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PROGRESS IN K* SPECTROSCOPY†

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ABSTRACT

The progress in the field of K* spectroscopy is reviewed within the framework of the simple harmonic oscillator quark model, and contrasted with the recent progress made in the charmonium spectroscopy.

1. INTRODUCTION

I will review the progress in K* spectroscopy, (i.e., the spectroscopy of meson states containing one strange quark) since the last Experimental Meson Spectroscopy Conference,[1] in 1974. During this period there has been great excitement and very rapid progress associated with the observation of the production of new kinds of particles in e^+e^- collisions, which have been heralded as the signal for the existence of a new quark—the charmed quark. It is interesting to follow the progress in "old" spectroscopy during this period of rapid growth in the "new" physics.

I begin by listing the four K* states that were accepted at the time of the last EMS;[1]

K(490)

K*(890)

K*(1420)

and the rather dubious S-wave K-π scattering state, the

$\kappa(1200)$.

The first three of these strangeness one mesons belong to the following well established SU(3) nonets

the pseudoscalars ;	$J^P = 0^-$;	(π, K, η, η')
the vector states ;	$J^P = 1^-$;	$(\rho, K^*, \omega, \phi)$
the tensor states ;	$J^P = 2^+$;	(A_2, K^*_{1420}, f, f') .

The scalar states are discussed separately in Section 3.

For the remainder of this review I will discuss the new K* states that have been discovered during the last three years. I would like to carry out the review within the framework of the simple harmonic oscillator quark model. This model has received both respectability and credibility from its great success in explaining the charmonium spectrum observed in e^+e^- collisions, and discussed by Feldman[2] yesterday. Within this model we discuss

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(Invited talk at the V International Conference on Experimental Meson Spectroscopy, Northeastern University, Boston, Mass., April 29-30, 1977) the mesonic states as a quark-antiquark system (see Fig. 1), and the quantum numbers of the meson are derived from the internal quantum numbers of the ($q\bar{q}$) system. (See Table 1.)

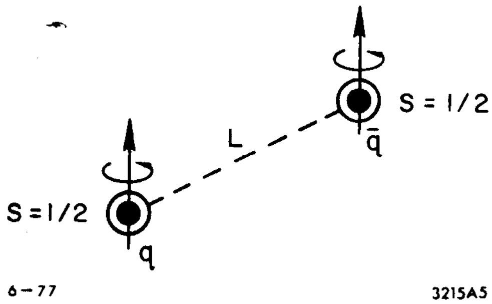

Fig. 1. Schematic of a quark-antiquark meson system.

Table 1. Quantum numbers of meson ($q\bar{q}$) system.

$J = L + S$
$P = (-1)^{L+S}$
$C = (-1)^{L+S}$
$G = (-1)^{L+S-I}$

The spectrum of states expected from such a model of mesons is indicated in Fig. 2. Nuclear physicists are familiar with this kind of display as

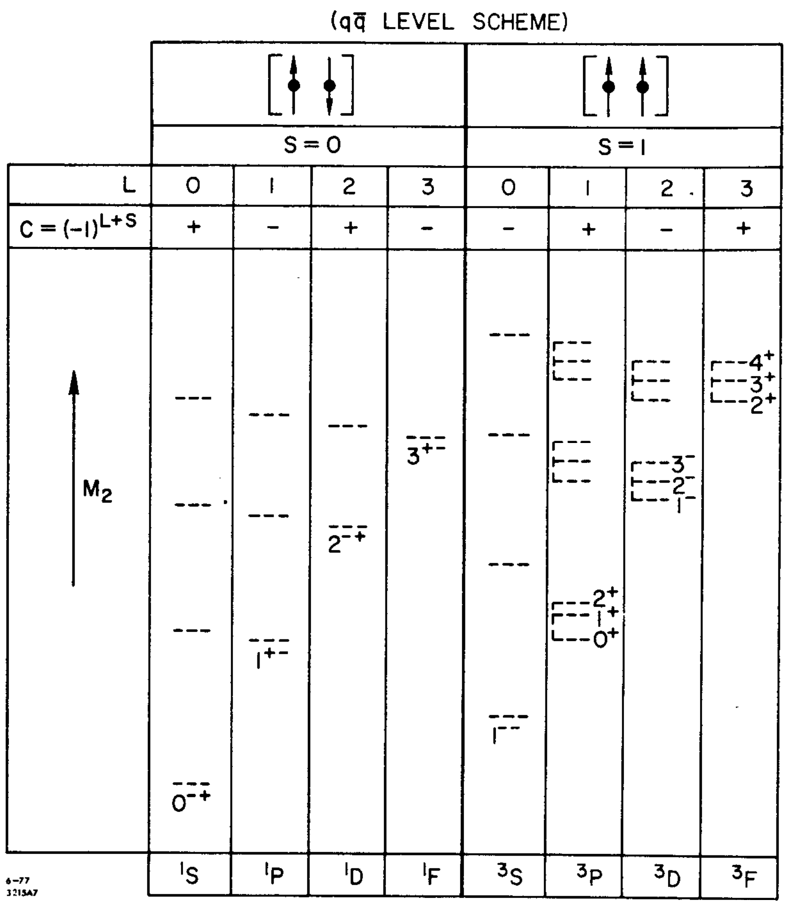

Fig. 2. The level diagram for a quark-antiquark meson system. On the left the antiparallel spin singlet states are shown, and on the right the parallel spin triplet states are shown.

a Grotrian plot. On the left, the states with the quark spins antiparallel are shown. For relative orbital angular momentum between the $(q\bar{q})$ pair, L=0, 1, 2, 3 units we have the mesonic states with $J^P = 0^-, 1^+, 2^-, 3^+$. These correspond to the spectroscopic notations ^1S, ^1P, ^1D, ^1F for the $(q\bar{q})$ states. The states on the right-hand side of Fig. 2 are generated by the $(q\bar{q})$ system with spins parallel. For zero relative orbital angular momentum in this $(q\bar{q})$ system we have the ground state with $J^P=1^-$. When we add one unit of angular momentum, L=1, we find a triplet of levels, ^3P, corresponding to the vector addition of L=1 and S=1 and giving rise to states with $J^P=2^+$, 1^+ and 0^+. Further relative angular momentum gives rise to more triplet levels with higher and higher spins.

The great progress in studying the charmonium spectrum is indicated in Fig. 3, where the observed states are shown on the $(c\bar{c})$ Grotrian plot. We see clear evidence of radial excitations of the $(q\bar{q})$ system, both for the 0^- states and in the remarkable tower of the 1^- ψ states. We also see the complete p-wave triplet level structure appearing with the $\chi(3550)$, $\chi(3510)$ and $\chi(3470)$ states.

What did the K* states look like on such a plot in 1974? The situation is shown in Fig. 4. Just the ground state 0^-, 1^- mesons and only the 2^+ meson of the p-wave triplet was in good standing with the dubious 0^+ κ handing around in the wings.

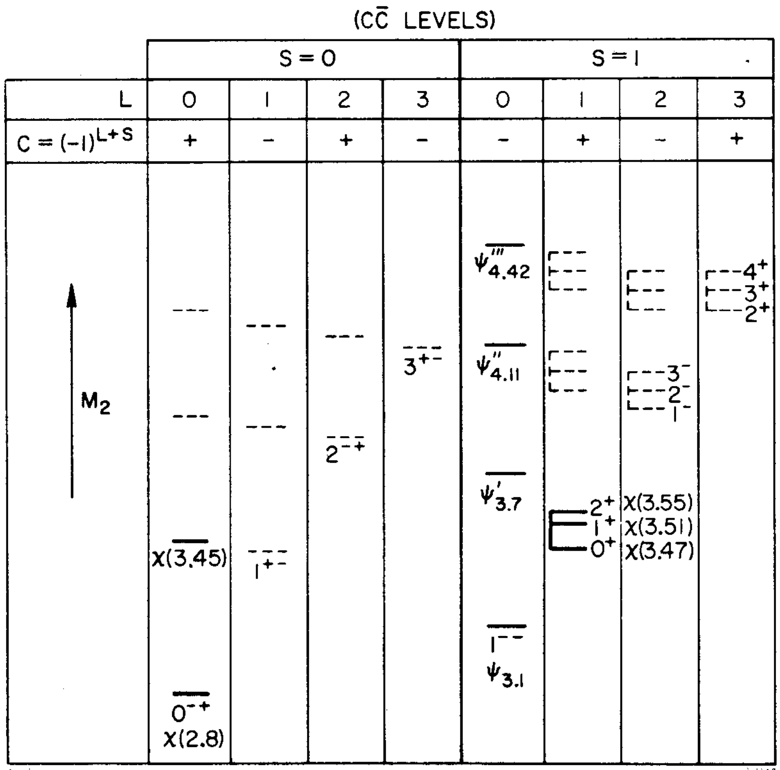

Fig. 3. The quark model level diagram for the charm quark states.

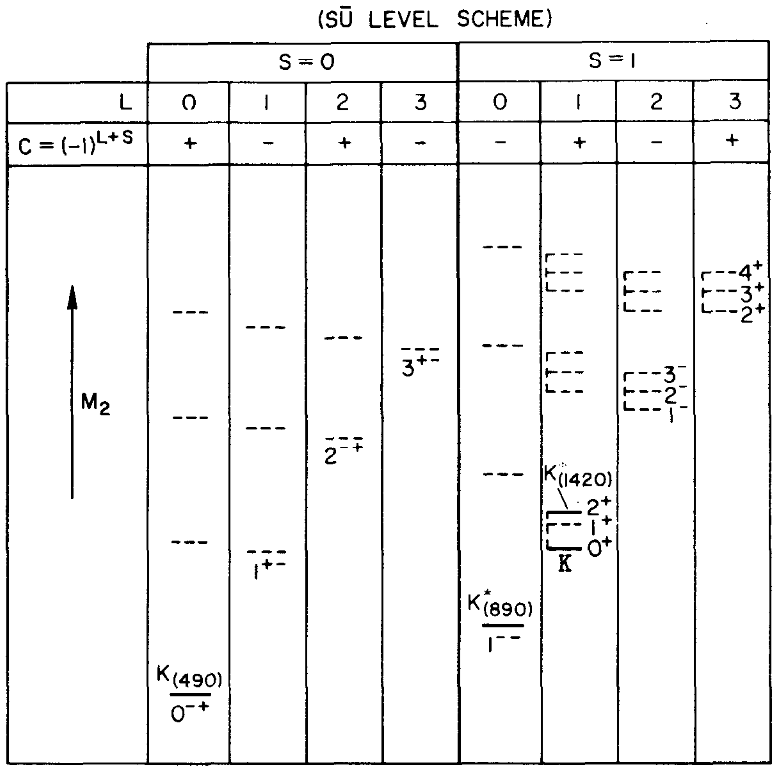

Fig. 4. The quark model level diagram for the $s\bar{u}$ quark states (i.e., for the K* states).

Let us now review the progress in K* spectroscopy in the three years intervening, while all the exciting story of charmonium was unfolding. Where are the triplet p-wave states, the L-excitations, the radial excitation states for the 'old' spectroscopy? First we will consider the missing triplet p-wave ($q\bar{q}$) states—the axial vector mesons and the scalar mesons. We will then examine the evidence for L-excitation and radial excitation in the K* states. Finally we will summarize the K* states and their properties.

2. AXIAL VECTOR MESONS

There has been a long history of searches for the axial vector mesons. Guided by SU(3) and the quark model, we expect two nonets with different charge conjugation quantum number, the A_1 nonet, with $J^{PC} = 1^{++}$ which is the triplet p-wave ($q\bar{q}$) state, and the B nonet, with $J^{PC} = 1^{+-}$, which is the singlet ($q\bar{q}$) state (see Fig. 2). Of these eighteen states only the B meson ($I=1$, $J^{PC} = 1^{+-}$), can be considered well established. The history of the Q meson searches has been summarized by Eisner at the last EMS.[3] Furthermore if the masses of the two eigenstates (Q_A and Q_B) are not too different, we expect mixing such that the physically observable states (the Q_1 and Q_2 mesons), will be a superposition of the two SU(3) eigenstates.

