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Reaction $K^-p \to \Xi^- K^0 \pi^+$ at 2.18 GeV/c*

Samuel R. Borenstein,† Jerome S. Danburg, George R. Kalbfleisch, Richard C. Strand, and Vance VanderBurg

Physics Department, Brookhaven National Laboratory, Upton, New York 11973

and

J. W. Chapman, Richard K. Kiang, and J. Lys

Department of Physics, University of Michigan, Ann Arbor, Michigan 48104

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From 730 $K^-p \to \Xi^- K^0 \pi^+$ events at 2.18 GeV/c a sample of 324 $\Xi^{*0}(1531)$ decaying to $\Xi^-\pi^+$ has been analyzed. This sample yields a mass $M = 1531.3 \pm 0.6$ MeV, corrected for systematic shifts. A width of $\Gamma = 8.4 \pm 1.4$ MeV is obtained; the mass resolution was unfolded taking account of the non-Gaussian nature of the resolution function. In addition, the $\Xi^{*0}(1635)$ reported by the Brandeis-Maryland-Syracuse-Tufts Collaboration is not detected. An upper limit of less than 2 μb (90% confidence level) is obtained for the cross section. The energy dependence of the ΞK and $\Xi^*(1531)K$ cross sections would suggest a substantial cross section ($\sim 7.5 \pm 3$ μb) for $\Xi^*(1635)K$ at 2.18 GeV/c. Thus either this state does not exist, or the energy dependence of its production cross section is different from that observed for the ΞK and $\Xi^*(1531)K$ reactions.

INTRODUCTION

The $\Xi^{*0}(1531)$ mass and width were previously measured separately in two different experiments.[1,2] We present here new values from a study of 2.18-GeV/c K^-p interactions. The Brandeis-Maryland-Syracuse-Tufts (BMST) Collaboration[3,4] has reported recently a $\Xi^{*0}(1635)$ state decaying to $\Xi^-\pi^+$. We do not observe such a state.

THE EXPERIMENT

Three exposures of the BNL 31-in. liquid-hydrogen bubble chamber with a four mole-percent admixture of neon and with tantalum and lead glass plates mounted in the chamber were made in 1968, 1970, and 1971. These exposures resulted in 1.5 million pictures in three views each, containing about 60 events/μb in total. A study of the reaction

$$K^-p \to \Xi^- K^0 \pi^+, \tag{1}$$

is described in this paper, from about one half of the data obtained (0.8 million pictures or about 32 events/μb). The two topologies used have a beam track associated with two outgoing charged prongs, one of which decays, and have one or two V's associated. Thus reaction (1) was restricted to those events having two or three visible strange-particle decays. The scanning and rough digitizing of the events was performed at BNL and the University of Michigan; the final digitizing was done by the BNL Flying Spot Digitizer. Standard analysis yielded a sample of 730 examples of reaction (1).

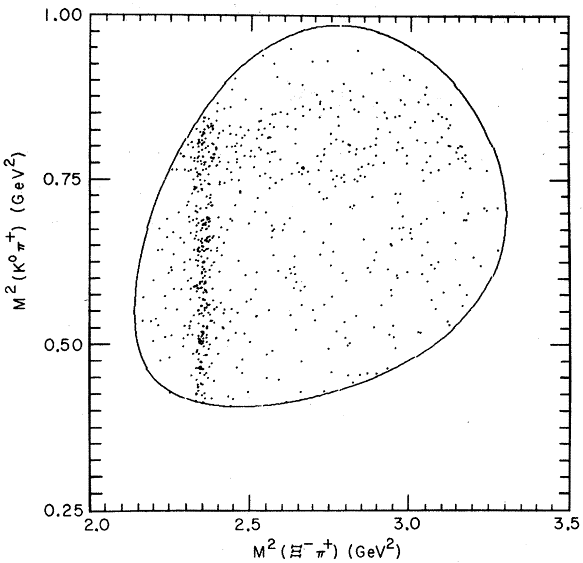

FIG. 1. Dalitz plot of 730 events from the reaction $K^-p \rightarrow \Xi^- K^0 \pi^+$ at 2.18 GeV/c.

