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HYPERON PRODUCTION BY 3 AND 3.5 GeV/c K^+

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1. Introduction

In the course of a systematic study of the $K^+ p$ interactions at 3 and 3.5 GeV/c in the 81 Saclay hydrogen bubble chamber, particular emphasis has been put upon the identification of reactions of the type $K^+ p \rightarrow K K Y$ and $K^+ p \rightarrow K K Y \pi$ with $Y = \Lambda, \Sigma$.

The success obtained by the SU 3 approach to the classification of elementary particles and resonances(1) makes it plausible that more resonances will be found in addition to those already observed. In particular, multiplets of the 27-fold type may well exist requiring the presence, among others, of systems with value of the hypercharge equal to 2. Further, the strong decay of an S = 2 resonance should in principle be observable, as an enhancement in the mass spectrum of the K K system. It is in view of such a possibility that the above reactions are particularly interesting.

A preliminary report on these reactions at 3 GeV/c was presented earlier(2). Here we shall discuss the following reactions:

$$K^+ p \rightarrow K^+ K^+ \Lambda \qquad (1)$$
$$K^+ K^+ \Sigma^o, \quad \Sigma^o \rightarrow \Lambda \gamma \qquad (2)$$
$$K^+ K^+ \Lambda \pi^o \qquad (3)$$
$$K^+ \pi^+ \Lambda K^o, \quad K^o \text{ - decay seen or unseen} \qquad (4)$$

all of them accompanied by a visible Λ - decay. The number of events observed together with the cross sections corrected for unseen decay modes are given in Table I. The study of the charged Σ production is under way and will be ready for the time of the Conference.

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TABLE I

Incident K^+ momentum (GeV/c)	2.97 ± 0.02		3.43 ± 0.04	
Reaction	number of events[a]	cross section (μb)	number of events[a]	cross section (μb)
$K^+ K^+ \Lambda$	23 (0)	26 ± 6	49 (6)	22 ± 3
$K^+ K^+ \Sigma^o$	4 (0)	5 ± 2	9 (4)	4 ± 1
$K^+ K^+ \Lambda \pi^o$	4 (0)	5 ± 2	18 (6)	8 ± 2
$K^+ \pi^+ \Lambda K^o$	12 (3)[b]	13 ± 4	36 (3)[c]	16 ± 3

(a) Within parentheses the number of "ambiguous" events (see text).

(b) 11 with visible, 25 with invisible K^o decay mode.

(c) 4 with visible, 8 with invisible K^o decay mode.

The conclusions of the present analysis are the following. No resonant state decaying into K K appears to be produced in K^+ p collision at these energies. Up to a mass of ~ 1.6 GeV, the limit on the cross section for production of such a state can be put to ~ 8 μb.

2. Experimental method

Reaction (1) to (4) were looked for among the 2 p V^o and 2 p 2 V^o topologies. All examples of such topologies were measured in the 3 GeV/c film. As for the 3.5 GeV/c film, instead, the events chosen for the measurements had to satisfy a certain number of selection criteria: the tracks of the V^o were roughly measured at the scanning table and only those events were accepted for which the estimated momentum and ionization were compatible with those of a Λ - decay. By this procedure we were able to reduce the background of undesired events (mostly $K^o p \pi^+$, $K^o p \pi^+ + \pi^o$'s, $K^o \pi^+ \pi^+ n$, etc. ...) by almost one order of magnitude. Appropriate checks were made, of course, to make sure that this procedure would not affect the acceptance of the desired events.

In all cases a fiducial volume was imposed. This had the effect of eliminating events which were too near the boundary of the chamber to provide reliable measurements; furthermore it eliminated events in the region where the scanning efficiency is known to be low.

The events were then measured on IEP-machines and analysed through the usual chain of CERN programs (i.e. THRESH and GRIND). Reactions (1) to (4) were identified as follows. As a first step, a fit was attempted on the V^o alone assuming that it could be either a $K^o \rightarrow \pi^+ \pi^-$ or a $\Lambda \rightarrow p \pi^-$ decay. Such a fit was considered satisfactory if the obtained χ^2 - value was not larger than 10 (when 3 was expected). With a successful Λ - decay fit, all possible production hypotheses involving a Λ were then tried. When one of these was acceptable ($\chi^2 \leq 13$ for 4 - constraint fits and $\chi^2 \leq 7$ for 1 - constraint fit), an overall fit to that particular production-decay sequence was performed. Fitted values from this multivertex fit were used for the rest of the analysis (programs BAKE, SLICE, etc. ...). In addition, the event was checked for agreement between the expected and observed values of the ionization.

If the K^o - decay fit was also successful, the same procedure was applied with respect to the possible production hypotheses involving a K^o.