Three experiments have made big advances in this area in the last three years with the result that not only have the resonant Q_1 and Q_2 states been resolved from the Deck background, but the properties of the eigenstates

Q_A, Q_B have been successfully unravelled. The experiments are:

I. The SLAC wire spark chamber experiment[4] studying both K^+ and K^- reactions at 13 GeV/c

$K^+p \to K^+\pi^+\pi^-p$ (72,000 events for analysis)

$K^-p \to K^-\pi^+\pi^-p$ (56,000 events for analysis).

II. A conglomerate of bubble chamber experiments[5] studying K^-p interactions at 10, 14 and 16 GeV/c that combined their data for this study of the Q region

$K^-p \to K^-\pi^+\pi^-p$ (~ 7,000 events for analysis)

$\bar{K}^o\pi^-\pi^op$.

III. The (100 event/μb) big European bubble chamber collaboration (ACNO Collaboration),[6] studying K^-p collisions at 4.2 GeV/c

$K^-p \to K^-\pi^+\pi^-p$ (~ 15,000 events for analysis)

$\bar{K}^o\pi^-\pi^op$.

This experiment should have ~25,000 events available for detailed analysis by the end of the year.

All three experiments perform partial wave analysis on the $K\pi\pi$ system to search for structure in the individual scattering amplitudes. However, the groups use quite different methods to obtain the partial wave amplitudes, using either the Ascoli program to fit the density matrix elements, or the SLAC-LBL program describing the scattering amplitudes themselves. It is really encouraging that the results from all three experiments agree very will on the mass dependence of the amplitudes and phases for all the main waves.

In order to proceed we need to endure a brief description of the isobar model, and discuss the labelling of the resulting partial wave amplitudes. All three analysis describe the $K\pi\pi$ final state in terms of an isobar model, i.e., they discuss the three-body final state as a superposition of two-body states involving a bachelor particle and an isobar state. The isobars used are the K* and ρ vector meson states and the K-π and π-π S-wave scattering states represented as κ and ϵ. The amplitude is then defined for a given $K\pi\pi$ mass in terms of J^PM^η (isobar) L, where J is the spin, P the parity and M the magnetic substate, η the naturality of the exchange in the t-channel (defined as $\eta = (-1)^J \cdot P$), (isobar) is the isobar state being considered—(K*, ρ, κ, ϵ), and L is the relative orbital angular momentum between the isobar and the bachelor particle (see Fig. 5). For example, the well known tensor K*(1420) would be identified as dominating the amplitude labelled 2^+1^+ (K*π) D, while the Q meson would be expected to appear in the amplitude labelled 1^+0^+(K*π) S.

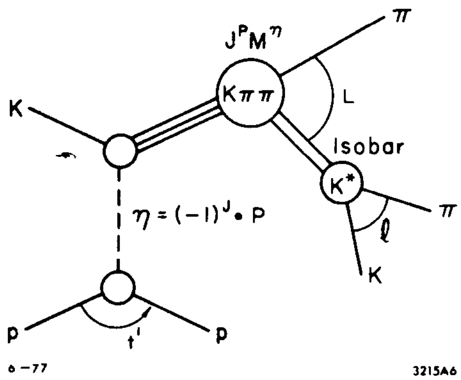

Fig. 5. Schematic diagram describing the isobar model for $K \rightarrow K\pi\pi$ scattering.

Let us now examine the partial wave amplitudes from these analysis. In Figs. 6 and 7 the results from the highest statistics experiment—the 13 GeV/c $K^{\mp}p$ experiment of Carnegie et al.[4] from SLAC—are presented. Let me emphasize that the same behavior is observed in all three experiments.

Figure 6 displays the amplitudes for the $K^*\pi$ final state, with the K^+p amplitudes on the left-hand column and the K^-p amplitudes on the right-hand column. The top row gives the cross section for diffractively produced $K^*\pi$ in the $J^P=1^+$ state as a function of $K\pi\pi$ mass. Below, the M=1 $K^*\pi$ cross sections for both $J^P=1^+$ and 2^+ amplitudes are shown, together with their phases with respect to the diffractive 1^+0^+ wave. The important features of the data are: (a) The rapid rise of the 1^+0^+ cross section from threshold to a peak around 1200 MeV, followed by a shoulder, or second peak, at a mass around 1400 MeV. (b) The nondiffractive $1^+1^+K^*\pi$ amplitudes show the same low mass behavior as the 1^+0^+ amplitude but with an order of magnitude smaller cross section. The

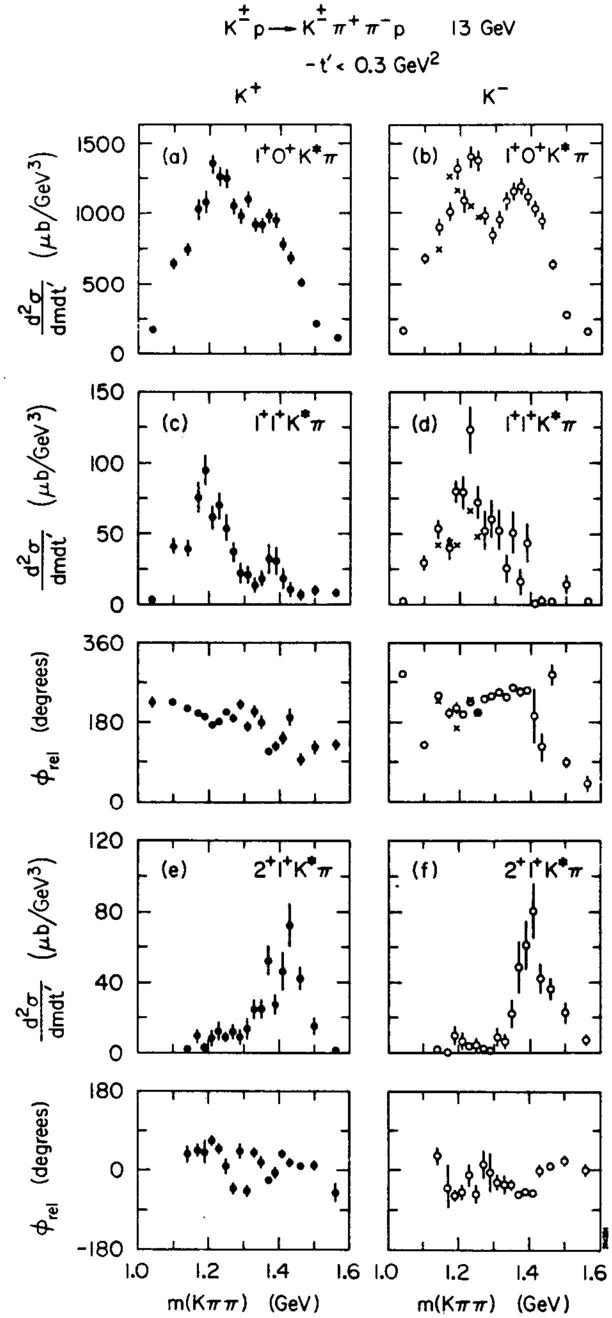

Fig. 6. The results of the partial wave analysis for $K^{\pm} \rightarrow K^{\pm}\pi^+\pi^-$ scattering, for the $K^*\pi$ amplitudes. The phases are measured relative to the $1^+0^+K^*\pi$ wave. See text for full explanation.

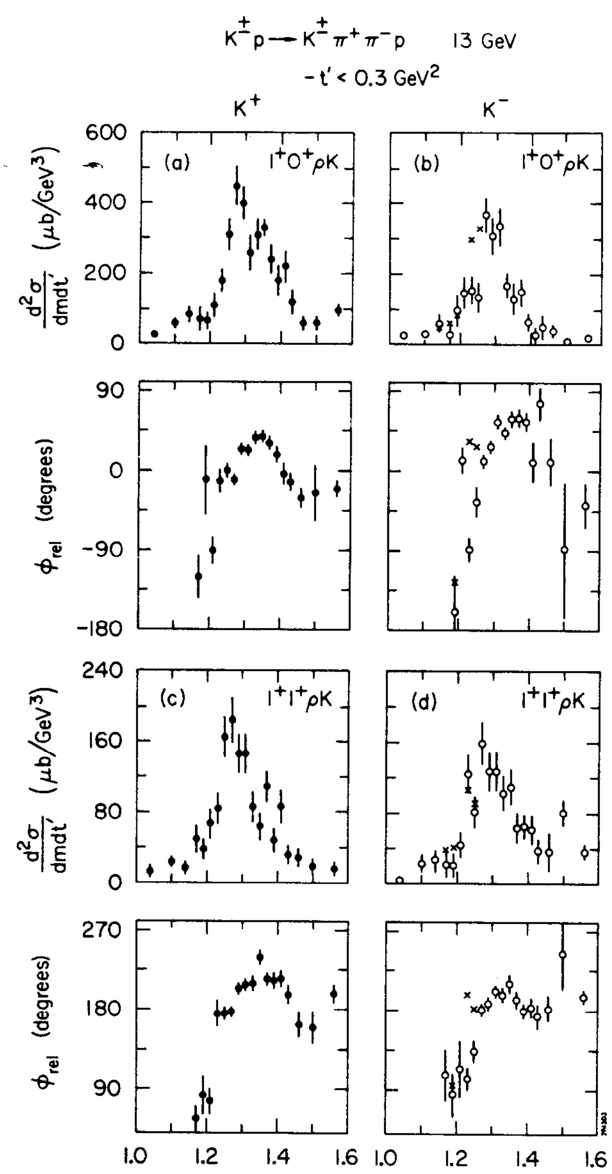

Fig. 7. The results of the partial wave analysis for $K^{\pm} \rightarrow K^{\pm}\pi^+\pi^-$ scattering, for the $K\rho$ amplitudes. The phases are measured relative to the $1^+0^+K^*\pi$ wave. See text for full explanation.

relative phase between 1^+1^+ and 1^+0^+ shows little structure. (c) The $2^+1^+K^*\pi$ cross section exhibits a bump around 1420 MeV, with the position and width expected for the well known K*(1420). The magnitude of the cross section enchancement, when corrected for the accepted decay branching ratio, also agrees well with the measured K*(1420) production in the two-body channel ($K^0\pi^{\pm}$) observed in the same experiment. The phase motion between this well-established resonance and the $1^+0^+K^*\pi$ wave does not exhibit the full Breit-Wigner resonant shape—only a partial, or suppressed resonant phase motion is observed.

The $K\rho$ channel is shown in Fig. 7, using the same format, with the K^+ and K^- reaction results side by side. The top row shows the diffractive $1^+0^+K\rho$ cross section which exhibits a sharp peak at about 1300 MeV and about 200 MeV wide. The same behavior is seen in the 1^+1^+ cross section, but with only about 30% of the cross section. The K^+ and K^- results are very similar. The phase of both 1^+0^+ and $1^+1^+K\rho$ waves with respect to the $1^+0^+K^*\pi$ wave shows very rapid motion—more than 60^o forward and 90^o backward in the (1200-1500) MeV mass range.

It is also interesting to examine the relative phase between the $2^+K^*\pi$ wave and the $1^+K\rho$ wave, as shown in Fig. 8. The cross section exhibits a clear peak for the K*(1420) as was shown earlier in Fig. 6, but now the full Breit-Wigner phase motion is observed, when beat against the $K\rho$ amplitude.

