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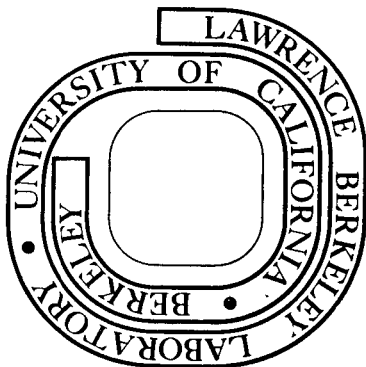
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ELIMINATION OF IMAGE BLURRING DUE TO DOUBLE SCATTER EVENTS IN $\gamma$  IMAGING MWPC DETECTORS

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In multiwire proportional chambers used with honeycomb lead converters for detecting 511 keV  $\gamma$  rays from positron annihilation, a source of image blurring is generated by multiple interaction events due to the escape photoelectric x-ray or from the Compton scattered photon. Using the delay line readout method the majority of these double events are eliminated by using the fact that the sum of the time intervals from the prompt anode signal to the signal arrival at each end of the delay line is a constant to within the timing accuracy for a single interaction. Double interaction events produce a time sum which is shorter. Good improvement in image quality is obtained. The observed number of multiple events is larger than calculations would predict.

INTRODUCTION

In  $\gamma$  imaging devices there are various contributions to the background and the degradation of the spatial resolution. One such contribution is multiple interactions where ionization occurs at more than one point in the detector. This can occur when either a photoelectric escape  $\gamma$ -ray or a Compton scattered  $\gamma$ -ray converts in the detector producing a second pulse. In order to retain image quality one must either reject such multiple events or identify which of the interactions is due to the primary  $\gamma$ -ray. In NaI crystals for energies below 300 keV and MWPC where the  $\gamma$ -ray is below 60 keV such events can be rejected effectively by using pulse height selection.<sup>1</sup> However, at higher energies pulse height selection is not as effective since the photoelectric peak is broadened. Furthermore when MWPC detectors are equipped with honeycomb lead converters or lead-glass tubing assemblies<sup>2</sup> (for imaging 511 keV  $\gamma$ -rays) the spectrum of conversion electrons is continuous and hence rejection of such events is not feasible by pulse height selection.

We have studied this problem for the case where  $\gamma$ -rays from positron annihilation are detected by MWPC's with honeycomb lead converters. By using a MWPC with electromagnetic delay line readout we directly determine the presence of more than one event in the chamber as shown below. We find that there are a significant number of such events and their removal improves the image quality.

MEASUREMENTS

A typical MWPC fitted with honeycomb lead converters is shown in Figure 1. For maximum detection efficiency a converter is used on each side of the proportional chamber. However, for the purposes of the measurements described here only the

bottom converter was in place. A photograph of the converter is also shown in figure 1. The converter cell size was 2.5mm with a height of 15mm. It is divided into 4 bands in order to provide a drift voltage of 330 V/cm to extract the electrons. The efficiency of the single converter has been measured to be 4.2%. The gas mixture was Ar (70%) CO<sub>2</sub>(30%) at STP.

A small NaI detector was used in coincidence with the prompt signal from the anode plane to provide a well collimated beam of 511 keV photons. A point source of a few  $\mu$ Ci of Ge<sup>68</sup> was used. From the geometry the size of the beam at the converter was approximately 3mm.

The position was recorded by electromagnetic delay lines<sup>3</sup> with a delay of 2.5 ns/mm. Low noise amplifiers utilizing "electronic cooling"<sup>4</sup> were used at each end of the delay line. Zero-cross discriminators were used for timing<sup>5</sup>. Slewing for these discriminators was less than 500 ps over a dynamic range of 30 to 1; this is important for converter work since the range in signal amplitude is large.

