IS THERE AN $\eta(550)\pi$ RESONANCE AT 980 MeV?*

David J. Crennell, Uri Karshon,† Kwan Wu Lai, John S. O'Neall, and J. Michael Scarr
Department of Physics, Brookhaven National Laboratory, Upton, New York 11973

and

Philip Baumel, Robert M. Lea, Thomas G. Schumann, and Ernest M. Urvater
Department of Physics, City College of the City University of New York, New York, New York

(Received 23 April 1969)

The 980-MeV enhancement in the effective-mass spectrum of the π^-+neutrals is observed in the reaction $K^-n \rightarrow \Lambda\pi^-$neutrals, when the effective mass of the neutrals lies in the $\eta(550)$ region. However, no corresponding enhancement is seen when the η decays by the charged modes. An effect found in the $\rho^0\pi^-$ system from the final state $\Lambda\pi^+\pi^-\pi^-$, when extended to $\Lambda\rho^-\pi^0(\rightarrow\Lambda\pi^-\pi^0\pi^0)$, predicts the observed enhancement in the $\Lambda\pi^-$neutrals final state and accounts for its absence when charged η decays are considered.

Recently an enhancement at 980 MeV, named $\pi_N(980)^-$, has been reported in two reactions: $K^-p \rightarrow \Lambda\pi^+\pi_N(980)^-$ [1] and $K^-n \rightarrow \Lambda\pi_N(980)^-$ [2] where $\pi_N(980)^-$ subsequently decays into "$\eta_N(550)$"π^-. "$\eta_N(550)$" includes two types of events: (1) true $\eta(550)$ events decaying via neutral modes and (2) background events with the effective mass of the missing neutrals in the η region fitted to the hypothesis of the missing $\eta(550)$. The latter are fake $\eta(550)$ events. No evidence has been presented which shows the $\pi_N(980)$ from events with charged η decay.

In this experiment we see a similar strong peak at ~1.0 GeV in the π^-"η_N" mass distribution. However, when the η events with charged decay modes, denoted by $\eta_C(550)$, are examined, no corresponding peak is observed in the $\pi^-\eta_C$ mass spectrum. Therefore, we see no evidence for the $\pi_N(980)^- \rightarrow \pi^-\eta_C$. After careful examination of the $\Lambda\pi^-$neutrals and other related final states, we find an explanation of this anomaly in the final state $\Lambda\rho^-\pi^0 \rightarrow \Lambda\pi^-\pi^0\pi^0$.

The Brookhaven National Laboratory 80-inch bubble chamber filled with liquid deuterium was exposed to a separated beam of 3.9-GeV/c K^- mesons. About 200 000 pictures (yielding ~16 events/μb) were analyzed[3] to yield the following event samples of these reactions:

$$K^-d \rightarrow p_s\Lambda\pi^-\eta_C, \quad \eta_C \rightarrow \pi^-\pi^+(\pi^0 \text{ or } \gamma) \quad (173 \text{ events}), \qquad (1)$$

$$K^-d \rightarrow p_s\Lambda\pi^- + \text{neutrals} \quad (8906 \text{ events}), \qquad (2)$$

$$K^-d \rightarrow p_s\Lambda\pi^+\pi^-\pi^- \quad (2740 \text{ events}), \qquad (3)$$

$$K^-d \rightarrow p_s\Lambda\pi^0\pi^+\pi^-\pi^- \quad (2771 \text{ events}). \qquad (4)$$

Here p_s denotes a spectator proton of momentum less than 250 MeV/c.

Since we are interested in the final state $\Lambda\pi^-\eta$, it is important to make the best possible selection of η events. For η_C events in Reaction (1) we estimate the contamination from the $\pi^+\pi^-\pi^0$ background to be less than 20%. The loss of η_C events due to a low laboratory momentum for the π^0 or γ is estimated to be about 15%; this loss does not bias the subsequent analysis. The "η_N" events from Reaction (2) pose a greater problem. Figure 1(b) shows the missing-mass-squared distribution for this reaction, with those events with a visible spectator (and hence better resolution) shaded. Figure 1(a) shows the same distribution for Reaction (1) when the η_C is treated as a missing particle of unknown mass. From this plot we estimate the η to be centered at 0.31 GeV^2 with experimental full width 0.18 GeV^2. This selection of missing-mass-squared, indicated in Fig. 1(b), will be called the η region.