Once more let me emphasize that these features are common to the analysis of all three experiments, within their statistical accuracy. All of the features are well accommodated by a model involving the production of

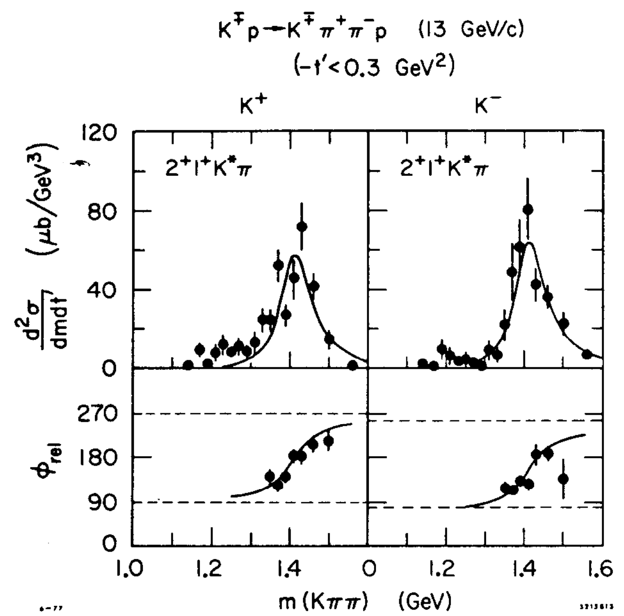

Fig. 8. The partial wave amplitude for the $K^*\pi$ wave with $J^P=2^+$, with the phase measured with respect to the $K\rho$ wave with $J^P=1^+$.

two Q mesons, one with mass of 1300 MeV and coupling mainly to the $K\rho$ channel, and the other of mass about 1400 MeV, coupling mainly to the $K^*\pi$. These two Q mesons are produced coherently with a Deck background. The qualitative features of this model are summarized in Figs. 9 and 10, where the relative phase motion between the $K^*\pi$ and $K\rho$ waves are shown. The suppressed Breit-Wigner motion of the $2^+K^*(1420)$ wave, and the rapid backward-forward motion of the $K\rho$ phase (both with respect to the $1^+0^+K^*\pi$ wave), are seen to be a natural consequence of the resonant phase motion of the two Q meson resonances.

A quantitative application of such a model has been attempted by the SLAC group,[7] and by Bowler.[8] Both achieve a good description of the data.

The SLAC model postulates two Q mesons which are coherently produced with a background that is simply parametrized by a gaussian form. The Bowler model treats the background more seriously and uses a formal Deck amplitude plus rescattering corrections, to describe this piece of the reaction. As mentioned before, both descriptions provide a good fit to the data and there is fair agreement on the values of the various resonance parameters. Figures 11 and 12 show the fit of the Bowler model to the 13 GeV/c SLAC data. Bowler,[8] and Lasinski[9] at SLAC, have attempted fits with only one Q resonance and find such a description of the data implausible.

Another approach to the problem has been introduced by Berger and Basdevant.[10] They have formally included unitarity and coupled channel effects into the two to three body scattering phenomenology. Initially they proposed a description of the $K\pi\pi$ data which called for only one Q meson and the Deck background. Their approach does account qualitatively for many of the observed features of the data, but the model can not quantitatively account for the detailed phase and amplitude behavior without the inclusion of a second resonance. These authors are continuing their study of diffractive 2 → 3 body processes and are now attempting to quantitatively fit to the experimental data. Their initial attempts[11] confronted the 40 GeV/c experiments of Antipov et al.[12] on $\pi^-p \to \pi^+\pi^-p$, where they uncovered probable resonant behavior associated with the A_1. They are currently working on a quantitative fit to the SLAC 13 GeV/c $K\pi\pi$ data,[4] and from their early experience with the model, agree on the necessity for two Q mesons.

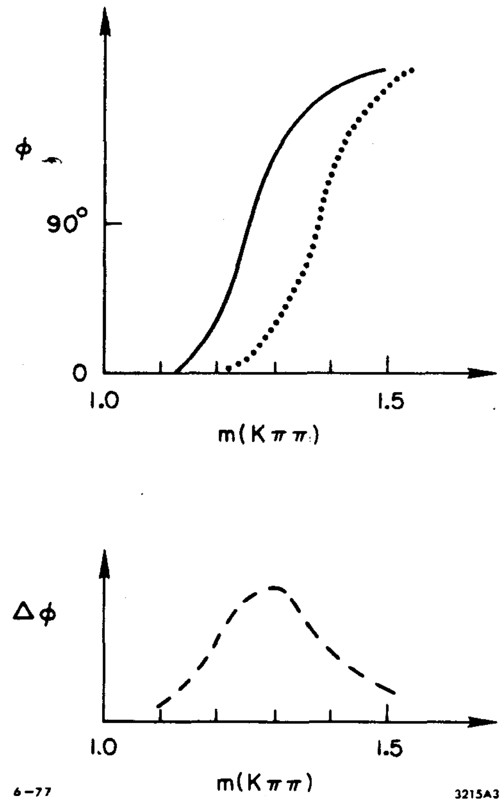

Fig. 9. The phases of the $Q_1(1300)$ $\rightarrow K\rho$ and $Q_2(1400) \rightarrow K^*\pi$ are shown schematically, and the phase difference between them. This picture qualitatively accounts for the large backward-forward motion of this phase difference observed in the data.

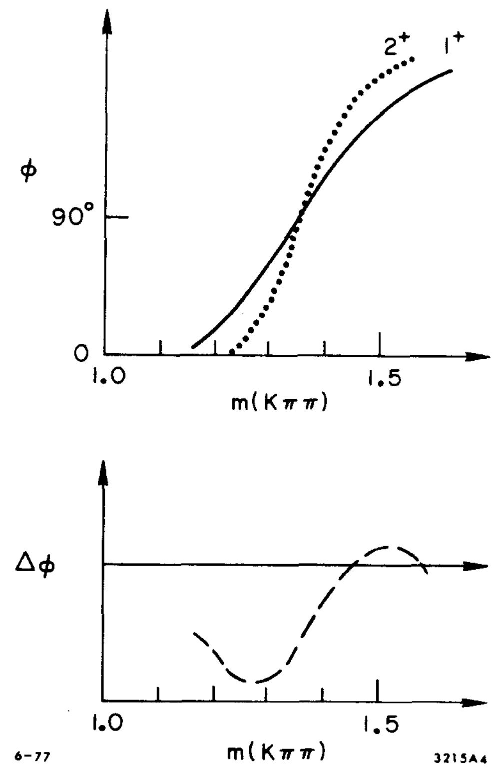

Fig. 10. The phases of the $Q_2(1400)$ $\rightarrow K^*\pi$ and $K^*(1420) \rightarrow K^*\pi$ are shown schematically, together with their relative phase difference. This picture qualitatively accounts for the suppressed Breit-Wigner resonant phase motion observed in Fig. 6.

Two further experimental points should be mentioned with reference to the Q meson situation. Firstly, the European HBC collaboration studying K^-p interactions at 10, 14 and 16 GeV/c have found evidence of the lower Q meson coupling to the $K\omega$ channel.[13] Second, the ACNO collaboration[14] have studied the charge exchange process

$$K^- p \rightarrow K^o \pi^+ \pi^- n \qquad \text{at } 4.2 \text{ GeV/c}$$

They find a substantial enhancement of the $J^P=1^+$ amplitude throughout the (1250-1450) MeV region, i.e., the region of the two Q mesons in the diffractive analysis. When they attempt to study each of the individual isobar amplitudes their results are consistent with a resonant $K^*\pi$ amplitude around 1400 MeV, but no resonant behavior in the $K\rho$ around 1300 MeV.

It is important to find evidence of the Q_1 and Q_2 mesons in both the diffractive and the charge exchange reactions, to show that they are indeed

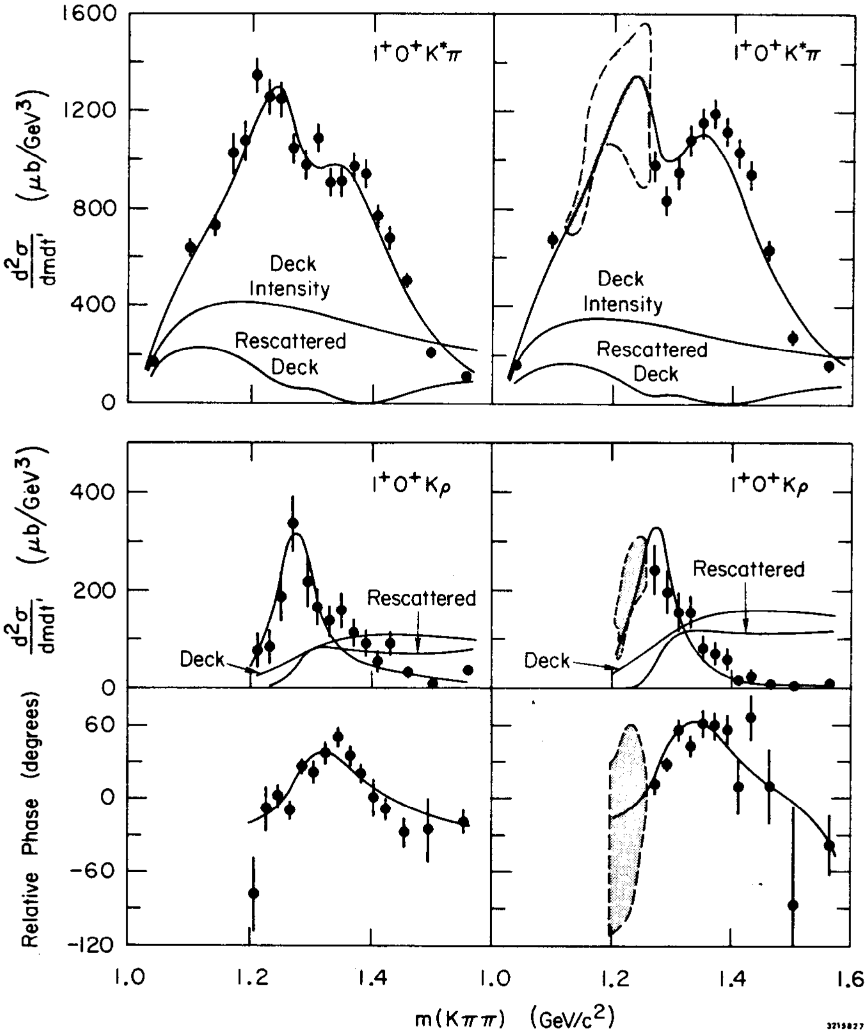

Fig. 11. The results of the Bowler model fits to the SLAC 1^+0^+ partial wave amplitudes, for both $K^*\pi$ and $K\rho$ isobar waves.

reliable resonant states. However, the cross section for the production of these states in nondiffractive processes is not expected to be large—hence the experiment is rather difficult. Indeed, the total statistics in the 4.2 GeV/c charge exchange study are somewhat less than in a typical 20 MeV single mass bin of the SLAC 13 GeV/c experiment. In other words, the statistical sensitivity to the details of the amplitude and phase motion, are marginal. It is encouraging that the 1^+ wave does show an enhancement in the Q_1 and Q_2 regions and that the $K^*\pi$ does behave resonance-like in the Q_2 region, but for the moment, the lack of $K\rho$ resonance behavior is not a serious blow to the existence of the Q_1 state. The ACNO experiment expects a substantial increase in statistics over the next year, and it will be interesting to see the resulting effects on their analysis.

