HIGH-ACCURACY DRIFT CHAMBERS AND THEIR USE IN STRONG MAGNETIC FIELDS

G. CHARPAK and F. SAULI
CERN, Geneva, Switzerland

W. DUINKER
Utrecht State University, Holland

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A method is proposed that allows the construction of drift multwire proportional chambers with adjustable electric field suitable for the detection of high-energy charged particles in strong magnetic fields. Typical measured accuracies go from 50 to 200 μm, varying with the drift length, at 16 kG. The simple mechanical construction allows the wire distance to be adapted to the expected counting rate, even in the same chamber. Furthermore, the advantages of a current division method to obtain both orthogonal coordinates from the same wire are discussed.

1. Introduction

The correlation between the position of an ionized track produced by a charged particle and the time of appearance of an electric pulse at the wire of a proportional chamber can be used to measure the distance of the trajectory from the wire.†,§

Several types of localization detectors have been imagined based on this principle. Let us describe two of them.

1) One keeps the structure of a normal multwire proportional chamber, and measures the time distance from the wire. The electric field between the wires is however not uniform, and is in fact zero in the centre of the separation between two wires, since the drift velocity of electrons is in general a function of the field, a complicated space-time relationship may result with long tails in the time distribution. In some gas mixtures, however, the drift velocity approaches a constant value for moderately large fields, as illustrated in fig. 1 (from ref. 3). Furthermore, addition of a corrective "field" wire between two sense wires increases the electric field in the critical region. As will be seen in the next chapter, however, the method is effective only if the ratio of the cathodes to wire distance is close to one; for larger wire separation, the electric field becomes too small to saturate the drift velocity.

A difficulty of such a method is the right-left ambiguity, one does not know from which side of a wire the electrons are collected.

The ambiguity can be solved in several ways; the simplest one that comes to mind is to use two chambers displaced by half a wire distance. However, problems may occur for inclined tracks since the wire distance cannot be much larger than the average chamber thickness, which is of the order of 1 cm.

A group from the Heidelberg University has used a simple method to solve the right-left ambiguity. The single sense wire is replaced by a triplet of wires. Two thin wires close to each other and electrically separated are used to amplify the avalanches. They are separated by a thick wire which plays the role of an electric shield, the distance between the wires of a triplet is 1 mm. The triplets are 2 cm apart and are separated by a field wire which increases the drift field between the wires and reduces the spread of velocities along the drift path. Large chambers having this structure, have been successfully operated, with a
typical accuracy of localization of 0.35 mm (standard deviation) for a maximum drift of 10 mm. Some lack of linearity in the space–time relation was observed, that was corrected by having a non-linear clock.

We have recently proposed another method for solving the right–left ambiguity\(^7\)). It was shown that if two wires of 20 \(\mu m\) are placed at a distance between 0.1 and 0.2 \(mm\) apart, the avalanche surrounds only one wire. This is demonstrated by the strong asymmetry introduced in the positive pulse induced at the neighbouring wire: the pulse is much higher in the wire which is on the same side of the collecting wire as the track. The electrostatic repulsion between the wires causes, however, electrostatic instabilities for long wires, and these have to be mechanically tightened together at regular distances.

2) One can build a special structure where a drift space is provided with a uniform field optimized for the best resolution. The electrons are collected through a grid to one or many amplifying sense wires where the time of arrival is measured.

Such a chamber of small dimension was tried at CERN in 1969\(^8\)). It proved that an accuracy of the order of 100 \(\mu m\) could be obtained over a few centimetres, and that with two drift chambers the time of passage of a particle in a chamber could be measured within 5 ns or better.

A group at Saclay extended this method. They found a gas in which it is possible to drift the electrons over distances as big as 25 cm, with a reduction of accuracy which was almost unobservable – at least within their accuracy of measurements, of the order of 0.3 \(mm\)\(^9\).