Finally, for the case of a Λ - decay, all possible hypotheses were tried assuming that the event was due to an incident π^+. This last possibility was considered in view of the fact that, although the pion contamination of the beam was of the order of 5 o/o, the Λ production by π^+ at these energies is considerably higher than that by K^+. Thus it may happen that some event of the type $\pi^+ p \rightarrow K \pi Y$ or $\pi^+ p \rightarrow K \pi \pi Y$ may give a spurious fit to the hypotheses (1) to (4). A considerable reduction of this contamination was achieved independently by means of a Čerenkov counter positioned in front of the chamber during the run; the presence of one pion (or more) among the particles entering the chamber was recognized and recorded for each photograph. It turned out that $\sim$ 50 o/o of the pictures were free from pions.

As a result of the above procedure, one was ordinarily left in the majority of the cases with a unique good fit. When more than one good fit was obtained, the following criterium was applied. The event was unambiguously attributed to the hypothesis for which the product of the number of constraints and the probability (of having a χ^2 that large or larger) was at least 5 times larger than this product for any other fit. Thus, for example, a 1 - constraint fit (such as reaction (3) and (4)) was accepted only when its probability was 5 times greater than that for any other 1 - constraint fit and more than 80 times the probability for any competing 4 - constraint fit (such as reaction (1)).

Those events which could not be uniquely identified even after these criteria, were assigned to the category of the "ambiguous". With the exception of a few events for which the alternative fit was one of the much more frequent reactions $K^+ p \rightarrow K^o p \pi^+$, $K^o p \pi^+ \pi^o$, $K^o n \pi^+ \pi^+$, (their ambiguity being therefore very doubtful) all the "ambiguous" events have been included in the analysis. Their number appears in Table I. As for their influence on the results of this study, one can see from the graphs below that the ambiguous events are not a source of bias and can be safely included, or excluded, according to one's preference, without changing the conclusions of the analysis.

One should further mention that ample use of the program MILLSTONE[3] has been done throughout the experiment. This fitting program, in contrast with the standard GRIND version, deals with one particular event at a time, relaxing unwanted constraints or combining otherwise unconnected measurements. An over- or under-estimation of the measurement errors can here be corrected and special hypotheses can be introduced. It may be worth noticing, incidentally, that this one - by - one treatment of the events, although neither necessary nor advisable when vast numbers of events must be processed, becomes instead almost unavoidable in such cases as the present, where the events must be extracted from a background one to two orders of magnitude larger than the signal.

The values of the cross sections which appear in Table I have been calculated on the basis of the number of τ - decays found in the same fiducial region as the events. For each category the cross sections include the "ambiguous" cases. In the same table we give the central values of the incident momenta as obtained by the 3 - constraint fit of a sample of τ- decays; these values, averaged with the measured momenta of the incident track, were used in the fitting of all the events.

3. Results

(a) 3-body reactions

Figs. 1 and 2 show the Dalitz plot for reaction (1) at 3 and 3.5 GeV/c respectively. The symmetry introduced by the two identical particles allows one to fold the contour of the plot around the 45 - degree line which is the scale for the K K mass.

Figs. 3 and 4 show the projections of the preceding plots on the $K^+ K^+$ and $K^+ \Lambda$ axes.

As already observed earlier[2], the 3 GeV/c data show an accumulation of events in the K K mass interval between 1.2 and 1.3 GeV; this is observable both in the Dalitz plot and in the projection. However, the statistical significance of this effect ($\sim$ 2 standard deviations from phase space) is too weak to allow further speculations. In addition, no such enhancement can be detected in the 3.5 GeV/c data, where the Dalitz plot population is quite uniformly distributed over the allowed area.

It is worth noticing that no enhancement can be found in the K Λ spectra corresponding to the mass of the I = 1/2 third and fifth nuclear isobar, N^*_{1688} and N^*_{2185} respectively. Comparison of these data with those from reactions of the type $K^+ p \rightarrow K^+ p \pi^o$, $K^+ n \pi^+$, etc. ... should in principle allow to set a limit on the branching fraction of these resonances into the K Λ channel. At the present stage, however, the latter data are not available and the problem will be investigated later.

In order to detect possible correlations between particular values of the mass of a composite system and its production mechanism, we have plotted in Figs. 5 to 8 the scattered diagrams of the K K and K Λ mass versus the cosine of their respective c.m. production angles. Apart from the usual high-energy characteristic of a strong backward emission of the baryon (see Figs. 5 and 6, remembering that $-\cos\theta_{KK} = \cos\theta_{\Lambda}$) no other remarkable effect seems to be present.

We conclude that if a resonant $K^+ K^+$ state does indeed exist, with mass between threshold and $\sim$ 1.6 GeV, then its production cross section in $K^+ p$ collisions at these momenta cannot be higher than that corresponding to the largest fluctuation observed in our mass spectra, i.e. $\sim$ 8 μb.

As for the much fewer examples found of reaction (2), we can only say that their general behaviour is similar to that observed for reaction (1). Here not only the statistics is very limited, but also the percentage of ambiguous events is too large to make them dependable. Fig. 9 shows the combined 3 and 3.5 GeV/c spectra for the $K^+ K^+$ and $K^+ \Sigma^o$ systems.

