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SOLENOIDAL DETECTOR NOTES

GAS STUDIES OF 4MM STRAW DRIFT CHAMBERS

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1) Introduction

We are investigating the the feasibility of continuous cathode drift chambers using aluminized mylar walls (straw chambers) at the SSC. Several drift chamber designs using small diameter (4 mm) straws of several meters in length have been proposed for SSC detectors. While a number of chambers have been built and run successfully at PEP and CESR, SSC will impose many new demands. The high crossing frequency of the SSC will a require using the very fastest gasses in these chambers. These gasses must be studied and understood. High instantaneous rates and high radiation backgrounds also will impose design requirements.

We have carried out a series of measurements on a six tube straw detector. We measured the efficiency, drift time, gain, and resolution of a number of gases in 4 mm diameter straws.

2) Description of detector

The drift chamber constructed for this series of tests was a six tube array with a length of 40 cm as shown in Fig. 1. The straws were fabricated by Precision Paper Tube Company., Rockville, Ill. Each straw consists of a layer of 0.5 mil polycarbonate film aluminized on the inside surface, covered by an 0.5 mil mylar film. The two films are wound with overlapping pitch and bonded by an application of glue between them. The resulting tube is gas tight, and robust enough to handle easily. The inside diameter is 0.157 in or 4.0 mm.

The anode is a gold plated tungsten wire 25 μm in diameter. It is tensioned and held centered by two Delrin pins inserted in each end of the straw. The Delrin pins are inserted into an aluminum gas manifold, which positions the wires and provides a robust mechanical support. The triangular gas manifolds sit in a precision V groove that is machined in a long aluminum bar. The V groove aligns both manifold ends and holds the straws in position. Mechanical tolerances for the construction were about ± 50 μm.

Two scintillators positioned above and below the the straw tube array were used to define the trigger for a cosmic ray. The dimensions were 5 cm x 33 cm for the lower scintillator and 23 cm x 33 cm for the upper one (see Fig. 1)

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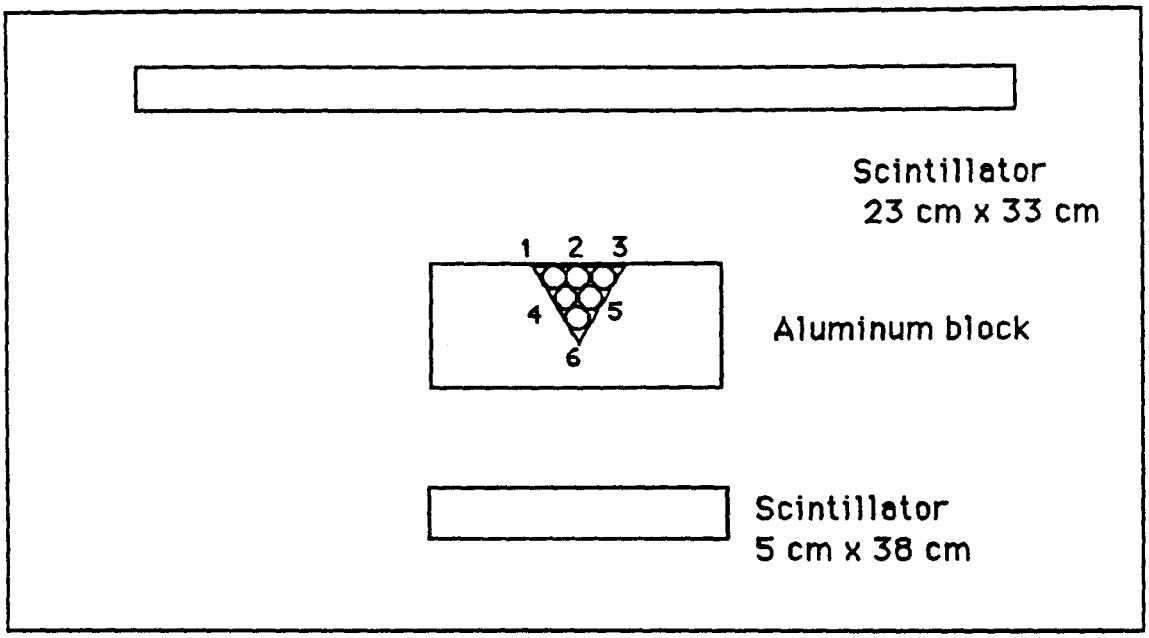

Fig 1 Test array of six straws with cosmic ray trigger

3) Electronics

A negative high voltage supply was used to establish the voltage difference between the cathode surface and anode wire. The anode wire signals were then taken out directly without capacitive coupling. A combination preamplifier-discriminator with typically a 600 μV threshold into 500 Ω. was used to form discriminated signals for the TDC. The coincidence between the two scintillators was used to start a LeCroy TDC (200ps/div) and the discriminated anode signals were used for a stop. The data were collected locally on an LSI-11 and transfered to a VAX system for later analysis.

