Diffractive dissociation $n \rightarrow p\pi^-\pi^0$ induced by 12-GeV/c K^- mesons

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A sample of 198 events, corresponding to a cross section of 110 $\pm$ 15 μb, has been isolated of the baryon-diffractive-dissociation process $n \rightarrow p\pi^-\pi^0$ for three-body masses less than 2.5 GeV/c^2. These dissociations are induced by 12-GeV/c K^- mesons. To isolate this process from background, it is necessary to observe the final-state proton explicitly by its ionization in the bubble chamber. The three-body mass spectrum seems different from that of the $n\pi^+\pi^-$ neutron diffractive breakup. A Δ^0 signal is seen as well as possible N^*_{1470}, but no clear Δ^+ is observed. The angular distribution of the proton in the $p\pi^+\pi^-$ rest frame indicates that a multiperipheral mechanism is present.

I. INTRODUCTION

The three-body dissociation of the proton into $p\pi^+\pi^-$ induced by various beam particles at various energies has been a major topic of study in recent years.[1-6] This process occurs with a substantial cross section and is easily observed in most hydrogen bubble-chamber experiments of beam momentum $\gtrsim 5$ GeV/c. Neutron dissociation into $n\pi^+\pi^-$ has also been studied in deuterium experiments[7,8] as have the two-body baryon-dissociation processes[5] into nucleon-π.

Despite considerable amounts of work, however, the exact nature of the three-body dissociations remains in doubt. The low-mass enhancement which indicates the process is generally thought to consist of a nonresonant part together with N^* signals; these latter are usually agreed to lie in the vicinity of 1.5 and 1.7 GeV/c^2 of nucleon-π-π mass. A chief problem for both the $p\pi^+\pi^-$ and $n\pi^+\pi^-$ final states is the predominance of Δ^{++} signals in the former and Δ^- in the latter. With these strong signals it is difficult to study other structures, such as N^*'s whose decays do not involve Δ's, or Δ^0 and Δ^+ states. There is also the possibility of significant interference effects between the $\Delta\pi$ and other final states.

Using proton and neutron targets there are 24 possible nucleon to nucleon-π-π reactions which might be observed. Six of these can be excited diffractively, i.e., maintaining the electric charge of the initial baryon. The proton to $p\pi^+\pi^-$ is the only one which involves no neutral particles and can be studied in four-constraint (4C) fits. The neutron to $n\pi^+\pi^-$ process and the neutron to $p\pi^-\pi^0$ contain only a single neutral particle, while the others are multineutral processes and cannot be studied with standard apparatus.

The subject of this report is the last of these three possible nucleon to nucleon-π-π reactions which can be produced diffractively and studied in a bubble chamber. It is unique in suppressing via charge conservation the usual strong Δ signals since neither Δ^{++} nor Δ^- is allowed, in having a differently charged baryon in the initial and final states, and in forbidding a σ state ($I=0$, $s=0$) in the dipion system. This dissociation has also been studied with π^+ beams[9,2] of 5.4 and 7 GeV/c, but we know of no studies of it with K beams or with K beams or with beam momentum as high as ours.

Owing to the final-state π^0, these events must be found in a one-constraint-fit category, and at our beam momentum of 12 GeV/c such fits are known to lead to a large background contamination. The first purpose of this report is to detail those procedures used to isolate a reasonably pure sample of the dissociation under consideration, while the second is to present the physics results obtained, especially in comparison with the $n\pi^+\pi^-$ state where results exist from the same exposure.

II. ISOLATION OF $p\pi^-\pi^0$ EVENTS AND CROSS SECTION

The data for this report come from 0.25×10^6 pictures of 12-GeV/c incident K^- in the SLAC 82-in. liquid-deuterium bubble chamber. The three- and four-prong event samples are used and neutron-target events are selected by requiring a spectator proton of momentum less than 0.2 GeV/c or backward in the laboratory frame. The details of the exposure and of this selection procedure were published earlier.[8]

The first step in obtaining a sample is to remove all those events already classified as another final state or observed as having visible neutral decays (vees) inconsistent with γ-ray conversions. In particular, the event samples for the reactions

$$K^-d \rightarrow K^-\pi^+\pi^-d\,, \qquad (1)^{10}$$

$$K^-d \rightarrow K^-\pi^+\pi^-np_s\,, \qquad (2)^{8}$$

and

$$K^-d \to K^-\pi^- p p_s \quad (3)$$

are rejected. Furthermore, as mentioned above, only neutron-target events are considered.

