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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

A comparison of CF_4 + hydrocarbon fast gases for drift chambers and straw tubes

A.P. Heinson and D. Rowe

University of California, Irvine, Irvine, CA 92717, USA

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Measurements have been made of the signal charge, drift time distributions and sensitivity to soft photons and charged particles, for several CF_4 + hydrocarbon fast gas mixtures. Comparisons are made with $Ar + C_2H_6$ (50 : 50) and with other standard gases. $CF_4 + CH_4$ (30 : 70) is found to have many advantages over $CF_4 + iC_4H_{10}$ (80 : 20), which may make it appropriate for use in high rate particle physics experiments.

1. Introduction

Gas mixtures with fast electron drift velocities are needed in drift chambers and straw tube detectors for very high rate experiments, such as the rare kaon decay searches at the Brookhaven Alternating Gradient Synchrotron, and in the tracking detectors at the Tevatron and the SSC. Many current proposals involve the use of $CF_4 + iC_4H_{10}$ (80 : 20), as suggested by Fischer et al. [1]. This has a drift velocity of about 100 μm/ns [2] at the electric field strengths commonly used. It needs an operating voltage about 1.3 times that used for gas mixtures such as $Ar + C_2H_6$ (50 : 50) for the same gain, and its radiation length is $\approx 59\%$ as long. We have attempted to find a different fast gas mixture with a higher gain than $CF_4 + iC_4H_{10}$ (80 : 20), and a longer radiation length, which may be more suitable for large drift chambers and straw tubes.

2. Detector and readout system

Measurements were made using straw tubes obtained from the EVA heavy ion experiment at Brookhaven, E850. The straws were 75 cm long and had an inner diameter of 1 cm. The walls were made of 0.1 mm Mylar, with 0.015 mm aluminum wound diagonally on the inner surface. The sense wires were gold plated tungsten, 20 μm diameter. The gases used were Ar, CO_2, CF_4, iC_4H_{10}, C_2H_6 and CH_4, which were mixed using mass flow controllers made by Edwards High Vacuum. These were calibrated for Ar, C_2H_6 and CF_4, so for these gases, the error on the proportion is $\pm 1\%$. Calibration factors for the other gases were obtained using the molar specific heats, and the errors are $\pm 2\%$.

High voltage was applied to the sense wires using a Bertan power supply. The signals were read out through a fast preamplifier into a LeCroy qVt. For the drift time measurements, a scintillator telescope was set up above and below the straws, and a coincidence of scintillator signals was used to start the timing. For the rate tests, the discriminated signals were fed into a scalar. A 1 mCi ^{55}Fe source was used for the signal charge and rate measurements. Cosmic rays were used for the drift time tests.

3. Gas mixtures

The fast gases studied were $CF_4 + iC_4H_{10}$, $CF_4 + C_2H_6$ and $CF_4 + CH_4$, with various proportions of hydrocarbon. Properties of these fast gases will be compared to those of the standard drift chamber gas mixture, $Ar + C_2H_6$ (50 : 50), which has a drift velocity of 52 μm/ns at 1 kV/cm [3]. The gains of other standard gas mixtures containing various proportions of $Ar + CO_2$, $Ar + CH_4$ and $Ar + iC_4H_{10}$ are also shown, so that people working with any of these mixtures may compare the fast gas results shown here with their own experiences.

Most of the measurements focus on three fast gas mixtures: $CF_4 + iC_4H_{10}$ (80 : 20), $CF_4 + C_2H_6$ (60 : 40) and $CF_4 + CH_4$ (30 : 70). The first mixture with isobutane has been chosen because many groups are proposing to use it. The ratios for ethane and methane have been picked to minimize the amount of Freon-14,

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Table 1
Properties of the four gas mixtures being tested

Gas mixture	Density [g/L]	Radiation length [m]	Primary ionizations [#/cm]	Cost [a] [$/m^3]	Drift velocity at 2.4 kV/cm [μm/ns]
$Ar+C_2H_6$ (50:50)	1.568	225	32.7	19	50
$CF_4+iC_4H_{10}$ (80:20)	3.497	133	49.5	195	105
$CF_4+C_2H_6$ (60:40)	2.765	210	40.8	150	117
CF_4+CH_4 (30:70)	1.613	491	29.7	89	126

[a] Prices from Matheson Specialty Gases, with a 15% university discount.