4). Efficiencies of 4 mm Straw Tubes

We anticipate that with typical ionization constants that there will be about 40 electron-ion pairs produced by a minimum ionizing particle in a 4 mm straw. Electron attachment and lower intrinsic ionization may lower this number for many gasses. One of the first measurements made was a plateau curve for a number of candidate gasses . The following gas mixtures were used in cosmic ray tests: Argon-Ethane(50%), HRS gas {Ar-CO_2(10%)-CH_4(1%)}, CF_4(99.9), and CF_4-Isobutane(20%, 10%, and 5%). These were measured at 600μV into the 500Ω input resistance of the preamp, which was the lowest threshold we could run without noise in our setup.
The efficiency of the straws was determined by looking at the middle layer of straws of the array of 6 straws.(see Fig 1) . It is defined as the ratio of the number of 2*(4 or 5)*6 hits to the number of 2*6 hits. Any cosmic ray going through straws 2 and 6 must also go through either straw 4 or 5 and thus the average efficiency of the middle layer straws is defined as:

$$\varepsilon = \frac{2*(4 \text{ or } 5)*6}{2*6}$$

The data for Ar-Ethane (50%) and for HRS gas are show in Fig 2. HRS gas did not plateau before the tubes began drawing current above 1350 V. Ar-Ethane(50%) reached 95% efficiency and appeared to plateau before 1700 V where it began drawing excessive current

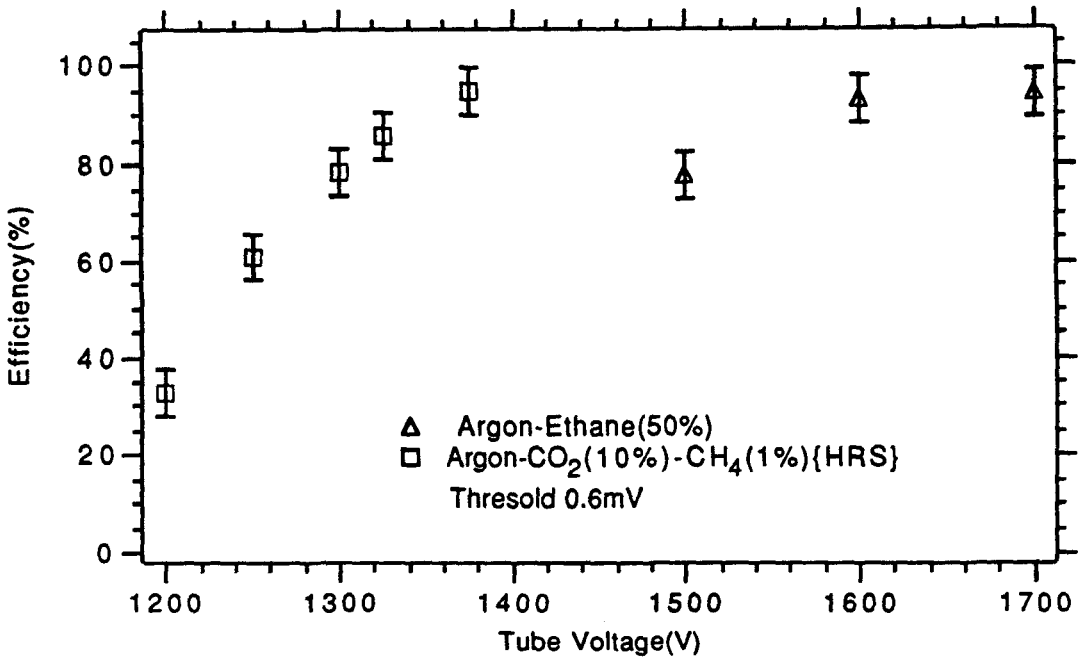

Fig. 2 Plateau curves

The efficiency measurements for the various CF_4 mixtures is shown in Fig.3. The pure CF_4 mixture does not reach full efficiency by 2400 volts.. It is likely that this is due to electron attachment. As has been reported in previous studies [1] the cross section for electron attachment is a resonant reaction. Small fractions of a quenching gas such as Isobutane cools the electrons below the threshold for attachment. Of the mixtures tested 20% Isobutane performed the best, reaching an efficiency of 98%. We expect about 1% inefficiency is due to the 40 microns of wall thickness. The remaining 1% can be ascribed to a 40 micron region near the wall where the path length is less than 300 microns and the cluster statistics are poor.

