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Observation of a New $K_N(1760)$ in the $K\pi$ and $K\pi\pi$ Systems*

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A new K^* resonance which we denote $K_N(1760)$ is observed. Its mass is 1759 ± 10 MeV and its width 60 ± 20 MeV. We assign it to the natural–spin-parity series on the basis of 5-standard-deviation evidence for a $K\pi$ decay mode. Decays into $K^*(890)\pi$ and $K\rho$ with the same mass and width are observed with 4-standard-deviation significance. It is suggested that this state is the analog of the g meson. In addition, we see evidence for further high-mass structure.

In this Letter we report the observation of a new natural-parity K^* resonance whose mass of 1759 ± 10 MeV and favored spin and parity of 3^- suggest that it is the strange component of the g-meson octet.

We have studied 4030 and 558 events, respectively[1] (8 events/μb nucleon) of the charge-exchange reactions

$$K^+n \to K^+\pi^-p \tag{1}$$

and

$$K^+n \to K^0\pi^+\pi^-p \text{ (visible vee)} \tag{2}$$

at an incident momentum of 9 GeV/c in the Brookhaven National Laboratory 80-in. deuterium bubble chamber. The cross sections for the two reactions are 505 ± 20 and 210 ± 30 μb. In Reactions (1) and (2) all track ambiguities are eliminated if we require that the four-momentum transfer squared $|t|$ between the neutron and the proton be less than 1 GeV^2. With the imposition of such a momentum-transfer cut, 3580 and 505 events remain in Reactions (1) and (2), respectively. In addition, we have analyzed (from half the film) 394 events[2] for the final states $K^+\pi^-\pi^0p$ and $K^0\pi^+\pi^-p$ where the vee is not seen.

Figure 1(a) shows the $K\pi$ mass spectrum for Reaction (1). We have fitted this spectrum with a superposition of the Breit-Wigner distributions for the well-known $K^*(890)$ and $K_N(1420)$ as well as a fourth-order polynomial background. The resulting curve (solid line) describes the data

