Quasielastic Neutron-Induced Deuteron Breakup

Katrina Koehler*, Peter Kroening*, Jonathan Slye*, Jared Turkewitz, Sho Uemura**, June Matthews**, and Mark Yuly***

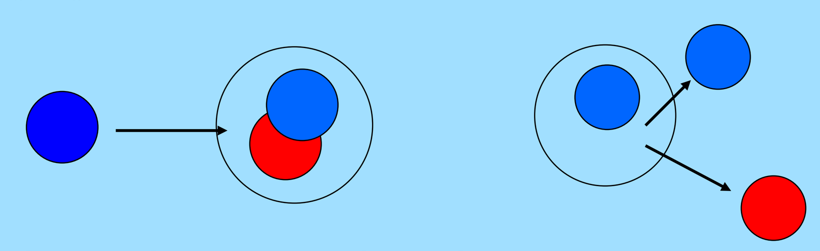
* Houghton College, One Willard Avenue, Houghton NY 14744 ** Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139

I. Abstract

At the Weapons Neutron Research Facility part of the Los Alamos National Lab in Los Alamos, NM, the quasielastic scattering experiment was performed on flight path 15R in the summer of 2009. The cross-section for this experiment is being measured at intermediate incident neutron energies, ranging up to 800 MeV. Scattered protons from deuteron breakup travel through a magnetic spectrometer on beam right, consisting of a thin ΔE scintillator, three drift chambers, two permanent magnets, and two thin scintillators. An array of nine two-meter high plastic scintillators detect scattered neutrons on beam left.

II. Motivation

Although n-d elastic scattering has been measured to a great degree of accuracy, there have been few measurement for n-d quasielastic breakup at any kinematics. In the quasielastic breakup, the incident neutron interacts with the proton in the deuterium nucleus, breaking up the deuteron. The energy of the incident neutron is conserved in the sum of the energies from the outgoing proton and neutron.



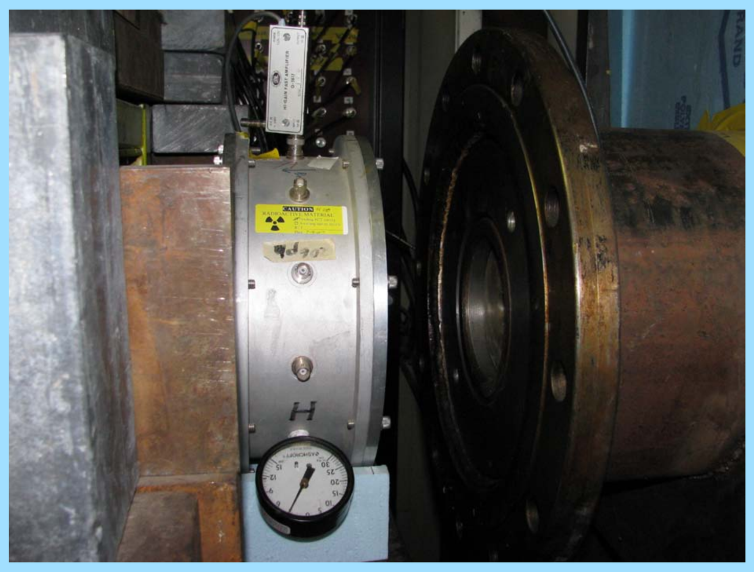
In the quasielastic reaction, the incident neutron interacts primarily with the proton, breaking the nucleus apart without transferring any of its momentum to the deuteron's neutron.

Previous measurements of the n-d quasielastic breakup reaction have been performed at the lower energies of 10-15 MeV [1, 2] and there have been p-d quasielastic breakup reactions at the higher energy of 65 MeV [3] and 200 MeV [4], but there have been no n-d quasielastic breakup reactions using the full range of energies from a few MeV to 800 MeV, such as is available at the Los Alamos Neutron Science Center.