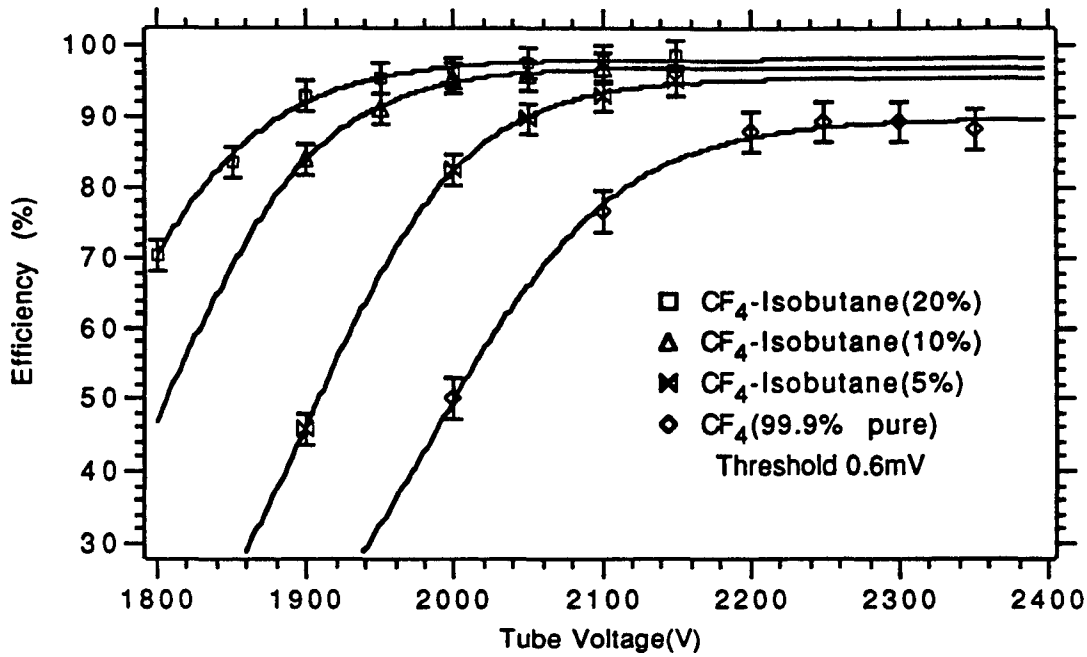

Fig. 3

The efficiencies for CF_4 and CF_4-Isobutane were fit to the function :

$$\varepsilon(V)=\frac{\varepsilon_0}{1+e^{\frac{-(v-a)}{b}}}$$

The values for ε_0, the asymptotic value of the efficiency, are:

CF_4 (99.9%)	89.8%
CF_4-Isobutane(20%)	98.2%
CF_4-Isobutane(10%)	97.1%
CF_4-Isobutane(5%)	95.5%

We also have made a number of more incomplete (quick) measurements on several nonflammable gas mixtures. These are shown in Fig. 4. HRS gas mixed with 50% CO_2 shows an efficiency of 95% and a plateau point near 2000 Volts. Argon-CF_4 (50%) mixture reaches only 87% before drawing current, and CF_4-CO_2(15%) has an efficiency of 85% at 2250 Volts.

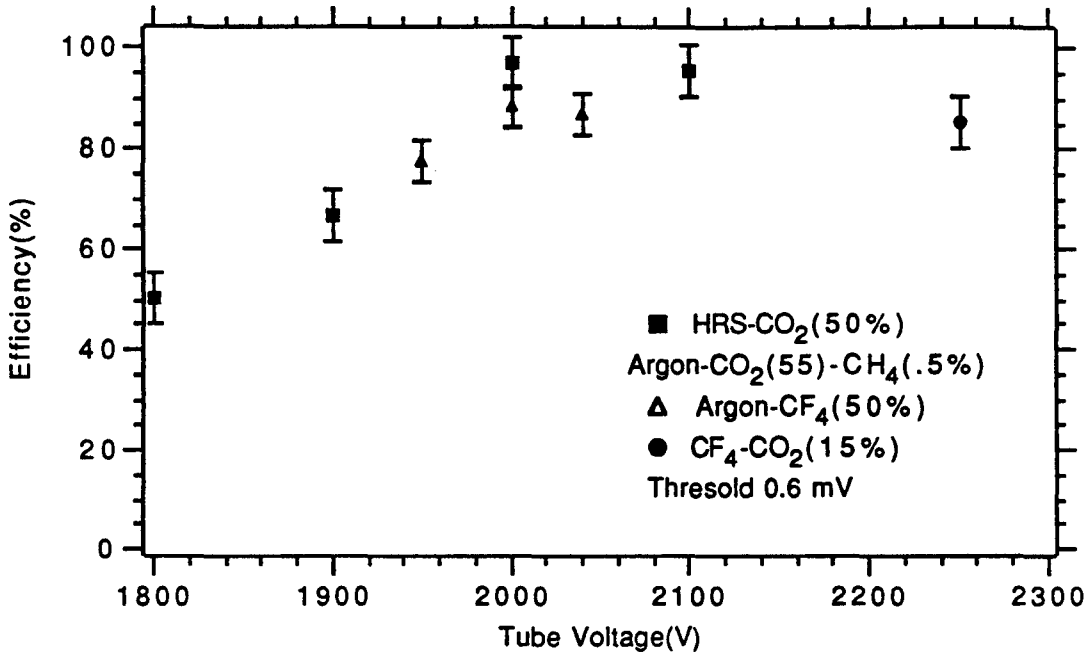

Fig. 4 Efficiency measurements

5) Gain of 4 mm Straw Tubes

The gain of the straw chambers was measured for four different gas mixtures: Ar-Ethane(50%), CF_4(99.9) and CF_4-Isobutane(20% and 10%). A Fe^{55} source was used to produce at constant pulse height signal. The Fe^{55} x-ray has an energy of 5.9 keV. Assuming an average energy to produce an ion-electron pair of 24.5 eV [2], the primary ionization of the xray from Fe^{55} gives 240 electrons in Ar-Ethane. The total charge from each x-ray interaction was measured with a charge sensitive amplifier with an integration time of about 10 μsec, followed by a Ortec model 575 amplifier and then displayed on an Ortec 7100 multichannel analyzer. A calibration of the charge was obtain with a pulser and oscilloscope. The gain for CF_4 and CF_4-Isobutane mixtures was calculated assuming the same primary ionization as Ar-Ethane(50%).[3] The charge and gain are shown in Fig. 5. Notice, in particular, that the gain of the CF_4-isobutane (20%) mixture is about 5×10^4 at 2000 V (at the beginning of the efficiency plateau).

