EVOLUTION OF SOME PARTICLE DETECTORS BASED ON THE DISCHARGE IN GASES

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1. INTRODUCTION

In this year 1969, if we look into the experimental techniques used around high-energy accelerators we observe the following situation: the bubble chamber is still an important tool, absorbing a large fraction of the activity of the community of experimentalists. Its evolution is directed towards a greater efficiency and rapidity in the automatic evaluation of pictures, and towards the building of giant chambers.

What is it that keeps the bubble chamber surviving in the hostile surroundings of fast-growing counter techniques? Let us quote, for discussion, some qualities and defects of a typical large hydrogen bubble chamber, 2 metres long:

- Accuracy in localization	70 μ
- Interaction length	10 m
- Minimum detectable momentum	1200 GeV/c
- The target and the measuring media are identical, permitting the visualization of very complex configurations around the interaction point.	
- Sensitive time	milliseconds
- Non-selective data-taking	
- Maximum number of pictures	several per beam burst
- Maximum number of beam particles per picture	20
- Maximum number of pictures analysed in one experiment	$\sim 10^6$

As we shall see, it may well be that there is not any single property of the bubble chamber that cannot be equally well achieved by an electronic detector; or that could be achieved at least in the foreseeable future. However, there is not any one detector that incorporates all these properties at the same time.

The electronic detectors usually look at a very specific aspect of a reaction, and do it with the highest accuracy. These days one hears about wanted accuracies of 10^{-4} in symmetry problems, requiring at least 100 million events that are asked for in order to confront some theory with nature. In these two lectures, I am going to summarize the properties of some of the detectors that are commonly used in counter experiments to localize charged particles, and which are based on discharge in gases under the influence of electric fields. Since I also wish to underline the trends in the research being carried out on these detectors, I will refresh your memory about some basic facts of gaseous amplification in homogeneous and inhomogeneous fields.

2. FIELD DISTRIBUTION AROUND ELECTRODES MADE OF WIRE

Since I will have to discuss phenomena occurring in chambers where the electrodes are made of wires, let me start immediately with the properties of such structures. They are of general importance, since streamer chambers are often equipped with electrodes made of wires in order to have them transparent, and they are used in all types of wire chambers.

Let us consider two cases. In the first one, the electrode made of wires is facing a single electrode. In the second one, it is placed in the medium plane of two other electrodes.

In both cases, the field is very nearly uniform at distances from the wire greater than the wire spacing. This is why such electrodes are usually a good approximation for plane electrodes. However, as can be seen from the equipotentials (Fig. 1), a sizeable fraction of the potential can be lost in the gradient around the wire, and this is something of a nuisance when one aims only at obtaining a given uniform field at the lowest voltage. In the case of the symmetrical structure, the region around the wire is of great interest in the proportional detector, and it is quite easy to have a quantitative evaluation of the field distributions.

We assume an infinite assembly of wires, of diameter d, spacing s, distance from the wires to the external electrodes L. We centre the coordinate system on one wire, with x in the plane of the wires and y perpendicular to the plane. Then for infinitely thin wires, a straightforward calculation, done by summing up at one point the effects of all the wires, gives these very simple formulae for the field along the three symmetry lines:

$$V(0,y) = 2q \ln \sinh \frac{\pi y}{s} \rightarrow E_y = \frac{2q\pi}{s} \coth \frac{\pi y}{s}$$

$$V(x,0) = 2q \ln \sin \frac{\pi x}{s} \rightarrow E_x = \frac{2q\pi}{s} \cot \frac{\pi x}{s}$$

$$V(s/2,y) = 2q \ln \cosh \frac{\pi y}{s} \rightarrow E_y = \frac{2q\pi}{s} \tanh \frac{\pi y}{s} .$$

At very small distances, such as 100 μ, sinh πy/s and sin πx/s are equal within 10^{-3}. We thus see that the infinitely thin wire approximation is a very good approximation to the physical situation, and the wires of that thickness can be assimilated to an equipotential of the field distribution to a great accuracy. A rigorous treatment of these problems can be found in many textbooks[1].

At a distance s/2 from the wires, the field is uniform within 10%. At a distance 1.2 s, it is uniform within 10^{-3}.

In the vicinity of the wires, the field varies as 1/r, as in a cylindrical chamber. We will see that this feature is one of the essential reasons why such electrodes can work like independent arrays of proportional counters.

3. EFFECT OF ELECTRIC FIELDS ON FREE ELECTRONS IN A GAS -- MEMORY OF CHAMBERS

If we apply electric fields to such structures, we meet different situations according to the field amplitude. Let us assume that the gap is filled, at atmospheric pressure, with noble gases where the electrons liberated by ionizing particles or by discharges are free from attachment to the heavy atoms. The mean collision free path of electrons is typically 10^{-5} cm in argon and 3×10^{-5} in helium. Fields of considerable strength would be required in order to give to an electron enough energy between two collisions for it to reach the energies necessary to ionize the atoms of rare gases (A : 16 eV; Ne : 21 eV; He : 24 eV). But the electrons lose only a negligible fraction of their energy in one elastic collision, and they can capitalize the energy gained between two collisions.

