Multiwire Chambers, Drift Chambers and Some of their Applications

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Gaseous detectors have played a major role in elementary particle physics during the past 20 years, starting with the spark chambers and streamer chambers in the sixties. These rely mostly on well-established physical phenomena known since decades to experts in gaseous electronics. It was indeed to the credit of the inventors of these detectors that they created instruments with properties quite revolutionary in the field of particle physics[1]). A memory time of 1 µs, permitting the selection of events from among hundreds of thousands of candidates, and a spatial resolution of better than one millimetre, represented a great advance on the existing detectors, such as cloud chambers or bubble chambers used to visualize the complex configuration of trajectories from high-energy interactions.

The step that followed the introduction of the spark chambers was the invention of methods replacing the use of film for the retrieval of data ; sonic chambers, delay line chambers, current division chambers, ferrite core chambers, magnetostrictive chambers, vidicon chambers, all bear witness to the efforts and ingenuity that were deployed to make use of the powerful tools offered by the fast developing electronics industry to improve the quality and the amount of information treated in an experiment[2]). The creation of new accelerators, more intense and more energetic, the desire to investigate rarer reactions submerged in a huge flow of uninteresting or unusable reactions, created a constant pressure to improve the speed and accuracy of the available detectors.

At CERN in 1968, the introduction of the multiwire proportional chambers (MWPCs) and drift chambers into high-energy physics, showed that with the proper use of well-known properties of electrons, drifting or multiplying in electric fields, and of the tremendous parallel developments of modern electronics, it was possible to take a step forward in particle detector technology. Orders of magnitude have been gained in the speed of data taking in subnuclear physics, and nearly all experiments requiring a coordinate measurement, of particles use multiwire or drift chambers. Even bubble chambers are often used in parallel with huge auxiliary systems of such detectors.

At the same time, the properties displayed by the multiwire structures showed that they were an ideal instrument for the two-dimensional imaging of low-energy neutral radiation. Although the efforts to make use of this technique in other fields started almost in parallel with applications in high-energy physics, it may well be that only the next decade will see its potentialities developed.

Multiwire Proportional Chamber

A MWPC is a structure made of thin anode wires (20 µm diameter) closely spaced (2 mm), sandwiched between two cathode surfaces distant by about 6 mm (Fig. 1a). We are quoting some widely used parameters. The wire spacing rarely goes below 1 mm ; it can be as large as a few centimetres if the cathode-anode distance is also larger.

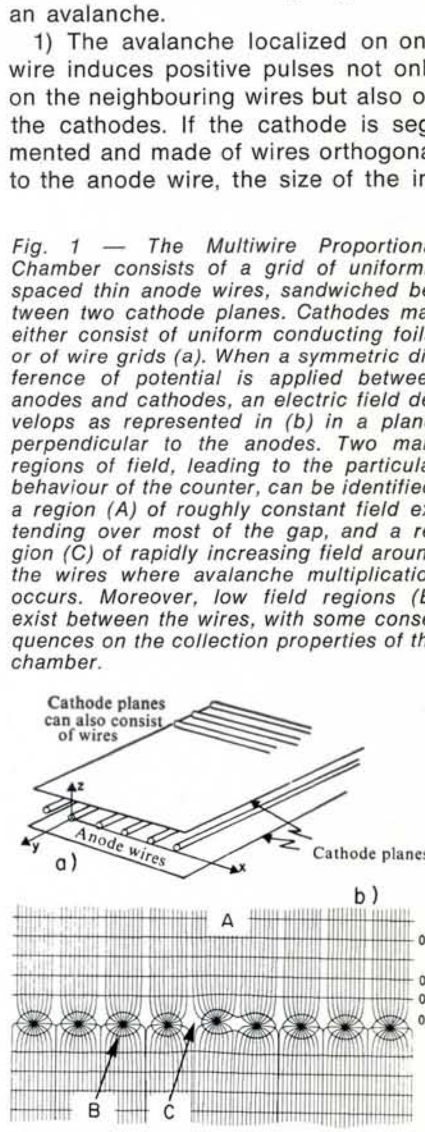
The electrodes are usually planar although for some applications they can be made cylindrical, with the wires parallel to the axis. Rare and scattered use of such structures had been made before 1968, but it was at this date[2,3]) that their essential features were clarified and their most useful potentialities brought to light.

