BOSON RESONANCE OF MASS 980 MeV DECAYING INTO $\pi^-\eta$*

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An enhancement has been observed in the $\pi^-\eta$ system at mass 980 ± 10 MeV with width 80 ± 30 MeV. This boson state, denoted by $\pi_N(980)$, yields a decay angular distribution having about 10% probability for isotropy. It is produced peripherally in the reaction $K^- + p \to Y_1^{*+}(1385) + \pi_N^-(980)$ at 5.5 GeV/c.

We present here the results of a search for a charged meson produced in K^-p interactions at 5.5 GeV/c and decaying via the $\pi\eta$ mode. These data were obtained from the analysis of a 7-event/μb exposure in the 30-in. hydrogen bubble chamber at the Argonne zero-gradient synchrotron. Details on the exposure and analysis have already been presented.[1,2]

There were ~8500 events with two outgoing charged tracks and an observed decaying neutral (two-prong + V) in which the neutral particle was fitted as a Λ originating from the production vertex. Of these, 571 fit the hypothesis

$$K^- + p \to \Lambda + \pi^+ + \pi^- + \eta \qquad (1)$$

with the mass of the missing neutral within ±50 MeV of the η mass,[3] a figure dictated by our mass resolution. The number of genuine missing η events in the two-prong + V topology may be estimated from the η peak seen in the missing-mass distribution for all 8500 events[2] as well as from events in which the η decays via the charged mode.[4] More than 80% of the genuine missing η events pass the missing-mass selection as was verified directly using a subset of our data, namely ΛX^0 events in which the X^0 decays into $\pi^+\pi^-\eta$ and the η decays neutrally, a final state for which there is a rather clean signal in this experiment.[2,5] In this manner we estimate that about 50% of the 571 events in this sample represent genuine η events, with the remainder being spurious fits consisting primarily of events with more than one missing π^0. Preliminary results based on this data have already been presented.[6]

The $\pi^-\eta$ invariant-mass distribution for the above 571 events is shown in Fig. 1(a). An enhancement is apparent at ~1 GeV. The shaded area shows the effect of selecting events in which the $\pi^-\eta$ system was peripherally produced. In this case the enhancement appears to stand out more clearly above the background. In addition, a second enhancement is apparent at ~790 MeV. However, this is a reflection of the decay $X^0 \to \pi^+ + \pi^- + \eta$. Both the $\pi^-\eta$ and $\pi^+\eta$ invariant-mass distributions are fed from this decay, so that a similar enhancement is also produced in the $\pi^+\eta$ invariant-mass distribution of Fig. 1(b). Both the $\pi^+\eta$ and $\pi^-\eta$ enhancements near 790 MeV disappear if one removes events representing X^0.

Strong evidence for the $\pi\eta$ enhancement at ~1 GeV does not appear to be present in the positively charged state as is evident in Fig. 1(b), particularly for the peripheral selection. This is consistent with the expectations of the one-meson-exchange model as it would require the exchange of a doubly charged meson.

The mass and width of the observed peak are 980 ± 10 MeV and 80 ± 30 MeV, respectively. The quoted width has been corrected for our experimental mass resolution, which has a full width at half-maximum of ~40 MeV. The strong decay into $\pi\eta$ establishes that the spin and parity belong to the series $0^+, 1^-, 2^+, \cdots$ and that the G parity is -1. This decay mode also establishes that its isospin is 1 and that, therefore, the charge-conjugation quantum number of the neutral member is $C = +1$. For the remainder of this paper we will refer to this state as $\pi_N(980)$.

Strong production of $Y_1^{*+}(1385)$ is present in Reaction (1). To see if the observed $\pi_N(980)$ signal was produced in a quasi-two-body reaction with this Y^*, we studied the process

$$K^- + p \to Y_1^{*+}(1385) + \pi^- + \eta. \qquad (2)$$

A Dalitz plot for this final state is shown in Fig. 1(c), where evidence for $\pi_N^-(980)$ production may be seen. This is particularly clear in Fig. 1(d), which shows the projection of the Dalitz plot onto the axis representing the square of the