Events of Reaction (2) in the η region were fitted to the reaction $K^-n \rightarrow \Lambda\pi^-\eta$. The π^-"η_N" mass distribution from these fits and the $\pi^-\eta_C$ mass distribution from Reaction (1) are shown in Figs. 1(d) and 1(c), respectively. The curve in Fig. 1(c) is the two-body phase space distribution normalized to the whole plot. It is seen to fit the $\pi^-\eta_C$ distribution well. This curve, after being corrected for the known neutral-to-charged decay rate of the η, the loss of events in the tails of the η, and the differing analysis losses,[4] is replotted in Fig. 1(d). It describes the shape badly. In particular we note the sharp significant peaks at ~980 and ~1270 MeV. It is clear, as we expected from an examination of the η signal in Fig. 1(b), that a large amount of background has been included with the "η_N" selection. This background must account for the excess of events above the solid curve in Fig. 1(d).

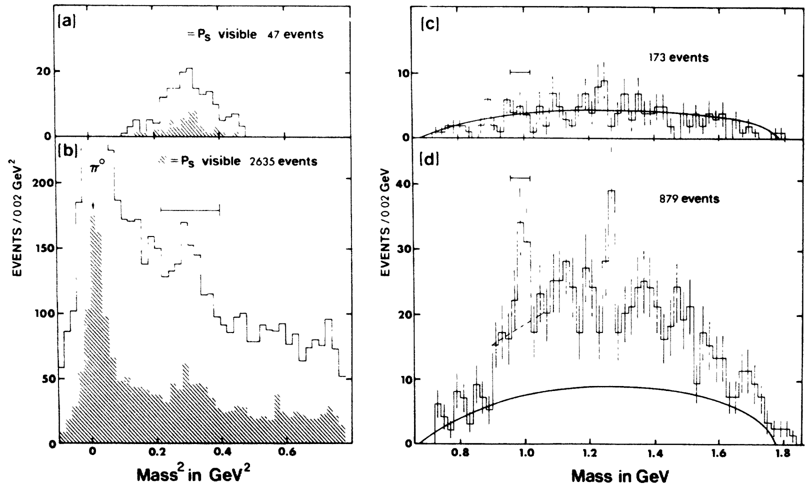

FIG. 1. (a) Mass-squared distribution for $\pi^+\pi^-(\pi^0$ or $\gamma)$ from Reaction (1) calculated from measured quantities. (b) Mass-squared distribution for neutral(s) from Reaction (2). The horizontal bracket indicates the region of η selection. (c) Mass distribution of $\pi^-\eta_C$, $M(\pi^-\eta_C)$, from Reaction (1). The curve is normalized two-body phase space (see text for details). (d) Mass distribution of π^-"η_N," $M(\pi^-$"η_N"), from Reaction (2), selected in the η region and refitted to "η_N" as described in the text. The curve is obtained from that of (c) corrected and normalized as described in the text. The dotted line is an estimation of the background under the "π_N" mass region.

If it is not from real η events, what causes the 1-GeV peak in the π^-"η_N" spectrum? All possible causes with the exception of the $\Lambda\pi^-\pi^0\pi^0$ final state can be eliminated in our data.[5]

The charged counterpart of the final state $\Lambda\pi^-\pi^0\pi^0$ is $\Lambda\pi^+\pi^-\pi^-$ [Reaction (3)]. We draw a correspondence between the $\pi^0\pi^0$ and $\pi^-\pi^-$ combinations, since the same symmetry properties are required for these two-boson states. Then the appropriate mass cut corresponding to the η region in Fig. 1(b) is a selection of the $\pi^-\pi^-$ effective mass in the range 0.47-0.63 GeV, which we refer to as "η^{--}", although it does not correspond to any known or predicted two-boson resonance. The $\pi^+\pi^-\pi^-$ effective mass from Reaction (3) with the "η^{--}" selection on the $\pi^-\pi^-$ mass is shown in Fig. 2(b). Strong enhancements are observed at ~1.0 GeV and in the "A_2" region (1.27 GeV), just as in the π^-"η_N" mass spectrum [Fig. 1(d)]. The strengths of these 1-GeV effects are similar and we shall return to this point later. This $\pi^+\pi^-\pi^-$ effect is associated only with the "η^{--}" selection; this is illustrated in Figs. 2(a) and 2(c) which show the $\pi^+\pi^-\pi^-$ effective mass spectra with selections of the $\pi^-\pi^-$ mass in regions adjacent to the "η^{--}", namely below "η^{--}" [$0.15<M^2(\pi^-\pi^-)<0.22$ GeV²] and above "η^{--}" [$0.4<M^2(\pi^-\pi^-)<0.5$ GeV²].

