

INVESTIGATION OF LONG DRIFT CHAMBERS FOR A NUCLEON-DECAY DETECTOR*

L. E. Price, J. Dawson, D. Ayres, and R. St. Denis[†]

ANL-HEP-PR--81-46

Argonne National Laboratory

DE83 009446

Argonne, IL 60439

The use of long drift chambers for a nucleon-decay detector is discussed as a means of achieving a detector with very fine tracking, but with a modest number of readout channels. Strategies for reducing the attenuation of drifting electrons are considered, particularly the necessity of shaping the electric field to reduce the effects of diffusion and of nearby grounded conductors. Measured results are presented for a chamber with 1 cm drift gap and 50 cm maximum drift distance. The measured attenuation is 12%.

the gas be substantially free of electronegative components which will tend to attach drifting electrons and hence prevent them from drifting to the sense wire. The most likely such contaminant is oxygen, which can enter the chamber from the atmosphere, either through small leaks in the chamber or by diffusion through thin walls. We have measured the attenuation as a function of oxygen concentration and find for our conditions that oxygen must be kept below 10 ppm (See Section III).

I. Introduction

This paper describes the development of long drift chambers for a proposed nucleon decay detector¹. The detector will be built by a collaboration from the University of Minnesota, Argonne National Laboratory, and Oxford University in the Soudan iron mine in northern Minnesota. The detector was conceived as having very fine tracking (1 ionization measurement for each 5 gm of detector) and an average density of at least 2 gm/cm³. With a planned total mass of 1000 metric tons, the detector requires the ability to read out more than 10⁸ distinct positions. In order to have a practical design with drastically fewer readout channels, the idea was adopted to use drift chambers with drift distances of order 1 m. A drift distance of 50 cm was finally chosen on the basis of the linear extent of a nucleon decay event, which is typically 1 m in the proposed detector. Most events will then have at least one track that crosses from one drift chamber to the next, providing a constraint by which a starting time for the drifting can be fixed. Several possible drift structures with these general dimensions are being investigated by the collaboration. The one reported on here uses planar drift chambers with a drift gap of 1 cm and a maximum drift distance of 50 cm.

In Section II of the paper, we discuss some general considerations for practical drifting over long distances in a relatively small gap. Section III contains the design of our test cell and the measured results. A brief summary is presented in Section IV.

II. General Design Considerations

A. Attenuation of Drifting Electrons

Three parameters chiefly determine the fraction of produced ionization electrons that is collected after drifting from a given distance. The three are gas purity, electric field (or drift velocity) and electron temperature. The latter affects diffusion of drifting electrons and is itself a function of gas composition and electric field.

The main consideration about gas purity is that

Sensitivity to electronegative gases can be reduced by increasing the drift velocity through the choice of gas mixture and electric field. Drifting electrons then spend less time exposed to the possibility of attachment. A high drift velocity, however, is generally associated with high electron temperature and hence large diffusion of the drifting electrons. Further, large electric fields may require impractically large applied potentials when the drift distance is large. In many applications a large drift velocity is desirable to reduce collection time for an event and hence avoid confusion between successive events, but this is not an important consideration for nucleon decay experiments. Thus we have chosen the gas and electric field to minimize diffusion.

Diffusion of the drifting electrons is governed by the equation²

$$\partial \rho / \partial z = (k T_e / e E) (\partial^2 / \partial x^2 + \partial^2 / \partial y^2) \rho$$

where ρ is the electron density, T_e is the electron temperature, k is the Boltzmann constant, e is the electron charge, and we have chosen the drift direction to be parallel to the z axis. The electron temperature has been measured for a wide variety of gases and electric fields². It is bounded from below by the temperature of the gas (0.025 eV). Of the commonly-used additions to argon for drift chambers, the lowest electron temperatures at practical drift velocities are given by CO₂. Figure 1 plots the measured electron temperatures in CO₂ as a function of the reduced electric field E/p .³ In Figure 2 these measurements are used to predict the diffusion after 8.5 cm drift in 0.2 atm of CO₂ and compared with measured values in a gas composed of 80% argon, 20% CO₂. The fair agreement shows that the argon plays little role, as is to be expected because the cross section of argon for electrons at thermal energies is almost zero. On the right hand axis of the plot, we have scaled the diffusion to that expected after 50 cm of drift. Since the gas we have used in the test chamber described below is 90% argon and 10% CO₂, the amount of diffusion will rise more sharply for electric fields above 10 kV/m. Thus the minimum diffusion will be about 1.5 mm, so that we can expect a loss from diffusion into the walls of the chamber of about 30% in

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an uniform electric field parallel to the walls.

