RESONANCE PRODUCTION IN $\Xi K\pi$ AND $YK\bar{K}$ FINAL STATES FROM K^--p INTERACTIONS AT 4.25 BeV/c *

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We report on three-body final states observed in the Brookhaven National Laboratory (BNL) 80-inch hydrogen bubble chamber. The incident K^- beam had a momentum of 4.25 BeV/c, with a total path length of 5.4 μb equivalents. This film was double-scanned (with a 99% efficiency) for events displaying the decay of two or more strange particles. The data indicate the presence of considerable structure in the $(K^0\bar{K}^0)$ system, and at best weak production of Ξ^* resonances in quasi-two-body processes.

Table I lists the final states to be discussed, along with the observed number of events and the cross section. The observed number of events indicated in the table includes some which are consistent with two hypotheses. These have been assigned in proportion to the number of events assigned unambiguously to those hypotheses. Cross sections are based on the resulting numbers weighted for geometric losses and neutral decay modes. All errors quoted are statistical and are based on the number of unambiguous events. In most channels the ambiguity level is very low. In the $\Xi^-(K\pi)^+$ channels, however, the ambiguity level between $(K^0\pi^+)$ and $(K^+\pi^0)$ is approximately 15%. Our data are consistent with other measurements in this energy region.

Turning our attention first to the $(\Lambda, \Sigma^0)K^0\bar{K}^0$ final state, we note that the $(\Lambda, \Sigma)K^0$ system shows no significant departure from phase space. Figure 1(a) shows the $K_1^0K_1^0$ mass-squared spectrum for events where both K_1^0's decay visibly in the chamber. In a similar K^--p experiment at 4.6 and 5.0 BeV/c, a BNL-Syracuse collaboration[1] found an enhancement in the K_1K_1 mass spectrum centered at 1500 MeV with a width of 80 MeV. A related effect was noted by Crennell et al.[2] in a π^--p experiment at 6.0 BeV/c in the state $nK_1^0K_1^0$ which favored a mass value of 1480 MeV. In an effort to reduce background near this $f^*(1500)$, we have investigated the production angular distribution of the $K\bar{K}$ system. In Fig. 1(a) all forward $K_1^0K_1^0$ combinations with $\cos\theta_{\text{c.m.}} \geq 0.5$ have been shaded. While the sample size is quite small, the $f^*(1500)$ is prominent and corresponds to a cross section for the process

$$K^- + p \to (\Sigma^0, \Lambda) + f^*(1500), \quad f^*(1500) \to K_1^0 + K_1^0$$

Table I. Cross sections and observed numbers of events for $\Xi K\pi$ and $YK\bar{K}$ final states.

Final state	Observed No. of events	σ (μb)
$\Xi^-K^+\pi^0$	23.2	15.6 ± 3.7
$\Xi^-K^0\pi^+$	46.9	19.9 ± 3.2
$\Lambda + \varphi(\varphi \to K_1^0 + K_2^0)$	46.0	22.7 ± 3.4
$\Lambda K_1^0K_1^0$	18.3	9.8 ± 2.4
$\Lambda K_1^0K_2^0$(non φ)	16.7	8.0 ± 2.8
$\Sigma^0K_1^0K_1^0$	11.3	6.0 ± 1.9

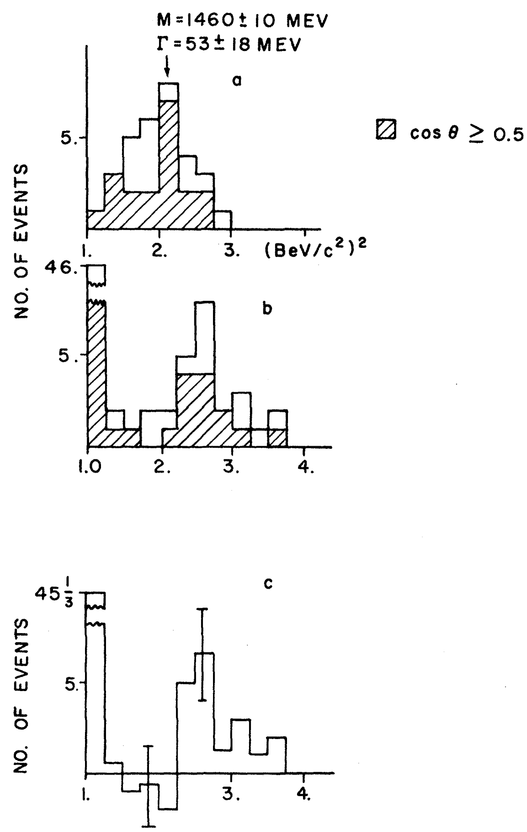

FIG. 1. The invariant mass squared of the $K^0\bar{K}^0$ from the final state $(\Lambda, \Sigma^0)K^0\bar{K}^0$ for (a) the $(\Lambda, \Sigma^0)K_1^0K_1^0$ events, (b) the ΛK_1^0 (K^0 unseen) events, and (c) ΛK_1^0 (K^0 unseen) $-\frac{2}{3}\Lambda K_1^0K_1^0$.

of 4.3 ± 1.4 μb, where we have called all events in the region $2.00 \leq M_{KK}^2 \leq 2.25$ $(\mathrm{BeV}/c^2)^2$ f^* events.