III. Experimental Apparatus

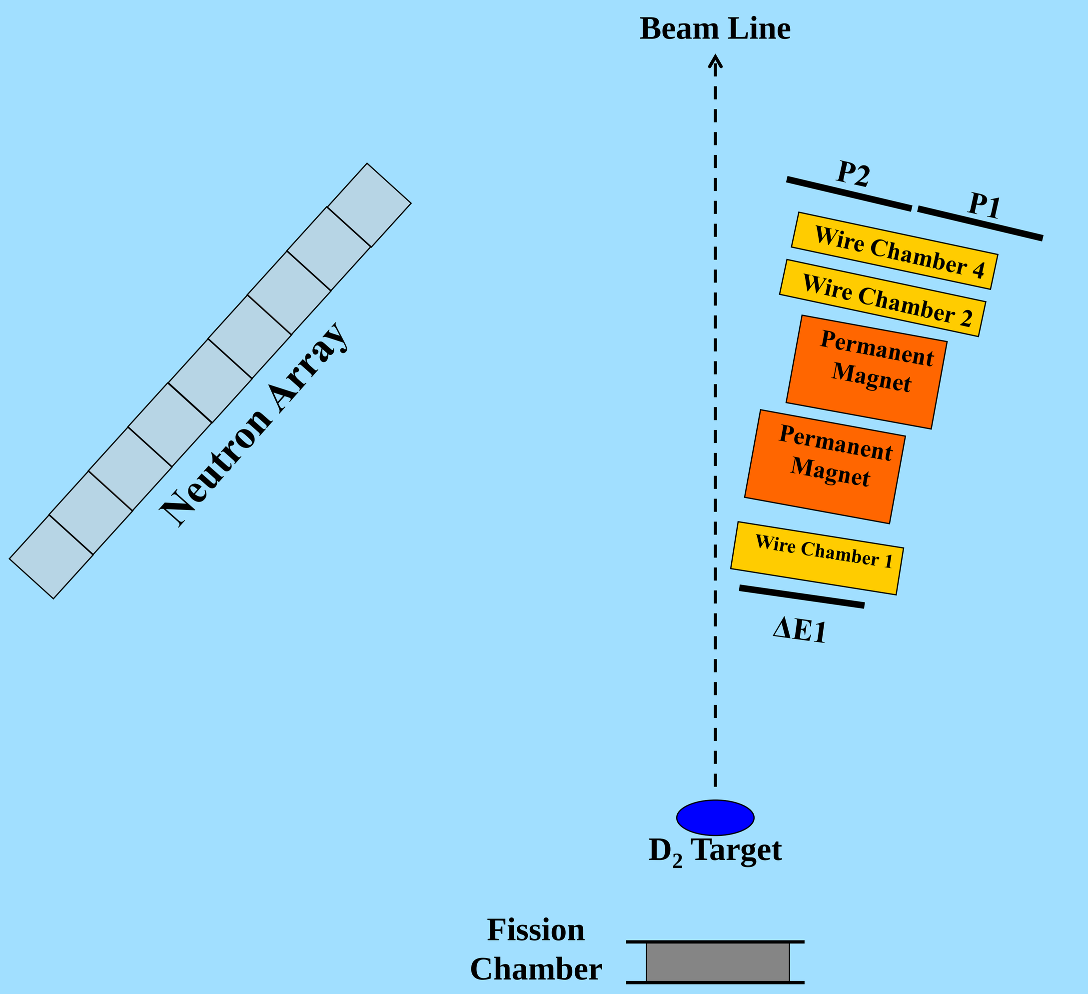
A. Fission Chamber

The incident neutron flux must be monitored, so the measured cross-section for the d(n,np)n reaction may be normalized and changes to the beam intensity noted.