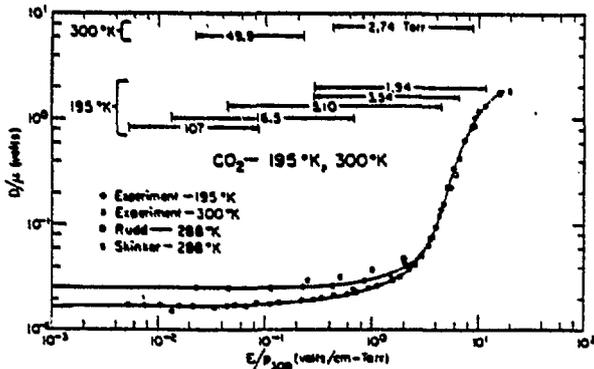


Fig. 1. Electron temperature kT_e in CO_2 as a function of the reduced field E/p at 195°K and 300°K, from Ref. 3. The electron temperature is essentially the thermal temperature for E/p below 1 volt/cm-Torr, but grows rapidly for higher values of E/p .

B. Electric Field Shaping

From the above discussion, we see that diffusion produces a large attenuation of the drifting electrons, comparable to the size of fluctuations in ionization energy loss from minimum ionizing particles, which have a σ of about 40%. The effect of diffusion can, of course, be reduced by using a larger drift gap than 1 cm, but this expedient would reduce the average density of the detector. Another avenue, the one we have adopted, involves the use of a focusing electric field,⁴ i.e. the field at the walls of the drift gap is given a small component into the wall (the force on electrons is then toward the center of the gap), so that drift electrons diffusing toward a wall are made to drift away from the wall instead of being lost on it. The solution of Laplace's equation for the potential which produces a constant

angle of the field at the wall is

$$\phi = \phi_0 + a e^{-bz} \cos(by)$$

where $z = 0$ is the position of the sense wire, and $y = 0$ is the center of the gap. Then

$$E_z = ab e^{-bz} \cos(by)$$

$$E_y = ab e^{-bz} \sin(by)$$

i.e. a field which increase exponentially along the drift path. The angle of the field at the wall is then given by

$$\tan(\theta) = E_y/E_z = \tan(by_{\max})$$

If we choose the angle to restore diffusion of 0.5 mm, which occurs for Δz of 3 cm, we need an angle of 0.016, or $b = 0.03/\text{cm}$, since $y_{\max} = 0.5$ cm. The increase in field along the 50 cm drift path is then a factor of

$$\exp(50 \text{ cm} \times 0.03/\text{cm}) = 4.5$$

Two field configurations were used in our tests: a constant field and an exponential field that increased by a factor of 4.0.

We next consider the configuration of electrodes used to apply the electric field. The standard arrangement of conducting strips on an insulating surface cannot be used for the planned detector, because the chambers are surrounded by steel plates at ground potential. The resulting distortion of the electric field is illustrated in the equipotential plots of Figure 3a and 3b. This distortion of the electric field by the steel plates acting as unwanted electrodes can be avoided by making the surface between conducting strips and resistive instead of insulating, so that the potential is defined everywhere on the surface and not just on the discrete strips. For this reason, we have coated the insulating surface with resistive ink⁵ with surface resistivity $\sim 10^{10}$ ohms per square.

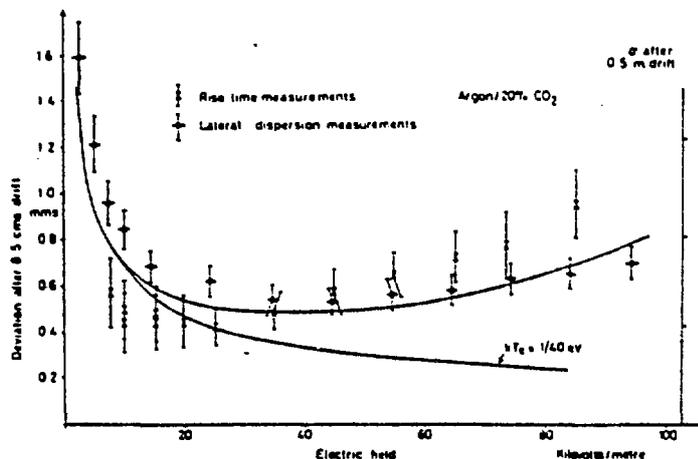


Fig. 2. Calculated and observed effects of diffusion after drifting 8.5 cm in 80% argon--20% CO_2 , from Ref. 2. The upper curve is calculated for 0.2 atm CO_2 , ignoring the argon. On the right hand axis, the diffusion has been scaled to that expected for 50 cm drift.