(b) 4-body reactions

The mass spectra for reactions (3) and (4) at 3.5 GeV/c are shown in all possible 2-body combinations in Figs. 10 and 11 respectively[*]. Here we notice that, although the available statistics is too limited to afford definite conclusions, both Y^*_{1385} and K^* seem to be produced in the appropriate mass combinations.

[*] The 3 GeV/c data are too scarce to allow a detailed study.

A simple estimate, based on phase space subtraction, indicates that in $\sim$ 15 o/o of the cases reaction (3) proceeds through

$$K^+ p \longrightarrow K^+ K^+ Y^{*o}_{1385}, \quad Y^{*o}_{1385} \longrightarrow \Lambda \pi^o \qquad (5)$$

and in $\sim$ 30 o/o through

$$K^+ p \longrightarrow K^+ \Lambda K^{*+}, \quad K^{*+} \longrightarrow K^+ \pi^o \qquad (6)$$

Analogously, reaction (4) proceeds, in $\sim$ 25 o/o of the cases, through

$$K^+ p \longrightarrow K^+ K^o Y^{*+}, \quad Y^{*+} \longrightarrow \Lambda \pi^+ \qquad (7)$$

and in $\sim$ 25 o/o through

$$K^+ p \longrightarrow K^+ \Lambda K^{*+}, \quad K^{*+} \longrightarrow K^o \pi^+ \qquad (8)$$

The ratio between the cross sections for reactions (6) and (8) appears to be in good agreement with the expected value of 1/2.

As for the presence of other resonances, like N^*_{1688}, K , etc. ..., we feel that the hints offered by the spectra of Figs. 10 and 11 are tantalizing but too meagre to be taken seriously.

4. Acknowledgments

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Figure Captions

Fig. 1 Dalitz plot for 23 reactions $K^+ p \longrightarrow K^+ K^+ \Lambda$ at $P_K = 2.97$ GeV/c.

Fig. 2 Dalitz plot for 46 reactions $K^+ p \longrightarrow K^+ K^+ \Lambda$ at $P_K = 3.43$ GeV/c. The open circles represent ambiguous events.

Fig. 3 Mass spectra for 23 reactions $K^+ p \longrightarrow K^+ K^+ \Lambda$ at $P_K = 2.97$ GeV/c: (a) invariant mass for the system $K^+ \Lambda$; (b) invariant mass for the system $K^+ K^+$. The continuous line is the normalized Lorentz-invariant phase space.

Fig. 4 Mass spectra for 46 reactions $K^+ p \longrightarrow K^+ K^+ \Lambda$ at $P_K = 3.43$ GeV/c: (a) invariant mass for the system $K^+ \Lambda$; (b) invariant mass for the system $K^+ K^+$. The ambiguous events are dotted. The continuous line is the normalized Lorentz-invariant phase space.

Fig. 5 Cosine of the c.m. production angle of the $K^+ K^+$ system in reaction (1) at $P_K = 2.97$ GeV/c versus the mass of this system. 23 events.

Fig. 6 Cosine of the c.m. production angle of the $K^+ \Lambda$ system in reaction (1) at $P_K = 2.97$ GeV/c versus the mass of this system. 23 events.

Fig. 7 Cosine of the c.m. production angle of the $K^+ K^+$ system in reaction (1) at 3.43 GeV/c versus the mass of this system. 46 events, of which 6 ambiguous (open circles).

Fig. 8 Cosine of the c.m. production angle of the $K^+ \Lambda$ system in reaction (1) at 3.43 GeV/c versus the mass of this system. 46 events, of which 6 ambiguous (open circles).

Fig. 9 Mass spectra for 13 reactions $K^+ p \longrightarrow K^+ K^+ \Sigma^o$ (4 at $P_K = 2.97$ and 9 at $P_K = 3.43$ GeV/c): (a) invariant mass for the system $K^+ \Sigma^o$; (b) invariant mass for the system $K^+ K^+$. The ambiguous events are dotted.

Fig. 10 Two-body spectra for 18 reactions $K^+ p \longrightarrow K^+ K^+ \Lambda \pi^o$ at $P_K = 3.43$ GeV/c: (a) $K^+ K^+$; (b) $K^+ \Lambda$; (c) $K^+ \pi^o$; (d) $\Lambda \pi^o$. Ambiguous events are shaded. The continuous line is the normalized Lorentz-invariant phase space.

Fig. 11 Two-body mass spectra for 36 reactions $K^+ p \longrightarrow K^+ \pi^+ \Lambda K^o$ at $P_K = 3.43$ GeV/c: (a) $\Lambda \pi^+$; (b) $K^o \pi^+$; (c) ΛK^+ ; (d) $K^+ \pi^+$; (e) ΛK^o ; (f) $K^+ K^o$. Ambiguous events are shaded. The continuous line is the normalized Lorentz-invariant phase space.