Development of multiwire proportional chambers

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It has happened quite often in the history of science that theoreticians, confronted with some major difficulty, have successfully gone back thirty years to look at ideas that had then been thrown overboard. But it is rare that experimentalists go back thirty years to look again at equipment which had become out-dated. This is what Charpak and his colleagues did to emerge with the 'multiwire proportional chamber' which has several new features making it a very useful addition to the armoury of particle detectors.

In the 1930s, ion-chambers, Geiger-Muller counters and proportional counters, were vital pieces of equipment in nuclear physics research. Other types of detectors have since largely replaced them but now the proportional counter, in new array, is making a comeback.

Although CERN was the first to show the possibilities offered by these chambers physicists had for long toyed with the idea of using the wire chamber as a proportional counter. Now, the introduction of micro-electronics makes it possible to purchase miniature components for amplification of the signal on a wire for a thousandth of the cost only ten years ago. It should also be mentioned that certain attempts had been made to build multiwire counters, but these had not proved practical. Before discussing them it will be interesting to say a little about the properties of the proportional counter amplification in gases.

The conventional proportional counter was, for a long time, one of the detectors most widely used by nuclear physicists. In most cases, however, it was replaced by the scintillation counter as soon as the latter was introduced. There were numerous reasons for this, the most significant being its poor time resolution and the restrictions on its shape, which was normally cylindrical.

A proportional counter generally consisted of a very fine wire (less than 0.1 mm in diameter) located on the axis of a cylinder containing a suitable gas. When a particle traverses the cylinder and liberates ions in the gas the electrons are attracted to the wire, which is at a positive potential, in such a way that, in the vicinity of the wire, where the electric field gradient is high, electron multiplication occurs : a single electron creates an avalanche of M electrons (M being the multiplication coefficient). M can reach a value of 10^5 in stable conditions which makes it easy to detect very small energy losses since the electron avalanche can amplify the initial signal by this factor of 10^5. The avalanche starts at a distance from the wire of the order of the radius of the wire and develops rapidly, generally in less than 1 ns. The poor time resolution is due to the time taken by a primary electron to come near to the wire. This time depends upon the distance between the particle causing the electron and the wire ; in typical cases, for a distance of 1 cm it is several hundred nanoseconds. (We will see that with the multiwire chambers at least one order of magnitude has been gained on this figure.)

The cylindrical shape does not lend itself to providing large surface areas for detection of particles, but flat multiwire counters were built a long time ago for special purposes. These were usually composed of wires situated between two flat electrodes, alternate wires having the potential of the planes and a positive potential in relation to the planes. There were two reasons for this.

At first sight, it would seem that the equipotential lines are more regular in such a design and that there are no 'dead' areas between the wires. In fact, however, as the Figure on page 176 shows, even with a plane of wires all at the same potential, the equipotentials are cylinders in the region close to the wire which is of importance for amplification.

The main reason, however, for alternating the potentials in the old systems was the fear of coupling between wires. It is clear that capacitative coupling occurs between wires and, if a pulse is communicated to one of the wires, the adjacent wires are affected. If the electronic system is built to be sensitive to a wide range of pulse intensities there would be signals coming from a large number of wires and this would hamper localization of the particle. But by using alternating potentials on adjacent wires, the wires on each side of the wire receiving the true signal act as screens.

This view of the importance of coupling has proved to be incorrect. The situation is not at all what one might expect, and actually proves to be an advantage. It might be expected that capacitative coupling would result in a pulse of the same sign on all wires in a plane. As the coupling acts in a different manner, it is worthwhile describing it, since it bestows interesting and unexpected properties on the chambers.

