Fermi National Accelerator Laboratory

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Fast Non-Explosive Gases for Drift Chambers

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Operated by Universities Research Association Inc. under contract with the United States Department of Energy

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Introduction

Typical gases which are stock at Fermilab are Ar:C_2H_6 (50:50) and Ar:CO_2 (80:20). Argon:Ethane has the virtue of high gas gain and a saturated drift velocity. In fact, parametrizing the drift velocity as a function of electric field we find[1] $v_d(E) = v_o(1\text{-}e^{-E/E_o})$ with $v_o \simeq 5.4$ cm/μsec and $E_o = 160$ V/cm. However, safety considerations make this gas somewhat inconvenient. The addition of alcohol as quencher also raises the saturation field to, for example, $E_o \simeq 500$ V/cm for 1.5 % added alcohol. This gas also tends to break up in a high-beam flux environment and leave carbon deposits. The addition of alcohol to avoid such aging often takes a unit cell out of saturation over its entire volume. Finally, for collider applications it is useful to exclude free protons from the gas in order to reduce the sensitivity to the sea of slow neutrons which are present in the collider environment.

In contrast, Ar:CO_2 (80:20) is a gas with more moderate gas gain. The drift velocity at high field is,[1] $v_d(E > 1.5$ kV/cm$) \simeq 5.8$ cm/μsec. For most field configurations this gas does not saturate, causing a long tail in the drift time distribution due to low field regions in the unit cell. The virtues of this gas mixture are that it is cheap, not flammable, and stable under high-beam flux. However as the Collider Upgrade progresses, we wish to find a gas which is faster than 5.0 cm/μsec since the time separation between collisions will at some point be less than the drift time of 1 μsec for drift distance of 5 cm.

Test Setup

As a test cell we used the 5 cm drift cell described in Ref. 2. This cell has a wire potential V_w and a field shaping pad potential V_{p_5}. For Ar:C_2H_6 (50:50) with $V_w = +5.6$ kV, $V_p = 3.0$ kV we have a gas gain ~ 1.8×10^5 due to the 160 kV/cm field at the surface of the 50 μm diameter wire. At these potentials, the equipotential and isochron lines are shown in Fig. 1. The field is $\geq$ 500 V/cm everywhere, leading to a drift velocity everywhere within 95% of saturation.

The experimental setup used with the test cell is shown in Fig. 2. This test cell design is planned to be used later in DØ as a muon-chamber gas monitor cell. The cell uses trial gases at ambient pressure which are not recirculated. We used premixed Ar:CO_2 (80:20),

$Ar:C_2H_6$ (50:50) and $Ar:CH_4$ (90:10). Other gases were mixed by our gas mixing system. This gas mixing system has a 1.4 liter batch tank with three inputs and one output. Each input has a 200 cc/MIN(AIR)-Maximum flowmeter or a 50 cc/MIN(AIR)-Maximum flowmeter with a NUPRO Valve(B-4HK2) for open/close operation and a NUPRO "S" Series Fine Metering Valve for fine adjustment. In addition to these instruments, we used an Infrared Gas Analyzer (ANARAD. Inc.) for monitoring of the CO_2 (0-25%) percentages.

The trigger was formed using scintillators in coincidence for cosmic rays. External tracking was provided by two standard[3] PWC's with 1 mm wire pitch. The 12.8 cm width was sufficient to cover the 10 cm drift cell. Readout was accomplished using the front end electronics developed[2] for the DØ muon chambers. The data acquisition system used an IBM/PC-XT reading a CAMAC crate (a TRANSIAC-6002 Microprocessor CAMAC Interface and a LeCroy 3512 Buffered ADC). We required a single cosmic ray in software by demanding a single hit for both top and bottom PWC's.