The mean free path for ionization by electrons is strongly dependent on the gas composition, and is typically, for voltages of about 10 kV/cm, applied in spark chambers of the order of 10^{-3} cm; it is close to 10^{-4} cm in the region around the wire of proportional chambers where the field reaches 10^5 V/cm.

At equilibrium, with no electric field, the average energy of the electrons is the same as that of the ions, so the random thermal velocity of the electrons is much higher than that of the ions. With an electric field, the energy of the electron is higher, and one defines a fictitious electron temperature corresponding to this increased energy. This temperature can be decreased by mixing small amounts of complicated organic gases. These molecules can be broken by the electrons in inelastic collision, as it requires only a few electron volts to do this. In the electric field, the electron distribution drifts towards the anode with a velocity that is dependent on the field and on the electron temperature. The lower the temperature, the higher the velocity. This is partly why organic additives are added in proportional chambers since, as we will see, this velocity controls the time resolution.

The field dependence of the drift velocities in a gas made of argon + organic additive is illustrated by Fig. 2. The velocities are in the range of 10^6 to 5×10^6 cm/sec in the mixture of A + methane, widely used in proportional counters. In the neon-helium mixtures used in spark chambers, the drift velocity is also of the same order of magnitude.

If we apply a voltage of 4000 V to a structure made of wires of 20 μ, 2 mm apart, with a gap of 8 mm, we have a field of 2.2×10^5 V/cm at the wire surface. It decreases as $1/r$, and it is of only 3000 V/cm in the uniform region. Only the very limited region around the wire has enough field to have the electrons multiplying by inelastic collision. The electrons liberated in the gas outside this region will simply be drifted towards the wire where the amplification occurs.

If, however, we apply fields (10 kV/cm in spark chambers with neon filling, or 20 kV/cm in streamer chambers) that are such that even in the uniform region the mean free path for ionization is smaller than the gap length, then very fast phenomena occur as we will see, and the amplification at the wire has no time to play a role.

These predisruptive phenomena leading to the sparks are of basic importance for the understanding of spark chambers. Their description can be found elsewhere[2].

I will come back later to the case where the only region of amplification is concentrated around the wire. However, in spark chambers all the intermediate situations coexist to some extent. Between the application of high fields leading to break-down, low d.c. fields are applied to clear away electrons from old tracks, and it is this time of clearing that determines the "memory" of the chambers, or its time resolution. It is usually, at best, of the order of 300 nsec for small-gap chambers, and often of the order of 10 μsec for large-gap streamer chambers. Figure 3 shows the variation of the memory of a spark chamber as a function of the clearing field.

4. GASEOUS AMPLIFICATION IN THE UNIFORM REGION

If, in the region of uniform field, one electron makes α ionizing collisions per centimetre, then the number of electrons produced in the development of one avalanche along a distance X is

$$N = \exp(\alpha X) .$$

All exponential developments have to come to an end. When the field is maintained, different processes occur in succession, each of them corresponding to different types of detectors: the avalanche multiplication, the streamer process, the breakdown of a spark.

4.1 Region of avalanche multiplication

Let us take neon as the medium. The development occurs at about the same speed as the drift motion; in 10 nsec we have reached a dimension of about 1 mm. Because of diffusion this avalanche has also grown laterally to a dimension of about 1 mm.

The ideal visual gaseous detector would be the one for which we could interrupt the development at this stage and take pictures of it. However, nature has put a kind of universal limit on this growth. For $N = 10^8$, the electric field of the positive ions compensates the external field and the avalanche stops.

Is 10^8 sufficient?

Experiments show that in neon there is about one visible photon per electron. With an optical system accepting 10^{-5} of the total solid angle, 1000 photons can be concentrated on one grain of 7 μ of the photographic emulsion and can trigger it. But this is not sufficient to make it stand out from the background.

If we were to use image intensifiers, then with modern photocathodes 10% of the photons can produce an electron giving a spot that has the brightness needed for photography. This is the technique used at CERN by F. Schneider, and with it he can easily see avalanches. Figure 4 shows one of his resulting pictures. He estimates that the accuracies that can be reached by this method are 0.28 mm in the direction orthogonal to the electric field and 0.4 mm in the direction of the field[9].

