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Multi-Wire Proportional Counter for Soft X-Ray Detection

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The design and performance of a multi-wire proportional counter for 2-6 keV X-rays are presented. We also report on the use of this detector in a Bragg crystal spectrometer in the application of X-ray diagnostics of the plasma of the Alcator C tokamak at MIT.

1. Introduction

In this report we describe the design, construction, and use of a multi-wire proportional counter for detection of soft X-rays in the energy range 2 to 6 keV. The purpose of the device is to detect photons in a Bragg crystal spectrometer. The photons in the spectrometer are wavelength dispersed along the x-direction while the image of the source is in the y-direction; the source in this case is the hot plasma of the Alcator C tokamak at MIT. In the application we require good spatial x-resolution of $\lesssim$ 100 μm, moderate y-resolution of the order of millimeters and a count rate capability of better than 100 KHz. This can be achieved with the detector described here.

The detector constructed is a fast pulse, low impedance delay line proportional counter[1]. It has a cathode plane which is a printed circuit board delay line. The anode plane of 2 mm spaced wires gives y-information using an external delay line. The aim is to build a 300 x 100 mm^2 (x x y) detector to cover the whole dispersion plane of the X-ray spectrometer. Here, however, we report on the design and use of a prototype detector of the dimensions 35 x 35 mm^2.

2. Design

The detector is enclosed in an aluminium box. The plate with the entrance window (35 x 9 mm^2) is screwed to the box and sealed with an O-ring (Fig. 1). The entrance window is 0.076 mm thick beryllium (51 x 51 mm^2) which is glued with epoxy to the Al plate. The area of the Be foil was appropriately relieved into the aluminimum plate to provide a flat inside surface. This surface served as one of the detector cathode planes (see Fig. 1). The other cathode plane is a helical delay line made from two printed circuit boards. The boards are etched to give 0.2 mm wide conductor ribbons 1 mm apart. For the sake of fabrication convenience, we used two parallel circuit boards where the conductor ribbons are soldered at the two ends (see Fig. 1). To avoid charge accumulation on the circuit boards, the surfaces were coated with a thin layer graphite deposited in the form of micro-graphite in aqueous base (aqua dag). Between one of the circuit boards and the Al-Be cathode surface, was the anode plane at a distance of 1.6 mm from each cathode. It consisted of 20 μm diameter gold plated tungsten wires with a spacing of 2 mm. The wires were suspended on a frame of epoxy board (G-10). In this prototype detector we disregarded the potential spatial information from the anode plane and simply shorted all anode wires.

The delay line was designed to have a low impedance of 100Ω which was chosen for the sake of time resolution. The delay per unit length of the delay line was 0.66 ns/mm.

3. Operation

The detector was tested with 5.9 keV X-rays from a ^{55}Fe source. The 25mm line source was collimated to a width of about 50 μm (FWHM). Gas mixtures of both argon-ethane and xenon-ethane were tried with pressure between 0.85 and 2.25 kg/cm^2. This pressure range was safely below the point of any noticeable window bulging and, consequently, we found no change in the electronic performance due to cathode plane deformation. The applied high voltage was varied in a range up to the point of breakdown for the gas conditions tested.

The positive cathode signals were inverted and then amplified a factor of 100 using Hewlett-Packard HP8947A amplifier followed by a LeCroy 612 amplifier. The amplifier noise level was about 6 mV measured into 50Ω. Unfortunately, these modules presented an impedance mismatch to the detector delay line (50Ω compared to 100Ω) which resulted in some loss in signal amplitude and signal reflections. Because of the fast time characteristics of the signals (the rise time was $\lesssim$ 3 ns and the width was about 8 ns, FWHM) the reflections did not affect the leading edge signal shape; the detector was connected to the amplifiers using 2 m long 100Ω cables. The amplified signals were fed into two constant fraction discriminators (EG&G ORTEC Model 934) which provided the start and stop pulses for a time-to-amplitude converter (Tennelel model TC 861) which in turn was read by a multi-channel analyzer (see Fig. 2).

