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EVIDENCE AGAINST THE EXISTENCE OF A STRANGENESS +2 MESON RESONANCE AT A MASS OF 1280 MeV*

T. Joldersma, R. B. Palmer, and N. P. Samios
Brookhaven National Laboratory, Upton, New York
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Among the many bosons observed to date, the states with spin parity 0^-, 1^-, and 2^+ are composed of nine particles each and have the isospin (I) and hypercharge (Y) properties that can be associated with the constituent states of the representations 1 and 8 of the SU(3) group. Although no representations of larger dimensions have been definitely established, it is of critical importance in the study of strong interactions to determine whether such states actually exist in nature. This question has special relevance with respect to composite quark models, as to whether the presently known bosons are in reality composed of two quarks with increasing angular momentum to account for higher spin states or of multiple quark states, i.e., 4, 6, etc., with zero angular momentum, the higher spin coming from the addition of the individual quark spins. To this end the existence or nonexistence of an $I=1$, $Y=2$ resonance, such as a K^+K^+ state, is highly significant, since the 27 is the smallest representation which can accommodate such a particle and its existence would require the multiple quark approach. In this Letter we wish to report our results as well as present a world compilation concerning this question obtained from a study of the following reactions:

$$K^+ + p \to K^+ + K^+ + \Lambda^0, \quad (1a)$$

$$\to K^+ + K^+ + \Sigma^0, \quad (1b)$$

$$\to K^+ + K^0 + \Sigma^+, \quad (1c)$$

$$\to K^+ + K^+ + \Lambda^0 + \pi^0, \quad (2a)$$

$$\to K^+ + K^0 + \Lambda^0 + \pi^+. \quad (2b)$$

The evidence for the possible existence of a K^+K^+ resonance comes from CERN data for the above reactions obtained with K^+'s of momenta of 3.0, 3.5, and 5.0 BeV/c.[1] If one examines each final state individually, one notes that the bulk of the data, as well as the main contribution to the effect, comes from the ΛK^+K^+ at the two lower energies. We have therefore repeated the experiment with K^+'s at 3 BeV/c, essentially doubling the CERN data at this energy, and find no evidence for any K^+K^+ resonance.

The exposure consisted of 120 000 pictures taken in the Brookhaven National Laboratory (BNL) 80-inch hydrogen bubble chamber at the alternating gradient synchrotron (AGS) in the dc separated beam.[2] 4200 τ's were found in a fiducial region whose length was 160 cm. This corresponds to an event rate of 5.75 events/μb. The pictures were scanned for all topologies involving one hyperon decay, either Λ^0 or Σ^+ decay. In the case of V events it was further required that the line of flight of the V be closer to the positive than the negative track. This had the desired effect of eliminating ≈40% of the K^0 decays. It was difficult to detect short decays, and a cutoff of 1 cm was applied, amounting to a ≈5% correction. Similarly, tracks which interacted within 5 cm of their origin were difficult to measure with the necessary precision and were therefore eliminated at the scanning phase, this corresponding to a 2% correction. The events were then measured on an image plane digitizer and analyzed with the TRED-KICK programs. For each event the χ^2 probability and track ionizations were determined. All events which fit hypotheses 1 or 2 were re-examined by a physicist for consistency with ionization. In almost all cases the calculated χ^2 probability for the different hypotheses were widely different, and this coupled with the estimated ionization allowed a selection to be made. The minimum accepted χ^2 probability was 1%. The only possible sources of difficulty were π^+ contamination and $\Lambda^0\Sigma^0$ ambiguities.