Since in the future such intensifiers are going to progress and become cheaper, this technique will have more applications. It should in principle make feasible the visualization of complex events around the vertex in dense gases, thus competing seriously with one of the main attractive features of the bubble chambers, and even with additional flexibility. For instance, one could imagine a pressurized helium avalanche chamber in which hypernuclei are formed, and in which such a rare and theoretically important process as the β-decay of the hyperfragment is studied. One of the most important parameters, the direction of the recoil proton, is out of reach with helium bubble chambers because the range is too low. In an avalanche chamber, the pressure could be adjusted to fit to the problem. So the progress in high-voltage pulses together with the progress in light amplifiers may open the way to a serious competitor for bubble chambers in the field where they are excellent.

4.2 Streamer chambers

For the time being, it would appear to be more practical and cheaper, and also more accurate, for large systems to apply the voltage for a longer time and to enter into the streamer region. If we keep applying the voltage after the critical size of 10^8, we have secondary avalanches formed around the initial avalanche. Since the electric fields are higher in front of and behind an avalanche, these avalanches develop faster. This is the reason for the line of avalanches along the electric field, called streamers. The propagation speed is about 10^8 cm/sec. In 10 nsec we have a streamer length of 1 cm. If we look through transparent electrodes in the direction of the electric field, and if the depth of focus is higher than the length of the streamer, we can increase the amount of light in proportion to the number of avalanches, about a hundred. If we want to keep a stability of 10% in the streamer length, we need a stability of 1 nsec in the pulse length. Even like this, and using the best available films with demagnifications of 80, apertures of about f/2 are necessary in order to have a mediocre image. The accuracy reached with the present techniques is 0.5 mm in the directions orthogonal to the electric field, and about 2 mm in the direction of the field. This is attained with neon at atmospheric pressure at fields of 20 kV/cm. With helium, fields of 30 kV give good images. The use of hydrogen is still not practical. To study interactions in hydrogen, it is necessary to use hydrogen targets inside the chamber. One then loses the view of the vertex, but in many cases this is irrelevant; and recently published results of experiments show that such a technique is superior to bubble chambers for the study of very complex events such as photoproduction of resonances decaying with a high multiplicity. In such reactions the requirement of a production of hadrons in the reaction reduces by orders of magnitude the background due to electromagnetic interaction, which still represents 90% of the pictures.

4.3 Spark chambers

If we keep the voltage on while the streamers grow, then they touch the electrodes and the real spark occurs. It is a propagation of charges with a phase velocity that is huge. It can reach 10^{10} cm/sec. The light can be increased by three orders of magnitude if enough energy is delivered by the pulse.

4.3.1 Large-gap chambers

There are cases where the interaction between avalanches gives rise to an instant streamer, and the spark follows the line of the initial avalanches. Such avalanches are in use in some laboratories, and even at CERN you will see such an automatic chamber in the boson missing-mass experiment. One of its virtues is that it is 100% efficient for any number of particles, but this property is now shared by narrow-gap wire chambers built as transmission lines.

The only remaining virtue of a wide-gap chamber is to my knowledge, that in a strong background of X-rays it may lead to a reduction of the spurious tracks, since very curled tracks are suppressed or have a lower efficiency than nearly straight tracks connecting the electrodes. In the most general case, gaps of below 1 cm are used.

4.3.2 Properties of small gap chambers

I have already mentioned the memory as being one of the main characteristics. I should now mention the localization accuracy.

With optical chambers, the accuracy is a function of the angle. Figure 5 shows that the accuracy varies from 0.2 mm below 15° to 1 mm at 45°; this is because a spark may break down from any point along the trajectory. One can fight against this by reducing the gap width; but then there is a drop in efficiency. In neon the number of primary ion pairs per centimetre is 12. In one millimetre there is a strong probability of having no electron.

It was recently emphasized by Alvarez that there are great advantages in trying to use liquid argon as a medium[4], and active research is being performed on this subject in several laboratories.

Since it has been demonstrated in the past that electron multiplication occurs in liquid or solid argon, one can hope to reduce the thickness of the gaps to 50 μ and to have accuracies of 5 μ.

This is of fundamental importance for the physics around the 300 GeV machine, where any gain in accuracy means a gain in length of the spectrometers or in the magnetic field strength.

For the time being, a more simple approach has been undertaken at CERN by C. Rubbia. At high pressures he uses gaps of 1 mm, and has shown that accuracies of ±30 μ can be reached with minimum ionizing particles.

I should point out that such accuracies have already been achieved by Fischer[5], who also used a narrow gap, but with particles 10 times more ionizing than the minimum, which is equivalent to a higher pressure.

5. AUTOMATIC SPARK CHAMBERS

Up to now I have mentioned the two properties that gave incentive to the wide use of spark chambers: the memory and the accuracy. The accuracy was poorer than that of bubble chambers, but the memory allowed the selection of events by additional counters, which resulted in a considerable increase in statistics for some phenomena.

