MEASUREMENTS OF THE PROTON-NEUTRON CORRELATION IN DEUTERON BREAKUP AT 260 MEV

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Experiment CE10 was designed to study the proton-neutron correlation from deuteron breakup in order to provide important information, such as the possible intensity and energy resolution of a tagged, polarized neutron beam with good resolution created by the breakup of polarized deuterons in the cooler ring. Studies of the interference between Fermi and Gamow-Teller transition amplitudes by the $(\vec{n},p)$ reaction on a light polarized target, and of the isovector term in the nucleon-nucleus interaction by measurement of cross sections and analyzing powers in neutron scattering on nuclei with a neutron excess, would be important sample experiments utilizing such a beam.[1]

The experiment was divided into two parts. The first part, done in the T-region of the Cooler ring in February 1992, was to study the angular correlation of the two breakup nucleons in a small angular range. The second part, done in the G-region in March 1992, measured energies of the two nucleons with a detection system intended to provide about 400 keV resolution.

Angular Correlation Measurements

In this part of the experiment, the angular correlation of neutrons and protons from the C(d,np), Cu(d,np) and Pb(d,np) reactions were measured in the horizontal angular ranges of $0° < \theta_p \leq 6°$ and $0° \geq \theta_n \geq -6°$ (on the opposite side of the beam). A stored beam of 260-MeV deuterons with an intensity of about 90 μA and a cycle period of 45 s was used with the data-taking time in each cycle being 25 s. Three "skimmer" targets were made from natural C, Cu and Pb, with thicknesses of 650 mg/cm^2, 680 mg/cm^2, and 2400 mg/cm^2 respectively.

A proton telescope, consisting of a delay-line wire chamber with both x and y wire planes sandwiched between a pair of 0.3 cm-thick scintillators and followed by two 8.3 cm-thick NaI(Tl) detectors, was located downstream from the T-region 6° magnet. The distance between the target and the wire chamber was 124 cm, and the spacing between two adjacent anode wires in each wire plane was 4 mm. The telescope covered breakup protons from nearly $\theta_p = 0°$ to $\theta_p = 6°$ with vertical acceptance of about $\Delta\phi_p = 3°$. Elastic deuteron scattering events, used as the luminosity monitor for the experiment, were also detected with the same telescope. The horizontal acceptance for these deuterons was $4.5° < \theta_d < 10.5°$. While breakup protons were stopped in the first NaI(Tl) detector, the elastically-scattered deuterons passed through it and were stopped in the second NaI(Tl). Gain matching of the two NaI(Tl) detectors was obtained by degrading the energy of the elastically-scattered deuterons with absorbers of different thicknesses placed in front of one NaI(Tl) with the other taken away.

Neutrons were detected with an array of 102 cm × 15 cm × 10 cm plastic scintillator bars placed on the opposite side of the beam pipe from the proton telescope, and about 9.5 m away from the target with the long side parallel to the breakup neutrons. They were arranged so that each one measured neutrons of a particular scattering angle θ_n with a horizontal acceptance of $\Delta\theta_n = 0.67°$ and a vertical acceptance of $\Delta\phi_n = 1°$. By measuring timing at both ends of each scintillator, the position at which (n,p) conversion occurred could be determined with an accuracy of about 3.5 cm (out of 102 cm).[2] In order to measure the efficiency of each scintillator, one identical scintillator was placed in front of these scintillators with its 102 cm × 15 cm side facing the target and 8.1 m away. Placed in this way, the efficiency of this "front" scintillator was known based on previous measurements; by comparing its yield with that of the "rear" scintillators, one can estimate the efficiency of each scintillator. Charged-particle veto was provided by a thin scintillator pad in front of all the above detectors.

A neutron signal was defined by a hit in any one of the scintillator bars with charged-particle veto. The coincidence of this signal with both scintillators in the proton telescope triggered (d,np) events, and the time of flight (TOF) of neutrons were measured with a "start" from the proton telescope. Triple coincidence of both scintillators and the second NaI in the proton telescope, vetoed by the neutron signal, triggered (d,d) events which (prescaled by a factor of 10) were simultaneously taken with the (d,np) events.

Several short runs were taken to measure (d,d) and inclusive (d,px) events simultaneously. Coincidence of the two scintillators in the proton telescope triggered both events, and separation of deuterons and protons was done in software. In addition to measuring the cross section angular distribution for (d,px), these runs also helped to determine accidental backgrounds in (d,np) events.

Data analysis is in progress which includes: calibrate NaI(Tl) detectors to get E_p and E_d; extract position $\vec{x}_p$ ($\vec{x}_d$) relative to the target when p(d) hits the wire chamber; calculate θ_p (θ_d) using ray-trace from E_p (E_d), $\vec{x}_p$ ($\vec{x}_d$), and the field map of the 6° magnet; calculate solid angles of p(d) at each scattering angle using ray-trace; calibrate neutron TOF to get E_n; subtract accidental background; estimate efficiency of the neutron detectors; calculate luminosity using (d,d) yield and optical potential calculations; and estimate systematic errors.

