REVIEW OF EVIDENCE FOR HIGH-MASS K^* STATES[†]

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ABSTRACT

Evidence for strange mesons above the $K^*(1420)$ is reviewed. The $K_{\pi}^*(1760)$ now appears to be well confirmed with a 9 GeV/c K^+n experiment reporting a mass of 1769 ± 12 MeV and a width of 130 ± 50 MeV and a 7.2 GeV/c K^-p experiment finding a mass of about 1760 MeV and a width of less than 80 MeV. Decays into $K\pi$, $K\rho$, $K^*(890)\pi$ and $K^*(890)\rho$ are seen. The K^+n experiment also reports a state of mass 2115 ± 45 MeV and width 300 ± 100 MeV which is identified with a previously reported antilambda-nucleon state. Decays into $K\pi$, $K^*(890)\pi$, $K\rho$, $K^*(890)\rho$, $K^*(1420)\pi$ and Kf are also found. A 12 GeV/c K^+n experiment finds a single broad enhancement in the high $K\pi$ mass region.

INTRODUCTION

I would like to review the evidence for high mass K^* states as presented in our contribution to this conference (K^+n at 9 GeV/c, about 10 events per microbarn)¹ as well as discuss the other evidence for or against these states which comes primarily from a K^-p experiment² at 7.2 GeV/c and from a K^+n experiment³ at 12 GeV/c.

THE $K\pi$ FINAL STATE

The dominant features of the reaction

$$K^+n \rightarrow pK^+\pi^- \text{ or } K^-p \rightarrow nK^-\pi^+ \quad (1)$$

are a low mass enhancement in the nucleon-pion system ($M < 1.7$ GeV) and a number of resonances in the $K\pi$ system. Fig. 1 shows the $K\pi$ mass spectrum for 4581 events of the 9 GeV/c K^+ experiment with the events with $M(p\pi^-) > 1.7$ GeV shown shaded. The solid curve is a fit to the data from 1.0 to 3.0 GeV (a small $K^*(890)$ tail is removed) assuming quadratic background and three simple Breit-Wigner resonances. The χ^2 probability of the fit is 37%. The probability of a fit is 1% with one broad resonance (dashed curve) or one narrow resonance (dotted curve) above the $K^*(1420)$. Additional evidence for two states above the $K^*(1420)$ is the observation that the lower enhancement is also present when we require that $M(p\pi^-) > 1.7$ GeV whereas the upper state is made primarily in association with this low mass enhancement. Furthermore, we present in Fig. 2 the unnormalized moments $\langle Y_6^0 \rangle$, $\langle Y_8^0 \rangle$, and $\langle Y_{10}^0 \rangle$. The $K\pi$ scattering moments are determined in the Jackson frame and

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Fig. 1:
 $K\pi$ effective mass at 9 GeV/c
 from reaction (1)

we require that the four-momentum transfer $t'(K, K\pi)$ be less than $0.2 \text{ GeV}^2/c^2$. The Y_8^0 moment is large only in the $K_N(2100)$ region whereas the Y_6^0 moment is large both in the $K_N(1760)$ and $K_N(2100)$ region. In Fig. 3a the $K^-\pi^+$ mass spectrum of 5330 events of reaction (1) is shown from an experiment at 7.2 GeV/c. A bump at 1.76 GeV with a width of less than 80 MeV is seen. In Fig. 3b the $K^+\pi^-$ mass spectrum from 6400 events of reaction (1) at 12 GeV/c is shown. Although the resolution is comparable (about 15 MeV), the two states are not resolved. The broad enhancement seen could well contain these structures which would be less important at this energy if pion exchange is the primary production mechanism.

THE $K\pi\pi$ FINAL STATE

We turn now to a study of 1540 events of the final state

In Fig. 4 the $p\pi^-$, $K^0\pi^+$ and $\pi^+\pi^-$ effective mass distributions are shown. Shown shaded are the $\Delta^0(1236)K^*(890)$ events which have been removed from the analysis. The $K^0\pi^+\pi^-$ effective mass spectrum is shown in Fig. 5a. The $K_N(1760)$ is clearly seen and there is also an excess of events at a mass of 2.1 GeV. The histogram has been

Fig. 2:
 Y_6^0 , Y_8^0 , and Y_{10}^0 moments
 of the $K\pi$ system for
 $t' < 0.2 \text{ GeV}^2/c^2$
 (Jackson system)

Fig. 3: a) $K^- \pi^+$ mass of R(1) at 7.2 GeV/c. b) $K^+ \pi^-$ mass of R(1) at 12 GeV/c.

Fig. 4: a) $M(\pi \pi^-)$. b) $M(K^0 \pi^+)$ c) $M(\pi^+ \pi^-)$ from R(2) at 9 GeV/c. $\Delta(1236)K$ events are shaded.