The well known method of reading the signal from each end of the delay line provides a means of distinguishing multiple events. The time intervals between the avalanche on the anode wires and the arrival of the pulse at each end of the delay line is measured. For single events the sum of the intervals to each end should simply be the length of the delay line plus some fixed delay in the processing electronics; a constant to within the accuracy of the timing measurements. Contributions to the timing jitter are signal to noise, pulse shape and rise time<sup>6</sup>. An advantage in reading from both ends is that in the case where the accuracy is limited by timing errors averaging the positions obtained from each end of the line improves the resolution by a factor of  $\sqrt{2}$ . It is also clear that if a second particle interacts in the chamber before the readout is completed, the sum of the two intervals will be some value less than the length of the line. Fig. 2 shows the time sum distribution for an Fe<sup>55</sup> source. As expected for a single interaction type event, the distribution is symmetric and narrow with a 5 ns FWHM.

In order to correct for accidental coincidences between the NaI detector and the MWPC, data was taken with the NaI signal delayed 3 $\mu$ s which provided more than enough time for the delay line to clear.

In Fig. 3 an x-projection of the point response function for the positron source is plotted with accidental background subtracted. In all cases discussed here accidental background is removed by applying identical cuts to the delayed coincidence data and subtracting the resultant distributions. The FWHM of the distribution is 7mm, larger than one would expect from the geometry discussed previously. There are also a number of events outside the main peak.

Figure 4 shows the time sum distribution for this data. When compared with the distribution for Fe<sup>55</sup>, it is seen that the distribution is wider (FWHM=20ns) skewed to the low side and there are more events on the high side of the peak than one would expect. We have determined that the events on the right side are due to saturation of the linear electronics by signals whose amplitude out of the amplifier is greater than 3V. Signals as small as 30 mV are accepted so the dynamic range is high. One can effectively eliminate this problem by using upper level thresholds on the discriminators. These events are shown in the plot as a demonstration of one problem that is corrected by time sum information. In order to make sure we are not affected by these large sums, events are rejected if the sum is larger than 168ns; this cut is indicated on Figure 3. Figure 5 shows the point response function after this cut has been applied: the FWHM is reduced to 6.5 ns.

On the left hand side of the time sum peak there appear to be a significant number of cases where a multiple interaction has occurred. Once away from the peak, the distribution is relatively flat until it reaches a sum of 150ns at which point it drops off. A sum of 150ns would be expected for the case where a photon converted at the center of the chamber producing a secondary photon which converted very close to one edge of the chamber giving a sum approximately equal to half the length of the delay line.

In Figures 6a and 6b the point response function is plotted for events with a time sum between 141 and 168ns and 150 and 168ns respectively. These cuts should remove many of these multiple events. As can be seen the number of off-target events (outside the main peak) is reduced and the peak is sharpened.

Table I summarizes the results giving the number of events contained within different intervals about the mean for various sum cuts. As can be seen improvement in the fraction of events contained within a given interval can be obtained with some reduction in the total number of events within the interval.

A Monte Carlo calculation was performed to determine the probability of secondary interactions from photoelectric escape photons and Compton scattering and their contribution to the spatial resolution. The photon is assumed to enter the converter approximately perpendicular. The material in the converter is assumed to be distributed uniformly throughout its volume. The point at which the 511 keV photon converts is determined and an average detection probability is assigned. A conversion is considered detected if an electron escapes from the wall of the honeycomb into the gas. The average probability for this to occur for 511 keV  $\gamma$ 's was determined assuming a .1mm wall thickness. This probability is .57 for photoelectric conversion and .12 for Compton scattering. At 511 keV the cross section for photoelectric effect is 1.20 times the Compton cross section.

The Compton scattered photon or the 88 keV escape photon for Pb is followed until it converts or escapes from the converter. Figure 7a gives the probability of secondary interaction as a function of lateral distance from the primary conversion. There is a 64% chance of producing a secondary interaction. Figure 7b gives the probability of actually detecting the secondary interaction. Note that there is a 17% chance of detecting a secondary photon. But if we require that the primary interaction also be detected then the probability of having a 2 photon event drops to 4%.