The Dalitz plot for these events is shown in Fig. 1, where the $\Xi^*(1531)$ and the $K^*(890)$ bands are evident. The $\Xi^-\pi^+$ and $K^0\pi^+$ mass distributions are shown in Figs. 2 and 3. The shaded region of Fig. 2 excludes the K^* band, and the shaded area of Fig. 3 is restricted to events in the $\Xi^*(1531)$ band. The absence of an excess of events in the $\Xi^*(1635)$ [$1605 < M(\Xi\pi) < 1665$ MeV] band indicated on Fig. 2 corresponds to a 90% confidence-level limit of fewer than ten events.[5] This upper limit for $\Xi^*(1635)$ production will be discussed below.

MASS AND WIDTH OF THE $\Xi^*(1531)$

A sample of 324 events with a $K^0\pi^+$ mass less than 900 MeV [for $K\pi$ mass squared values > (900 MeV)^2, the Dalitz-plot boundary does not allow all $\Xi\pi$ mass values in the $\Xi^*(1531)$ band; see Fig. 1] and a $\Xi^-\pi^+$ mass between 1510 and 1555 MeV was chosen for analysis. The $\Xi^-\pi^+$ mass distribution for this sample is shown in Fig. 4, and the fitted $\Xi\pi$ mass errors are histogrammed in Fig. 5(a) and "ideogrammed"[6] in Fig. 5(b). The light dashed curve in Fig. 5(b) is an "equivalent" Gaussian, having the same full width at half maximum (FWHM) and the same area as the true resolution function. To determine the mass and width of the $\Xi^*(1531)$, we have followed the resolution-unfolding procedure of Coyne *et al.*[7] The shape of the resolution function shown in Fig. 5(b) is well fitted with a polynomial of the form $[\sum a_n(\Delta M)^{2n}]^{-1}$, with n running from 0 to 3. This function was broadened (i.e., ΔM was scaled by a multiplicative factor; see below), convoluted with an S-wave Breit-Wigner curve, added to a linear background, and fitted to the observed mass spectrum. (We note that a P-wave Breit-Wigner curve gives the same

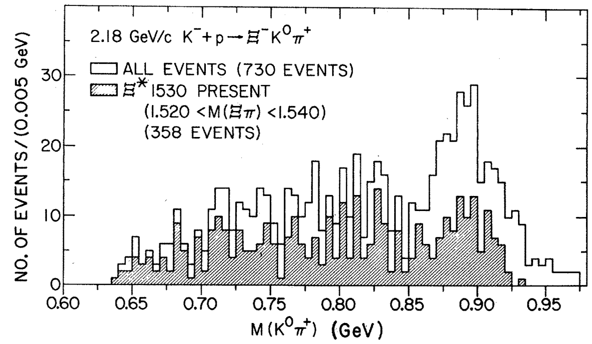

FIG. 3. The $K^0\pi^+$ mass distribution of events in the Dalitz plot of Fig. 1.

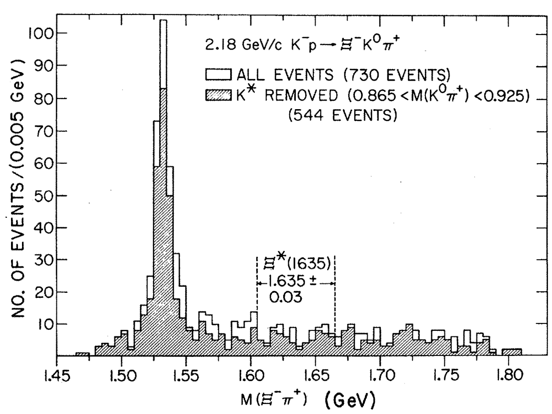

FIG. 2. The $\Xi^-\pi^+$ mass distribution of events in the Dalitz plot of Fig. 1. The $\Xi^*(1635)$ band is defined by the dashed lines.

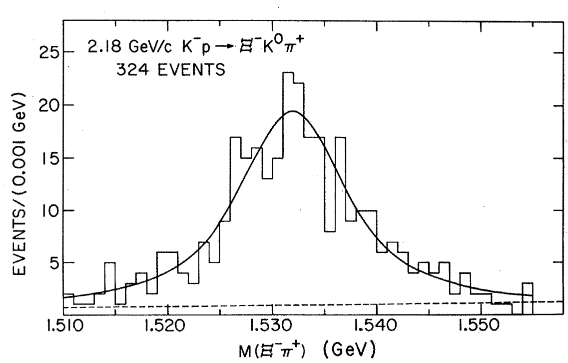

FIG. 4. The $\Xi^-\pi^+$ mass distribution in the $\Xi^*(1531)$ mass band; only those events from the Dalitz plot of Fig. 1 with $m(K^0\pi^+) < 900$ MeV are shown. The solid curve is the result of a fit to this spectrum (see text); the dashed curve is the (linear) background estimate.

