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TESTS OF SMALL PROPORTIONAL TUBES WITH CF_4–HRS GAS MIXTURES

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We have investigated the operating characteristics and drift times of small proportional tubes (active width = 3.17 mm) containing mixtures of CF_4 and HRS gas (89% Ar, 10% CO_2, 1% CH_4). As the fraction of CF_4 is varied from zero to 100%, maximum drift times decrease from about 32 to 16 ns. The operating voltage increases and the energy resolution worsens significantly with increases in the CF_4 component.

1. Introduction

The proposed Superconducting Super Collider (SSC) presents a very challenging environment to the designers of experiments [1]. At the expected luminosity of 10^{33} cm^{-2} s^{-1} the inelastic collision rate is about 10^8 per second with each event generating on average about 100 secondary particles. Three basic problems must be addressed when planning for SSC experiments: rates, radiation damage, and the implementation of suitable triggers. We believe it will be exceedingly important to reduce the spread in signal arrival times within an event down to a level where event pileup is a manageable problem. Since the average time between events is 10 ns, it is desirable that the time smearing of signals approach this value.

Proportional wire chamber (PWC) technology has been an essential component of many high energy physics experiments. Indeed, nearly all tracking of charged particles has been done with this versatile detection method. PWCs have also found major application in both electromagnetic and hadronic calorimetry. Such calorimetry will play a central role in most SSC experiments. Wire chambers have a number of properties which make them attractive for SSC detectors. Their application to apparatus with large areas or volumes is comparatively inexpensive and their construction is generally straightforward. Unlike scintillating or semiconducting materials, wire chambers are rather immune to radiation damage when not powered. This is a potential advantage during SSC machine development and beam manipulations. However, to be suitable as SSC detectors, wire chambers must satisfy certain radiation or "ageing" requirements [2] and they must allow fast signal collection times as indicated above. These requirements lead naturally to the consideration of chambers with small cell diameters and the use of gases with high drift velocities.

In our judgement ease of construction is an important factor for detector systems that may contain tens of thousands of proportional cells. This effectively places a lower limit on the cell diameter of about 3 to 4 mm. This follows from the observation that large chamber systems are best operated at atmospheric pressure where the typical number of ionization electrons per mm of track length is about ten. Moreover, the mechanical problems of handling cells much smaller than 3 mm are formidable. Mechanical considerations also lead one to a choice of sense wire diameters that are not too small. Operating voltages increase only slowly with diameter whereas the mechanical strength varies as the square of that dimension. We have found from experience that sense wires with a diameter of 38 μm give a good compromise between operating characteristics and handling ease. With these factors in mind, we have chosen to test PWCs with an interior cell width of 3.17 mm and with a sense wire diameter of 38 μm.

The choice of proportional counter gas involves a number of considerations. The gas must give a sufficient number of ionization electrons, quench avalanche photons to ensure stable operation at reasonable gain, exhibit good "ageing" properties and yield high drift velocities for operation at SSC. Regarding this last point, research by others [3–8] has shown that drift velocities above 10 cm/μs can be obtained with gas mixtures containing carbon tetrafluoride (CF_4). This is about a factor of 2 higher than the drift velocity in common mixtures of argon and CO_2 or hydrocarbons.

There is one additional consideration regarding the choice of proportional counter gases for SSC detectors and especially SSC calorimeters. Hadronic showers in such calorimeters will lead to a large flux of low-energy

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(~ 1 MeV) neutrons which can interact within and outside the calorimeter. Elastic scattering of these neutrons with the protons of any hydrogen component of the PWC gas can result in signals equivalent to those from several hundred minimum-ionizing particles. Such large signals can cause crosstalk problems in tracking chambers or give erroneous energy measurements in calorimeters. For this reason it may be important to minimize or avoid the use of hydrogen in the gas or construction materials of SSC wire chambers.

A gas mixture which minimizes the hydrocarbon content and which has shown good operating characteristics is "HRS gas" consisting by volume of 89% argon, 10% carbon dioxide and 1% methane [9]. The small amount of methane helps to absorb avalanche photons at wavelengths around 1200 Å where carbon dioxide is relatively transparent. Because of its minimal hydrogen content, HRS gas should be rather immune to low-energy neutrons while also being safe to handle in terms of fire hazards.

