Coherent Dissociation and Total Cross Sections of Neutrons in their Collisions with Nuclear Targets at Fermilab Energies


We present preliminary results from an investigation of the coherent dissociation of neutrons into \( (p^+ \) system in the 120 GeV/c - 300 GeV/c range of neutron momenta. Using a variety of nuclear targets, we observe for light elements the dominance of diffraction dissociation over the electromagnetic excitation of neutrons. Conversely, for the heaviest elements coherent dissociation of neutrons is dominated by production in the nuclear Coulomb field. Cross sections for dissociation dissociation on nuclei change by less than 10% in this neutron-momentum range.

The experiment was performed at the Beson Detector Laboratory of Fermilab.

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We have measured the dissociation of neutrons into $\left( p\pi^- \right)$ systems in neutron-nucleon collisions between 200 GeV/c and 300 GeV/c. The experiment was performed in the 1 mrad $\pi$-3 neutral-beam line of the Bevatron Detector Laboratory at the Fermi National Accelerator Laboratory.

The apparatus, which is sketched in Fig. 1, consists of a large aperture forward wire-plate spark chamber V-spectrometer. The nuclear-target box is located 150 meters downstream of the neutron-beam production target. (During our run 360 GeV/c protons from the main ring of the accelerator were used for targeting at the Bevatron Lab.)

Each target, typically 0.2 radiation lengths in thickness, were used to study coherent production of $p\pi^-$ systems. The target box was surrounded with scintillating $\pi/\nu$ muon-rich veto counters so as to be able to detect nuclear back-up processes and thus reduce the trigger level for the experiment. The trigger requirements were designed to suppress incoherent production as well as the production of more than two charged particles within the target box. Fiducial and spark coordinates from all eighteen chamber planes were read out incoherently (simultaneously from both ends) whenever the logic requirement $A \cdot G \cdot H$ was satisfied. Here, $A$ represents the logical OR of all the veto counters i.e., the counters surrounding the target box, the $\frac{1}{35}$ inch thick scintillation veto counter at the entry to the target box (indicating that the particle initiating the collision was charged rather than neutral), and the various baffle counters surrounding the magnet aperture (indicating presence of charged or neutral particles in addition those entering the magnetic field volume); $G$ represents a $\frac{1}{35}$ inch scintillation counter, located 2 inches downstream of the nuclear target sample; this counter provides
the information that at least one charged particle hit the region of interaction. Two and only two of the eight NaI detectors elements were required to have signals before the acceptance requirement was fulfilled. The spark chambers were capable of being pulsed 15 times during the 21 sec beam-spill. A typical run consisted of 10,000 triggers taken over a six hour period. Quality of the performance of the apparatus was monitored using an online PDP-11 VIC computer; reconstruction of events and analysis was performed off-line. Approximately 80% of the 600,000 triggers yielded successfully reconstructed events.

The coherent dissociation of neutrons can proceed either through the hadronic diffractive dissociation process (often referred to as Pomeron exchange)\(^1\) or through the electromagnetic excitation of the neutron in the Coulomb field of the target nucleus (Primakoff effect, or photon exchange).\(^2\) The dissociation of neutrons has been studied at lower energies,\(^3\) where kinematic restrictions cause substantial dropping of the cross section for coherent hadronic excitation at large values of \(p_{\tau N}\) mass \(^4\) as well as a suppression of the cross section, at all values of \(M,\) for contributions from the Coulomb production process.\(^5\) The present data were obtained in an investigation of neutron dissociation in the 120 GeV/c-300 GeV/c momentum band for a variety of nuclear targets, ranging from Iron through Uranium. In this note we will display the general characteristics of the \(p\tau^-\) mass spectra and the momentum-transfer distributions obtained in the coherent dissociation of \(n \rightarrow p\tau^-\) for Pb, Cu, C and Be targets. We will also present results for total cross sections of neutrons on nuclear targets in the 50 GeV/c to 300 GeV/c momentum range.
Figure 2 displays distributions of the square of the four-momentum transfer \( t \) between the incident neutron and the produced \( p^- \) system for three regions of \( M \): (1) The \( \Delta(1236) \) mass region, defined as \( M < 1.28 \) GeV; (2) The \( \Xi^+(1400) \) region, defined as \( 1.35 < M < 1.45 \) GeV; and (3) The \( \Xi^- \) region, defined as \( 1.55 < M < 1.80 \) GeV. (We use the variable \( t' = |t - t_0| \), where \( t_0 \) is the kinematically allowed minimum value of \( t \) for the production of a \( p^- \) system having mass \( M \) at a given value of the incident momentum for the neutron.) Corrections for target-empty measurements and for small variations in the geometrical acceptance of the apparatus have been calculated using a Monte Carlo program and were applied to the data. The steep rises observed at small \( t' \), with values of diffractive slopes characteristic of the sizes of the nuclear targets, give us full confidence that the inelastic production process takes place coherently over the entire nucleus. (It should be recalled that we do not measure the momenta of the recoil nucleus and consequently the reaction \( n + A \rightarrow (p^-) + A' \) has no constraints. We believe, however, that background from other coherent or incoherent channels is not important for the data which we present in this paper. (5))

The distributions in \( t' \), for each target, appear to show similar dependences on \( M \). Namely, for the \( \Delta(1236) \) region all the distributions display a sharpening of the \( t' \) spectrum at \( t' < 0.001 \) GeV\(^2\). This excess contribution can be attributed to coalesced production of \( p^- \) systems, which because of the known bare \( NN \) coupling is dominated by \( \Lambda^0(1236) \) production. Taking our experimental resolution into account, the initial falloff of the cross section in \( t' \) is consistent with the theoretically expected form for coalesced production. (6)