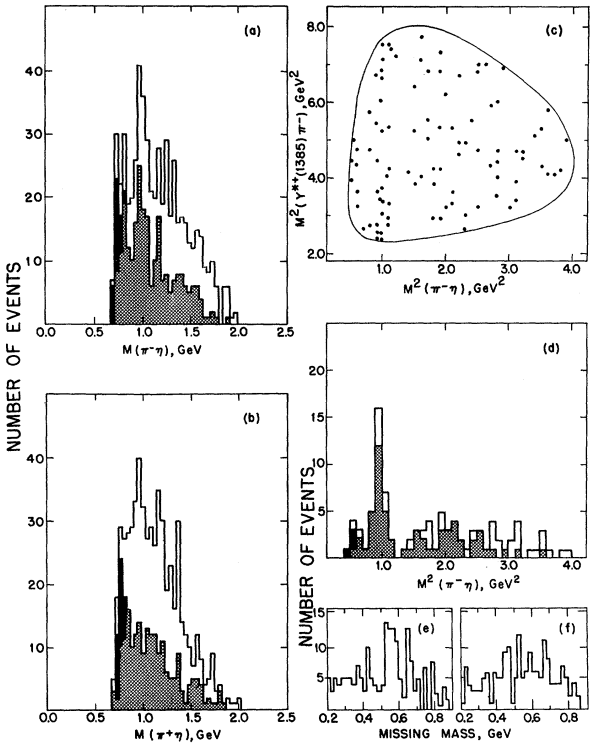

FIG. 1. (a) The $\pi^-\eta$ invariant-mass distribution for 571 events fitting Reaction (1), in which the η is a missing neutral with a missing mass within ±50 MeV of the η mass. There were 274 events which had the square of the four-momentum transfer to the $\pi^-\eta$ system $\Delta^2(\pi^-\eta) \leq 1.5$ $(\mathrm{GeV}/c)^2$, and they are shown cross-hatched. Of these latter events, 31 represent the decay $X^0 \to \pi^+ + \pi^- + \eta$ and are shown completely blackened. (b) The $\pi^+\eta$ invariant-mass distribution for the same events as in (a) and with similar cuts. There were 231 events with $\Delta^2(\pi^+\eta) \leq 1.5$ $(\mathrm{GeV}/c)^2$. (c) Dalitz plot of the three-body final state for 96 events representing Reaction (2). The Y_1^* was selected to have a $\Lambda\pi^+$ invariant mass between 1335 and 1435 MeV. (d) Projection of the Dalitz plot of (c) onto the axis representing the square of the $\pi^-\eta$ invariant mass. The cross hatched and blackened areas have the same significance as in (a) and (b). (e) Mass of the missing neutral, M^0, for a subset of the 8500 two-prong + V events interpreted as Reaction (3), and having a squared four-momentum transfer to the π^-M^0 system $\Delta^2(\pi^-M^0) \leq 1.5$ $(\mathrm{GeV}/c)^2$. The π^-M^0 invariant mass was selected to lie between 940 and 1040 MeV. (f) Similar to (e) except that the π^-M^0 invariant mass was selected to lie between either 890 and 940 MeV or between 1040 and 1090 MeV. All plots in this figure, except (e) and (f), are made using quantities kinematically fitted to Reaction (1).

$\pi^-\eta$ invariant mass. There are a total of about 20 events above background for the $\pi_N(980)$ in this plot as compared with ~40 events in Fig. 1(a), where there was no Y^* selection.

The $\pi_N(980)$ signal, which is prominent in Fig. 1(d), is completely absent when we select the mass of the missing neutral to lie in a control region on either side of the η mass band. This supports the hypothesis that we are observing a genuine $\pi\eta$ decay mode for the $\pi_N(980)$. Additional support for this comes from a study of the mass distribution of the missing neutral, M^0, for a subset of the 8500 two-prong + V events interpreted as

$$K^- + p \to \Lambda + \pi^+ + \pi^- + M^0 \qquad (3)$$

and selected to have a low four-momentum transfer to the π^-M^0 system. When one chooses events having a π^-M^0 invariant mass appropriate to the $\pi_N^-(980)$, a clear missing-η signal is apparent as in Fig. 1(e). By comparison, events selected from a control region immediately outside the $\pi_N^-(980)$ mass band do not show such a signal as is evident from Fig. 1(f). Independent evidence bearing on the $\pi\eta$ decay mode may be obtained from events in which the η decays into $\pi^+\pi^-\pi^0$,[4] and is consistent with our results based on the neutral decay of the η.