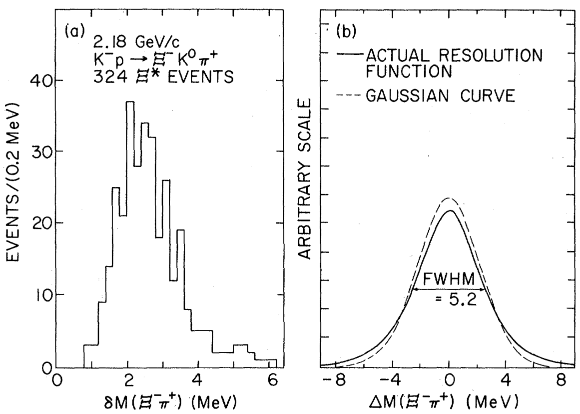

FIG. 5. (a) $\Xi^-\pi^+$ mass error (standard deviation) distribution for the $\Xi^*(1531)$ events of Fig. 4. (b) Resolution function (solid curve) obtained from the events in (a); the dashed curve is a Gaussian with the same area and the same full width at half maximum as the resolution function.

results, within errors, as an S-wave Breit-Wigner curve.)

We have assumed that deviations from flatness of the probability distribution obtained from the kinematic fits to the final state $\Xi^- K^0 \pi^+$ can be removed by multiplying each kinematic χ^2 value by a constant factor f^2. First the probability distributions for the kinematic χ^2 were examined for flatness. The highly constrained fits to reaction (1) involve three or four vertices with usually eight or fourteen constraints. If each χ^2 is multiplied by a factor f^2, a value of this factor can be found which makes the probability distribution nearly flat.[7,8] Then f^{-1} is the factor by which the errors of Fig. 5 must be scaled. For the 324 $\Xi^*(1531)$'s, a value of $f(\Xi^*) = 0.88 \pm 0.04$ is obtained, where

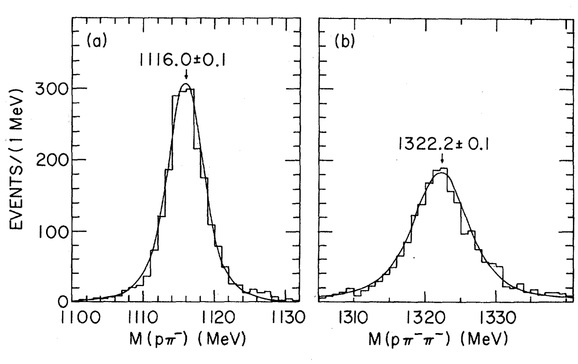

FIG. 6. Mass spectra with scaled resolution functions of approximately 2200 $\Xi^- \to \Lambda\pi^-$, $\Lambda \to p\pi^-$ events; the masses are calculated using the measured (unfitted) values of momentum. (a) $M(p\pi^-)$; the central mass value 1116.0± 0.1 is indicated. (b) $M(p\pi^-\pi^-)$; the central mass value 1322.2± 0.1 is indicated.

the error in f includes an estimate of the systematic error. As a check, this procedure has also been applied to the reactions $K^-p \to \Lambda\omega$, $\omega \to \pi^+\pi^-\pi^0$ and $K^-p \to \Lambda\phi$, $\phi \to K^+K^-$. The values $f(\omega)$ and $f(\phi)$ for these two channels are both 0.82 ± 0.04. The values 10.5 ± 1.5 and 3.8 ± 0.6 MeV were then obtained for the widths Γ_ω and Γ_ϕ, respectively. These are to be compared with the known values[9] 11.4 ± 0.9 and 4.0 ± 0.3 MeV, respectively, or with the "world average" ω width of Coyne *et al.*[7] of 10.1 ± 0.7 MeV.

The value $f(\Xi^*) = 0.88$, corresponding to a $\Xi\pi$ mass resolution $\Gamma_R = 6.0$ MeV (FWHM), was used to obtain the fitted curve shown in Fig. 4. We obtain an uncorrected mass $M = 1531.9 \pm 0.5$ MeV and a width $\Gamma = 8.4 \pm 1.4$ MeV. The background level shown matches that required by the mass distribution of Fig. 2. The errors include estimates of systematic effects. To give an idea of the size of the width correction obtained by scaling all ΔM values by f^{-1}, we note that a value of $f = 1.0$ would yield a $\Xi^*(1531)$ width of 9 ± 1 MeV.

