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SPIR 145

Blowfish Analysis for October 2010 Deuterium at 18 MeV

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Abstract

This document describes an investigation of the light output anomaly for the *Blowfish* BC-505 cells.

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1 Introduction

This document describes an investigation the gains for the *Blowfish* cells runs during the October 2010 running period. This was an experiment using a deuterium target and a photon energy of 18 MeV. The experiment was designed to investigate the discrepancy between the measured light output and the light output predicted by a simulation that was observed in previous experiments. This discrepancy was discussed at length in the technical note SPIR-142 [3].

In these runs the output of two of the *Blowfish* cells (cells 49 and 64) were split using a passive splitter. One output was fed into the usual VME QDC while the other was fed into a Camac ADC. This was to investigate if the gain anomaly had something to do with the type of ADC used.

2 Gain Calibration

The gains of each BC-505 cell were determined as usual using a radioactive source. The gain relates ADC channel number to light output in equivalent electron energy units [1, 2]. The gain for a particular cell i is define by

$$g_i = E_{ee}/A_i \tag{1}$$

where E_{ee} is the equivalent electron energy of some feature in the light output spectrum and A_i is the ADC channel number of that feature.

The Compton edge was used as the calibration feature as described in SPIR-142 [3]. The calibration runs taken during this period are listed in Table 1.

For The AmBe source the Compton edge of the 4.430 MeV gamma ray is used to establish the gain. In the background runs it is possible to isolate the Compton edges of the ^{232}Th 2.614 MeV gamma ray and the ^{40}K 1.461 MeV gamma ray. These three data points may be used to establish the linearity of the cell gains.

The linearity was investigated when two calibration runs, one with the AmBe source and one with background, were taken near each other in time. The results for the two cells, 49 and 64, using the VME ADC are shown in figures 1, 2, 3, and 4. It can be seen that the gain is linear. It can also be noted that, unlike what was previously observed, there is a very small gain offset. This simplifies the analysis since, once the gain is determined, equation 1 may be used without modification.

We also show the gain determined for the same cells using the CAMAC ADC in figures 5 and 6. Again we see that the gain is linear however in this case there is a significant gain offset for both channels.

Table 1: Calibration runs for the October 2010 running period.

Run Number	Source	Date/Time	Notes
89	Background	Oct 28 08:55	
93	Background	Oct 28 10:29	AmBe in last 3 min
94	AmBe	Oct 28 11:01	
118	AmBe	Oct 28 18:32	Gate width 75 ns
121	AmBe	Oct 28 19:30	Gate width 125 ns
123	AmBe	Oct 28 19:41	Gate width 75 ns
132	AmBe	Oct 28 23:17	Gate Width 125 ns
133	Background	Oct 28 21:34	
136	AmBe	Oct 29 09:01	
137	AmBe	Oct 29 09:33	Long cable added to cell 48
138	AmBe	Oct 29 09:50	Long cable and short cable with barrel on Cell 48
139	AmBe	Oct 29 10:11	
140	Background	Oct 29 10:36	
165	AmBe	Oct 30 00:28	
166	Background	Oct 30 00:41	

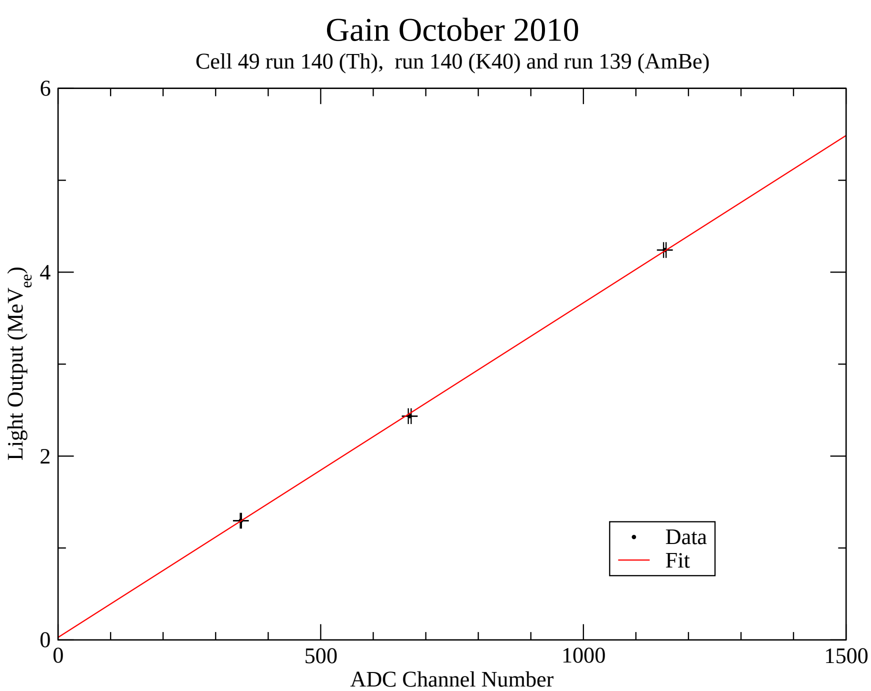

Figure 1: The gain linearity using the VME ADC for cell 49 determined using the AmBe source and background gamma rays.