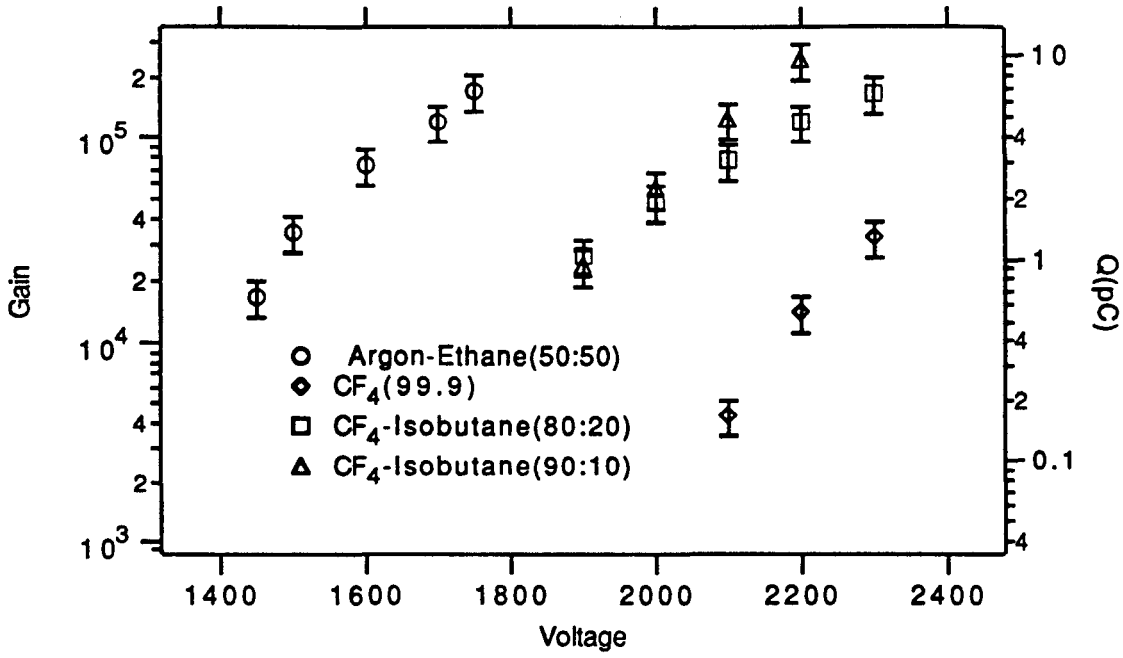

Fig. 5 Gain in 4mm straw with 25 μ sense wire

6) Resolution

The resolution of the middle layer of straws was measured with cosmic rays using the same 6 straw setup described previously. A track was fitted through straws 2 and 6.(see Fig. 1) The distribution of the residual between the track fitted and the actual drift distance in the central two straws (4 and 5) was calculated, displayed, and fitted with a gaussian.The standard deviation of this distribution is directly related to the intrinsic resolution of each straw. The resolution was measured for all the gasses discussed in Sec. 2.

The resolutions for Ar-Ethane(50%) and HRS gas are shown in Fig. 6. Both gasses showed improvement in resolution as the voltage was increased, but the rather poor values (150-200 μ) probably are due the effects of poor cluster statistics which is reflected in the efficiency. Improvements in our drift time model for the gasses might also improve some of the resolution effects.

