BigBite Neutron Bar Shielding Tests

P. Monaghan[1], R. Shneor[2], J.W. Watson[3]

[1] *Massachusetts Institute of Technology, Cambridge, MA 02139, USA*

[2] *Tel Aviv University, Tel Aviv, 69978, Israel*

[3] *Kent State University, Kent, Ohio 44242, USA*

Abstract

Three 50cm neutron bars were set-up on a test platform in Hall A at the Jefferson Lab, each with differing amounts of radiation shielding in order to determine the most efficient use of shielding. By counting the number of coincident signals from the two photomultiplier tubes attached to either end of each bar, we try to determine the effect of the room background radiation and the best shielding configuration. The results indicate that the room background is only a small percentage of the detected radiation compared to the amount of radiation coming from the target. The results also show that only a front lead shield will be required for the proposed neutron detector for the Short-Range Correlations experiment.

1 Introduction

The commissioning experiment of the BigBite spectrometer will study short range nucleon-nucleon correlations in carbon-12 through the triple coincident reaction (e,e'pN). For the neutron detection, a large array of neuton bars will be built and placed behind the detector package within a *line-of-sight* of the target. We wished to test several different radiation shielding configurations to try and determine the most effective one for the neutron array currently being designed. The following experimental test of radiation shielding was carried out as a parasitic experiment to the main experiment currently running in hall A.

2 Experimental Set-Up

Three 50 x 10 x 10 cm neutron bars were provided by John Watson of Kent State University. Each bar already had a photomultiplier tube (PMT) attached to the lightguides on either end - the bars had previously been used in an experiment in Hall C. The voltage divider *base* for each PMT were also provided by Kent State from their stockpile in storage here at the Jefferson Lab.

Unfortunately, probably during the set-up of the neutron bars in the hall, one of the PMTs became detached. The PMT was glued back on to the neutron bar using an optical cement. However, subsequent tests indicated the PMT was not functioning properly. In trying to remove the damaged PMT, it was destroyed, leaving its glass lense stuck to the lightguide. This glass was removed by filing it off and then the end of the lightguide was resanded and finally polished until it was transparent again. A spare PMT from the BigBite trigger plane was glued on to the lightguide using a silicon elastomer; the base appropriate for this PMT was then attached.

The bases which were attached to each PMT on the neutron bars are noted below.

Neutron Bar #	Channel #	Base #
1	1 (Right)	BigBite
	2 (Left)	BA 5
2	3 (Right)	FA 110
	4 (Left)	FA 105
3	5 (Right)	BA 315
	6 (Left)	BA 247

Table 1: The base attached to each PMT and their corresponding channel numbers as shown.

2.1 Shielding Configuration

The basic configuration of the three neutron bars was that bar #3 would use approximately four feet of concrete, bar #2 would be encased in lead and bar #1 would be shielded only by a lead wall in front of it. The complete shielding configuration is illustrated in figure 1. In this configuration, bar # 3 is completely shielded from the radiation coming from the target and so only detects the background radiation in the hall. Both bars #1 and #2 can detect the radiation from the target, with bar #2 being completely surrounded by lead shielding. The lead acts as a photon filter but does not block the neutrons.