4. Performance

The detector performance was investigated with the 5.9 keV X-ray source. Of particular interest was the spatial resolution achieveable for different operating conditions. In Fig. 3 is shown the resolution as function of applied high voltage (V) in the range 2.3 to 2.7 kV. Using argon-ethane gas at 2.5 kg/cm^2, we notice that the timing resolution (Γ) changes only slightly above 2.4 kV while there is a significant decrease in the observed resolution below 2.4 kV. The signal amplitude (S) has then decreased to 60 mV so that the noise at the level of 6 mV is no longer neglible at V = 2.3 kV; we note that the rate of change in resolution ($\Delta\Gamma/\Delta V$) approaches that of the exponential variation in S(V). The decrease in time resolution in this region can therefore be ascribed to the increase in the noise-to-signal ratio. At a ratio of 1:10 and a pulse rise-time of 3 ns, we estimate that the timing peak broading should be 7 channels (FWHM) of the observed 8 channels shown in Fig. 3; a peak width of 7 channels corresponds to a broadening in the line of 0.25 ns which is equivalent to 0.18 mm spatial detector resolution. Above 2.5 kV, or pulse amplitudes of $\gtrsim$200 mV, the electronic noise is no longer what limits the accuracy in the position determination.

In the amplitude range $\gtrsim$200 mV, one limiting factor for the spatial resolution is the finite stopping range of the photoelectron from the photo-absorption process[2]. The significance of this range effect is illustrated in Fig. 4 where the observed resolution for Ar and Xe gas mixtures at 1.1, 1.6,

and 2.3 kg/cm^2 pressures are shown. Since the excited states created by the photo-absorption process mostly decay by Auger electron emission and the energies of these electrons are lower than the energy of the photo-electron[2], we may assume that the photo-electron energy characterizes the range differences between Ar and Xe; i.e., the range[2](ℓ) is about a factor of 1.5 greater for Ar than for Xe ($R_{Ar} = 1.5\ R_{Xe}$). We use this assumption to fit the data on the time resolution by the function $[(R/P)^2 + C^2]^{1/2}$ which simply expresses the resolution as the sum of two terms in quadrature namely C (fixed) and R/P (density dependent); P is the pressure expressed in kg/cm^2. This determines C to be in the range 2.4-2.9 channels or 60 to 75 μm for R ≈ 11.0 in units of $[kg/cm^2]^{-1}$. A significant portion of the value of C stems from the finite source width of about 50 μm. Accounting for the source contributions, we are still left with a residue of some 30 to 50 μm which could be due to thermal diffusion of the electrons while drifting from the point of initial ionization to the anode wire or other subtle effects. We make no attempt to study these effects here, partly because the contributions from the source width and alignment dominate the resolution below 100 μm. It may suffice to show the time spectrum (Fig. 5) recorded after careful source alignment for optimizing the resolution using Xe at 2.25 kg/cm^2. The observed resolution was 80 μm (FWHM).

5. Applications

The detector was used as the position sensitive element in a Bragg crystal spectrometer[3] for soft X-rays in the energy region 2.4-2.7 keV. In this spectrometer application the detector operates in vacuum with a gas pressure of 1 atm and a high voltage of 2.0 kV. The detector gas was a mixture of krypton(60%) + ethane(40%) which was allowed slowly to flow through the detector. The purpose of the spectrometer measurements is to analyze the characteristic X-ray emission of impurity ions in the hot plasma of the Alcator C tokamak at MIT.

A typical spectrum obtained with the present detector is shown in Fig. 6. The four prominent peaks are each identified with transitions between the n=2 and n=1 electron orbits of chlorine ions. At the high plasma temperatures of about 1.2 keV, these ions are stripped of all but the last two electrons. We have made a line fit to the observed spectrum and find line widths of between 9.9 and 13.8 channels (FWHM) for the four most prominent lines (see Fig. 6). We then determine the average line width to be about 11.8 channels or 0.73 mm (FWHM). Apart from the detector resolution, there are three major contributors to the line broadening of these X-ray lines; namely, the entrance slit of the spectrometer (0.4 mm), the Bragg diffraction width of the pentaerythritol (PET) crystal ($\Delta\lambda$ = 0.89 mÅ, from the specification resolution for the 002-planes of the crystal of $\Delta\lambda/\lambda$ = 1/5000 at λ = 4.444 Å) and the Doppler broadening ($\Delta\lambda$ = 1.9 mÅ) due to the temperature of the radiating ions (estimated to $T_{ion} \approx 1.2$ keV). The unit conversions are 1 mÅ = 0.27 mm = 4.49 channels. These three

components, when added in quadrature, account for most of the observed line width. In particular, the result is consistent with a neglible (<0.2 mm) contribution from the detector. With this detector, we can thus approach the resolution limit of the spectrometer which is set by the crystal; the slit can be decreased with the practical lower limit set by intensity requirements.

