Existence of Ξ Resonances above 2 GeV

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(Recieved 30 June 1983)

Ξ^{*-} production was studied in the reaction $K^- + p \to K^+_{\rm slow} + X^-$ at 5 GeV/c. The slow K^+ was electronically detected, while the X^- was observed as a missing mass, thus allowing for observation of all Ξ^* independent of decay mode. The observed Ξ states were Ξ(1320), Ξ(1530), Ξ(1820), Ξ(2030), Ξ(2250), Ξ(2370), and Ξ(2500). These data establish and confirm the existence of Ξ(2250) and indicate a peculiar production-cross-section behavior for the Ξ^*(2370).

PACS numbers: 14.20.Jn, 13.75.Jz

In comparison with baryons of strangeness 0 or −1, very little is known about Ξ or Ω states. An earlier attempt to understand the baryon spectrum in a semiempirical QCD model leads one to expect at least 30 Ξ^* states[1] with masses below 2300 MeV/c^2. The SU(6)⊗O(3) classification of three-quark baryons[2] includes the Ξ(1317) and Ξ(1530) in the $[56,0^-]$ ground state, but apart from that, no other $S = -2$ baryons have been classified. Somewhat confusing, unconfirmed experimental evidence does exist for Ξ^*'s with masses at 1630, 1680, 1940, 2250, 2370, and 2500 MeV/c^2, though some of these are most likely no more than statistical fluctuations.[3] Good evidence for states at 1820 and 2030 MeV/c^2 has also been found in several experiments. However, the parity of the 1820 and the spin and parity of the 2030 are not known which precludes their unambiguous classification in any scheme.

Much of the reason for this situation is that the majority of the data on Ξ^* resonances are from low-sensitivity bubble-chamber experiments. In the present experiment, we make use of electronic techniques to study the baryon exchange reaction

$$K^- + p \to K_{\rm slow}{}^+ + X^- \text{ at } 5 \text{ GeV}/c,$$

in which we require only observation of the K^+. The Ξ^* states are included in X^- and detectability problems of the decay products are completely avoided. Furthermore, the overall sensitivity, including detection efficiency for the K^+, and the choice of beam momentum at a point to maximize quasi two-body production of Ξ^* in the 2-GeV/c^2 mass range provide an excellent opportunity to reexamine earlier claimed resonances.

The data were obtained at the Brookhaven National Laboratory multiparticle spectrometer (MPS). Several prior publications give details of other aspects of this experiment and the MPS.[4] Figure 1 shows the MPS where the target was 60 cm of liquid hydrogen and the magnetic field was 5 kG. Detectors K_A and K_B identified K^+ mesons with momenta between 200 and 550 MeV/c and triggered the MPS. The active area of the K^+ detectors was 60×100 cm^2 for K_A,[5] and 110×140

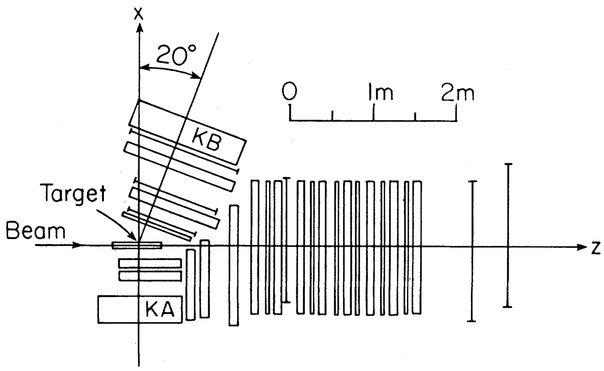

FIG. 1. MPS (top view). K_A and K_B are K^+ detectors, single lines are proportional multiwire chambers, and rectangles are spark chambers.

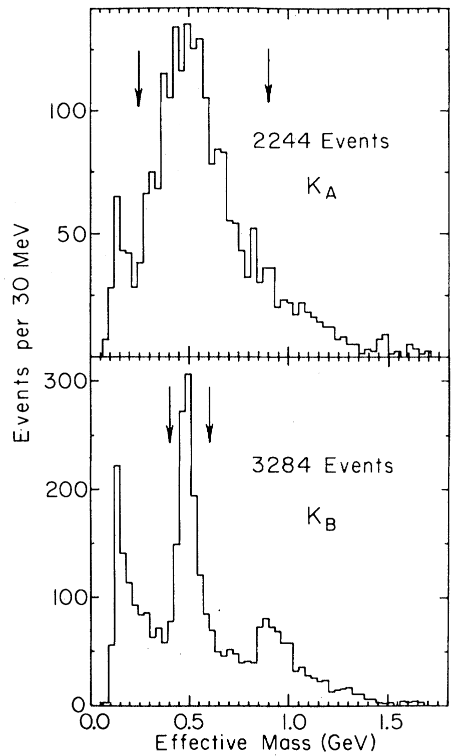

FIG. 2. Mass of particles impinging on K^+ detectors. Arrows show mass cuts. Mass is computed from range and curvature.

cm^2 for K_B. The detection of a K^+ was accomplished by stopping the K^+ and observing the decay products 8 to 50 ns after the stop. Each K^+ detector had eight layers of 1-cm-thick brass plates and, sandwiched between them, segmented scintillators that detected forward and backward decays. Since the ratio of K^+ to charged particles incident upon K_A and K_B was less than 1/10 000, some pions and protons also triggered the K^+ detectors. An extensive software package was developed to use analog-to-digital and time-to-digital convertor information to clean up the data. For each stopping particle the range (from the K^+ detectors) and the momentum (from the spectrometer) were used to calculate a mass, as shown in Fig. 2. Mass cuts around the K^+ peaks yield reasonably pure samples of K^+ events. Jenkins[6] gives details of this experiment.