However, the limitation came again from the number of pictures that one can normally handle with a decent budget, and within a decent time, and the automatic chamber provided an answer to it.

I am not going to discuss all the methods that have been invented and even used: the vidicon method, the sonic chamber, the current division method, the wire chambers with core read-out, with magnetostrictive read-out or with capacitive read-out. The description of some of them can be found in the literature[2,6].

I just wish to say some words about the methods that have been most widely used in large high-energy laboratories: the wire chambers.

5.1 Wire chambers with core read-out

The electrodes are made of wires spaced by a distance s. When a spark occurs, the current will spread among the wires close to the spark. The problem is to read out the wire transporting the current.

The first method, put forward by Krienen and still popular, is to have each wire going through a memory core that gets flipped by the current. Two other wires also go through the centre of the cores: a read-out wire and a sense wire.

The technology of these read-out systems is well worked out, and at CERN several systems with 50,000 wires are in use. The accuracy reached is about ±0.3 mm for 1 mm spacing for tracks orthogonal to the planes.

The weakness of this method lies in its cost and its sensitivity to magnetic fields. Even fields of 100 gauss can prevent the cores from flipping.

The main advantage is that any number of sparks can be handled, and recent progress in the construction has brought the efficiency close to unity for almost any number of sparks.

5.2 Wire chambers with magnetostrictive read-out

The second method, which is widely developed, is the magnetostrictive method.

A magnetostriction line is placed across the electrode wires, at a small distance from the electrodes. When the current passes through the wire, the magnetic field reorients the magnetic domains of the magnetostriction line. An elastic signal propagates along the line at a speed of about 5 mm/μsec. This signal can be read out with a pick-up coil placed at the end. By measuring the time of arrival of the signal, one knows the position of the wire responsible for the current signal.

The wire has to be slightly magnetized longitudinally by a field of about 100 gauss to give its best signal.

This method has several attractive features.

It can, in principle, work in a magnetic field. If the magnetostriction lines are orthogonal or nearly orthogonal to a uniform magnetic field, they operate very well. If coordinates with several orientations are to be measured, then certain problems arise; however, these can be overcome by several methods. One method that has been described recently for a system of cylindrical wire chambers built into a large magnet for use at the Brookhaven AGS, is to have the wires supported by weightless rigid material and oriented in different directions, but all coming out parallel to the magnetic field at the place where the magnetostriction line measures the position.

Another advantage of the above-mentioned method is its low cost. The increase in the size of the chambers leads to almost no increase in the read-out system if one is ready to sacrifice reading speed. Systems with 10^5 to 10^6 wires are under construction, or are envisaged in the near future, using this technique.

Let me mention the double spectrometer of Lindenbaum[7)], where complex events with two V's are selected, and where chambers of 7 m are to be used. However, it should be stressed that in non-uniform magnetic fields, such as those often encountered inside large magnets, this method also fails because the signals become too small.

5.3 Wire chambers in magnetic fields

Different techniques have been designed to replace these two methods in case one wants the chambers inside strong inhomogeneous magnetic fields. One is the sparkostrictive method, the other one is the capacitive storage method.

In the first one, the current in the wire is used to produce an auxiliary spark in a line in which it produces a sound wave, the time of arrival of which is measured via piezo-electric transducers.

In the second one, the charge of a wire is fed to a large capacitor[6], typically 10^3 pF, where it is stored for some milliseconds; this brings it to a voltage of, say, 15 V.

After an event, an electronic system reads out each capacitor and brings it to ground afterwards. The same read-out hardware as that used for cores can be employed.

Thus we see that in principle, even in the most general case, we can stuff the space with detectors giving typically an accuracy of ±0.3 mm to ±1 mm, depending on the direction, with a repetition rate of about 200 events/second, i.e. 20 to 50 events per machine burst. Rather great statistics can thus be accumulated.

5.4 The vidicon method

Finally, the vidicon system is now strongly advocated by some physicists. Their enthusiasm is based on the improvement of the properties of the commercial vidicons, and on the fact that for very complex arrangements with hundreds of gaps it is the only economical approach.

I refer you to the proceedings of the last Conference on Instrumentation for High-Energy Physics, held at Versailles in September 1968, where each of the methods I have mentioned is dealt with by several authors.

I now wish to speak of the most recent development, which makes use only of the amplification in the inhomogeneous part of the chamber.

6. THE MULTIWIRE PROPORTIONAL CHAMBERS[9,10]

If an electric field is applied to the structure represented in Fig. 1, and if it is such that inelastic collisions start occurring in the proximity of the wire, then we have what is called the proportional amplification. The reason for this is that if a particle produces electrons in the region far from the wire, it is collected on the wire and the signal is proportional to the number of electrons. Each wire operates as in a normal cylindrical counter, and the old theory relative to these counters applies.

