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Section A

Multiwire chambers with a two-stage gas amplification

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Some unique features of multistep avalanche chambers are investigated. This type of chamber is very well suited for the analysis of thin-layer radiochromatograms (labeled with ^{3}H, ^{14}C or ^{32}P). A resolution of 0.5 mm FWHM in the two coordinates is routinely achieved.

1. Introduction

Multistep avalanche chambers, first described by Breskin and Charpak [1], offer some unique features, which makes them especially suited for a wide range of imaging problems of ionizing radiation in nuclear physics and other sciences. For the beam monitoring and for the experiments at the new relativistic heavy-ion accelerator SIS/ESR in Darmstadt, this type of wirechamber has been investigated in more detail and about 20 of these counters of various sizes are now in routine operation. As it turned out, these chambers are also well suited for many other applications.

2. Construction and principle of operation

A schematic layout of a MWPC with a two-stage gas amplification is shown in fig. 1. The plane labeled A is the anode plane, consisting of 20 μm gold-plated tungsten wires with a pitch of 2 mm. The planes X and Y are the cathode electrodes, made of 50 μm gold-plated tungsten wires with a pitch of 1 mm. The wire directions in X and Y are orthogonal to each other, the wires of plane A are in the diagonal direction. The anode–cathode spacing is 5 mm. To this ordinary MWPC, a planar electrode structure is added, consisting of the two meshes labeled G and T with a spacing of 6 mm. Both are woven fabrics of plastic, coated with a nickel layer. Typical potentials applied to these electrodes are: G = −10 kV, T = −2.6 kV, A = +2.5 kV. The readout planes X and Y are on ground.

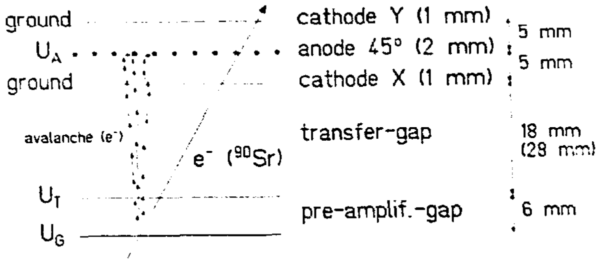

Fig. 1. Schematic layout of a two-stage MWPC.

Ionizing particles which hit the active area of the chamber produce primary electrons in the chamber gas, which will be multiplied in the high electric field of the planar electrode structure, called preamplification gap or simply pre-gap. The gain in this first stage is about 10^2. The avalanche then drifts into the 20 mm wide transfer gap between T and the first cathode plane. There a low electric field is maintained; the transfer efficiency is about 15%.

Finally, the avalanche reaches the anode plane and there the second gas amplification by about a factor of 10^3 occurs. Due to the transverse diffusion, the electron cloud broadens on its long driftpath and typically two adjacent anode wires carry a signal. Due to the exponential behaviour of the Townsend avalanche process, the very first primary electrons produced directly at the entrance gap G contribute most to the avalanche. This is very important in understanding two essential features of a two-stage MWPC:

(i) the measured position is the impact point of the particle on the first grid plane G; the position does not depend on the angle of incidence of the particle.

This is clearly demonstrated in fig. 2. This plot is a two-dimensional position spectrum of a planar ^{14}C source, placed directly on the first grid. The source plate has 1 mm wide ^{14}C deposits, each separated by 10 mm. Despite the emittance of the β-particles into 2π all the activity spots are clearly resolved. Fig. 3 is a projection of fig. 2 onto the horizontal axis. Radiochromatograms labelled with tritium, ^{14}C or any other beta-emitter can thus be measured fast and quantitatively accurately.

