Observation of a New $K_N^*(1758)$ Resonance and
High Mass Structure in the $K\pi$ System[†]

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A New K^* resonance which we denote $K_N^*(1758)$ is observed. Its mass is 1758 ± 10 MeV and its width 110 ± 40 MeV. We assign it to the natural spin-parity series on the basis of six 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 five standard deviation significance. It is suggested that this state is the analogue of the ρ -meson. In addition, better than three standard deviation evidence for K^* states, which we denote $K_N^*(1880)$, $K_N^*(2007)$, and $K_N^*(2145)$ is presented.

In this letter we report the observation of a new K^* resonance whose mass is 1758 ± 10 MeV and indicate the possible existence of three other high mass K^* states. We have studied 4030 and 558 events respectively¹ (8 events/ μ b per nucleon) of the charge exchange reactions

$$K^+n \rightarrow K^+\pi^-p$$

(1)

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and

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

at an incident momentum of 9 GeV/c in the BNL 80" deuterium filled bubble chamber. The cross sections for the two reactions are 505 ± 20 and 211 ± 20 mb respectively. In reaction (2) we require that the K^0 be visible and hence both reactions are highly constrained kinematically. All track ambiguities are eliminated if we require that the four-momentum transfer squared between the neutron and the outgoing proton be less than 1 GeV^2 . With the imposition of such a momentum transfer cut 3580 and 412 events remain in the reactions (1) and (2) respectively.

The $K\pi$ mass spectrum for reaction (1) is presented in Fig. 1a and shows enhancements at 1.75, 1.88, 2.0 and 2.14 GeV with significance of 6, 3, 3, and 4 standard deviations respectively.^{2,3} If these peaks are interpreted as resonances, they have to be in the natural spin-parity series. They are consequently denoted as K_N in Table I.

As additional evidence for structure in this mass region, we present in Fig. 1b the $K\pi\pi$ mass for 318 events of reaction (2) as well as 394 one constraint events⁴ of the reactions $K^+ n \rightarrow K^0 \pi^+ \pi^- p$ and $K^+ n \rightarrow K^+ \pi^- \pi^0 p$. Events with a $\Delta^0(1236)$, i.e. with $1.18 \leq M(\pi^- p) \leq 1.32 \text{ GeV}$, have been excluded. Two clear signals above 1.6 GeV confirm the presence of the $K_N(1758)$ and $K_N(2145)$ with 6 and 4 standard deviations respectively. The two arrows in Fig. 1b point at the mass values obtained from the fitted $K\pi$ spectrum of reaction (1) (see Table I and the discussion below). The following analysis is restricted to the four constraint reactions (1) and (2).

Fig. 1c shows the $K\pi\pi$ effective mass for reaction (2) and shaded with a $K^*(890)$ (0.84 to 0.94 GeV) or p (0.68 to 0.84 GeV) selected and $\Delta^0(1236)$ (1.18 to 1.32 GeV) excluded. The $K_N(1758)$ signal stays nearly the same over

a reduced background, indicating dominant $K^*(890)\pi$ and $K\rho$ decay modes in the $K\pi\pi$ final state (see discussion below). A mass of 1758 ± 10 MeV and a width of 110 ± 40 MeV for the $K_N(1758)$ resonance are obtained by averaging the fitted values for reactions (1) and (2) in Table I. We do not associate our $K\pi\pi$ signal with the L-enhancement⁵ at a similar mass, because our reaction is a charge exchange reaction, and because, as seen in the Dalitz plot inserted into Fig. 1c ($M(K^0\pi^+\pi^-)$ between 1.68 and 1.84 GeV), there is no evidence for a $K^*(1420)\pi$ decay mode which is the dominant L decay.

In order to analyze the high mass $K\pi$ spectrum of reaction (1) in greater detail, one has to obtain a reliable estimate of the non-resonant background. One possible source for the $K\pi$ background are reflections from competing baryon resonance production. No such resonances exist in the K^+p system. The π^-p mass spectrum has been presented in a previous publication⁶ and is dominated by a broad 500 MeV wide low mass enhancement. No indication of the $\Delta(1236)$, which should give the leading contribution for $I = \frac{3}{2}$, is seen. The data are compatible with the production of a small amount of $I = \frac{1}{2}$ πp resonances upon a broad diffractive background. Since baryon resonance production is very weak in reaction (1), it is neglected in the following discussion of the $K\pi$ background.