Shown in Fig. 1 is the distribution of the square of the missing mass in the reaction

$$K^-d \to K^-\pi^- p p_s(\mathrm{MM}) \quad (4)$$

for all remaining events, each included twice for the two permutations of π^- and K^- in the negative tracks. Shown either shaded or blackened in the figure are all those combinations belonging to events making the 1C fit

$$K^-d \to K^-\pi^-\pi^0 p p_s \quad (5)$$

with χ^2 probability greater than 2.5%. There is a large enhancement in the region (−1.0)–(+2.0) $(\mathrm{GeV}/c^2)^2$, which corresponds to the fitted event sample. However, this enhancement is primarily background which must be removed by the methods discussed below.

The key to obtaining a clean sample is that for the target-dissociation process under consideration the produced protons are slow in the laboratory and can be identified by ionization. All events for which the momentum of the nonspectator positive track is less than 1.5 GeV/c have been examined and the event retained only if the observed ionization value is consistent with that predicted for a proton. Events where the momentum of this track is greater than 1.5 GeV/c are discarded at this time, and the effects of this cut are seen below.

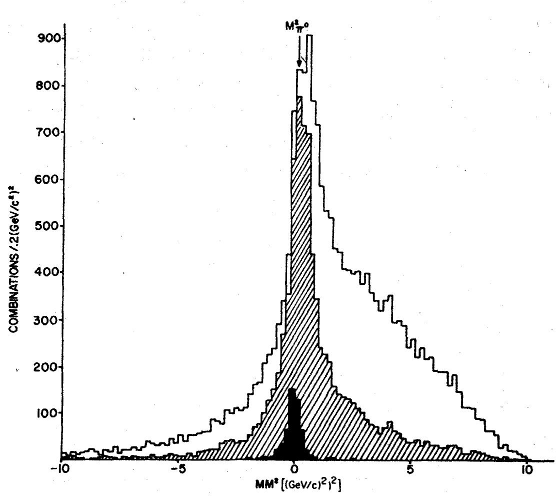

FIG. 1. Distribution of the square of the missing mass of reaction 4 for a large sample of events possibly of reaction 5. The shaded and darkened regions represent those events fitting reaction 5 with probability greater than 2.5%. The darkened region represents the final sample selected. In all cases there are plotted two combinations per event.

Some tracks with momentum < 0.7 GeV/c were looked at by scanners but all of the higher-momentum ones were examined by the author. It should be pointed out that if there is a component of reaction 5 which leads to faster protons, that component is totally lost. It is our intention, however, to isolate a sample of the neutron dissociations in question, and not to study the 1C fit sample per se.

The result of this study was that 60% of the fits were eliminated as not having a slow positive track, and an additional 22% (55% of the remainder) as having ionization inconsistent with the proton hypothesis. The events remaining still evidence considerable background, noticeable particularly in a peak of backward K^- in the overall c.m. frame.

An attempt was made to understand the types of processes having final-state protons which might contribute background to this reaction. To this end the sample of events with observed decays of K^0, Λ, or $\bar{\Lambda}$ were subjected to the same analysis procedure, including ionization determination, as was the normal sample. The result was that a number of these events would have been included were it not for observation of the vee. Extrapolation of this sample to that with vees unobserved due to neutral decay modes, escape before decay, or scan inefficiency led to the conclusion that events with K^0's made up ~50% of the remaining sample of reaction 5. From the events with observed K^0 it was found that all of this contamination could be removed through a cut that the final-state K^- laboratory momentum be >7.5 GeV/c. Through comparison with the dissociation

$$n \to n\pi^+\pi^- \quad (6)$$

subsample of reaction 2, it can be seen that this cut affects 13% of the events, but for $n\pi^+\pi^-$ mass less than 2.5 GeV/c^2, the region in which this dissociation sample is relatively uncontaminated by other processes, only 1% of the events are affected. With this cut the K^- momentum spectra are similar for the $n\pi^+\pi^-$ and $p\pi^-\pi^0$ dissociations.