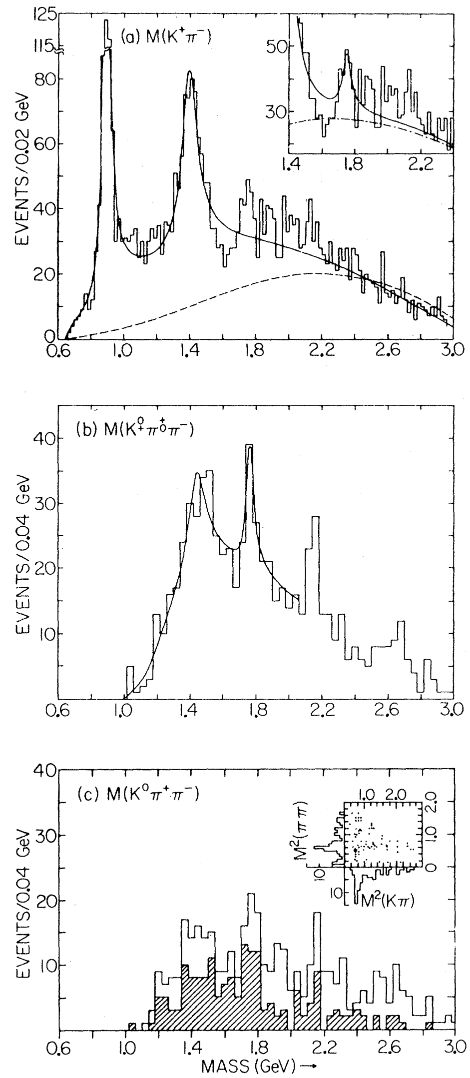

FIG. 1. (a) $K\pi$ mass spectrum for reaction $K^+n \to K^+\pi^-p$ with $-t_{np} < 1$ GeV^2, fitted with a superposition of two Breit-Wigner distributions and a fourth-order polynomial background (solid line). The insert shows a fit including a third Breit-Wigner distribution for the $K_N(1760)$ and the polynomial background as a dash-dotted line. The dashed curve represents a double-Regge background. (b) $K\pi\pi$ mass spectrum for the combined sample of one- and four-constraint events from reactions $K^+n \to K^0\pi^+\pi^-p$ and $K^+n \to K^+\pi^-\pi^0p$ with $-t_{np} < 1$ GeV^2 and $\Delta^0(1236)$ (1.18 to 1.32 GeV) excluded, together with a superimposed fit. (c) $K\pi\pi$ mass distribution for the four-constraint reaction $K^+n \to K^0\pi^+\pi^-p$ with $-t_{np} < 1$ GeV^2, and (shaded) with $K^*(890)$ (0.84 to 0.94 GeV) or ρ (0.68 to 0.84 GeV) selected and $\Delta^0(1236)$ (1.18 to 1.32 GeV) excluded. The insert is the Dalitz plot for the $K\pi\pi$ mass range between 1.68 and 1.84 GeV.

rather well in the regions below 1.6 and above 2.2 GeV, but it does not account for the structure in the intermediate region. The most striking feature above $K_N(1420)$ is the rising edge[3] at 1.7 GeV which suggests the existence of a third resonance. In an additional fit we have included a third Breit-Wigner distribution. The resulting curve is shown in the insert to Fig. 1(a) where the third Breit-Wigner distribution accounts for 76 ± 15 events. The mass and width of this newly observed $K_N(1760)$, determined from the $K\pi$ spectrum, are 1753 ± 12 MeV and 60 ± 20 MeV, respectively. The fitted curve still has a very low probability for describing the data between 1.9 and 2.2 GeV. It appears possible that other resonant structures may exist in this region although with the current data it is not possible to extract their parameters. The $K_N(1760)$ is not clearly separated from these structures, but a much larger width for the resonance is ruled out by the shape of the spectrum below 1.8 GeV. Although similar in mass, the $K_N(1760)$ is not the L meson[4] since the L meson has never been observed in the $K\pi$ decay mode and is associated with the unnatural-spin-parity series.

The expected shape of the nonresonant background of Reaction (1) (or, what is equivalent, the observed low-mass $p\pi$ enhancement) has been independently calculated, assuming that to leading order the Pomeranchuk trajectory is responsible for the nonresonant production.[5] This leads us to a double-Regge mechanism including Pomeranchuk exchange for elastic $K\pi$ scattering and pion exchange at the nucleon vertex, first successfully applied by Berger[6] to various reactions. Recent publications[7,8] on the charge-exchange reaction

$$K^-n \to K^-\pi^-p \qquad (3)$$

show that the double-Regge amplitude describes the dominant nonresonant part of this reaction in considerable detail. The result of our calculations is shown by the dashed curve in Fig. 1(a) and by no means accounts for the enhancement above 1.6 GeV. Its shape is similar to the fourth-order polynomial background used in the previous fit, except for $K\pi$ mass values below 1.6 GeV where it is lower than the data. The parametrization of the double-Regge amplitude we have used and the justification for the choice of a proper set of parameters will be presented in a separate publication.[9] The calculated curve is an absolute prediction, since it was normalized to the published cross section for the 12.6-GeV/c data[8] on Reaction (3).

Figure 1(b) shows evidence for the existence of additional decay modes of the $K_N(1760)$. It contains the $K^0\pi^+\pi^-$ mass spectrum for both visible and invisible vees as well as the spectrum of $K^+\pi^-\pi^0$. Events with a $\Delta^0(1236)$, i.e., with $1.18 \leq M(\pi^-p) \leq 1.32$ GeV, have been excluded. The four-momentum transfer squared $|t|$ was required to be less than 1 GeV^2. A 4-standard-deviation signal is observed in the $K_N(1760)$ region with approximately the same mass and width obtained from the $K\pi$ spectrum. The solid curve shows the fit including the $K_N(1420)$ and the $K_N(1760)$. The mass and width obtained for the $K_N(1760)$ are 1768 ± 14 MeV and 50 ± 20 MeV. Since we have presented the $K\pi\pi$ spectrum from our charge-exchange reaction only, any confusion with the L meson (which has only been seen in non-charge-exchange reactions) is avoided.[4]

In addition to the $K_N(1760)$, we see in the $K\pi\pi$ spectrum of Fig. 1(b) a 4-standard-deviation signal at 2150 MeV. In conjunction with the structures in the $K\pi$ spectrum in this region, this may indicate that other high-mass K^* resonances exist in the data.