The mass value must be corrected for systematic shifts as determined by shifts seen for the Λ and Ξ^- masses. The normalization of the magnetic field of the bubble chamber was adjusted using K^0 and Λ decays from abundant one-V events. These mass distributions yield a normalization of the field which agrees closely with the Hall probe measurements of the magnetic field. The K^0 mass obtained was 497.4 ± 0.1 MeV versus 497.8 MeV expected; and the Λ mass obtained was 1116.2 ± 0.1 MeV versus 1115.6 MeV expected. In addition, the Λ and Ξ^- masses from cascade events (all events where a $\Xi^- \to \Lambda\pi^-$, $\Lambda \to p\pi^-$ decay sequence is observed) were examined. The $p\pi^-(\Lambda)$ and $p\pi^-\pi^-(\Xi^-)$ mass distributions for this 2200-event sample are shown in Fig. 6. The solid curves shown are the resolution functions calculated from the geometry errors and scaled by factors of 0.89 ± 0.04 and 1.03 ± 0.04, respectively. The mass of the Λ and the Ξ^- are shifted from the accepted values[9] by $+0.4 \pm 0.1$ and $+0.9 \pm 0.1$ MeV, respectively. The mass of the Ξ^- using fitted $\Lambda \to p\pi^-$ decays from the 324-event Ξ^* sample (histogram not shown) gives a mass which is too high by $+0.6 \pm 0.3$ MeV. We estimate from this that the uncorrected Ξ^* mass is too high by 0.6 ± 0.3 MeV. Our value for the mass of the $\Xi^*(1531)$ is then 1531.3 ± 0.6 MeV, and we find its width to be 8.4 ± 1.4 MeV. These are to be compared with the previously determined values of 1528.9 ± 1.1 MeV and 7.3 ± 1.7 MeV, respectively.[1,2,9]

$\Xi^*(1635)$

The 90% confidence-level upper limit for the production of $\Xi^*(1635)$ in our data was found to be

10 events. We wish to make a comparison of our data with the BMST results[3,4] and a report by Ross *et al.*[10] The cross sections[11-22] for the four reactions $K^-p \rightarrow \Xi^-K^+$, Ξ^0K^0, $\Xi^{*-}(1531)K^+$, and $\Xi^{*0}(1531)K^0$ versus the incident K^- momentum p are shown in Fig. 7. These cross sections rise rapidly at threshold, level off, and then fall with increasing momentum with a dependence between p^{-3} and p^{-5}. In addition we note that the $\Xi^*(1815)$, $\Xi^*(1940)$ have been observed to have the same general behavior within the limited data available.[23] Thus these curves are typical of Ξ^* production cross sections in general – a rapid rise to the maximum value at a beam momentum about 0.2 GeV/c to 0.7 GeV/c above threshold, followed by a power-law falloff at higher energies. Ross *et al.*[10] give an upper limit of 1.5 μb for the $\Xi^*(1635)$ cross section at 3.3 GeV/c. The BMST Collaboration reports 40 ± 12 $\Xi^*(1635)$ events and 200 ± 14 $\Xi^*(1531)$ events.[4] We have an upper limit of 10 $\Xi^*(1635)$ events (90% confidence level) and 324 $\Xi^*(1531)$ events. The ratio of the numbers of $\Xi^{*0}(1635)$ to $\Xi^{*0}(1531)$ events times the cross sections for $\Xi^{*0}(1531)$ from the data in Fig. 7(d) yields the values $\sigma(\Xi^{*0}(1635)) = 3.6 \pm 1.6$ μb at 2.87 GeV/c and <2 μb (90%) at 2.18 GeV/c. These $\Xi^*(1635)$ cross sections are shown in Fig. 8. The shaded region shown superimposed on these data represent the shape of all the ΞK and Ξ^*K cross sections shown in Fig. 7; the cross-hatched region is that of the $\Xi^*(1531)K$ cross sections only [Figs. 7(c) and 7(d)]. For Fig. 8 all the ΞK and Ξ^*K cross-section points of Fig. 7 were shifted (scaled) parallel to the momentum axis so that their threshold beam momenta coincide with that of the $\Xi^*(1635)K$ reaction. The envelopes defined by the one-standard-deviation cross-section error bars were then shifted (scaled) vertically so that the upper-limit envelopes passed through the BMST upper limit, and the lower-limit envelopes passed through the BMST lower limit. The Ξ^0K^0 reaction suggests a lower limit just meeting our upper limit. We note that the K^- momentum of our experiment, 2.18 GeV/c, corresponds to the maximum