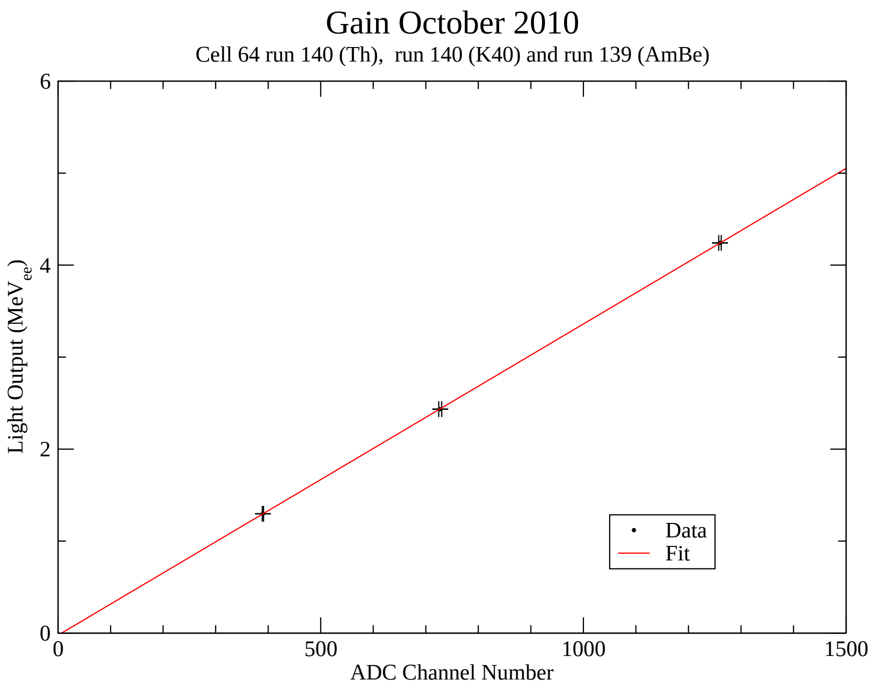

Figure 2: The gain linearity using the VME ADC for cell 64 determined using the AmBe source and background gamma rays.

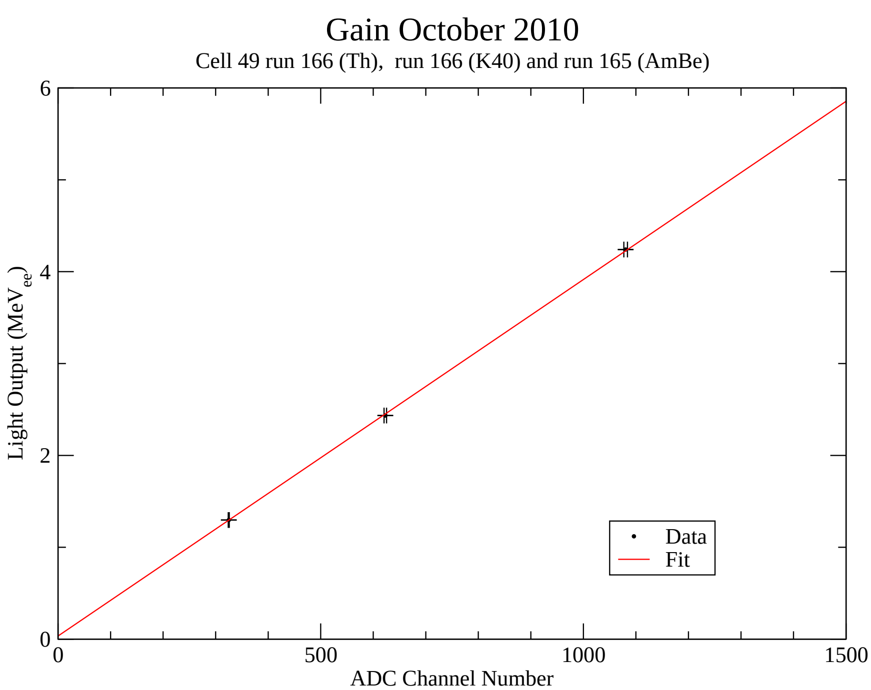

Figure 3: The gain linearity using the VME ADC for cell 49 determined using the AmBe source and background gamma rays.