The two experiences of Heidelberg and Saclay have clearly demonstrated the potential of drift chambers and their ease of operation. Two remarks can be made about these two methods of exploiting the space-time correlation.

a) With chambers where the electrons are drifted in non-uniform fields there exist limits to the accuracy of measurements which may be very far from the intrinsic limit of the method. This may be even more true if the chambers are placed in magnetic fields.

In a structure with wire triplets placed at distances of 1 \(mm\) there should exist variations in the position accuracy around these wires. This is of no importance as long as accuracies of the order of the wire spacing in the triplet are aimed at. But we shall see that much greater accuracies are within reach by the drift method.

b) With chambers with a single amplifying wire and a large drift space it seems difficult to go beyond the dimensions already reached at Saclay, namely 25 cm. This drift length gives rise to a time resolution for accidentals of the order of 6 \(\mu s\), which may be prohibitive in many cases.

2. A method of obtaining uniform drift fields with a multiwire structure

We will show in this article that it is possible to construct chambers having a roughly uniform drift field, still keeping the structure of a normal multiwire proportional chamber.

The idea is to have the cathodes made of parallel equidistant wires placed at increasing potentials, to generate a well-controlled electric field along the drift space. This is shown schematically in fig. 2. The potential on the cathode wires grows uniformly from a minimum \((V_m)\) in front of the amplifying wire, at left in the figure, to a maximum \((V_M)\) at the end of the drift space. Addition of a field wire in the centre of the separation between two sense wires makes it possible

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Fig 2 Principle of construction of the adjustable field drift chamber. The cathode wire spacing is 2 mm, the gap 6 mm in total, the distance between two sense wires 48 mm. The equipotentials are shown for \(V_m = 0.58\) and \(V_M = 1.0\), in relative units.
to eliminate the critical low field region. In the figure, the equipotentials (measured with a conductive paper method) are shown for a uniformly increasing potential applied to the cathode wires, going from $V_m = 0.58$ to $V_m = 1.0$.

The value of the electric field, for $V_M = 1$ kV, on a central cut across the chamber (parallel to the cathode wires) is shown in fig 3, curve A. For a comparison, curve B shows the same quantity in the absence of the field wire, and curve C the field in a chamber of similar structure but having all cathode wires (and the field wire) at the same potential, as in a standard MWPC. Since in the real case (see the next section) $V_M \geq 3.2$ kV, one can see that for the described structure the field is nowhere smaller than $\approx 600$ V/cm, resulting in a constant drift velocity if the indicated gas mixture is used (see fig. 1). This is not the case for the structures whose field is represented by curves B and C. One can obviously vary $V_m$ and $V_M$ independently, in order to optimize the gain and the drift properties of the chamber.

The structure is very flexible, and the sense wire distance can be varied at will according to the experimental needs (mainly the expected counting rate per unit area), in principle one can also have a variable wire distance in the same chamber, since the operating voltage is mostly determined by $V_m$. The mechanical construction presents no problems; all cathode wires having the same potential are connected on a printed circuit to one of a set of bus-lines, and the voltage distribution can be organized at one end of the chamber, for example by means of a resistor network. Two power supplies can be used to vary $V_m$ and $V_M$ independently.

We have constructed several drift chambers with the described structure, and with the following parameters:

- sense wire diameter: 20 $\mu$m,
- sense wire length: 35 mm to 30 cm,
- distance between sense wires: 48 mm,
- distance between cathodes: 6 mm,
- cathode wire diameter: 100 $\mu$m,
- cathode wire spacing: 2 mm

Fig 3 Electric field along a central cut of a structure like the one shown in fig 2. A) using an increasing potential on the cathode wires as described in the text, and with the field wire connected to $V_M$. B) as (A), but without the field wire. C) applying the same potential to both cathode and field wires, as in a normal multwire proportional chamber.

