Minimizing Room Return Neutrons

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ABSTRACT

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It is often difficult to accurately determine the number of neutrons incident on a detector because of room return, or the scattering of neutrons from nearby material into the detector. We developed a neutron detection platform mounted on a scissor lift so that room return can be minimized in our counting experiments. We measured the neutron counting rate as a function of the height of the platform above a concrete slab located below the lift. This measurement was taken with a Li-6 glass neutron detector used in conjunction with a Li-7 glass detector to subtract gamma background. We used neutrons from a Cf-252 source located at a fixed position on the platform. We found that room return became minimal when the lift was raised to a height of five meters above the concrete. This result is important for helping reduce room return in neutron detection research. With neutron detectors that are sensitive to low energy or thermal neutrons, as is our Li-6 detector, an effective way to account for room return is to have the detector and source beyond five meters from the wall and floor.

Keywords: neutrons, room return, detection, pulse shape discrimination

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Chapter 1

Introduction

1.1 Historical Perspective and Background

Since the discovery of neutrons, methods have been developed to detect both low and high energy neutrons. He-3 detectors were discovered to be an effective method of neutron detection by means of a simple nuclear reaction: the neutron is captured by the He-3 atom to make an energetic He-4. This short-lived particle rapidly decays into a triton (H-3) and a proton. Both of these particles are accelerated in an electric field and detected in the same manner as a Geiger Counter (Knoll 2000). In the past, He-3 was plentiful as it was a byproduct of building nuclear weapons. With the decrease in mass scale nuclear weapons production, He-3 has diminished in availability, creating a subsequent skyrocketing in its price (Morgan & Shea 2010). To combat this problem, various affordable methods have been developed to create innovative methods to detect neutrons (Feder 2009).

In this scramble to improve and test new detectors, various challenges must be met. One such problem that has always existed with neutron detection is the phenomenon of room return neutrons. As neutrons emanate from a source, they radiate isotropically. Some neutrons will enter

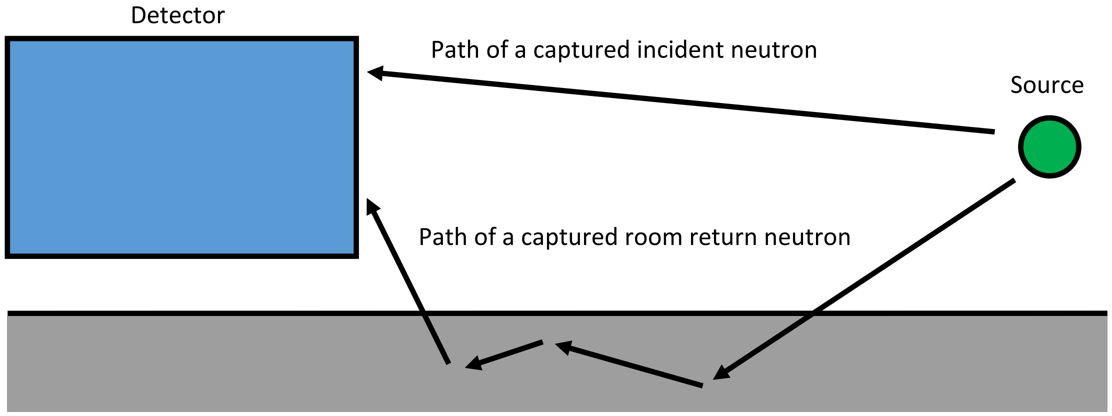

Figure 1.1 The diagram shows an example of a room return neutron which is captured by the detector. The neutron source emits a neutron which moves toward the ground. This neutron collides with several protons as it travels through the ground and exits as a low energy neutron into the detector.

directly into the detector giving the desired signal. Others travel to nearby walls and the floor where they interact with the material and deposit a significant amount of energy, bouncing around in a Brownian fashion with some entering the detector (see Fig. 1.1). Depending on the proximity of the detector to the walls and floor, the number of neutrons that enter the detector varies greatly. Thus, many methods have been developed and continue to be improved upon to account for the error created by the capture of these room return neutrons. We have reviewed some of these methods including the use of a shadow bar, Monte Carlo simulations, and expensive facilities, and found them to be potentially inadequate or unnecessarily extensive. For these reasons, we have worked to identify an affordable and simple solution to the problem.

1.2 Motivation

The detection of neutrons is vital to further our understanding of particle physics. The strong force or proton-neutron and neutron-neutron interaction is poorly understood and sensitive neutron detectors are needed to understand the intricate details of these interactions. Without improvements in technology and techniques, these details will remain indiscernible. An example of this lack of knowledge is the question of how neutrons radiate from a source following a fission event. There are two conflicting theories which have yet to be established or debunked by convincing experimental evidence. The first idea theorizes that the fission occurs with all the neutrons radiating off the two new energetic nuclei. The other theory predicts that as the nucleus divides, some neutrons radiate from the splitting point of the nucleus during the fission event and that some neutrons may come off in pairs as the neutrons are slightly attracted to each other. With more improvements to modern neutron detectors, we could answer this and other questions relating to particle physics.

National security also requires improvements in neutron detection. As neutrons are uncharged, they seldom interact with other particles–the exceptions being the strong force. As a result, shielding neutrons that are emitted from a radioactive source is much more challenging than shielding other radiation. Alpha and beta particles can be shielded with a thin layer of material while gamma radiation can be absorbed by a few centimeters of lead or another dense material. Neutrons, on the other hand, need thick layers of hydrogen-dense material to be adequately shielded; this makes neutrons a prime target for national security officers to identify radioactive material. Were someone to bring radioactive material into an airport, it would be difficult to shield the neutrons from being detected if sensitive and affordable detectors are developed.

1.3 Background Information

Many methods have been developed to efficiently detect neutrons. The method previously discussed consists of using He-3 detectors, though this carries an obvious disadvantage: the shortage and consequent price explosion of He-3.

The most common method for detecting neutrons is through scintillation. Scintillators are materials that emit light when exposed to radiation including alpha, beta, gamma, and neutron radiation. For neutrons, this works through knockon protons. As the neutron enters the scintillating material it may collide with or “knock on” protons (hydrogen). When this occurs, energy is passed to the proton which then transmits that energy as phonons (quantized vibrations) in the latice of the structure. These vibrations are then absorbed by the material and will excite the scintillator to emit photons which can then be detected by photodetectors (Knoll 2000).