We have used the dominance of the coalesced cross section for production on Pb to extract the momentum spectrum of the incident neutron beam.
The observed $p^-n$ momentum spectrum in Pb for $t' < 1.28$ and $t' < 0.09$ was first corrected for diffractive event background. The subsequent unfolding of the resolution and of the known coulomb production process\(^{(6)}\) provided the corrected momentum spectrum, \((\text{Fig. 3})\) which is consistent with the directly measured neutron spectra using calorimetry.\(^{(7)}\)

The data in the $N^0(1400)$ and $N^0(1688)$ regions, particularly where coulomb production is quite small, exhibit a sharp exponential fall off with $t'$ characteristic of the individual nuclear sizes. The smooth curves drawn on the figure are superpositions of the contributions from coulomb\(^{(6)}\) and from diffractive coherent production. The latter is based on an optical model description for the production process described by Margolis.\(^{(8)}\) Standard Woods-Saxon parameters were used to describe the nuclear shapes.\(^{(9)}\)

The total cross section of a neutron on a nucleon was taken to be a constant 32 mb and the elastic forward scattering amplitude for $n$-nucleon and $(p^-)$-nucleon was taken to be real. The experimental resolution was folded into the overall prediction for the shape of the $t'$ spectrum. The value for the $(p^-)$-nucleon total cross section was also taken to be 32 mb, a value consistent with the shape observed for the $t'$ distribution and consistent with similar measurements made at incident neutron energy of 0.12 GeV/c.\(^{(3)}\)

Figure 4 displays the spectra for two regions of $t'$: (1) $t' < 0.03$ GeV$^2$, a region where coulomb production is important; and (2) 0.005 < $t' < 0.03$ GeV$^2$, where diffractive production dominates. The data in Fig. 3 indicate substantial $A(1236)$ production, particularly at small $t'$; a shoulder is evident at the $N^0(1236)$ and a small enhancement is observed at the $N^0(1688)$, both mainly at the larger $t'$ values. The difference in the various $t'$ spectra can be attributed largely to the known dependence of the coulomb production process on $t'$ and $\theta$ (the reaction plane).
The cross section for \( \Lambda^0(1236) \) production, in particular, is approximately proportional to \( z^2 \) for \( t < 0.001 \) GeV\(^2\). The curve superimposed on the Pb data is the predicted shape of the mass spectrum expected on the basis of coalescence production. (The absolute normalization is also consistent with the data.) The curve displayed on the Be data is based on a calculation of the reggeized PDD effect. (10) The shape of the predicted mass distribution is in reasonable agreement with the data.

The energy dependence of the cross section for several mass intervals for Be, C, Cu and Pb targets is displayed in Fig. 5. Only Pb appears to show an increase of the cross section with momentum. This rise is consistent with the dominance of the coalescence process in Pb, (even for large \( \beta \)-values), and the consequent rise of the cross section with energy. The cross sections for production using the other elements is constant to within 10% possible systematic uncertainties.

The cross section for neutron dissociation into \( \mu^- \) systems on Pb is 41% of the total \( n-Pb \) cross section. Therefore, our V spectrometer can be considered as a neutron detector having excellent positional and energy resolutions. We have utilized this aspect of the spectrometer to perform a precision measurement (limited only by statistics) of neutron-nucleon-total cross sections. Using nuclear transmission targets located 200 meters upstream of the spectrometer Pb target, we measured cross sections as a function of momentum. The transmission targets were cycled automatically, typically every ten minutes (a target empty position was included in the cycling). Counter telescopes were used to monitor the neutron flux throughout the data taking. Small \( (< 0.5\%) \) corrections for elastic scattering of the neutrons in the transmission target were also measured and applied to the data.
5. The contribution from the $p^{3+}$ dissociation, for example, which we consider to be the dominant source of the signal, is estimated to be $2.5\%$ of the $p^{1+}$ dissociation for $18.63^3$. Compared to the $p^+$ signal events the trigger rate of the background is rather low.
6. We have used the theoretical results of G. Fricke, Inst. Phys. 114, 328 (1975) and C. C. Cawkwell et al., Inst. Phys. J 75, 1 (1974). The $p^{3+}$ cross section were obtained from the compilation of H. Grzel and W. E. B., Fenn Univ. Report 466 (1972).
10. See, for example, P. R. Berger, Phys. Rev. Letters 21, 781 (1968).
1. Schematic of spectrometer setup.

2. Distributions in a magnetic field for p"Cu and p"Fe nuclei. In each case, we display the spectra for proton ranges: < 1.25 GeV, 1.25-1.75 GeV, and > 1.75 GeV. (Figure 1).

3. Nuclides and their abundances in the sample.

4. Beam energy: 1200 MeV. The half-life of the beam is 4.2 x 10^-12 seconds, and the cut-off is determined by the beam current. The beam current is measured on a half cycle basis.

5. Energy dependence of the yield and spread over the sample.

6. Fluence dependence of the yield and spread over the sample. The current indicates the consistency of the data over a longer period.
Neutron Dissociation Spectrometer

![Diagram of Neutron Dissociation Spectrometer]

Fig. 1
Fig. 2. Distributions in momentum transfer for a strong dissociation off Be, C, Cu and Pb nuclei. In each case, the display the spectra for proton ranges \(<1.25 \text{ GeV}, 1.35-1.6 \text{ GeV} \text{ and } 1.6-1.8 \text{ GeV}\) (data for the lowest mass band are shown at the bottom of each plot). The curves indicate the contribution of diffractive production (bottom curves) and the sum.
BEAM MOMENTUM SPECTRUM
Based on Central Production in Pb
Acceptance Corrected

\[ P_L \ (\text{GeV/c}) \]

Fig. 3