In order to exhibit the specific decay modes for the $K\pi\pi$ final state, we restruct ourselves to Reaction (2) where the vee is visible. We show in Fig. 1(c) the $K\pi\pi$ spectrum of Reaction (2) with only a $|t|$ cut at 1 GeV (unshaded), and (shaded) with a $K^*(890)$ (0.84 to 0.94 GeV) or ρ (0.68 to 0.84 GeV) selected and $\Delta^0(1236)$ (1.18 to 1.32 GeV) excluded. The $K_N(1760)$ signal remains with nearly the same magnitude over a reduced background. In the insert to Fig. 1(c) we present the Dalitz plot for the $K_N(1760)$ region $[1.68 \leq M(K^0\pi^+\pi^-) \leq 1.84$ GeV$]$ which is completely dominated by the $K^*(890)$ and ρ bands, very much unlike the L meson which decays mainly to $K_N(1420)\pi$.

The remainder of this Letter is devoted to the discussion of the quantum numbers and branching ratios of the $K_N(1760)$. If we assign isospin $\frac{3}{2}$ to this state and assume that the same $I=1$ exchange mechanism is responsible for the $K^+\pi^-$ system in Reaction (1) and the $K^-\pi^-$ system in Reaction (3), we would expect a 9-times more significant signal for the $K_N(1760)$ in the $K^-\pi^-$ spectrum. No such signal is observed in 5.5- and 12.6-GeV/c data[7,8] for Reaction (3), and consequently we assign $I=\frac{1}{2}$ to the $K_N(1760)$. With this isospin assignment we determine its branching ratio (corrected for unseen decays) to be

$$\frac{\Gamma(K_N(1760)\to K\pi)}{\Gamma(K_N(1760)\to K^*(890)\pi + K\rho)} = 0.40 \pm 0.10.$$

The $K_N(1760)$, observed in the $K\pi\pi$ final state, is consistent with decaying entirely via $K^*(890)\pi$ and $K\rho$ with relative amounts of $(40\pm 15)\%$ and $(60 \pm 25)\%$, respectively. [See the Dalitz plot and its projections inserted into Fig. 1(c).] The fraction of nonresonant $K^0\pi^+\pi^-$ decays is $(0 \pm 12)\%$. No evidence for a $K^*(1420)\pi$ decay is seen and an upper limit of 6% at a confidence level of 90% is found.

The cross section for the $K_N(1760)$ in the $K\pi$ decay mode is 15 ± 3 μb (corrected for unseen decays). The branching ratio and the cross section are lower limits since they were obtained with the conservative choice of a fourth-order polynomial background, assuming no structure beyond the $K_N(1760)$. The associated errors are purely statistical. The differential cross section $d\sigma/dt$, fitted in the $|t|$ range between 0.04 and 0.4 GeV^2 with an exponential function, has a slope of 8.7 ± 1.0 GeV^{-2}. This slope is the same as that in the $K^*(890)$ region of our data. No background subtraction has been attempted in determining the slopes.

Because of its observed $K\pi$ decay mode, the $K_N(1760)$ belongs to the natural-spin-parity series. The favored spin assignment can be obtained from the observation of the decay angular distribution, with the directions of the incoming and outgoing kaons in the $K\pi$ rest system defining the decay angle (Jackson frame). In Figs. 2(b), 2(a), and 2(c) we present the angular distributions for $K_N(1760)$ (1.7 to 1.8 GeV) and two control regions (1.6 to 1.7 and 1.84 to 1.92 GeV). With increasing $K\pi$ mass the angular distributions are increasingly forward peaked in agreement with double Regge calculations (solid curve). In the forward hemisphere the decay angular distributions are totally distorted by interference with the nonresonant double Regge amplitude. In the backward hemisphere of the Jackson frame the lower control region shows a backward peak, characteristic of the tail of the $K^*(1420)$. The shape of the distribution in the $K_N(1760)$ region differs from the control region significantly. The dashed curve in Fig. 2(b) gives the angular distribution for the decay of a $J^P=3^-$ state produced by π exchange (i.e., $\rho_{00}=1$).[10] The curve fits the data in the backward hemisphere nicely. The Y_6^0 moments, calculated for the backward hemisphere only, show a 3-standard-deviation signal in the $K_N(1760)$ band [Fig. 2(d)] and are compatible with zero elsewhere in the $K\pi$ range from 1.0 to 2.2 GeV. All higher moments are zero in this region. Therefore, we conclude