At this energy the cross section for Λ^0 production by π's is a factor of 6 greater than that by K^+'s. Therefore, a π^+ contamination as small as 10% can cause appreciable difficulty. In the present case we believe that the π^+ contamination was negligible for the following reasons: (1) The K^+-π^+ separation at 3 BeV/c in the dc separated beam is very large, the image/width separation of K^+ to π^+ being $\gtrsim 4/1$. This is because the beam was designed to operate up to 5 BeV/c and the separation varies as $1/p^3$. Assuming then that no π^+'s pass the separator slit, any π^+'s that come to the chamber must arise from K^+'s that decay between the slit and the bubble chamber. This fraction is small, and since the π's are of lower momentum than the beam, they are either physically removed by sweeping magnets or eliminated from consideration by our use of a small error in the trapped incoming beam momentum. (2) No unambiguous π^+ four-constraint fits were obtained, and there were only four events which fit both a π^+ and K^+ four-constraint hypothesis. There is a finite but small probability that events of one type will make a four-constraint fit to a wrong hypothesis. It is thus quite reasonable, given no π^+ contamination, that out of 100 fits, four (4%) will also make four-constraint fits to the π^+ beam hypothesis. In contrast, it is quite unreasonable to assume that all four four-constraint π^+ fits correspond to a real π^+ contamination, since all of these events (100%) do make the alternative, and much more likely, K^+ beam fit. Since we know[3] that approximately half of all Λ production from π^+ gives four-constraint fits, the above result indicates a negligible π^+ beam contamination in the one-constraint as well as the four-constraint cases.

As an aid in resolving the Λ^0, Σ^0 ambiguity, two tantalum plates, each 1.5 radiation lengths thick, were inserted into the chamber for half of the run. By detecting the γ rays from Σ^0's which were produced in a forward direction in the laboratory system, we were able to confirm that the kinematics fitting correctly distinguished between the two hypotheses. Nine events remained ambiguous between hypotheses 1a and 1b and these were apportioned in the same ratio as the unambiguous events. The total number of events for each channel as well as the corrected cross sections for both the BNL and CERN data are shown in Table I. One notes the excellent agreement between the two measurements.

The Dalitz plots for our sample of events for Reactions (1a) and (1b) are shown in Fig. 1. They are combined because individually they show the same behavior. There are two points per event because of the indistinguishability of the two K^+ mesons. Also shown are the two projections, namely, the mass square, M^2, of the $K^+(\Lambda^0$ or $\Sigma^0)$ and the K^+K^+ final states with their respective phase-space distributions. There is no evidence for a resonance in either system. In Fig. 2(a) is plotted the K^+K^+ and K^+K^0 effective mass for all 105 events of Reaction (1), including Σ^+ events. The charged Σ events are of lesser value since we miss a significant fraction ($\approx$30%) of the decays $\Sigma^+ \to p+\pi^0$ in which the proton makes a very small angle <3° with respect to the Σ^+. However, since the previous evidence[1] for a possible K^+K^+ enhancement included this channel, they are also included here. The shaded events are those in which the hyperon is produced peripherally, $\cos\theta < -0.6$. Again there is no evidence for any resonance, both KK distributions having the expected phase-space distributions. Finally, we show in Fig. 2(b) the world data on a possible K^+K^+ enhancement from Reaction (1a) and (1b), which include 102 BNL events, 103 CERN events, and 105 Wisconsin events.[4] The

Table I. Cross sections for three- and four-body final states.

Final state	Number of events	BNL cross section (μb)	CERN cross section (μb)
$K^++K^++\Lambda$	71	22.3 ± 3.3	23.0 ± 4.5
$K^++K^++\Sigma^0$	31	9.8 ± 2.0	7.5 ± 2.5
$K^++K^0+\Sigma^+$	51	19.4 ± 4.7	15.0 ± 5.0
$K^++K^++\Lambda+\pi^0$	15	4.7 ± 1.3	7.5 ± 2.5
$K^++K^0+\Lambda+\pi^+$	29	9.1 ± 1.9	12.5 ± 3.5

