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A HIGH RATE PROPORTIONAL CHAMBER

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Abstract

Gas mixtures with high specific ionization allow the use of small interelectrode distances while still maintaining full efficiency. With the short electron drift distances the timing resolution is also improved. We have built and operated two 25 cm^2 chambers with small interelectrode distances. Also single wire detector cells have been built to test gas mixture lifetimes. Various admixtures of CF_4, DME, Isobutane, Ethane and Argon have been tested. Possible applications of such chambers are as beam profile monitors, position tagging of rare events and front end chambers in spectrometers.

Introduction

At TRIUMF there is considerable interest in using high rate MWPC's. For example there is a requirement for an 'active' slit capable of tagging the position of particles in secondary beamlines in a flux exceeding $1x10^8$ particles/s-cm^2. Also requirements of $1x10^6$ particles/s-cm^2 exist for front end chambers of our spectrometers. This has led us to construct two prototype high rate chambers with a 5 cm x 5 cm aperture. A schematic of these chambers is shown in Fig. 1. Chamber 1 has a 0.76 mm wire spacing with a 0.8 mm anode to cathode distance and an anode wire diameter of 12.7 μm. Chamber 2 has a 1.52 mm wire spacing with a 1.6 mm anode to cathode distance and an anode wire diameter of 20 μm. A desirable feature of these chambers is that they can be easily and compactly stacked in the same gas enclosure should multiple sense planes be required.

There are several difficulties in the design and construction of a high rate MWPC :

(a) Interelectrode distances should be as small as possible. In the case of detector 1 the anode wire spacing was 0.76 mm and the anode to cathode distance was 0.8 mm. Such spacings may cause difficulties when active areas larger than the present 5 x 5 cm are required.

(b) To minimize the input capacitance per channel and the corresponding rise time of the output pulse, the preamplifier should be very close to the wire pads. With our present chambers this distance is less than 2.5 cm. The measured input capacitance being less than 1.5 pf.

(c) Instrumentation of each channel with a preamplifier (13 per cm) without fanning out. Fanning out the traces from the wire pads would considerably increase the input capacitances of some channels, introducing an instrumental asymmetry and also make more difficult larger active area chambers of the same configuration. With chamber 1 alternate channels are read out at the two ends of the wire plane board, also at each end the signals alternate between preamplifiers on the top and bottom surfaces. This allows a 3 mm spacing between each of the hybrid preamplifier circuits.

(d) To insure that the active volume is flushed efficiently with the gas mixture. This could be very important since studies [1,2] on several gas mixtures have indicated that high flushing rates seem to extend their life-times. When the shape of the active volume of detector 1 was considered (6.3 x 6.3 x 1.6 mm) it was decided that a forced gas flow system was required. Figure 1 shows a sectional view of the test chamber, the gas volume is contained by an upper and lower aluminium gas box section and a number of spacer layers, one less than the number of wire planes. The stack is bolted together at the four corners (not shown) and these same bolts accurately position the detector layers. A 1.6 mm thick G10 spacer is laminated on one side of the wire plane board to cover the output traces and the high voltage trace to the cathode foils. As shown the gas mixture must move from one layer of the stack to the next, entering the active volume at each end near the wire pads, exiting at the middle of the sides through exit manifolds and a hole through the board to the next layer. Thus even though the total gas volume of our test detector stack was typically 450 cc the active gas volume of detector 1 (only 6.3 cc) would be changed eight times per minute by a small gas flow of 50 cc/min.

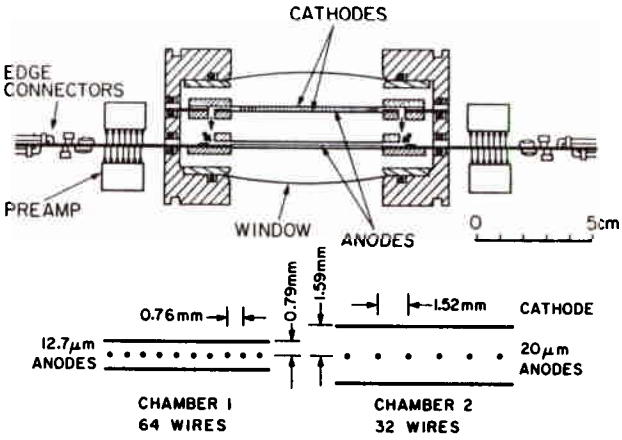

Figure 1. Cross sectional view of fast wire chamber with schematic views of the two chamber geometries.

