EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/EP 80-71
20 May 1980

$E(1320)$ AND $E(1530)$ PRODUCTION IN K^-p INTERACTIONS AT 4.2 GeV/c

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* The investigation is supported by the joint research program of FOM and ZWO.

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Submitted to Nuclear Physics B

ABSTRACT

The reactions $K^-p \rightarrow \Xi^0(1320)K^+$, $\Xi^-(1320)K^+(890)$, $\Xi^0(1530)K^+$ and $\Xi^-(1530)K^+(890)$ are studied at 4.2 GeV/c incident momentum. The data come from a high statistics bubble chamber experiment with a sensitivity of ~ 133 events/ μb . Total and differential cross sections are presented. The results are compared to the SU(3)-related processes $K^+p \rightarrow pK^+$ and $K^+p \rightarrow pK^+(890)$ in the backward hemisphere. In the forward hemisphere "forbidden" peaks are observed and current ideas about them are discussed.

1. INTRODUCTION

In this paper we present a study, at 4.2 GeV/c incident momentum, of $\Xi(1320)$ and $\Xi(1530)$ production in the two and quasi two-body reactions which are shown below together with their contributing final states:

<u>Reactions</u>		<u>Final states contributing</u>	
$K^- p \rightarrow K^0 \Xi^0(1320)$	(A)	$K_1^0 + \text{missing neutrals}$	(1)
$K^- p \rightarrow K^+ \Xi^-(1320)$	(B)	$K^+ \Xi^-(1320)$	(2)
$K^- p \rightarrow K^+(890) \Xi^-(1320)$	(C)	$\pi^+ K_1^0 \Xi^-(1320)$	(3')
		$\pi^+ K_2^0 \Xi_1^-(1320)$	(3'')
		$\pi^0 K^+ \Xi_1^-(1320)$	(4)
$K^- p \rightarrow K^0 \Xi^0(1530)$	(D)	$\pi^+ K_1^0 \Xi^-(1320)$	(3')
		$\pi^+ K_2^0 \Xi_1^-(1320)$	(3'')
$K^- p \rightarrow K^+ \Xi^-(1530)$	(E)	$\pi^0 K^+ \Xi_1^-(1320)$	(4)
$K^- p \rightarrow K^0(890) \Xi^0(1530)$	(F)	$\pi^+ \pi^- K^+ \Xi^-(1320)$	(5)
		$\pi^0 \pi^+ K_1^0 \Xi^-(1320)$	(6)
$K^- p \rightarrow K^+(890) \Xi^-(1530)$	(G)	$\pi^0 \pi^+ K_1^0 \Xi^-(1320)$	(6)
		$\pi^+ \pi^- K_1^0 + \text{missing neutrals}$	(7)

Ξ_1^- means that only events with an associated visible Λ decay have been used. $K_1^0(K_2^0)$ indicates events with seen (not seen) $K^0 \rightarrow \pi^+ \pi^-$ decay.

We will denote these reactions by the general formula $K^- p \rightarrow K \Xi$. When interpreted in terms of one particle t-channel exchanges, they have the interesting common property of providing badly lacking experimental evidence either for exotic ($|S| = 2$) meson or normal baryon exchange depending on whether the forward or backward production hemisphere is considered. Forward (backward) hemisphere is defined by $\cos \theta^* > 0$ ($\cos \theta^* < 0$), where θ^* is the angle between the directions of the incident K^- and the outgoing meson in the reaction c.m. system.

This collaboration has already made contributions to the general knowledge of these exchanges. Thus for exotic exchanges [1] we have presented in earlier publications [2,3] evidence for the existence of

"forbidden" peaks in the reactions $K^-p \rightarrow \pi^+\Sigma^-(1197)$ and $K^-p \rightarrow \pi^+\Sigma^-(1385)$. We have also shown [4,5] that backward production of non-strange pseudoscalar and vector mesons is dominated by baryon exchange at our energy.

The aim of this paper is to extend those analyses to the production of $S = +1$ mesons. The data used come from an experiment with a sensitivity of about 133 events/ μb and thus provide statistics which are almost an order of magnitude larger than previous experiments studying the same reactions over the complete angular range. For many reactions this allows for the first time the extraction of the differential cross sections in the energy region of this experiment.

The plan of the paper is the following: the experimental details are given in sect. 2. The extraction of the total and differential cross sections is described in sect. 3. In sect. 4 we determine the amplitudes governing the reaction $K^-p \rightarrow K^+(890)\Xi^-(1320)$ and discuss all the results in terms of an exchange picture. Final conclusions are derived in sect. 5. In Appendix A the method for extracting amplitudes using the information of the weak sequential decays $\Xi^-(1320) \rightarrow \Lambda(1115)\pi^-$ and $\Lambda(1115) \rightarrow p\pi^-$ is presented.

2. EXPERIMENTAL DETAILS

The data come from the high statistics experiment performed in the CERN 2m hydrogen bubble chamber exposed to a 4.2 GeV/c K^- beam. The selected events were restricted to occur within a limited fiducial volume and were subjected to cuts to enable corrections to be made for scanning losses. For Ξ^- , cuts were made on the projected decay length (5 mm) and on the projected decay angle (60-70 mrad); for K^0 's a cut of 3 mm on the projected decay length was introduced. Well-known weighting procedures were then applied to correct for these cuts and for a small loss of decays with low momentum pions.

The absolute normalization of all cross sections presented has been obtained from a count of τ decays.

As shown in sect. 1, the reaction $K^- p \rightarrow K^0 \Xi^0(1320)$ has been extracted from the events in the zero prong plus 1 V^0 topology in which the V^0 gives a $K^0 \rightarrow \pi^+ \pi^-$ fit associated to the production vertex and the $\Xi^0(1320)$ manifests itself as a neutral missing mass. Similarly that part of the reaction $K^- p \rightarrow K^+(890) \Xi^-(1530)$ in which $\Xi^-(1530) \rightarrow \Xi^0 \pi^-$ has been extracted from events in the 2 prong + V^0 topology in which the V^0 fits $K^0 \rightarrow \pi^+ \pi^-$ and the Ξ^0 is observed as a missing neutral mass. All other reactions involve a $\Xi^-(1320)$ with decay seen.

Since the kinematical fits often lead to ambiguous interpretations, it is necessary to explain how the ambiguities have been resolved.

The fits to channels (2), (3') and (5) having four constraints are subject to little ambiguity after using the bubble density information. Important ambiguities with non Ξ^- hypotheses exist only for the $\pi^0 \pi^+ K_L^0 \Xi^-$ final state, in the subsample without a visible Λ decay; then the V^- fits also a Σ^- decay (20% of the total sample) or a K^- decay (25% of the total sample). Events ambiguous with the Σ^- hypothesis were all excluded from the Ξ^- sample after comparing the p_t distributions obtained for the two hypotheses with those obtained for events with a unique fit; p_t is the transverse momentum of the decay pion with respect to the fitted V^- direction. Its well-known distribution is closely followed when the ambiguous events are added to the unique Σ^- sample while, adding these ambiguous events to the unique Ξ^- events resulted in a p_t distribution strongly in disagreement with the expected one.

The K^- ambiguity, on the contrary, was solved in favour of the Ξ^- hypothesis. This resulted from a study of the lifetime distributions and the phenomenological knowledge of the relevant cross sections; the residual K^- contamination was estimated to be only a few per cent.

That these decisions led to a clean separation with very small contamination and little loss of events was checked a posteriori by studying the behaviour in the final samples of the distributions of parameters such as decay p_t , pulls, missing mass and fit probabilities.

The final states $\pi^+ K_2^0 \Xi_1^-$ and $\pi^0 K^+ \Xi_1^-$ are mutually ambiguous approximately 30% of the time; while this is the only major ambiguity, it is difficult to resolve. A detailed comparison of the distributions of parameters such as beam pulls, missing mass and fit probability obtained for each hypothesis has led us nevertheless to the conclusion that a reasonably good separation is achieved by selecting as correct the hypothesis with the larger χ^2 fit probability. The checks that have been made and which justify a posteriori the validity of this decision will be given in sect. 3 although the remark can already be made here that the distinct narrow $\Xi^-(1530)$ peak observed in the $\pi^0 K^+ \Xi_1^-$ final state comes out unaffected by the adopted separation criterion.

To further purify all the samples, events having a χ^2 fit probability lower than 1% were excluded from the analysis.

The final number of weighted events for the final states (2)-(6) are given in table 1 together with the estimated cross sections.

