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INITIAL IMAGES FROM A 24-WIRE LIQUID XENON γ-CAMERA

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Summary

A prototype liquid xenon γ-camera has been constructed and preliminary results obtained. The sensitive volume is 7 cm × 7 cm in area and 1.5 cm thick. Orthogonal coordinates for each interacting γ-ray are provided by 24 anode wires 5 μ in diameter spaced 2.8 mm apart and 24 cathode strips.

Discussion

We show the image of a point source of 279-keV γ-rays at two positions differing by 5 mm in both coordinates. The spatial resolution was better than 4 mm FWHM and the energy resolution was 19% FWHM.

A liquid xenon multiwire proportional chamber has been constructed and preliminary results obtained. In an earlier paper we reported some of the properties expected from this new approach to γ imaging.[1] The advantages of using liquid xenon instead of NaI are primarily the improved spatial resolution and the higher counting rate (in practice, these factors are limited by the wire spacing, the cost of electronics, and the collimator). The sensitive volume is 7 cm × 7 cm in area and 1.5 cm thick, and contains an array of 24 anode wires and 24 cathode strips.

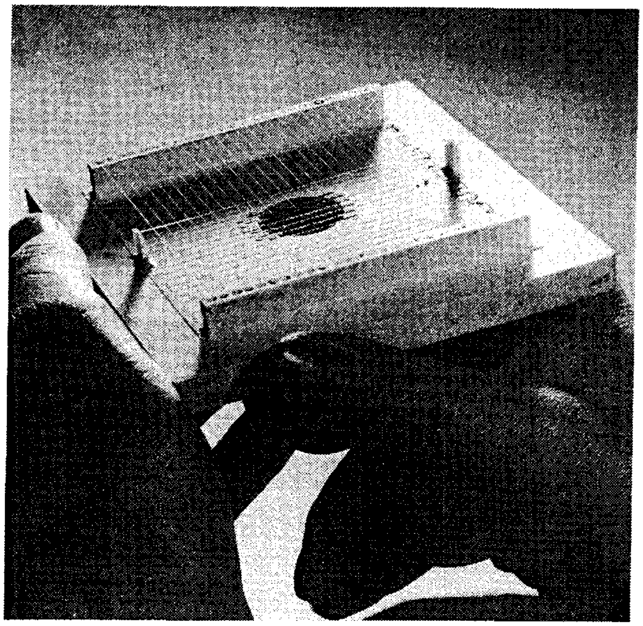

Figure 1. Anode-cathode assembly of the liquid-xenon detector. Anode wires (5 μ diam.) and cathode strips are spaced 2.8 mm apart. Wires are centrally supported by passing between two quartz fibers.

Two types of wires were used: 3.5 μ and 5 μ diam. Most of the studies were made with the 5-μ wire because of its greater strength. The anode wires are spaced 2.8 mm apart and stretched over 7 cm distance, but are centrally supported by passing between two 0.020" quartz fibers as shown in Fig. 1. The cathode consists of conductive strips spaced 2.8 mm apart to provide the orthogonal coordinate.

The readout consists of two, almost identical, charge division networks, shown schematically in Fig. 2. The charge at the cathode is induced over several strips. The readout automatically finds the center of gravity of this induced charge. The resolution, R (FWHM), contributed by the charge division readout is approximately represented by $R \approx \frac{AMN}{S}$, where A is the spacing of the anode wires (or cathode strips), M is the number of wires (or strips), N is the charge amplifier noise level (FWHM), and S is the γ-ray signal level. That is, the resolution, R, is equal to the linear size of the chamber, AM, divided by the signal-to-noise ratio, S/N. For the case where A = 2.8 mm, M = 24, $N = 3 \times 10^{-16}$ C, and $S = 10^{-14}$ C, we find that R = 2.4 mm.

The lower cathode is a 0.005" stainless steel sheet that serves as the window for the incoming radiation. The chamber is placed in the Dewar (also thin windowed) containing Freon-11, and cooled by means of liquid nitrogen.

The gas was specially purified[4] before condensing.

In a recent paper[2] we measured pulse height as a function of voltage for the 279-keV photopeak in a single-wire chamber. From these data, we calculated the first Townsend coefficient as a function of electric field. We found that avalanche ionization in liquid xenon requires electric fields only 20 times higher than

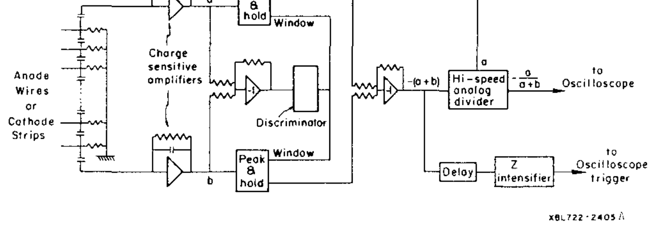

Figure 2. Charge division readout is identical in both coordinates. The position is calculated by a/a+b, where a and b are the charges at the ends of the array. We used 100 pf capacitors and 10 MΩ resistors.