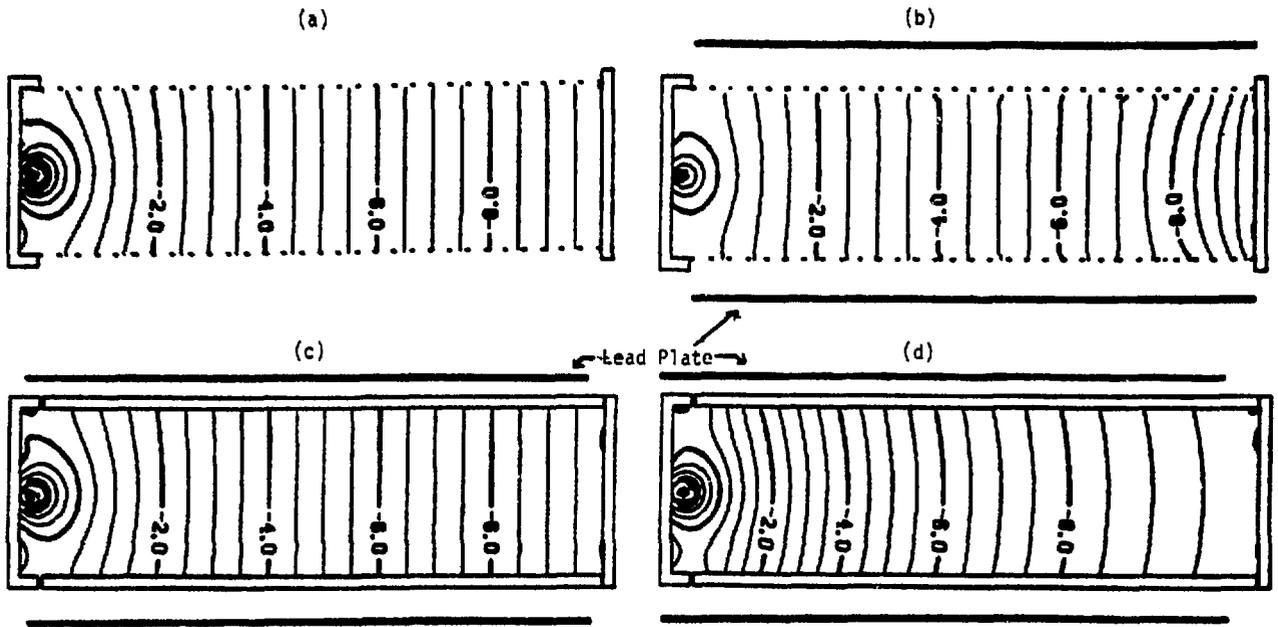


Fig. 3. Equipotential plots in the chamber for a) linear resistor chain with discrete electrodes; b) same with nearby grounded plates; c) linear resistor chain with continuous electrode (resistive ink), showing no effect from grounded plate; and d) exponential resistor chain with continuous electrode. The equipotentials are labeled in kilovolts. The concentric circular equipotentials on the right surround the sense wire. Note that vertical and horizontal scales are different. The dimensions are as shown in Fig. 4.

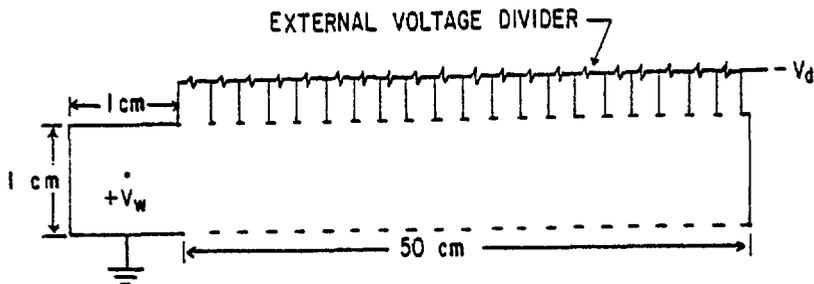


Fig. 4. Cross-section of prototype chamber with 50 cm drift region. The drift field is shaped by the conducting strips (printed circuit lines) connected to an external resistor chain as shown, and also by a continuous film of resistive ink (not shown) that interpolates the potentials between conducting strips. Top and bottom conductors are connected to the same resistor chain.