In order to investigate the source of the ~1-GeV $\pi^+\pi^-\pi^-$ enhancement [Fig. 2(b)], we examine the Dalitz plot for the $\pi^+\pi^-\pi^-$ system in the "π_N" enhancement region.[6] The mass-squared

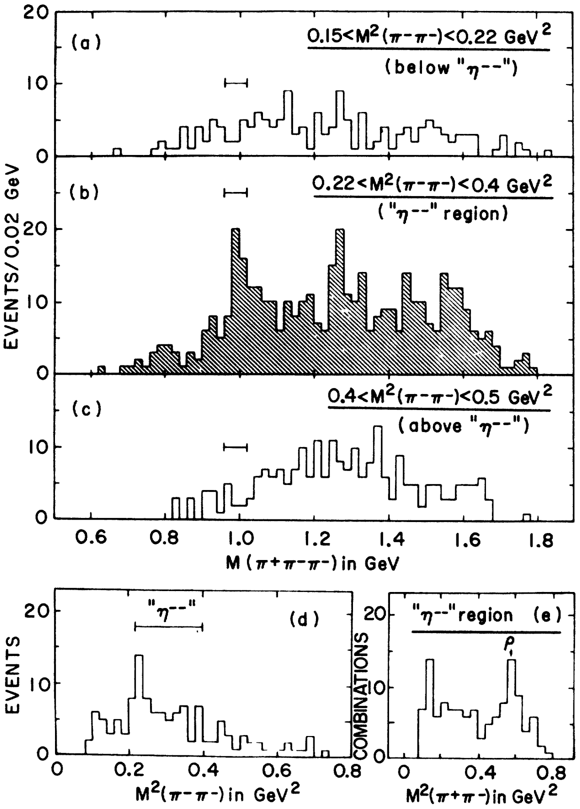

FIG. 2. (a)-(c) $\pi^+\pi^-\pi^-$ mass distributions from Reaction (3) for selected $\pi^-\pi^-$ mass regions as shown. Di-pion mass-squared distributions for events in the "π_N" mass region (see Ref. 6 for details) are shown in (d) and in (e) with an additional selection on $\pi^-\pi^-$ mass as indicated.

projection of the $\pi^-\pi^-$ is shown in Fig. 2(d); a clear enhancement is seen in the “η^{--}” region as indicated. Fig. 2(e) is the $\pi^+\pi^-$ mass-squared distribution (two combinations for each event) for events with the $\pi^-\pi^-$ mass in the “η^{--}”. A marked ρ^0 signal is evident, and the excess in the low di-pion-mass region is due to the other $\pi^-\pi^+$ combination from ρ^0 events. We estimate that about 70% of the “π_N” $\rightarrow \pi^+\pi^-\pi^-$ events in the “η^{--}” region come from the process $\rho^0\pi^- \rightarrow \pi^+\pi^-\pi^-$. The total $\rho^0\pi^-$ mass spectrum is shown, for events with no $\Sigma(1385)$, in Fig. 2(a) of Crennell et al.,[7] and a broad enhancement at 1.1 GeV is seen.[8] From isospin invariance, we expect the ratio of the cross sections $(\Lambda\rho^-\pi^0 \rightarrow \Lambda\pi_\rho{}^-\pi_\rho{}^0\pi^0)/(\Lambda\rho^0\pi^- \rightarrow \Lambda\pi_\rho{}^+\pi_\rho{}^-\pi^-)$ to be 1. In view of this, it is not surprising that the “η” selection of the $\pi_\rho{}^0\pi^0$ (or $\pi_\rho{}^-\pi^-$) produces a $\rho^-\pi^0$ (or $\rho^0\pi^-$) peak at ~1.0 GeV.[9] The decay angular distributions (not shown) for the π^+“η^{--}” and π^-“η_N” events in the “π_N” mass region from this experiment are similar and essentially isotropic like those of Ref. 2. Both production distributions are peripheral and again are similar to those of Ref. 2. This further substantiates that the two processes are similar, so that the $\pi_N(980)$ enhancement observed in the π^-“η_N” mass spectrum arises from $\rho^-\pi^0$ events and not $\eta(550)\pi^-$ events. The same argument can also be applied to the peak near the “A_2” mass region (1.27 GeV)[10] from the π^-“η_N” mass spectrum [see Fig. 1(d)], although there may be some real $\eta\pi$ decay. Hence it will complicate any estimate of the $\eta\pi/\rho\pi$ branching ratio for the “A_2” based on neutral decays of the η.