Figure 2(a) presents a Chew-Low plot for the $\pi^-\eta$ system for those events with a $Y_1^{*+}(1385)$. There is a marked clustering of events with low four-momentum transfer in the mass region of the $\pi_N(980)$ corresponding to a forward peak in the production angular distribution of the meson system, suggesting production by the exchange of a single boson.

The decay of the $\pi_N^-(980)$ has been investigated in terms of the angles θ and ψ which are the usual polar and azimuthal angles of the decay pion in the $\pi_N(980)$ rest system, the z axis being taken as the direction of the incident K^- and the y axis as the direction of the normal to the production plane. Figures 2(b) and 2(c) show the distributions in $\cos\theta$ and ψ for the peripheral $\pi_N^-(980)$ events shaded in Fig. 1(a). We also investigated the decay of those $\pi_N^-(980)$ produced in association with $Y_1^{*+}(1385)$, where the signal-to-noise ratio is particularly good. The decay angular distributions for these events are given in Figs. 2(d) and 2(e). The probability that these $\cos\theta$ distributions are consistent with isotropy is ~10%. Thus although a spin and parity of 0^+ does not appear to be favored, it cannot be ruled out.

If the $\pi_N(980)$ is a scalar meson, then the exchange of a vector meson is forbidden by the conservation of angular momentum and parity. If the exchanged particle is a pseudoscalar meson, then in the reaction $K^- + p \to Y_1^{*+}(1385) + \pi_N^-(980)$,

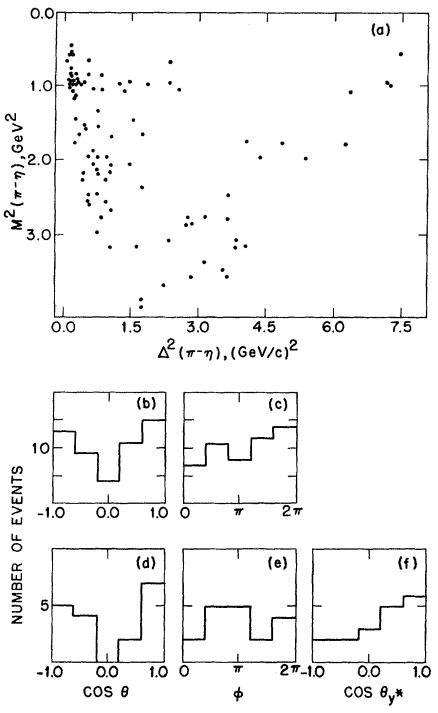

FIG. 2. (a) Chew-Low plot showing $\Delta^2(\pi^-\eta)$, the square of the four-momentum transfer to the $\pi^-\eta$ system versus $M^2(\pi^-\eta)$, the square of the invariant mass of the system for the 96 events shown in Fig. 1(c). (b), (c) Decay angular distributions for 52 events having a $\pi^-\eta$ invariant mass between 940 and 1040 MeV, selected from the peripherally produced events of Fig. 1(a). The angles θ and ψ are the usual polar and azimuthal angles of the decay pion with respect to the incident K^- direction as measured in the rest frame of the resonance. (d), (e) Same as (b) and (c) except that in addition events were required to have a $\Lambda\pi^+$ invariant mass between 1335 and 1435 MeV. There were 18 such events. (h) Distribution of the corresponding polar angle in the decay $Y_1^{*+}(1385) \to \Lambda + \pi^+$ for the same events as in (d) and (e). All plots in this figure are made using quantities kinematically fitted to Reaction (1).

the Y^* is produced in an aligned state having only the helicity states $\pm\frac{1}{2}$ of the incident proton. As a result, the decay angular distribution of the Y^* would be of the form $1+3\cos^2\theta_{Y^*}$, where θ_{Y^*} is the usual polar angle of the decay pion with respect to the incident-proton direction as measured in the rest system of the Y^*. The observed angular distribution, shown in Fig. 2(f), is inconclusive at the present statistical level.