Fig. 5: a) $M(K^0 \pi^+ \pi^-)$ of R(2) b) $M(K^+ \pi^- \pi^0)$ from final state $p K^0 \pi^+ \pi^0$ with $K^*(890)^0$ shaded.

fitted with a quadratic background plus two (dotted curve) or three (solid curve) Breit-Wigner resonances. An acceptable fit (11%) can be obtained without the third resonance but then the 2100 MeV region shows a 4 standard deviation excess. The probability of the fit rises to 67% with the inclusion of the third state. In Fig. 5b we show the $K^+ \pi^- \pi^0$ effective mass distribution of 1984 events of the final state $p K^0 \pi^+ \pi^0$. This reaction contains considerable contamination and is of poor resolution but if a $K^*(890)^0$ is required (shaded histogram) a significant $K_N(1760)$ signal is seen.

If the $K\pi$ and $K^0 \pi^+ \pi^-$ enhancements are assumed to be different decay modes of the

Fig. 6: a) $K^+\pi^-$ mass. b) $K^0\pi^+\pi^-$ mass. c) $K^+\rho$ mass. Curve is fit to a and b.

FIG 7. $K^+\pi^+\pi^-$ mass spectrum from the final state $K^+\pi^+\pi^-n$. The shaded histogram results from selecting either $K^*(890)$ or ρ intermediate states in the $K^+\pi^+\pi^-$ system.

same states and if only one resonance is assumed in addition to the $K^*(1420)$ the mass spectra are incompatible since the probability of a simultaneous fit is 0.05%. If, however, we assume separate quadratic backgrounds and resonant amounts for the above two reactions but require the same masses and widths for the three resonances we obtain the solid curve in Fig. 6a,b which is a good fit to the data (10% prob.).

In the 7.2 GeV/c K^-p experiment 920 events of the final state $n\bar{K}^0\pi^+\pi^-$ also show evidence of a three meson decay at 1.76 GeV especially if a $K^*(890)$ or ρ is required (Fig. 7). The $K^0\pi^+\pi^-$ effective mass distribution at 12 GeV/c is given in Phys. Rev. Letters 26 1460 1971 and may also show a slight excess at 1.76 GeV.

ADDITIONAL EVIDENCE FOR HIGH MASS STATES

We have considered the two reactions at 9 GeV/c:

$$K^+n \rightarrow pK^+\pi^+\pi^-\pi^- \quad (1310 \text{ events}) \quad (3)$$

and

$$K^+n \rightarrow pK^0\pi^+\pi^-\pi^0 \quad (710 \text{ events}) \quad (4)$$

In reaction (3) the K^+/π^+ ambiguity is resolved by kinematics if the spectator proton is seen and even if the spectator isn't seen, those events which are $p K^*(890)_\rho$ have a unique track assignment. The $K^+\pi^-$ and $\pi^+\pi^-$ effective mass distributions for reaction (3) with two combinations per event are shown in Fig. 8 and the dominance of the $K^*(890)$ is clearly seen. Rho production is also important especially in association with a K^* in the other meson pair (shaded histogram of Fig. 8b). The two body masses for the other reaction (4) are not shown but are similar. The $K^*(890)_\rho$

Fig. 8: a) $K^+\pi^-$. b) $\pi^+\pi^-$ mass (two comb./event. The $\pi\pi$ with associated K^* is shaded.

Fig. 9: $\bar{\Lambda}N$ mass. a) from several K^+p experiments. b) this experiment.

mass spectrum from reactions (3) and (4) combined is shown in Fig. 6c. The arrows indicate the masses found in the simultaneous fit to the $K\pi$ and $K\pi\pi$ channels. The dominant feature of the $K^*(890)_\rho$ effective mass distribution is an enhancement(s) from 1.68-2.2 GeV. Although there is a three standard deviation dip at 1.85 GeV, we cannot rule out a single broad enhancement (about 500 MeV) but the most reasonable interpretation is that both the $K_N(1760)$ and $K_N(2100)$ decay into two vector mesons. In reaction (4) we find $\sim 10 K_N$ decays of the $K_N(1760)$ but there is insufficient data to determine much more than an upper limit to this decay (not shown).

We have also examined the antilambda-nucleon effective mass distribution choosing that nucleon in the final state $\bar{\Lambda}ppn$ which gives the lowest momentum transfer between the incident K^+ and the outgoing $\bar{\Lambda}N$. In Fig. 9 we show the lambda-dabar-nucleon mass spectrum for a number of K^+p experiments in the energy range 8-13 GeV² and in Fig. 9b for our experiment. We conclude the $K_N(2100)$ also has an antilambda-nucleon decay mode.

Finally, we have also examined the $K\pi$ mass spectrum in the non charge exchange reaction $K^+N \rightarrow NK^0\pi^+$. We see a small $K_N(1760)$ signal (Fig. 10) which because of the known $K\pi/K\pi\pi$ branching implies $K_N(1760)$ production in the reaction $KN \rightarrow N(K\pi\pi)$. Since the $K_N(1760)$ has nearly the same mass as the L-meson, this presumably explains why some authors², particularly at lower energies have

Fig. 10: $K^0 \pi^+$ mass for non-charge exchange, $K^+ N \rightarrow K^0 \pi^+ N$.