Fig 4 Pulse-height spectrum in the drift chamber, operating with an argon (73%) and isobutane (25%) mixture and with $V_m = 1.5$ kV, $V_M = 3.2$ kV. a) for a $^{55}$Fe X-ray source, 20 mV/division; b) for a 1 GeV/c momentum pion beam, 5 mV/division.
In the first instance, we have preferred as a gas filling, mixtures in various proportions of argon and isobutane since, as already mentioned, in this gas the drift velocity is only slowly varying with the field for fields larger than \( \approx 600 \text{ V/cm} \). The linearity between space and time should then be preserved even if the electric field is not perfectly constant. This gas may not be the best, however, for reducing the electrons’ diffusion which is the cause of the decrease of accuracy with the drift distance.

The structure of the electric field is such as to make a drift chamber a rather good proportional counter. Figs. 4a and 4b show, as an example, the pulse-height spectra obtained with an \(^{55}\text{Fe} \) X-ray source and in a beam of fast (1 GeV/c momentum) particles; the horizontal scales are 20 and 5 mV/div respectively. A resolution of 17% fwhm is observed on the 5.9 keV X-ray. A threshold of detection of \(-3 \text{ mV}\) was found to be sufficient to guarantee full efficiency for relativistic particles.

### 3. Experimental method of measuring very high accuracies

In order to study the space-time relationship and the accuracy of the described drift chambers, we had to find a method by which a beam of charged particles could be precisely defined. This was done using the space-time correlation in two small single-wire collimation drift chambers similar in design to the chamber under study. The chambers were placed in a high-energy (1 GeV/c momentum) pion beam, a couple of accurately timed scintillation counters defined the trigger and the zero time reference. A given delay was imposed on the detection of a pulse from the two collimating chambers, and events were accepted only if they did fall within a very narrow coincidence time.

Two narrow regions were thus selected on each side of the detecting wire, allowing in principle four distinct track directions. With a delay on the collimating chambers around 20 ns, two regions about 1 mm on each side of the sense wires were selected, and owing to the small divergence of the beam only two parallel beams were in fact accepted.

Taking into account the dispersion on the zero time definition (fwhm 0.8 ns) and the width of the time coincidence (1.5 ns), and for a typical drift time of 22 ns/mm (see next paragraph), we could then obtain an electronic accuracy in the definition of the two monitor beams of about 30 \( \mu \text{m} \) (standard deviation). The quoted definition was kept constant through all measurements described in the following.

![Fig 5 Time difference between two single-wire drift chambers, as a function of their alignment on a beam. The time scale is 20 ns/division (or 2 ns/channel), and the three pictures represent the spectra obtained in three positions one mm apart from each other. In the position providing the spectrum (c), the two chambers are centred on the mean direction of the beam.](image)
The drift chamber under study was then placed between the two collimating ones and displaced on a high-precision optical bench for accurate scanning.

We shall mention here that the time coincidence between two single-wire drift chambers is a very effective method of aligning chambers on beams, or vice versa. The time difference between the unselected pulses from the two chambers is indeed centred at zero with a dispersion corresponding to the electronic jitter and the beam divergence only if the two wires are aligned to the central direction of the beam. A small offset would produce two peaks, symmetric around the zero value, plus a constant rate in between. This is seen in figs 5a, b, and c, here the time difference between the two collimation chambers is shown for three positions, in steps of 1 mm. The horizontal scale is 20 ns/div. Assuming an accuracy in the peak determination of 2 ns, and for a distance of 10 cm between the chambers, this corresponds to a definition of the mean beam direction of about 1 mrad.

4. Efficiency, linearity and accuracy of the drift chamber

With the method outlined in the previous section, one then obtains from the drift chamber under study two peaks in the time distribution, corresponding to the two selected collimated beams. This is shown in fig. 6, where the time spectrum of the chamber on the

Fig. 6 Time spectrum of pulses provided by a drift chamber, detecting two narrow beams about 2 mm apart, collimated with the method described in the text. The drift lengths are 10 and 12 mm, respectively. Horizontal scale: 1 ns/channel.

