PHYSICAL REVIEW D VOLUME 13, NUMBER 7 1 APRIL 1976

Resonances in the $K_S K_S$ system[*]

D. P. Wilkins,[†] J. R. Albright, S. Hagopian, V. Hagopian, and J. E. Lannutti
Department of Physics, Florida State University, Tallahassee, Florida 32306

(Received 11 August 1975)

The $K_S K_S$ mass spectrum is studied in a $\pi^+ d$ experiment at 15 GeV/c. Two separate mass enhancements at (1047 ± 10) and (1190 ± 10) MeV are observed. The lower mass enhancement is most likely associated with the S^* and the δ while the one at 1190 MeV could be a new resonance or the $A_{1.5}$. Neither enhancement is produced peripherally. An interesting interpretation of this nonperipherality is that the decay of the S^* or δ is dependent on the charge of the beam meson.

Experimental studies have shown that the mass spectrum of mesons between 900 and 1400 MeV is full of enhancements, and not all of them are well understood. It is not uncommon for one experiment to see a statistically significant enhancement while another equally sensitive experiment does not observe the same enhancement. The region below 1100 MeV is even more perplexing, since there are many resonances crammed in an interval of a few hundred MeV. In an attempt to separate out many of these enhancements for analysis, the present experiment used the reaction

$$\pi^+ + d \to K_S + K_S + \text{anything} \qquad (1)$$

in the 82-in. SLAC bubble chamber. The $K_S K_S$ system has stringent restrictions on the quantum numbers, which are as follows:

$$\begin{aligned} J^P &= 0^+, 2^+, 4^+, \ldots, \\ I &= 0, 1, \\ C &= +1, \\ G &= (-1)^I . \end{aligned} \qquad (2)$$

Near the $K\bar{K}$ threshold there are several known resonances, among them the S^*, δ, and ϕ. The S^* and δ resonances always seem to be produced peripherally. Also, not all of these resonances have been seen in all experiments in which they were expected to be seen. This study of reaction (1) may have helped to untangle some of this confusion. The inclusive form of reaction (1) was chosen by necessity to obtain a sensible sample of data. First we present some of the details of the experiment.[1]

The pion beam at a momentum of 15 GeV/c was rf-separated; 369 000 stero triads were photographed. The cross-sectional equivalent was 9.5 ± 0.2 events/μb. The pictures were scanned for two (or more) V's that point to the same vertex. Events were measured on an image-plane digitizer at a magnification of 25 from the film to the table. Geometric reconstruction was done using TVGP; kinematic fitting used SQUAW. As a check on the correctness of the entire measurement and computational procedure we studied the distribution of the unconstrained mass of the K_S and obtained a value of (497.0 ± 1) MeV, with $\sigma = 7$ MeV.

Even at this high a value of the momentum one has little trouble distinguishing K_S decays from Λ decays. Most of the Λ's are produced with low laboratory momenta, so that the fitting in SQUAW usually yields an unambiguous answer. The few V's that were ambiguous were all reexamined visually, checked for consistent ionization, and assigned accordingly. We obtained a sample of 634 events. After correcting for scanning efficiency, computational efficiency, and invisible decays we obtained 202 ± 20 μb as the cross section for reaction (1).

Figure 1 shows the $K_S K_S$ spectrum. There are two well-defined peaks in this graph, each of which rises 3.5 to 5 standard deviations above background, the precise amount depending on how background is estimated. A fit to the two peaks plus

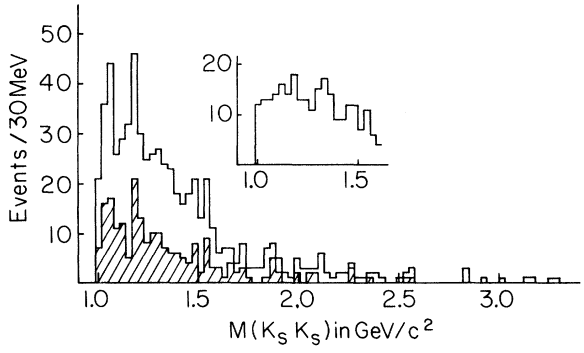

FIG. 1. Mass spectrum for $K_S K_S$ produced by $\pi^+ d$ at 15 GeV/c. The shaded events are those for which $|t'| > 1.8$ GeV^2. The inset shows the events for which $|t'| < 0.9$ GeV^2.

