OBSERVATION OF KAPPA (730 MeV) PRODUCTION IN $\pi^+ p$ INTERACTIONS AT 3.2 GeV/c*

N. M. Cason,† S. Mikamo, and A. Subramanian‡
Department of Physics, University of Wisconsin, Madison, Wisconsin
(Received 8 August 1966)

A narrow peak in the $K\pi$ effective-mass spectrum corresponding to the so-called kappa meson has been observed in the reaction $\pi^+ + p \rightarrow \Lambda^0 + K^{+,0} + \pi^+ + \pi^{0,+}$ at 3.2 GeV/c. We have shown that this peak cannot be explained by triangular or box singularity effects.

In a study of the reactions

$$\pi^+ + p \rightarrow \pi^+ + \pi^+ + \Lambda^0 + K^0 \quad (1)$$

and

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

at 3.2 GeV/c, we have observed a narrow peak in the $(K\pi)^+$ effective-mass spectrum at a mass of 730 MeV. This peak corresponds to the previously reported kappa meson.[1-8] In view of the current interest[9-11] in determining whether the kappa corresponds to a true resonance or is the result of a kinematic effect, we present here the results of applying a kinematic test to our data to see whether the peak which we observed could be explained as being due to an effect of a box graph. Our conclusion is that such an explanation is inconsistent with the data.

The experiment involved an exposure of 150 000 pictures in the Shutt 20-inch hydrogen bubble chamber to a beam of positive pions at 3.2 GeV/c at the alternating-gradient synchrotron at Brookhaven National Laboratory. This Letter is based on the analysis of about 75% of the film and includes events from the 2-prong–single-V and 2-prong–double-V topologies. The events were measured on measuring microscopes and were analyzed utilizing the DIANA spatial reconstruction and kinematic fitting programs. Events were selected for Reactions (1) or (2) which either fit the respective reaction uniquely or fit the reaction with a probability which is at least three times greater than the probability for any other fit.

Figure 1 is a scattergram of the $(K\pi)^+$ effective mass vs the $(\Lambda\pi)^+$ effective mass for events from Reactions (1) and (2). Also shown are the projections on the $(K\pi)^+$ and the $(\Lambda\pi)^+$ axes. The smooth curve shown is phase space normalized outside the $K^*(890)$ and $Y^*(1385)$ peaks. In Reaction (1), there are two combinations plotted per event. The $(K\pi)^+$ mass projection shows a peak around 730 MeV in addition to the peak at $K^*(890)$. The scatter plot shows that $K^*(890)$ is frequently produced in association with $Y_1^*(1385)$. It is noted that events near 730 MeV do not show strong association with any baryon resonance.

In order to obtain an effective-mass plot for the $(K\pi)^+$ system with as little background as possible, we have shown as cross-hatched events in Fig. 1 the $(K\pi)^+$ mass distribution, using only one entry on the scatter plot for the events of Reaction (1) if the $K^0\pi^+$ mass of one combination lay in the K^* band (858-918 MeV) or if

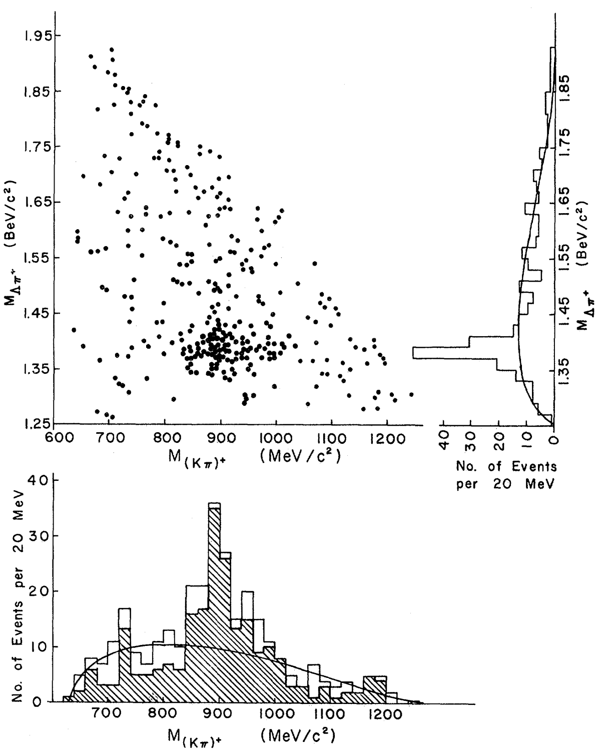

FIG. 1. A plot of $(K\pi)^+$ mass vs $(\Lambda\pi)^+$ mass for 101 events belonging to Reaction (1) and 112 events belonging to Reaction (2). One event corresponds approximately to 1-μb production cross section. The histograms show projections on the two axes. The cross-hatched histrogram in the $(K\pi)^+$ distribution is obtained by removing background of wrong combinations associated with $K^*(888)$ or $Y_1^*(1385)$ production.