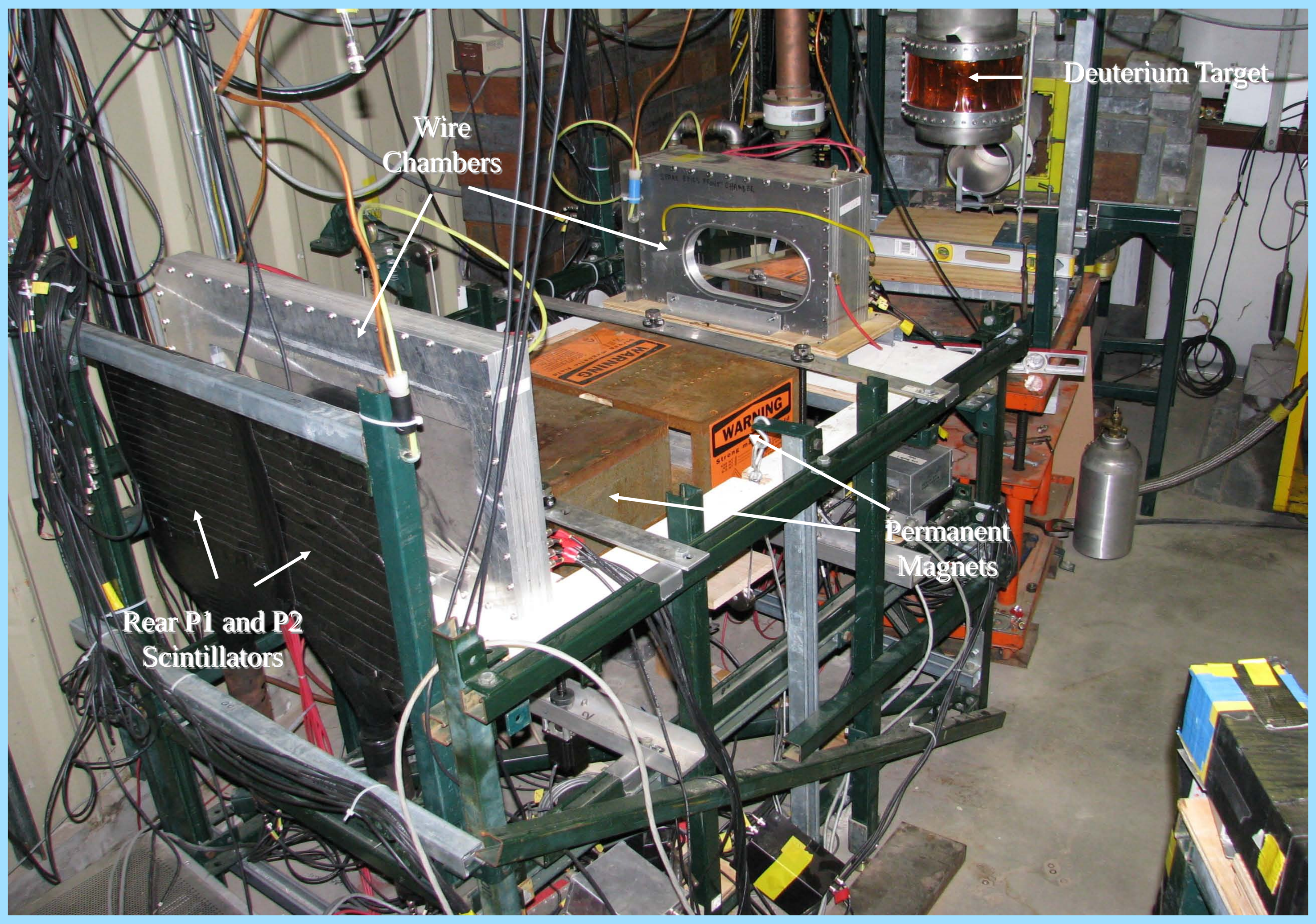
The fission chamber is located upstream of the target to normalize the data collected.

This is accomplished using a fission chamber, which is a cylindrical chamber filled with a 90% argon and 10% methane gas mixture. The chamber contains eight steel foils, one of which has a U^{238} deposit electroplated to it. The incident neutron beam induces fission in the uranium, and the fission fragments ionize the gas. Since the blank steel foils are held at a 290 V difference to the foil with the deposit, the charge from the ionized gas is attracted to the collecting foil, which then reads out an ADC and TDC pulse for each alpha particle and fission fragment. The ADC pulse height is used to distinguish alpha particles from fission fragments, so the number of fission events can be determined. The TDC pulses are used to determine the energy of the incident neutron using time of flight.



B. Target

After the neutron beam from target 4 passes through the fission chamber, it strikes the target. Consisting of a 0.5 inch thick, 5 inch diameter horizontal cylindrical chamber, the target can be filled with either liquid deuterium or liquid hydrogen. This is accomplished by condensing gaseous hydrogen or deuterium using a refrigeration system. A 32-inch diameter stainless steel cylindrical chamber surrounding the target is evacuated in order to help prevent the liquid in the target from overheating and subsequently evaporating and expanding.