A similar method of detecting neutrons is through capture reactions. Certain materials such as Li-6 or cadmium have high capture rates of neutrons. The capture rate is directly related to how much energy the neutron has; thus, moderating material is necessary to decrease the neutron’s energy to make a capture event more likely. Moderating material can vary, but often a scintillator with high amounts of hydrogen is used as a moderator to detect incoming neutrons and lower their energy through proton knockon collisions. Following this, the neutron may be readily captured by materials such as cadmium or Li-6 and will deposit a large amount of energy in the scintillator. As explained previously, this will once again lead to a release of a cascade of photons giving a second pulse. If the moderator does not scintillate, only a single pulse will be emitted.

1.4 Existing Methods and Approaches

One of the most common methods used to account for room return neutrons is through computational methods. Monte Carlo simulations have been extensively developed to calculate the interaction of particles and photons with matter (Rees & Czirr 2012). These simulations are used to estimate how many neutrons radiate from a given source and how many of those enter the detector. Monte Carlo simulations take into account the material in the room, detector, etc. to try to provide the best estimations possible. When conducting experiments, scientists subtract the estimated neutrons captured in the Monte Carlo simulation from their neutron counts. While this technique is often used to make room return estimates, it also includes many approximations as the real experimental setup may be difficult to replicate in a Monte Carlo simulation. This is true especially when the experimental environment is complex.

Many have recognized the challenges and limitations of the Monte Carlo simulations and continue to use them, but only as a supplement to other methods that try to reduce room return. One of these methods is to use a shadow bar to experimentally determine the number of room return neutrons. A shadow bar is a bar of dense material that is placed directly in front of the detector. It blocks all the neutrons that are directly incident on the detector; presumably the only neutrons detected will be from the ambient background and room return. These data can then be subtracted from the normal run to identify only the neutrons directly from the source. This method may be less accurate than it would seem. By placing the shadow bar to block all incident neutrons directly from the source, they are not being eliminated, only redirected through elastic collisions. These neutrons may then return to enter the detector and subsequently increase room return. This creates an overestimate of the neutrons from room return and results in an over-subtraction of room return neutrons.

An additional method to account for room return is to build a facility that places the detector about three meters above the ground and far from the walls, such as the one found at the Los Alamos Neutron Science Center (LANSCZ). While this method seems effective, some have questioned whether or not the experimental area is sufficiently isolated as Monte Carlo simulations seem to suggest. With high amounts of radiation in the facility, the neutrons may build up and the size of the room may not be large enough to avoid high amounts of room return. Our research has been conducted to explore this fundamental question. Additionally, we seek for a more cost-effective method of conducting neutron research other than building a facility.

1.5 Addressed Question

Our research goal is to determine how room return decreases as a function of height. Furthermore, we aim to determine if using a scissor lift to escape room return would be an effective way to conduct neutron research in an affordable manner. Lastly, we seek to determine at what height room return neutrons could be considered negligible in order for similar future experiments to be conducted with minimal room return.

Chapter 2

Methods

2.1 Introduction

This section addresses the methods used in our experiment. The first section will discuss the experimental setup on the scissor lift. The next section discusses how the lithium detectors detect radiation and produce an output to the hardware. The following section then discusses how the hardware receives and digitizes the output from the detector. Next, the importance of gain matching the lithium detectors will be discussed and how gain matching is accomplished. It will then be discussed how the data from the experiment are processed and analyzed. Finally, I will discuss the numerical techniques we will use to do pulse shape discrimination with our Li-6 detector.

2.2 Scissor Lift Setup

Our approach places the detector and the neutron source on a twenty-foot scissor lift outdoors (away from buildings or walls) to escape the effect of room return neutrons (see Fig. 3.4). Not only is this a significantly affordable method–much more affordable than having to build an entire facility–but it is also potentially much more effective at reducing room return. Our goal is to test

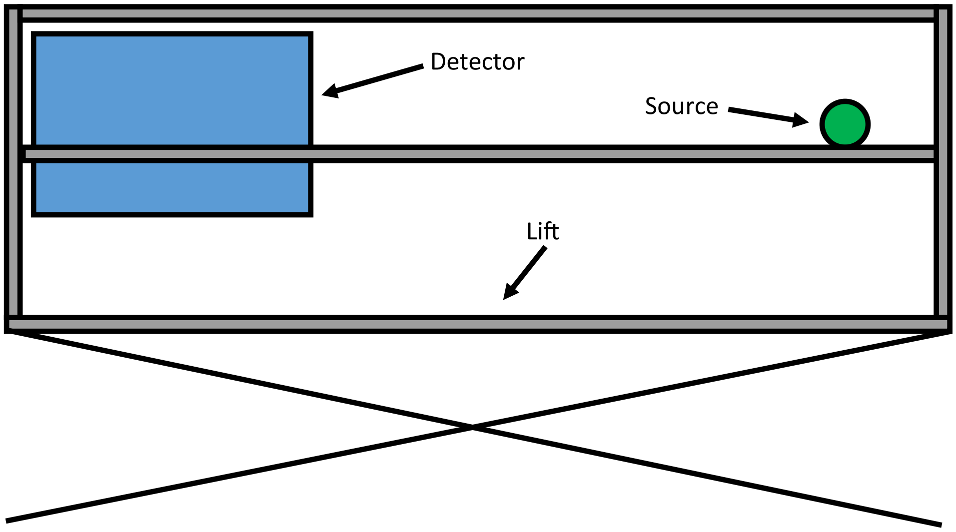

Figure 2.1 Shown here is a diagram of the experimental setup. The detector and source can be seen on the lift which varies in height to find the relationship between room return and height from the ground.

this hypothesis and to identify at what height the effects from room return neutrons taper off and become negligible.

We are using a Li-6 detector for neutron detection. Since Li-6 detectors are responsive to both neutron and gamma radiation and are unable to distinguish between the two, we have also taken identical data on a Li-7 detector that has been gain matched (see section 2.5) to detect the amount of gamma counts in our Li-6 data. Data were taken with both the source present and not present for both detectors. With these data we can isolate the neutrons detected that come directly from the source from those that come from room return. This is done by first subtracting off the ambient background from the Cf-252 runs. Then, the Li-7 data, which contains only gamma events, are subtracted from the Li-6 data which contain both gamma and neutron events. Thus, we were able to isolate the neutron counts from the source.