(ii) Since the electrons which contribute most to the signal have a constant driftpath from the first grid to the nearest anode wire, such a chamber exhibits a

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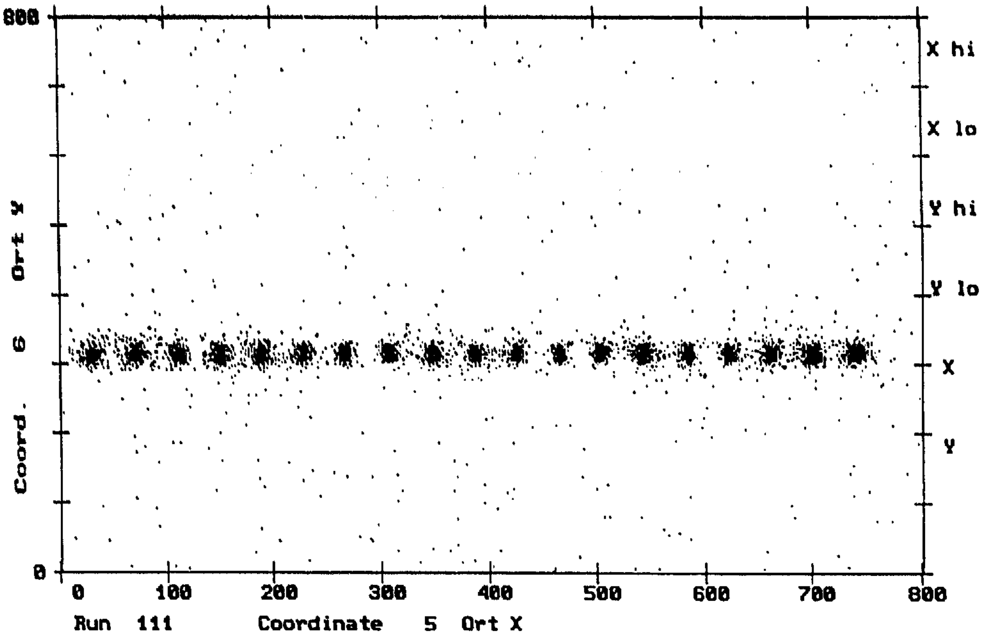

Fig. 2. Two-dimensional position-spectrum of a ^{14}C source.

much better time-resolution than an ordinary MWPC. For β-particles we measured 20 ns, for heavy ions less than 10 ns FWHM.

(iii) Such a chamber can easily be gated by applying properly chosen voltages to the electrode T (cf. fig. 1).

3. Detection efficiency

The potential on the first grid G has the most important influence on the gas gain of the chamber. Fig. 4 shows the efficiency for minimum ionizing particles as a function of the potential on grid G. The plateau for heavily ionizing radiation is reached some hundred volts earlier.

4. The chamber gas

Pure P-10 gas (90/10 argon–methane mixture) is well suited, but it lacks sufficient quenching properties. After-pulses could be observed, separated in time just