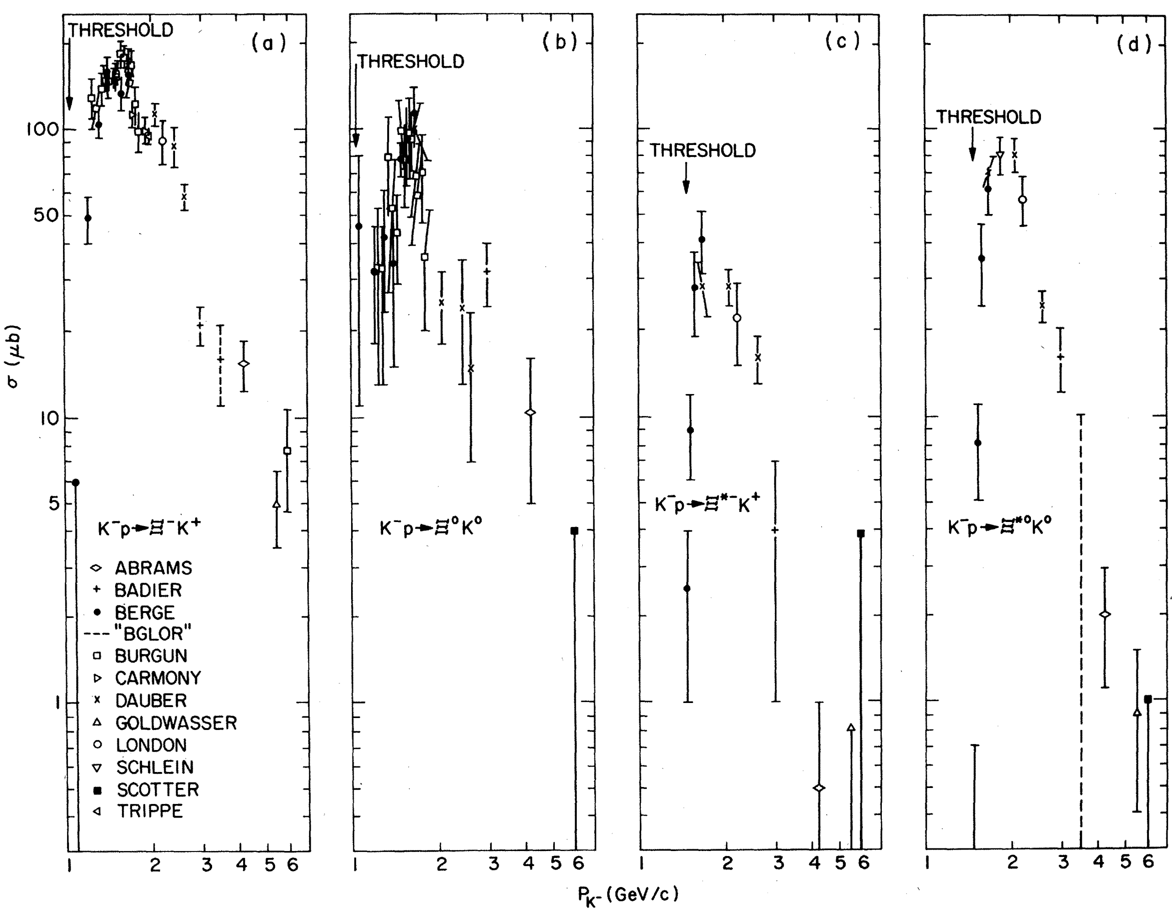

FIG. 7. Cross sections *versus* beam momentum for K^-p interactions yielding (a) Ξ^-K^+, (b) Ξ^0K^0, (c) $\Xi^{*-}(1531)K^+$, and (d) $\Xi^{*0}(1531)K^0$. The sources of the data are Refs. 11–22, and are denoted by the symbols given.