In this note we report results from tests of small proportional wire tubes operating with mixtures of CF_4 and HRS gas [10]. The CF_4 is a non-flammable, non-toxic gas which increases the drift velocities markedly. The motivation for these tests is the establishment of parameters for the design of possible SSC prototype wire chambers.

2. Experimental setup

The test wire chamber consists of eight identical square brass tubes arranged in a plane as shown in fig. 1 The length of these tubes is 74.6 mm, the outer width is 3.97 mm, and their wall thickness is 0.40 mm. The maximum drift distance for ionization electrons from perpendicularly incident tracks is therefore 1.59 mm. Each tube contains a 38 μm diameter gold-plated tungsten wire which is held and centered by a small brass tube inserted into a G-10 fiberglass plug at each end of the chamber tube. Small holes are drilled into the body of each of the eight proportional tubes for gas inlet and outlet and for allowing exposure to an ^{55}Fe X-ray source.

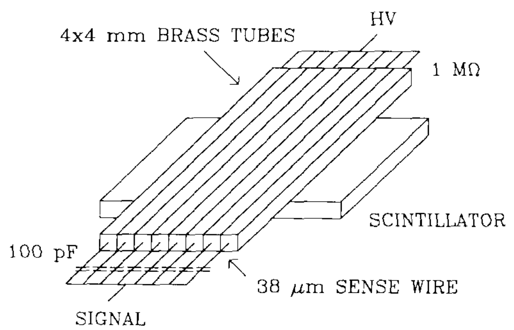

Fig. 1. Schematic of the proportional wire chamber (PWC) and scintillator used for cosmic ray triggers.

At one end of each tube positive high voltage is transmitted to the sense wire through a 1 MΩ resistor. (The brass body of the chamber is held at ground potential.) At the other end signals are taken out via a 100 pF decoupling capacitor. For the purposes of this test all eight tubes were ganged together at both the signal and high voltage ends so that the chamber was operated as a single-channel device.

For measurements of rates and drift times, the signals from the chamber were sent to a LeCroy LD604 amplifier–discriminator chip with an input termination of 100 Ω and a threshold of about 0.4 mV. When measuring pulse height spectra with the ^{55}Fe source, the chamber signal was routed directly to a Quantum 8 pulse height analyzer [11]. Drift time measurements were made with cosmic rays for which the start times were determined with a scintillator placed directly below the chamber as shown in fig. 1. The time interval between the scintillator and chamber signals was converted to a pulse height using a Canberra model 2043 time analyzer. The output from this time analyzer was then displayed with the Quantum 8 pulse height analyzer.

HRS gas and CF_4 were mixed from separate bottles using flow meters. Care was taken to insure that the total flow of the mixed gas was the same for all mixtures to avoid possible systematic rate-dependent effects when comparing results from different mixtures. This total flow rate was 0.5 ft^3/h

3. Results

The proportional wire chamber was tested with four gas mixtures consisting of 100% HRS, 20% CF_4–80% HRS, 50% CF_4–50% HRS, and 100% CF_4 where the percentages are by volume. The first step in testing the chamber was the determination of operating voltages for each of these mixtures. Fig. 2 shows the coincidence rate from cosmic rays of the scintillator and chamber signals as a function of chamber voltage. Fig. 3 shows the singles rate from just the chamber versus the applied voltage. In this figure a sudden rise of the singles rate is observed at 1500 V for 100% HRS, 1875 V for 20% CF_4–80% HRS, 2250 V for 50% CF_4–50% HRS, and 2725 V for 100% CF_4. At these voltages the chamber signals become very large and regenerative causing multiple firing of the amplifier–discriminator chip. These voltages are close to the point of spontaneous chamber breakdown. Comparison of figs. 2 and 3 indicates that the width of the voltage plateau for good efficiency varies from about 75 V with 100% HRS to about 200 V for 100% CF_4.