During many years, two factors limited the development of this technique. Before solid-state amplifiers became available the volume and the cost of the necessary electronics were too excessive. But the main factor was a widespread false appreciation of the electrostatic interaction between two neighbouring wires.

It was believed that because of the capacitive coupling, the wires next to the amplifying wires would receive a sizeable part of the signal, and for this reason many attempts were made to have each sensitive wire separated by a shielding wire. However, this was costing a factor of two in the spatial resolution, and was limiting the lower distance between wires since a high voltage had to be applied between them.

In fact, if it is true that when you send a negative pulse, with an external generator, on one wire, you receive a sizeable negative pulse on the neighbouring wire, then the situation is different when you detect a particle by proportional amplification on a wire. You have indeed a negative pulse on this wire, but positive pulses on the neighbouring ones. This effect is due to the mechanism generating these pulses, namely the motion of the positive ions in the strong fields around the wires. This effect is responsible for the perfect localization of the pulses on the sensitive wires, irrespective of the distance between the wires. It is sufficient to have amplifiers that are sensitive only to the good polarity, to avoid the spurious effect of capacitive coupling between wires.

6.1 Limits of proportional amplification

It was observed[8] that the proportional amplification ceases when the size of the avalanche exceeds a given value corresponding to about

3×10^6 ion pairs. In other words, with one electron we can reach a gain of about 10^6, which means that for the average energy loss corresponding to a minimum ionizing particle traversing 1 cm of argon, we can expect a maximum average gain of 10^4. In fact, since one is interested in detecting losses 10 times smaller than the average, one can push the gain to 10^5.

The capacity of wires of 20 μ spaced by 2 mm is about 10^{-1} pF/cm, and the limit of 3×10^6 ions corresponds to about 5×10^{-13} Coulombs/cm, while the charge per cm at 3 kV is $10^{-13} \times 3 \times 10^3 = 3 \times 10^{-10}$ Coulombs/cm. However, over the avalanche length, which may be of the order of 10^{-1} to 10^{-2} mm, the local positive charge facing the avalanche is of the same order as the maximum observed charge. We can thus explain this effect of gain saturation by space charge, similar in a sense to the limit reached by the critical avalanche in a uniform field.

If we keep increasing the voltage, then photons emitted by the positive cloud start playing a role. The development of avalanches along the wire leads to the Geiger-Müller mechanism. I will not discuss this in these lectures, despite the fact that the use of multiwire chambers in the Geiger-Müller mode may have some future.

If we stop in the porportional region, what can we expect?

The capacity of a wire, because of its connections, is almost always larger than 20 pF. The maximum pulse-height that we can have is about 100 mV.

Because of the Landau fluctuations in the energy loss, we expect a large energy spread. In practice, it appears that in order to have 100% efficiency with minimum ionizing particles, we need to be sensitive at the level of 0.5 mV at least.

Such a method is clearly dependent on how well one can use such small pulses. Before discussing this, I wish to summarize the properties of these chambers, and to explain to you why a great effort is being made by several groups to develop them.

6.2 Spatial resolution

One may wonder how close to each other one can bring the wires and still keep them working independently.

As already mentioned, if one sends pulses to a wire with a generator, one finds induced pulses of the same sign on the neighbouring wire, and of a size increasing when the wire spacing is decreasing. The pleasant surprise with these chambers is that when one observes a negative pulse induced on a wire by an avalanche, the pulses induced on the neighbouring wires are of opposite sign.

A naive belief is that the collection of electrons is responsible for the negative pulses. This is not true. Since the most important part of the avalanche is produced at distances from the wires the order of microns, the effect of the collection of the negative charge $-Q$ is almost completely counterbalanced by the effect of the appearance of the positive charge $+Q$ so close to the wire. It is only when the positive ions move fast in the fields that reach several hundred kilovolts near the wire, that a negative pulse is induced. This motion induces a charge $-Q$ on the wire, and a charge $+Q = Q_1 + Q_2 + \ldots$ on the surrounding electrodes, like the neighbouring wires on the high-voltage electrodes. This is why we have an excellent localization on the wire collecting the avalanche.

Indeed, if tracks are inclined, it may well be that electrons liberated along a trail get amplified on different wires.

With wires of 20 μ diameter, distances of 2 mm between the wires give an easy operation. It is possible to detect a few ion pairs lost in the gas, by using electronics sensitive to 0.5 mV. If one wants to go to better resolutions, we should have in mind that the field around a wire is $2q/r$, where q is the charge per unit length. By increasing the number of wires, we decrease the charge per wire and we have to compensate this by increasing the voltage. The relation between the charge and the different parameters of a chamber is:

$$q = V/2 \left[\ln \sinh \frac{\pi L}{s} - \ln \sinh \frac{\pi d}{s} \right] ,$$

where L is the distance grid-wire, s is the distance between wires, d is the wire diameter. For $L = 8$ mm, $d = 20$ μ, this charge varies in the ratios 1, 1.27, 2.2 when s goes from 1 mm to 2 mm and 3 mm, respectively for a given voltage.