In a further comparison of the $p\pi^-\pi^0$ production with that of $n\pi^+\pi^-$ the only other indication of contamination is a small forward peak for the π^0 direction in the overall c.m. frame. Whether or not these events represent a background to reaction 5, they certainly do not belong in the neutron dissociation signal and have been removed by the requirement that $\cos\theta_{\mathrm{beam}-\pi^0} < +0.5$, a 2.5% effect in the $n\pi^+\pi^-$ case for mass < 2.5 GeV/c^2.

In summary we have isolated events believed to be of the category $n \to p\pi^-\pi^0$ induced by K^- at 12 GeV/c. The sample includes all neutron-target three- and four-prong events inconsistent with 4C fits, making the 1C fit 5 with probability greater than 0.025, and satisfying the following cuts:

(1) $p_{\text{proton}} < 1.5$ GeV/c and ionization consistent with proton hypothesis,

(2) $p_{K^-} > 7.5$ GeV/c,

(3) $\cos\theta_{\text{beam}-\pi^0}$ in overall c.m. $< +0.5$.

While these cuts eliminate any possibility of studying any features of reaction 5 other than this target dissociation, they have a small and measurable effect on this sample.

The events included are shown as darkened in Fig. 1, the MM^2 plot. They are seen to be centered well at $m_\pi{}^2$, a good indication that multineutral processes are no longer important, and to have a reasonable width compared with that for the π^0 in the reaction

$$K^-p\to K^0\pi^-\pi^0 p,\quad K^0\to\pi^+\pi^- \tag{7}$$

at 14.3 GeV/c.[11]

To obtain a cross section for this reaction the effects of the proton momentum cut must be evaluated. If a similar cut is imposed on the momentum of the final-state neutron for the $n\pi^+\pi^-$ dissociation, 22% of the events are lost, 13% for $n\pi^+\pi^-$ mass less than 2.5 GeV/c^2. The neutron momentum is shown in Fig. 2 normalized in the range of 0 to 1.5 GeV/c to the proton spectrum for the current study. Since these two are the same in the observed region, it is assumed that the cut has the same effect on the proton as on the neutron sample.

We observe 198 events as examples of the dissociation $n\to p\pi^-\pi^0$ with three-body mass less than 2.5 GeV/c^2, corresponding to a cross section of 110 ± 15 μb. Fifteen percent of the event sample selected has mass greater than this value. These events cannot be used for cross-section purposes due to large effects of cuts in this region, but appear otherwise unremarkable and have been included in the physics analysis.

For masses less than 2.5 GeV/c^2 this cross section leads to the ratios

$$\frac{\sigma(n\to p\pi^-\pi^0)}{\sigma(n\to n\pi^+\pi^-)}=0.49\pm0.05$$

and

$$\frac{\sigma(n\to p\pi^-\pi^0)}{\sigma(p\to p\pi^+\pi^-)}=0.79\pm0.06\,,$$

where the $p\to p\pi^+\pi^-$ value is taken from Ref. 6.

III. PHYSICS ANALYSIS

The invariant-mass distribution for $p\pi^-\pi^0$ is shown in Fig. 3. Also included in this figure is the $n\pi^+\pi^-$ mass from the target-dissociation sample of reaction 2 with the restriction that p_{neutron} be less than 1.5 GeV/c. The $p\pi^-\pi^0$ spectrum looks similar to that reported by Morse *et al.*[2] for π^+ induced dissociations. There is some indication of the 1.7-GeV/c^2 enhancement, but no real evidence for the 1.5-GeV/c^2 one. There seems to be a difference between the $p\pi^-\pi^0$ and $n\pi^+\pi^-$ spectra.