Fig. 7. Measured space-time relationship and efficiency in a drift chamber, in a high-energy beam perpendicular to the chamber as a function of the drift length. The drift velocity is constant for most of the chamber length, with the exception of the region very near to the amplifying wire where the electric field rises by several orders of magnitude.
collimated beams is given, the distance between the two peaks corresponds to about 2 mm, and the drift length is 10 and 12 mm, respectively. In fig. 7 the measured space–time relationship is shown, as well as the efficiency through the 24 mm of drift space on one side of a sense wire. For this measurement the following conditions were set:
- gas mixture argon 75%, isobutane 25%,
- high voltages: $V_m = 1.5$ kV, $V_M = 3.2$ kV,
- threshold of detection on the drift chamber pulses $-3$ mV.

It can be seen that the drift velocity is constant through most of the chamber, and only slightly increasing near to the sense wire. The efficiency is constant at about 99.6% and shows a steep drop at the limiting region, proving that no smearing effects are produced, at least for a beam perpendicular to the chamber.

The accuracy in the response can be inferred from the width of the time distributions such as those in fig. 6. At least five factors contribute to the measured width:
1) the intrinsic physical jitter in the three chambers owing to the thermal diffusion of the primary electrons during the drift time,
2) the uncertainty in the zero time definition as given by the scintillation counters,
3) the width of the time coincidence used to select the collimated beams,
4) the time jitter introduced by the simple threshold detection of pulses in the three drift chambers;
5) the multiple scattering in the mylar windows (two per chamber, 12 μm thick each) and in the wires.

The raw data were corrected only for the dispersions introduced by effects (2) and (3), accounting for about 30 μm (standard deviation, see section 3). Also, the intrinsic jitter of the three chambers was assumed to be equal for a drift of 1 mm in the central one, and then the (fixed) contribution of the two collimation chambers was subtracted in the Gaussian sense ($\sigma = 35$ μm each).

For example, at 2 mm drift length the measured raw value of 75 μm is corrected to 45 μm. The result is shown in fig. 8, where the corrected accuracy of the central chamber is plotted as a function of the drift space; it increases from a minimum of 40 μm close to the wire, to a maximum of 180 μm. The full curve in the drawing represents the classical diffusion equation:

$$
\sigma_x = \sqrt{2Dt} = \sqrt{\left(2D/w\right)x},
$$

(1)

where $x$ is the average drift length and $w$ the drift velocity. For the curve shown, the coefficient of diffusion $D$ equals 0.32 m²/s.

A slight decrease in accuracy is observed close to zero; this was expected as a consequence of the statistical fluctuations in the position of the primary electrons. Indeed, the average distance between primary electrons produced by a charged particle is about 300 μm, and this introduces an additional jitter when the track is very close to the sense wire. Multiple Coulomb scattering on the wire may also contribute.

Extrapolation of the observed points with eq (1) to longer drift spaces shows that a 10 cm drift, for example, should allow an accuracy of about 400 μm in the gas used.

5. Operation in a magnetic field

We have investigated in great detail the effect of strong magnetic fields on the drift of electrons. The worst case is of course the one in which the magnetic field has a component parallel to the wires, since the charges drifting towards the wires are lifted to the outside of the chamber and the track may be lost. We have observed that already at 5 kG the efficiency of detection decreases towards zero after about 12–13 mm of drift.

The lateral displacement of electrons drifting in an electric field $E$ for a time $t$ is given by

$$
Ax = \frac{E}{B} \frac{v^2 \tau^2}{1 + v^2 \tau^2} t,
$$

(2)

where $v = eB/m$ is the Larmor frequency, $B$ the magnetic induction perpendicular to $E$, and $\tau$ the mean free time for collision of electrons. At a given $B$, it can be seen that $Ax$ increases with $\tau$. Hence, one way of extending the efficiency region of a drift chamber in a magnetic...
field is to decrease the mean free path (e.g., increase the gas density).