The magnetic spectrometer is used to determine the energy of the scattered protons. A wire chamber behind the rearmost wire chamber was added since the photograph.

C. Neutron Bar Array

Ionizing radiation causes scintillation—a flash of light—in certain organic materials. This is how the detectors for the nd breakup experiment work: when the ionizing radiation passes through the material of the detector, it excites the molecules to a higher energy state. Some of the energy is lost through lattice vibrations in the form of heat, resulting in a lower excited energy. The molecules de-excite to ground state by emitting a photon, which can then be detected by the photomultiplier tubes attached to the detector. These photomultiplier tubes amplify the weak signal from the photons traveling through the scintillator because when a photon strikes the cathode of the photomultiplier tube (PMT), it ejects an electron, which is accelerated toward a dynode in the PMT. The electron then ejects more electrons from the PMT's dynode, which are accelerated toward the next dynode. This produces a cascade of electrons, which can be read out as an amplified signal.

The scattered neutrons are detected in a 2-meter high plastic scintillator array. Because neutrons are not charged, they cannot be detected directly, but only through a collision with a proton, which is charged and can excite the molecules in the scintillator. For this reason, the bars that detect the neutron are 10 cm thick to increase the likelihood of such an interaction. The neutron bars also have photomultiplier tubes at either end, so the vertical position of the neutrons can be determining using the TDC pulses from both photomultiplier tubes.

D. Magnetic Spectrometer

Scattered protons are detected in the magnetic spectrometer located on beam right. The magnetic spectrometer first detects the proton with a ΔE detector. The proton then pass through a wire chamber. Wire chamber tracking is used to determine the horizontal and vertical position of the particle.

The proton path is then deflected away from the beam line by the two SmCo permanent magnets located behind the first wire chamber. The amount of deflection depends on the proton's momentum. Various computational approaches have been implemented to determine the proton momentum from the wire chamber positions. Efficient methods such as a simple determination of the angle and first-order approximation of the impulse imparted by the magnets are used for online computation of the proton momentum. A more accurate method using numerical tracking of the particle in a map of the non-uniform magnetic field is used for precise momentum analysis after data has been collected.

After the permanent magnets, the proton's position and path is re-determined after it passes through two more wire chambers, before it is finally detected by the rear P1 or P2 scintillator. The magnetic spectrometer is set up so that the proton's momentum can be calculated using the amount of deflection by the magnets or using time of flight between the ΔE detector and the rear scintillators.

IV. Data Analysis

A. Energy Computations

To calculate the differential cross sections for this scattering experiment, the energies are needed for the incident neutrons, the scattered protons, and the scattered neutrons. First, the energy of the scattered proton is calculated. Ideally, this would be done using the magnetic spectrometer. The wire chambers would be able to track the proton's tangential paths before and after the magnets, and because the magnets deflect the charged proton's path relative to its momentum, the amount of path deflection can be used to calculate the proton's energy.

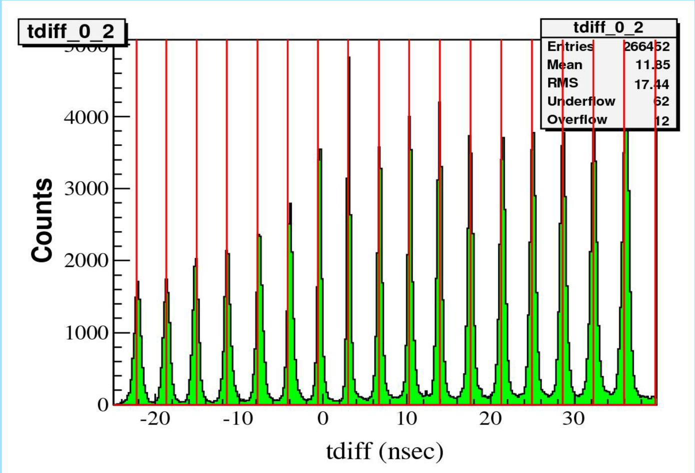
However, because the amount of deflection is not substantial, the proton energy may also be calculated using time of flight from the ΔE1 to the back P1 or P2 scintillators. From this energy, it is possible to backtrack from the ΔE1 scintillator to the target to figure out when the neutron hit the deuteron. Using this time and the pulsed nature of the incident neutron beam, the time of flight and thus the energy of the incident neutron can be calculated.