At too high voltages trouble occurs, such as corona effects on the external electrodes. If you consider that we are dealing with millivolt pulses, whilst 10 kV may be necessary for 1 mm spacing, it is clear that the finest break-down is catastrophic.

An easier operation can be obtained by disentangling the region of amplification and the region of drift by means of an additional grid[11]) placed at a small distance from the wire. At a distance of 1.2 s, the field is already uniform within 10^{-3}, so the addition of a metallic grid placed at this potential does not alter the field distribution. We observed that with 20 μ wires placed at 1 mm distance, with a grid at 2 mm, we have had perfect operation at voltages of 3 kV on the screen and 4 kV on the external electrodes, whilst 10 kV would have been necessary with a normal single-gap structure.

6.3 Time resolution

With chambers having 3 mm spacing and argon-isobutane filling we obtain a maximum jitter time of 36 nsec; with 2 mm spacing it goes down to 25 nsec; with 1 mm it reaches 18 nsec (Fig. 6), but there the electronics we used contributes in a non-negligible way.

Even there we observe a correlation between the position of the track between the wires and the time delay of the pulse arrival.

A repetition rate of 10^6/wire is possible if the electronics on each wire can deal with it.

6.4 Operation problems

We are now faced with the problem of using these chambers.

Compared with spark chambers, we have gained a factor of 10 in time resolution and a huge factor in repetition rate. We are now facing the problem of using a hodoscope with thousands of elements. The difference with a scintillator hodoscope is in the slightly poorer resolution time, but there is a great decrease in the amount of matter (a factor of 100), and a gain in cost per element (a factor of 10).

We have lost an important quality of spark chambers, namely the memory. We could regain it by using the drift space of a modified chamber, and pulse it. The grid will shield the wires. We then lose the resolution time and just win some repetition rate with respect to a spark chamber, but at a very high cost.

The ideal circuit that we need with these chambers should have the following function: amplification from a level of 0.2 mV, shaping, delivery of undelayed pulses for fast decision-making logic, delivery of delayed pulses and transmission gates to control the admission in the memory, storage and read-out.

Since we are planning detectors with 10^5 wires, it is clear that we are considerably dependent on the reliability and the cost of such a system.

There is room for much imagination and ingenuity in the development of the electronics systems connected to these chambers, in order to bring their cost to a level that justifies their use in all the cases where they are superior to other detectors in physical performance.

7. CONCLUSION

In these two lectures I wanted simply to give a rapid survey of some of the tools that are now in the hands of the experimentalists, and to give you some understanding of those techniques that are undergoing rapid evolution: the avalanche and streamer chambers for the visual techniques dealing with very complex configurations; and the proportional multiwire chambers, which will probably, in most of their applications, be associated with large systems of wire spark chambers to act as a trigger hodoscope with many elements.

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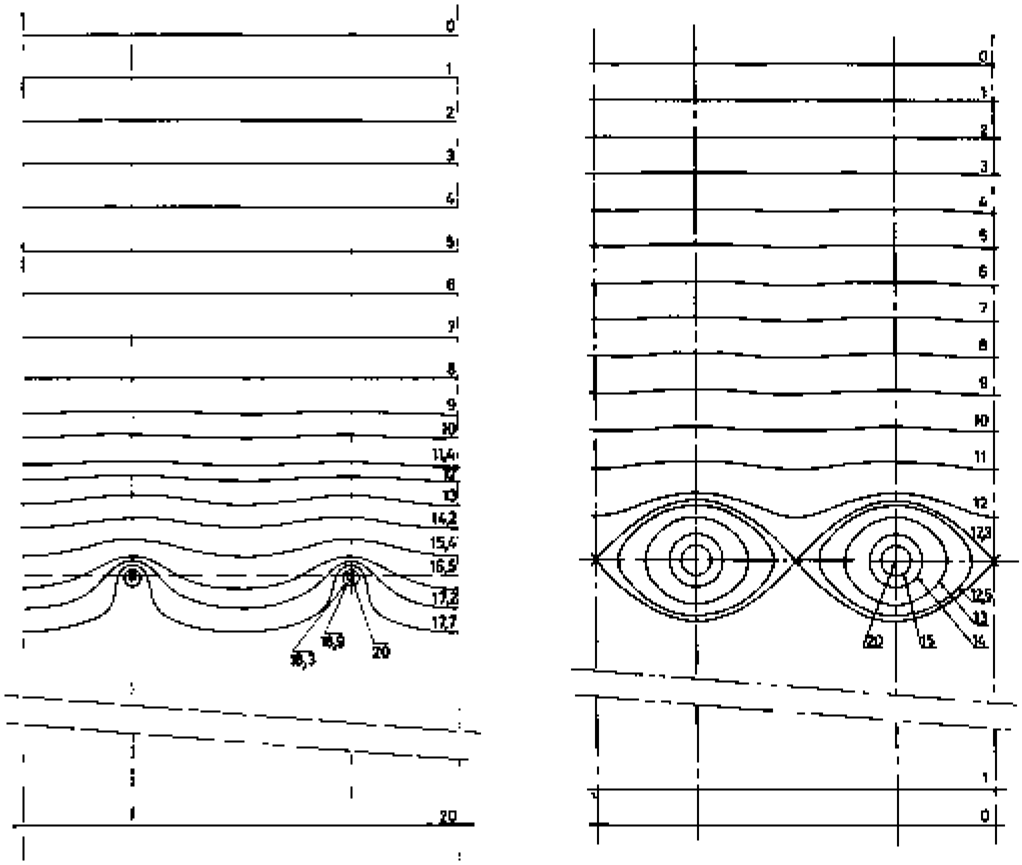