By isolating neutron counts from our Cf-252 run at different heights, we were able to see how the neutron counts varied as the distance from the detector and the distance from the source to the ground changed. This helped us determine a comfortable height at which we can confidently say our detector picked up virtually no room return neutrons. The error in this method is that some room return neutrons will be detected from the lift itself which could be approximated (but was not) with a Monte Carlo simulation and additionally subtracted off for further precision.

2.3 Lithium-Glass Detectors

The Li-glass detectors are able to detect radiation through neutron captures. The Li-6 and Li-7 glass sheets are identically prepared with cerium, the scintillating material. When gamma radiation enters the Li-6 or Li-7 glass, it undergoes Compton scattering in the material. The Compton electrons then transfer energy to the glass as vibrations or phonons. The energy gained excites the cerium in the material to release photons in the visible light spectrum. These photons are detected by the photomultiplier tube (PMT). Thus, gammas events are found in both the Li-6 and the Li-7 data.

However, the Li-6 also captures neutrons. This occurs when a lower energy neutron, a thermal neutron, is captured by a Li-6 nucleus to make an excited Li-7 nucleus. This nucleus decays quickly into an alpha and a triton (H-3). These particles then go on to interact with the glass creating visible light as before.

2.4 Hardware Setup

The PMT in the detector outputs a voltage pulse correlating to the amount of light seen. This output runs into a 100 Ω t-terminator to eliminate ringing. The signal continues into an amplifier to maximize resolution. The amplifier setting is found by looking at signals from the detector and maximizing it to the point where the larger signals do not clip, insuring that signals do not exceed 1.0 V. This limitation is due to the amplifier output leading into a 250 MHz CAEN digitizer which cannot handle voltages larger than 1.0 V. The CAEN digitizer then takes the incoming voltage and digitizes the voltage input every four nanoseconds (one channel). These voltage values are stored in a computer for later analysis. The data are processed by software techniques in a Matlab program where a threshold is applied to eliminate the majority of gamma and noise events.

2.5 Gain Matching Detectors

It is important that the Li-6 and Li-7 detectors pick up the same counts from gamma radiation above the required threshold where neutrons are detected. To achieve this, we took data from both detectors with a Co-60 source from which only gammas are emitted. We once again took background data to subtract off neutrons and gammas from the room, and we matched the bias voltages on the two detectors until the gamma counts were identical. The optimal voltages for the detectors were found to be 1200 V for the Li-6 detector and 1305 V for the Li-7 detector.

To determine the threshold, we looked at data from the Li-6 detector from our Cf-252 source. Making a histogram of the peak areas results in two distinct peaks. The gamma data tend to have smaller areas and fall in the first two smaller peaks while the neutrons fall into the third large peak (see Fig. 2.2 and 2.3). As shown, there is significant overlap between the neutron peak and the second gamma peak; this requires the necessity for the Li-7 detector to provide gamma data for the Li-6 detector. The valley between these two peaks in the Li-6 data is used as the threshold when analyzing our data.

2.6 Numerical Techniques

Counts from the Li-6 (both gammas and neutron events) were subtracted from the Li-7 data (gammas only) to isolate neutron information. This was done for both the Cf-252 and background data. Background data were then subtracted from the source data to isolate the neutrons from the source.

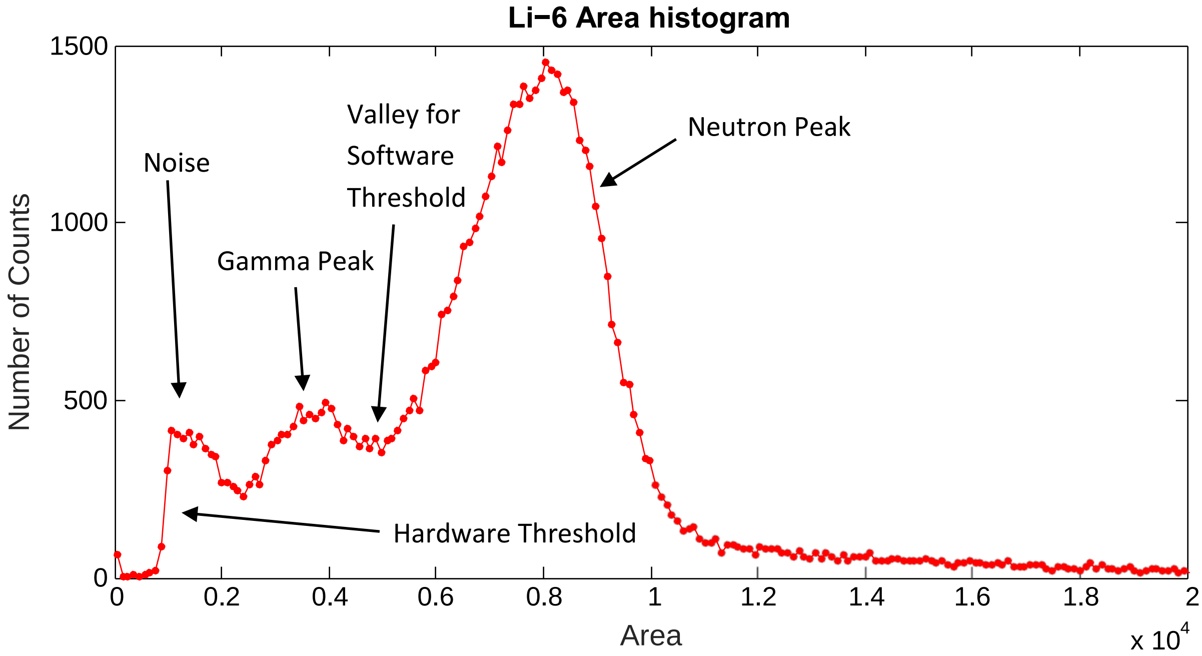

Figure 2.2 This graph shows all of the events in the 40 minute run for the Li-6 detector before background subtraction and application of the software threshold. The first peak tends to be gamma events while the second peak tends to be neutron events. Thus, the valley in the middle is used as a software threshold to remove the majority of gamma events. Area is determined by integrating the voltage peak seen by the Cain detector with respect to time.