In a preliminary set of measurements, we have used for convenience a localized collimated 55Fe X-ray source to scan the chamber, with and without a magnetic field, and defined the detection efficiency through the counting rate. The main results are presented in fig. 9. We observe a behaviour which at first is surprising: the efficiency of collection depends on the direction of the magnetic field (curves B and C, as compared with the rate measured without magnetic field: A). This comes from the fact that photons emitted by the source are mainly absorbed in the first few millimetres of the gas layer in the chamber; if then the magnetic field has the right polarity, the drifting electrons are displaced towards the sense wire and they still reach it, at least for moderate fields. The effect of reducing the mean free path, increasing the gas density, can be seen by comparison of curve C (15% isobutane, 85% argon) and D (43% isobutane). Some improvement is observed, but only for relatively low magnetic fields.

A more general solution has been found which allows the use of drift chambers in much stronger fields. By using separate voltage distribution lines on the two cathodes of a chamber, the electric field direction can be tilted so as to produce a component of electric force parallel and opposite to the Lorentz force. Let $E$ be the electric field in a direction parallel to the cathode planes and $B$ the magnetic induction perpendicular to $E$. One can easily obtain the tilting angle $\alpha$ necessary to oblige the electrons to drift parallel to the cathode planes:

$$\alpha = \arctan \frac{B \omega}{E}.$$  

With the previously given values of the drift velocity $\omega$ and of $E$, one obtains for a magnetic field of 15 kG, $\alpha \approx 45^\circ$. A variable tilting can easily be produced by using separate $\text{hv}$ distributors on the two cathode wire planes.

In fig. 10 the equipotentials in a drift chamber with the described structure, and about 50° tilting of the electric field all across the chamber are shown. The tilt corresponds to a shift by two cathode wire spacings, on each side of the symmetry axis, of the potentials $V_M$ and $V_m$ as defined in fig. 2.

As before, $V_M = 1$ is the maximum potential, applied

* Suggested to us by O. Guildebeaster.

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**Fig. 9. Counting rate in a drift chamber, given by a collimated 55Fe X-ray source, as a function of the drift length**

- **A** in normal conditions, without magnetic field.
- **B** in a magnetic field of +5 kG, parallel to the wires.
- **C** in a magnetic field of -5 kG.
- **D** as in (C), but with an increased amount of isobutane.

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**Fig. 10 Electric field in a drift chamber, where the voltages applied to the cathode wires are chosen so as to tilt the equipotential by a given angle**

In the figure, the tilt is of about 50° which, according to eq. (3), makes it possible to drift the electrons properly towards the sense wire in a magnetic field of 18 kG perpendicular to the drawing.
Three small single-wire drift chambers, with adjustable electric field as described, installed inside a magnet for the measurements in a strong magnetic field.

to the field wire as well, and $V_m = 0.64$ is the minimum; the voltage of the cathode wires is uniformly increasing between $V_m$ and $V_M$. Calculation of the field across a central cut would give a curve essentially equal to curve A in fig. 3.

The set of three drift chambers used for measurements in a strong magnetic field can be seen in fig. 11; the sense wires were only 35 mm long, since the useful gap of the available magnet was 10 cm. Fairly uniform fields up to 16 kG could be obtained. To adjust the tilting angle, we used separate power supplies on the two sides of the cathode wires, as a general rule, we kept constant the mean potential between two facing cathode wires, changing the voltage difference $\Delta V$. For a given drift distance, then, the efficiency versus $\Delta V$ was measured. As expected, the voltage difference giving the best efficiency is the same all through the chamber; fig. 12 illustrates the measurement for a drift of 20 mm. The comfortable length of the plateau makes of the tilt angle regulation a not very critical one.