Almost all of the secondary events are predicted to occur within 1 cm of the primary interaction. There are not enough double events to explain the

experimental measurements. For example the observed time sum distribution indicates that there should be a 5% probability of producing a double event with the spacing between primary and secondary larger than 2cm. In the Monte Carlo program we have not taken into account the possibility that the secondary photon could leave the converter and convert in the aluminum lid of the vessel. Since the mean free path in gas is long this could produce a secondary event far from the primary, however, the probability of producing a detectable electron from the cover would be lower than from the converter. It is probably likely that even after this is taken into account that there will be some multiple events that can not be explained. Our confidence in the Monte Carlo code itself is bolstered by the fact that it predicts the detection efficiency of the converter to within 20%.

### CONCLUSIONS

At this point the observed effect is not completely understood. Work on the problem will continue, both from the point of view of understanding the physics involved and actually implementing this time sum technique in the U.C.S.F. MWPC positron camera. What is clear is that there are multiple interactions in the chamber which spoil the resolution, and that this method provides a means of correcting the problem.

### ACKNOWLEDGEMENTS

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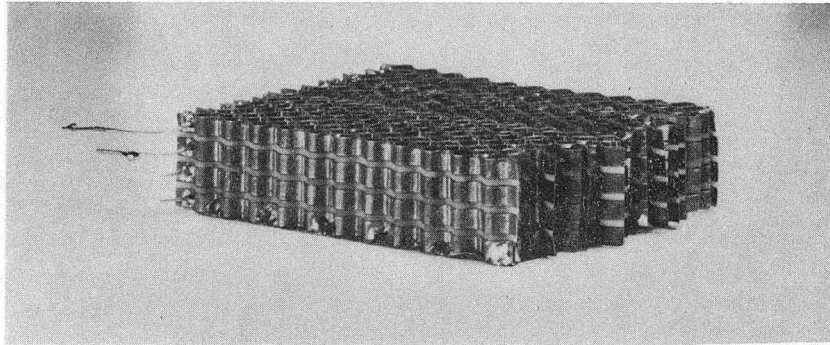
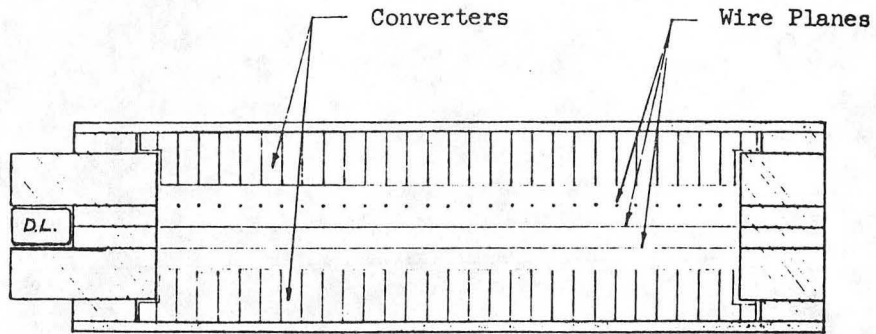
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CAPTIONS

- Fig. 1. Schematic Diagram of a MWPC with honeycomb lead converters. The honeycomb converter is also shown.
- Fig. 2. Time sum distribution for an  $\text{Fe}^{55}$  source.
- Fig. 3. X-projection of point response function for the positron source.
- Fig. 4. Time sum distribution for the positron source. The cut on the high side of the peak is shown.
- Fig. 5. X-projection of point response function for those events with time sums less than 168 ns.
- Fig. 6a. X-projection of point response function for those events with sums between 141 and 168 ns.
- Fig. 6b. X-projection of point response function for those events with sums between 150 and 168 ns.
- Fig. 7a. Probability of a secondary interaction as a function of distance from the primary interaction. The total fraction of photoelectric and Compton interactions is shown. Also given is the probability of only a primary interaction.
- b. Probability of detecting a secondary interaction. Double refers to the sum of the Compton and photoelectric contributions when both secondary and primary interactions are detected. The scale for the double curve is on the right hand side.

