Coherent Pion Dissociation into Three Pions on Nuclear Targets*

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A partial-wave decomposition has been made of the final-state 3π system produced in the reaction $\pi^- + A \rightarrow (\pi^-\pi^-\pi^+) + A$ at 23 GeV/c and for the elements C, Al, Cu, and Ag. For low 3π masses, the 1^+ state is dominant and its t' distribution shows the expected combination of coherent and incoherent components. The t' distribution of the 2^+ A_2 state also requires both coherent and incoherent components.

Coherent dissociation of pions and protons on nuclear targets has been studied in a series of high-statistics experiments by the Northwestern-Carnegie-Mellon-Rochester collaboration.[1] The experiments were performed at the Brookhaven alternating-gradient synchrotron using the Lindenbaum-Ozaki Mark I magnetic spectrometer[2] to analyze the forward dissociated system. This Letter reports on results of a partial-wave analysis, using the University of Illinois scheme,[3,4] of the 3π system produced in the reaction

$$\pi^- + A \rightarrow (\pi^+\pi^-\pi^-) + A \qquad (1)$$

at 23 GeV/c.

In a previous study of 3π and 5π dissociation[5,6] the A dependence of the coherent cross sections was interpreted to yield total cross sections for nucleon scattering of the produced 3π and 5π systems by use of an eikonal model.[6,7] The 3π-nucleon cross sections were found to be approximately the same as for πp scattering and the 5π-nucleon cross sections were also smaller than anticipated. This has led to several new models for the description of absorption of multipion systems in nuclear matter.[8,9]

The present spin and parity analysis shows that the coherent signal is dominated by states with $J^P = 0^-$, 1^+, and 2^- as expected for pure orbital-angular-momentum exchange. Of these, the 1^+ state is the most prominent. The most important new result of this analysis is the evidence found for *coherent* production of the A_2 ($J^P = 2^+$) meson, a reaction which clearly violates this simple exchange rule.

In performing a fit to the data, it is necessary to correct for the system geometrical acceptance. Events used in the analysis include those with either two of three or three of three mesons traversing the magnet, corresponding, under the coherent assumption, to no and one constraint (0C and 1C), respectively. For carbon in the range $M_{3\pi} < 1.4$ GeV, the 1C events have also been analyzed separately. This sample gave the same results as the 0C and 1C samples combined, giving rise to confidence that the acceptances are well understood and that the combined sample can in general be used to improve the statistics. The acceptance calculation has not been corrected for rejection of nuclear-breakup events in the veto box which surrounded the target. However, this only affects the *overall normalization* of the *incoherent* segment of the data but not its spin and parity decomposition.

In order to study the mass dependence of each partial wave, the data were divided into 100-MeV mass bins and into two t' intervals, $0 < t' < 0.05$ (GeV/c)^2 corresponding primarily to coherent data, and $0.05 < t' < 0.3$ (GeV/c)^2 corresponding primarily to incoherent production. The results for carbon, showing the contributions of

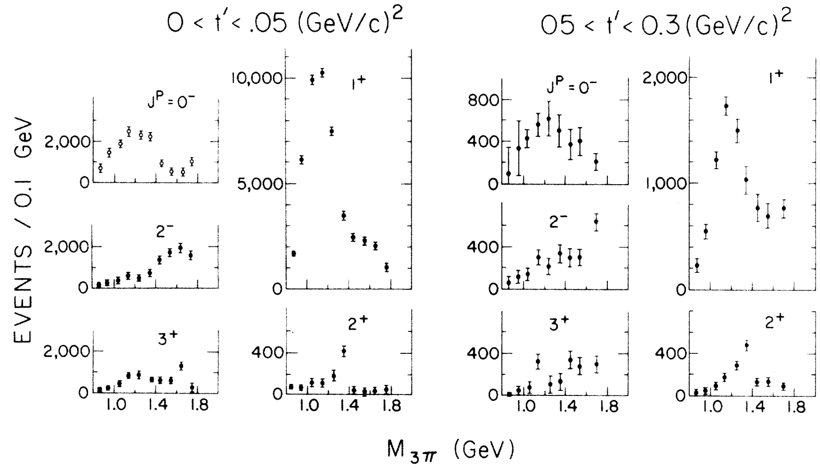

FIG. 1. Spin and parity contributions to 3π states produced in carbon for low t' $[0<t'<0.05\ (\mathrm{GeV}/c)^2]$ and high t' $[0.05<t'<0.3\ (\mathrm{GeV}/c)^2]$. The scale for the $J^P=2^+$, low-t' plot is the same as for the high-t' plots.

the important spin and and parity states, are given in Fig. 1(a) ("coherent") and Fig. 1(b) ("incoherent"). They reveal the same spin and parity states as the hydrogen data.[4,10] In the low-t' group the 1^+ state dominates. However, there is also a significant peak for $J^P=2^+$ in the region of the A_2.

In order to analyze the A_2 region in greater detail the carbon events were divided into 50-MeV mass bins. The 2^+ amplitude obeys a typical Breit-Wigner resonance behavior with the usual mass and width. Further, the 2^+ state is produced predominantly with $|J_z|=1$ in the t channel. Both of these effects are independent of t' and in good agreement with the behavior observed in hydrogen.[10] This gives us confidence that we are observing the same kind of events at both low and high t', and that the large 1^+ background at low t' does not distort the 2^+ state observed. Furthermore, the detailed features of the 2^+ signal remain substantially the same when higher-order partial waves are included in the fit.

