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AS TIME PROJECTION CHAMBER END-CAP OR VERTEX DETECTOR**

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DEVELOPMENT OF A MULTISTEP PARALLEL-PLATE CHAMBER AS TIME PROJECTION CHAMBER END-CAP OR VERTEX DETECTOR

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(Presented by F. Sauli)

Introduction

Parallel-plate counters are in many cases a valuable alternative to proportional counters and multiwire chambers because of their simpler construction and fast timing characteristics. The major limitation of this kind of detector comes from the relatively small gain that can safely be attained before spontaneous breakdown, between 10^3 and 10^4 at atmospheric pressure, depending on conditions. This has prevented the use of parallel-plate counters as general-purpose detectors at low ionization yields; on the other hand, large-surface, parallel-plate, position-sensitive chambers are successfully used for the detection of heavily ionizing particles in nuclear physics, with excellent localization and timing properties [1-3].

In the course of development of the multistep avalanche chamber we have realized several multiple electrode parallel-plate devices exhibiting stable gains well in excess of 10^5 ; they are thus capable of detecting minimum ionizing particles [4-6]. The possible advantages of having a parallel-plate structure to replace the multiwire proportional chamber (MWPC) as end-cap detector for the time projection chamber (TPC) have been already discussed by one of us [7], and are briefly the following:

- Because of the uniform velocity of ions in the constant electric field, their contribution to the detected signal is easily removed by electronics differentiation, leaving the very fast electron component, a few nanoseconds wide.
- Using narrow multiplication gaps, the two-track resolution in the plane of the detector is very good, around 1 mm.
- Because of the large ratio of fields between the multiplication and the drift regions, the ion feedback into the drift space is very reduced (a few percent, compared to around 20% in the classic TPC design).
- Owing to the avalanche extension over all the gap, space charge field distortions do not sensibly modify the gain characteristics; no gain reduction is observed at rates exceeding 10^5 counts/mm²·s.
- In the presence of an external magnetic field parallel to the electric drift field, $E \times B$ distortions are minimized in the multiplying region (such is not the case in a MWPC).
- And, of course, there are no thin fragile wires used in the detector.

We will report here on some progress made in the study of such a structure, with a view to developing a high-resolution, high-accuracy vertex detector.

The multistep avalanche chamber

The basic design of a two-step parallel-plate avalanche chamber is shown in Fig. 1 [7]. A region of moderate electric field—the drift region where charges are released by ionizing radiation—is followed by two layers of comparable and very high field where charge multiplication occurs. Owing to the choice of the electrodes—either cross-wire meshes or parallel, thick-wire grids at small pitch—the electric field is uniform over most of the gaps, and charge multiplication proceeds through a parallel-plate avalanche mode. In most gases, if they are not too heavily quenched, the lateral spread of the avalanche exceeds the grids' pitch, and transfer of a substantial fraction of the electron charge from the first to the second gap is observed [4-7]. Although not completely independent, the avalanche sizes in the two gaps combine, producing an over-all gain that largely exceeds the one attainable in a single layer before breakdown.

Fig. 1 A two-step parallel-plate avalanche chamber. Ionization produced in the drift space is multiplied in the two high-field gaps and detected.

In order to obtain a fast signal and a reduced avalanche spread, in our prototypes we have adopted rather narrow gaps, typically 4 mm for the first amplification region and 1 mm for the second. Operating the first gap at gains around 10^4 and the second at around 30, we obtain a very fast signal (corresponding to the avalanche over 1 mm) without the difficulty of realizing large gains on a small gap, which would require rather large field values.

To avoid edge sparking, we have adopted one of the geometries described in Ref. 7: either a gap increase at the edges, obtained with a mechanical pusher, or the insertion of thin mylar foils all around the frame's edges.

The last electrode in the structure, which we have made with a printed-circuit board, is the only one equipped with electronics and is conveniently operated at ground potential. In our prototype, this electrode is realized with a geometry functionally similar to the one of the TPC end-cap, except for the sizes of the elements, shown in the detailed view in Fig. 2. Rows of parallel strips, 500 μ m apart, cover most of the surface of the plane and serve a function equivalent to that of the anode wires in a conventional MWPC measuring the drift time and the pulse height. Moreover, since in most of the cases the avalanche spreads over two strips (see below), the centre of gravity of the recorded signals provides an accurate measurement of the coordinate perpendicular to the strips.

At regular intervals (40 mm in the prototype) four rows of pads are used to determine—always through a centre of gravity measurement—the coordinates of the tracks in selected positions along a direction parallel to the strips; the signals from the pads are extracted from the back plane of the printed-circuit board using plated-through holes filled with epoxy for gas tightness. The pads are square, 1 mm on each side, and are 1.27 mm apart. The active surface of the prototype is 20 $\times$ 20 cm², although only a fraction of the readout elements were equipped with electronics at this time.

In view of the use of the detector as a TPC, we have used argon + methane as gas filling in the proportions 90%-10%, although other choices would be possible and probably more convenient—for example, to lower the operating potentials.

Fig. 2 The readout electrode in the parallel-plate chamber; a printed-circuit board with alternate strips and pad rows (visible in the detailed picture).