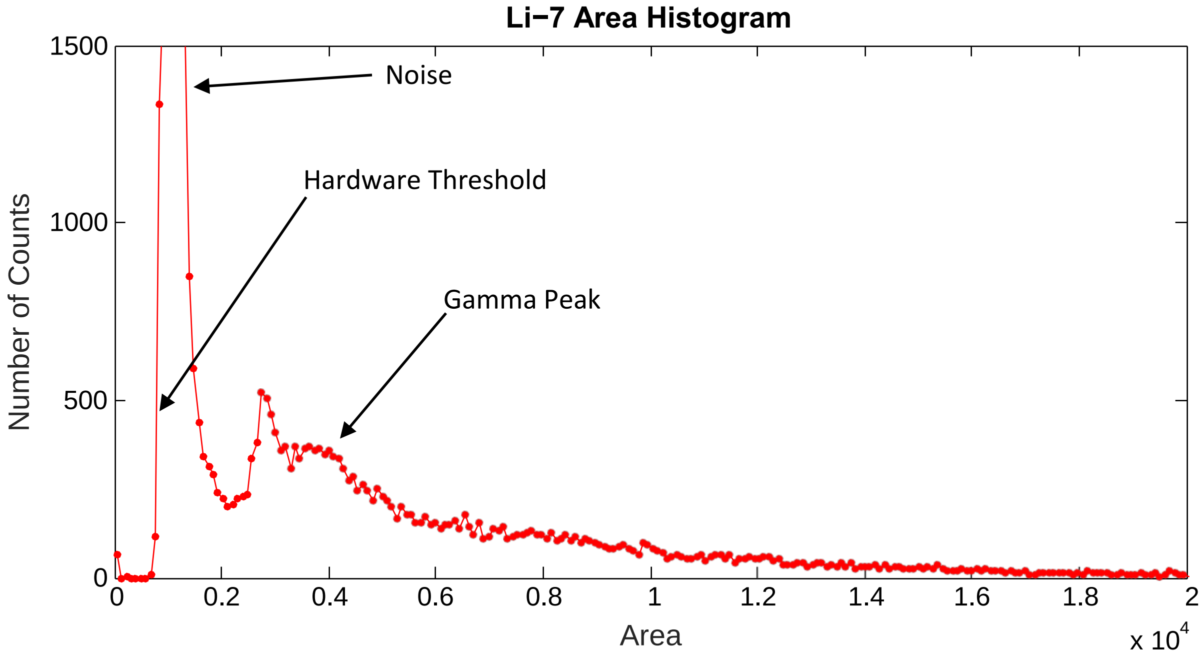

Figure 2.3 This graph shows all of the events in the 40 minute run for the Li-7 detector before background subtraction and application of the software threshold. The first peak that is not entirely shown are noise events not removed by the hardware threshold (but that will be removed by the software threshold). The second peak consists of gamma events. Area is determined by integrating the voltage peak seen by the Cain detector with respect to time.

Thus we identify the relationship between neutron counts as a function of height.

The duration of experimental runs is limited so as to minimize diurnal cosmic neutron variations (Kouzes et al. 2010) and to maintain similar weather conditions (all of which affect our measured room return). We used Poisson statistics to calculate the percent uncertainty for the runs after background subtraction.

We repeated the experiment a second time to check for reproducibility and it yielded similar results. With the uncertainty we obtained, we were unable to distinguish between the room return of 5.17 m and 6.60 m and therefore conducted an additional experiment comparing only those two heights for four times the original length to reduce our uncertainty by a factor of two.

We also calculated the efficiency of our Li-6/Li-7 detectors together in tandem by using the data at the highest height (to minimize room return). The efficiency is found by taking the number of fissions per second of the source, multiplied by the average number of neutrons per fission, multiplied by the fraction of neutrons that enter the detector (based on the solid angle); the found value is the number of neutrons per second that enter the detector (not those that hit the Li-glass which would yield a higher efficiency). The found value is then multiplied by the runtime of the detector to get the total number of neutrons that entered the detector during the run. Lastly, we divide the neutrons that were seen by the detector by the total number of neutrons that entered the detector to determine the overall efficiency.

2.7 Pulse Shape Discrimination (PSD)

We were also interested in improving our ability to distinguish the gamma and neutron events in our Li-6 detector. We looked at a variety of characteristics of the peaks to determine how we could best discriminate between gamma and neutron events in our Li-6 data. We compared these events with our Li-7 data which contained only gamma events. We found that the best separation of events occurred when comparing the area of the peaks against the percent of the area that came toward the beginning of the peak. This separation worked well because the gamma peaks tend to be sharp and short (see Fig. 2.4) while neutron peaks tend to have a longer tail (see Fig. 2.5). Thus, the fraction of the area that comes early for gamma events is high, while it is much lower for neutron peaks.

The first line on the peak graphs shows what we call the beginning of the peak. Following 25 channels (100 nanoseconds) after the first line, we then add the blue line. This value was found through trial and error until we found what seemed to give us the best separation of the neutron peak. The area of the region between the first green line and the blue line is what we call the "early area." The last green line is the end of the peak and the area between the two green lines is the total area of the peak. We then take the early area and divide it by the total area to obtain the "fraction early area." Using the fraction early area and the total area to separate our peaks is what separates our gamma events from our neutron events. These are the parameters we used to attempt pulse shape discrimination (PSD) for our Li-6 detector.