3. TOTAL AND DIFFERENTIAL CROSS SECTIONS

3.1 Reaction (A): $K^- p \rightarrow K^0 \Xi^0(1320)$

In this experiment no fits to the decay $\Xi^0 \rightarrow \Lambda \pi^0$ have been attempted and consequently events in this channel are only detected indirectly studying the missing mass squared, MM^2 , in the final state $K_1^0 MM$. Fig. 1 shows the MM^2 distribution for events in which the K_1^0 is emitted in the backward hemisphere, i.e. events with $u' < 3 \text{ GeV}^2$, where $u'(t')$ is defined as $|u - u_{\max}| (|t - t_{\max}|)$, $u(t)$ being the square of the four-momentum transfer from the beam (target) particle to the outgoing baryon and $u_{\max}(t_{\max})$ the maximum allowed value of $u(t)$. In the figure a clear $\Xi^0(1320)$ peak appears over a very small background. The total backward cross section is given in table 2; it has been determined by counting events in the region $1.5 \leq MM^2 \leq 2.02 \text{ GeV}^2$. The differential cross section (fig. 10(a)) has been determined in the same

way up to $u' \leq 2$ GeV when the signal to background ratio becomes too small to detect the Ξ^0 . The background in the $\Xi^0(1320)$ region, although small, was difficult to evaluate and was not subtracted. To cover the error so introduced and the possible losses in the reconstruction chain, the statistical error in the backward cross section has been increased by 15%.

3.2 Reaction (B): $K^+\Xi^-(1320)$

The number of events in the finally selected sample and the total cross section as well as those in the forward and backward hemispheres are given in table 2.

The differential cross section, on which we will comment in sect. 4.1, is shown in fig. 10(b).

3.3 The final states $\pi^+K^0\Xi^-(1320)$ and $\pi^0K^+\Xi^-(1320)$; the reactions (C): $[K^-p \rightarrow K^+(890)\Xi^-(1320)]$ and (D,E): $[K^-p \rightarrow K^0\Xi^0(1530)]$

3.3.1 The final state $\pi^+K^0\Xi^-(1320)$

This final state is obtained combining the samples of reactions (3') and (3''). Its general features are illustrated by the Dalitz and Chew-Low plots of figs 2(a-c). In the Dalitz plot two clear bands, corresponding to $K^+(890)$ and $\Xi^0(1530)$ production, are seen. From the Chew-Low plot of fig. 2(b) it is seen that in the reaction $K^-p \rightarrow K^+(890)\Xi^-(1320)$ the $K^+(890)$ is produced mainly in the backward direction ($u' < 3$ GeV²). Some "exotic" production is also present but without clear peaking near $t = 0$.

On the contrary, the K^0 in the reaction $K^-p \rightarrow K^0\Xi^0(1530)$ shows (fig. 2(c)) distinct peaking in the forward direction and a stronger backward peak.

3.3.2 The final state $\pi^0K^+\Xi^-(1320)$

The Dalitz and Chew-Low plots are given in figs 3(a-c). In the Dalitz plot accumulations of events are visible in the $\Xi^-(1530)$ band and to a greater extent in that of the $K^+(890)$. Inspection of the Chew-Low

plot for the $K^+\pi^0$ system confirms the findings in the previous final state for the reaction $K^-\bar{p} \rightarrow K^+(890)\Xi^-(1320)$ where $K^+(890) \rightarrow K^0\pi^+$, i.e. strong backward peaking and flat forward production of $K^+(890)$.

The Chew-Low plot of fig. 3(c) shows that the K^+ in the channel $K^+\Xi^-(1530)$ is emitted almost exclusively in the backward direction.

3.3.3 The reactions (C) $[K^-\bar{p} \rightarrow K^+(890)\Xi^-(1320)]$ and (D,E) $[K^-\bar{p} \rightarrow K^0\Xi^0(1530)]$

The total cross sections for these reactions were determined using the number of $K^+(890)$ and $\Xi^0(1530)$ events resulting from a fit to the relevant mass distributions in the $\pi^+K^0\Xi^-(1320)$ and $\pi^0K^+\Xi^-(1320)$ final states. An incoherent superposition of a p-wave Breit-Wigner function and a polynomial background was used. A first fit, in which the $K^+(890)$ parameters were left free, gave values in good agreement with the PDG values [6]; the latter were kept fixed in a second fit used for the cross section determination. For the $\Xi^0(1530)$, the apparent width, being determined by the experimental resolution (~ 5 MeV FWHM for the 4C channel and ~ 20 MeV FWHM for the 1C), was left free in the fit.

The forward and backward cross sections were similarly obtained in separate fits although the $\Xi(1530)$ width was kept fixed at the value previously found.

A summary of these results is given in table 2.

We have also performed maximum likelihood fits to the Dalitz plots of reactions (3) and (4) in order to have a more complete description of these channels. The probability functions used contained Breit-Wigner terms for the $K(890)$ and $\Xi(1530)$ as well as a phase space term. The results of the fits are summarised in table 3 and the effective mass distributions $K\pi$, $\Xi\pi$ and ΞK displayed in figs 4(a), (b) and (c), for reaction (3) and figs 5(a), (b) and (c), for reaction (4). As can be seen, the representation of the data is good and the production rates for the $K(890)$ and $\Xi(1530)$ are in good agreement with those previously obtained from the one-dimensional fits.

We can now check that the decision made in sect. 2 to resolve the $\pi^+ K_2^0 \Xi_1^-(1320) - \pi^0 K^+ \Xi_1^-(1320)$ ambiguity in favour of the hypothesis with the better χ^2 fit probability was the sound one. This is verified by noting that, within errors:

- (a) in the reaction $K^- p \rightarrow K^+(890) \Xi^-(1320)$ the correct decay branching ratio of the $K^+(890)$ into $K_2^0 \pi^+$ and $K^+ \pi^0$ is obtained;
- (b) the cross section for the reaction $K^- p \rightarrow K^0 \Xi^0(1530)$ determined separately from the final states $\pi^+ K_1^0 \Xi^-(1320)$ and $\pi^+ K_2^0 \Xi_1^-(1320)$ is the same.

All this gives at the same time confidence in the selection of events from which the $K^+ \Xi^-(1530)$ cross sections are determined.

In view of the consistent results obtained for the reaction $K^- p \rightarrow K^+(890) \Xi^-(1320)$ using either $K^+(890)$ decay mode, the two samples have been combined for the determination of the differential cross section. For the total cross section the weighted average of the independent determinations is also given in table 2.

The differential cross sections (figs 10(c,d,e)) for reactions (C), (D) and (E) were determined by counting resonant events in the $K(890)$ or $\Xi(1530)$ mass regions (given in table 2) for each $t'(u')$ bin and normalising them to the forward (backward) total cross sections. The resonant events in each bin were obtained by subtracting from the observed number of events background events estimated from suitably selected control regions.

The soundness of this procedure has been checked, whenever the statistics allowed it, by performing Breit-Wigner fits in broad $t'(u')$ bins. Within statistics, the check was always satisfactory.

3.4 The final state $\pi^+ \pi^- K^+ \Xi^-(1320)$ and the reaction (F): $[K^- p \rightarrow K^0(890) \Xi^0(1530)]$

For the study of reaction (F) we have used only the above final state since this sample is much larger than that of the final state $\pi^0 \pi^+ K_1^0 \Xi^-(1320)$, the latter being disfavoured both by Clebsch-Gordan coefficients and by the fact that only the $K_S^0 \rightarrow \pi^+ \pi^-$ decay is observable.

In an earlier publication of this collaboration [7] it was shown that the decay $\Xi^-(1820) \rightarrow \Xi^0(1530)\pi^-$ occurs, with very small background, in the final state (F). In the analysis that follows events satisfying $1.80 \leq M(\Xi^0(1530)\pi^-) \leq 1.84$ GeV have been eliminated. The loss of non- $\Xi(1820)$ events is estimated to be less than one per cent of the total sample.

In figs 6(a), (b) and (c) the $(K^+\pi^-)$ and $(\Xi^-\pi^+)$ effective mass two-dimensional plot and its projections are shown. The $K^0(890)$ and $\Xi^0(1530)$ bands are evident as well as a strong concentration in their overlapping region which corresponds to the production of reaction (F). This can be seen from the shaded histograms in figs 6(b) and 6(c), where we have plotted, respectively, the $(K^+\pi^-)$ mass in the $\Xi^0(1530)$ mass region (defined by $1.52 \leq M(\Xi^-\pi^+) \leq 1.56$ GeV) and the $\Xi^-\pi^+$ mass in the $K^0(890)$ mass region (defined by $0.84 \leq M(K^+\pi^-) \leq 0.94$ GeV). A fit to the $K\pi$ spectrum with the $K(890)$ mass and width taken from ref. [6] indicates a background level of $\sim 35\%$ under the $K(890)$. A similar fit to the $\Xi^-\pi^+$ mass spectrum indicates a background of $\sim 15\%$ in the $\Xi^0(1530)$ region. In this fit, the width was left as a free parameter and a value of (11 ± 1) MeV was obtained for it, consistent with the PDG value [6] after folding in the experimental resolution (≈ 5 MeV FWHM).