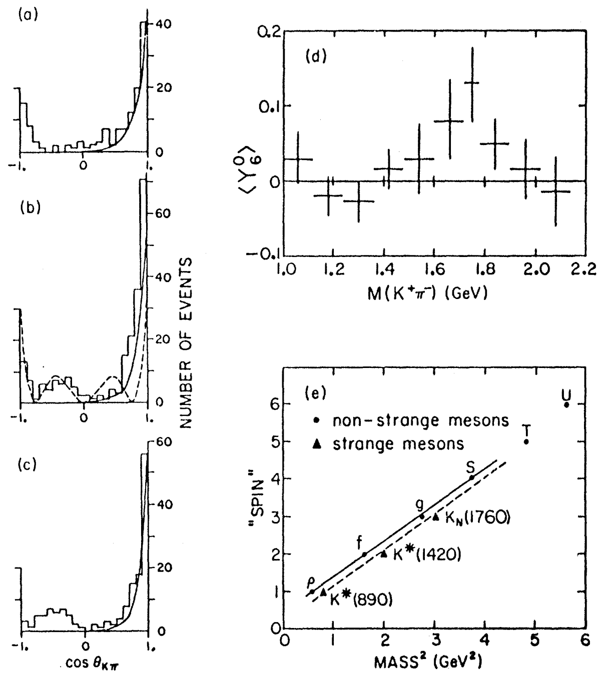

FIG. 2. Decay angular distribution of the kaon in the $K\pi$ Jackson frame of the reaction $K^+n \to K^+\pi^-p$ for (a) a lower control region, $1.6 < M(K\pi) < 1.7$ GeV, (b) the $K_N(1760)$ region $1.7 < M(K\pi) < 1.8$ GeV, and (c) the region $1.84 < M(K\pi) < 1.94$ GeV (all with $-t_{np} < 1$ GeV^2). The full curves give the double-Regge background and the dashed curve is the decay angular distribution of a $J^P = 3^-$ state produced via π exchange. The $Y_6{}^0$ moments as a function of the $K\pi$ mass are shown in (d) and the Chew-Frautschi plot for $\pi\pi$ and $K\pi$ states in (e).

from the data in the backward hemisphere that the favored spin and parity assignment of the $K_N(1760)$ is $J^P = 3^-$.

It is well known that the ρ, f, and g all lie on a line on a Chew-Frautschi plot. If we assume that the $K_N(1760)$ is the analog of the g, then the $K^*(890)$, $K^*(1420)$, and $K_N(1760)$ should lie on a line of similar slope. With a common slope of 0.95 for the nonstrange and strange mesons, this condition is fairly well satisfied in Fig. 2(e).

In summary, we see overwhelming evidence for a new K^* state of mass 1759 ± 10 MeV and width 60 ± 20 MeV[11] whose isospin is $\frac{1}{2}$. Decays into $K\pi$, $K^*(890)\pi$, and $K\rho$ are seen. The most probable spin and parity assignment is 3^- and thus this state is quite naturally interpreted as the analog of the g meson. The structure observed beyond the $K_N(1760)$ needs further experimental clarification.

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[1]The current data sample is about $\frac{3}{4}$ of the final sample of 380 000 pictures.

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[10]A maximum-likelihood fit of the diagonal density-matrix elements to the backward $K_N(1760)$ decay angular distribution resulted in $\rho_{00} = 0.50 \pm 0.12$, $\rho_{11} = 0.11 \pm 0.06$, $\rho_{22} = 0.06 \pm 0.06$, and $\rho_{33} = 0.08 \pm 0.06$.

[11]These values of the mass and width are averages of the $K\pi$ and $K\pi\pi$ values. The quoted errors do not include systematic effects due to the uncertainty of the true background shape for the $K\pi$ spectrum. A fit assuming the multi-Regge curve as background gave a mass of 1754 ± 10 MeV and a width of 120 ± 40 MeV. Our $K\pi$ mass resolution in the range from 1.6 to 2.2 GeV is estimated to be 18 MeV.