The A_2 band, 1.2 to 1.4 GeV, has been reanalyzed in small t' bins and the resultant t' distributions for the 1^+S and 2^+D components are presented in Fig. 2 for the elements carbon, aluminum, copper, and silver. For a given target the 1^+S shows two exponential components, and we have fitted the data with a two-term form, $d\sigma/dt' = Ae^{-\alpha t'}+Be^{-\beta t'}$, where the exponent α is large [60–300 $(\mathrm{GeV}/c)^{-2}$] corresponding to coherent production, and the exponent β is ~10 corresponding to incoherent production. The data for the incoherent component are distorted by the trigger veto for large-t' events as noted above, and therefore the term $Be^{-\beta t'}$ represents only an empirical fit to this region. For the 2^+D the t' distribution is expected to vanish as t' in the forward direction because of the helicity change from $J_z=0$ to $|J_z|=1$ at the meson vertex. Therefore, these data were fitted with the two-term form $d\sigma/dt' = At'e^{-\alpha t'}+Bt'e^{-\beta t'}$, where again the exponent α

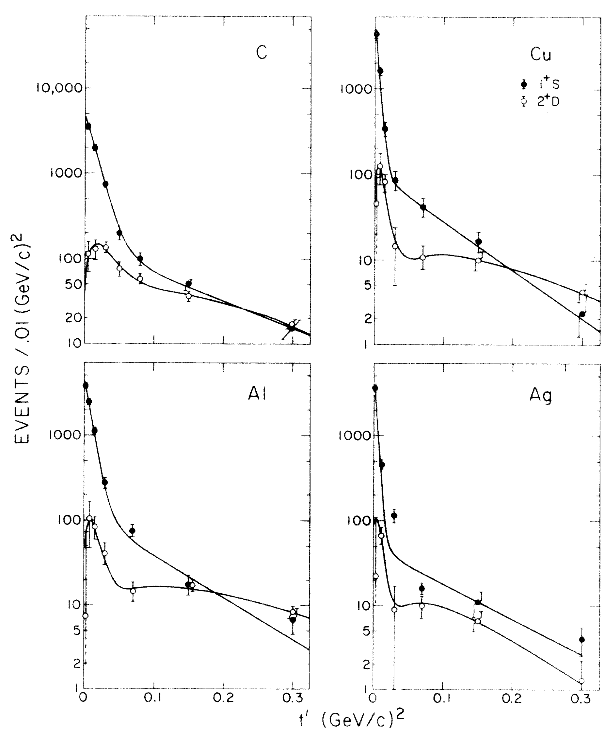

FIG. 2. Distributions in t' for the 1^+S and 2^+D states from C, Al, Cu, and Ag for the mass range $1.2<M_{3\pi}<1.4$ GeV. The curves are the fits described in the text.

TABLE I. Parameters of the coherent component in four-parameter fits to the t' distributions.

Element	1^+S A	1^+S α	2^+D A	2^+D α
C	$(5.1 \pm 0.3) \times 10^5$	73 ± 4	$(2.4 \pm 0.7) \times 10^6$	64 ± 11
Al	$(4.7 \pm 0.4) \times 10^5$	109 ± 8	$(3.1 \pm 1.7) \times 10^6$	118 ± 29
Cu	$(6.7 \pm 0.6) \times 10^5$	227 ± 20	$(5.8 \pm 2.8) \times 10^6$	171 ± 36
Ag	$(5.9 \pm 0.7) \times 10^5$	275 ± 25	$(6.4 \pm 6.5) \times 10^6$	218 ± 105

is large, corresponding to coherent production.

It is clear from the angular distributions that two terms are needed to fit the data for 2^+D. Fits with only a single term $Ct'e^{-\gamma t'}$ gave gave confidence levels smaller than 0.002. The values of A and α (the parameters for the coherent component) found for 1^+S and 2^+D states are given in Table I. The similarity of the values of α found for 1^+S and 2^+D for a given element again reinforces an interpretation of coherent production for the 2^+ state. We conclude that we have definite evidence for both coherent and incoherent production of the 2^+ resonance from nuclear targets.

The ratio of the A coefficients for 2^+D and 1^+S in Table I shows that the coherent 2^+D is an inherently strong signal. This ratio is between 5 and 10 for the four nuclei and is similar to the value 5.7 ± 0.7 found on protons[11] and also seen in the incoherent scattering region in this experiment. The reason that the coherent 2^+D signal represents only a small fraction of the total is that the nuclear form factor restricts coherent production to the forward direction. In this region, the kinematic factor t' associated with the helicity change in 2^+D production suppresses the coherent signal. Apart from this kinematic factor, the 2^+D contribution is large.

Previous experiments have found that the energy dependence for $\pi^-p \to A_2^-p$ is more gradual than expected for the exchange of f or ρ trajectories.[10] This fact and the present observation of coherent A_2 production in nuclear targets are consistent with a picture in which Pomeranchuk exchange dominates A_2 production at high energies.[12] It appears that an important modification of our concept of elastic and inelastic diffractive scattering to include a helicity-flip amplitude as well as the conventional nonflip amplitude is in order. Further measurements to determine the incident-momentum dependence of A_2 production in nuclei will be of great interest and will aid the determination of the relative magnitude of Pomeranchuk and f contributions in this process.

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