High Luminosity Operation of a Large Solid Angle Neutron Detector Array in Jefferson Lab's Hall A

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Abstract

In April 2001, a dedicated neutron detector test was performed in Jefferson Lab's experimental Hall A. The test was conducted to demonstrate the feasibility of experiment E01-015, which requires using a scintillator array for neutron detection in a high luminosity (1×10^{38} cm^{-2} sec^{-1}) environment. The demonstration was conducted in two stages. First, the scintillator array was used as a proton detector along with a High Resolution Spectrometer, HRS, to measure the reaction D(e,e$'$p). Second, a 2 inch thick lead wall was placed front of the scintillator array. The array was then used for neutron detection in conjection with the two Hall A HRS to measure the over-determined reaction D(e,e$'$pn). The results of these measurements are presented herein.

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1 Introduction

There are presently two approved experiments for Jefferson Lab's experimental Hall A that will require neutron detection [1,2]. In order to gain experience with neutron detection and test whether such experiments can be performed in the Hall, a dedicated test was done in April 2001. For this test, twelve $160 \times 10 \times 10$ cm^3 scintillator bars from the University of Virginia were used. The bars were arranged in an array 4 bars high and 3 bars deep. Each bar had two photomultiplier tubes attached to it, one on each end. There was no shielding around the counters, though a two inch lead wall was placed in front of the counters during the D(e,e$'$pn) test.

This array was placed on a steel stand such that the center of the bars was the same height as the center of the Hall A target. The stand, loaded with the neutron bars, was moved and positioned using a fork lift. For data acquisition, the neutron detector's photomultiplier signals were sent directly into the left spectrometer ADCs and TDCs; and thus, each time the left spectrometer recorded an event, the scintillator array's information was recorded. To improve the signal from the photomultiplier tubes, an amplifier and a discriminator for each tube was install on the platform and shielded by lead.

The tests took place in two distinct parts. The first was to use the scintillator array as a proton detector in order to check the gain and timing of the array's photomultiplier tubes. For the second test, the detector was used as a neutron detector in coincidence with both high resolution spectrometers. An overview and the results of these test will be presented herein. Further details on the tests can be found on-line [3].

2 D(e,e$'$p) Kinematics

The initial gains of the individual tubes were set prior using cosmic radiation. A recheck and adjustment of the gains as well as an overall check of the electronics, data acquisition, and timing was done using protons from quasi-elastic scattering from a deuterium target. For this measurement, the scintillator array was positioned 7.29 m from the Hall A target at an angle of 52° left of the beam line. The right High Resolution Spectrometer (HRS) was placed at an angle of 23° with a negative polarity central momentum of 2083 MeV/c. The left HRS was not used. The CEBAF accelerator provided a 10 uA beam of 2561 MeV electrons which was rastered in a 4 x 4 mm^2 uniform pattern on a 10 cm long cryogenic deuterium target.

The gains of the scintillator array's photomultiplier tubes were adjusted by selecting quasi-elastic events in the HRS and then checking the ADC signals created by the protons passing through the scintillator array. The protons were of sufficient energy to pass through the entire array, depositing approximately the same amount of energy in each bar. After adjusting the tube's voltages to change their gain, more data were taken and checked.

This procedure was repeated several times until a stable solution was found for all of the photomultiplier tubes. In Fig. 1, the coincidence timing spectrum between the HRS and the scintillator array is shown. The plot is plotted on a log scale in order that the negligible background events can be seen.