Some preliminary results are shown in Fig. 1-3. The angular distribution of the deuteron yield for C(d,d) is shown in Fig. 1. Figure 2 plots the proton energy versus neutron energy for C(d,np). The angular correlation for C(d,np), plotted as the proton angular distributions for specific coincident neutron angles, is shown in Fig. 3. The error bars shown in all figures are purely statistical.

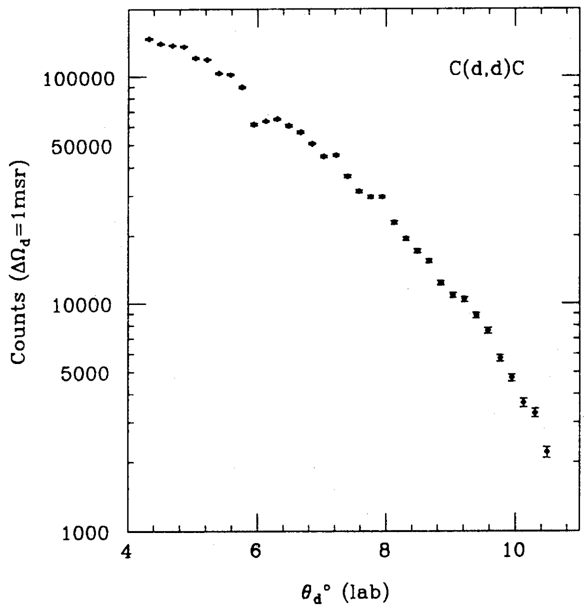

Figure 1. Measured angular distribution of C(d,d) elastic scattering at 260 MeV.

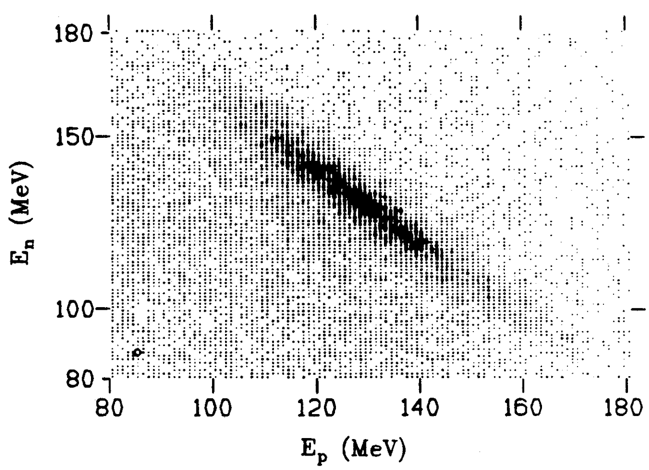

Figure 2. Energy correlations for C(d,np) deuteron breakup at 260 MeV.