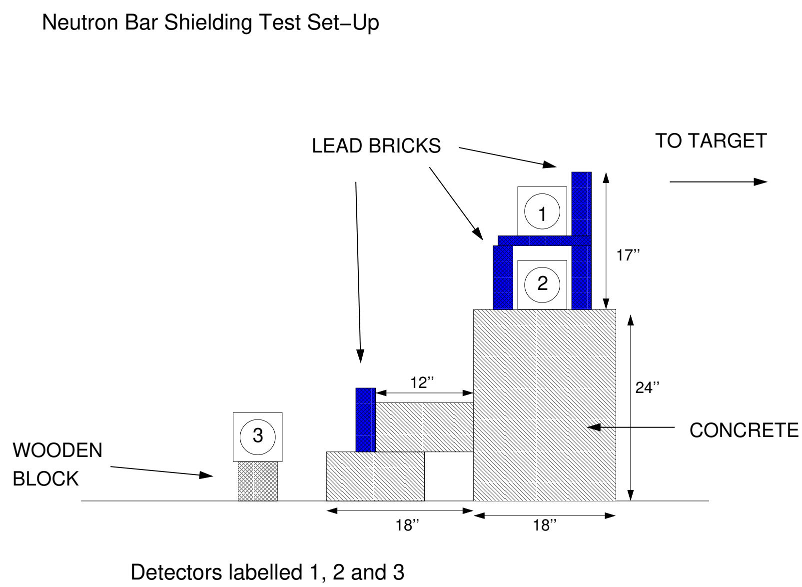
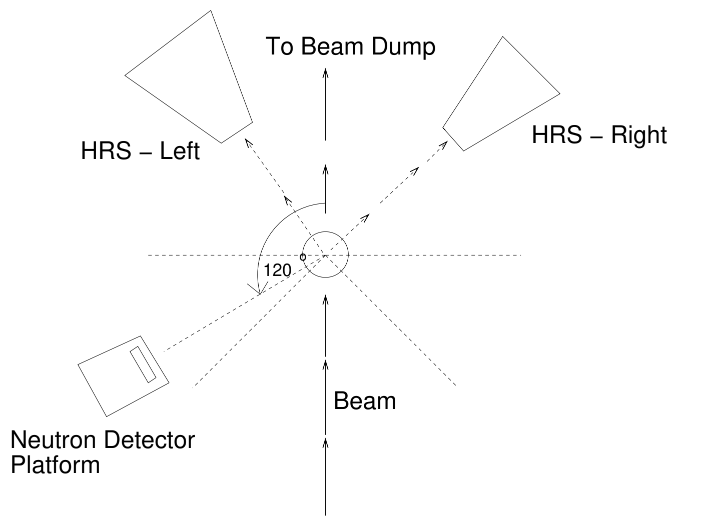


Figure 1: The different amounts of shielding used for each neutron bar are shown; beam height is about 2 feet above bar # 1.

To test the difference between various amounts of radiation shielding, the three neutron bars were placed on a test platform in the hall. This platform was around 4-5 feet below beam height and so a small concrete wall, 24 inches high and 18 inches deep, was built so that two of the bars could be nearer to beam height. (Beam height in the hall is 10 feet.) Bar #2 was placed on top of the concrete wall and a lead wall built around it; the lead bricks were 2 x 4 x 8 inches. A cover of 1 x 6 x 12 inch lead bricks was placed on the wall surrounding bar #2. Then bar #1 was placed on top of this lead case and a wall of lead bricks (2 inches thick) was placed in front of it. Bar #3 was placed on a wooden block on the test platform, behind the concrete wall - it was several feet below beam height. We did not have enough concrete blocks to built a shield 4 feet thick so instead we put 2.5 feet of concrete followed by a 2 inch thick wall of lead bricks to simulate approximately 4 feet of concrete. Thus, bar #3 will test the room background radiation and not what comes from the target. The details are clearly seen in figure 1.

In order to be a parasitic test, we had to position our detector platform such that it did not interfere with the current experiment in the hall. After consulting with the spokespersons of the upcoming experiments, it was decided to place the platform at approximately

125^o, around 7 metres from the target on the left-hand side of the beam. The hall set-up is shown in figure 2.



Floor plan of Hall A – shows the position of the neutron detectors relative to the beam line and target. Neutron detector is about 9m from the centre of the target.

Figure 2: The layout of the hall and position of our test platform.

2.2 Electronics Set-Up

The high voltage power supply cables and the signal cables for each PMT were connected to a patch panel in the centre of the hall. This panel is connected directly to a similar panel in the Hall A *electronics cage* located on the second floor of the counting house. Here, we had the high voltage power supplies for each PMT and also a NIM crate for our electronics modules.

The raw signals from each PMT were sent into a simple level threshold discriminator. This discriminator allowed a minimum signal threshold to be set for all the PMT channels. For each signal input above the set threshold, the discriminator outputs a logic signal. The logic signals for each bar are then fed into a coincidence module which was set for AND. Thus, the coincidence unit only gave a logic signal output when both PMTs on a neutron bar gave a signal, within a certain time interval, with a magnitude larger than the discriminator threshold. The logic output from the coincidence unit was then passed into a counter for each neutron bar. A schematic of the electronics set-up is shown in figure 3.

