NEUTRON DIFFRACTION DISSOCIATION AND COULOMB DISSOCIATION FROM NUCLEI ‡

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Preliminary results of a spark-chamber experiment are presented on the reaction

$$n + A \rightarrow (p + \pi^-) + A$$

where the $(p\pi^-)$ pair is produced coherently off the nucleus A. A 0^o neutron beam derived from a beryllium target in the external beam of the Brookhaven proton synchrotron was used. The mean effective momentum of the neutrons was about 23 GeV/c. Forward-going $(p\pi^-)$ pairs were detected in a wire spark-chamber spectrometer and the momentum and angles of each particle were determined. The observation of a sharp forward peak (of width appropriate to the nuclear radius) indicated that a large fraction of the events were produced coherently.

Mass spectra for coherently produced events from carbon, copper and lead targets are presented. The lead data show a peak at low masses due to Coulomb production of the $\Delta(1236)$. The most striking result of the experiment is the lack of any appreciable production of the well-established $I = \frac{1}{2}$ nucleon isobars.

A spark-chamber experiment has been carried out to study with good statistics the reaction

$$n + A \rightarrow N^{*o} + A \rightarrow (p + \pi^-) + A \qquad (1)$$

where the incident neutron dissociates into a $(p\pi^-)$ pair in scattering coherently off a nucleus A. The experiment was exploratory in nature since this process has never been observed with nuclear targets [1]. Results are presented for carbon, copper and lead targets. The neutron beam, with a mean effective momentum of about 23 GeV/c, was taken at 0^o from a beryllium target in the external proton beam of the Brookhaven AGS. The data discussed in this article were taken with a proton momentum of 28.5 GeV/c.

The experimental arrangement is shown in fig. 1. The neutron beam with a diameter of approximately 2.2 cm was incident on the target. The target was surrounded by a rather complete anti-shield (shown only schematically in fig. 1) whose function was to veto events accompanied by charged particles or photons. A hole in the shield permitted charged particles produced near 0^o to enter the spectrometer. The spectrometer consisted of a single $75 \times 180\,\mathrm{cm}^2$ magnet with a 15 cm gap and $\int B\,dl = 36$ kGm. The magnet was preceded and followed by pairs of wire chambers. Each chamber had wire planes with horizontal wires, vertical wires and $\pm 45^o$ wires so that a total of 16 coordinates were recorded per track. The chambers had a magnetostrictive readout with electronics capable of digitizing four sparks per line.

The triggering requirement, $P_1L_2R_2\bar{A}$ or $P_1L_3R_3\bar{A}$, was purposely kept simple to facilitate efficiency calculations. About 16% of the triggers contained two tracks from particles of opposite sign which appeared to come from the same point in the target. The spectrometer had a resolution of approximately ± 1.2 mr in the opening angle of the pair and a momentum resolution of 1.5% at 15 GeV/c.

Each two-track event was fitted to the hypothesis that it was from the reaction given in eq. (1). Since the magnitude of the momentum of the incident neutron and the vector momentum of the recoil nucleus (or its fragments) were unknown, this is a zero-constraint fit. However, the observation of a sharp forward peak of width

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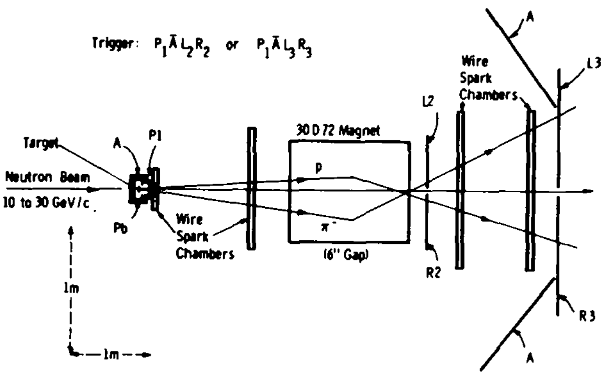

Fig.1. Schematic of experimental arrangement. Note different horizontal and vertical scales.