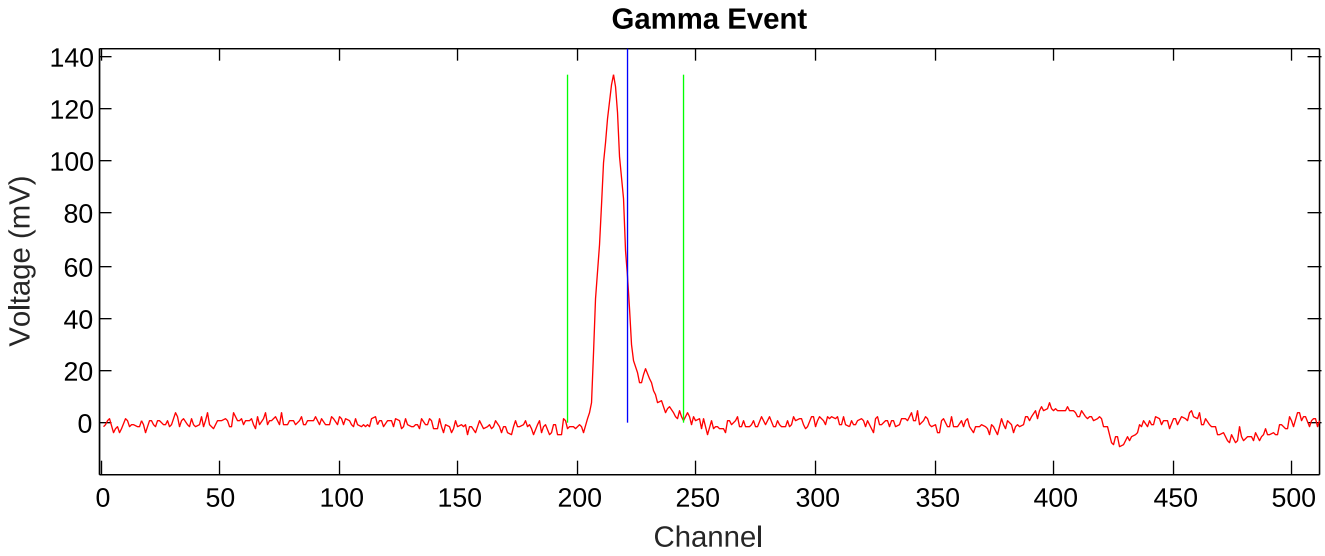

Figure 2.4 Shown here is a typical gamma event in our Li-6 glass detector. The first green line represents the beginning of the peak, while the last green line is the end of the peak. The blue line is set 25 channels (100 nanoseconds) after the first green line. This helps determine the fraction of the area that comes early on in the peak. A channel is four nanoseconds which is determined by the CAEN digitizer.

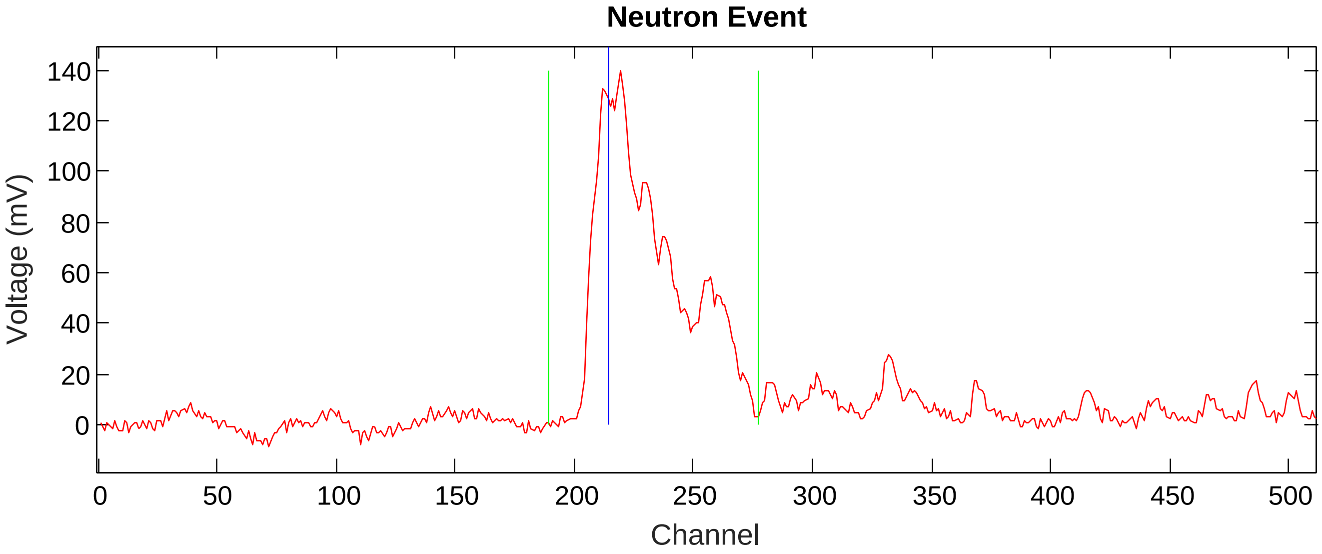

Figure 2.5 Shown here is a typical neutron event in our Li-6 glass detector. The first green line represents the beginning of the peak, while the last green line is the end of the peak. The blue line is set 25 channels (100 nanoseconds) after the first green line. This helps determine the fraction of the area that comes early on in the peak. A channel is four nanoseconds which is determined by the CAEN digitizer.

Chapter 3

Results

3.1 Introduction

The first section will discuss the data found from our experiment. Next, I will discuss the relevance of our results to future experiments. Following this, the pulse shape discrimination results for our Li-6 glass detector will be discussed. Lastly, I will discuss the further work to be done to reduce uncertainty in our results.

3.2 Room Return Data

The data from the three runs are presented in Tables 3.1–3.3 with the results presented in Table 3.4. These data show that there is a drop in the room return as the height increases. Viewing the top two heights, the determined experimental error shows no significant difference between the neutron counts and thus, the room return. However, there is significant room return when data are taken below five meters, which could be cause for concern in experiments with neutrons (see Fig. 3.1).

For Run 3, the data were taken for four times as long to determine if reducing our uncertainty

Detector	Height (m)	Counts without Source	Counts with Source
Li-6	1.559	3364	15001
	3.635	3392	14100
	5.170	3357	13823
	6.598	3295	13930
Li-7	1.559	2626	3115
	3.635	2695	3011
	5.170	2675	2996
	6.598	2673	3234

Table 3.1 Run 1 data after applying the software threshold. Li-6 data has both neutron and gamma events while Li-7 contains only gamma events. Each combination of detector, source, and height was taken for 10 minutes.

would yield a distinction between the two heights. However, even with four times as much data, the two heights were indistinguishable from each other (see Fig. 3.2).

We also used our top height data from the longer runs to find the neutron count efficiency from our Li-6/Li-7 detectors. The efficiency was determined to be 3.5%.

3.3 Results In Perspective

Our data show that for experiments with detectors and sources similar to those we used in our experiment, the detector and the source should be kept at least five meters from the ground. Attempting to increase the distance from the ground beyond five meters is unlikely to further remove neutron room return.