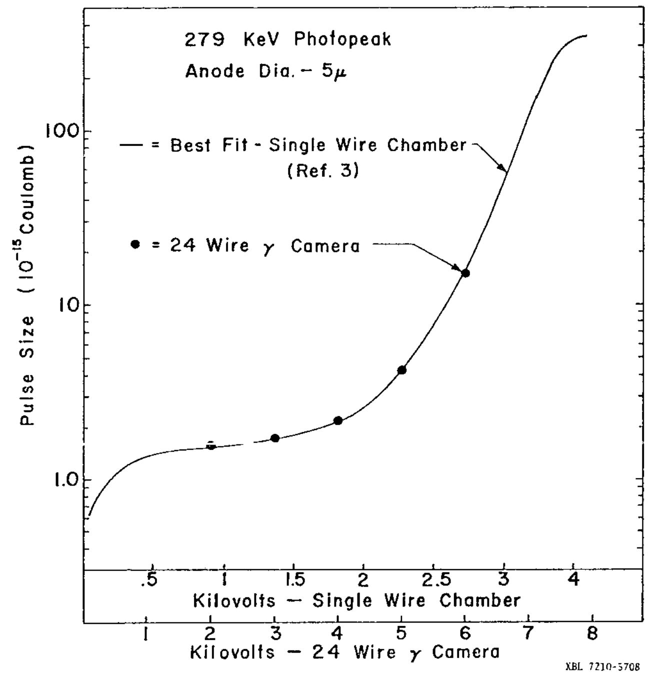

Figure 3. Pulse height vs voltage for the 5-μ wire in the γ-camera superimposed on the best-fit curve to data from the single-wire chamber. Due to differences in geometry, the voltage scales differ by a factor of 2.2.

in gaseous xenon at 1 atm pressure. This is surprising, as this ratio might have been as high as 500, the ratio of the densities.

Results

In the multiwire detector chamber we found that due to differences in geometry the voltage required to obtain the same gain is higher than in the cylindrical

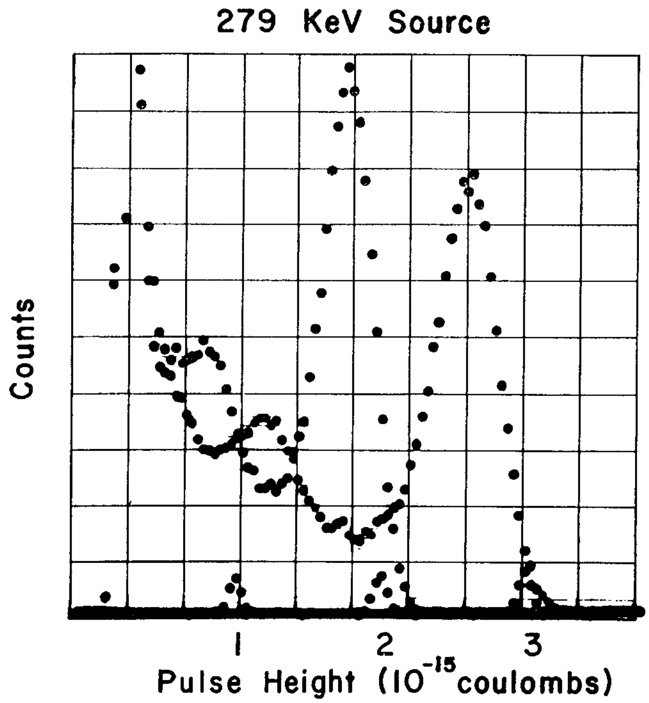

Figure 4. Energy resolution in the camera (5-μ wires). At 3000 V the resolution is 22% FWHM (lower curve) and at 4400 V the resolution is 19% FWHM (upper curve).

geometry by a factor of 2.2 for both 3.5-μ and 5-μ wires. Figure 3 shows the 5-μ wire pulse height vs. voltage data in the γ-chamber superimposed on the single-wire-chamber data.

Operation at the higher voltages may cause breakage of the wires. The problem of wire instability at high electrostatic forces has been treated elsewhere.[3] In order to solve this problem the wires have been supported by quartz fibers. In the 3.5μ case, the wires were supported by three pairs of quartz fibers and a gain of 70 was obtained at 5.5 kV. In the 5μ case the wires where supported only at the center, as