Electronics

The hybrid preamplifier we adopted is a modification of that of Fisher et al [3]. The circuit is shown in Fig. 2 and consists of a diode protected common base input and two cascaded emitter followers in the output. The dc current return for the output emitter follower is provided by a -6V rail through the 330 ohm resistor shown. We use a 330 ohm resistor instead of their 680 ohm value, this extends the output saturation signal from 100 mV to 180 mV. This resistor and the 0.1 uf decoupling capacitor are located off the hybrid to minimize its power dissipation and thickness. The hybrid power dissiption is typically 24 mW. The rise time of the preamplifier impulse response is 0.8 nsec, the decay time constant is 45 nsec which is consistent with the collector resistance of 27 kohm and the 1.6 pf stray capacitance of the node at the collector of the first transistor.

We find that the long fall-time of the preamplifier response to a delta function can be cancelled by a clip circuit with a 2 nsec cable, see Fig. 3. Figure 4 shows the preamplifier response to conversions of 5.9 keV x-rays from ^{55}Fe (practically a point ionization), the tail due to the slow motion of the positive ions is clearly visible. This $(1+t/t_0)^{-1}$ tail is well cancelled

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by a simple pole-zero network. These results agree with those of Fisher et al and gives a pulse with a 5 nsec rise-time, 8 nsec fall-time and an effective pulse-pair resolution of approximately 15 nsec for a leading-edge discriminator. Filter-discriminator circuits are now being evaluated with a view to using a low priced hybrid.

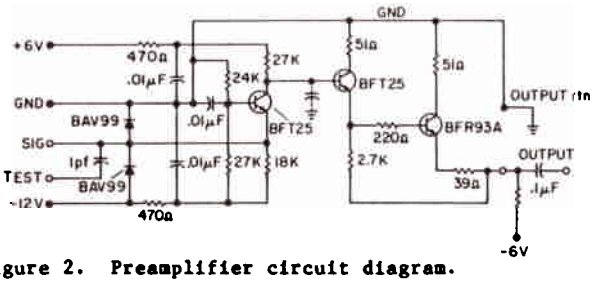

Figure 2. Preamplifier circuit diagram.

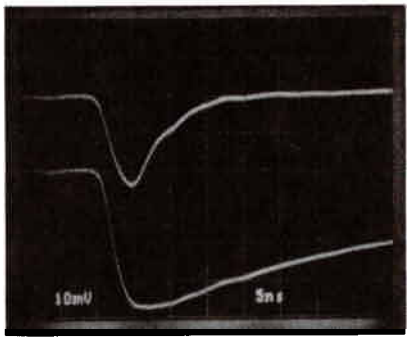

Figure 3. Preamplifier response to a delta function input (lower), and clipped response to a delta function (upper).

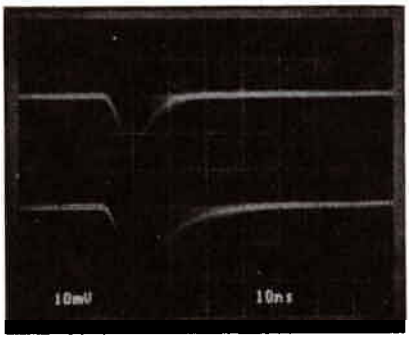

Figure 4. ^{55}Fe preamplifier response with cable clipping (lower), and with both clip and pole-zero cancellation (upper).

Operation

The pulse height resolution of chambers 1 and 2 are shown in Fig. 5, for an Argon/Ethane gas mixture and a ^{55}Fe source. As expected the thicker chamber 2 has the better energy resolution. A variety of gas mixtures have been tested in these chambers; primarily Argon/Ethane, DME/Isobutane and CF_4/DME combinations. In the upper part of Fig. 6 gas gains of some of these mixtures are shown for chamber 1, the lower part of Fig. 6 shows a set of gas gains for chamber 2. Gas gains were calculated from the preamplifier output pulse height (without shaping) and a measured charge gain of 1.3×10^{-4} mv/e-. We assumed a primary ionization of 30 e- from the ^{55}Fe source used for these tests. The preamplifier used at that time saturated on negative pulses greater than 100 mV (see Electronics section). This corresponds to a gas gain of approx. 1.2×10^5, hence all gains in Fig. 6 greater than this were calculated from the associated positive (unsatur-