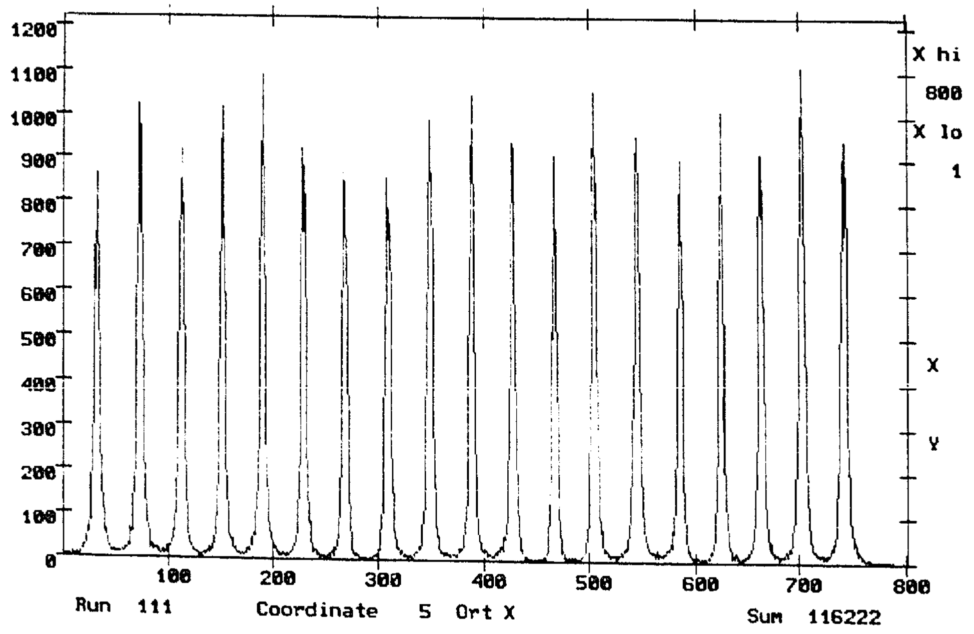

Fig. 3. Projected spatial distribution of a ^{14}C source (from fig. 2).

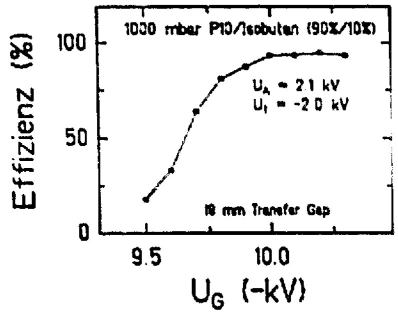

Fig. 4. Efficiency curve for beta-particles.

by the drift time of several 100 ns between the plane G and the anode. These pulses are initiated by photons emitted from the first pulse and then absorbed near the electrode G, where they start a second avalanche. This effect can strongly be reduced by increasing the thickness of the transfer gap and/or by adding some percents of isobutane or heptane. After some time of operation of these counters with P-10 in a relativistic heavy ion beam, strong ageing effects on the anode wires could be observed. The accumulated charge has been estimated to about 1 C/cm anode wire, a critical value which can also be found in the literature [2]. Subsequently, the chamber gas has been changed to a mixture of Argon–CO_2 (86/14) with some admixture of alcohol. Up to no ageing effects have been observed.

5. Readout methods

The negative anode signal induces positive signals on the adjacent cathode wires in the X and Y direction and these signals can be effectively used for the position determination of the incoming ionizing particle. The width of the Gaussian-shaped induced charge distribution on the cathode planes is 20 mm (FWHM) and is very well suited for a position determination by means of a center-of-gravity (COG) calculation. There exist several methods to extract the position, differing in complexity and performance. They will be briefly discussed.

5.1. Single wire readout

A chamber with 120×40 cm^2 active area for the KAON spectrometer at the SIS has been equipped with this rather complex and expensive readout method [3]. Five cathode wires are connected to one amplifier and ADC. Sixteen of these amplifier-ADC channels are read out and processed by one transputer T212, mounted directly on the chamber. There the COG calculation is performed and after this substantial data-reduction the data are transfered via another transputer chain to the host computer. In total there will be about 600 readout channels (for the two cathode planes and the anode).

5.2. Delay-line readout

A more simple and economic approach is the well-known delay-line technique. Each wire of the planes X and Y are connected to a tap of a commercially available delay chip with a delay of 4 ns per tap. The signal propagates through the left and the right side of the delay line. At the end of the delay line the signals are amplified (the amplifier sits directly on the chamber) and are fed in the STOP of a TDC. The START signal for the TDC is derived from the anode. All the anode wires are on one common bus. The time difference