Choice of Trial Gases

A perusal of Ref. 1 leads to some observations about possible 2 and 3 component gases. For $Ar:CO_2$ in a (90:10) mix the velocity at high fields is $v_d(E > 1.0\ kV/cm \simeq 4.2\ cm/\mu sec$. Although this is asymptotically slower than an (80:20) mix, it is comparable to $Ar:C_2H_6$ (50:50) and for $E > 450$ V/cm has $v_d > 4\ cm/\mu sec$. Lower concentrations of CO_2 are faster at lower fields but slower for $E > 500$ V/cm. A 2 component mixture of $Ar:CH_4$ (95:5) is fast at low fields [$v_d(E \sim 100\ V/cm) \sim 5.5\ cm/\mu sec$] but slow for $E > 500$ V/cm [$v_d(E > 500\ V/cm) \lesssim 3\ cm/\mu sec$]. Finally, for $Ar:CF_4$ (90:10) the maximum velocity is ~ 12 cm/μsec, which occurs at a field of 450 V/cm. However, this gas is very field dependent: $v_d(E = 2\ kV/cm) \sim 6\ cm/\mu sec$.

Considerations of cost, safety, and high drift velocity lead us to consider Ar with minority concentrations of CO_2, CH_4, or CF_4 in 2 or 3 component mixes. The benchmark against which to compare is $Ar:C_2H_6$ (50:50). Data for this mix is shown in Fig. 3. The vertical axis is PWC position. The horizontal axis for Fig. 3a is drift time, while that for Fig. 3b is total induced pulse height on the pads. Note that ($V_w = 5.2$ kV, $V_p = 3.0$ kV) the velocity is quite constant over the entire drift cell at $v_d \simeq 5.5\ cm/\mu sec$ indicating a

saturated drift velocity. The pad pulse height (Fig. 3b) is fairly uniform, with a dip at y = $\pm$ 2.5 cm (see Fig. 1) due to a shorter length in Z over which the ionization is collected on the wire. This data verifies our electrostatic calculations.

Test Data and Discussion

A table of test gas mixes is included as Table 1. Three mixtures of Ar: CO_2 were tried as were 2 mixtures of Ar:CO_2:CH_4. Finally a series of mixtures of Ar:CO_2:CF_4 were measured. For each mixture the wire-pad voltage was varied such as to yield the same gas gain as for the benchmark gas. Operationally this meant varying V_w - V_p until the pad pulse height looked similiar to that seen in Fig. 3b. Finally, the overall level of V_p was raised, keeping V_w - V_p constant, such that the drift field over the cell was $\geq$ 500 V/cm. For Ar:CH_4 (90:10), and Ar:CF_4 (90:10) this could not be accomplished due to sparking. However, the addition of only 2% CO_2, i.e., Ar:CO_2:CF_4 (88:2:10) was sufficient to meet these criteria.

TABLE 1.

Ar	CO_2	CH_4	CF_4	V_p (kV)	V_w (kV)	v_d (cm/μsec)
95	5	-	-	3.0	4.7	4.91
90	10	-	-	3.0	4.95	5.5
80	20	-	-	2.3	4.7	2.8
90	-	10	-	2.3	4.2	3.9
88	10	2	-	2.9	4.9	5.6
95	-	-	5	3.0	4.85	7.4
90	-	-	10	2.3	4.7	12.2
88	2	-	10	3.0	5.2	10.0
80	4	-	10	3.0	5.2	8.3
84	6	-	10	3.0	5.2	7.3
82	8	-	10	3.0	5.15	6.3
50	-	-	50	2.5	5.7	10.9
-	-	-	100	2.5	6.5	9.8

As seen from Table 1, $Ar:CO_2$ (90:10) has a comparable drift velocity integrated over the test cell as does the $Ar:C_2H_6$ (50:50) benchmark. Test data for this mix is given in Fig. 4a. The data is almost indistinguishable from that of the benchmark shown in Fig. 3. We consider this gas as a replacement (at low luminosity running) for the $Ar:C_2H_6$ (50:50) Fermilab stock gas mix; at least for DØ muon chambers.

Faster gas mixes were studied in 3 component mixes; $Ar:CO_2:CF_4$. Pure mixes of $Ar:CF_4$ could not achieve sufficient gas gain. The added CO_2 quencher slowed the gas, and hence we chose for further study the minimum quenching mix of $Ar:CO_2:CF_4$ (88:2:10). The data for V_p = 2.5 kV, V_w = 4.85 kV is shown in Fig. 4b. The drift velocity is ~ 1.8 times faster that $Ar:CO_2$ (90:10), and v_d is fairly uniform over the volume of the test cell. Since the drift velocity is non-saturating, we took data at roughly constant gas gain (V_w - V_p ~ 2.3 kV) with different drift fields; V_p = 2.0, 2.5, 3.0 kV. Note that a larger percentage of CF_4 does not lead to noticably higher drift velocities. In fact, elevated wire voltages are needed to maintain adequate gas gain.