Figure 3(a) shows the Monte Carlo–computed acceptance of each detector under the assumption of an exp($3u$) distribution for K^+ production. To obtain the best resolution in missing mass, the range and spectrometer information were simultaneously fitted to obtain the K^+ momentum. The final missing-mass resolution varies from event to event, but generally is better for higher missing masses. Figures 3(b) and 3(c) show the missing-mass spectra. The two detectors have very different geometrical acceptances and resolutions; therefore, the plots are shown separately. The background curves are simple polynomial distributions.

Figures 3(b) and 3(c) have a number of enhancements above the background. Gaussian peaks, representing the resonances, were superimposed on the background curve and were fitted to the missing-mass spectrum. The widths of the Gaussian functions are due to the resolution rather than the resonance widths. The background curves are in agreement with the computed phase space times acceptance. Table I summarizes masses, widths, and cross sections obtained from a fit to our data. The peak of events at 4.4 (GeV/c^2)^2 in the K_A sample [Fig. 3(b)] is due to the crossover of the rising phase space and the falling acceptance. The fit of this peak is very sensitive to the choice of parametrization of the background curve. The resonances observed are insensitive to the details of background curve. From Table I, it is evident that all the masses and cross sections determined from K_A are consistent with those from K_B. The resonance widths differ in the manner expected from our resolution. Table I also includes the result of combining both sets of data, and shows the existence of five bumps with a significance of more than 3 standard deviations.

An indication of a true Ξ resonance is that its cross section varies in a reasonable manner as a

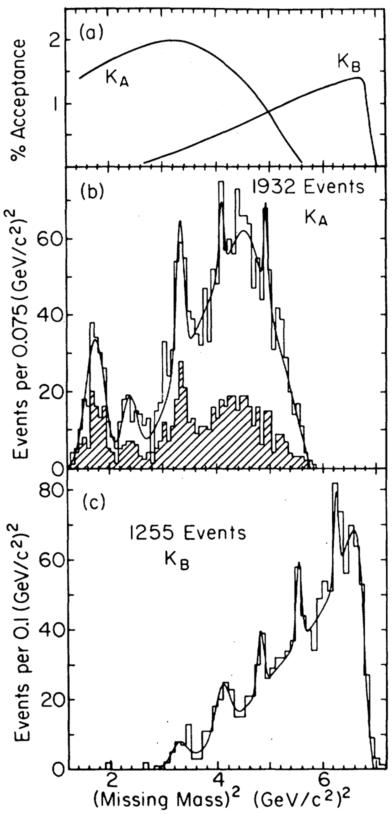

FIG. 3. Missing mass squared (X) for $K^- + p \rightarrow K^+ + X$. (a) Acceptance. (b) K_A; cross hatched areas are events with detected $\Lambda \rightarrow p\pi$. (c) K_B. Smooth curves in (b) and (c) are fits to background plus resonances.

function of incident K^- momentum (P_{lab}), and that its decay modes are consistent at a variety of P_{lab} values. An empirical relationship for the variation of two-body production in the reaction $K^- p \rightarrow \Xi^{*-} K^+$ is

$$\sigma = A P_{lab}^{-\alpha}$$

with $\alpha \sim 3.0$ to 3.5.[7] A source of data for such reactions comes from the CERN 4.2-GeV/c bubble-chamber experiment.[8,9] Table I also lists the computed cross sections using $\alpha = 3.5$ and shows that there is good agreement with our measurement for all the well-established Ξ states.

Many experiments have observed the four well established states $\Xi(1317)$, $\Xi(1530)$, $\Xi(1820)$, and $\Xi(2030)$.[9] The downstream MPS detectors enabled the detection of Λ's associated with some of the events, and helped in verifying that the bumps indeed behave like particles. The $\Xi(1317)$, $\Xi(1530)$, and $\Xi(1820)$ have Λ's in over 95% of their decays. Λ selection is indicated in the shaded region of Fig. 3(b), and in fact, about 50% of the events in these three peaks have a detected Λ, consistent with the observation probability of the Λ.