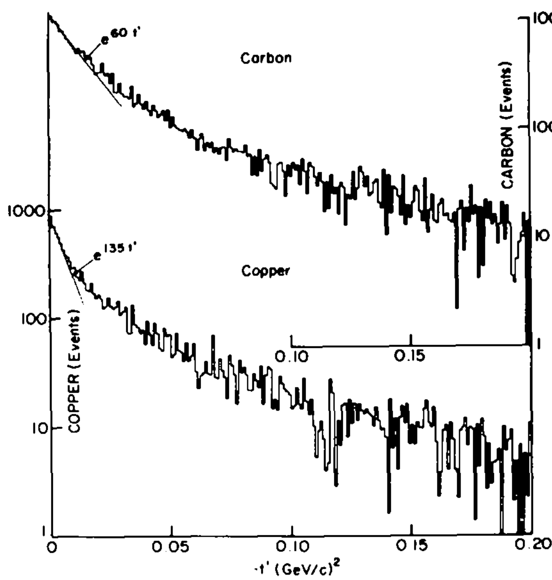

Fig.2. Distribution of events with t' for carbon and copper targets. 'Target-out' background has been subtracted. The straight line is hand-fitted to the data at small t'. Expected values of b are 53 (GeV/c)$^{-2}$ for carbon and 160 (GeV/c)$^{-2}$ for copper.

appropriate to the size of the nucleus shows that the nucleus acted coherently and recoiled in a well-defined state for a large fraction of the events and that the contamination of the sample by processes other than ($p\pi^-$) production is small. Fig. 2 gives the distributions of the events in $t' \equiv (t - t_{min})$ for carbon and copper targets where $t' \approx -p_\perp^2$ and $t_{min} \approx -\frac{1}{4}[(m_{p\pi}^2 - m_n^2)/p_n]^2$. A straight-line extrapolation indicates that incoherent backgrounds under the coherent peak are $\lesssim$ 30%, and that the slopes are about those expected for these nuclei.

The momentum of the incident neutron can be calculated for each event [on the basis of reaction (1)]. Most of the events correspond to neutrons with momentum between 18 and 29.4 GeV/c with a mean momentum of about 22.8 GeV/c.

The ($p\pi^-$) mass distributions obtained with carbon, copper and lead targets are shown in fig.3. The 'target-out' back-ground, typically about 30% of the total sample of events, has been subtracted. The geometric efficiency of the apparatus is also shown. The efficiency, almost independent of t' over the range studied, was determined from a Monte Carlo simulation which used the experimentally observed angular distribution for the decay of the 'N*'. The decay distributions were found to be anisotropic in the N* c.m. system. This makes it difficult to estimate the absolute efficiency of the apparatus accurately since the efficiency varied strongly with decay angle and the angular distribution outside the sensitive region is unknown †.

The mass resolution of the apparatus is typically 10 MeV at 1.2 GeV. This was calibrated by looking at e^+e^- pairs produced from a lead target by the small contamination of high-energy γ-rays in the beam ‡. The most striking result of the experiment is the apparent absence of any of the well-established $I = \frac{1}{2}$ nucleon isobars in the mass distributions ‡‡. This is true for all the nuclei studied over the entire range of four-momentum transfers within the coherent peaks [i.e., $-t' <$ 0.04 (GeV/c)^2 for carbon, $\lesssim$ 0.02 (GeV/c)^2 for copper and $\lesssim$ 0.01 (GeV/c)^2 for lead]. From the carbon data, by assuming a smooth background one can place upper limits on N*(1470) and N*(1688) of approximately 6% and 5%, respectively, of the total sample of events.

The total cross section for coherent dissociation into ($p\pi^-$) systems with masses between 1.08 and 1.50 GeV is estimated at 1.1 mb, 2.5 mb and 3.3 mb for carbon, copper and lead, respectively, with a systematic uncertainty of 20% in the relative cross sections and of 70% in the absolute

† The apparatus is most sensitive to decays in which the π^- goes generally along the beam direction in the N* rest system. Typically the efficiency varies from nearly 100% for pions going forward (0°) to approximately 10% at 90°.

‡ Almost all the γ-rays had energies < 15 GeV. Cutting the data at 20 GeV effectively removed the γ-ray contamination.

‡‡ There have been previous indications of a broad peak at low masses in the Nπ system produced in both pp and πp collisions [1].

