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THE USE OF RISE-TIME INFORMATION IN DRIFT OR PROPORTIONAL CHAMBERS
FOR NEUTRAL RADIATION LOCALIZATION

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ABSTRACT

When ionization clusters of small size are produced in a drift space by neutral radiation they grow in size during the drift because of diffusion. This results in a change in the rise-time of the pulse detected in a proportional counter; this information can be used to measure the coordinates along the electric field. Measurements with 5.9 keV photoelectrons show that an accuracy around 40% FWHM of the drift length can be achieved, up to 8 cm total drift. Although rather modest, this accuracy can permit the use of thicker conversion volumes.

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2. EXPERIMENTAL SET-UP

A drift space 8 cm deep is mounted on a $10 \times 10 \text{ cm}^2$ multiwire proportional chamber (MWPC) (Fig. 2). The anode wires are connected in groups of six to a positive potential through protection resistors; each group has an independent signal output. To obtain a uniform field in the drift region, a negative potential is applied to the back copper-plate electrode, and the electric field at the frame boundaries is shaped by a set of electrodes, 1 cm apart, maintained at suitable intermediate potentials.

We have used as a gas filling a mixture of argon, isobutane and methylal in the proportion of about 67%, 30%, 3%¹⁰⁾; the chamber was operated in the proportional region. Beams of 5.9 keV X-rays collimated to about 1 mm, were sent, through a thin mylar window, at different depths of the drift space; we have used a fast ($t_r = 1 \text{ nsec}$), low-noise, voltage-sensitive amplifier^{*)} with an input impedance of 300Ω for the detection of the fast component of the anodic signal.

3. RISE-TIME MEASURING TECHNIQUES

Contrary to most of the methods used in previous work (Refs. 2 to 4) we have preferred to measure the rise-time of the fast, differentiated current pulse and this to be compatible with the high expected counting rates of this kind of detector. Essentially, two methods were tried:

- 1) An inversion and differentiation of the fast pulse to obtain a zero-crossed signal; the time difference between the discriminated direct signal and its derivative was assumed to represent the rise-time. Two kinds of discriminators have been used for a comparison, i.e. a fixed-threshold discriminator (LRS 620 AL), and a constant-fraction discriminator (ORTEC 463).
- 2) A direct measurement of the rise-time was attempted with an existing rise-time to amplitude converter (Schlumberger 7112), although used outside the recommended range.

We have also tried, following Ref. 4, to measure the ratio of pulse height between the fast current signal and its integral; this method is necessarily slower than the one previously described, but gave essentially the same results.

4. EXPERIMENTAL RESULTS

The effect of diffusion on the current pulse shape can be seen in Fig. 3 as a function of the drift distance and for two values of the drift field. Notice that in all cases the total charge is constant, as proved in Fig. 4 where the

*) Developed at CERN by J.C. Santiard.

1. INTRODUCTION

Whoever is familiar with proportional or drift chambers has observed that the rise-time of the pulses induced by the avalanches on a sense wire is variable and is a function of many parameters: the wire diameter, the electric field intensity, the type of gas, and the spatial distribution of the primary electric charges collected by the wire.

In particular, for a given counter, the rise-time can be correlated with two physically important parameters:

- i) *The nature of the particle:* soft X-rays or slow neutrons produce very localized primary charges, leading to fast rise-times, while charged particles crossing the chambers or long-range secondary particles lead to rise-times proportional to the collecting times¹⁾.
- ii) *The position of the primary ionization:* the diffusion of the primary electric charge along the drift path leads to a widening of the distribution and a subsequent increase of the rise-time. This characteristic behaviour has been used successfully to discriminate soft X-rays from cosmic-ray backgrounds, and work in this direction is still in progress²⁻⁴⁾, for example in the field of X-ray astronomy.

For a point-like cluster of electrons produced at the time $t = 0$, the r.m.s. of the spatial distribution after a time t is given by⁵⁾:

$$\sigma_x = \sqrt{6Dt} ,$$

where D is the diffusion coefficient, function of the gas nature and condition, and of the electric field. Owing to the process of avalanche amplification on the anode wire of a counter, the rise-time of the detected pulse will depend on the amount of diffusion in the gas. This can suggest a method for localizing the photon conversion point in a drift chamber. Indeed, soft X-ray bi-dimensional proportional chambers are increasingly in use for biomedical and protein crystallography applications⁶⁻⁸⁾. In the conventional design, a conversion volume, the drift space, is followed by the amplifying and imaging element; this is obviously subject to a position error proportional to the sensitive volume depth and photon incidence angle (Fig. 1). Efficiency is therefore seriously affected by the need to keep the angular aberration small. Recently, systems using a radial electric field conversion volume have been successfully developed⁹⁾ to circumvent the problem. However, if it were possible to reconstruct the distance of conversion from the imaging plane, flat drift conversion spaces could be used with significant simplifications.

The γ -rays from a ruthenium source were used to simulate such a situation. Figure 9 shows the rise-time distribution of 5.9 keV X-rays only (9a) and in the presence of β -rays having five times higher intensity (9b). More than 95% of the pulses produced by the β -rays can be identified by their slow rise-time. This rejection power is not as good as the one obtained by the authors in Refs. 4-6, but it should be kept in mind that we use only the fast component of the proportional pulse, thus obtaining the discrimination in very short times (20-30 nsec) compatible with high counting rates.