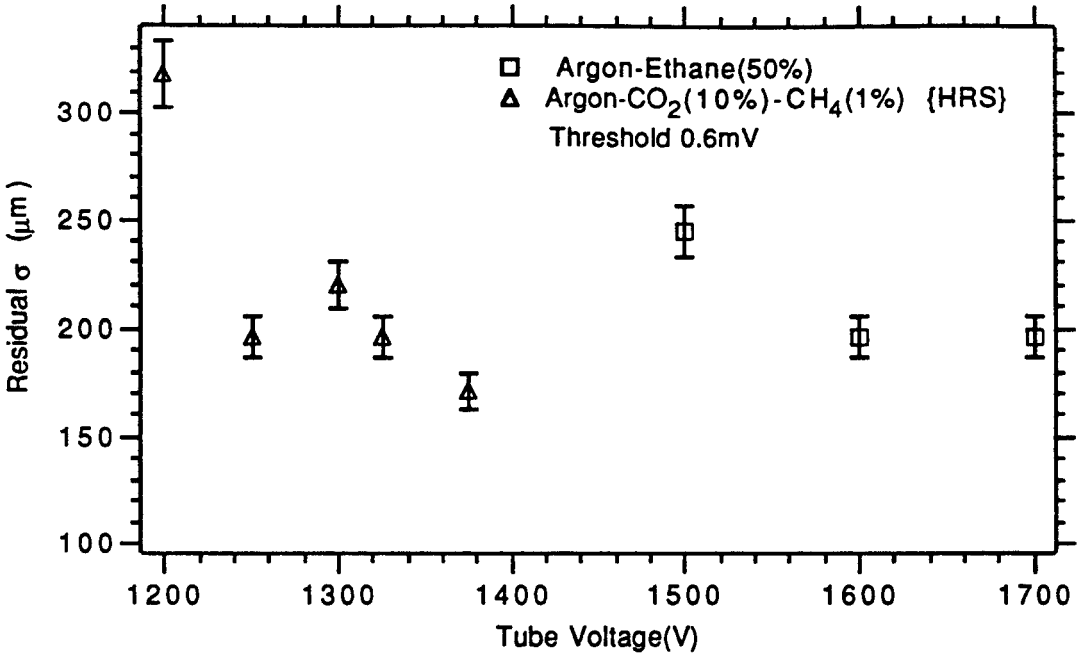

Fig. 6. Resolution measurements for Ar-Ethane(50%) and HRS gas

The resolutions for CF_4 and CF_4-Isobutane(20%-10%-5%) are shown in Fig. 7, 8, and 9, respectively. Due to the known problems with electron attachment in pure CF_4 the resolution is expected to be poor. The plotted data of pure CF_4 represent the average of two points with the horizontal error bar representing the width of the average.The resolution of CF_4-Isobutane (20%), measured to be about 100 μm on the plateau, was the smallest of the CF_4 mixes . We believe that part of the relative performance of the CF_4 to the other gasses is the quality of the drift velocity model we used for CF_4.