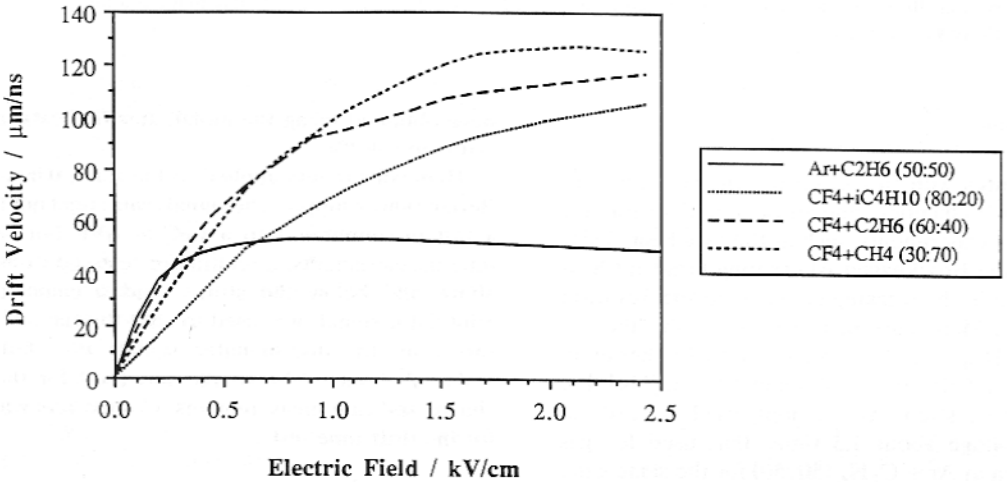

Fig. 1. Electron drift velocities vs electric field strength for each of the four gas mixtures being studied.

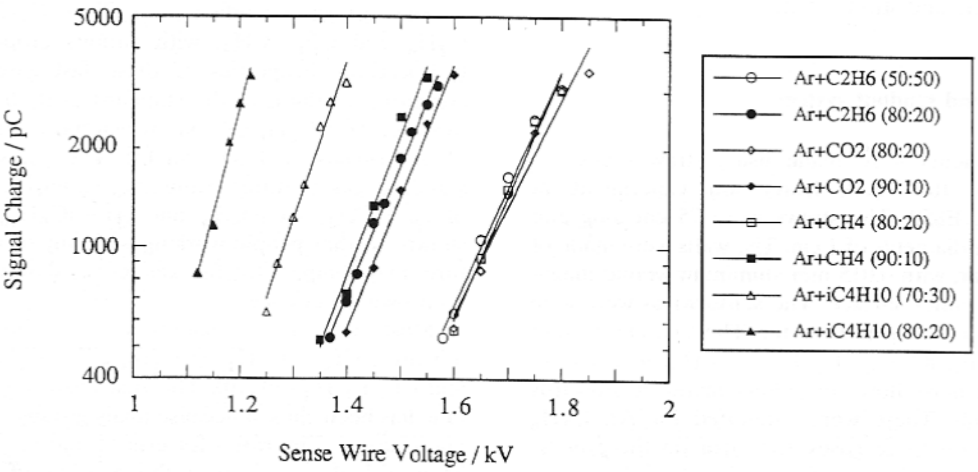

Fig. 2. Signal charge vs sense wire voltage for several gas mixtures with standard drift velocities.

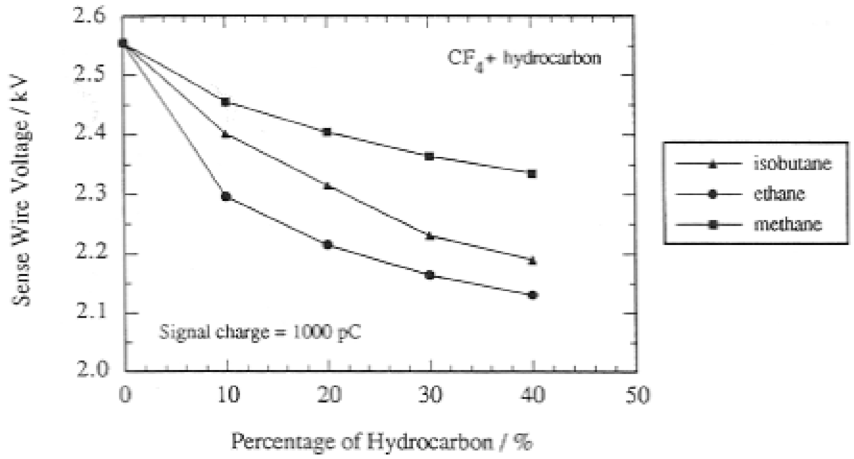

Fig. 3. Sense wire voltage needed to produce 1000 pC signals vs proportion of hydrocarbon in CF_4 based fast gas mixtures.

whilst keeping the electron drift velocity large at high electric field strengths. For larger proportions of hydrocarbon, the drift velocities fall off rapidly [2]. Increasing the proportion of hydrocarbon will be shown to give a larger signal gain. Decreasing the proportion of CF_4 will be shown to give a longer radiation length and to lower the cost.

