# INVESTIGATIONS OF SINGLE-ELECTRON AVALANCHES IN A PROPORTIONAL DRIFT TUBE

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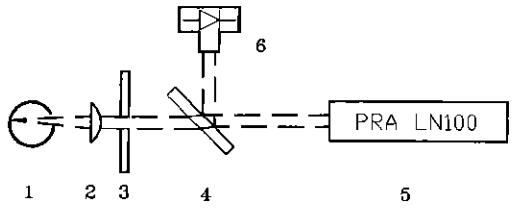
**Abstract**

Investigations of single-electron avalanches in a proportional drift tube have been carried out with a pulsed $N_2$ laser. The study consists of two aspects: timing properties, and fluctuations in the gas avalanche.

Detailed information on single-electron drift and avalanche behaviour has a basic interest in an investigation of gas-chamber performance. Its timing, avalanche distribution, attachment by the working gas mixtures, *etc.*, provide various criteria for choosing the best suitable gas mixture under a specific experimental circumstance.

### Timing Studies with Single Electrons

A sketch of the experimental set-up is shown in Fig. 1.




1.Test proportional tube
2.Plano–convex lens
3.Diaphragm 4.Beam splitter
5.Pulsed $N_2$ laser
6.Photodiode RCA C30905E

Figure 1: Sketch of the experimental set-up.

The $N_2$ laser generates pulsed 337-nm (3.67-eV) UV photons, with a pulse length of about 350 ps. The pulse energy is about 50 $\mu$J, corresponding to about $10^{14}$ photons. The test drift tube was made of 7.67-mm-diameter aluminum tubing with a 25-$\mu$m-diameter gold-plated-tungsten anode wire.

The laser beam was focused onto the inner wall of aluminum tube after passing through a 1-mm-diameter hole in the wall. The hole is offset by 1 mm from the center line of the tube. Because the beam spot on the inner surface of the tube is quite small, we can neglect mechanical imperfections and consider that the drift distance of the photoelectrons was just the radius of the tube. A beam splitter was used to reflect part of the laser beam to a photodiode (RCA C30905E), which generates a fast, large electric pulse as a start signal for TDC system. A preamplifier was directly connected to the test drift tube through a high-voltage capacitor. The drift-tube signal was used as a stop signal.

Two different preamplifiers have been used in our measurements: a LeCroy TRA402 and U. Penn/AT&T preamplifier.[1] The U. Penn preamplifier was used for studying the performance of $CF_4$/Ar and $CF_4$/isobutane mixtures with different mixing ratios. The other gas mixtures were measured by LeCroy preamplifier.

Due to the very small quantum efficiency and large number of primary UV photons, the number of photoelectrons in each pulse should vary according to a Poisson distribution. We reduced the aperture of the iris diaphragm until only 1 in 10 laser pulses yielded any photoelectrons, and hence at least 90% of the recorded events were initiated by single photoelectrons.

Using simplified formulae to approximate the published curves on the drift velocity $w$ *vs.* $E/P$,[2, 3] we are able to calculate the total drift time. The results are shown in Fig. 2. The agreement is impressive. Because our data are collected under various pressures, and the drift velocity curves used in our fitting were measured or calculated at 1 atm, our results further confirm the well-known fact: $w \propto f(E/P)$.

We have directly measured the time resolution $\sigma_t$, and converted to the spatial resolution $\sigma_x$ using the $x$ *vs.* $t$ curve near the tube wall. Figure 3 shows our data as well as a fit of the form

$$\sigma_x = \sigma_0 + A/\sqrt{P}$$

for Ar/$CO_2$, Ar/$CH_4$ and Ar/$C_2H_6$.

We made a further investigation for gas mixtures containing $CF_4$. This "fast" gas is believed to be one of the most attractive candidates for the SSC environment.[2, 4]

We summarize the drift-time results of $CF_4$ gas mixtures in Fig. 4. The dependence of the drift time on the percentage of $CF_4$ and $V/P$ is insensitive for Ar/$CF_4$.

*On sabbatical from Carleton U.

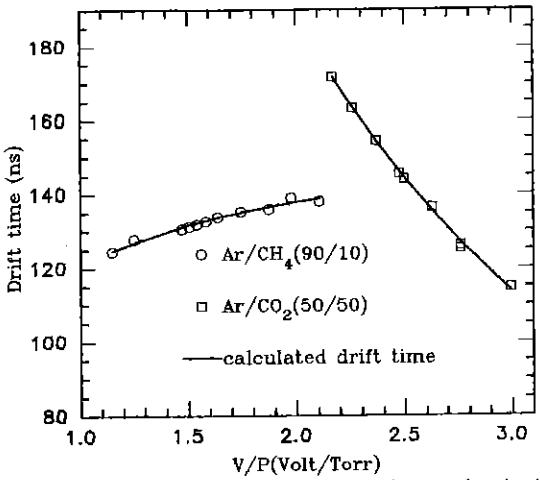



Figure 2: Drift time of $Ar/CO_2$ (50/50), $Ar/CH_4$ (90/10).

