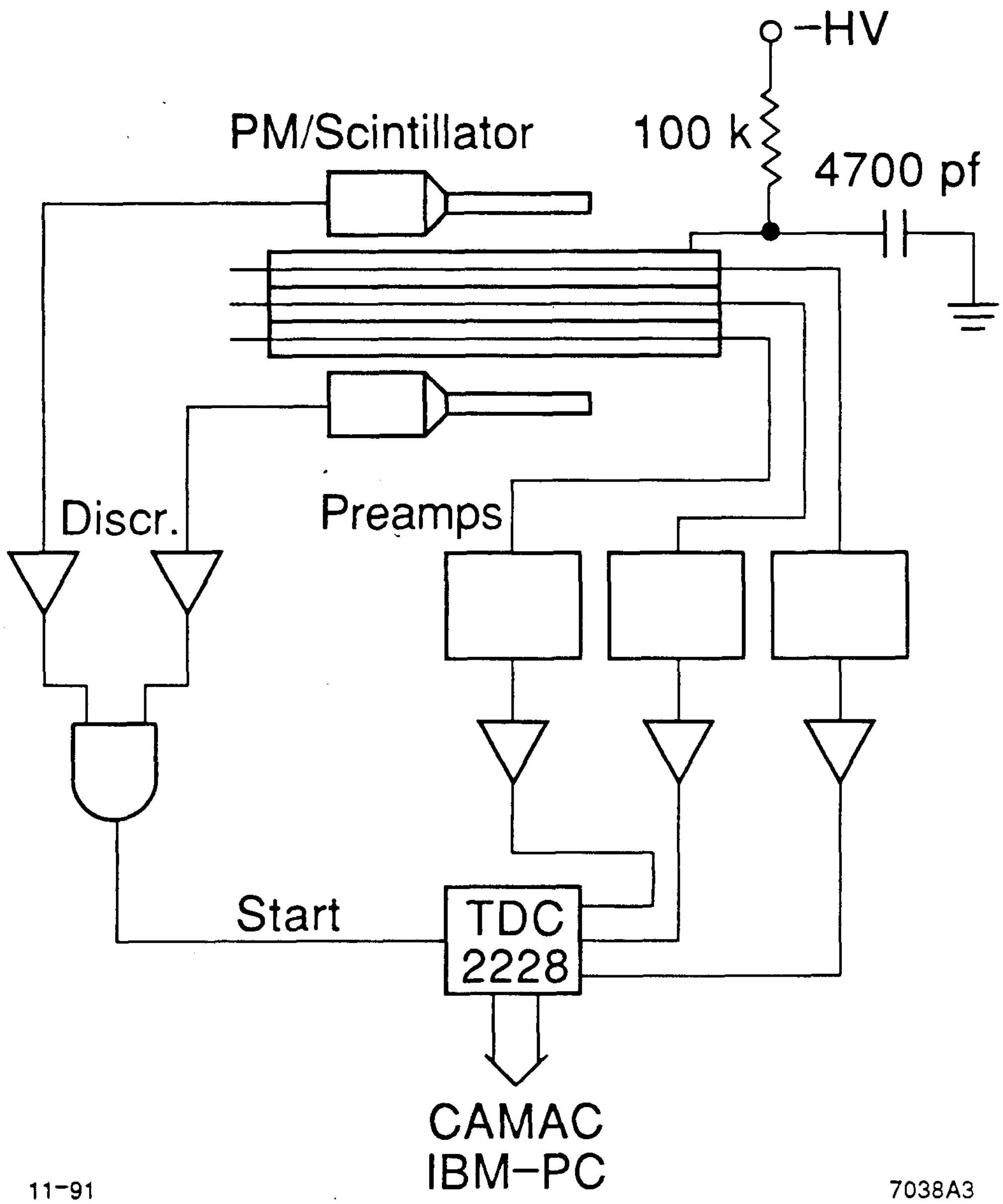
10
1
0.1
0.1
1
10
W (cm/μs)
E/p (V/cm/Torr)
M. Basile et al.
T.L. Cottrell et al.
DME
11-91
7038A1

Fig. 1



10^1
10^0
10^-1
10^-2
Average Pulse Height (V on 10 pf)
+ Flashlight
○ 55Fe
DME (1 atm)
3
4
5
6
7
HV (kV)
11-91
7038A2

Fig. 2



-HV
100 k
4700 pf
PM/Scintillator
Discr.
Preamps
Start
TDC
2228
CAMAC
IBM-PC
11-91
7038A3