The average value of v_d was 8.8, 9.65, 10.0 cm/μsec for these 3 voltages, which implies a sensitivity of $\Delta v_d/v_d$ ~ 3% for a 10% variation $\Delta V_p/V_p$. As can be seen from Table 1, a $\pm$ 2% variation in CO_2 concentration causes a drift velocity variation to $\Delta v_d/v_d$ ~ $\pm$ 2%.

In order to indicate non-saturation effects, the data of Fig. 4 were fit to a drift velocity for each cm of the 5 cm drift distance (intercept not constrained to t = 0 at y = 0). The results of the fits Fig. 4a and Fig. 4b are shown in Fig. 5a and Fig. 5b, respectively. The bands correspond to $\pm$ 10% and $\pm$ 5% limits on $v_d(y)$, respectively. It would appear that any differential non-linearities are contained within these bands. For comparison, a similiar plot for $Ar:C_2H_6$ (50:50) is entirely contained in a $\pm$ 2.5% band of limits which indicates a limit of systematic uncertainties.

We conclude that for many purposes $Ar:CO_2$ (90:10) will perform as a rugged drift gas with adequate gas gain and reasonably ($\pm$ 10%) constant drift velocity. This gas is stable in high-flux environments and insensitive to neutron backgrounds. It is safe and cheap. In higher speed applications $Ar:CO_2:CF_4$ (88:2:10) is a factor 1.8 faster but otherwise behaves very similiarly to $Ar:CO_2$ (90:10) and shares similiar virtues.

References

Ref. 1. Pesiert A., and F. Sauli, "Drift and diffusion of electrons in gases: a compilation," CERN 85-08.

Ref. 2. Green, D. et al., "Accurate two dimensional drift tube readout using time division and vernier pads," NIM 256A, 305 (1987).

Ref. 3. Fenker, H., "A standard beam PWC for Fermilab," TM-1179.