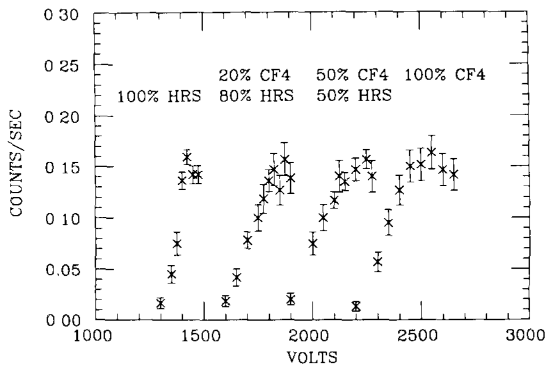

Fig. 2 Coincidence rate from cosmic rays of PWC and scintillator signals as a function of PWC voltage.

The relative gain of the chamber was measured by observing the peak from the 5.89 keV X-ray line of an ^{55}Fe source. This is displayed in fig. 4 as a function of chamber voltage. The peak from this source is clearly resolved in all gas mixtures except for 100% CF_4 for which the ^{55}Fe gives just a very broad, smeared out distribution. The ^{55}Fe spectra for the other three gas mixtures are shown in fig. 5 at voltages giving similar gain. The resolution clearly worsens with increasing fractions of CF_4, an effect already established in ref. [4].

The drift time distributions from cosmic rays, which illuminate the chamber area uniformly, are shown in fig. 6. The operating voltages indicated in the figure correspond to approximately equal chamber gain for the different gas mixtures. We also recorded drift time distributions at somewhat lower and higher voltages and found the widths of these distributions essentially independent of voltage. The width of the drift time range which encompasses 90% of the chamber signals in each distribution is given to the nearest ns by:

100% HRS:	32 ns,
20% CF_4–80% HRS:	22 ns,
50% CF_4–50% HRS:	19 ns,
100% CF_4:	16 ns.

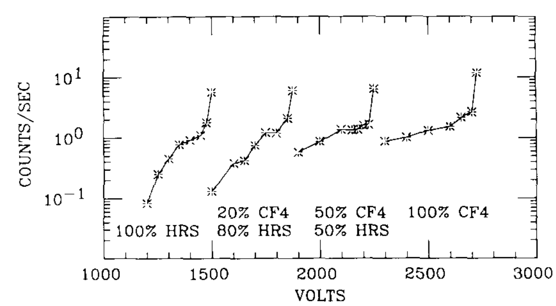

Fig. 3. Singles rate of the PWC as a function of voltage.

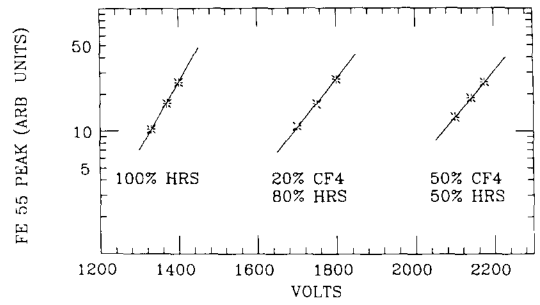

Fig. 4. Measurement of relative gain as a function of voltage using the peak from the 5.89 keV X-rays of an ^{55}Fe source

The factor of 2 decrease in drift times with increasing CF_4 fraction is consistent with the observations in refs. [3–8].

We note that for uniform illumination of the chamber as in fig. 6, the height of the drift time distribution at a particular value of the drift time is proportional to the drift velocity at the corresponding position in the cell. As the fraction of CF_4 is increased, one observes a clear asymmetry in the drift time distribution for short and long drift times. The variation in the corresponding