In order to describe the non-resonant background in the $K\pi$ spectrum, (or, what is equivalent, the lowmass πp enhancement) we use the Freund-Harari conjecture,⁷ that the Pomeranchuk trajectory is responsible for the non-resonant production. This leads us to a double Regge exchange mechanism including Pomeranchuk exchange for elastic $K\pi$ scattering and pion exchange at the nucleon vertex, first successfully applied by Berger⁸ to various reactions. Recent publications^{9,10} on the charge exchange reaction

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

show that the double Regge amplitude describes the dominant non-resonant part of this reaction in considerable detail. The parametrization of the double Regge amplitude we used and the justification for the choice of a proper set of parameters will be presented in a separate publication.¹¹ The result of our calculations is shown by the curve in Fig. 1a. This curve is an absolute prediction, since it was normalized to the published cross section for the 12.6 GeV/c data¹⁰ of reaction (3).

From Fig. 1a we see that the predicted non-resonant background agrees with the observed $K\pi$ spectrum above a mass of 2.2 GeV. Below 2.2 GeV we see a clear excess of events over the non-resonant background. We fitted the experimental $K\pi$ spectrum between 1.6 and 2.6 GeV with an incoherent superposition of the non-resonant background, four Breit-Wigner distributions, and the tail of the $K^*(1420)$. We let the masses, widths, and fractions of the resonances as well as the fraction of the background and the tail of the $K^*(1420)$ vary as free parameters. The results of this 14 parameter fit, which has a confidence level of 40%, are given in Table I and illustrated in the insert to Fig. 1a. (The dashed curve is the non-resonant background and the dotted curve includes also the $K^*(1420)$ tail). The fraction of non-resonant background is changed by the fit by less than 5% from the value calculated by our double Regge model.¹¹ If we now leave out the three highest mass Breit-Wigners the probability of the fit drops to 2%. This is a way of measuring the collective significance of the upper three peaks. Since the individual significance of the $K_N(1880)$ and $K_N(2007)$ is limited, their additional confirmation is required. However the evidence for high mass $K\pi$ structure beyond the $K_N(1758)$ is supported by the observation of the $K_N(2145)$ in two different final states.

In order to examine the production mechanism of these states we have plotted the $K\pi$ mass for forward going (Fig. 2a) and backward going kaons (Fig. 2b) in the Jackson frame. The non-resonant background contributes only to the spectrum in Fig. 2a. All four peaks show up in the forward hemisphere and only the first two in the backward hemisphere. The two higher mass enhancements may appear because of the interference of their production amplitudes with the strong non-resonant background. A similar interference has been seen in the production of high mass $\pi\pi$ states in 13 GeV/c π^+p interactions.¹²

The remainder of this letter is devoted to the discussion of the quantum numbers and branching ratios of the $K_N(1758)$. 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 nine-times more significant signal for the $K_N(1758)$ in the $K^-\pi^-$ spectrum. No such signal is observed in 5.5 and 12.6 GeV/c data^{9,10} for reaction (3), and consequently we assign $I = \frac{1}{2}$ to the $K_N(1758)$. With this isospin assignment we determine its branching ratio (corrected for unseen decays) to be:

$$\frac{\Gamma(K_N(1758) \rightarrow K\pi)}{\Gamma(K_N(1758) \rightarrow K^*(890)\pi + K\rho)} = 1.2 \pm 0.5$$

The $K_N(1758)$, observed in the $K\pi$ final state, is consistent with decaying entirely via $K^*(890)\pi$ and $K\rho$ with relative amounts of $41 \pm 15\%$ and $59 \pm 25\%$ respectively. (See the Dalitz plot and its projections inserted into Fig. 1c). The fraction of non-resonant $K^0\pi^+\pi^-$ decays is $0 \pm 12\%$. No evidence for a $K^*(1420)\pi$ decay is seen and a upper limit of 6% at a confidence level of 90% is found.