The cross sections for the two reactions: $K^-p \rightarrow K^0(890)\pi^+\Xi^-(1320)$ and $K^-p \rightarrow \pi^+K^-\Xi^0(1530)$ are given in table 2, where the quoted values for the backward and forward cross sections result from fits to the relevant mass spectra identical to those just described.

The cross section for the reaction $K^-p \rightarrow K^0(890)\Xi^0(1530)$ was obtained with the slicing technique [8], i.e. the $\pi^+K^-(\pi^+\Xi^-)$ effective mass spectrum was divided into several slices and for each successive one the associated $\pi^+\Xi^-(\pi^-K^+)$ mass distribution was fitted with a polynomial background and a p-wave Breit-Wigner function for the $\Xi(1530)$ [or the $K(890)$]. The resonance parameters used in these fits were those given in ref. [6] except for the $\Xi(1530)$ width for which the value determined in the previous fit was used to take into account the experimental resolution.

From these fits, distributions were obtained giving the number of $\Xi(1530)[K^0(890)]$ resonant events as a function of the mass of the recoiling $\pi^-K^+(\pi^+\Xi^-)$ system. These are given in figs 7(a), (b). The number of events $K^0(890)\Xi^0(1530)$ were obtained by fitting these distributions with an incoherent superposition of a Breit-Wigner function and a polynomial background. The number of events obtained by considering either the $K\pi$ or the $\Xi\pi$ as recoiling systems are consistent within errors: the average of the two values has been used to determine the cross sections given in table 2. The forward (backward) cross section was obtained following exactly the same procedure for events with the $K^+\pi^-$ system emitted in the forward (backward) hemisphere; they are also given in table 2. Fig. 7(c) and 7(d) show clearly the presence of an important "exotic" contribution to the reaction $K^0(890)\Xi^0(1530)$.

The differential cross section (fig. 10(f)) was obtained from the number of events contained in the overlap region defined in table 2. The number of resonant events was determined by subtracting from them the $(K\pi)$ part of the background as determined from control regions above and below the $K(890)$ region. The small residual $(\pi\Xi)$ contamination was assumed to be constant in t' .

3.5 The final state $\pi^0\pi^+K_1^0\Xi^-(1320)$ and the reaction (G): $K^-p \rightarrow K^+(890)\Xi^-(1530)$

To obtain the cross section for reaction (G) we consider first the final state $\pi^0\pi^+K_1^0\Xi^-(1320)$. The scatter diagram mass $(K^0\pi^+)$ versus mass $(\Xi^-\pi^0)$ and its two projections are given in figs 8(a), (b) and (c). Although both $K^+(890)$ and $\Xi^-(1530)$ signals are clearly present, the extraction of the $K^+(890)\Xi^-(1530)$ cross section is made difficult by the combination of limited statistics and a signal to background ratio close to 1. Nevertheless, as shown by the dashed histograms of figs 8(b) and (c), a resonant $K^+(890) [\Xi^-(1530)]$ signal is still present when the events are restricted to the $\Xi^-(1530) [K^+(890)]$ band. These events have been verified not to overlap with the competing reaction $K^-p \rightarrow K^0(890)\Xi^0(1530)$.

The cross section for reaction (G) has been obtained using a simplified slicing technique in which the background was estimated by a linear extrapolation of the number of events in adjoining control regions. As usual the $K^+(890)$ parameters were fixed at the PDG values while those of the $\Xi^-(1530)$ were determined from a fit to the mass spectrum of fig. 8(c), so as to take into account the experimental resolution (~ 20 MeV at FWHM). The resulting cross sections are given in table 2 where it must be noted that only an upper limit can be quoted for the forward cross section. The number of events is too small to determine the differential cross section in the backward hemisphere and therefore only the total cross section there is given.

In table 2 the cross sections are also given for the reactions $K^-p \rightarrow K^+(890)\pi^0\Xi^-(1320)$ and $K^-p \rightarrow \pi^+K^0\Xi^-(1530)$; the number of events belonging to each have been determined in the process of extracting those belonging to reaction (G).

Two checks have been performed in order to gain confidence in the results obtained for the latter reaction. A first, direct, check has been made using the final state $K_1^0\pi^+\pi^-$ + missing neutral particles, where the $\Xi^-(1530) \rightarrow \pi^-\Xi^0(1320)$, with $\Xi^0 \rightarrow \Lambda\pi^0$, should manifest itself as an enhancement in the (missing mass π^-) system. This enhancement is seen clearly over a large background for events in which the $(K_1^0\pi^+)$ system is emitted in the backward hemisphere. Under these conditions in fact the $(K_1^0\pi^+)$ mass spectrum exhibits a clear $K^+(890)$ signal while a peak at the $\Xi^-(1530)$ mass is seen in the recoiling system when events in the $\Xi^0(1320)$ mass region ($1.24 \leq MM \leq 1.39$ GeV) are selected. Using again the simplified slicing technique, the results given in table 2 are obtained for the cross section. Within large errors it agrees with that previously found from the final state $\pi^0\pi^+K_1^0\Xi^-(1320)$. As a second, indirect, check we have used the same technique to recalculate the cross section of reaction (F). The relevant scatter plot and projections, displayed in figs 9(a), (b) and (c), show that the experimental conditions are similar to those just discussed. The agreement between this new determination, given also in table 2, and the more accurate value from channel (5) is satisfactory.

4. DISCUSSION OF THE RESULTS

The differential cross sections for the six reactions (A-F) are presented in figs 10 and table 4. The quoted errors are statistical only. As an illustration of the peripheral nature of these reactions, we give in table 5 the results of fits to the backward differential cross sections with a simple exponential form. For reactions (B) and (C) the $\Xi^-(1320)$ polarization is also shown in figs 10(b), (c) and tables 4 and 6 as a function of t' and u' . For the $K^+\Xi^-(1320)$ channel this was calculated by means of an expression which allows a proper determination of the polarization regardless of scanning losses, provided these are symmetric with respect to the production normal:

$$P_{\Xi^-} = \frac{1}{\alpha} \frac{\langle \cos \theta_p \rangle}{\langle \cos^2 \theta_p \rangle},$$

where α is the asymmetry parameter for the weak decay $\Xi^-(1320) \rightarrow \Lambda \pi^-$ ($\alpha = -0.392$ [6]), and θ_p is the angle between the decay lambda in the Ξ^- rest frame and the normal to the production plane defined as $\vec{n} = \vec{K} \times \vec{\Xi}$, where $\vec{K}$ and $\vec{\Xi}$ are unit vectors in the direction of incident K^- and final Ξ^- in the overall centre of mass. In the second case the Ξ^- polarization was obtained from the amplitudes governing the reaction as explained in sect. 4.2.

After making a few qualitative remarks about each reaction separately, we will describe an amplitude analysis of the reaction $K^- p \rightarrow K^+(890)\Xi^-(1320)$ which represents the statistically more important sample. Finally, general properties of $\Xi^0(1320)$ and $\Xi^0(1530)$ productions in the backward and forward hemisphere will be discussed.

4.1 $K^- p \rightarrow \Xi^0(1320)K^+$

In the backward region the $d\sigma/du'$ distribution shows a steeper u' dependence for reaction (A) than for reaction (B) (figs 10(a), (b) and table 5) while the integrated backward cross section of the first reaction is about half that of the second one. This suggests that $I = 0$ exchange is important in the non-charge-exchange reaction. Reaction (B) shows an "exotic" contribution essentially constant throughout the forward hemisphere. The Ξ^- polarization is large and positive in the backward direction.

(a) $K^- p \rightarrow K^+(890) \Xi^-(1320)$

The differential cross section exhibits strong backward production with a turnover at $u' = 0 \text{ GeV}^2$. The forward production is flat (fig. 10(c)).

(b) $K^- p \rightarrow K^+(890) \Xi^-(1530)$

For the neutral $\Xi^0(1530)$ production the differential cross section exhibits clear backward and forward peaks with a flattening off at $u' = 0 \text{ GeV}^2$ (fig. 10(d)). Reaction (E) (fig. 10(e)) is, instead, well fitted by a single exponential in the whole backward hemisphere.