The resulting electric fields are shown in the equipotential plots of Figure 3c (constant field) and Figure 3d (exponential field), and are seen to be unaffected by the nearby grounded plates.

III. Measurements and Results

A. Construction of Prototype Drift Chamber

Performance of the proposed drift chambers has been tested in the prototype device shown schematically in Figure 4. It has a drift gap of 1 cm and a maximum drift length of 50 cm. The walls and drift electrodes are formed of 1.6 mm thick G-10 sheet, laminated on the inside with copper foil which has

been etched to make a pattern of drift electrodes. These electrodes are strips running normal to the drift direction, whose width is 0.5 mm and whose center-to-center spacing is 5 mm. These strips are connected to an external resistor chain that grades the applied negative drift voltage V_d (normally 10 kV) to the right value on each strip. Two resistor chains have been used: one distributes the potential linearly to produce a uniform field parallel to the z axis; the other chain establishes an exponential field with $b = 0.028/\text{cm}$ for a focussing field as described above. The drift electrodes and spaces between are covered with a film of resistive ink over 30 cm of their 45 cm length in the direction perpendicular to the plane of Fig. 4. The remaining length was left with insulating surface between the conducting strips so that the efficacy of the resistive ink could be determined. At the end of the

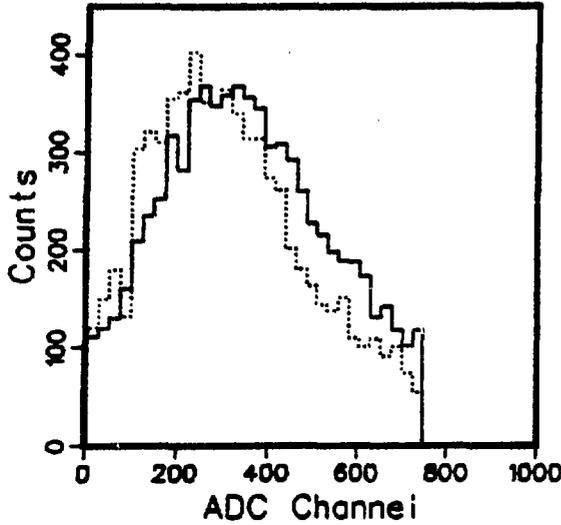


Fig. 5. Spectra of signals in prototype chamber with $V_d = 10$ kV, oxygen concentration of 6 ppm, using the exponential resistor chain, for drift distances of 4 cm (solid line) and 50 cm (dashed line) in gas composed of 90% argon and 10% CO_2 .

Fig. 6 (cont'd)

All measurements are for $V_d = 10$ kV, using the exponential resistor chain.

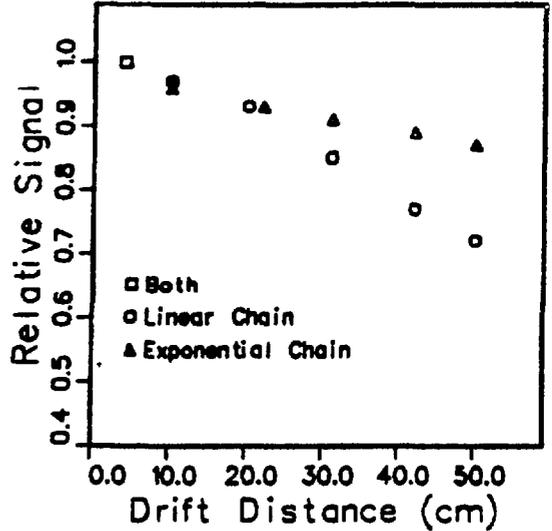


Fig. 7. Signal on sense wire as a function of drift distance for linear and exponential resistor chains. Measured signals have been corrected for attenuation from oxygen contamination and normalized to those obtained with 4 cm drift distance. All measurements are for $V_d = 10$ kV.