the $\Lambda\pi^+$ mass of one combination is in the Y_1^* band (1360-1410 MeV). The reduction in background thus achieved reveals the narrowness of the kappa peak, which is estimated to be $\lesssim$12 MeV. The peak is centered at a mass of 731 ± 2 MeV, slightly higher than the value 725 ± 2 MeV quoted from previous works.[11]

The nature of the kappa is quite unclear at the present time because of the fact that although it is observed in many reactions at many incident energies at about the same mass and width, it does not appear in many of the same reactions at somewhat different energies. This might indicate that a highly energy-dependent production mechanism is present if the kappa is a resonance, or that an energy-dependent kinematic effect produces the kappa peak.

Such an energy-dependent effect can be found in the so-called triangle and box diagrams [Figs. 2(a) and 2(b)]. These diagrams have singularities when the intermediate lines are on the mass shell and hence produce enhancements in certain kinematic regions. There have been attempts to explain the kappa peak by the triangle diagram in two cases.[8,9] The explanation in at least one case appears to be unsatisfactory.[11]

In an attempt to find a consistent explanation for all experiments bearing on the question, we have examined experiments[1-8] which have observed the kappa and some experiments,[1,2,4,12-19] which have not observed the kappa. For each experiment we have considered various ways in which the triangle or box diagrams might contribute to the experiment using the kinematic formulas collected by Rosenfeld.[11] The results of these calculations are summarized by the following comments: We note that several of the experiments[1,2,4] observing the kappa do fall into the kinematically allowed region for triangle and/or box singularities, but not all of them do.[5,8] Furthermore, the experiments not observing the kappa do not fall into kinematically allowed regions for these singularities. Thus, except for a few exceptions of kappa production where some other explanation is required, kappa production can seemingly be predicted by whether or not a triangle or box singularity is possible.

To check further this hypothesis in our experiment, we have tested our events for consistency with the box diagram, the most likely candidate for such a kinematic mechanism at our energy. The triangle mechanism does

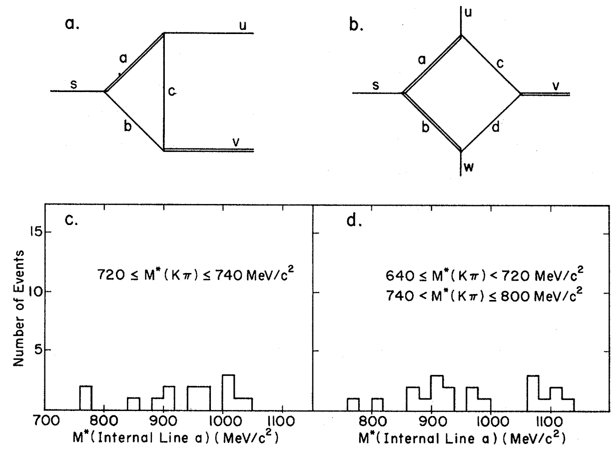

FIG. 2. (a) and (b) show the triangle and box graphs. s, u, v, and w represent the four-vectors of external particles, and a, b, c, and d those of internal particles. It is possible to calculate one of the internal vectors given the external ones and the masses of all the other internal lines. (c) and (d) show the results of calculating line a of the box diagram assuming that line b is a $Y_1^*(1385)$, that line c is a K, and that line d is a π. (c) is for the kappa region and (d) is for the control region.

not have a singularity here. In addition, copious production of K^*-Y_1^* favors the box mechanism, where a and b of Fig. 2(b) are the K^* and the Y^*. It is possible to calculate the mass of one internal line in the box graph assuming the masses of the other three lines for each event in the kappa peak. The mass of the supposed $K^*(890)$ was calculated for each case, and the resulting distribution is shown in Fig. 2(c) for events in the kappa region and in Fig. 2(d) for events in control regions above and below the kappa. Figure 2(c) is much too broad to be associated with the $K^*(890)$, even when one takes the width of the Y_1^* into account. Furthermore, there is no significant difference between the kappa region and the control region. Finally we note that if the kappa were produced solely as a kinematic reflection of the box diagram, a peak should appear in the $K^+\pi^+$ mass distribution at the kappa mass. We observe no such effect and consider this to be further evidence against such a mechanism. Hence, although the box mechanism seems to be a possible explanation for the kappa in our experiment, closer analysis shows that this is not the case. We conclude that kappa production is not caused by the kinematic effects of the box or triangle diagrams in our experiment.

We wish to acknowledge a helpful discussion with Professor C. Goebel. The assistance of the scanning and measuring crew is gratefully acknowledged. We are thankful to Professor M. L. Good for his support and encouragement in this experiment.