To proceed to the details of the couplings of the Q_1 and Q_2 mesons, we study the quantitative fits of the two models describing the $K\pi\pi$ data—the

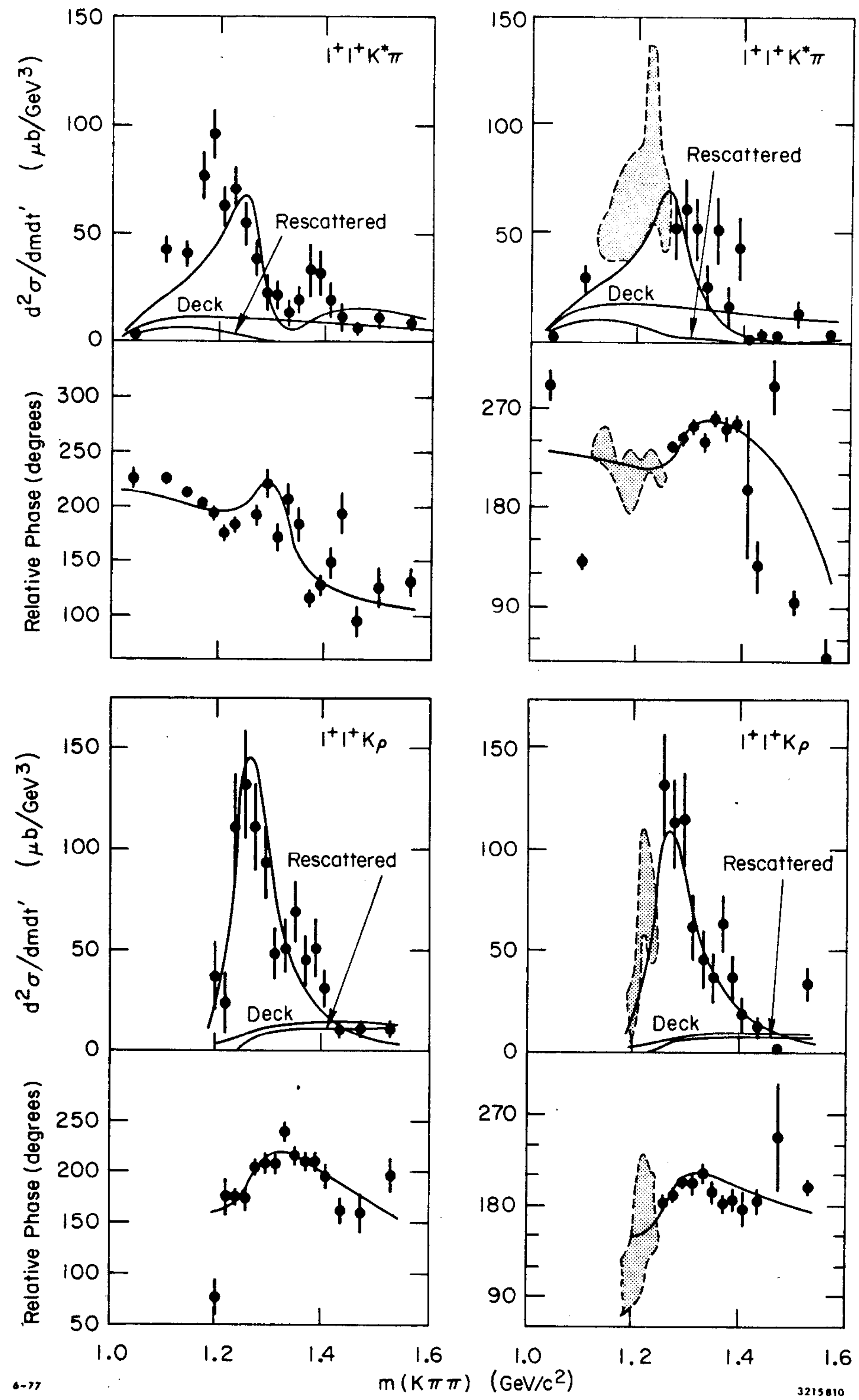

Fig. 12. The results of the Bowler model fits to the SLAC 1^+1^+ partial wave amplitudes, for both $K^*\pi$ and $K\rho$ isobar waves.

Table 2. Properties of the Q_1 and Q_2 mesons.

	Q_1 Meson	Q_2 Meson
Mass (MeV)	1290 ± 25	1400 ± 10
Width (MeV)	210 ± 80	190 ± 65
Partial Widths (MeV)		
$K^*\pi$	12 ± 12	154 ± 52
$K\rho$	100 ± 35	2 ± 1
$K\omega$	32 ± 11	~0
$\kappa\pi$	35 ± 13	31 ± 11
$K\epsilon$	29 ± 10	31 ± 11

SLAC model[7] and the Oxford model.[8] The differences in the estimated couplings from the two models we take to reflect the systematic error involved in the model representation and use this in assigning rather conservative errors to the Q_1 and Q_2 partial widths. In addition to the $K^*\pi$ and $K\rho$ waves discussed above, we include the available experimental information on the $K\omega$,[13] $\kappa\pi$,[4] and $K\epsilon$[4] waves. The results are given in Table 2.

Having discussed the properties of the physical states Q_1 and Q_2 we must remember that they are not necessarily the eigenstates which we want to learn about (i.e., the $J^{PC}=1^{++}$ and 1^{+-} states Q_A and Q_B, which belong to the SU(3) A-, and B-nonets). The Q_1 and Q_2 states are mixtures of the eigenstates Q_A and Q_B. The mixing may be described in terms of a mixing angle θ_Q, and allows the masses and decays to be written as:

$$M_A^{\,2} = \frac{1}{2}\left[M_1^2 + M_2^2 + \left(M_1^2 - M_2^2\right)\cos 2\theta_Q\right] \tag{1}$$

$$M_B^{\,2} = \frac{1}{2}\left[M_1^2 + M_2^2 - \left(M_1^2 - M_2^2\right)\cos 2\theta_Q\right] \tag{2}$$

and

Decay Mode \ State	Q_1	Q_2
$K^*\pi$	$\frac{1}{2}g_A\cdot\cos\theta_Q + \frac{3}{\sqrt{20}}\cdot g_B\cdot\sin\theta_Q$	$-\frac{1}{2}g_A\cdot\sin\theta_Q + \frac{3}{\sqrt{20}}\cdot g_B\cdot\cos\theta_Q$
$K\rho$	$\frac{1}{2}g_A\cdot\cos\theta_Q - \frac{3}{\sqrt{20}}\cdot g_B\cdot\sin\theta_Q$	$-\frac{1}{2}g_A\cdot\sin\theta_Q - \frac{3}{\sqrt{20}}\cdot g_B\cdot\cos\theta_Q$

(3)

where the subscripts A, B refer to the eigenstates and 1, 2 refer to the physical states, and where g_A (and g_B) are the F-type (and D-type) coupling constants governing the decays $Q_A \rightarrow$ vector + pseudoscalar, ($Q_B \rightarrow$ (V)$\cdot$ (PS)).

From the fact that Q_1 decays mainly to $K\rho$ and Q_2 mainly to $K^*\pi$, it is clear that θ_Q must be very nearly 45°. Indeed a quantitative analysis of the decay data finds the mixing angle for the Q_A and Q_B states is $41 \pm 4^{\circ}$. This means that the unmixed states have nearly degenerate masses.

$$M(Q_A) = 1340 \pm 30 \text{ MeV}$$

$$M(Q_B) = 1355 \pm 30 \text{ MeV} \quad .$$

We may also study the partial decays of the Q_1 and Q_2 states to estimate the value of the F- and D-type coupling constants involved in the decays of the pure SU(3) states—Q_A, Q_B. We write the partial width as a product of a kinematic factor times the reduced width, γ

$$\Gamma = (q/m^2)\, \gamma^2 \tag{4}$$

where q is the center of mass momentum in the decay (averaged over the line shape) and m is the mass of the state. The reduced width may be written (as a generalization of Eq. (3))

$$\gamma = c g_A + c' g_B \tag{5}$$

where c, c' are Clebsch-Gordan coefficients. Now, if we plot each decay mode on a g_A versus g_B plane, each would appear as a straight line whose slope and intercept depend on γ and the constants c, c'. If the analysis is consistent we expect to find all the lines intersecting at one point, and that point determines the values of g_A and g_B. Such an analysis[4] is shown in Fig. 13. The width of the lines is a measure of how well a given partial width is measured—narrow representing a well measured decay mode. Also shown on the plot is a line representing the B meson decay into the $\omega\pi$ channel. This line is horizontal, since the B meson is unmixed with the A-nonet, and therefore its decay depend only on the value of g_B. Furthermore

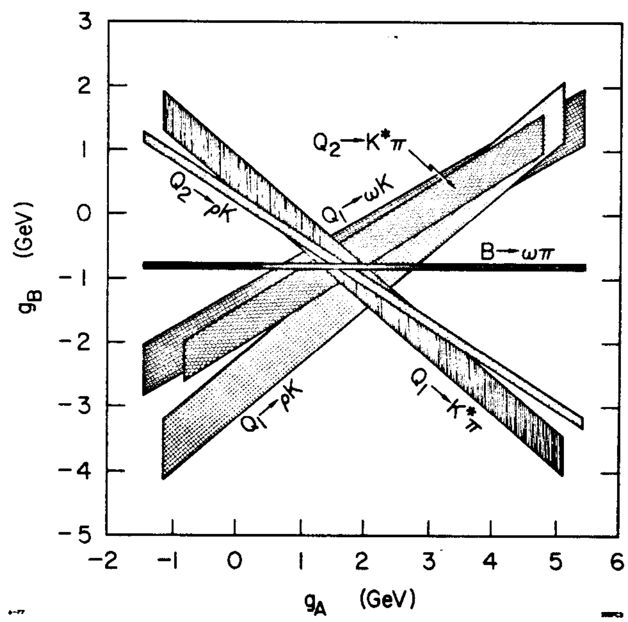

Fig. 13. The decay modes of the Q_1 and Q_2 mesons plotted on a g_B versus g_A plane, where g_B and g_A are the F-type and D-type coupling constants for axial-vector mesons decaying into vector + pseudoscalar mesons.

all the Q $\rightarrow$ (vector) $\cdot$ (pseudoscalar) decays are observed to proceed dominantly through the S-wave and so the B $\rightarrow \omega\pi$ rate has been adjusted to represent only the S-wave decay rate.

It is clear from Fig. 13 that the lines representing the major Q decay modes do indeed intersect and moreover the line corresponding to B $\rightarrow \omega\pi$ decays passes through this region of overlap. This gives additional credence to the consistency of the two Q meson picture and to the quantitative analysis of the decays. The intersection region allows a measure of the SU(3) coupling constants:

$$g_A = 1.7 \pm 0.2$$
$$g_B = -0.8 \pm 0.03 \qquad (6)$$

Given a knowledge of g_A we can determine the width of the elusive non-strange axial-vector meson, the A_1. From Eqs. (4) and (5) we may write

$$\Gamma(A_1) = (2/3) \cdot g_A^2 \cdot (q/M^2) \qquad (7)$$

Then, for an A_1 mass of 1100 MeV, we would calculate that the width should be ~300 MeV, and for an A_1 with mass around 1350 MeV (as being discussed in several 3π partial wave analysis[11, 15]), the width would be ~400 MeV. At any rate, the width of the A_1 appears to be larger than we had previously thought.

We have seen good evidence for the existence of the two strangeness one axial-vector mesons—the Q_A and the Q_B expected in the quark model. Referring back to Fig. 2, this means that we have a good candidate for the ^1P state—the Q_B meson—and for the middle level of the ^3P $(q\bar{q})$ states—the Q_A meson.

Now that the $J^P=2^+$ and 1^+ levels of the triplet P wave system have been found, what is the situation for the lowest level—the $J^P=0^+$ state?

3. THE SCALAR MESONS ($J^P=0^+$)

These are interesting states to study, as they allow, (i) a measure of the spin-orbit splitting in the quark-antiquark interaction through comparison with the $J^P=2^+$ and 1^+ states, and (ii) a comparison of the decay rates of three different nonets (2^+, 1^+ and 0^+ SU(3) nonets) within the same angular momentum band of the $(q\bar{q})$ system which is important for higher symmetry schemes. However, the experimental situation is rather confused, running the gamut from the optimistic viewpoint[16] which asserts that there are just the correct number of states and that they fit together well to form the expected scalar nonet of states, to the pessimists[17] who would propose that the existing scalar candidates are not resonances in good standing since they are so broad (500-800 MeV).