Repeating this experiment with other detectors may yield significantly different results depend-

Detector	Height (m)	Counts without Source	Counts with Source
Li-6	1.559	3026	14578
	3.648	2920	13507
	5.185	3082	13327
	6.598	2966	13543
Li-7	1.559	2637	3084
	3.648	2696	2922
	5.185	2658	3000
	6.598	2687	3171

Table 3.2 Run 2 data after applying the software threshold. Li-6 data has both neutron and gamma events while Li-7 contains only gamma events. Each combination of detector, source, and height was taken for 10 minutes.

Detector	Height (m)	Counts without Source	Counts with Source
Li-6	5.175	12595	51314
	6.598	12608	51662
Li-7	5.175	9664	10832
	6.598	9956	11337

Table 3.3 Run 3 data after applying the software threshold. Li-6 data has both neutron and gamma events while Li-7 contains only gamma events. Each combination of detector, source, and height was taken for 40 minutes.

	Height (m)	Neutron Counts	Percent Difference Between Averaged Top Values
Run 1	1.559	11148±155	10.28±1.53
10 min	3.635	10392±152	2.80±1.50
	5.170	10145±151	0.36±1.49
	6.598	10072±152	-0.36±1.50
Run 2	1.559	11105±153	11.07±1.53
10 min	3.648	10361±148	3.63±1.48
	5.185	9903±149	-0.95±1.49
	6.598	10093±150	0.95±1.50
Run 3	5.175	37551±291	-0.16±0.77
40 min	6.598	37673±293	0.16±0.78

Table 3.4 Neutron counts for the three runs with varying height. Run 1 and Run 2 were for ten minutes per height while Run 3 was for 40 minutes. Percent difference between averaged top values is determined by averaging the top two runs. The percent difference between this value and the experimentally found values is then given to emphasize the differences between the tested heights.

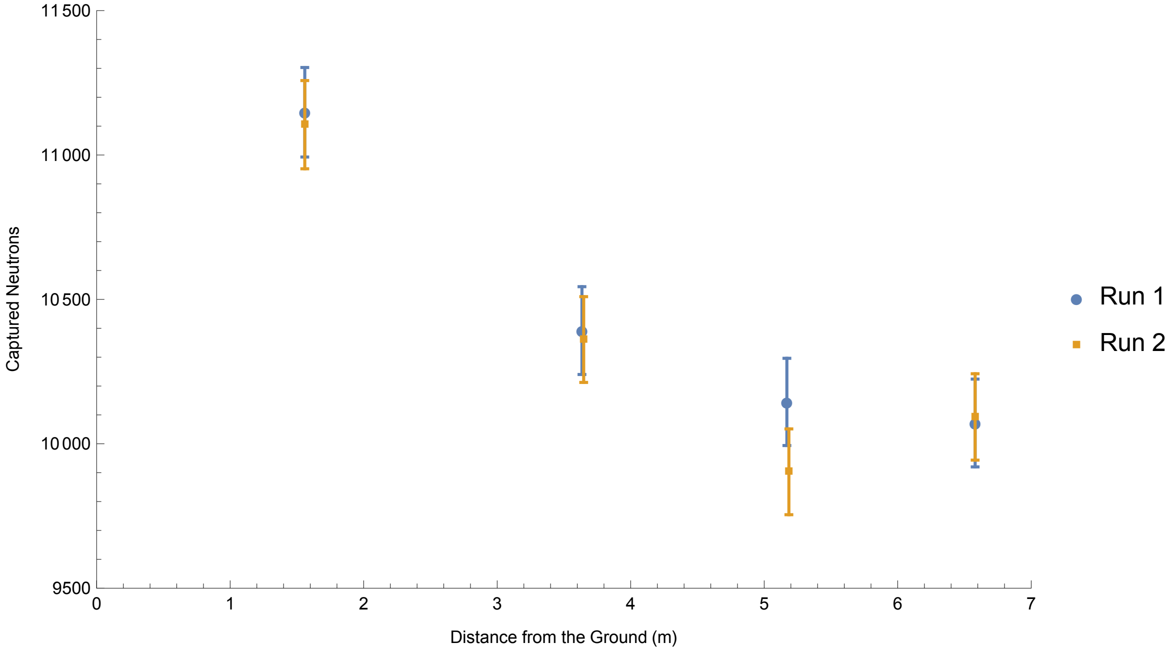

Figure 3.1 Neutron count data from ten minute runs for the Li-6 with Li-7 background subtraction. The points shown are the individual runs with their uncertainty obtained though Poisson statistics.