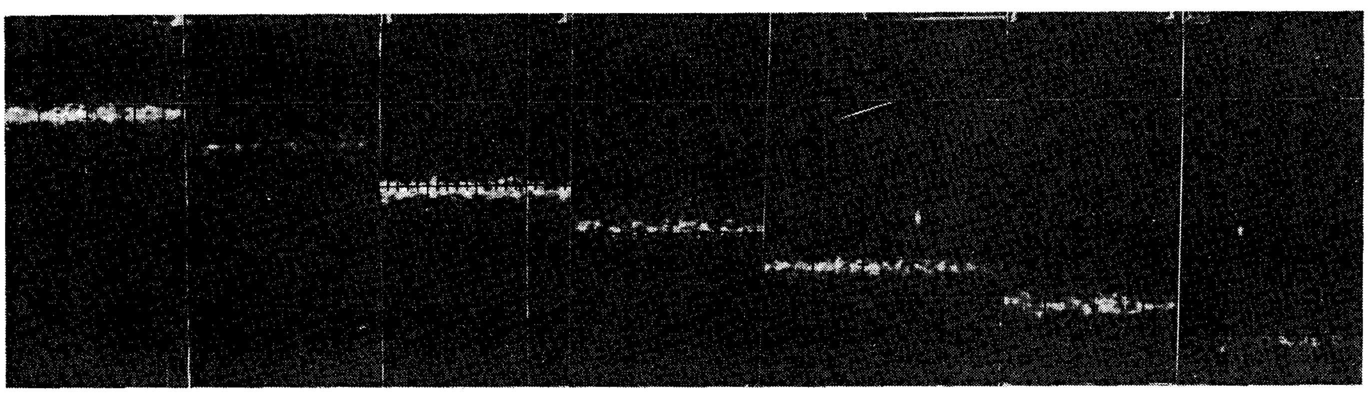

Figure 5. The individual wires of the anode plane imaged on an X-Y plotting oscilloscope using a Hg^{203} source collimated to a circle 2 mm FWHM at the chamber. The vertical coordinate corresponds to position; and the horizontal coordinate was assigned at random by allowing an oscilloscope circuit to sweep periodically. The source is moved a distance equal to the wire spacing (2.8 mm). In this case readout resolution is better than the wire spacing, and the wires are clearly resolved due to their electrostatic focusing property.

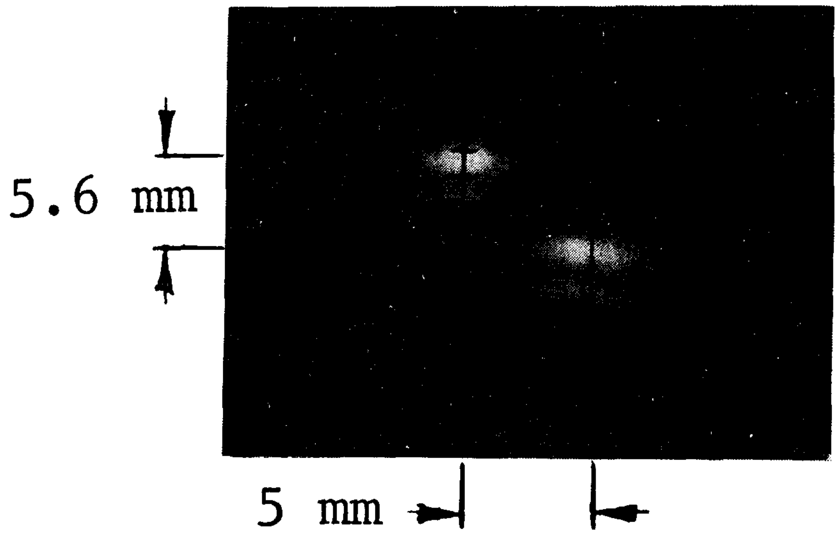

Figure 6. Image of a 279-keV source collimated to 2 mm at the chamber. It was first imaged at one position, then moved 5 mm in both coordinates and re-imaged. The wires (running in the horizontal direction) produce two points when the source is not aligned exactly on one wire. The motion in the vertical direction resulted in dot centers of 5.6 mm (double the wire spacing) due to the electrostatic focusing property of the wires. We estimate the resolution to be 4 mm FWHM.

shown in Fig. 1, and a gain of 10 was obtained at 6.5 kV, a voltage above which the wires tended to break.

The energy resolution was found to be 19% FWHM, similar to our single-wire data.[1] The resolution was not degraded with the increase in gain; in fact, Fig. 4 shows an improvement of the FWHM energy resolution from 3 kV to 4.4 kV. The chamber was maintained in a liquid state for periods as long as 24 hours. By the method of electronegative ion pumping described in Ref. 1 we were able to clean the liquid reliably over a 12-hr period to a level such that the electron attachment was < 1% per mm of drift. For a chamber of a few centimeters thickness, we see that the purity level does not affect the energy resolution. During the run this process had to be repeated every hour, but we expect that future designs will remove even this requirement.

Figure 5 is the result of operating the anode readout only. The vertical coordinate corresponds to position; and the horizontal coordinate was assigned at random by allowing an oscilloscope circuit to sweep periodically. The source was moved in steps equal to the wire spacing of 2.8 mm. As seen in the picture, each is clearly resolved. This condition occurs when the readout has a resolution substantially better than the wire spacing. This pattern produced by the anode wires can be eliminated by moving the detector during the time of exposure and making the corresponding correction to the image in the manner of a Potter-Bucky filter.

In order to investigate the chamber's spatial response, the point source was imaged and then re-imaged after the source was moved 5 mm in both coordinates (Fig. 6). We noted that, for the reasons discussed earlier, the wires (running in the horizontal direction) produced two points when the source was not aligned exactly on one wire. We estimate the resolution to be 4 mm FWHM.

We conclude, on an optimistic note, that the multiwire liquid xenon γ-camera promises significant improvements in the field of medical imaging. Clinical testing in vivo will be conducted in the near future.

Acknowledgment

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