The high priest of the optimistic point of view is Morgan,[16] who, at the time of the last EMS conference, had studied the scalar states and found that a complete nonet could be formed from the following 0^+ states:

I=0 ; ϵ M ~ 1300 MeV , Γ ~ 800 MeV $(\pi\pi)$

I=0 ;	S^*	$M \sim 993$ MeV ,	$\Gamma \sim 100$ MeV	$(\pi\pi, K\bar{K})$
I=1 ;	δ	$M \sim 975$ MeV ,	$\Gamma \sim 100$ MeV	$(\pi\eta, K\bar{K})$
I=1/2 ;	κ	$M \sim 1250$ MeV ,	$\Gamma \sim 450$ MeV	$(K\pi)$

Morgan found that reasonable agreement with the SU(3) mass formula could be obtained with a mixing angle of 69^o between the SU(3) singlet and octet isoscalar states. This mixing angle also allowed agreement among the available decay partial widths. It is a strange value for the mixing angle, and the relative mass ordering of the S^* (presumably more ϕ-like), and the ϵ states is unusual, but it all hung together at that time.

In the meantime new experimental information has become available throwing this tidy arrangement into disarray. The situation for the I=0 ϵ states has been impacted by recent high statistics studies of the reactions:

$$\pi^- p \to K_S^o K_S^o n$$

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

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

by groups at CERN,[18] Notre Dame[19] and ANL.[20] This question is covered in some detail in the talk by Cohen,[21] but the conclusion of these studies is that there is evidence of resonant behavior in I=0, S-wave $K\bar{K}$ at a mass ~1300 MeV and with a width of ~200 MeV. The Morgan ϵ, is very broad, and the mixing angle of 69^o decouples the ϵ from the $K\bar{K}$ channel,[16] while the ANL analysis shows an ϵ-like state width $\Gamma \sim 200$ MeV and coupling very strongly to $K\bar{K}$. Further evidence against the broad ϵ comes from study of $\psi' \to \psi\pi\pi$ decays at SPEAR. The $(\pi\pi)$ system accompanying the ψ is allowed only even orbital angular momentum and must have I=0. The observed $\pi\pi$ mass spectrum does not show signs of an 800 MeV wide ϵ à la Morgan, but is reminiscent of the old situation (pre-1974), with two I=0 states under the ρ and the f mesons and both with widths of order 200-300 MeV.

Similar problems have arisen for the κ meson. In the Morgan nonet the I=1/2 member is associated with the S-wave $K\pi$ scattering phase shift slowly wandering up through 90^o. New data exists on the $K\pi$ scattering amplitudes and has been summarized in the talk by Estabrooks.[22] The high statistics 13 GeV/c SLAC experiment[23] studying

$K^+p \to K^+\pi^-\Delta^{++}$	(110,000 events)
$K^+\pi^+n$	(15,000 events)
$K^-p \to K^-\pi^+n$	(51,000 events)
$K^-\pi^+\Delta^o$	(45,000 events)
$K^-\pi^-\Delta^{++}$	(25,000 events)

has been analyzed to obtain the Kπ partial wave scattering amplitudes. A unique description is obtained below 1450 MeV, but for higher energies there is a four-fold ambiguity. All solutions have an f-wave resonance ($J^P=3^-$) at a mass ~1780 MeV, and all have activity in the Kπ S-wave just above 1400 MeV. (See Fig. 14.) The motion of the S-wave amplitude is very resonance-like and would imply a 0^+ κ state with M ~ 1425 MeV and with a width ~250 MeV. The S-wave behavior below 1400 MeV is in good agreement with the existing Kπ analysis—i.e., if one wants to believe the slow meandering of the S-wave Kπ scattering up through the 90° value is resonance behavior then that also exists in the new high statistics analysis. There is however, very good evidence for new, quite narrow, structure in the 0^+ wave.

Is this the real κ or is it κ'? This is an interesting question. If the new κ(1425) is the real 0^+ state, what is the old κ(1250)? Is it a sign that there exist states which do not belong to the simple quark model? Is it a possible ($qq\bar{q}\bar{q}$) exotic state of the type predicted by Jaffe?[24] (See Lipkin's talk[25] for more details on this point.) Is it a resonance at all?

What of the new κ(1425)? If it is the 0^+ state, then there is essentially no spin-orbit splitting for the triplet p-wave K* states (i.e., 2^+-K*(1420); 1^+-Q_A(1350); 0^+-κ(1425)). This is unusual given the large splitting observed for the χ states in the charmonium spectrum[2] and our expectation

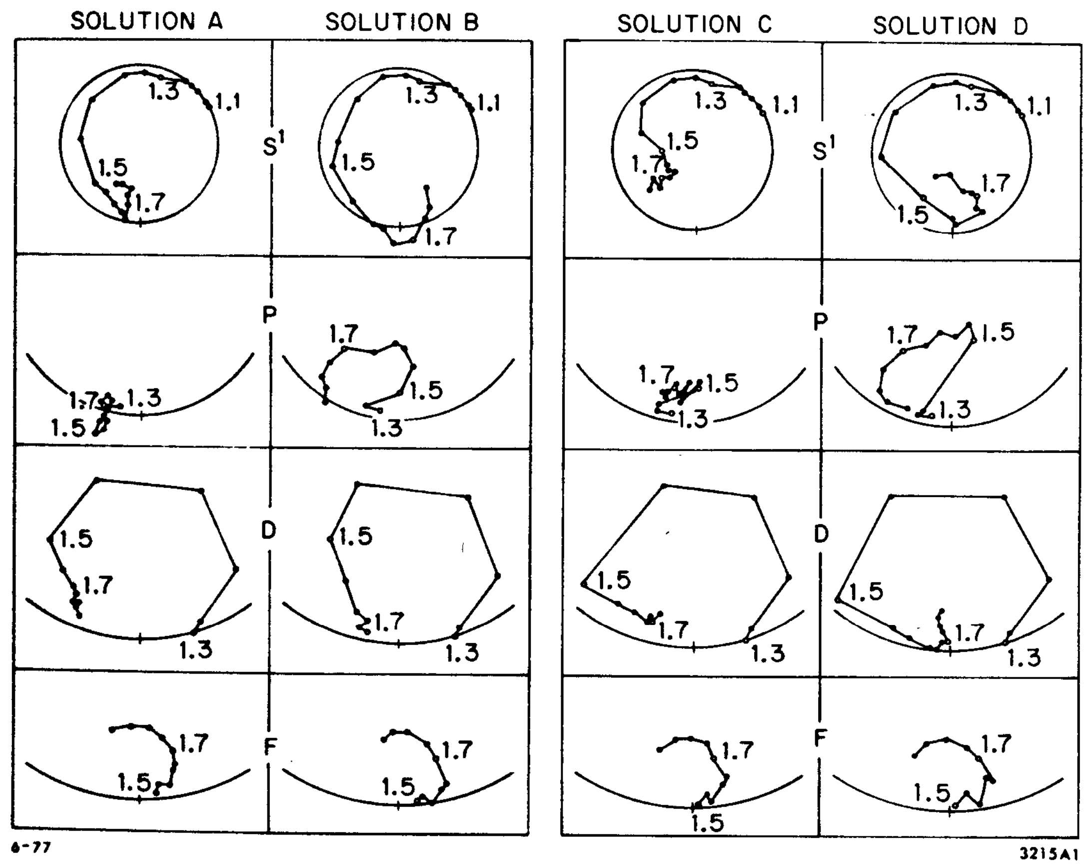

Fig. 14. The Argand diagrams for Kπ scattering from the SLAC-Carleton-McGill partial wave analysis.

that the light quark splitting (i.e., relativistic situation) should be even larger.

The situation for the scalar mesons is very interesting and throws the tidy old 0^+ nonet of Morgan into confusion. There are also many interesting questions being raised with respect to the quark-quark interaction both on the issue of the existence of exotics and on the strength of the spin-orbit $(q\bar{q})$ force. However, no ready answers appear to be at hand, either for the spectroscopy (i.e., which is the correct nonet?) or on the mysteries of the $q\bar{q}$ dynamics.

4. UP THE QUARK LADDER—L EXCITATION

Let us continue "up the quark ladder" and look at the L-excitation structure of the $(q\bar{q})$ spectra (i.e., the spectrum of states generated as the relative orbital angular momentum, L, between the quark and antiquark increases). The Grotrian plot of Fig. 2 shows two sets of levels unfolding as L increases—the singlet states (on the left), coming from the antiparallel spin $(q\bar{q})$ states, and a series of triplet levels (on the right), generated by the parallel spin $(q\bar{q})$ states. An alternative display for the meson levels is shown in Fig. 15. This is called a Chew-Frautchi plot, and displays the trajectory of states on a spin, J, and mass squared, M^2, plane. The upper plot shows the expected trajectories for states with unnatural spin-parity, while the lower plot is for states with natural spin-parity. The unnatural J^P states of Fig. 15 are the singlet states on the left of Fig. 2, together with the middle levels of the triplet states on the right-hand side of Fig. 2. The natural J^P trajectories may be identified with the upper and lower states of the triplet levels from Fig. 2. We see immediately, in Fig. 15, that the unnatural J^P trajectories are degenerate (or nearly so), and that for every spin value there will be two states with the same mass, spin and parity and differing only in the charge conjugation quantum number, C. This means, for K* states, that we must face the same disease we encountered for the Q meson—i.e., the two quark model states mix and we physically detect a superposition of the two states. Therefore, a study of the 1^+, 2^-, 3^+, 4^- series of K* states will require high statistics experiments together with detailed and sophisticated analysis to uncover the quark model L-excitation structure. To make progress in such an investigation we should study the leading trajectory of the natural J^P series. The first two members of this trajectory are

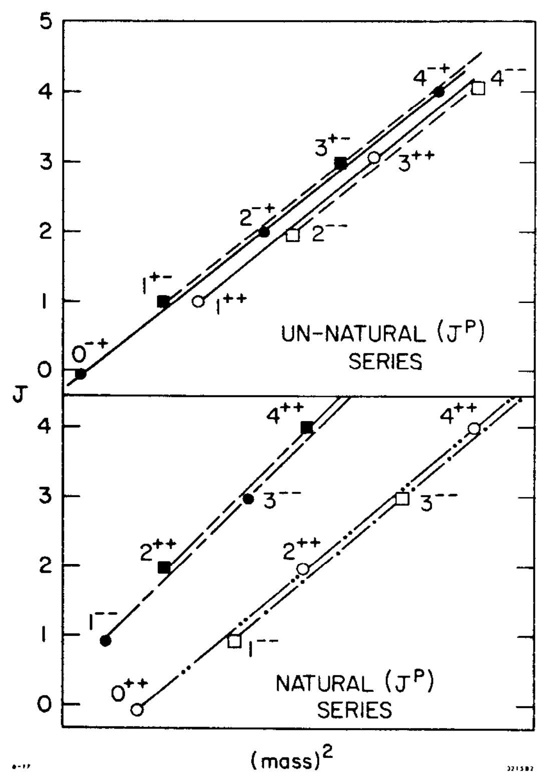

Fig. 15. A Chew-Frautchi plot for meson states.

the states with $J^P=1^-$ and 2^+, which are identified with the SU(3) nonets (ρ, K*(890), ω, ϕ) and (A_2, K*(1420), f, f'). The third member has $J^P=3^-$ and is associated with the incomplete nonet; (g, ?, ω', ?). What of the K* state?