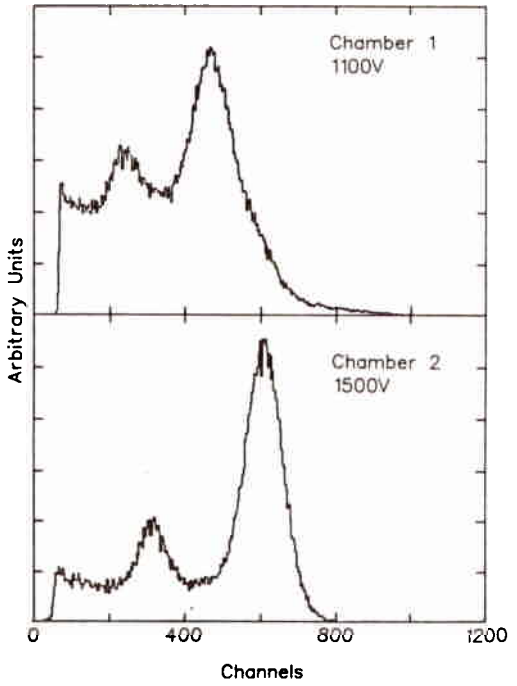

Figure 5. Pulse height spectra for 50:50 Argon/Ethane in chamber 1 and chamber 2 using an ^{55}Fe source.

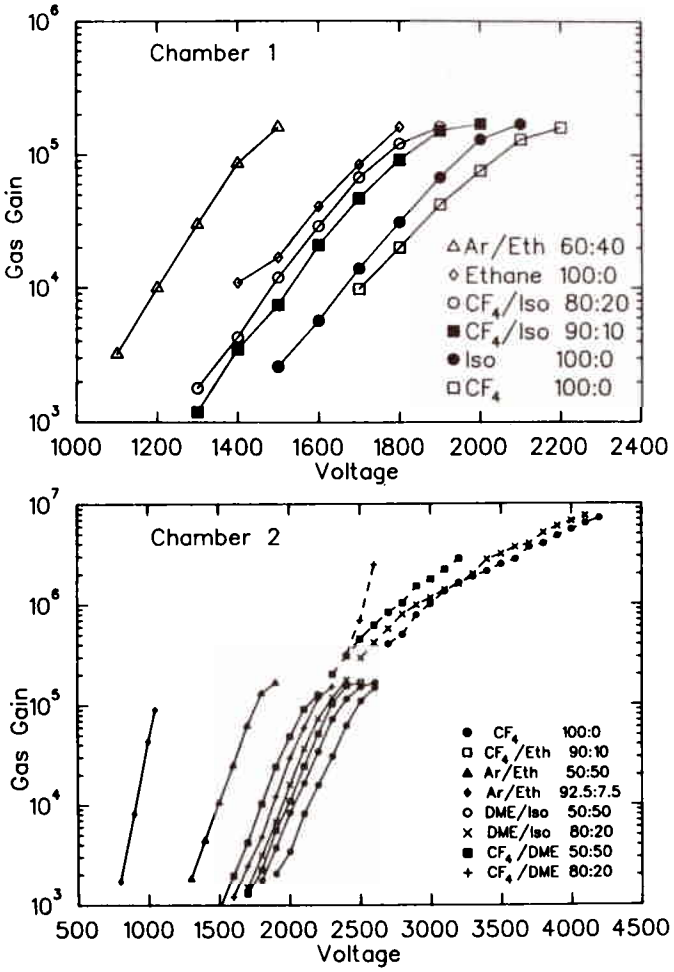

Figure 6. Gas gains in chamber 1 and chamber 2 for various gas mixtures.

ated) constant ratio pulse induced on adjacent wires (this is indicated by dotted lines). Due to the time constants of the preamplifier the output pulse represents only 1/5 of the charge deposited in the chamber by the original avalance, this factor was included in the gain calculations.

Some general features of these gas mixtures are:
1) Pure DME or DME/isobutane allow high to very high gas gains before sparking or runaway.
2) Argon mixtures allow low maximum gains before breakdown.
3) Pure isobutane or pure ethane allow high maximum gains.
4) CF_4 mixtures allow a low maximum gain unless they have as much as 20% isobutane or 50% ethane. Then they allow high to very high maximum gains.
5) CF_4/DME mixtures allow medium gains.