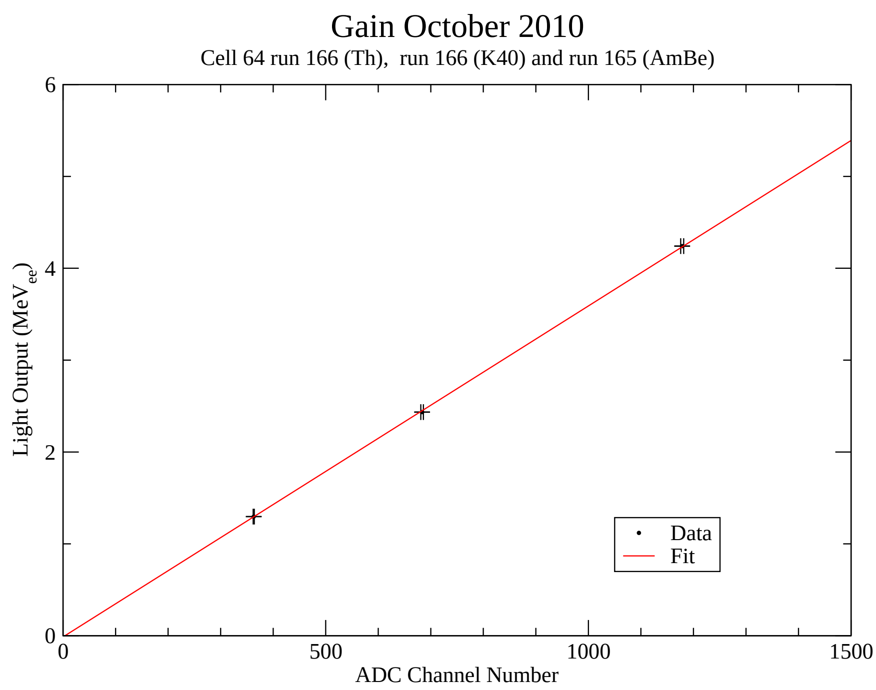

Figure 4: The gain linearity using the VME ADC for cell 64 determined using the AmBe source and background gamma rays.

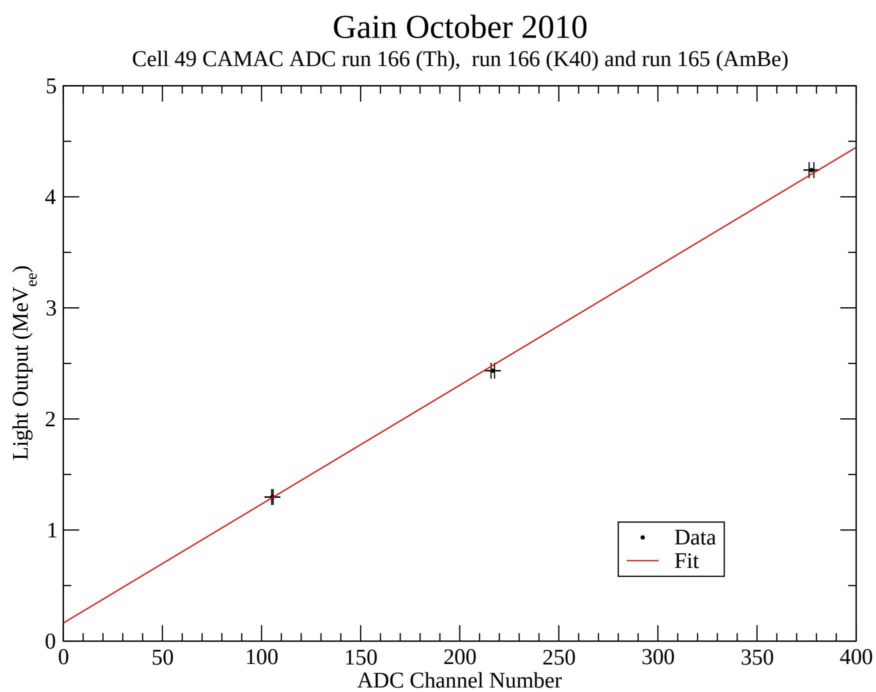

Figure 5: The gain linearity using the CAMAC ADC for cell 49 determined using the AmBe source and background gamma rays.

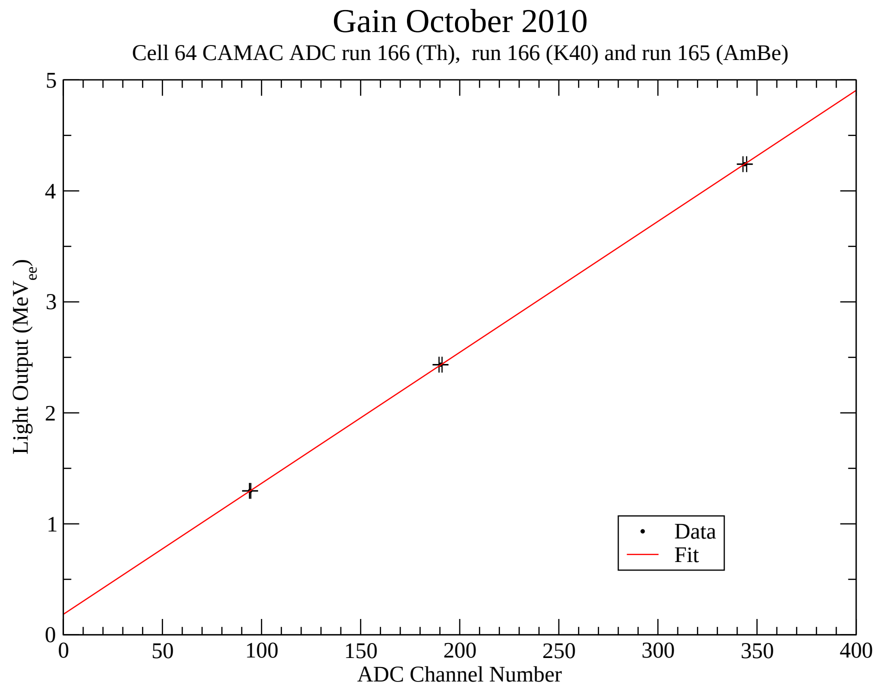

Figure 6: The gain linearity using the CAMAC ADC for cell 64 determined using the AmBe source and background gamma rays.

