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PRODUCTION AND DECAY PROPERTIES OF THE $\delta(970)$ MESON

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ABSTRACT

Using an 80 events per microbarn sample of K^-p interactions at 4.2 GeV/c the production and decay properties of the $\delta(970)$ have been investigated in the following reactions: $K^-p \rightarrow \Sigma^+(1385)\eta\pi^-$ and $K^-p \rightarrow \Sigma^+(1385)K^0K^-$.

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There have been many reports of a relatively narrow $I = 1$ meson resonance near 970 MeV. The first claims came from missing-mass experiments [1], but were not confirmed [2]. Later it was noted that the threshold enhancement observed in the $(K\bar{K})^\pm$ system could be interpreted as the effect of a narrow $I = 1$ resonance below threshold [3]. Finally, observations of an $\eta\pi$ enhancement near 970 MeV have been reported [4]. However, the $\eta\pi$ observations were made essentially with the neutral decay of the η , the background being significant in the η region and the number of events in the $\eta\pi$ peak being small. Moreover, it has been shown [5] that kinematical effects may be important in the interpretation of such a final state. Thus the parameters of the peak have been poorly determined.

In this letter we present new experimental results on the $\delta(970)$ meson. We have observed 80 δ -meson events in the reaction

$$K^- p \rightarrow \Sigma^+(1385) \eta \pi^- \quad (1)$$

with the η being detected via its charged decay mode.

The data come from a high-statistics systematic study of $K^- p$ interactions at 4.2 GeV/c incident momentum in the CERN 2m hydrogen bubble chamber. With about 2/3 of the data analyzed, our present experimental sample corresponds to 80 events/ μ b.

We have isolated 16 271 events that fit the reaction

$$K^- p \rightarrow \Lambda \pi^+ \pi^+ \pi^- \pi^- \pi^0 \quad (2)$$

with a production fit confidence level larger than 2%. The $\pi^+ \pi^- \pi^0$ effective mass spectrum shows an η peak^(*) with a mass of 550 MeV and a FWHM of

(*) The η -peak parameters were determined by a fit to the $\pi^+ \pi^- \pi^0$ spectrum in the η region with a Gaussian on a polynomial background.

23 MeV, corresponding to 1219 events of the channel

$$K^- p \rightarrow \Lambda \pi^+ \pi^- \eta \quad (3)$$

The production of $\Sigma^+(1385)$ in reaction (3) is strong and peripheral. Furthermore a large fraction (24%) of reaction (3) consists of $\eta'(958)$ production via the channel

$$K^- p \rightarrow \Lambda \begin{array}{l} \eta'(958) \\ \downarrow \\ \eta \pi^+ \pi^- \end{array} \quad (4)$$

Keeping the above facts in mind, we have obtained a relatively clean sample of reaction (1) by making the following selections on events of reaction (2):

$$\begin{aligned} 0.53 < M(\pi^+ \pi^- \pi^0) < 0.57 \text{ GeV} & \quad (\eta \text{ selection}) \\ M(5\pi) > 1.05 \text{ GeV} & \quad (\eta' \text{ antiselection}) \\ 1.34 < M(\Lambda \pi^+) < 1.44 \text{ GeV} & \quad (\Sigma^+(1385) \text{ selection}) \\ \text{and } t' < 1 \text{ GeV}^2 & \quad (\text{peripheral } \Lambda \pi^+ \text{ selection}) \end{aligned}$$

where $t' = |t| - |t|_{\min}$, and t is the squared four-momentum transfer from the target proton to the $(\Lambda \pi^+)$ system.

Fig. 1a shows the $\eta \pi^-$ effective mass spectrum for reaction (1). We attribute the peak observed near 1 GeV to the $\delta(970)$. A smaller enhancement is also observed in the region of the $A_2(1310)^{(*)}$.

(*) From the accepted $A_2(1310)$ branching ratios, combined with the number of events observed in this experiment for the reaction $K^- p \rightarrow \Sigma^+(1385) A_2^-$ with the $A_2 \rightarrow \pi^+ \pi^- \pi^-$, we obtain a prediction of 15 events for the number of $A_2 \rightarrow \eta \pi^-$ events in the histogram of fig. 1a, in agreement with the observation.