The anode wires are independent detectors acting as single cylindrical proportional counters. From an electrostatic point of view, this is evident (Fig. 1b). The potential distribution of Fig. 1 shows that there exist two main regions of electric field : in most of the volume the field is uniform, and electrons liberated in the gas will be attracted to the anode wires at a constant speed ; near the wire the field is radial. Since the whole multiplicative process in a proportional counter occurs over a very short path length, it will be exactly the same as in a single-wire cylindrical counter.

What was not obvious is that for the detectable pulses the anode wires will also be independent detectors, despite their close spacing and unavoidable coupling. What is observed is that, as a negative pulse is produced on a wire collecting the electrons from an avalanche, a positive pulse is induced in the neighbouring wires, thus making the localization of the detecting wire very easy. The advantage of such a structure is that the electrons liberated in the gas by a charged particle crossing the chamber, will always find a wire very close to them to give rise to an avalanche. The time resolution is then quite good, 25 ns for a 2 mm wire spacing, in contrast to the cylindrical counters where it was of the order of 0.5 µs. Localization precision is of the order of the wire spacing, and the repetition rate incredibly high, of the order of 10^6/s per wire, limited only by the electronics. Since large surfaces of several square metres could be built, as illustrated by the first experiments started at CERN by the group of J. Steinberger, one could easily foresee a future for this type of detector when comparing its characteristics with those of the most popular electronic detectors at that time — the spark chambers — which have a resolution time of 1 µs, with a maximum repetition rate of 10^3/s. However, our studies made in 1968 and 1969 showed that the information from the pulses was much richer than the simple localization on the wires giving rise to an avalanche.

1) The avalanche localized on one wire induces positive pulses not only on the neighbouring wires but also on the cathodes. If the cathode is segmented and made of wires orthogonal to the anode wire, the size of the in-

Fig. 1 — The Multiwire Proportional Chamber consists of a grid of uniformly spaced thin anode wires, sandwiched between two cathode planes. Cathodes may either consist of uniform conducting foils, or of wire grids (a). When a symmetric difference of potential is applied between anodes and cathodes, an electric field develops as represented in (b) in a plane, perpendicular to the anodes. Two main regions of field, leading to the particular behaviour of the counter, can be identified: a region (A) of roughly constant field extending over most of the gap, and a region (C) of rapidly increasing field around the wires where avalanche multiplication occurs. Moreover, low field regions (B) exist between the wires, with some consequences on the collection properties of the chamber.



duced pulses decreases in proportion to the distance from the avalanche, and the maximum of the pulse-height distribution is centred at the avalanche position (Fig. 2) ; it is then possible to determine this position. A MWPC is thus a two-dimensional localization device. This property is essential for the imaging of low-energy X-rays or neutrons, since those radiations are detectable only by their production of low-energy secondary particles, of very low range, confined to one gap.

Several methods, analogue or digital [1,2]) have been used by the groups which have pioneered this type of application in order to localize the centroid of the avalanche. They showed that the coordinate along the wire was the most accurate and could easily be determined to about 100 μm.

2) The time delay in the detection of a pulse on a wire is a function of the distance of the trajectory with respect to a wire [2]). This permits the position between the wires to be interpolated if the initial time of passage of the particle can be determined by a fast detector such as a scintillation counter which led to the development of detectors built in such a way as to make optimum use of this property — the drift chambers. These are assuming a growing importance and will be dealt with in Section 3.