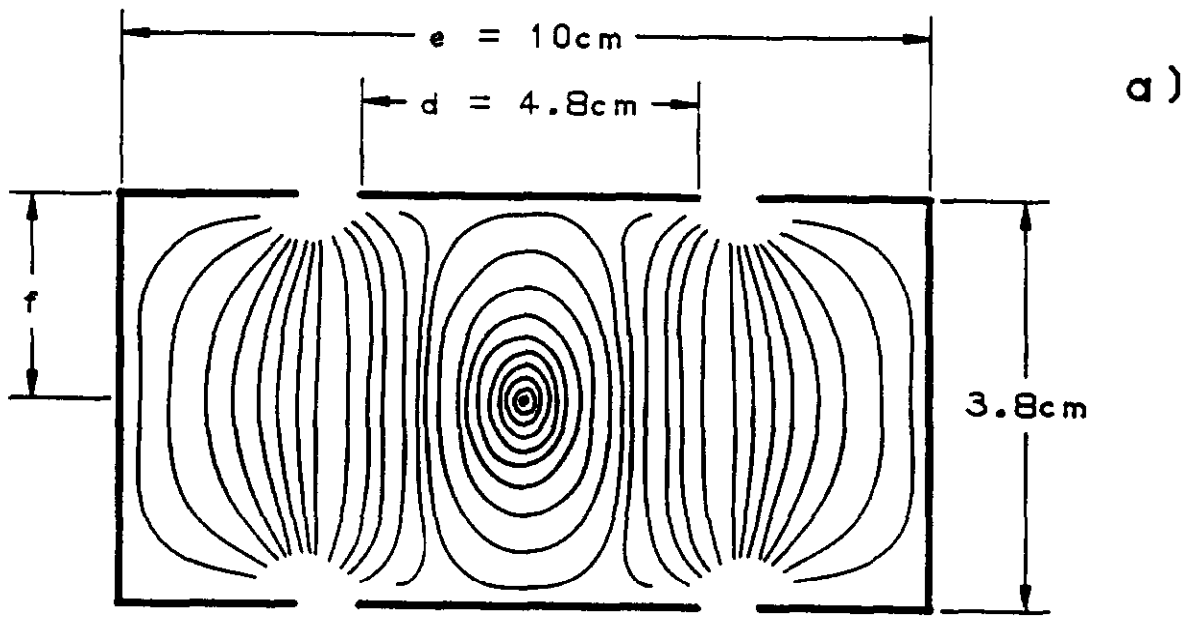

Fig. 1. Electrostatics for DØ muon proportional drift tubes. Cross sections of tube.

Fig. 1a. Equipotential contours.

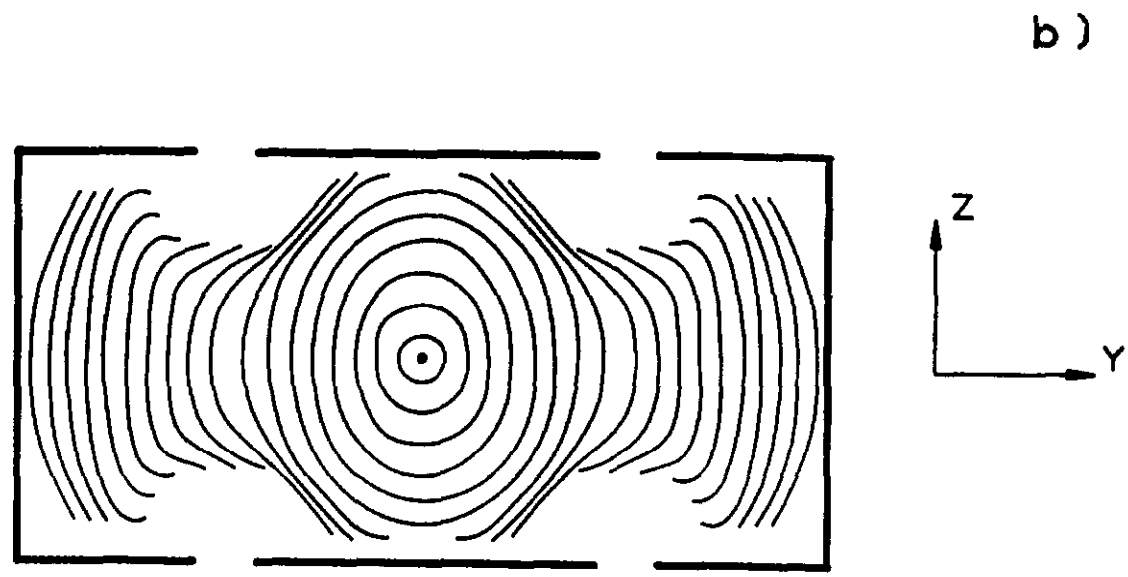

Fig. 1b. Equal time drift contours for Ar:C_2H_6 (50:50).