3 Effect of Gate Width

The aim of this experiment was to determine the reason why the measured light output spectra for neutrons using the gains determined from a gamma ray source did not match the predicted light output using the GEANT4 simulation. One suspect variable was the width of the ADC gate. The conjecture, originally put forward by Blackston[7], is that if the ADC gate with is not long enough, some of the longer pulse from the recoil proton from a neutron interaction may be cut off, while the shorter pulse from the recoil electron from a photon is fully integrated.

In this experiment the gate width was set to 125 ns. For some runs the gate width was reduced to 75 ns which is short enough to possibly cut off a portion of the pulse.

In order to compare the light output to the simulation it is necessary to know the energy of the incident neutron. In this experiment we used a target of D_2O. From the photodisintegration of deuterium and the known photon energy of 18 MeV we can calculate the neutron energy hitting a particular cell. The neutron energy can also be measured using time-of-flight.

We use pulse shape discrimination to tell if we are seeing neutrons. An example of the PSD parameter against pulse height for cell 49 is show in figure 7. It can bee seen that with a pulse height cut of 500 the PSD provides almost perfect discrimination between photons and neutrons. With that pulse height cut a PSD cut of 6 results in nearly all the photons being removed without removing any of the high pulse height neutron events.

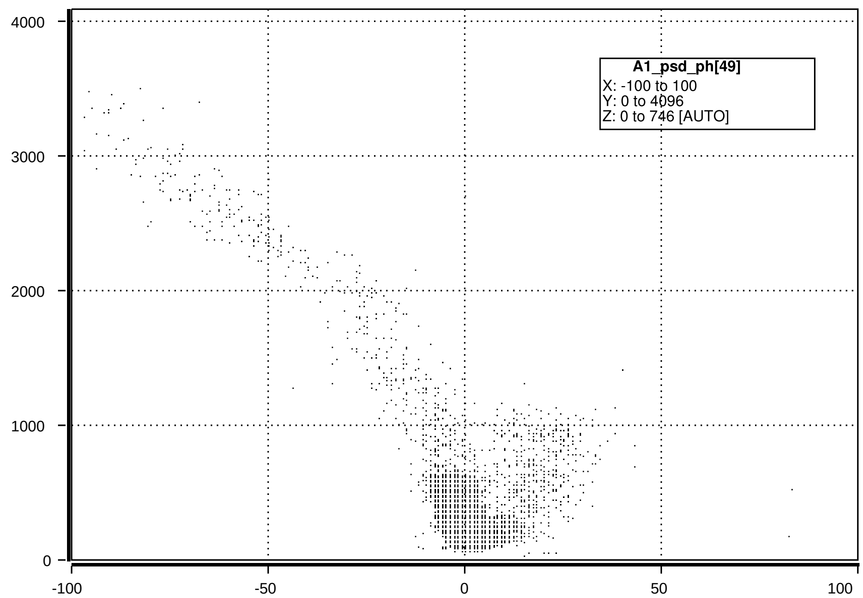

Figure 7: The PSD parameter verses pulse height for cell 49 in run 159. Photons appear on the left while neutrons appear on the right.

For the events remaining after these cuts are applied the neutron energy was calculated from time of flight and compared to the expected neutron energy calculated using deuteron photodisintegration kinematics. The difference between these is shown in figure 8. A further cut requiring that this energy difference be within 3 MeV of zero is applied to arrive at the final data set of neutrons whose light output is to be compared to the GEANT4 simulation. This is the same procedure that was used in the analysis described in SPIR-142 [3].

The GEANT4[5] simulation to which we compare the measured light output spectra included the full *Blowfish* array and the target configuration used in this experiment. The neutrons generated in the target take into account the beam profile on the target and follow the energy and angular distribution expected from deuteron photodisintegration. The simulation included the effects of scattering from nearby cells and other parts of the *Blowfish* support structure.

The light output spectra using the VME ADC for several cells are shown in figures 9 and 10 for run 159 for which the ADC gate width was 125 ns. The energy scale for the measured spectra are determined from the gain determined from the AmBe source run 165 and using the gain monitoring system[6, 3] to predict the gain for run 159. There was no rotation of *Blowfish* between these run. It has been observed that a rotation of *Blowfish* has the possibility of changing the "R values" (see [3]) which can introduce an uncertainty in the gains.

It can be seen that there is excellent agreement between the measured and simulated light output spectra. The end-point energies agree very well and there is no necessity to adjust the measured energy scale by factor as was previously observed[3].