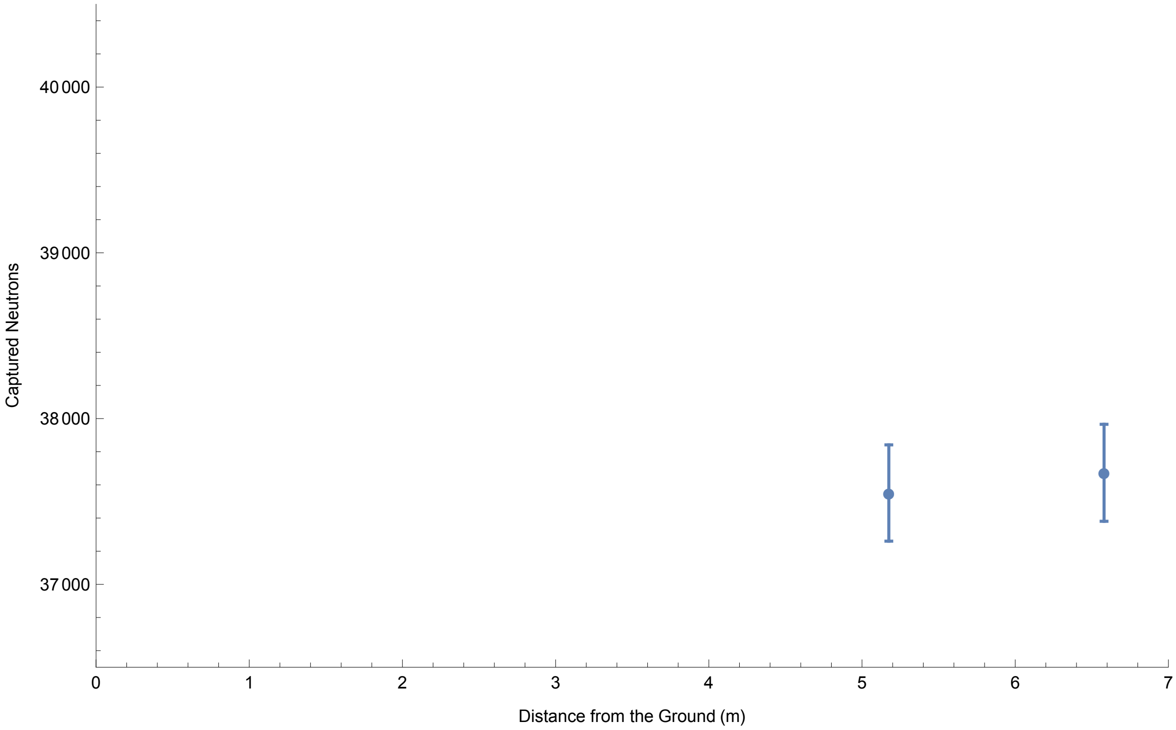

Figure 3.2 Neutron count data from 40 minute runs for the Li-6 with Li-7 background subtraction. The points shown are the individual runs with their uncertainty obtained though Poisson statistics.

ing on the type of detector used. Since room return neutrons lose significant amounts of energy in their cascade of collisions until they reach the detector, detectors sensitive to low energy neutrons will likely be much more sensitive to room return neutrons. Our Li-6 detector is especially sensitive to these low energy neutrons. Thus, five meters is likely to be appropriate for similar detectors that are sensitive to low energy neutrons. On the other hand, high energy neutron detectors can take data at moderately lower heights without concern for room return though exact heights would need to be determined through experimentation.

Our data additionally show the effectiveness of our experimental setup. While other painstaking methods may be conducted to reduce room return neutrons, it is fairly simple to conduct the experiments of neutron detection on a scissor lift and the room return is clearly shown to be drastically reduced.

One potential limitation with our setup is the requirement to conduct research outdoors. With large or immobile detectors, the scissor lift would not be an ideal solution for reducing room return. Furthermore, it is tedious to re-setup an experiment outdoors as electronics cannot be exposed to unfavorable weather conditions. Additionally, data can only be obtained when weather conditions are agreeable.

From our results, it is clear that facilities used for neutron experiments seeking to remove room return by conducting the experiment away from the walls, floor, and ceiling should give the detector and source at least five meters in each direction to reduce room return. If stronger sources than our Cf-252 source are used creating higher levels of radiation, it would be better to have an even larger distance than five meters as room return will only worsen in that situation. Similarly, when using a scissor lift with a stronger source than our Cf-252 source, it would be recommended to increase the distance from the walls and floor beyond five meters. We can safely conclude that an affordable and effective way to reduce room return is to use a scissor lift which can go well beyond the required height to minimize room return.

3.4 PSD Results

While Li-6 has been considered ineffective at discriminating between gamma and neutron events (Bart Czirr, private communication), or pulse shape discrimination (PSD), we had surprisingly good separation between gamma and neutron events when comparing our Li-6 data (see Fig. 3.3) to our Li-7 data (see Fig. 3.4). As shown in the Li-6 data there is a dense region of data points in the lower middle section of the graph. These points represent neutrons as they are moderately large events with a small fraction of the area that comes towards the beginning of the peak. As predicted, neutron events tend to have long tails which helps to statistically distinguish them from gamma events. We can also improve upon our analysis of room return neutrons by using counts in the neutron region of the fraction early area vs area plot. This would improve our statistics and the uncertainty in our results.

From our PSD results, we feel that the Li-6 detector may work well as a stand-alone detector to identify neutron events. We felt previously that a Li-6 detector would require an identical Li-7 detector to remove gamma events. However, those gamma events could potentially be statistically removed by PSD. Further work needs to be done to determine the quality, efficiency, and error of using PSD on an Li-6 detector to determine if it is, in fact, an effective detector for practical purposes.

3.5 Further Work

More research needs to be conducted to compare the effectiveness of our scissor lift method with the use of a shadow bar. Also, it would be interesting to use Monte Carlo techniques to see if a shadow bar overestimates the room return counts as predicted while our technique of using a scissor lift may underestimate it (as there may be significant room return from the lift itself).

Further work can also be done to decrease the uncertainty of our results by using our analysis