There have been many reports from limited statistics bubble chamber experiments[26] of an effect in the $K\pi$ system at a mass around 1700-1800 MeV and associated with natural spin-parity assignment, most probably with $J^P=3^-$. However, during the past two years three new high statistics experiments and two $K\pi$ partial wave analysis provide clear evidence for a $K\pi$ resonance with $J^P=3^-$ at a mass around 1780 MeV. The new experiments are:

1) The SLAC 13 GeV/c experiment[27] studying

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

$$K^-p \rightarrow K^-\pi^+\underset{(\Delta)}{n} \quad ,$$

2) The University of Geneva experiment of Baldi et al.,[28] using a nonmagnetic proportional wire chamber spectrometer to study

$$K^+p \rightarrow K^o p\,\pi^+ \qquad \text{at } 10\ \text{GeV/c} \quad ,$$

3) The BNL-Brandeis-CCNY-U.M-U.Penn collaboration[29] using the BML Multiparticle Spectrometer (MPS) to study

$$K^-p \rightarrow K^-\pi^+n \qquad \text{at } 6\ \text{GeV/c} \quad .$$

The other sources of confirmation are two analysis of $K\pi$ scattering, one by Bowler et al.[30] studying 5.5 GeV/c $K^+n \rightarrow K^+\pi^-p$, and the other by Estabrooks et al.[23] using the 13 GeV/c SLAC $K^\pm p \rightarrow K^\pm\pi^\pm$"N". Both analysis find a resonant signal in the leading f-wave for $K\pi$ scattering at a mass around 1750-1800 MeV. For example, see the Argand diagrams from the SLAC experiment in Fig. 14. These analyses are discussed more fully in the talk by Estabrooks.[22]

Let us look briefly at each of the new experiments. The $K\pi$ mass spectrum from the MPS experiment[29] is shown in Fig. 16. This data is uncorrected for acceptance losses due to geometrical and trigger biases, which explains, for example, why the K*(890) peak is so small with respect to the K*(1420). This group is working hard on understanding the corrections to the data and hope to have an analysis of the corrected $K\pi$ scattering distributions by the end of the year. Qualitatively, they already see clear evidence of structure around 1780 MeV and strong indications that it is associated with the onset of J=3 waves. A detailed analysis of the 10^5 $K\pi$ events from this experiment, when the acceptance corrections are finished, should provide good information on the properties of the K*(1780).

Figure 17 shows the $K^o\pi^+$ mass spectrum and the Y^5 and Y^6 moments of the $K\pi$ decay angular distribution from the experiment of Baldi et al.[28] A clear peak at 1780 MeV is seen in the mass spectrum, while evidence of interference between L=2 and L=3 waves is seen in the Y^5 moment reflecting the interference between the high mass tail of the K*(1420) and the onset of

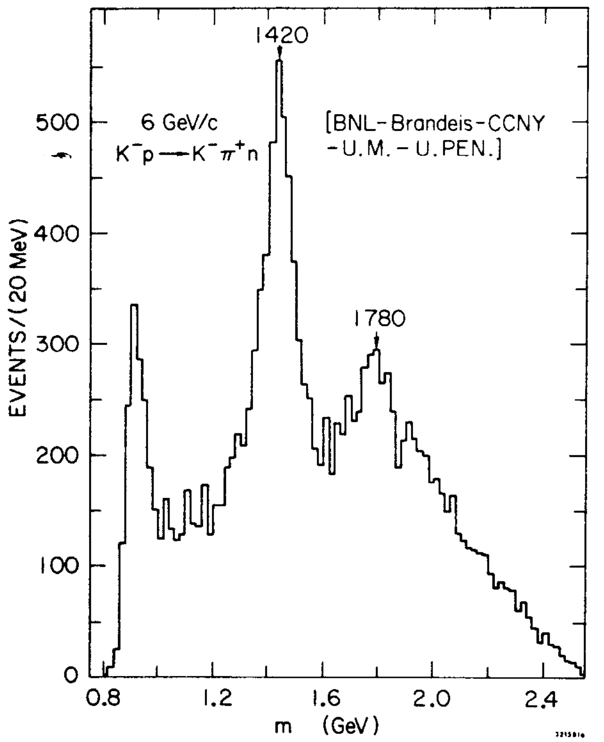

Fig. 16. The uncorrected $K\pi$ mass spectrum from the MPS experiment studying $K^-p \to K^-\pi^+n$ at 6 GeV/c.

the K*(1780). The Y^6 moment shows a peaking structure consistent with the existence of an L=3 resonance around 1780 MeV.

Finally, Fig. 18 displays the Y^5 and Y^6 moments describing the $K\pi$ angular distributions from the SLAC 13 GeV/c K^+ and K^- experiments. The solid curves represent the simultaneous fits to both K^+ and K^- data with K*(1420) and a $J^P=3^-$ state around (1700-1800) MeV.

All experiments agree fairly well on the mass of the new resonance, but the determination of the width is more difficult. The onset of higher waves in the $K\pi$ scattering has a strong influence on the behavior of the Y^5 and Y^6 moments above ~1800 MeV, making an analysis of the full

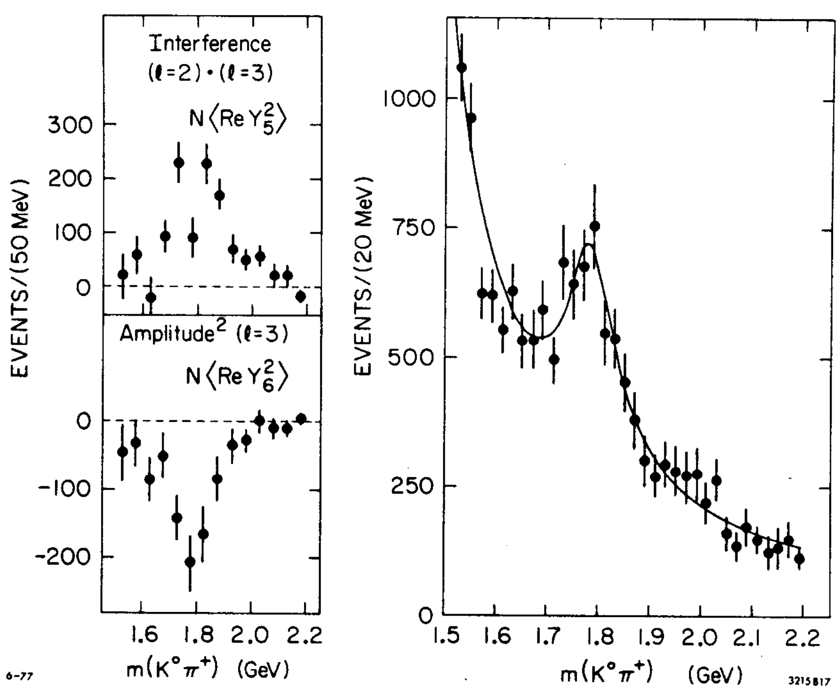

Fig. 17. Results on the mass spectrum and Y^5 and Y^6 moments of the $K\pi$ scattering angular distribution from the experiment of Baldi et al. on $K^+p \to K^0p\pi^+$ at 10 GeV/c.

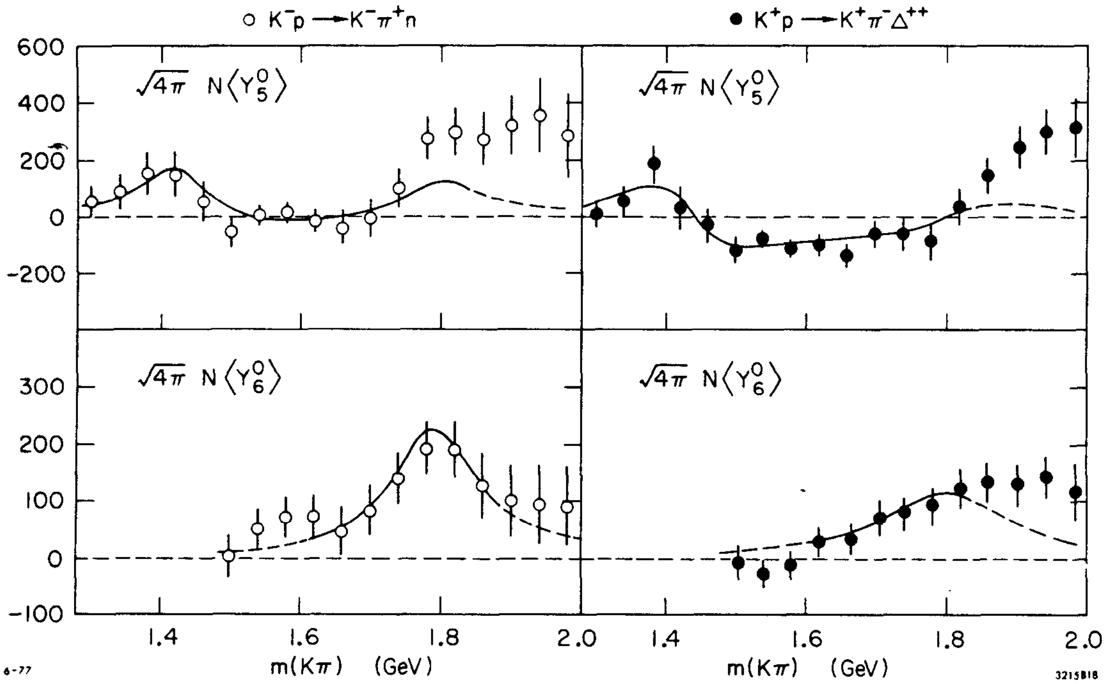

Fig. 18. Y^5 and Y^6 moments of the $K\pi$ scattering angular distribution from the SLAC $K^{\pm}p$ experiments.

line shape both difficult and dangerous. Dunwoodie[31] has performed a careful study of the data from Baldi et al. and from the SLAC experiment and obtained stable values for the width of the new resonance by fitting only the leading edge of the moment distributions. His results are given below and summarized in Table 3.

In summary, there is very clear evidence for a $J^P=3^-$ K* state with $M=1780$ MeV and $\Gamma=175\pm35$ MeV. The elastic phase shift analysis gives the coupling of this state to the $K\pi$ channel as (19±1)%. There is also clear evidence from a variety of bubble chamber experiments that this state has substantial coupling to $K\pi\pi$. However, there is no good data to allow a partial wave analysis and to provide quantitative measurement of the coupling strength and a determination of the specific isobars involved in the three-body decay. Such an experiment is currently being analyzed by the Lindenbaum-Ozaki group using the MPS, and should provide very detailed information on the inelastic properties of the K*(1780). (See Table 4.)

In Fig. 2 or 4, we saw that the D-wave ($q\bar{q}$) would produce a triplet of levels with $J^P=3^-, 2^-, 1^-$. We have seen good evidence for the K*(1780) as the leading trajectory $J^P=3^-$ state. What of the other levels of the triplet?