One run (run 126) was done where the ADC gate width was changed from 125 ns to 75 ns. The gain for this run was determined from the AmBe source run 123 where the gate

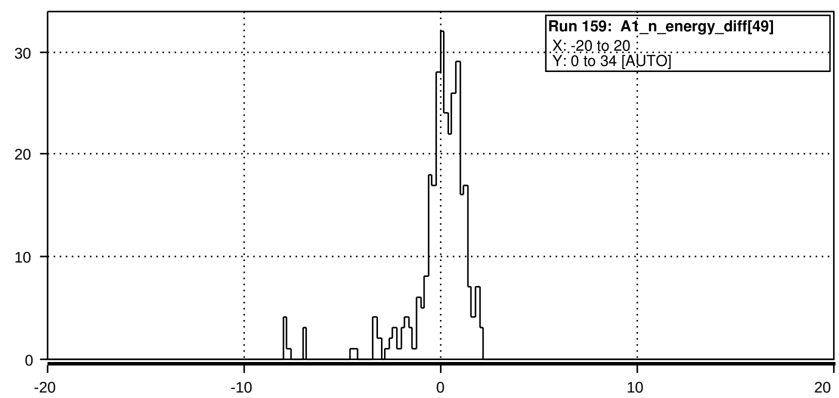

Figure 8: The difference in the neutron energy calculated from time-of-flight and the expected neutron energy calculated from deuteron photodisintegration kinematics. The horizontal axis is in MeV.

width was also 75 ns. There were also no rotations of *Blowfish* between runs 123 and 126. The light output spectra for several cells run 126 are compared to the simulation in figures 9 and 10. It can be seen that for some cells the measured light output energies do not agree with the simulation. In most cases the measured light output is lower the simulation which would be consistent with the hypothesis that if the ADC gate with is not long enough, some of the longer pulse from the recoil proton from a neutron interaction may be cut off. However cell 52 shows that with the shorter gate width the measured light output energies are too large. This would be inconsistent with the above conjecture.

Nevertheless it is clear that the shorter gate width in some way compromises our determination of the cell gains. This appears to affect different cells in different ways.