Table 1 summarizes some of the properties of the three fast gases chosen and compares them to those of Ar + C_2H_6 (50:50). The values in the table are from refs. [2–5]. The radiation length of CF_4 has been estimated using its density.

Fig. 1 shows the drift velocity for each of these four gas mixtures as a function of the electric field strength at atmospheric pressure. These results are from refs. [2,3]. It can be seen that the three fast gases have nonsaturated drift velocities, especially at low electric field strengths. The mixture with isobutane varies the most, and is quite slow at low field strengths. The drift velocity in CF_4 + iC_4H_{10} mixtures is also most dependent on the proportion of quencher present [2]. Small diameter straw tubes tend to have high electric fields in them, and the drift velocities at 2.4 kV/cm are shown in table 1.

4. Signal charge

Fig. 2 shows the signal charge measured for eight different gas mixtures with standard drift velocities. It can be seen that adding more quencher to the argon reduces the gain. Fig. 3 shows the signal charge mea-

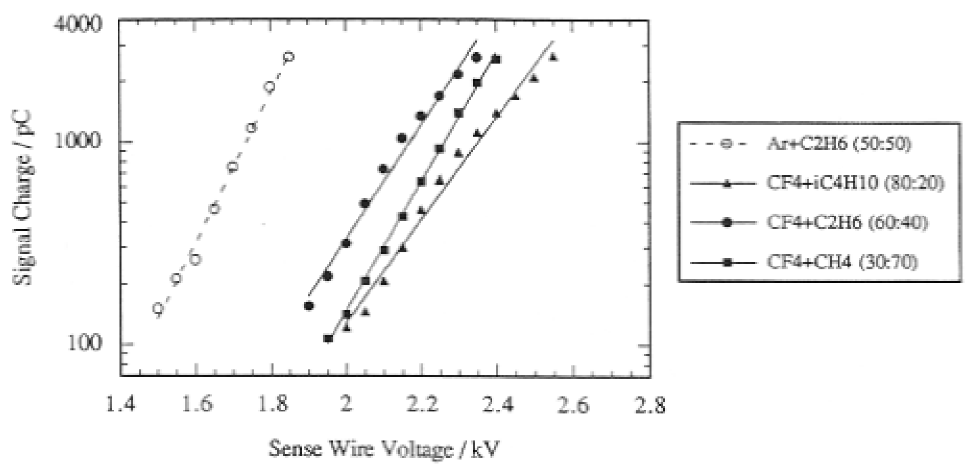

Fig. 4. Signal charge vs sense wire voltage for each of the four gas mixtures being tested.