6. CONCLUSION

Our preliminary work with X-rays of 5.9 keV and argon-isobutane-methylal filling shows that conditions can be found where the rise-time of the pulses can help to determine the position of the photoelectron generated in the gas with an accuracy of $\Delta s/s \sim 0.4$ FWHM for a maximum of 8 cm of drift and at low values of drift field. Although this accuracy is too poor to challenge the advantages of spherical drift chambers, it may have some applications.

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fast pulse and its integral are compared for two positions of the source, 40 mm apart in a field of 200 V/cm. In the range of fields and drift distances we have covered, an integration constant between 200 and 500 nsec proved to be sufficient to reconstitute the full pulse height.

Figure 5 shows the experimentally measured FWHM time spread of the detected electrons, ΔT , as a function of the drift field for a fixed drift distance (1 cm). Since the value of the drift velocity is known in the gas mixture we used¹⁰⁾, we could deduce the space dispersion Δs that appears to be almost independent of the electric field¹¹⁾.

We therefore expect the intrinsic accuracy of localization obtained from a rise-time measurement to be almost independent of the drift field, in the quoted range. Because of electronics limitations, however, low fields (and therefore large time spreads) are more convenient.

In Fig. 6, a comparison is shown between the actual rise-time (10-90%) as seen on a scope, and the results of the quoted methods of measurement.

The leading-edge discriminators' thresholds were set up in such a way as to measure the time difference corresponding to the rise-time; this was also the case with the rise-time to amplitude converter. In the case of the constant-fraction discriminator, we were measuring approximately the total rise-time (0-100%). Some of the error bars, corresponding to the FWHM of the rise-time distribution, are presented in Fig. 6. The measured points fit quite well to the real rise-time.

At a given position, the rise-time distribution has a nearly Gaussian shape (see Fig. 7) with an FWHM Δt_r . Using the rise-time-position relations from Fig. 6, we were able to compute, for each value of Δt_r , the corresponding value of Δs , which represents the error on the position (FWHM); this is shown in Fig. 8 as a function of the drift coordinate s . Notice that $\Delta s/s$ does not vary much for the different methods of measurement. For low values of E , Δs is nearly equal to $0.4 \cdot s$, which corresponds to a standard deviation $\sigma_s \approx 0.17 \cdot s$ in the localization.

We have repeated the measurement in a gas mixture known to have a larger diffusion coefficient, i.e. argon-methane¹¹⁾, without any significant improvement, showing that the major contribution to our accuracy is given by electronic noise.

5. DISCRIMINATION BETWEEN SOFT X-RAYS AND LONG-RANGE ELECTRONS

As was already mentioned in the first section, X-rays or slow neutrons can give rise to very localized primary charges leading to fast rise-times, while secondary charged particles, emitted generally in arbitrary directions, lead to rise-times proportional to the collecting times of the primary charges.

Figure captions

- Fig. 1 : The error in position localization of X-rays at large angles, due to the spread in the position of the conversion point along the track.
- Fig. 2 : Schematic views of the experimental drift chambers. The MWPC has the following characteristics: wire diameter, 20 μm ; gap width, 8 mm; wire spacing, 2 mm. The length of the drift volume is 8 cm.
- Fig. 3 : Pulse shape of 5.9 keV X-rays at positions $s = 10, 40$, and 70 mm.
- a) $E = 375 \text{ V/cm}$
 - b) $E = 1225 \text{ V/cm}$.
- Fig. 4 : Comparison of the fast current pulse and its integral ($\tau = 500 \text{ nsec}$) for 10 and 50 mm drift, at 200 V/cm, proving the constancy of the collected charge.
- Fig. 5 : Measured average FWHM time diffusion, Δt , and space diffusion, Δs , for 1 cm drift as a function of the drift field. The value of the drift velocity W has been deduced from Ref. 10.
- Fig. 6 : Rise-times as function of drift field and position, for several methods of measurement. The full lines correspond to 10-90% rise-times measured on the oscilloscope.
- Fig. 7 : Rise-time distribution (10-90%) using two leading-edge discriminators.
- a) positions $s = 10$ and $s = 70 \text{ mm}$, $E = 375 \text{ V/cm}$
 - b) " $s = 10$ and $s = 20 \text{ mm}$, $E = 375 \text{ V/cm}$
 - c) " $s = 10$ and $s = 70 \text{ mm}$, $E = 1125 \text{ V/cm}$.
- The horizontal scale is about 2.7 channels per nsec.
- Fig. 8 : Δs (FWHM of the position distribution) as function of the position s , for two values of the drift field and several of the methods of measurement discussed.
- Fig. 9 : Rise-time distribution of ^{55}Fe 5.9 keV X-rays at a position $s = 70 \text{ mm}$,
- a) alone and b) in presence of a five times higher intensity ^{106}Ru β -ray source. Drift field $E = 1125 \text{ V/cm}$.

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Fig. 2

Maximum error $d \tan \theta$

Fig. 1

Fig. 4

Fig. 3

Fig. 6

E (V/cm)

Fig. 5

Fig. 8

a)

b)

c)

Fig. 7

a)

b)

Fig. 9