The measured linearity and efficiency for detection of high-energy charged particles in a magnetic field of 15.6 kG parallel to the wires are presented in fig. 13 for $\Delta V = 1.1$ kV. For comparison, the broken line shows...
the efficiency measured with $\Delta V = 0$, i.e. without tilting the electric field. In fig 14, the space-time relationship is shown in detail around zero, it can be seen that, although the slope of the curve is slowly changing close to zero, a smooth behaviour is still observed.

For the same magnetic field value, the measured accuracies as a function of the drift space are shown in fig 15, where the full curve represents the diffusion eq (1) with the same value of $D$ as in fig 8. Contrary to what one would expect\(^6\), the accuracy is slightly worse in the magnetic field, however, since a different set of chambers was used for the two measurements, the contribution of multiple Coulomb scattering on the beam, non-subtracted, could have been different.

6. Open problems and possible solutions for the use of adjustable field drift chambers

We have seen that the most attractive feature of the drift chamber with adjustable electric field is the high accuracy. However, several factors that contribute to the stability of the results will need further investigations, let us mention some of them:

a) Temperature affect. In principle, the drift velocity is very slowly affected by the gas temperature, since the electron energy in a strong electric field is about two orders of magnitude higher than the thermal energy\(^6\). We have not observed any fluctuation within a range of $\pm 10^\circ C$ for the argon–isobutane mixture used.

b) Change in the gas composition. We have observed that a 10% variation in the isobutane content results in about 30% change in the mean pulse height, and about 1% change in the drift velocity. If one does not want to lose accuracy, a 0.5% control of the gas percentage is probably necessary.

c) Stability of the high voltage. Our measurements show that a 1% change in $V_m$ results in about 0.3% change of the drift velocity. Looking back to fig. 1, this may mean that we were still too near to the knee before the saturation of $w$, to keep the maximum delay (about 500 ns) stable within $\pm 1$ ns implies a stability on $V_m$ of about $\pm 15$ V. Higher values of the field in the drift region may reduce the effect.
d) Angular dependence Because of the small size of our first chambers, we could not explore the dependence of the space-time relationship on the angle of incidence (all measurements were performed with a perpendicular beam). Probably a slightly different relation holds for large angles, and one may be obliged to correct the raw data with a given law during the software track reconstruction.

e) Electrostatic interactions The electric field inside a chamber may be sensitive to external components or electrodes, especially if the cathode wire spacing is large. Some screening may be necessary to construct multigap thin drift chambers, or perhaps one can build the electrodes with conductive strips replacing the wires (e.g., by vacuum evaporating aluminium on a thin insulating sheath).

Several procedures can be envisaged for controlling the drift velocity continuously or on a sampling basis. For example, the unbiased distribution in time of the pulses provided by any wire makes it possible to infer the maximum drift time. By comparison, one can quickly discover variations in the drift velocity.

More refined checks can be imagined when several drift chambers are used to detect a track, we shall mention some in the next section.

f) Large-size chambers The mechanics of an adjustable field drift chamber is not more complicated than

* This is the solution used at Saclay, ref 9
for a normal multiwire proportional chamber. Because of the large wire spacing, one does not expect electrostatic instability of the wires, for a set of 20 \( \mu \)m tungsten wires, 50 mm apart, the length at which electrostatic instabilities should occur is about 250 cm. It is clear, however, that for large dimensions of the chamber, corrections will have to be introduced to the raw data because of the finite propagation time of the signals along the wires.

- A normal multiwire proportional chamber, with a wire spacing that is small compared to the drift space, can be placed in front of and very near to the drift chamber. Either each wire is used as a detector or, in cases where only one particle has to be detected, it is sufficient to connect together all the wires corresponding to the right and to the left drift spaces, respectively.

