vert hidden-variable emergence rates into quantum mechanical counting rates.

[9]It has been shown by D. Bohm and Y. Aharonov, Phys. Rev. 108, 1070 (1957), that the WS experiment is a decisive refutation of a hypothesis studied by W. H. Furry, Phys. Rev. 49, 393, 476 (1936).

[10]For details see M. A. Horne, thesis, Boston University, 1969 (unpublished).

[11]The distribution is given in H. S. Snyder, S. Pasternack, and J. Hornbostel, Phys. Rev. 73, 440 (1948).

Ξ RESONANCES IN $K^-p \rightarrow \Xi\pi K$ AT 2.87 GeV/c*

S. Apsell, N. Barash-Schmidt, L. Kirsch, and P. Schmidt
Department of Physics, Brandeis University, Waltham, Massachusetts 02154

and

C. Y. Chang, R. J. Hemingway, B. V. Khoury, A. R. Stottlemyer, H. Whiteside,† and G. B. Yodh
Department of Physics and Astronomy, University of Maryland, College Park, Maryland 20742

and

M. Goldberg, K. Jaeger, C. McCarthy, B. Meadows, and G. C. Moneti‡
Department of Physics, Syracuse University, Syracuse, New York 13210

and

J. Bartley, R. M. Dowd, J. Schneps, and G. Wolsky
Department of Physics, Tufts University, Medford, Massachusetts 02155

(Received 25 August 1969)

Evidence is presented for four Ξ resonances in the reaction $K^-p \rightarrow \Xi^-\pi^+K^0$. In addition to the well known $\Xi(1530)$, significant structures are observed in the $\Xi\pi$ system at masses of 1630, 1800, and 1960 MeV, although the latter two are not statistically distinguishable from a single broad structure at 1950 MeV. No significant enhancements at these masses are observed in the $\Xi^-\pi^0K^+$ final state.

Ξ resonances are produced with relatively small cross sections, cannot be studied in formation experiments, and have complex decay topologies. For these reasons, only large bubble-chamber exposures have yielded significant information bearing on the existence and properties of these particles. This experiment, designed for the study of Ξ resonances below a mass of 2 GeV, involves 10^6 pictures of K^-p interactions at 2.87 GeV/c taken at the Brookhaven National Laboratory 31-in. bubble chamber at the alternating-gradient synchrotron.[1] The equivalent of 24 events/μb has been accumulated to date. In this Letter, we report on $\Xi\pi$ mass spectra observed in the reactions

$$K^-p \rightarrow \Xi^-\pi^+K^0, \quad (1)$$

$$K^-p \rightarrow \Xi^-\pi^0K^+. \quad (2)$$

For this study, all film was scanned twice for events with at least two visible decays of strange particles. Those events with one or more successful kinematic fits (confidence level $\geq 0.1\,\%$) were inspected for consistency with observed ionizations. A total of 635 events achieved a unique fit to Reaction (1), while 265 events fit Reaction (2) uniquely. The 94 events fitting both reactions[2] have been apportioned to each with a weight of 0.5.

The Dalitz plot for Reaction (1), shown in Fig. 1, shows strong production of $\Xi^0(1530)$ and

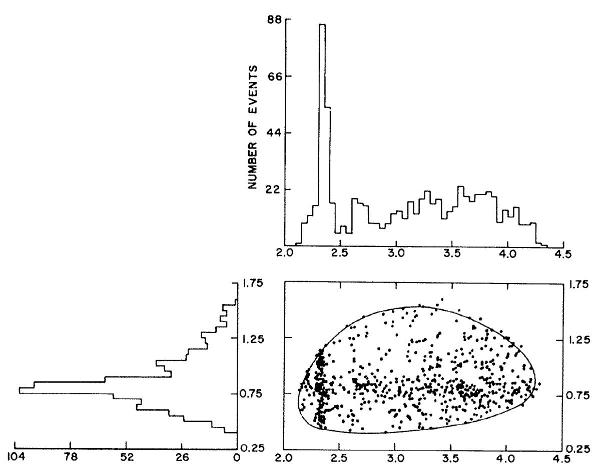

FIG. 1. Dalitz plot for the reaction $K^-p \rightarrow \Xi^-\pi^+K^0$, with $M^2(\Xi^-\pi^+)$ and $M^2(K^0\pi^+)$ projections.

$K^{*+}(890)$. Further structure in the $\Xi^-\pi^+$ system can be seen more clearly in the mass projection of Fig. 2(a). The plot shows, in addition to the $\Xi(1530)$, peaking near 1630, 1800, and 1960 MeV. Of the four peaks, the structure at 1630 MeV has not been previously observed, and corresponds to a >3 standard deviation effect.[3] Resonances in the 1750- to 2000-MeV region have been previously reported,[4-8] but no enhancement in $M(\Xi\pi)$ spectra has been seen near 1800 MeV. All peaks remain, with reduced significance, when events in the $K^{*+}(890)$ band are removed (shaded spectrum). On the other hand, the $M(\Xi^-\pi^0)$ spectrum of Reaction (2) [see Fig. 2(b)] with less than half the events and poorer resolution,[9] exhibits no obvious structure in addition to the $\Xi^-(1530)$ and $K^{*+}(890)$ (latter not shown).