We estimate from this peripheral sample and our known resolution in this region (~2 MeV/c^2) that the mass of the f^* is 1460 ± 10 MeV with a width of 53 ± 18 MeV. Our data apparently favor a lower mass value than that measured by BNL; however, background estimates are crucial to the mass determination and it is difficult to make a reliable estimate with our data.

We now consider Fig. 1(b), which displays the $K^0\overline{K}^0$ projection for all events which fit $\Lambda K^0\overline{K}^0$ and which have the Λ and one K_1^0 decaying visibly in the chamber. Such events include both $\Lambda K_1^0 K_1^0$ and $\Lambda K_1^0 K_2^0$. A strong φ signal is seen in the region $1.00 \leq M_{KK}^2 \leq 1.25$ $(\mathrm{BeV}/c^2)^2$; these φ events are all produced peripherally in agreement with other experiments. To estimate the amount of $\Lambda K_1^0 K_2^0$ we subtract $\frac{2}{3}$ of the observed $\Lambda K_1^0 K_1^0$ spectrum[3] from Fig. 1(b) and plot the result in Fig. 1(c). The dominant features of this histogram are the φ peak near 1.0 BeV and no $K_1^0 K_2^0$ production in the $f^*(1500)$ region. We further note a statistically significant enhancement in the vicinity of 2.5 $(\mathrm{BeV}/c^2)^2$; our data indicate a central value of 1590 ± 45 MeV and a width of 160 ± 40 MeV. Since the enhancement is seen in $K_1^0 K_2^0$ and not in $K_1^0 K_1^0$, we conclude that $C = -1$. Further, since $C = P = (-1)^J$ for a $K\overline{K}$ system, J is odd. It is tempting to identify this effect with a resonance seen in π-p experiments in the $\pi\pi$[4-8] and $K\overline{K}$[9] systems whose mass and width are within two standard deviations of the values we obtain.

We now consider the three-body final state $\Xi K\pi$ which we observe in the channels $\Xi^- K^+ \pi^0$ and $\Xi^- \pi^+ K^0$. In Fig. 2 we show a Dalitz plot for this state as well as projections onto the $\Xi\pi$ and $K\pi$ mass-squared axes. The $\Xi\pi$ mass histogram is seen to have no marked deviations from phase space, with perhaps a suggestion of $\Xi^*(1530)$ appearing at 2.3 $(\mathrm{BeV}/c^2)^2$. In the region of the $K^*(890)$ we see an enhancement of about 28 events above background corresponding to a cross section for $\Xi^- K^{*+}(890)$ of 14 ± 2 μb. No other statistically significant structure is evident in the $K\pi$ mass spectrum.

In conclusion we note that our data in the $(\Lambda, \Sigma^0)K^0\overline{K}^0$ final state are consistent with almost 100% quasi-two-body processes, and that at least 40% of the $\Xi^-(K\pi)^+$ appears as a quasi-two-body reaction. Our data also indicate that if higher excited states of the Ξ are being produced in these channels at 4.25 BeV/c, then their cross sections must be small (a few μb at most) unless they are quite broad.