(c) $K^- p \rightarrow K^+(890) \Xi^0(1530)$

The broad features are similar to those of the previous reactions. The differential cross section for the neutral production (fig. 10(f)) exhibits backward and forward peaks while in reaction (G) only backward production is observed.

4.2 Transversity amplitude analysis of the reaction $K^- p \rightarrow \Xi^-(1320) K^+(890)$

In previous studies of hypercharge exchange reactions [3,4,7] the weak $\Lambda \rightarrow p \pi^-$ decay has been used to extract, in a model-independent way, the almost complete set of production amplitudes for reactions of the type

$$0^- \frac{1^+}{2} \rightarrow 1^- \frac{1^+}{2} ; \quad 0^- \frac{1^+}{2} \rightarrow 0^- \frac{3^+}{2} ; \quad 0^- \frac{1^+}{2} \rightarrow 1^- \frac{3^+}{2} .$$

The aim of the present section is to extend this procedure to quasi two-body reactions containing a Ξ^- in the final state. In this case the six-dimensional joint angular distribution of the decay sequences

$$\Xi^- \rightarrow \Lambda \pi^- \quad \text{and} \quad K^+(890) \rightarrow K \pi$$

$$\quad \quad \quad \downarrow$$

$$\quad \quad \quad p \pi^-$$

can be used to determine the underlying amplitudes. We give in Appendix A the details of the method which essentially extends the technique described e.g. in ref. [4].

As explained there, for an unpolarized target, parity conservation at the production vertex reduces to six the number of non-zero transversity amplitudes T_{pq}^r (*) contributing to reactions of the type

$$0^- \frac{1}{2}^+ \rightarrow 1^- \frac{1}{2}^+.$$

Following ref. [4] these are

$$(T_{-+}^{-1}, T_{++}^0, T_{-+}^1) \text{ and } (T_{+-}^{-1}, T_{--}^0, T_{+-}^1),$$

where the short-hand notation + or - is used for the third component + 1/2 or - 1/2 of the proton spin. The advantage of working in a transversity (**) frame is that the experimental observables allow the determination of the moduli of six amplitudes and four phases, the absolute phases of the two sets of amplitudes with proton transversity up and proton transversity down being unmeasurable in the absence of target polarization information.

These amplitudes are related to the Byers-Yang amplitudes

$$a_{\pm} = -T_{\pm\pm}^0$$

$$b_{\pm} = \pm \sqrt{\frac{1}{2}} (T_{\pm\pm}^1 + T_{\mp\mp}^{-1})$$

$$c_{\pm} = \pm \sqrt{\frac{1}{2}} i (-T_{\pm\pm}^1 + T_{\mp\mp}^{-1})$$

which have been extensively studied in non-strange vector meson production by our collaboration [4]. In this analysis we use the combined samples of events from the final states

$$K^- p \rightarrow \Xi^- K^0 \pi^+$$

and

$$K^- p \rightarrow \Xi^- K^+ \pi^0$$

for the extraction of amplitudes. The K(890) mass region was defined by the interval $0.84 \leq M(K\pi) \leq 0.94$ GeV. The effect of the background,

(*) p, q and r are the spin components of the initial proton, the final hyperon and the final vector meson, respectively.

(**) Transversity frames have the normal to the production plane as quantization axis.

$\sim 20\%$ in the backward region considered ($u' < 1.2 \text{ GeV}^2$), was not taken into account in the analysis. A maximum likelihood fit to the data, in 4 u' bins, was performed using simultaneously events with seen or unseen associated lambda decay. This was done using a likelihood function of the type

$$L = \prod_{i=1}^N I(\Omega_1^i \Omega_2^i \Omega_3^i) W_i \prod_{j=1}^{N'} I'(\Omega_1^j \Omega_2^j) W_j$$

where N and N' are the events having a detected or undetected lambda decay respectively, $I(\Omega)$ and $I'(\Omega)$ are the theoretical intensity functions described in Appendix A and W_i represents the weight of the i th event.

The Byers and Yang amplitudes, obtained minimizing the function $-\text{Log}L$, are presented in table 6. An idea of the goodness of the maximum likelihood fit is given by the comparison of the six experimental single angular distributions with those obtained by the fit. This is illustrated in fig. 11 for the overall sample with $u' \leq 1.2 \text{ GeV}^2$. A complete test of the goodness of the solution using the multipole moments defined in Appendix A gives an overall χ^2 of 31 for 31 moments. We can then conclude that the maximum likelihood result provides a satisfactory description of the data. The $K(890)$ density matrix elements and the Ξ^- polarization obtained from the transversity amplitudes are given in table 6. The $K(890)$ is found to populate mainly the $m = 1$ spin states in this backward region while the Ξ^- polarization is small at $u' \approx 0 \text{ GeV}^2$ and becomes positive and large for $u' > 0.2 \text{ GeV}^2$.

4.3 Backward production

Interpreted in terms of u -channel single particle exchanges, only $I = 1$ (Σ and Σ^*) particles can contribute to backward neutral meson production (reactions (A), (D) and (F)) while both $I = 1$ and $I = 0$ (Λ) exchanges may do so for the other reactions (B, C, E and G).

The measurement of more than one charge configuration allows [9] the following bounds on the isospin exchange to be obtained

$$(\sqrt{4\sigma(\Xi^- K^+)/\sigma(\Xi^0 K^0)} - 1)^2 \leq \frac{|\Lambda|^2}{|\Sigma + \Sigma^*|^2} \leq (\sqrt{4\sigma(\Xi^- K^+)/\sigma(\Xi^0 K^0)} + 1)^2,$$

where Λ and $\Sigma + \Sigma^*$ represent just the isospin contents of the exchange.

Applied to the integrated backward cross sections this gives:

- for reactions (A) and (B)

$$0.06 \pm 0.02 \leq \frac{|\Sigma + \Sigma^*|^2}{|\Lambda|^2} \leq 0.22 \pm 0.06, \quad (8)$$

- for (D) and (E)

$$0.08 \pm 0.04 \leq \frac{|\Sigma + \Sigma^*|^2}{|\Lambda|^2} \leq 0.40 \pm 0.18, \quad (9)$$

- and for (F) and (G)

$$0.08 \pm 0.04 \leq \frac{|\Sigma + \Sigma^*|^2}{|\Lambda|^2} \leq 0.40 \pm 0.22. \quad (10)$$

From these values it can be seen that when both exchanges can occur, Λ exchange predominates.

Using SU(3) and factorization, ΞK production can be related to other backward production processes. We start recalling some results of interest in this discussion. An analysis [9] of backward production of pseudoscalar mesons in $\pi N \rightarrow N\pi$, $K^- p \rightarrow \Lambda \pi^0$ and $K^- p \rightarrow \Sigma \pi^-$ in which the u-channel quantum numbers correspond to those of a non strange baryon - led to the conclusion that for them the N_α trajectory dominates and that SU(3) symmetry provides a reasonable description of these $0^- 1/2^+ \rightarrow 1/2^+ 0^-$ reactions. The analysis resulted in the determination of the F/D ratio for the pseudoscalar meson-baryon-antibaryon coupling

$$0.33 \leq F/D \leq 0.42 \quad (11)$$

the normalization being such that $\langle N/N\pi \rangle = D + F$.