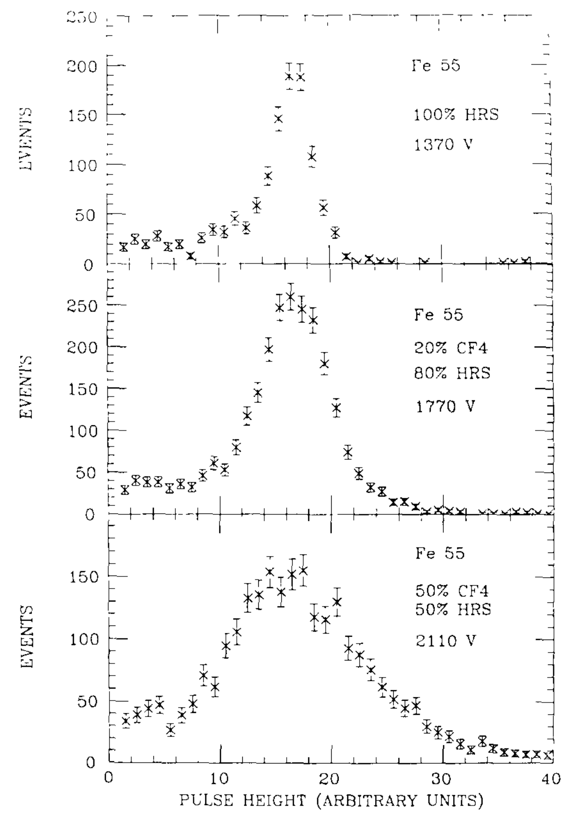

Fig. 5. Pulse height spectra from ^{55}Fe as measured with the PWC.

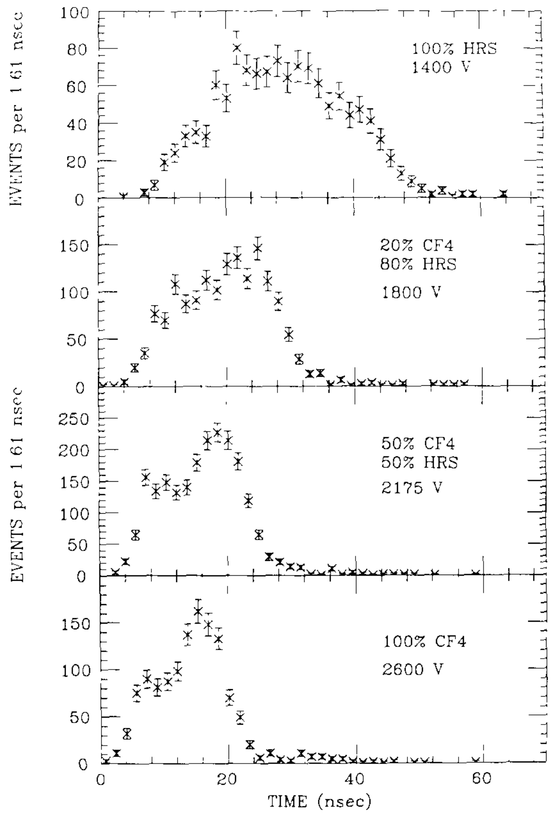

Fig. 6. Drift time distributions from cosmic rays as measured with the PWC for several gas mixtures.

drift velocities is roughly a factor of 2 when the gas is 100% CF_4. When operating the chamber at 2600 V and atmospheric pressure the ratio of electric field to pressure, E/P, varies from about 4.9 V cm^{-1} $Torr^{-1}$ at the tube wall to 400 V cm^{-1} $Torr^{-1}$ at the sense wire surface

4. Conclusion

Motivated by a desire to find proportional chamber parameters suitable for use at the SSC, we have tested 3.17 mm wide proportional tubes with several mixtures of CF_4 and HRS gas (89% argon, 10% CO_2, 1% CH_4). As the fraction of CF_4 is varied from zero to 100%, the maximum drift times decrease from about 32 to 16 ns corresponding to average drift velocities of 5.0 to 10 cm/μs, respectively. HRS gas was chosen for admixture since its low hydrogen content insures fire safety and promises relative immunity to large pulses from interactions with low-energy neutrons. The operating voltage increases and the energy resolution worsens with increases in the CF_4 fraction. Good efficiency was obtained with all gas mixtures. The voltage plateau increases as the CF_4 component increases. A final judgement of the suitability for SSC use of PWCs as tested here requires further systematic studies of rate capabilities and of chamber degradation with radiation exposure.

Acknowledgements

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[11] Manufactured by Nucleus, Inc