6. Conclusion

We have reported on the design and construction of a multi-wire proportional counter for detection of soft X-rays in the region 2-6 keV. In tests with a 5.9 keV X-ray source we have demonstrated that a spatial resolution of 80 $\mu m_{(FWHM)}$ can be achieved successfully with this design. We have reported on the use of this detector in a spectrometer application for analyzing soft X-rays in the energy region 2.4-2.7 keV. At the level of a measured line width of 0.7 mm, the detector contribution is found to be neglible.

Acknowledgements

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References

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2. F. Sauli, "Principles of Operation of Multiwire Proportional and Drift Chambers", CERN NP Internal Report 77-09 (1977).

3. L. van Hamos, Ann. der Physik 17 (1933) 716.

Figure Captions

Fig. 1: (a) Photograph of the detector with one side opened. Visible are the anode wires and the cathode of printed circuit boards.
(b) Schematics of detector.

Fig. 2: Schematics of the electronic set up.

Fig. 3: Time resolution and signal amplitude as function of applied high voltage using 5.9 keV X-rays of an ^{55}Fe source with a detector gas mixture of argon(60%) + ethane(40%) at a pressure of 2.25 kg/cm^2.

Fig. 4: Time resolution as a function of the inverted value of the pressure in the detector for gas mixtures of argon(60%) + ethane(40%) and xenon(60%) + ethane(40%). The curves present fits to the data for the parameters C = 2.4 and R_{Xe}= 11.0 (see text).

Fig. 5: Time spectrum for four source positions using a detector gas mixture of xenon(60%) + ethane(40%) at 2.25 kg/cm^2 pressure and a high voltage of 2850 V.

Fig. 6: Example of X-ray spectrum obtained with the Bragg crystal spectrometer using the present detector with a krypton(60%) + ethane(40%) gas mixture at 1.0 kg/cm^2 pressure and a high voltage of 2.0 kV. The lines are

due to characteristic n=2 to n=1 transitions of He-like Cl of which the prominant lines (w,x,y, and z) are identified with the transitions from the excited states $1s2p\ ^1P_1$, $1s2p\ ^3P_2$, $1s2p\ ^3P_1$, and $1s2s\ ^3S_1$ to the $1s^2\ ^1S_0$ ground state with λ = 4.444, 4.465, 4.468, and 4.497 Å. The fitted line widths are indicated for these lines. The spectrum refers to the sum of three plasma discharges of 100 ms duration each.