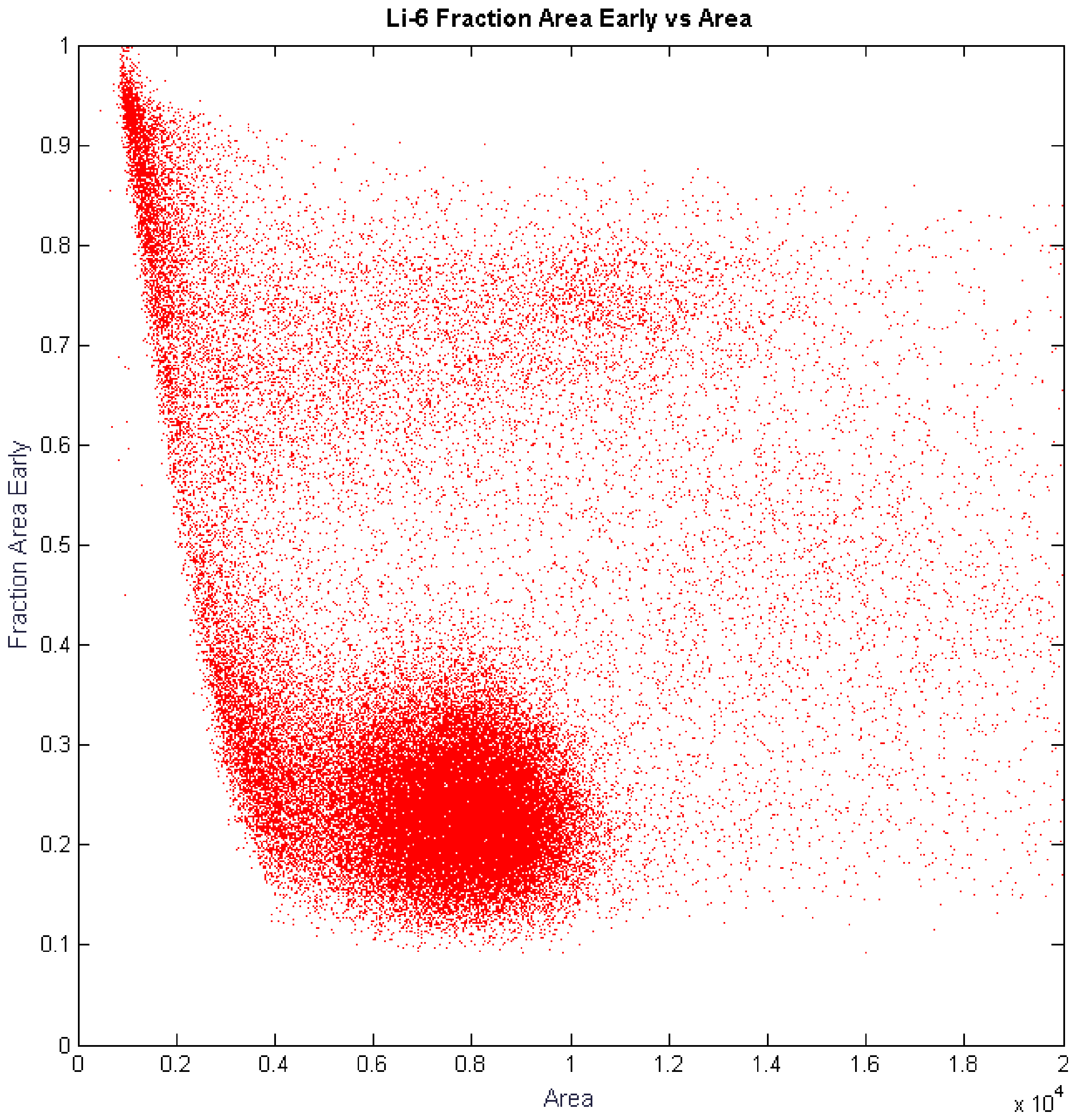

Figure 3.3 Shown here are data from the Li-6 detector. Points represent events comparing their total area to the fraction of the area that comes early on in the peak. Neutron events tend to clump together in the lower middle region.

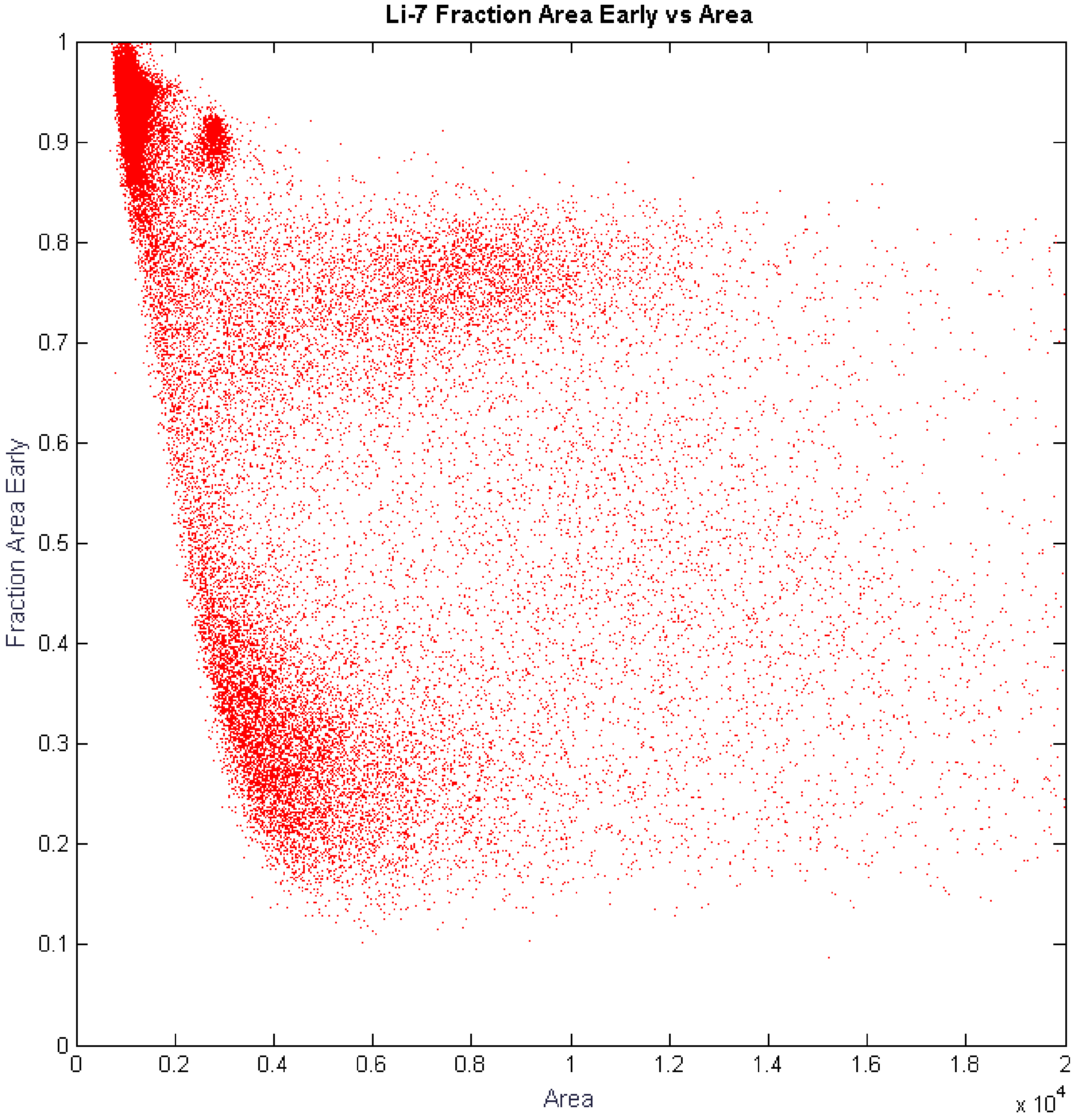

Figure 3.4 Shown here are data from the Li-7 detector. Points represent events comparing their total area to the fraction of the area that comes early on in the peak.

of the PSD results. Having identified the neutron region, we can isolate data in that region. This would significantly decrease the gamma radiation counts that we would see in our Li-6 data. From this we would be less dependent on the Li-7 data to identify the neutrons, and results with improved statistics and precision in our room return results.

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