When the wire collects the electrons from an avalanche which has occurred against it, the induced pulse is virtually zero : if collection of the charge (—Q) produces a pulse (—Q/C) in which C is the capacitance of the wire, the positive ions, since they are suddenly deprived of their electrons and are still very close to the wire (within 10^{-3} cm) because they move more slowly, will produce a pulse of (+Q/C) which cancels the first one. On the other hand, as the positive ions begin to move in the very intense field surrounding the wire, they induce charge (—Q') on the wire, with a rapid rise-time whilst they cover the distance of high field gradient, which is of the order of the diameter of the wire. The rise time varies between 10 and 100 ns in the chambers we have studied. If, during this time, the induced charge on the wire is (—Q'), it is (+Q') on the adjacent conductors, and

$$+ Q' = Q'_i + Q'_2 + Q'_s \ldots$$

where the indices 1, 2, ... designate the other conductors : adjacent wires, high voltage wires, etc.

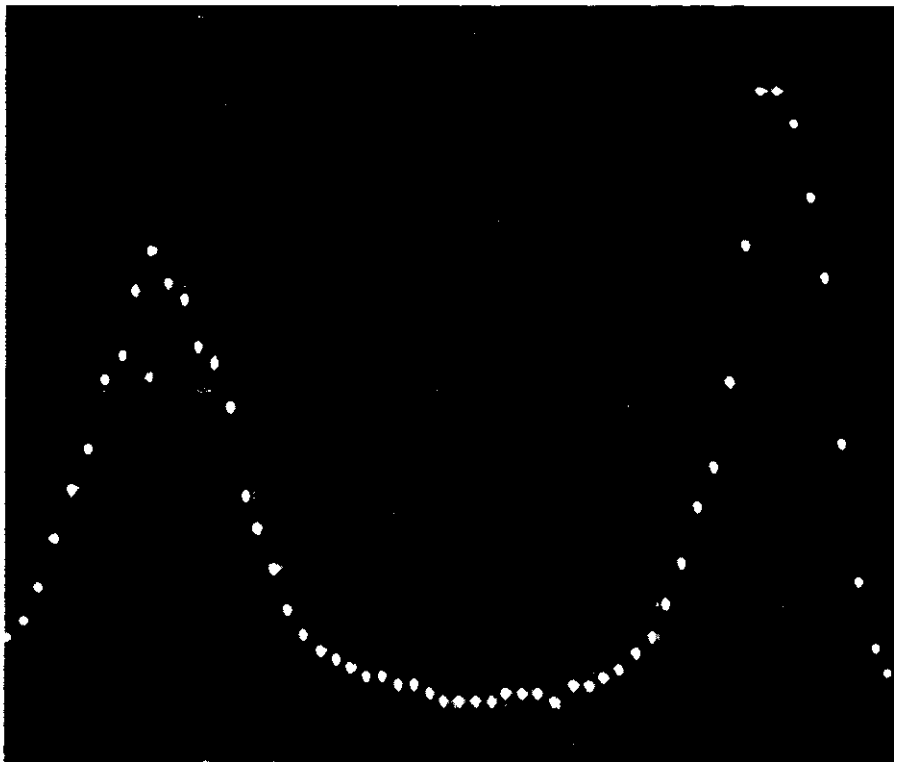
This opposed coupling has two important consequences :

a) it enables the position of the pulse to be traced to the wire which picks up the electrons. The positive pulse cancels the negative pulse on other wires which would result from capacitative coupling only

b) it induces positive signals on the high voltage electrodes which can be used for various purposes, such as measuring the total energy loss in the chamber (as it can integrate the pulses of several wires) or position-determination giving another coordinate. The same chamber can, if the three wire planes are differently arranged, provide three coordinates ; this prevents any ambiguity

A multiwire proportional chamber produced these signals of the profile of a secondary beam from the proton synchrotron. The two peaks correspond to the beam cross-section and particle distribution in two directions at right angles. The chamber was here monitoring a burst containing 50 000 particles lasting 100 ms.

Right : A chamber in use for an experiment at the synchro-cyclotron.





resulting from the combination of co-ordinates when there are several tracks.

There are certain chamber applications (such as the detection of X-rays or neutrons) in which the secondary charged particle cannot normally pass through two chambers ; the possibility of measuring two coordinates with a single chamber opens up a wide range of applications in these particular fields.