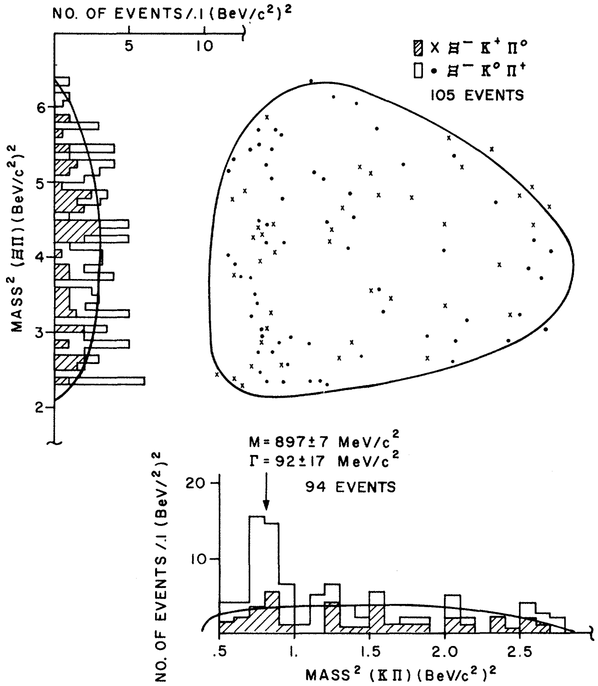

FIG. 2. Dalitz plot of the mass squared of the $(K\pi)^+$ versus the mass squared of the $\Xi^-\pi^{0+}$ from the $\Xi^-(K\pi)^+$ final states. The smooth curves on the projections are simply phase-space estimates and are normalized to the total number of events for the $(\Xi\pi)$ mass-squared axis and to the number of events above 1.0 $(\mathrm{BeV}/c^2)^2$ for the $(K\pi)$ axis. All events are given unit weight in the Dalitz plot, while on the projections ambiguous events have been given a weight of 0.5.

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[1]V. E. Barnes et al., Phys. Rev. Letters 15, 322 (1965).

[2]David J. Crennell et al., Phys. Rev. Letters 16, 1025 (1966).

[3]If we demand to see both K_1^0's decay, then we see only $\frac{4}{9}$ of all $\Lambda K_1^0 K_1^0$, while 8/27 of the total $\Lambda K_1^0 K_1^0$ are seen as a charged Λ decay and only one charged K_1^0 decay.

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EXPERIMENTAL TEST OF A HIDDEN-VARIABLE QUANTUM THEORY

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The probabilistic interpretation of the quantum mechanical measurement process, although extremely successful, seems to many to be unsatisfactory as an ultimate description of the physical universe.[1] One would like to believe that if a system is prepared with sufficient care, then its behavior in any well-defined experiment is completely predictable. If the system is only partially prepared, leaving some of its significant variables unspecified, then the system's behavior will not be completely predictable. The uncertainty in the outcome of an experiment would merely reflect the uncertainty of the unspecified variables. This explanation of the probabilistic results of measurement was proved by von Neumann to be incompatible with quantum mechanics.[2] The validity of the von Neumann proof has recently been contested, and several new descriptions of the measurement process, compatible with the existence of hidden variables,[3,4] have been proposed. One of these new descriptions, the Bohm-Bub theory, is capable of being tested experimentally.

The essential features of this theory are easily understood by considering a two-state quantum system. The physical realization of a two-state system used in this experiment is the photon,[5] which can exist in one of only two independent states of polarization (or a linear combination of these two states). Any experiment that can distinguish between the two states of polarization constitutes a measurement and is performed by means of linear polarizers.[6] The parts of the Bohm-Bub theory that are needed to understand this experiment are the following:

(1) Each photon has associated with it the usual quantum mechanical wave function $\Psi = \psi_1|a_1\rangle + \psi_2|a_2\rangle$, where $|a_1\rangle$ and $|a_2\rangle$ form the basis set of states and ψ_1, ψ_2 are complex numbers. The wave function can be normalized so that $|\psi_1|^2 + |\psi_2|^2 = 1$.

(2) Each photon has associated with it a pair of complex numbers (called the hidden variables) ξ_1, ξ_2. These numbers can be made to satisfy $|\xi_1|^2 + |\xi_2|^2 = 1$.

(3) The transformation properties of ξ_1, ξ_2 are the same as those of ψ_1, ψ_2 under a unitary transformation. This ensures that the theory is independent of the choice of the basis set.

(4) The dynamical equation that connects the quantum variables ψ_1, ψ_2 with the hidden variables ξ_1, ξ_2 during the measurement process is such that the normalization conditions are maintained.

(5) The outcome of a measurement S is completely predictable if $|\psi_1|$ and $|\xi_1|$ are known. If $|a_1\rangle$, $|a_2\rangle$ are eigenstates of the operator that corresponds to the measurement S, then the measurement S will take Ψ into $|a_1\rangle$ with certainty, if just before the measurement $|\psi_1| > |\xi_1|$. If just before the measurement $|\psi_1| < |\xi_1|$, then the measurement S will take Ψ into $|a_2\rangle$. In the case of plane polarizers, the photon can emerge only in one state, say $|a_1\rangle$, whereas state $|a_2\rangle$ is completely absorbed. This means that for polarizers, $|\psi_1| > |\xi_1|$ implies transmission and $|\psi_1| < |\xi_1|$ implies no transmission. The usual quantum mechanical results are obtained if ξ_1 is assumed to be uniformly distributed in its complex space inside the unit circle.

(6) The process of measurement can and usually does change the wave function, but the hidden variables remain approximately constant during the measurement, provided that the time for measurement is sufficiently short. In an ensemble of systems the distribution of the hidden variables relaxes to the uniform distribution with a characteristic time τ. Bohm and Bub estimate that $\tau \approx h/kT \approx 10^{-13}$ sec at room tem-