On the other hand the authors of ref. [10] performed a comparison, for incident momenta between 2 and 5 GeV/c, of the then available $K^- p \rightarrow \Xi^-(1320)K^+$ data with the ones on backward $K^+ p$ elastic scattering. Their analysis in terms of Reggeized baryon exchange included the following

assumptions: (a) absence of $I = 1$ exchange; (b) strong exchange degeneracy for the Λ_Y (an almost pure SU(3) singlet) and Λ_α (the strange $I = 0$ member of the N_α octet) trajectories. With this scheme they found for the F/D ratio a value of ~ 1.3 which is in disagreement with the result of [9] (eq. (11)). The discrepancy in the value of the F/D ratio could have as origin the assumption made in the analysis of ref. [10]. Firstly we observe that the introduction of $I = 1$ exchanges, as implied by eq. (8), could modify the result of this analysis. Then we note that, even in the assumption of $I = 0$ exchange dominance, agreement can be obtained if one releases the assumption of strong Λ_α Λ_Y exchange degeneracy. In fact the value of the ratio

$$R = \frac{\sigma(K^+ p \rightarrow p K^+)}{\sigma(K^- p \rightarrow \Xi^-(1320) K^+)} \quad (12)$$

is expected to be one - as it is the case experimentally [10 and our experiment] - also in the case of Λ_Y exchange dominance, while for Λ_α exchange dominance it would be $R = (3F/D + 1)^2 / (3F/D - 1)^2$ in disagreement with the data if one uses the F/D value of eq. (11). Λ_Y exchange dominance is also consistent with the data concerning the other octet production reaction $K^- p \rightarrow \Xi^-(1320) K^+(890)$ to be related by SU(3) with the process $K^+ p \rightarrow p K^+(890)$. Interpolating the measurements at various incident momenta between 2 and 5 GeV/c, quoted in ref. [11], we have obtained a value of $\sim 12 \mu\text{b}$ for the total backward production cross section of the second reaction. This value can be naturally related to the $10.5 \mu\text{b}$ which we find for the corresponding contribution in $K^- p \rightarrow \Xi^-(1320) K^+(890)$ if the singlet Λ_Y exchange dominates also these two processes. We also notice that the two backward differential cross sections appear to have similar slopes and that the $K^+(890)$ density matrix element ρ_{11} is dominant in the backward hemisphere in both reactions ([11] and table 6). The somewhat different behaviour at $u' \approx 0 \text{ GeV}^2$ observed between the reactions

$K^-p \rightarrow \Xi^-(1320)K^+$ and $K^-p \rightarrow \Xi^-(1320)K^+(890)$ (figs 10(b,c)) might then be ascribed to the fact that different spin amplitudes are important in these two processes. As a final remark we note that even if this scheme ($I = 0$, singlet Λ_Y exchange dominance) seems to work for the octet production reactions and not to contradict the F/D measurement of ref. [9], we cannot rule out a violation of the SU(3) relations involving different exchanged particles or the presence of $I = 1$ exchanges as alternative explanations of the discrepancy between the results of refs [9,10]. Concerning the decuplet production reactions $K^-p \rightarrow \Xi^0(1530)K^0$ and $K^-p \rightarrow \Xi(1530)K(890)$ we only note that they have to be mediated by octet exchange.

4.4 Forward production

The different reactions have a dissimilar behaviour in the forward hemisphere. A peaking at $t' = 0$ is visible, figs 10(d) and (f), for the reactions $K^-p \rightarrow K^0\Xi^0(1530)$ and $K^-p \rightarrow K^0(890)\Xi^0(1530)$, while an almost flat t' dependence is observed for the charged Ξ channels $K^+\Xi^-(1320)$ and $K^+(890)\Xi^-(1320)$ (figs 10(b) and (c)). For the reaction $K^-p \rightarrow K^+\Xi^-(1530)$ the pooriness of the statistics allowed only the measurement of the total cross section in the forward hemisphere and for $K^-p \rightarrow K^+(890)\Xi^-(1530)$ only an upper limit to this cross section could be determined.

In forward production of the reactions $K^-p \rightarrow K\Xi$ the t-channel corresponds to an $S = -2$ exotic meson, i.e. a meson not having the quantum numbers of a $q\bar{q}$ -pair. While both isospin one and zero mesons can mediate the neutral reaction only isospin one is allowed for charged Ξ production.

If only isospin one exchange mediated these reactions, the charged to neutral Ξ cross section ratio should be four. This is clearly in disagreement with the experimental values of < 0.3 for the ratio between the $K^+(890)\Xi^-(1530)$ and $K^0(890)\Xi^0(1530)$ cross sections and of 0.7 ± 0.4 for that between the $K^+\Xi(1530)$ and $K^0\Xi^0(1530)$ reactions. Neutral Ξ production appears therefore to be governed predominantly by isospin zero exchange.

Previous evidence of forbidden peaks in reactions corresponding to an $S = -2$ t-channel exchange has been obtained in two experiments.

The first [12], at an incident momentum of 2.6 GeV/c, observed forward peaks in the reactions $K^-p \rightarrow K^0\Xi^0$ and $K^+\Xi^-(1530)$. For the latter reaction the forward and backward peaks had approximately the same magnitude. In this energy region, however, the production angular distributions of the $K\Xi$ reactions vary very rapidly as a function of incident momentum [12-13] and have those characteristics expected in the formation of Y^* 's for which direct evidence has been obtained in other experiments [14]. It would therefore appear reasonable to interpret the observation of "forbidden" peaks at these low energies in terms of s-channel dynamics, although, as pointed out in [12], the absence of a forward peak in $K^-p \rightarrow K^0\Xi^0(1530)$ at 2.6 GeV/c incident momentum would then have to be explained by the interference of two Y^* 's with different isospins.

The second experiment [15] has studied the differential cross section at zero degrees for the reaction $K^-p \rightarrow K^+\Xi^-$ at incident momenta of 3, 4 and 5 GeV/c. It establishes the existence of a forbidden cross section at all energies with a value at 4 GeV/c ($\sim 0.6 \mu\text{b}/\text{GeV}^2$) in agreement with our own measurement. They have considered the energy variation of this forward cross section but, given the poor statistics of the data, cannot rule out the s^{-10} behaviour observed in the energy region where s-channel effects are known to be predominant.

Whether our own results can be explained as a result of production and decay of Y^* 's is difficult to assess. Nevertheless, the different behaviour of the differential cross sections of neutral and charged Ξ production and the near equality of the "forbidden" $K^+\Xi^-(1320)$, $\pi^+\Sigma^-(1197)$ [2] cross sections appear difficult to reconcile with a simple s-channel picture. Together with previous evidence on forward and backward quasi two-body production presented by our collaboration [2-5,8], it would appear more plausible to attribute the different "forbidden" effects to t-channel exchanges. The most likely interpretations are the exchange of two normal Regge poles or that of one four quark system (baryonium). An analysis of these two alternative mechanisms [1] using a large variety of reactions which also show forbidden peaks seems to indicate that at the quantitative level the existing double Regge models cannot reproduce

all the experimental data. However, a more sensitive check of the four quark exchange picture requires the observation of similar exotic peaks at higher energies. Without such data no discrimination between different production mechanisms can be made.

5. CONCLUSIONS

We have studied forward and backward production of the $\Xi(1320)$ and $\Xi(1530)$ in two-body and quasi two-body processes at an incident K^- momentum of 4.2 GeV/c. The asymmetric weak decays of the Ξ^- allowed an almost complete determination of the production transversity amplitudes for the reaction $K^-p \rightarrow \Xi^-(1320)K^+(890)$ and they were used to extract the $K^+(890)$ helicity density matrix elements. In the backward direction $I = 0(\Lambda)$ exchange is found to dominate those reactions in which no charge is exchanged. The octet production reactions $K^-p \rightarrow \Xi^-(1320)K^+$ and $K^-p \rightarrow \Xi^-(1320)K^+(890)$ have been compared with the SU(3) related processes $K^+p \rightarrow pK^+$ and $K^+p \rightarrow pK^+(890)$, respectively; the integrated backward cross sections and the slope of the differential cross section are found to be approximately equal for both pairs of reactions and ρ_{11} helicity density matrix element is found to dominate both $K^+(890)$ productions. These observations may be reconciled with the recently precisely determined [9] F/D ratio for backward pseudoscalar productions if the commonly assumed exchange degeneracy [10] between the octet Λ_α and the singlet Λ_γ trajectories is badly broken and Λ_γ dominates these processes.

For the first time evidence has been presented for forward "exotic" peaks in $K\Xi$ reactions above the s-channel resonance region.

Acknowledgements

We wish to thank A. Irving and M. Pennington for fruitful discussions. We also wish to thank the operating crews at the CERN Proton Synchrotron and the 2m hydrogen bubble chamber and the designers and constructors of the beam. We are also indebted to the scanning, measuring and computing staffs at our laboratories.

APPENDIX A

TRANSVERSITY AMPLITUDE ANALYSIS OF THE REACTION $K^- p \rightarrow K^+(890) \Xi^-$

The maximum amount of information which can be used to extract an almost complete set of amplitudes for the reaction

is contained in the six angle joint decay distribution.

The transition amplitude for such a process has the form

$$A \sim \langle p_f^{mn} | T | p_i \ 0 \ \mu \rangle \langle \Omega_1 00 | M_1 | 1m \rangle \langle \Omega_2 \frac{1}{2} \lambda | M_{\frac{1}{2}} | \frac{1}{2} n \rangle \langle \Omega_3 \frac{1}{2} \nu | M_{\frac{1}{2}}^1 | \frac{1}{2} \lambda \rangle$$

where μ, m, n, λ, ν are the spin components of the proton target, $K(890)$, Ξ^- , Λ and outgoing proton along appropriate quantization axes.