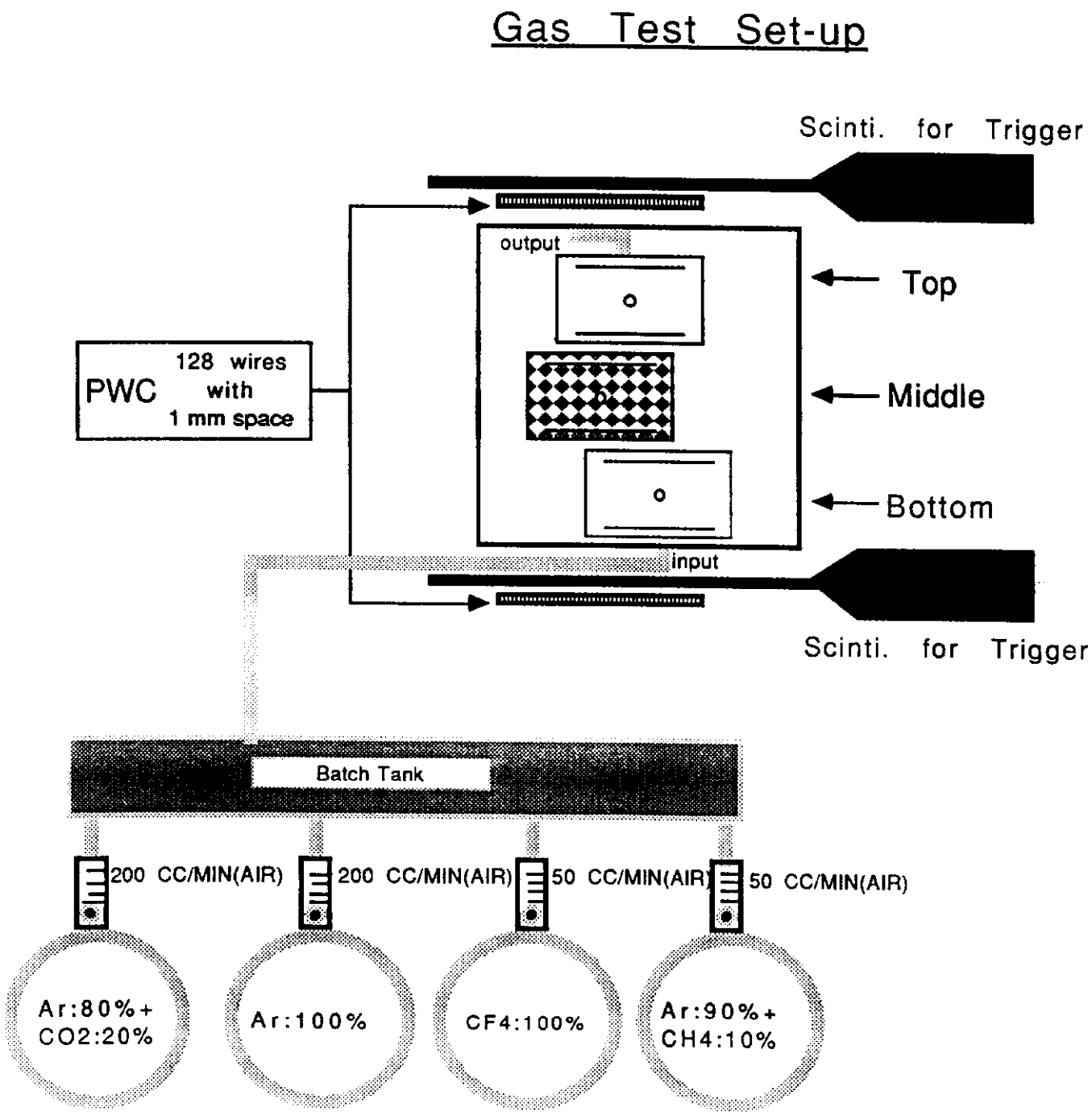

Fig. 2. Gas test setup. A three component gas mixing tank is used. The cosmic ray trigger is formed using scintillators top and bottom. Tracking is done using a PWC top and bottom.