Fig. 1 Equipotentials around electrodes made of wires:

a) Two-electrode configuration.

b) Three-electrode symmetrical configuration.

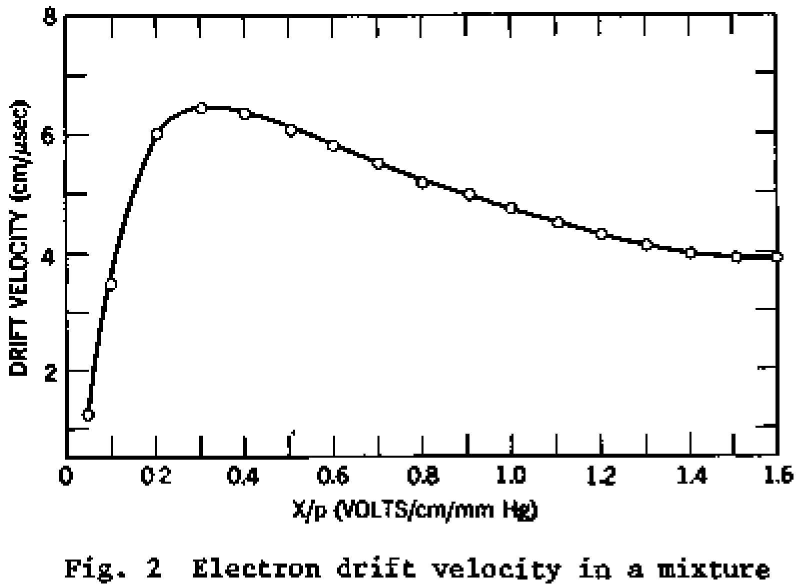


Fig. 2 Electron drift velocity in a mixture of 90% argon and 10% methane.

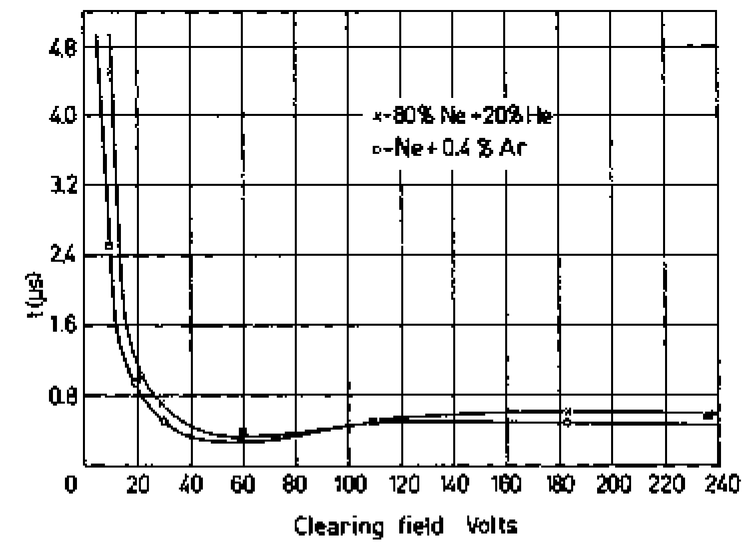


Fig. 3 Dependence of the memory time on the value of the clearing field I.I. [taken from Gromova et al. (1964)].