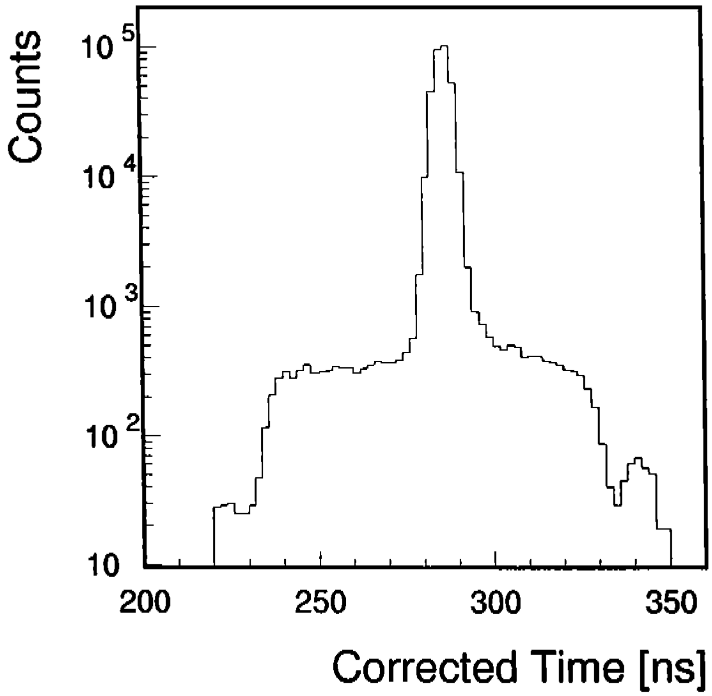

Fig. 1. Shown on a log scale is the spectrum of coincidence timing between the HRS and the scintillator array. For this measurement, the neutron bars were used for proton detection and HRS was used for electron detection for the reaction D(e,e′p). This nearly background free data was used for setting the gains and checking the signal timing of the neutron bar's photomultiplier tubes.

3 D(e,e′pn) Kinematics

For the triple coincidence kinematics, the scintillator array was placed at an angle of 90° 4.2 m left of the target. A 2 in thick lead shield was placed in front of the array to reduce the amount of low energy charged particles incident on the array. The left HRS was placed at 16° with a negative polarity central momentum of 2106 MeV/c. The right HRS was placed at 57° with a positive polarity central momentum of 980 MeV/c. Again, the CEBAF accelerator provided a 10 uA beam of 2561 MeV electrons which was rastered in a square 4 x 4 mm^2 uniform pattern on a 10 cm long cryogenic deuterium target.

This target and beam current provided the same per nucleon luminosity of 1×10^{38} cm^{-2} sec^{-1} and the same neutron momentum as will be required by proposal E01-015 [1]. This was done in order to satisfy the condition of PAC19 that a realistic test of the capability of the scintillator array to measure (e'pn) coincidences be performed [4]. Doing the test with a deuterium target provided the added advantage that the measured neutron arrival times could be compared to the arrival time which can be calculated from the D(e,e′p) reaction.

In Fig. 2 the neutron coincidence time is plotted. The usual Hall A analyzer, ESPACE, was used to analyze the data and to make a time of flight correction for the coincidence time between the two spectrometers. The events in the peak are the triple coincidence events and in the flat region are the random events. The width of the neutron peak, about 35 ns at the base, is due to the range in detected neutron momenta. The background signal ratio is a factor of 1.5 higher than those used for calculating rates in the proposal. By taking the time different between the photomultiplier tubes on the scintillators, the position of events in the scintillator bars could be determined. This analysis should that roughly a third of the background was coming from low energy radiation incident on the sides of the scintillator array. This experimental observation agreed with the calculations of P.V. Degtyarenko [5]. To reduce this background, shielding material can be placed around the scintillator array.

Since a deuterium target was used, the premise that the events in the shown timing peak are neutrons can be checked by using the neutron momentum determined by the measured D(e,e′p) reaction to correct the timing spectrum for the expected difference in neutron arrival times. The result of this time of flight correction is shown in Fig. 3. This figure shows not only that the events are neutrons, but also demonstrates that the raw neutron arrival time can be used to measure the neutron's momentum.

4 Conclusions and Outlook

The first dedicated neutron detector test has been successfully performed in Hall A. The tests clearly show that neutron detection can be performed in the Hall with a per nucleon luminosity of 1×10^{38} cm^{-2} sec^{-1} even with background rates which were slightly higher than expected.

While the E01-015 experiment could tolerate the rate, there are plans to improve the signal to noise ratio. First, the timing between the two spectrometers will be improved by approximately a factor of four. This will be done by upgrading the present trigger scintillators. The resulting trigger system should have a trigger timing width of 500 ps FWHM as is routinely achieved in Hall C. Second, John Watson, who has extensive experience with neutron detection, is designing a shielded hut for the Hall A neutron bars similar to the one used in Hall C. The addition of the shielded hut will directly reduce the singles rates on the bars, while the improved trigger timing will allow for tighter