-- A second drift chamber of the same type is used, staggered by half a wire spacing*. This configuration not only allows the resolution of the ambiguity, but since for a given angle the sum of the two drift times \( T_1 + T_2 = \text{const} \), a continuous check of the drift velocity is possible. Also, particles accidentally crossing the chambers at a time different from the one of the real event will not satisfy the time condition and can be disregarded. From the previous measurements, we can estimate an accuracy in the time correlation of about 5 ns and this will be the resolution against accidentals.

One may also think of using mean timer circuits, such as those used for scintillation counters\(^{12} \), to obtain accurate timing informations. This can be a precious property, for example at the CERN Intersecting Storage Rings, where the proportional chambers alone have too bad a time resolution to distinguish between beam-beam and beam-gas interactions using a time-of-flight measurement.

In case one gets two tracks on the same drift region, the information of the existence of a double track is given, e.g., by pulse height in scintillation counters, the independent measurement of \( T_1 \) and \( T_2 \) still gives

\[ T = T_1 + T_2 = \text{const} \]

* Two other groups are now envisaging a similar approach at CERN, C. Rubbia (private communication), at Heidelberg, J. Hemtze and A. H. Walenta, contribution to the Tirrena Meeting, September 1972.

7. Discussion of a few schemes of utilization of drift chambers

We have already discussed the question of the right–left ambiguity in drift chambers. Although the methods of solving the problem proposed in refs. 4–7 are very attractive, they may lead to mechanical difficulties or they can spoil the high accuracy we were able to measure. One can think of alternative schemes in which the ambiguity is resolved by a combination of drift and/or proportional chambers. Elegant solutions can be imagined whenever the divergence of the tracks in a given chamber is very small, as in beams or magnetic spectrometers.
the distances of the two tracks from the respective wires.

In the general case of tracks having large angular spread, three chambers can be used to solve the ambiguities. By a proper choice of the respective positions of the wires, one can also eliminate the need for having a zero time definition given by other detectors. This can be seen in fig 16. three chambers with parallel wires are stacked so that the central one has the wires displaced by half a wire distance with respect to the other two. Suppose a particle traverses the chambers, at any angle, at the unknown time \( t_0 \), and let the drift times in the three chambers be \( t_1 - t_0 \), \( t_2 - t_0 \), and \( t_3 - t_0 \). The following relation holds (for constant drift velocity):

\[
t_0 - t_2 = \frac{1}{2} \left[ (t_1 - t_2) + (t_3 - t_2) \right] - \frac{1}{2} T,
\]

where \( T \) is the maximum drift time (time to drift along half the wire distance). Hence, by using the central chamber as a time definition, and recording \( t_1 - t_2 \) and \( t_3 - t_2 \), one obtains the zero time \( t_0 - t_2 \) and then a unique track reconstruction (fig 17). With the measured time accuracies (section 3) for each drift time, one may expect to define the time reference within about 4 ns. It is also possible with three such chambers to select a given sagitta in a magnetic field, thus permitting a rapid momentum selection. Again, with the measured average 100 \( \mu \)m accuracy per chamber, with three chambers 10 cm apart, a 1 GeV/c momentum should be measured at about 2%.

8. Two-dimensional read-out of drift chambers

Since a drift chamber of the type we have described leads to a relatively moderate number of sense wires, even for large surfaces, it becomes highly interesting to investigate any method, however elaborate, of obtaining the position of the avalanche along the wire. The obvious advantage is that if many particles have to be detected, the fundamental ambiguities arising from an independent measurement of the two orthogonal coordinates disappear. It is known from different measurements that the avalanche produced on the sense wires is very localized, within perhaps 0.1 mm.

If the two ends of the wire are then grounded, an amount of charge proportional to the position of the avalanche will flow out of each end. The ratio of the charge flowing out on one side to the total charge, gives then the coordinate along the wire. The method is often called “current” division. It was used in spark chambers\(^{14,15}\) and gave accuracies of the order of 1 mm by simply measuring the difference of the charges flowing at the end, with the help of pulse transformers. This method has also been used with other detectors, the pioneering work with single-wire proportional counters was done by Kuhlman et al.\(^{16}\) The difficulty with proportional counters in contrast to spark chambers is that the total charge is not constant and varies within a broad spectrum; it is then necessary to normalize the split charges to the total charge. This is done most easily by taking the ratio of the charges flowing at each end; which, for a given position, is independent from the absolute pulse height.