TABLE I. The number of events contained in intervals about the mean of x projection of the point response function is given for various time sum cuts. The fraction of those events passing the cut, which fall within the interval is also given.

| Interval | No Sum Cuts  | Sum < 168ns  | 141 < Sum < 168ns | 150 < Sum < 168ns |
|----------|--------------|--------------|-------------------|-------------------|
| 5 mm     | 14003<br>49% | 12495<br>50% | 11481<br>65%      | 8464<br>72%       |
| 10 mm    | 21604<br>75% | 19105<br>77% | 15057<br>86%      | 10655<br>91%      |
| 15 mm    | 24867<br>86% | 21942<br>88% | 16472<br>94%      | 11346<br>97%      |



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Fig. 1



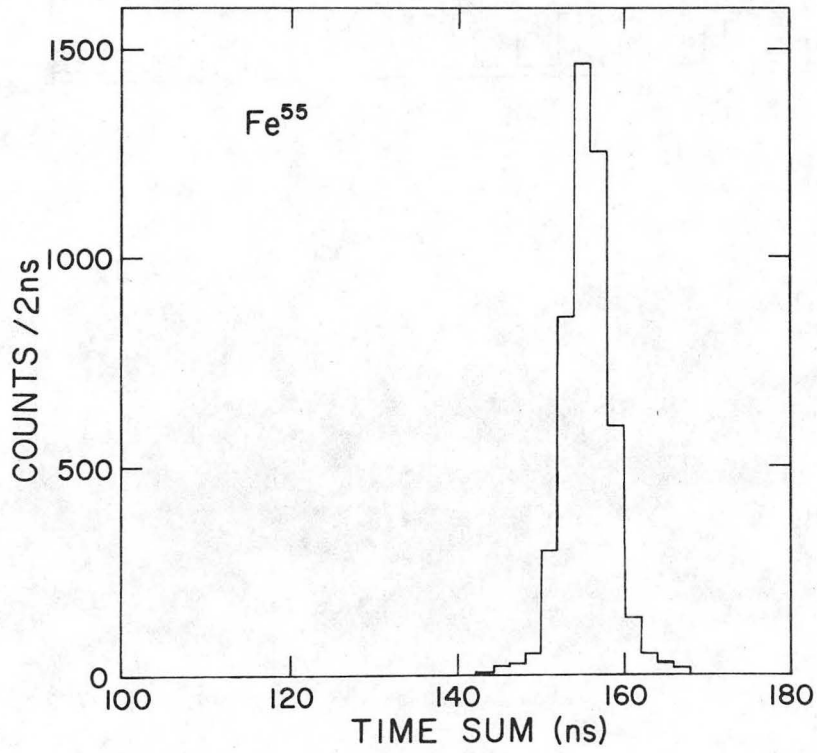


Fig. 2

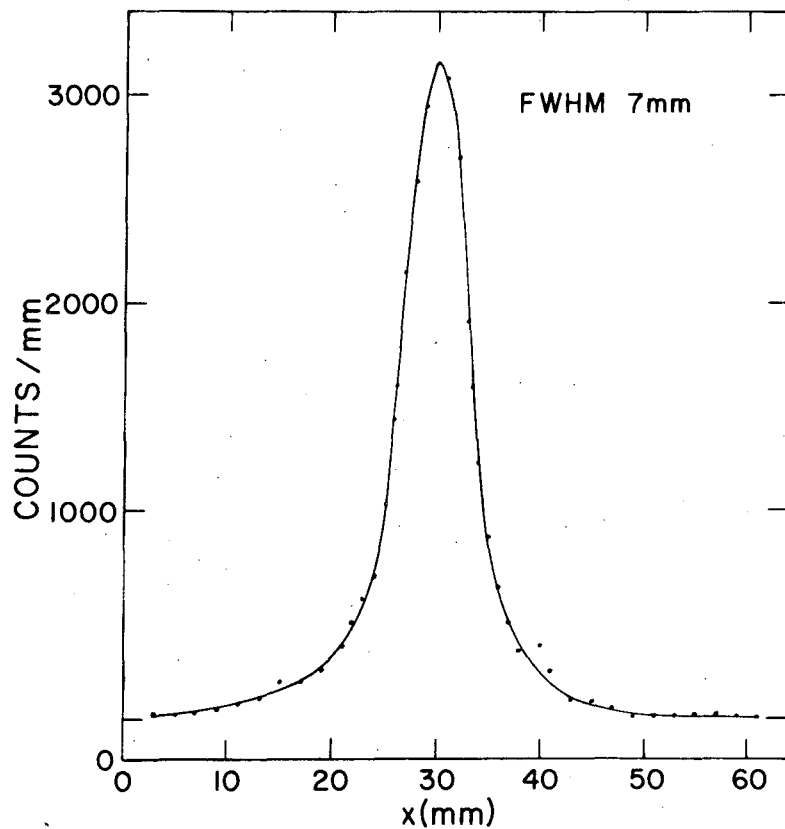


Fig. 3

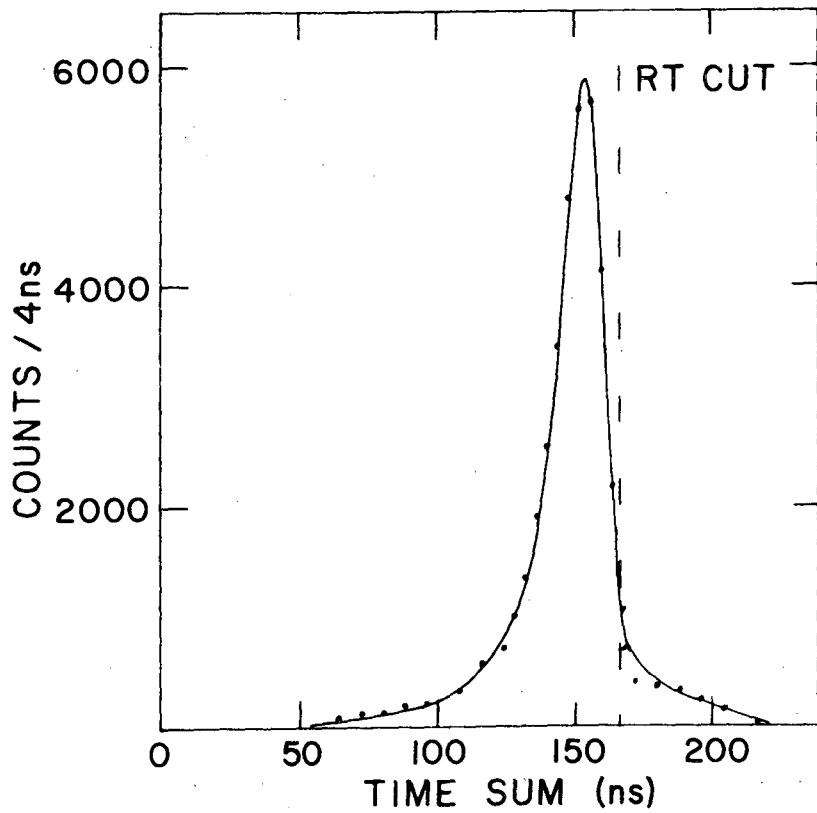