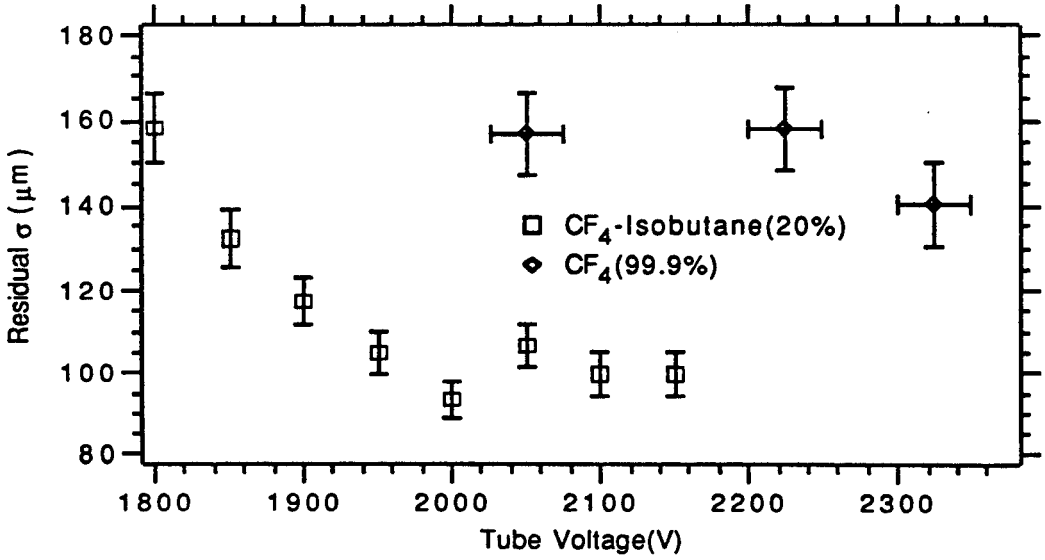

Fig. 7. Resolution for CF_4-Isobutane(20%) and CF_4

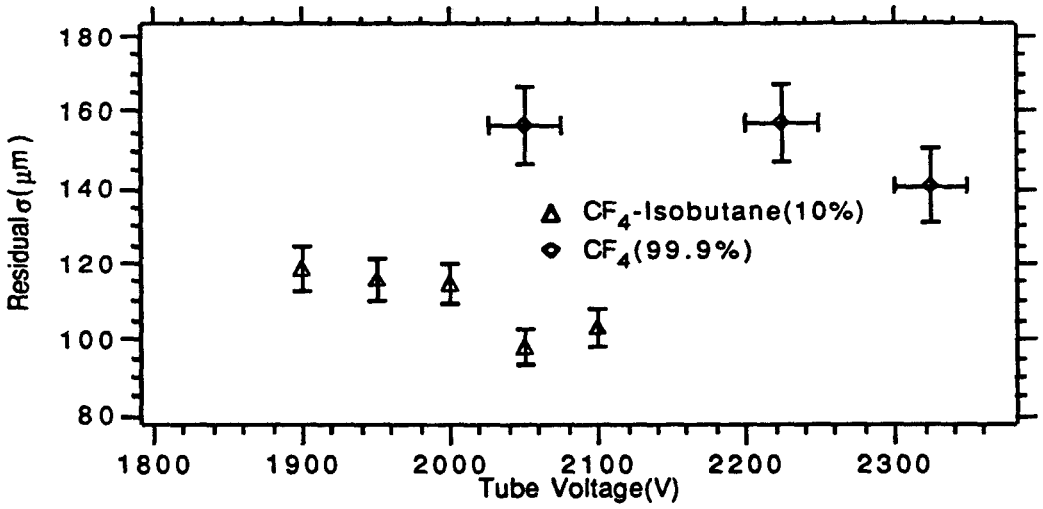

Fig. 8 Resolution for CF_4- Isobutane(10%) and CF_4

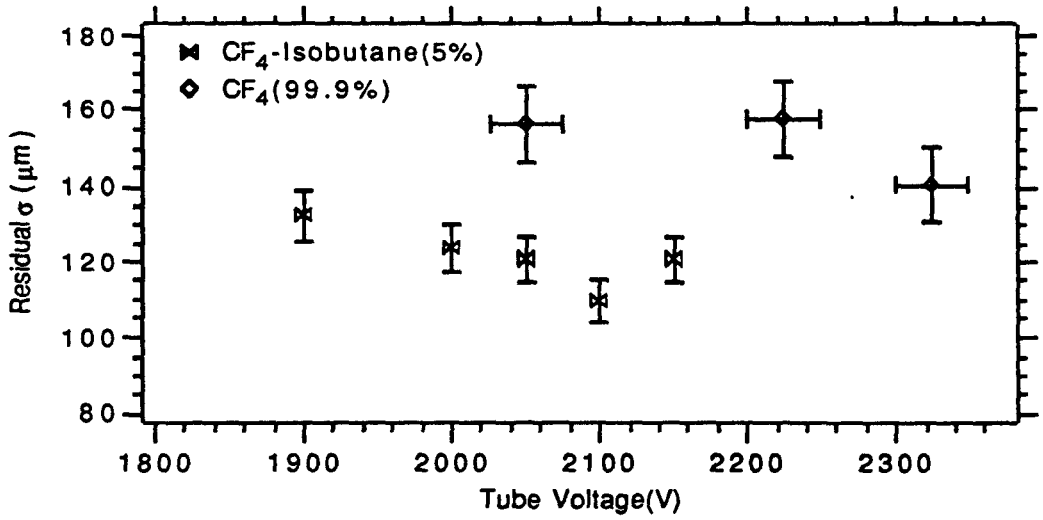

Fig. 9 Resolution for CF_4-isobutane (5%) and CF_4

7) Drift Velocity

The short time (16 nsec) between bunch crossings at the SSC dictates the use of a gas with a high drift velocity. We have looked at a number of gasses which might have the necessary speed. Using the previously described chamber, a rough estimate of the drift velocity can be made by measuring the full width of the TDC distribution with a cosmic ray trigger. The full widths of traditional gasses like Ar-Ethane(50%) and HRS gas are shown in Figs. 10 and 11. They were measured to have drift times of 40 nsec for 2 mm drift. This is probably too slow to make them good choices for the SSC.

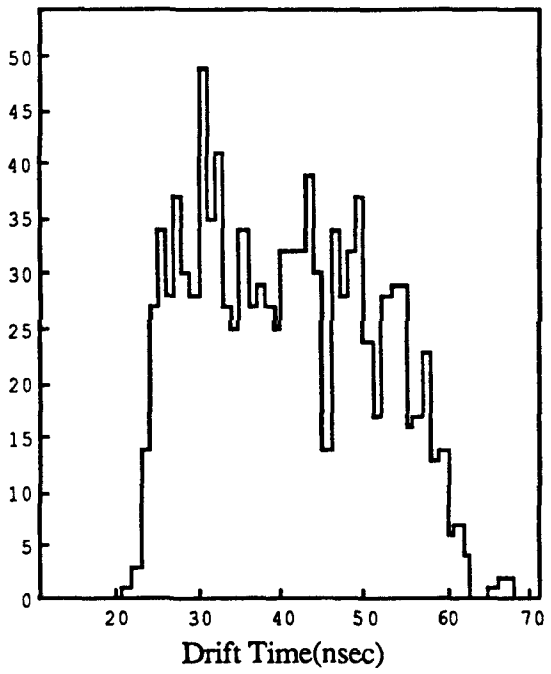

Fig. 10 Ar-Ethane(50%)
1700 V Threshold 0.6 mV

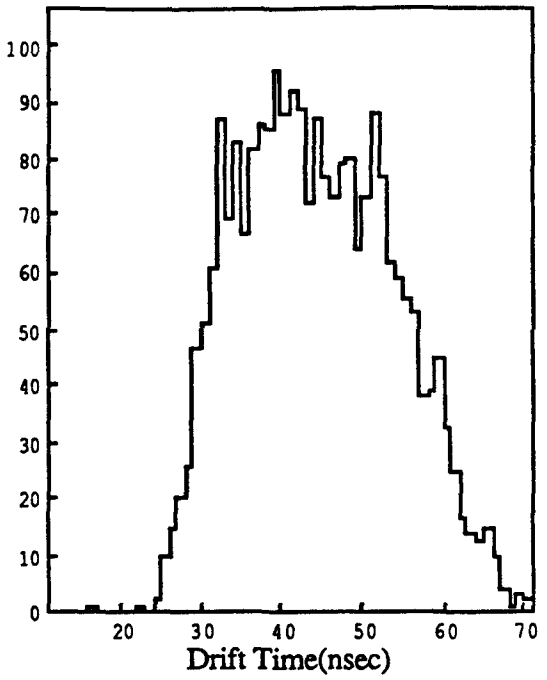

Fig. 11 HRS (Ar-CO_2(10%)-CH_4(1%))
1350 V Threshold 0.6mV

The full widths of CF_4 and CF_4-Isobutane(20%, 10%, 5%) range from 18 to 22 nsec for a 2 mm drift, making any of these gasses suitable for the SSC. They are shown in Figures 12, 13, 14 and 15. We do not yet understand in detail the shape of these distributions.