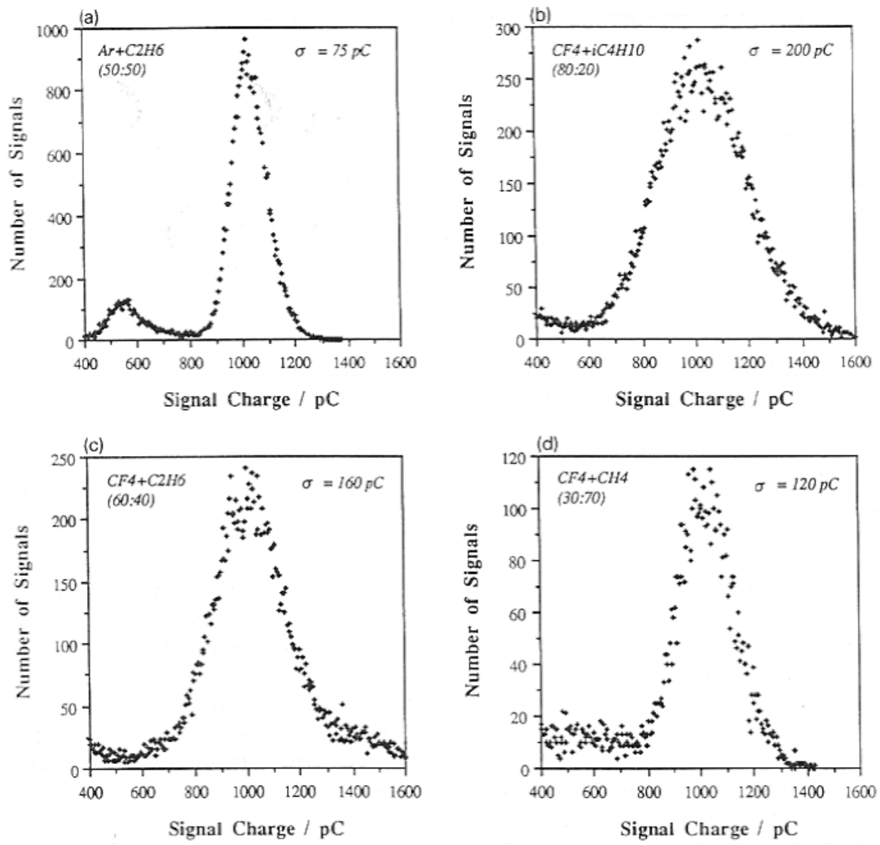

Fig. 5. qVt charge spectra for the four gas mixtures. Only the gas mixture containing argon has twin peaks.

sured for CF_4 with various additions of isobutane, ethane and methane. Adding more quencher now increases the signal gain for the same voltage. Therefore, to obtain a good signal-to-noise ratio and reduce the chances of discharge in the gas or on the outside of the detector, it is advantageous to choose a fast gas mixture containing a high proportion of hydrocarbon. Fig. 4 shows the signal charge measured for the four gas

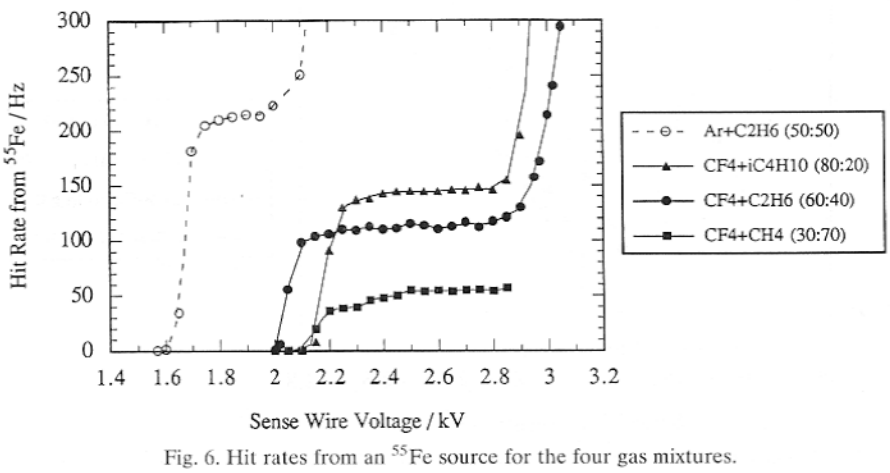

Fig. 6. Hit rates from an ^{55}Fe source for the four gas mixtures.

mixtures under investigation, for comparison with each other. A lower threshold was used for these measurements than for those shown in figs. 2 and 3. The fast gas with the highest gain is $CF_4 + C_2H_6$ (60:40). However, the voltage still needs to be raised by 25% to get the same size signals as those from the standard gas $Ar + C_2H_6$ (50:50). For the same size signals from $CF_4 + CH_4$ (30:70), the voltage needs to be raised by 30%, and for $CF_4 + iC_4H_{10}$ (80:20), the voltage has to be raised by 36%.

Fig. 5 shows the signal charge distributions for the four gas mixtures. These were generated using an ^{55}Fe source. The widths of the charge spectra are indicative of the energy resolution obtainable in a detector which uses charge measurement to determine a particle's energy. $Ar + C_2H_6$ has the narrowest peak, and for the three fast gases, the $CF_4 + CH_4$ mixture has the smallest σ, at 120 pC, and the $CF_4 + iC_4H_{10}$ mixture has the largest, at 200 pC.