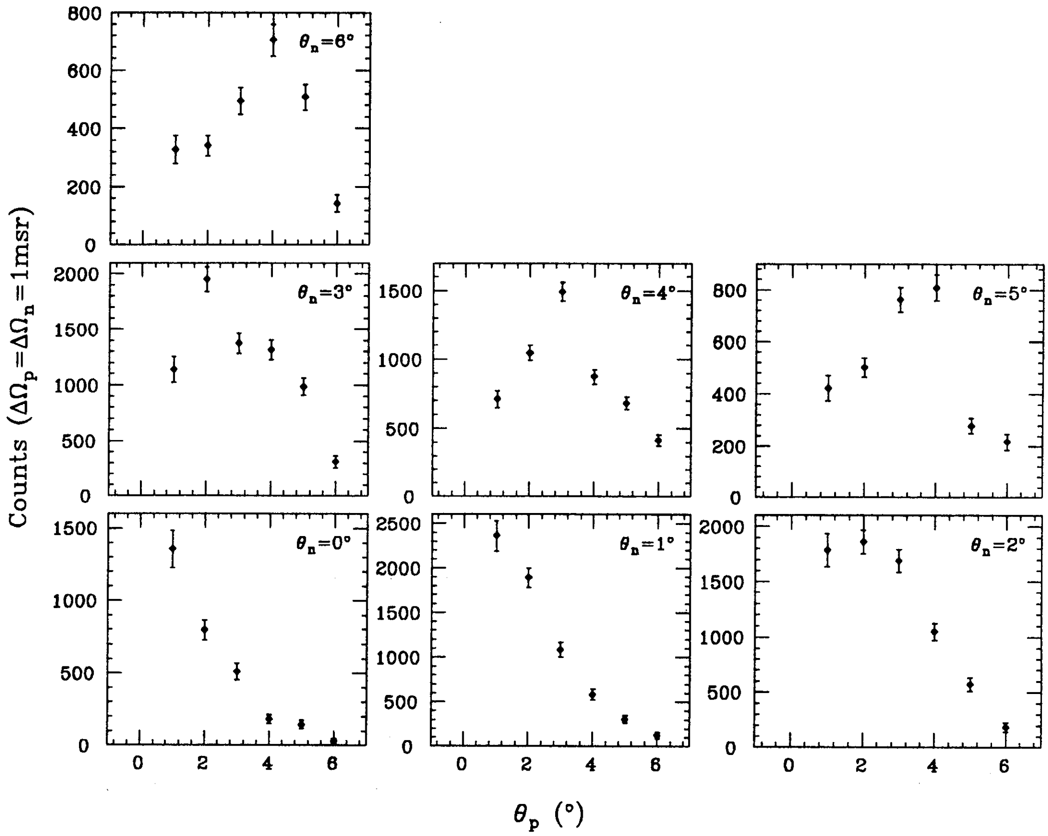

Figure 3. Angular correlations for C(d,np) deuteron breakup at 260 MeV.

Energy-Resolution Measurements

A detection system, designed to be able to measure energies of the protons (neutrons) with energy resolution about 200 keV (400 keV), is shown in Fig. 4. It consisted of two identical arms which were placed at the opposite sides of the beam pipe downstream from the target box in the G-region of the Cooler ring. Each arm consisted of a 0.5 mm-thick Si strip detector, a 3 mm-thick "front" scintillator, a multiwire four-plane drift chamber, a stack of intrinsic Ge detectors of total thickness of 3 cm, a 3 mm-thick "back" scintillator, and a 7.62 cm-thick NaI(Tl) detector. A 200-MeV, 100-μA stored deuteron beam and a 0.3 mm-thick Pb skimmer target were used during the experiment. The protons emitted at lab angles of 3.5° to 5.5° (or −3.5° to −5.5°) and neutrons at lab angles of −3.5° to −5.5° (or 3.5° to 5.5°) were detected in coincidence.

The breakup protons were stopped in Ge, and their energies E_p were obtained from measuring the pulse height from the Ge with an expected resolution of about 200 keV. The breakup neutrons were converted to protons in the front scintillators through (n,p) reactions with a conversion efficiency of about 10^{-4}. The angles between the converted

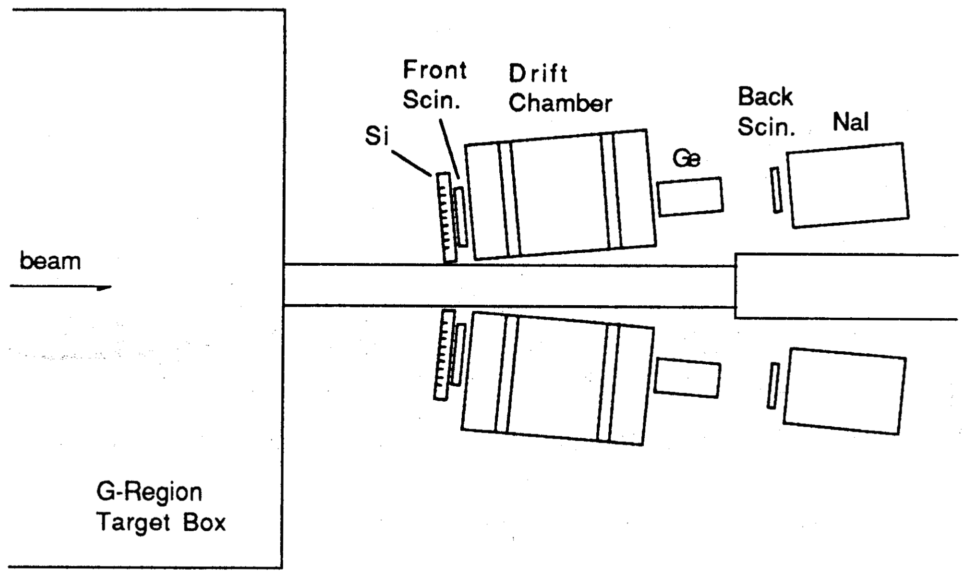

Figure 4. Schematic drawing of the detection system in the (d,np) energy resolution measurement.

protons and the neutrons, θ_{np}, were measured with a resolution of about 1° using the drift chambers. θ_{np} and E_p were then used to calculate the energies of the breakup neutrons.

The coincidence of the two front scintillators gave hardware triggers of the (d,np) events. Since the (n,p) conversion efficiency was very small, (d,pp) events may have a comparable rate with the (d,np) trigger. Thus the Si detectors were used, in software, to distinguish between (d,np) events and (d,pp) events. The coincidence of the front and back scintillators in the same arm triggered the deuteron elastic scattering events which were used as the luminosity monitor for the experiment. The elastically-scattered deuterons were stopped in one of the NaI detectors.

Problems were encountered during the experiment due to the limited lifetime of the Ge detectors in the high radiation field. Several detector changes were necessary. Data analysis for this experiment will start after the angular correlation analysis is finished.

1. IUCF Proposal to NSF: "Chicane/Spectrometer System for the IUCF Cooler Ring," submitted April 24, 1992.
2. W. Huang *et al.*, IUCF Sci. and Tech. Rep., May 1988 - April 1989, p. 100.