It has already been mentioned that the $K_N(1758)$ 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. 3a to 3c we present the angular distributions for a lower control region (1.6 to 1.7 GeV) and for the $K_N(1758)$ (1.7 to 1.8 GeV) and $K_N(1880)$ (1.84 to 1.92 GeV) regions. With increasing $K\pi$ mass the angular distributions are increasingly forward peaked in agreement with the prediction of the non-resonant background (solid curve). In the forward hemisphere the decay angular distributions are totally distorted by interference with the non-resonant 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 $K_N(1758)$ region differs from the control region significantly. The dashed curve in Fig. 3b gives the angular distribution for the decay of a $J^P = 3^-$ state produced by π -exchange (i.e. $\rho_{00} = 1$).¹³ The curve fits the data in the backward hemisphere nicely. If one calculates the Y_6^0 moments for the backward hemisphere they show a three standard deviation signal in the $K_N(1758)$ band (Fig. 3d) 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 from the data in the backward hemisphere that the favored spin parity assignment of the $K_N(1758)$ is $J^P = 3^-$. We show the angular distribution in the $K_N(1880)$ region as a matter of interest, but we cannot draw any conclusion from it.

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 $K_N(1758)$ is the analogue of the g , then the $K^*(890)$, $K^*(1420)$ and $K_N(1758)$ should lie on a line of similar slope. With a common slope of 0.95 for the $\pi\pi$ and $K\pi$ states, this condition is fairly well satisfied in Fig. 3e. Continuing the $K\pi$ trajectory to spin 4

we find that the $K_N(2007)$ constitutes the possible analogue of the S-meson.

In summary we see overwhelming evidence for a new K^* state of mass 1758 ± 10 MeV and width 110 ± 40 MeV whose isotopic spin is $\frac{1}{2}$. Decay into $K\pi$, $K^*(890)\pi$ and $K\rho$ are seen. The most probable spin-parity assignment is 3^- and thus this state is quite naturally interpreted as the analogue of the g-meson. The structure, observed beyond the $K_N(1753)$, needs further experimental clarification.

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References and Footnotes

- † Work supported in part by the U.S. Atomic Energy Commission.
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TABLE I

Fit to the $K^+\pi^-$ mass spectrum of reaction (1)			
	Mass (MeV)	Width (MeV)	Number of Events
$K_N(1758)$	1754 ± 10	120 ± 40	238 ± 40
$K_N(1880)$	1880 ± 11	60 ± 30	72 ± 22
$K_N(2007)$	2007 ± 14	80 ± 40	78 ± 24
$K_N((2145))$	2145 ± 15	100 ± 50	103 ± 27
Fit to the $K^0\pi^+\pi^-$ mass spectrum of reaction (2)			
	Mass (MeV)	Width (MeV)	Number of Events
$K_N(1758)$	1769 ± 18	90 ± 50	38 ± 10

Figure Captions

- Figure 1. (a) $K\pi$ mass spectrum and double Regge background for reaction $K^+n \rightarrow K^+\pi^-p$ with $-t_{np} < 1 \text{ GeV}^2$. The insert represents a fit with a superposition of four Breit-Wigner distributions, the double Regge background (dashed line) and the tail of the $K^*(1420)$ (dotted line).
- (b) $K\pi\pi$ mass spectrum for the combined sample of one and four constraint events from reactions $K^+n \rightarrow K^0\pi^+\pi^-p$ and $K^+n \rightarrow K^+\pi^-\pi^0p$ with $-t_{np} < 1 \text{ GeV}^2$ and $\Delta^0(1236)$ (1.18 to 1.32 GeV excluded).
- (c) $K\pi\pi$ mass distribution for the four constraint reaction $K^+n \rightarrow K^0\pi^+\pi^-p$ with $-t_{np} < 1 \text{ GeV}^2$, 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.
- Figure 2. $K\pi$ mass spectrum of the reaction $K^+n \rightarrow K^+\pi^-p$ for forward going (a) and backward going (b) kaons in the Jackson frame ($-t_{np} < 1 \text{ GeV}^2$). The curve represents the double Regge background.
- Figure 3. Decay angular distribution of the kaon in the $K\pi$ Jackson frame of the reaction $K^+n \rightarrow K^+\pi^-p$ for (a) a lower control region, (b) the $K_N(1753)$ region and (c) the $K_N(1880)$ region ($-t_{np} < 1 \text{ GeV}^2$). 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).