A maximum-likelihood fit to the events of Reaction (1) has been carried out to obtain the masses, observed widths, and percentages of the four $\Xi\pi$ enhancements.[10] The results of this fit are given in Table I, and the best fit curve is superimposed on the histogram of Fig. 2(a). An average[11] χ^2 of 18.3 is calculated from the $\Xi^-\pi^+$ mass spectrum for 12 degrees of freedom. An equally acceptable fit to Reaction (1) is obtained when the resonant amplitudes at 1800 and 1960 MeV are replaced by a single amplitude (χ^2 of 23.6 for 15 degrees of freedom); the resulting mass and width in this case are 1952 ± 26 MeV and 300 ± 110 MeV, respectively.[12] A similar fit to Reaction (2), including $\Xi(1530)$, $K^*(890)$, and phase space, yields a χ^2 of 18.8 for 19 degrees of freedom. The curve corresponding to this fit is superimposed on the histogram of Fig. 2(b). There is no evidence for additional resonant activity[13] in the $\Xi^-\pi^0$ system.

We now compare our results with those of other groups reporting resonances in $M(\Xi\pi)$ spectra

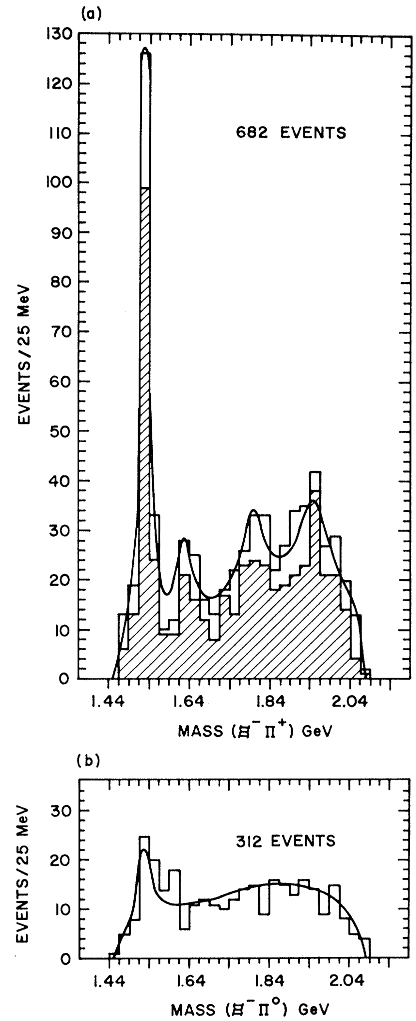

FIG. 2. (a) Mass of the $\Xi^-\pi^+$ system of Reaction (1). The shaded distribution shows the spectrum after removal of $K^*(890)$ events [$865 < M(K\pi) < 915$ MeV]. (b) Mass of the $\Xi^-\pi^0$ system of Reaction (2). The solid curves result from maximum-likelihood fits to the data (see text).

Table I. Best values of resonant masses, observed widths, and fractions of resonance production and phase space, resulting from maximum-likelihood fits to the $\Xi\pi K$ final state (see text). Underlined numbers were not varied in the fit.

Process	$K^-p\to\Xi^-\pi^+K^0$ M (MeV)	Γ (MeV)	(%)	$K^-p\to\Xi^-\pi^0K^+$ M (MeV)	Γ (MeV)	(%)
$\Xi(1530)K$	$\underline{1530}$	13 ± 2	22 ± 2	$\underline{1530}$	28 ± 22	12 ± 3
$\Xi(1630)K$	1628 ± 5	15 ± 5	3 ± 1			
$\Xi(1800)K$	1801 ± 13	78 ± 33	9 ± 2			
$\Xi(1960)K$	1962 ± 14	147 ± 55	22 ± 3			
$\Xi K^*(890)$	$\underline{891}$	72 ± 12	44 ± 4	$\underline{891}$	65 ± 30	26 ± 5
Phase space			0 ± 5			62 ± 6