3) Electrons liberated in drift spaces could be transferred to MWPCs

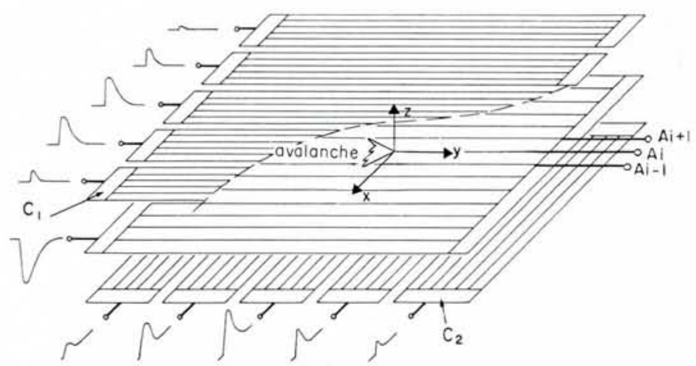
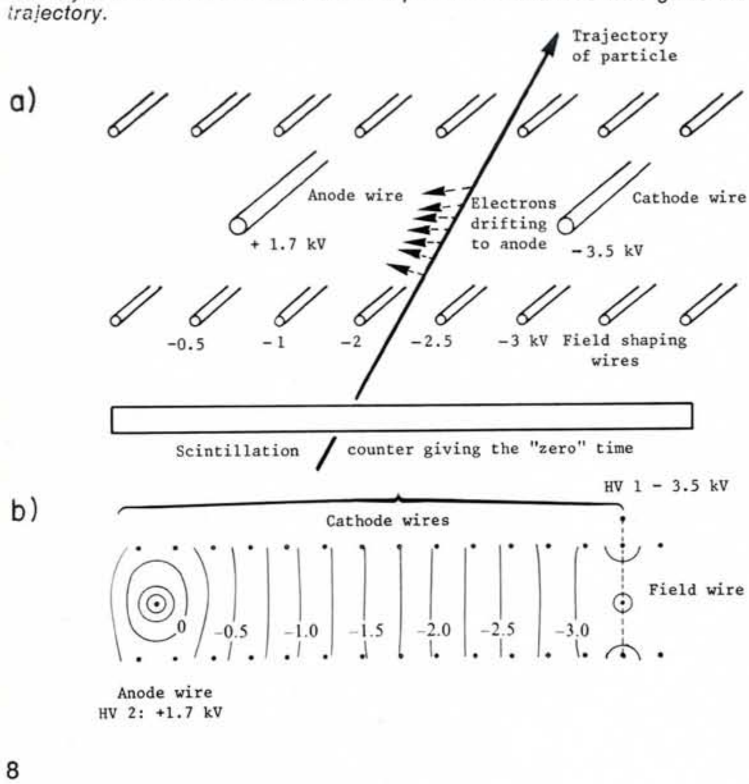


Fig. 2 — Charge centroid of the induced pulses in a multiwire proportional chamber. The motion of ions leaving the vicinity of the anode wires induces positive pulses on all surrounding electrodes. The centroid of the pulses is centred on the avalanche.

through transparent grids, thus increasing the possibilities of adapting the volume of the gas to the nature of the neutral radiation to be detected [3]). This indeed made use of well-known structures used by Frisch a long time ago in ionization chambers, for quite different purposes — the shielding of the collecting electrodes from the moving ions. We shall see that in the spherical drift chambers at present being actively developed for X-ray diffraction techniques, such structures play an essential rôle.

By the end of 1968 we thus had a handful of exciting properties revealed by the study of the multiwire structure; a programme of fast and competitive development was started in many laboratories and resulted, within 10 years, in a considerable variety of particle detectors, quite different in their structure and in their utilization.

Fig. 3 — Principle of construction of a common type of multiwire drift chamber : a) schematic view ; b) equipotential lines. Cathode wires are connected to uniformly decreasing potentials, starting from ground in front of the anode. Field wires reinforce the field in the transition region to the next cell. The time interval between the detection of the particle by a scintillation counter and the pulse on the anode wire gives the position of the trajectory.



The Drift Chamber

The first structure specially built to measure the coordinates of a charged particle comprised a region of uniform field created by wires at a rising potential where the liberated electrons drift at a constant speed, and an amplifying region, where the time of arrival of electrons is measured with respect to a scintillation counter. With such a drift chamber, it was shown in 1968 that accuracies of 100 μm could be reached and that the correlation in three consecutive chambers permitted a timing accuracy of 5 ns. Several distinct, significant development programmes started then in 1969.

A group at Saclay [1]) developed such structures up to drift lengths of 25 cm and built a remarkably simple detection system for a 1 GeV nuclear physics magnetic spectrometer.

A group at Heidelberg [4,5]) developed a simple structure made of an ordinary MWPC with field-correcting wires between the anode wires. With a wire spacing of about 1 cm, an interpolation accuracy of about 200 μm was reached. A group at Harvard [1,4]) showed that it was possible to build chambers of 3 m × 3 m with this structure, still keeping a reasonable accuracy.