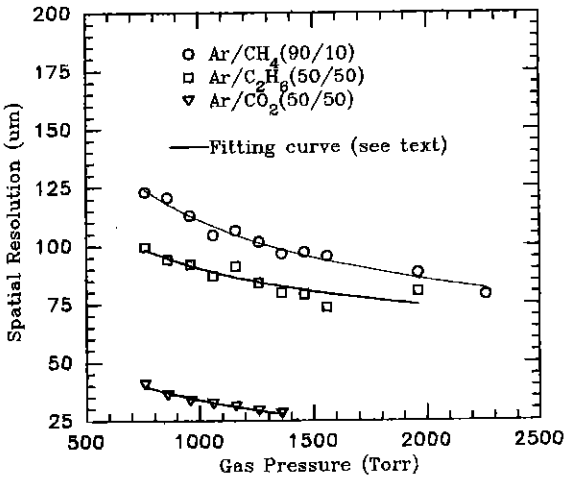



Figure 3: Spatial resolution of $Ar/CO_2$ (50/50), $Ar/C_2H_6$ and $Ar/CH_4$ (90/10).

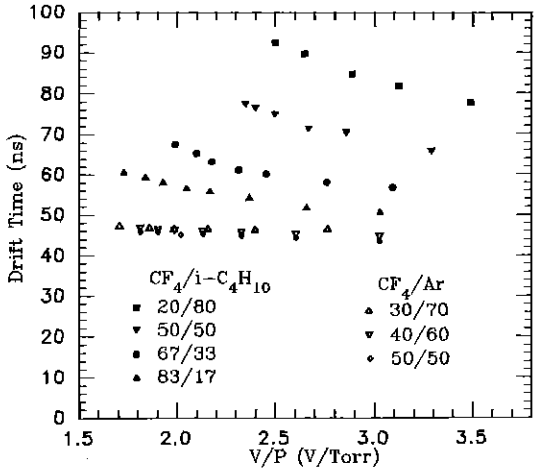



Figure 4: Total drift time of $CF_4$/Ar and $CF_4$/isobutane.

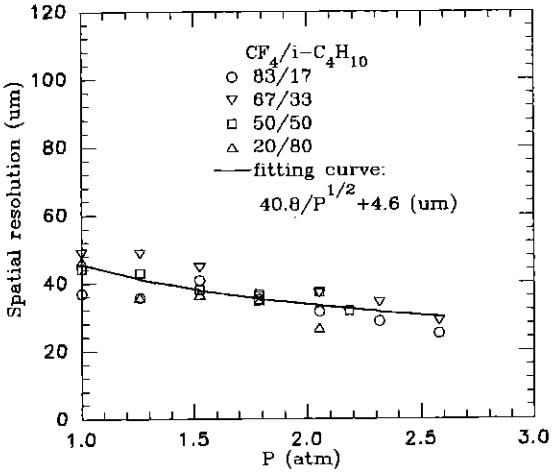



Figure 5: Spatial resolution of $CF_4$/isobutane.

The time resolutions are in the 0.55-0.75 ns range for $Ar/CF_4$ mixtures, and 0.55-1.0 ns for $CF_4$/isobutane mixtures. Using data from T. Yamashita *et al.*[5] we can infer the spatial resolution for Ar/isobutane near the tube wall. All of the resolutions are 25-50 $\mu$m, as shown in Fig. 5. Because there is no existing drift-velocity data for $CF_4$/isobutane (83/17), (67/33), we have adopted the (80/20), (70/30) data instead.

### Fluctuations in Single-Electron Avalanches

We have studied this with the same experimental set-up as in the timing measurements. Here we use an EG&G ORTEC 142PC charge-sensitive preamplifier instead of the transresistance preamplifier used for timing measurements.

The single-electron-avalanche spectra from $Ar/CF_4$ and Ar/isobutane have been measured for several different mixing ratios. The single-electron-avalanche spectra were then fitted with the Polya distribution [6]

$$P(a) \propto (ba/\bar{a})^{b-1} e^{-ba/\bar{a}},$$

where $a$ is the amplitude of an avalanche, $\bar{a}$ is the mean gas gain, and $b$ is a measure of the fluctuation of gas gain: $(\sigma_a/a)^2 = 1/b$.

We are able to observe the presence of electron attachment in the chamber gas as follows. Charge spectra were also recorded for each gas mixture at several different high voltages using an $Fe^{55}$ source. If the signal size observed with the $Fe^{55}$ source is not $\sim 200$ times that from a single photoelectron ejected by a laser pulse, then attachment has occurred. Comparisons of avalanches due to single photoelectrons with those from $Fe^{55}$ x-rays are shown in Fig. 6.