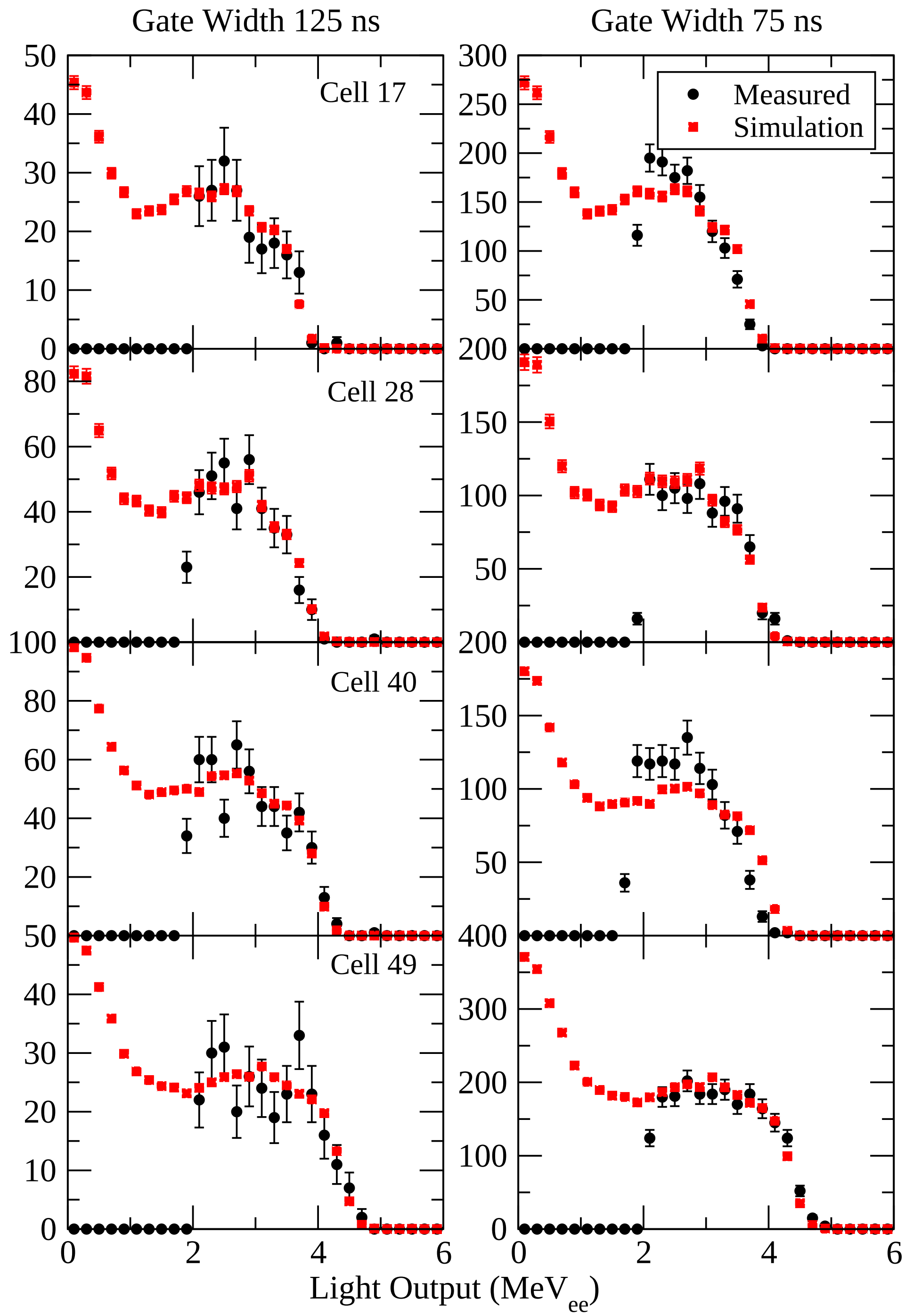

Figure 9: The light output spectra measured for several cells compared to the predicted light output from the GEANT4 simulation. The left column shows the measured spectra for run 159 where the ADC gate width was 125 ns. The right column shows the measured spectra for run 126 where the ADC gate width was 75 ns.

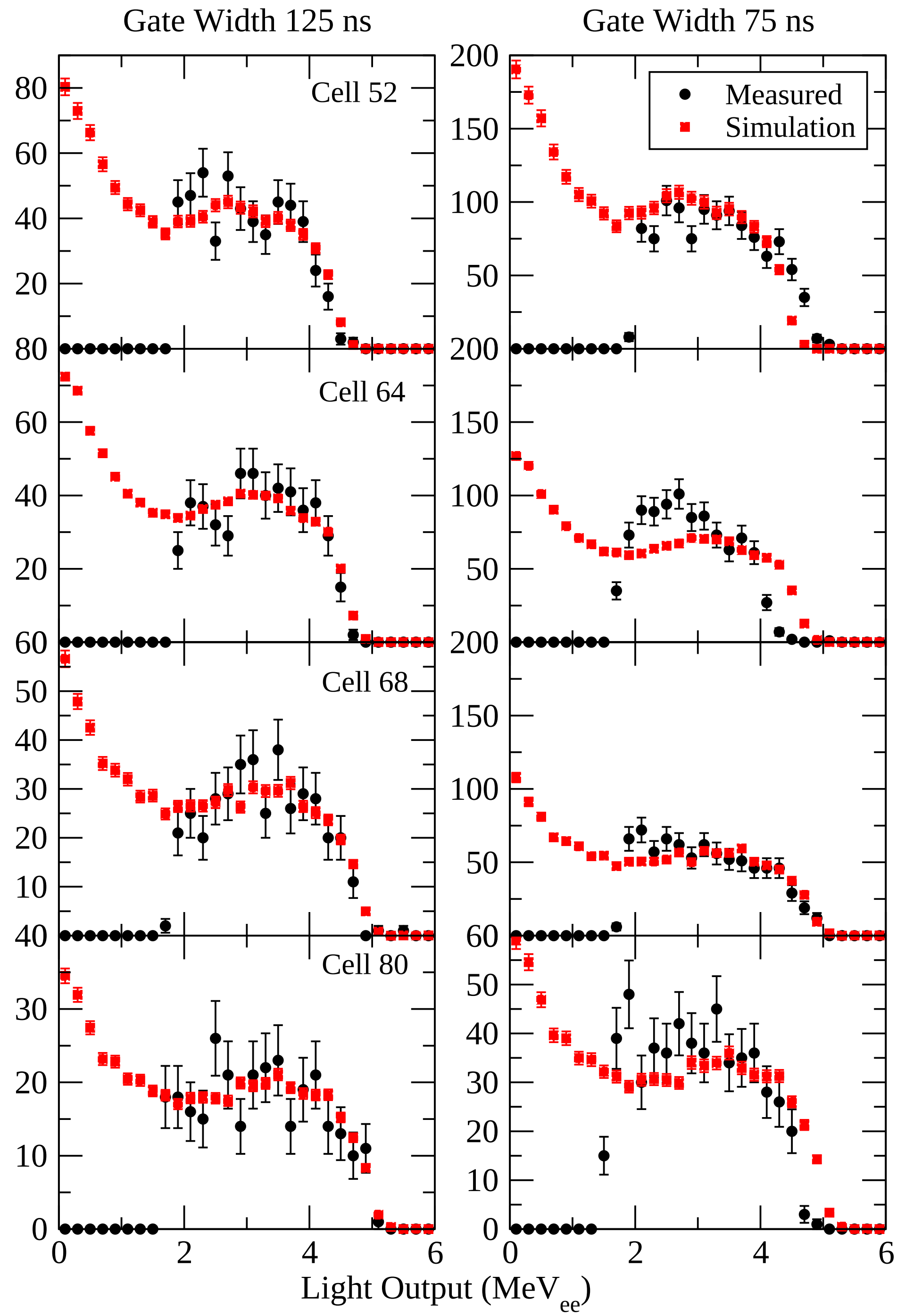

Figure 10: The light output spectra measured for several cells compared to the predicted light output from the GEANT4 simulation. The left column shows the measured spectra for run 159 where the ADC gate width was 125 ns. The right column shows the measured spectra for run 126 where the ADC gate width was 75 ns.