$\Xi(2030)$ is not observed in the cross-hatched area in Fig. 3(b), as expected, because it decays predominantly to ΣK where only 20% have a detected Λ. The difference in cross section for the $\Xi(2030)$ between K_A and K_B is attributed to statistical fluctuations. No Λ selection is presented

TABLE I. Reported Ξ states are listed in column 1. The PDG (Particle Data Group) status (Ref. 3) is listed in column 2 (4 means well established, 1 means weakly established). FWHM are the detector resolutions. The cross-section errors are statistical first and systematic second. An extrapolation of the $K^- p \rightarrow K^+ \Xi^{*-}$ cross sections from the 4.2-GeV/c experiment is in column 9 (σ_{extrap}). The last column has the weighted average cross sections for $\Xi(1820)$ and $\Xi(2030)$ and the best value from either detector for the other states—errors are statistical only. The upper-limit σ's are 95% confidence level.

State	PGD	K_A Mass (MeV)	K_A FWHM (MeV)	K_A σ (μb)	K_B Mass (MeV)	K_B FWHM (MeV)	K_B σ (μb)	σ_{extrap} (μb)	K_A and/or K_B σ (μb)	K_A and/or K_B Mass (MeV)
$\Xi(1320)$	4	1320 ± 6	158	7.2 ± 0.6 ± 0.6				7.4	7.2 ± 0.6	1320 ± 6
$\Xi(1530)$	4	1541 ± 12	106	2.8 ± 0.6 ± 0.2				2.7	2.8 ± 0.6	1541 ± 12
$\Xi(1630)$	2			< 1.0					< 1.0	
$\Xi(1680)$	2									
$\Xi(1820)$	3	1823 ± 6	49	3.4 ± 0.6 ± 0.3	1813 ± 15	92	2.7 ± 0.7 ± 0.2	3.0	3.1 ± 0.5	1822 ± 6
$\Xi(1940)$	2			< 1.3			< 0.8		< 0.8	
$\Xi(2030)$	3	2022 ± 9	26	1.1 ± 0.6 ± 0.1	2022 ± 12	63	2.1 ± 0.5 ± 0.2	1.5	1.7 ± 0.4	2022 ± 7
$\Xi(2120)$	1			< 1.1			< 1.4		< 1.1	
$\Xi(2250)$	1	2218 ± 6	28	2.0 ± 1.0 ± 0.2	2197 ± 12	32	1.0 ± 0.3 ± 0.1		1.0 ± 0.3	2214 ± 5
$\Xi(2370)$	2				2356 ± 10	36	0.9 ± 0.3 ± 0.1		0.9 ± 0.3	2356 ± 10
$\Xi(2500)$	2				2505 ± 10	36	1.0 ± 0.5 ± 0.1		1.0 ± 0.5	2505 ± 10

for the K_B sample because for these data the probability of Λ detection is less than 25%.

The $\Xi(2250)$ resonance has a checkered history and Roos *et al.* classify it as a "weakly established" state.[3] It was reported by experiments[10] with sensitivities of 4 to 12 events/μb and at masses varying from 2240 to 2295 MeV/c^2 and widths varying from 50 to 130 MeV/c^2. A more recent result at 6.5 GeV/c with a 46-event/μb sensitivity[11] did not observe this resonance.

Our experiment observes the $\Xi(2250)$ resonance in both the K_A and K_B samples. In the K_B sample, the significance of the signal is 3.2 standard deviations. Also, the peak observed in the K_A sample is consistent with the K_B data. Thus, our experiment enhances the status of the $\Xi(2250)$ resonance.

A clear $\Xi(2370)$ signal exists in the data, and could be associated with the 6σ peak in K^-p at 8.25 GeV/c.[12] Somewhat weaker evidence for this state was also presented in the K^-p experiment at 6.5 GeV/c.[11] Our data, however, rule out the interpretation of the effect seen at 8.25 GeV/c as an ordinary Ξ^* state. The reaction

$$K^-p \to \Xi(2370)^{*-}K^+ \text{ at } 8.25 \text{ GeV}/c$$

has a measured cross section of 1.1 ± 0.3 μb. As noted above, for most Ξ^* states, the $\Xi^{*-}K^+$ two-body reaction has a cross-section dependence of $P_{lab}^{-\alpha}$ with $\alpha \sim 3.5$. At $P_{lab} = 5$ GeV/c the two-body cross section, including u_{min} effects, is close to the peak for production of $\Xi(2370)$. On the basis of the 8.25-GeV/c data it is therefore expected that a cross-section value of at least 6.3 ± 1.7 μb be observed, while in fact we observe only 0.9 ± 0.3 μb. In view of this discrepancy, it appears that the $\Xi(2370)$ reported earlier is not a normal Ξ resonance and does not seem to be produced via normal baryon exchange.

In conclusion, new evidence for $\Xi(2250)$ has been presented. New evidence is also presented on the $\Xi(2370)$, confirming the existence of this state. However, the two-body production cross section compared to the 8.25-GeV/c result forces the conclusion that this is not an ordinary Ξ^*.

The authors are grateful for the technical support of the Brookhaven multiparticle spectrometer group under the leadership of Dr. Sam Lindenbaum and Dr. Satoshi Ozaki. We thank J. P. Astbury for the loan of the K_A detector. We are also indebted to Dr. Joseph Lannutti and Dr. James Bensinger for encouragement, support, and discussions throughout the experiment. This work was supported in part by the U. S. Department of Energy and the National Science Foundation.

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