To estimate the form of the background in the $\eta\pi^-$ mass spectrum of reaction (1), we have returned to reaction (3) by retaining only the selections on the $\pi^+\pi^-\pi^0$ and 5π masses. We have performed a multidimensional maximum-likelihood fit [6] to the resulting sample, introducing Breit-Wigner resonances for the $\Sigma^+(1385)$, $\rho(770)$, $\Lambda(1520)$, and $D(1285)$, in the $\Lambda\pi^+$, $\pi^+\pi^-$, $\Lambda\pi^+\pi^-$, and $\eta\pi^+\pi^-$ systems, respectively. In addition a t -dependence was introduced for the production of the $\Sigma^+(1385)$. This global fit gave a reasonable representation of all the mass spectra, except for that of the $\eta\pi^-$ system recoiling against the $\Sigma^+(1385)$.

The discrepancy is illustrated in fig. 1b, which shows the $\eta\pi^-$ mass spectrum with each event weighted by the probability that it belongs to reaction (1). The weighting procedure is described in ref. [7]. The dotted curve, normalized to the total number of events, shows the result of the fit. The $\delta(970)$ peak is clearly significant^(*).

We have fitted the histogram of fig. 1b with an s-wave Breit-Wigner parameterization and a resolution of 14 MeV (FWHM) folded in, on a background contribution proportional to the dotted curve. We obtain a mass of (981 ± 6) MeV and a width of (55 ± 5) MeV. The previously described global fit was then repeated adding the channel $K^-p \rightarrow \Sigma^+(1385)\delta^-$ with the δ^- having the above parameters. The result of the fit is given by the full line of fig. 1b. The number of δ events from the fit is 80 ± 17 , corresponding to a cross section of $(6.2 \pm 1.3)\mu\text{b}$, after corrections for all decay modes, for the reaction:

We have fitted the differential cross section of reaction (5) to the form $Ae^{-Bt'}$. In the t' range $0 < t' < 1 \text{ GeV}^2$ we find: $B = (4.0 \pm 0.8)\text{GeV}^{-2}$.

(*) Although δ production via $D(1285)$ decay has been reported, the production of $D(1285)$ in reaction (3) is found to be much smaller than δ production.

We have investigated the decay angular distribution of both the δ^- and the $\Sigma^+(1385)$ in reaction (5) with a restriction to forward production angles: $\cos(K_{inc}^-, \delta^-)_{CM} > 0.8$. Figs 2a and 2b show the distributions of the cosine of the decay angle for events of reaction (3) obtained by weighting each event with the probability that it belongs to reaction (5). The distributions are consistent with the assignments $J^P = 0^+$ for the $\delta^-(970)$ and $J^P = 3/2^+$ for an aligned $\Sigma^+(1385)$. However, the limited statistics do not allow us to exclude other natural-spin-parity assignments for the δ^- . We also show in fig. 2c the weighted distribution of the angle ϕ in the overall c.m. system between the production plane and the decay plane of the δ^- (the Treiman-Yang angle) without restriction on production angle. The flat distribution is consistent with spin-zero exchange.

Reaction (1) may also be analyzed, as in previous experiments [4], in the channel $K^-p \rightarrow \Lambda\pi^+\pi^-$ (MM). The η is then observed as a peak in the missing-mass (MM) spectrum. Reflections from the large (69%) background below the η may affect the δ signal, as indicated in ref. [5]. We observe a δ signal which, although somewhat broader and with a larger background, is in reasonable agreement with our observation using the charged decay mode of the η .

As previously mentioned, threshold enhancements in the $(K\bar{K})^+$ system have been related to the $\delta(970)$. Fig. 1c shows the K^0K^- effective mass spectrum for the reaction:

using only events for which the Λ and K^0 were observed. The $\Sigma^+(1385)$ has been defined by the same $\Lambda\pi^+$ mass and t' selection as for reaction (1). The superimposed dotted curve has been derived from a Monte-Carlo phase-space calculation for reaction (6), introducing the experimentally observed t dependence for the $\Sigma^+(1385)$. A small excess of events near $K\bar{K}$ threshold is observed.

If the δ is a resonance with a coupling to $K\bar{K}$, its effect should be seen in fig. 1c near threshold, even if the resonance mass is below threshold. Furthermore, if the coupling of the δ to $K\bar{K}$ is large, then the shape of the $\eta\pi$ spectrum may be significantly different from that of a simple Breit-Wigner. To investigate the effect of this possibility, we have refitted the $\eta\pi$ mass spectrum of fig. 1b using a two channel resonance parametrization [8] instead of a single channel s-wave formula. The coupling constant ratio $g_{\eta\pi}^2/g_{K\bar{K}}^2$ was fixed at the SU(3) value of 2/3, but the mass, the $\eta\pi$ partial width and the background fraction were allowed to vary. This fit reproduces equally well the $\eta\pi$ spectrum and yields a mass of (974 ± 9) MeV and an $\eta\pi$ partial width of (72 ± 51) MeV. The coupled channel parametrization allows, after unseen decay mode corrections, a prediction for the $K^0\bar{K}^-$ mass spectrum, and this is shown by the solid curve in fig. 1c^(*). In fig. 1d the full curve represents the addition of the fixed $K\bar{K}$ contribution from the δ and the Monte-Carlo phase space previously described and is normalised to the histogram. The agreement with the data is good.