Some properties of multiwire proportional chambers

Let us consider a very simple structure, similar to that of a wire spark chamber : a series of wires, each 20 or 30 {i in diameter, stretched in a plane between two other planes 7 mm apart. The separation between the wires in the planes themselves is 2 to 3 mm. The two outside planes are composed of taut wires, 0.1 mm in diameter, one having its wires running in a direction parallel to the wires in the central plane and the other in a direction at right angles. Circulating between these electrodes is a gas, such as an argon-isobutane mixture (80% and 20%). A constant negative voltage of 5 kV is applied to the two external planes. Each wire is connected to a very compact integrated circuit which amplifies and shapes the current pulses received by the wire.

This structure operates as a multiwire proportional chamber and I would like to describe, briefly, its properties as they appear from the studies made by several groups at CERN. I will refer only to the most promising aspects and add that further work is certainly necessary if we are to avoid any unpleasant surprises when full-scale versions of the detectors are finally made.

Pulse height

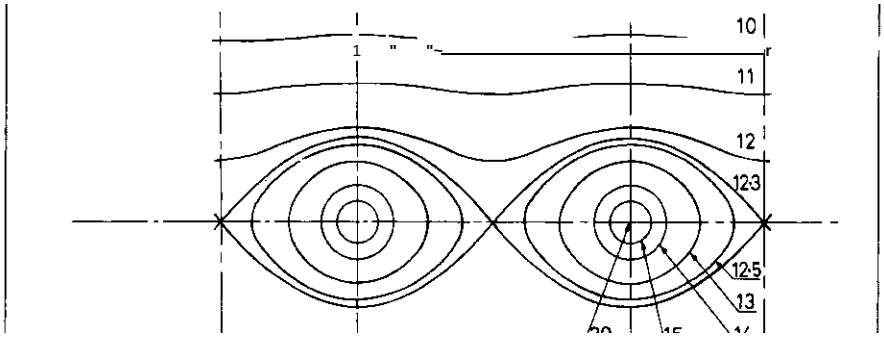
Pulses of 200 mV can sometimes be obtained from a wire, following the passage of a particle which loses energy of 6 keV in the gas. The chamber is then operating at the upper limit of the proportional amplification region ; depending on the diameter of the wire and the type of gas, it enters the Geiger-Muller region finally giving spark breakdown if the voltage is taken higher. It is convenient to use an electronic system capable of detecting all pulses of 0.5 mV and above. Using wires with a 3 mm separation, it has been shown that the efficiency exceeds 99.9% for particles producing minimum ionization.

Detecting simultaneous tracks

A pulse will cause a disturbance of the order of 10^{-6} on the potential of the wire which receives it. No drop in the efficiency of the chamber to detect particles is expected, irrespective of the number of particles arriving simultaneously. This has been verified for up to four simultaneous particles.

Resolution time

With a 2 mm separation between the wires, the maximum time fluctuation which has been observed for particular gases is 24 ns ; with a 3 mm separation, the time is 36 ns. The accuracy of the chamber in measuring times precisely is therefore the same, to within a factor of two or three, as that of the simplest scintillation hodoscopes.



A diagram showing the way the electric field is distributed around the wires in a multiwire proportional chamber. Note the way that the equipotentials are cylindrical in the immediate vicinity of the wire where the proportional amplification occurs. The figures denote voltages.

The Table compares some typical properties of different detectors.

