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DETECTION OF 500 eV X-RAYS WITH THE
X-RAY DRIFT CHAMBER (XDC) TECHNIQUE

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ABSTRACT

The detection of tagged low-energy X-rays in a gas proportional counter is reported in order to demonstrate the capability of the X-ray drift chamber technique to identify low-energy X-rays. The drift-time distributions of X-ray lines of different energies vary because of the strong energy dependence of the X-ray absorption cross-section. Soft X-rays display a drift-time spectrum that is sharply peaked at late drift-times, while X-rays of higher energy show a more uniformly spread drift-time distribution. The drift-time information therefore supplements the amplitude information in the low-energy region where the resolution is poorer. We have used a ^{54}Mn source that emits 0.5-0.65 keV and 5.5 keV X-rays in coincidence with 835 keV γ -rays which are well suited for tagging.

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1. INTRODUCTION

The X-ray drift chamber (XDC) technique¹⁾ has been proposed with a view to improving both the energy resolution and the identification capability of wire chamber arrays used to detect soft X-rays. This technique relies on the measurement of the drift-time distribution of the cluster of primary electrons produced when an X-ray is absorbed in the chamber gas, and can be applied in all cases where the X-rays incident on the detector can be tagged by a prompt signal providing the zero time for the drift-time measurement. It appears to be particularly suitable for the identification of X-rays from exotic atoms formed by stopping negative particles in a target where the zero time is given by the stop signal. It could also be exploited for X-rays from synchrotron radiation, where the zero time is given by the traversal time of the bunch through the wiggler, and for X-rays from transition radiation (zero time = passage of the radiating particle through the transition region).

The XDC technique consists in exploiting the drift-time spectrum in order to extract information about the X-ray energy and to help identify X-rays against background. This is possible because the drift-time distribution depends strongly on the X-ray energy, since the absorption cross-section σ of soft X-rays is very much dependent on the X-ray energy E *).

A monochromatic tagged X-ray beam, well collimated and incident normal to the detector entrance window (Fig. 2a), would be attenuated exponentially in the gas chamber (Fig. 2b) and would give a drift-time distribution of the type shown in Fig. 2c. The X-ray mean free path could be derived from the drift-time distribution. From this measurement the X-ray energy would be deduced with a resolution $\Delta E/E$ independent of the X-ray energy, since the drift-time distribution does not depend on the number of primary electrons produced by the absorption of the X-ray in the gas. On the contrary, the fluctuation of the number of these electrons is

*) $\sigma \propto E^{-\alpha}$, $2 < \alpha < 3$ away from the absorption edges of the counter gas. Consider Fig. 1 for the case of Ar: the mean free path of 3 keV X-rays is ~ 250 times larger than for 300 eV X-rays.

the principal limit to the energy resolution in the amplitude spectrum. Experimental work in well-defined geometrical conditions, which would demonstrate and exploit the XDC technique for improving the energy resolution for soft X-rays, has not yet been done.

In the case of an uncollimated source, very soft X-rays are expected to give a peak at the maximum drift-time, since they are preferentially absorbed near the entrance window of the detector, while other X-rays will be absorbed more uniformly in the active volume of the detector. This, in conjunction with the amplitude information, allows the identification or the rejection of low-energy X-rays to be improved by making cuts in the energy and drift-time, and it appears to be of particular importance for the study of X-rays from $\bar{p}p$ atoms. In a search for these X-rays, antiprotons were stopped in a H_2 gas target which was surrounded by a wire chamber array used as an X-ray detector²⁾. The Balmer series (L X-ray series, 1.7-3.1 keV) of $\bar{p}p$ atoms was thus detected³⁾, but the spectrum was dominated by the 3 keV Ar fluorescence line due to charged particles from $\bar{p}p$ annihilations that crossed the cells of the proportional chamber. By using the drift-time information and a convenient choice of wire and field configuration, one could reject a large amount of the Ar fluorescence background that contaminates the $\bar{p}p$ L and M series.