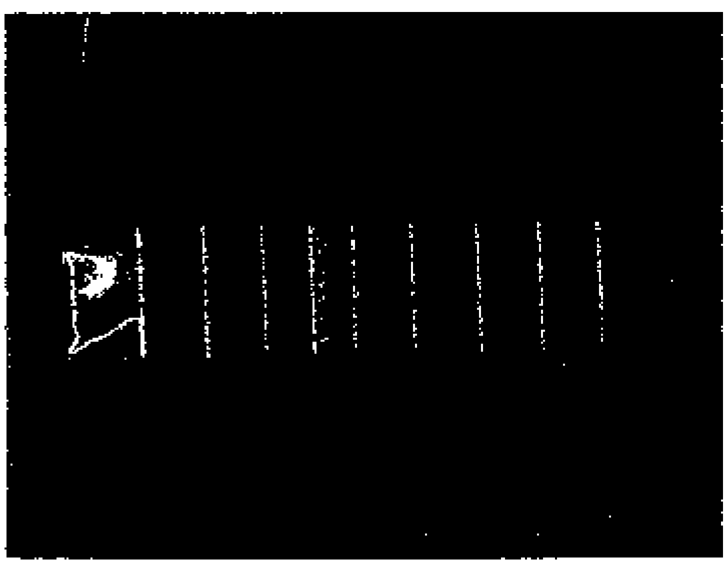


Fig. 4 Electron tracks in an avalanche chamber [F. Schneider, CERN]. Helium-neon; 10 cm length; field of 25 kV/cm; 10 nsec width. Image intensifier - equivalent aperture f/30.

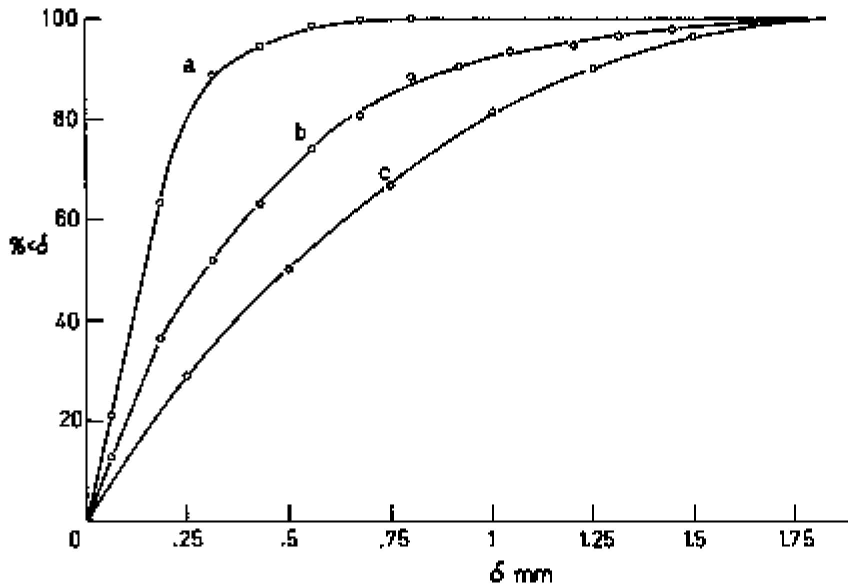
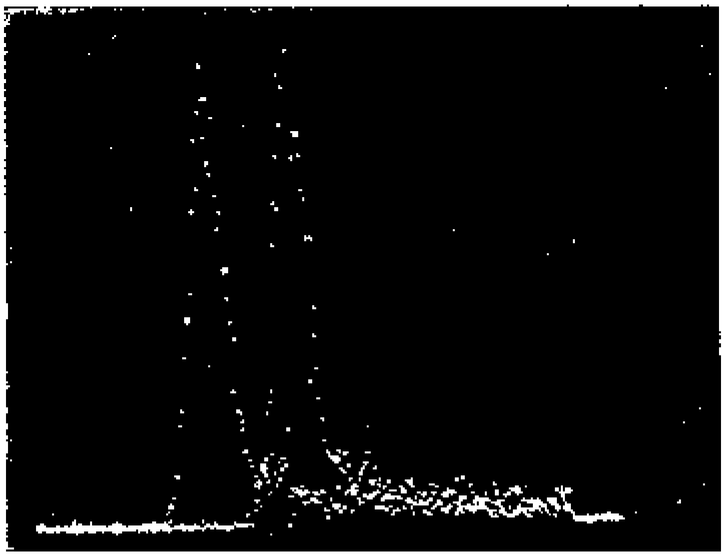


Fig. 5 The percentage of sparks with deviations less than δ plotted as a function of δ in mm. The three curves represent the following angular intervals:

a) 0°-15° b) 15°-30° c) 30°-45°

[taken from J.C. Rutherglen et al. (1961)].



|18nsec|

Fig. 6 Time resolution of a proportional multiwire chamber. Distribution of the time interval between the passage of a particle and its detection on a wire.

- Wire spacing s = 1 mm.
- Distance between wires and outer electrodes: L = 2 mm.
- Argon-isobutane (80/20).
- HV = 3900 V.

The maximum time jitter is 18 nsec.