The difficulty of such a method is that the impedance of the wire has to be great with respect to the impedance of the device measuring the charges at the end of the wires, in order to achieve a good sensitivity.

By using chrome-nickel wires with \( \rho = 40 \) \( \Omega \)/cm, Kuhlman et al achieved accuracies of the order of 1.5 mm over 30 cm. Accuracies as low as 0.5 mm have been measured by Hough.\(^{17}\)

Let us mention a very related method where the
position is obtained by measuring the change of the rise-times of the pulses as a function of the origin of the avalanche – there, also, very resistive wires have to be used (80 kΩ/cm). Spectacular accuracies of the order of 75 µm have been obtained with highly ionizing particles. Spectrometers using proportional chambers with current division read-out over 0.7 m length have been built, and a typical 1.6 mm accuracy was measured. However, again high resistivity wires were used, and times of the order of 1 ms were required to measure the position. For high counting rates this may be prohibitive.

It seems to us difficult to adopt such methods for a fast large-scale detector. Therefore, it appeared worthwhile to investigate the possibility of using low-resistance wires, and we carried out some preliminary tests.

1) With normal tungsten wires of 20 µm (resistance = 1.8 Ω/cm) we have measured the ratio $V_1/V_2$ of the amplitudes of the pulses arriving at each end using amplifiers with low input impedance (of about 2 Ω) and a specially built fast divider†. The total conversion time to obtain the ratio $V_1/V_2$ was about 5 µs.

We obtained an accuracy corresponding to $\sigma = 4$ mm, which is quite encouraging. Such an accuracy could be quite sufficient for the removal, in most cases, of the orthogonal ambiguities.

† Designed at CERN by H. Verbeij.
† Built at CERN by J. Olsfors

2) We used a wire of constantan, 50 µm in diameter, with a moderate resistivity, namely 3 Ω/cm; the accuracy we obtained in a first simple test over a length of 20 cm was $\sigma = 2.5$ mm. This can be seen in fig. 18 where the ratio of the signals on the two sides, $V_1/V_2$, is shown for five positions of a collimated $^{55}$Fe source, 2 cm apart from each other. Notice that the scale is obviously not linear with the distance, and that the accuracy in space is about constant with $\sigma = 2.5$ mm. It seems to us that this is the line of research to be actively pursued, since it would lead to an ideal detector for cylindrical drift chambers in magnetic fields. The resistive wire does not have to be the wire collecting the avalanches; it can as well be a cathode wire, and the current division can be done on the induced pulses. Localization detectors using pulses induced in auxiliary electrodes have already been built. In this case the mechanical requirements, such as the strength or the diameter of the read-out wire are much simplified.

The task of producing a simple and cheap electronics for fully exploiting the high potential performances of the drift chambers is not a simple one. However, it seems that if one is satisfied with the accuracies obtained by spark chambers, 0.3 mm in space and 0.5 µs in time, a detector can be built at a cost as low as or lower than that of spark chambers with still considerable advantages: continuous operation, much lower dead-time, higher efficiency for single and multi-track events, and easier operation in magnetic fields.

For the construction of detectors with a large volume, the combination of proportional wire chambers and of drift chambers may be the ideal solution. The first should rapidly provide information such as the multiplicity and participate in the fast event selection, while the second give the accurate localization.

For the future developments on the high-accuracy detectors required for the exploitation of the very high-energy machines, the drift chamber offers a most promising solution. It is already clear that with a succession of drift chambers, trajectory positioning with accuracies much better than 0.1 mm is within reach without introducing a prohibitive amount of material in the beam.

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