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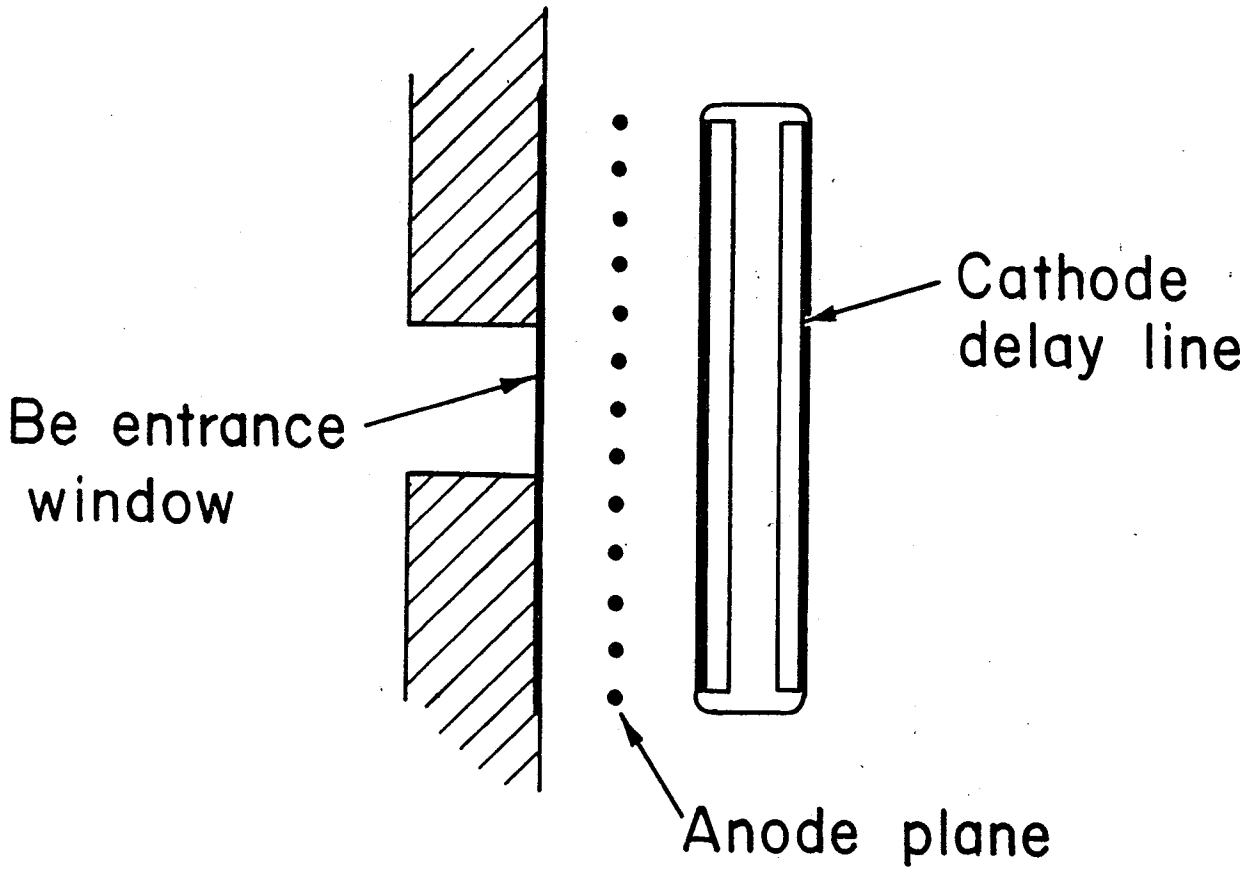
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