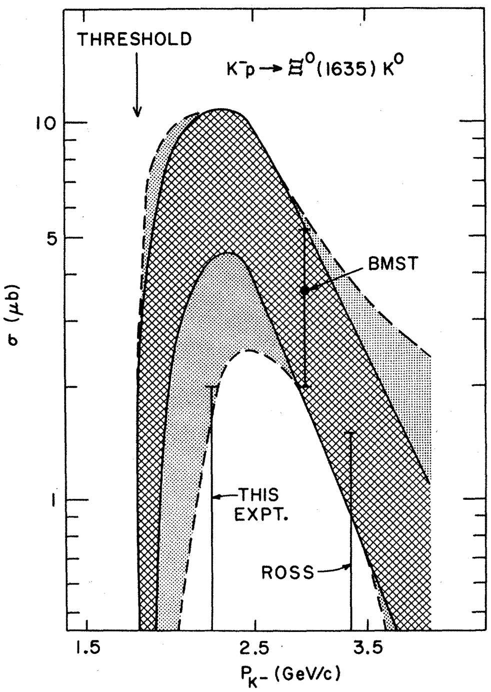

FIG. 8. Cross section *versus* beam momentum for $K^-p\to\Xi^{*0}(1635)K^0$. The upper and lower limits for the range of values for this cross section are taken from the data of Fig. 7 (shaded area), with the cross-hatched region corresponding to $K^-p\to\Xi^*(1531)K$ only (see text). The cross-section values for $K^-p\to\Xi^{*0}(1635)K^0$ inferred for the BMST Collaboration (Ref. 4) as well as upper limits on this cross section from the present experiment and that of Ross *et al*. (Ref. 10) are also shown.

of the $\Xi^*(1635)$ cross section expected from Fig. 7; the cross-hatched region of Fig. 8 suggests that the $\Xi^*(1635)$ cross section should be 7.5 ± 3 μb at 2.18 GeV/c, which is inconsistent with our upper limit. Conversely, our upper limit, using the curves of Fig. 8, would suggest at most 10 events in the BMST experiment, which could not constitute a significant signal for them. We conclude that either the energy dependence of the $\Xi^*(1635)K$ production cross section is strikingly different from that for the ΞK and $\Xi^*(1531)K$ reactions (and for other Ξ^*K reactions), or that an experimental fluctuation is responsible for the enhancement at 1635 MeV seen in the BMST data.

CONCLUSION

We have presented data on 730 examples of the reaction $K^-p\to\Xi^-K^0\pi^+$ at 2.18 GeV/c and obtained new values for the $\Xi^{*0}(1531)$ mass and width: 1531.3 ± 0.6 MeV and 8.4 ± 1.4 MeV, respectively. In addition, we do not observe the $\Xi^{*0}(1635)$ reported by the BMST Collaboration.

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†Permanent address: York College, City University of New York, Queens, N. Y.

[1]G. W. London *et al.*, Phys. Rev. 143, 1034 (1966).

[2]P. E. Schlein *et al.*, Phys. Rev. Letters 11, 167 (1963).

[3]S. Apsell *et al.*, Phys. Rev. Letters 23, 884 (1969).

[4]Brandeis-Maryland-Syracuse-Tufts Collaboration, in *Hyperon Resonances—70*, edited by E. C. Fowler (Moore, Durham, North Carolina, 1970), p. 317.

[5]The 10-event upper limit was determined as follows: The spectrum of Fig. 2 is flat in the region of 1635 MeV. There are 100 events in the control bands 1575–1605 and 1665–1695 MeV and 84 events in the $\Xi^*(1635)$ region in between. Since the $\Xi^*(1635)$ band and the control bands are equally wide, there is a "signal" of -16 ± 14 events, or an upper limit of about 10 events with a 90% confidence level.

[6]The resolution curve is an ideogram with central value zero and with the errors δM of Fig. 5(a), as is usual.

[7]D. G. Coyne *et al.*, Nucl. Phys. B32, 333 (1971).

[8]The χ^2 distributions generally have an excess of counts at high χ^2, causing an excess of events with low probability. For the value $f=0.88$, the distribution is reasonably flat, except for a slight excess at low probability values. This value of f yields equal numbers of events above and below 50% probability. Twenty-four excess events with probability less than 5% were then treated as a systematic uncertainty in the determination of f. The value of $f=0.88\pm0.02$ (statistical only) becomes 0.88 $\pm$ 0.04 to include the systematic error.