The solid decay angles $\Omega_1, \Omega_2, \Omega_3$ refer to the $K(890) \rightarrow K\pi$, $\Xi^- \rightarrow \Lambda\pi^-$ and $\Lambda \rightarrow p\pi^-$ respectively. For the $K(890)$ and Ξ^- decays s-channel transversity reference frames are used whereas for the Λ decay a s-channel helicity frame is adopted.

The decay amplitudes for the $K(890)$, Ξ^- and Λ have the form

$$\begin{aligned}
 \langle \Omega_1 00 | M_1 | 1m \rangle &= \sqrt{\frac{3}{4\pi}} F^1 D_{m0}^{1*}(\Omega_1) \\
 \langle \Omega_2 \frac{1}{2} \lambda | M_{\frac{1}{2}} | \frac{1}{2} n \rangle &= \sqrt{\frac{1}{2\pi}} F_{\lambda}^{\frac{1}{2}} D_{n\lambda}^{\frac{1}{2}*}(\Omega_2) \\
 \langle \Omega_3 \frac{1}{2} \nu | M_{\frac{1}{2}}^1 | \frac{1}{2} \lambda \rangle &= \sqrt{\frac{1}{2\pi}} G_{\nu}^{\frac{1}{2}} D_{\lambda\nu}^{\frac{1}{2}*}(\Omega_3) .
 \end{aligned}$$

Using the expression for the density matrix given by

$$\rho_{nn'}^{mm'} = \sum_{\mu} \langle p_f^{mn} | T | p_i \ 0 \ \mu \rangle \langle p_f^{m'n'} | T | p_i \ 0 \ \mu \rangle^*$$

we obtain the six-angle joint decay distribution

$$I(\Omega_1 \Omega_2 \Omega_3) = \frac{3}{16M^3} \sum_{\substack{mm'nn' \\ \lambda\lambda'\nu}} \rho_{nn'}^{mm'} \\ D_{m0}^{1*}(\Omega_1) D_{m0}^1(\Omega_1) D_{n\lambda}^{\frac{1}{2}*}(\Omega_2) D_{n,\lambda}^{\frac{1}{2}}(\Omega_2) D_{\lambda\nu}^{\frac{1}{2}*}(\Omega_3) D_{\lambda,\nu}^{\frac{1}{2}}(\Omega_3) \\ |F^1|^2 F_{\lambda}^{\frac{1}{2}} F_{\lambda'}^{\frac{1}{2}*} |G_{\nu}^{\frac{1}{2}}|^2.$$

The helicity decay amplitudes are given by

$$|F^1|^2 = 1 \\ F_{+}^{\frac{1}{2}} = \sqrt{\frac{1 + \alpha_{\Xi}}{2}}, \quad F_{-}^{\frac{1}{2}} = \sqrt{\frac{1 - \alpha_{\Xi}}{2}} e^{i\phi_{\Xi}} \\ |G_{\pm}^{\frac{1}{2}}|^2 = \frac{1 \pm \alpha_{\Lambda}}{2}$$

where $\alpha_{\Xi} = -0.392 \pm 0.021$, $\phi_{\Xi} = (2 \pm 6)^{\circ}$ and $\alpha_{\Lambda} = 0.642 \pm 0.013$. Due to the small value of ϕ_{Ξ} , $F_{-}^{\frac{1}{2}}$ is taken real for the computation of $I(\Omega_1 \Omega_2 \Omega_3)$ as well as in the derivation of the symmetry properties of the multipole moments.

In the transversity frames (quantization axis normal to the reaction plane) the relations coming from parity conservation in the production process

$$\eta(-1)^{m+n-\mu} T_{n\mu}^m = T_{n\mu}^m,$$

(where the shorthand notation $T_{n\mu}^m = \langle p_f^{mn} | T | p_i^{0\mu} \rangle$ is used and η is the naturality of the produced meson) reduces to six the number of non-zero amplitudes

$$(T_{++}^0 \quad T_{-+}^1 \quad T_{-+}^{-1}); \quad (T_{--}^0 \quad T_{+-}^1 \quad T_{+-}^{-1}).$$

When the Λ decays via the mode $n\pi^0$, which is not detected in a bubble chamber experiment, the four-angle joint decay distribution is obtained by integrating $I(\Omega_1 \Omega_2 \Omega_3)$ over the solid angle of the Λ decay (Ω_3). The following expression is obtained

$$I'(\Omega_1 \Omega_2) = \frac{3}{4\pi^2} \sum_{\substack{mm'nn' \\ \lambda}} \rho_{nn'}^{mm'}$$

$$D_{m0}^{1*}(\Omega_1) D_{m'0}^1(\Omega_1) D_{n\lambda}^{\frac{1}{2}*}(\Omega_2) D_{n,\lambda}^{\frac{1}{2}}(\Omega_2) |F^1|^2 |F_{\lambda}^{\frac{1}{2}}|^2.$$

As is well-known (e.g. [4]) the information contained in this angular distribution also permits the determination of an almost complete set of amplitudes governing the reaction (6 moduli and 4 phases). The generalized multipole moments are defined by

$$H(LML'M'L''M'') = \int d\Omega_1 d\Omega_2 d\Omega_3 I(\Omega_1 \Omega_2 \Omega_3) D_{MO}^L(\Omega_1) D_{M'M''}^{L'}(\Omega_2) D_{M''O}^{L''}(\Omega_3).$$

Using the explicit form of $I(\Omega_1 \Omega_2 \Omega_3)$ we can rewrite

$$H(LML'M'L''M'') = \sum_{\substack{mm'nn' \\ \lambda\lambda'\nu}} \rho_{nn'}^{mm'} F_{\lambda}^{\frac{1}{2}*} F_{\lambda'}^{\frac{1}{2}} |G_{\nu}^{\frac{1}{2}}|^2$$

$$(LM1m' | 1m) (L010 | 10) (L'M'\frac{1}{2} n' | \frac{1}{2} n) (L'M''\frac{1}{2} \lambda' | \frac{1}{2} \lambda) (L''M''\frac{1}{2} \lambda' | \frac{1}{2} \lambda) (L''O\frac{1}{2} \nu | \frac{1}{2} \nu)$$

where $L \leq 2$, $L' \leq 1$ and $L'' \leq 1$.

Assuming $F_{\lambda}^{\frac{1}{2}}$ to be real, the hermiticity property of the density matrix

$$\rho_{nn'}^{mm'} = \left(\rho_{n'n}^{m'm} \right)^*$$

implies

$$H(LML'M'L''M'') = (-1)^{M+M'} H^*(L - M L' - M' L'' M'')$$

and the relations coming from parity conservation in the production process

$$\rho_{nn'}^{mm'} = (-1)^{m-m'+n-n'} \rho_{nn'}^{mm'}$$

imply

$$H(LML'M'L''M'') = (-1)^{M+M'} H(LML'M'L''M'').$$

These symmetry relations together with the restrictions imposed by the properties of the Clebsch-Gordan coefficients give a set of independent $H(LML'M'L'M'')$ which can be used to investigate the goodness of the solution.

From the transversity amplitudes and associated covariance matrix the full transversity density matrix in the transversity frame can be reconstructed. The rotation

$$H_{nn'}^{mm'} = \sum_{rr', ss'} D_{mr}^1(-R) D_{ns}^{\frac{1}{2}}(-R) T_{ss'}^{rr'} D_{s'n'}^{\frac{1}{2}}(R) D_{r'm'}^1(R)$$

gives the full helicity density matrix. The $K(890)$ density matrix elements and Ξ^- polarization can then be calculated using the expressions

$$\rho_{nn'}^{mm'} = \sum_n \rho_{nn}^{mm'}$$

$$P = 2\text{Im} \left\{ \rho_{-+}^{11} + \rho_{-+}^{00} + \rho_{-+}^{-1-1} \right\}.$$

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TABLE CAPTIONS

- Table 1 Events and cross sections for final states (2-6).
- Table 2 Results of fit to mass spectra, total, forward and backward cross sections for reactions (A-G).
- Table 3 Results of the Dalitz plot fit for reactions $K^-p \rightarrow \pi^+ K^0 \Xi^-(1320)$ and $K^-p \rightarrow \pi^0 K^+ \Xi^-(1320)$.
- Table 4 Differential cross sections and Ξ^- polarization. The errors are statistical only.
- Table 5 Results of fits to the differential cross sections with a simple exponential form, $e^{-bu'}$. The ranges of u' over which the fit was performed are indicated in each case.
- Table 6 Byers-Yang amplitudes, $K^+(890)$ density matrix element and $\Xi^-(1320)$ polarization as function of u' for the reaction $K^-p \rightarrow \Xi^-(1320)K^+(890)$.