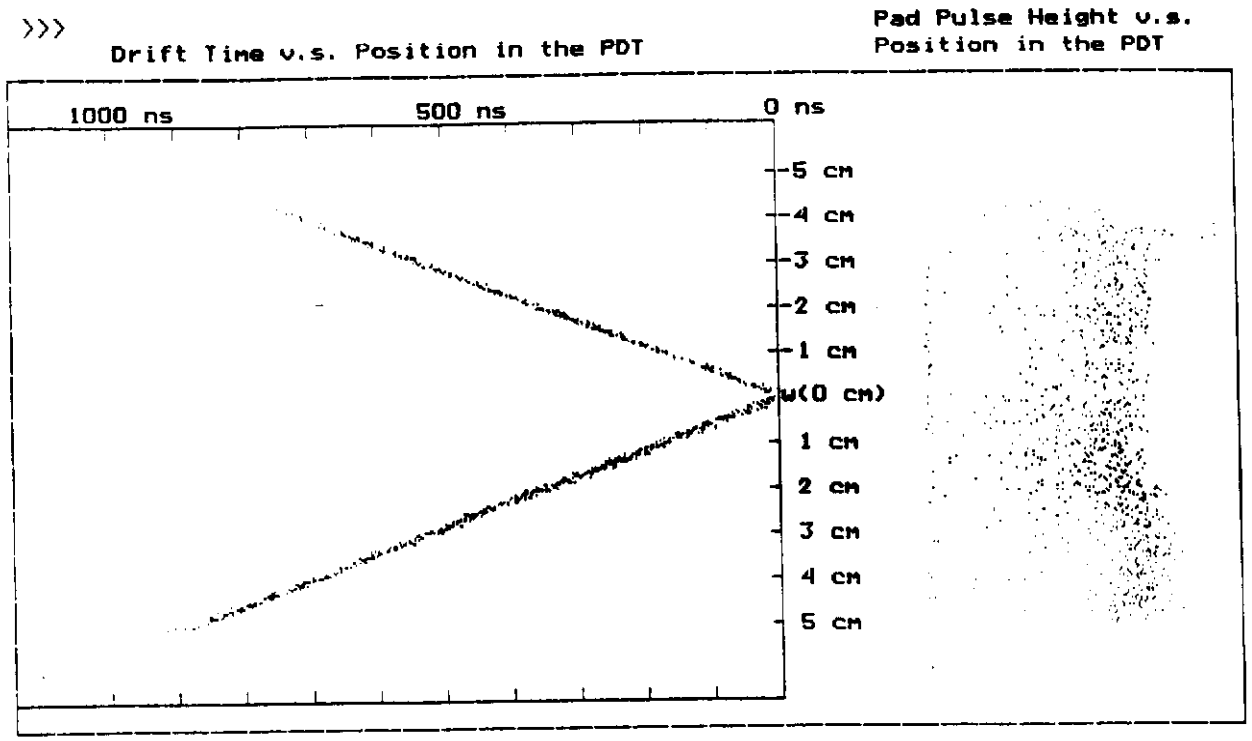

Fig. 3. Benchmark data using $Ar:C_2H_6$ (50:50)in the test cell.

Fig. 3a. Position vs. drift time.

Fig. 3b. Positions vs. induced pad pulse height.