To study the localization properties of the detector, we have used a set of fast amplifiers connected to adjacent pads in a row and to several strips, and followed by a system of CAMAC-based analog-to-digital converters (ADC). Timing and localization properties were analysed separately, although in a real detector a system of flash ADC or of charge-coupled devices should be used.

Because of the small gaps chosen, and of the quoted gas mixture rich in methane, in some particular geometries of charged tracks or in the detection of localized X-rays it could be expected that in a fraction of the events all charge is detected by a single pad, thus spoiling the localization by the centre-of-gravity method. This can be prevented either by increasing the gap or reducing the pad size, or else by using a gas mixture where the avalanche spread is larger (for example, avalanche widths up to 1 mm FWHM have been observed in argon + acetone mixtures, see Ref. 5).

Experimental results

The gain of the combined two-step detector has been measured by irradiating the chamber with a collimated 5.9 keV X-ray source and recording the pulse height for various voltage settings. Figure 3 shows the measured gain in the first amplification element, as a function of the electric field; in Fig. 4, the gain curves are given as measured in the second amplifying gap for several values of the gain in the first. At small

Fig. 3 Measured gain in the first amplification gap, 4 mm thick, as a function of field.

Fig. 4 Gain of the combined structure, measured on the printed-circuit board for several values of preamplifying gains, as a function of the field in the second gap (1 mm thick).

values of the field in the second gap, E_2 , and until multiplication starts in this gap, the detected signal corresponds simply to an increasing transfer of electrons from the first multiplying gap. The contribution of the second gap can be estimated comparing the results of Figs. 3 and 4. As already mentioned, a convenient choice for stable operation appears to be a gain around 10^4 in the first gap, followed by a gain of 30 in the second; the fields being about equal, the transfer efficiency for electrons from the first to the second gap is around 50% and the over-all gain about 10^5 .

In the conditions described, the detected signal develops mostly across the second, thin gap, and its electron component, obtained by simple differentiation of the charge, is very fast. Figure 5 shows a single pulse, which was recorded using a fast current amplifier on a storage oscilloscope. Neglecting the small reflections, due to impedance mismatching, the full width at the base of the signal is about 8 ns.

Eight adjacent pads in a row were equipped with amplifiers, and the pulse-height distribution was recorded event by event. A typical pulse-height profile is shown in Fig. 6 for an event corresponding to an

Fig. 5 A single pulse, detected using a fast amplifier, for a 5.9 keV X-ray conversion.

Fig. 6 Pulse-height profile recorded on a row of adjacent pads for a single event.

Fig. 7 Computed distribution of the centre of gravity of the signals recorded on the pads, for X-ray detection. The FWHM of the distribution corresponds to about $350 \mu\text{m}$.

X-ray conversion; two pads have a signal above background, and the corresponding weighted average provides the measured photon position. A distribution of computed centres of gravity for a source collimated between two pads is shown in Fig. 7. It has a standard deviation of about $150 \mu\text{m}$; this includes the collimation width ($200 \mu\text{m}$ full width), as well as other sources of dispersion, such as electronics noise, the photoelectron range, and parallax effects in the drift space. A singularity appears, i.e. the single channel peak at the right, due to events that produced a signal above background in one pad only; the probability of this happening is rather small for a source positioned between pads, but increases notably in our geometry when collimating the radiation over the centre of a pad.

Although this should not present a problem in the general case of continuously ionizing tracks with skew angles, it certainly spoils the localization accuracy in the detection of X-rays. As possible solutions—apart from the obvious ones to decrease the pad size or increase the gap thickness—we are investigating the possibility of using gases with larger avalanche spread, or else to add one more electrode in the structure so as to detect, on the printed-circuit board, not the direct, narrow electron charge of the avalanche but the (positive) induced charge distribution whose width is determined by the last gap thickness (see also Ref. 7).

Displacing the collimated source by known amounts, and disregarding the events with a single pad pulse height, we have measured the correlation between the centre of gravity and the real position shown in Fig. 8. The correlation is linear, within the errors, and the average localization accuracy is around $150 \mu\text{m}$ as mentioned.

Fig. 8 Correlation between the computed centre of gravity and the real collimated source position. The average r.m.s. localization accuracy is $150 \mu\text{m}$.

Conclusions and summary

We have tested a prototype two-step parallel-plate avalanche chamber capable of large stable gains (in excess of 10^5) and having very good intrinsic localization and timing properties. The only active electrode consists of a printed-circuit board with densely packed readout strips alternated with small pad rows. Recording pulse-height distributions on several adjacent strips and pads, we have determined the gain characteristics of the device and its localization accuracy in the detection of soft X-rays. The results are promising, and with this device we intend to study the timing and localization properties in the detection of minimum-ionizing particles, in a geometry similar to the one of the TPC.

Because of the high density of detecting electrodes, the parallel-plate chamber is expected to be very powerful but also very expensive, and its use can be envisaged only for small-sized end-cap detectors. With perhaps a different electrode geometry (a larger number of pad rows) the parallel-plate chamber may be suitable as an accurate, densely packed vertex detector; because of the absence of thin wires, a cylindrical geometry seems easier to implement than in the MWPC approach.

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