---

*Supported in part by the U. S. Atomic Energy Commission under Contract No. AT(11-1)-881 and COO-881-73.

†Now at the Department of Physics, University of Notre Dame, Notre Dame, Indiana.

‡On leave from Tata Institute of Fundamental Research, Bombay, India.

[1]G. Alexander, G. R. Kalbfleisch, D. H. Miller, and G. A. Smith, Phys. Rev. Letters 8, 447 (1962). The kappa is observed in the reaction $\pi^- + p \rightarrow K + \pi + \Sigma$ but not in the reaction $\pi^- + p \rightarrow K + \pi + \Lambda$.

[2]D. H. Miller, G. Alexander, O. I. Dahl, L. Jacobs, G. R. Kalbfleisch, and G. A. Smith, Phys. Letters 5, 279 (1963). The kappa is observed in the reaction $\pi^- + p \rightarrow K + \pi + \Sigma$ but not in the reaction $\pi^- + p \rightarrow K + \pi + \Lambda$.

[3]S. G. Wojcicki, G. R. Kalbfleisch, and M. H. Alston, Phys. Letters 5 283 (1963).

[4]S. Goldhaber, in Proceedings of the Athens Topical Conference on Recently Discovered Resonant Particles, Ohio University, Athens, Ohio, 1963, edited by B. A. Munir and L. J. Gallahar (Ohio University Physics Department, Miami, Ohio, 1963), p. 92. The kappa is observed in the reaction $K^+ + p \rightarrow K + \pi + \pi + p$ but not in the reaction $K^+ + p \rightarrow K + \pi + p$.

[5]Y. S. Kim, G. R. Burleson, P. I. P. Kalmus, A. Roberts, and T. A. Romanowski, Phys. Letters 19, 350 (1965).

[6]J. Fisk, H. K. Ticho, D. H. Stork, W. Chinowsky, G. Goldhaber, S. Goldhaber, and T. F. Stubbs, in Proceedings of the International Conference on High-Energy Nuclear Physics, Geneva, 1962, edited by J. Prentki (CERN Scientific Information Service, Geneva, Switzerland, 1962), p. 358.

[7]M. Ferro-Luzzi, R. George, Y. Goldschmidt-Clermont, V. P. Henri, B. Jongejans, D. W. G. Leith, G. R. Lynch, F. Muller, and J. M. Perreau, Phys. Letters 12, 255 (1964).

[8]G. W. London, R. R. Rau, N. P. Samios, S. S. Yamamoto, M. Goldberg, S. Lichtman, M. Primer, and J. Leitner, Phys. Rev. 143, 1034 (1966).

[9]M. Month, Phys. Rev. 139, B1093 (1965).

[10]A. T. Goshaw, A. R. Erwin, W. D. Walker, and A. Weinberg, to be published.

[11]A. H. Rosenfeld, in Proceedings of the Oxford International Conference on Elementary Particles, Oxford, England, 1965 (Rutherford High-Energy Laboratory, Chilton, Berkshire, England, 1966) p. 5.

[12]D. Colley, N. Gelfand, U. Nauenberg, J. Steinberger, S. Wolf, H. R. Brugger, P. R. Kramer, and R. J. Plano, Phys. Rev. 128, 1930 (1962).

[13]L. J. Curtis, C. T. Coffin, D. I. Meyer, and K. M. Terwilliger, Phys. Rev. 132, 1771 (1963).

[14]G. A. Smith, J. Schwartz, D. H. Miller, G. R. Kalbfleisch, R. W. Huff, O. I. Dahl, and G. Alexander, Phys. Rev. Letters 10, 138 (1963).

[15]S. S. Yamamoto, L. Bertanza, G. C. Moneti, D. C. Rahm, and I. O. Skillicorn, Phys. Rev. 134, B383 (1964).

[16]T. P. Wangler, A. R. Erwin, and W. D. Walker, Phys. Rev. 137, B414 (1965).

[17]G. R. Lynch, M. Ferro-Luzzi, R. George, Y. Goldschmidt-Clermont, V. P. Henri, B. Jongejans, D. W. G. Leith, F. Muller, and J. M. Perreau, Phys. Letters 9, 359 (1964).

[18]S. P. Almeida and G. R. Lynch, Phys. Letters 9, 204 (1964).

[19]J. Badier, M. Demoulin, J. Goldberg, B. P. Gregory, C. Pelletier, A. Rouge, M. Ville, R. Barloutaud, A. Leveque, C. Louedec, J. Meyer, P. Schlein, A. Verglas, D. J. Holthuizen, W. Hoogland, and A. G. Tenner, Phys. Letters 16, 171 (1965).