an empirical background yielded

$$M = 1047 \pm 10 \text{ MeV}, \quad \Gamma = 70 \pm 20 \text{ MeV},$$

$$M = 1190 \pm 10 \text{ MeV}, \quad \Gamma = 40 \pm 10 \text{ MeV}.$$

The peak at 1047 MeV is probably associated with the $S^*(993)$ and the $\delta(970)$. Both of these resonances have $J^P = 0^+$ and are known to couple to the K_SK_S system. But unlike many other observations, the events in this peak are not peripherally produced.

Figure 2 shows the distribution of t, the invariant square of the four-momentum transferred from the π^+ to the K_SK_S system, for all the events. It is not peaked at $t = 0$ because of the inclusive nature of reaction (1). Selecting events with $-t < 1.0$ $(\text{GeV}/c)^2$ completely excludes the events in both mass peaks. A better variable to use is $t' = t - t_{\min}$. Figure 3 gives the t' distribution, showing that it is strongly peaked at $t' = 0$. The two insets show the t' distributions for the events in mass intervals including the two mass peaks. The t' distribution of the events in the 1047 MeV peak does not peak as sharply at $t' = 0$ as does the over-all data. Hence, although in general the over-all t' is very peaked at $t' = 0$, the two enhancements are strongly associated with events with $|t'| > 1$ $(\text{GeV}/c)^2$. The shaded histogram in Fig. 1 gives the K_SK_S mass distribution for $|t'| > 1.8$ $(\text{GeV}/c)^2$, showing that both enhancements are clearly visible. The inset in Fig. 1 gives the mass distribution for $|t'| < 0.9$ $(\text{GeV}/c)^2$, showing that in that case the two enhancements are not present.

The 1047-MeV mass peak observed at large t rather than small t is at variance with results obtained in other experiments at lower energy.[2-11] The situation is summarized in Table I, where it will be noticed that most of the other experiments used π^- beams. In many cases[4-8] they observed near threshold a peripheral K_SK_S peak that is interpreted as the S^*. We have considered several ideas to explain our nonperipheral result. We are confident that it is not the result of experimental bias against fast forward K_S, since the bubble chamber is long enough so that few K_S decay outside the chamber.

We propose two possible explanations, which may or may not be independent: (a) It could be a result of interference between the S^* and the δ, leading to a suppression of peripheral events at our energy. (b) It could be a manifestation of the influence of planar duality diagrams of the type introduced by Harari[12] and Rosner.[13] The experiments in Table I which show peripheral K_SK_S peaks were all done using π^- beams, with which it is easy to produce a planar duality diagram that suggests peripheral production of $K^0\bar{K}^0$, but not for K^+K^-; the π^- experiments that study K^+K^- do not show any S^* at low t (except for Ref. 11, for which the S^* cross section is suppressed by a factor of at least ten from that which is observed in π^- making $K^0\bar{K}^0$). For a π^+ beam the situation is reversed, i.e., there would be peripheral production of K^+K^- but not $K^0\bar{K}^0$. In fact, Harari mentioned this very circumstance in his paper.[12] The experiments listed in Table I are all consistent with this hypothesis. In many cases listed in the table an experiment was not sensitive to production of a resonance at high momentum transfer, usually because of counters that trigger on slow protons; these cases are marked with ellipses in the table. A consequence of the duality interpretation is that a resonance seems to "remember"

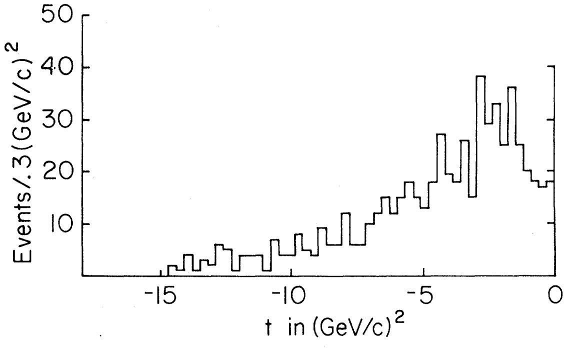

FIG. 2. Momentum-transfer spectrum; t is the invariant square of the four-momentum transferred from the π^+ to the K_SK_S system.