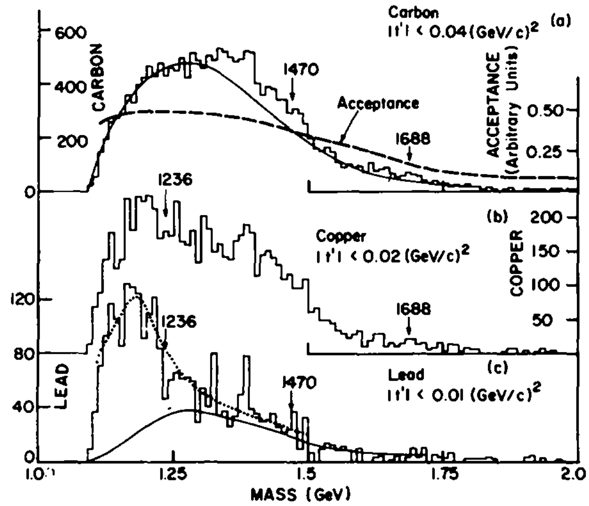

Fig.3. Mass distributions (events per 10 MeV) for the $p\pi^-$ system observed with carbon, copper and lead targets. The efficiency of the apparatus versus mass, shown by the dashed curve in (a), has not been unfolded. The curves in (c) are explained in the text.

cross sections because of the uncertainty in the decay distributions discussed above.

The observed mass spectrum for lead shows a strong peaking at low masses. This can be accounted for by Coulomb dissociation of the neutron into the $\Delta(1236)$. Since the Coulomb production varies as Z^2 it is expected to be small for copper and negligible for carbon [2-4]. The shape of the $\Delta(1236)$ is badly distorted by dynamic factors and the peak is shifted to 1180 MeV. The dotted curve in fig. 3c shows the expected shape for Coulomb production of the $\Delta(1236)$ from lead as calculated from formulas in ref. [4] by using experimental data for pion photoproduction. A non-Coulomb background similar in shape to the carbon data has been assumed as indicated by the light line in fig. 3c. The agreement between the observed and calculated shapes for lead is excellent. About one half of the events from lead are due to Coulomb production, and the observed Coulomb production cross section agrees with that expected to within a factor of two. As expected [2-4], the data for lead for masses < 1.3 GeV (where Coulomb production dominates) show a sharper t' dependence than that for masses > 1.3 GeV (where diffraction dissociation dominates).

It does not seem possible to explain our carbon data in terms of overlapping resonances at 1300, 1470, 1520 and 1690 MeV as suggested by Morrison [5], although a large number of overlapping resonances obviously cannot be ruled out.

Our results are generally consistent with the picture that the diffraction dissociation is dominated by a 'Deck effect' mechanism [6] ‡ in which the incident neutron virtually dissociates into a $(p\pi^-)$ pair and either the proton or pion scatters diffractively off the nucleus. This mechanism produces a broad enhancement of low masses in agreement with our results. The solid curve on fig. 3a is from a Monte Carlo calculation based on such a model [8]. This picture also predicts anisotropic angular distributions in the rest system of the $(p\pi^-)$, again in agreement with the present data. Furthermore the mass distributions for carbon show little change in shape over the momentum range 15 to 29 GeV/c, again in agreement with the broad peak being due to a Deck-effect type of mechanism. (This also proves that the fall-off in the mass spectrum above 1500 MeV is not due to a kinematic effect resulting from the increase of $|t_{min}|$ with increasing mass.)

In summary, Coulomb dissociation has been observed of high-energy neutrons into the $\Delta(1236)$ off a lead target with a cross section about that expected. At neutron momenta of 25 GeV/c the coherent diffraction dissociation off low-Z nuclei proceeds almost solely through non-resonant dissociation with no appreciable production of isospin $\frac{1}{2}$ nucleon resonances.

It is a pleasure to thank Norman Alders for his help in setting up the experiment and Thomas McCorriston for his assistance in measuring the neutron beam intensity.

‡ For a Reggeized version of a Deck-type model applied to a reaction similar to neutron dissociation, and references to more recent papers, see ref. [7].

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