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[19]See Ref. 1.
[20]See Ref. 2.
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[23]These Ξ^*'s have been observed near threshold, i.e., in the mass spectrum near the end of phase space; see Refs. 3, 12, and 17; see also S. Apsell *et al.*, Phys. Rev. Letters 24, 777 (1970).

PHYSICAL REVIEW D VOLUME 5, NUMBER 7 1 APRIL 1972

f^0- A_2^0 Interference and the $f^0 \to K\bar{K}$ Branching Ratio*

N. N. Biswas, N. M. Cason, E. A. Harrington,† V. P. Kenney, and W. D. Shephard
Department of Physics, University of Notre Dame, Notre Dame, Indiana 46556
(Received 2 August 1971)

Interference in the $K\bar{K}$ decay mode of the f^0 and A_2^0 mesons is discussed in terms of the mass-matrix formalism. It is shown that the measurement of the $f^0 \to K\bar{K}$ branching ratio can be in error by an order of magnitude if interference is not properly accounted for. Data from π^+p and π^-p reactions at 18.5 GeV/c are used to determine the $(f^0 \to K\bar{K})/(f^0 \to \pi\pi)$ branching ratio R_{f^0} using the known $A_2 \to K\bar{K}$ branching ratio and assuming a value for the coherence factor. We find $9\% \le R_{f^0} \le 18\%$.

I. INTRODUCTION

The $f^0 \to K\bar{K}$ branching ratio has been a rather difficult quantity to measure for several reasons. First, the rate is small. But perhaps more important, interpretation of the $(K\bar{K})^0$ mass spectrum is complicated by the presence of the A_2^0. Since the A_2^0 and f^0 both have $J^P = 2^+$ and have masses which are close relative to their widths, interference in the $(K\bar{K})^0$ mass spectrum is expected to be strong.[1] The $A_2 \to K\bar{K}$ branching ratio itself can be determined without this complication by looking at the $K^\pm K^0$ decay mode since the A_2 has $I = 1$.

Previous experiments[2] have attempted to measure the $f^0 \to K\bar{K}$ branching ratio without taking interference into account. Here we describe the interference effects in detail and show that differences in the branching ratio of one order of magnitude can arise depending on whether the interference is constructive or destructive. This theory, based on the mass-matrix formalism, is developed in Sec. II. The experimental data are discussed in Sec. III and the data are fitted using the interference formalism in Sec. IV.

II. THEORY

If one observes a $K\bar{K}$ pair of invariant mass m from the decay of either an f^0 or an A_2^0, the amplitude for this observation is given, in the mass-matrix formalism,[3] by the matrix product

$$S(K\bar{K}) = (B_1 \quad B_2)P(m)\begin{pmatrix} T_1 \\ T_2 \end{pmatrix}, \tag{1}$$

where B_1 and B_2 are the f^0 and A_2^0 production amplitudes and the T's are their $K\bar{K}$ decay amplitudes. The matrix P is given by

$$P(m)^{-1} = \begin{pmatrix} (m - m_1 + i\gamma_1) & \delta \\ \delta & (m - m_2 + i\gamma_2) \end{pmatrix}, \tag{2}$$

where m_1 and m_2 are the f^0 and A_2^0 masses, the γ_i's are their half-widths, and $\delta = -\langle f^0 | M | A_2^0 \rangle$ denotes the f^0-A_2^0 transition due to the electromagnetic mass operator. (Here δ must be electromagnetic because of the different isospins of the f^0 and the A_2.) Neglecting terms of order δ^2, Eqs. (1) and (2) yield

$$S(K\bar{K}) = B_1 T_1 b_1 + B_2 T_2 b_2 - \delta(B_1 T_2 + B_2 T_1)(b_1 b_2), \tag{3}$$

where $b_i = 1/(m - m_i + i\gamma_i)$. The B's and T's in (3) are complex, and thus the expression is quite complicated in general. The magnitude of these amplitudes can be estimated from the f^0 and A_2^0 production cross sections and from their $K\bar{K}$ partial widths. Furthermore, an estimate of δ can be obtained from the work of Coleman.[4] These estimates show that the absolute magnitude of the third term in (3) is less than 5% of the magnitude of the first two terms, and thus we neglect the term linear in δ. Thus we can write

$$dN(K\bar{K})/dm = |B_1 T_1 b_1 + B_2 T_2 b_2|^2.$$