The two $p\pi$ submass distributions are shown in Fig. 4. Either of these could show Δ or N^* signals if any were present. The $p\pi^-$ mass shows a clear Δ^0; the $p\pi^0$ distributions seem simply to peak at low mass but have no particular resonances. The mass resolution on the $p\pi^0$ plot is calculated to be ~0.04 GeV/c^2, or slightly less than one bin width. This resolution is not poor enough to obscure a signal as strong as that of the Δ^0, so the Δ^+ is presumed to be absent or somewhat reduced in strength. This is in agreement with results in the $n\pi^+\pi^-$ final state where Δ^+ was absent in the neutron dissociations. The shaded regions of these curves are for low values of mo-

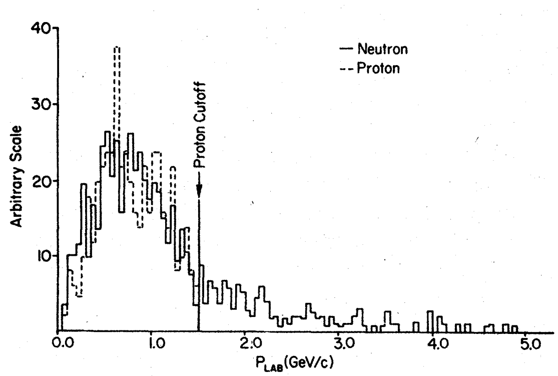

FIG. 2. Laboratory-momentum spectra for neutrons and protons from neutron-target dissociations. The solid curve is for the neutrons of reaction 2; the dashed curve is for the protons of the current experiment up to the cutoff value of 1.5 GeV/c. The curves are normalized to each other below this cutoff.

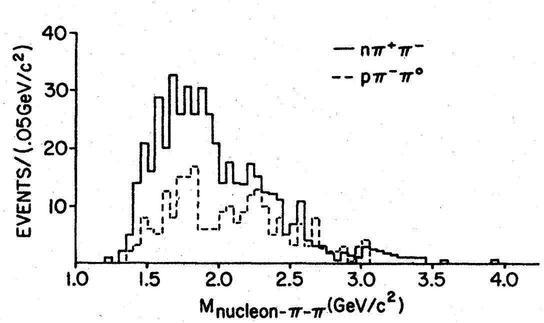

FIG. 3. The $n\pi^+\pi^-$ mass spectrum for the neutron-dissociation subsample of reaction 2, solid curve; the $p\pi^-\pi^0$ mass spectrum for the current experiment, dashed curve. Similar kinematic cuts are imposed on both sets of data.

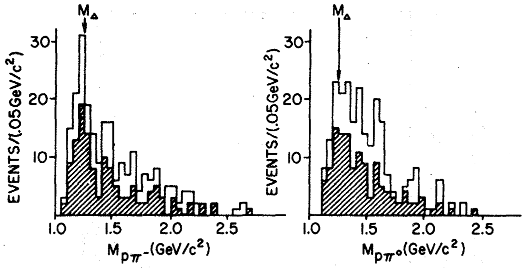

FIG. 4. The $p\pi^-$ and $p\pi^0$ mass spectra for the $p\pi^-\pi^0$ neutron dissociation. A clear Δ^0 signal is present. The shaded region represents those events with a low-momentum transfer from the target neutron to the $p\pi^-\pi^0$ system.

mentum transfer

$$|t_{\text{targ}\to p\pi^-\pi^0}| < .3\ (\text{GeV}/c^2)$$

where signals might be expected to be enhanced. No striking differences are seen.

A comparison of the Δ^0 signal obtained here with the Δ^- of the $n\pi^+\pi^-$ dissociation leads to the ratio

$$\frac{n\to\Delta^0\pi^0\to p\pi^-\pi^0}{n\to\Delta^-\pi^+\to n\pi^-\pi^+}=0.3\pm0.1\,.$$

The large error results from difficulty in determining the backgrounds in the Δ regions. This ratio is in agreement with the value $\frac{2}{9}(0.22)$ expected if the Δ's are produced by pion exchange such as in one leg of a Deck mechanism.