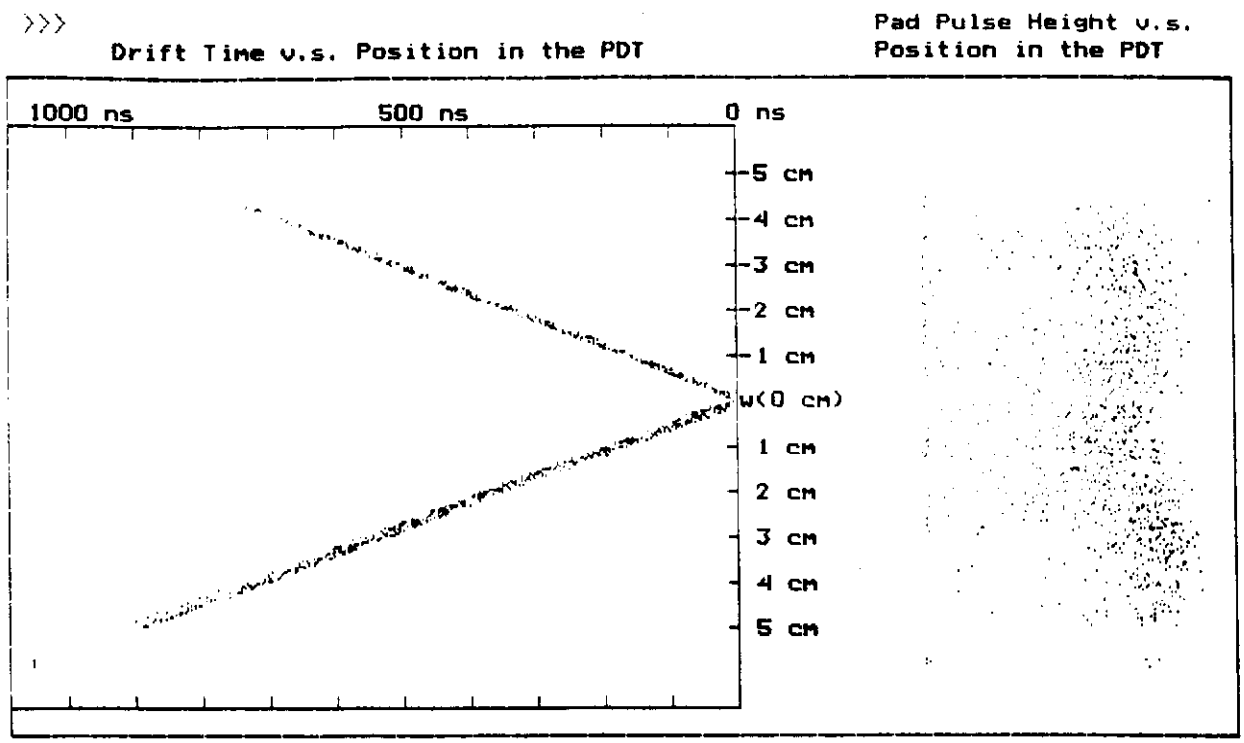

Fig. 4. Selected gas mix test data. Axes exactly as for Fig. 3.

Fig. 4a. $Ar:CO_2$ (90:10).

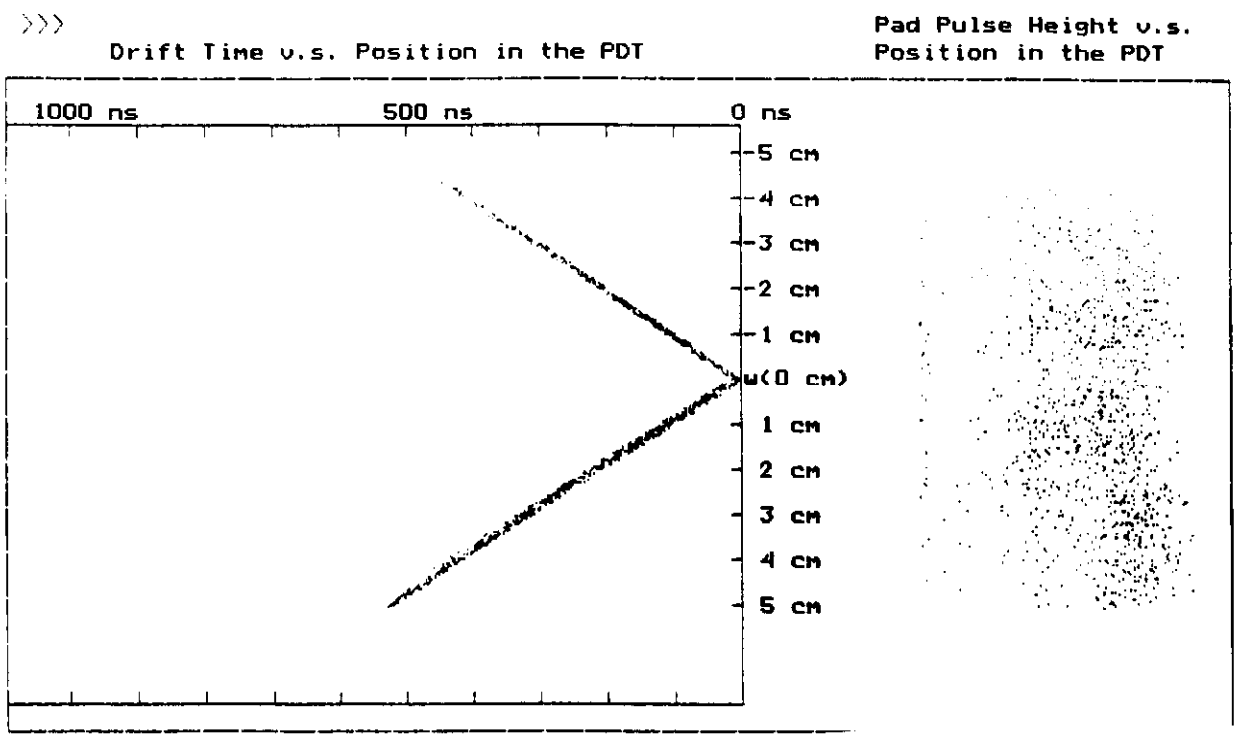

Fig. 4b. $Ar:CO_2:CF_4$ (88:2:10).