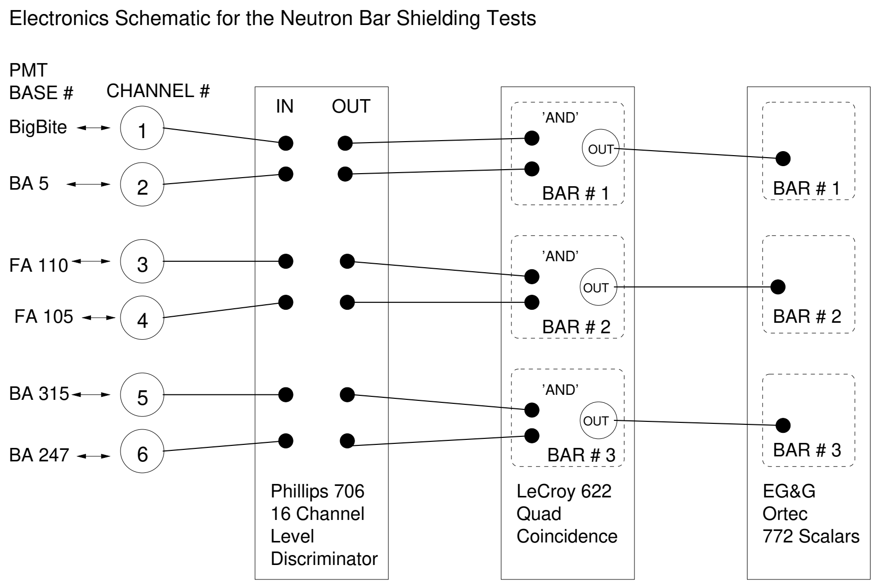


Figure 3: Diagram showing the details of the electronics set-up used.

2.3 Calibration of the PMTs

A thorium-228 γ-ray radioactive source was used to calibrate the PMTs and set their gains. This source has an activity of 10 microcuries (μCi) and emits γ-rays with an energy of 2.28 MeV. This source is as if electrons were depositing energy in the scintillator. The response of the scintillator to electrons is linear but it is non-linear for hadrons. Thus, the threshold set for each experiment will also be given in MeV-ee or MeV-electron equivalent. Hence, if we double the threshold, this would lead to double the energy of electrons detected but not double the energy of hadrons.

The source was placed on each neutron bar in turn and the signals from the two PMTs was viewed on an oscilloscope. By setting the trigger level on the oscilloscope appropriately, the Compton energy peak from the emitted γ-rays was observed for both PMT signals. The voltages applied to each PMT were carefully adjusted until the peak corresponded to around -40 millivolts on the oscilloscope trace. This means the gains were set on the PMTs to correspond to $\frac{2.28MeV}{40mV} \sim 0.057$ MeV per mV of signal magnitude. This value is used later in converting the threshold to MeV-ee. The voltages set for each PMT and their output currents for a beam current of around 100 microamps are given in table2.

N.B. When the beam was off all the photomultiplier tubes gave negligible output current.

To test the calibration, data was taken for five minutes with cosmic rays - beam off - at different threshold settings. The results, shown in table 3, indicated the bars were counting similar number of cosmic rays over the same time interval, except at the lowest threshold; at the lowest threshold the signals were very noisy which is the most likely reason for any difference between the numbers counted by each bar. At the higher thresholds, the numbers indicate the PMT gains have been set appropriately.

Bar #	Channel #	Base #	$\frac{V_{PMT}}{kV}$	$\frac{I_{out}}{\mu A}$
1	1 (Right)	BigBite	-1.55	-64
	2 (Left)	BA 5	-2.14	-165
2	3 (Right)	FA 110	-2.06	-110
	4 (Left)	FA 105	-2.06	-107
3	5 (Right)	BA 315	-2.25	-33
	6 (Left)	BA 247	-2.35	-43

Table 2: The voltages applied to each PMT and their corresponding output currents.

Bar #	$\frac{Threshold}{mV}$	$\frac{Threshold}{MeV-ee}$	Counts
1	-30	1.71	2913
2			4816
3			2698
1	-60	3.42	2362
2			2362
3			2341
1	-120	6.84	1757
2			1792
3			1757

Table 3: The number of counts from each bar with only cosmic rays; the similarity between bars at higher threshold settings indicates the gains on the PMTs have been set correctly.

3 Results

To obtain each set of results, the experiment was run for approximately 30 minutes and then the number of counts in each bar was noted. The duration of any beam trips was taken into account when deciding the actual duration of each data taking run. Data has been taken at several different discriminator threshold settings. The target used during the experiment was a liquid deuterium target and the beam current was over 100 microamps. The results of each test are given in table 4.