Also using the time of event and the TDC pulse from the neutron bars, the energy of the scattered neutron can be calculated using time of flight. However, from this, it can be seen that energies of the incident neutron and the scattered neutron are all dependent on the energy result of the scattered proton, so improving the accuracy of these results is very important. For the magnetic spectrometer to give accurate results, precise wire chamber tracking is particularly important.

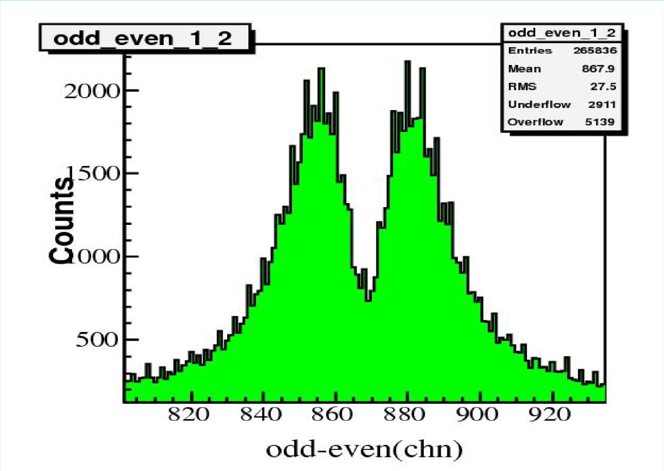
B. Wire Chamber Tracking

The wire chambers are used to track the proton's path through the magnetic spectrometer. The wire chamber planes work using alternating anode and cathode wires. When the charged protons ionize the argon-isobute gas mixture as they travel through the wire chamber, the charge is collected on the anode wires, and induce a pulse in the cathode wires. The anode and cathode wires are bussed together with a delay line and the pulse is recorded at each end of the plane. The time difference is used to determine which anode wire was closest to the event and the time sum is used to calculate the drift time. In this way, the position of the proton can be accurately determined to within one hundred microns.

However, from this information one cannot determine on which side of the anode wire the drift distance is. This can calculated using one of two methods. The first method fits a line to each possible combination of points. The one closest to a straight line is used as the track for the proton. This method works well on the rear wire chambers, where there are three working planes. Three points overdetermine a line, so the track is chosen such that it minimizes the distance between the track and the point.