Fig. 3

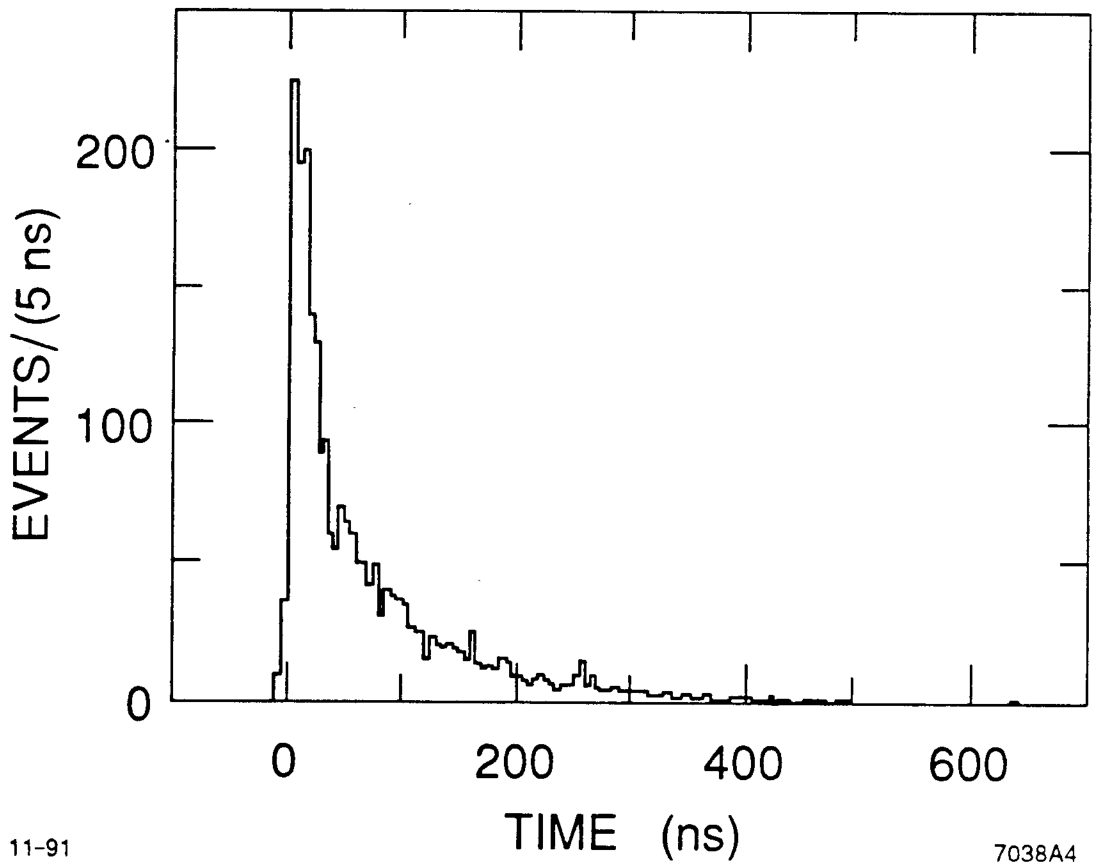


Fig. 4