Fig. 4

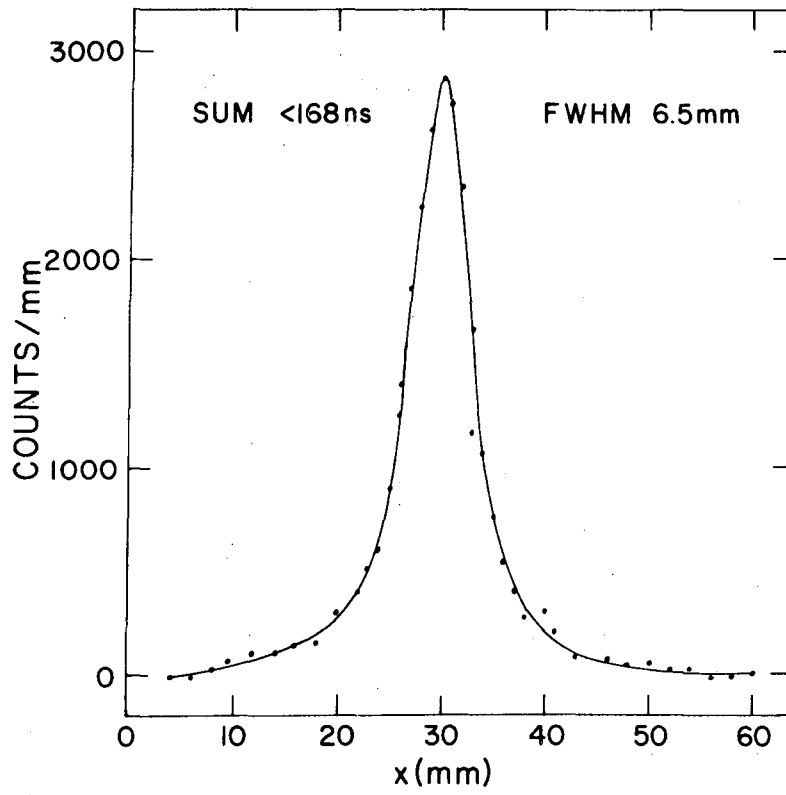


Fig. 5

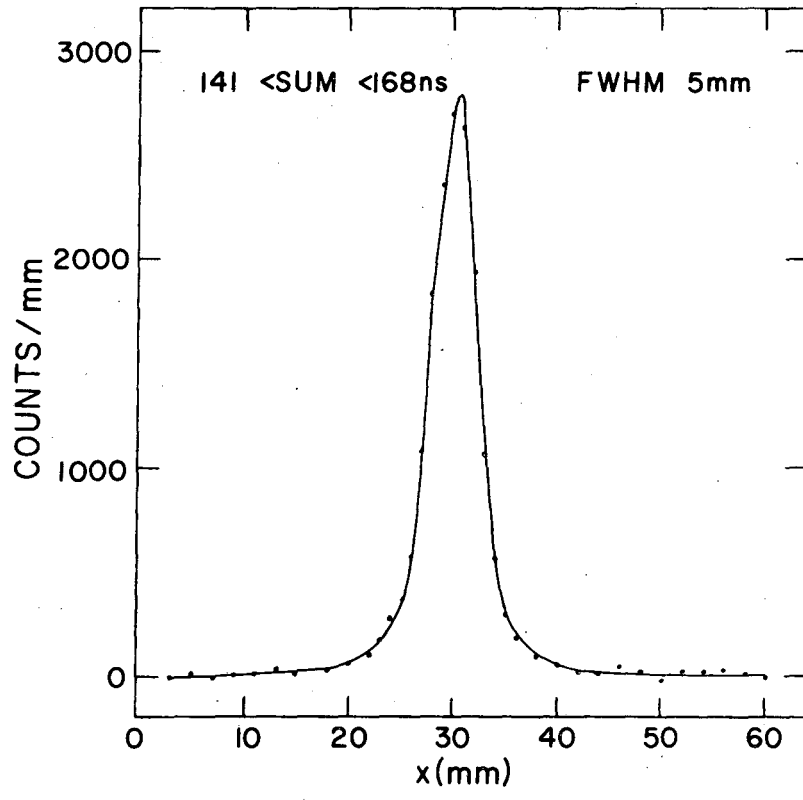


Fig. 6a

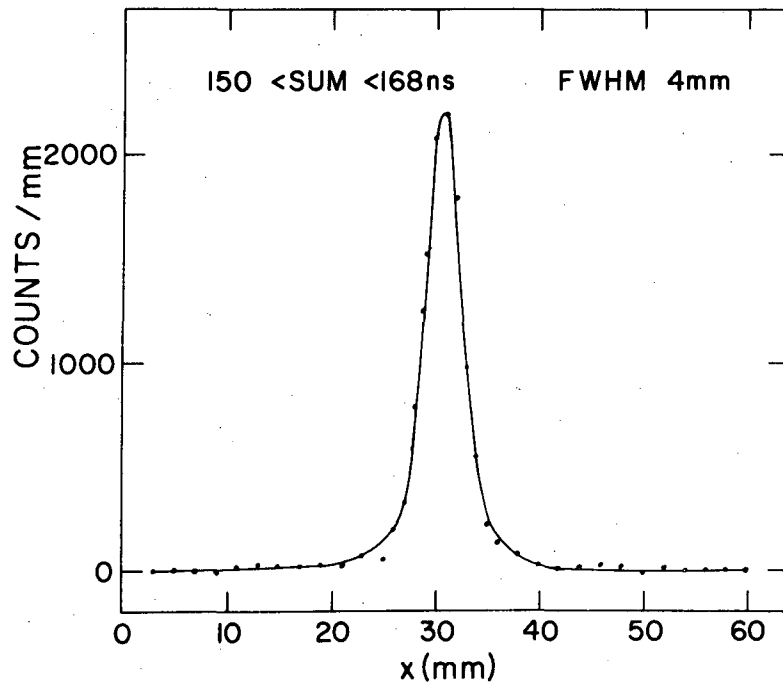


Fig. 6b

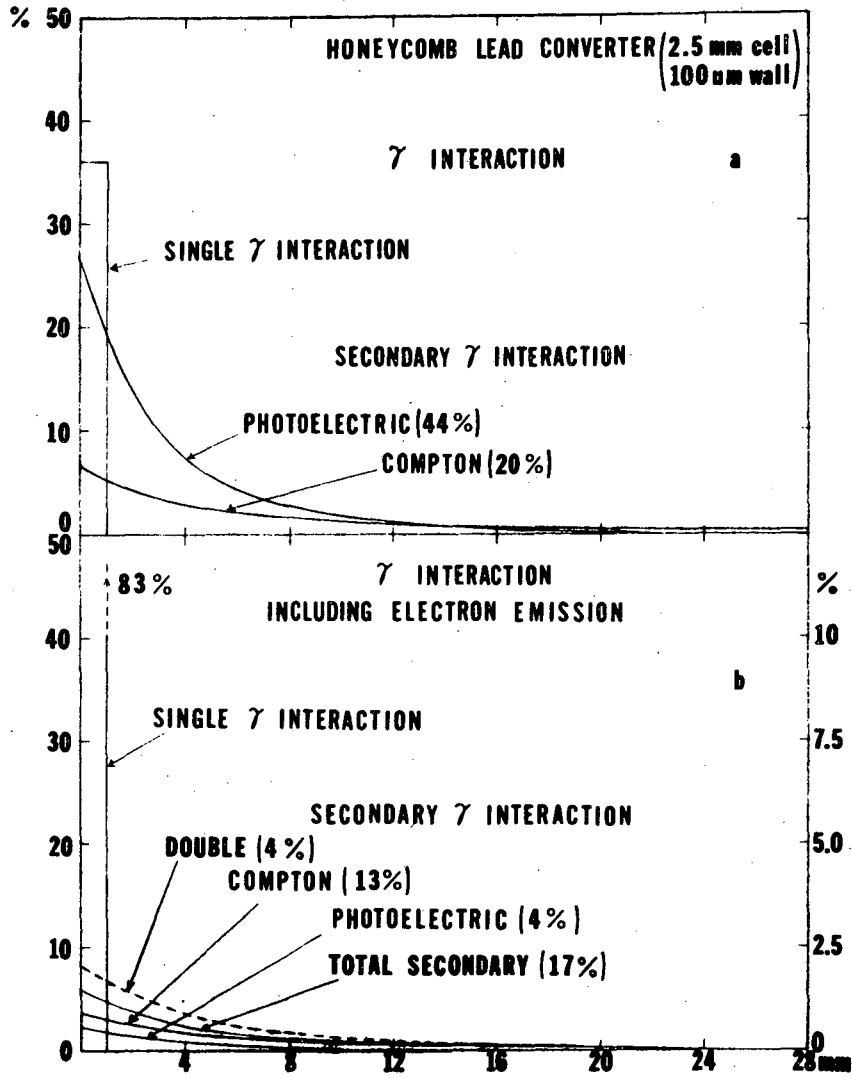


Fig. 7

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