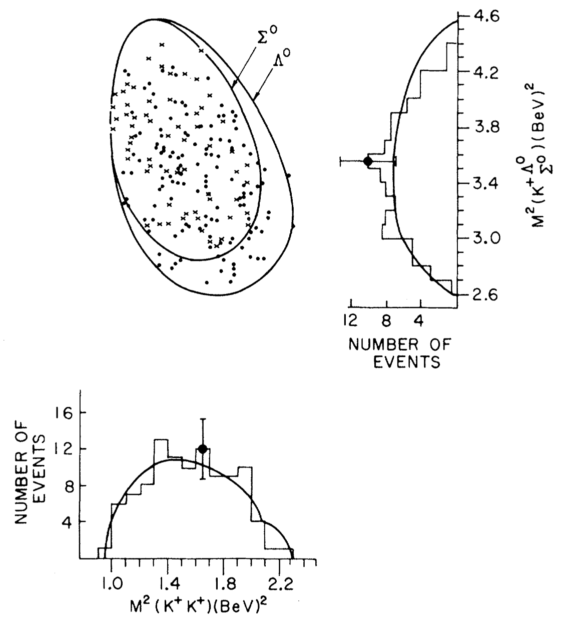

FIG. 1. Dalitz plot for 102 Brookhaven National Laboratory events for the reactions $K^+ + p \rightarrow K^+ + K^+ + \Lambda^0$, $K^+ + p \rightarrow K^+ + K^+ + \Sigma^0$ at 3 BeV/c. The dots correspond to 71 $K^+K^+\Lambda^0$ events and the crosses to 31 $K^+K^+\Sigma^0$ events. Each event is plotted twice because of the indistinguishability of the two K^+ mesons. Also shown are the two projections. The solid curves are the respective phase-space distributions for the two cases.

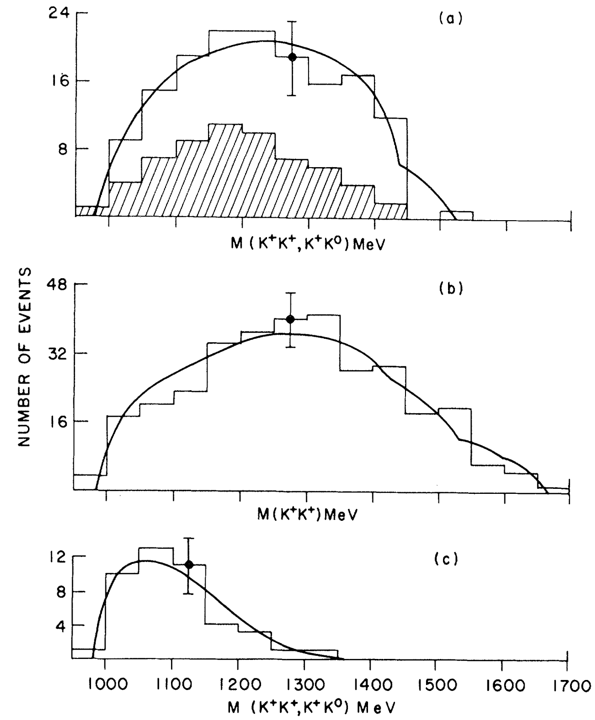

FIG. 2. (a) KK effective mass plot of 153 Brookhaven National Laboratory events at 3 BeV/c. These include 71 $K^+K^+\Lambda^0$, 31 $K^+K^+\Sigma^0$, and 51 $K^+K^0\Sigma^+$ events. The shaded events correspond to those events in which the hyperon is produced backwards in the center-of-mass system with $\cos\theta < -0.6$. The solid curve is the phase-space distribution normalized to the total number of events. (b) World compilation of K^+K^+ effective mass for the reactions $K^+ + p \rightarrow K^+ + K^+ + \Lambda$ and $K^+ + p \rightarrow K^+ + K^+ + \Sigma^0$. This includes 102 Brookhaven National Laboratory and 57 CERN events at 3 BeV/c, and 56 CERN and 105 Wisconsin events at 3.5 BeV/c. The solid curve is the expected phase-space distribution. (c) KK effective mass for the four-body final states $K^+K^+\Lambda^0\pi^0$ (15 events) and $K^+K^0\Lambda\pi^+$ (29 events. The smooth curve is the phase-space distribution.

solid curve is the phase-space distribution expected for the two energies and reactions. Again there is excellent agreement between the data and a phase-space distribution, the χ^2 probability for the fit being 40%.