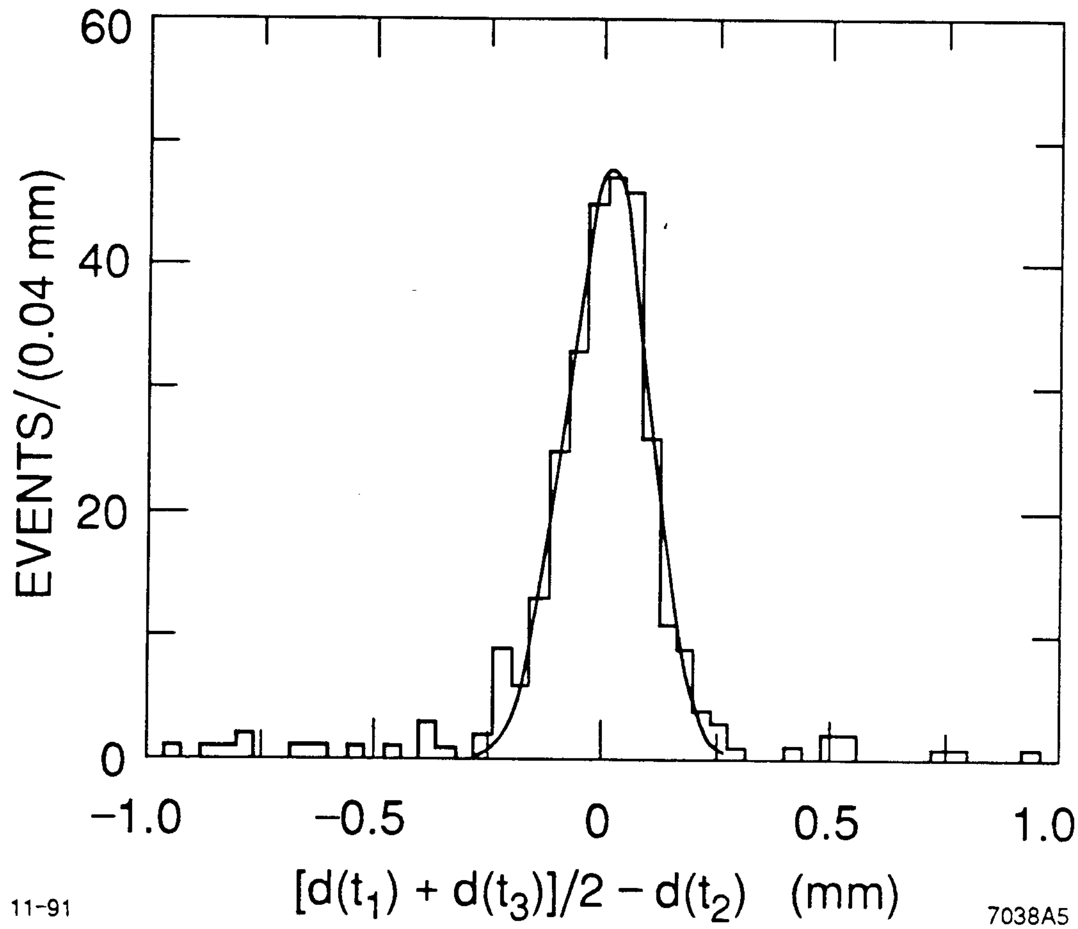
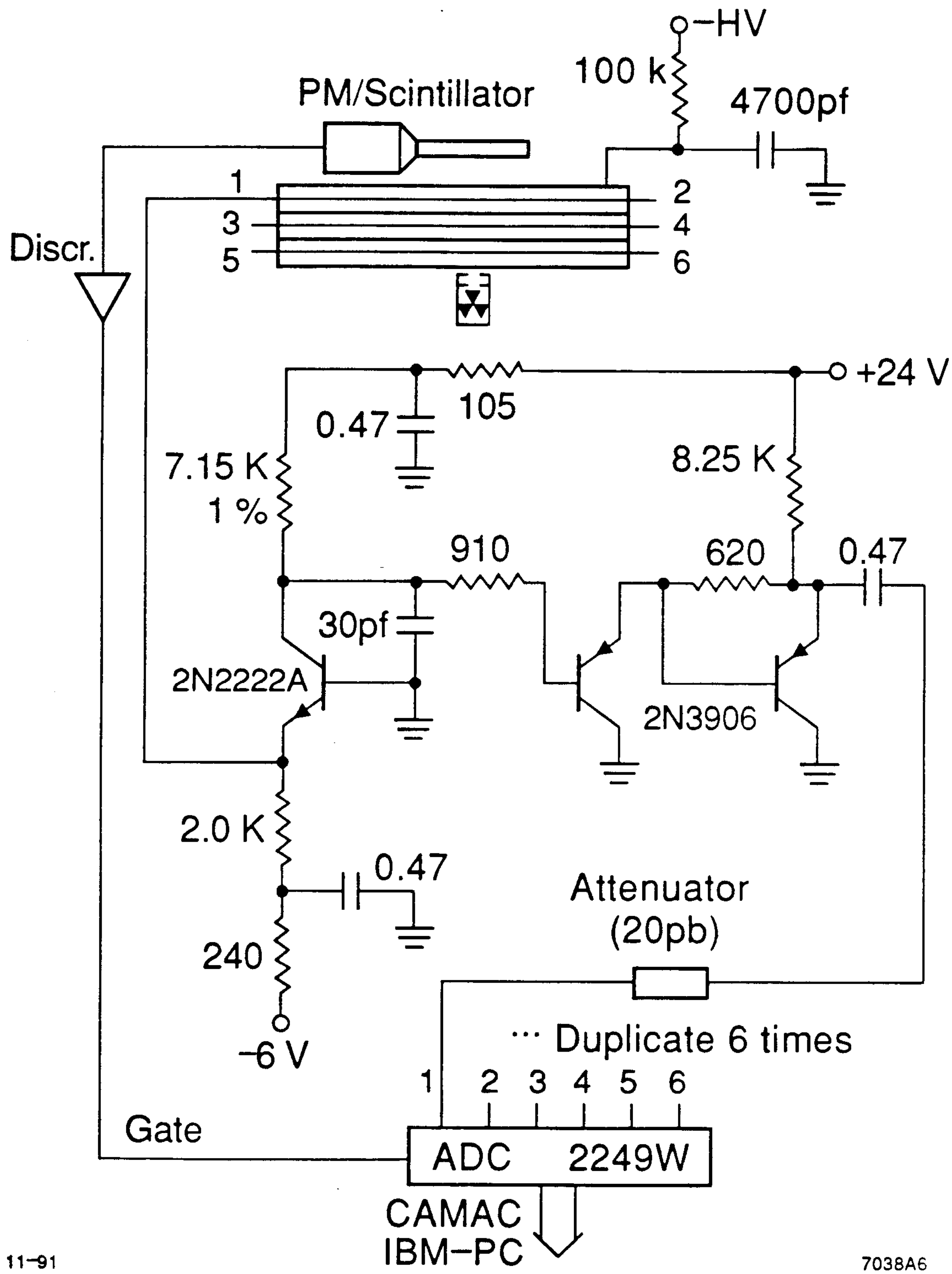