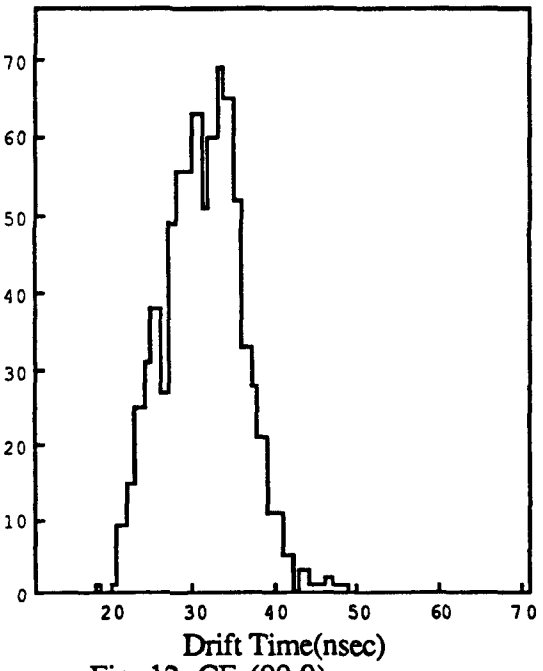

Fig. 12 CF_4(99.9)
2300 V Threshold 0.6 mV

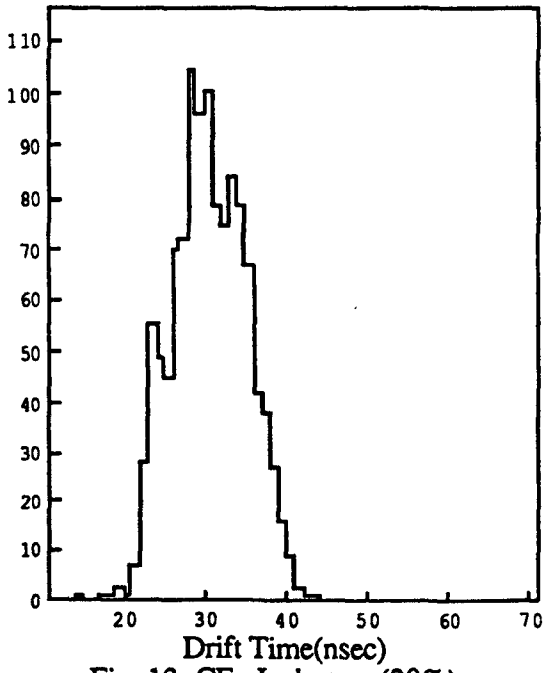

Fig. 13 CF_4-Isobutane(20%)
2100 V Threshold 0.6mV

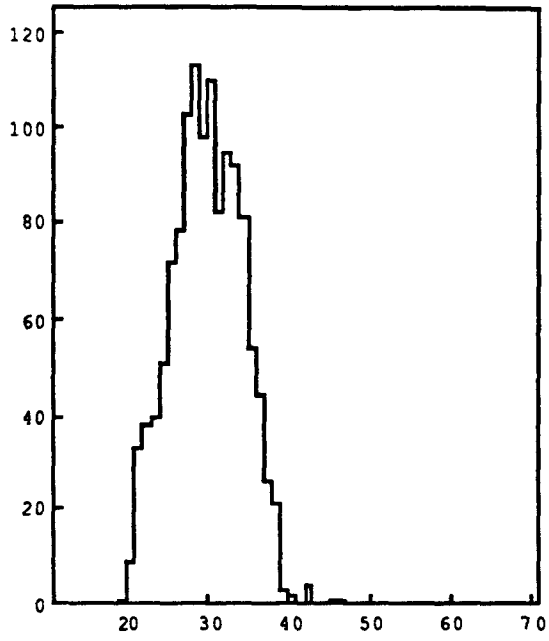

Fig. 14 CF_4-Isobutane(10%)
2300 V Threshold 0.6 mV

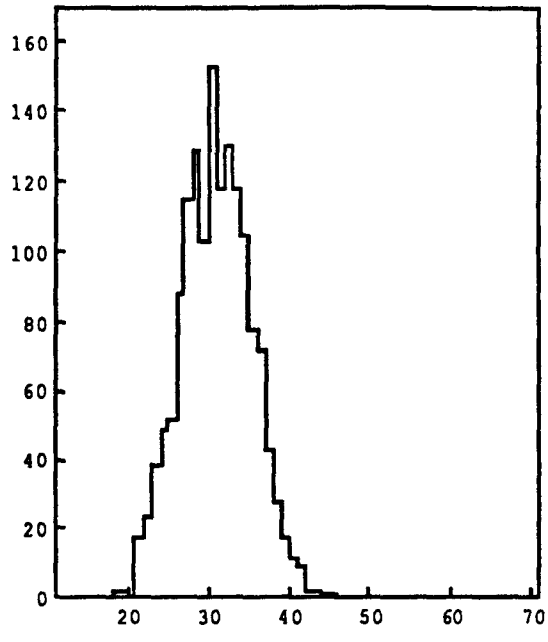

Fig. 15 CF_4-Isobutane(5%)
2100 V Threshold 0.6mV

In addition to the gasses already tested we measured drift velocities. for several other gas mixtures. However, the exact compositions for optimum operation have not yet been determined. One of these gasses tested was HRS-CO_2(50%) this mix was an approximation to Ar-CO_2(50%). As can be seen in Fig. 16 this gas has a long tail which may in part be due to its unsaturated drift velocity.
Another $C0_2$ mix we looked at was CF_4-CO_2(15%). As can seen in Fig 17 this gas has a full width of 28 nsec but like Ar-CO_2(50%) it also has some events at longer drift time. We also measured Ar-CF_4(50%). This gas has a fast drift time of 24 nsec as can be seen in Fig 18. However this gas didn't plateau, as was shown in Fig 4.