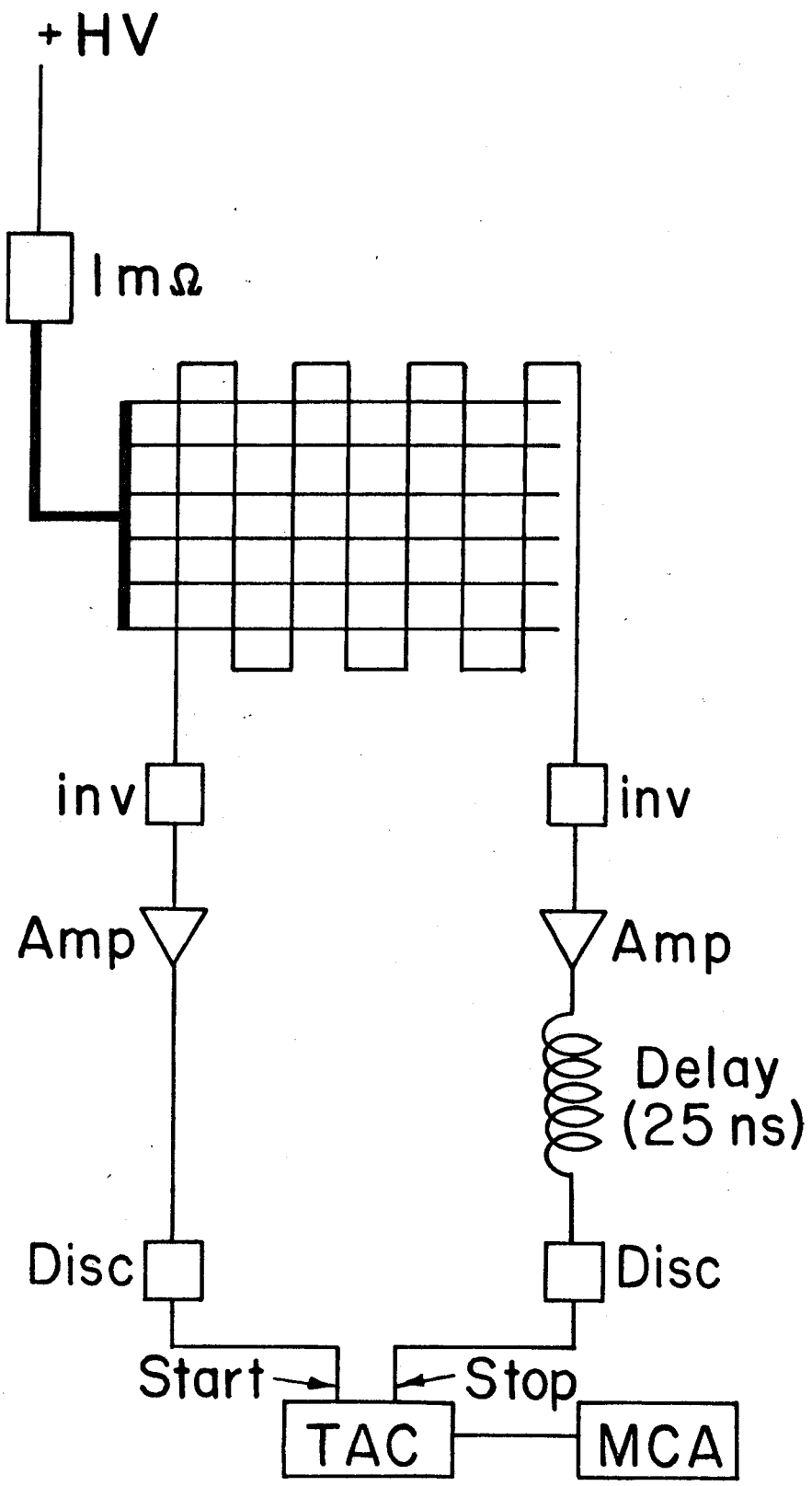
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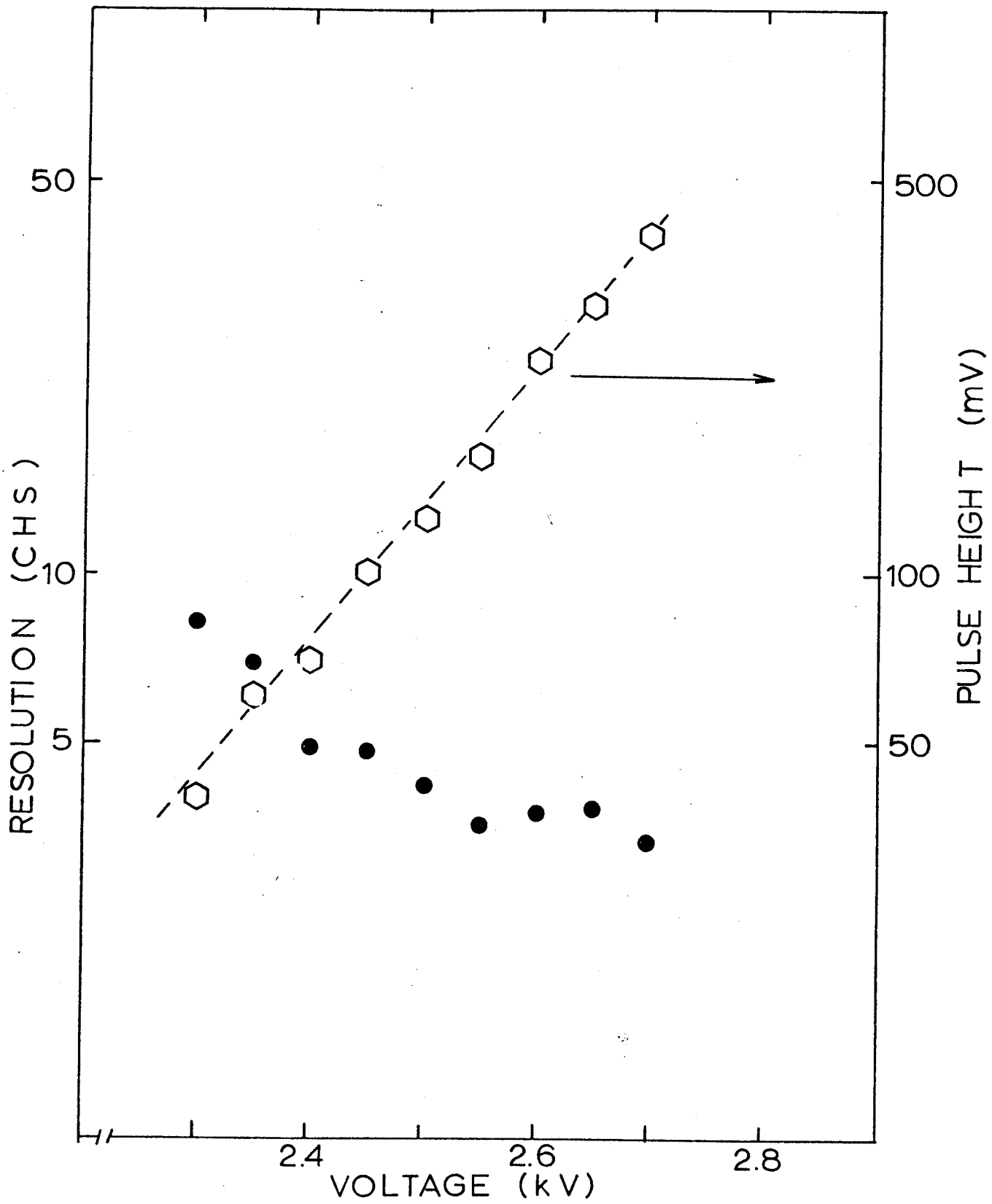