The timing jitter for chambers 1 and 2 have also been measured for several gas mixtures. The experimental arrangement is straightforward and measures the time differences between the passage of an electron from a ^{90}Sr source and the detector signal using a constant-fraction discrininator. Minimium ionizing particles are selected by requiring a coincidence between a pair of scintillators following the gas detector, 3.2 mm and 6.4 mm thick respectively. Of particular interest are CF_4/hydrocarbon mixtures, since these have a high specific ionization and a fast electron drift velocity [3]. Figure 7 shows the timing jitter for chamber 1 as a function of detector voltage for CF_4/Isobutane mixtures. It is interesting to note from Fig. 8 that the minimum jitter for these mixtures varies very little in FWHM and only moderately in FWTM. This is surprising since it was expected that higher concentrations of isobutane would reduce the drift velocity by dilution with the slower gas.

The effect of CF_4 concentration on pulse height structure was measured in chamber 1 with an ^{55}Fe source. As can be seen in Fig. 9, admixtures with 10 to 50 percent isobutane have good resolution.

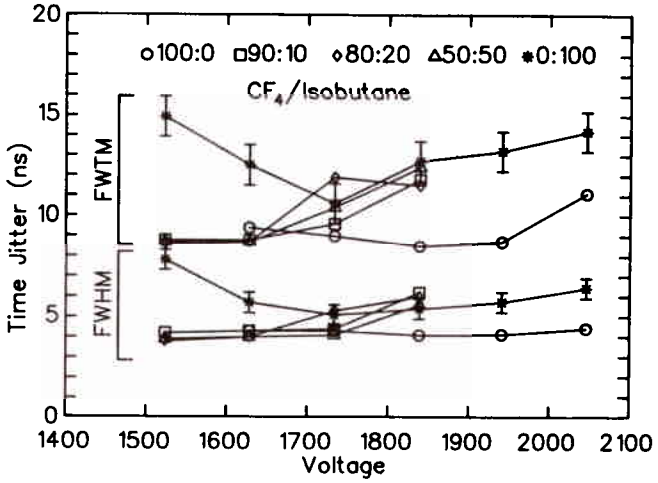

Figure 7. Timing jitter for Chamber 1 as a function of voltage for several Freon/Isobutane mixtures. Full width half maximum (FWHM) and full width tenth maximum (FWTM) are shown.

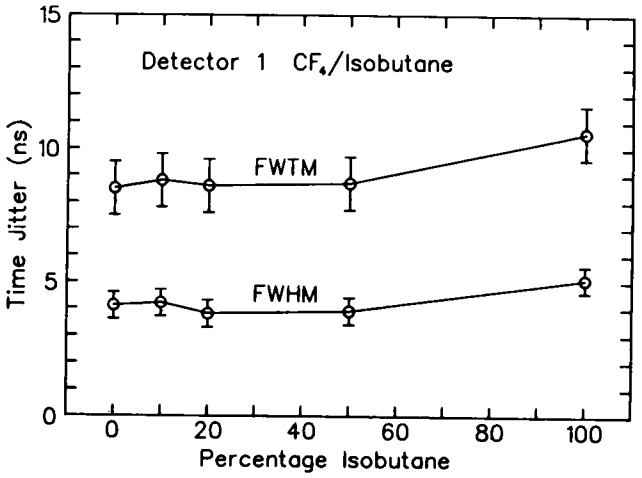

Figure 8. Minimum timing jitter for Chamber 1 for Freon/Isobutane mixtures as a function of percentage of Isobutane.

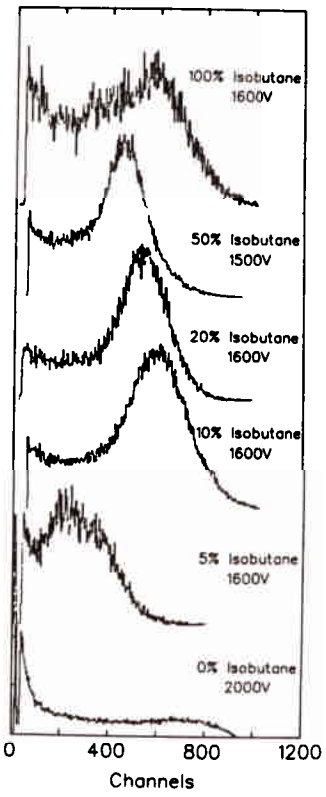

Figure 9. Pulse height spectra for Freon/Isobutane mixtures in Chamber 1.