The number of counts for each bar indicate that in every case, bar #3 counts significantly less than either of the other two bars. This means that the room background radiation is much less than the radiation from the target. There is also very little difference between the number of counts registered by bars #1 and #2 which means that little is gained by completely enclosing the neutron bar in a lead shield. Hence, this means that a single lead shield in front of our proposed neutron detector should provide sufficient shielding

Bar #	Duration	$\frac{Threshold}{mV}$	$\frac{Threshold}{MeV-ee}$	Current	Counts	$\frac{bottom}{top}$
1 2 3	25 mins	-60 mV	3.42	109 uA	866 060 502 711 158 224 182 529 699	0.214
1 2 3	24 mins	-60 mV	3.42	110 uA	662 809 913 733 382 234 80 508 176	0.121
1 2 3	28 mins	-120 mV	6.84	109 uA	340 265 395 346 901 725 21 735 303	0.064
1 2 3	26 mins	-120 mV	6.84	110 uA	334 153 059 330 163 520 20 494 541	0.061
1 2 3	26 mins	-180 mV	10.26	109 uA	235 662 810 236 009 916 11 455 693	0.049
1 2 3	26 mins	-240 mV	13.68	110 uA	183 005 721 177 960 767 5 569 794	0.03
1 2 3	25 mins	-480 mV	27.36	109 uA	42 748 383 33 083 387 637 698	0.015

Table 4: The parameters and results from the counting tests. The ratio of $\frac{bottom}{top}$ refers to the ratio of counts from bar #3 (room) to bar #1 (target).

from the target radiation.

The ratio of the number of counts from bar #3 (bottom) and bar #1 (top) is also given in table 4. These results show a decreasing ratio with increasing threshold and also indicate that the room background radiation is only a small percentage of the radiation detected by the neutron bar which detects the target radiation. This ratio is plotted in figure four which clearly illustrates the trend.

4 Conclusions

The results indicate that bar # 3 counts the *least* in each test; significantly less than either bars # 1 or # 2. The difference is due to the fact that bar # 3 detects only the room background radiation, whereas both bars # 1 and # 2 detect radiation from the target. This means that the room background radiation is only a small fraction of the total radiation that the neutron bars detect from the target. This point is illustrated by taking the ratio of the number of counts in the bottom (room) to the top (target) neutron bars.

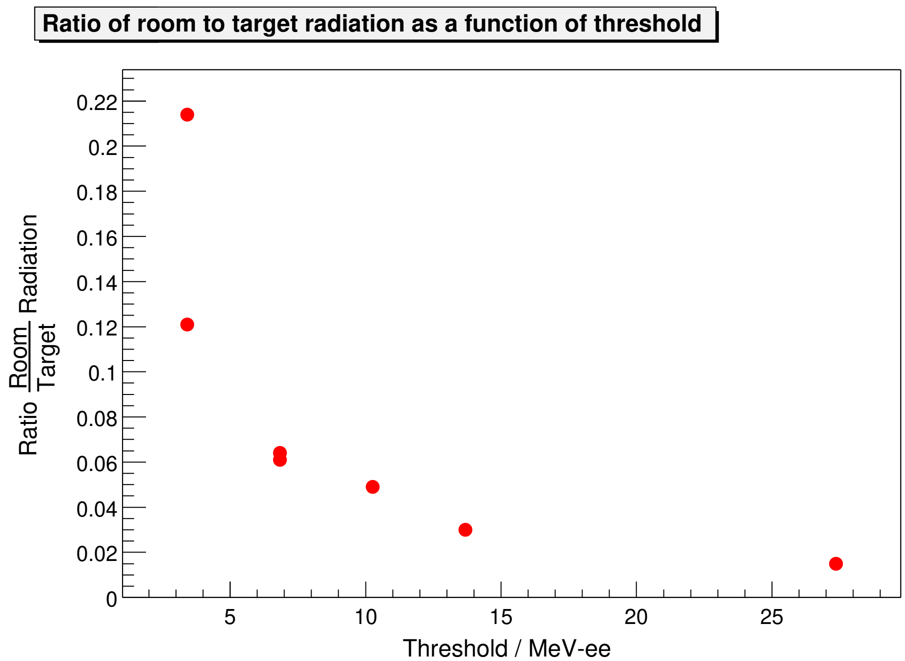


Figure 4: The ratio of the number of counts from bar # 3 (room) to bar # 1 (target) as a function of threshold energy of the incoming neutron (in MeV - electron equivalent). Note, that two of the points at the lowest thresholds were duplicated from two tests at a different time from the rest of the tests.

There is also very little difference in the number of counts in bars # 1 (front lead shield only) and # 2 (completely encased in lead). This means that a complete lead shield is not necessary for our proposed neutron detector and instead a front lead shield will be sufficient. This reduces the cost of the detector and the effort required to incorporate the shielding into the proposed detector design.