4 Using the CAMAC ADC

As noted before the output of cells 49 and 64 were split with one output going to a CAMAC ADC gated by the same long gate as for the VME ADC. The CAMAC ADC was calibrated using the same technique as for the VME ADC. However, as noted above, the CAMAC ADC exhibited a significant offset. This offset was taken into account in calculating the light output determined from the two cells in the CAMAC ADC. However the presence of the offset does not allow us to use the gain monitoring system to correct the gain for run 159. This should not introduce a larger error since the gain correction observed for the VME ADC between run 159 and the AmBe calibration run 165 was less than 2%.

When the gate width was set to 75 ns only one calibration run with an AmBe source was done so no determination of the offset was possible. Therefore only the multiplicative gain was used for the analysis of the CAMAC ADC in run 126 with the gate width set to 75 ns.

The comparison of the CAMAC ADC light output spectra to the simulation for these cells is shown in figure 11. It can be seen that in all cases the measured light output is smaller than that predicted by the simulation. The reason for this is unclear. The discrepancy is worse for cell 64 when the gate width is reduced to 75 ns. This is consistent with the observation using the VME ADC. This would lead us to conclude that the error introduced by using a shorter gate width does not depend on the type of ADC used.

There is evidence that the discrepancy observed when using the CAMAC ADC is not simply due to an error in determining the gains. In the raw cell data during a normal run, before cuts are made, it is possible to see the Compton edge for the room background ^{40}K gamma ray. This shows that the gain error is certainly less than 0.1 MeV. But the measured light output for neutrons seen in figure 11 is about 0.5 MeV different from the simulation when the gate width was 125 ns. Therefore it appears that the light output discrepancy has something to do with the longer pulses from neutrons.

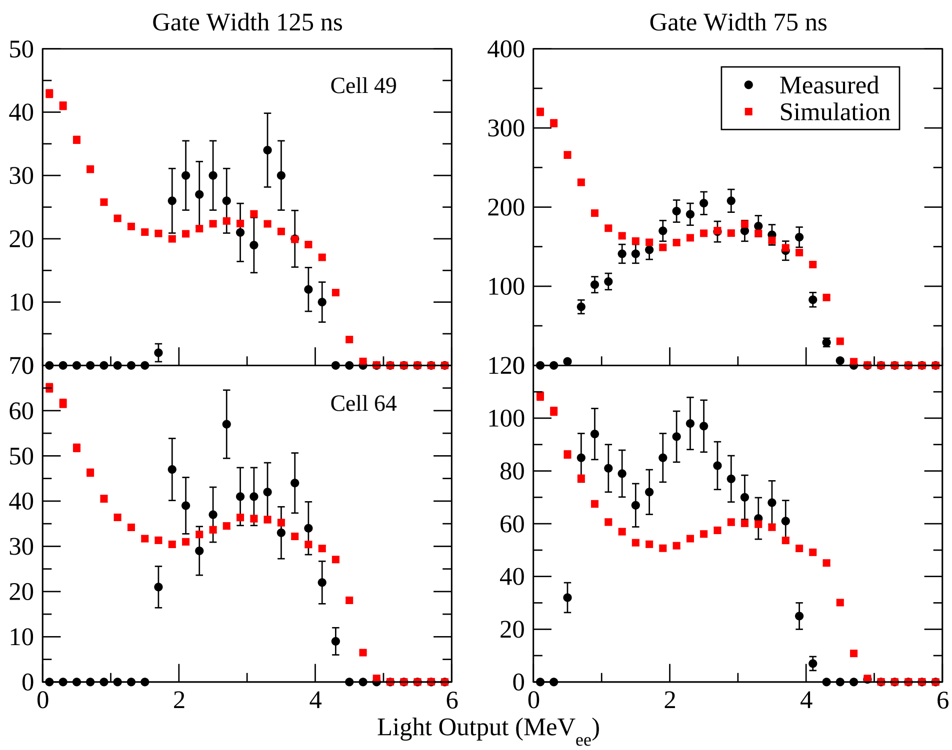

Figure 11: The light output spectra measured for cells 49 and 64 using the CAMAC ADC compared to the predicted light output from the GEANT4 simulation. The left column shows the measured spectra for run 159 where the ADC gate width was 125 ns. The right column shows the measured spectra for run 126 where the ADC gate width was 75 ns.