A qualitative illustration of the use of the XDC technique to improve the X-ray identification was given in Ref. 1 by comparing spectra containing the Ar fluorescence line and 3.9 keV X-rays from antiprotonic helium⁴⁾: these two lines have energies just above and below the 3.2 keV Ar K edge, and the ratio of the corresponding absorption cross-sections is ~ 5 . The geometry of the proportional chamber²⁾ was, however, not well suited for taking full advantage of the XDC technique. In the present report we illustrate the identification power of the XDC technique with a much simpler set-up and in a more direct way, by comparing the 0.5 and 5.5 keV X-ray lines emitted by a ^{54}Mn source for which the ratio of the corresponding absorption cross-sections is large (~ 40) and the accompanying

835 keV γ -ray can be comfortably used for tagging. The work reported is part of the design and test activity for a 4π cylindrical XDC with radial field configuration, which it is foreseen will surround a gaseous H_2 target in an experiment⁵⁾ proposed at the newly planned LEAR facility at CERN⁶⁾. The XDC will allow selection of the initial state of $\bar{p}p$ annihilations at rest and transitions to baryonium states, by detecting in coincidence the pattern of X-rays emitted before the end of the atomic cascade (typical energies are 10, 2, 0.6, 0.3 keV).

2. MEASUREMENTS

The set-up used is shown in Fig. 3. The ^{54}Mn source consisted of a mylar support with a deposit of MnCl salt containing $\sim 1 \mu\text{Ci}$ of ^{54}Mn . The deposit was obtained by evaporation of a droplet of HCl containing ^{54}Mn in solution, and was covered with a $100 \text{ \AA}$ thick Al layer -- deposited by vacuum evaporation -- which provided a conductive layer on the surface of the source.

The radiation emitted by the source is indicated in Table 1⁷⁾. The X_L X-rays (0.5-0.65 keV) are absorbed within less than 0.5 mm in the counter gas, so their detection can be expected at the maximum of the drift-time independently of their direction of incidence, provided they were emitted on the source side facing the anode wire. The X_K X-rays (5.5 keV) have a mean free path of ~ 8 mm under our working conditions, and one therefore expects a much less sharp drift-time distribution. A large fraction of 835 keV γ -rays emerge from the counter vessel and can readily be used for tagging since they accompany the X-ray radiation almost 100% of the time.

The γ -ray detector (a cylinder of plastic scintillator -- $\phi = 40$ mm, $L = 40$ mm) triggered the data acquisition system and gave the zero-time of the drift-time measurement. The anode signal of the chamber was sent to an ADC and stopped a TDC fired by the γ signal. The threshold of the discriminator used to send the Stop signal corresponded to an energy deposition, inside the chamber, of less than 100 eV. The amplitude and the drift-time for individual events were sent to a PDP-11/10 computer via CAMAC and recorded on tape.

Typical sets of data are shown in Figs. 4 and 5, which display spectra where the count rate is a function of both energy and drift-time. Figure 4 shows a spectrum obtained with the ^{54}Mn source screened by a 20 μ thick mylar foil. Figure 5 shows the corresponding spectrum with the source unscreened. The 20 μ thick mylar screen prevented L X-rays, and K and L Auger electrons from the ^{54}Mn , from entering the active volume of the counter. In Fig. 4 one can see the peak in energy due to 5.5 keV X-rays and the associated escape peak at 2.5 keV, both of which have maximum counts corresponding to the maximum drift-time. The background at low energy is negligible since the data taking is triggered by the source via the γ signal. The low-energy noise is distributed uniformly in time, and therefore continues to be present also after the maximum drift-time. This noise shows as a flat band at minimum amplitude, corresponding to the ADC pedestal.

Data from an unscreened source (Fig. 5) indicate the superposing on the spectrum due to the 5.5 keV X-rays discussed above, of a band of signals all coming at maximum drift-times and generating a new peak at about 0.5 keV. These new features of the spectrum are interpreted as being due to the appearance of the X_L X-ray lines at 0.5-0.65 keV and of the e_{AK} Auger electrons, which are spread over the whole energy range from zero to the nominal energy because of energy degradation in traversing the source and its Al coverage. Auger electrons and L X-rays display almost the same drift-time spectrum because their range and mean free path are comparable, and are of the same order of magnitude as the drift space resolution of the detector.