In addition, we comment on the observation of the $\pi_N(980)^-$ in the reaction $K^-p \rightarrow \Lambda\pi^+\pi^-$“$\eta_N$”.[1] In analogy with the previous case, we consider the reaction $K^-n \rightarrow \Lambda\pi^0\pi^+\pi^-\pi^-$, where, again for reasons of symmetrization, we take the $\pi^-\pi^-$ mass in the “η^{--}”. We now define the “η^{--}” mass as being 0.5-0.6 GeV in order to duplicate exactly the selection of Ref. 1. The resulting $\pi^+\pi^-\pi^-$ mass distribution is shown in Fig. 3(b). Again a peak appears near 1.0 GeV, and closely resembles the corresponding distribution shown in Fig. 3(a) from Ref. 1.[11] However a detailed comparison may not be possible since the experiments are at two different energies.

In summary we have found no evidence for an $\eta(550)\pi$ resonance at ~980 MeV; the $\pi_N(980)^-$ enhancement observed in the $\Lambda\pi^-$“η_N” final state is well explained by the $\rho^-\pi^0(\rightarrow\pi^-\pi^0\pi^0)$ enhancement in the 1-GeV region. Our result does not apply either to the $\pi_N(980)^-$ observed by other means such as by inference from isospin-one $(K\bar{K})$ scattering lengths near threshold, or to the narrow $\delta(960)$ effect.[12]

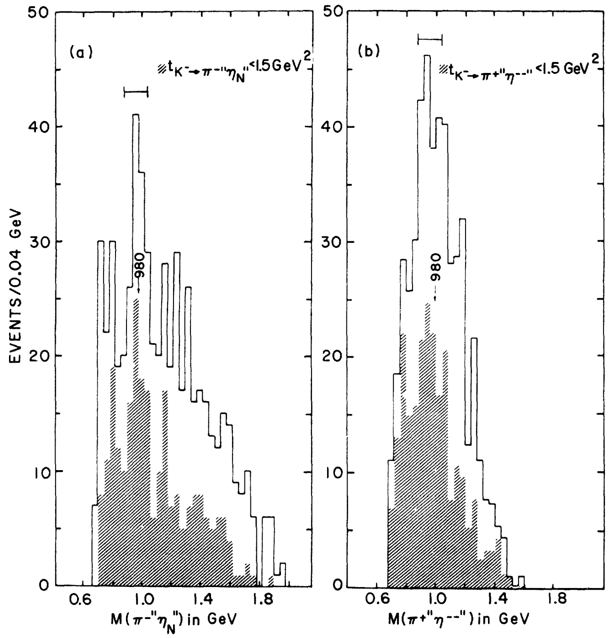

FIG. 3. (a) Mass distribution of π^-“η_N” (“η_N” defined by $0.5 <$ “η_N” < 0.6 GeV) from 5.5-GeV/c $K^-p \rightarrow \Lambda\pi^-\pi^+$“$\eta_N$” (Ammar et al., Ref. 1). (b) Mass distribution of π^+“η^{--}” (“η^{--}” defined by $0.5 < M(\pi^-\pi^-) < 0.6$ GeV) from 3.9-GeV/c $K^-n \rightarrow \Lambda\pi^0\pi^+\pi^-\pi^-$ (this experiment).

We are indebted to our scanning and data-reduction personnel for their contribution to the experiment. It is our pleasure to thank Dr. Ralph P. Shutt for his continued interest and encouragement throughout the experiment.

---

*Work performed under the auspices of the U. S. Atomic Energy Commission. The work at City College was partially supported by the National Science Foundation.

†On leave of absence from the Weizmann Institute of Science, Rehovoth, Israel.

[1] R. Ammar, R. Davis, W. Kropac, J. Mott, D. Slate, B. Werner, M. Derrick, T. Fields, and F. Schweingruber, Phys. Rev. Letters 21, 1832 (1968). We thank Dr. R. Ammar for permission to show Fig. 1(a) in our Fig. 3(a).

[2] D. H. Miller et al., Purdue University Report No. COO-1428-110. See also J. H. Campbell et al., Phys. Rev. Letters 22, 1204 (1969).

[3] The pictures were scanned for events with one neutral V and an odd number of outgoing primary tracks (except for a possible visible spectator proton with track length less than 6 cm). These events were mea-

sured with the Brookhaven flying spot digitizer and analyzed with the Brookhaven QLOD system of programs. The selection on competing hypotheses was made from a fit to the measured ionization and the usual chi-square value from the kinematic fit. Events for which there were insufficient or no measurements of ionization available were examined visually. Spectator protons with insufficient energy to leave a visible track were assumed to have momentum components 0 ± 50 MeV/c for the purposes of fitting and for calculations of missing mass.