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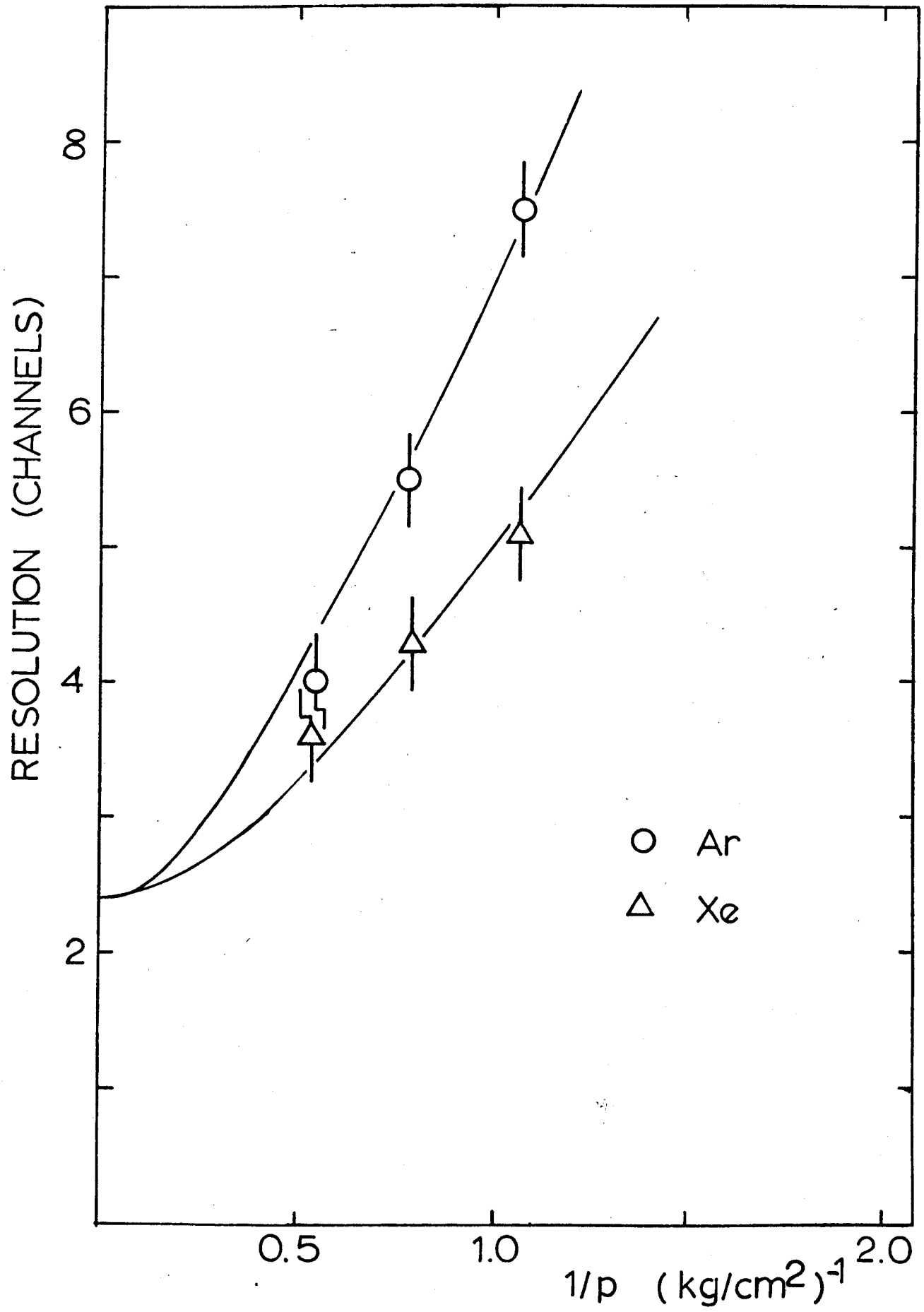
2.8
VOLTAGE (kV)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