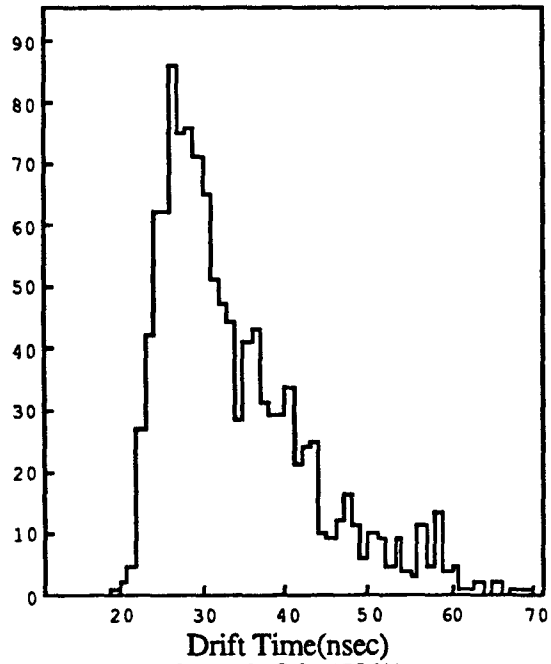

Fig. 16 HRS-CO_2(50%)

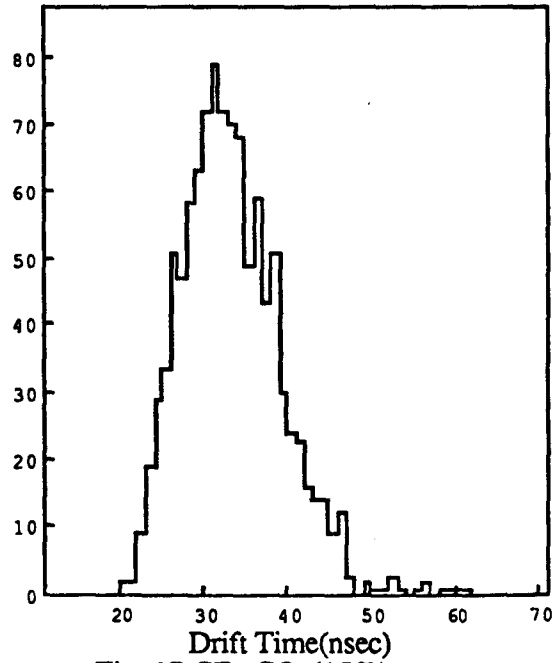

Fig. 17 CF_4-CO_2(15%)

2100 V Threshold 0.6mV

2250 V Threshold 0.6 mV

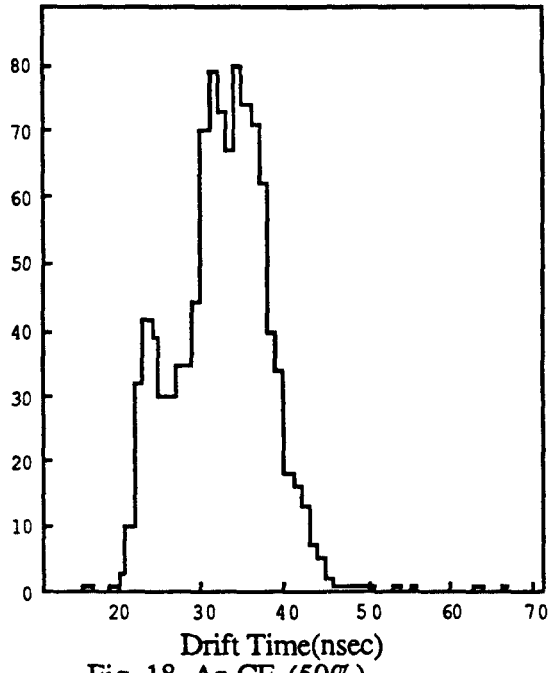

Fig. 18 Ar-CF_4(50%)
2040 V Threshold 0.6mV

8.) Conclusions

We have measured several basic properties of 4 mm diameter straw drift tubes. A gas mixture of CF_4 -Isobutane (20%) would appear to satisfy all the requirements for a fast detector at SSC. This mixture has full eficiency at 2000 V, a gain of 5×10^4, an intrinsic resolution of about 100 μ, and a drift time of less than 20 ns in a 4mm diameter straw. However, we would much rather use a nonflammable gas in the tracking system. We will continue to explore other gas mixtures.

References:

1. J. Fischer, et .al., Nuclear Instruments and Methods A238(1985) 249