The Saclay and Heidelberg groups performed the first experiments with drift chambers. At CERN, we developed high-accuracy chambers [4]) which are a simple repetition of uniform-field drift regions, keeping a moderate drift length (Fig. 3). This has led to a most widespread structure for large-surface detectors. It exploits the main advantages of drift chambers:

A considerable reduction in the number of detecting wires; distances of 5 to 15 cm are quite pratical, and the cost per unit length is thus significantly reduced with respect to MWPCs.

An effective accuracy and linearity unmatched by any other approach ;

an accuracy of 50 µm has been reached, limited in practice by the physical extension of the ionization cloud or mechanical uncertainty.

Currently some experiments are employing chambers with a detection surface of several hundred square metres.

This was not the end of the development of drift chambers. A considerable variety of structures adapted to different geometries have been developed: cylindrical drift chambers; chambers giving the direction of the tracks; chambers giving the three-dimensional position of trajectories. This last development, undertaken by D. Nygren and co-workers at Berkeley [6]) will lead to a purely electronic, continuous, visual detector of large volume, similar to a streamer chamber but with considerable advantages; one coordinate is obtained from the drift time along a path of up to 1 m, and the other two coordinates are obtained by a single MWPC, using a two-dimensional read-out method. It will also give the specific energy loss of the particles in the gas filling, and they hope to be capable of selecting particles by measuring their relativistic rise in ionization. Some slightly more modest detectors along these lines are also in operation in Europe [5]). An insight into the methods used to retrieve all the information from an event in such a chamber is not possible within the frame of this article. I wish only to stress that it illustrates the tremendous power given to us by modern electronics. One single event in such a chamber results in 10,000 words of 32 bits from the associated electronics.

Fields of Application

In low-energy or high-energy nuclear physics the chambers are used for localization of the trajectories or sometimes for the sampling of energy losses in the gas of a succession of detectors. Very complex events can be analysed. One can take millions of counts per second in the detectors and select by fast logics only the few events of interest, with time resolutions ranging from 25 ns to 150 ns. The discovery of the rare J/ψ particle and of the τ was made, with proton machines, by using MWPCs at the very limit of their speed possibilities.

In the field of low-energy X-rays commonly used for diffraction techniques, ranging from 8 to 20 keV, the chambers offer an ideal tool for two-dimensional imaging. The pioneer work done in San Diego by N. huu Xuong et al. [5]) with simple, small-size chambers has already shown that

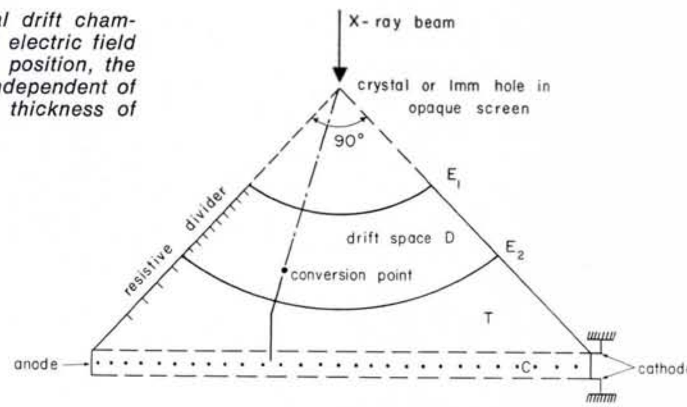


Fig. 4 — Spherical drift chambers. With a radial electric field centred on source position, the accuracy is kept independent of inclination for any thickness of drift space.

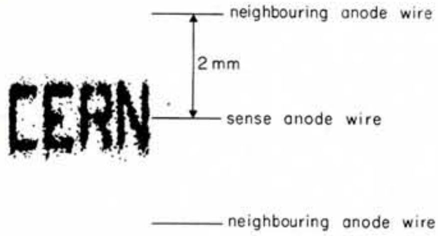


Fig. 5 — Continuous response of a wire chamber. Dimensions of the word CERN : 1.5 mm x 4 mm. 100 µm letters cut in a copper mask ; 6 keV X-rays ; avalanches on only one wire : 2 mm wire spacing.