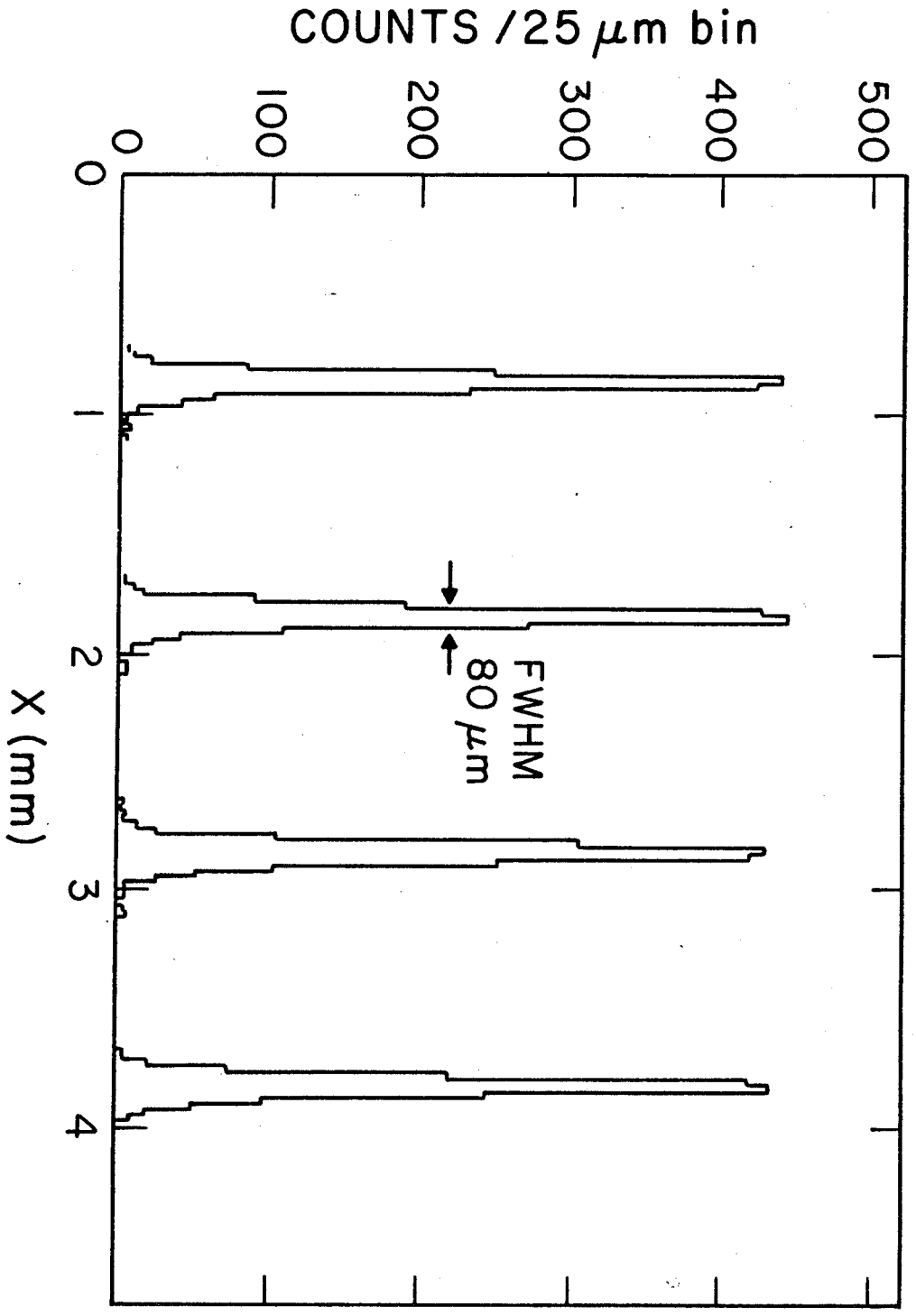
Xe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300
400
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2
3
4
X (mm)