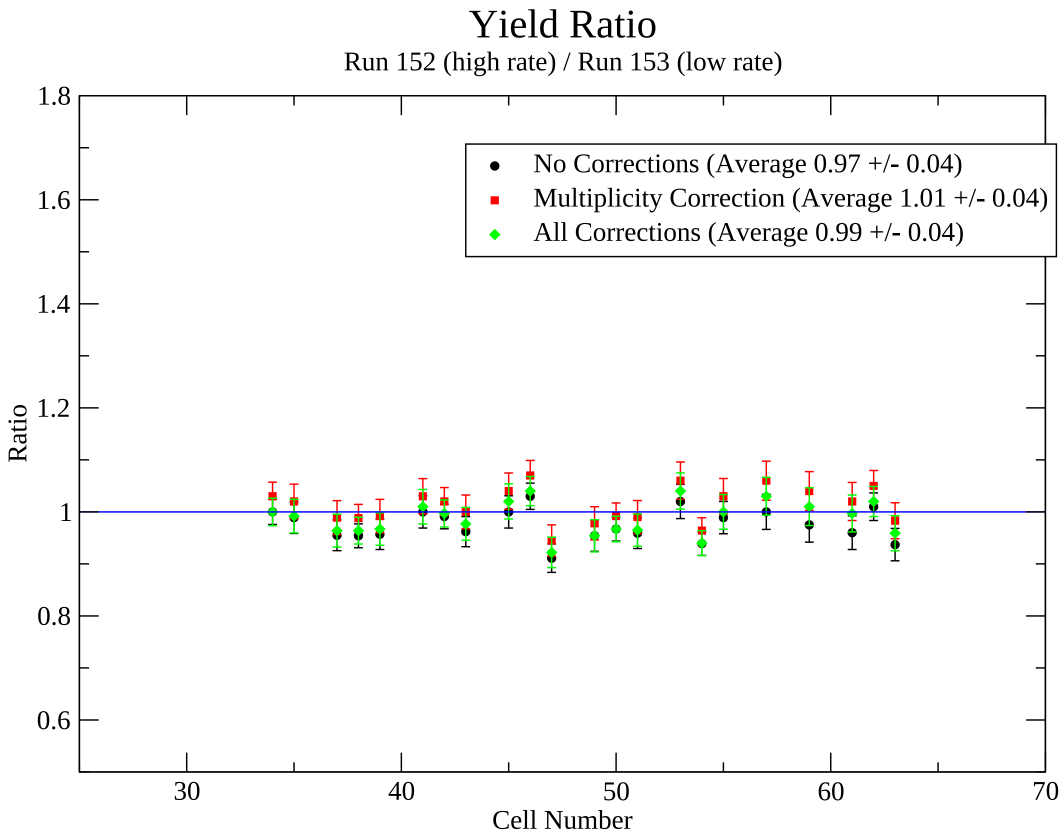

Figure 12: The ratio of the yields for several cells for runs 152 and 153 which were taken at different photon rates.

5 Effect of Photon Flux Rate

We did two runs at different photon flux rates to test how well we could make the appropriate rate corrections to the photon flux monitor. These two runs were run 152, which was take at a normal rate of about 10^7 photons/s, and run 153, for which attenuator 1 was inserted into the beam line reducing the flux to about 4×10^6 photons/s.

The 5-paddle photon flux monitor was calibrate in the usual way (see SPIR 146). The resulting calibration factor was used to calculate the number of photons incident on the target during the live time of the experiment. For each cell the total number of neutrons passing the cuts described in Section 3 is divided by the number of incident photon to produce a yield for that cell. This yield has been calculated for a set of cells near the centre of *Blowfish* where the count rate is reasonably high. The ratio of the yields for each cell for the two runs (152 and 153) are shown in Figure 12.

The yield for the two runs taken at different photon rates should, of course, be the same. Even with no rate corrections applied this appear to be the case (the black points in Figure 12. However, there are two rate dependent corrections that must be applied: a neutron multiplicity correction and a photon rate correction.

5.1 Neutron Multiplicity Correction

It is not possible to analyze *Blowfish* cell data when there is hit in more than one cell in a particular event. This is because it is not known which cell determined the timing for the generation of the long and short gates to the ADC. If the timing is not appropriate for the cell being analyzed, the PSD and gain of the cell is compromised. If only one cell fires then we can be sure that the ADC gate timing is correct. For this reason only events with cell multiplicity of one can be analyzed to determine the yield of neutrons.

Let N_i be the total number of hits on cell i during the live time of the experiment. Of these hits only N_{1i} are members of multiplicity one events. Of the multiplicity one hits only a number n_{1i} make it through all the cuts to determine the final yield of neutrons. We make the assumption that all hits on a cell (if they could be analyzed) have the same probability of making it past all the cuts. Therefore, if we could analyze all hits, the total number of neutrons passing the cuts would be

$$n_i = n_{1i} \frac{N_i}{N_{1i}} = n_{1i} f_{mi} \tag{2}$$

The correction factor f_{mi} is cell and rate dependent. For run 152 (the high rate run) the factor is of the order 1.2. For run 153 (the lower rate run) the factor is of the order 1.15.

Applying this correction gives the yield ratio shown by the red points in Figure 12. The average yield ratio for these points is 1.01 ± 0.04.

5.2 Photon Rate Correction

If the flux monitor is counting too few photons at high rates, due to multiple hits in a beam bunch, the yield will be too high. The rate dependent flux monitor correction can be calculated as described in detail in SPIR 146. The photon number correction factor for run 152 (the high rate run) was 1.04 and the correction factor for run 153 (the low rate run) was 1.02. Applying this correction gives the green data points in Figure 12 with an average value of 0.99 ± 0.04.

5.3 Conclusion

Unfortunately this test does not provide a definite conclusion since, within errors, both the high rate and low rate runs give the same yield. Nevertheless, with the corrections applied the two runs are closer to having the same yield than without corrections applied.

References

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[3] Rob Pywell and Ward Wurtz, SPIR-142 *Blowfish Gain Analysis for 2008 Runs.* `http://nucleus.usask.ca/technical_reports/report_index.html`.

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