5. Rates

Hit rates were measured using a scaler to count the discriminated straw tube hits. From these results, a voltage plateau for each gas was found, where the hit rate was roughly uniform. If the voltage was too low for a particular gas, then the hit rate was very low because the system was inefficient. If the voltage was too high, then the straw tube started to draw a little current, which could be seen on the signal line as continuous variations in amplitude. If these became large enough that they passed the threshold, then the hit rate increased enormously. The length of the plateau is a measure of how much variation in electric field across a cell there can be, with the cell still efficient in all regions.

Table 2
Relative sensitivity of each gas mixture to soft photons and to minimum ionizing particles

Gas mixture	Relative sensitivity to soft photons	Number of cosmic ray hits per minute
$Ar+C_2H_6$ (50:50)	1	3.58
$CF_4+iC_4H_{10}$ (80:20)	0.69	3.66
$CF_4+C_2H_6$ (60:40)	0.52	3.64
CF_4+CH_4 (30:70)	0.26	3.85

Fig. 6 shows hit rates vs sense wire voltage for $Ar + C_2H_6$ (50:50), $CF_4 + iC_4H_{10}$ (80:20), $CF_4 + C_2H_6$ (60:40) and $CF_4 + CH_4$ (30:70) from the ^{55}Fe source. The same straw was used for each measurement and the source was in exactly the same position. Therefore the relative levels of the plateaux may be taken as an indication of the relative sensitivity of each gas mixture to 5.89 keV photons. All the mixtures without argon were less sensitive than $Ar + C_2H_6$ (50:50). The sensitivity of each of the fast gases to soft photons scales approximately with the ratios of their densities and the relative sensitivities are shown in table 2.

For detecting minimum ionizing particles, one would choose to operate a detector towards the highest end

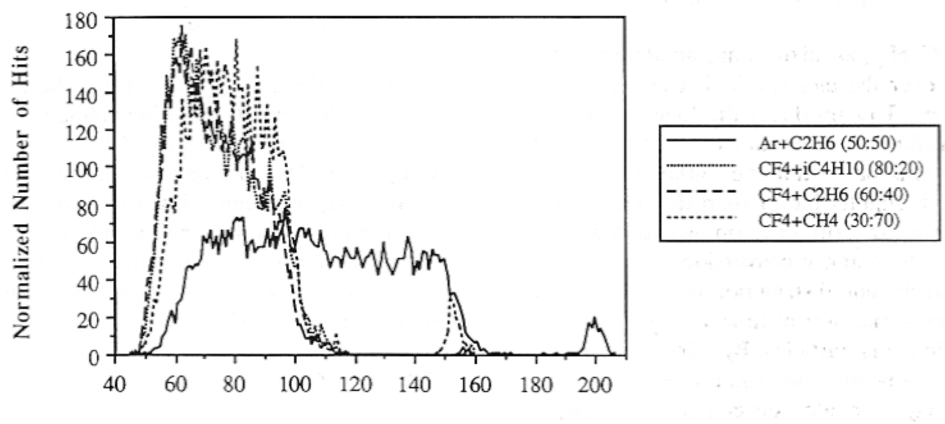

Fig. 7. qVt drift time distributions for the four gas mixtures.

of the plateau, to ensure the highest efficiency possible.

6. Drift time distributions

For the four gas mixtures being considered, the drift time distributions were measured using the qVt, the two scintillators in coincidence, and cosmic rays. A signal from the scintillators was used to start the clock and a signal from a straw tube was used to stop it. The drift time distributions tell us many things about the behavior of the gases. The width at the base of the distribution may be used to calculate an approximate drift velocity, assuming a linear drift relation and a maximum drift distance of 5 mm. The steepness of the leading edge of the distribution is indicative of how efficient each gas mixture is near the sense wire. How flat the top of the distribution is tells us how linear the drift velocity is over the range of electric field strengths found in the tube. Any long tail to the distribution may show that there is some current being drawn in the gas which is producing noise hits.

Fig. 7 shows the four drift time distributions measured. The voltages used were $Ar + C_2H_6$ 2.00 kV, $CF_4 + iC_4H_{10}$ 2.65 kV, $CF_4 + C_2H_6$ 2.61 kV and $CF_4 + CH_4$ 2.70 kV. These were chosen to produce approximately the same gain. The small peaks with long drift times at 200 ns for $Ar + C_2H_6$, at 152 ns for $CF_4 + CH_4$ and between 155 and 160 ns. for the other two gases are not understood. The four graphs have been normalized to the amount of time over which each data set was recorded.