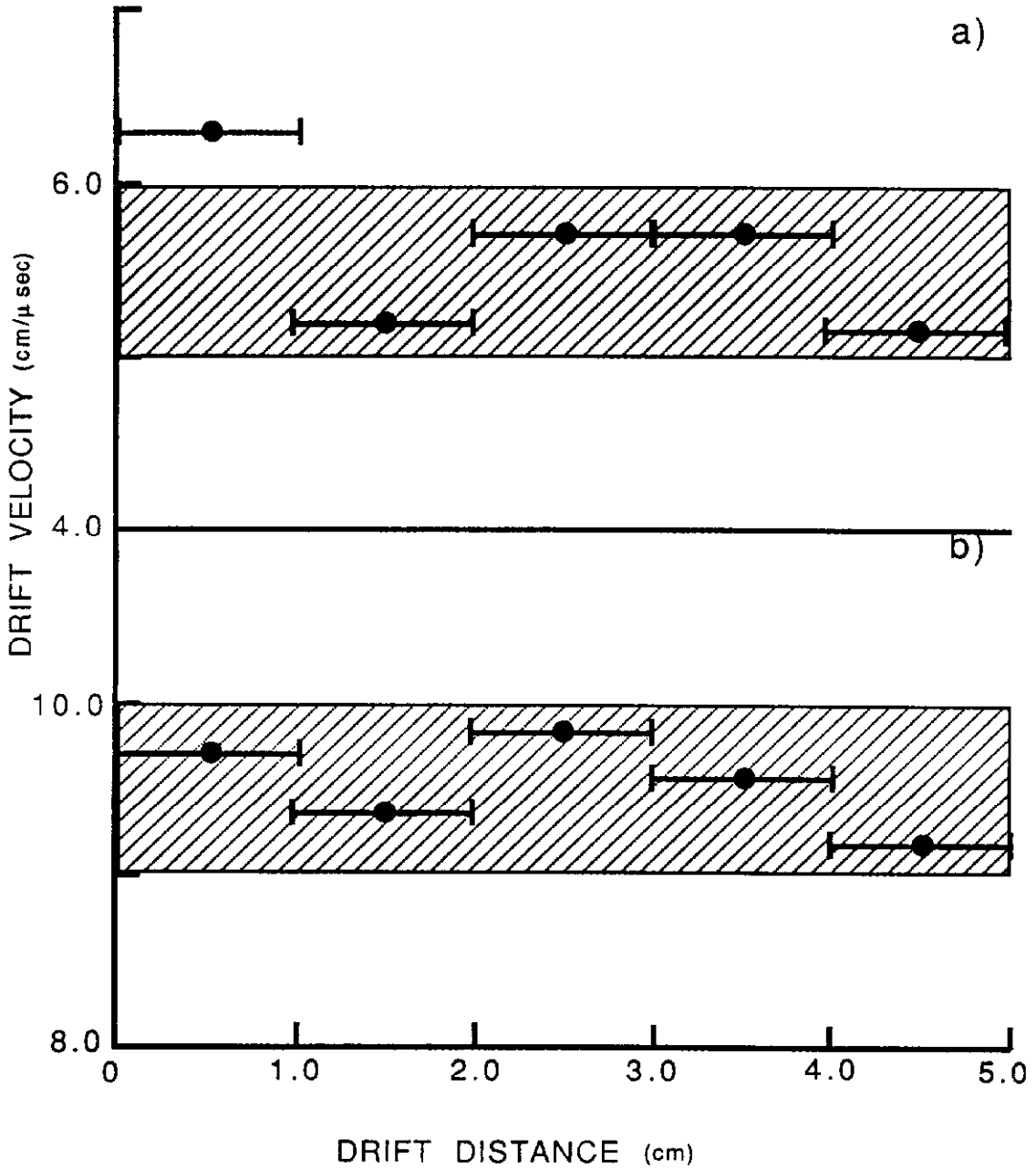

Fig. 5. Variations in drift velocity as a function of drift distance for the data shown in Fig. 4a (a) and Fig. 4b (b), respectively.