FWHM
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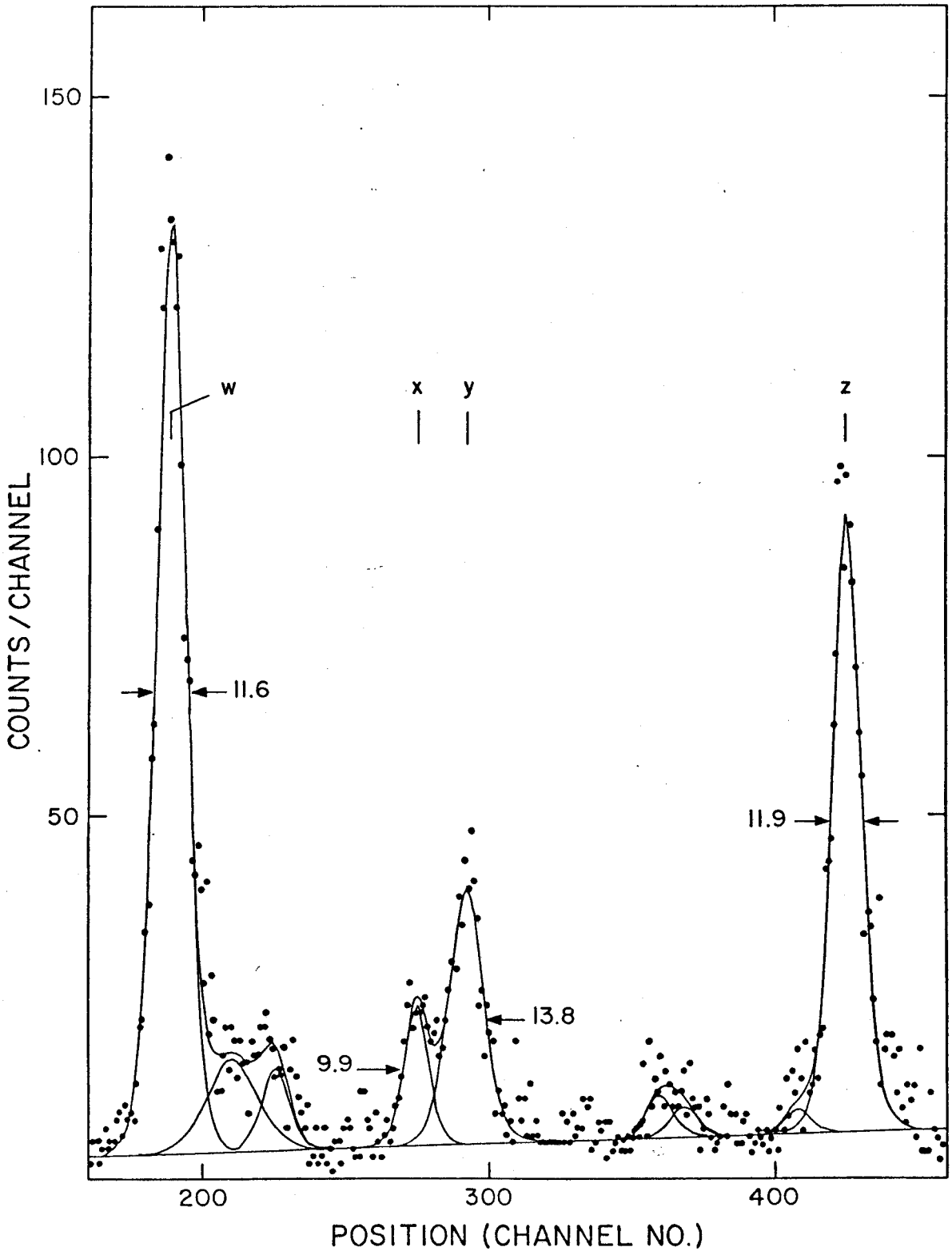
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