TABLE 1

Final state	Weighted events	Mean weight	Cross section (μb) (a)
$\text{K}^+\Xi^-$	1840	1.36	15 ± 1
$\pi^+\text{K}^0\Xi^-$ (b)	970	1.55	26.5 ± 3
$\pi^+\text{K}^0\Xi^-$ (c)	1203	1.35	29 ± 7
$\pi^0\text{K}^+\Xi^-$ (c)	1023	1.35	18 ± 4
$\pi^+\pi^-\text{K}^+\Xi^-$	2728	1.26	24 ± 3
$\pi^0\pi^+\text{K}^0\Xi^-$ (b)	1125	1.43	31 ± 3

- (a) The values are fully corrected for all cuts and unseen decay modes.
- (b) Only events with a visible K^0 decay are considered.
- (c) These samples are restricted to events with a visible Λ decay associated to the Ξ^- decay vertex. The K^0 and π^0 are unseen tracks.

TABLE 2

Final state	(Fitted) number of events (a)	Cross section (μb) (b)	Cross section (μb) $\cos\theta^* > 0$ (b)	Cross section (μb) $\cos\theta^* < 0$ (b)	Meson mass cut (GeV)	Baryon mass cut (GeV)	Events inside meson mass cut	Events inside baryon mass cut
$\text{K}^0 \Xi^0 (1320)$	233 (c)			5.5 ± 1.0				
$\text{K}^+ \Xi^- (1320)$	1840	15 ± 1	1.3 ± 0.2	13.7 ± 0.9				
$\text{K}^+ (890) \Xi^- (1320)$ $\downarrow, \text{K}^0 \pi^+$	611 ± 33	11.4 ± 1.5	0.9 ± 0.2	10.5 ± 1.3	$0.84 - 0.94$		434	
$\text{K}^+ (890) \Xi^- (1320)$ $\downarrow, \text{K}^+ \pi^0$	227 ± 26	12 ± 3	1.6 ± 0.5	10.4 ± 3.0	$0.84 - 0.94$		154	
$\text{K}^+ (890) \Xi^- (1320)$ NEAN	NEAN	11.5 ± 1.3	1.0 ± 0.2	10.5 ± 1.2				
$\text{K}^0 \Xi^0 (1530)$ $\downarrow, \pi^+ \Xi^- (1320)$	214 ± 23	4.0 ± 0.6	1.0 ± 0.2	3.0 ± 0.6	$1.52 - 1.56$			205
$\text{K}^+ \Xi^- (1530)$ $\downarrow, \pi^0 \Xi^- (1320)$	99 ± 18	5.7 ± 1.5	0.7 ± 0.4	5.0 ± 1.5	$1.52 - 1.56$			67
$\text{K}^0 (890) \pi^+ \Xi^- (1320)$ $\downarrow, \pi^- \text{K}^+$	797 ± 43	10.5 ± 1.4	3.1 ± 0.5 (d)	7.4 ± 1.0 (d)				
$\pi^- \text{K}^+ \Xi^0 (1530)$ $\downarrow, \pi^+ \Xi^- (1320)$	873 ± 32	11.6 ± 1.5	5.6 ± 0.8 (d)	6.0 ± 0.8 (d)				
$\text{K}^0 (890) \Xi^0 (1530)$ $\downarrow, \pi^- \text{K}^+ \downarrow, \pi^+ \Xi^- (1320)$	238 ± 20	5.0 ± 0.4	2.0 ± 0.4	3.0 ± 0.5	$1.52 - 1.56$		154	
$\text{K}^0 (890) \Xi^0 (1530)$ $\downarrow, \pi^0 \text{K}^0 \downarrow, \pi^+ \Xi^- (1320)$	33 ± 10	4.0 ± 2.0						
$\text{K}^+ (890) \pi^0 \Xi^- (1320)$ $\downarrow, \pi^+ \text{K}^0$	240 ± 26	10.0 ± 1.5	2.8 ± 0.8 (e)	7.2 ± 1.1 (e)				
$\pi^+ \text{K}^0 \Xi^- (1530)$ $\downarrow, \pi^0 \Xi^- (1320)$	204 ± 23	17 ± 2.5	2.4 ± 0.9 (e)	14.6 ± 2.2 (e)				
$\text{K}^+ (890) \Xi^- (1530)$ $\downarrow, \pi^+ \text{K}^0 \downarrow, \pi^0 \Xi^- (1320)$	34 ± 14	4.0 ± 2.0	< 0.7 at 95% CL	4.0 ± 2.0				
$\text{K}^+ (890) \Xi^- (1530)$ $\downarrow, \pi^+ \text{K}^0 \downarrow, \pi^- \Xi^0 (1320)$	74 ± 20			6.0 ± 2.0				
$\text{K}^+ (890) \Xi^- (1530)$ NEAN	NEAN			5.0 ± 1.4				

(a) Not corrected for cuts and unseen decays.

(b) Fully corrected for cuts, K^0 and Λ unseen decay modes and other $\text{K}(890)$, $\Xi(1530)$ decays.

(c) Refers to the backward hemisphere.

(d) 0^* refers to the $\pi^- \text{K}^+$ system.(e) 0^* refers to the $\pi^+ \text{K}^0$ system.

TABLE 3

Reaction	Dalitz plot fit (a)			
	K(890) rate %	K(890) events	$\Xi(1530)$ rate %	$\Xi(1530)$ events
$\pi^- K^0 \Xi^-$	31.3 ± 1.4	646 ± 30	10.3 ± 0.7	213 ± 17
$\pi^- K^+ \Xi^-$	23.7 ± 1.9	242 ± 19	8.6 ± 1.1	88 ± 11

(a) K(890) parameters from PDG; $\Xi(1530)$ parameters from fit.

TABLE 4

$K^- p \rightarrow \Xi^0 K^0$		$K^- p \rightarrow \Xi^- K^+$		$K^- p \rightarrow \Xi^- K^+(890)$		$K^- p \rightarrow \Xi^0(1530) K^0$	
$u^*(\text{GeV}^2)$	$\frac{d\sigma}{du^*} (\mu\text{b}/\text{GeV}^2)$	$u^*(\text{GeV}^2)$	$\frac{d\sigma}{du^*} (\mu\text{b}/\text{GeV}^2)$	$u^*(\text{GeV}^2)$	$\frac{d\sigma}{du^*} (\mu\text{b}/\text{GeV}^2)$	$u^*(\text{GeV}^2)$	$\frac{d\sigma}{du^*} (\mu\text{b}/\text{GeV}^2)$
0.0 - 0.1	11.6 ± 1.7	0.0 - 0.1	26.8 ± 1.5	0.0 - 0.1	12 ± 1.6	0.0 - 0.1	3.4 ± 0.8
0.1 - 0.2	7.6 ± 1.4	0.1 - 0.2	21.4 ± 1.3	0.1 - 0.2	13.1 ± 1.7	0.1 - 0.2	2.8 ± 0.7
0.2 - 0.3	3.7 ± 1.0	0.2 - 0.3	12.8 ± 1.0	0.2 - 0.3	15.3 ± 1.8	0.2 - 0.3	3.4 ± 0.8
0.3 - 0.4	3.0 ± 0.9	0.3 - 0.4	11.6 ± 1.0	0.3 - 0.4	12.8 ± 1.6	0.3 - 0.4	4.0 ± 0.9
0.4 - 1.0	0.9 ± 0.2	0.4 - 0.5	10.0 ± 0.9	0.4 - 0.5	6.0 ± 1.1	0.4 - 0.55	3.0 ± 0.6
1.0 - 2.0	1.3 ± 0.3	0.5 - 0.6	7.4 ± 0.8	0.5 - 0.6	4.7 ± 0.9	0.55 - 1.00	0.99 ± 0.20
		0.6 - 0.7	5.7 ± 0.7	0.6 - 0.7	5.8 ± 1.0	1.00 - 1.7	0.46 ± 0.11
		0.7 - 0.8	5.0 ± 0.6	0.7 - 0.8	4.5 ± 0.9	1.7 - 2.7	0.39 ± 0.08
		0.8 - 0.9	4.0 ± 0.6	0.8 - 0.9	4.8 ± 0.9	$t^*(\text{GeV}^2)$	$\frac{d\sigma}{dt^*} (\mu\text{b}/\text{GeV}^2)$
		0.9 - 1.0	2.7 ± 0.5	0.9 - 1.1	3.0 ± 0.5	0.0 - 0.5	0.62 ± 0.15
		1.0 - 1.2	2.9 ± 0.3	1.1 - 1.4	2.2 ± 0.4	0.5 - 1.0	0.49 ± 0.14
		1.2 - 1.4	2.9 ± 0.3	1.4 - 1.7	1.4 ± 0.3	1.0 - 1.7	0.24 ± 0.08
		1.4 - 1.6	1.9 ± 0.3	1.7 - 2.1	1.2 ± 0.2	1.7 - 2.7	0.26 ± 0.07
		1.6 - 1.8	1.2 ± 0.2	2.1 - 2.6	0.8 ± 0.2		
		1.8 - 2.0	1.6 ± 0.3				
		2.0 - 2.5	0.8 ± 0.1				
		2.5 - 3.0	0.7 ± 0.1				