Figure 6 shows the energy spectrum with signals in the drift-time window 0-600 ns from zero to the maximum drift-time. The energy calibration is given by the subset of this spectrum obtained by taking signals only in the drift-time window 0-440 ns that excludes X_L X-rays and Auger electrons. The relative yields of K_K and K_L X-rays, which can be extracted from Fig. 6, and the number of γ -rays that triggered the data acquisition system ($\sim 10^3 K_L$, $\sim 4 \times 10^4 K_K$, $\sim 5 \times 10^5 \gamma$) are consistent within $\pm 30\%$ with the source specifications. The total number of e_{AK} Auger electrons ($\sim 1.5 \times 10^4$) is one order of magnitude below the nominal

source yield. This indicates that self-absorption in the source is already important for the e_{AK} electrons, and excludes that the peak at 0.5 keV may be predominantly due to e_{AL} Auger electrons.

Figure 7 compares the drift-time spectra for signals in the energy regions 0.2-0.8 keV (Fig. 7a) and 4.8-6.2 keV (Fig. 7b) which contain the X_L and X_K X-ray lines. Figure 7b displays the expected strong peaking at maximum drift-times for softer X-rays.

3. CONCLUSIONS

Data in the low-energy region confirm the capability of the XDC technique¹⁾ to identify low-energy X-rays and reject noise and background.

The identification of X-ray signals against signals from charged particles traversing the chamber can be further improved by rejecting signals corresponding to the arrival at the anode of several successive clusters of primary electrons. This can be done efficiently by exploiting FADC/RAM electronics of the type developed for the CERN UA1 experiment⁸⁾.

Finally, we would like to underline the usefulness of ^{54}Mn , which can allow calibration of drift chambers, both in energy and drift-time, in beam-off conditions, and monitoring of the drift velocity and the dependence of the amplitude signal from the drift path in beam-on conditions^{2,3)} with a source of minimal activity.

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Table 1

^{54}Mn source emission

Radiation	Energy (keV)	Absolute yield (%)	Notes				
γ -ray	835	99.98	a)				
X-ray	5.4-6 <5.5>	25.5	b)				
X_K			mean free path λ in				
			Al	Mylar	Ar (NTP)		
			25 μ	250 μ	20 mm		
			X_L	0.5-0.65	0.45	0.9 μ	0.7 μ
Auger e^-			b)				
e_{AK}			effective range in				
			Al	Mylar	Ar (NTP)		
			4.6-6	63.8	0.2-0.4 μ	0.5-0.8 μ	0.4-0.6 mm
			e_{AL}	0.4-0.7	149	$\sim 200 \text{ \AA}$	$\sim 400 \text{ \AA}$

a) Emitted in nuclear transitions from ^{54}Mn to ^{54}Cr .

b) Emitted in de-excitations of excited atomic states of ^{54}Cr .

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Figure captions

- Fig. 1 : Mean free path of X-rays in Ar and Ne at NTP.
- Fig. 2 : a) Scheme for the use of a XDC for precise energy measurements;
b) expected X-ray absorption distributions for two monochromatic sources; and c) corresponding drift-time distributions.
- Fig. 3 : Layout of the test set-up. Counter gas: Ar with 2% C₃H₈ at 2.5 abs atm NT; sense-wire grounded, cathode at -1275 V.
- Fig. 4 : Bidimensional spectrum with ⁵⁴Mn source screened by 20 μ thick mylar foil. Energy scale: ~ 140 eV bin⁻¹; drift-time scale: 22 ns bin⁻¹.
- Fig. 5 : Bidimensional spectrum with unscreened ⁵⁴Mn source. Energy scale: ~ 130 eV bin⁻¹; drift-time scale: 22 ns bin⁻¹.
- Fig. 6 : Energy spectrum with unscreened ⁵⁴Mn source: a) drift-time window 0-600 ns; b) drift-time window 360-440 ns. The noise contribution in the first energy bin is indicated by the dashed area.
- Fig. 7 : Drift-time spectrum of a) 5.5 keV X-rays and b) 0.5-0.65 keV X-rays. Energy windows: 0.2-0.8 keV for spectrum (a) and 4.8-6.2 keV for spectrum (b).

Fig. 1

Fig. 3

Fig. 4

UNSCREENED SOURCE

Fig. 5

Fig. 6

Fig. 7