The $J^P=2^-$ state suffers from the "Q-disease" as we discussed above; it will be a confused region involving physical states which are mixtures of the two $J^{PC}=2^{--}, 2^{-+}$ K* states. A preliminary analysis of the $K\pi\pi$ partial waves from the SLAC 13 GeV/c experiment, through the region where we would expect the $J^P=2^-$ K* is shown in Fig. 19. Indeed a strong resonance-like peak is observed for the 2^- wave around 1750 MeV. This has been

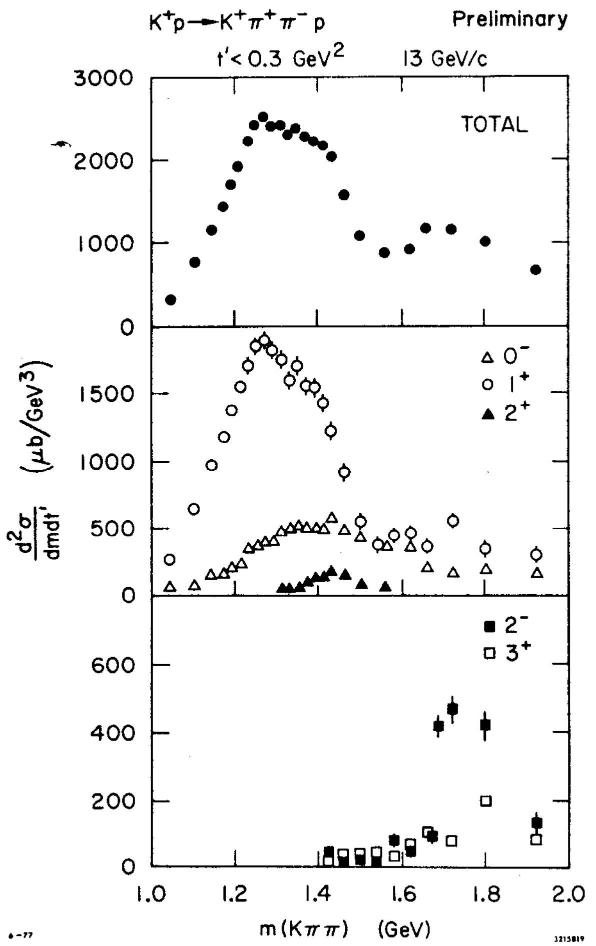

Fig. 19. Preliminary results of a partial wave analysis of the $K^{\pm} \rightarrow K^{\pm}\pi^{+}\pi^{-}$ scattering by the SLAC group, extended into the high mass region.

called the L region. However, it will require very high statistics experiments and detailed partial wave analysis to unfold the mixing and determine the properties of the bare quark model states.

The 1^- state from the D-wave triplet levels may be confused with the radial excitation of the ground state S-wave $(q\bar{q})$ system (see Fig. 2), so we postpone discussion of the level until later.

Let us briefly consider the next level of L excitation of the $(q\bar{q})$ system. For L=3, we expect a triplet with $J^P = 4^+, 3^+, 2^+$ and a singlet state with $J^P=3^+$. For reasons we have discussed above, we only consider the leading natural spin-parity state—the K* with $J^P=4^+$. Possible SU(3) partners for this state are known; the I=1 S meson at 1930 MeV, and the I=0 h meson at 2020 MeV.

Several years ago Carmony et al.[32] had an indication of the existence of such a K* state from their studies of the reaction $K^+n \rightarrow K^+\pi^-p$ at 9 GeV/c. They found structure in the Y^8 moment of the $K\pi$ scattering distribution at 2100 MeV, indicating activity in the $J^P=4^+$ wave. The high statistics SLAC $K^{\pm}p$ experiment also observes such an effect in the Y^8 moment at 2100 MeV, but unfortunately it is very close to the edge of the spectrometer acceptance. Figure 20 shows a scatter plot of the $K\pi$ angular distribution against the mass of the $K\pi$ system, and the projection of the Y^6 and Y^8 scattering distribution moments. The solid curve represents the behavior of the spectrometer acceptance moment. The Y^8 moment shows structure around 2100 MeV. In Fig. 21, the data from all three reactions from the SLAC experiment have been combined, and the resulting Y^8 moment displayed. Again, clear structure is seen in this moment around 2100 MeV, indicative of activity—perhaps resonant behavior—in the $J^P=4^+$ wave. This effect needs confirmation.

In concluding this section on the L excitation of the K* states we see much of the expected quark model pattern unfolding. The leading states are shown in Fig. 22 where candidates have been found for L=0, 1, 2 and 3, and

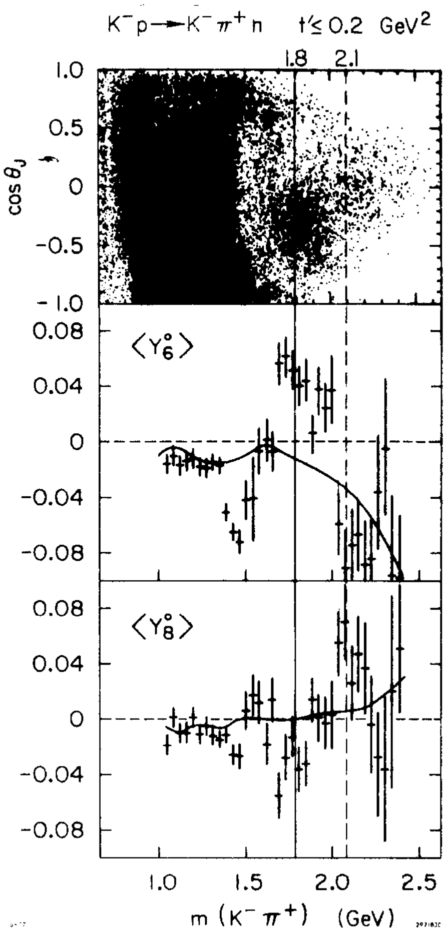

Fig. 20. A scatter plot of the cosine of the $K\pi$ scattering angle and the $K\pi$ mass from the 13 GeV/c SLAC experiment. The Y^6 and Y^8 moments of the scattering angular distributions are also shown. The solid lines represent the spectrometer acceptance moments.

there is even a tantalizing hint of the L=4 state (see Fig. 21). The triplet level structure has been studied only for the p-wave case, but large experiments are in progress which should allow these studies to be extended to the d- and f-wave triplet levels in the near future. However, pushing these studies to higher spin, higher mass K* states is not going to be easy. These states are produced mainly by pion exchange, which becomes more dominant as the spin and mass increase. However, the coupling strength of these new states to the elastic $K\pi$ channel appears to decrease rapidly as the mass and spin increase, as indicated in Fig. 23. We can therefore expect a much harder time in studying the higher excited K* states.

5. RADIAL EXCITATIONS

When we first considered the spectrum of states we might expect to encounter in Fig. 2, we found the ground state pattern reproduced at higher masses. These excited states are interpreted as radial excitations of the $(q\bar{q})$ system. In Fig. 3 we saw good examples of radial excitations, especially for the ψ states. What is the evidence for such radial structure in "old" spectroscopy? We know of examples in baryon spectroscopy where members of the radially excited [56] L=0 representation have been discovered.[33] They are the $P_{11}(1470)$, a radial excitation of the nucleon, and $P_{33}(1700)$, a radial excitation of the $\Delta(1236)$. In the period since the last EMS conference two candidates for radially excited K* mesons have been found in the analysis of the SLAC 13 GeV/c $K^{\pm}p$ experiment; a heavy K meson and a vector meson.

K'(1400). The evidence for this state is found in the partial wave analysis[34] of the 13 GeV/c experiment in $K^{\pm}p \rightarrow (K\pi\pi)^{\pm}p$ by Carnegie et al., discussed in detail in the Q-meson section above. The cross sections as a function of $(K\pi\pi)$ mass for the $J^P=0^-$ waves in both the K^+ and K^- experiments are shown in Fig. 24. The relative phase between this wave and the $1^+0^+K\rho$ wave is given in the second row. The bottom two rows show the

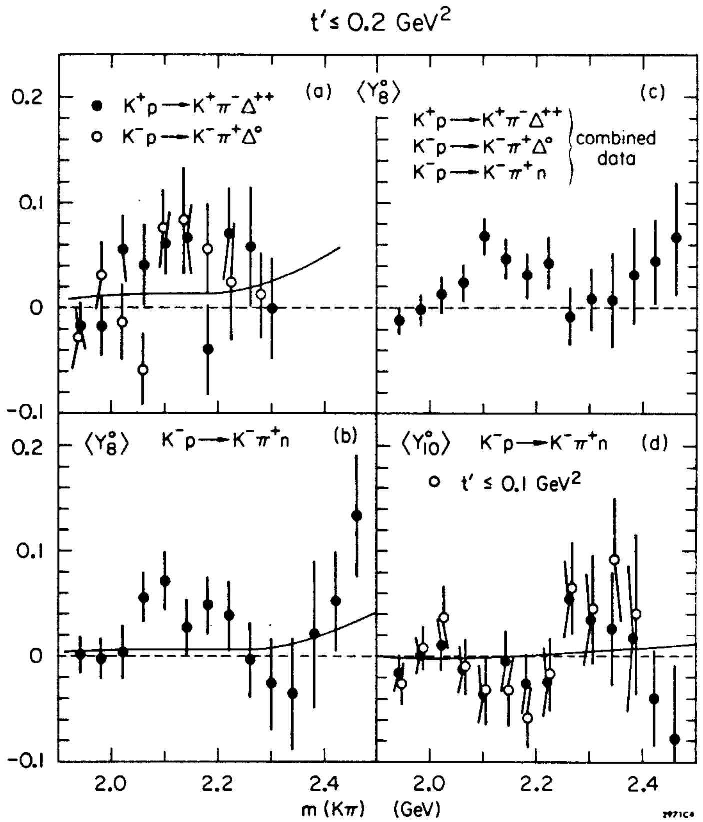

Fig. 21. The Y^8 moment of the $K\pi$ scattering distribution from the 13 GeV/c SLAC experiment on the three reactions—$K^+p \to K^+\pi^-\Delta^{++}$, $K^-p \to K^-\pi^+\Delta^0$, and $K^-p \to K^-\pi^+n$.

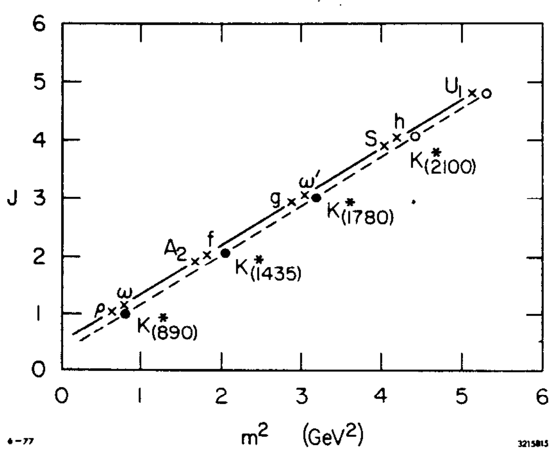

Fig. 22. A Chew-Frautchi plot for the leading natural spin-parity trajectory. Candidates for the $J^P = 1^-$, 2^+, 3^-, 4^+ K^* states have been observed.

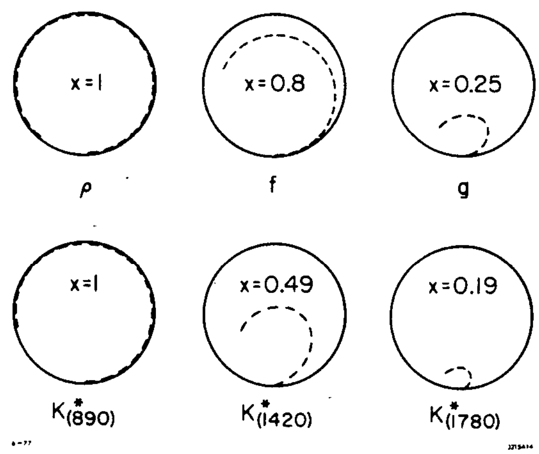

Fig. 23. Schematics of the Argand plots for π-π and K-π scattering showing the decreasing coupling strengths to the elastic $\pi\pi$, $K\pi$ channels as the spin and mass of the resonant states increase.