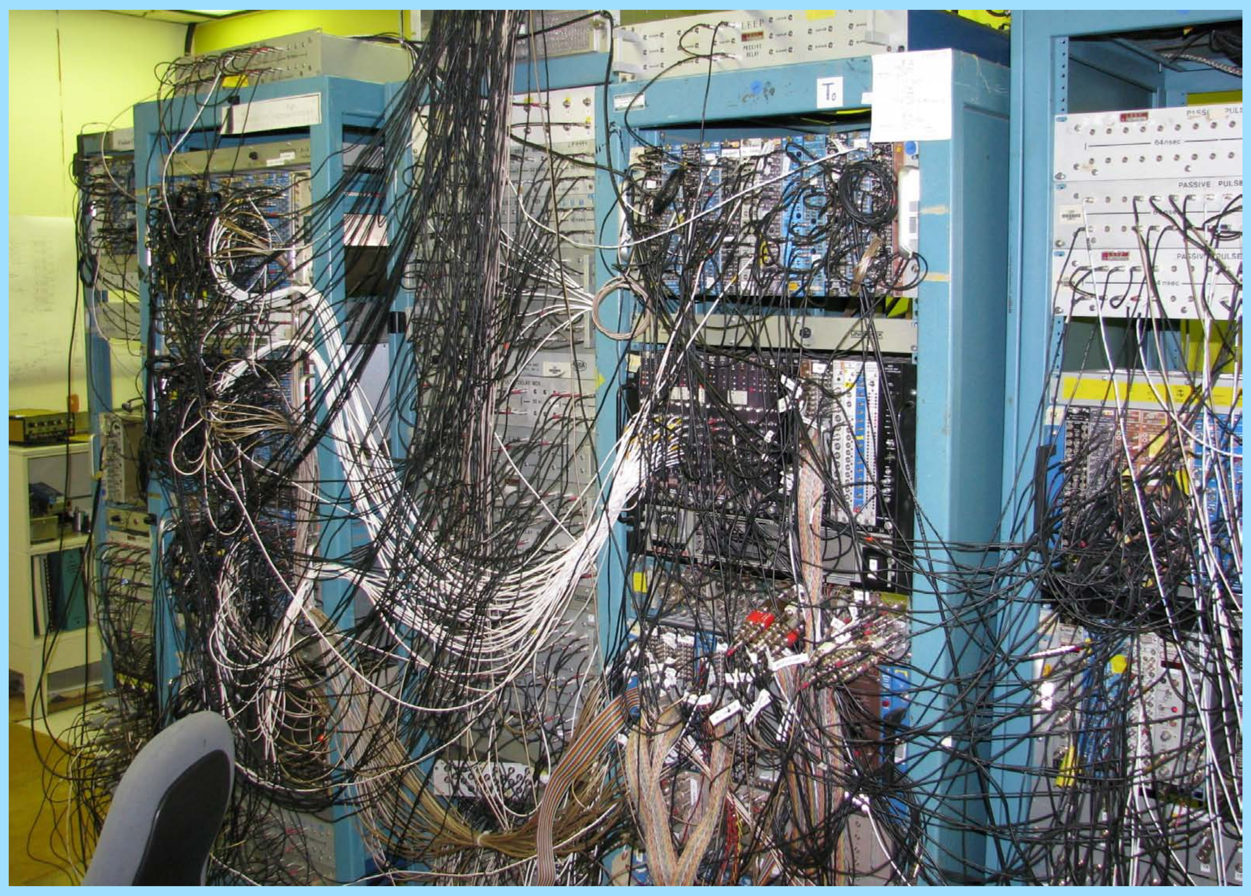
The time difference spectrum between the pulses from either end of the plane shows the individual wires in the plane. The overlaid red lines show where the analyzer expects the wires to be.



A histogram showing the odd-even spectrum, so events can be categorized as happening on the right or left of an anode wire.

This method does not work for the front chamber, however, because there are only two planes. For this wire chamber, we use the pulses from the cathode wires to settle the left-right ambiguity. Even cathode wires are bussed together and odd cathode wires are bussed together, so any given event will induce a pulse in an odd and an even cathode wire.

The induced pulse will be slightly larger in one, depending on which side of the anode wire the event is. From the difference of these pulses, it is possible to determine whether the event was closer to an odd or an even wire, so the left-right ambiguity of the drift distance is resolved.



FERA modules read the electrical outputs of the circuit into the computer for analysis.

E. Electronics

The electronics for this experiment are set up to record the pulses from the detectors. The most important part of the electronic setup is the trigger system, which is set up to record data when one of the triggers is tripped. These triggers include a neutron singles trigger, where a single neutron bar detects a particle, and a proton singles trigger, where the ΔE detector and one of the two P1 or P2 scintillators detect a proton. Since a deuteron breakup is determined when a proton is detected in the magnetic spectrometer and a neutron is detected in the neutron array, the coincidence of the neutron singles and proton singles triggers is used to determine good deuteron breakup events.

V. Conclusion

Analysis of the data collected from hydrogen runs taken earlier in the summer of 2009 is close to being finished. Data for deuterium is currently being collected and will be analyzed to find differential cross-sections for the d(n,np)n reaction. This will be compared to theoretical calculations and the results of the previous experiment conducted in the summer of 2007.

Bibliography

*[1] C. R. Howell, et al. Phys. Rev. Lett. **61**, 1565 (1988).*
*[2] M. Stephan, et al. Phys. Rev. C **39**, 2133 (1989).*
*[3] M. Allet, et al. Phys. Rev. C **50**, 602 (1994).*
[4] W. Pairsuwan et al., Phys. Rev. C 52, 2552 (1995).