Damage Tests

One serious problem a high rate detector must face is that of ageing. We estimate that chamber 1 operating at an optimal gas gain of $3x10^4$, will generate approximately $3x10^5$ ions for the passage of a minimum ionizing particle. In a flux of 10^8 particles/cm^2-sec each wire would have a rate of $7.6x10^6$/cm-sec and would accumulate charge at $3.8x10^{-7}$ coulomb/cm-sec. Useable lifetimes of between 0.2 and 1.0 Coulomb/cm have been reported by various groups [1,2] for the more common gas mixtures. This implies a life of between 6 and 33 days for chamber 1 under the above conditions. Clearly

a search for hardier gas mixtures is necessary. As the literature on chamber damage is somewhat inconsistent (due to the many variables involved) and in particular is quite scarce for CF_4 mixtures, we have undertaken a systematic series of damage tests.

Our damage test apparatus consists of several identical aluminium chambers (one of which is shown in Fig. 10) arranged in a stack separated by 3.2 mm lead collimators. A 2.5 cm diameter 10 millicurie ^{90}Sr source is positioned above the detector stack and the lead collimators restrict the irradiated length of the chambers to approximately 2 cm. High voltage, gas mixture, flow rate and plumbing components can be arranged independently for each of the chambers. Periodically, typically once per day, the ^{90}Sr source is removed and the stack is separated. The pulse height structure of a collimated ^{55}Fe source is observed at a reference voltage for three marked locations of each chamber, the center of the exposed area, 5 cm upstream and 5 cm downstream. In addition the current draw is monitored for each chamber, not only while it is being exposed to the ^{90}Sr source but also immediately after the source is removed. These latter observations are to monitor the "Malter effect" sustained dark currents. Pulse heights (with ^{55}Fe) from the irradiated area are compared to those upstream and downstream; not only to measure any pulse height degradation in the exposed region, but also to reveal any effect due to the direction of the gas flow. In addition reference chambers are continually flushed with each of the gas mixtures under test (one per mixture), then turned on only to obtain a reference ^{55}Fe pulse height measurement at the testing times. This latter technique is used to correct for gain variations due to temperature and pressure changes and also to monitor possible gain changes in the test chambers beyond the irradiated region. To minimize uncertainties, a single electronics chain is used to consecutively measure the pulse height structure of each chamber. This electronics chain is calibrated by injections of pulser pulses through a 1 pf capacitor to the preamplifier input, at the beginning and end of each testing time.

We have observed two distinct types of damage. The first, sometimes called the Malter effect, is characterized by an increase in current at constant gain and irradiation, sustained currents after removal of the source (dark currents) and cathode deposits (primarily hydrocarbons). The second type causes a decrease in chamber current, permanently reduced pulse heights and is usually accompanied by deposits on the anode wire containing carbon, hydrogen, silicon, nitrogen and sulphur. Table 1 summarizes our damage tests and the conditions such as gas gains, flow rates, operating currents, observed dark currents and the pulse height degradation (in percent per coulomb/cm).

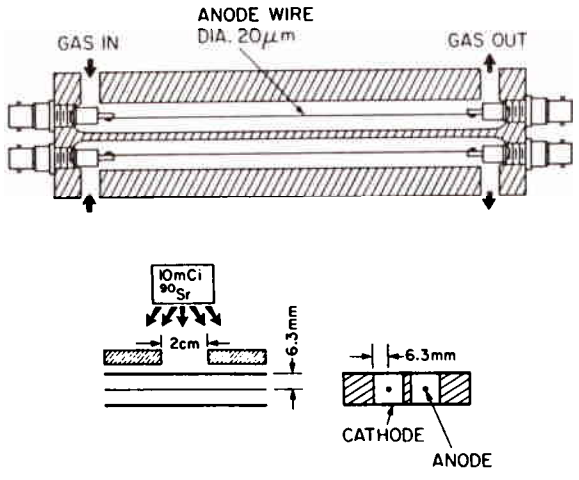

Figure 10 Schematic diagram of damage testing cells.

Table 1. Results of damage tests.