Estimates of the drift velocities obtained from the drift time distributions are consistent with the values found in refs. [2,3]. The leading edge of the $CF_4 + CH_4$ distribution is slightly less steep than the other two fast gas mixtures. This may be due to the lower number of primary ionizations per cm for this gas, shown in table 1.

The $Ar + C_2H_6$ gas mixture has an almost constant drift velocity over the electric field strengths found in the straw tubes. This produces the long flat top to its drift time distribution. None of the three fast gas drift time distributions has a flat top, although the $CF_4 + CH_4$ mixture is slightly flatter than the other two fast gases. A nonlinear drift relation would have to be found for time to distance conversion.

From the drift time distribution measurements, it is possible to get a measure of how sensitive each gas is to minimum ionizing particles. By calculating the number of cosmic ray hits per minute for each gas, a comparison may be made between the four gases under consideration. The number of hits per minute for each gas mixture is shown in table 2. The runs were between 1000 and 2737 min long. It can be seen that all four gases are approximately equally sensitive to minimum ionizing particles, which means that they are all probably suitable for use in real detectors.

7. Conclusions

7.1. $Ar + C_2H_6$ (50:50)

This standard drift chamber gas has the most stable drift velocity of all the gases, the lowest operating voltage and is the cheapest. It has the shortest operating plateau, which may lead to regions of inefficiency. It is also sensitive to soft photons because it contains argon. If a fast gas is not necessary, then this is a good gas to use.

7.2. $CF_4 + iC_4H_{10}$ (80:20)

This is the gas that many SSC tracking groups and other groups with high rate experiments are investigating. Its best feature is that it has the highest number of primary ionizations per unit length in the gas, (1.67 times as many as $CF_4 + CH_4$ (30:70)), meaning it can be used efficiently if the detector is very thin, and also that it probably has good resolution near the sense wire, which is important if the maximum drift distance is very short. On the down side, it has the worst radiation length, the highest operating voltage, the greatest variation in drift velocity as a function of electric field and proportion of quencher, and is the most expensive. Isobutane is a difficult gas to handle, since it is heavier than air and if there are leaks in the detectors then it may collect underneath an experiment and could explode. Special ventilation precautions have to be taken.

This gas mixture is good for very thin small cell detectors which need a fast gas.

7.3. $CF_4 + C_2H_6$ (60:40)

Of the three fast gases studied here, this gas mixture has the lowest operating voltage. For every other property, it lies between the $CF_4 + iC_4H_{10}$ and $CF_4 + CH_4$ values. It would only be a gas mixture of choice if there were problems with a detector holding voltage which were helped by being able to run a couple of hundred volts lower, although it could also be useful if a trade-off between radiation length and number of ionizations was desirable.

7.4. $CF_4 + CH_4$ (30:70)

This gas mixture is the fastest of the gas mixtures tested (about 20% faster than $CF_4 + iC_4H_{10}$ (80:20)). It has the best radiation length (3.7 times longer than for $CF_4 + iC_3H_{10}$ (80:20)). It is the least sensitive to soft photons (it sees about 0.37 times the rate that $CF_4 + iC_4H_{10}$ (80:20) sees). It has a long plateau for good operating efficiency, little variation in drift velocity as a function of electric field or proportion of quencher, and costs less than half what the CF_4 + iC_4H_{10} mixture does. On the down side, it has a relatively low number of primary ionizations per unit length. This value is still higher than for other standard drift chamber gases such as $Ar + CO_2$, and the gas mixture has been measured to be as sensitive to minimum ionizing particles as the other fast gases. (The value of the number of primary ionizations per cm may also be higher than quoted here, due to a possible systematic increase in the values in ref. [5] with respect to earlier values, and this reference did not quote a value for CF_4). $CF_4 + CH_4$ (30:70) may be operated efficiently at a slightly lower voltage than $CF_4 + iC_4H_{10}$.

This gas mixture is good for detectors which are not minimally thin, and have drift distances longer than one or two millimeters. For very large volume detectors it has many advantages over the $CF_4 + iC_4H_{10}$ (80:20) gas mixture.

Acknowledgements

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References

[1] J. Fischer et al., Nucl. Instr. and Meth. A238 (1985) 249.
[2] T. Yamashita et al., Nucl. Instr. and Meth. A283 (1989) 709.
[3] B. Jean-Marie et al., Nucl. Instr. and Meth. 159 (1979) 213.
[4] Particle Properties Data Booklet, Phys. Lett. B239 (1990).
[5] A.V. Zarubin, Nucl. Instr. and Meth. A283 (1989) 409.