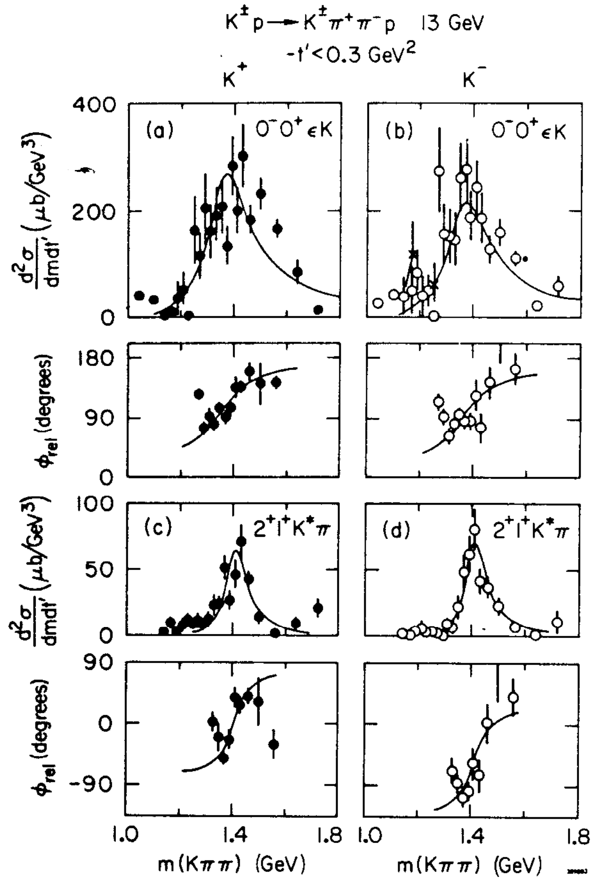

Fig. 24. The 0^- ϵK partial wave amplitude from the analysis of the 13 GeV/c SLAC $K^{\pm}p$ experiment. The phases are measured relative to the 1^+0^+ Kρ wave. The solid curves are Breit-Wigner resonance shapes for the K*(1420) and a new heavy K meson, K'(1405).

cross section for the well established K*(1420) in the 2^+ K*π wave and the relative phase between that wave and the 1^+0^+ Kρ. The 0^- wave shows clear evidence of a resonant peak in the cross section and the full Breit-Wigner phase motion. In fact the similarities between the 0^- and 2^+ waves are striking. We take this as evidence for a resonance in $J^P=0^-$ with $M = 1404 \pm 12$ MeV, and $\Gamma = 230 \pm 15$ MeV. Such a state can only be accommodated within the simple quark model as a radial excitation. It decays strongly into Kϵ, and also into K*π and Kρ.

Similar behavior for the 0^- wave is observed in the 4.2 GeV/c ACNO experiment.[6]

It is interesting to note that the production distribution for the heavy K meson is very steep. In fact, the differential cross section is observed to fall off as $(d\sigma/dt) \propto \exp(-18t)$. This behavior was also found for the radial excitation of the nucleon. The differential cross section for the production of the $P_{11}(1470)$ state in high energy collisions is found to behave like $(d\sigma/dt) \propto \exp(-20t)$. It appears that these radially excited states are produced with very steep differential cross sections, and so behave like spatially, extended objects. This is very much in keeping with our intuition for radially excited states, but what does it really teach us?

<u>K*(1650)</u>. The evidence for this state comes from the Kπ partial wave analysis reviewed by Estabrook.[22] The Argand plots from the SLAC-Carleton-McGill analysis[23] are shown in Fig. 14. Two of the four solutions display resonant behavior in the p-wave scattering amplitude around 1600-1700 MeV. The scattering amplitude travels round the outside of the Argand plot tracing out the fully elastic K*(890) behavior, and then curls up in a small "pig's tail" which may be indicative of a K*(1650). This behavior is completely analogous to the behavior observed in the π-π elastic scattering studies, which indicate the presence of a ρ'(1600) in the p-wave $\pi\pi$ scattering.[35] The Kπ partial wave analysis from Bowler <u>et al.</u>[30] also find evidence

for this state. The properties as determined from the partial wave analysis are

$$M = 1650 \pm 50 \text{ MeV}$$

$$\Gamma = 275 \pm 50 \text{ MeV}$$

x, the coupling to the $K\pi$ channel, ~ 0.3.

This state could be either a radial excitation of the K*(890), or it could be the lowest level of the d-wave $(q\bar{q})$ triplet. Other possible SU(3) partners for this K* are the $\rho'(1600)$ [36] and the $\omega'(1780)$. [37]

Finally, an amusing statistic about these radially excited states. There is a well known empirical rule that the difference in the squares of the masses of the related vector and pseudoscalar particles is equal to 0.58 GeV^2, to a surprising degree of accuracy. This works for ρ and π, K* and K, and even the D* and D mesons:

$$\left(M_\rho^2 - M_\pi^2\right) = \left(M_{K^*}^2 - M_K^2\right) = \left(M_{D^*}^2 - M_D^2\right) = 0.58 \pm 0.01 \text{ GeV}^2 \quad .$$

Now for our two new states, assuming that the K*(1650) is indeed a radial excitation of the K*(890), we have

$$\left(M_{K^{*\prime}}^2 - M_{K'}^2\right) = (0.75 \pm 0.15) \text{ GeV}^2 \quad .$$

The masses are not so well determined as the well known states above, but the difference is in the right ball park.

6. CONCLUSION

We have seen evidence for seven new K* states discovered in the past three years. These states, and their properties, are listed in Table 3. The top part of the table deals with the unnatural spin-parity states, and the bottom summarizes the natural spin-parity states. On the top, we have the radial excitation of the K meson, K'(1405), coupling to $K\epsilon$, $K^*\pi$ and $K\rho$. Evidence was also presented for the existence of the Q_A and Q_B mesons, the long missing axial-vector states, which decay to $K^*\pi$, $K\rho$, $K\omega$, $\kappa\pi$, $K\epsilon$. It is interesting to note that although the Q_1 and Q_2 were of comparable width, the pure SU(3) states are quite different, Q_A being about twice as wide as Q_B.

In the bottom section of Table 3, we have the new scalar state, the $\kappa'(1425)$, the vector recurrence K*'(1650), the spin three K*(1780) and a probable spin 4 state, the K*(2100). The best estimate of the mass and width of each state is given, and the various decay modes listed. For those states coupling to the $K\pi$ channel, the elasticity x $(=\Gamma_{K\pi}/\Gamma_{tot})$, is also given.

Not only have we discovered many new states but the level structure we expect from the quark model, and which we discussed at length in Figs. 2, 3 and 4, is clearly emerging for the "old" spectroscopy as well as the "new".

Table 3. Summary of K* resonances and their properties.

	J^P	State	Mass (MeV)	Width (MeV)	Decay Modes	
(Unnatural)	0^-	K	490			
		K'	1450 ± 15	230 ± 20	$K\epsilon, K^*\pi, K\rho, K\pi, \ldots$	New
	1^+	Q_A	1340 ± 30	$\gtrsim 250 \pm 60$	$K^*\pi, K\rho, K\pi, K\epsilon, K\pi, \ldots$	New
		Q_B	1355 ± 30	$\gtrsim 110 \pm 10$	$K^*\pi, K\rho, K\pi, K\epsilon, K\pi, \ldots$	New
(Natural)	0^+	κ	~1200	~450	$K\pi$ (x=1.0)	
		κ'	1425 ± 50	250 ± 50	$K\pi, \ldots$ (x ~ 0.5-0.9)	New
	1^-	K*	896 ± 1	55 ± 1	$K\pi$ (x=1.0)	
		K*'	1650 ± 50	275 ± 50	$K\pi, \ldots$ (x ~ 0.3)	New
	2^+	K**	1435 ± 1	100 ± 4	$K\pi, K^*\pi, K\rho, \ldots$ (x=0.49)	
	3^-	K***	1780 ± 15	175 ± 35	$K\pi, K\pi\pi, \ldots$ (x=0.16)	New
	4^+	K****	~2100	~200	$K\pi, \ldots$	New ?

This is summarized in Fig. 25. We observe the orbital excitation of mesons for the leading natural spin-parity series, and radial excitations of the singlet and triplet S-wave $(q\bar{q})$ ground states. The emergence of the triplet level structure for the S=1 $(q\bar{q})$ states is also observed.

Despite the great progress in our information about the "old" spectroscopy which we have reviewed above, there are many questions still to be answered. For example, now that the 1^+ χ-state, and the Q mesons have been observed where is the A_1? If there is a heavy K meson at 1405 MeV, where is the heavy pion, π' ? Given that the ρ' and K*' states have been found, how do we tell if they are radial excitations or d-wave $(q\bar{q})$ states? The answer to this question implies an enormous effort both in terms of the quality of the data required and in the analysis of the scattering amplitudes. For example,

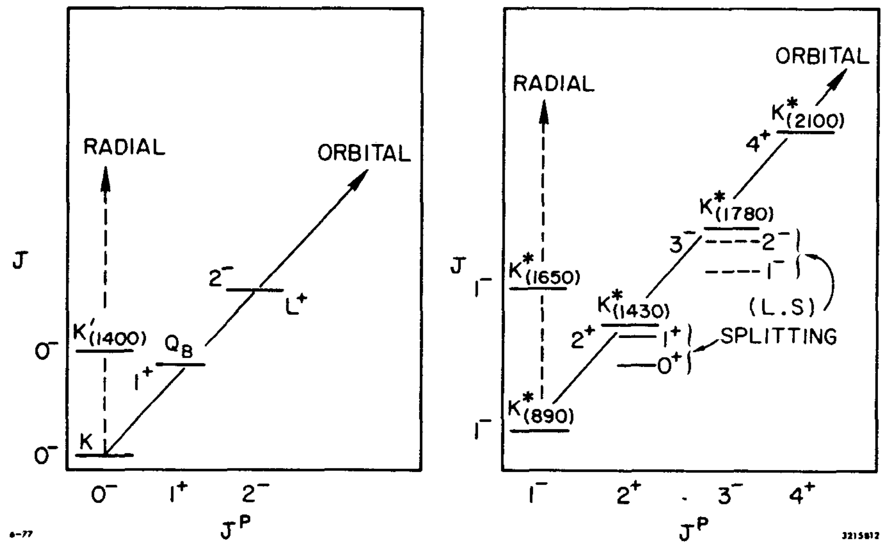

Fig. 25. Schematic Chew-Frautchi plots for the singlet and triplet $(q\bar{q})$ systems. Clear evidence for radial and orbital excitation of the $(q\bar{q})$ system is observed.

for the case of the K*(1650), it would require performing an experiment where the interference between the K*(1780) and K*'(1650) could be measured in an inelastic final state, and the relative sign of the couplings of the two states obtained; e.g.,

$$K\pi \rightarrow K^*(1780) \rightarrow K^*\pi$$

$$K\pi \rightarrow K^{*\prime}(1650) \rightarrow K^*\pi \quad .$$

Using some higher symmetry scheme, for example SU(6), the classification of the K*'(1650) as an S-wave or a D-wave $(q\bar{q})$ system could then be attempted.

A similar effort, both for data taking and the subsequent phenomenological analysis, will be required to unfold the structure of the unnatural spin-parity K* mesons. The 2^+, 3^-... states will be mixed with the middle level of the corresponding triplet series and will require efforts like those discussed in the Q meson section above, to finally untangle the pure quark model states.

We have, however, made very substantial progress and the meson spectroscopy study has not been just a dull bookkeeping of the states but is beginning to confront very basic questions of quark-quark dynamics in such areas as exotics, level splittings and mixing of states. There are several large experiments in progress, or just starting, which should allow these questions to be pursued to greater lengths in the near future. (See Table 4.)

Finally, let me emphasize that it is not only the "new" physics which is exciting and important to our understanding of the basic structure of nature, but the "old" physics has taken a shot in the arm from the excitement and progress in the charm world and is now beginning to ask important questions

Table 4. K^-p experiments in progress.

Energy (GeV/c)	Technique	Group	Sensitivity (event/μb)
4.2	HBC	ACNO collaboration	130
6.0	MPS	BNL/MPS	200 ($K\pi$)
			2000 ($K^0\pi\pi$)
6.0	HBC (12')	ANL collaboration	100
8.2	HBC	European collaboration	100
11.0	LASS	SLAC-Carleton	1000

on the quark-quark interaction and dynamics. A new wave of experiments is upon us, and the new "tools" have been shown to work—the big multiparticle spectrometers to take great volumes of high precision data and the sophisticated partial wave analysis programs to probe the details of the scattering amplitudes. We have seen today some of the early results of this generation of experiments—more is to come!

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