A similar negative effect is concluded from a study of the four-body final states [Reaction (2)]. These channels are much more complicated to analyze because of the multiple resonances that can be produced among the four particles, i.e., Y^*, K^*, N^*, etc. However, in the present case we find evidence only for the production of $Y_1^*(\Lambda\pi)$ with mass of 1385 MeV, the $K\pi$ and $K\Lambda$ distribution essentially fitting phase space. The KK effective mass plot for the 44 four-body events is shown in Fig. 2(c). It is evident that the limited number of events show no evidence for any KK resonance.

From this total study we therefore conclude that any previous evidence for any K^+K^+ resonance is negated by the accumulation of additional data at the same energies.

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DYNAMICAL MODELS AND MASS FORMULAS FOR RESONANCE MULTIPLETS*

G. L. Kane†
Summer Institute for Theoretical Physics, University of Washington, Seattle, Washington
(Received 15 August 1966)

It is customarily assumed that if SU(3) is a valid symmetry, resonances will occur in complete SU(3) multiplets. It is equally customary to assume that (except for mixing effects, which we do not consider) the masses in a resonance multiplet will satisfy a mass formula of the usual type. A related assumption is that mass formulas for Regge recurrences will be the same as those for the lowest member on the trajectory. The purpose of this note is to suggest that for multiplets which can be obtained by dynamical arguments based on forces generated by unitarity and inelastic effects, these assumptions about mass formulas may not be correct. Such multiplets may include the Regge recurrences of the baryon octet and decuplet, the multiplet which contains the $N_{1/2}^*(1518)$, and others.

To see this we first recall that Cook and Lee,[1] and Auvil and Brehm,[2] have proposed to account for the existence of a number of resonances by considering the strongly attractive forces provided by coupling inelastic channels through unitarity. In these models the inelastic amplitudes are driven by single-particle-exchange contributions. The work of Wali, Warnock, and Ernst[3] has made it plausible to conjecture that amplitudes constructed from single-particle exchanges will exhibit mass splittings consistent with octet symmetry-breaking assumptions, whenever the input particles do so. Because unitarity couples the square of the inelastic amplitude to the elastic channel, the resulting elastic amplitude will include contributions to a mass formula from all the terms in the product of two octets. Okubo[4] has derived the mass formula for this situation. In general, it contains six arbitrary parameters, so for octets it will not lead to any relations at all among the four masses. For the 10 and 10* multiplets the relation $I=\frac{1}{2}Y+1$ holds[4] and the general formula reduces to $M=M_0+M_1Y+M_2Y^2$. In this case there is one relation among the split masses.

Note that the effect of the Y^2 term need not be proportional to the square of the coefficient of Y in the input mass formulas, because several product terms occur, giving enhancements (or cancellations); and, in addition, they occur with scales set by different couplings. On the other hand, dynamical calculations such as those we are considering will give heavier output masses to resonances involving heavier input masses, so that the resonance mass will tend to increase with hypercharge. Thus the deviation from a mass formula with mass also increasing with hypercharge is not likely to be a large effect.

These arguments appear to imply that the mass splittings inside resonance multiplets are not likely to satisfy the usual mass formulas.[5] Of course, it is possible that some more subtle situation holds, and mass formulas will continue to hold to good accuracy (this would occur if cancellations occurred and some of the six coefficients in the general formula were small). This is not inconsistent with the dynamical models but would suggest either that we do not understand all of their implications or that they are inadequate to account for all of the properties of the observed resonances.

One resonance which has been obtained in such models[1] is the $J^P=\frac{3}{2}^-$ $N_{1/2}^*(1518)$, expected to be an octet member.[6] It has proved quite difficult to complete this octet by the usual methods. Our considerations may help account for this by making it unlikely that the usual mass formula should be satisfied. Similarly, Auvil and Brehm[2] have proposed that the Regge recurrences of the baryon octet and decuplet follow from such a model, so again we would not expect the former to satisfy a mass formula, while the latter could at best satisfy $\Omega_0^* = N_{3/2}^* + 3(\Xi_{1/2}^* - Y_1^*)$, rather than an equal-spacing rule. Another application[7] is to a possible resonant 10*, where a linear mass formula