The present investigation has been confined mainly to events fitting Reaction (1), but we have studied several other kinds of fits in order to investigate the possibility of alternate explanations of the $\pi^-\eta$ enhancement. In particular the background reaction $K^- + p \to \Lambda + K^+ + \pi^- + \bar{K}^0$, with the $\bar{K}^0$ undetected and with a strong $K^{*-}(890)$ signal, may produce spurious peaks in the $\pi^-\eta$ mass distribution when interpreted as Reaction (1). However in the cases of interest the positive track has low momentum, and the event is quite sensitive to the π^+/K^+ interpretation. Our studies indicated that this reaction and other similar ones, including those induced by the $\lesssim$5% pion contamination of the beam, do not pose a serious problem.

We are now making a search for other decay modes of the $\pi_N(980)$. Such information seems essential for understanding the complex mass spectrum near 1 GeV. There are several nonstrange mesons reported in this mass region, and in particular there are two charged mesons with a mass close to that observed in the present experiment, namely, the $\delta(962)$[7,8] and the $\pi_N(1016)$.[9] Very little is known about the decay modes of the $\delta(962)$. However, on the basis of the measured mass and width, it appears unlikely that the present enhancement should be identified with the $\delta(962)$. The measured mass and width of the $\pi_N(1016)$ also appear to be inconsistent with our values for the $\pi_N(980)$. However, the $\pi_N(1016)$ has been observed primarily as an enhancement in the $K\bar{K}$ system, and may represent a state below the $K\bar{K}$ threshold with a $\pi\eta$ decay mode.[10]

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PRODUCTION OF THE $N^*(1470)$ IN $pd \to p_S pp\pi^-$ AT 7.0 GeV/c

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We see a significant peak ($M = 1.446 \pm 0.011$ GeV, $\Gamma = 198 \pm 40$ MeV), consistent with a $I = \frac{1}{2}, J = \frac{1}{2}$ state, in the $p\pi^-$ mass distribution of the reaction $pd \to p_S pp\pi^-$ at 7.0 GeV/c. We interpret it as the $N^*(1470)$ produced in the reaction $pn \to pN^{*0}(1470)$ [$N^{*0}(1470) \to p\pi^-$] in deuterium. The production of the $N^*(1470)$ is strongly peripheral and favors $I = 0$ exchange. A discussion of this peak in terms of a double-Regge-pole exchange mechanism is presented.

Several counter and spark-chamber experiments[1] have measured the missing-mass spectrum against a recoiling particle in high-energy pp and $\pi^\pm p$ collisions. These experiments, covering a wide range of incident momenta, indicated the presence of an enhancement in the missing mass corresponding to a nonstrange isobar with mass and width of about 1.40 GeV and 200 MeV, respectively. Phase-shift analyses[2] of πN scattering suggest the existence of a P_{11} isobar with a mass of about 1.47 GeV, a width of ~200 MeV, and a large inelasticity. Recently, πN and $\pi\pi N$ enhancements in the 1.45-GeV region, interpreted in terms of resonance production, have been found in several production experiments.[3] Other explanations of the enhancements in terms of kinematic effects[4] or double-Regge-pole-exchange model[5] (DRPEM) were also suggested. In this Letter we report the observation of a significant peak ($M = 1.446 \pm 0.011$ GeV, $\Gamma = 198 \pm 40$ MeV) consistent with an $I = \frac{1}{2}, J = \frac{1}{2}$ state in the $p\pi^-$ distribution for the reaction $pd \to p_S pp\pi^-$. We interpret this peak as the $N^*(1470)$ produced in the reaction $pn \to pN^{*0}(1470)$ [$N^{*0}(1470) \to p\pi^-$] in deuterium.

This study is based on a 7.0-GeV/c pd experiment in the 80-in. Brookhaven National Laboratory liquid-hydrogen bubble chamber filled with deuterium. We have selected for measurement all four-prong events in 48 000 frames which satisfied fiducial volume requirements and which had a positive stopping track shorter than 25 cm (visible spectator). In a smaller sample of 14 000 frames all three-prong events in the fiducial volume were also measured. The sample of events used in this study consists of about 3980 four-prong events and about 1920 three-prong events. A partial sample of events, namely those from the 14 400 frames in which both three- and four-prong events were measured, was used to determine the cross section for the reaction

$$pd \to p_S pp\pi^-, \tag{1}$$

where p_S denotes the visible or invisible spectator. After normalizing our observed number of events to the expected number from the known pd cross section,[6] we infer that each event in the partial sample corresponds to 3.0 μb and that the overall cross section for Reaction (1) is 1.01 $\pm$ 0.13 mb.

The angular distribution of the proton specta-