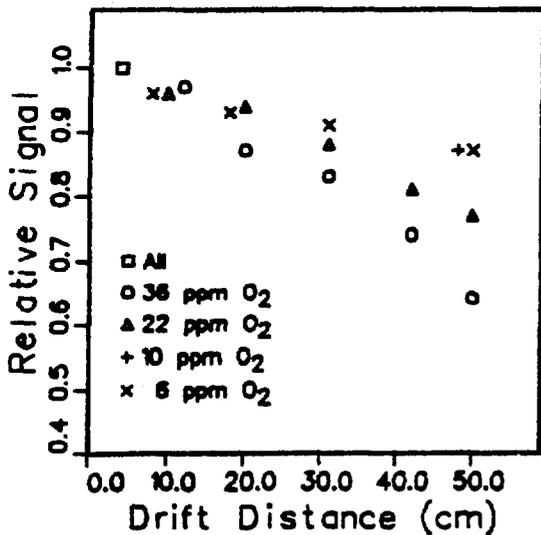


Fig. 6. Signal on sense wire as a function of drift distance for different concentrations of oxygen. Measured signals have been normalized to those obtained with 4 cm drift distance.

drift region, the sense wire sits at the center of a box of cross section 1 cm x 1 cm. Three sides of the box are covered with copper foil at ground potential, which forms the cathode for the sense wire, while the fourth side is open to the drift region. The wire itself is 37 μ m diameter goldplated tungsten and operates at a positive potential, typically 1.8 kV. Testing was done with electrons from a Ru^{106} source which were required to pass through the chamber, including both walls, and to make signals in two scintillation counters below the chamber. The chamber was filled for the measurements a mixture of 90% argon and 10% CO_2 .

B. Drift Velocity and Position Resolution

At our normal drift field of 200 v/cm, the drift velocity is measured to be 1 cm/ μ sec. The velocity is proportional to the field at these values, so the collection time from 50 cm stays 50 μ sec with either resistor chain. Use of a non-saturated drift velocity, especially one that varies with position, raises difficult requirements of detailed knowledge of electric field and gas properties if high position resolution is required. In the nucleon decay application, we plan to read out the chamber in time "buckets" corresponding to 6 mm in the chamber or $\sigma = 1.7$ mm. In order

that knowledge of drift velocity not affect the resolution by more than this figure, it will be necessary to monitor the electric field, pressure in the chamber, etc., to a precision of 0.3%. Drift time resolution measurements have been done with the Ru¹⁰⁶ source, and were therefore limited by the size of the source spot after passing through the top G-10 sheet. The measured time resolution σ corresponds to 2.2 mm, essentially independent of resistor chain or position in the chamber, and consistent with the source spot size.

C. Efficacy of Resistive Ink

In the section of the chamber without resistive ink, collected charge dropped quickly as the drift distance was increased. Beyond about 30 cm, no drifting signal could be detected. At small distances, where a significant signal could be seen, the fall in signal became even more precipitous when a grounded metal plate was placed against the outside of the upper G-10 wall of the chamber. Under these conditions, no signal could be seen beyond about 15 cm.

When these tests were repeated in the section covered by resistive ink, the results were quite different. A strong signal was seen at the maximum drift distance of 50 cm. In the best case, attenuation of the signal amounted to only 12% over that distance (see below). The grounded plate produced only a momentary reduction of signal, presumably while the drift electrode surface was charging in response to the changed conditions. Pulse height spectra for drift distances of 4 cm and 50 cm are shown in Figure 5.

D. Gas Purity

The relative signal as a function of drift distance is plotted in Figure 6 for different measured concentrations of oxygen. It can be seen that the attenuation is increased for concentrations above 10 ppm. At 36 ppm of oxygen, about 20% attenuation can be attributed to the presence of oxygen.

E. Electric Field Shape

The relative signal as a function of drift distance is plotted in Figure 7 for the two resistor chains, linear and exponential. As predicted from diffusion calculations, there is a substantial attenuation (~30%) for the uniform field, while the exponential (focussing) field largely overcomes the effect of diffusion and attenuation is held to a rather small value (~12%)

IV. Summary

We have built a successful prototype of a long drift chamber to be used for a nucleon decay experiment. In order to minimize the attenuation of drifting electrons, it was necessary to produce the drift electric field with a continuous electrode, realized with a film of resistive ink, which prevented charging of dielectric surfaces and eliminated outside effects.

A focussing electric field shape was used to reduce loss of electrons by diffusion into the walls of the chamber.

- * Research supported by USDOE.
- + Undergraduate Summer Research Participant from University of Illinois, Urbana, IL

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