	Scintillation hodoscope '	Wire spark chamber	Multiwire proportional chamber
Self-triggering	Yes	No	Yes
Minimum space resolution	2 mm to 1 cm (depending on length)	0.5 mm	1 mm
Time resolution	5 ns	500 ns	25 ns
Dead-time	less than 100 ns	100 ns	less than 100 ns
Unit price (relative)	50	1	5
Minimum thickness (relative)	100	2	1
Magnetic fields	sensitive	sensitive	insensitive

Localization

On collecting the electrons, which the passage of a charged particle liberates in the gas, a wire in the central plane produces a negative pulse. The adjacent wires, provided that they have not collected any electrons, will receive a positive pulse (for reasons brought out above). Consequently, if amplifiers are used which are sensitive to a single polarity (they only click when they receive a negative pulse), this type of coupling between adjacent wires presents no difficulty. Using wires with a 3 mm separation, a precision of ± 0.76 mm has been obtained when measuring the position of a particle trajectory by means of four chambers. With a 2 mm separation, we can expect an accuracy of ± 0.6 mm, which is comparable to that of spark chambers.

Energy Measurement

If one of the external planes is in the form of a metal sheet, mesh or a number of wires connected electrically together, it will receive a positive pulse proportional to the total energy lost by the charged particle in the chamber. The accuracy to which these chambers can measure the energy is equal to that of the best cylindrical proportional counters (15% at 6 keV). To be able to distinguish roughly between particles which give very different ionization (for example, a proton compared with a pion at 300 MeV/c) the resolution is sufficient.

Multiple coordinates

If the orthogonal wires of the external planes are also connected to amplifiers, they will detect positive pulses whose position will be located, though with less accuracy than in the case of pulses on central wires. Nevertheless, they enable a second coordinate of the track of the particle through the chamber to be obtained. In the case of neutral radiation (for example, X-rays or neutrons) which produce charged particles in the chamber that have not enough energy to leave the chamber, the multiwire proportional chamber is the only detector which provides both coordinates.

Use as a hodoscope

If the wires of the high voltage planes are grouped together (for example, in 5 cm bands), a pulse is collected on one band after the passage of a particle. This will provide a rough indication of particle position, similar to that given by a conventional hodoscope, and can be used to trigger other detectors or operate read-out systems. If the angle of the bands on the high-voltage planes is varied, not only will the chambers be able to provide both coordinates, but it will also be possible to measure the coordinates of several particles with the one chamber.

Counting rate

The counting rate is limited in practice by the electronic system which collects the pulses. A detection rate of 10^6 particles per wire per second seems possible with a suitable electronic system.

Comparison with other detectors

A comparison with conventional wire spark chambers shows that the time resolution is ten times better, spatial resolution is equivalent or perhaps a little poorer. In certain cases, however, by using the correlation between the arrival time of the pulse and its position, more accurate measurements can be made. Chambers have been built to exploit this effect, and an accuracy of ± 100 [JL in positioning the particle track was obtained.

Where the comparison is not so favourable is in the price. It is likely that 50 Swiss Francs worth of components per wire will be needed to take the pulse from the wire through a ^ate to a memory. This is higher than the price per wire of a conventional chamber and for the giant systems which are planned to be built (10^5 wires and above) the price difference might be prohibitive. Most physicists feel, therefore, that, in such large systems, the multiwire proportional chamber will be used more often to trigger magnetostriction wire chambers. Scintillation hodoscopes, for their part, still maintain the lead where time resolution of better than 10 ns is required, but they introduce more matter in front of the particle, do not provide the same spatial resolution and are more expensive.

Conclusions

My description of the properties of multiwire proportional chambers has, perhaps, been rather optimistic because, at present, we lack sufficient experience to know what their limitations are. Nevertheless, two experiments at CERN are already using these chambers, and they are standard equipment for beam profile measurements. A detector of this type with at least 5000 wires is being designed by a CERN-Heidelberg group.

Finally, there are several groups investigating the various aspects of the mechanism of amplification in the chambers. It may therefore be expected that practical information will very soon be available for work on large units. There are already certain applications where proportional chambers can probably play a very useful part : in low-energy nuclear physics, as detection equipment in the focal planes of spectrometers, and, maybe, in medical physics for constructing large-surface detectors which measure the spatial distribution of X-rays emitted by radioactive elements in human organs. These various possibilities are at present being actively studied.