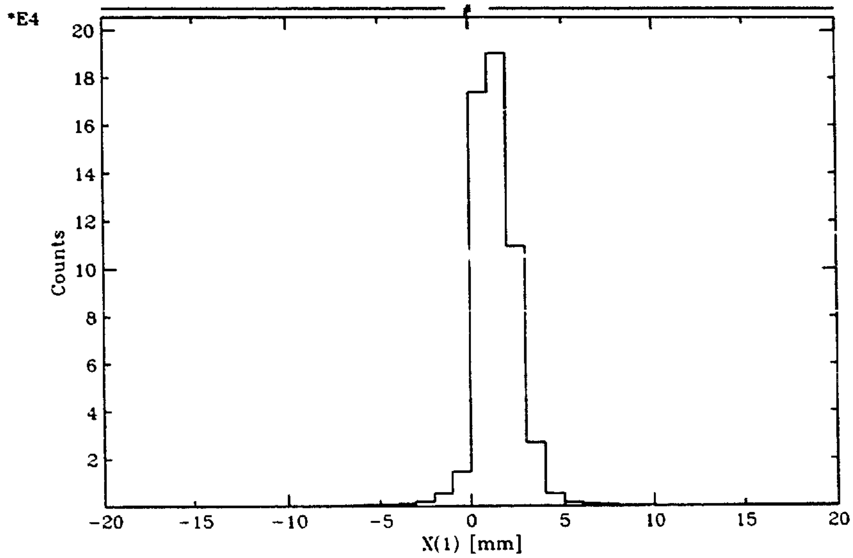

Fig. 5. Position distribution of 600 MeV/u gold particles.

between the left and the right side of a delay line gives the position; whereas the sum of left and right should be a constant, namely the total length of the delay line (in our case ~ 1 μs). Despite its simplicity and cheapness, this method yields excellent results, as demonstrated in figs. 2 and 3. The signal averaging, as done explicitly in the COG method, is here performed in the delay line.

There are, of course, some drawbacks to this method:

(1) During the total delay time of the delay line no other particle may hit the detector. In the chamber described, the delay line is 1 μs, e.g. the maximum particle rate is 1 MHz, in practice a factor of 10 less. But these double hits can be recognized, since the sum of left and right is less than the total length of the delay line.

(2) Relativistic heavy ions produce numerous delta-electrons when passing through matter. These delta electrons spoil the position determination in a chamber with delay line readout. A solution of this problem is to lower the voltage on grid G such, that the signal of the electrons is below threshold.

Bearing these limitations im mind, MWPCs equipped with delayline readout show excellent performance. Fig. 5 shows a position spectrum of 600 MeV/u gold-ions. The steep slopes of the distribution indicates a resolution of ≪ 1 mm.

5.3. Current readout

In cases where one does not need the position information on an event-by-event basis, but just global information on the spatial distribution of the particles in the detector plane, the current integrating readout method is the appropriate one. The current of the positive ions onto the wires of the cathode planes X and Y is amplified and integrated during some milliseconds and the charge on each wire reflects the projected spatial distribution of the particles. These projected spatial distributions are normally sufficient for beam-diagnostic purposes and a number of these counters, with an active area of 90×90 mm^2, are now in routine operation in the beam-lines of the SIS. Due to the high gas gain of these two-stage MWPCs, rather low-intensity beams can be diagonized. The lower limit is about 100 neon particles per second. For high-intensity beams, the gas gain can be easily reduced.

By subdividing the last cathode plane into small areas (pixels) and reading them out by the method described above, a true two-dimensional image of the particle distribution is obtained. This requires a rather complex readout electronic, which is currently developed.

6. Other applications

These two-stage MWPCs offer some unique features, which make them useful for imaging of ionizing radiation in other fields of science.

As already pointed out in [1], such a chamber can be used for the two-dimensional imaging of radiochromatograms, labeled with ^{14}C or any other beta-emitting isotope. (In the case of tritium, the chamber has to be operated without a window. Tests have shown that this is feasible). Fig. 2 shows an example of a radiochromatogram, taken with a ^{14}C source consisting of 10 activity spots, each 1 mm wide and separated by 10 mm.

The quantitative imaging of the dose distribution of the gamma flux applied in medical radiotherapy is still an open problem. It is currently investigated, whether such a chamber is suited for this purpose. Due to the high flux, an event-by-event recording is not possible, one has to use an integrating readout method. The current-integrating readout of pixels seems to be the most promising method for such a counter.

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