TABLE 5

Final state	u' range (GeV ²)	b (GeV ⁻²)
$\Xi^0(1320)K^0$	0.0 - 1.0	4.4 ± 0.5
$\Xi^-(1320)K^+$	0.0 - 1.0	2.5 ± 0.1
$\Xi^-(1320)K^+(890)$	0.2 - 1.4	1.9 ± 0.2
$\Xi^0(1530)K^0$	0.3 - 1.7	2.5 ± 0.5
$\Xi^-(1530)K^+$	0.0 - 2.0	2.9 ± 0.8
$\Xi^0(1530)K^0(890)$	0.0 - 2.2	1.4 ± 0.2

TABLE 6

$u'(K^- \rightarrow \Xi^-)$ (GeV ²)	0.0 - 0.2	0.2 - 0.4	0.4 - 0.7	0.7 - 1.2
a_+	0.56 ± 0.07	0.52 ± 0.08	0.31 ± 0.14	0.22 ± 0.18
a_-	0.41 ± 0.07	0.52 ± 0.05	0.74 ± 0.09	0.69 ± 0.07
b_+	0.30 ± 0.07	0.44 ± 0.08	0.30 ± 0.12	0.32 ± 0.11
b_-	0.20 ± 0.09	0.16 ± 0.13	0.26 ± 0.13	0.24 ± 0.12
c_+	0.38 ± 0.10	0.36 ± 0.10	0.32 ± 0.13	0.52 ± 0.09
c_-	0.50 ± 0.10	0.33 ± 0.10	0.33 ± 0.11	0.23 ± 0.17
$\delta(b_+)$	4.14 ± 0.70	0.00 ± 0.13	1.05 ± 0.94	4.72 ± 1.00
$\delta(b_-)$	3.28 ± 1.16	2.98 ± 0.80	0.14 ± 0.71	1.86 ± 0.64
$\delta(c_+)$	0.92 ± 0.73	4.72 ± 0.16	0.64 ± 0.74	3.06 ± 1.04
$\delta(c_-)$	3.17 ± 0.91	4.54 ± 0.55	2.17 ± 0.61	1.85 ± 0.82
ρ_{00}	$.13 \pm .04$	$.22 \pm .04$	$.15 \pm .04$	$.16 \pm .03$
$\text{Re } \rho_{10}$	$-.01 \pm .03$	$.00 \pm .03$	$.04 \pm .04$	$.03 \pm .04$
ρ_{1-1}	$.05 \pm .08$	$.16 \pm .07$	$.21 \pm .09$	$.10 \pm .06$
P	$-.21 \pm .10$	$+.19 \pm .14$	$+.47 \pm .16$	$+.68 \pm .25$

FIGURE CAPTIONS

- Fig. 1 Missing mass squared to the K^0 for the reaction $K^- p \rightarrow K^0 + \text{missing neutrals}$ for $u' \leq 3 \text{ GeV}^2$.
- Fig. 2 (a) Dalitz plot, (b) $M^2(K^0\pi^+)$ vs $-u(K^- \rightarrow \Xi^-)$ and (c) $M(\Xi^-\pi^+)$ vs $-u(p \rightarrow K^0)$ for $K^- p \rightarrow \Xi^- K^0\pi^+$.
- Fig. 3 (a) Dalitz plot, (b) $M^2(K^+\pi^0)$ vs $-u(K^- \rightarrow \Xi^-)$ and (c) $M(\Xi^-\pi^0)$ vs $-u(p \rightarrow K^+)$ for $K^- p \rightarrow \Xi^- K^+\pi^0$.
- Fig. 4 (a) $M(K^0\pi^+)$, (b) $M(\Xi^-\pi^+)$, (c) $M(\Xi^-K^0)$ for $K^- p \rightarrow \pi^+ K^0\Xi^-$. The curves represent the results of the Dalitz plot fit.
- Fig. 5 (a) $M(K^+\pi^0)$, (b) $M(\Xi^-\pi^0)$, (c) $M(\Xi^-K^+)$ for $K^- p \rightarrow \pi^0 K^+\Xi^-$. The curves represent the result of the Dalitz plot fit.
- Fig. 6 (a) $M(K^+\pi^-)$ vs $M(\Xi^-\pi^+)$, (b) $M(K^+\pi^-)$, (c) $M(\Xi^-\pi^+)$ effective mass distributions for $K^- p \rightarrow \pi^+\pi^-K^+\Xi^-$ after removal of events with $1.80 \leq M(\Xi^0(1530)\pi^-) \leq 1.84 \text{ GeV}$. The shaded histograms are the same mass spectra after the selection (b) $1.52 \leq M(\Xi^-\pi^+) \leq 1.56 \text{ GeV}$ and (c) $0.84 \leq M(K^+\pi^-) \leq 0.14 \text{ GeV}$.
- Fig. 7 (a-b) Distribution of the number of $\Xi^0(1530)$, $K^0(890)$ events as a function of the $(K^+\pi^-)$, $(\Xi^-\pi^+)$ effective mass from the reaction $K^- p \rightarrow \pi^+\pi^-K^+\Xi^-$.
(c-d) The same distributions for events with the $(K^+\pi^-)$ systems emitted forward.
- Fig. 8 (a) $M(K^0\pi^+)$ vs $M(\Xi^-\pi^0)$, (b) $M(K^0\pi^+)$, (c) $M(\Xi^-\pi^0)$ effective mass distribution for $K^- p \rightarrow \pi^0\pi^+K^0\Xi^-$. The shaded histograms are the same spectra after the selection (b) $1.52 \leq M(\Xi^-\pi^0) \leq 1.56 \text{ GeV}$ and (c) $0.84 \leq M(K^0\pi^+) \leq 0.94 \text{ GeV}$.
- Fig. 9 (a) $M(K^0\pi^0)$ vs $M(\Xi^-\pi^+)$, (b) $M(K^0\pi^0)$, (c) $M(\Xi^-\pi^+)$ effective mass distributions for $\pi^0\pi^+K^0\Xi^-$. The shaded histograms are the same spectra after the selection (b) $1.52 \leq M(\Xi^-\pi^+) \leq 1.56 \text{ GeV}$; (c) $0.84 \leq M(K^0\pi^0) \leq 0.94 \text{ GeV}$.

FIGURE CAPTIONS (Cont'd)

- Fig. 10 Differential cross sections for (a) $K^-p \rightarrow \Xi^0 K^0$; (b) $K^-p \rightarrow \Xi^- K^+$; (c) $K^-p \rightarrow \Xi^- K^+(890)$, (d) $K^-p \rightarrow \Xi^0(1530)K^0$, (e) $K^-p \rightarrow \Xi^-(1530)K^+$; (f) $K^-p \rightarrow \Xi^0(1530)K^0(890)$ and Ξ^- polarization for (b,c). The abscissa have u' running from left to right and t' running from right to left. The break occurs at a point corresponding to 90° scattering in the overall centre of mass.
- Fig. 11 Solid decay angles for (a) $K^+(890) \rightarrow K^0 \pi^+$, (b) $\Xi^- \rightarrow \Lambda \pi^-$ and (c) $\Lambda \rightarrow p \pi^-$ for the reactions $K^-p \rightarrow \Xi^- K^0 \pi^+$ after the selections $0.84 \leq M(K\pi) \leq 0.94 \text{ GeV}^2$ and $u' < 1.2 \text{ GeV}^2$.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10(a)

Fig. 10(b)

Fig. 10(c)

Fig. 10(d)

Fig. 10(e)

Fig. 10(f)

Fig. 11