Fig. 11: Spin of the strange mesons as function of mass².

reported $K^* \pi$ and $K \rho$ decay modes for the L-meson whereas the highest energy experiments are consistent with the L-meson being purely $K^*(1420) \pi$.

SPIN AND PARITY

The $K_N(1760)$ and $K_N(2100)$ are both isospin 1/2 states and the existence of two and three body decay modes restricts the spin and parity J^P to the values $1^-, 2^+, 3^-, 4^+, \dots$. As can be seen in Fig. 2 the Y_6^0 moment is large in the 1760 MeV region (and all higher moments are zero) and the Y_8^0 moment is large in the 2100 MeV region (and higher moments are zero). An analysis of the events which are produced backward in the Gottfried-Jackson system and thus do not overlap with the low mass proton-pion enhancement finds three standard deviation evidence for $J^P = 3^-$ for the $K_N(1760)$ (see Phys. Rev. Letters 27 1160 1971). If this J^P is assumed then the ρ_{00} density matrix element for events with $c' < 0.2 \text{ GeV}^2/c^2$ is 0.75 ± 0.12 indicating that pion exchange plays a dominant role in the production process. If we were to speculate that the meager evidence provided by the Y_8^0 moment implies spin = 4 for the $K_N(2100)$, we can produce a Chew-Frautschi plot (Fig. 11) and we see that the hypothesis of linear degenerate Regge-trajectories would be well satisfied.

BRANCHING RATIOS

The fraction of $K^*(890) \pi$ and $K \rho$ as well as uncorrelated three body decays of the two high mass states was found using a maximum likelihood fit to the Dalitz plot. Only for the 1760 region is a background subtraction meaningful. In the $K_N(1760)$ region we now find $33 \pm 12\%$ $K^*(890) \pi$ and $48 \pm 14\%$ $K \rho$ whereas we earlier reported 40% and 60% respectively. In addition, the amount of $K_N(1760) \rightarrow K \pi$ increased somewhat when we allowed for an additional higher mass state and thus we now find the ratio $(K^* \pi + K \rho) / K \pi = 1.60 \pm 0.44$.

Fig. 12: $K^0 \pi^+$ and $\pi^+ \pi^-$ mass for various $K^0 \pi^+ \pi^-$ masses, from top 1.57-1.67, 1.67-1.87, 1.87-2.05, 2.05-2.25, and 2.25-2.65 GeV.

Table I Branching Ratios		
Quant.	$K_N(1760)$	$K_N(2100)$
$K^* \pi / K \pi$	0.54 ± 0.24	0.17 ± 0.07
$K \rho / K \pi$	1.05 ± 0.42	0.16 ± 0.06
$K^{**} \pi / K \pi$	< 0.06	0.45 ± 0.18
$K f / K \pi$	-----	0.05 ± 0.02
$K \omega / K \pi$	0.12 ± 0.10	< 0.1
$K^* \rho / K \pi$	0.60 ± 0.22	0.18 ± 0.10
$\bar{N} N / K \pi$	-----	seen
$K \pi / \text{all}$	0.28 ± 0.07	0.45 ± 0.2

Here, $K^* = K^*(890)$, $K^{**} = K^*(1420)$

which is in good agreement with the 7.2 GeV/c experiment which finds (using our new $K^* \pi$ and $K \rho$ fractions) 1.35 ± 0.8 .

In Fig. 12 we present the $K^0 \pi^+$ and $\pi^+ \pi^-$ effective mass distributions for various slices of $K^0 \pi^+ \pi^-$ mass: a) 1.57-1.67, b) 1.67-1.87 i.e. the $K_N(1760)$ region, c) 1.87-2.05, d) 2.05-2.25 i.e. the $K_N(2100)$ region and e) 2.25-2.65 GeV. In contrast to the background slices, which unfortunately have considerable resonance tail effects, the $K_N(2100)$ appears to have $K^*(1420) \pi$ and $K f$ decay modes. The various

branching ratios corrected for unseen decays are given in Table I.

CONCLUSIONS

Evidence for two high mass K^* states is found. The $K_N(1760)$ with mass 1769 ± 12 MeV and width 130 ± 50 MeV decays into $K \pi$, $K^* \pi$, $K \rho$, and $K^* \rho$ and appears to be the companion to the g meson in the 3^- nonet. The $K_N(2100)$ with mass 2115 ± 45 MeV and width 300 ± 100 MeV decays into $K \pi$, $K^* \pi$, $K \rho$, $K^*(1420) \pi$, $K f$, $K^* \rho$, and $\bar{N} N$.

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4. P. Slattery, U. Rochester report UR 875-332.
5. See Review of Particle Properties, Rev. Mod. Physics **45** S104 1973. Except for the 4.6 GeV/c experiment which finds 0.2 ± 0.2 for the ratio $K^*(1420) \pi / \text{all}$, the experiments listed are all 10-13 GeV experiments and are consistent with nearly 100% $K^*(1420) \pi$.