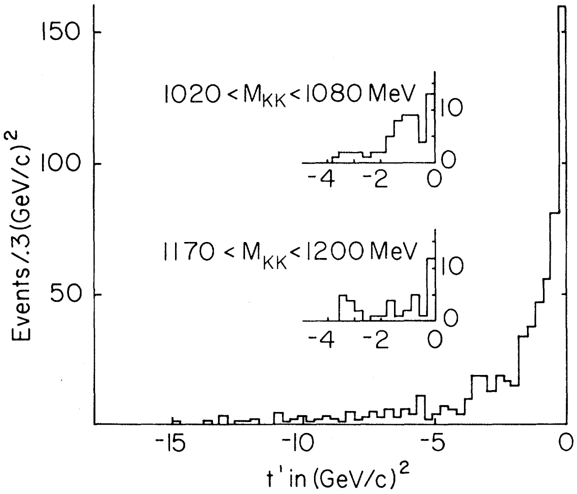

FIG. 3. Spectrum of t', the difference between t and its smallest (absolute) value. The insets show the distribution of t' for those events that fall in the peaks of Fig. 1.

TABLE I. Comparison of experiments with pion beams that have produced $K\bar{K}$ spectra in the S^*, δ and the f, A_2 regions.

Beam	Target	P_{beam} (GeV/c)	$K\bar{K}$	S^*, δ Low t	S^*, δ High t	f, A_2 Low t	Refs.
π^+	d	15	K_SK_S	No	Yes	No	this expt.
π^+	p	7.1	K_SK_S	No	Yes?	No	2
π^+	p	7.1	K^+K^-	Yes	···	Yes	2
π^+	p	5	K^+K^-	Yes	···	Yes	3
π^-	p	5, 7, 12	K_SK_S	Yes	···	Yes	4
π^-	p	6	K_SK_S	Yes	···	Yes	5
π^-	p	4, 6.2	K_SK_S	Yes	···	Yes	6
π^-	p	4, 5	K_SK_S	Yes	···	Yes	7
π^-	p	1.5–4.2	K_SK_S	Yes	···	Yes	8
π^-	p	1.5–4.2	K^+K^-	No	···	···	8
π^-	p	11	K^+K^-	No	···	No	9
π^-	p	9.8	K^+K^-	No	···	?	10
π^-	p	6	K^+K^-	Small[a]	···	Small[a]	11

[a] The effects in question were observed, but with cross sections reduced by a factor of at least ten compared with the predictions from $K^0\bar{K}^0$ results.

how it was formed, and its decay is dependent on its formation. This idea is, of course, at variance with the more conventional notion that decay properties of resonances are independent of formation. It also ignores requirements of conservation of I spin; however, the more conventional and less controversial explanation (a) also involves mixing of I-spin states. An additional interesting observation from Table I is that the observation or nonobservation of a $K\bar{K}$ decay of the f and the A_2 seems to follow the same principle as in the case of the S^*.

The second peak, at 1190 MeV, is not so easily identified in terms of previously reported resonances. We discern several interpretations, listed here in increasing order of probability: (a) it could be a statistical fluctuation; (b) it could be an interference effect involving known resonances; (c) it could be the $A_{1.5}(1170)$, an effect reported by the Notre Dame group[14] and subsequently seen by other experimenters,[15] all with low statistics; (d) it could be a new resonance with quantum numbers different from those of the $A_{1.5}(1170)$.