Gas Mixture	Flow cc/min	Gas Gain	Current Setting μA/cm	Dark Current μA	Pulse Ht Degrade %/C/cm	Accum Charge C/cm
Ar/Eth 50:50	50	$4x10^5$	1.0	<0.005	-27±3	0.6
		$4x10^5$	1.0	0.25	0±3	1.1
		$2x10^6$	2.0	2.5	1±5	2.5
		$2x10^5$	2.0	2.0	0±2	2.3
					total	6.5
Ar/Eth 50:50	250	$3x10^5$	1.0	<0.005	0±3	0.8
		$3x10^5$	1.0	0.07	0±3	0.9
		$1x10^6$	2.0	1.5	0±2	2.5
		$4x10^4$	2.0	<0.005	0±2	2.3
					total	6.5
CF_4/Iso 80:20	50	$2x10^5$	2.0	<0.005	0±2	1.4
		$6x10^3$	0.29	<0.005	0±2	0.06
					total	1.46
CF_4/Iso 80:20	50	$6x10^5$	2.0	<0.005	0±2	1.8
CF_4/Iso 80:20	10	$2x10^5$	2.0	<0.005	0±2	1.1
Ar/Et 50:50	10	$4x10^6$	2.0	1.8	0±4	0.7
		$4x10^5$	0.51	<0.005	0±4	0.1
					total	0.8

Note: Volume of the damage test cell is 28 cm^3.

Discussion

Initial tests used a 50% Argon/50% Ethane mixture as a considerable body of literature exists for comparison. Also noticeable damage was expected at less than 0.5 coulomb per cm of wire and this could act as a damage reference. We also tried to accelerate the rate of damage by operating this mixture at high gains, up to $1x10^6$. Interestingly although we expected the lifetime to be somewhat increased by operating at $1x10^6$ instead of $3x10^4$ [2], we have seen far less pulse height degradation at the 0.5 coulomb/cm level than was expected. As shown in Table 1, one of the chambers with this gas mixture has accumulated greater than 6.5 coulomb/cm of wire and shows no observable gain drop, although it did develop significant sustained dark current as early as 0.6 coul/cm. Clearly this test cell had not been damaged at the rate reported by Kotthaus [2], reported as approximately 31 percent/coulomb.

A second chamber was operated under the same conditions but with one fifth the gas flow (50 cc/min instead of 250 cc/min). This chamber showed a 17% pulse height degradation after an accumulated charge of 0.6 coul/cm, however continued ageing of this chamber to 6.5 coul/cm produced no further pulse height change.

As flow rate was the only obvious difference between the two tests, a third chamber was operated at a still lower flow rate of 10 cc/min (0.3 detector volumes per minute). No discernable pulse height change was seen after accumulating 0.8 coul/cm, however very high gains of $4x10^6$ were used in this test. All of the Argon/Eth-

ane chambers have acquired dark currents after irradiation at gains greater than $1x10^5$.

Juricic and Kadyk have reported decreases in damage rates from 227% per coulomb to less than 1% per coulomb when the gain is increased from $3x10^3$ to $1x10^5$ at flow rates similar to ours. Kotthaus on the other hand reports damage rate decreases of factors of only two for gain changes from $5x10^4$ to greater than 10^6. However he used much smaller flow rates of 0.05 volumes/minute. It is possible that the combined effect of large gains and large flow rates can drastically decrease damage rates.

The 80:20 CF_4/Isobutane mixture has also been tested up to 2 coul/cm without observing either pulse height degradation or Malter effect currents. The absence as yet of any observed damage with this gas mixture is encouraging. It should be realized that all the results of our damage tests are preliminary and will have to be repeated under a variety of conditions before any reliable predictions can be drawn from them.

Conclusions

Two high rate wire chambers have been designed and constructed at TRIUMF. We have measured pulse height resolution and timing jitter of the chambers for a variety of gas mixtures. As well, chamber 1 has been operated for short duration bench tests with flux rates equivalent to $7x10^6$ minimum ionizing particles/sec-cm^2 at a gas gain of $4x10^4$. Damage tests are under way to determine what the maximum chamber lifetimes and optimum gas mixtures will be. In test cells, built for this purpose, charges in excess of 6.5 coulombs/cm of wire have been collected without showing significant pulse height degradation, although Malter effects have been observed.

References

[1] I. Juricic and J. Kadyk, "Results from some anode wire aging tests", in Proceedings of the Workshop on Radiation Damage to Wire Chambers, 1986, pp. 141-151.

[2] R. Kotthaus, "A laboratory study of radiation damage to drift chambers", in Proceedings of the Workshop on Radiation Damage to Wire Chambers, 1986, pp. 161-193.

[3] J. Fischer et. al., "Proportional chambers for very high counting rates based on gas mixtures of CF_4 with hydrocarbons", Nucl. Instr. and Meth., vol. A238, pp. 249-264, 1985.