There is also noted in Fig. 4 a peak centered at 1.45 ± 0.02 GeV/c^2 of $p\pi^-$ mass with a width of 0.05–0.1 GeV/c^2. This peak represents a 2.5 standard deviation enhancement above background, although the dip between it and the Δ^0 is only of about 1.5 σ significance. This signal probably represents evidence for N^*_{1470}. The narrow width seen here is in fair agreement with the parameters $M = 1.49\pm0.01$ and $\Gamma = 0.080\pm0.015$ GeV/c^2 reported by Morse *et al.*[2] for a signal seen in π^+n mass. This width of <0.1 GeV/c^2 is narrower than that reported for three-body decays in production experiments and in phase-shift analyses of this region. There is also observed a signal in $p\pi^0$ mass in the vicinity of 1.6 GeV/c^2 with width again in the range of 0.05–0.10 GeV/c^2. This mass and width correspond to no baryon resonances which have been reported. It would be interesting to see whether the effect remains in a higher-statistics experiment similar to this one.

The differential cross section for this reaction is seen in Fig. 5. The momentum transfer distribution from the target to the $p\pi^-\pi^0$ system is fitted in $t'(t-t_{\min})$ over the range 0.0–0.5 (GeV/c)^2 with a slope value of $(3.5\pm0.7)/(\text{GeV}/c)^2$. This is in good agreement with the value 3.9 ± 0.5 in reaction

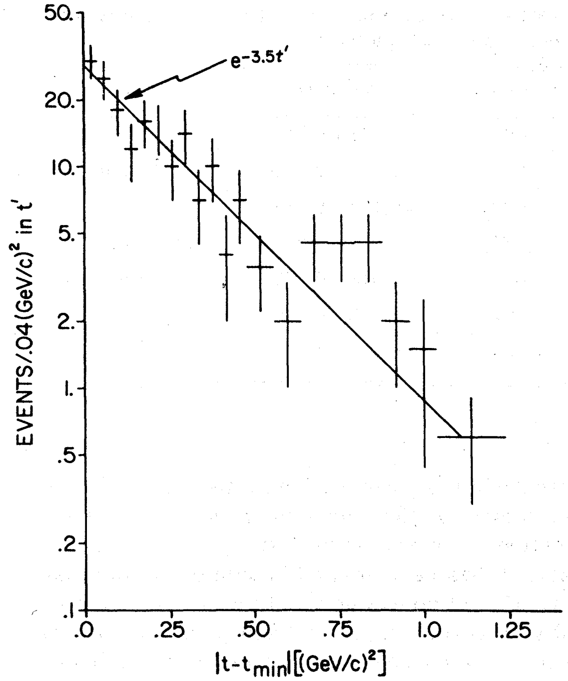

FIG. 5. The differential cross section for neutron to $p\pi^-\pi^0$ dissociations.

2 and with a preliminary value[12] of 3.7 ± 0.3 in the reaction

$$K^+n\to K^+\pi^+\pi^-n \qquad (8)$$

at 12-GeV/c beam momentum for the $n\pi^+\pi^-$ neutron dissociation. In the reaction

$$\pi^+n\to\pi^+\pi^-\pi^0p \qquad (9)$$

at 5.4 GeV/c (Ref. 9) an apparent target-dissociation sample has been isolated with a slope of ~8 ±0.7 in the $p\pi^-\pi^0$ mass range to 1.8 GeV/c^2. The current experiment disagrees with this result as do the $n\pi^+\pi^-$ dissociations induced by K^- and K^+ when calculated in the same mass region. Note that resolution effects are not serious for this quantity since it is determined primarily from measurements of the beam and outgoing K^-.

The moments of the angular distribution of the $p\pi^+\pi^0$ decay plane normal in the Jackson frame are given in Table I. They are in good agreement with the corresponding moments for $n\pi^+\pi^-$ averaged over the target dissociation mass range. The value of $\langle Y_2^0\rangle$ in the current experiment may be more extreme than in the $n\pi^+\pi^-$ case.