We have searched for δ production in two other reactions:

$$K^- p \rightarrow \Sigma^-(1385)\eta\pi^+ \quad (7)$$

and

$$K^- p \rightarrow \Sigma^+\eta\pi^- \quad (8)$$

Reaction (7), which is a sub-channel of reaction (3), has been analyzed by the same procedure as used for $\Sigma^+(1385)\delta^-$ production. We find a small, non-significant effect for $\Sigma^-(1385)\delta^+$ production: $\sigma = (1.4 \pm 0.7)\mu\text{b}$. This is expected, as the production of δ^+ would imply baryon or double-charge exchange.

(*) Although the coupled channel fit is less sensitive in the parameters than a simple Breit-Wigner, the prediction for the amount of $K\bar{K}$ from the resonance is relatively stable.

Reaction (8) shows no evidence for $\delta^-(970)$. We can give an upper limit of $1.0 \mu\text{b}$ for $\delta(970)$ production in this reaction.

We conclude that we have observed the peripheral production of the $\delta(970)$ as an $\eta\pi$ enhancement that can be fit with a Breit-Wigner of mass $(981 \pm 6)\text{MeV}$ and width $(55 \pm 15)\text{MeV}$. A small excess of events near threshold in the $K\bar{K}$ channel has been shown to be consistent via a coupled-channel parametrization with a δ coupling to $K\bar{K}$, the ratio $g_{\eta\pi}^2/g_{K\bar{K}}^2$ being fixed to the SU(3) value of $2/3$. The decay distribution of the δ events is consistent with $J^P = 0^+$ although other possibilities are not ruled out. The cross section of the reaction $K^-p \rightarrow \Sigma^+(1385)\delta^-$ is found to be $(6.2 \pm 1.3)\mu\text{b}$ for $t' < 1 \text{ GeV}^2$.

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FIGURE CAPTIONS

- Fig. 1 Effective mass distributions for systems recoiling off the $\Sigma^+(1385)$ in 4.2 GeV/c K^-p interactions.
- a) $\eta\pi^-$ distribution for events of the reaction $K^-p \rightarrow \Sigma^+(1385)\eta\pi^-$ obtained by selections discussed in the text (contents = 245).
 - b) $\eta\pi^-$ distribution obtained for events of the reaction $K^-p \rightarrow \Lambda\pi^+\pi^-\eta$ weighted by the probability of the events belonging to the reaction $K^-p \rightarrow \Sigma^+(1385)\eta\pi^-$. The dashed curve is the expected distribution from the channel-likelihood fit to the reaction $K^-p \rightarrow \Lambda\pi^+\pi^-\eta$ without inclusion of $\delta^-(970)$. The full curve has included the $\delta^-(970)$ channel.
 - c) K^0K^- distribution for events of the reaction $K^-p \rightarrow \Sigma^+(1385)K^0K^-$. The dashed curve represents the phase space contribution. The full line is the $K\bar{K}$ threshold contribution as described in the text.
 - d) K^0K^- distribution for events of the reaction $K^-p \rightarrow \Sigma^+(1385)K^0K^-$. The full curve normalized to the number of events (59 events) represents $K\bar{K}$ threshold contribution plus phase space.

- Fig. 2 Decay angle distributions for $K^-p \rightarrow \Sigma^+(1385)\delta^-$ events with weights as described in the text.

- a) distribution of $|\cos \theta_s|$ where θ_s is the angle between the incident K^- and the η in the δ^- rest frame.
- b) Distribution of $|\cos \theta_\Sigma|$ where θ_Σ is the angle between the incident proton and the Λ in the $\Sigma^+(1385)$ rest frame.
- c) Treiman-Yang distribution (ϕ) for the decay of the δ^- .

The dotted curves on a) and b) are the expectations for a spin zero δ^- and an aligned spin $3/2^-$ $\Sigma^+(1385)$ respectively.

Fig. 1

Fig. 2