[4] The charged-to-neutral decay ratio for the η is 0.29:0.71. This rate is corrected for the 15% loss of neutrally decaying η's which are outside the "η_N" region, giving a ratio of 0.33:0.67 for the rates of η_C to η_N which we expect to see in our data. Since the η_C events have more tracks measured, their failure rate in the analysis programs is slightly greater (by ~1%). This makes an insignificant change in the above ratio.

[5] We have considered and eliminated the following possible causes: (1) It is not a reflection of the $\Sigma(1385)^-$ in the $\Sigma(1385)^-$"η_N" final state since the effect remains with equal strength when events showing $\Sigma(1385)^-$ are removed. (2) It is not due to the tail of the π^0 peak in Fig. 1(b) contaminating the "η_N" sample since we estimate this at less than 15 events in the whole π^-"η_N" effective mass spectrum. (3) The final state $\Sigma^0\pi^0\pi^-$ will appear in Reaction (2). From the similar final state $\Sigma^-\pi^+\pi^-$ we find predominant $Y_0^*(1520)\pi^-$ and some $\Sigma^-\rho^0$ production, and predict that from the decay $Y_0^*(1520) \to \Sigma^0\pi^0$ there will be essentially no events with the missing mass $(\pi^0\gamma)$ in the η region. From Monte Carlo calculations on the $\Sigma^0\rho$ final state, by selecting events with $\pi^0\gamma$ mass lying in the η region, we find a 300-MeV-broad distribution centered at 1 GeV consisting of about 40 events. This is much too wide to account for the effect in question. (4) From the Σ^0-$\pi^+\pi^-\pi^-$ final state we estimate that there will be about 70 events from the reaction $\Sigma^0\pi^-\pi^0\pi^0$ which appear in Reaction (2) with missing mass in the "η_N." These events populate the π^-"η_N"spectrum uniformly with ~6 events in the "π_N"region. (5) The $\pi^0\pi^0\pi^0$ spectrum from the $\Lambda\pi^-\pi^0\pi^0\pi^0$ final state is limited by phase space in the η region so that contributions from it are negligible.

[6] The region from 980 to 1060 MeV is taken as the "π_N" region. Although the enhancement in Fig. 1(d) peaks below 1000 MeV, the center was at 1020 MeV before the events were kinematically constrained to the η mass.

[7] See D. J. Crennell et al., Phys. Rev. Letters 22, 1327 (1969).

[8] Inclusion of events showing $\Sigma(1385)$ production does not materially change the shape of the distribution in the 1 GeV region.

[9] Although the total $\rho^0\pi^-$ mass spectrum shows a broad enhancement at 1.06 GeV, the "η^{--}" effective-mass selection creates a narrower peak shifted towards 1.0 GeV.

[10] From Figs. 2(a)-2(c) we find that in the Dalitz plot of the "A_2"$\to\pi^+\pi^-\pi^-$ region the "η^{--}" area is populated more densely than the adjacent $\pi^-\pi^-$ regions.

[11] All the other figures of Ref. 1 compare well with our data from Reaction (4).

[12] For a review see B. French, in Proceedings of the Fourteenth International Conference on High Energy Physics, Vienna, Austria, September, 1968 (CERN Scientific Information Service, Geneva, Switzerland, 1968), p. 104.

COMPARISON OF PHASE-SHIFT ANALYSIS SOLUTIONS TO π^-p SCATTERING DATA*

A. D. Brody, D. W. G. S. Leith, B. G. Levi, and B. C. Shen
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

and

D. Herndon, R. Longacre, L. Price, A. H. Rosenfeld, and P. Söding†
Lawrence Radiation Laboratory, University of California, Berkeley, California 94720

(Received 28 April 1969)

A comparison between the π^-p scattering data and the predictions of the various phase-shift analyses is presented. In particular, it is pointed out that the dispersion relation fit of the CERN group fails to represent the data.

In the past few years, several experiments making precise determinations of the $\pi^\pm p$ elastic differential cross section[1-5] and proton polarization,[6-11] over wide energy regions, have made possible extensive phase-shift analyses.[12-18] The results of these analyses have led to substantial progress in the understanding of pion-nucleon scattering. One of the features of these studies was the discovery, in different partial waves, of several resonances which could not be readily identified as peaks in total cross sections.[13-15] A notable example of this is the so-called "third pion-nucleon resonance" at 1688 MeV, which was shown to include resonant states in S_{31}, D_{15}, F_{15}, and possibly other partial waves. More recently, by using partial-wave dispersion relations to pro-