Let us suppose that this peak is the $A_{1.5}$; then J^P cannot be 0^+ because the $A_{1.5}$ was discovered in its three-pion decay mode. That leaves $2^+, 4^+, \ldots$ as possible spin-parity assignments. Arguments based on a simple quark-antiquark shell model for mesons[16] militate against a spin of 4 or higher; these same arguments indicate that this approximate mass range already has enough mesons with $J^P = 2^+$; in fact, the most natural explanation within the quark shell model is that the $A_{1.5}$ has $J^P = 1^+$, making it incapable of decaying into K_SK_S. There is the possibility that our effect at 1190 MeV is a different object, having $J^P = 0^+$ and fitting into the quark shell model as a radial excitation with the configuration 2^1S_0. In order to test this hypothesis we examined angular distributions for the decay of the 1190 MeV peak in our data. Once again, the inclusive nature of this experiment coupled with the fact that the peaks are formed at high t turned out to be a disadvantage, since the Jackson angle is useful only at low t and even the helicity angle is hard to interpret for inclusive reactions. We studied distributions of the cosines of both these angles (i.e., Jackson and helicity) and found them consistent with uniformity through both the S^*, δ region and the 1190 MeV peak region. This result suggests (but of course does not prove) that $J^P = 0^+$ for both the peaks that we have observed. The isotropic angular distribution at the 1190 MeV peak does not favor f-A_2 interference.[11] Incidentally, the angular distribution of the Jackson angle departs from flatness above 1200 MeV, assuming a shape consistent with the 2^+ behavior that one would expect from the f-A_2 region; the mass spectrum of Fig. 1 shows at best a shoulder in this region, an unresolved effect of two different well-established resonances.

Assuming that this second peak at 1190 MeV is not merely a statistical fluctuation, the most probable explanation consistent with the angular distributions is that it is a new resonance with $J^P = 0^+$.

We wish to thank our scanning staff for their fine work. Special thanks to the SLAC bubble-chamber group, especially to R. Watt and Dr. J. Ballam in obtaining the excellent quality photographs. We also wish to acknowledge great benefits derived from conversations with Dr. J. D. Kimel, Dr. P. K. Williams, and Dr. L. Thébaud. We would also like to thank J. R. Bensinger, B. Wind, N. D. Pewitt, and C. P. Horne for their contributions during the data taking and data reduction.

---

*Research supported in part by the U. S. Energy Research and Development Administration.

†Presently with the U. S. Army.

[1] D. P. Wilkins, Ph.D. Dissertation, Florida State Univ. Report No. FSU-HEP 75-6-6, 1975 (unpublished).

[2] S. D. Protopopescu *et al.*, Phys. Rev. D 7, 1279 (1973).

[3] D. Z. Toet *et al.*, Nucl. Phys. B63, 248 (1973).

[4] W. Beusch *et al.*, Phys. Lett. 25B, 357 (1967).

[5] D. Crennell *et al.*, Phys. Rev. Lett. 16, 1025 (1966).

[6] W. Beusch, in *Experimental Meson Spectroscopy*, proceedings of the Philadelphia Conference, 1970, edited by C. Baltay and A. H. Rosenfeld (Columbia Univ. Press, New York, 1970), p. 185.

[7] T. F. Hoang *et al.*, Phys. Rev. 184, 1363 (1969).

[8] R. I. Hess *et al.*, Phys. Rev. Lett. 17, 1109 (1966).

[9] B. D. Hyams *et al.*, Nucl. Phys. B22, 189 (1970).

[10] G. Grayer *et al.*, in π-π *Scattering—1973*, proceedings of the International Conference on π-π Scattering and Associated Topics, Tallahassee, 1973, edited by P. K. Williams and V. Hagopian (A. I. P., New York, 1973), p. 117.

[11] A. J. Pawlicki *et al.*, Phys. Rev. D 12, 631 (1975).

[12] H. Harari, Phys. Rev. Lett. 22, 562 (1969).

[13] J. L. Rosner, Phys. Rev. Lett. 22, 689 (1969).

[14] N. M. Cason *et al.*, Phys. Rev. Lett. 18, 880 (1967).

[15] Particle Data Group, Phys. Lett. 50B, 1 (1974).

[16] M. G. Bowler, in *Experimental Meson Spectroscopy—1974*, proceedings of the Boston Conference, 1974, edited by D. A. Garelick, (A. I. P., New York, 1974), p. 1.