between 1750 and 2000 MeV. Badier et al.,[4] at incident K^- momentum of 3.0 GeV/c, observed an enhancement ($M = 1933 \pm 16$, $\Gamma = 140 \pm 35$) representing $26 \pm 6\%$ of 150 events in Reaction (1). In 44 events of Reaction (2), no enhancements were observed. Considering the limited statistics at 3 GeV/c, the results of Badier et al. are consistent with the gross features of the $\Xi^-\pi^+K^0$ state found in this experiment. On the other hand, Dauber et al.[6] at 2.7 GeV/c, find no significant structure in the same mass region of Reaction (1) from a sample of 312 events, while in Reaction (2) an enhancement ($M = 1894 \pm 18$, $\Gamma = 98 \pm 23$) representing $25 \pm 7\%$ of 150 events is observed. The lowering of their peak position may be explained by the limited phase space available at their energy, but this does not explain the absence of a significant signal at this mass in the $M(\Xi^-\pi^+)$ spectrum. Finally, Alitti et al.[7] have observed a resonance in the $M(\Xi^-\pi^+)$ spectrum ($M = 1930 \pm 20$, $\Gamma = 80 \pm 40$) representing 13% of 150 events in the $\Xi^-\pi^+\pi^-K^+$ final state. This narrower structure could be associated with the $\Xi(1960)$ state observed in this experiment.

In summary, our study of the $\Xi\pi K$ channel indicates a probable new resonant state in the $\Xi\pi$ system at 1630 MeV, and suggests a splitting of the broad high mass enhancement into two narrower states at 1800 and 1960 MeV.

We gratefully acknowledge the assistance of the Brookhaven National Laboratory personnel and the scanning and measuring staffs of the contributing physics departments. The Maryland group wishes to thank Dr. R. Glasser for several illuminating discussions.

---

*Work supported in part by the National Science Foundation and the U. S. Atomic Energy Commission.

†Now at Federal City College, Washington, D. C.

‡On leave from the University of Rome, Rome, Italy.

[1]A description of the beam may be found in H. Brown, Brookhaven National Laboratory EP & S Divison Technical Note No. 6, 1967 (unpublished). The chamber parameters are described in D. Gordan et al., Brookhaven National Laboratory Report No. 11641 (unpublished).

[2]The ambiguous events show no structure in $M(\Xi\pi)$ but contain a substantial percentage of $K^*(890)$. The inclusion or deletion of these events does not significantly alter our conclusions.

[3]We have used binomial statistics in the region 1565 MeV $< M(\Xi^-\pi^+) <$ 1715 MeV to establish the significance of this peak.

[4]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).

[5]G. A. Smith and J. S. Lindsey, in Proceedings of the Second Topical Conference on Resonant Particles, 10-12 June 1965, Athens, Ohio, edited by B. A. Munir (Ohio University Press, Athens, Ohio, 1965), p. 251.

[6]P. M. Dauber, J. P. Berge, J. R. Hubbard, D. W. Merrill, and R. A. Muller, Phys. Rev. 179, 1262 (1969). This work partially updates that of Ref. 5.

[7]J. Alitti, E. Flaminio, W. Metzger, D. Radojicić, R. R. Rau, C. R. Richardson, N. P. Samios, I. Skillicorn, D. Bassano, M. Goldberg, and J. Leitner, Phys. Rev. Letters 21, 1119 (1968).

[8]J. Alitti, V. E. Barnes, E. Flaminio, W. Metzger, D. Radojicić, R. R. Rau, C. R. Richardson, N. P. Samios, D. Bassano, M. Goldberg, and J. Leitner, Phys. Rev. Letters 22, 79 (1969).

[9]The $M(\Xi\pi)$ resolution in Reaction (1) varies from ±3 MeV in the $\Xi(1530)$ region to ±10 MeV in the 1900-MeV mass region. The $M(\Xi^-\pi^0)$ resolution of Reaction (2) is approximately ±14 MeV in all regions.

[10]These fits to the Dalitz plot of Reaction (1) include phase space, $K^*(890)$ and $M(\Xi\pi)$ Breit-Wigner amplitudes with momentum-independent widths. No interference is assumed between these processes. The fitting program MURTLEBERT was used. For a description of the method, see J. Friedman, Alvarez Group Programming Note No. P-156, 1966 (unpublished).

[11]The χ^2 is calculated by averaging over five different binnings of the mass spectrum. Mass bins of 25 MeV, with starting values of the first bin differing by 5 MeV, were used for the χ^2 determination.

[12]The existence of a $\Xi(2030)$ resonance has been reported in Ref. 8. If such a state decays to $\Xi^-\pi^+$, its presence could systematically increase our width determination in the high $M(\Xi\pi)$ region.

[13]The addition of a resonant amplitude at 1952 MeV with a width of 300 MeV gives a χ^2 of 18.3 for 16 degrees of freedom. The fitted production rate of $7 \pm 10\%$ is consistent with zero. On the other hand, a fit to the $\Xi^-\pi^+K^0$ channel without any high $\Xi\pi$ mass enhancement gives a χ^2 of 68.8 for 18 degrees of freedom. This implies the clear need for additional resonant activity in $\Xi^-\pi^+$.