An interesting feature of baryon-dissociation angular distributions is that in both the $p\pi^+\pi^-$ and $n\pi^+\pi^-$ breakup of protons and neutrons respectively, the final-state proton (neutron) maintains the direction of the incident proton (neutron) in the

TABLE I. Angular moments of the $p\pi^-\pi^0$ decay plane normal in the Jackson frame.

Moment	Real part	Imaginary part
$\langle Y_1^0 \rangle$	0.037 ± 0.015	...
$\langle Y_1^1 \rangle$	0.002 ± 0.014	-0.009 ± 0.014
$\langle Y_2^0 \rangle$	-0.102 ± 0.016	...
$\langle Y_2^1 \rangle$	-0.017 ± 0.012	0.006 ± 0.012
$\langle Y_2^2 \rangle$	0.018 ± 0.015	-0.001 ± 0.014
$\langle Y_3^0 \rangle$	-0.012 ± 0.016	...
$\langle Y_4^0 \rangle$	0.032 ± 0.017	...

three-body rest frame. This effect leads to large magnitudes for the moments of the angular distribution if the baryon direction is used as analyzer. It has been studied in data of the International K^+ Collaboration[13] and found to be consistent with results expected from pion-nucleon scattering. The current experiment enjoys the unique feature of being able to examine this effect in the case where the final-state baryon (proton) is not identical to the initial-state one (neutron). In Fig. 6 is shown the relevant angular distribution, the cosine of the proton Jackson angle in the $p\pi^-\pi^0$ c.m. frame. This distribution agrees well with that for the final-state neutron in the $n\pi^+\pi^-$ case. The extreme backward direction on this plot corresponds to events with faster protons, and is somewhat depressed by the cut on proton laboratory momentum.

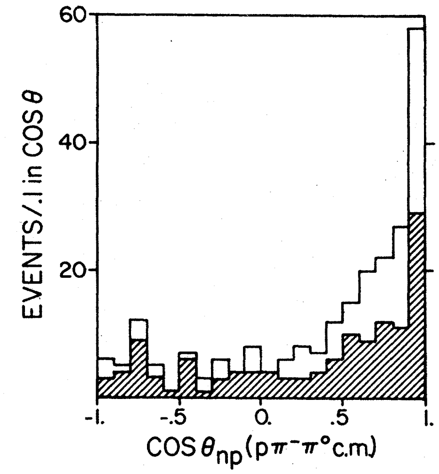

FIG. 6. The angular distribution of the final-state proton with respect to the direction of the initial-state neutron evaluated in the $p\pi^-\pi^0$ c.m. frame. The shaded region represents those events with a low momentum transfer from the target neutron to the $p\pi^-\pi^0$ system.

IV. SUMMARY AND CONCLUSIONS

We have studied the dissociation

$$n \to p\pi^-\pi^0$$

in the 1C-fit reaction

$$K^-d \to K^-\pi^-\pi^0 pp_s$$

at 12 GeV/c. The cuts needed to purify this 1C-fit sample from multineutral and K^0 production backgrounds are seen not to have serious effects on the dissociation under investigation for $p\pi^-\pi^0$ masses less than 2.5 GeV/c^2.

The data evidence a possible enhancement in the vicinity of 1.7 GeV/c^2 of $p\pi^-\pi^0$ mass. A clear Δ^0 signal is seen in the $p\pi^-$ system while there is no comparable Δ^+ in $p\pi^0$. There is also some evidence seen for N^*_{1470} decay into $p\pi^-$. The cross section of 110 ± 15 μb for $p\pi^-\pi^0$ masses less than 2.5 GeV/c^2 is found to be one-half of that for the neutron dissociation into $n\pi^+\pi^-$ in the same region, with results coming from the same exposure. The angular and momentum transfer distributions for the two samples are similar.

The data, with the exception of the 1.7-GeV/c^2 resonance, seem to agree best with a multiperipheral picture, that resonance presumably being produced directly by Pomeron exchange. In particular, the angular distribution of the proton is most easily explained if the protons are thought of as produced in pion-neutron charge-exchange scattering.

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