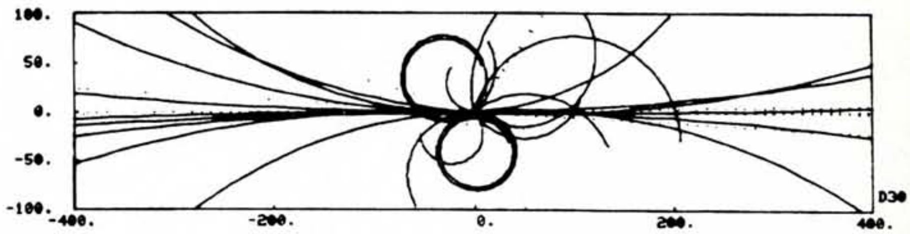


Fig. 6 — Computer simulation of an expected collision in the CERN proton-antiproton storage rings.

gains of 50 could easily be obtained over what was possible using conventional diffaction spectrometer techniques. With the present spherical drift chambers, combined with the high intensity of synchrotron-radiation X-ray sources, a gain of three orders of magnitude is expected. In such a chamber, realized at CERN in 1974 and now being installed at the Synchrotron Radiation Facility at Orsay (Fig. 4), the crystal made of the molecules under study is placed at the focus of two concentric electrodes, 10 cm distant; one is made of a thin window, transparent to the X-rays, and the other is made of a mesh transparent to electrons. The ionization electrons liberated in the gas filling are drifted in a radial field, extracted from the drift chamber, and transported to a MWPC where the coordinates are measured. This permits an efficiency of 100% at atmospheric pressure without degradation of accuracy due to the parallax, as in planar chambers or detectors of any kind of finite thickness. With an aperture of 90°, an angular accuracy of a few milliradians, and repetition rates of the order of 1 MHz, this instrument should have a serious impact on molecular structure investigation based on X-ray diffraction methods.

Thermal neutrons can be used like soft X-rays for structure studies, and very important programmes exist at such high-flux neutron reactor centres as the Laue-Langevin Institute. There, also, MWPCs are generally adopted as a solution for two-dimensional imaging [5].

In nuclear medicine, the scintillation counters have proved to be adequate for most problems of γ-ray imaging. So far, the low efficiency of gaseous detectors has almost kept them out of this field. However, the limitation of NaI scintillation in position accuracy (0.6 cm) and in data rate ($\sim 10^5$/s) is opening the way to MWPCs for a few special applications that are being actively investigated by some groups [5].

The Future

Active research on the processes playing a rôle in MWPCs and drift chambers is continuing. Already a better understanding of all the mechanisms involved has resulted in quite unexpected progress. For instance, it was shown that by using the computed charge centroid in a structure like that of Fig. 2, it is possible to have information on the position of an initial electron cluster localized between wires. It has long been considered as a postulate that it is not possible to have an accuracy better than the wire distance, except by using the time of drift and even in this case, there was a fundamental ambiguity concerning the side of the initial ionization with respect to the collecting wire.

This is illustrated by the first two-dimensional image (Fig. 5) of an object smaller than the wire spacing, made at CERN in 1977 [5]. The accuracy has been pushed to a limit where down to less than 10 µm, the read-out can give the exact centroid of an ionizing event. There is still a considerable demand to improve the characteristics of the chambers with respect to the flux limits. Many recent experiments with proton accelerators require the operation to be at the limit of the chambers, while available proton fluxes could have given a higher rate of events. The limit is set by the slow motion of heavy positive ions accumulated after the avalanches. A recent step has been taken at CERN to overcome this difficulty, and at least one order of magnitude in speed has been gained [6]. Another limitation comes from the desire to see more and more complex configurations. In this respect it is illustrative to consider a simulation of a reaction expected at the proton-antiproton storage ring experiments at CERN in 1980 (Fig. 6).

To deal with the fantastic complexity of such an event, one can think of the time projection chambers now being developed by D. Nygren [7], or of other combinations of drift and multiwire chambers. It is easy to understand that groups tackling such problems have to invest considerable effort in technological research, both in the gas detector operations and the associated electronics. Research into gaseous detectors is still a very active and lively area in high-energy physics laboratories.

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