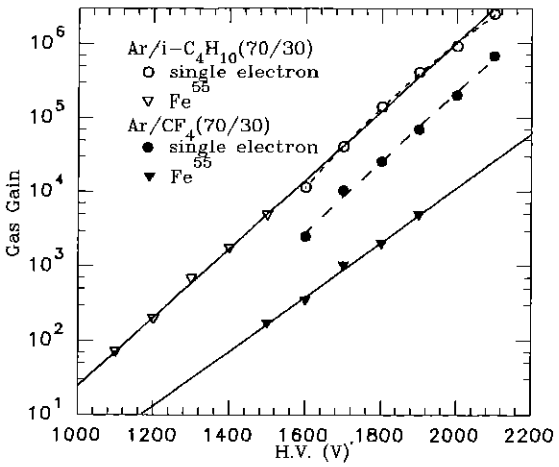



Figure 6: Gas gain from single photoelectrons and from $Fe^{55}$ x-rays in Ar/isobutane and $Ar/CF_4$.

All three of the Ar/isobutane gas mixtures gave rather consistent results, both from single electrons as well as from $Fe^{55}$ x-rays. Then when $Ar/CF_4$ gas mixtures were tested, the large discrepancy between single-electron and $Fe^{55}$ measurements indicates that $CF_4$ may have serious electron attachment.[2] The gas gain from single electrons was about ten times higher than that from $Fe^{55}$.

Additional evidence for electron attachment is the poor energy resolution observed with $Ar/CF_4$ mixtures. Previous work[2] yielded energy resolutions with $Ar/CF_4$ (95/5) and (90/10) of $\sim$ 60% and $\sim$ 75%, respectively. We have measured the energy resolution for the mixing ratios (80/20), (70/30), (60/40), and (50/50) under different gas pressures. Typical values are summarized in Table 1.

A statistical model of the energy resolution of proportional counters has been well established,[7] which yields the relative variation of gas-gain A as following

$$\left(\frac{\sigma_A}{A}\right)^2 = \frac{1}{n_0}\left(F + \frac{1}{b}\right),$$

where $F$ is the Fano factor and $b$ is the parameter of Polya distribution.

Typical values of $F$ and $b$ are 0.05-0.2 and 1-2, respectively. Since $n_0$ is the number of ion pairs created by the incident radiation, for $Fe^{55}$, $n_0 \sim 200$. The Polya parameters $b$ for these gas mixtures are greater than 1.

A rather surprising fact is that even under the worst case of $F$ and $b$ (but no electron attachment), the energy resolution of 5.9-keV x-rays still should be better than 18%. For $Ar/CF_4$ the measured energy resolution is worse than this by a factor of 3-5. If $n_0$ has been reduced by a factor of 9-25 due to electron attachment this behavior would be explained. As noted previously, such a reduction is consistent with the low mean value of the gas gain observed for $Ar/CF_4$ mixtures with an $Fe^{55}$ source .

Table 1: Energy resolution of $Ar/CF_4$ and Ar/isobutane using an $Fe^{55}$ source.

| $Ar/CF_4$ | $P$ (Torr) | Gas Gain ($Fe^{55}$) | Resolution ($Fe^{55}$) |
|---|---|---|---|
| 80/20 | 760 | 98.8 | 48% |
| | 1160 | 105.9 | 61% |
| | 1960 | 107.2 | 82% |
| 50/50 | 760 | 119.0 | 53% |
| | 1160 | 92.2 | 63% |
| | 1960 | 89.1 | 98% |
| Ar/isobutane | | | |
| 80/20 | 760 | 206.0 | 16% |
| | 1160 | 377.1 | 18.4% |
| | 1960 | 243.8 | 17.3% |
| 70/30 | 760 | 210.5 | 16.4% |
| 29/71 | 760 | 994.9 | 16.7% |
| 90/10 | 760 | 188.5 | 13.3% |
| | 1160 | 2564.0 | 12.5% |
| | 1960 | 1861.0 | 15.2% |

# References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[4] J. Fischer *et al.*, *Proportional Chambers for Very High Counting Rates Based on Gas Mixtures of $CF_4$ with Hydrocarbons*, Nucl. Instr. and Meth. A238, 249-264 (1985).

[5] T. Yamashita *et al.*, *Measurements of the Electron Drift Velocity and Positive Ion Mobility for the Gases Containing $CF_4$*, Preprint.

[6] J. Byrne, *Statistics of the Electron Multiplication Process in Proportional Counters*, Proc. Roy. Soc. Edin. **66A**, 33 (1962).

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