Fig. 5



-HV
100 k
4700pf
PM/Scintillator
1
2
3
4
5
6
Discr.
+24 V
105
0.47
7.15 K
1 %
8.25 K
910
620
0.47
30pf
2N2222A
2N3906
2.0 K
0.47
240
-6 V
Attenuator
(20pb)
··· Duplicate 6 times
1 2 3 4 5 6
Gate
ADC 2249W
CAMAC
IBM-PC
11-91
7038A6

Fig. 6

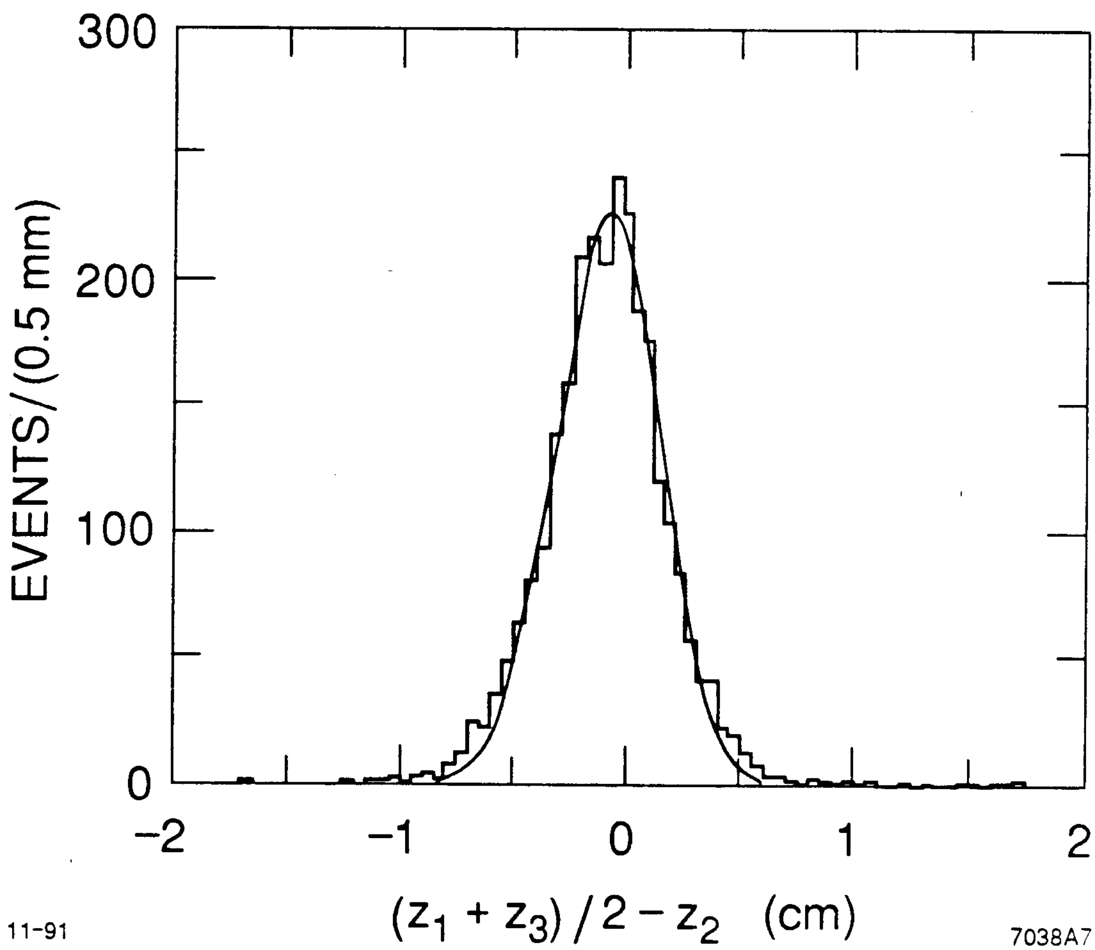


Fig. 7

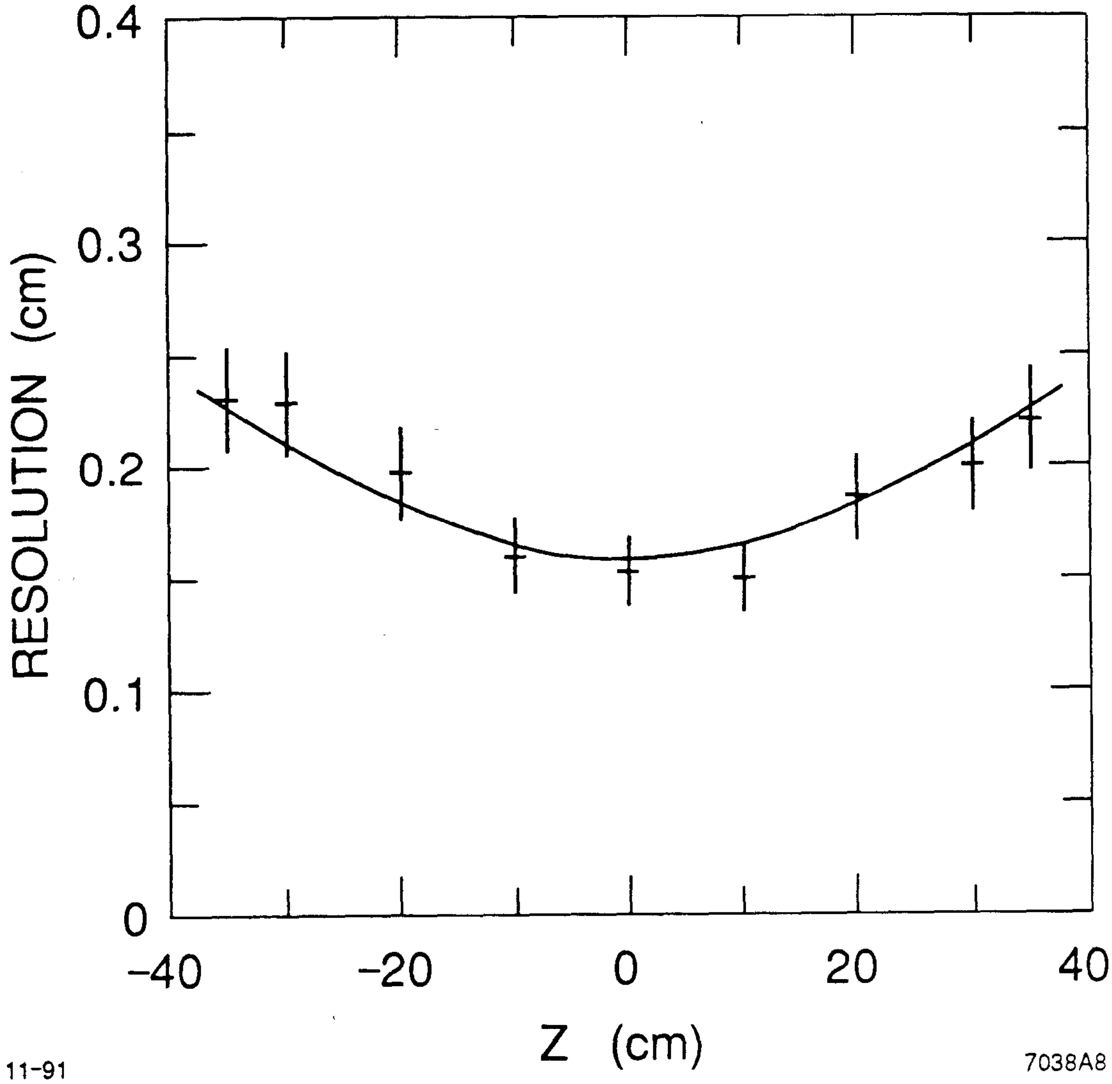


Fig. 8