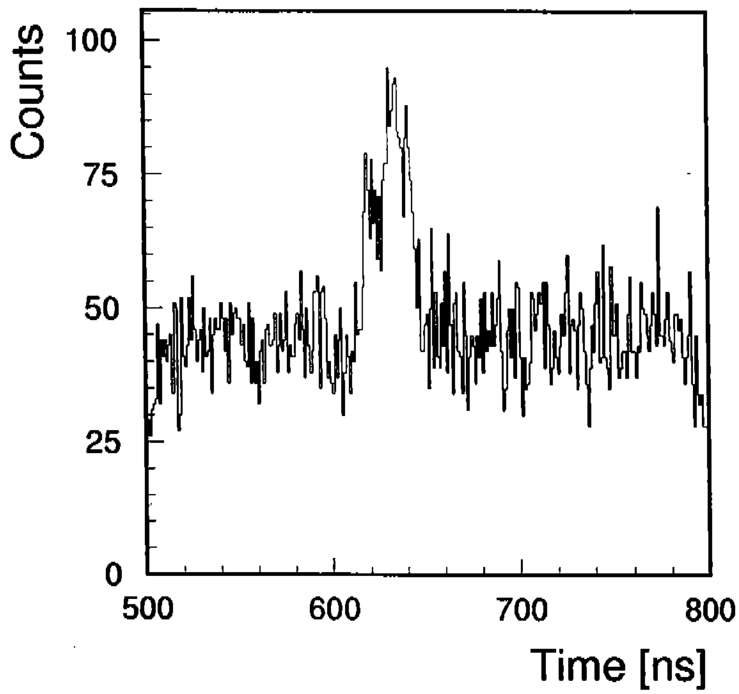

Fig. 2. Raw the D(e,e′n) coincidence timing spectrum for (e,e′pn) events. The peak in the spectrum is distributed over approximately 35 ns. The flat region on either side of the peak is due to random coincidences.

coincidence timing windows. Third, during the E01-015 experiment, the neutron bars will be placed behind the large acceptance BigBite spectrometer, the dipole magnet of this spectrometer will act as a sweeping magnet to reduce the background rates even further.

In addition, a detailed Monte Carlo study was done of the experiment [6]. This study shows that the broadening of the timing peak and the wider angular spread due to the pair motion in carbon can also be tolerated, further demonstrating that the proposal measurements of (e,e'pn) and (e,e'pp) are feasible under the proposed high luminosity conditions.

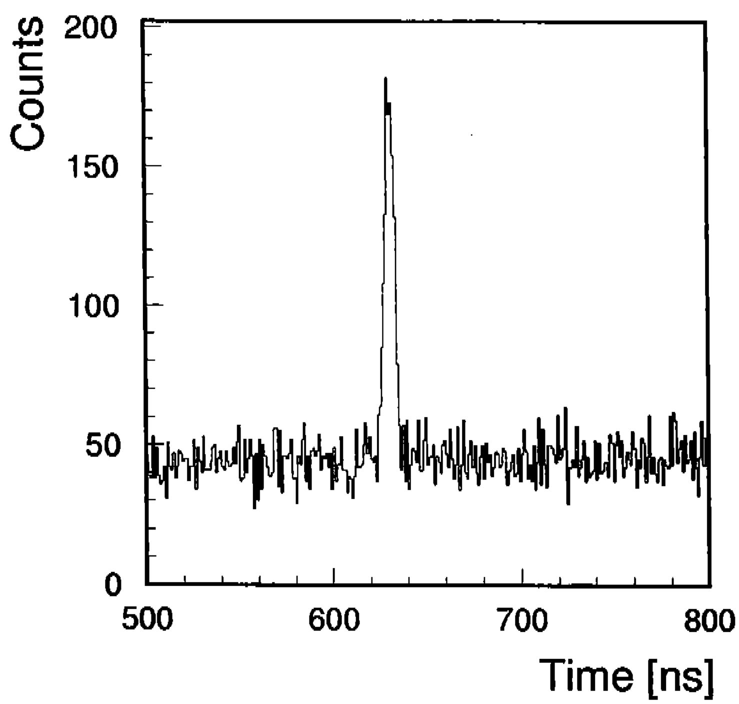

Fig. 3. The (e,e′n) coincidence timing spectrometer corrected for the neutron momentum as determined by the D(e,e′p) measurements. The fact that the timing peak becomes narrower, FWHM of 6 ns, shows that the events are indeed neutrons and that the arrival time is correctly correlated with momentum. In fact during the carbon (e,e′pn) experiment, the arrival time would be used to determine the neutron momentum.

References

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